Solar Panel Bar Joist System

A Baccalaureate thesis submitted to the
Department of Mechanical and Materials Engineering
College of Engineering and Applied Science
University of Cincinnati

In partial fulfillment of the
requirements for the degree of

Bachelor of Science

in Mechanical Engineering Technology

by

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Problem Definition

Problem Statement

Solar panels are becoming more and more popular in today's world. There are multiple companies that could benefit from having access to them. One of the issues with solar energy is the space needed for panels. Solar panels can take up a lot of space depending on how many are used. Solar panel farms take up acres upon acres of land. Meanwhile, large scale commercial buildings with bar joist systems have a massive amount of real estate on the roof that can be utilized for solar energy.

Background

Two arrays of solar panels were fabrication and built on the roof of Superior Structures Inc. This company is the sponsor of the project. The goal of the project is to see if solar panels are worth covering the entire building. Each array is different, with one stable set and one sun tracking set. After a period of time studying the panels energy output, Superior Structures will decide what to do moving forward with the rest of their building.

Research

Scope of the Problem

Solar panels are a newer form of energy, partially in the last half century. To meet the required voltage and/or current requirements for their operation, solar panels (also known as photovoltaic (PV) modules) are made up of several solar cells, made from silicon, that convert the energy contained in the solar radiation of the sun into electrical energy. Light excites the electrons in the cell, causing them to travel to the other side of the panel, creating an electrical current. On average, about 96 or more individual solar cells are used to create large-scale commercial solar installations, and solar panels are typically connected in a solar array (1). To provide energy to the building, solar panels first convert sunlight into DC electricity and then an inverter converts the DC electricity into usable AC electricity (120/240VAC) that is sent to an existing electrical switchboard which distributes power to the building. A meter is attached to the electrical switchboard to measure the power consumption. This creates the clean energy we know as solar.

There is an issue though, renewable energy sources can take up to 1000 times more space than fossil fuels (2). Solar energy is obviously much cleaner than fossil fuels, and there is a need for 3d integration. With the increase in population, production of food and need for housing a competition of land will take place. For this not to happen, commercial rooftop solar systems need to be integrated. Most commercial and industrial solar installations are substantially larger than residential installations. Depending on the electricity needs of the facility, a commercial solar energy system can be up to several megawatts while a residential system, on average, is around 8 kilowatts (3*)*. Since commercial solar power is used at or near the point of generation, it is considered distributed generation. A typically commercial solar power system is connected to the local electric grid, allowing commercial property owners to participate in net metering. Net metering benefits commercial customers by letting them be reimbursed for unused electricity sent back to the grid (4).

Everyone in our world is impacted by the use of fossil fuels. 17.6 million Americans are exposed daily to toxic air pollution from active oil and gas wells (5). The article goes on to state that coal-fired power plants are responsible for 2/3 of U.S. sulfur dioxide emissions which contributes to acid rain and soot in the air. This is a major issue, and soon enough it will be too late to reverse the effects not only on us, but on earth. Emissions need to be reduced by almost half in 2030 and reach net-zero by 2050 if we do not want to see lasting effects on our climate (6). The addition of these solar panels to bar joist systems will help that happen.

Solar is 5000 times cheaper than when it first started being used in 1958, while fossil fuels costs about the same as they did 100 years ago once adjusted for inflation (7). It is becoming easier to access this technology and with time the trend will continue. Farmer's data has also shown that harnessing renewable energy today is generally cheaper than building new fossil-fueled plants. The current problem is being addressed by multiple forms of renewable energy but two mainly being the previously mentioned solar farms, and wind farms. This still isn't enough though. Fossil fuels still account for 80% of global energy production while 29% are from renewable energy sources. To reach the United Nations goal, solar needs to gain traction across the world. As stated before, there is an issue with the shear amount of land needed to create a feasible solar farm. The cost to build solar has gone down, but that does not account for the property needed. Bar joist structures across the country could be used for solar panel farms and the price of implementing could decrease even more. These systems could also be integrated with wind sensors so that the panels go flat and don't create an uplift that could possibly damage the roofs. The most energy is used in areas with larger populations, and those places all have manufacturing, shopping, etc. to utilize for renewable energy.

Applicable Standards

IEC 61215 ED 2.0 - "Requirements for the design qualification and type approval of terrestrial photovoltaic modules suitable for long term operation in general open-air climates (8)."

IEC61730- Addresses the fact that solar panels are electronic parts and carry the risk of electrical shock. Encompasses testing and construction of module to look at electrical, mechanical, thermal and fire safety (8).

UL1703- Covers panels intended for installation on buildings, this covers roof mounting systems and roof covering systems (8).

UL2703- Standard for mounting systems, but in addition is used to determine the fire classification of a rooftop mounted system (9).

State of the Art

Solar Panel Shingles: Originally panels were attached to roofs and were obvious and took away from the look and aesthetic of a home. Now, solar panels shingles are made apart of the roof and from a distant look similar if not identical to actual shingles. These special shingles work in the same way as a regular solar panel converting solar energy to usable power of your home. Excess power can be stored in a power bank in your home (10). A pro of this concept is the fact that it can blend into the overall look of the home, compared to standard panels. A con would be the fact that solar panels can be easily damaged and now you're not only replacing a panel but replacing a piece of your roof too. This could lead to potential leakage issues that people do not have to face as often on a standard roof.

Reverse solar panels: This is a new process, introduced in 2020 by two students at UC Davis. It is still being studied and has a long way to go but the overall concept has been proven. In this process we can think of the earth as the heat source and the sky as a heat sink. It allows us to harvest electricity from the night sky. At night, the heat escapes the earth in the form of infrared radiation. Light is emitted and the current and voltage go in the opposite direction of the standard solar panel (11). A pro of this design is that it finds an additional way to harness renewable and clean energy. A con of this is that it is new and hasn't been tested for a while in the field. Therefore, there could be potential issues we are not aware of.

PERC cells for higher efficiency: PERC stands for Passivated Emitter and Rear Cell/Contact. Attention has shifted more towards this type of cell to achieve more efficiency when converting sunlight to electricity (12). In addition to efficiency, PERC solar cells perform better than traditional BSF (Bifacial Solar Cells) in both low-light and high temperature conditions. This efficiency and better performance are achieved by the integration of a back surface passivation layer that provides reflection of light back through the cell, reduced electron recombination, and reduced heat absorption (13).

Foldable Solar Panel System: A Swiss company along with Kronberg and St. Gallish-Appenzellische Kraftwerke (SAK) have created a solar folding roof to come out when the sun is out and go back in when it is cloudy, nighttime, or raining. In addition to these features, the solar folding roof provides shade for vehicles residing under it. In total, the solar roof is comprised of 1,320 solar panels and produces 350,000 kWh per year (14). A pro of this design is the fact that it can easily collapse on itself, therefore taking up less space and having less of a chance of a panel being damaged when not in use. A con would be the fact that depending on the system, it could take a lot of energy for all the panels to move every time they aren't in use, which would take away from their exact use.

End User

The end user of this product will be an owner of a large-scale building (manufacturing facilities, department stores, etc.) that is either looking to "go green" and use cleaner forms of energy or wants to mitigate or possibly eliminate electric costs by putting their building roof to use. These owners might not have the real estate to put solar panels in a field next door, but instead wanting to harness the full value of the property they occupy could potentially open them up to huge amounts of savings on their electric bill every year.

