Renewable Energy Project
Final Report:
Design and Construction Planning for a Residential Hybrid Photovoltaic System

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DISCLAIMER

This report was prepared by students as part of a university course requirement. While considerable effort has been put into the project, it is not the work of licensed engineers and has not undergone the extensive verification that is common in the profession. The information, data, conclusions, and content of this report should not be relied on or utilized without thorough, independent testing and verification. University faculty members may have been associated with this project as advisors, sponsors, or course instructors, but as such they are not responsible for the accuracy of results or conclusions.

EXECUTIVE SUMMARY

Introduction

This report is a culmination of the work completed by the Renewable Energy Capstone Project team, for ME 476c at Northern Arizona University, for the Department of Mechanical Engineering. This required course allows engineering students to engage in the engineering process in a controlled environment, with the guidance of professors and peers. The capstone process requires students to conduct research, testing, reports, and the overall implementation of a large scale project with a preallocated budget.

Project Description

Mr. Steve Winiecki, the client for this project, requests that the team design, optimize, and implement a solar photovoltaic (PV) system. The system is to be capable of both off grid and grid tied use, in order to generate power for his off grid cabin located in Camp Verde, Az; this functionality is known as a hybrid solar system. The system is to be safe, efficient, adaptable, and must minimize feedback into the grid.

Design Solution

The proposed solution and final design is Design 2. This design has been deliberated upon in previous deliverables, but will be expanded upon within this report, in Section 6. Conclusion. This design incorporates cost effective and efficient materials, and meets all of the customer requirements. A decision matrix used in determining this design is located in Appendix XV, along with a full Bill of Materials located in Appendix XI. An electrical diagram of this system is located in Figure 1.

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1 Background

1.1 Introduction

This document is a preliminary report detailing the initial stages of the Renewable Energy Project. The processes of problem identification, determining customer and engineering requirements, literary research, system benchmarking, concept generation, and final design selection are included within this document. This document is a critical step in an expansive and detailed project, which will involve several more intermediary stages and deliverables. Technical analysis to include energy modeling, structural analysis, wind projections, and load analysis will be the next initial steps, following a formal presentation of this report. Prototyping, testing, material procurement, and construction will follow within the final stages of the project.

1.2 Project Description

The stakeholder and client, Mr. Steve Winiecki, will be constructing an off-grid cabin in Camp Verde, Az. This cabin will act as a permanent residence for him and his family. Construction plans are already completed, however power generation has not been acquired. It is the Renewable Energy Team's responsibility to design and oversee the implementation of a power generation system; this system will consist of a solar photovoltaic (PV) system. The customer and engineering requirements are detailed below in section 2. Requirements.

2 Requirements

The initial proposal that comes from the client gives the team a foundational groundwork requirements to build off of. Once the evaluation of these requirements are finalized, the team then sets up their own criteria of how each requirement will be met. Each requirement will have its own value of importance and determining how to move from there will be discussed within a later section of this document.

2.1 Customer Requirements

Upon speaking with the customer, a few key elements were communicated right away. Our grade scale is on a 1-5 point scale, 1 being the least of customer concerns and 5 being the highest. Down below is the team's customer requirements with its scale value attached.

* Cost Efficient - 3
* Energy Storage - 2
* Hybrid Islanding Inverter - 4
* Solar Generation - 5
* Safe to operate - 5

Having a cost efficient system is scaled at a midpoint value based on our customer's requests in the way that he wants to set up his system. As he understands that the cost of the system will be expensive he has given the team a range of costs that he would be willing to spend compared to the cost that he is hoping to spend.

The team's client is hoping to create an off-grid system which would rely solely on the solar generators that would create electricity throughout his house. He will need to have an adequate store system capable of retaining some of that power for later use when the sun isn't present. Since he will be having the option to take power from the grid in the event of an emergency his storage system isn't one of the highest requirements.

Although the client's house will run from an off-grid system, the option of taking power from the grid will be put in place just in case of emergencies. However, since the client is going to do what he can to not rely on the grid, this requirement isn't placed on the highest scale level.

With any off-grid system, the energy being produced from outside sources is the top priority of that system. The team's client wants the option of a full off-grid system which means the solar generation that will be generated daily will be one of the main priorities for the client and the team.

Within every engineering field having a safe, reliable and adaptable system is essential for any product being made. The team also has to take into consideration the laws and regulations of the area that this solar system is being built on so that the grid tied company that the client will be connected with, won't deconstruct the system and reconstruct it back to code.

2.2 Engineering Requirements

As the team evaluated the Customer Requirements, the same amount of engineering requirements are in place as shown below. With each requirement that is shown, not all requirements have a positive impact on the others. Each requirement is listed below along with its targeted requirements as well as the tolerances.

*	Decrease Design Cost	$35,000 −10,000
*	Increase Efficiency	>15%
*	Increasing Generation	1280 kWh/month $\pm$3
*	Increase Storage	15 kWh
*	Decrease $/Watt	< $4/watt

With the budget for this project having a varying range, the team has decided to aim for the smallest amount of cost for the client with an understanding that certain items may be more expensive based on the quality of products, failed tests, and degradation of the system overtime. In order for the team to minimize the cost of the design, looking at a long term timeline and understanding the replacement costs are taken into account. The targeted value for the cost is around 35,000 dollars with a negative 10,000 dollars if possible.

The house itself also holds a role in the way that energy is saved. The installation process of the house will be a determining factor of the amount of energy needing to be produced on a daily basis. If the installation process has high marks, the energy that is being produced will be able to be more efficient in other areas of the house and vice versa if the process is poor. Another factor that can play a part within the efficiency would be the angle of tilt of the solar panels. The targeted value for the efficiency is 2.99 dollars per Watts with a positive or negative 0.5 tolerance.

The positioning of the solar panels does determine how much generation of electricity will be produced. By understanding the best angle to place a solar panel throughout the year will give the user the most generation from the system. The type of panels used within the system also plays a part when taking into account the losses of that generation process. The targeted value for the energy generation is 30 kilo-Watt-hours per month with a tolerance of positive or negative 3.

As the client doesn't want to rely on the grid, a battery system is a needed aspect within the project. Being able to utilize the extra generation of the solar panels at a later time is very beneficial to the client when the sun sets and he will be reliant on that leftover energy until the panels generate more power the following day. In many instances having a backup storage unit of a minimum of 3 day usage is recommended for any off grid system. With that in mind, the team needs to locate the best quality, at a reasonable cost, battery storage unit that will give its user a 3 day lifespan if no generation from the solar panels are being produced. The targeted value for energy storage is 15 kilo-watt-hours with a positive 5 tolerance.

With a hybrid system the components of incorporating the electrical company and their policies will be followed to a degree. Since the client doesn't want to back feed his solar generation to the grid the safety measures for the electric company isn't as big of a problem since power will not be constantly going to and from the house. If the electric company, for whatever reason, needs to shut off the power being provided to its clients, the team's client will not be affected by the shut off switch and would still be able to use his own power that has been generated with the solar panels. The targeted value for the amount of sources of energy being directed to the house is 3 with a tolerance of positive 1.

2.3 Functional Decomposition

The purpose of the functional decomposition is to break the entire design challenge into small-scale solutions. Decomposing and dissecting the design increases clarity on the engineering requirements and goals to outline a baseline functionality of the design and highlight interactions between subsystems. A hybrid PV system and its subsystems combine to create a complex network of energy and signal flows. To simplify the design, the team has employed two levels of functional decomposition: a black box model and a function chain diagram. The black box model is the most simplified decomposition as it focuses directly on the inputs and outputs of the system. It demonstrates that the design ultimately transfers energy from one location to another. The function chain diagram elevates the level of detail by creating a map of signal and energy flows between the subsystems within the design.

2.3.1 Black Box Model

The black box model depicted below in Figure 2 (Appendix VII) shows the appropriate inputs and outputs for our overall solar system. There are no physical material inputs or outputs for our system. Our system is based on energy and signal inputs and outputs only. The main inputs and outputs for our system are energy. For a renewable energy solar system, solar energy is the dominant input and source. As shown above, the dominant input of the system is solar photons.

The Solar photon input then directly outputs to either battery electrons or an AC to power the house.

The grid electrons are also an input to our system. Once the solar energy has been transferred into energy, the grid can input this energy to output AC loads to the house. The AC loads are the exact desired output of the overall system.This output will ultimately be the desired output and use that the client requires from the system .

The final input to the system is an AC/DC signal. This is the only signal input for our system and the only non energy input for our system. This signal comes from any signal in the clients house (ex. A light switch). This signal input will be the catalyst that starts the energy transfer from the grid to the house. Because the house is the final destination for the power, there is no output signal in our system.

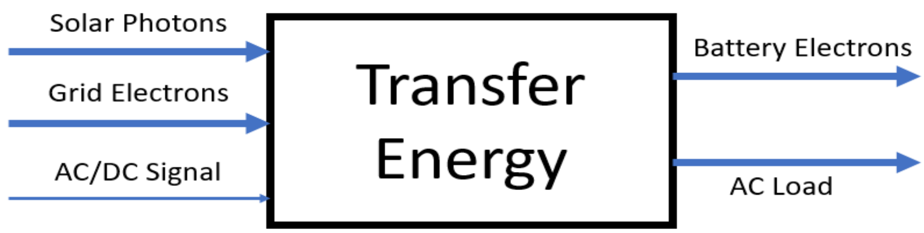

Figure 1: Black Box Model

2.3.2 Functional Model / Work-Process Diagram

A functional model is used to loosely define the overall process that the device will be subjected to during normal operation. It is designed to show the flow of inputs, outputs, and operations between subsystems and components so the team can have a simplified view on what the design is accomplishing at any given point. This simplification allows the team to be more effective and creative when implementing and designing small-scale solutions between each step.

The benefit of having a hybrid PV system comes from the varying forms of energy that can be used to power the home. However, it adds a layer of difficulty because the system needs to be self sufficient at managing these power inflows and directing the most efficient method into the home. This decomposition also includes several subsystems such as the panels, storage bank, and battery controller. Below in Figure 3 (Appendix VIII) is a functional chain that describes the process of the hybrid PV system and how the system will need to manage the flow of electricity. The chain's arrows depict the flow of electricity and the dashed lines depict a signal transfer. This diagram demonstrates the flow of energy once a load is detected by the system and the multitude of paths that the electricity can take depending on the originating signal. In our system, the start of the transfer of electricity is signaled by an electrical need from the house. It is then up to the system and battery controller to determine the source of the power needed. The electricity could be sourced from the panels, the battery storage bank, or the grid depending on the states of each source. For example, if the sun has set and the panels are not generating any power, then the controller will source the power from the battery bank. However, If the battery bank is depleted then the system will source the needed electricity using grid power as a last resort.

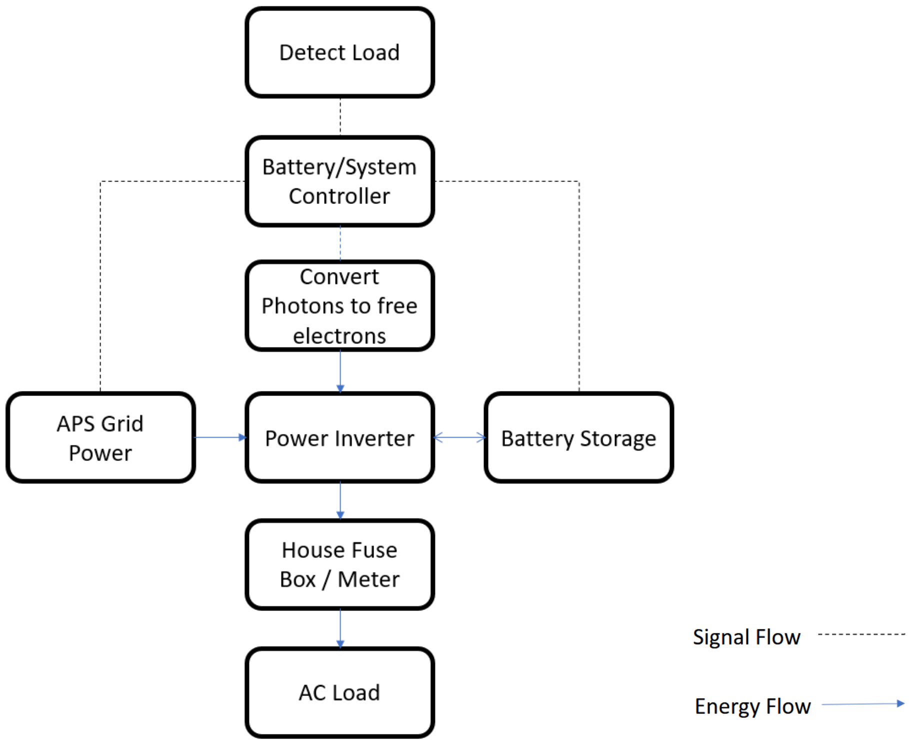

Figure 2: Work Process Chain Diagram

2.3 House of Quality

Taking the information from above, the team constructed a House of Quality document that states the importance of what the customer is asking for along with the improvements that the team can provide. The full House of Quality can be seen in Appendix IX. As stated above the Customer's Requirements and the Engineering Requirements with their targeted values are as follows:

1. Cost Efficient	3	1. Decrease Design Cost	$35,000
2. Energy Storage	2	2. Increase Storage	15 kWh
3. Safe to Operate	5	3. Decrease Investment	$4/watt
4. Solar Energy Generation	5	4. Increase Generation	40 kWh/day
5. Hybrid Island Inverter	4	5. Increase Efficiency	>15%

2.4 Standards Codes and Regulations

Under standard conditions in the private sector, licensed solar design and installation companies are legally obligated to adhere to federal, state, and local standards. These standards and codes are implemented to ensure the safety of consumers, contractors, and the general public by preventing subpar workmanship and unsafe installation practices. For this particular project involving a privately owned home, compliance with various codes and regulations is necessary, including electrical codes, building codes, fire codes, and permit regulations. Local and federal regulations must be followed if the homeowner wishes to avail themselves of government incentives and incentives. It is worth mentioning that, in this case, the system will be considered separate from the home during the construction phase, thereby exempting the client from permitting and inspection requirements. However, our team will still adhere to the established standards to maintain a high level of quality. The expertise of our faculty adviser, Dr. Carson Pete, who possesses prior professional experience in designing and installing solar systems, will be invaluable. Dr. Pete will serve as the site manager, overseeing the team's work, identifying any installation or quality issues, and providing necessary corrections. The table below (Table 1) outlines several standards that the team will adhere to during the PV system installation process.

Table 1: Installation Standards Relevant to PV System

Standard Number or Code	**Title of Standard**	**How it applies to Project**
NEC 2017	National Electrical Code	This code outlines the requirements for electrical installations, including PV systems, to ensure safety and proper functionality.
IBC 2018	International Building Code	It provides guidelines for building design and construction, including structural considerations for PV system installations.
IRC 2018	International Residential Code	This code focuses on residential buildings and addresses requirements for PV system installations in single and multi-family dwellings.
IEEE 1547	Standard for Interconnecting Distributed Resources with Electric Power Systems	This standard outlines the technical requirements for the interconnection of PV systems and other distributed energy resources with the electric grid.
UL 1741	Standard for Inverters, Converters, and Controllers for	It covers the safety and performance requirements for inverters, converters, and other control devices used in PV systems.

	Use in Independent Power Systems	
NABCEP	North American Board of Certified Energy Practitioners	Standards - NABCEP provides a range of standards, including the NABCEP PV Installation Professional Certification Standard, which ensures proper design, installation, and maintenance of PV systems.
NFPA 70	National Electrical Code	While primarily an electrical code, it includes provisions for fire safety related to electrical installations, such as wiring methods and equipment clearances to prevent fire hazards.
UL 9540	Standard for Energy Storage Systems and Equipment	UL 9540 is a safety standard that covers the testing and certification of energy storage systems, including battery storage systems. It ensures that the systems meet specific safety criteria for various hazards, such as electrical, fire, and environmental risks.
IFC	International Fire Code	The IFC includes provisions for the storage, handling, and use of batteries, including battery storage systems. It covers aspects such as storage location, fire protection, ventilation, and emergency response requirements.

Table 2: Permitting Codes

NEC 705.12	National Electric Code	Connecting additional power production sources to the existing wiring system from the primary source of electricity. This mainly focuses on interconnecting alternate power sources.
NEC 690.14	National Electric Code	This focuses on the way in which the installation process is handled.
NEC 690.7	National Electric Code	This code specifies the maximum voltage output that can be produced between two circuit conductors.
NEC 690.54	National Electric Code	A support system that helps interconnect the interactive systems.
NEC 690.35	National Electric Code	A recommended code used when the PV system is a distance away from the inverter. It recommends using an underground electrical system that goes from the panels to the inverter.
NEC 690.12	National Electric Code	This code is for an emergency shutdown switch that is needed in all photovoltaic systems.

3. Design Space Research

3.1 Literature Review

Before designing a PV system, it is important to research comparable designs and find relevant data that can aid both the development and selection of a design. Our team focused on three main areas of research: Energy Modeling, Financials, and PV Systems. The main deliverable for the first semester of this project is to develop an accurate energy model that depicts the energy usage and heat losses of the home. With this being a pivotal part of the project, it was important that the team understands what energy modeling is, how it is used, and why it is relevant. The second area of research was regarding the financials of a PV system. Because our team is reliant on funding from the customer, it is imperative that our designs be cost effective and that our quotes take into account any applicable tax credits and incentives. Finally, the third section of the literature review covers existing and leading edge technologies within the PV system. By having three distinct research areas within the literature review our team will develop an encompassing competency around the PV design. The result should be a design that will meet and exceed all engineering and customer requirements.

3.1.1 Energy Modeling Review

The following sources all relate to energy modeling. As the main deliverable for the first semester, it is important that the team develops a strong foundational knowledge of what energy modeling is, how it is used, and how we can apply it to our project. CAD Design Lead Garrett Cornelius, will be taking on the majority of the research and apply his findings and knowledge during the creation and development of the cabin energy model.

a. https://www.energy.gov/eere/buildings/about-building-energy-modeling [1]

The Office of Energy and Efficiency & Renewable Energy is the forefront of information on how the United States Government utilizes building energy modeling (BEM) systems. This particular article explains what exactly BEM systems are and how they work. The useful information in this article is how construction projects can benefit from the use of BEM software.

b. https://www.energy.gov/eere/buildings/articles/energyplus [2]

The second source of the team's literature review is an article that was written by the office of energy efficiency and renewable energy in August of 2014. The main point of this article, as it pertains to this project, is that energy plus has received $83 million in funding to date. This program serves as a backbone to any energy modeling project that can/will be converted into a physical solar system. With the growing interest in renewable energy across the United States, this article discusses how the DOE (department of energy) is funding this energy plus project to help current and future renewable energy projects.

c. https://www.energy.gov/eere/buildings/articles/building-energy-modeling-101-hvac-design-and-operation-use-case [3]

The third article from the The Office of Energy and Efficiency & Renewable Energy demonstrates BEM software's application with respect to HVAC systems. The article also shares vital information on the application or "Real-Time Modeling". Mr. Winecki will be running two mini split HVAC systems to cool his home in the summer and the information from this article will help the CAD team understand how to use adaptive weather based modeling systems. Understanding this should create a more accurate assessment of the electrical needs of the home.

d. https://www.energy.gov/eere/buildings/articles/building-energy-modeling-101-inherent-performance-rating-use-case [4]

The fourth article is also from the Office of Energy and Efficiency & Renewable Energy. This article speaks to the performance of the building itself by defining an energy asset score. The author focuses on the optimization of the construction to attain higher levels of efficiency. Using BEM software, a user can compare materials, locations, appliances and more to define the greatest energy losses in the system. While our team will not be constructing the home, this knowledge can be applied when creating a baseline assessment of how energy efficient the home is before any material or electrical needs are in place.

e. https://journals.sagepub.com/doi/10.1177/2399808319841909 [5]

The fifth source under Energy modeling is a 2019 journal written by Tarek Rakhand and Rawad El Kontar about the optimization of BEM to the real world. A major design challenge for the team is to develop a system that meets the energy needs of the home. Unfortunately, this creates a large problem when it comes to modeling according to the journal source. The issue stems from the differences in the energy uses of the resident. Some residents used less than modeled, and others used much more than modeled. The work also notes that modeling systems only estimate the usage for today's appliances and does not take into account an increase in electrical usage over time. This source will give the design team insight on the idea of tailoring a system to our specific user and the financials of over and under-building a system.

3.1.2 Financial Review

Mr. Winecki is the sole funding source for this project. He is a retired firefighter and is looking for a system that will provide a great value and profitable return on investment over the life of the solar system. Our goal is to present Mr. Winiecki with a system that we believe is best suited for his financial and electrical needs. However, funding status can change for private clients and the team will need to be prepared to opt for a lower cost system. Understanding every aspect of the cost for a PV system is imperative. Team Lead Michael Horn and Nicholis Santana have been delegated with the roles and responsibilities pertaining to the project and design budget. They will be working together to find, research, and apply the most cost effective solutions to this project. The following sources are all in regards to funding, tax breaks, and return on investment for PV systems.

a. https://www.electricitylocal.com/states/arizona/camp-verde/ [6]

Understanding a home's energy needs is the first step in designing a PV system. Most solar companies utilize an existing energy bill to understand the average kW needed for the home. With a known KW draw, a system can be designed to meet those needs. For this project, the house is yet to be constructed and there are no energy bills to work from. This source identifies the average price per KWh for the Camp Verde Area. This data will be used to develop a return on investment and financial model for the budget team.

b. https://www.iea.org/reports/clean-energy-innovation [7]

The International Energy Agency flagship report was completed in 2020. This source identifies the overall return on investment for PV systems worldwide. The report identifies that manufacturing and material improvements have brought the total costs of solar down dramatically with respect to time. The budget team will utilize this information during benchmarking to identify the differences in cost from a solar system completed 10 years ago to a system that was installed recently. With the cost of solar panels decreasing, the team will be able to demonstrate the capability of a larger system within the same budgetary constraints.

c. https://www.usda.gov/sites/default/files/documents/renewable-energy-trends-2020.p df [8]

The USDA submitted a report regarding renewable energy trends. The report describes the decrease in capital costs of PV systems and other forms of renewable energy systems across the board. The article provides great financial and system data to support the benchmarking and budget aspects of the project. Another benefit of this source is the application of renewable energies in a real world environment and specifically agriculture.

d. https://palmetto.com/learning-center/blog/everything-you-need-to-know-about-the-solar-tax-credit [9]

When quoting the price of multiple systems to our customer, any applicable tax credits can make a sizable difference in the scale and affordability of the system. This article speaks on the specifics of the Inflation Reduction Act which is a federal tax credit for residential solar systems. According to the article, up to 30 percent of a PV system's price can be written off as a rolling tax credit. Our design must meet all of the requirements to take full advantage of this program and will be used by both budget and design teams.

e. https://azdor.gov/forms/tax-credits-forms/credit-solar-energy-credit [10]

Related to the source above, Arizona has its own tax credit program for privately owned residents. The article defines the requirements for the solar system as well as showing the possibility for a $1,000 Arizona tax credit. More importantly, this tax credit applies to the property value increase. Adding a forty thousand dollar system to a property can raise property taxes over the life of the system. This is an aspect that the budget team will need to account for when creating a return on investment report for the project.

f. https://www.solarpanelstore.com/blogs/solar-panel-store-blog/solar-home-grid-tie-system-sizing-part-1-using-a-utility-bill [11]

This source is a simple step by step procedure on how to find your home's energy use and how it could be improved by solar polar. The article shows a 4 step process that will show the user what solar system might be a good fit for their circumstance. This source was used as a starting point for the group when designing a solar system. This source also serves as a way to estimate how much energy could be transferred to solar by a given system. Thus reducing a percentage of a monthly energy bill.

3.1.3 System and Subsystem Review

The sources below all relate to the PV system or a subcomponent of a PV system. Research into this area allows the team to have a better understanding of existing technologies and designs. The team's test engineer Issac Granados will be utilizing most of these sources to become an expert in various designs and components. This will allow him to create a test methodology that the team can use to compare and benchmark our design. The team as a whole will also be conducting research to develop concepts and understand the advantages and differences between a multitude of existing designs and systems.

a. https://www.forbes.com/home-improvement/solar/most-efficient-solar-panels/ [12]

This article is directly related to the design of our panels in this project. This source describes the top of the line panels and the most affordable models. This will directly impact our design of our solar panels. The goal is to be as close to efficiency of the top of the line models whilst still maintaining the cost efficiency of the most affordable models. This article was directly used in the benchmarking of our panel design.

b. https://www.forbes.com/home-improvement/solar/what-is-a-solar-battery/ [13]

An engineering requirement for this project is to have some degree of battery storage. Electrical storage can easily become one of the most cost prohibitive components of the system. This article speaks on the usage scenarios as well as various forms of battery technologies that are applicable to this scenario. With cost, life-cycle, and capacity being a major factor in concept selection, understanding the entirety of battery technology and its drawbacks is imperative.

c. https://www.forbes.com/home-improvement/solar/ground-mounted-solar-panels [14]

Due to the location of the cabin, a ground mounted solar panel system is looking to be the most applicable. To understand the advantages and disadvantages of a ground mounted system, the team will be using this article from Forbes. The author claims that ground mounted systems can be more versatile and efficient compared to roof mounted designs and have no apparent drawbacks. This article and its sources will provide viable justification in the selection process to go with a ground system.

d. https://www.solar.com/learn/micro-inverter-string-inverter-comparison-solar-equipment/ [15]

The article above, written in 2022, compares traditional string inverters with a newer technology of inner-panel micro inverters. While micro inverter panels are more costly, the article outlines several key advantages that microinverters have. The budget and design team must compare subcomponents to decide if the increase in capability, scaling, and installation advantages will outweigh the cost impact.

e. https://www.solar-electric.com/learning-center/what-components-typically-used-off-grid-solar-power-system/ [16]

Researching efforts and designs within the project radius can lead to understanding the requirements and complications that specific areas present. This article was written by a company in Northern Arizona. It specifically speaks on off-grid applications and the components that are primarily used. Within the article, the author speaks on the importance of designing a system around the local environment. Our design team will need to do just that when taking into consideration weather and sun data for the PV system.

f. https://unboundsolar.com/blog/best-solar-panel-mounts [17]

This source will be used directly for our 3 sub system benchmarking. This article goes over the different types of mounting systems for solar systems. This article shows not only options for roof mounted systems but also for ground mounted systems. Our design will be a ground mounted system. With this source, the team will be able to compare our design to various different designs.

g. https://s3.amazonaws.com/zcom-media/sites/a0i0h00000KyCXiAAN/media/mediamanager/OutBack_Radian_4048A_8048A_Inverter_manual.pdf [18]

A string inverter is one of the most fundamental subcomponents of a PV system. The following pdf is a manual of an inverter made by Outback Power. This type of information is extremely valuable because it shows the capacities of this particular inverter. Understanding manufacturer specifications is paramount for both safety and design. This manual also demonstrates the proper wiring layout when installing. Manuals such as this will be used by the design and install team throughout the second half of the project.

h. https://www.outbackpower.com/downloads/documents/appnotes/gridzero_app_note.pdf [19]

This PDF published by Outback Power is an application note for one of the company's premier PV system controllers. A controller similar to the one cited will be used by our team to manage the entire system. Outback's GridZero mode enables a renewable energy system owner to maximize the use of their generated electricity and minimize energy purchased from the utility by fully utilizing energy storage. This documentation will aid the team during the design and procurement process by showing what is capable with off-the-shelf components.

i. https://www.solarreviews.com/blog/what-are-solar-inverters[20]

This article is a buyer's guide to inverters. The article outlines the different types of inverters of a solar system and the associated pros and cons. An inverter in our design will be the "middle man" between our solar panels and the clients house. The inverter of our design will be treated as a sub system. The team will use this article as a starting point when designing and choosing an inverter for the project.

3.2 Benchmarking

Benchmarking is a pivotal step for our team's design process. While this project does not rely on reverse engineering or groundbreaking research, it is still important to compare our design to existing applications. Benchmarking reveals relevant problems and gives insight on how other engineers have developed solutions. To be thorough, our team will be conducting online research and comparison into a system-wide solution as well as diving into individual components and subsystems. Invaluable information can be gathered from current designs and component selection decisions. The following sections will discuss system and component level benchmarking tactics.

3.2.1 System Level Benchmarking

With regards to photovoltaic systems, there are countless mounting styles, panel arrangements, system scales, and applications. To narrow this field of view for benchmarking that will be most impactful to our system, this will be narrowed into mounting arrangement and scale of the system. This level of benchmarking will be comparing several system layouts and locations to find the advantages and disadvantages of each.

3.2.1.1 Ground Mounted Solar Design

A singular ground mounted system has more advantages than a roof solar system. Having the ability to direct panels to the best possible angle for consumption, choosing the area of least obstruction, and creating a higher return on investment are the main advantages. There are two different types of systems, Standard and Pole Mounted. Each of these systems have their own advantages and disadvantages compared to one another. Below describes the differences between the two systems.

- Standard Ground Mount
    - Low to the ground surface,
    - Large surface area from its own metal frame that has a fixed angle towards the sun
    - Option of being mounted above the surface
    - Simple installation and maintenance aspect
    - Doesn't work as well under snow conditions

Figure 3: Standard Ground Mounted Solar Panels

- Pole Mount
    - Higher off the ground
    - Varies in surface area with its additional height
    - Capable of both a fixed or tracking system that follows the sun
    - Only option is to be mounted within the surface
    - High maintenance
    - Cost is higher
    - Electricity is needed to support the tracking system

Figure 4: Pole Ground Mounted Solar Panels

3.2.1.2 Roof Solar Design

The first type of solar design started on the roofs of an individual home. These houses had limited space based on the size of the roof. This simple construction only allowed homeowners with a small reduction cost within their electricity bills based on the roof's tile for the panels to be placed on. Since then, the panel designs have improved from laying panels directly on the roof to having a stand that raises the panel above the roof's surface. It was discovered that the hotter the panels get, the greater the losses of energy generated. Now panels are lifted to create a channel of airflow underneath each panel to cool down the system to produce as much electricity as possible. There are still designs being tested/perfected when it comes to angle of tilt of the panels on roofs however most people use the original angle that their roofs already have and don't get the full energy generation as they were expecting.

Figure 5: Solar Panels on the roof

3.2.1.3 Community Solar Farms

Solar Farms are community based solar systems that affect the lives of more than one home. These farms are all ground mounted systems that vary from fixed to solar tracking systems dependent on the company, budget, and average energy needed for the community. Most of these farms have slowly been integrated within larger electric companies to lower their carbon footprint by using this simple renewable energy system. Larger companies and organizations also use solar farms to produce their own energy for their buildings to reduce the cost of electricity and sell electricity to the electric companies to generate a small profit. Typically the owners of solar farms charge more if not the same cost as the electric companies.

Figure 6: Solar Farm within California used by the local college

3.2.2 Subsystem Level Benchmarking

Subsystem level benchmarking allows the team to compare existing components of a solar PV system. Within this section, different devices of the same category will be determined and compared. This important step provides valuable insight on different existing designs for achieving similar functions.

3.2.2.1 Panels

The solar panels are a component of our system that innaties the transfer of solar energy into free electrons. This is the catalyst for our whole system. With the development of solar panels over the years it is crucial for our design to be on par with the current models. Our design needs to include solar panels that are as efficient as existing designs/products.

3.2.2.1.1 Monocrystalline: Most Efficient

Monocrystalline panels are the most efficient panels on the market. The only thing that makes this design non useable is the price point. These panels are far out of budget for most commercial projects and thus will be far out of our budget. However these panels have an efficiency of 15 to 22 over a 25 year life span. Some of our requirements include cost efficiency and solar generation. This existing design is at the high end of both. Our goal is to be comparable to this panel's efficiency whilst being more cost effective.

3.2.2.1.2 Polycrystalline: Most Affordable

Polycrystalline panels are a more realistic option for our design. They are more commonly used in solar systems. They provide an efficiency between 13% and 17%. This is below the efficiency of the monocrystalline, but still a viable option. Because most affordable systems are between 13% and 17% efficient, this will serve as an efficiency benchmark for our panel design. Ideally, our design would top this efficiency whilst still being as cost effective.

