Renewable Energy Lab Weather Station

By:

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Project Description

The goal of this project is to make a weather station for the RE Lab at NAU that will last for years. This station will provide accurate and current measurements for various weather conditions and will be accessible from anywhere with an internet connection.

Measure:

- Temperature
- Humidity
- Wind Speed
- Wind Direction
- Barometric Pressure
- Solar Irradiance

Purpose:

For academic use within the Wind Power and Renewable Energy courses. Weather stations are important for weather forecasts, disaster preparedness, and agricultural information.

Figure 1: Example Weather Station

Design Requirements

Customer Requirements:

- Measurement of Key Weather Parameters - Station will measure temperature, humidity, wind speed and direction, barometric pressure and solar irradiance.
- Data Transmission - Data collected will be transmitted via internet
- Remote Data Access - Live and stored data should be accessible through a web interface
- Renewable Power Supply - Any components which require power must run on solar energy
- Weather Durability - Station must withstand outdoor weather conditions
- Low Maintenance - Station should require less than 2 hours of maintenance per year
- User Friendly - User interface should be easily navigable
- Ease of Installation - Installation should require minimal tools or training
- Low Cost - Station should be cost effective and within budget
- Safety Compliance - Must comply with relevant electrical and operational safety standards
- Data Storage - Data should be stored in an accessible and organized database for at least one year.

Engineering requirements:

- Long Term Data Storage - Database should log data in an organized manner over the course of 4 years
- Increased Data Accuracy - Sensor readings should be highly accurate, within 3% or less. Data average calculations should be properly computed
- Multiple Wind Speed Readings - Wind speed and direction should be measured at both standard height and atop existing tower at lab providing at least 2 readings.
- Measured at Industry Standards - Sensors should be properly positioned according to industry standards
- Proper Calibration - Sensors should be properly calibrated to upload accurate data from raw readings within 3% of true values
- Measurement of All Data Types - Station should record 6 data types including temperature, pressure, humidity, solar irradiation, wind speed and wind direction.
- Low Power Requirement - Station should be capable of fully operating under existing solar generated power means located at lab, with a target of 0.2 kWh per day or less.

System QFD

Project: RE Weather Station QFD
Date: 6/16/2025

#	Technical Requirement	1	2	3	4	5	6
1	Long Term Data Storage						
2	Increased Data Accuracy	1					
3	Multiple Windspeed Readings	1	3				
4	Measured at Industry Standards	1	9	9			
5	Proper Callibration	3	9	3	9		
6	Temp, Pressure, Humidity, Wind spd/dir, Solar Irradiance	3	9	3	9	9	
7	Low Power Requirement	3	1	1	1	1	9

Legend

A	KFLG	
B	Tempest	
C	Davis Vantage	

#	Customer Needs	Customer Weights	Technical Requirements: Long Term Data Storage	Increased Data Accuracy	Multiple Windspeed Readings	Measured at Industry Standards	Proper Callibration	Temp, Pressure, Humidity, Wind spd/dir, Solar Irr	Low Power Requirement	Customer Opinion Survey: 1 Poor	2	3 Acceptable	4	5 Excellent
1	Data Transmission	5	9	1	3			9	9			A	B	C
2	Data Storage	3	9	1	1	1		9	3		AB		C	
3	Weather Durability	5	1				3		1		B	A		C
4	Safety Compliance	5	3				1	3	3			C	B	A
5	Low Maintenance	3	3	1	3	1	9	3	1			A	BC	
6	Low Cost	3	1	3	3	3	1	9	3		A	C		B
7	User Friendly	3	9	1	1		9	3					ABC	
8	Easy Installation	3			9	1	9	3	1		A		C	B
9	Remote Data Access	5	9	1	1			1					B	AC
10	Measurement of Weather Parameters	5	3	1	3	3	9	9	9				B	AC
11	Renewable Power Supply	5	1					3	9	B		A	C	
	Technical Requirement Units		years	%	Readings	N/A	%	Readings	kWh					
	Technical Requirement Targets		4	3	2	N/A		5	0.2					
	Absolute Technical Importance		82	98	75	12	1223	80	8					
	Relative Technical Importance		4	5	1	3	6	7	2					

Figure 2: QFD

Benchmarking

1. Flagstaff Pulliam Airport (KFLG)
    a. This is an airport weather station in Flagstaff. It provides multi-day forecasts.
    b. Automated Surface Observing System (ASOS)

Humidity
Wind Speed
Barometric Pressure
Dewpoint
Visibility
Heat Index
Last Updated Time

There is also an easy-to-access 7 day history on the website.

This displays temperature, dewpoint, and humidity in a graph, as well as much more information in table form below.

Benchmarking

2. Tempest Home Weather Station

Personal home weather station which broadcasts to a phone app. Features an auto-calibration self-learning system.

Measurements:

- Air Temperature
- Relative Humidity
- Wind Chill
- Barometric Pressure
- Wind Speed and Direction
- Lightning Activity
- Rain Intensity and Duration
- UV Index and Solar Radiation

Cost- $350

Key Features:

- Custom weather alerts through Tempest Home app
- 10 day forecast
- Requires WiFi Connection

Figure 3: Tempest Home Weather Station

Benchmarking

3.Davis Vantage Pro2 is a high-end professional weather station launched by Davis Instruments in the United States. It is widely used in agriculture, scientific research, universities and meteorological stations.

Its main features include:

Sensor integration: integrated with temperature, humidity, wind speed, wind direction, air pressure, rainfall and other sensors.

Wireless transmission: supports 900 MHz or 2.4 GHz wireless communication, up to 300 meters.

Solar power supply system: with solar panels and backup batteries, suitable for long-term deployment in the field.

Strong scalability: users can choose modules such as ultraviolet light and light intensity.

Structural design:

The module adopts a tower installation structure, and the anemometer is installed on the top to minimize interference. The overall shell is made of ABS material, which is waterproof and anti-aging. All parts can be quickly disassembled for easy maintenance and transportation.

