**Document Title:**

# Green Roof Team

## Temporary Wind Turbine

## Green Roof Team Limited Partnership
## Southern Illinois University Carbondale

Last Updated: 04/28/2021

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# Acknowledgements

The Green Roof Team appreciates the support of stakeholders across campus towards our mission of transforming the SIU Green Roof into a multidisciplinary innovation hub. Most importantly, recognizing the SIU Advanced Coal and Energy Research Center for their sponsorship of the Green Roof Team and support towards the renewable energy initiatives. The SIU Plant & Service Operation, specifically Justin Harrell and Brian Gorecki, for their feedback and progressing our project. The SIU Sustainability Office for offering the Green Fund Grant which partially paid for the project. The SIU Foundation for launching the SalukiFunder and SIU Day of Giving Campaigns for fundraising towards the project. Dr. John Groninger, associate Dean of the College of Agriculture, for his support towards the Green Roof Project which enabled the renewable energy initiatives to grow and develop. And the SIU Research Park for offering the University Innovation Fellows program and handling the accounting for the project whom of which made all Green Roof activities possible.

# Executive Summary

The Green Roof Team formed during the 2019-2020 academic year for the purpose of accomplishing the Green Roof Project. The goal was to transform the SIU Green Roof, an existing green space, into a multidisciplinary innovation hub for academic research across campus. One solution for encouraging researchers to know and become inspired to use the SIU Green Roof was by showcasing opportunities. As a result, the Green Roof Team pursued different projects including an autonomous irrigation system, micro wind turbine, and photovoltaic system.

The Green Roof Team under the University Innovation Fellows program secured stakeholder support across campus towards the Green Roof Project. One important aspect of the project explored renewable energy initiatives from wind and solar energy. SIU Carbondale is a well-known university for its research in clean coal and operating a coal-fired power plant on campus which produces steam, which is used to heat campus buildings, produce chilled water for cooling, and to generate electricity. As a result, the team is bringing a new resource with the intent of expanding and sustaining for future years, student engagement hands-on with renewable energy.

The Green Roof Team's Renewable Energy Initiative is encompassed in a two year plan before sustaining for future renewable energy related opportunities for undergraduates:

2020-2021 Install a hybrid solar-wind turbine on the SIU Agriculture Building.

2021-2022 Acquire the finances for more small wind turbines and grid-tied photovoltaic system while training future renewable energy students on campus.

2021-2022 Provide documentation, support, and finances for future renewable energy projects for a new Registered Student Organization focused on the implementation of renewable energy on-campus.

The Renewable Energy Initiative is focused on providing Salukis with the hands-on training and certification of the implementation of renewable energy, or consultation.

# Table of Contents

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# Design Problem and Objective

This project is a subproject of the Green Roof Project focused on the implementation of a temporary wind turbine for inspiring students and faculty to become engaged on the SIU Green Roof for their own research projects. The wind turbine designed by the Green Roof Team has an overall height of a nine-feet with a vertical axis design supported with ballast material to minimize harm to the roof's surface. The primary problem solved was the development of a reliable ballast mounted wind turbine with a reasonable factor of safety.

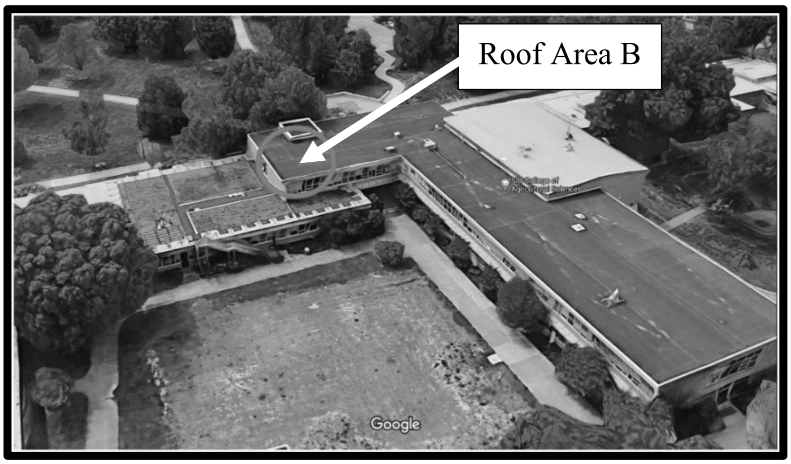


Figure 1 Project Site

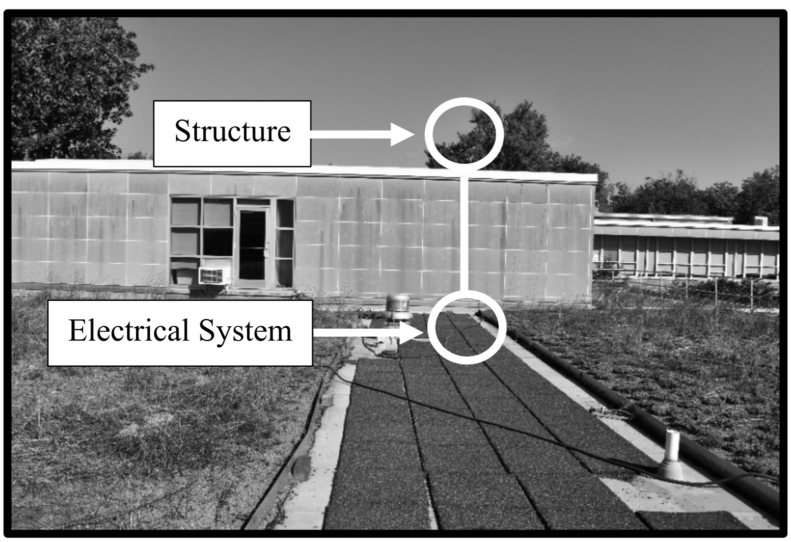


Figure 2 Relative System Location

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# Feasibility Study

The following section explains the feasibility study for understanding the constraints of installing a temporary wind turbine structure on the SIU Agriculture Building.

## Wind Speed Feasibility Study

The Green Roof Team analyzed different climatographic weather sources for finding the maximum wind speed which were recorded in the below figures. The Figure 3 shows the wind speed in miles per hour, while Figure 4 shows the accompanying wind force.

The wind force was calculated with the below equation:

$$F = \frac{\left(\frac{1}{2} * \rho * V^2 * A\right)}{32}$$

where the velocity is measured in miles per hour and rho is a constant of 0.08 lbm/ft$^3$ and area is calculated as 5.97 ft$^2$ based on the blade's dimensions and wind turbine hub.

The moment caused by the wind force was calculated with the below equation:

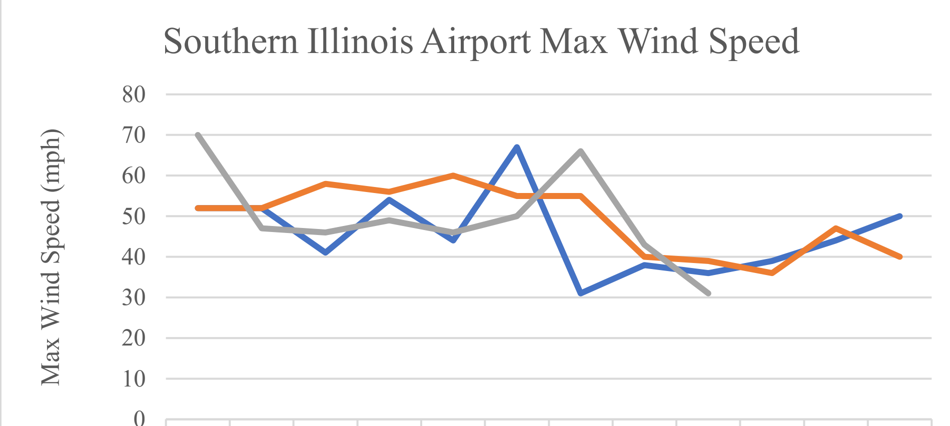
$$M_{wind} = F * cos(\theta_{wind}) * height_{wind}$$

where $\theta_{wind}$ was found by calculating the arcsine of the base's radius (18 inches) divided by the hypotenuse of the wind force with respect to the base, and the $height_{wind}$ was found by calculating the distance from the base to the center of the generator's hub.

The counteracting moment caused by the structure's mass was calculated with the below equation:

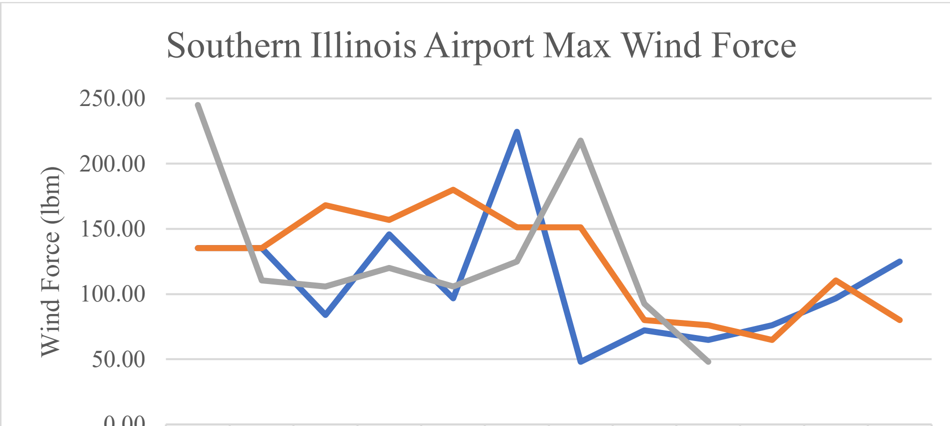
$$M_{mass} = m_{total} * cos(\theta_{mass}) * height_{mass}$$

where $\theta_{mass}$ was found by calculating the arcsine of the base's radius (18 inches) divided by the hypotenuse of the structure's center of mass with respect to the base, and the $height_{mass}$ was found by calculating the distance from the base to the structure's center of mass.




| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2018 | 52 | 52 | 41 | 54 | 44 | 67 | 31 | 38 | 36 | 39 | 44 | 50 |
| 2019 | 52 | 52 | 58 | 56 | 60 | 55 | 55 | 40 | 39 | 36 | 47 | 40 |
| 2020 | 70 | 47 | 46 | 49 | 46 | 50 | 66 | 43 | 31 | | | |

Figure 3 Carbondale Wind Speed Recorded




| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2018 | 135.2 | 135.2 | 84.05 | 145.8 | 96.80 | 224.4 | 48.05 | 72.20 | 64.80 | 76.05 | 96.80 | 125.0 |
| 2019 | 135.2 | 135.2 | 168.2 | 156.8 | 180.0 | 151.2 | 151.2 | 80.00 | 76.05 | 64.80 | 110.4 | 80.00 |
| 2020 | 245.0 | 110.4 | 105.8 | 120.0 | 105.8 | 125.0 | 217.8 | 92.45 | 48.05 | | | |

Figure 4 Max Wind Force for the Accompanying Max Wind Speed

# Ballast Calculations

Based on the given max gust speed of 70 mph, the wind force expected moment is 6440 in*lbf where we recommend 400 lbs of ballast to produce an expected counteracting moment by mass of 8859 in*lbf. With a round foundation for the mount, we plan to equally distribute the ballast with 100 lbs per quadrant, see Figure 9Figure 34 for the CAD rendering.

**Note**. $m_{total}$ is the total mass of system, including the ballast which is used to calculate the dead load weight ($F_{DeadLoad}$) on the roof. Please refer to the Appendix A: Ballast Calculations via EES for equations used and each variable's result for the recommended amount of ballast.

| | |
|---|---|
| $n = 1.376$ | *Factor of Safety* |
| $M_m = 8859$ [in-lbf] | *Moment Mass* |
| $M_w = 6440$ [in-lbf] | *Moment Wind* |
| $height_m = 11.47$ [in] | *Center of Mass* |
| $m_{total} = 492.2$ [lb] | *Total Mass of System* |
| $m_{ballast} = 400$ [lb] | *Mass of Ballast* |
| $V_{Tipping} = 82.1$ [mph] | *Tipping Velocity* |
| $F_{DeadLoad} = 69.66$ [lbf] | *Dead Load* |

**Parametric Table: Table 1**

| | $m_{ballast}$ [lb] | $n$ | $V_{Tipping}$ [mph] | $m_{total}$ [lb] | $F_{DeadLoad}$ [lbf] |
|---|---|---|---|---|---|
| Run 1 | 320 | 1.152 | 75.13 | 412.2 | 58.34 |
| Run 2 | 330 | 1.18 | 76.04 | 422.2 | 59.76 |
| Run 3 | 340 | 1.208 | 76.93 | 432.2 | 61.17 |
| Run 4 | 350 | 1.236 | 77.82 | 442.2 | 62.59 |
| Run 5 | 360 | 1.264 | 78.69 | 452.2 | 64 |
| Run 6 | 370 | 1.292 | 79.56 | 462.2 | 65.42 |
| Run 7 | 380 | 1.32 | 80.41 | 472.2 | 66.83 |
| Run 8 | 390 | 1.348 | 81.26 | 482.2 | 68.25 |
| Run 9 | 400 | 1.376 | 82.1 | 492.2 | 69.66 |
| Run 10 | 410 | 1.404 | 82.93 | 502.2 | 71.08 |
| Run 11 | 420 | 1.431 | 83.75 | 512.2 | 72.5 |
| Run 12 | 430 | 1.459 | 84.56 | 522.2 | 73.91 |
| Run 13 | 440 | 1.487 | 85.37 | 532.2 | 75.33 |
| Run 14 | 450 | 1.515 | 86.17 | 542.2 | 76.74 |

Figure 5 Ballast Calculations for Varying Ballast Mass

## Dassault Systèmes SOLIDWORKS Corp. Simulation

The simulations were made for the validation of the analytical results. The base is fixed with a 180 lbf force applied, equivalent to a maximum wind gust of 70 mph, to the wind turbine's hub. The yield for 4130 Steel is 435 MPa. Figure 6 shows a Stress Study with a maximum yield of 300 MPa and Figure 7 shows the Displacement Study. We conclude the structure will tip before the structure fractures.