3.2.2.2 Batteries

The batteries are the component of our system that will store power and energy for future use. Once energy has been transferred from the panels into free electrons, it can be used in the house or be stored. If there is no use for the free electrons/energy at the moment it's converted, then the batteries will be what holds the energy for future output.

3.2.2.2.1 Lead-Acid

Lead acid batteries are more commonly used by homeowners in solar systems. This is because they are one of the most affordable options. Recent technology has made these types of batteries more viable and effective. Lead-acid batteries will serve as a minimum benchmark for our project. Because one of our client requirements is to be cost effective, this type of battery will be a viable and realistic option.

3.2.2.2.2 Lithium Ion

Lithium ion batteries are a newer option. Lithium-ion batteries have a high energy density and offer a smaller, lighter and more efficient option. The only con with this type of battery is the cost associated with it. This type is very much more expensive than the Lead-acid alternative. Because of this, Lithium ion batteries may not be a realistic option for our design and client. However the energy density and efficiency of lithium ion batteries will serve as a high end bench mark for our time. The goal will be to strive for as close to the performance of Lithium ion while reducing the cost as much as possible to fit the clients budget.

3.2.2.3 Mounting systems

A mounting system is the structural support of a solar system. The team will use a mounting system in our design to keep us in place. On the project grounds, the mounting system will also serve as a way to protect the system from the wind forces. It is imperative that our design includes a robust mounting system to ensure there are no system failures. The two current designs that the team will benchmark with are Fixed Ground Mounts and Pole Mounts.

3.2.2.3.1 Fixed Ground Mounts

The first existing design that the team will use for benchmarking mounting systems will be a fixed ground mounted system. This system is just a simple metal frame to attach the panels to with footings to structurally support the system. As previously mentioned, this system is simple and will serve as a minimum requirement for the team's design. The one con with this system is the fact that it is not adjustable. This is something the team will look into improving when coming up with the final design.

3.2.2.3.2. Pole Mounts

Pole Mounts will serve as a goal for the team to strive for. These mounts are usually adjustable and have enough clearance from the ground to protect the panels. Pole mounts are also a way to protect the panels from heavy rain and snow falls. These mounts will serve as a goal for the team to achieve.

4. Concept Generation

In order to adequately determine an appropriate solution for the project, the team must engage in concept generation. Within this section it is described how the team effectively and concisely determined an appropriate design. Full system concepts and subsystem concepts are analyzed using decision enabling tools, such as a Pugh chart and decision matrix, in order to fully determine adequate solutions. These concepts are detailed below.

4.1 Full System Concepts

This comparison highlights the attributes and disadvantages of each design, allowing the team and client to qualitatively assess each design. Using a Pugh chart, these designs are compared to a datum, based on meeting the engineering requirements. This Pugh chart can be viewed in Appendix V. All of the following designs are for a hybrid solar PV system. Variations, such as alterations in components, are the driving force of difference among each design. Three full system concepts are listed below, with their corresponding pros and cons.

4.1.1 Full System Design 1 - Original System

Full System Design 1 is the datum. This system is the original system of the project, conceptualized by the previous team of ME 451 Renewable Energy students. The pros and cons of this system are as follows:

Pros:

- Satisfactory - Meets customer requirements
- Simplified - Bill of materials already completed
- Balanced - Good middle ground between cost and effectiveness

Cons:

- Mediocre - Does not exceed in any areas
- Cost - Not the most cost effective
- Outdated - Components and materials were selected a long time ago

4.1.2 Full System Design 2 - Highest Cost Efficiency

Full system design 2 is based on maximizing the cost efficiency of the design. It incorporates a higher wattage panel, and a median sized battery system. The focus of this design is to gain the lowest cost per wattage for both energy storage and generation. The pros and cons of this system are as follows:

Pros:

- Cost - Both the initial and long term costs of power are much lower
- Quality - The overall quality of the system is acceptable
- Capacity - The overall capacity for renewable power usage is moderately high

Cons:

- Reliability - Certain weather conditions or product quality may inhibit generation
- Warranty - The warranties included with this design are slightly more limited
- Durability - The products may be less durable over an extended period

4.1.3 Full System Design 3 - Highest Capacity

This design is focused on maximizing the power generation and storage capacity of the system. It utilizes a higher wattage panel, automated tilt angle adjustment, and larger battery bank. The pros and cons of this system are listed below:

Pros:
- Power Generation - This system generates the maximum amount of power
- Battery Capacity - The system has the largest battery capacity, at 47kWh
- Quality - The components are high quality and reputable

Cons:
- Cost - The system is very expensive
- Size - The system would take up more space
- Part Availability - The system would require more specialized parts
- Installation - The system will be harder to install
- Reliability - More electromechanical components are capable of failing

4.2 Subsystem Concepts

The subsystem concepts are derivatives of full system concepts. These design concepts are intended to vary each individual full system design and are as follows:

4.2.1 Subsystem 1 - Panel Type

Subsystem 1 describes the quality of panels that could be used and how much power would be lost during hotter temperatures of the day. The two panel types are listed below with their respective pros and cons.

4.2.1.1 Design 1 - Q.Peak 365

Pros:
- Reputable - Good quality panel with proven track record
- Warranty - 25 year material warranty
- Power Generation - Panel produces an adequate amount of power (365 W)
- Efficiency - High initial efficiency for energy production at 79.3%
- Integrated micro inverter

Cons:
- Cost Efficiency - The ratio of cost to power generation is y higher, at $.82/ Watt
- Power Generation - This panel produces less power at maximum voltage

4.2.1.2 Design 2 - Trina Tallmax TSM-DE15V(ii)

Pros:
- Cost - Significantly less upfront cost with a ratio of cost to power generation of $.54/Watt
- Quality - Good quality panel with a good track record

- Warranty - 12 product warranty/ 25 linear production
- Power Generation - This panel produces significantly more power, 480W
- Efficiency - Comparable initial efficiency of 79.6%

Cons:

- Temperature Coefficient - Slightly higher temperature coefficient
- Weight - This panel is significantly heavier

4.2.2 Subsystem 2 - Battery Storage

Subsystem 2 describes two designs for the differences of battery systems being used as the energy storage for a hybrid PV system. The two batteries below are listed with their respective pros and cons.

4.2.2.1 Design 1 - Big Battery Kong Elite - 19kWh

Pros:

- Cost - Less expensive
- Expectations - Hits the required amount of storage needed

Cons:

- Space - Requires a larger storage unit to house batteries
- Safety - Greater potential for fire hazard/ electrical shock
- Limited storage - Client needs to be more reserved based on storage capacity
- Degradation - Would last a shorter amount of time based on consistent recharging daily

4.2.2.2 Design 2 - Mammoth Pro - 23.5kWh

Pros:

- Space - Requires a smaller storage unit to house batteries
- Safety - Can neutralize any issues sooner based on inspection of batteries
- Larger supply - Larger equipment could be used more frequently as client needs
- Lower Degradation - Would last a longer amount of time

Cons:

- Cost - More expensive
- Expectations - Overshoots the expectations of the storage

4.2.3 Subsystem 3 - Tilt Angle

The tilt angle of the solar panels is an integral factor in the overall power generation of a PV system. Tilt angle can be described as the positioning angle required for sunlight to be normal to the panels. Two designs may be considered regarding tilt angle, fixed tilt angle and variable tilt angle. Variable tilt angle is achieved using an electromechanical device which physically adjusts the tilt angle, corresponding to the position of the sun. The pros and cons of each subsystem design are listed as follows:

4.2.3.1 Design 1 - Fixed Tilt Angle

Pros:
- Installation - Less complex installation
- Durability - Less opportunity for component failure
- Cost - Less initial and maintenance costs
- Power Generation - Adequate power is still generated

Cons:
- Power Generation - Less power will be accumulated throughout operation, compared to variable tilt angle
- Consistency - The magnitude of power generation will vary more significantly throughout daily operation
- Reliance - Greater reliance on weather conditions and sun positioning
- Efficiency - Peak sun hours may not be fully utilized

4.2.3.2 Design 2 - Automatic Variable Tilt

Pros:
- Consistency - More consistent power generation throughout operation
- Power Generation - More overall power will be accumulated
- Reliance - Less dependence on weather conditions and sun positioning
- Efficiency - Peak sun hours are fully utilized

Cons:
- Cost - Higher initial and maintenance costs
- Durability - Additional electromechanical components will decrease the durability
- Panel Lifespan - The lifespan on the panels will slightly decrease
- Installation - Installation of panels becomes more difficult

5 Design Selected

Design selection is based on the compatibility of each design to the engineering requirements for this project. Each requirement is given a weight, or relative importance to the project. Each design is scored in respect to each individual, weighted requirement. A final score is tallied, and compared among the designs. The highest scoring designs are selected for a final decision. It is important to note that the decision matrix is a suggestive tool, and scores may be overridden due to team or client preferences.

5.1 Design Description

5.1.1 Main Design Components

The final design is intended to function as a hybrid photovoltaic solar system, equipped with the capability to function completely off grid. In order to achieve this, some specialty components are necessary. An electrical diagram of the system is located in Figure 8.

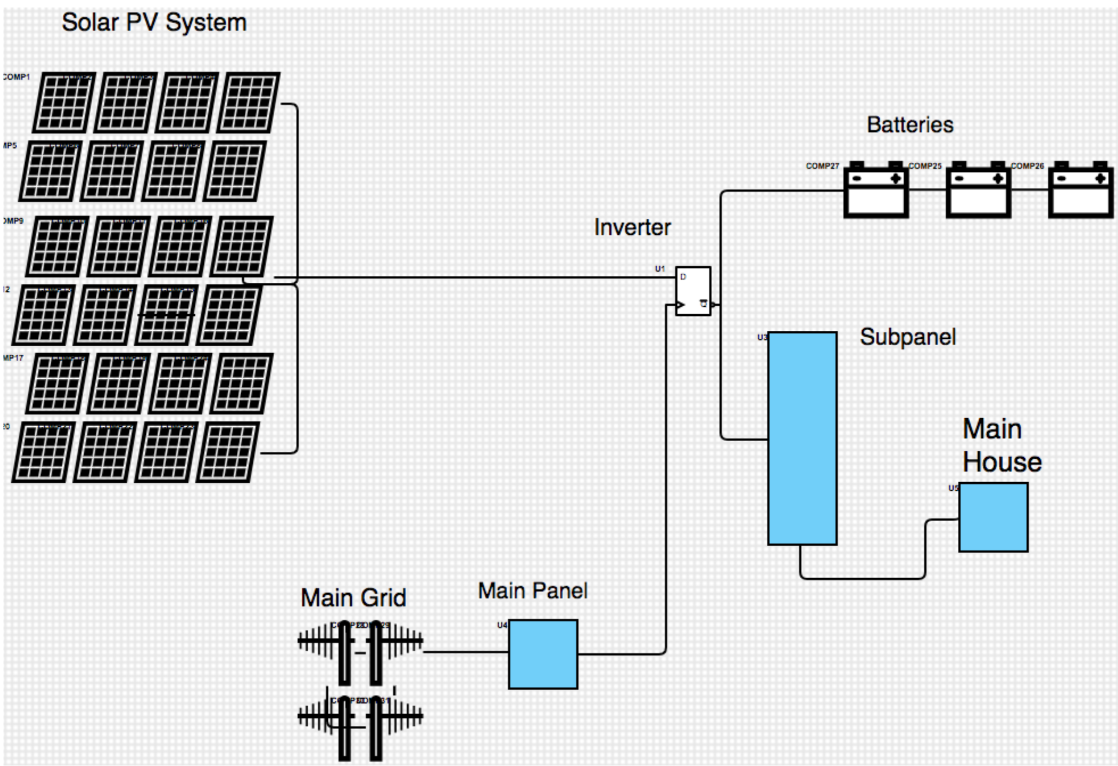

Figure 7: Electrical Diagram of PV System

5.1.1.1 Inverter

The inverter has the function of receiving all electrical inputs from the system, before redirecting them to their appropriate location. The inputs to the inverter are as follows: solar energy, battery energy, and grid energy. The outputs of the inverter are the main panel, subpanel, and batteries. As mentioned, this system is a hybrid system with no feedback; this inverter is responsible for calculating and maintaining the most optimal energy balance among all inputs and outputs, while minimizing feedback to the grid. The chosen inverter for this design is the Outback Radian Series Inverter/Charger. A more detailed electrical diagram of the system is available in Appendix X.

5.1.1.2 Solar Panels

The solar panels are the component responsible for converting electromagnetic waves from the sun into usable DC electricity, and essentially function as large semiconductors. All energy generated independently of the grid will be sourced from the solar panels. The solar panels selected for the design are the Trina Tallmax TSM DE15(II) 480; these solar panels produce 480W at max generation. A full spec sheet for the panels can be found in Appendix XII.

5.1.1.3 Batteries

Because the system needs to be able to generate and supply power off grid, batteries are recommended for the final design. The batteries allow the system to store and draw power as needed, although the duration of power supply may be limited. The batteries selected are the Big Battery Kong Elite Max, which provide 19kWh of energy storage each.

5.1.1.4 Grid Power

The final design is a hybrid solar system, meaning that grid connected power is still readily available at the user's discretion. In order to achieve this, the power company must make electrical connections to the main panel, which will then be connected to the inverter. Appropriate settings will be determined by both the team and client in order to ensure the system is calibrated correctly, and to the user's liking.

5.1.1.5 Complementary Components

Some additional components are necessary for the system to function to its full potential. Some of these components, but not all, are listed below:

- Mate3 Inverter Interface - Allows user to interact with inverter/ adjust settings
- SnapNRack Ground Mounting System - Enables solar panels to be mounted securely
- Panel Boxes - Allow electrical connections to be established and directed
- FLEXmax Solar Charge Controller - Optimizes battery charging for highest efficiency

Other components are necessary for the implementation of the system, such as construction materials, permits, and electrical components. A full Bill of Materials is available in Appendix XI.

5.1.2 Relevant Calculations

In order to determine the sizing of the system, or other terms, how much energy needs to be generated and stored, back-of-the-envelope calculations were made. These calculations were based on the expected load of a two person household, with additional consideration for higher load equipment that may be used by the client. These calculations are located in Appendix VI. Other calculations were conducted to determine the expected output of energy from the system; these calculations were done using PVWatts calculator, and give a good indication of the expected energy generation of the solar array; these may be found in Appendix III. Technical analysis were conducted by each team member, focusing on the structural stability of the mounting system, energy optimization, energy storage, and energy production and consumption.

Other calculations, including budget considerations and those regarding the bill of materials, were conducted but not recorded, as they are less significant in nature. Calculations were also conducted during the prototyping phase, specifically during energy modeling and physical prototyping.

5.1.3 Prototyping

5.1.3.1 Physical Prototyping

Physical prototyping was conducted in two iterations throughout the project. The Renewable Energy Lab was utilized in this stage; the team had the opportunity to physically interact with a solar system, and implement different components. During this prototyping, the team first tested an existing solar array, took measurements using a voltmeter, and determined that the panels were not functional. The team then deconstructed the array, and sourced functional solar panels. The solar panels were then wired, with their voltage measured. After concluding the panels were functional, the team turned on the inverter, ensuring the system was functional. Measurements from the inverter were recorded, are available to view in Appendix XIV.

5.1.3.2 Digital Prototyping

During the project, the team prioritized using digital software to analyze the system in conjunction with the house. In addition to PVWatts calculator, the team utilized Autodesk Revit to perform digital energy load estimations. A 3D CAD model of the house was created, and the software was used to calculate approximations for energy consumption, based on different factors, such as equipment, lighting, and room geometry. A more detailed explanation of the CAD energy modeling is provided in section 5.2 Design Validation.

5.2 Design Validation

To validate the scale, output, and success of the proposed design, the team was instructed to develop a comprehensive energy model for the off-grid cabin. This deliverable would serve as a replacement for the standard SolidWorks models and assemblies typically required for all ME476C teams.

After conducting various tests and research, the team determined that AutoDesk Revit would be the optimal choice for hosting the Energy Model. Revit is a comprehensive civil design program widely recognized for its professional-level designs in the private sector. Specifically, Revit features an energy model platform based on the EnergyPlus Engine. The energy analysis provided by this program includes variables such as energy requirements, HVAC loads, and solar usage analysis. Using Revit, the team was able to create a scaled house based on the provided plans, which encompass framing plans, foundation plans, electrical plans, and more. Moreover, Revit offers an extensive library of materials and components, enabling the team to construct the home with a high degree of accuracy even before the commencement of construction. Figures 9 and 10 demonstrate the front and rear facing renders of the cabin built in Revit.

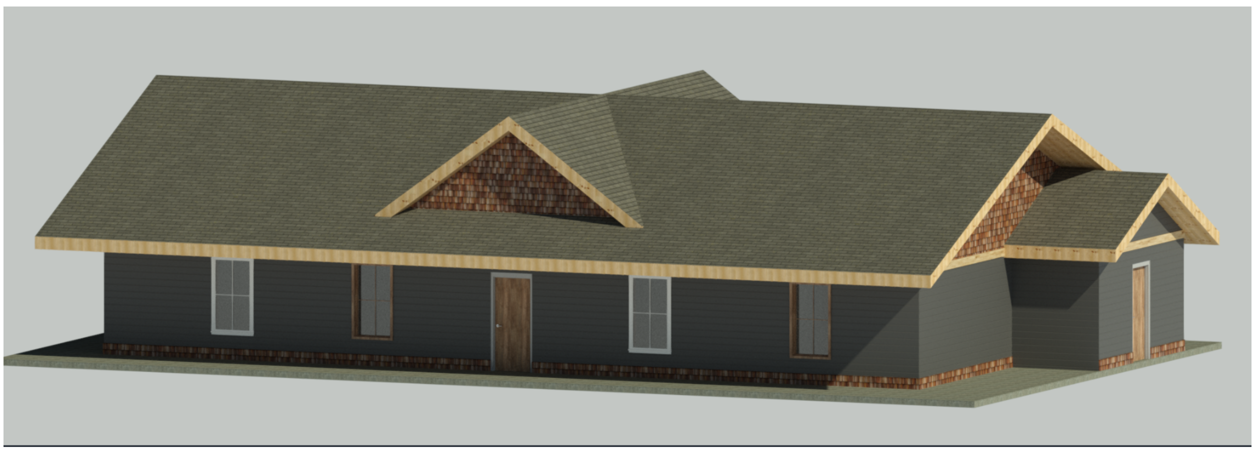

Figure 8: Front of House Render

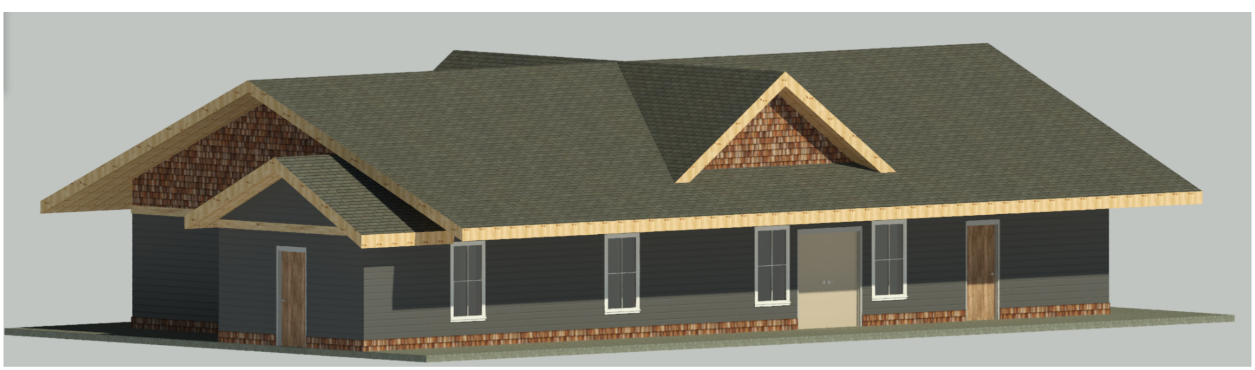

Figure 9: Front of House Render

With the house virtually created, complete with designated material types and spaces, the team proceeded to input the electrical loads that the house and PV system would experience. Autodesk Revit offers the capability to assign specific lighting, appliance, and HVAC loads to each room and space in the home. Each space was designated with its specific usage type and the average occupancy load it would have. This feature enables the program to determine which spaces, such as living rooms and bedrooms, require cooling while disregarding closets and unoccupied areas.

Revit utilizes the USDE's EnergyPlus engine to simulate the electrical, heating, and cooling loads for the house. It relies on location and weather data to simulate the house under average monthly conditions. Figure 4 displays the closest weather station accessible to Revit, which is within 5 miles of the home's location and provides excellent weather and condition data. Accuracy in specifying the location is crucial to minimize errors resulting from imperfect weather conditions. The results of the energy model are presented in Appendices XVI through XIX.

Appendix I showcases the monthly energy usage chart for the cabin, which is the most significant metric for validating the chosen design. The system must supply equal or more energy than the estimated amount to ensure the cabin does not rely on grid power. Due to technical issues, HVAC and appliances are grouped under the general category of "interior equipment." Electrical and HVAC loads were inputted based on provided specifications, assuming usage times and types in line with a residential home. The chart indicates that the PV system needs to supply at least 1400 kW of power per month to meet the simulated electrical loads. The yearly total energy consumption is calculated to be 15,500 kW. Based on this output, the team's chosen design has been validated as capable of supplying sufficient energy to the home.

Appendix XVIII presents the resulting heating and cooling loads for the home, which directly reflect the home's efficiency. Heating and cooling account for the majority of the cabin's electricity consumption. The simulation also considers heat loss from the home using the assigned material types. Air exchanges, penetrations, exterior door openings, and weather data are factored in to estimate the heating and cooling load. Revit establishes a set temperature point of 70 degrees to determine the amount of thermal energy needed to maintain a constant temperature in the simulation. It's important to note that energy usage can vary significantly depending on the occupants' preferred temperature settings. Based on these preliminary results, the PV system will meet the usage requirements of the HVAC system, even during peak heating and cooling loads. For details on heating and cooling loss through the home, please refer to Appendix XIX.

To further validate the design, the team will continue updating and refining the model to accommodate any changes in the PV system or cabin design. Next semester, as a significant part of this effort, the team plans to model the PV system in conjunction with the energy model to refine and simulate how the PV system will handle load changes and optimize any modifications to the home design that would result in meaningful energy savings.

6 Project Management – Second Semester

6.1 Gantt Chart

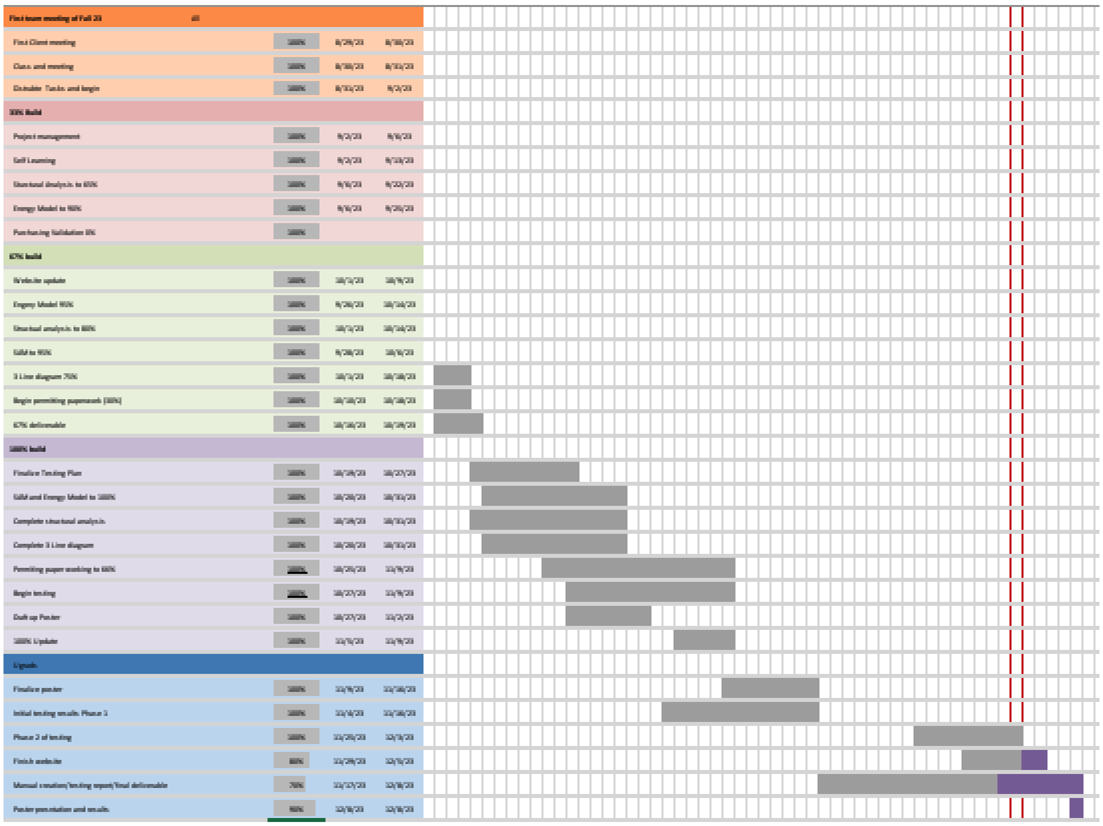

Figure 10: Gantt chart

As the semester started, our project underwent a significant transformation, transitioning into a comprehensive analytical project. Thisshift necessitated a thorough reevaluation and reconstruction of our Gantt chart to accurately reflect the altered project landscape. Subsequent to this adjustment, each newly assigned analytical task was promptly integrated into the updated Gantt chart. The initial stages of this transition proved to be a period of gradual momentum for the team, as everyone acclimated to the new demands and dynamics introduced by the analytical focus. However, once the team adjusted to the intricacies of the new tasks, a surge in productivity ensued. With a collective determination to make up for lost time during the transitional phase, the team rapidly caught up with the project schedule. From that point onward, and for the remainder of the semester, the team consistently met or surpassed project milestones. Reflecting on the experience, it is evident that the pivotal moment for improvement lay in the initial stages of the semester, specifically during the transition to an analytical project. A closer examination of this period may reveal opportunities for refining communication strategies, ensuring comprehensive skill readiness, optimizing resource allocation, and fortifying the project plan to enhance overall preparedness for future transitions of a similar nature.

6.2 Purchasing Plan and Manufacturing Plan

From an analytical standpoint, the purchasing plan and manufacturing plan is limited. The Bill of Materials was generated based on the clients needs with the help and support of Dr. Pete having ties of obtaining more cost effective materials. Most of the prices listed in Figure 11 are off the shelf prices with a few exceptions such as the inverter, racking system, and panels. This final BOM differs from the original based on the panels and the battery being used within the PV system. The energy generation is the same with more panels and less generation from each panel. The battery system is decreased by more than a half of what the recommended storage capacity should be based on client preference and reliable source of having his house tied to the grid.

The manufacturing process involved the construction and installation process of the racking system, inverter, and panels on site. Unfortunately the house construction is still in process with the team on standby, so no manufacturing was implemented.

Quantity	Item	Description	Price ($)	Total Price ($)
24	Q.Peak Duo Blk 365	QCELLS Q.PEAK DUO BLK-G10+ 365 Watt monocrystalline solar panel, 120 half cells, black frame, 25 year product warranty, 25 year linear performance warranty	$261.45	$6,275
2	SnapNrack-200 4x6-72	SnapNrack Series 200 Ground Mount System for 24 (72 cell) solar panels, 6 columns, braced with 18" wide grade beams, includes 1.5" steel pipe and rebar	$1,790	$3,580
10	Concrete	Concrete with delivery, per yard	$147.50	$1,475
1	FPR-8048A-300VDC	Outback Power Systems pre-wired inverter system, includes a Radian GS8048A-01 inverter (8000 Watt, 120/240Vac, 48Vdc), two FM100 solar charge controllers, MATE3S display and control, FLEXnet DC monitor, HUB 10, GFDI bypass assembly, 5-year warranty	$4,900	$4,900
1	Victron Lynx Power In	Vietron Power Lynx Power In 1000A distribution for parallel combining up to 5 lithium batteries, with plastic cover	$125	$125
10	4/0 Blk Battery Cable	4/0 Black UL Listed battery Cable - Price Per Foot	$12	$120
10	4/0 Red Battery Cable	4/0 Red UL Listed Battery Cable - Price Per Foot	$12	$120
4	4/0 Battery Lug	4/0 3/8 Copper UL Lug	$8.75	$35
1	Fortress eVault 18.5 Max	Fortress Power eVault Max LFP Battery, 51.2V (48V), 360 Ah, 18.5KwH total, 10-year warranty, up to 6000+ cycles	$7,000	$7,000
1	Kohler 20RCA	Kohler 20 kW Standby Generator, 20RCA, LPG or Natural Gas, 120/240Vac, Aluminum enclosure, 3600 RPM, NO OFF-GRID WARRANTY, includes freight and starting battery	$4,000	$4,000
1	Kohler Gen Pad	Kohler 3" Concrete Mounting Pad for 14/20kW Generators	$1,200	$1,200
1	Job Materials	Wire, conduit, breakers, j-boxes, etc $1500	$1,500	$1,500
1	Permit	Building Permit, Variance, or Conditional Use Permit fees		$0
24	Drawings/Permits	Drawings/Paperwork for permits and/or APS Interconnect (grid-tied only)		$0
1	Equipment Rental	Rental fees for excavation or lift equipment	$1,000	$1,000
65	Ground Mount Labor	Ground Mount Labor		$0
35	Labor	Labor, per man-hour		$0
36	Logistics	Logistical support - travel expenses, equipment handling, student support etc.	$13.88	$500
		Total		$31,830

Figure 11: Final Bill of Materials

6.3 Bonuses & Substitutions

Because the preliminary construction of the cabin will not be adequately completed by the expected deadline, Hardware Status Updates are substituted by Technical Analysis Status Updates. The technical analysis' conducted in place of these hardware updates are as follows:

- Energy Modeling: An energy analysis will be performed using technical energy modeling software. The purpose of this analysis is to determine an estimation for the expected energy loads required by the fully constructed house and its components. This tool will validate the PV system design, and help the team to optimize the system. The team will also be able to use this tool to help deliberate important information and design decisions. This stage of the analysis will involve creating a digital model of the cabin, according to the construction plans.

- Structural Analysis: A structural analysis of the mounting system and panels will be necessary to ensure the structural integrity of the system will not be compromised. This analysis will include wind loads, dead loads, and snow loads.

- Permitting Plan: A permitting plan, adhering to local standards, practices, and regulations is completed. This allows for the team to provide a streamline process for actual construction permitting for the solar array. Depending on the context of the construction, expediting this process may be an integral part of successful and timely project completion.

Due to the nature of an analytical project, certain deliverables were altered to allow the team to successfully complete the appropriate benchmarks for the course. Hardware status updates specifically were altered to incorporate the previously mentioned analysis'. Additionally, some minor details regarding the presentation of results, including the purchasing plan, manufacturing plan, and demonstrations, are altered as well. Testing however is still completed, using certain components of the Renewable Energy Lab at Northern Arizona University, as these components are the same as what the original project design calls for.

7. Final Hardware: Complete Analysis

7.1 Final Hardware Images and Descriptions

Our solar PV project's success hinges on key analytical tasks. The creation of a three-line diagram, using AutoCAD based on a single-line foundation, validated our design and bill of materials. This diagram played a pivotal role in developing a robust mock permitting set. Additionally, a comprehensive structural analysis of the panel mounting system showcases a remarkable factor of safety exceeding 10. A critical task involved crafting and securing approval for three permits: electrical, site, and panel permits. The electrical permit, referencing the 3 Line Electrical Diagram, featured callouts for the electric company and county. The site permit detailed land layout, construction areas, obstacles, and routes. The panel permit focuses on a single array, specifying series connection, grounding, and junction box association. These permits ensure regulatory compliance and safety for the seamless PV system installation.