Figure 4: Davis Vantage Pro2

Literature Review

[1] *Setra Systems, Inc, "Barometric Pressure Sensors | Setra Systems," Setra.com, 2025. https://www.setra.com/product/pressure/barometric (accessed Jun. 18, 2025).* This source is a storefront for barometric pressure sensors. For the purpose of our project, this has been used to help determine some benchmarks for the pressure sensor specifically. It displays 5 different models and compares them to one another using the criteria of pressure fittings, electrical terminations, output, media compatibility, thermal effect, compensated temperature range, operating temperature, accuracy FS, ranges in PSI, sensing technology, and sample applications. This will become more useful to us as we begin to tinker with our provided barometric pressure sensor. This website also explained some of the basics of barometric pressure sensors, which was useful in determining exactly why this sensor is important.

[2] *N. US Department of Commerce, "Standards and Policy," www.weather.gov. https://www.weather.gov/coop/standards.* This is a government-run website which has a number of useful resources. The one used for this project was NWSI 10-1302: Requirements and Standards for NWS Climate Observations. This document discusses the site and exposure standards of weather stations, as well as more specific air temperature measurement standards and precipitation measurement standards. It also discusses soil temperature measurement standards and pan evaporation measurement standards, although that is not useful information for this project. This is where we learned that thermometers must be able to measure between –20 degrees Fahrenheit and 115 degrees Fahrenheit, and that precipitation measurements must be able to reach 20 inches. The discussion of each sensors' standards has informed our decision making throughout our design process.

[3] *World Meteorological Organization, Guide to meteorological instruments and methods of observation., Volume 1. Geneva, Switzerland: World Meteorological Organization, 2008.* This is my most important source so far. Each chapter in this book explains a different measurement and its standards. Each chapter discusses different sensors and tools to measure each weather feature. It goes in-depth on everything from standards to calibration. I have already utilized chapters one through seven. These are, in order: General, Measurement of Temperature, Measurement of Atmospheric Pressure, Measurement of Humidity, Measurement of Surface Wind, Measurement of Precipitation, and Measurement of Radiation. This is a vital source that will continue to contribute to our understanding and development of the weather station.

[4] *ISO-CAL, "What is a Pyranometer? 10 Important Points to Consider.," isocalnorthamerica.com, Jan. 16, 2023. https://isocalnorthamerica.com/what-is-a-pyranometer/* This website was used to better understand pyranometers. It discussed what exactly solar irradiance is and what it is used for, which are things like climatology and solar power generation. It described that they measure both diffuse and direct sunlight to record the amount of solar energy reaching a surface per unit area.. It also briefly mentions the two common types of pyranometers as well as the importance of calibration. It does not discuss directly how to calibrate, as they are trying to sell their calibration services. This source has allowed us to understand pyranometers in simpler terms than discussed in the book mentioned above.

[5] *C. Gittins, "Considering the energy consumption of a Raspberry Pi," IOT Insider, Sep. 23, 2024. https://www.iotinsider.com/news/considering-the-energy-consumption-of-a-raspberry-pi/* This website was used to help determine how much power consumption our weather station will have overall. This was used in my first mathematical modelling exercise, which will be discussed in section 3.3 of this report. This website said that a Raspberry Pi will typically use 5W with normal load.

[6] *NiuBol, "How much power does a weather station use?," Niubol.com, 2024. https://www.niubol.com/Product-knowledge/How-much-power-does-a-weather-station-use.html.* This website was also used to complete my mathematical modeling calculations. Here, they talked about how much power weather measuring sensors use typically. It was very low, as each sensor is expected to only use .3W each hour. NiuBol is itself a company that sells weather stations, but it was a useful source for calculation and comparison nonetheless.

[7] *US, "National Weather Service," Weather.gov, 2025. https://forecast.weather.gov/MapClick.php?lat=35.19814000000002&lon=-111.65112499999998 (accessed Jun. 18, 2025).* I used this source as my benchmark weather station. The weather station I am choosing to be the benchmark is the Flagstaff Pulliam Airport weather station. This weather station will act as a benchmark for both our website design and each sensors' accuracy. We will compare our readings to theirs, in the hopes of the readings being similar. This benchmark was already discussed above in section 3.1.

[8] *J. Portilla, "Python Bootcamps: Learn Python Programming and Code Training," Udemy, 2019. https://nau.udemy.com/course/complete-python-bootcamp (accessed Jun. 22, 2025).* I used this Udemy course to teach me Python. I have no coding experience in Python and needed to start from the beginning. I have continued to use this source as a means to learn how to code and will continue to do so. This project will require a great amount of coding, so this is a vital resource for me.

[9] *Raspberry Pi, "Build Your Own Weather Station," Raspberrypi.org, 2017. https://projects.raspberrypi.org/en/projects/build-your-own-weather-station/0 (accessed Jun. 27, 2025).* The Raspberry Pi website has been very helpful in the design aspect of this project so far. This website discusses how to make a weather station out of a specific kit that Raspberry Pi sells. We will be using this as an outline for our own coding in the project, as it discusses the entire set up of a weather station from start to finish. We will not be copying it, as we do not have the kit that was used.

[10] *Raspberry Pi, "Raspberry Pi Documentation - Getting Started," www.raspberrypi.com. https://www.raspberrypi.com/documentation/computers/getting-started.html (accessed Jun. 27, 2025).* I used this website to help me understand how to access and use a Raspberry Pi. When I tried to access the provided device, it unfortunately had a password on it. Luckily, this website discusses a number of workarounds, including a full reset or just replacing the SD card within it.

[11] *Raspberry Pi, "Raspberry Pi OS," Raspberry Pi, 2025. https://www.raspberrypi.com/software/ (accessed Jun. 27, 2025).* To actually activate the Raspberry Pi after replacing or wiping the SD card, we would need to upload the Raspberry Pi operating system. This website discusses how to do so as well as providing the operating system download and documentation. This will be used to fully access the Pi.

[38] *Shilleh, "Beginner Tutorial: How to Connect Raspberry Pi and BME280 for Pressure, Temperature, and Humidity," YouTube, Nov. 20, 2023. https://www.youtube.com/watch?v=T7L7WMHbhY0 (accessed Jul. 30, 2025).* This resource is a YouTube video which clearly outlined how to connect the BME280 sensor that we purchased for our prototyping to the Raspberry Pi. It outlines both the connections physically and the code needed to get it to function. I used this in conjunction with source [8] and source [9] to complete the second prototype. Without this resource, we would not have had a functional prototype.