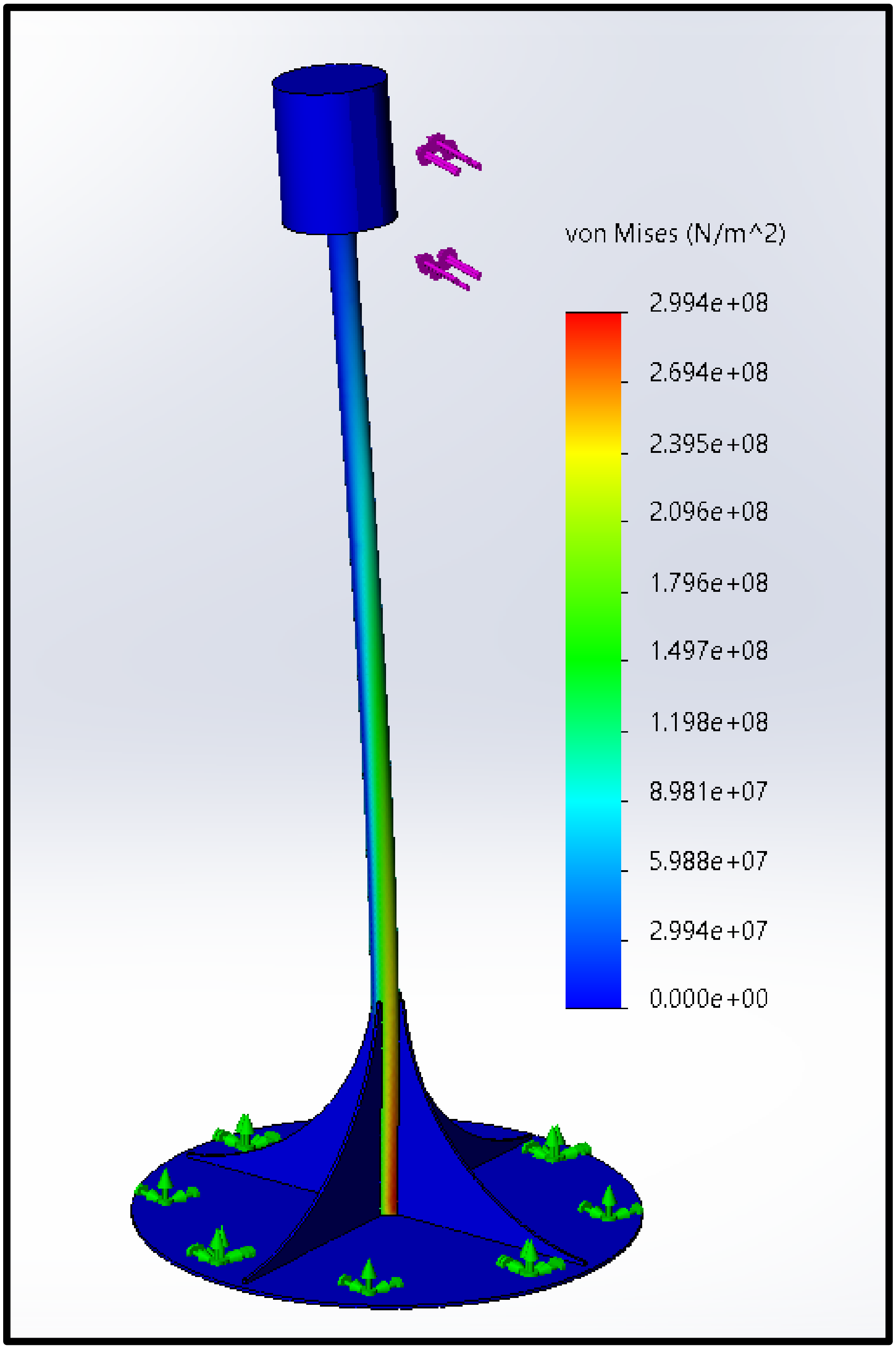



Figure 6 Stress Study

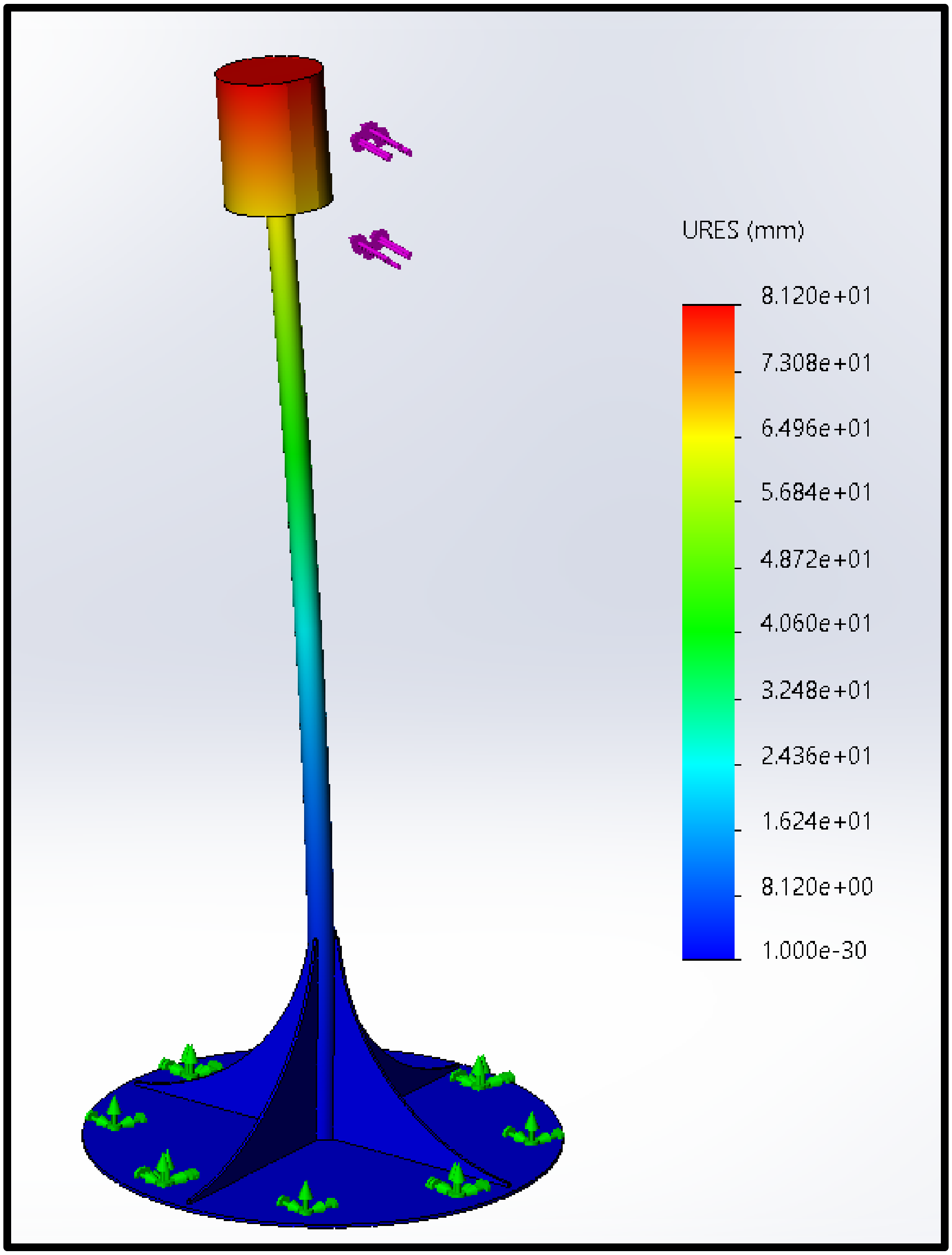



Figure 7 Displacement Study

# Design Process

In this section, we discuss the design process used by the Green Roof Team.

1. Conceptual Design
    a. Researched different components of the system.
    b. Brainstormed solutions and design choices.
    c. Evaluated the different solutions through a morphological matrix based on criteria (possibility, feasibility, cost effectiveness) seen in Figure 12.

2. Feasibility Study
    a. Conducted a site assessment of max gust force on the structure.
    b. Determined the optimal ballast amount seen in Ballast Calculations on page 10 and ballast material can be seen in Figure 8 Ballast Material.
    c. Concluded to the Agriculture Building's Roof Area B seen in Figure 1.


Figure 8 Ballast Material

3. Preliminary Design
    a. Based on the conceptual design, chose a vertical axis system due to its innovative aesthetics.
    b. Contacted Michael Duffy, PhD from Georgia Tech, for advice based on his research on small wind turbines mounted on existing buildings.
    c. The structure features a slender, 2” diameter, tube with gussets all welded seen in Figure 9.

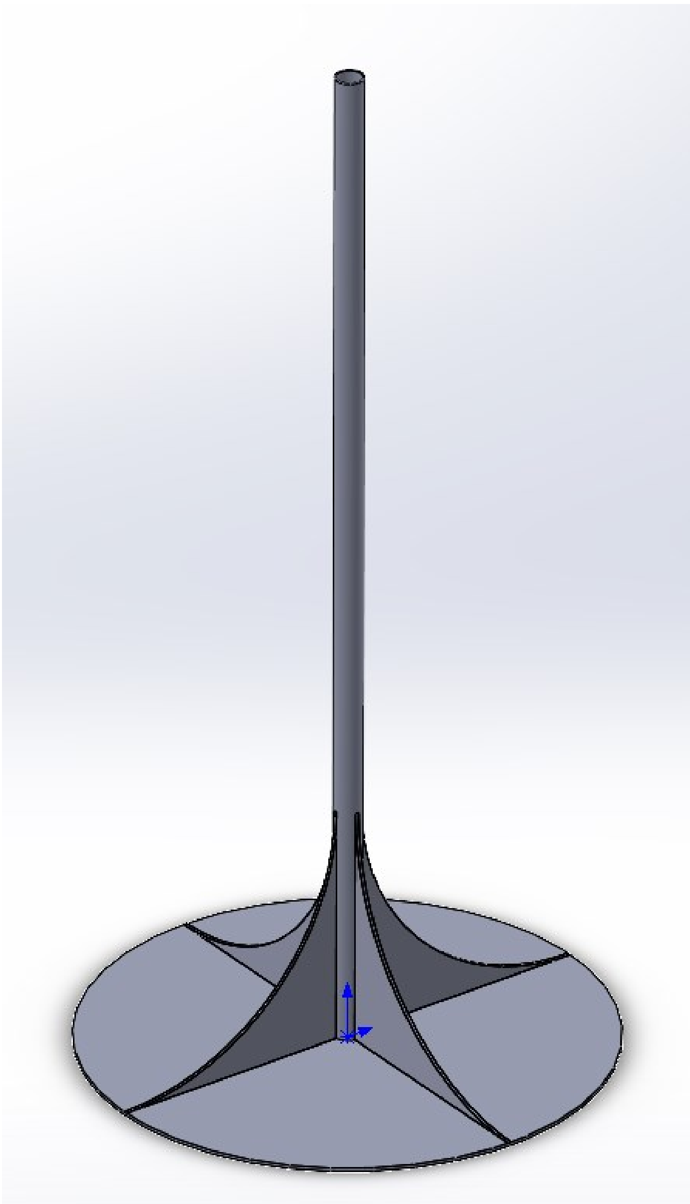


Figure 9 Preliminary Design CAD

4. Final Design
    a. Based on the preliminary design, the following calculations were defined:
        i. The dimensions of the wind turbine.
        ii. The dimensions of the pole.
        iii. The dimensions of the base.
        iv. The size of the ballast necessary for support.

5. Construction
    a. A plasma cutter in the College of Engineering was used on a 3'x3'x0.25" sheet of 4130 steel alloy for a circular design as seen in Figure 10 and excess pieces used as gussets.


Figure 10 Structure's Base Following Plasma Cutter Service

6. Future Design Considerations
    a. In collaboration with the photovoltaic sub-team of the Green Roof Team, we have design plans for integrating solar modules into the standalone system.
    b. Guidewires would be added from the module's mount to the wind turbine's mount for added stability.

| Morphological Matrix | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Function \ Option | Aron T | Brady K | Gustavo | Nelson F | Pedro O | Ruben R | Stephen | Zach B | Aaron L | Alex E | Drew F | Edward L | Hein HA | Iyke G | Kat G | MAX | WINNER |
| Mount | 54 | 0 | 49 | 54 | 0 | 0 | 0 | 6 | 0 | 51 | 54 | 0 | 41 | 0 | 55 | 55 | Kat G |
| Mount Location | 44 | 0 | 45 | 0 | 0 | 0 | 51 | 0 | 0 | 0 | 0 | 0 | 51 | 0 | 43 | 51 | Stephen S |
| Rotor Blades | 0 | 44 | 54 | 43 | 32 | 24 | 33 | 35 | 34 | 0 | 48 | 0 | 45 | 0 | 34 | 54 | Gustavo FP |
| Structure | 38 | 41 | 53 | 27 | 43 | 0 | 27 | 42 | 0 | 48 | 53 | 0 | 51 | 0 | 0 | 53 | Gustavo FP |
| Yaw System | 0 | 0 | 42 | 27 | 0 | 0 | 0 | 0 | 0 | 0 | 50 | 0 | 52 | 0 | 53 | 53 | Kat G |

Figure 11 Morphological Matrix

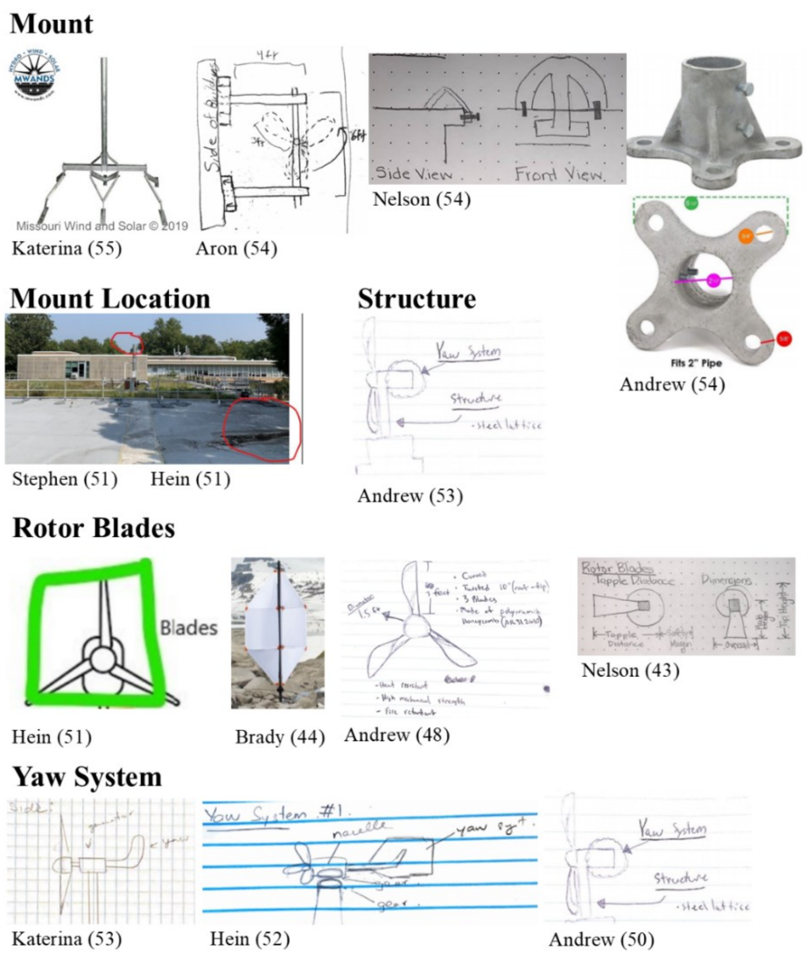



Figure 12 Morphological Matrix Results

# Design Documentation

## Structure Manufacturing

Manufacturing began with setting up our 3'x3'x ¼" thick 4130 steel plate on the ShopSabre CNC plasma cutting table seen in Figure 10. The square sheet was set flat, moved in a way that made the front edge parallel to the x-axis of the table, and the x-y (0,0) home coordinate was set on the lower left corner of the sheet. A 35.5" circle was then plasma cut out of the center of our sheet that actually measured 36.125" square. The Green Roof Team's logo was also cut out of a section of the circle. With the amount of material taken away by the plasma cutter, we were left with 4 corners of the sheet, held together by ⅛" to ¼" of material. These 4 corner "triangles" were cut apart at the midpoint of each edge of the original square to be used for gussets that would brace the tube supporting the turbine.