7.1.1 Line diagram

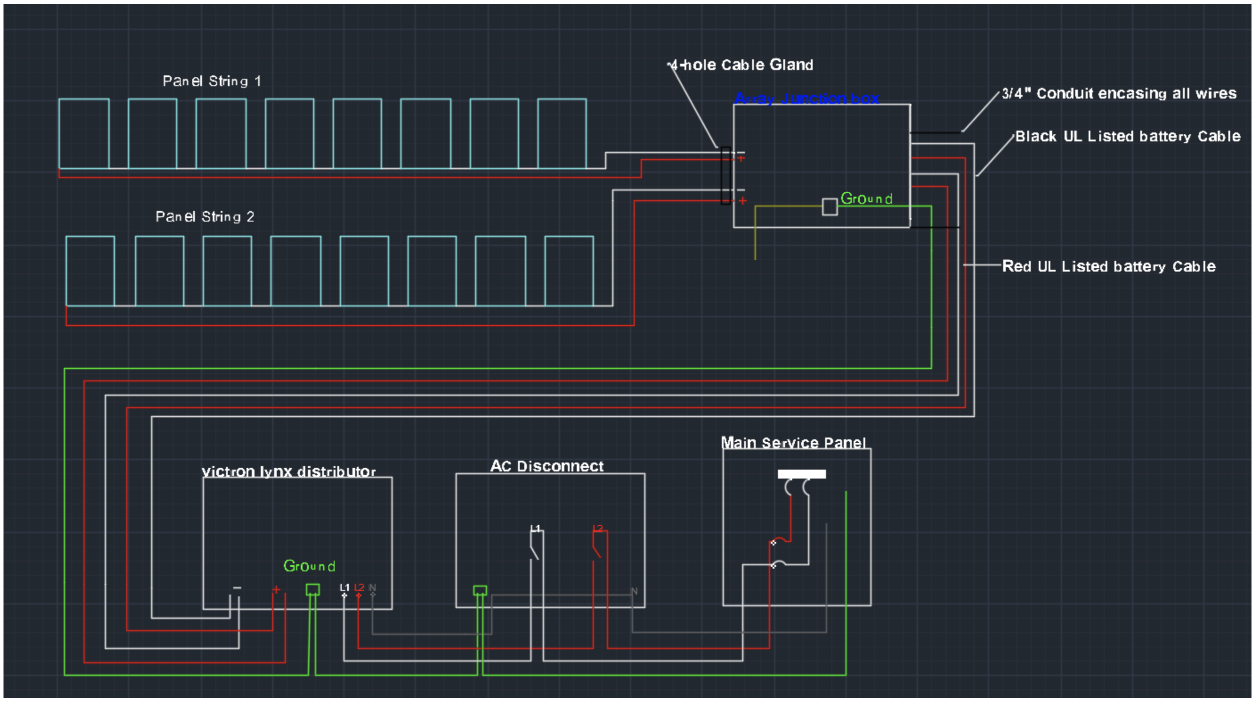

Figure 12: Final 3 Line Diagram

A pivotal analytical task that the team successfully executed involved the creation of a three-line diagram, a crucial component in validating both our design and the associated bill of materials. The meticulous construction of this diagram was facilitated through the utilization of AutoCAD, with the single-line diagram serving as the foundational blueprint. By leveraging the single-line diagram as a starting point, our team was able to craft a comprehensive representation that not only verified the accuracy of the bill of materials but also provided a visual elucidation of our design. This three-line diagram subsequently played a pivotal role in the development of our mock permitting set, contributing to the overall robustness and reliability of our project documentation.

7.1.2 Ground Mounting System Structural Analysis

A full structural analysis of the mounting system for the panels is completed, where it is determined the maximum stress incurred upon the mounting system was far exceeded by the tensile and compressive strength of the mounting system. Reaction forces from wind loads, dead loads, and snow loads were determined. A truss analysis of the system was then conducted, where the maximum stress incurred was then determined. The factor of safety for this component can be considered 10+. The full version of the structural analysis is available in Appendix IV, however, some integral equations for calculating bending and axial stress used during this analysis are shown below.

$$\sigma_{bending} = M_c / I_{xx}$$

$$\sigma = F / A_x$$

Where: M = Maximum moment I = Moment of inertia F = Force

A = Cross sectional area

Table 3: Wind Loads Summary

Wind Speed: 113 mph	Direction = 0 degrees		Direction = 180 degrees	
Load Case	Windward (psf)	Leeward (psf)	Windward (psf)	Leeward (psf)
A	-36.41	-36.41	42.48	42.48
B	-50.58	-10.12	52.60	20.23

Additionally, Solidworks Simulation is used to complete a finite element analysis (FEA) of the mounting system. This analysis is conducted for all load case scenarios, where Load Case A describes wind flow perpendicular to leading edge and Load Case B describes flow parallel to leading edge; the FEA simulation also incorporates snow loads and dead loads into each test. Figure 13 shows the results from Load Case 1B, and the full structural analysis report for the ground mounted system is located in Appendix XVIII.

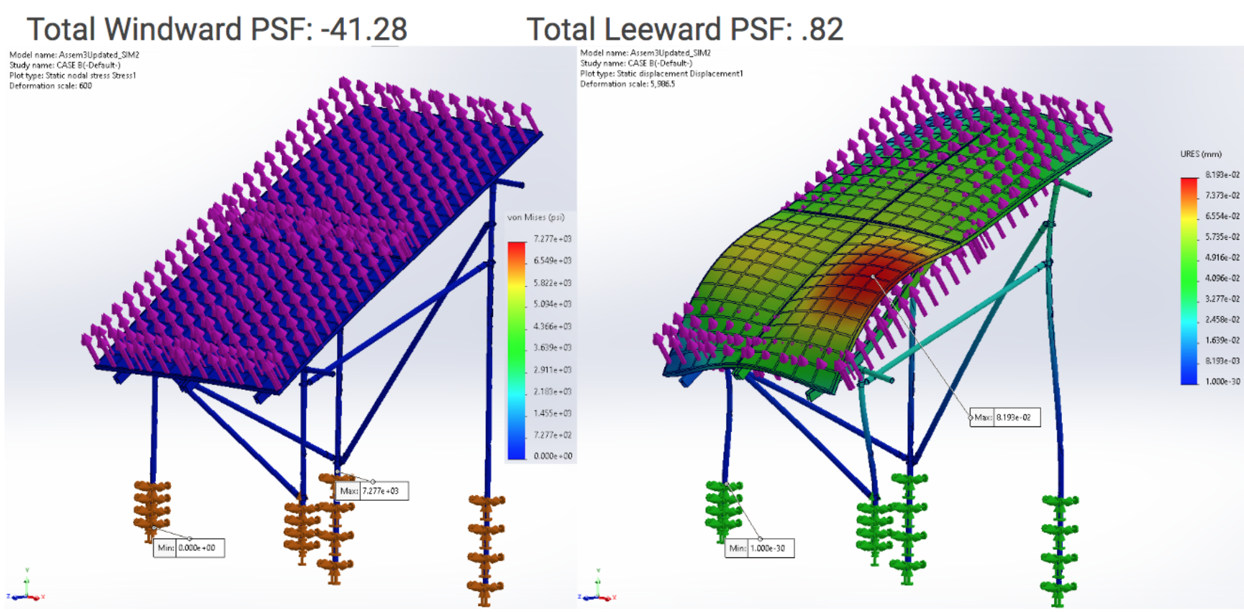

Figure 13: Finite Element Analysis for Load Case 1B

7.1.3 Electrical, Site, and Panel Permitting

Soon after the construction of the house, a permit plan needs to be approved by the county to start the installment of the PV system. The permit plan is the outline for the construction process and verifies the safety factors of the entire PV system as a whole. The three permits that were constructed consist of the electrical permit, the site permit, and the panel permit. The electrical permit plays off the 3 Line Electrical Diagram with extra call outs that are generated for the electric company and county. The site permit shows the area and layout of the land. It demonstrates where everything will be constructed, all the obstacles in the area, and the routes taken to get to both the house and the panel layout. The panel permit shows one array of the 12 panels in series, grounded, and connected to the junction box.

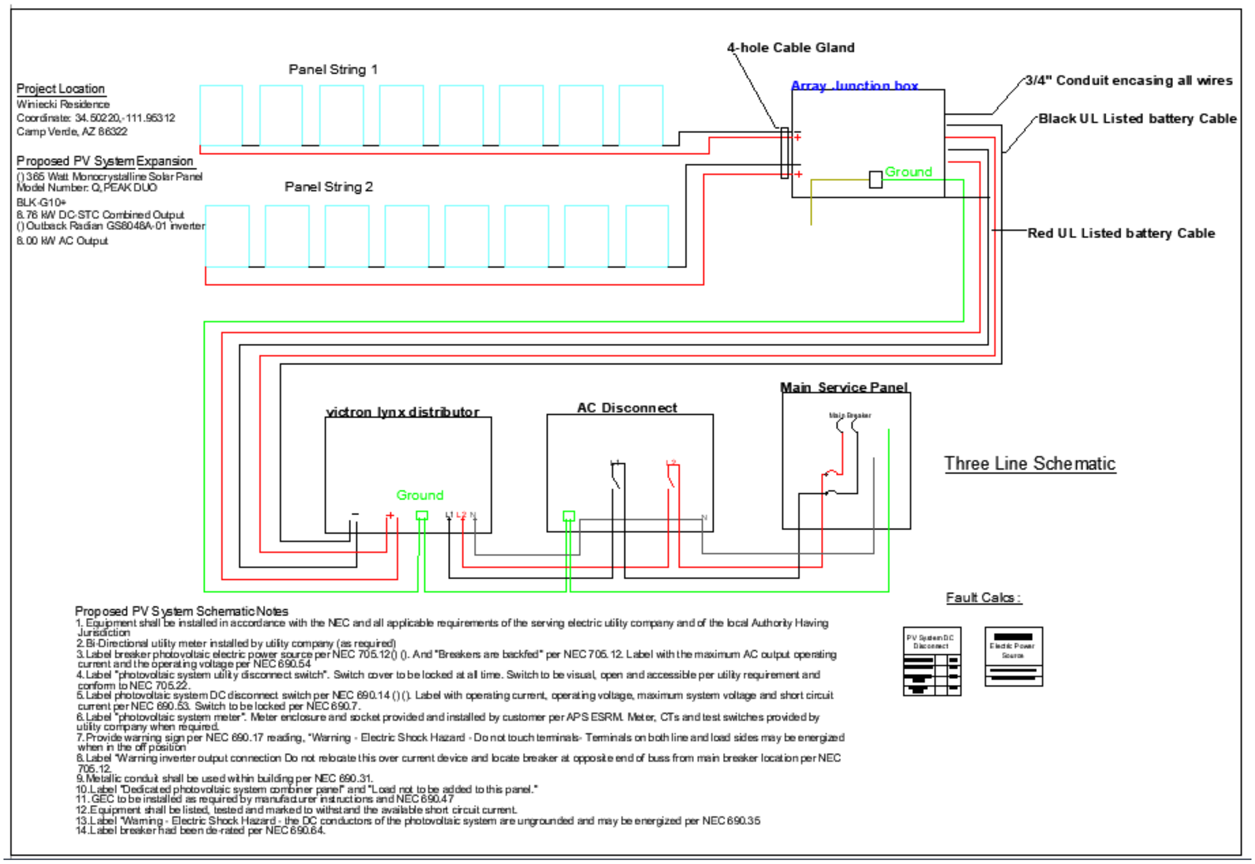

Figure 14: Electrical Permitting Diagram

The main takeaways from the permit are the schematics established below for the utility company. There are additional codes that call out the recommended set up in case repairs and other services are needed.

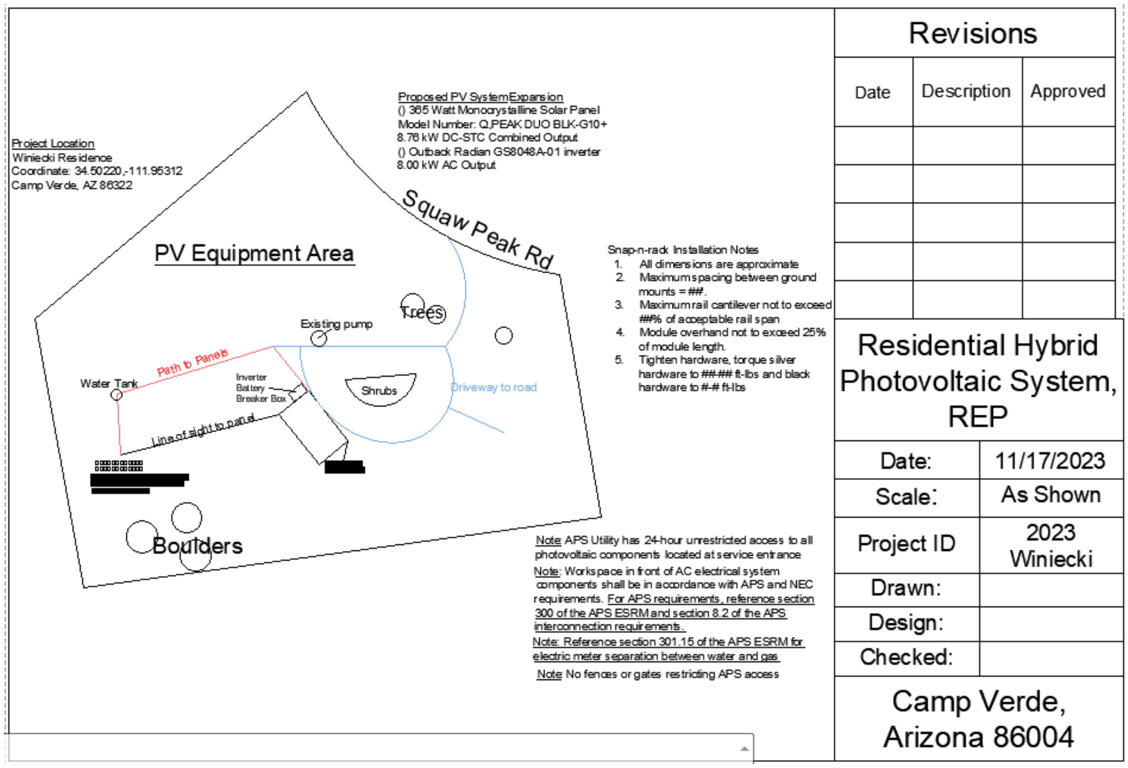

Figure 15: Site Permit

From Figure 15, the main takeaway is the location and surrounding obstacles that are present. It provides a good lay of the land with the space needed to construct everything.

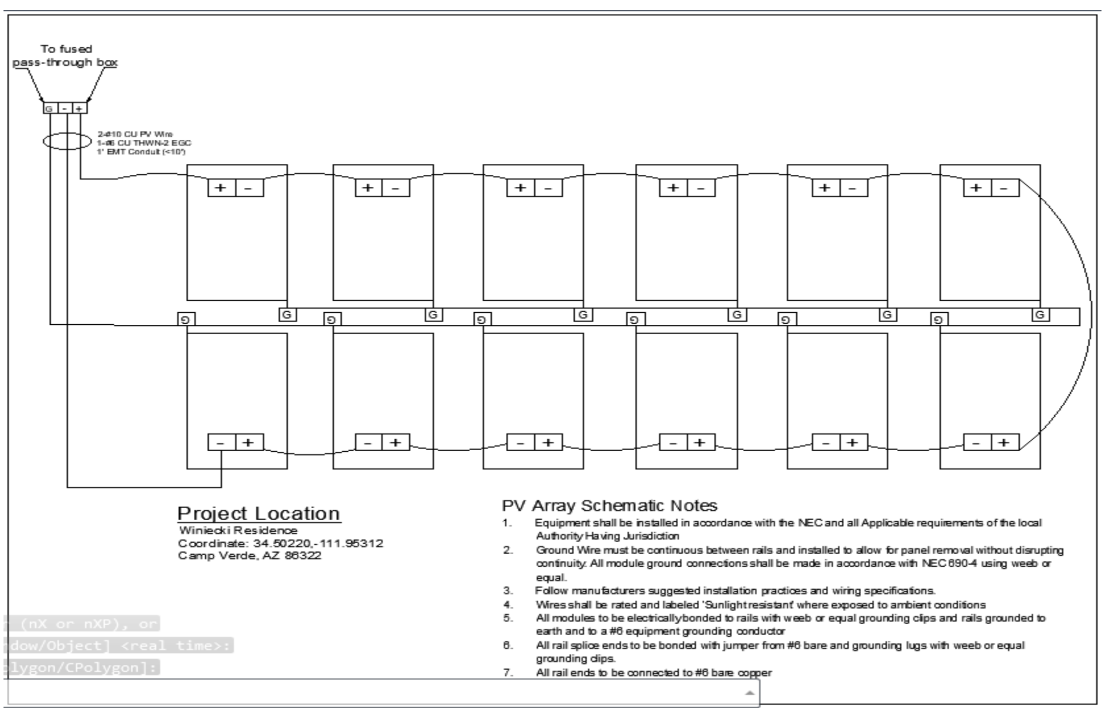

Figure 16: Panel Permit

7.2 Design Changes in Second Semester

Due to an analytical conversion of the project, client specification changes and software difficulties, several iterations to the project and design were required to finalize the design. The iterations listed below were implemented during the second semester to ensure the correct and timely completion of the analytical project.

7.2.1 Design Iteration 1: eQuest Energy Model

Autodesk Revit was initially used to generate the first energy models to define the system scale. However, due to difficulties with the program and inconsistent results, the team decided to move to a different modeling system to ensure correct data. The new program is called eQuest. It is the Department of Energy's in-house modeling software and uses the same simulation engine as Revit. Using the new software, the house was built from the provided blue prints. While the software is more basic and the graphics are outdated, the results from the simulation were accurate, reliable and trustworthy. The rendered house can be shown in Figure 17.

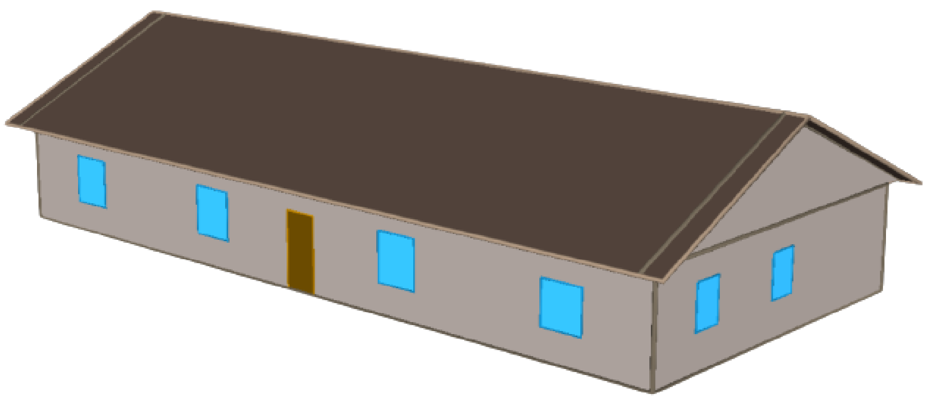

Figure 17 : Equest Render

Using eQuest, the team was able to model and simulate two usage scenarios of the house. The first scenario is an expected demand simulation. This simulation was based on expected usage values for 2 energy conscious inhabitants with electrical efficient appliances and habits. The results of this simulation was an annual consumption of 9,300 kWh. This is well inside the production of the panel system and validates existing calculations and material selections. The output of the analysis can be seen in Figure 18 and Figure 19 .

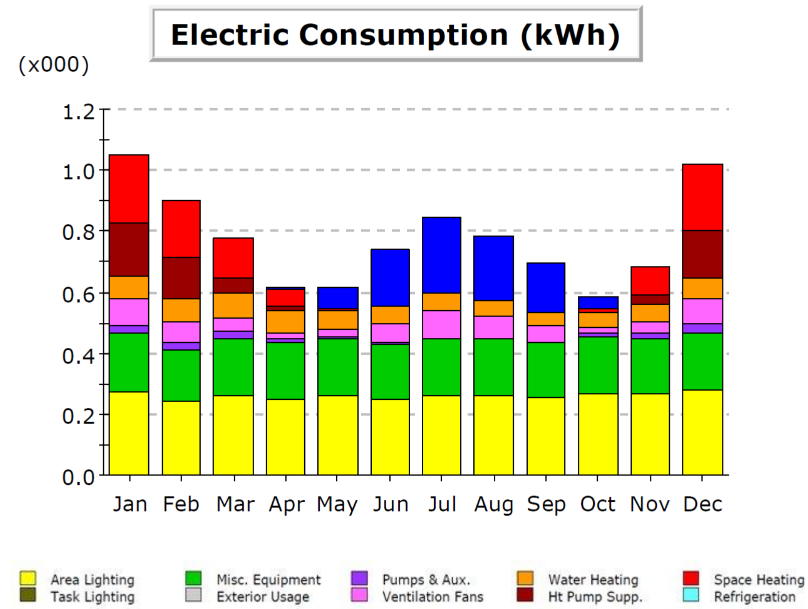

Figure 18: Expected Consumption Chart

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	0.00	0.07	0.18	0.25	0.21	0.16	0.04	0.00	-	0.91
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	0.22	0.19	0.13	0.06	0.00	-	-	-	-	0.01	0.09	0.22	0.93
HP Supp.	0.18	0.14	0.05	0.01	0.00	-	-	-	-	0.00	0.03	0.16	0.58
Hot Water	0.07	0.07	0.08	0.07	0.07	0.06	0.05	0.05	0.05	0.05	0.06	0.07	0.74
Vent. Fans	0.08	0.07	0.04	0.02	0.02	0.06	0.09	0.07	0.06	0.02	0.03	0.08	0.66
Pumps & Aux.	0.03	0.03	0.02	0.02	0.01	0.00	0.00	-	0.00	0.01	0.02	0.03	0.17
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	0.19	0.17	0.19	0.18	0.19	0.18	0.19	0.19	0.18	0.19	0.18	0.19	2.21
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.28	0.24	0.26	0.25	0.26	0.25	0.26	0.26	0.25	0.27	0.27	0.28	3.12
Total	1.05	0.90	0.78	0.61	0.62	0.74	0.85	0.78	0.70	0.59	0.69	1.02	9.32

Figure 19: Expected Consumption Data

Additionally, to create an extreme case scenario, the team simulated the energy usage of the home assuming an extremely high demand. This was calculated with extensive HVAC usage and minimal regards to energy conservation. The simulation represented a fully occupied house and near maximum energy demand case. The result of the analysis, shown in Figure 20, demonstrates a yearly demand of 15,230 kWh. This use case assisted the team during the late stage design process to ensure that the panel system will meet and exceed any use case.

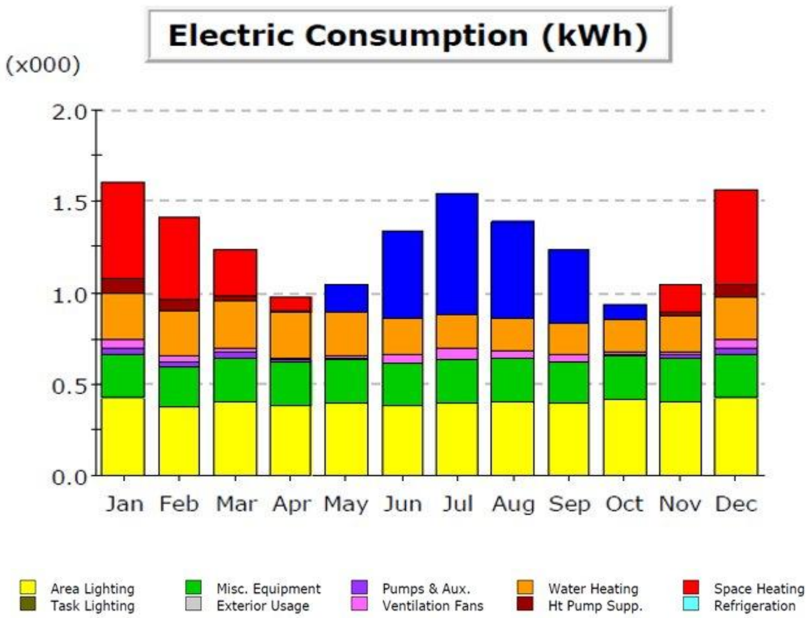

Figure 20 : High Demand Simulation Results

7.2.2 Design Iteration 1: System Advisory Model

Following the transition from Revit, the System Advisory Model (SAM) focused on the energy production of any PV system depending on the panels and inverter. With all the information at hand, plugin in the numbers for the model to run became simple. The way that this model was utilities was primarily with a fixed system. The angle that was best used for one fixed position all year round was a 30 degree angle.

Metric	Value
Annual AC energy in Year 1	15,652 kWh
DC capacity factor in Year 1	20.4%
Energy yield in Year 1	1,787 kWh/kW
LCOE Levelized cost of energy nominal	9.18 ¢/kWh
LCOE Levelized cost of energy real	7.33 ¢/kWh
Electricity bill without system (year 1)	$1,514
Electricity bill with system (year 1)	$1,514
Net savings with system (year 1)	$0
Net present value	$-13,512
Simple payback period	NaN
Discounted payback period	NaN
Net capital cost	$26,032
Equity	$0
Debt	$26,032

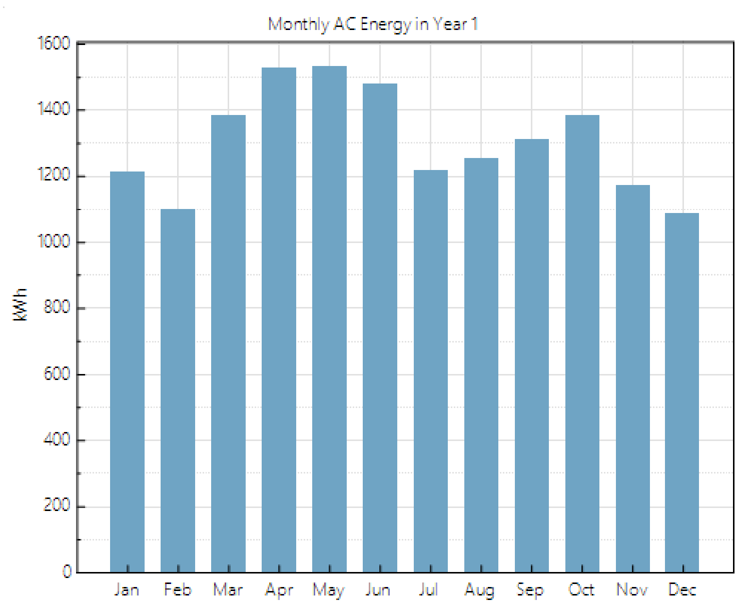

Figure 21: 30 Degree Fixed Angle System

The team decided that an optimized angle could be generated if the racking system was capable of rotating to 2 different angles throughout the year. The two times throughout the year that the panels should be moved are the beginning of summer and beginning of winter, March 15 and September 15. During the summer months the angle should be propped to 11 degrees while in the winter months the angle should show 50 degrees. With these small changes throughout the year, the energy generation will increase by 1000 kWh.

1						
2	Tilt angle of 11 degrees		Tilt angle of 50 degrees			
3	Time stamp	System power generated | (kW)	Time stamp	System power generated | (kW)		16474.28
4	1/1/2023 0:00	0	1/1/2023 0:00	0	0	
5	1/1/2023 1:00	0	1/1/2023 1:00	0	0	
6	1/1/2023 2:00	0	1/1/2023 2:00	0	0	
7	1/1/2023 3:00	0	1/1/2023 3:00	0	0	
8	1/1/2023 4:00	0	1/1/2023 4:00	0	0	
9	1/1/2023 5:00	0	1/1/2023 5:00	0	0	
10	1/1/2023 6:00	0	1/1/2023 6:00	0	0	
11	1/1/2023 7:00	0	1/1/2023 7:00	0	0	
12	1/1/2023 8:00	1.3899	1/1/2023 8:00	2.34156	2.34156	
13	1/1/2023 9:00	1.88859	1/1/2023 9:00	2.57784	2.57784	
14	1/1/2023 10:00	1.82377	1/1/2023 10:00	1.90319	1.90319	
15	1/1/2023 11:00	3.47589	1/1/2023 11:00	4.31585	4.31585	
16	1/1/2023 12:00	5.00151	1/1/2023 12:00	6.84603	6.84603	
17	1/1/2023 13:00	3.0621	1/1/2023 13:00	3.67019	3.67019	
18	1/1/2023 14:00	0.815271	1/1/2023 14:00	0.62859	0.62859	
19	1/1/2023 15:00	0.49281	1/1/2023 15:00	0.381348	0.381348	
20	1/1/2023 16:00	1.28773	1/1/2023 16:00	2.73373	2.73373	
21	1/1/2023 17:00	0	1/1/2023 17:00	0	0	
22	1/1/2023 18:00	0	1/1/2023 18:00	0	0	
23	1/1/2023 19:00	0	1/1/2023 19:00	0	0	
24	1/1/2023 20:00	0	1/1/2023 20:00	0	0	
25	1/1/2023 21:00	0	1/1/2023 21:00	0	0	
26	1/1/2023 22:00	0	1/1/2023 22:00	0	0	
27	1/1/2023 23:00	0	1/1/2023 23:00	0	0	
28	1/2/2023 0:00	0	1/2/2023 0:00	0	0	

Optimized | Summer degrees | Winter Degrees

Figure 22: 50-11-50 Degree Angle System

7.2.3 Design Iteration 1: Battery Capacity Change

The team was notified during the start of the second semester that the house will no longer be an off-grid cabin and that grid power from APS will be connected to the house. While the existing design is not affected by the change due to an inverter setting that prevents backfeed, the customer requested to reduce the battery storage to just 1 day. This new requirement halved the expected battery storage from 2 contained systems down to 1. The result of the change can be seen in the updated BOM and reduced the cost of the overall system design.

7.3 Hardware Challenges Bested

This project is to be considered as an analytical project with no construction or hardware involved related to the system design. No issues were encountered.

8 Testing Plan

This multifaceted project involves three crucial experiments aimed at optimizing solar photovoltaic (PV) systems, each grounded in specific theories. Firstly, the analysis of tilt angles leverages the theory that the orientation of solar panels significantly affects energy generation. By measuring irradiance at different angles, we validate design decisions based on the relationship between tilt angles, power output, and irradiance. In the second experiment, comparing ground-mounted and roof-mounted systems aligns with the theory that panel temperature influences the efficiency and production of PV panels. This investigation, conducted under controlled conditions, delves into the impact of mounting styles on voltage and current values, providing insights into system optimization.Lastly, the inverter management experiment is guided by the theory that understanding and interpreting inverter signals is crucial for system maintenance. The step-by-step guide, rooted in the inverter manual, aims to empower users to connect the inverter effectively and comprehend emergency protocols, contributing to overall system reliability. Together, these experiments and their underlying theories form a comprehensive approach to advancing the efficiency and functionality of solar PV systems for hybrid applications.

8.1.1 Irradiance Summary

The objective of this project is to qualitatively measure, assess, and determine the influence of tilt angle in regard to a solar photovoltaic (PV) system. This project will be conducted in accordance with a ME 486c Capstone project, which involves the design of a photovoltaic solar system for hybrid application. The angle at which a solar panel is positioned in relation to the sun, both azimuth and vertical, directly affects the amount of energy generated by the panel. Students from the Renewable Energy Project in ME 486 have conducted design and optimization of a solar PV system, and calculated an optimal tilt angle for the panels at a specified location. Within this project, the irradiance at specified angles will be determined, with the respective voltage and current output of the panel, where a consequent relationship between irradiance and output power will be determined. This project will help validate the team’s design decisions, and quantify the relationship between tilt angle and power output. The design requirements being tested will be increasing efficiency, and increasing energy generation. In order to conduct such tests, some simple equipment is necessary. To measure the irradiance at the panel, a pyranometer will be used in conjunction with a data acquisition module. To measure both the output voltage and current, a simple voltmeter will be used. A tabulated version of this Bill of Materials is located below in Table 4.