[39] *DwyerOmega, "Modular Weather Monitoring and Data Storage Stations," Dwyeromega.com, 2015. https://www.dwyeromega.com/en-us/modular-weather-monitoring-and-data-storage-stations/p/WMS-25-Series?srsltid=AfmBOopea9LGqjBDOoZJngG3fUaw1xYvItpGe5olf4VLMBsv2Ow8Cz9z# (accessed Jul. 15, 2025).* This source was used in my mathematical modelling of the storage requirements for our project. Specifically, this was used to be a benchmark and validation for how much storage our station would eventually use. The station outlined in this source was also using an SD card for their storage solution.

[40] *P. Keheley, "How Many Pages In A Gigabyte? A Litigator's Guide," www.digitalwarroom.com, 2020. https://www.digitalwarroom.com/blog/how-many-pages-in-a-gigabyte (accessed Jul. 15, 2025).* I used this website to assist in my calculations for our storage estimate. This provided me with the conversion information between different levels of bytes. It also discussed exactly what size a byte is. A singular byte, according to this source is equivalent to one character

Literature Review

[3] World Meteorological Organization, Guide to meteorological instruments and methods of observation., Volume 1. Geneva, Switzerland: World Meteorological Organization, 2008. This resource has been shared between several members of our group as it contains a ton of vital information for our project. I primarily utilized this resource to find and understand the industry standards for weather measurement across all types of sensors we will be utilizing. Additionally, it outlines the various subtypes of each of these sensors and their strengths and weaknesses. This source provided me with the equation for a specific thermometer output calculation shown below in section 3.3.

[12] "Tempest Weather Station," Tempest, 2024. https://shop.tempest.earth/products/tempest msclkid=1236cca887f915b3bbd3a4f8024b2f08&utm_source=bing&utm_medium=cpc&utm_campaign=Bing-Search-B2C-NB-Broad US&utm_term=home%20weather%20station&utm_content=Weather%20Station (accessed Jun. 18, 2025). This source is the purchase page for the Tempest Home Weather Station; one of our benchmarks mentioned previously. It was used to understand the features and components of the weather station. It also includes customer reviews which were helpful in validating the product's performance.

[13] A. Overton, "A Guide to the Siting, Exposure and Calibration of Automatic Weather Stations for Synoptic and Climatological Observations," 2009. Accessed: May 01, 2024. [Online]. Available: https://www.rmets.org/sites/default/files/2019-02/aws-guide.pdf This source is a published paper from a member of the Royal Meteorological Society which outlines the calibration and long-term considerations of various weather sensors. It served as a cross-reference to other calibration research as well as a guide to the potential obstacles to maintaining accurate readings over a long period of time. It also contains a lot of information on data archiving that may be useful to us down the line.

[14] Wisconsin DNR, "Calibration & barometric pressure | | Wisconsin DNR," dnr.wisconsin.gov. https://dnr.wisconsin.gov/topic/labCert/BODCalibration2.html This website from the Wisconsin Department of Natural Resources discusses barometric pressure and the variations in readings based on environmental and elevation factors. Since most pressure data will be corrected to altitude, it is important to understand this process when comparing our readings to nearby stations and when calibrating our database.

[15] R. Coquilla, J. Obermeier, and B. White, "American Wind Energy Association," 2007. Accessed: May 16, 2023. [Online]. Available: https://research.engineering.ucdavis.edu/wind/wp-content/uploads/sites/17/2014/03/AWEA-2007-Final-Paper.pdf This research paper was published by graduate students from University of California, Davis. It highlights uncertainty factors when calibrating an anemometer and the various roots of uncertainty that may arise and how to calculate them. It also contains test data from an anemometer calculation performed in a wind tunnel. This was an important resource for our understanding of anemometer calibration and a guideline for my uncertainty calculation self-learning assignment.

[16] "Login - CAS – Central Authentication Service," Udemy.com, 2025. Available: https://nau.udemy.com/course/statistics-intro/learn/lecture/35671972#overview. [Accessed: Jun. 25, 2025] This Udemy course was my primary self-learning resource when refreshing myself of statistics and how uncertainty arises and can be calculated. Not all sections were utilized, just sections three, four, eight, and ten. These gave me an important baseline understanding of statistical processes to help me build a MATLAB program to calculate uncertainty in an anemometer reading.

[17] EngineerItProgram, "Experimental Uncertainty," YouTube, Mar. 18, 2013. Available: https://www.youtube.com/watch?v=xJBta_HWTRc. [Accessed: Jun. 26, 2025] This YouTube video paired with the Udemy course gives me more specific information on how engineers calculate and handle uncertainty in their designs and experiments. This contributed to my self-learning assignment and will help us handle the inevitable uncertainty that will arise in our data down the line.

[18] RDS, Ed., "Certificate for Calibration of Cup Anemometer," SOH Wind Engineering LLC, 141 Leroy Rd - Williston, VT 05495 USA, Jun. 2021. Accessed: Jul. 26, 2025. [Online]. Available: https://www.nrgsystems.com/support/product-support/technical-product-sheets/technical-product-sheet-40 This certificate is a specific calibration test report for the anemometer we own. It was found in the NRG database using the serial number found on the box. It contains useful testing information and calibration constants that we will need for our Raspberry Pi code to produce accurate wind data.

[19] "Certificate of Calibration," NRG Systems, 110 Riggs Rd - Hinesburg, VT 05461 USA, Jun. 2021. Accessed: Jul. 26, 2025. [Online]. Available: https://www.nrgsystems.com/support/product-support/instruction-sheets/nrg-bp60-barometric-pressure-sensor-instructions This source is the calibration certificate for our barometric pressure sensor. It was found in the NRG database using the serial number on the box label. It contains the calibration constants we will need for the Raspberry Pi code to produce accurate pressure data.