With all our pieces cut out, we began setting up to weld. Before welding, we cleaned each welding area with a wire wheel then wiped it with acetone to remove any dirt and oil. We started placing pieces by marking the center of our circular plate and awing a position for our center tube to set. With the tube centered and plumb, we placed 2 adjacent gussets on the plate, brought them to the tube, and ensured that they were 90° apart and perpendicular to the base seen in Figure 13. We used magnets, shims, and an extra set of hands to ensure that everything was in place and aligned while welding. With everything temporarily set in place, we tack welded each gusset to the plate at either end of the gusset, each gusset to the tube at the highest and lowest points, and the tube to the plate. Following this, we added one more gusset and placed it and tack welded it in the same fashion. After repeating this with the final gusset and approving the placement of all pieces, we began fully welding. The mount was TIG welded in the College of Engineering with Argon shielding gas and ER70S-2 filler rod. After fully welding the structure, all heat affected zones surrounding the welds were heated with an Oxy-Acetylene torch to a dull, dark red color then covered with sand. This was done to "normalize" the structure and relieve any internal stresses due to the air-hardening effect of 4130 Chromoly steel.

Figure 13 Gusset Alignment Pre-Welding

With finishing the manufacturing of the structure, we received Powder Coating service from a local business in Marion, Illinois, RAZ Coatings seen in Figure 14. The service is a dry finishing process of a thermoplastic powder material which hardens into a protective coating. The service offers a long-lasting and durable, hard finish for protection and aesthetics. The structure is more resistance to impact, moisture, chemicals, and extreme weather than liquid coatings. Additionally, acts as an electrical insulator by withstanding hours of salt spray contact.

For additionally protection and noise reduction, we will use a 1/4" thick silicon rubber sheet, seen in Figure 15, which will be located between the wind turbine's blades and top surface of the generator, where the blades are screwed into the generator. This cushioning is waterproof, heat resistance, and shock absorptive.

Figure 14 Structure Post-Powder Coating Service

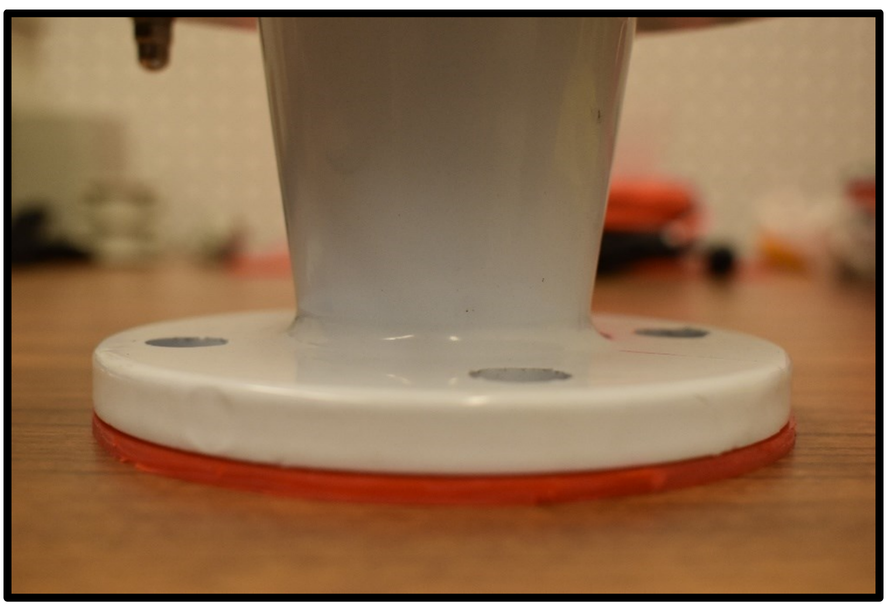


Figure 15 Rubber Skimmer

# Electrical System

While the goal of the project is focused on successfully installing a temporary wind turbine on a rooftop, the project features a fully functional standalone system. The location of the systems can be seen in Figure 16. The detailed circuit schematic is shown in Figure 17. The electrical system contains the generator, wind charge controller provided with the generator's manufacturer, fuse box, 12V battery, and microcontrollers. A flowchart version can be seen in Figure 18.

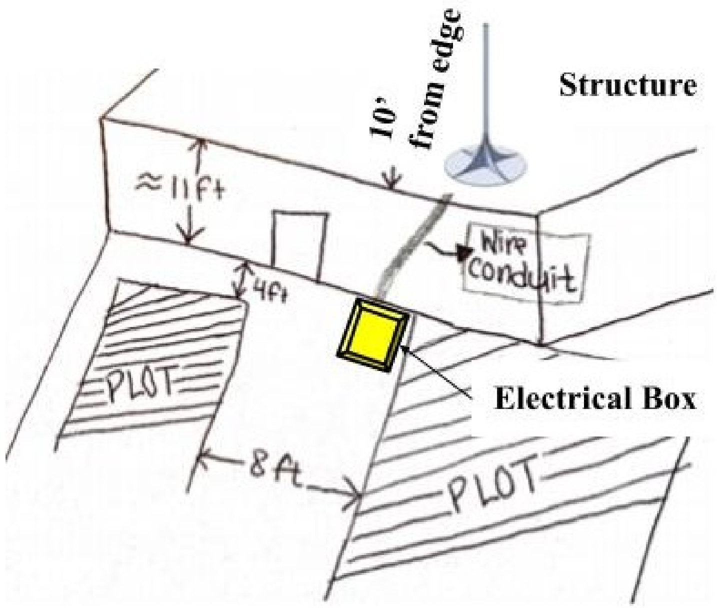



Figure 16 Wiring Isometric

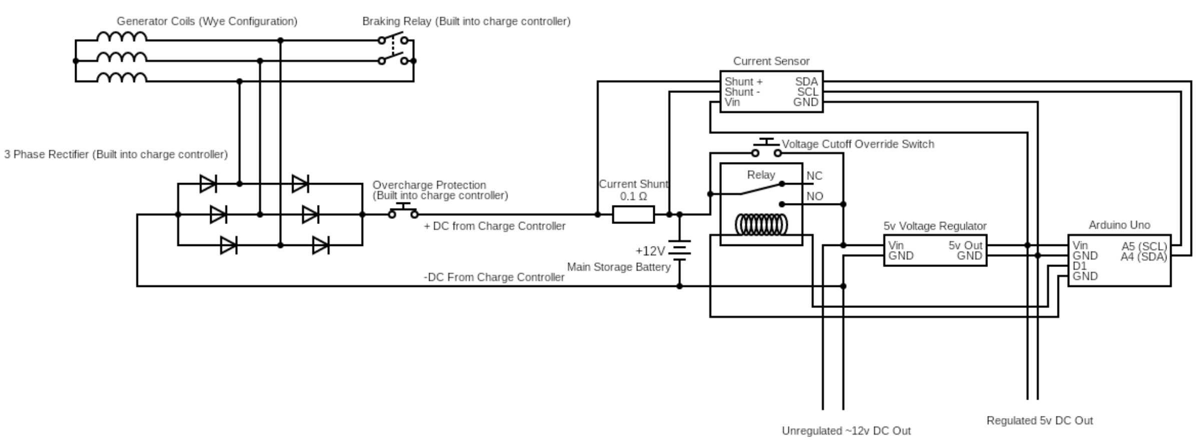



Figure 17 Electrical System Schematic

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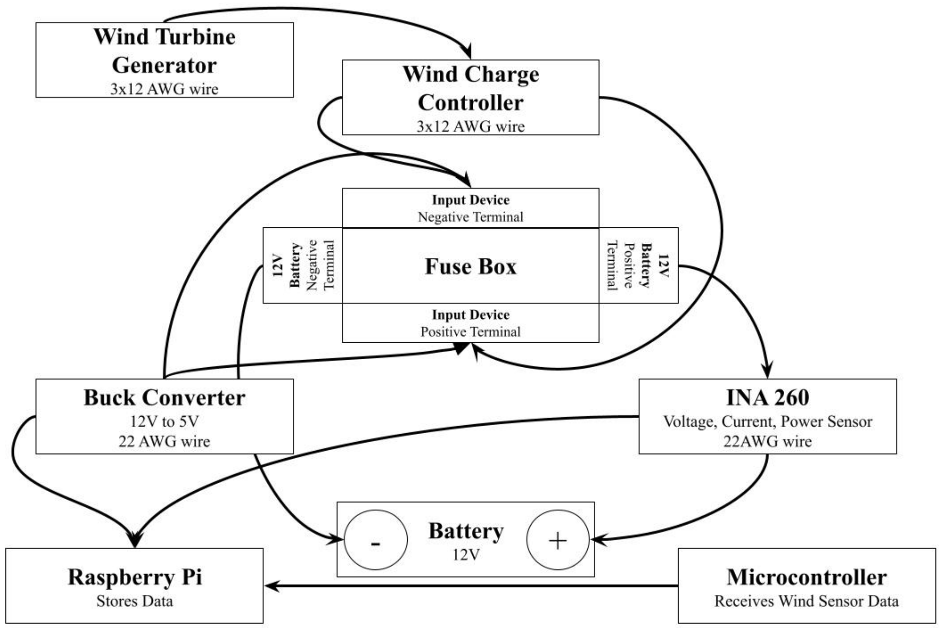


Figure 18 Standalone System Wiring Flowchart

For connections, we used 4-pin screw terminals with 12 AWG silicon wire from the generator, which is a higher gauge, to the electrical box as seen in Figure 19. From the generator, the wire moves through the mount's thin tube and exists at the bottom through a drilled hole. Note there is a hole through the based under the thin tube for any watering entering to exist. Once the wire exists the internal mount, a ½" flexible PVC pipe is the conduit to allow the three-phase wire and wind sensor's RJ11 cable to travel to our electrical box. There is one screw terminal to extend the 12 AWG wire. Once the wires reach the electrical box, a ¾" conduit fitting (gland) was drilled and snuggly fits to minimize water entering the electrical box as seen in Figure 20.


Figure 19 4-pin Screw Terminal

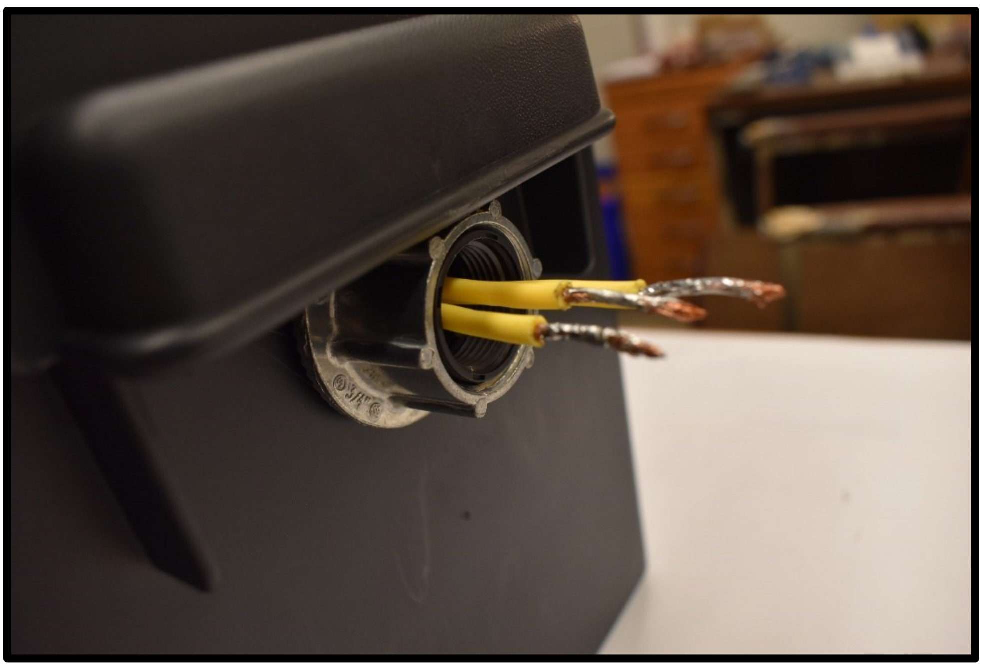

Figure 20 Electrical Box Weatherproof Hole

The charge controller seen in Figure 21 is IP67 protected and will operate at 12V; therefore, the breaking voltage is DC 15V with static power consumption of 8mA, as well as rated at 50A for 600W. The device has a work indicator LED light on the front view, adjacent to the wires, which will show the system's power generation status as 'on' or 'off'.

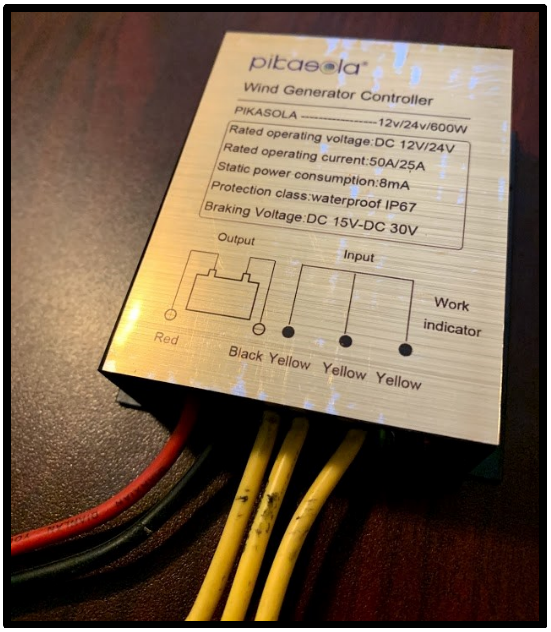


Figure 21 Wind Charge Controller by Pikasola

For the electrical box, we used a fuse box for distributing the power from the 12V battery and wind generator to the Raspberry Pi through a 12V to 5V Buck Converter. Additionally, the INA260 sensor measures the voltage, current, and power across the battery and send the data to the Raspberry Pi for storage. The fuse box contains a 10A fuse for the wind charge controller and a 1A fuse for the Buck Converter as seen in Figure 22. An identified view of the electrical box can be seen in Figure 23 and a closer view can be seen in Figure 24. For more information, refer Installation Work Instructions on page 32.