Table 4: Bill of Materials for Test 1

Component	Measurement Variable	Cost
Solar Panel	N/A	Provided
Pyranometer	Irradiance	Provided
FLUKE 45 Multimeter	Current/ Voltage	Provided
Protractor	Angle	$3
RIGOL DL3021	Current/ Voltage/ Resistance	Provided

8.1.1.1 Irradiance Testing Procedure

This project will be conducted to two students and the Renewable Energy Laboratory, located at Northern Arizona University. With the objective of determining a relationship between panel tilt angle, power output, the irradiance of the panel must be measured at specified azimuth and vertical angles. Because the irradiance is in direct relation to the sun location, measurements must be conducted within the same hour for greater precision, although the constant movement of the sun will be a source of systematic error.

Once measurements are ready to be conducted, the panels will be placed in a fixed azimuth location, where the vertical angle will be varied in small increments of 10 degrees. The vertical tilt angle will be measured from a range of 10 to 90 degrees with the ground. The irradiance of the panel will be measured at each interval, as well as the output voltage and current of the panel.

Next, the vertical tilt angle will be fixed at a specified angle of 30 degrees to the ground. The azimuth angle will be varied from 120 to 240 degrees, in increments of 10 degrees. Again, the irradiance, output voltage, and output current of the panel will be measured at each interval. Fixing each variable and testing them individually will provide ease of measurement, allowing the team to complete the testing in a relatively short time frame, increasing the consistency of the measurement conditions. Once the data is collected, correlations among tilt angle, output voltage, current, and irradiance will be determined and compared to the optimized tilt angle previously determined by the Renewable Energy Project team.

8.1.1.2 Irradiance Test Expect Results

Relating the measurements to theoretical calculations will be an important factor for this experiment. Using the following relationships, power can be calculated in two different ways.

$$P = I_{irrad} * A * \eta$$

$$P = IV\eta$$

P = power

I_{irrad} = irradiance

A = panel surface area

I = Current

V = Voltage

η = panel efficiency

With some approximations for the experiment variables, the expected power output is 250-300 Watts.

8.1.2 Panel Heat Efficiency Test Summary

Solar panels use semiconductors to convert photons into electrons for energy generation. These semiconductors are affected by the temperature of the panel. Thus, the efficiency and production of the panel is correlated to the temperature of the panel. To maximize efficiency of a system, it is important to compare the two mounting styles through an experiment and analysis. This experiment will simulate and compare a ground mounted and a roof mounted solar system. The objective of this experiment is to find the correlation and effect that panel temperature has on a photovoltaic system's voltage and current values as well as the effects of panel age on total power output.

8.1.2.1 Panel Heat Efficiency Testing Procedure

The plan for this experiment is to utilize materials available to the team from both Dr. Dou and Dr. Pete. The experiment will take place at the Renewable Energy shed. The solar panels, provided by Dr. Pete, will be 2 identical panels and will be measured for similarity on-site. One panel will be ground mounted at a pitch that matches that of the roof of the shed. The second panel will be mounted to the roof of the solar shed, without penetrations, on an existing roof mount. The goal is to have the panels start the test at the same temperature and then every minute over a 30 minute period, a temperature measurement of the panel will be taken along with the voltage and current outputs. A high accuracy laser temperature gun will be used to find the surface temperature of the panel, and a high accuracy voltmeter will be used for the output of the panel. After the data has been collected, excel will be used to track the performance vs temperature data throughout a peak sun exposure period.

Table 5: Bill of Materials (Test 2)

Item	**Description**
Qty 2, 20 Watt Solartech Panels	Provided by Renewable Energy Lab
Klein Tools IR1 IR Temperature Gun	Provided by Renewable Energy Lab
Fluke 87 III Multimeter	Provided by Dr. Pete
Timer	Will use phone timer
Empire Polycast Magnetic Protractor	Acquire to match roof angle
Qty 4, 6 Foot Alligator clip leads	Provided by Renewable Energy Lab

8.1.3 Inverter Summary

The goal of this test is to completely give a step by step guide to the client in order to understand the system so that he will be able to maintain and understand what the inverter is communicating to its user. Since the inverter that will be used is the same as the inverter located within the Renewable Energy Laboratory here at NAU, the team has read and has a better understanding to communicate with the client with what the inverter will be relaying.

8.1.3.1 Procedure

.GIP File Installation for Grid Support

To enable Grid support functionality in different parts of the world, it may be necessary to update the inverter firmware. The .ZIP files for update can be downloaded from the **Radian Grid Support** section of the **Firmware Update** page at **www.outbackpower.com**. Each .GIP file available with an update contains a "package" of grid support settings associated with different utility companies or regional standards.

IMPORTANT:

- The MATE3s system display is required for this process.
- Make certain to extract (unzip) all the files before loading all of the contents onto the MATE3s. If the files are loaded to the card in compressed form, they will be unusable.
- These contents contain a Readme text file which is necessary to the instructions below.

To install Grid Support .GIP Files:

1. Perform a firmware update as noted above.

   NOTES:

   - The MATE3s should be revision 1.001.000 or higher for grid support functionality.
   - For grid-interactive parameters, the Installer Password is required and may need to be changed from the default setting of **1732**. See the *MATE3s Programming Guide* for more information.

2. From the MATE3s ***Main Menu*** (**A** in Figure 35), choose ***Firmware Update*** (**B**) and then ***GS Inverter*** (**C**). The display will show that new firmware is present. (The revision should be 001.006.063 or higher.) Press ***Update*** (**D**) to download this firmware into the Radian inverter.

Figure 23: Grid Support Breakdown

From the inverter manual, simple step by step guides are already in place showing the user how to connect the inverter to its designated area. Figure 23, shows the guide of how to set up the inverter with the grid support services. In case of emergencies this signal will be sent to the support team so that the grid will stop sending electricity to the inverter to not cause a larger problem.

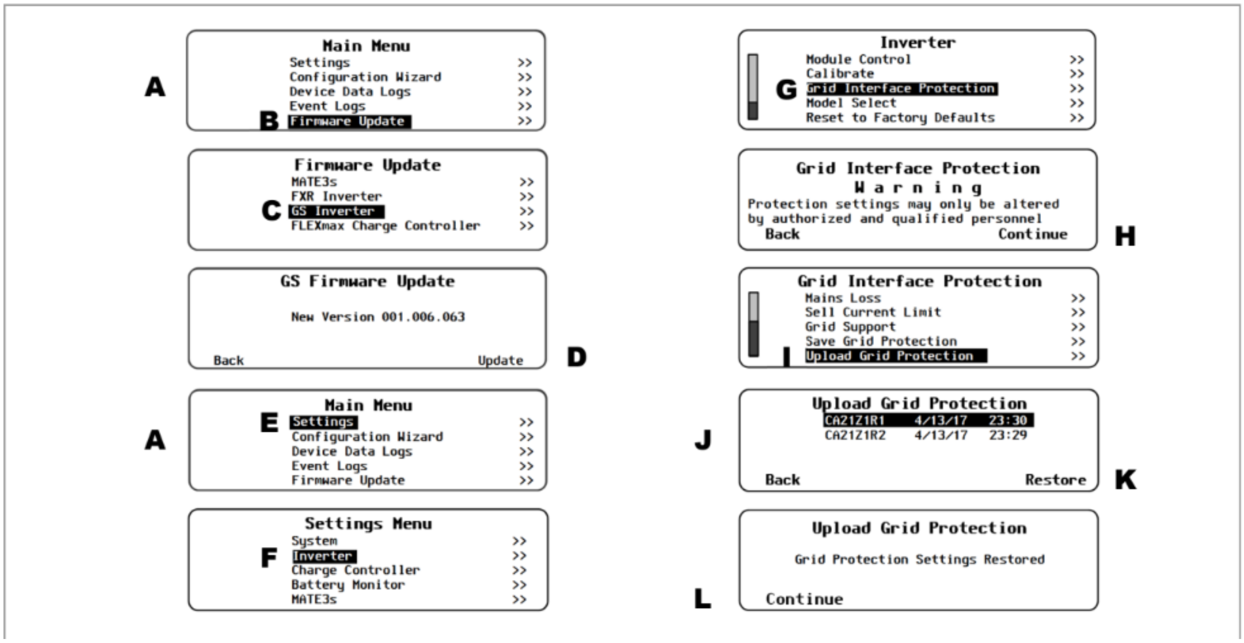

Figure 24: Grid Support Step by Step Guide

The step by step process is demonstrated within Figure 24 that has its own flow chart. As long as the user is able to see the same screen as it shows within the flow chart he should be able to create that connection with the grid support team.

8.2 Testing Results

8.2.1 Irradiance Testing Results

Test 1 resulted in I-V curves, power curves, and some efficiency data, all of which displays the consequent relationships among tilt/ azimuth angle and power. Figures 25-26 show the resultant plots for each subtest.

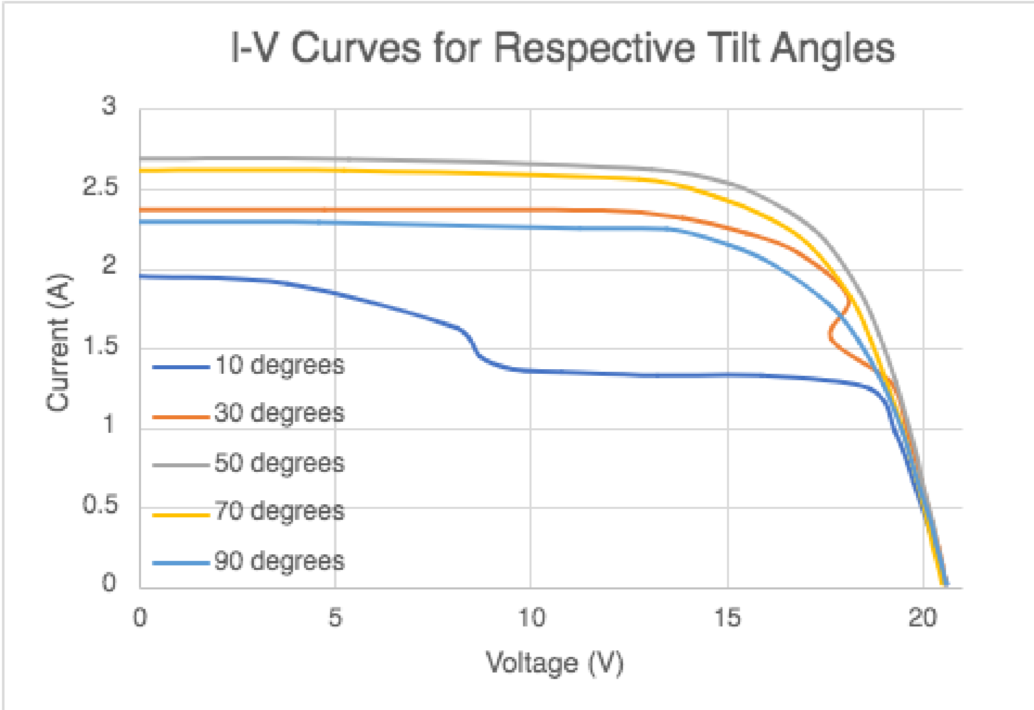

Figure 25: IV Curves for Varying Tilt Angles

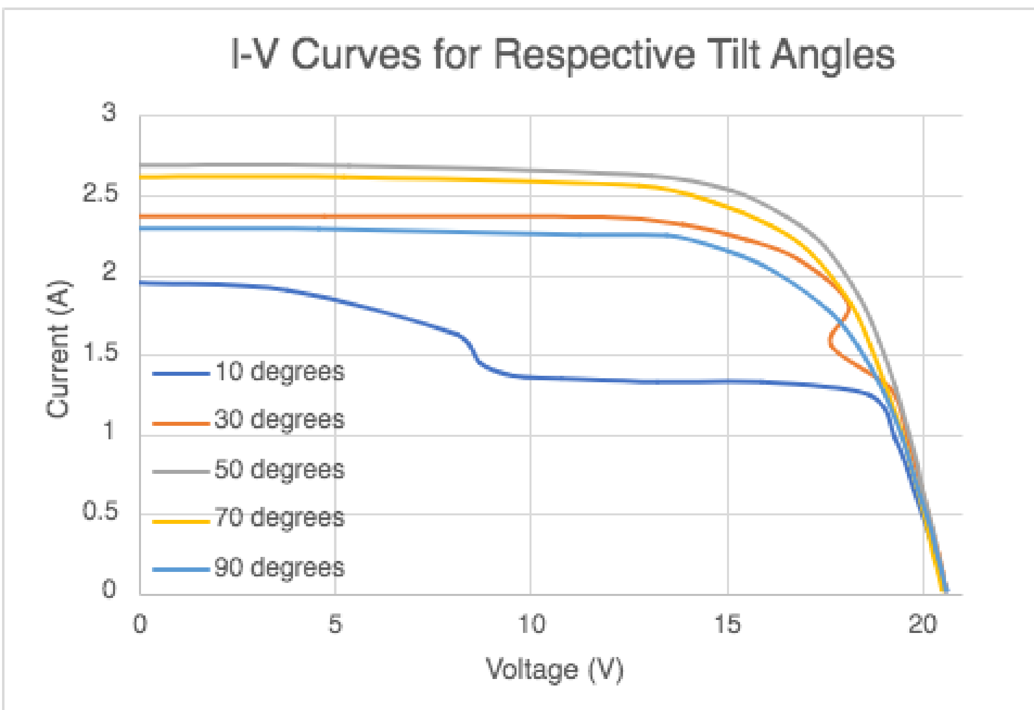

Figure 26: Power Curves for Varying Tilt Angles

As seen in the plots for varying tilt angle, a dynamic exists where there is a maximum power output at a specific, distinct tilt angle. From the test, it can be seen that this occurs at a tilt angle of 50 degrees. When considering the time of year (winter) and latitude of the testing location (Flagstaff, AZ) this data is validated by observation. A similar trend is observed when analyzing the azimuth of the panels, whose plots are displayed in Figures 27-28.

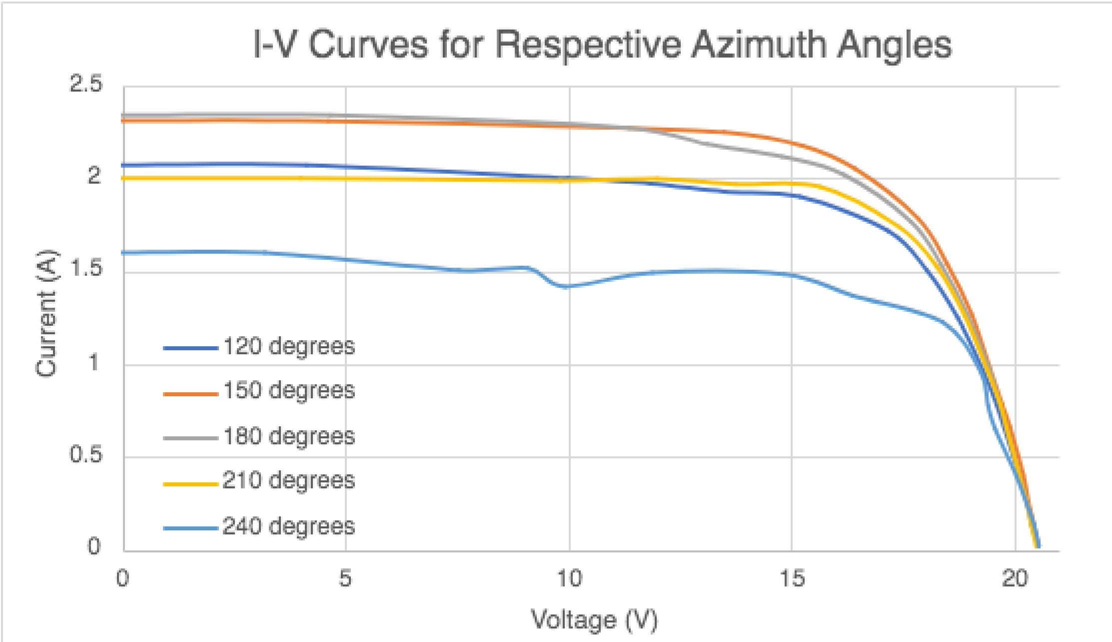

Figure 27: IV Curves for Varying Azimuth Angles

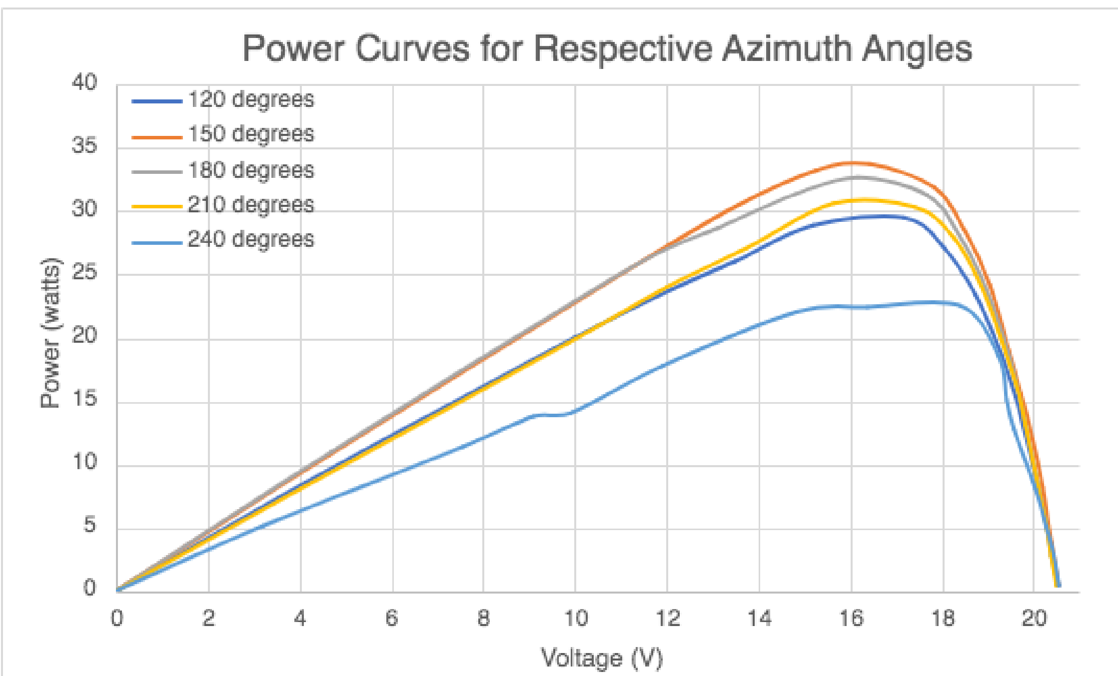

Figure 28: Power Curves for Varying Azimuth Angles

Again, a similar and distinct angle provides a maximum power output, as seen before. In this scenario, this maximum power output occurs at 150 degrees SE. This data, by observation, correlates to the expected maximum irradiance received for the time of year and location testing is conducted, again being Flagstaff, AZ during the winter.

Through conducting the aforementioned tests, the team is able to conclude that there does exist a certain tilt and azimuth angle for which power output is maximized. This enables the team to further optimize the system for its projected location and expected loads.

Additionally, irradiance data is collected using a pyranometer, at varying azimuth and tilt angles. This data further validates the concept that a specific, distinct array configuration in relation to the sun will result in a maximized power output. Overall system efficiency is also calculated, however a relationship between tilt angle and panel efficiency is not readily apparent. Figures 29 and 30 show the plots relating azimuth and tilt angle, respectively, to irradiance and panel efficiency.

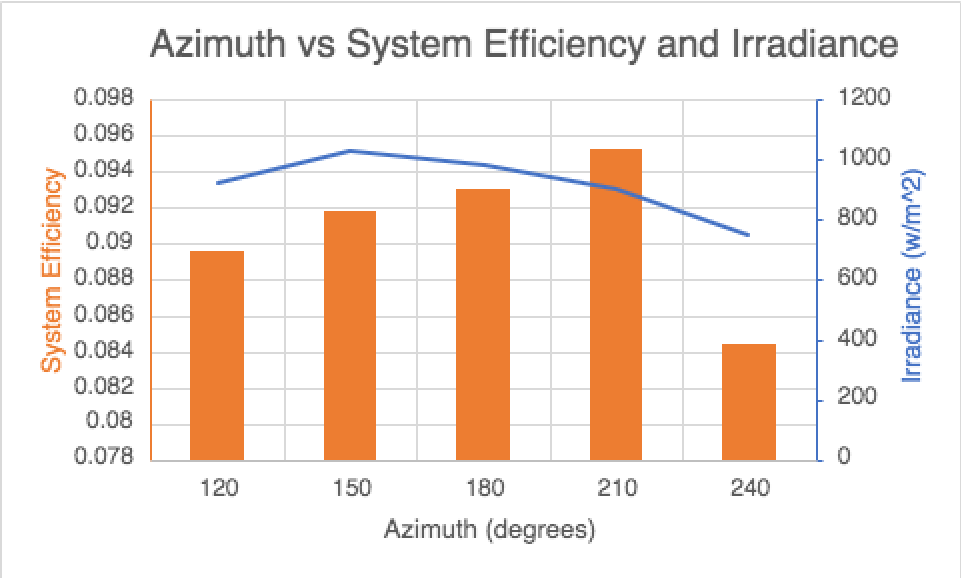

Figure 29: Azimuth vs Irradiance and Efficiency

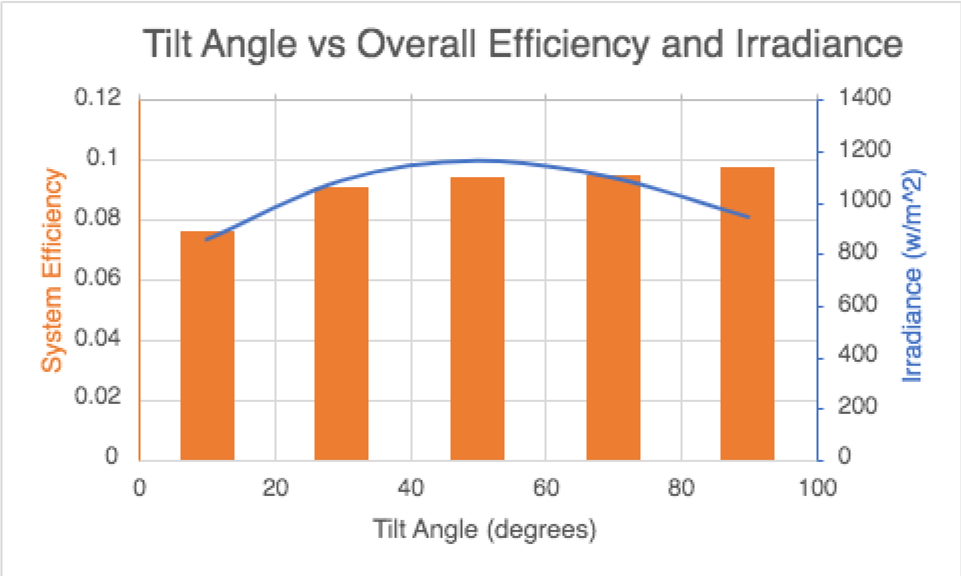

Figure 30: Tilt Angle vs Irradiance and Efficiency

8.2.2 Panel Heat Efficiency Testing Results

The goal of the test is to ultimately prove that a ground mounted system is more efficient as it allows the panels to passively cool. Semiconductors operate more efficiently at lower temperatures and result in higher panel efficiencies. Figures 31 and 32 demonstrate the drastic effect that the mounting style has on overall panel temperature. The roof mounted panel reached a maximum temperature of 111 F while the ground mount panels reached a maximum of 78 F. This is a temperature delta of 33 degrees when the exterior temperature was recorded at 73 degrees Fahrenheit.

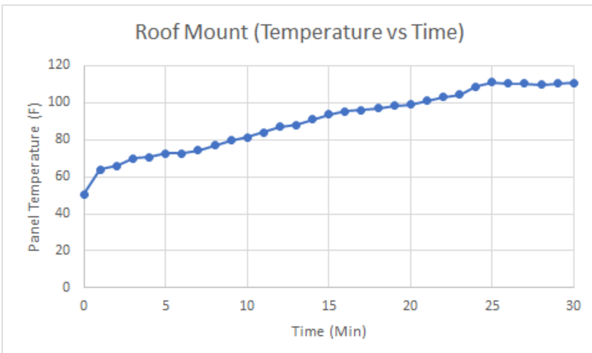

Figure 31 :Roof Mount Temperature

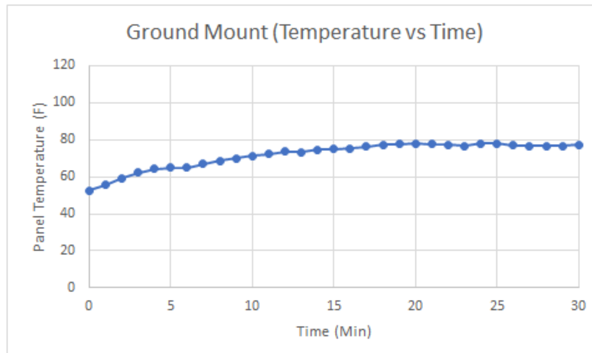

Figure 32: Ground Mount Temperature

Additionally, the short circuit Amps and open circuit Volts were measured directly from the leads of the panels. It was shown that the temperature of the panel had a drastic effect on the output voltage. Both Voltage and Current have linear relationships with temperature. The coefficient of Voltage was found to be 0.302%/℉. Figures 33 and 34 demonstrate the effect of temperature on both current and voltage.

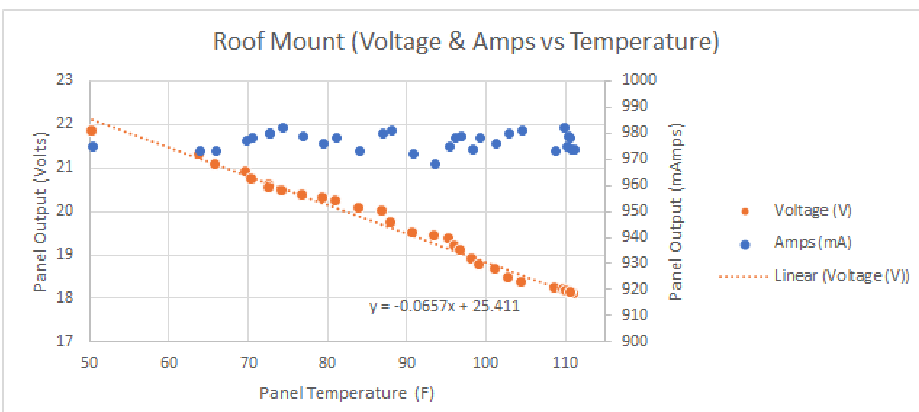

Figure 33 : Effects of Temperature (Roof Mount)

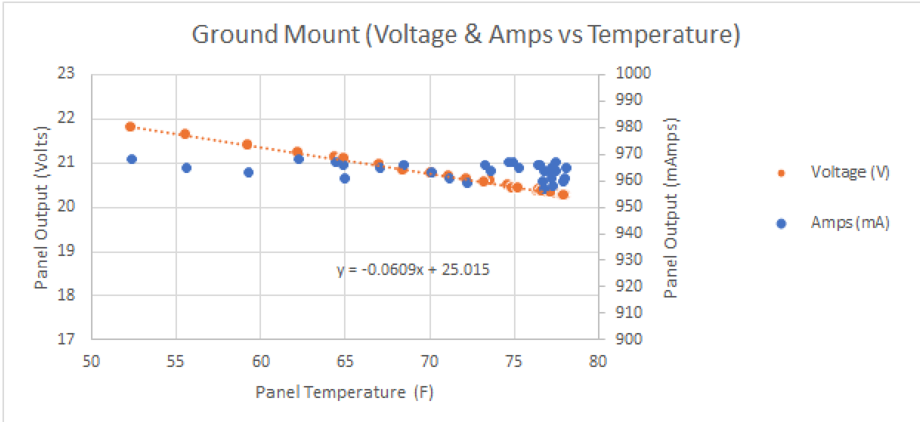

Figure 34: Effects of Temperature (Ground Mount)

Using the specified IR curve from the panel manufacturer, shown in Appendix XIX, the actual power of the system was able to be calculated from a linear regression model within MatLab. This code took the Voc and Isc data from the panel test at normal operating temperature and calculated the actual voltage and current values as well as the actual power output of the solar cell. Shown in Figure 35, the actual production of the cell was found to equal 13.11 Watts. The panel has only 65% of its original efficiency after 25 years of use. This equates to 1.4% drop in efficiency per year on average.

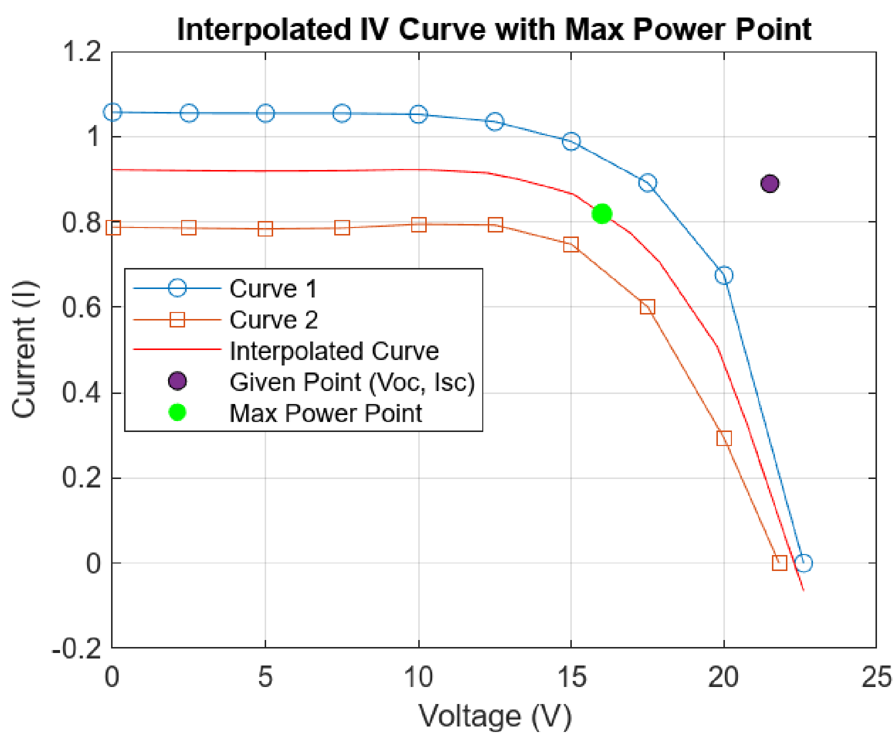

Figure 35: Interpolated IV Curve

8.2.3 Inverter Testing Results

Understanding how to turn on the inverter, running the search function and reading the power going in and out. The turn on process involves pressing the inverter button and pressing the on or search button. For this client, the on button will be sufficient enough since the entire house will be connected to the inverter as it is also connected to the grid. If the inverter was not connected to the grid, some of the outlets would be taking power directly from the grid and not from the solar panels. The search function ultimately determines which outlets are connected to the inverter and won't send power to that outlet unless an amperage over 0.6 amps is needed. The on function will send current throughout the entirety of the house and power everything regardless of how much amperage is needed.

Figure 36: Lights connected to the Inverter

Figure 36 shows the lights that are connected to the inverter. The colored ones use less amperage than the clear lights. They increase in brightness and amperage from left to right and front to back. The darker lights won't run alone when the inverter is on search mode because the amperage is less than 0.6 amps but they will blink to notify the user that it is connected to the inverter.