Summary of Research

There are multiple companies and cities that could benefit from having access to solar panels and not be confined by the land they have available. One of the main issues with solar energy is the space needed. Solar panels can take up a lot of space depending on how many are used. Meanwhile, large scale commercial buildings with bar joist systems have a massive amount of real estate on the roof that can be utilized for solar energy. As shown in the research, there are multiple advancements in the recent years of solar panels that make it quite competitive and intriguing. If we fully utilize the real estate already taken up by large buildings, then we can move toward a cleaner future.

Customer Features:

- Attach to a bar joist roof system.
- Modular-easy to add additional panels to the system if needed.

- Wind Sensor
- Sun tracking
- Testing Types: Stable panels, Single pivot panels
- Safe

Product Objectives:

We will address the customer features by making a system that is not only safe, but compatible with large scale flat roof structures (mainly bar joist systems). In order to be safe, the system will have wind sensors. If it becomes too windy the panels will "go flat" to the roof in order so that they are not susceptible to wind gusts that could rip them off the roof, creating leaks and damage to the system and building. The customer is very curious about solar energy and how beneficial it can be to society. In order to tests all aspects of solar the customer is requesting a set of stable panels. The second set will use sun tracking software/hardware and rotate throughout the day. These versions will be designed in a way that it is very easy to add or take panels away if needed.

Quality Function Deployment:

Engineering Characteristics

- Panels that move up/down based on wind speed
- Structurally stable system
- Mechanical system that can move based on sun tracking
- "Snap in" system to easily add/remove panels

House of Quality

The chart is located in Appendix A.

Design Analysis:

Initial Stationary Design:

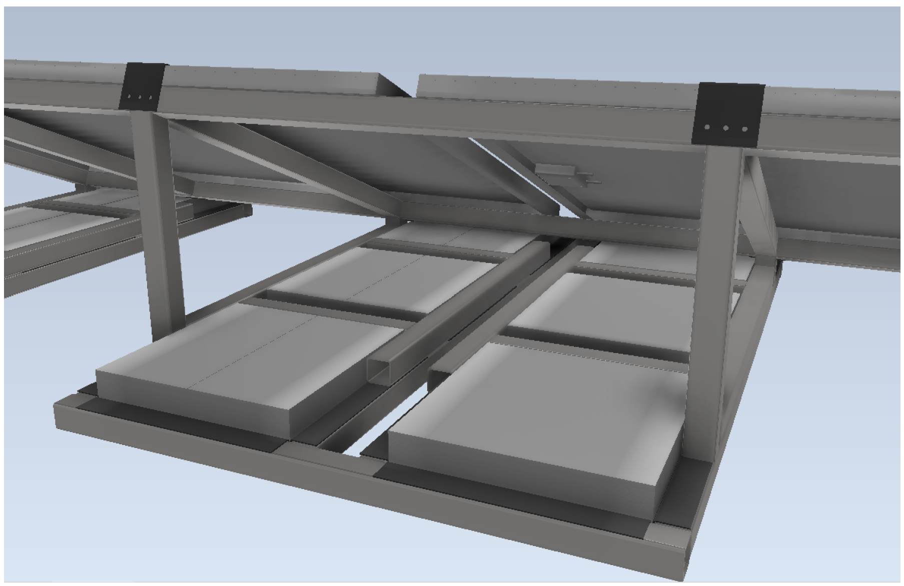


Figure 1: Shows the cinder blocks and their containment

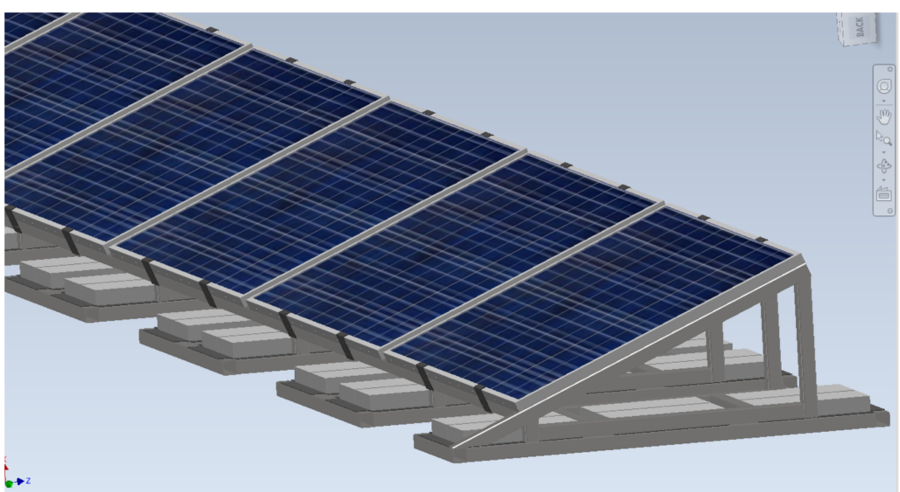


Figure 2: Panel side view

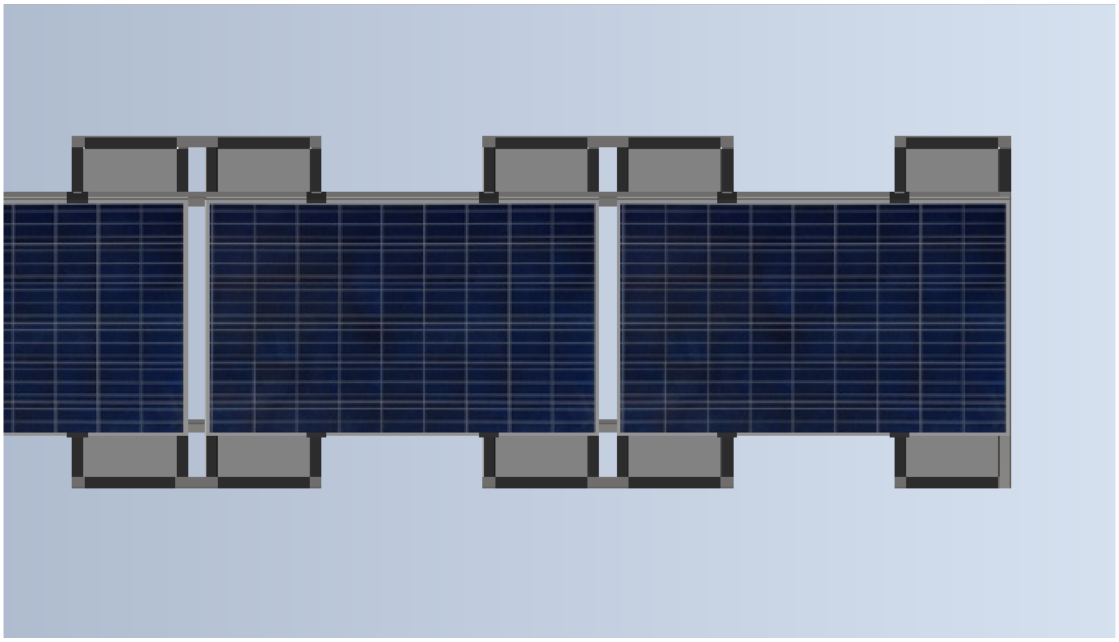


Figure 3: Panel top view

The first design utilizes a stationary structure that has “sleds” at each corner of a panel. These sleds hold 16” x 4” x 8” cinder blocks which act as a ballast in dead load. The array consists of panels at 22.5 degrees. The entire assembly would be welded.