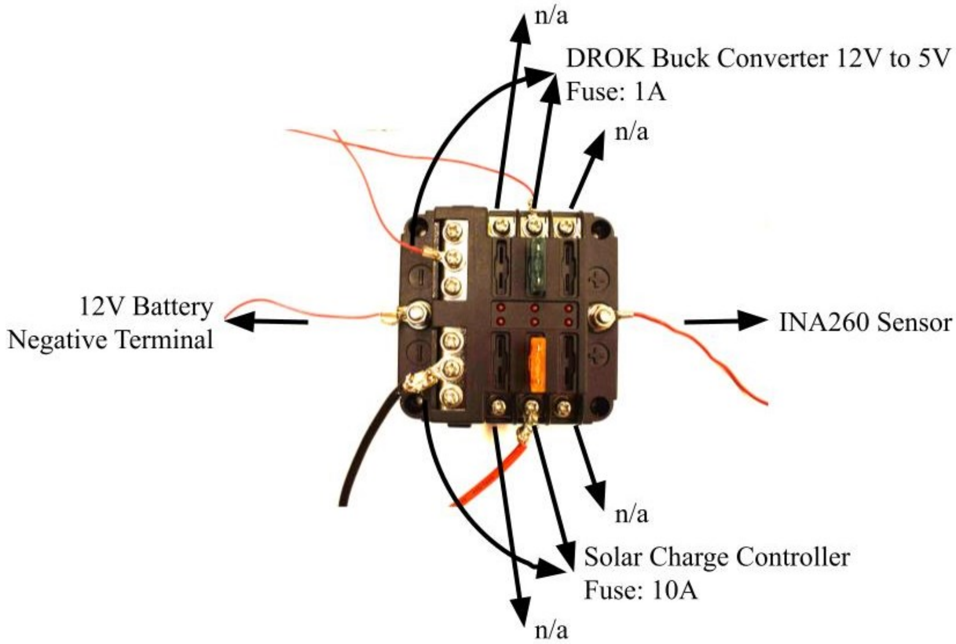


Figure 22 Fuse Box Diagram

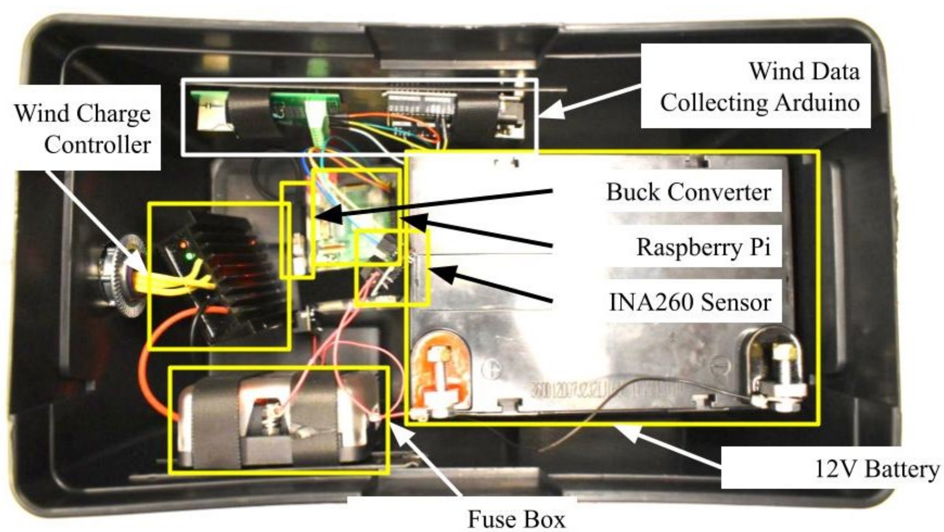


Figure 23 Electrical Box Diagram

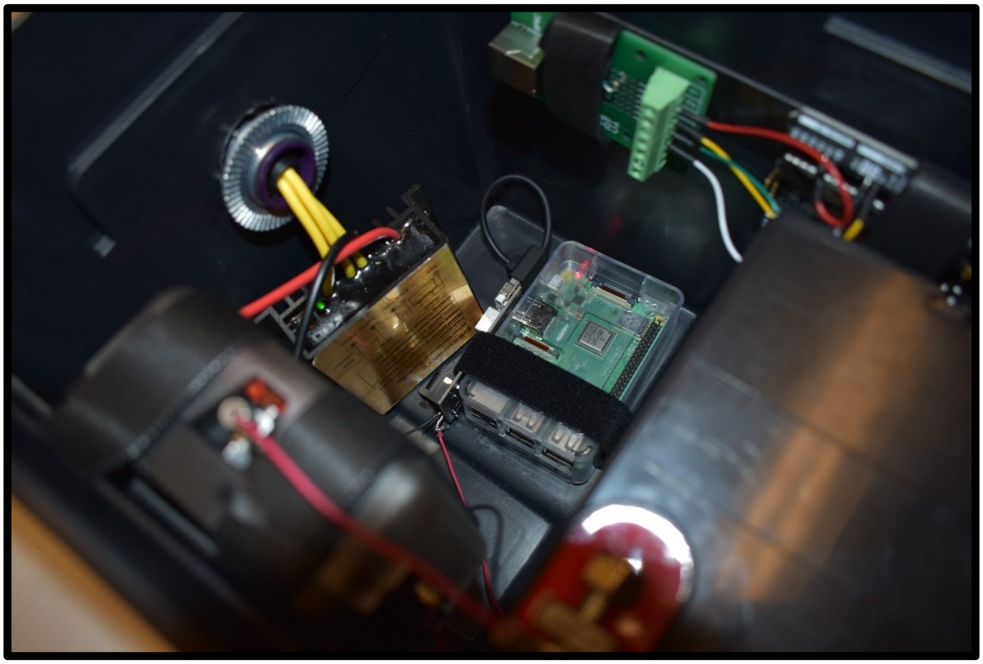

Figure 24 Electrical Box Close View

## Microcontroller System

One component of the project is effectively collecting data through a student designed microcontroller system. We used the previously mentioned INA260 sensor with a Raspberry Pi for collecting power related data and a third-party Arduino for collecting wind related data. The INA260 sensor is integrated in the circuit within the electrical box as seen in Figure 25 and discussed in the Electrical System within the Design Documentation section.

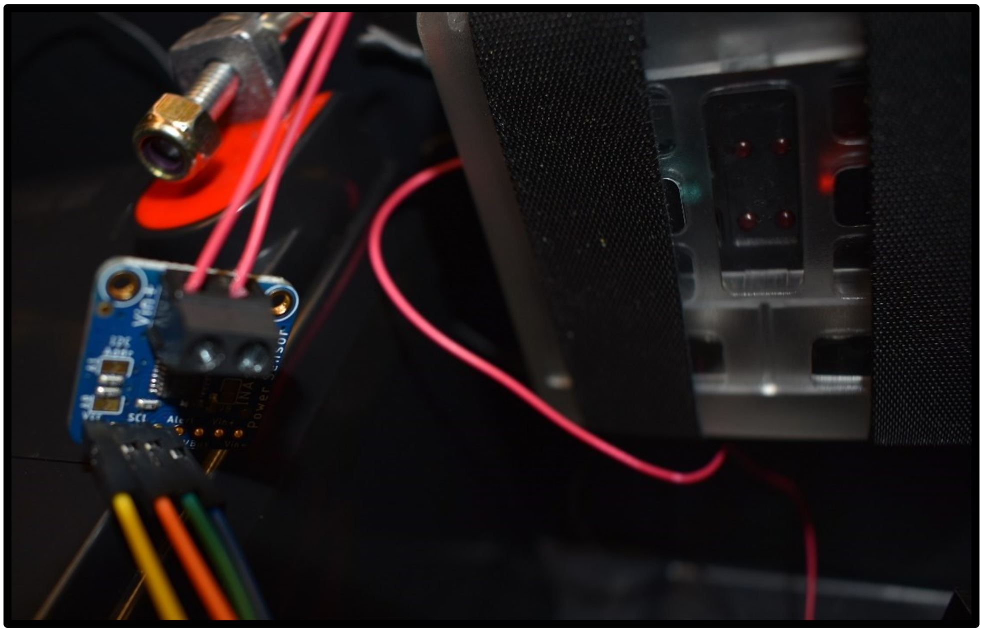

Figure 25 INA260 Sensor in the Electrical Box

The wind related sensors include an anemometer and wind vane seen in Figure 26 will be mounted to a 3D printed stand held down by the structure's ballast as seen in Figure 27 where the sensor's provided pole, inner diameter of 0.72", will be inserted into our manufactured mount. The cable will be included within the conduit seen in Figure 19 which is fed into the electrical box. The sensors send the data via a RJ11 cable into the RJ11/RJ12 Jack Breakout Board which is connected to an Arduino which is connected to the Raspberry Pi as seen in Figure 28.

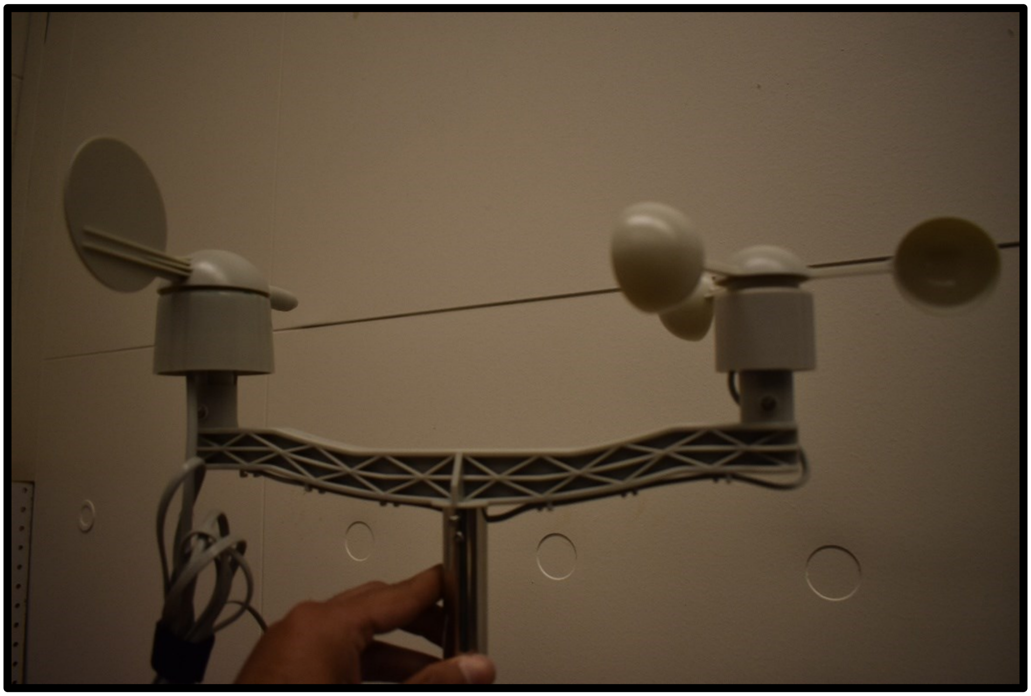

Figure 26 Anemometer and Wind Vane Sensors

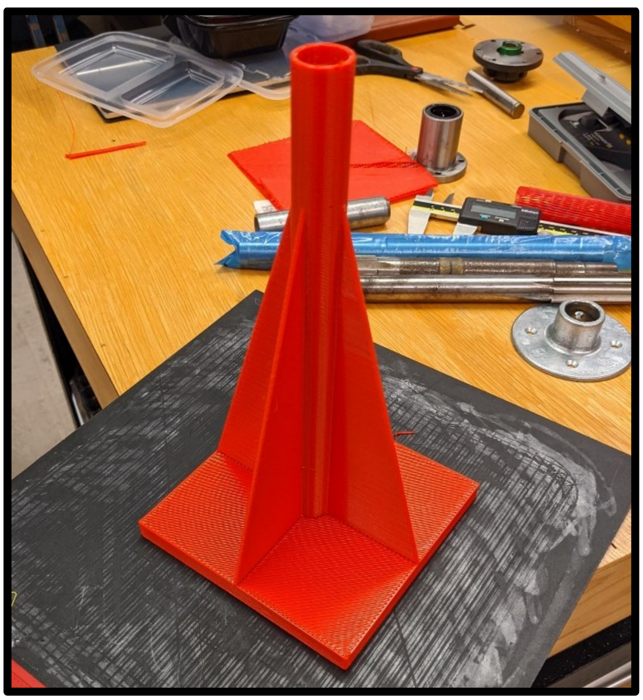

Figure 27 Wind Sensor Mount

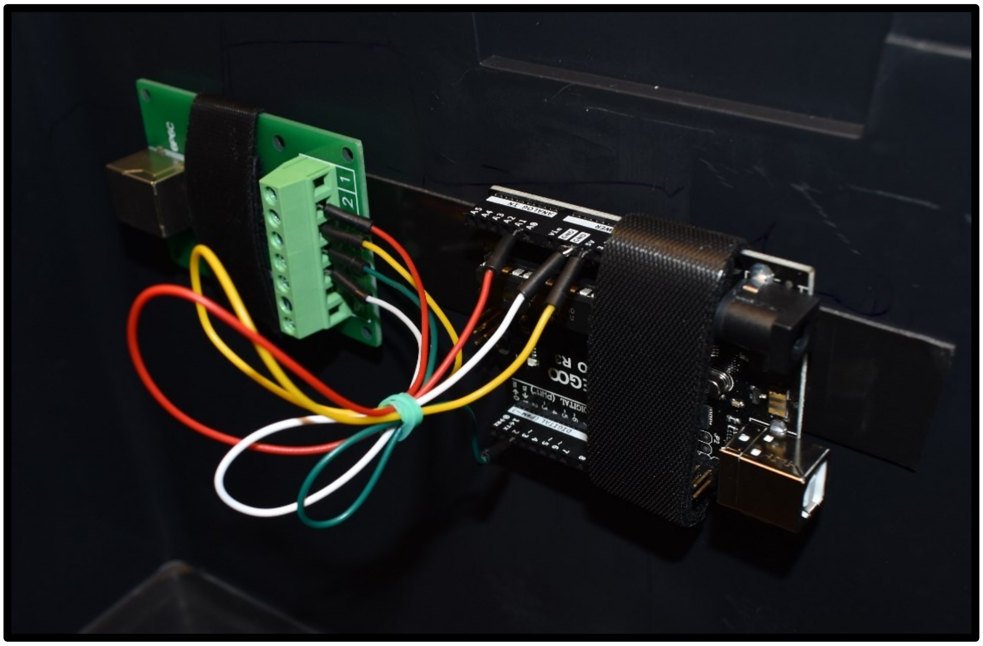

Figure 28 Wind Sensor Microcontroller

A functioning view of the sensor’s output can be seen in Figure 29.

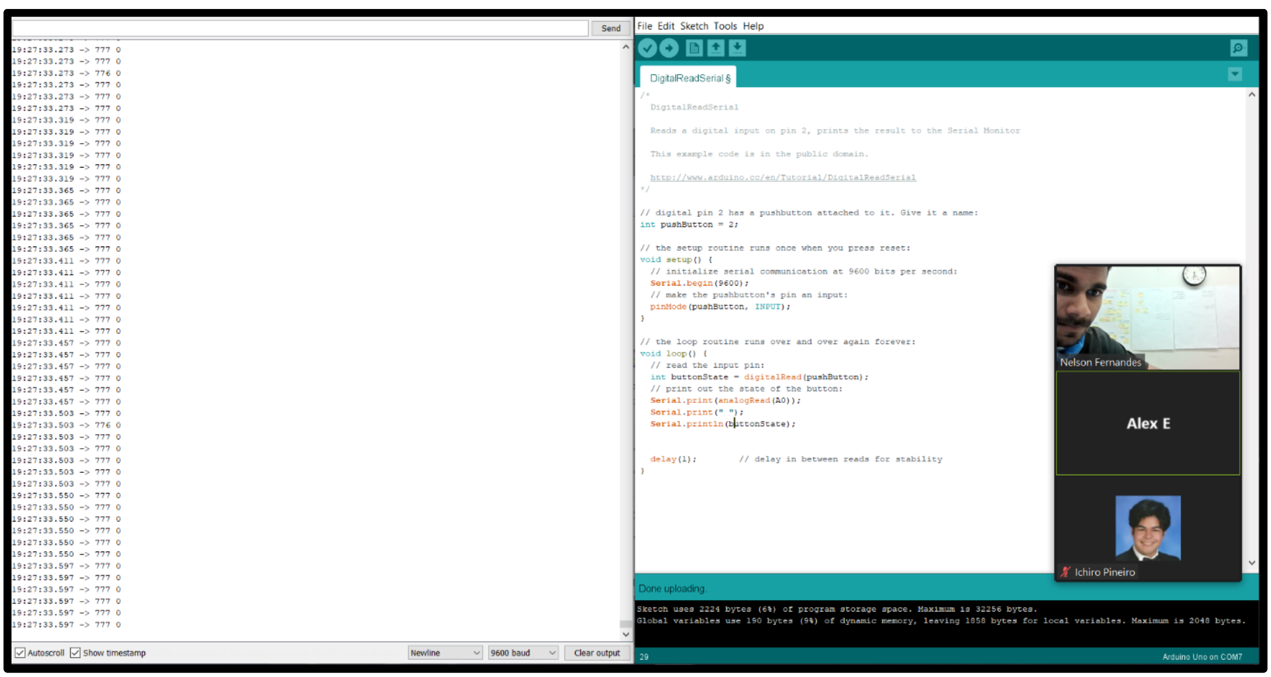


Figure 29 Wind Sensor Testing

The INA260 sensor has four connections required in our circuit. The four pinouts connect to the Raspberry Pi's GPIO: 5V, GND, SLD, and SLC as seen in Figure 30.