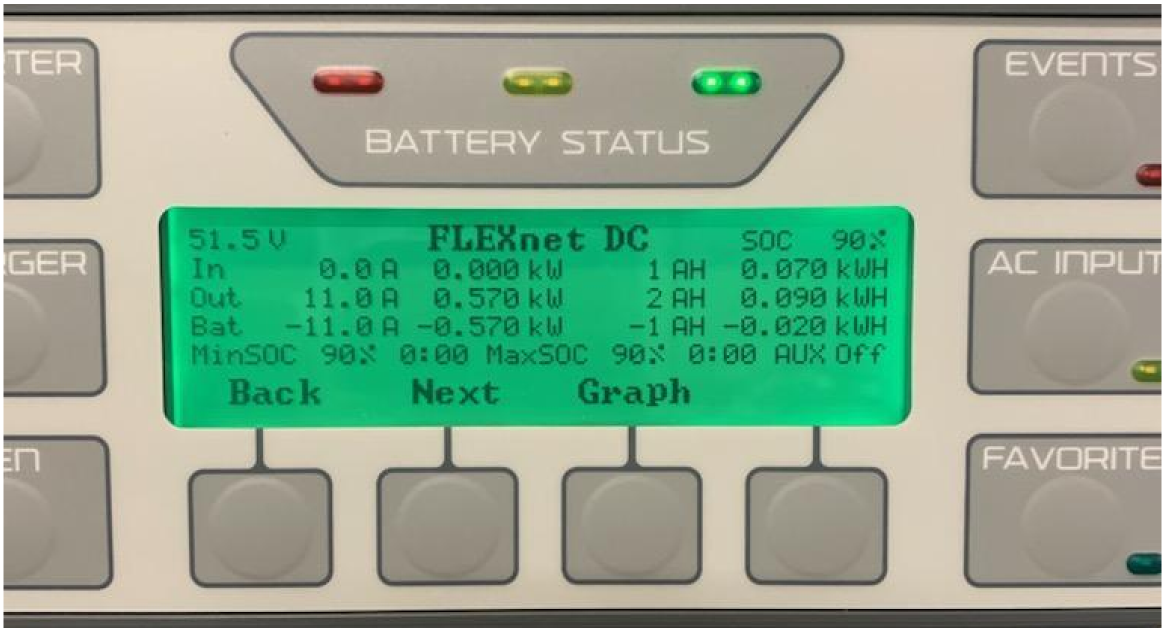

Figure 37: Generation and Consumption

Figure 37 demonstrates the power being generated, being consumed, and the amount of stored energy within the battery. There is an ability to see what it looks like graphically over time but needs to be running for a few hours before reasonable calculations can be obtained.

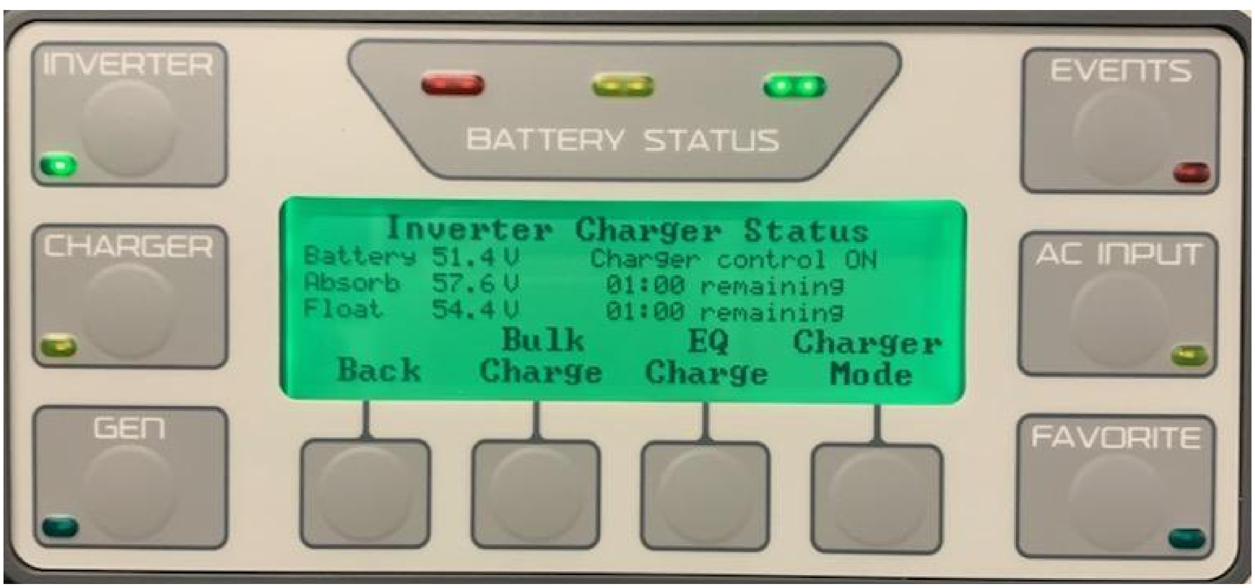

Figure 38: Charger Settings

When the inverter is on rest mode, activating the charger also has a few modes when it comes to the amount of energy that is already in the battery storage. Figure 38 shows a few options of how the inverter can charge the battery and itself. The Bulk Charge option is equivalent to a “fast charge” idea to when the battery is empty/low it will take any energy source and direct it to the battery and not be distributed throughout the other outlets. When the battery gets to a certain percentage, the bulk charge will automatically stop and a floating charge will begin. This charge is much slower and will top off the battery but send most of the energy throughout the outlets at this point. If the user charges EQ Charging, the energy will be distributed as equally as possible throughout the outlets and battery recharge.

8.3 CR and ER Testing Validation

The tests conducted are also meant to validate the specified customer and engineering requirements. Culminating the results obtained from each test, the team is able to validate that these requirements are met. This information is tabulated in Tables 6 and 7.

Table 6: Customer Requirement Breakdown

Customer Requirement	CR Met?	Client Acceptable
Safety	Yes - Fire, Building, Residential, Equipment and Electrical codes met	Acceptable
Cost Efficiency	Yes - BOM lists total amount that is under budget	Acceptable
Energy Storage System	Yes - Fortress eVault 18.5 Max	Acceptable
Grid Tied	Yes - Using APS as an additional source when solar generation isn't sufficient	Acceptable
Solar Powered	Yes - Q. Peak Duo Blk 365 panels	Acceptable

Table 7: Engineering Requirement Breakdown

Engineering Requirement	Target	Tolerance	Measured/ Calculated Value	ER Met?	Client Approved?
Decrease Design Cost	<$35,000	-$5,000	$31,830	Yes	Approved
Decrease $/W Investment	<4.00 $/W	-$0.50 $/W	$3.58/W	Yes	Approved
Maximize Efficiency	>15 % Irradiance	+5%	20.3 % Irradiance	Yes	Approved
Sufficient Energy Generation	1280 kWh/month	+260 kWh/month	1372 kWh/month	Yes	Approved
Increase Stored Energy	15 kWh	+15 kWh	18.5 kWh	Yes	Approved

Testing the safety of the system requires a breakdown of all the codes that need to be met in order for construction to begin. Since the panels, batteries, cables, and building are standard with no customization taking place, the codes on everything will ensure safety to the entire system.The client at the start of January was given a full breakdown of the cost of the project from an outside company which fell way over budget by $6000. The current Bill of Materials that is being used fits right under budget with the team being in charge of the manual labor.

From an expected value of roughly under 15kWh being used within the client's household, the client has accepted a smaller storage unit with the Fortress eVault 18.5 Max battery. This will be capable of sustaining the household's power for over 1 full day.From the lack of extra storage, the client has also specified a backup solution in case the energy generation isn't enough during the colder months to connect into the grid with the local electrical company of APS. However, the client has specifically requested not to back feed into the grid in order for his power to remain on and functional during any power outages that APS may experience.

The final requirement is the use of a photovoltaic system that is capable of producing enough energy for daily usage. Since the house will be constructed shortly the process of installing the photovoltaic system would take longer if it would be placed on the roof, however with the land owned by the client a ground mounted system away from the home will be in place to have the best angle of tilt and least amount of ground coverage.

8.4 Testing Challenges Bested

Several challenges are encountered during the testing phase of the project. For Test 1, which involved testing the tilt and azimuth angles to determine an optimized power output, the team encountered some significant issues; some of which controllable by the team, others not. For example, environmental conditions are an integral aspect of testing solar panels. If the weather conditions are cloudy, or even partially cloudy, data regarding power output may be inconsistent. Additionally, testing using an artificial lightsource was attempted, but is inherently not appropriate due to the spectral properties of sunlight, for which solar panels are specifically designed for. In order to mitigate these challenges, the team is required to wait and utilize optimal testing conditions regarding the weather.

In terms of actual data measurement, the team encountered other difficulties. Specifically during Test 1, obtaining voltage and current data is much more complicated than original ly anticipated by the team. In beginning iterations, the team attempted to measure current and voltage data using a simple multimeter, however, later realized this is incorrect; the team mistakenly only measured open circuit voltage and short circuit currents in these scenarios. The team later learned that in order to obtain voltage and current data, and consequently power data, a variable resistive load is required. Using a Rigol DL3021 Electronic Load, the team is able to vary resistance in a range of 2-1000 ohms for each iteration of tilt and azimuth angle desired. Finally, the team was able to recreate I-V and power curves for respective tilt and azimuth angles, displaying the relationships of such angles to power output.

Additionally, original tests where irradiance data was collected were conducted incorrectly. In beginning iterations, the team used a pyranometer in conjunction with a DAQ and accompanying software, however the testing apparatus was not set up appropriately; the specified calibration for the pyranometer is not originally accounted for, as well as the resolution of the DAQ output being far too low. Later iterations saw this corrected; a circuit board is created where the voltage drop of the pyranometer output is measured across a 147 ohm resistor, as per the calibration requirements. This allows the team to collect accurate irradiance data manually, and further analyze the relationship between azimuth and tilt angle, and power output, as well as efficiency data.

9 Risk Analysis and Mitigation

It is important as engineers to minimize any forms of risk within a design. Below is an analysis completed on possible risks and areas of failures on the solar array design.

9.1 Critical Failures

A critical failure is any point or mode of failure that will entirely stop the performance and or usage of the device. Listed below are several scenarios that could create a critical failure.

9.1.1 Potential Critical Failure 1: Solar Panel failure

The first potential failure is a solar panel failure. This could be caused by a variety of factors. The most likely cause of this failure is wear and tear. Every solar panel has an expected lifespan. Once the panel nears the end of that lifespan it is likely to fail. This would result in minimal to no energy production from the panel. Ultimately it would result in a total system failure. This failure could only be mitigated by replacing the panel. The user/client should check regularly to ensure that the system is outputting the max results. If there is a decrease in production due to a panel failure, a new one should be ordered to avoid a total system failure.

9.1.2 Potential Critical Failure 2: Ground Mounting Kit Yield

The second potential failure is the ground mounting system of the panels yielding. This could be caused by either wear and tear or external forces. In our design, the most likely cause would be wind forces. Since the clients home is located in camp verde, it is most likely that a strong gust would cause this failure. If this failure occurred, it would result in a total system failure. This is because it is likely that this would not only ruin the panel, but the wiring as well. This means there would be no energy produced. The best case scenario of this failure is that the panel just changes in tilt angle. Which would result in less energy production, but not a total failure. The way to mitigate this failure is to ensure that this component is installed properly. The user should also visually inspect the mounting to ensure there is no wear, cracks, etc.

9.1.3 Potential Critical Failure 3: Concrete Footing Failure

The third potential failure is the concrete footing yielding. This failure mode is very similar to failure number three. This failure is due to yielding. The cause of this failure can also vary. Similar to failure three, the most likely cause would be external forces. Wind forces would be the most likely force to cause this as well. Since this component will be underground, the only way to mitigate this would be to install properly. The design the team goes with will have a high factor of safety. Thus, this failure is very unlikely to occur.

9.1.4 Potential Critical Failure 4: Inverter Failure

The fourth potential failure is an inverter failure. This is caused by fatigue and wear. Just like the panels of our design, the inverter has a lifespan. Towards the end of this lifespan is when the inverter is likely to fail. It is also possible that the inverter malfunctions, however this is unlikely. The outcome of this failure would be a total system failure. The main purpose of our system is to convert solar energy into AC electricity. If the inverter fails, there is no way to convert this energy. This means the user would not be able to use the power generated in their home. This problem can not be mitigated. However, the inverter the group has chosen for our design is very unlikely to occur. If installed properly, the inverter should last as long as the panels if not longer. If the inverter fails, it can be replaced to keep the system running. The user/client can visually check the inverter regularly to ensure it is working properly.

9.1.5 Potential Critical Failure 5: Display and Controller Failure

The fifth failure is a display and controller failure. Out of all the critical failures, this is the least critical. This failure could be caused by a malfunction. This would only be a visual failure. In theory this means that the system would still be able to work. There would just be no way to visually monitor the generation of power. There is no way to mitigate this failure. However if it does occur, the failure can be fixed easily and quickly. This means the effects of this failure can be mitigated.

9.1.6 Potential Critical Failure 1: Battery Failure

The sixth failure is a battery failure. One of the most common causes of this failure is over-discharging. This would lead to the batteries overheating and failing. Other possible causes include low output voltage, low current, and sulfation. If this failure does happen, it is possible that the whole system will fail. There are still ways to run the system with this failure, but it will not be as efficient. The way to mitigate this failure is for the user to properly operate the system according to the manual. This would ensure that the battery's lifespan is maximized.

9.1.7 Potential Critical Failure 7: Cable Failure

The seventh failure is a cable failure. This could be caused by multiple factors. In our case and design the most common cause would be corrosion. This is due to wear and tear. The cables can be exposed to the natural elements in some cases. They also could just corrode over time in the wrong conditions. This would lead to a total system failure. There would be nothing powering the system. This would be a critical failure. The way to mitigate this would be to use high quality conduits. This is something the team took into consideration for our final design.

9.1.8 Potential Critical Failure 1: Conduit and J box Failure

The eighth and last critical failure that our team has taken into consideration is conduit and/or J box failure. This could be due to normal wear and use. If the conduit is exposed to natural elements, such as rain, it potentially fails. This is unlikely and has been mitigated because the conduit chosen by the team is high quality. This in turn will help stop the cables and j boxes from failing.

9.2 Potential Non-Critical Failures

A Non-Critical Failure is a case or scenario that inhibits partial function and performance of the design. Below is a list of identified scenarios that could cause or lead to failure.

9.2.1 Non-Critical Failure 1: Snow Accumulation

This non-critical failure pertains to a severe weather event causing excessive snow accumulation on the solar array. Under normal winter conditions in the Camp Verde area, snowfall is expected to be minimal, with accumulations of less than one inch. This would slightly affect the efficiency of the panels throughout the day but would not lead to system failure due to the presence of the battery storage system. However, in the event of a severe storm with significantly higher snow accumulations than average, the panels could remain covered for more than three days. Consequently, the home would deplete the battery storage and rely on grid power to maintain standard functionality.

This case is classified as non-critical because the system itself will not be damaged, but the homeowner's ability to be self-reliant will be compromised as they source power from the grid. The proposed solution to this issue is to clear the array of any snow or debris that significantly impacts energy production. This clearing process should be relatively straightforward as the ground-mounted system is easily accessible, and the panels have a 30-degree slope, facilitating snow removal.

9.3 Potential Failures Identified This Semester

Due to the nature of the analytical aspect of the project, very few potential failure modes were able to be identified during the second semester of the course. However, there still exists potential for failure during future iterations of the project, and it should be noted that being aware of any potential failures may mitigate risks incurred to the user.

9.3.1 Non-Critical Failure 2: Extreme Energy Draw

This non-critical failure is related to a situation where the homeowner depletes the battery bank during off-peak sunlight hours. This condition can arise when the system is connected to additional energy demands that were not originally accounted for in the design, such as RV power draw, additional building space power draw, or an exceptionally high simultaneous power draw from the home. In these scenarios, the homeowner would be exceeding the expected usage from the system by two or three times.

This case is classified as non-critical because the system will draw power from the grid to meet the demand. However, it should be noted that in such extreme usage scenarios, the homeowner will lose the ability to rely on the system's three-day storage capacity, resulting in a failure of the system to provide sufficient energy. It is important to emphasize that the system itself will not be damaged. To avoid this scenario, homeowners should refrain from drawing excessive energy during off-peak hours.

9.4 Risk Mitigation

Most of the failures on our design will be caused due to wear and tear. A solar system will always have a finite life span. This means that besides external forces, wear and tear will be the main cause of failure in our system. There is no mitigation that will affect another failure mode. However replacing a piece of the system after the life span will subsequently mean that other pieces of the system will need to be replaced as well to be uniform.

It will be the users decision on whether or not to replace a part. The risk of running a part that potentially could fail due to lifespan will be a financial decision. This also means that some components will have a shorter life span than high end systems. This will be due to financial constraints of our client. However the team feels like the system and design that was chosen is the best quality for the price range.

In order to mitigate risks associated with energy draw, it is important for the user to understand the inherent limitations of the system. These risks are non critical, however, and would only result in the user not being able to generate enough energy to maintain the loads applied to the system. It should be noted that the result of this will be increased cost to the user, as the system is island capable. In order to avoid this scenario, the user must be aware of the loads incurring to the system's energy generation. The team recommends that the net loads applied to the system are below 40 kWh per day.

10 Looking Forward

This project was initially intended to be a design-build engineering collaboration. However, due to client issues with permitting and incomplete house construction, the project was shifted towards an analytical style project to eliminate the construction requirements. Due to this project scope change, there is a large amount of work to still be accomplished and much of the future testing will serve as design validation. The following sections outline future testing and construction plans that can be implemented.

10.1 Future Testing Procedures

10.1.1 Panel Output Testing

After the array has been constructed, it is advised to measure the output of the array. The measurements should be displayed directly from the inverter control panel. The measured values should be then compared to the expected output of the array. If the results are not meeting expected values, further spot testing can be completed to determine if any panels or wiring are faulty. This test is used to primarily serve as design validation and fault identification.

10.1.2 House Electrical Consumption Testing

The electrical demand of the home was originally simulated using Revit and eQuest. The results were then utilized to scale the designed array system and battery size. Using a whole home house meter provided by Carson Pete, the actual consumption of home will be able to be accurately measured over a period of several weeks. The results of the testing should provide highly accurate usage data that can be used to determine the successful scaling of the system and validate that the array will produce excess energy for the home and storage system.

10.1.3 Battery Storage Testing

The customer has identified a need to have a minimum of 1 day of battery storage for the home to ensure continuous operation in a severe weather event. With the array and storage bank installed, the test will involve a manual override to stop panel production and allow the home to run off the battery bank alone. The house should run under normal conditions and will be monitored closely during the one day period. This test can also be done with calculations but a live test will enable the battery to be drained fully and simulate actual conditions. This test will validate battery scale and minimize any faults in the system while ensuring inverter function and settings.

10.2 Future Iterations

Early in the project, the client mentioned that he would like to build additional infrastructure on the property. This could include an additional dwelling unit as well as a large footprint shop space. Both of these additions will outpace the original designed scale of the system. These changes will require additional iterations to the design.

10.2.1 Array Expansion

The main iteration will be an expansion of the existing panel array. With knowledge of this possible change, the inverter selected was over-specified to handle nearly double the original array size. While some electrical changes will need to be made, additional infrastructure will only require additional panels and mounting hardware. The ground mount system is simple to install and mate to existing hardware. Additionally, there is ample space in the specified construction array for array expansion.

10.2.2 Battery Expansion

In a severe weather event lasting longer than one day, the existing battery bank will not have a large enough storage capacity to power the home under normal operating scenarios. If the client, at a later date after construction, feels that this is inadequate, additional battery storage can be purchased and installed. There will need to be additional electrical connections to facilitate the change however the addition will be simple to accomplish. A major roadblock for this iteration will be the cost barrier as the electrical storage for this project is the single most expensive component.

11 Conclusions

The Renewable Energy Project has encountered a tremendous amount of scope changes, scheduling issues, and deliverable adjustments since the project began in the Fall of 2022. Despite the hurdles, the team has successfully designed, specified, and analyzed a 8.8 kW panel array for an off-grid cabin. The proposed system meets and exceeds all of the customer and engineering requirements put forth. Ultimately this project validates the feasibility of economically deploying a residential scale solar array as a stand alone clean energy solution.

11.1 Reflection

In developing a photovoltaic (PV) system for Camp Verde residents, our engineering team diligently applied design principles to meet specific needs while considering a myriad of factors. We initiated the project with a comprehensive needs assessment, identifying energy requirements and peak demand periods. Public health and safety, we strictly adhered to regulations, integrating measures to ensure the system poses no risk to residents. Environmental impact mitigation was a priority, encompassing life cycle analysis, material selection, and sustainable disposal practices. Cultural and social considerations guided our design to seamlessly integrate the PV system into the community. Globally, we recognized the impact of transitioning to solar energy, contributing to broader sustainability goals. An economic lens was applied, with a thorough cost-benefit analysis ensuring the system's long-term viability and affordability for Camp Verde residents. The result is a holistic solution that addresses local needs while considering broader implications, fostering sustainability, safety, and community integration. Our PV system design prioritized safety and environmental sustainability through a systematic approach and testing. Adhering to established engineering standards and regulations of the city of camp verde, we implemented protective measures like circuit breakers and grounding systems. Comprehensive risk assessments identified and mitigated potential hazards. Because this was an analytical project, these measures were not fully submitted to the city of Camp Verde for approval. However, if given the opportunity, our design would have been submitted to the city for approval to ensure safety.

11.2 Project Applicability

This project required the team to come together and replicate the efforts and analysis completed by a professional solar design firm. The processes incurred throughout the project included that which would be endured throughout a professional solar design project. On a macro level, students are given the opportunity to be presented with a unique engineering problem, and provide the most appropriate and efficient solution given the circumstances, with minimal direction and guidance. On a more detailed note, students applied engineering methods to design a solar photovoltaic system fully equipped for residential hybrid island application.

This required students to be well versed in not only principals of mechanical engineering including project management, heat transfer, electronics applications, data collection and analysis, and computer programming, but also principles from electrical and civil engineering. Specifically, a structural analysis is conducted where civil engineering principles are required to be applied. Similarly, certain principles of electrical engineering are required, such as concepts regarding the relationship among voltages, currents, and applied loads within a circuit. More than all, this project provided real world scenarios where the team is responsible for the client's good service and safety, delivering a product which is not only satisfactory but optimal. Utilizing teamwork and engineering design methods, including concept generation, design selection, testing, and analysis, the team is able to successfully deliver a working design to the respective client, and fulfill the team-client contract.

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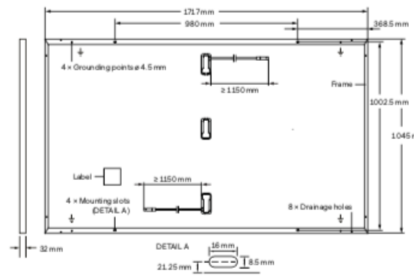
APPENDICES

Appendix I: Original System Spec Sheets

MECHANICAL SPECIFICATION

Format	1717 mm × 1045 mm × 32 mm (including frame)
Weight	19.9 kg
Front Cover	3.2 mm thermally pre-stressed glass with anti-reflection technology
Back Cover	Composite film
Frame	Black anodised aluminium
Cell	6 × 20 monocrystalline Q.ANTUM solar half cells
Junction box	53-101 mm × 32-60 mm × 15-18 mm Protection class IP67, with bypass diodes
Cable	4 mm² Solar cable; (+) ≥1150 mm, (−) ≥1150 mm
Connector	Stäubli MC4; IP68

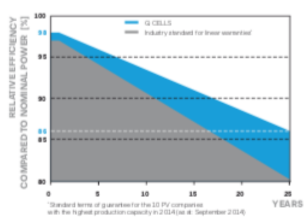


ELECTRICAL CHARACTERISTICS

POWER CLASS				350	355	360	365	370
MINIMUM PERFORMANCE AT STANDARD TEST CONDITIONS, STC[1] (POWER TOLERANCE +5 W / −0 W)								
Minimum	Power at MPP[1]	P_{MPP}	[W]	350	355	360	365	370
	Short Circuit Current[1]	I_{SC}	[A]	10.97	11.00	11.04	11.07	11.10
	Open Circuit Voltage[1]	V_{OC}	[V]	41.11	41.14	41.18	41.21	41.24
	Current at MPP	I_{MPP}	[A]	10.37	10.43	10.49	10.56	10.62
	Voltage at MPP	V_{MPP}	[V]	33.76	34.03	34.31	34.58	34.84
	Efficiency[1]	η	[%]	≥19.5	≥19.8	≥20.1	≥20.3	≥20.6
MINIMUM PERFORMANCE AT NORMAL OPERATING CONDITIONS, NMOT[2]								
Minimum	Power at MPP	P_{MPP}	[W]	262.6	266.3	270.1	273.8	277.6
	Short Circuit Current	I_{SC}	[A]	8.84	8.87	8.89	8.92	8.95
	Open Circuit Voltage	V_{OC}	[V]	38.77	38.80	38.83	38.86	38.90
	Current at MPP	I_{MPP}	[A]	8.14	8.20	8.26	8.31	8.37
	Voltage at MPP	V_{MPP}	[V]	32.24	32.48	32.71	32.94	33.17

[1]Measurement tolerances P_{MPP} ±3%; I_{SC}; V_{OC} ±5% at STC: 1000 W/m², 25±2 °C, AM 1.5 according to IEC 60904-3 • [2]800 W/m², NMOT, spectrum AM 1.5

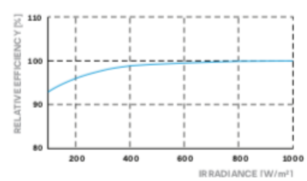
Q CELLS PERFORMANCE WARRANTY



At least 98% of nominal power during first year. Thereafter max. 0.5% degradation per year. At least 93.5% of nominal power up to 10 years. At least 86% of nominal power up to 25 years.

All data within measurement tolerances. Full warranties in accordance with the warranty terms of the Q CELLS sales organisation of your respective country.

PERFORMANCE AT LOW IRRADIANCE



Typical module performance under low irradiance conditions in comparison to STC conditions (25 °C, 1000 W/m²).

TEMPERATURE COEFFICIENTS

Temperature Coefficient of I_{SC}	α	[% / K]	+0.04	Temperature Coefficient of V_{OC}	β	[% / K]	−0.27
Temperature Coefficient of P_{MPP}	γ	[% / K]	−0.34	Nominal Module Operating Temperature	NMOT	[°C]	43±3

PROPERTIES FOR SYSTEM DESIGN

Maximum System Voltage	V_{SYS}	[V]	1000	PV module classification	Class II
Maximum Reverse Current	I_R	[A]	20	Fire Rating based on ANSI / UL 61730	C / TYPE 2
Max. Design Load, Push / Pull		[Pa]	3600 / 2660	Permitted Module Temperature on Continuous Duty	−40 °C - +85 °C
Max. Test Load, Push / Pull		[Pa]	5400 / 4000		

QUALIFICATIONS AND CERTIFICATES

Quality Controlled PV - TÜV Rheinland;
IEC 61215:2016; IEC 61730:2016.
This data sheet complies with DIN EN 50380.
QCPV Certification ongoing.

www.tuv.com ID 1111220277

Note: Installation instructions must be followed. See the installation and operating manual or contact our technical service department for further information on approved installation and use of this product.

Hanwha Q CELLS GmbH

Specifications subject to technical changes © **Q CELLS** Q.PEAK DUO BLK-G10+_350-370_2021-08_Rev01_EN

OutBack POWER™
an EnerSys company

FLEXpower Radian™

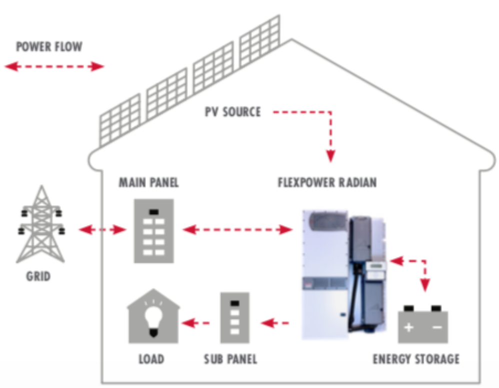
Fully Pre-assembled 4 and 8kw Inverter Systems

- 4kW: Ideal for smaller power applications including homes, cabins, remote communication sites and backup power systems.
- 8kW: Ideal for medium-sized power requirements including larger homes, light commercial or backup power systems.
- Radian inverter/charger is programmable for seven different operational modes, with generator assist
- 300VDC models provide up to 99% peak efficiency with FLEXmax 100 charge controller

OutBack's pre-assembled and pre-wired power systems take the concept of fast, easy installation to a new level of value and flexibility with the FLEXpower Radian.

Everything needed, outside of power sources and battery backup, is completely integrated—just install the mounting bracket, hang the system on a wall, make the necessary connections and the system is fully operational.

Available in the Radian A Series 4kW or 8kW inverter/charger, both models incorporate OutBack's GridZero technology, a superior level of intelligence in energy management for self-generation and self-consumption programs. It provides precise balancing between using stored energy, solar and utility power, blending-in the latter to overcome surges and load spikes. Both models support leading-edge battery technologies such as lithium-ion and others, and enhanced diagnostics for improved performance.



FLEXpower Radian Specifications

08/2019

Model*	Description	Inverter	GSLC	Bypass	Inverter OCPD**	PV OCPD**	GFDI	AFCI	RTS	Charge Controller
FPR-4048A-300AFCI	GS4048A FLEXpower Radian AFCI	GS4048A	GSLC-PV1-300VDC	120/240VAC	175A	80A	Yes	Yes	Yes	(1) FLEXmax 100 AFCI
FPR-4048A-300VDC	GS4048A FLEXpower Radian 300VDC	GS4048A	GSLC-PV1-300VDC	120/240VAC	175A	80A	Yes	No	Yes	(1) FLEXmax 100
FPR-4048A-01	GS8048A FLEXpower Radian	GS4048A	GSLC175-PV1-120/240	120/240VAC	175A	80A	Yes	No	Yes	(1) FLEXmax 80
FPR-8048A-300AFCI	GS8048A FLEXpower Radian AFCI	GS8048A	GSLC-PV-300VDC	120/240VAC	(2×) 175A	(2×) 80A	Yes	Yes	Yes	(2) FLEXmax 100 AFCI
FPR-8048A-300A-LT	GS4048A FLEXpower Radian AFCI Lite	GS8048A	GSLC-PV1-300VDC	120/240VAC	175A	80A	Yes	Yes	Yes	(1) FLEXmax 100 AFCI
FPR-8048A-300VDC	GS4048A FLEXpower Radian	GS8048A	GSLC-PV-300VDC	120/240VAC	(2×) 175A	(2×) 80A	Yes	No	Yes	(2) FLEXmax 100
FPR-8048A-01	GS4048A FLEXpower Radian	GS8048A	GSLC175-PV-120/240	120/240VAC	(2×) 175A	(2×) 80A	Yes	No	Yes	(2) FLEXmax 80

Details	FPR-4048A-300AFCI	FPR-4048A 300VDC	FPR-4048A	FPR-8048A-300AFCI	FPR-8048A-300A-LT	FPR-8048A 300VDC	FLEXpower Radian 8048A
Finished Dimensions H × W × D (in/cm)	47.0 × 33.5 × 9.84 / 119.4 × 85.1 × 24.9	47.0 × 33.5 × 9.84 / 119.4 × 85.1 × 24.9	47.0 × 33.5 × 9.84 / 119.4 × 85.1 × 24.9	47.0 × 33.5 × 9.84 / 119.4 × 85.1 × 24.9	47.0 × 33.5 × 9.84 / 119.4 × 85.1 × 24.9	47.0 × 33.5 × 9.84 / 119.4 × 85.1 × 24.9	47.0 × 33.5 × 9.84 / 119.4 × 85.1 × 24.9
Weight (lb/kg)	199 / 91	201 / 91.2	195 / 88.5	258 / 116.4	238 / 107.4	262 / 118.8	250 / 113.4
Shipping Dimensions H × W × D (in/cm)	48 × 40 × 18 / 121.9 × 101.6 × 45.7	48 × 40 × 18 / 121.9 × 101.6 × 45.7	48 × 40 × 18 / 121.9 × 101.6 × 45.7	48 × 40 × 18 / 121.9 × 101.6 × 45.7	48 × 40 × 18 / 121.9 × 101.6 × 45.7	48 × 40 × 18 / 121.9 × 101.6 × 45.7	48 × 40 × 18 / 121.9 × 101.6 × 45.7
Shipping Weight (lb/kg)	218 / 98.6	220 / 99.8	213 / 96.6	280 / 126.4	260 / 117.4	284 / 128.8	272 / 123.4

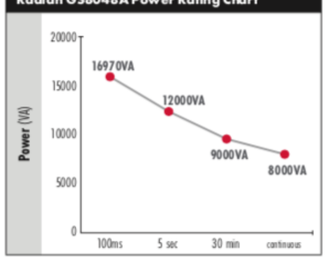
*All pre-wired systems include a Radian Series inverter/charger, FLEXmax charge controller(s), MATE3s system display and communications, FLEXnet DC system monitor, AC and DC wiring boxes, HUB10.3 communications, surge protector and remote temperature sensor (RTS). The FLEXpower Radian is also equipped with battery, PV array breakers, GFDI, AFCI and input-output-bypass. See individual product datasheets or product guide for full specifications.
**Overcurrent protective device.