Final Stationary Design:

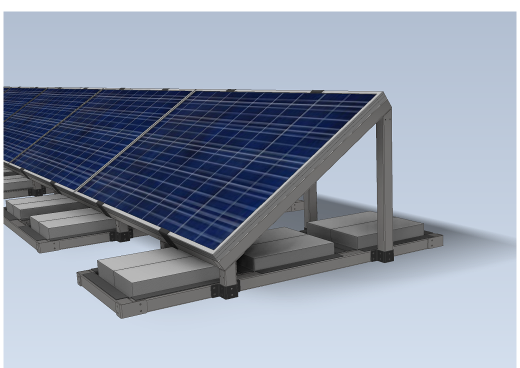


Figure 4

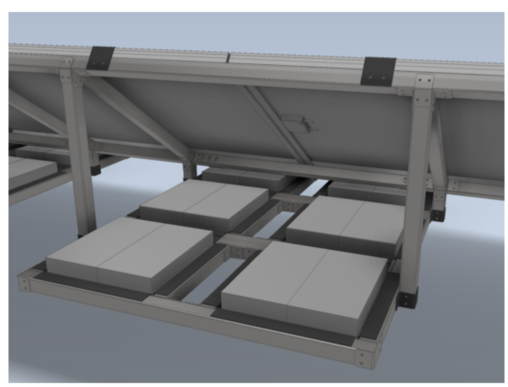


Figure 5

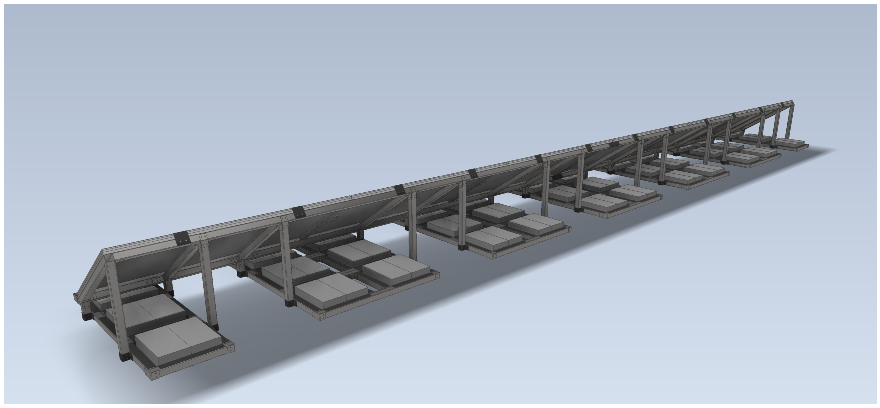


Figure 6:

These three figures show CAD views of the final stationary design

Ideal for Cincinnati being 38 degrees is recognized, but to stay within ASCE 7-16 a maximum angle of is 35 degrees is allowed. Therefore, the panels are set at 34 degrees. This design also used brackets instead of welding the entire assembly. This made for a quicker assembly without the need for a welder.

Figure 7 *Figure 8* *Figure 9*

These three figures show actual views of the final stationary design with and without panels

Initial Single Axis Design:

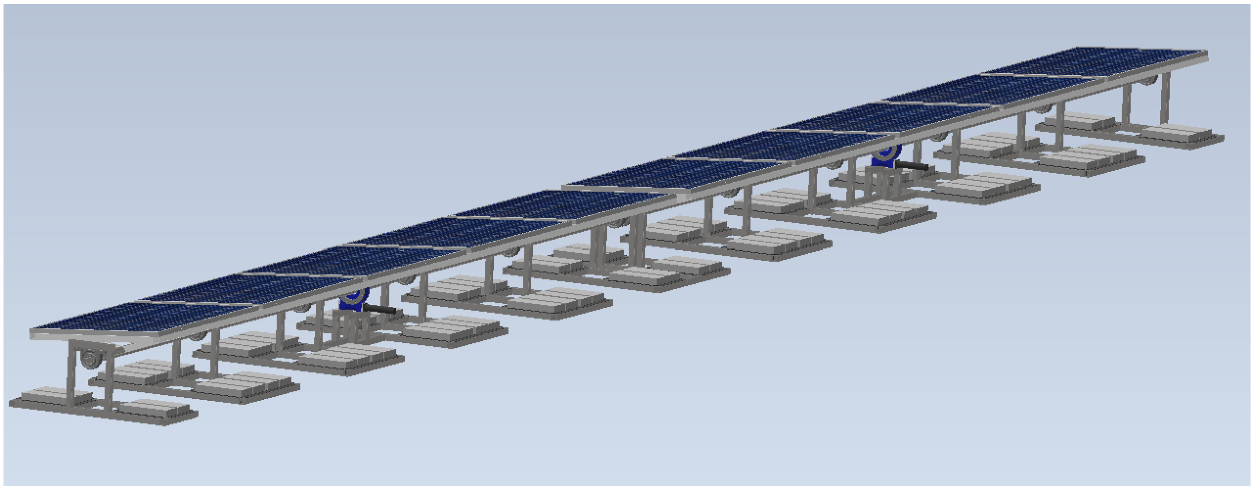


Figure 10: Entire single axis panel array

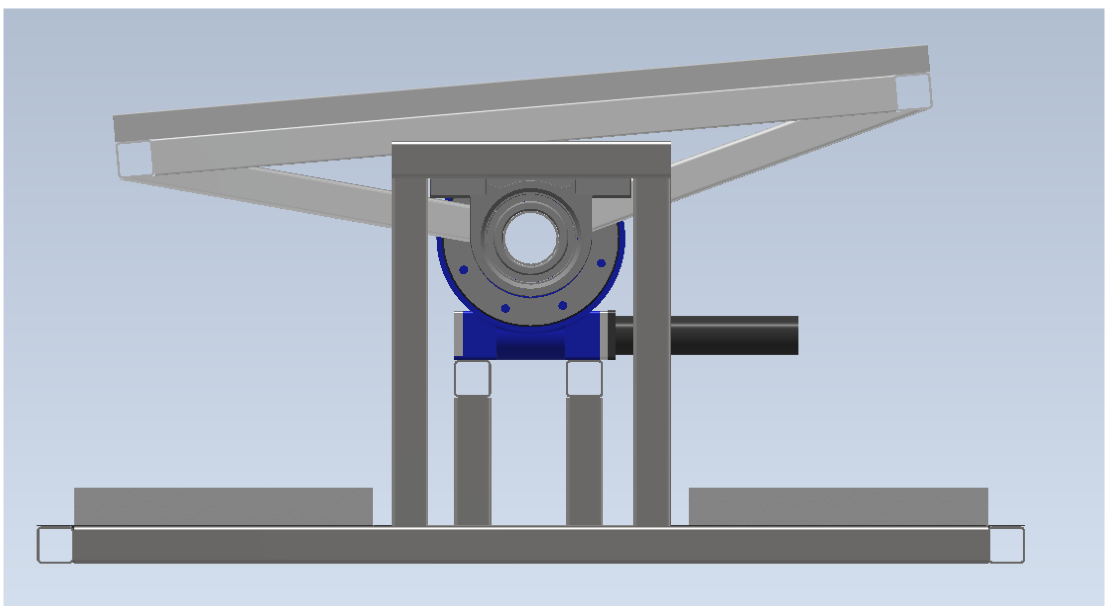


Figure 11: Side view of single axis system

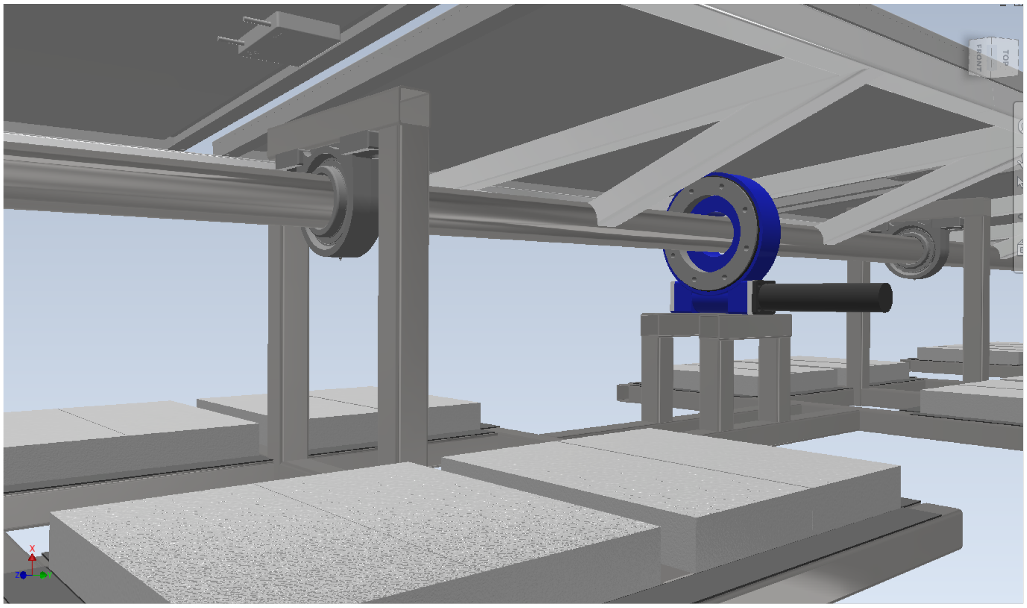


Figure 12: Underneath view of single axis system

In this design we have an array of panels that tracks the sun using a solar tracker (that will be coded by our EE member). Ballasts are not as heaving as the stationary design because of the use of a wind sensor. If the panels experience too high of a wind, they will move to an angle of 0 degrees to decrease the load. Each set of five panels will be powered by a slew gear, with bearings holding the shaft in place at the center of each ballast.

Final Single Axis Design:

Figure 13

Figure 14

Figure 15

Figure 16

Figure 17

Figure 18

Figures 13 and 14 show bearings along with an actuator, Figures 15-17 show assemblies with and without panels, Figure 18 shows the wind sensor



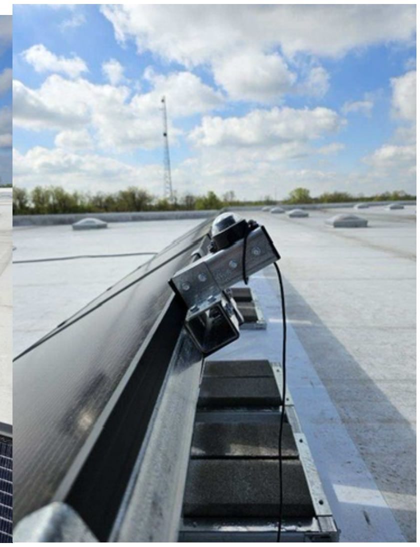


Figure 19 *Figure 20* *Figure 21*

Figure 19 shows a view of the actuator while 20, 21 show the light sensor

Compared to the initial design, we are using two 8” linear actuators at 650 lbs a piece. These were chosen because of shipping time for the slew gear and the overall price. These actuators are directly tied to the solar tracker and depending on the sensors output it will either push the actuators in or out to move the panels east or west. This design still utilized the wind sensor and also has a program that if the light value is to low the panels will go flat, as there is no need to be sitting on an angle at night.

Loading Conditions:

To stay in accordance with a minimum safety factor of 1.5, a new design of the clip to hold the panels in place was made. This clip will be made of 12ga galvanized sheet metal. As you can see below the new clip has a safety factor of 1.77 and a max displacement of .01792 in.

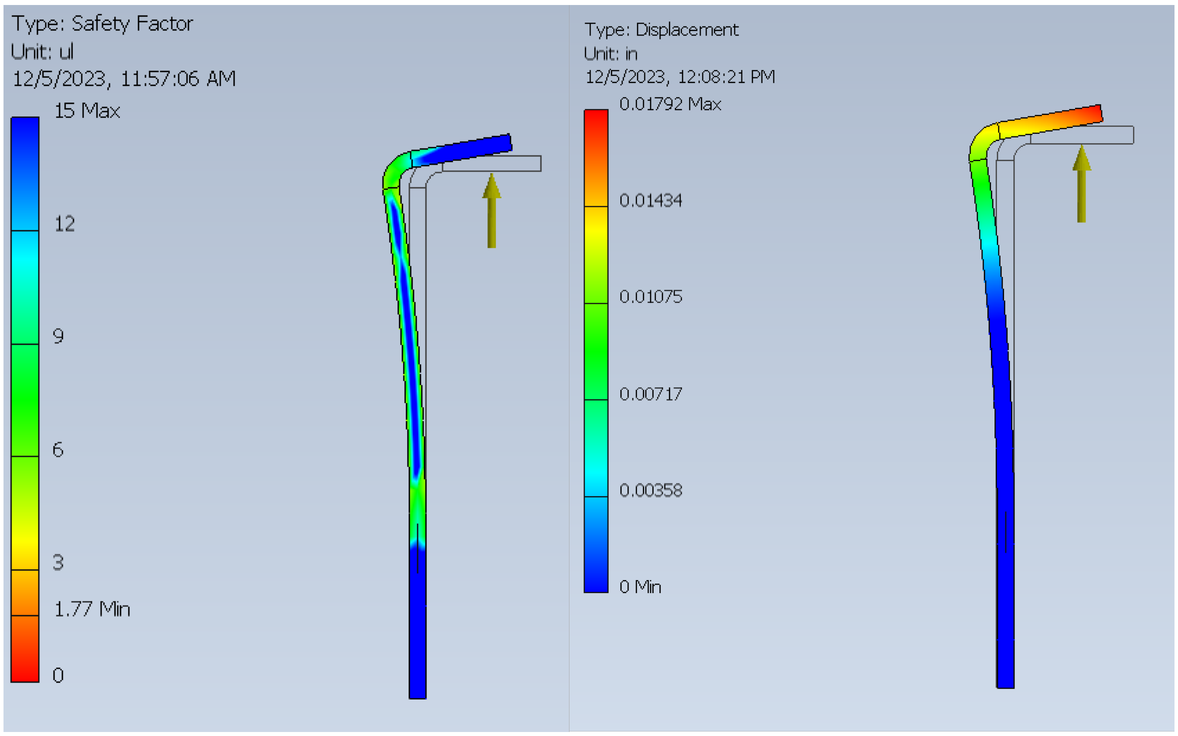


Figure 22: Analysis of clip to hold panels to system

The shaft for the single pivot desing was also studied. A 2” round tube was used in the desing with downward forces being shown at every contact where the panel above is being connected to the cross bars. Fixed points are shown at the bearings. We can see from this analysis that the max displacement of the tube is very low, specifcially .01458 in.