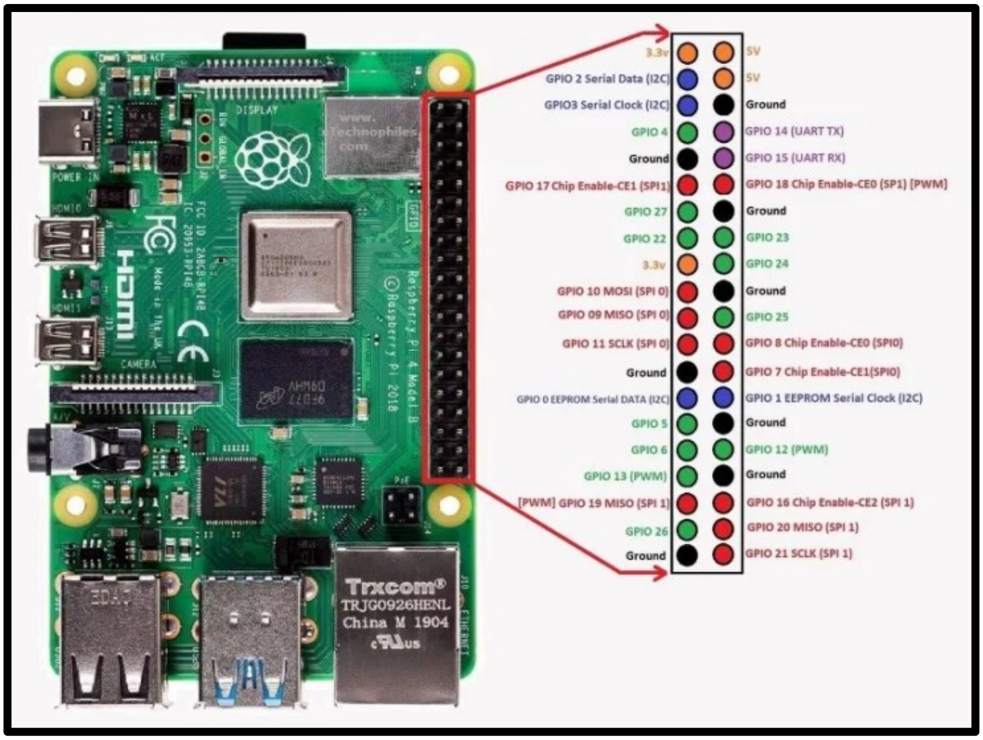


Figure 30 Raspberry Pi GPIO

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A functioning view of the sensor's output can be seen in Figure 31.

Figure 31 Power Sensor Testing

Future iterations of the microcontroller system will include displaying the data collected on the Green Roof's website. An early development is seen in Figure 32.

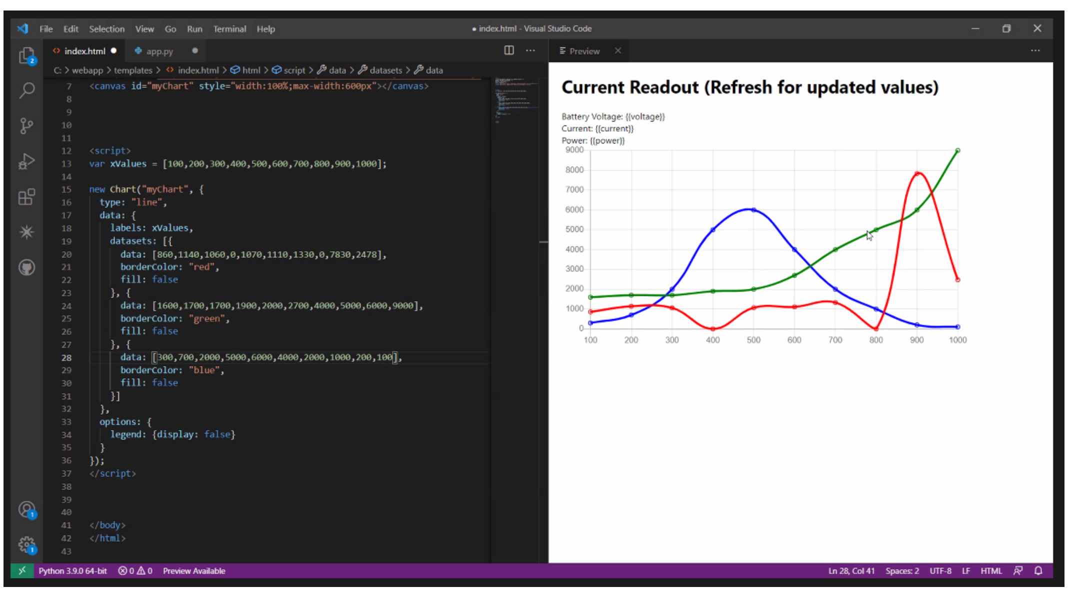


Figure 32 HTML Data Display

# Installation Work Instructions

Below contains detailed work instructions for the Green Roof Team who communicated with SIU Plant & Service Operations well in advance of the design details for approval and assistance with the installation. The primary role of SIU Plant & Service Operations is transporting the mount from the SIU Green Roof onto Roof Area B, refer to Figure 1 on page 7.

**Safety Precautions**

- AVOID wet or rainy days.
- DO NOT position ladder at an angle steeper than 70 degrees.
- Have a person holding the ladder or use sandbags at the bottom step.
- More than one person on the roof is safer than one alone.
- Wear durable, but flexible protective gloves.
- Wear snugly-fitting rubber-soled, low-heeled shoes or boots.

**Materials**

The following materials denoted with a (*) will be transported onto Roof Area B either by pulling the item in a duffle bag by a rope, or by a ladder on the SIU Green Roof, or by climbing the ladder located in the rear of the building complex.

1) Safety and Common Tools
   a) *Allen Keys
   b) First Aid Kit
   c) Gloves
   d) *Pliers, *small than the structure's wire hole*
   e) Safety Goggles
   f) *Screw Drivers
   g) *Stepstool (3' Tall), 2 units
   h) *Wrench

2) Phase 1 – Structure System
   a) *50-lb All-Purpose Sand (*8 units*)
   b) *Carabiners
   c) *Diamond Grip Floor Mat
   d) *Mount
   e) *Polypropylene Sandbags, empty
   f) *Rubber Skimmer
   g) *Stainless Steel Metal Strap Pipe Clamp
   h) *Stainless Steel Wire
   i) *Type III Paracord

j) Wind Turbine Kit
   i) *Generator, *refer Appendix Wind Turbine by PikolaSolar*
   ii) *Blades
   iii) Charge Controller, *refer Figure 21*
   iv) *Associated Screws, Nuts, Washers, etc.

3) Phase 2 – Electrical System
   a) *12 AWG Silicon Wire
   b) 12V Deep Cycle Battery, *refer Appendix Battery by PowerStar*
   c) Battery Box
   d) Fuse Box Blade

4) Phase 3 – Microcontroller System
   a) Cable Ties
   b) Microcontroller System, *refer to Section: Microcontroller System.*
   c) RJ11 Extension Cord
   d) *Weather Meter Kit

**Pre-Installation Goals**

- Assemble Battery Box containing the below items:
  - Battery
  - Charge Controller
  - Fuse Box
  - Microcontroller System
- Assemble Conduit with 3 12 AWG wires and RJ11 cable running through 22’ of ½” flexible PVC pipe.

**Installation Steps**

All materials will be transported to the SIU Green Roof an hour prior to a set installation time provided by SIU Plant & Service Operations.

1) Phase 1 – Structural System
   a) Structure
      i) Transport the Diamond Grip Floor Mat onto Roof Area B.
         (1) Position no farther than 5’ from the Roof Area B’s edge, refer to Figure 1 on page 7.
      ii) Assist SIU Plant & Service Operations with transporting the mount onto Roof Area B.
         (1) Position the mount center of the Diamond Grip Floor Mat.

b) Transportation
   i) Transport the remaining items denoted (*) above under Materials in the current section to Roof Area B either by pulling the item in a duffle bag by a rope, or by a ladder on the SIU Green Roof, or by climbing the ladder located in the rear of the building complex.

c) Ballast
   i) Add 2 50-lb all-purpose sandbags in a polypropylene sandbag, for a total of four 100-lb bags.
   ii) Place on bag in a quadrant of the structure's base.
   iii) Use the Type III Paracord or Steel Wire and/or carabiners for holding the ballast to the structure and avoiding the ballast moving off the structure by wind or external forces.

d) Wind Turbine Assembly
   i) Electrical Wiring
      (1) Unravel the three 12 AWG silicon wires connected to the generator.
      (2) Tape the end of the three wires temporarily.
      (3) Use the stepstool to send the wire from the top of the structure down to the bottom.
      (4) Use pilers to fish the wires from the hole drilled at the bottom back-end of the structure.
      (5) Refer to Phase 2 – Electrical System for further instructions.
   ii) Option 1: *Attach the blades before attached the generator to the mount.*
      (1) Position the rubber skimmer center of the top of the generator.
      (2) Have one person hold the generator while the second person screw one blade at a time to the generator.
         (a) NOTE. the top plate
         (b) NOTE. the washers
         (c) NOTE. Preferably the inner screw before the outer screw.
      (3) Use the step stool where one person holds the generator in place while the second person uses the bolts to attach the generator into the structure's flange.
   *iii)* Option 2: *Attach the blades after attached the generator to the mount.*
      (1) Use the step stool where one person holds the generator in place while the second person uses the bolts to attach the generator into the structure's flange.
      (2) Position the rubber skimmer center of the top of the generator.
      (3) Have one person hold the generator while the second person screw one blade at a time to the generator.
         (a) NOTE. the top plate
         (b) NOTE. the washers
         (c) NOTE. Preferably the inner screw before the outer screw.
      (4) Use the step stool where one person holds the generator in place while the second person uses the bolts to attach the wind turbine hub into the structure's flange.

2) Phase 2 – Electrical System
   a) Refer to Phase 1 – Structural System => Step d => Step i) Electrical Wiring before proceeding.
   b) Once the wires exit the structure, insert into the flexible conduit before moving the wire down the wall.
   c) Use adhesive to fix the conduit along the building.
   d) Insert the end of the conduit through the battery box with a plastic cable gland joints with gaskets for weatherproofing.
   e) Use the 3 pin external junction box cable connector for connecting the 12 AWG silicon wire to the charge controller.
   f) Connect the charge controller, battery together based on Figure 18.

3) Phase 3 – Microcontroller System
   a) Assemble in the Green Roof Hub within the battery box prior to installation.

# Bill of Materials

Below contains the list of items used for the project as well as the link used for ordering the material. Images of the various items can be found at the end of the section as well as throughout the report in addition to Appendix E: Manufacturers' Specification on page 63.

**Project Total Cost**: $1,318.62

## Wind Turbine Materials

12' x 12' x 1/8" Silicon Rubber Sheet – $14.49
    Amazon

Wind Turbine Kit – $269.00
    Amazon

## Structural Materials

1/16" Stainless Steel Wire Aircraft Cable with Crimping Loop and Wire Rope Clamps – $19.99
    Amazon

12kN Carabiners – $9.99
    Amazon

2" Stainless Steel Metal Strap Pipe Clamp – $3.99
    Amazon

3M Heavy Duty Mounting VHB Tape – $16.99
    Amazon

¾" Insulated Hub Conduit Fittings – $4.78
    Lowes

3' x 5' x 0.25" Anti-Fatigue Mat – $61.24
    Lowes

4130 Alloy Steel Round Tubes. 0.120" Wall Thickness. 2" OD. Length 6ft – $111.07
    McMaster-Carr

4130 Alloy Steel Sheets and Bars. 1/4" Thickness. 36" Width. 3ft Length. – $226.41
    McMaster-Carr

50-lb All-Purpose Sand, 0.5 $ft^3$ (10 unites) – $4.28
Lowes

Plastic Cable Gland Joints with Gaskets – $15.99
Amazon

Polypropylene Sandbags – $16.99
Amazon

## Electrical Materials

12 Gauge 25' Silicone Wire (5 units) – $15.98
Amazon

1A Automotive Fuses Blade – $5.29
Amazon

3 Pin External Junction Box Cable Connector – $8.99
Amazon

6-Way Fuse Box Blade – $15.88
Amazon

0.5" x 25' Non-Metal Flex Conduit – $24.57
Lowes

Heat Shrink Tubing Tube – $8.99
Amazon

Non-Insulated Ring Crimp Terminals Cable Wire Connectors – $12.99
Amazon

PowerStar 12V 35Ah Deep Cycle Battery SLA1155 for Solar, Backup, Marine – $89.55
Walmart

Snap-Top Battery Box, Group 27 – $12.99
Amazon

## Microcontroller System

3/4" Nylon Fastening Tape Cable Ties – $14.00
Amazon

400 tie-Points Breadboard – $7.99
Amazon

Adafruit 4226 INA260 Voltage, Current, Power Sensor – $13.74
Amazon

Buck Converter 12v to 5v – $9.99
Amazon

ELEGOO UNO R3 Board – $13.98
Amazon

Jumper Wires Ribbon Cables Kit – $7.65
Amazon

PCB Board Prototype Kit – $12.99
Amazon

Raspberry Pi 4 Model B 2019 Quad Core 64 Bit WiFi Bluetooth (4GB) – $59.98
Amazon

Raspberry Pi Screen Touchscreen – $41.99
Amazon

RJ11/RJ12 Jack Breakout Board – $8.99
Amazon

RJ11 Extension Cord – $6.98
Amazon

UL 36825 Extension Cord 3 Outlet – $12.96
Amazon

Weather Meter Kit – $69.95
Amazon

# Ethical Consideration

Bird considerations were discussed due to the proximity of the turbine located close to Thompson Woods, home of birds and wildlife. As a result of the vertical axis design, birds and other wildlife will have a more sufficient vision of the blades in comparison to horizontal axis systems.

# Safety Considerations

The system will be installed on a non-accessible roof top on the SIU Agriculture Building which requires a key to access. Calculated ballast was used with a significant Factor of Safety for preventing tip over or runaway system. Additionally, guidewires from the solar modules will provide additional support.