Radian GS8048A Power Factor Chart

Power Rating Notes

Inverters that specify power in VA but do not use the unity standard Power Factor (PF) **could have misleading power specifications.** Volt-Amps (VA) is a total inverter output, while Watts (W) represent the power consumed by the electrical loads. PF, which varies by types of loads, is the ratio of W to VA, and the difference between the two is power in the circuit that does no useful work. At 1.0PF (unity), all power is used. This is the industry-standard used by OutBack Power.

Radian GS8048A Power Rating Chart



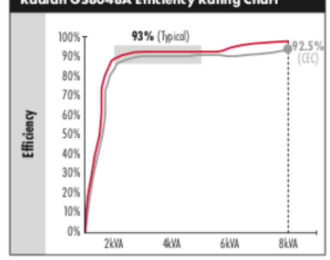
Instantaneous Power Rating
Most stringent, massive load start **GS8048A**: 16970VA

Surge Power Rating
Less stringent load start **GS8048A**: 12000VA

Peak Power Rating
Frequent "heavy duty" load requirements **GS8048A**: 9000VA

Continuous Power Rating
Sustained "real world" load requirements **GS8048A**: 8000VA

Radian GS8048A Efficiency Rating Chart



INVERTING | SELLING

Typical Efficiency Rating
Real world efficiency with variable loads **GS8048A**: 93%

CEC Efficiency Rating
Most stringent US rating **GS8048A**: 92.5%

Appendix II: Original Bill of Materials

Quantity	ITEMS	Description	Price	Total Price
24	Q.Peak Duo Blk 365	QCELLS Q.PEAK DUO BLK-G10+ 365 Watt monocrystalline solar panel, 120 half cells, black frame, 25 year product warranty, 25 year linear performance warranty	363	8712
2	SnapNrack-200 4x6-72	SnapNrack Series 200 Ground Mount System for 24 (72 cell) solar panels, 6 columns, braced with 18" wide grade beams, includes 1.5" steel pipe and rebar	240	480
10	Concrete	Concrete with delivery, per yard	125	1250
2	GS8048A-01	Outback Power Radian Grid-Interactive Battery-Backup Inverter, 8000 watts AC, 120/240VAC, 5 year warranty	4320	8640
2	GSLC	Outback Power Systems Radian GS Load Center with inverter bars, breaker bus, shunt, neg, ground, neutral and PV Pos busbars	764	1528
2	FM100-300VDC	Outback Power Systems FLEXmax 100 Solar Charge Controller, 100 amps, MPPT, 12,24,48VDC, up to 300VDC Input	1377	2754
1	MATE3s	Outback Power Systems Advanced Remote Display and Controller, S-version with upgraded processor and internet interface	490	490
1	HUB10.3	Outback Power Systems communications manager for up to 10 devices	362	362
1	FLEXnet DC	OutBack Power Systems Battery Monitor, FN-DC	382	382
2	PNL-125-300VDC	Outback Panel Mount Breaker, 125A, 300VDC	52	104
3	MNEPV20-300	Midnite Solar 20 A DIN rail breaker, 300Vdc	38	114
3	MNEAC50-2P	Midnite Solar 50A/2P 240Vac panel mount breaker	33	99
3	MNEDC-175	Midnite Solar Panel Mount 175A breaker	130	390
2	Transfer Switch-200	Manual Transfer Switch for Generator Bypass, 240Vac, 200A	180	360
1	Victron Lynx Power In	Victron Power Lynx Power In 1000A distribution for parallel combining up to 5 lithium batteries, with plastic cover	156	156
32	4/0 Blk Battery Cable	4/0 Black UL Listed Battery Cable - Price Per Foot	3.56	113.92
32	4/0 Red Battery Cable	4/0 Red UL Listed Battery Cable - Price Per Foot	30.65	980.8
20	4/0 Battery Lug	4/0 3/8 Copper UL Lug	103	2060
2	Fortress eVault 18.5 Max	Fortress Power eVault Max LFP Battery, 51.2V(48V), 360Ah, 18.5KwH total, 10-year warranty, up to 6,000+ cycles	10920	21840
1	Job Materials	Wire, conduit, breakers, j-boxes, etc.	500	500
1	Permit	Building Permit, Variance, or Conditional Use Permit fees	750	750
24	Drawings/Permits	Drawings/Paperwork for permits and/or APS Interconnect (grid-tied only), per hour	30	720
	Total Price	52785.72		

Appendix III: Original System PVWatts Report

RESULTS

Print Results

15,099 kWh/Year*

System output may range from 14,592 to 15,395 kWh per year near this location.
Click HERE for more information.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)
January	4.97	1,093
February	5.37	1,040
March	6.39	1,347
April	7.16	1,425
May	7.42	1,506
June	7.49	1,429
July	6.37	1,252
August	6.33	1,241
September	6.57	1,275
October	6.41	1,317
November	5.58	1,158
December	4.56	1,017
Annual	**6.22**	**15,100**

Appendix IV: Original System Quotes

Name / Address
Steve Winiecki 28395 E Squaw Peak R.d Dewey, AZ

Quantity	Item	Description
24	Q.Peak Duo Blk 365	QCELLS Q.PEAK DUO BLK-G10+ 365 Watt monocrystalline solar panel, 120 half cells, black frame, 25 year product warranty, 25 year linear performance warranty
2	SnapNrack-200 4x6-72	SnapNrack Series 200 Ground Mount System for 24 (72 cell) solar panels, 6 columns, braced with 18" wide grade beams, includes 1.5" steel pipe and rebar
10	Concrete	Concrete with delivery, per yard
1	FPR-8048A-300VDC	Outback Power Systems pre-wired inverter system, includes a Radian GS8048A-01 inverter (8,000 Watt, 120/240Vac, 48Vdc), two FM100 solar charge controllers, MATE3S display and control, FLEXnet DC monitor, HUB 10, GFDI bypass assembly, 5-year warranty
1	Victron Lynx Power In	Victron Power Lynx Power In 1000A distribution for parallel combining up to 5 lithium batteries, with plastic cover
10	4/0 Blk Battery Cable	4/0 Black UL Listed Battery Cable - Price Per Foot
10	4/0 Red Battery Cable	4/0 Red UL Listed Battery Cable - Price Per Foot
4	4/0 Battery Lug	4/0 3/8 Copper UL Lug
1	Fortress eVault 18.5 Max	Fortress Power eVault Max LFP Battery, 51.2V(48V), 360Ah, 18.5KwH total, 10-year warranty, up to 6,000+ cycles
1	Kohler 20RCA	Kohler 20 kW Standby Generator, 20RCA, LPG or Natural Gas, 120/240Vac, Aluminum enclosure, 3600 RPM, NO OFF-GRID WARRANTY, includes freight and starting battery
1	Kohler Gen Pad	Kohler 3" Concrete Mounting Pad for 14/20kW Generators
1	Job Materials	Wire, conduit, breakers, j-boxes, etc.
1	Permit	Building Permit, Variance, or Conditional Use Permit fees
24	Drawings/Permits	Drawings/Paperwork for permits and/or APS Interconnect (grid-tied only), per hour
1	Equipment Rental	Rental fees for excavation or lift equipment
65	Ground Mount Labor	Ground Mount Labor, taxable
35	Labor	Labor, per man-hour
36	Logistics	Logistical support - travel expenses, equipment handling, etc.

We include a LIFETIME workmanship warranty on all installations. This quoted price includes a 3% discount for payment made with cash or check. Payment by any other means will waive this discount. Quotes are valid for 30 days. A 50% down payment is required on all purchases over $5,000.00	**Sales Tax (6.9%)**	$884.93
	Total	$68,440.93

Name / Address
Steve Winiecki 28395 E Squaw Peak R.d Dewey, AZ

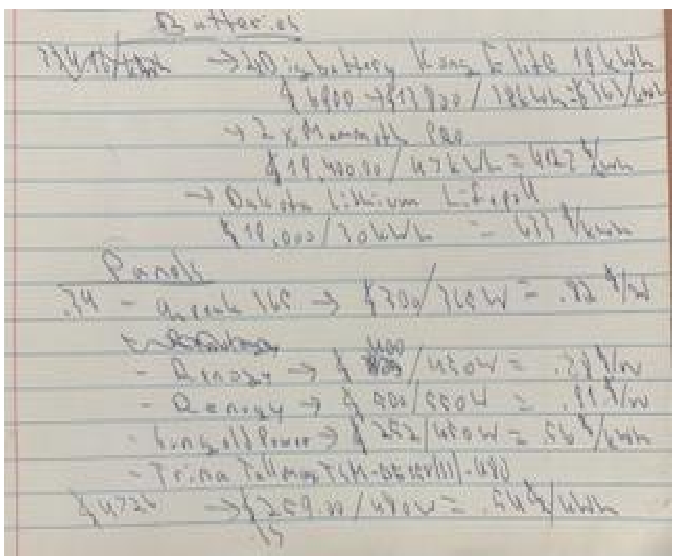
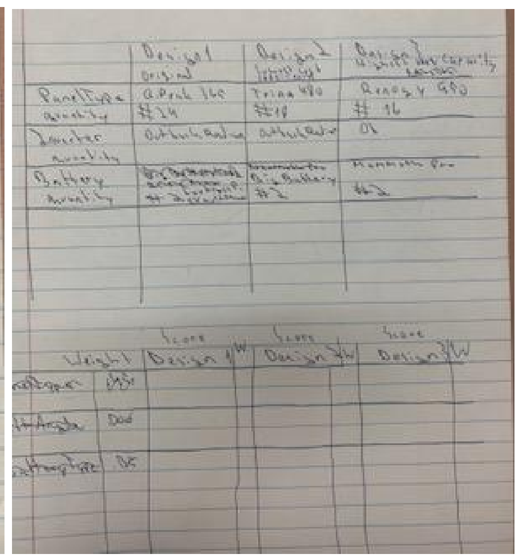
Quantity	Item	Description
24	Q.Peak Duo Blk 365	QCELLS Q.PEAK DUO BLK-G10+ 365 Watt monocrystalline solar panel, 120 half cells, black frame, 25 year product warranty, 25 year linear performance warranty
2	SnapNrack-200 4x6-72	SnapNrack Series 200 Ground Mount System for 24 (72 cell) solar panels, 6 columns, braced with 18" wide grade beams, includes 1.5" steel pipe and rebar
10	Concrete	Concrete with delivery, per yard
2	GS8048A-01	Outback Power Radian Grid-Interactive Battery-Backup Inverter, 8000 watts AC, 120/240VAC, 5 year warranty
2	GSLC	Outback Power Systems Radian GS Load Center with inverter bars, breaker bus, shunt, neg, ground, neutral and PV Pos busbars
2	FM100-300VDC	Outback Power Systems FLEXmax 100 Solar Charge Controller, 100 amps, MPPT, 12,24,48VDC, up to 300VDC Input
1	MATE3s	Outback Power Systems Advanced Remote Display and Controller, S-version with upgraded processor and internet interface
1	HUB10.3	Outback Power Systems communications manager for up to 10 devices
1	FLEXnet DC	OutBack Power Systems Battery Monitor, FN-DC
2	PNL-125-300VDC	Outback Panel Mount Breaker, 125A, 300VDC
4	MNEPV20-300	Midnite Solar 20 A DIN rail breaker, 300Vdc
4	MNEAC50-2P	Midnite Solar 50A/2P 240Vac panel mount breaker
4	MNEDC-175	Midnite Solar Panel Mount 175A breaker
2	Transfer Switch-200	Manual Transfer Switch for Generator Bypass, 240Vac, 200A
1	Victron Lynx Power In	Victron Power Lynx Power In 1000A distribution for parallel combining up to 5 lithium batteries, with plastic cover
32	4/0 Blk Battery Cable	4/0 Black UL Listed Battery Cable - Price Per Foot
32	4/0 Red Battery Cable	4/0 Red UL Listed Battery Cable - Price Per Foot
20	4/0 Battery Lug	4/0 3/8 Copper UL Lug
2	Fortress eVault 18.5 Max	Fortress Power eVault Max LFP Battery, 51.2V(48V), 360Ah, 18.5KwH total, 10-year warranty, up to 6,000+ cycles
1	Kohler 20RCA	Kohler 20 kW Standby Generator, 20RCA, LPG or Natural Gas, 120/240Vac, Aluminum enclosure, 3600 RPM, NO OFF-GRID WARRANTY, includes freight and starting battery
1	Kohler Gen Pad	Kohler 3" Concrete Mounting Pad for 14/20kW Generators
1	Job Materials	Wire, conduit, breakers, j-boxes, etc.
1	Permit	Building Permit, Variance, or Conditional Use Permit fees
24	Drawings/Permits	Drawings/Paperwork for permits and/or APS Interconnect (grid-tied only), per hour
1	Equipment Rental	Rental fees for excavation or lift equipment
80	Ground Mount Labor	Ground Mount Labor, taxable
44	Labor	Labor, per man-hour
36	Logistics	Logistical support - travel expenses, equipment handling, etc.

We include a LIFETIME workmanship warranty on all installations. This quoted price includes a 3% discount for payment made with cash or check. Payment by any other means will waive this discount. Quotes are valid for 30 days. A 50% down payment is required on all purchases over $5,000.00	**Sales Tax (6.9%)**	$993.60
	Total	$95,375.60

Appendix V: Renewable Energy Systems Pugh Chart

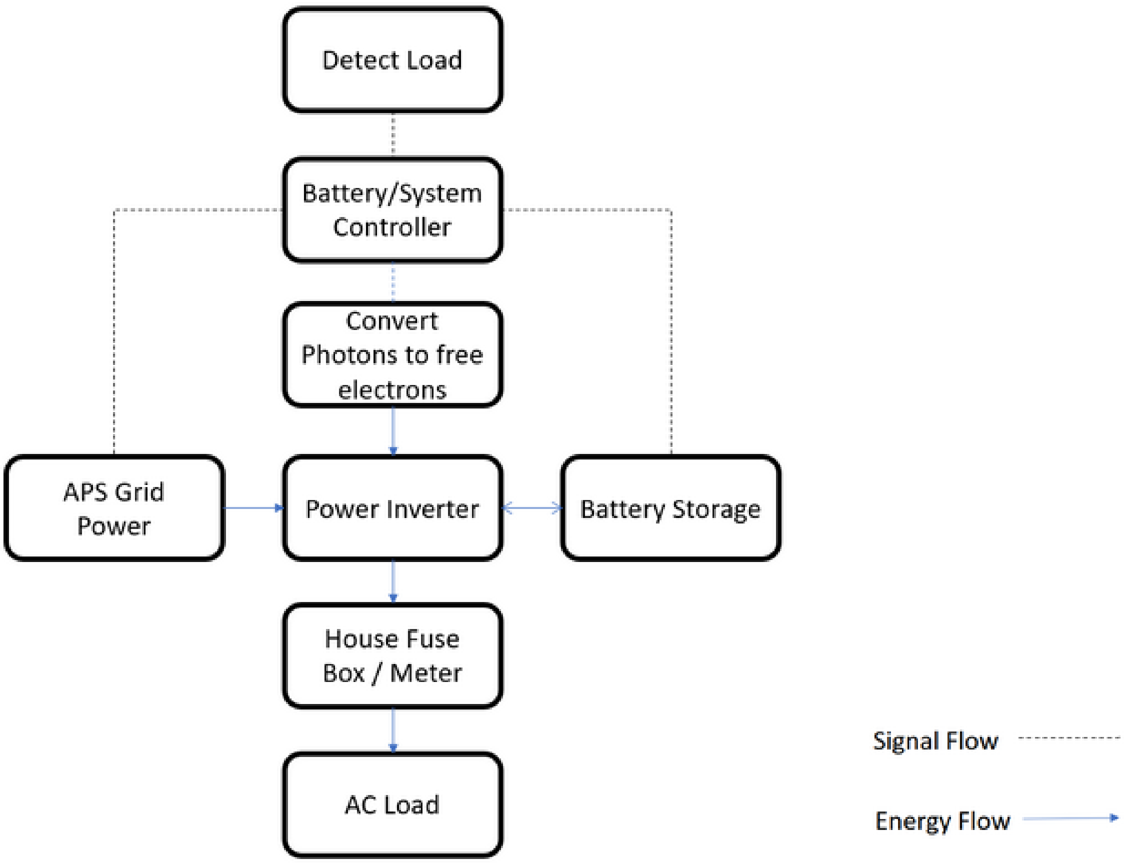
Concepts / Requirements \	Grid Tied	Design 1: Original	Off Grid Wind	Off Grid Hydro	Hybrid Solar PV
Safety	D	S	+	S	S
Cost	D	+	-	-	+
Energy Storage	D	+	+	+	+
Solar Generation	D	+	-	-	+
Adaptability	D	-	-	-	+
Total	0	2	-1	-2	4

Appendix VI: Back-of-the-Envelope Calculations

Appendix VII: Black Box Model

Appendix VIII: Work Process Chain Diagram



Appendix IX: House of Quality

System QFD

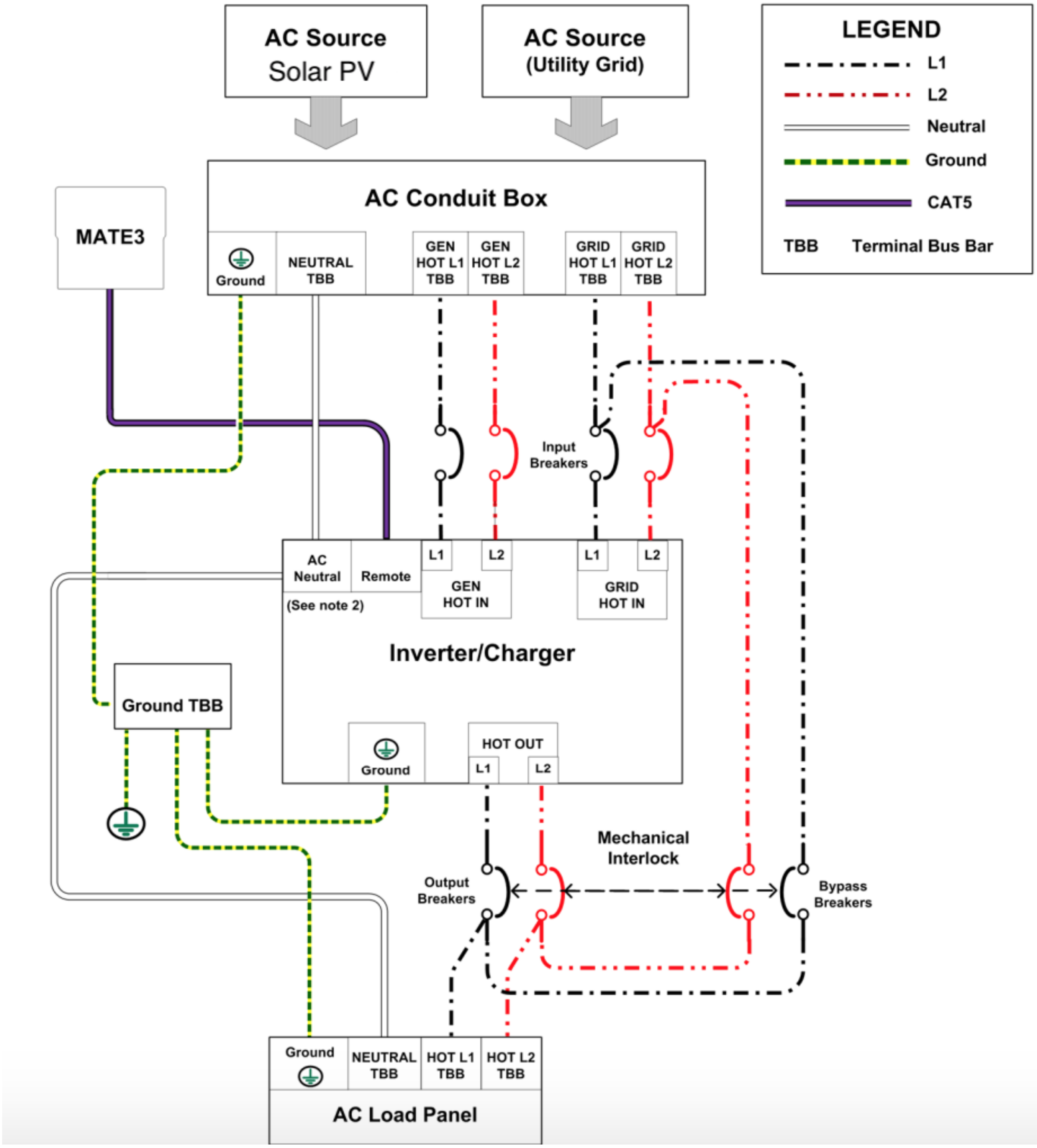
Project: Winiecki Renewable Energy System
Date: 9/8/23
Team 4 - Renewable Energy Project

1	Decrease Design Cost					
2	Decrease $/W Investment	-				
3	Maximize Efficiency	-	-			
4	SufficientEnergy Generation	- -	+++	++		
5	Increase Stored Energy Potential	- -	++	++		
6						
7						

Legend	
A	Solar Energy Generation
B	Grid Powered Energy
C	Diesel Generator

			Technical Requirements					Customer Opinion Survey				
	Customer Needs	Customer Weights	Decrease Design Cost	Decrease $/W Investment	Maximize Efficiency	Sufficient Energy Generation	Increase Stored Energy Potential	1 Poor	2	3 Acceptable	4	5 Excellent
1	Safety	5	3	0	3	0	3			C	A	B
2	Cost Efficiency	3	9	9	3	9	6	C		B	A	
3	Energy Storage	2	6	6	6	0	9	B		C	A	
4	Inverter option to drawback from grid	4	6	3	6	0	0	BC				A
5	Solar Panel Energy Generation	5	9	9	3	9	6	BC				A
6												
	Technical Requirement Units		$USD	$USD/Watt ($/W)	Panel Irradiance Efficiency	Kilowatt Hours/ Month (kWh/month)	Kilowatt Hours (kWh)					
	Technical Requirement Targets		35,000.00	4	>15%	1280	15					
	Absolute Technical Importance		123.0	96.0	75.0	72.0	81.0					
	Relative Technical Importance		1	2	4	5	3					

Appendix X: Detailed Electrical Diagram Displaying Inverter

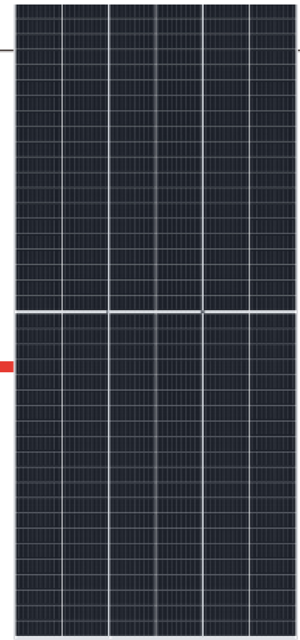


Appendix XI: Final Design Bill of Materials

Quantity	Items	Description	Price ($)	Total Price ($)
19	Trina Tallmax 480	Trina Tall Max 480W Solar Panels	259	4921
1	Ground Mounted Solar	Ground Mounted Solar Panel Kit	5089	5089
35 Bags	Concrete	Concrete with delivery per yard	663	663
2	GS8048A-01	Outback Power Grid Interactive Inverter	4320	8640
2	GSLC	Outback Power GS Load Center	764	1528
2	FM100-300VDC	Outback Power FLEXmax 100 Solar Charge Controller	1377	2754
1	MATE3s	Outback Power Remote Display and Controller	490	490
1	HUB10.3	Outback Power Communications Manager	362	362
1	FLEXnet DC	Outback Power Battery Monitor, FN-DC	382	382
2	PNL-125-300VDC	Outback Power Mount Breaker, 125a, 300VDC	52	104
3	MNEPV20-300	Midnite Solar 20 A DIN Rail Breaker	38	114
3	MNEPC50-2P	Midnite Solar 50A/ 2P 240Vac, 200A Panel Mount Breaker	33	99
3	MNEDC-175	Midnite Solar Panel Mount 175A breaker	130	390
2	Transfer Switch	Manual Transfer Switch for Generator Bypass, 240Vac, 200A	180	360
1	Victron Lynx Power In	Victron Power Lynx Power In 1000A distribution for parallel combining up to 5 lithium batteries, with plastic cover	156	156
32	4/0 BLK Battery Cable	4/0 Black UL Listed Battery Cable - Price Per Foot	3.56	113.92
32	4/0 Red Battery Cable	4/0 Red UL Listed Battery Cable - Price Per Foot	30.65	980
20	4/0 Battery Lug	4/0 3/8 Copper UL Lug	103	2060
2	BigBattery Kong Elite	Big Battery Kong Elite Max Battery	6900	13800
1	Job Materials	Wire, conduit, breakers, j-boxes, etc	500	500
1	Permit	Building Permit, Variance, or Conditional Use Permit fees	750	750
24	Drawings/ Permits	Drawings/Paperwork for permits and/or APS Interconnect (grid-tied only), per hour	30	720
		Total		44975.92

Appendix XII: Trina Tallmax Spec Sheet

Mono Multi Solutions



THE

TALLMAX[M]

FRAMED 252 LAYOUT MODULE

PRODUCTS	POWER RANGE
TSM-DE15V(II)	470-490W

252 LAYOUT
MONOCRYSTALLINE MODULE

470-490W
POWER OUTPUT RANGE

20.8%
MAXIMUM EFFICIENCY

0~+5W
POSITIVE POWER TOLERANCE

Founded in 1997, Trina Solar is the world's leading total solution provider for solar energy. With local presence around the globe, Trina Solar is able to provide exceptional service to each customer in each market and deliver our innovative, reliable products with the backing of Trina as a strong, bankable brand. Trina Solar now distributes its PV products to over 100 countries all over the world. We are committed to building strategic, mutually beneficial collaborations with installers, developers, distributors and other partners in driving smart energy together.

Comprehensive Products and System Certificates

IEC61215/IEC61730/IEC61701/IEC62716/UL61703
ISO 9001: Quality Management System
ISO 14001: Environmental Management System
ISO14064: Greenhouse Gases Emissions Verification
ISO45001: Occupation Health and Safety Management System

Trinasolar

High power

- Up to 490W front power and 20.8% module efficiency with third-cut and MBB (Multi Busbar) technology bringing more BOS savings
- Lower resistance and good reflection effect of MBB ensures higher power

High reliability

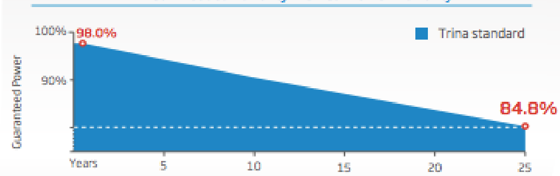
- Improved PID resistance through cell process and module material control
- Resistant to salt, acid, and ammonia
- Proven to be reliable in high temperature and humidity areas
- Mechanical performance: Up to 5400 Pa positive load and 2400 Pa negative load

High energy generation

- Excellent IAM and low light performance validated by 3rd party with cell process and module material optimization
- Better anti-shading performance and lower operating temperature

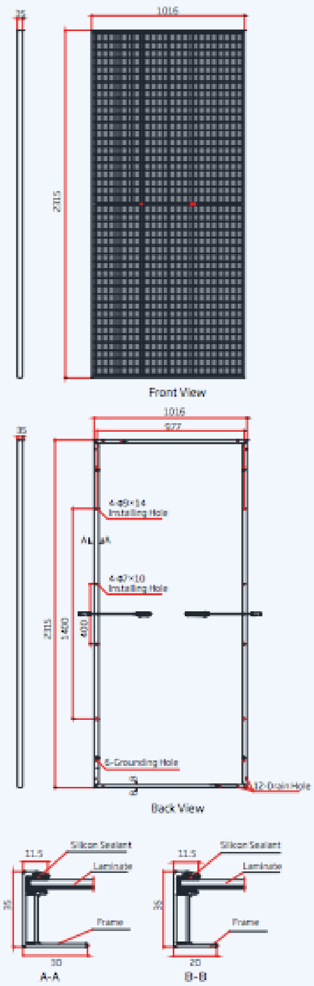
PERFORMANCE WARRANTY

12 Year Product Warranty · 25 Year Power Warranty

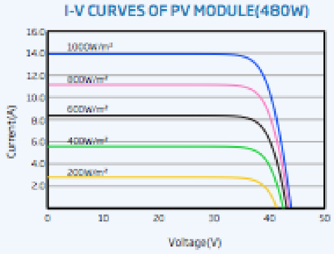


From the 2nd year to the 25th year, the average annual power decline will be no more than 0.6%.

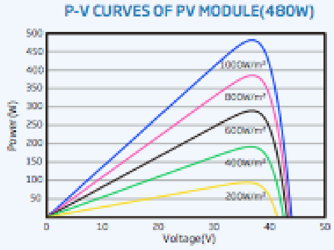
DIMENSIONS OF PV MODULE(mm)



I-V CURVES OF PV MODULE(480W)



P-V CURVES OF PV MODULE(480W)



ELECTRICAL DATA (STC)

Peak Power Watts-P_{MAX} (Wp)*	470	475	480	485	490
Power Tolerance-P_{MAX} (W)	0 ~ +5				
Maximum Power Voltage-V_{MPP} (V)	36.1	36.2	36.3	36.4	36.5
Maximum Power Current-I_{MPP} (A)	13.02	13.12	13.23	13.33	13.43
Open Circuit Voltage-V_{OC} (V)	43.0	43.1	43.2	43.3	43.4
Short Circuit Current-I_{SC} (A)	13.73	13.80	13.92	13.97	14.07
Module Efficiency η_m (%)	20.0	20.2	20.4	20.6	20.8

STC: Irradiance 1000W/m², Cell Temperature 25°C, Air Mass AM1.5.
*Measuring tolerance: ±3%.

ELECTRICAL DATA (NOCT)

Maximum Power-P_{MAX} (Wp)	354	358	362	365	369
Maximum Power Voltage-V_{MPP} (V)	33.6	33.8	33.9	34.0	34.1
Maximum Power Current-I_{MPP} (A)	10.53	10.59	10.68	10.72	10.80
Open Circuit Voltage-V_{OC} (V)	40.5	40.6	40.7	40.7	40.8
Short Circuit Current-I_{SC} (A)	11.06	11.12	11.22	11.26	11.34

NOCT: Irradiance at 800W/m², Ambient Temperature 20°C, Wind Speed 1m/s.