[20] J. Calandra, "Certificate of Calibration," ESSCO Calibration Laboratory, 27 Industrial Ave Unit #9 - Chelmsford, MA 01824 - 3618 USA, Jul. 2021. Accessed: Jul. 26, 2025. [Online]. Available: https://www.nrgsystems.com/products/met-sensors/detail/nrg-t60-temperature-sensor This source is the calibration certificate for our temperature sensor. It was found in the NRG database using the serial number on the box label for the sensor. It contains calibration constants that will be needed for the Raspberry Pi code to produce accurate temperature data.

[21] J. Brooks, "Certificate of Calibration for LI-COR Sensor," LI-COR, 4647 Superior Street - Lincoln, NE 68504 USA, Jun. 2020. Accessed: Jul. 28, 2025. [Online]. Available: https://www.licor.com/products/light/pyranometer This source is a calibration certificate for one of our pyranometers. It was found on the LI-COR website database using the serial number found on the box of the sensor. While we own a more precise pyranometer that will likely be used over this one, it is still important to have the calibration information for this sensor as a backup.

[22] E. Instruments, "Pyranometer EKO MS-60/MS-60S - Instruction Manual Ver. 8," EKO INSTRUMENTS CO., LTD, 111 North Market Street, Suite 300 San Jose, CA 95113 USA, Oct. 2023. Accessed: Aug. 04, 2025. [Online]. Available: https://eko-instruments.com/us/product/ms-60-pyranometer/ This source is the instruction manual for our better pyranometer, since I was unable to locate the calibration certificate. It will help to better understand the sensor and to make a decision on which pyranometer will be used in the final design. If we decide to use this sensor, the calibration certificate will need to be located using information from this manual.

Literature Review

[30] "Printed humidity sensors," Encyclopedia.pub. https://encyclopedia.pub/entry/7493.
This entry provides an overview of the three main types of humidity sensors: capacitive, resistive, and printed. It is particularly useful for distinguishing between their operating principles and basic applications. This resource helped me understand which sensors are best for long-term environmental monitoring. For example, capacitive sensors are known for their balance of accuracy, durability, and response time, making them a prime candidate for our station design.

[31] "Review of Printed Humidity Sensors," MDPI Sensors. https://www.mdpi.com/2079-4991/13/6/1110
This scientific paper provides a detailed technical comparison of printed humidity sensors, including their fabrication methods and sensing mechanisms. While we do not intend to use printed sensors in our designs, this paper provides an important benchmark for understanding cost-benefit trade-offs and short-term use advantages. This is particularly useful in concept evaluation and comparison with resistive and capacitive types.

[32] "Capacitive vs Resistive Humidity Sensors," Encyclopedia.pub. – https://encyclopedia.pub/entry/7493 This section specifically focuses on the comparison of capacitive and resistive sensors. It explains in detail how capacitive sensors work by detecting changes in dielectric constant, while resistive sensors work by tracking changes in the resistance of hygroscopic materials. I used this source when calculating relative humidity using a capacitance-based formula that assumes the sensor follows linear dielectric behavior.

[33] BOMS Review – Comparison of sensing layers – https://www.ias.ac.in/article/fulltext/boms/045/0238
This resource discusses the materials used in humidity sensor construction and how they affect response time and accuracy. It is very useful when considering calibration strategies, as drift of these materials over time can affect long-term performance. It also validates our decision to consider sensor replacement cycles in our final deployment plan.

[34] "Humidity and Dew Point," National Weather Service. https://www.weather.gov/media/epz/wxcalc/dewpoint_rh.htm
This government-hosted calculator tool is used to model relative humidity and dew point based on temperature and RH data. I referenced it to validate my sensor output calculations. It also provides insight into how the sensor interprets the environmental data into meaningful weather measurements.

[35] Ma, H. et al., "Graphene-Based Humidity Sensors," arXiv. https://arxiv.org/abs/2410.02255
This paper introduces a new class of printed humidity sensors using graphene. While still in the research phase, it demonstrates future directions for ultra-sensitive and flexible sensors, which could potentially enhance smart wearables or high-resolution atmospheric monitoring. I use this to contextualize the current sensor options we are evaluating with options that may become viable in future iterations of our space station.

[36] NOAA Sensor Siting Standards – https://www.weather.gov/coop/standards
The official guide outlines the proper installation protocol for humidity sensors, including height (1.25-2 m above the ground), shielding from direct sunlight, and location relative to vegetation.

[37] WMO Guide to Meteorological Instruments – https://library.wmo.int/index.php?lvl=notice_display&id=12407
This is where I learned about long-term stability, calibration requirements, and acceptable error ranges for humidity sensors. I specifically used its advice to ensure accurate RH data in my automated weather system.

[38] Bosch Sensortec. (n.d.). BME280 Datasheet. Retrieved from https://www.bosch-sensortec.com/products/environmental-sensors/humidity-sensors-bme280/

[39] NRG Systems. (n.d.). #40C Anemometer Product Manual. Retrieved from https://www.nrgsystems.com/

[40] NRG Systems. (n.d.). BP60C Barometer, T60C Thermometer, LI-COR LI200R & EKO MS-60 Pyranometers Specifications. Retrieved from manufacturer data sheets.

[41] Adafruit. (n.d.). BME280 Python Library. Retrieved from https://github.com/adafruit/Adafruit_Python_BME280

[42] Python Software Foundation. (n.d.). Python Requests Library Documentation. Retrieved from https://docs.python-requests.org/

[43] SQLite. (n.d.). SQLite Documentation. Retrieved from https://sqlite.org/

Literature Review

[23] National Instruments, “NI DAQ Sensor Calibration Guide,” *National Instruments*, 2021. Accessed: May 10, 2024. [Online]. Available: https://www.ni.com/en-us/innovations/sensor-calibration.html
This technical guide outlines procedures and best practices for calibrating sensors in data acquisition systems, especially using microcontrollers like the NI USB DAQ or Raspberry Pi. It helped us understand calibration drift and recommended frequency of recalibration.

[24] Adafruit Industries, “How to Connect Weather Sensors to Raspberry Pi,” *Adafruit Learning System*, 2022. Accessed: Apr. 25, 2024. [Online]. Available: https://learn.adafruit.com/pi-weather-station/overview
This online tutorial provides hardware wiring diagrams and Python libraries for interfacing weather sensors (e.g., DHT22, BMP180) with Raspberry Pi boards. It guided us through the sensor setup and initial data acquisition stages.