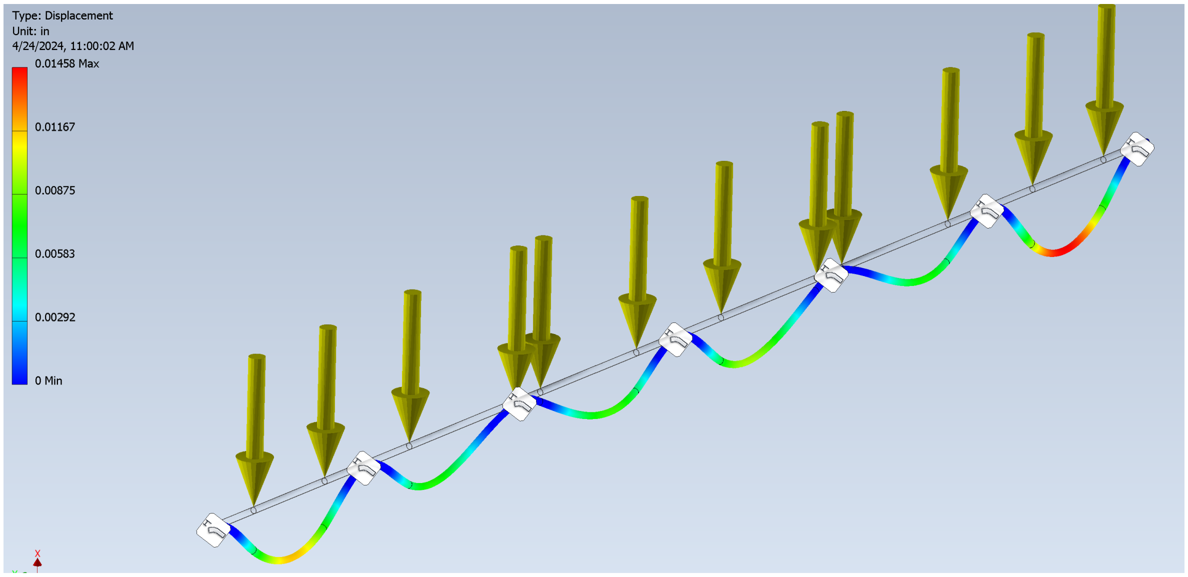


Figure 23: Analysis of shaft on single axis system

Factors of Safety and Applicable Regulations:

In addition to the applicable standards mentioned in the previous section, we will also be looking at ASCE 7-10 and ASCE 7-16. These two standards are related to wind loads on a roof and the loads of systems being placed on it.

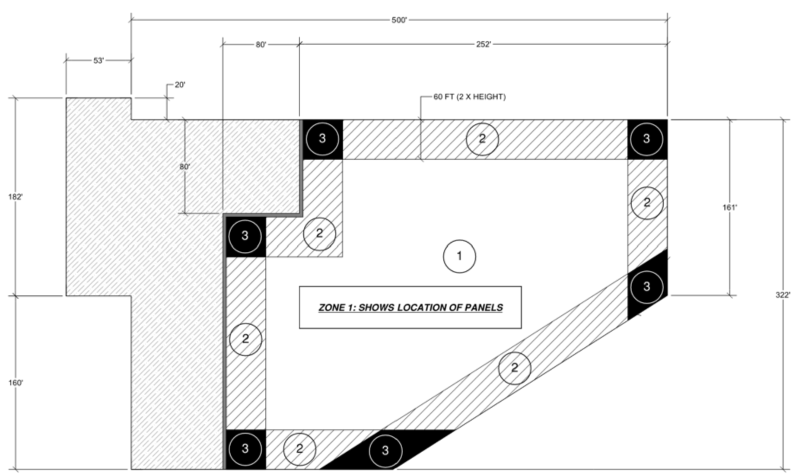


Figure 24: Roof wind zones

In figure 14 we can see the location of building the solar panels will be placed. The three roof zones are marked 1, 2, and 3. The two zones along the edge (2 & 3) are measured as 2X the height of the building. Corner zone (Zone 3) is considered a "no build zone" with very high wind loads. In Zone 2, structures are allowed to be built, but must be considered for a higher wind load. Panels for this project will be placed in Zone 1, where the wind load is the lowest.

Refer to ASCE 7-10 for the following variables of a 1 x 6 array of panels:

- Directionality Factor (K_d) =.85
- Topographic Factor (K_{zt}) =1.0 (Flat ground around building)
- Exposure = "C" (See ASCE 7-10 26.7.3)
- Risk Category II Building (See ASCE 7-10)
- Velocity Pressure Exposure Coeff. (K_z) =.98 (For roof height =30ft, and Exposure C)
- Wind Speed = 115 mph (ASCE7-10 Figure 26.5-1A)
- Velocity pressure: $q = .00256 K_z K_{zt} K_d V^{2} = 28.20205\ lb/ft^2$
- Area of selected panel (A) = 38.1" x 71.7" $= 19.12\ ft^2$

  Use the figures below to solve additional calculations on wind loads regarding ballast weight from ASCE 7-16

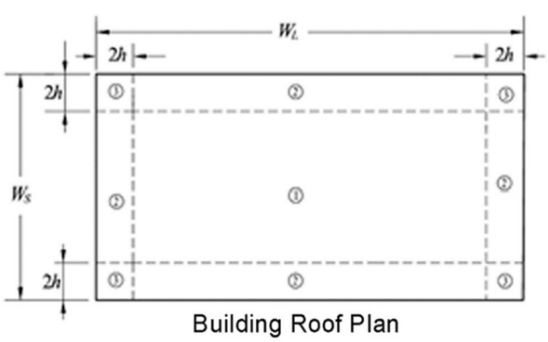


Figure 25: Roof wind zones.