MECHANICAL DATA

Solar Cells	Monocrystalline PERC
Cell Orientation	252 cells (12 × 21)
Module Dimensions	2315 × 1016 × 35 mm (91.14 × 40 × 1.38 inches)
Weight	26.0 kg (57.3 lb)
Glass	3.2 mm (0.13 inches), High Transmission, AR Coated Heat Strengthened Glass
Encapsulant Material	EVA
Backsheet	White
Frame	35 mm (1.38 inches) Anodized Aluminium Alloy
J-Box	IP 68 rated
Cables	Photovoltaic Technology Cable 4.0mm² (0.006 inches²), Portrait: N 450 mm/P 450 mm (17.72/17.72 inches), Landscape: N 1400/P 1400 mm (55.12/55.12 inches)
Connector	MC4 EVO2 / TS4

TEMPERATURE RATINGS

NOCT (Nominal Operating Cell Temperature)	43°C (±2°C)
Temperature Coefficient of P_{MAX}	- 0.34%/°C
Temperature Coefficient of V_{OC}	- 0.25%/°C
Temperature Coefficient of I_{SC}	0.04%/°C

MAXIMUM RATINGS

Operational Temperature	-40~+85°C
Maximum System Voltage	1500V DC (IEC) 1500V DC (UL)
Max Series Fuse Rating	25A

(Do not connect Fuse in Combiner Box with two or more strings in parallel connection)

WARRANTY

12 year Product Workmanship Warranty

25 year Power Warranty

(Please refer to product warranty for details)

PACKAGING CONFIGURATION

Modules per box: 31 pieces

Modules per 40' container: 620 pieces

Appendix XIII: FMEA for Design 2

System Name: Renewable Energy Group							FMEA Number		
Subsystem Name: Solar system							Date		
Component Name									
Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurance (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
Solar Pannels	Wear	This can lower production by up uo 20%	5	Over working and overall fatgiue of the system can cause this. Another cause can be manufacutring errors.	5	1	1	25	After the expected life of the pannels is over and they begin to fail due to wear and tear, it is best to replace the pannels.
Ground Mount kit	Yeilding	Mounting system can yeild due to wind forces or fatigue and cause the whole system to fail.	9	The main cause in our case is wind. The force of wind can cause the mount to yield either over time or suddenly with enough force.	3	6	2	54	For the ground mount kit, it is best to check them after any storm to ensure there is no wear on them. If so they will need to be replaced.
Concrete	Yeilding	Same as the grounf mount kit	9	The main cause in our case is wind. The force of wind can cause the mount to yield either over time or suddenly with enough force.	3	6	2	54	Since the concrete in underground in a footing, there is no way to isnpect it. However there is very low chance of this failure if installed correctly.
Inverter	Fatigue	Aftter years of fatigue, the inverter could stop working. Thus leaving the system with no way to convert DC to AC.	6	The main cause of this would be normal wear and tear. No solar system will last a lifetime.	5	4	4	120	failed is to try using anything that is powered by an AC load. If not, a fix is to replace this part.
Display and controller	Wear	The display and contorller can fail after years of wear.	3	The main cause of this is also Normal wear and tear. Or could also be due to batteries dying	4	2	2	24	This part can be visually inspected and replaced if needed.
Battery monitor	Wear	The display and contorller can fail after years of wear.	3	This could happen due to an electrical malfunction. Which can be caused by a variety of reasons.	4	2	2	24	This part can be visually inspected and replaced if needed.
batteries / cable	Corroison	The cables for the batteries could corrode over time.	6	This is caused by time. Over time , with the help of natural elements, the cables can corrode and begin to slowly fail overtime.	4	7	7	168	The Batteries and electrical compents need to be replaced if corroded. The conduit lines cannnot be inspected if they are burried. If the system is not working, this could very well be the reaosn why. However this probel should not arrise in the systems lifespan if installed properly.
conduit and j boxes	Corrosion	The cables for the batteries could corrode over time.	7	This is caused by time. Over time , with the help of natural elements, the cables can corrode and begin to slowly fail overtime.	3	7	7	147	

Appendix XIV: Select Prototyping Photos

Appendix XV: Final Design Decision Matrix

Decision Matrix

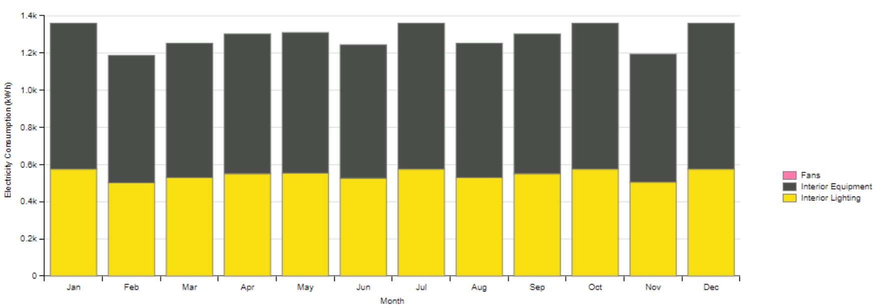
Concepts Requirements \	Weight	Design 1: Original	W.S.	Design 2: Cost Efficient	W.S.	Design 3: Highest Capacity	W.S.	Design 4: Varying Tilt Angle	W.S.
Safety	0.28	10	2.8	10	2.8	7	1.96	7	1.96
Cost	0.24	7	1.68	8	1.92	1	0.24	4	0.96
Energy Storage	0.24	6	1.44	7	1.68	10	2.4	7	1.68
Solar Generation	0.24	7	1.68	8	1.92	10	2.4	10	2.4
No Feedback	yes/ no	yes		yes		yes		yes	
Total	1		7.6		8.32		7		7

Appendix XVI: Energy Model Electricity Consumption Results

Monthly Overview

Electricity Consumption (kWh) - view table

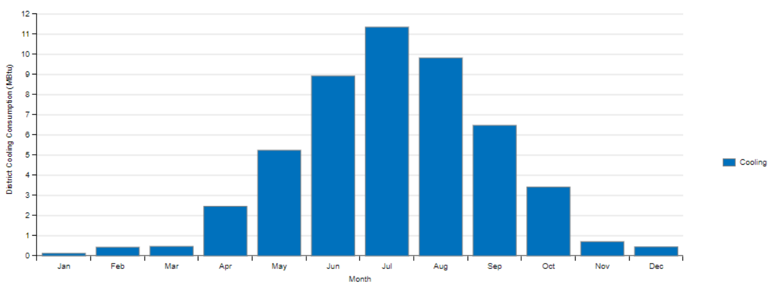
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Heating													
Cooling													
Interior Lighting	575.61	502.2	529.88	551.14	554.35	526.67	575.61	529.88	551.14	575.61	505.42	575.61	6553.11
Exterior Lighting													
Interior Equipment	784.92	684.82	722.57	751.55	755.93	718.19	784.92	722.57	751.55	784.92	689.21	784.92	8936.06
Exterior Equipment													
Fans													
Pumps													
Heat Rejection													
Humidification													
Heat Recovery													
Water Systems													
Refrigeration													
Generators													
Total	1360.52	1187.03	1252.45	1302.69	1310.29	1244.86	1360.52	1252.45	1302.69	1360.52	1194.62	1360.52	15489.17



Appendix XVII: Cooling & Heating Consumption Results

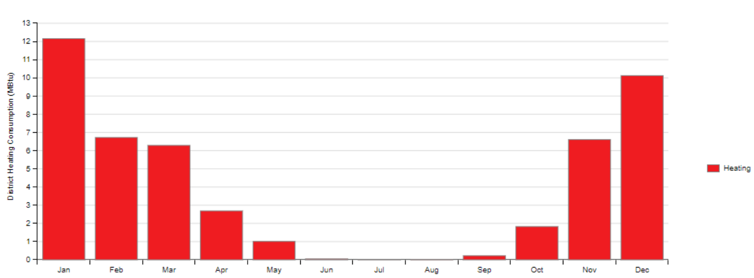
District Cooling Consumption (MBtu) - view table

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Heating													
Cooling	0.13	0.43	0.47	2.46	5.24	8.93	11.36	9.83	6.48	3.41	0.71	0.45	49.89
Interior Lighting													
Exterior Lighting													
Interior Equipment													
Exterior Equipment													
Fans													
Pumps													
Heat Rejection													
Humidification													
Heat Recovery													
Water Systems													
Refrigeration													
Generators													
Total	0.13	0.43	0.47	2.46	5.24	8.93	11.36	9.83	6.48	3.41	0.71	0.45	49.89



District Heating Consumption (MBtu) - view table

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Heating	12.16	6.72	6.29	2.69	1.01	0.05	0.0	0.01	0.22	1.82	6.61	10.12	47.69
Cooling													
Interior Lighting													
Exterior Lighting													
Interior Equipment													
Exterior Equipment													
Fans													
Pumps													
Heat Rejection													
Humidification													
Heat Recovery													
Water Systems													
Refrigeration													
Generators													
Total	12.16	6.72	6.29	2.69	1.01	0.05	0.0	0.01	0.22	1.82	6.61	10.12	47.69



Appendix XVIII: Heating and Cooling Load Model Results

Zone Load Summary | 1-3 Space | COOLING

CONDITIONS AT TIME OF PEAK

Time at Peak: 7/21 16:15:00

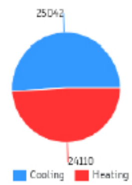
Outside
DB: **32.1 F**
HR: **18.5400 lb/lb**
WB: **96.7 F**

Zone
DB: **75.0 F**
HR: **0.0084 lb/lb**
RH: **45.6 %**

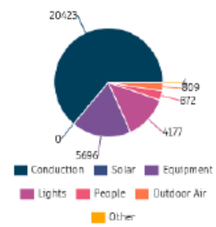
ENGINEERING CHECKS

Capacity per Floor Area: **22.50 Btu/hr-ft2**
Floor Area per Capacity: **44.4368 ft2/kBtu-hr**
Outdoor Air Percentage: **4.87 %**
Airflow per Floor Area: **1.409066 ft3/min-ft2**
Airflow per Capacity: **751.373731 ft3/min-ton**
Number of People: **2.0**

Peak Loads [Btu/hr]



Cooling Load Components [Btu/hr]



	Instant Sensible [Btu/hr]	Delayed Sensible [Btu/hr]	Latent [Btu/hr]	Total [Btu/hr]	Percent of Total [%]
Envelope					
Roof	-	14,699	-	14,699	58.7
Other - Roof	-	0	-	0	0.0
Ceiling	-	-1,087	-	-1,087	-4.3
Glass - Conduction	0	-	-	0	0.0
Glass - Solar	-	0	-	0	0.0
Door	-	0	-	0	0.0
Wall	-	1,852	-	1,852	7.4
Below-grade Wall	-	0	-	0	0.0
Partition	-	0	-	0	0.0
Other - Wall	-	0	-	0	0.0
Exterior Floor	-	0	-	0	0.0
Interior Floor	-	0	-	0	0.0
Slab	-	-2,382	-	-2,382	-9.5
Other - Floor	-	0	-	0	0.0
Infiltration	730	-	-328	402	1.6
Subtotal	**730**	**13,082**	**-328**	**13,484**	**53.8**
Internal Gains					
People	350	122	400	872	3.5
Lights	4,177	0	-	4,177	16.7
Return Air - Lights	0	-	-	0	0.0
Equipment	5,696	0	0	5,696	22.7
Subtotal	**10,223**	**122**	**400**	**10,745**	**42.9**
Systems					
Zone Ventilation	1,468	-	-660	809	3.2
Transfer Air	0	-	0	0	0.0
DOAS Direct to Zone	0	-	0	0	0.0
Return Air - Other	0	-	-	0	0.0
Power Generation Equipment	0	0	-	0	0.0
Refrigeration	0	-	0	0	0.0
Water Use Equipment	0	-	0	0	0.0
HVAC Equipment Loss	0	0	-	0	0.0
Subtotal	**1,468**	**0**	**-660**	**809**	**3.2**
Total					
Sizing Factor Adjustment	0	-	-	0	0.0
Time Delay Correction	-	4	-	4	0.0
Grand Total	**12,421**	**13,208**	**-587**	**25,042**	**100.0**

Zone Load Summary

1-1 Space | COOLING

CONDITIONS AT TIME OF PEAK

Time at Peak: 7/21 16:00:00

Outside
DB: **32.0 F**
HR: **18.6300 lb/lb**
WB: **97.3 F**

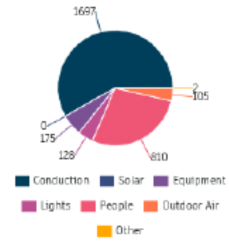
Zone
DB: **75.0 F**
HR: **0.0090 lb/lb**
RH: **48.7 %**

ENGINEERING CHECKS

Capacity per Floor Area: **72.34 Btu/hr-ft2**
Floor Area per Capacity: **13.8237 ft2/kBtu-hr**
Outdoor Air Percentage: **8.90 %**
Airflow per Floor Area: **3.725875 ft3/min-ft2**
Airflow per Capacity: **618.064674 ft3/min-ton**
Number of People: **2.0**

Peak Loads [Btu/hr]

Cooling Load Components [Btu/hr]



	Instant Sensible [Btu/hr]	Delayed Sensible [Btu/hr]	Latent [Btu/hr]	Total [Btu/hr]	Percent of Total [%]
Envelope					
Roof	-	1,475	-	1,475	59.8
Other - Roof	-	0	-	0	0.0
Ceiling	-	0	-	0	0.0
Glass - Conduction	0	-	-	0	0.0
Glass - Solar	-	0	-	0	0.0
Door	-	0	-	0	0.0
Wall	-	0	-	0	0.0
Below-grade Wall	-	0	-	0	0.0
Partition	-	0	-	0	0.0
Other - Wall	-	0	-	0	0.0
Exterior Floor	-	0	-	0	0.0
Interior Floor	-	0	-	0	0.0
Slab	-	-222	-	-222	-9.0
Other - Floor	-	0	-	0	0.0
Infiltration	0	-	0	0	0.0
Subtotal	**0**	**1,253**	**0**	**1,253**	**50.8**
Internal Gains					
People	350	60	400	810	32.8
Lights	128	0	-	128	5.2
Return Air - Lights	0	-	-	0	0.0
Equipment	175	0	0	175	7.1
Subtotal	**653**	**60**	**400**	**1,113**	**45.1**
Systems					
Zone Ventilation	235	-	-130	105	4.2
Transfer Air	0	-	0	0	0.0
DOAS Direct to Zone	0	-	0	0	0.0
Return Air - Other	0	-	-	0	0.0
Power Generation Equipment	0	0	-	0	0.0
Refrigeration	0	-	0	0	0.0
Water Use Equipment	0	-	0	0	0.0
HVAC Equipment Loss	0	0	-	0	0.0
Subtotal	**235**	**0**	**-130**	**105**	**4.2**
Total					
Sizing Factor Adjustment	0	-	-	0	0.0
Time Delay Correction	-	-2	-	-2	-0.1
Grand Total	**887**	**1,311**	**270**	**2,468**	**100.0**

Zone Load Summary

2-3 Analytical Space | COOLING

CONDITIONS AT TIME OF PEAK

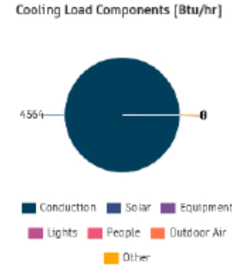
Time at Peak: 7/21 21:30:00

Outside
DB: **32.0 F**
HR: **15.8400 lb/lb**
WB: **82.7 F**

Zone
DB: **89.2 F**
HR: **0.0062 lb/lb**
RH: **21.1 %**

ENGINEERING CHECKS

Capacity per Floor Area: **-0.00 Btu/hr-ft2**
Floor Area per Capacity: **null ft2/kBtu-hr**
Outdoor Air Percentage: **0.00 %**
Airflow per Floor Area: **0.000000 ft3/min-ft2**
Airflow per Capacity: **null ft3/min-ton**
Number of People: **0.0**



	Instant Sensible [Btu/hr]	Delayed Sensible [Btu/hr]	Latent [Btu/hr]	Total [Btu/hr]	Percent of Total [%]
Envelope					
Roof	-	2,285	-	2,285	-956,614.3
Other - Roof	-	0	-	0	0.0
Ceiling	-	0	-	0	0.0
Glass - Conduction	0	-	-	0	0.0
Glass - Solar	-	0	-	0	0.0
Door	-	0	-	0	0.0
Wall	-	0	-	0	0.0
Below-grade Wall	-	0	-	0	0.0
Partition	-	0	-	0	0.0
Other - Wall	-	0	-	0	0.0
Exterior Floor	-	0	-	0	0.0
Interior Floor	-	-2,279	-	-2,279	954,285.7
Slab	-	0	-	0	0.0
Other - Floor	-	0	-	0	0.0
Infiltration	0	-	0	0	0.0
Subtotal	**0**	**6**	**0**	**6**	**-2,328.6**
Internal Gains					
People	0	0	0	0	0.0
Lights	0	0	-	0	0.0
Return Air - Lights	0	-	-	0	0.0
Equipment	0	0	0	0	0.0
Subtotal	**0**	**0**	**0**	**0**	**0.0**
Systems					
Zone Ventilation	0	-	0	0	0.0
Transfer Air	0	-	0	0	0.0
DOAS Direct to Zone	0	-	0	0	0.0
Return Air - Other	0	-	-	0	0.0
Power Generation Equipment	0	0	-	0	0.0
Refrigeration	0	-	0	0	0.0
Water Use Equipment	0	-	0	0	0.0
HVAC Equipment Loss	0	0	-	0	0.0
Subtotal	**0**	**0**	**0**	**0**	**0.0**
Total					
Sizing Factor Adjustment	0	-	-	0	0.0
Time Delay Correction	-	-6	-	-6	2,428.6
Grand Total	**0**	**-0**	**0**	**-0**	**100.0**

Zone Load Summary 1-3 Space HEATING

CONDITIONS AT TIME OF PEAK

Time at Peak: 12/21 24:00:00

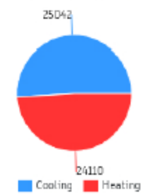
Outside
DB: **32.1 F**
HR: **-7.9000 lb/lb**
WB: **17.8 F**

Zone
DB: **70.0 F**
HR: **0.0046 lb/lb**
RH: **30.0 %**

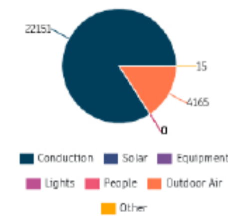
ENGINEERING CHECKS

Capacity per Floor Area: **-21.67 Btu/hr-ft2**
Floor Area per Capacity: **null ft2/kBtu-hr**
Outdoor Air Percentage: **4.87 %**
Airflow per Floor Area: **0.666450 ft3/min-ft2**
Airflow per Capacity: **null ft3/min-ton**
Number of People: **2.0**

Peak Loads [Btu/hr]



Heating Load Components [Btu/hr]



	Instant Sensible [Btu/hr]	Delayed Sensible [Btu/hr]	Latent [Btu/hr]	Total [Btu/hr]	Percent of Total [%]
Envelope					
Roof	-	-9,931	-	-9,931	41.2
Other - Roof	-	0	-	0	0.0
Ceiling	-	-5,049	-	-5,049	20.9
Glass - Conduction	0	-	-	0	0.0
Glass - Solar	-	0	-	0	0.0
Door	-	0	-	0	0.0
Wall	-	-3,678	-	-3,678	15.3
Below-grade Wall	-	0	-	0	0.0
Partition	-	0	-	0	0.0
Other - Wall	-	0	-	0	0.0
Exterior Floor	-	0	-	0	0.0
Interior Floor	-	0	-	0	0.0
Slab	-	1,111	-	1,111	-4.6
Other - Floor	-	0	-	0	0.0
Infiltration	-1,983	-	-400	-2,383	9.9
Subtotal	**-1,983**	**-17,547**	**-400**	**-19,929**	**82.7**
Internal Gains					
People	0	0	0	0	0.0
Lights	0	0	-	0	0.0
Return Air - Lights	0	-	-	0	0.0
Equipment	0	0	0	0	0.0
Subtotal	**0**	**0**	**0**	**0**	**0.0**
Systems					
Zone Ventilation	-3,467	-	-698	-4,165	17.3
Transfer Air	0	-	0	0	0.0
DOAS Direct to Zone	0	-	0	0	0.0
Return Air - Other	0	-	-	0	0.0
Power Generation Equipment	0	0	-	0	0.0
Refrigeration	0	-	0	0	0.0
Water Use Equipment	0	-	0	0	0.0
HVAC Equipment Loss	0	0	-	0	0.0
Subtotal	**-3,467**	**0**	**-698**	**-4,165**	**17.3**
Total					
Sizing Factor Adjustment	0	-	-	0	0.0
Time Delay Correction	-	-15	-	-15	0.1
Grand Total	**-5,450**	**-17,562**	**-1,098**	**-24,110**	**100.0**

Zone Load Summary 1-1 Space HEATING

CONDITIONS AT TIME OF PEAK

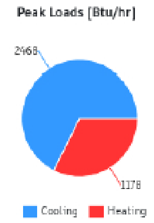
Time at Peak: 12/21 24:00:00

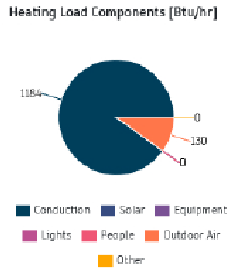
Outside
DB: **32.0 F**
HR: **-7.9000 lb/lb**
WB: **17.8 F**

Zone
DB: **70.0 F**
HR: **0.0049 lb/lb**
RH: **31.3 %**

ENGINEERING CHECKS

Capacity per Floor Area: **-34.54 Btu/hr-ft2**
Floor Area per Capacity: **null ft2/kBtu-hr**
Outdoor Air Percentage: **8.90 %**
Airflow per Floor Area: **1.241958 ft3/min-ft2**
Airflow per Capacity: **null ft3/min-ton**
Number of People: **2.0**





	Instant Sensible [Btu/hr]	Delayed Sensible [Btu/hr]	Latent [Btu/hr]	Total [Btu/hr]	Percent of Total [%]
Envelope					
Roof	-	-1,116	-	-1,116	94.7
Other - Roof	-	0	-	0	0.0
Ceiling	-	0	-	0	0.0
Glass - Conduction	0	-	-	0	0.0
Glass - Solar	-	0	-	0	0.0
Door	-	0	-	0	0.0
Wall	-	0	-	0	0.0
Below-grade Wall	-	0	-	0	0.0
Partition	-	0	-	0	0.0
Other - Wall	-	0	-	0	0.0
Exterior Floor	-	0	-	0	0.0
Interior Floor	-	0	-	0	0.0
Slab	-	68	-	68	-5.8
Other - Floor	-	0	-	0	0.0
Infiltration	0	-	0	0	0.0
Subtotal	**0**	**-1,048**	**0**	**-1,048**	**89.0**
Internal Gains					
People	0	0	0	0	0.0
Lights	0	0	-	0	0.0
Return Air - Lights	0	-	-	0	0.0
Equipment	0	0	0	0	0.0
Subtotal	**0**	**0**	**0**	**0**	**0.0**
Systems					
Zone Ventilation	-106	-	-23	-130	11.0
Transfer Air	0	-	0	0	0.0
DOAS Direct to Zone	0	-	0	0	0.0
Return Air - Other	0	-	-	0	0.0
Power Generation Equipment	0	0	-	0	0.0
Refrigeration	0	-	0	0	0.0
Water Use Equipment	0	-	0	0	0.0
HVAC Equipment Loss	0	0	-	0	0.0
Subtotal	**-106**	**0**	**-23**	**-130**	**11.0**
Total					
Sizing Factor Adjustment	0	-	-	0	0.0
Time Delay Correction	-	-0	-	-0	0.0
Grand Total	**-106**	**-1,049**	**-23**	**-1,178**	**100.0**

Zone Load Summary

2-3 Analytical Space | HEATING

CONDITIONS AT TIME OF PEAK

Time at Peak: 12/21 24:00:00

Outside
DB: 32.0 F
HR: -7.9000 lb/lb
WB: 17.8 F

Zone
DB: 50.4 F
HR: 0.0023 lb/lb
RH: 30.2 %

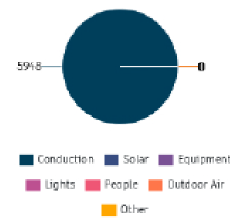
ENGINEERING CHECKS

Capacity per Floor Area: 0.00 Btu/hr-ft2
Floor Area per Capacity: 24523782.6602 ft2/kBtu-hr
Outdoor Air Percentage: 0.00 %
Airflow per Floor Area: 0.000000 ft3/min-ft2
Airflow per Capacity: 0.000000 ft3/min-ton
Number of People: 0.0

Peak Loads [Btu/hr]

Cooling Heating

Heating Load Components [Btu/hr]



	Instant Sensible [Btu/hr]	Delayed Sensible [Btu/hr]	Latent [Btu/hr]	Total [Btu/hr]	Percent of Total [%]
Envelope					
Roof	-	-2,974	-	-2,974	-8,717,000.0
Other - Roof	-	0	-	0	0.0
Ceiling	-	0	-	0	0.0
Glass - Conduction	0	-	-	0	0.0
Glass - Solar	-	0	-	0	0.0
Door	-	0	-	0	0.0
Wall	-	0	-	0	0.0
Below-grade Wall	-	0	-	0	0.0
Partition	-	0	-	0	0.0
Other - Wall	-	0	-	0	0.0
Exterior Floor	-	0	-	0	0.0
Interior Floor	-	2,974	-	2,974	8,715,400.0
Slab	-	0	-	0	0.0
Other - Floor	-	0	-	0	0.0
Infiltration	0	-	0	0	0.0
Subtotal	**0**	**-1**	**0**	**-1**	**-1,600.0**
Internal Gains					
People	0	0	0	0	0.0
Lights	0	0	-	0	0.0
Return Air - Lights	0	-	-	0	0.0
Equipment	0	0	0	0	0.0
Subtotal	**0**	**0**	**0**	**0**	**0.0**
Systems					
Zone Ventilation	0	-	0	0	0.0
Transfer Air	0	-	0	0	0.0
DOAS Direct to Zone	0	-	0	0	0.0
Return Air - Other	0	-	-	0	0.0
Power Generation Equipment	0	0	-	0	0.0
Refrigeration	0	-	0	0	0.0
Water Use Equipment	0	-	0	0	0.0
HVAC Equipment Loss	0	0	-	0	0.0
Subtotal	**0**	**0**	**0**	**0**	**0.0**
Total					
Sizing Factor Adjustment	0	-	-	0	0.0
Time Delay Correction	-	1	-	1	1,700.0
Grand Total	**0**	**0**	**0**	**0**	**100.0**

Appendix XVIII: Full Structural Analysis of Ground Mount System

Renewable Energy Project
Structural Analysis of Ground Mount System for PV Array

Michael Horn

ME 486C

FALL 2023

Northern Arizona University

Department of Mechanical Engineering

Project Sponsor: Steve Wineicki

Faculty Advisors: Dr. David Willy

Dr. Carson Pete

Dr. Robin Tuchscherer

Introduction

The purpose of this report is to analyze and document the structural integrity of the proposed design for the Winiecki Renewable Energy Project. This document will contain hand calculations for stress under different loads, and will further validate the current design in terms of its structural stability. The mounting system is to be assessed primarily, although the integrity of the panels will also be considered. Wind loads, snow loads, and dead loads will be statically analyzed. Recommendations will be given on the configuration of the ground mounted system, as many different combinations of components are available. The projected wind and snow loads at the site location will be the determining factors for the recommended configuration. For this analysis, a four panel, three-rail mounting system will be assumed for calculation purposes. This mounting system can be shown in Figure 1.

Figure 1: 4 Panel 3-Rail Ground Mounting System

Reference:
https://snapnrack.com/wp-content/uploads/2019/07/SnapNrack_NSSE_S200_02-04-2019_Complete_.pdf

As an additional resource, structural information regarding the mounting system, being the SnapNRack 200 series, will be referenced directly from the manufacturer's website. Detailed reports regarding the structural integrity of the mounting system are readily available, and will assist in calculating the projected loads the system will experience.

Projected Wind Loads

Wind loads will be calculated from a projected maximum wind speed of 113 mph. The resulting load on the panels, and consequently the mounting system, will be determined as a function of this wind speed, the tilt angle, and geometry of both the panels and mounting system. A side view of the mounting system is shown in Figure 2.

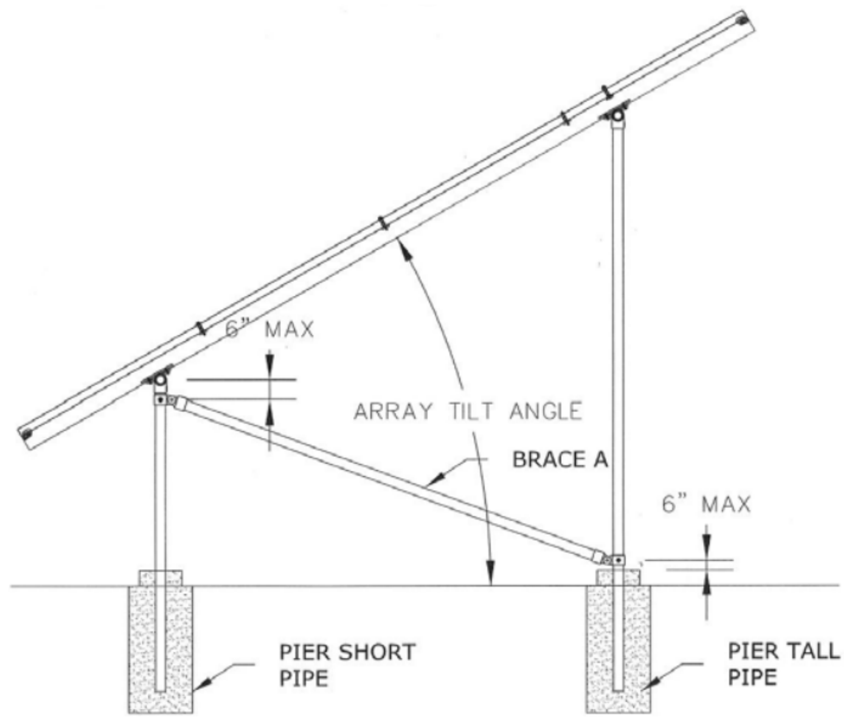


Figure 2: Side View of Mounting System

Reference:
https://snapnrack.com/wp-content/uploads/2019/07/SnapNrack_NSSE_S200_02-04-2019_Complete_.pdf

Several parameters and correction factors must be accounted for when calculating wind loads, as well as general assumptions. ASCE 7-16 will be used to calculate pressure forces from wind. The calculations are as follows:

L = 2.315m w = 1.016m t = .035m theta = 29 degrees

Basic Wind Speed (V)

Using ASCE 7-16, the basic wind speed for the Camp Verde area can be approximated as 113 mph. This figure can be viewed in Figure 3.