The generator includes electromagnetic brakes operated by electrical actuation but transmits torque mechanically. When electricity is applied to the coil of am electromagnet, the magnetic flux attracts the rotating coil to the face of the brake. As it does, it squeezes the inner and outer friction disks together. The hub is normally mounted on the shaft rotating. The brake housing is mounted solidly to the machine frame. As the disks are squeezed, torque is transmitted from the hub into the machine frame which stops and holds the shaft.

With the system exposed to natural weather conditions ranging from low temperatures to high temperatures along with snow and drought, the 4130 Alloy structure was treated with a powder coating service for good UV protection which will provide approximately 5 years of protection. The electrical components are contained within a weatherproofed battery box which is twice the size of the 12V battery for reference. All wires connections are contained within a weatherproofed screw terminal and any exposed wires were soldered as well as electrical taped for avoiding short circuits. Additionally, the wire from the generator to the battery box is contained within a ¾” flexible PVC pipe as a conduit to avoid flying wires.

# Risk Management

The table below demonstrates possible risks and lists multiple solutions for these risks. The risks are based on a long range of utilization of the wind turbine and its systems, and the actions of mitigation envision the maintenance of the systems for a long life of operation.

| **Risk** | **Action** |
|---|---|
| Too much pressure on roof | Spread weight over greater area |
| Ballast weight moving | Rope holding bags |
| Mount not being static | Sandbags |
| Blades getting brittle by the weather | UV protection / have a spare set of blades |
| Tipping | Arms extending from ballast |
| Not tall enough to produce power | Attach second pole to make telescopic |
| Bolts linking turbine to mount getting loose | Use a torque wrench to ensure all bolts are tightened to the same standard.<br>Use nylon lock nuts or lock washers to prevent loosening by vibration. |
| Lost bolts | Buy extra bolts for replacement |
| Rust problems | Have an information about paint in the report / powder coating |
| bolts/nuts rusting | Additional parts and torque wrench to remove accordingly |
| Solar PV<br>guidewires | Shading from the turbines<br>Additional stability? |
| **Electrical** | |
| Electronics components failure | Extra electronic parts |
| Water getting to the electronics | Sealing components |
| Code problem with the controller | Perform tests on controller before installation |
| Calibration problem for the sensors | |
| Problem retrieving data from the turbine | |
| Sustainability of code and electronics | Documentation (commenting in code)<br>Finding a faculty member for backup |

# Maintenance Plan

The temporary wind turbine will require minimal maintenance after initial testing and troubleshooting. Team members will be available during Fall 2021 and Spring 2022 for support and will have sustainable measures with a student organization dedicated to clean energy student installations, an academic department, campus unit, or SIU Plant & Service Operations for further maintenance and ownership in future years.

# Recommendations

The Green Roof Team at Southern Illinois University Carbondale recommends using 400 pounds of ballast on a wind turbine mount with a prefabricated wind turbine generator of vertical axis. The student designed mount has dimensions of a circular base of 0.25" thickness and 3' diameter where a thin tube of 6' height and 2" diameter is welded in the center and gussets are welded on four corners of the tube to the circular base. Transported onto the Agriculture Building at SIU Plant & Service Operation's discretion.

# References

Duffy, Michael. (2010). Small wind turbines mounted to existing structures.

Milos, director. *Ballast Calculations for Temporary Structures*. *YouTube*, Milos, 15 Mar. 2017, youtu.be/n1QhYFn4hI8.

# Appendices

## Appendix A: Ballast Calculations via EES Program

```
A_surface = 3.14 * (1.5)^2

// Wind Force
rho = 0.080 [lbm/ft^3]
V_mph = 70 [mph]
V = V_mph * convert(mph, ft/s)
A = 5.97 [ft^2]
F = 0.5 * rho * V^2 * A / 32.2

// Wind Moment (M_w)
height_w = 6*12 + 0.25 + 12
c_w = ((6*12 + 0.25 + 12)^2 + (18)^2)^(1/2)
theta_w = arcsin(18/c_w)
M_w = F * cos(theta_w) * height_w

// Mass Moment
m_sheet = 45.682 [lb] {91.69 total sheet}
h_sheet = 0.25 [in]
y_bar_sheet = (4 * 18) / (3 * 3.14)
cm_sheet = m_sheet * y_bar_sheet

m_gusset = 11.5 [lb]
h_gusset = 18 [in]
y_bar_gusset = h_gusset / 3 [in]
cm_gusset = m_gusset * y_bar_gusset

m_tube = 15 [lb]
h_tube = 6 * 12 [in]
y_bar_tube = (h_tube / 2) + h_sheet
cm_tube = m_tube * y_bar_tube

m_turbine = 26.5 [lb]
h_turbine = 24 [inch]
y_bar_turbine = (h_turbine / 2) + h_sheet + h_tube
cm_turbine = m_turbine * y_bar_turbine

m_blade = 1 [lb]
```

```
h_blade = 12 [in]

m_ballast = 400 {n=1.5}
h_ballast = 7 [in]
cm_ballast = m_ballast * h_ballast

m_structure = m_sheet + m_tube + m_turbine + 5 * m_blade
m_total = m_structure + m_ballast

height_m = (cm_gusset + cm_tube + cm_turbine + cm_ballast) / m_total {9.2 [in]}

c_m = ((height_m)^2 + (18)^2)^(1/2)
theta_m = arccos(18/c_m)
M_m = m_total * cos(theta_m) * c_m

// Analysis
//n = 1.5
n = M_m/M_w
V_Tipping = (n)^(1/2) * V_mph

//F_DeadLoad = 70
F_DeadLoad = m_total / A_surface
```

**Unit Settings: Eng F psia mass deg**

| | | | |
|---|---|---|---|
| $A = 5.97$ [ft^2] | $A_{surface} = 7.065$ | $cm_{ballast} = 2800$ | $cm_{gusset} = 69$ |
| $cm_{sheet} = 349.2$ | $cm_{tube} = 543.8$ | $cm_{turbine} = 2233$ | $c_m = 21.34$ [in] |
| $c_w = 86.15$ | $F = 78.17$ [lbf] | $F_{DeadLoad} = 69.66$ [lbf] | $height_m = 11.47$ [in] |
| $height_w = 84.25$ | $h_{ballast} = 7$ [in] | $h_{blade} = 12$ [in] | $h_{gusset} = 18$ [in] |
| $h_{sheet} = 0.25$ [in] | $h_{tube} = 72$ [kJ/kg] | $h_{turbine} = 24$ [inch] | $m_{ballast} = 400$ [lb] |
| $m_{blade} = 1$ [lb] | $m_{gusset} = 11.5$ [lb] | $M_m = 8859$ [in-lbf] | $m_{sheet} = 45.68$ [lb] |
| $m_{structure} = 92.18$ [lb] | $m_{total} = 492.2$ [lb] | $m_{tube} = 15$ [lb] | $m_{turbine} = 26.5$ [lb] |
| $M_w = 6440$ [in-lbf] | $n = 1.376$ | $\rho = 0.08$ [lbm/ft^3] | $\theta_m = 32.51$ |
| $\theta_w = 12.06$ [C] | $V = 102.7$ [ft/s] | $V_{mph} = 70$ [mph] | $V_{Tipping} = 82.1$ [mph] |
| $\bar{y}_{gusset} = 6$ | $\bar{y}_{sheet} = 7.643$ | $\bar{y}_{tube} = 36.25$ | $\bar{y}_{turbine} = 84.25$ |

Figure 33 Engineering Equation Solver Code for the Ballast Calculations

# Appendix B: Detailed Diagrams

The below figure shows a 3d rendering of the wind turbine's mount.

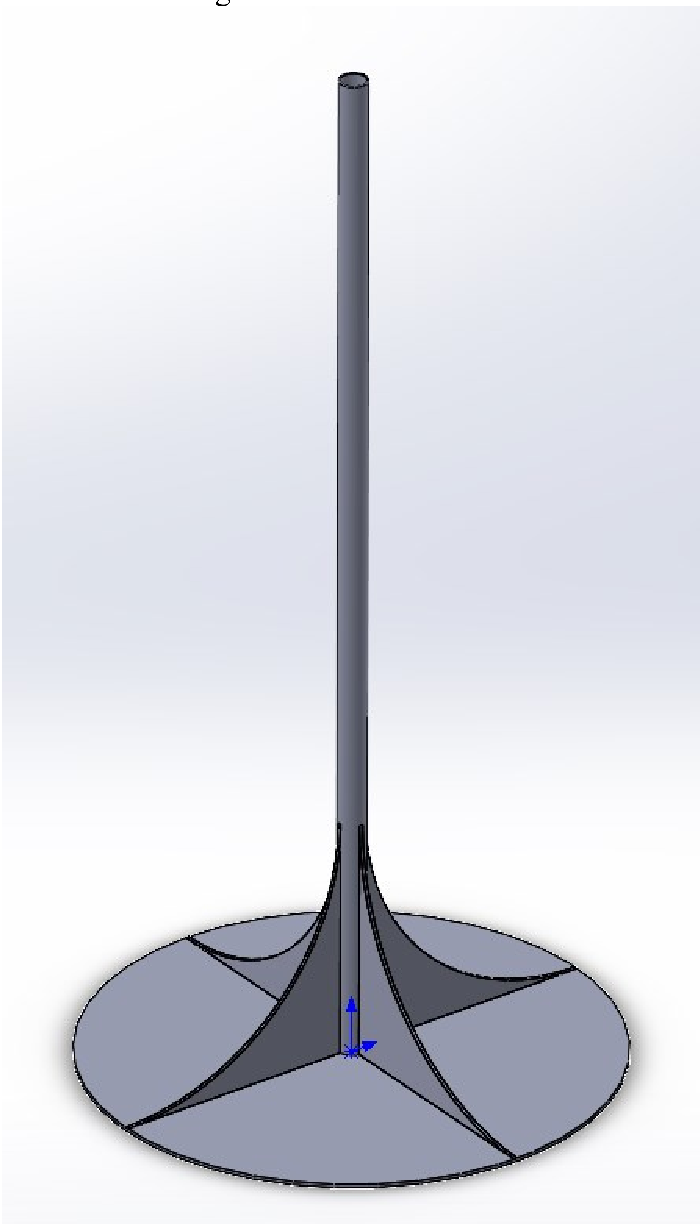

Figure 34 Structure CAD

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Figure 35 Generator's Mounting Flange CAD shows the mounting flange provided with the Wind Turbine Kit.

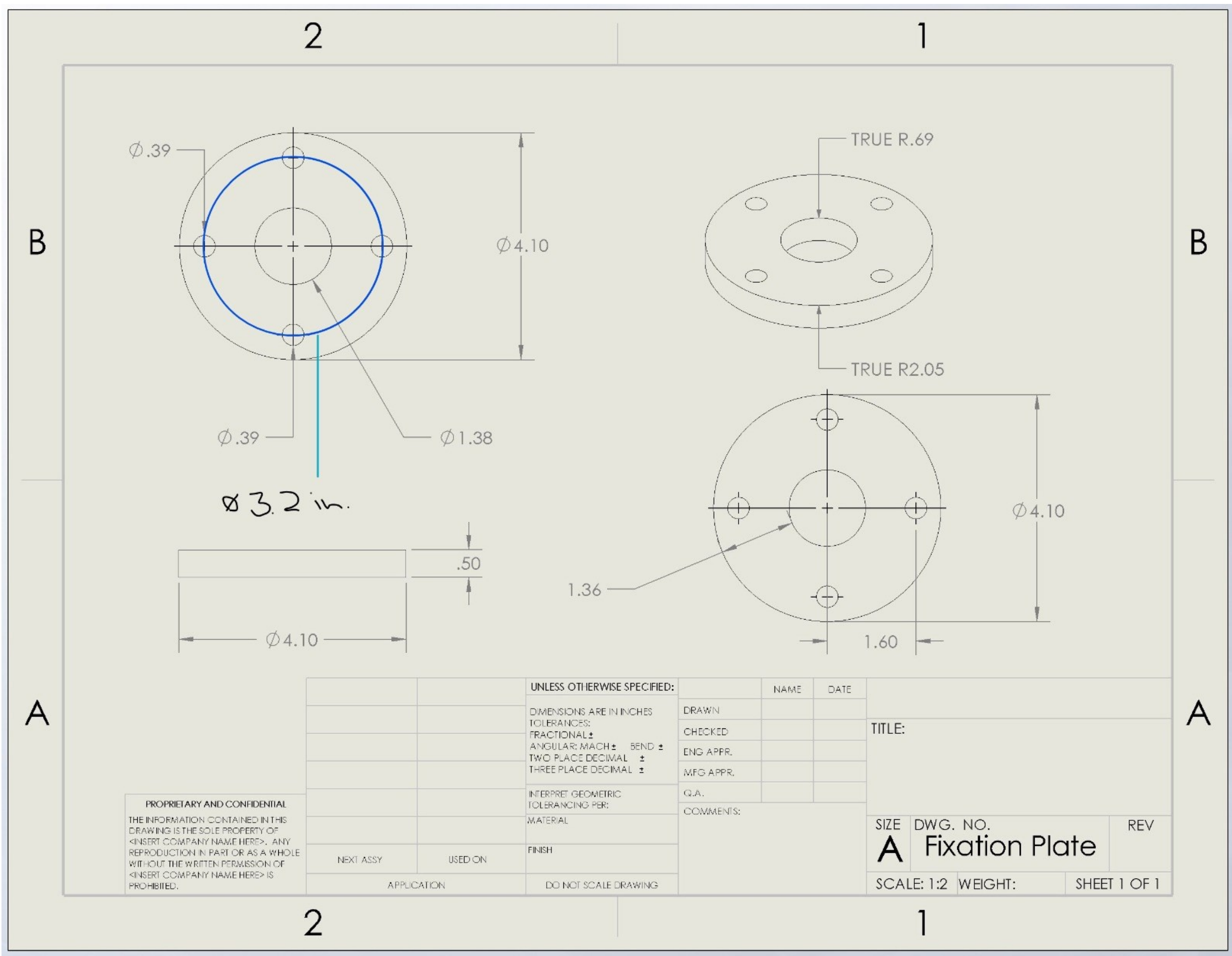


Figure 35 Generator's Mounting Flange CAD

Figure 36 Circuit Schematics shows the circuit schematics for the electrical system with a 12 AWG wire for connections.

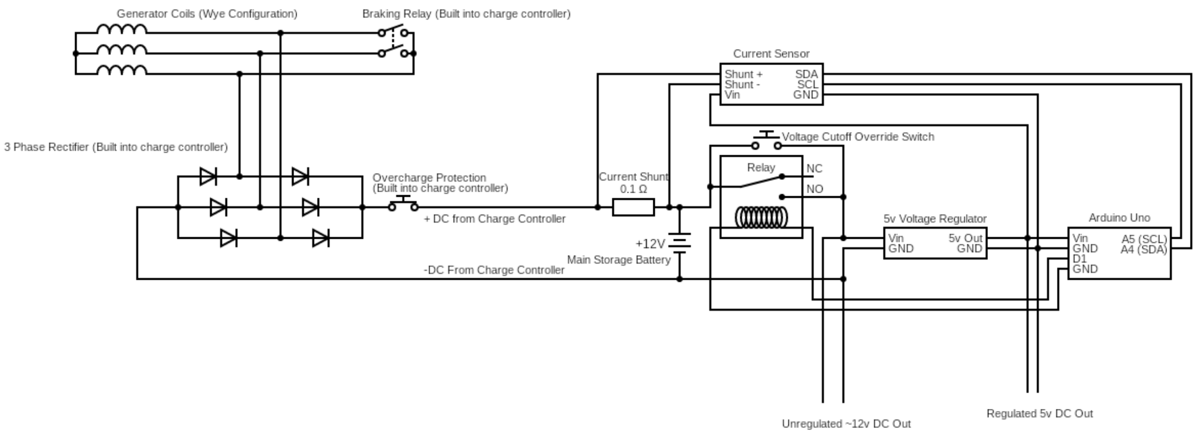


Figure 36 Circuit Schematics

# Appendix C: Microcontroller Code

This section contains the various lines of code used for the microcontroller devices used.