[25] M. A. Islam and R. Haque, “IoT-Based Real-Time Weather Monitoring System Using Raspberry Pi,” in *Proc. Int. Conf. on IoT and Applications*, 2020, pp. 44–49.
This conference paper presents a complete prototype for an IoT weather station using a Raspberry Pi and discusses methods for storing and visualizing long-term weather data. It helped validate our design choices and inspired our data storage approach.

[26] S. Pandey et al., “Analysis of Weather Monitoring Systems Using Cloud Integration,” *Journal of Sensor Networks and Data Communication*, vol. 10, no. 2, pp. 100–105, 2021.
This paper focuses on integrating weather stations with cloud platforms (like AWS and ThingSpeak). It supported our decision to use online dashboards for data visualization and remote monitoring.

[27] Ambient Weather, “Installation Guide for Ambient Weather WS-5000,” *Ambient Weather*, 2023. Accessed: May 15, 2024. [Online]. Available: https://ambientweather.com/ws5000manual
This commercial user manual describes sensor placement, calibration, and protective enclosure requirements for outdoor weather stations. It informed our decisions on shielding and mounting components against wind and precipitation.

[28] Texas Instruments, *“Thermal Design Considerations for Enclosures,”* Application Report SPRA953, 2009. Accessed: July 14, 2025. [Online]. Available: https://www.ti.com/lit/an/spra953/spra953.pdf
This technical application note discusses how enclosure material, surface color, and exposure to solar radiation can significantly influence internal temperatures in outdoor devices. It emphasizes the importance of minimizing heat absorption and suggests design strategies such as reflective coatings and sunshades. This resource guided our material and surface treatment decisions for the weather station housing to reduce passive solar heating.

[29] IPC, *“Standard for Determining Current-Carrying Capacity in Printed Board Design (IPC-2152),”* IPC, 2009. Accessed: July 14, 2025. [Online]. Available: https://www.ipc.org/TOC/IPCT-2152.pdf
This industry-standard document outlines methods to estimate internal temperature rise of electronic systems based on their power consumption and thermal environment. It highlights how enclosure design and airflow affect component longevity and performance. We used this reference to assess internal heating risks in our weather station and to support decisions regarding ventilation and spatial layout of sensors and the processor board.

Calculation Summary

Calculations				
Team Member	Focus	Result	ER	Validation
Ian Torp	Power	.0174 kwh/day	<0.2 kwh	NiuBol website
Rowan McCullough	Thermometer	$t = -\frac{A}{2B} + \frac{A}{2B}\sqrt{1 - \frac{4B}{A^2}\left(1 - \frac{R}{R_0}\right)}$	Calibration	IEC 60751
Chenxi Dong	Humidity	$RH = \frac{216-180}{250-180} \times 100 = \frac{36}{70} \times 100 = 51.4\%$	Calibration	Manufacturer
Shutong Wang	Heating	ΔT=P * R_θJA, Q_solar =G*A*α	Safety	Same product, measurement
Ian Torp	Storage	At least 9 years	4 years	Checked against similar products
Rowan McCullough	Anemometer Uncertainty	Within 3 %	Accuracy	Using random data
Chenxi Dong	Humidity Uncertainty	±2.51% RH	Accuracy	Simulation using model
Shutong Wang	Wind direction	225，100.02，34.56	Accuracy	Simulation using model
Ian Torp	Prototype Function	N/A (coding)	Fucntionality	Prototype
Rowan McCullough	Sensor Calibration Functions	Linear Relationships specific to S/N	Calibration	Certificates of Calibration
Chenxi Dong	Sensor life calculation	$\frac{60}{30} \times 60 \times 24 \times 365 = 1051200\ samples/year$	Maintenance	Manufacturer
Shutong Wang	Thermal Durability Analysis	Qsolar =α·G·A，Q _loss =hA(T−T a)+εσA(T^ 4−T a^4)	safety	Same product, measurement

Table 1: Calculation Summary

Functional Decomposition

The system function diagram outlines the weather station's workflow, organizing it into essential components: sensing, power supply, signal conversion, data processing, transmission, and enclosure. It visualizes how environmental input triggers sensor readings, which are digitized, processed by a Raspberry Pi, and sent to remote servers. The diagram highlights key interactions between modules, identifies technical needs like timestamping, ADC integration, and energy regulation, and reinforces a modular architecture to support reliable operation, remote updates, and component replacement.