V = 113 mph (ASCE 7-16)

reference: ASCE 7-16 Figure 26.5-1

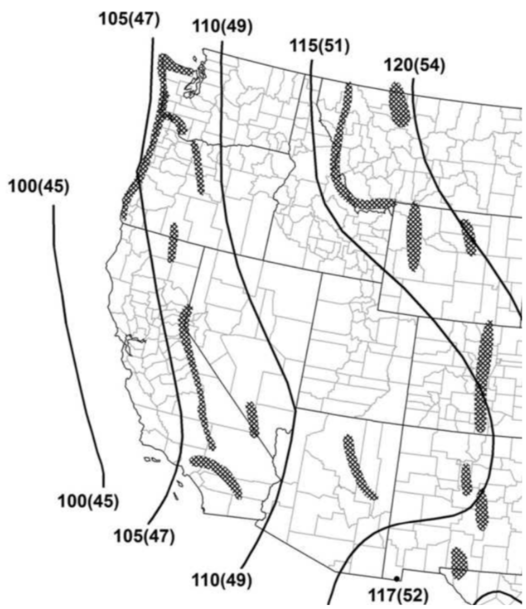


Figure 3: Figure 26.5-1C from ASCE 7-16

Exposure Category

The exposure category is a factor used to determine the exposure of a structure to direct wind. Because the solar panel site location is an open area with minimal, scattered obstructions less than 30ft, exposure factor C will be used; this factor will be used in determining the topographical factor Kzt and Kz

Wind Directionality Factor (K_d)

Because the solar panel array can be considered an open, monoslope structure, this factor will be .85, according to Table 26.6-1 of ASCE 7-16.

$$K_d = 1$$

Ground Elevation Factor (K_e)

The ground elevation factor is used to compensate for the elevation of the site location. It is assumed the site location elevation in Camp Verde is 3200 ft. This factor can be calculated using the following equation:

$$K_e = e^{-.0000362Z_g}$$

Where: $Z_g = 3200\, ft$

$$K_e = e^{-.0000362(3200)}$$

$$K_e = .89$$

Velocity Pressure Coefficient (K_z)

The velocity pressure coefficient accounts for corrections due to the height of the mounting system and is calculated as follows:

Velocity Pressure Coefficient for Mounting Height < 15 ft =

$$K_z = 2.01(15/Z_g)^{2/a}$$

Where, Z_g is the nominal height of the atmospheric boundary layer, and a is the width of the pressure coefficient zone. According to Table 26.9-1 of ASCE 7-16:

Z_g = 900 ft

a = 9.5

Therefore:

$$K_z = 2.01(15/900)^{2/9.5} = .85$$

Topographical Factor (K_{zt})

The topographical factor is used to account for characteristics of the site topography that may affect wind conditions. For this site location, this factor may be reasonably assumed to be 1.0, per ASCE 7-16.

$$K_{zt} = 1.0$$

Velocity Pressure (q_h)

The velocity pressure is a pressure resulting from velocity, and encompasses a force per unit area. Therefore, the dimensions of the panels do not need to yet be accounted for. The velocity pressure is calculated as follows:

$$q_h = .0025K_e K_z K_{zt} K_d V^2$$

Where:

$$q_h = .0025(.987)(1)(.89)(.85)(113)^2$$

$$q_h = 23.8\,psf$$

Gust Factor (G)

The gust factor, which accounts for periodic, positive discrepancies in wind speed, must now be accounted for. For a more in depth analysis, the gust factor would be determined by first calculating the natural frequency of the entire structure, in order to determine if the structure can be considered rigid or flexible. It will be assumed in this analysis that the structure will be rigid, and therefore, the gust factor can be assumed as being .85, based on section 26.11.5 of ASCE 7-16.

G = .85

Net Pressure Coefficient (C_N)

The net pressure coefficient will be used to calculate the overall pressure experienced by the structure. The structure will be assumed to be a monoslope roof, where Figure 27.3-4 will be used to determine values of C_N for both leeward and windward directions, at an orientation of 0 degrees and 180 degrees of wind direction. A portion of Figure 27.3-4 can be viewed below in Figure 4.

		Wind Direction, $\gamma = 0°$				Wind Direction, $\gamma = 180°$			
		Clear Wind Flow		Obstructed Wind Flow		Clear Wind Flow		Obstructed Wind Flow	
Roof Angle, θ	Load Case	C_{NW}	C_{NL}	C_{NW}	C_{NL}	C_{NW}	C_{NL}	C_{NW}	C_{NL}
0°	A	1.2	0.3	−0.5	−1.2	1.2	0.3	−0.5	−1.2
	B	−1.1	−0.1	−1.1	−0.6	−1.1	−0.1	−1.1	−0.6
7.5°	A	−0.6	−1.0	−1.0	−1.5	0.9	1.5	−0.2	−1.2
	B	−1.4	0.0	−1.7	−0.8	1.6	0.3	0.8	−0.3
15°	A	−0.9	−1.3	−1.1	−1.5	1.3	1.6	0.4	−1.1
	B	−1.9	0.0	−2.1	−0.6	1.8	0.6	1.2	−0.3
22.5°	A	−1.5	−1.6	−1.5	−1.7	1.7	1.8	0.5	−1.0
	B	−2.4	−0.3	−2.3	−0.9	2.2	0.7	1.3	0.0
30°	A	−1.8	−1.8	−1.5	−1.8	2.1	2.1	0.6	−1.0
	B	−2.5	−0.5	−2.3	−1.1	2.6	1.0	1.6	0.1

Figure 4: Figure 27.3-4 from ASCE 7-16 with Associated Values for C_n

Wind Loads (P)

Wind loads can now be calculated for load cases A and B. A short MATLAB code was generated to calculate the loads for each case and direction. The equation to calculate wind load is as follows:

$$P = q_h C_N$$

A snippet of the MATLAB code is shown below in Figure 5:

```
q = 23.8;

G = .85;
Cn_0 = [-1.8 -1.8; -2.5 -.5];
Cn_180 = [2.1 2.1;2.6 1];

P_0 = q*G.*Cn_0
P_180 = q*G.*Cn_180
```

```
P_0 = 2x2
    -36.4140   -36.4140
    -50.5750   -10.1150

P_180 = 2x2
     42.4830    42.4830
     52.5980    20.2300
```

Figure 5: Matlab Code to Calculate Wind Loads

The calculated results are tabulated in Table 1:

Table 1: Wind Loads on Solar Array for Each Orientation/ Direction

Wind Speed: 113 mph	Direction = 0 degrees		Direction = 180 degrees	
Load Case	Windward (psf)	Leeward (psf)	Windward (psf)	Leeward (psf)
A	-36.41	-36.41	42.48	42.48
B	-50.58	-10.12	52.60	20.23

Snow Loads

Because Camp Verde, Az experiences snowfall, the additional loads from snow experienced by the system will need to be accounted for. The governing equations to calculate snow load are as follows:

$$P_f = .7C_eC_tI_sP_g$$

Because the panel array will be tilted at an angle, a corrected form is this equation is necessary:

$$P_s = C_sP_f + P_r$$

As with the previous calculation, the snow load calculation will require several additional factors to determine. Using chapter 7 ASCE 7-16, these factors will be solved as follows.

Exposure Factor (C_e)

This factor accounts for the surface roughness of the site location, and the consequent exposure of the structure. It can be assumed for this analysis, and by satellite images of the site location, that the surface roughness can be classified as category C, according to Table 7.3-1, ASCE 7-16. Category C describes a site location which is open terrain with scattered, minimal obstructions less than 30ft high. This table can be viewed below in Figure 6.

Surface Roughness Category	Fully Exposed	Partially Exposed	Sheltered
B (see Section 26.7)	0.9	1.0	1.2
C (see Section 26.7)	0.9	1.0	1.1
D (see Section 26.7)	0.8	0.9	1.0

Figure 6: Table 7.3-1 ASCE 7-16

Consequently:

$$C_e = .9$$

Thermal Factor (C_t)

This factor is used to account for thermal conditions of the structure. Table 7.3-2 is used to determine the value of this factor.

Table 7.3-2 Thermal Factor, C_t

Thermal Condition[a]	C_t
All structures except as indicated below	1.0
Structures kept just above freezing and others with cold, ventilated roofs in which the thermal resistance (R-value) between the ventilated space and the heated space exceeds $25°F \times h \times ft^2/Btu$ ($4.4\ K \times m^2/W$)	1.1
Unheated and open air structures	1.2

Figure 7: Table 7.3-2 ASCE 7-16

The structure will be an unheated and open air structure; therefore:

$$C_t = 1.2$$

Importance Factor (I_s)

The structure is assumed to be Risk Category I, and therefore, the importance factor will be .8.

$$I_s = .8$$

Ground Snow Load

This factor is determined by Figure 7.2-1 of ASCE 7-16; a site specific case study is recommended by the text in order to determine the value of this factor. For this analysis, this load will be assumed to be 20, based on published articles from the Yavapai County government. References for this source are located in Appendix C.

$$P_g = 20\,psf$$

Flat Roof Snow Load (P_f)

The flat roof snow load can be calculated as follows:

$$P_f = .7C_eC_tI_sP_g$$

$$P_f = .7(.9)(1.2)(.8)(20)$$

P_f = 12.1 psf

Roof Slope Factor

The roof slope factor will be used to account for the tilt angle of the panel. This factor is determined from Figure 7.4-1 of ASCE 7-16, using a tilt angle of 29 degrees. Using the graphical figure, this factor is .8.

$$C_s = .8$$

Rain Surcharge Load (P_r)

This factor is meant to consider an additional 5psf for structures with P_g less than or equal to 20 psf, or with angle W/50 < tilt angle theta.

Where: W = wcos(theta)

W = $13.33cos(29)$ = 11.65 ft

$$11.65/50 = .233\ degrees < 29\ degrees$$

Because W/50 is much less than the tilt angle theta, this factor can be neglected.

$$P_r = 0$$

Sloped Roof Snow Load

With the previous factors accounted for, the sloped roof snow load may now be calculated:

$$P_s = C_s P_f + P_r$$

$$P_s = (.8)(12.1) + 0$$

$$P_s = 9.68\ psf$$

Now, accounting for the tilt angle of the panels, the projected snow load is as follows:

$$P_s = 9.68\,cos(29) = 8.47 \text{ psf}$$

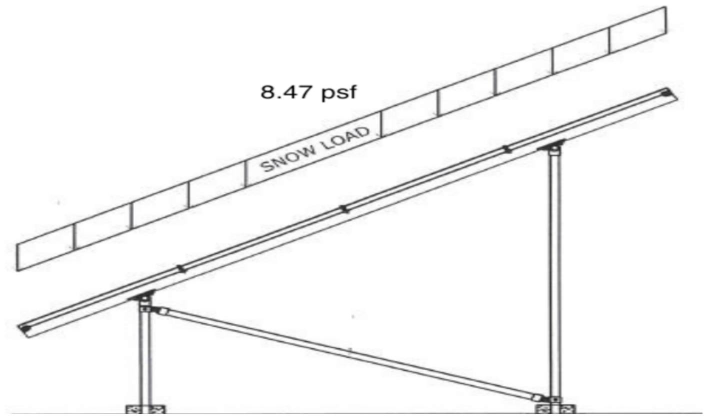


Figure 8: Projected Snow Load for Solar Panel Structure

Dead Loads

The final loading to be analyzed will be the weight of the panels themselves, upon the structure. Each panel has a weight of 57.3 lbs. For this analysis, four panels will be set upon each mounting system, giving a total weight of 229.2 lbs.

Structural Analysis

Bending stress resulting from moment can be calculated at this stage; however, the manufacturer report of the mounting system gives recommendations for components and configurations based on the loads experienced by the system. Using the loads determined in the previous section, configurations for the structure will be determined from the recommendations of the report, which have been tabulated into tables. These tables are shown below in Figures 9 and 10.

Table 2: Configuration Table for System Based on Wind and Snow Loads

110 mph Wind Load 11-20 psf Snow																
Tilt Angle θ	Standard Installation							Braced Installation							Number of Rails Required Per Panel	
	Max (PS)		12" Dia Pier		Required Braces			Max (PS)		12" Dia Pier		Required Braces			Module Size	
	Sch 40	Sch 80	Short	Tall	A	C	D	Sch 40	Sch 80	Short	Tall	A	E	F	40" x 66"	40" x 78"
θ = 0	87	100	30	30	No	Every 3rd Bay	No	180	180	30	30	Yes	Yes	Yes	2	2
0 > θ < 7.5	81	93	30	30	Yes	Every 3rd Bay	No	180	180	30	38	Yes	Yes	Yes	2	2
7.5 > θ < 15	82	93	30	36	Yes	Every 3rd Bay	No	180	180	30	48	Yes	Yes	Yes	2	2
15 > θ < 22.5	82	94	30	42	Yes	Every 3rd Bay	Every 3rd Bay	180	180	30	57	Yes	Yes	Yes	2	2
22.5 > θ < 30	81	92	30	46	Yes	Every 3rd Bay	Every 3rd Bay	174	180	30	61	Yes	Yes	Yes	2	2
30 > θ < 37.5	86	98	30	49	Yes	Every 3rd Bay	Every 3rd Bay	163	180	30	63	Yes	Yes	Yes	2	2
37.5 > θ < 45	88	101	30	52	Yes	Every 3rd Bay	Every 3rd Bay	153	175	30	66	Yes	Yes	Yes	2	2

Table 3: Number of Rails Based on Wind Velocity and Tilt Angle

22.6 to 30 Degrees														
	Number of Rails Per 40" x 78" PV Panel													
	Snow Load													
Wind Velocity (Vult) mph		0	10	20	30	40	50	60	70	80	90	100	110	120
	100	2	2	2	2	2	2	2	3	3	3	3	3	3
	110	2	2	2	2	2	2	2	3	3	3	3	3	NG
	120	2	2	2	2	2	2	3	3	3	3	3	3	NG
	130	2	2	2	2	2	3	3	3	3	3	3	NG	NG
	140	3	3	3	3	3	3	3	3	3	3	NG	NG	NG
	150	3	3	3	3	3	3	3	3	3	3	NG	NG	NG
	160	3	3	3	3	3	3	3	NG	NG	NG	NG	NG	NG
	170	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG

Reference:
https://snapnrack.com/wp-content/uploads/2019/07/SnapNrack_NSSE_S200_02-04-2019_Complete_.pdf

Based on the tables, the final structural design should incorporate schedule 80 pipe, with a footing depth for the tall and short pipes, respectively, of 61 and 30 inches. Braces should be installed at members A, E, and F, and two rails should be used to support the panels. Pictures of the structure, made by the manufacturer, can be found in Appendix A.

For the sake of consistency, a truss analysis was conducted for Case 1-B, to display the stability of the structure. Where,

$$\text{Max Axial Stress} = 55.9 \text{ psi}$$

$$\text{Max Bending Stress} = 129 \text{ psi}$$

Both of these values are far below the maximum stress levels of schedule 40 pipe. The full calculation, done by hand, can be found in Appendix D.

References:

[1]
http://medeek.com/resources/snow/DOCUMENTS/ARIZONA/YAVAPAI_COUNTY.pdf

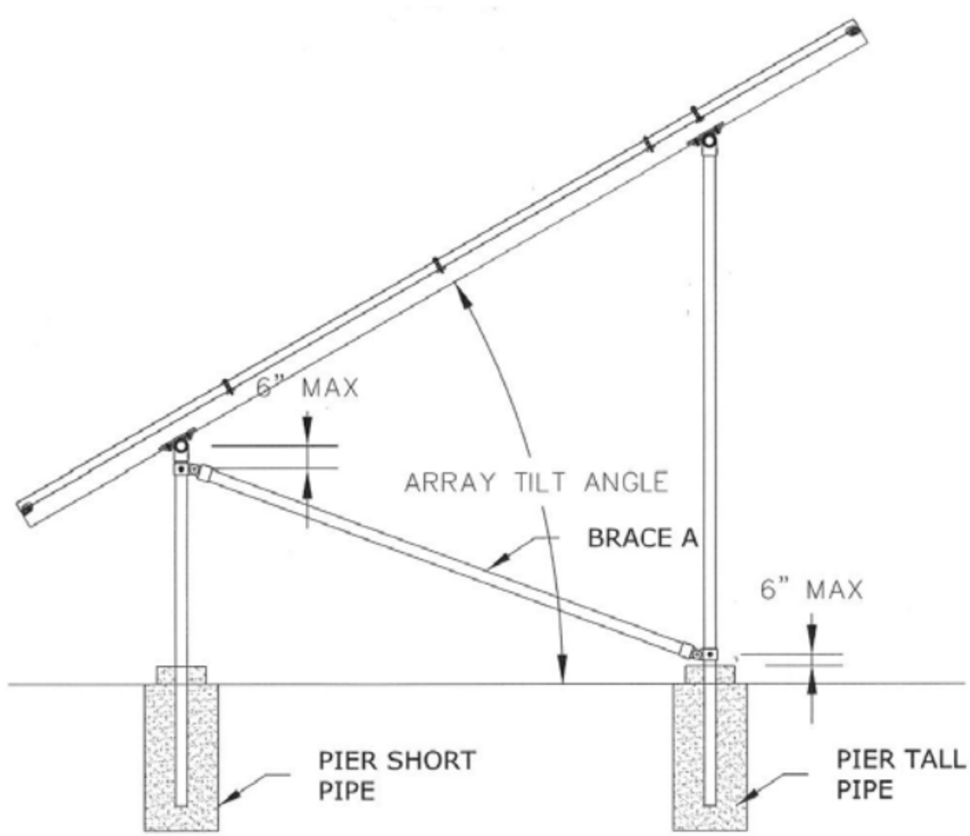
[2] SkyCiv. (2018, May 15). Solar Panel Wind Load Calculation per ASCE 7-16 [Online]. Available:
https://skyciv.com/docs/tech-notes/loading/solar-panel-wind-load-calculation-asce-7-16/

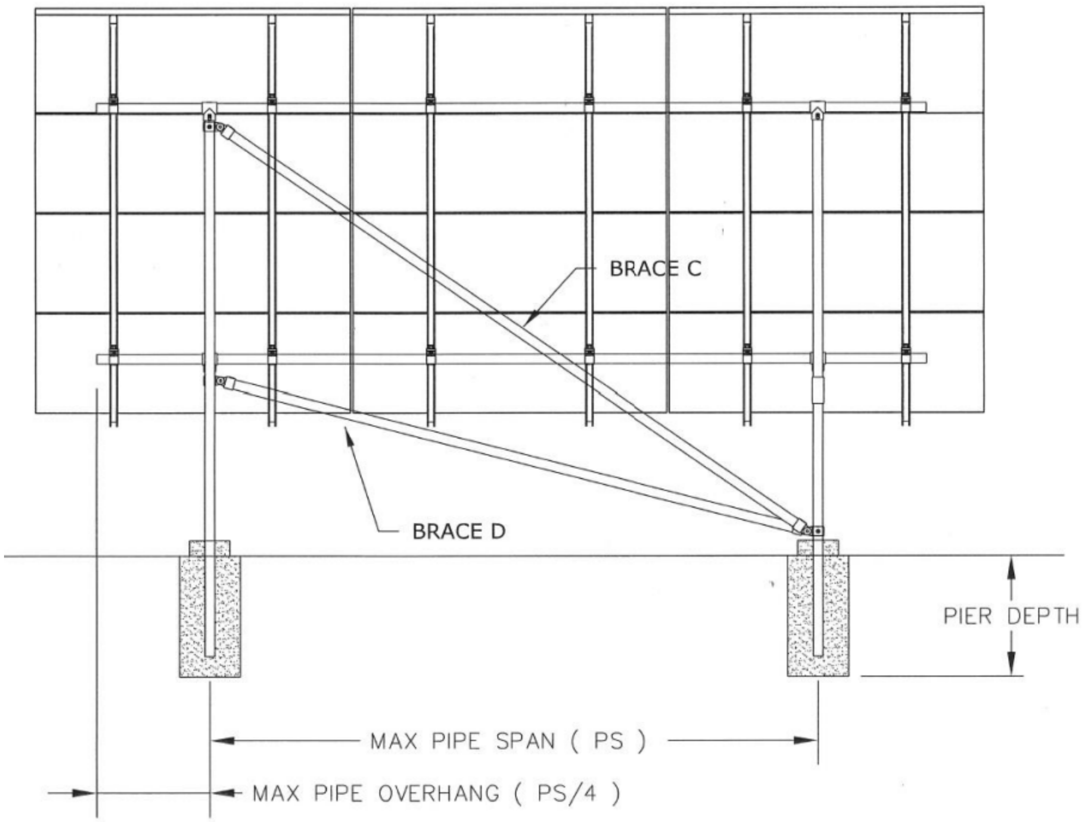
[3] American Society of Civil Engineers. (2017). Minimum Design Loads and Associated Criteria for Buildings and Other Structures. ASCE Standard 7-16. Reston, VA: American Society of Civil Engineers.

[4] SnapNrack. (2019, February 4). Ultra Rail Roof Mount System Installation Guide.

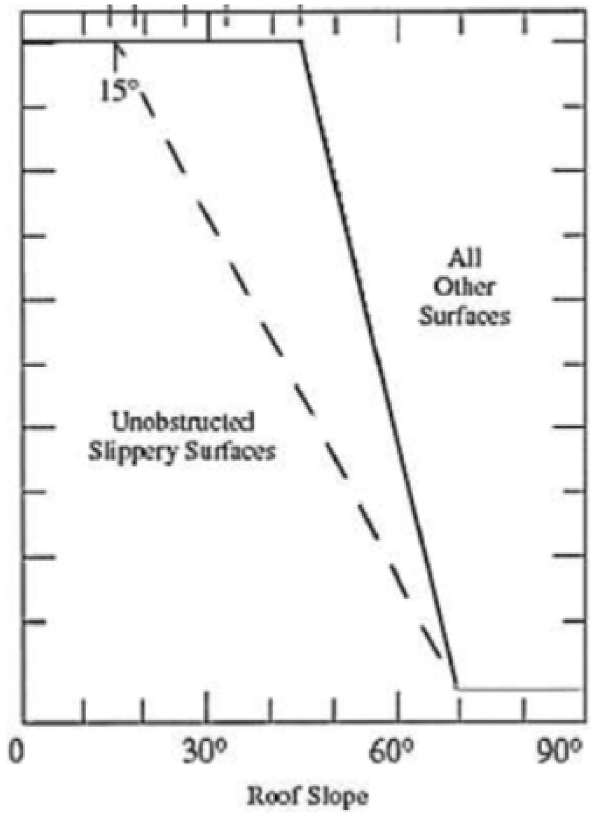
[Online]. Available:
https://snapnrack.com/wp-content/uploads/2019/07/SnapNrack_NSSE_S200_02-04-2019_Complete_.pdf

Appendix A: Manufacturer Pictures of Ground Mounted System





Appendix B: Roof Slope Factor Chart



7-2c: Cold roofs with C = 1.2 or larger

Appendix C: Yavapai County Snow Load Information

BUILDING SAFETY UNIT

POLICY	PB-16 **Page** 1 of 1 **Date: 11/10/10**

DESIGN CRITERIA
CLIMATIC AND GEOGRAPHIC DESIGN CRITERIA

Roof Snow Load	Wind Speed (mph)	Seismic Design Category	SUBJECT TO DAMAGE FROM			Winter Design Temp	Ice Barrier Underlayment Required
			Weathering	Frost Line Depth	Termite		
20 to 50	90 MPH Exposure A, B, C	C	Negligible Below 3000 Moderate Above 3000	6 inches below 4500 12 inches above 4500	Moderate to Heavy	20°	NO

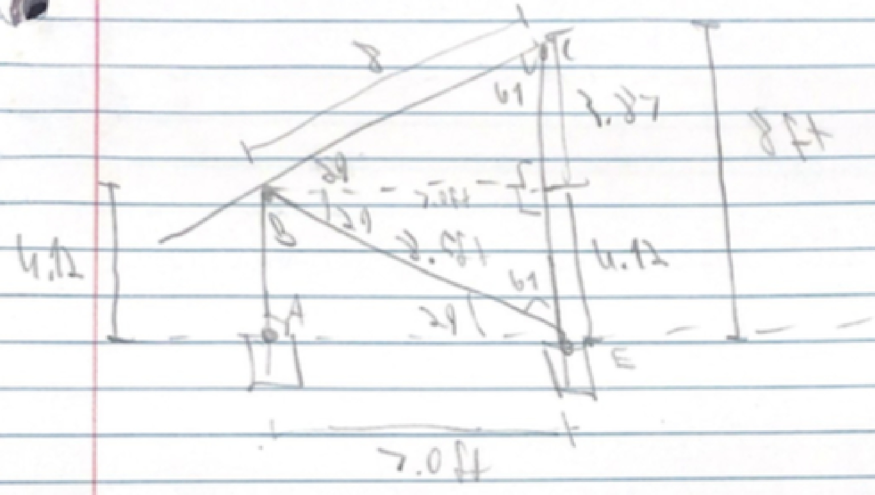
Flood Hazards	Air Freezing Index	Mean Annual Temp
Refer to Flood Plain Unit	194	53°

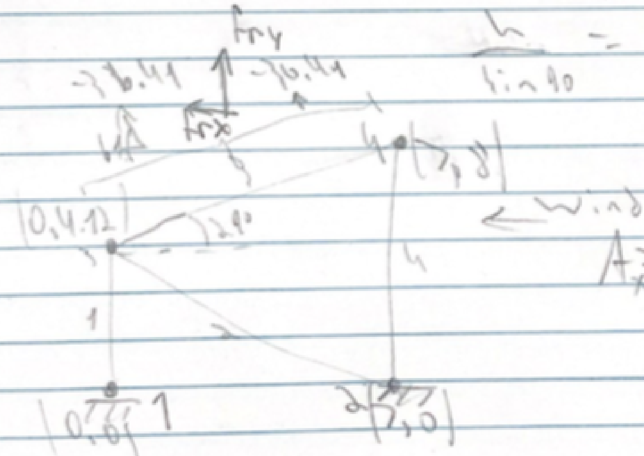
Yavapai County Snow Load by Elevation

	ELEVATION	SNOW LOAD	FOOTING DEPTH	ROOF SHEATHING
NOTE: Actual elevation may vary. **Specific site elevation will apply.**	3000 ft. to 5000 ft.	20 PSF	12" below 4500 ft. 18" above 4500 ft.	½"
	5001 ft. to 5900 ft.	30 PSF	18"	½"
	5901 ft To 6200 ft.	40 PSF*	18"	½" or 5/8" With tile over 60#TL
	6201 ft. to 6500 ft.	45 PSF*	18"	5/8"
	Over 6501 ft.	50 PSF*	18"	5/8"

*These values may be considered as ground snow loads and reduces as appropriate per Section 1608 of the 2006 IBC. Design Snow Loads for reductions shall be determined in accordance with Chapter 7 of ASCE 7-05 to include snow drift and unbalanced loads. The minimum reduction permitted is to 30 PSF.

Appendix D: Stress Calculations





$\frac{h}{\sin 90} = \frac{4.12}{\sin 29}$ $h = 8.5$ ft

$A_x = 25.3$ ft^2

1 A $F_{xww} = F_{xlw} = -36.41 \cos 61 = -17.65 \cdot 25.3$ ft^2

$F_{xlw} = 446.6$ lbs

$F_{xww} = 446.6$ lbs

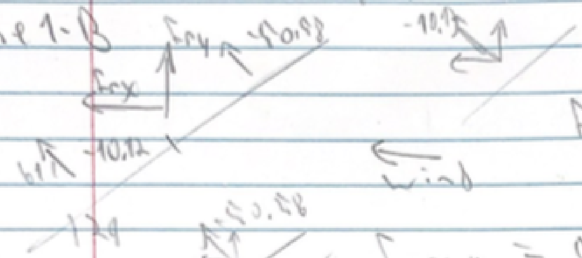
$F_{ylw} = F_{xww} = -36.41 \sin 61 = 805.67$ lbs

Case 1-A	$F_{ry} = 1610$ lbs	
	$F_{rx} = 892$ lbs	

$P_f = .7 C_e C_t I_s P_g$

$P_s = C_s P_f + P_r$

Case 1-B



$F_{xlw} = -10.1\cos 61 \cdot 25.3$

$F_{xlw} = -123.9$ lbs

$F_{ylw} = +10.1\sin 61 \cdot 25.3$

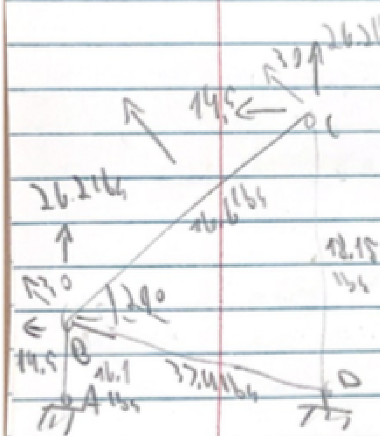
$= 223.5$ lbs

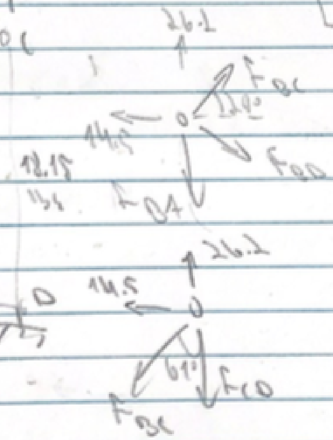
$F_{xww} = 50.58\cos 61 \cdot 25.3$

$F_{xww} = 619.8$ lbs

$F_{yww} = 50.58\sin 61 \cdot 25.3$

$F_{yww} = 1119.3$ lbs





$\Sigma F_y = 0: 26.2 - F_{BA} + 16.6\sin 29 - F_{BD}\sin 29 = 0$

$F_{BA} = 16.1$ lbs

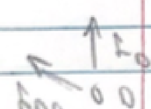
$\Sigma F_x = 0: -14.5 - F_{BC}\sin 61 = 0$

$-F_{BC} = 14.5/\sin 61$

$F_{BC} = -16.6$ lbs

$\Sigma F_y = 0: 26.2 - F_{CD} - 16.6\cos 61 = 0$

$F_{CD} = -18.15$ lbs



$\Sigma F_y = 0: -18.15 + F_{BD}\sin 29 = 0$

$F_{BD} = 37.44$ lbs

$\sigma_{DC} = F_{DC}/A_x$ $\quad A_x = \pi(1.66)^2/4 - \pi(1.38)^2/4$

$A_x = .669\ in^2$

$\sigma_{DC} = \frac{18.15}{.669} = 27\ lbf/in^2$

$\sigma_{BC} = 16.6/.669 = 25\ lbf/in^2$

$\sigma_{AB} = 16.1/.669 = 24\ lbf/in^2$

$\sigma_{BD} = 37.4/.669 = 55.9\ lbf/in^2$

$\sigma_{bending} = Mc/I_{xx}$ $\quad I_{xx} = .29\ in^4$

$\sigma_b = 129\ lbf/in^2 \ll 16E3\ psi$

Appendix XIX: Solartech M Series 2PM020P-A

SOLARTECH®
POWER, INC.

M-Series
20W PV Module
SPM020P-A

Solartech M-Series Modules

Solartech photovoltaic M-Series Modules are constructed with high efficient polycrystalline solar cells and produce higher output per module than others in it class. This industrial grade module is an industry standard among various industry professionals.

Features

- An UL-approved AWG 18 cable is put into the fully sealed junction box (weather and UV resistant) material meet UL1703
- (EVA) with TPT cushions the solar cells within the laminate an ensures the operating characteristics of the solar cells under virtually any climatic condition
- Rigid anodized aluminum frame and low iron tempered glass
- Easily accessible grounding points on all four corners for fast installation
- Proven junction box technology

Reliability

- Proven superior field performance
- Tight power tolerance

Qualifications and Certifications

C ETL US LISTED
Intertek

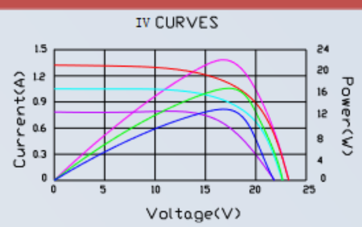
Applications

- Traffic & Safety
- Federal Government
- Agricultural
- Security
- Telecommunications
- Water and Wastewater
- Weather & Environmental Monitoring
- Telemetry
- Wi-Fi & Wi-Max
- Gate & Fence

Model Number
SPM020P-A

Electrical Characteristics	
Max power(Pm)	20W
Maximum power voltage(Vpm)	17.2V
Maximum power current (Ipm)	1.17A
Short circuit current (Isc)	1.25A
Open circuit voltage (Voc)	21.7V
Module efficiency	10.0%
Tolerance	±5%
Nominal Voltage	12V
Temperature coefficient of Voc	-0.36%/K
Temperature coefficient of Pm	-0.46%/K
Temperature coefficient of Isc	0.05%/K
NOCT	48℃±2℃
Maximum series fuse rating	10A
Maximum system voltage	600V

IV Curves



Certifications

UL 1703 certification

ETL Class I ,Division 2,Groups C and D certification

Mechanical Characteristics	
Construction	Tempered glass, silicon cell, EVA, Polyester with Tedlar
Solar Cells	36 cells (156mm x 26mm) in a 4x9 matrix connected in series
Front Cover	High transmission 3.2mm(1/8'') glass
Encapsulant	EVA(Double layers)
Back Cover	White polyester
Frame	Anodized aluminum
Junction Box	IP65, UL94-5VA material
Diodes	None
Terminal	Open end, 9 feet (3m) 18 AWG wire
Dimensions	21.7in (550mm)x13.8in (350mm)x0.98in (25mm)
Weight	6.16b (2.8kg)
Operating Temperature	-40℃ ~90℃
Storage Humidity	<90%