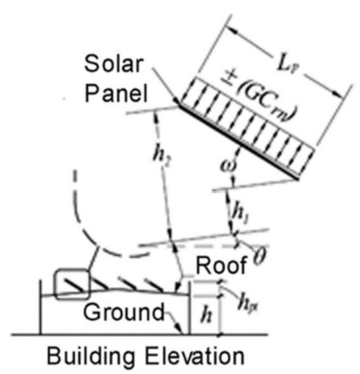


Figure 26: Solar Panel Variables

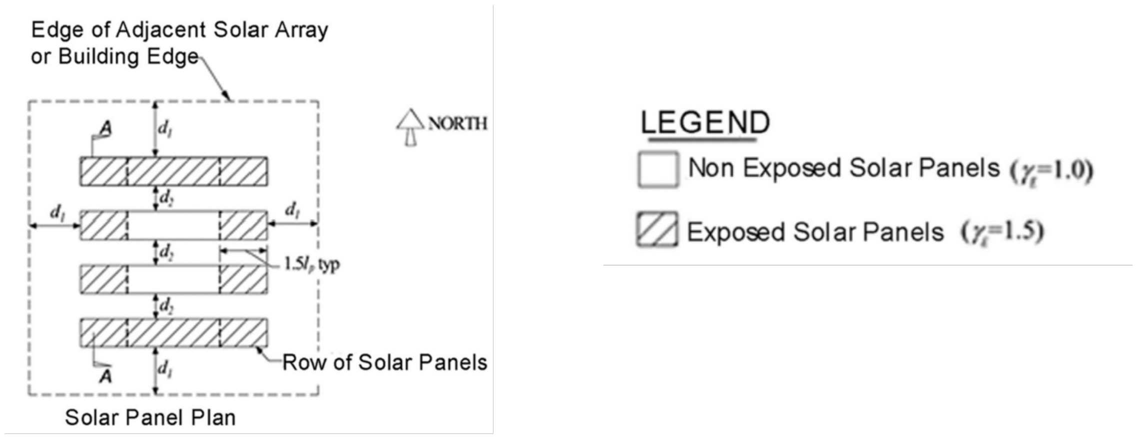


Figure 27: Edge factor

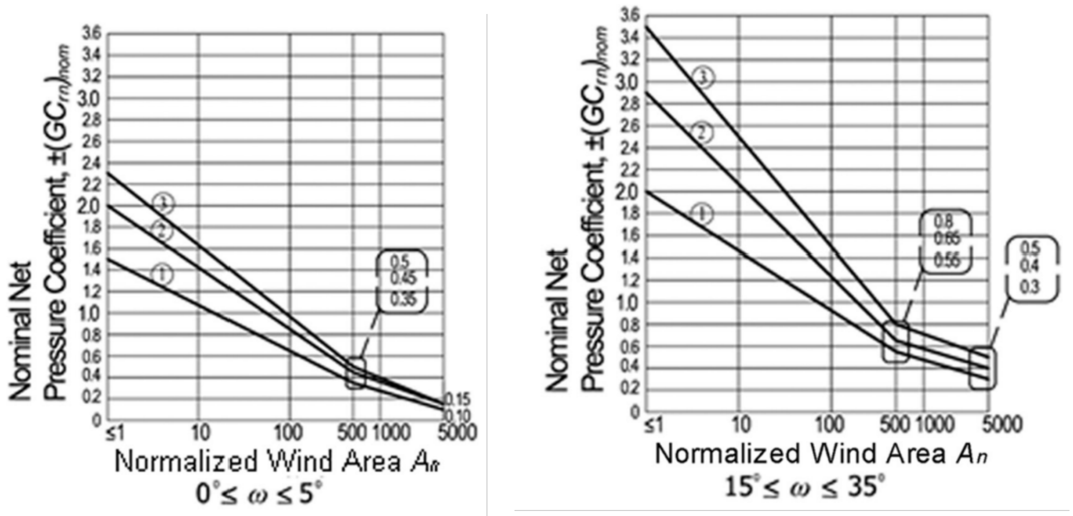


Figure 28: Finding nominal net pressure coefficient

- Parapet $(H_{pt}) = 1.5\ ft$ (Figure 16)
- Roof height $(H) = 30\ ft$ (Figure 16)
- Parapet factor $(\gamma_p) = \min(1.2, 0.9 + H_{pt}/h) = .95$
- $(L_p) = 3.2$ ft (Figure 16)
- Chord factor $(\gamma_c) = .8$
- Array edge factor $(\gamma_e) = 1.5$ (All panels aqre exposed in array) (Figure 17)
- Normalized building length $(L_b) = \min(0.4(h \times W_L)^{.5}, h, = W_s) = h = 30$ ft
- Normalized wind Area $(A_n) = \frac{1000}{(\max(L_b, 15ft)^2)} A = 127.467$ (for 6 panels)
- Nominal Net pressure Coeff. $(GC_{rn_{nom}})$ @ 0° = .6, @ 34° = .87
- Net pressure Coeff. $(GC_{rn}) = (\gamma_p)(\gamma_c)(\gamma_e)(GC_{rn_{nom}}) =$ @ 0° = .687, @ 34° = .991

  (Figure 18)
- Design Wind Pressure (p)=qGC_{rn} = @ 0° = 19.38, @ 34° = 27.93 psf
- Lifting force (F_{vert}) = (p) x ballast area covered x cos(angle)
- For corner ballast $(F_{vert}) = 27.93 \times \cos(34) \times (19.12) \times ¼$

  = @ 0° = 92.65 lbs, @ 34° = 110.71 lbs
- Panel Weight: 45 lbs
- Racking Weight: Stationary- 39.83 lbs per panel, Moving- 54.5 lbs per panel
- Corner Ballast weight > Fvert - (Panel weight x .25) - (Racking weight per panel x .25)

  Moving set => Corner ballast => (92.65 lbs/.9) = 102.94 lbs – (45 x .25)-(54.5 x .25) = **78.07 lbs** each corner

  Stationary Set => Corner ballast => (110.71 lbs/.9) = 123.01 lbs – (45 x .25)-(39.83 x .25) = **101.8 lbs** each corner

Component and Material Selection:

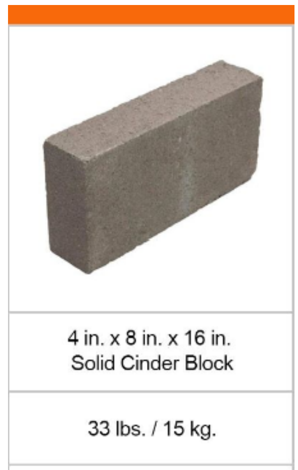


Figure 29: Cinder Block

As stated before, cinder blocks will be used for the ballast. With a heavy density, they will take up minimal space to apply to the dead load.

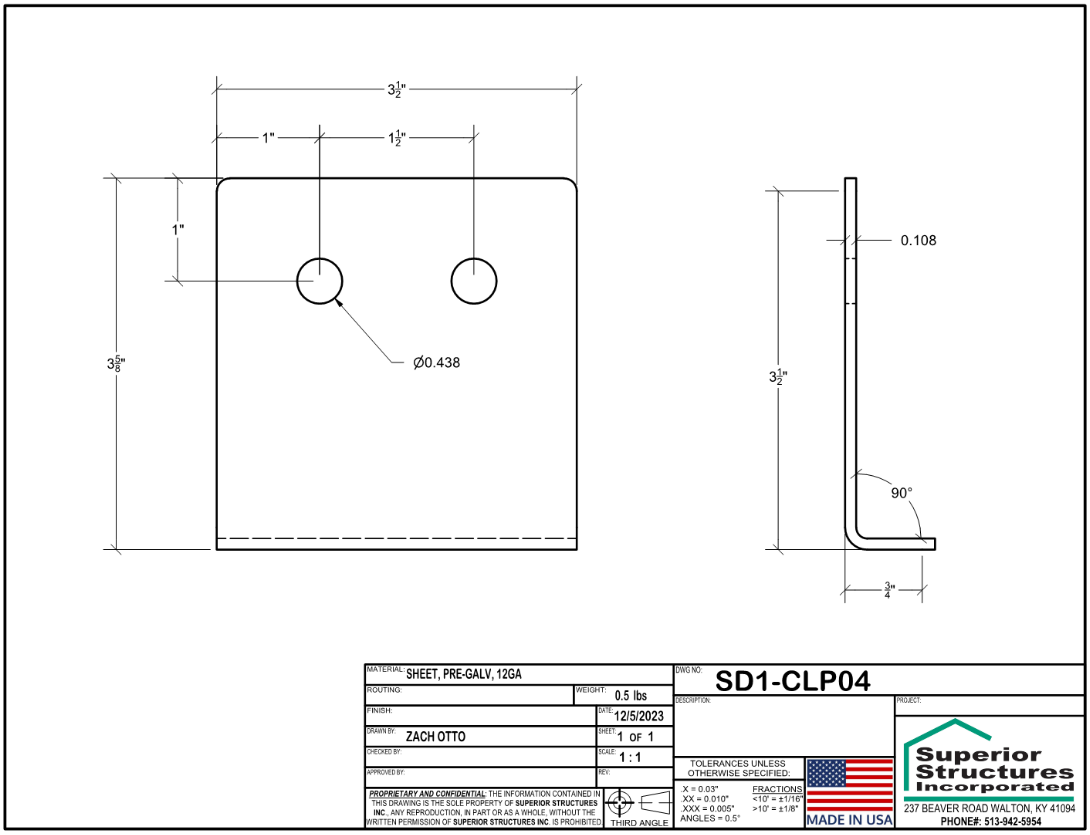


Figure 30: Panel Clip Drawing

The clip spoken of beforehand will be made of 12 ga galvanized steel. In order to comply with the 1.5 safety factor there will be 4 clips put on each racking system to hold down the panel.