## INA260 Sensor (ina260_simpletest.py)

```
import time
import board
import adafruit_ina260

i2c = board.I2C()
ina260 = adafruit_ina260.INA260(i2c)
while True:
    print(
        "Current: %.2f mA Voltage: %.2f V Power:%.2f mW"
        % (ina260.current, ina260.voltage, ina260.power)
    )
    time.sleep(1)
```

## INA260 Sensor - Arduino (ina260_test.ino)

```
#include <Adafruit_INA260.h>

Adafruit_INA260 ina260 = Adafruit_INA260();

void setup() {
  Serial.begin(115200);
  // Wait until serial port is opened
  while (!Serial) { delay(10); }

  Serial.println("Adafruit INA260 Test");

  if (!ina260.begin()) {
    Serial.println("Couldn't find INA260 chip");
    while (1);
  }
  Serial.println("Found INA260 chip");
}

void loop() {
  Serial.print("Current: ");
  Serial.print(ina260.readCurrent());
  Serial.println(" mA");

  Serial.print("Bus Voltage: ");
  Serial.print(ina260.readBusVoltage());
  Serial.println(" mV");

  Serial.print("Power: ");
  Serial.print(ina260.readPower());
  Serial.println(" mW");

  Serial.println();
  delay(1000);
}
```

## INA260 Sensor - Arduino (Adafruit_INA260.h)

```
/*!
 *  @file Adafruit_INA260.h
 *
 *      I2C Driver for INA260 Current and Power sensor
 *
 *      This is a library for the Adafruit INA260 breakout:
 *      http://www.adafruit.com/products/4226
 *
 *      Adafruit invests time and resources providing this open source code,
 *  please support Adafruit and open-source hardware by purchasing products from
 *      Adafruit!
 *
 *
 *      BSD license (see license.txt)
 */

#ifndef _ADAFRUIT_INA260_H
#define _ADAFRUIT_INA260_H

#include "Arduino.h"
#include <Adafruit_I2CDevice.h>
#include <Adafruit_I2CRegister.h>
#include <Wire.h>

#define INA260_I2CADDR_DEFAULT 0x40 ///< INA260 default i2c address
#define INA260_REG_CONFIG 0x00      ///< Configuration register
#define INA260_REG_CURRENT 0x01 ///< Current measurement register (signed) in
mA
#define INA260_REG_BUSVOLTAGE 0x02 ///< Bus voltage measurement register in
mV
#define INA260_REG_POWER 0x03      ///< Power calculation register in mW
#define INA260_REG_MASK_ENABLE                                             \
  0x06 ///< Interrupt/Alert setting and checking register
#define INA260_REG_ALERT_LIMIT 0x07 ///< Alert limit value register
#define INA260_REG_MFG_UID 0xFE     ///< Manufacturer ID Register
#define INA260_REG_DIE_UID 0xFF     ///< Die ID and Revision Register

/**
 * @brief Mode options.
 *
```

```
 * Allowed values for setMode.
 */
typedef enum _mode {
  INA260_MODE_SHUTDOWN = 0x00,   /**< SHUTDOWN: Minimize quiescient
current and
                              turn off current into the device inputs. Set
                              another mode to exit shutown mode **/
  INA260_MODE_TRIGGERED = 0x03,  /**< TRIGGERED: Trigger a one-shot
measurement
                               of current and bus voltage. Set the TRIGGERED
                               mode again to take a new measurement **/
  INA260_MODE_CONTINUOUS = 0x07, /**< CONTINUOUS: (Default)
Continuously update
                                the current, bus voltage and power
                                registers with new measurements **/
} INA260_MeasurementMode;

/**
 * @brief Conversion Time options.
 *
 * Allowed values for setCurrentConversionTime and setVoltageConversionTime.
 */
typedef enum _conversion_time {
  INA260_TIME_140_us,   ///< Measurement time: 140us
  INA260_TIME_204_us,   ///< Measurement time: 204us
  INA260_TIME_332_us,   ///< Measurement time: 332us
  INA260_TIME_558_us,   ///< Measurement time: 558us
  INA260_TIME_1_1_ms,   ///< Measurement time: 1.1ms (Default)
  INA260_TIME_2_116_ms, ///< Measurement time: 2.116ms
  INA260_TIME_4_156_ms, ///< Measurement time: 4.156ms
  INA260_TIME_8_244_ms, ///< Measurement time: 8.224ms
} INA260_ConversionTime;

/**
 * @brief Averaging Count options.
 *
 * Allowed values forsetAveragingCount.
 */
typedef enum _count {
  INA260_COUNT_1,    ///< Window size: 1 sample (Default)
  INA260_COUNT_4,    ///< Window size: 4 samples
```

```
  INA260_COUNT_16,   ///< Window size: 16 samples
  INA260_COUNT_64,   ///< Window size: 64 samples
  INA260_COUNT_128,  ///< Window size: 128 samples
  INA260_COUNT_256,  ///< Window size: 256 samples
  INA260_COUNT_512,  ///< Window size: 512 samples
  INA260_COUNT_1024, ///< Window size: 1024 samples
} INA260_AveragingCount;

/**
 * @brief Alert trigger options.
 *
 * Allowed values for setAlertType.
 */
typedef enum _alert_type {
  INA260_ALERT_CONVERSION_READY = 0x1, ///< Trigger on conversion ready
  INA260_ALERT_OVERPOWER = 0x2,        ///< Trigger on power over limit
  INA260_ALERT_UNDERVOLTAGE = 0x4,     ///< Trigger on bus voltage under limit
  INA260_ALERT_OVERVOLTAGE = 0x8,      ///< Trigger on bus voltage over limit
  INA260_ALERT_UNDERCURRENT = 0x10,    ///< Trigger on current under limit
  INA260_ALERT_OVERCURRENT = 0x20,     ///< Trigger on current over limit
  INA260_ALERT_NONE = 0x0,             ///< Do not trigger alert pin (Default)
} INA260_AlertType;

/**
 * @brief Alert pin polarity options.
 *
 * Allowed values for setAlertPolarity.
 */
typedef enum _alert_polarity {
  INA260_ALERT_POLARITY_NORMAL = 0x0, ///< Active high open-collector
(Default)
  INA260_ALERT_POLARITY_INVERTED = 0x1, ///< Active low open-collector
} INA260_AlertPolarity;

/**
 * @brief Alert pin latch options.
 *
 * Allowed values for setAlertLatch.
 */
typedef enum _alert_latch {
```

```
  INA260_ALERT_LATCH_ENABLED = 0x1,     /**< Alert will latch until
Mask/Enable
                                register is read **/
  INA260_ALERT_LATCH_TRANSPARENT = 0x0, /**< Alert will reset when fault is
                                cleared **/
} INA260_AlertLatch;

/*!
 *    @brief  Class that stores state and functions for interacting with
 *            INA260 Current and Power Sensor
 */
class Adafruit_INA260 {
public:
  Adafruit_INA260();
  bool begin(uint8_t i2c_addr = INA260_I2CADDR_DEFAULT,
             TwoWire *theWire = &Wire);
  void reset(void);
  float readCurrent(void);
  float readBusVoltage(void);
  float readPower(void);
  void setMode(INA260_MeasurementMode mode);
  INA260_MeasurementMode getMode(void);

  bool conversionReady(void);
  bool alertFunctionFlag(void);

  float getAlertLimit(void);
  void setAlertLimit(float limit);
  INA260_AlertLatch getAlertLatch(void);
  void setAlertLatch(INA260_AlertLatch state);
  INA260_AlertPolarity getAlertPolarity(void);
  void setAlertPolarity(INA260_AlertPolarity polarity);
  INA260_AlertType getAlertType(void);
  void setAlertType(INA260_AlertType alert);

  INA260_ConversionTime getCurrentConversionTime(void);
  void setCurrentConversionTime(INA260_ConversionTime time);
  INA260_ConversionTime getVoltageConversionTime(void);
  void setVoltageConversionTime(INA260_ConversionTime time);
  INA260_AveragingCount getAveragingCount(void);
  void setAveragingCount(INA260_AveragingCount count);
```

```
  Adafruit_I2CRegister *Config, ///< BusIO Register for Config
      *MaskEnable,              ///< BusIO Register for MaskEnable
      *AlertLimit;              ///< BusIO Register for AlertLimit

private:
  Adafruit_I2CDevice *i2c_dev;
};

#endif
```

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## Wind Sensor - Speed (speed.ino)

```
#include <math.h>

#define WindSensorPin (0) // The pin location of the anemometer sensor

volatile unsigned long Rotations; // cup rotation counter used in interrupt routine
volatile unsigned long ContactBounceTime; // Timer to avoid contact bounce in interrupt
routine

float WindSpeed; // speed miles per hour

void setup() {
Serial.begin(9600);

pinMode(WindSensorPin, INPUT);
attachInterrupt(digitalPinToInterrupt(WindSensorPin), isr_rotation, FALLING);

Serial.println("Davis Wind Speed Test");
Serial.println("Rotations\tMPH");
}

void loop() {

Rotations = 0; // Set Rotations count to 0 ready for calculations

sei(); // Enables interrupts
delay (3000); // Wait 3 seconds to average
cli(); // Disable interrupts

// convert to mp/h using the formula V=P(2.25/T)
// V = P(2.25/3) = P * 0.75

WindSpeed = (Rotations * 0.75) + 1;

Serial.print(Rotations); Serial.print("\t\t");
Serial.println(WindSpeed);

}

// This is the function that the interrupt calls to increment the rotation count
void isr_rotation () {
```

```
if ((millis() - ContactBounceTime) > 15 ) { // debounce the switch contact.
Rotations++;
ContactBounceTime = millis();
}

}
```

## Wind Sensor - Direction (direction.ino)

```
int VaneValue;// raw analog value from wind vane
int Direction;// translated 0 - 360 direction
int CalDirection;// converted value with offset applied
int LastValue;

#define Offset 0;

void setup() {
LastValue = 1;
Serial.begin(9600);
Serial.println("Vane Value\tDirection\tHeading");
Serial.println("5");
}

void loop() {
VaneValue = analogRead(A0);


Direction = map(VaneValue, 0, 1023, 0, 360);
CalDirection = Direction + Offset;

if(CalDirection > 360)
CalDirection = CalDirection - 360;

if(CalDirection < 0)
CalDirection = CalDirection + 360;

// Only update the display if change greater than 2 degrees.
if(abs(CalDirection - LastValue) > 5)
{
Serial.print(VaneValue); Serial.print("\t\t");
Serial.print(CalDirection); Serial.print("\t\t");
getHeading(CalDirection);
LastValue = CalDirection;
}
}

// Converts compass direction to heading
void getHeading(int direction) {
if(direction < 22)
```

```
Serial.println("N");
else if (direction < 67)
Serial.println("NE");
else if (direction < 112)
Serial.println("E");
else if (direction < 157)
Serial.println("SE");
else if (direction < 212)
Serial.println("S");
else if (direction < 247)
Serial.println("SW");
else if (direction < 292)
Serial.println("W");
else if (direction < 337)
Serial.println("NW");
else
Serial.println("N");
}
```

## Save As CSV from Arduino – Raspberry Pi

```
import serial
import re
#import time
arduino_port = "/dev/ttyACM1" #serial port of Arduino
baud = 9600 #arduino uno runs at 9600 baud
fileName="analog-data.csv" #name of the CSV file generated
ser = serial.Serial(arduino_port, baud)
print("Connected to Arduino port:" + arduino_port)
file = open(fileName, "a") #appends
print("Created file")
while True:
    getData=str(ser.readline())
    data=getData[0:][:-2]
    data2 = re.findall('\d', data)
    print(data2[0]);
    file = open(fileName, "a")
    file.write(data2[0]) #write data with a newline
```

# Appendix D: Iterative Design

Figure 37 Structure Base Iterative Design shows an alternative mount design for the base of the wind turbine.

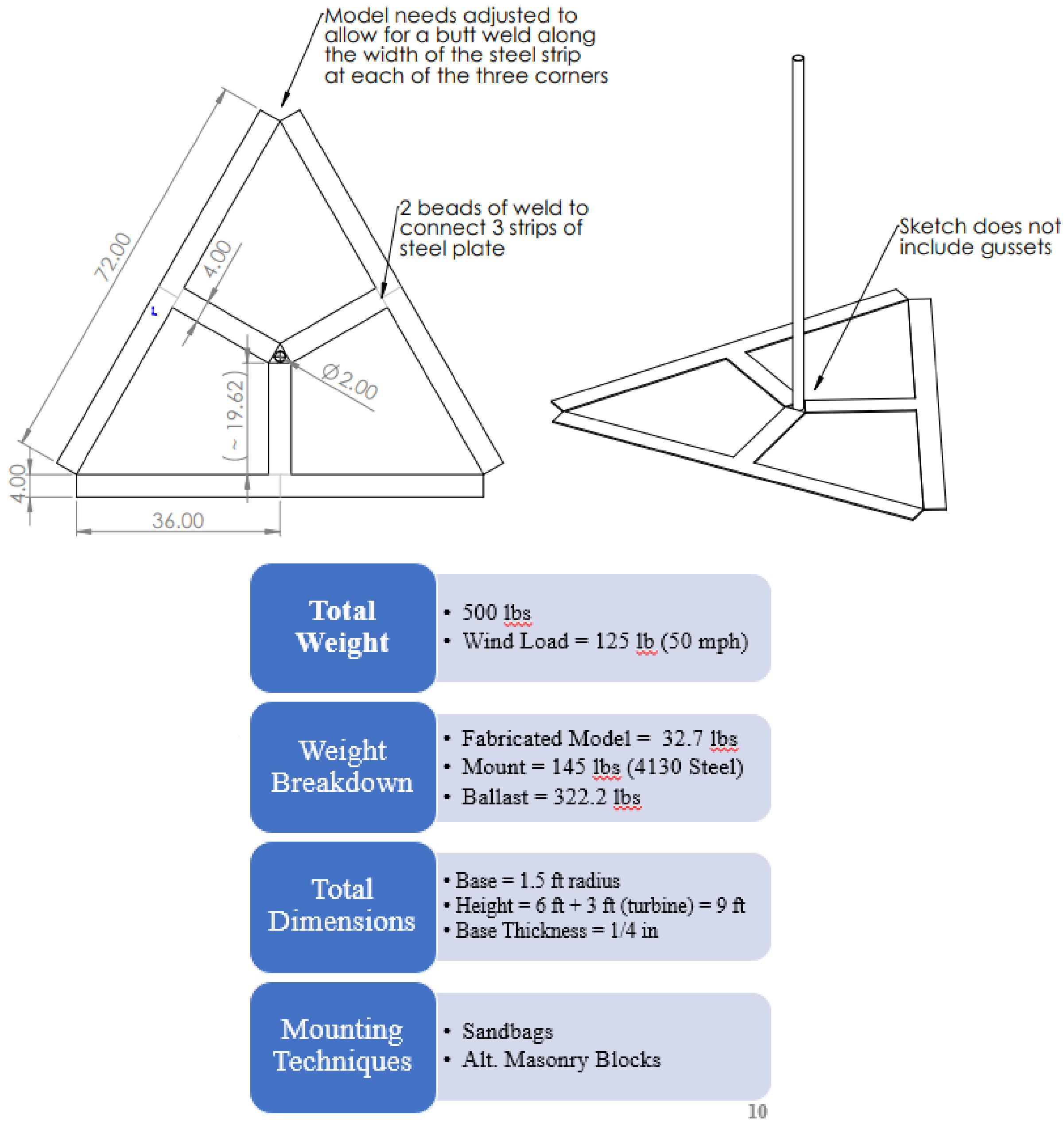



Figure 37 Structure Base Iterative Design

# Appendix E: Manufacturers' Specification

## Wind Turbine by PikolaSolar

| Specification: | |
|---|---|
| Product Name: | MOTORFANSCLUB Wind Turbine Generator |
| Max Power | 5000W |
| Rated Power: | 300 W |
| Rated Voltage: | DC 12V / 24V |
| Cut-in Wind Speed: | 2 m/s |
| Rated Wind Speed: | 12 m/s |
| Safe wind Speed: | ≤45 m/s |
| Net Weigh: | 26.5LB/12KG |
| Wind Wheel Diameter: | 35.4 inches / 0.9 m |
| Wind Wheel High: | 23.6 inches/ 0.6 m |
| Numbers of Blade: | 5 Pieces |
| Material: | Blade made of durable nylon fiber material ; Shell made of aluminum alloy |
| Alternator: | Three-phase AC Permanent Magnet Synchronous Generator |
| Manufacturer Part # | 7225 |