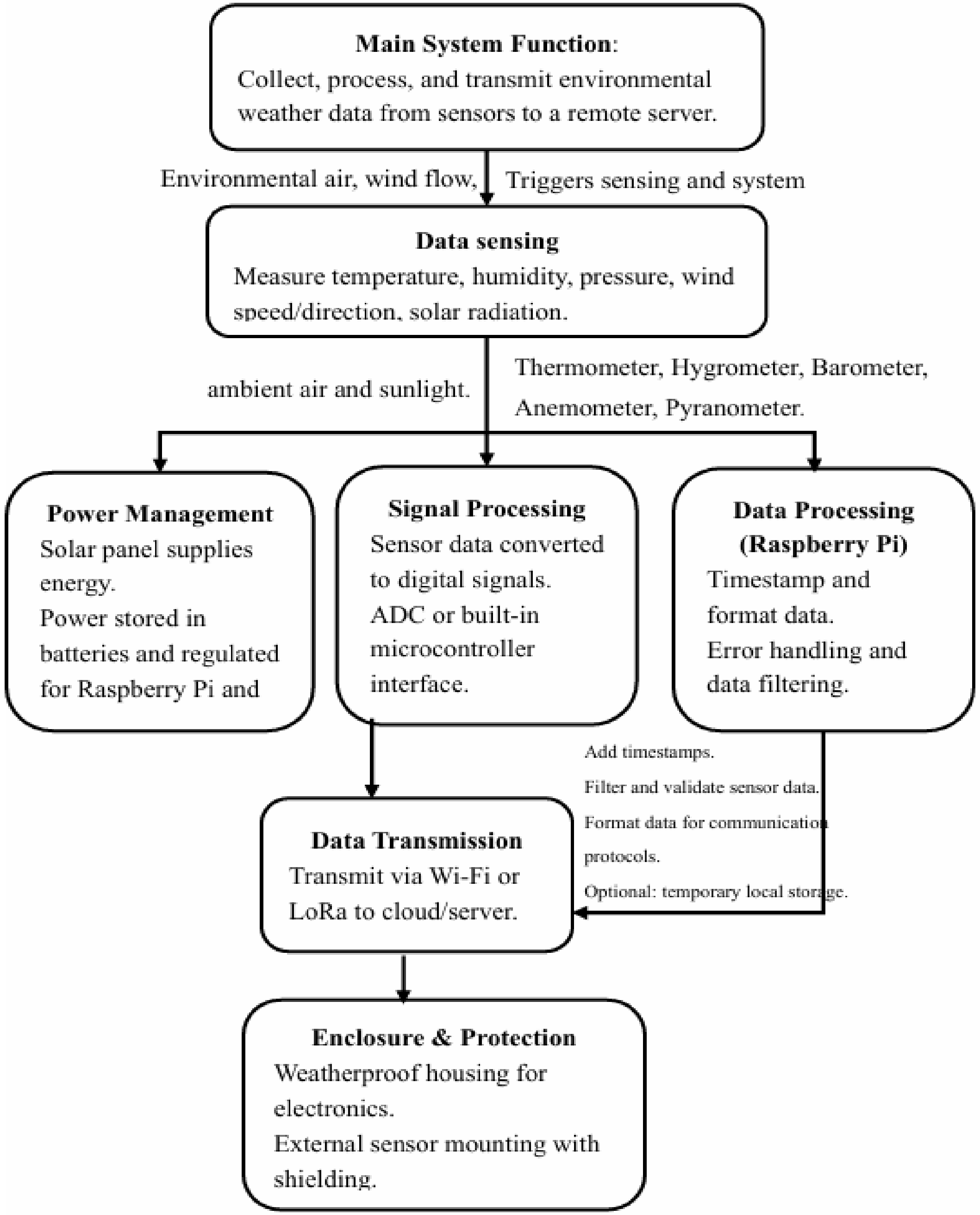


Figure 5: Functional Decomposition

Concept Generation

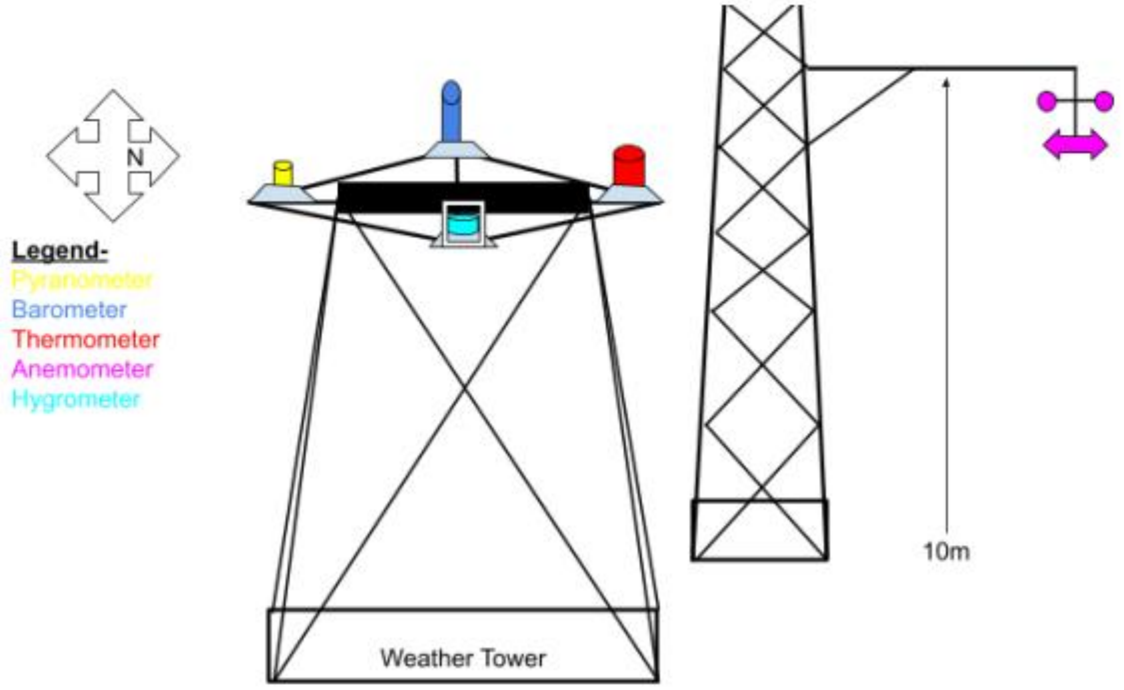


Figure 6: Structural Concept 1

Structural Design - DATUM

Pros:

- Stability
- Adherence to industry standards
- Low cost
- Durable

Cons:

- Crossbar must be built
- Boom installation may be difficult
- Potential safety hazard

Pseudocode Design – Design 3

Rolling 10-minute average updated every minute on website as live data.

Hourly buffer saved in Raspberry Pi and averaged for database upload.

Pros:

- Access to accurate, live data
- Low storage requirement
- Easy to implement

Cons:

- Less precise database
- High sensor reading frequency
- Low data backup

Concept Generation

Structure – Design 1

Pros:

- Modular structure allows for easy replacement and calibration
- Cable built-in aesthetically pleasing weatherproof
- Easy to maintain

Cons:

- Many things need to be built
- Insufficient height may affect some sensors
- Lightweight design, wind resistance rating may be lower.