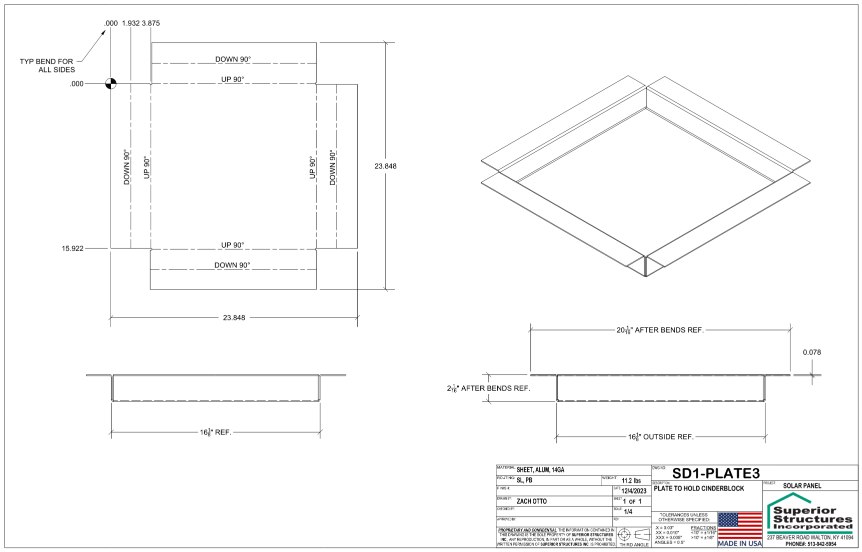
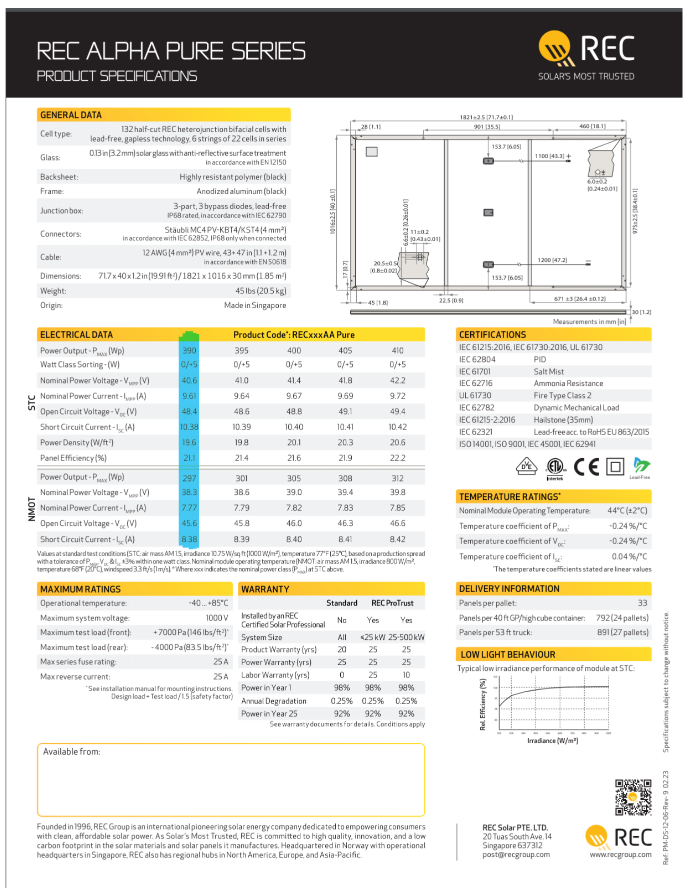


Figure 31: Cinder Block Containment



REC ALPHA PURE SERIES

PRODUCT SPECIFICATIONS

REC — SOLAR'S MOST TRUSTED

GENERAL DATA	
Cell type:	132 half-cut REC heterojunction bifacial cells with lead-free, gapless technology, 6 strings of 22 cells in series
Glass:	0.13 in (3.2 mm) solar glass with anti-reflective surface treatment in accordance with EN 12150
Backsheet:	Highly resistant polymer (black)
Frame:	Anodized aluminum (black)
Junction box:	3-part, 3 bypass diodes, lead-free IP68 rated, in accordance with IEC 62790
Connectors:	Stäubli MC4 PV-KBT4/KST4 ($4\ mm^2$) in accordance with IEC 62852, IP68 only when connected
Cable:	12 AWG ($4\ mm^2$) PV wire, 43+47 in (1.1 + 1.2 m) in accordance with EN 50618
Dimensions:	71.7 x 40 x 1.2 in ($19.91\ ft^2$) / 1821 x 1016 x 30 mm ($1.85\ m^2$)
Weight:	45 lbs (20.5 kg)
Origin:	Made in Singapore

Measurements in mm [in]

	ELECTRICAL DATA	Product Code*: RECxxxAA Pure				
STC	Power Output - P_{MAX} (Wp)	390	395	400	405	410
	Watt Class Sorting - (W)	0/+5	0/+5	0/+5	0/+5	0/+5
	Nominal Power Voltage - V_{MPP} (V)	40.6	41.0	41.4	41.8	42.2
	Nominal Power Current - I_{MPP} (A)	9.61	9.64	9.67	9.69	9.72
	Open Circuit Voltage - V_{OC} (V)	48.4	48.6	48.8	49.1	49.4
	Short Circuit Current - I_{SC} (A)	10.38	10.39	10.40	10.41	10.42
	Power Density (W/ft^2)	19.6	19.8	20.1	20.3	20.6
	Panel Efficiency (%)	21.1	21.4	21.6	21.9	22.2
NMOT	Power Output - P_{MAX} (Wp)	297	301	305	308	312
	Nominal Power Voltage - V_{MPP} (V)	38.3	38.6	39.0	39.4	39.8
	Nominal Power Current - I_{MPP} (A)	7.77	7.79	7.82	7.83	7.85
	Open Circuit Voltage - V_{OC} (V)	45.6	45.8	46.0	46.3	46.6
	Short Circuit Current - I_{SC} (A)	8.38	8.39	8.40	8.41	8.42

Values at standard test conditions (STC: air mass AM 1.5, irradiance 10.75 W/sq ft ($1000\ W/m^2$), temperature 77°F (25°C), based on a production spread with a tolerance of P_{MAX}, V_{OC} & I_{SC} ±3% within one watt class. Nominal module operating temperature (NMOT: air mass AM 1.5, irradiance $800\ W/m^2$, temperature 68°F (20°C), windspeed 3.3 ft/s (1 m/s). * Where xxx indicates the nominal power class (P_{MAX}) at STC above.