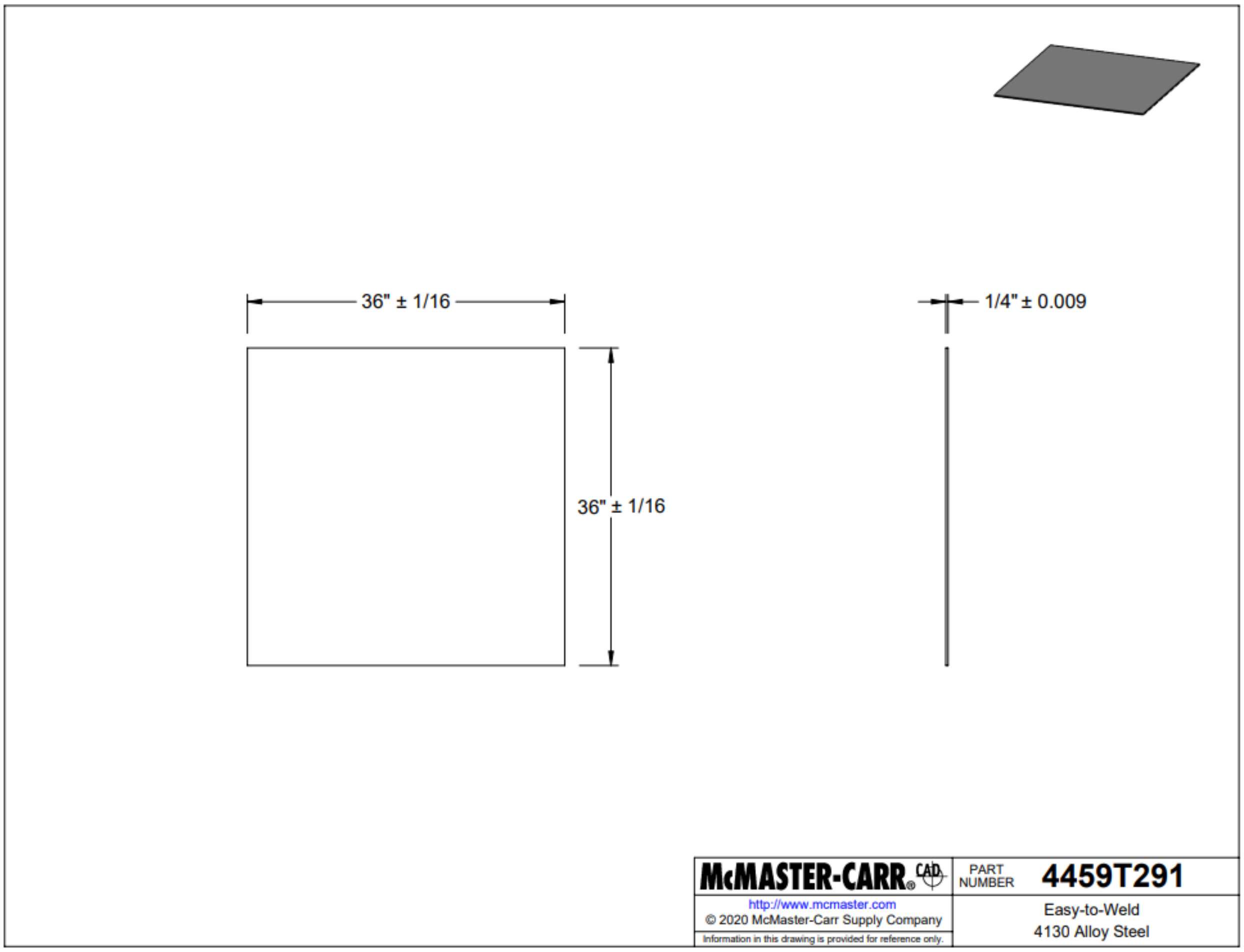
# Battery by PowerStar

- BATTERY TYPE: PS-12350 AGM Rechargeable Deep Cycle Battery with [+ -] terminal. | Leak free, sealed design prevents corrosion. Maintenance Free. No need to add acid.
- PS12-35-D Battery | 12V 35AH 360CCA AGM Gel Sealed Battery | Dimensions: L= 7.7" W= 5.1" H= 6.5"
- Fits and Replaces: PS-12350, D5880, EP33-12, PG-12V35FR, RA12-33, RA12-33EV, SLA1155, SLA1156, and More.
- 100% Compatible OEM replacement for Wheelchairs, Mobility Scooters, Golf Carts, and More.
- If It's Not a PowerStar, It's Just a Battery. | 2 Year Free Replacement Warranty

Specifications

| | |
|---|---|
| Brand | PowerStar |
| Manufacturer Part Number | PS12-35-D |
| Manufacturer | Battery Jack, Inc. |
| Assembled Product Weight | 23 lb |
| Assembled Product Dimensions (L x W x H) | 7.70 x 5.10 x 6.50 Inches |

## 4130 Alloy Steel Plate by McMaster-Carr



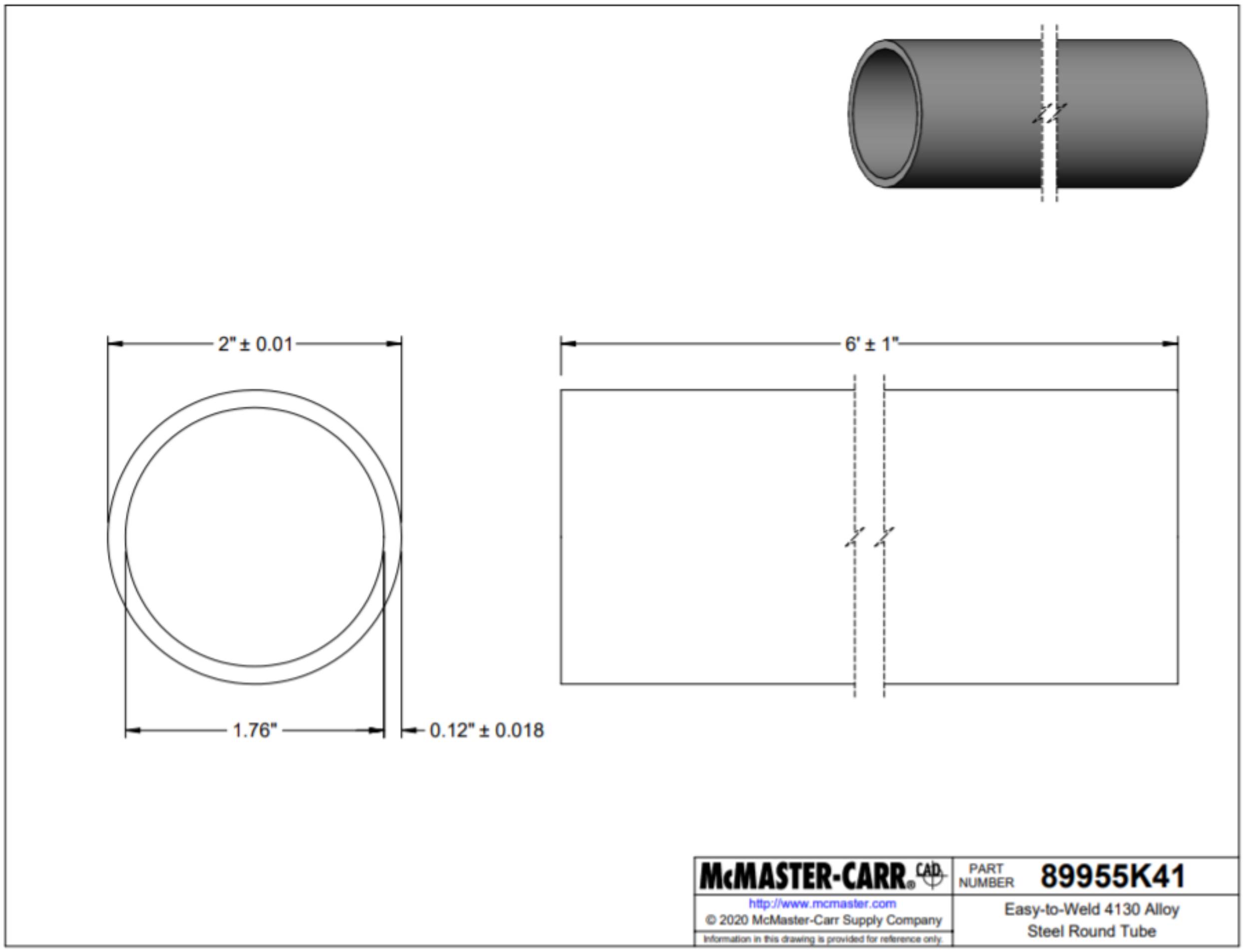

**Green Roof**
1205 Lincoln Dr
Carbondale, IL 62901
greenroof@siu.edu

| | |
|---|---|
| Material | 4130 Alloy Steel |
| Shape | Sheet and Bar |
| Shape Type | Sheets |
| Thickness | 1/4" |
| Thickness Tolerance | -0.009" to 0.009" |
| Tolerance Rating | Standard |
| Width | 36" |
| Width Tolerance | -1/16" to 1/16" |
| Length | 36" |
| Length Tolerance | -1/16" to 1/16" |
| Yield Strength | 50,000 psi |
| Fabrication | Hot Rolled |
| Heat Treatment | Annealed (Softened) |
| Hardness | Rockwell B85 |
| Hardness Rating | Medium |
| Maximum Hardness After Heat Treatment | Rockwell C60 |
| Heat Treatable | Yes |
| Certificate | Material Certificate with Traceable Lot Number |
| Appearance | Plain |
| Temperature Range | Not Rated |
| Specifications Met | SAE AMS6350, SAE AMS6351 |
| Flatness Tolerance | Not Rated |
| Coefficient of Thermal Expansion | $7.6 \times 10^{-6}$ |
| Elongation | 26.5% |

| | |
|---|---|
| Material Composition | |
| Aluminum | 0.039% |
| Carbon | 0.27-0.34% |
| Chromium | 0.80-1.15% |
| Copper | 0-0.25% |
| Hydrogen | 0-2 ppm Max. |
| Manganese | 0.35-0.60% |
| Molybdenum | 0.15-0.25% |
| Nickel | 0-0.25% |
| Niobium | 0.05% Max. |
| Phosphorus | 0.011-0.035% |
| Silicon | 0.15-0.40% |
| Sulfur | 0.002-0.04% |
| Titanium | 0.03% Max. |
| Vanadium | 0-0.035% |
| Iron | Remainder |
| Warning Message | Physical and mechanical properties are not guaranteed. They are intended only as a basis for comparison and not for design purposes. |
| RoHS | RoHS 3 (2015/863/EU) Compliant |
| REACH | REACH (EC 1907/2006) (06/25/2020, 209 SVHC) Compliant |
| DFARS | Specialty Metals Compliant (252.225-7008, 252.225-7009) |
| Country of Origin | United States |
| USMCA Qualifying | No |
| Schedule B | 722599.0002 |
| ECCN | EAR99 |

4130 alloy steel has a low carbon content for good weldability. It's often used for gears, fasteners, and structural applications.

## 4130 Alloy Steel Thin Tube by McMaster-Carr



| | |
|---|---|
| Material | 4130 Alloy Steel |
| Shape | Round Tube |
| Shape Type | Round Tubes |
| Wall Thickness | 0.12" |
| Wall Thickness Tolerance | -0.018" to 0.018" |
| Tolerance Rating | Standard |
| OD | 2" |
| OD Tolerance | -0.010" to 0.010" |
| ID | 1.76" |
| ID Tolerance | Not Rated |
| Yield Strength | 70,000 psi |
| Fabrication | Cold Worked |
| Hardness | Rockwell C20 |
| Hardness Rating | Hard |
| Maximum Hardness After Heat Treatment | Rockwell C49 |
| Heat Treatable | Yes |
| Certificate | Material Certificate with Traceable Lot Number |
| Appearance | Plain |
| Temperature Range | Not Rated |
| Specifications Met | MIL-T-6736B, SAE AMS-T-6736 |
| Straightness Tolerance | 0.030" per 3 ft. |
| Coefficient of Thermal Expansion | $7.6 \times 10^{-6}$ |
| Elongation | 26.5% |

| | |
|---|---|
| Material Composition | |
| Aluminum | 0.039% |
| Carbon | 0.27-0.34% |
| Chromium | 0.80-1.15% |
| Copper | 0-0.25% |
| Hydrogen | 0-2 ppm Max. |
| Manganese | 0.35-0.60% |
| Molybdenum | 0.15-0.25% |
| Nickel | 0-0.25% |
| Niobium | 0.05% Max. |
| Phosphorus | 0.011-0.035% |
| Silicon | 0.15-0.40% |
| Sulfur | 0.002-0.04% |
| Titanium | 0.03% Max. |
| Vanadium | 0-0.035% |
| Iron | Remainder |
| Warning Message | Physical and mechanical properties are not guaranteed. They are intended only as a basis for comparison and not for design purposes. |
| Length Tolerance | Plus |
| Length | 6 ft. |
| RoHS | Not Compliant |
| REACH | Not Compliant |
| DFARS | Specialty Metals COTS-Exempt |
| Country of Origin | Argentina, Australia, Brazil, Canada, France, Germany, India, Israel, Italy, Japan, New Zealand, Poland, Sweden, Taiwan, Ukraine, United Kingdom, or United States |
| USMCA Qualifying | No |
| Schedule B | 730451.0000 |
| ECCN | 9A991 |