CERTIFICATIONS	
IEC 61215:2016, IEC 61730:2016, UL 61730	
IEC 62804	PID
IEC 61701	Salt Mist
IEC 62716	Ammonia Resistance
UL 61730	Fire Type Class 2
IEC 62782	Dynamic Mechanical Load
IEC 61215-2:2016	Hailstone (35mm)
IEC 62321	Lead-free acc. to RoHS EU 863/2015
ISO 14001, ISO 9001, IEC 45001, IEC 62941	

Intertek · Lead-Free

TEMPERATURE RATINGS*	
Nominal Module Operating Temperature:	44°C (±2°C)
Temperature coefficient of P_{MAX}:	-0.24 %/°C
Temperature coefficient of V_{OC}:	-0.24 %/°C
Temperature coefficient of I_{SC}:	0.04 %/°C

*The temperature coefficients stated are linear values

MAXIMUM RATINGS	
Operational temperature:	-40 ... +85°C
Maximum system voltage:	1000 V
Maximum test load (front):	+ 7000 Pa ($146\ lbs/ft^2$)*
Maximum test load (rear):	- 4000 Pa ($83.5\ lbs/ft^2$)*
Max series fuse rating:	25 A
Max reverse current:	25 A

*See installation manual for mounting instructions. Design load = Test load / 1.5 (safety factor)

WARRANTY	Standard	REC ProTrust	
Installed by an REC Certified Solar Professional	No	Yes	Yes
System Size	All	≤25 kW	25-500 kW
Product Warranty (yrs)	20	25	25
Power Warranty (yrs)	25	25	25
Labor Warranty (yrs)	0	25	10
Power in Year 1	98%	98%	98%
Annual Degradation	0.25%	0.25%	0.25%
Power in Year 25	92%	92%	92%

See warranty documents for details. Conditions apply

DELIVERY INFORMATION	
Panels per pallet:	33
Panels per 40 ft GP/high cube container:	792 (24 pallets)
Panels per 53 ft truck:	891 (27 pallets)

LOW LIGHT BEHAVIOUR

Typical low irradiance performance of module at STC:

Rel. Efficiency (%) — Irradiance (W/m^2)

Available from:

Founded in 1996, REC Group is an international pioneering solar energy company dedicated to empowering consumers with clean, affordable solar power. As Solar's Most Trusted, REC is committed to high quality, innovation, and a low carbon footprint in the solar materials and solar panels it manufactures. Headquartered in Norway with operational headquarters in Singapore, REC also has regional hubs in North America, Europe, and Asia-Pacific.

REC Solar PTE. LTD.
20 Tuas South Ave. 14
Singapore 637312
post@recgroup.com

www.recgroup.com

Specifications subject to change without notice.

Ref: PM-DS-12-06-Rev- 9 02.23

Figure 32: Solar Panel spec sheet

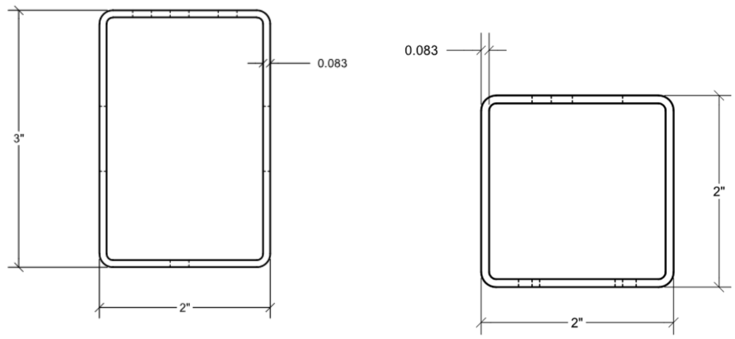


Figure 33: Square Tubing being used for design

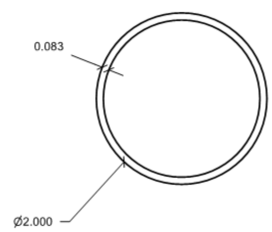


Figure 34: Round Tubing being used for design

These figures show the three different tubes being used for the frame. The tubes are made of galvanized steel which is resistance weather. This was also chosen because of it being a stock item at Superior Structures.

Figure 35: 8" Linear Actuator (650 lbs per actuator)

Figure 36: Block Bearing 2 1/8" Bore

Figure 37: Solar Tracker

Figure 38: Wind Sensor

Team Members and Responsibilities:

Zach Otto:

- CAD model & drawings of structural components
- Structural analysis / FEA on applicable parts
- Ordering of materials
- Fabrication / Assembly
- Tech Expo
- Final Report (MET)

Aaron Ogorzaly (EE)

- Circuit Analysis
- Sensor calibration and coding
- Fabrication / Assembly
- Tech Expo
- Final Report (EE)

Fabrication, Testing, and Assembly

Fabrication was done at Superior Structures machine shop. As stated before, galvanized tubing was used along with galvanized brackets. All parts were made using the shop's tube laser sheet laser and press brake. No welding was required for this project.

Project Management

Original Proposed Budget and Schedule

The original budget is $25,000 with current BOM (as of Dec 2023) sitting roughly $6500 over budget at $31,609. Original plan was to start buying items in January, testing in February / March, and final assembly in April.

ITEM #	PART NUMBER	QTY	DESCRIPTION (IF NEEDED)	PRICE
1	REC 405 SOLAR PANELS	20		
2	ENPHASE MICROINVERTERS	8		$11,340
3	BOS (BALANCE OF SYSTEMS)	1	Breaker, wire, conduit, electrical infra.	
4	SOLAR TRACKER SENSOR and MODULE	1		$ 59.99
5	WIND SENSOR	1		$ 40.00
6	REGO 12V 60A MPPT SOLAR CHARGE CONTROLLER	1		$ 399.99
7	ARDUINO UNO REV 3	5		$ 130.60
8	REGO 12V 400 Ah COLD WEATHER LIFE P04 BATTERY (2 PACK)	4		$ 13,599.96
9	TUBES, GALVANIZED STEEL 2X2X11GA	XX		
10	TUBE, ALUM 2X2X11GA	XX		
11	SHEET METAL, 18GA	XX		$5,000
12	SHEET METAL, 12GA	XX		
13	ROUND TUBING	XX		
14	SLEW DRIVE	2		$400
15	BEARINGS	6		$ 221.00
17	CONCRETE	200		$ 417.00
18				$31,609

Figure 39: Initial BOM

Actual Budget and Schedule

With a budget cut to $15,000 we decided to not use batteries on the system since they are just a test of solar for the company. A different system was bought. Instead of actually tying into the building, power was run to an outlet in the shop where various machines and lift batteries will be charged.

6772.16	NAZ Grid Tie in System
84.78	Ebay solar tracker
$1,046.68	Electrical Items (Home Depot, Lowes)
280.62	Grainger step up
68.45	Enphase breaker switch
419.94	Actuators
343.92	Bearings
70.13	Mcmaster rubber
27.87	Mcmaster bolts
$2,806	Tubing
$1,426.19	Sheet metal
$ 13,347.01	**Total**

Figure 40: Final BOM

Plan to Finish

The scope of the project has been completed. The company can now successfully monitor production at each panel and decide if they would like to forward one day with covering the entire building in solar panels. They can see production of panels through the Enphase app on a live feed.

Figure 41: Showing current energy results at each panel

Sustainability and Material Usage

I believe I could have used a much more sustainable material for the pans that hold the cinder blocks in place. A lot of these had to be cut and bent for the project which led to lots of material usage and C02 emissions. In the future I would look into sandbags as an option for the ballast.

Key Milestones

- CAD Model
- Structural/load calculations
- Circuit analysis
- Purchasing proper components
- Coding wind sensor and sun tracking
- Testing of structural members attached to roof
- Testing of mechanical and electrical components
- Changes to design based on testing.
- Fabrication of units
- Assembly of all units
- Final presentation

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Appendices

Appendix A: House of Quality Chart