Pseudocode Design – Design 1

Core Logic:

- Sampling is done every 10 minutes, and humidity data is added with abnormal judgment
- All data is first saved locally and then uploaded individually by sensor
- Clear cache and generate running reports daily

Pros:

- Automatically reduce frequency in a stable environment to save energy
- Outlier Identification Improves Accuracy
- Offline caching ensures data is not lost

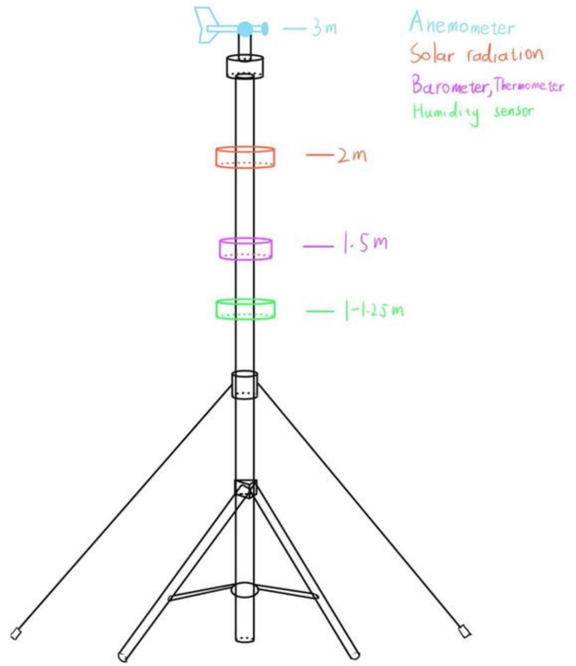


Figure 7: Structural Concept 2

Cons:

- Additional code needs to be written to monitor data changes
- Raspberry Pi handles rising pressure
- Increasing the sampling interval may cause the real-time performance of data to decrease

Concept Generation

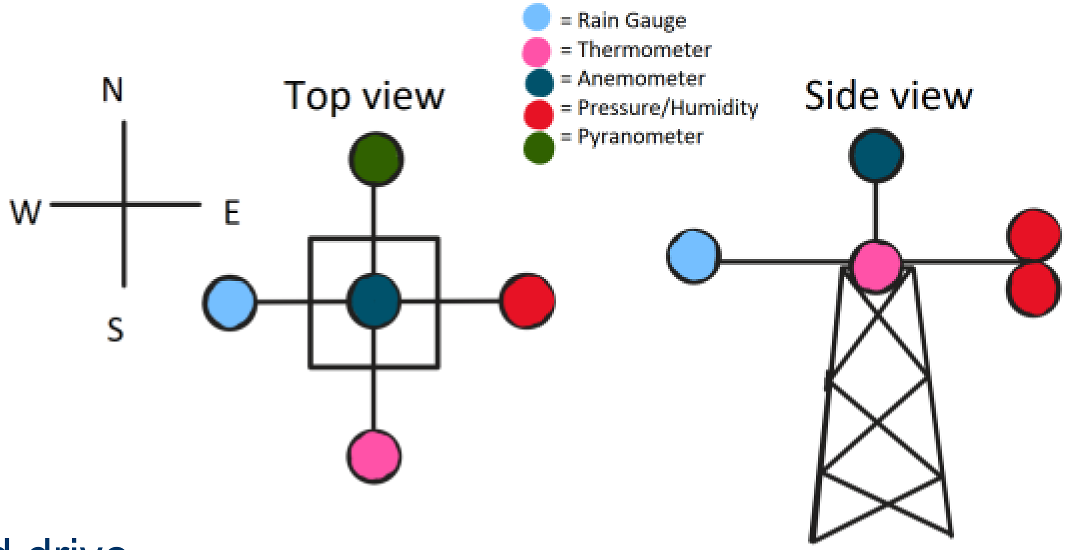


Figure 8: Structural Concept 3

Structure – Design 3

- Pros
  - All on one body
  - Easy maintenance
  - Most Standards met
- Cons
  - Anemometer not at standard
  - Flimsy connection points
  - Must build mounting hardware

Storage - DATUM
2 TB external hard drive

- Pros
  - Massive storage
- Cons
  - Extra expense
  - More power consumption
  - Bigger footprint

Pseudocode – DATUM
5 minutes upload, no extra code for power consumption or storage capacity.

- Pros
  - Simple
  - Low power
- Cons
  - Lots of data collected
  - Very frequent uploads, high bandwidth

Concept Generation

A compact weather station built on a tripod with a vertical mast. All sensors—including anemometer, wind vane, thermometer, hygrometer, barometer, and solar panel—are mounted centrally. Temperature, humidity, and pressure sensors are housed in a white louvered Stevenson screen to reduce solar interference.

Pros:

- Small footprint
- Fast deployment
- Centralized power and data routing

Cons:

- Anemometer height below 10-meter industry standard
- May reduce wind data accuracy

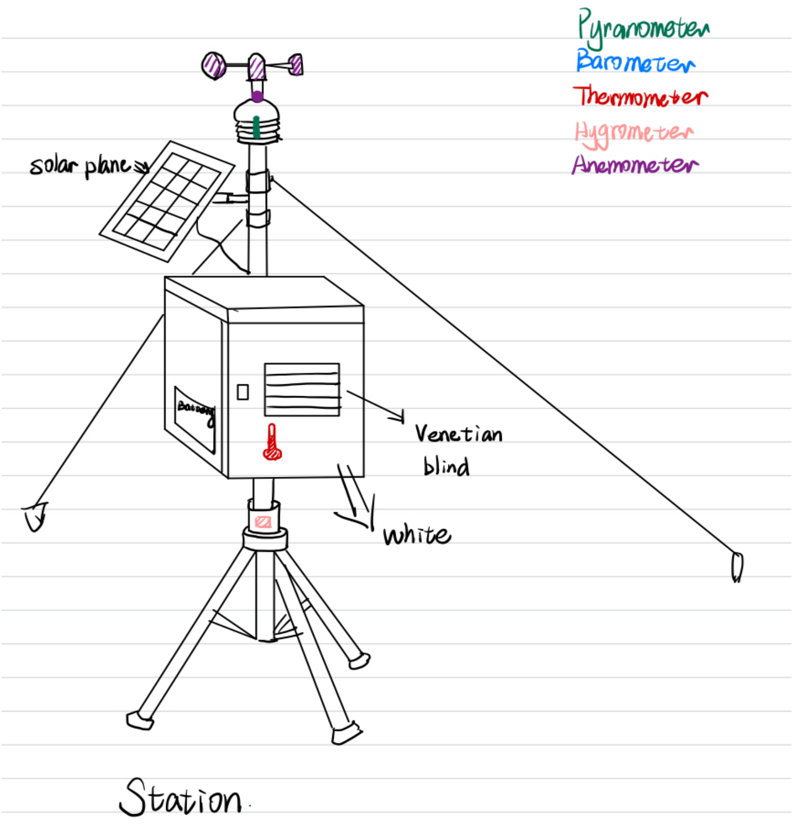


Figure 9: Structural Concept 4

Pseudocode:

- Load data from CSV
- Clean and convert timestamps
- Filter: temperature (–50°C to 60°C), pressure (800–1100 hPa)
- Keep only last 24 hours
- Plot and save temperature and pressure charts

Pros:

- Clear data filtering and validation
- Easy to use and implement
- Quick visualization of recent data

Cons:

- No live streaming or database upload
- Only visual output, no backups
- Supports temperature and pressure only

Specification Table

Specification:	DATUM	Design 1 (Chenxi)	Design 2 (Shutong)	Design 3 (Ian)
Anemometer at 10m	Y	N	N	N
Sunlight exposure for pressure, solar irr, temperature sensor	Y	N	N	Y
Pressure, solar irr, humidity sensors at 6-10ft	Y	N	N	Y
No sunlight for humidity sensor	Y	Y	Y	Y
No wind currents for barometer	Y	N	N	Y
Thermometer at least 100m from extensive concrete	N	N	N	N
Thermometer at 4-6ft	N	Y	Y	N
40ft from obstructions	N	N	N	N

Table 2: Specification Table

Pugh Chart

Structural:

- DATUM and Design 1 (by team tiebreaker vote) move on to decision matrix

Pseudocode:

- Design 1 and Design 3 move on to decision matrix

Pugh Chart

Criteria	DATUM (Rowan)	Design 1 (Chenxi)	Design 2 (Shutong)	Design 3 (Ian)
Weather Durability	0	-1	1	-1
Safety Compliance	0	1	1	0
Low Maintenance	0	0	-1	0
Easy Installation	0	0	-1	0
Multiple Windspeed Readings	0	0	0	0
Measured at Industry Standards	0	-1	-1	-1
	Totals	-1	-1	-2
	Rank	2	2	4

Table 3: Structural Concept Pugh Chart

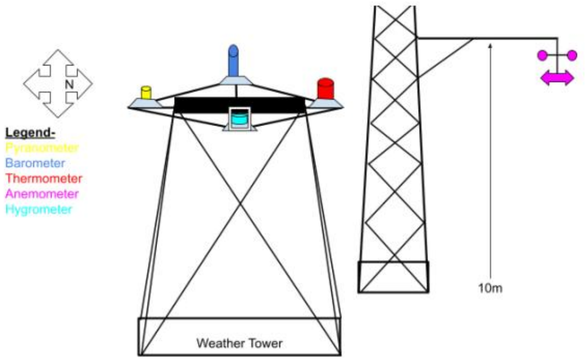
Pugh Chart

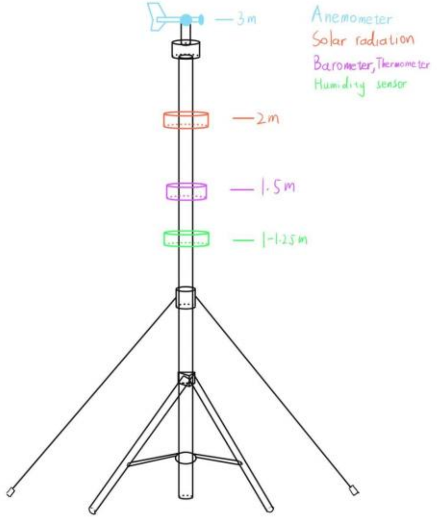
Criteria	DATUM (Ian)	Design 1 (Chenxi)	Design 2 (Shutong)	Design 3 (Rowan)
Long Term Data Storage	0	0	-1	1
Increased Data Accuracy	0	1	0	0
Remote Data Access	0	0	1	1
User Friendly	0	-1	0	0
Low Power Requirement	0	1	-1	0
Data Transmission	0	0	1	0
	Totals	1	0	2
	Rank	2	3	1

Table 4: Pseudocode Concept Pugh Chart

Decision Matrix - Structure

- Criteria weights and unweighted scores determined through team discussion.
- Winning design was the DATUM with a weighted score of 79.5 out of 100.





		Design DATUM (Rowan)		Design 1 (Chenxi)	
Criteria	Weights	Unweighted Score	Weighted Score	Unweighted Score	Weighted Score
Weather Durability	0.2	75	15	75	15
Safety Compliance	0.1	90	9	100	10
Low Maintenance	0.2	90	18	70	14
Easy Installation	0.15	50	7.5	30	4.5
Multiple Windspeed Readings	0.1	100	10	100	10
Measured At Industry Standards	0.25	80	20	60	15
Sum	1	485	79.5	435	68.5

Table 5: Decision Matrix for Structure Designs

Decision Matrix - Pseudocode

- Criteria weights and unweighted scores determined through team discussion.
- Design 3 scored highest with an 81.25 out of 100, however Design 1 was only 1.5 behind and may be referenced later.

		Dynamic sensor reading frequency based on data stability		Rolling 10-min average w/ hourly database upload	
		Design 1 (Chenxi)		Design 3 (Rowan)	
Criteria	Weights	Unweighted Score	Weighted Score	Unweighted Score	Weighted Score
Long Term Data Storage	0.25	75	18.75	85	21.25
Increased Data Accuracy	0.25	90	22.5	70	17.5
Remote Data Access	0.25	80	20	90	22.5
User Friendly	0.1	60	6	75	7.5
Low Power Requirement	0.1	80	8	80	8
Data Transmission	0.05	90	4.5	90	4.5
Sum	1	475	79.75	490	81.25

Table 6: Decision Matrix for Pseudocode Designs

Selected Design - Pseudocode

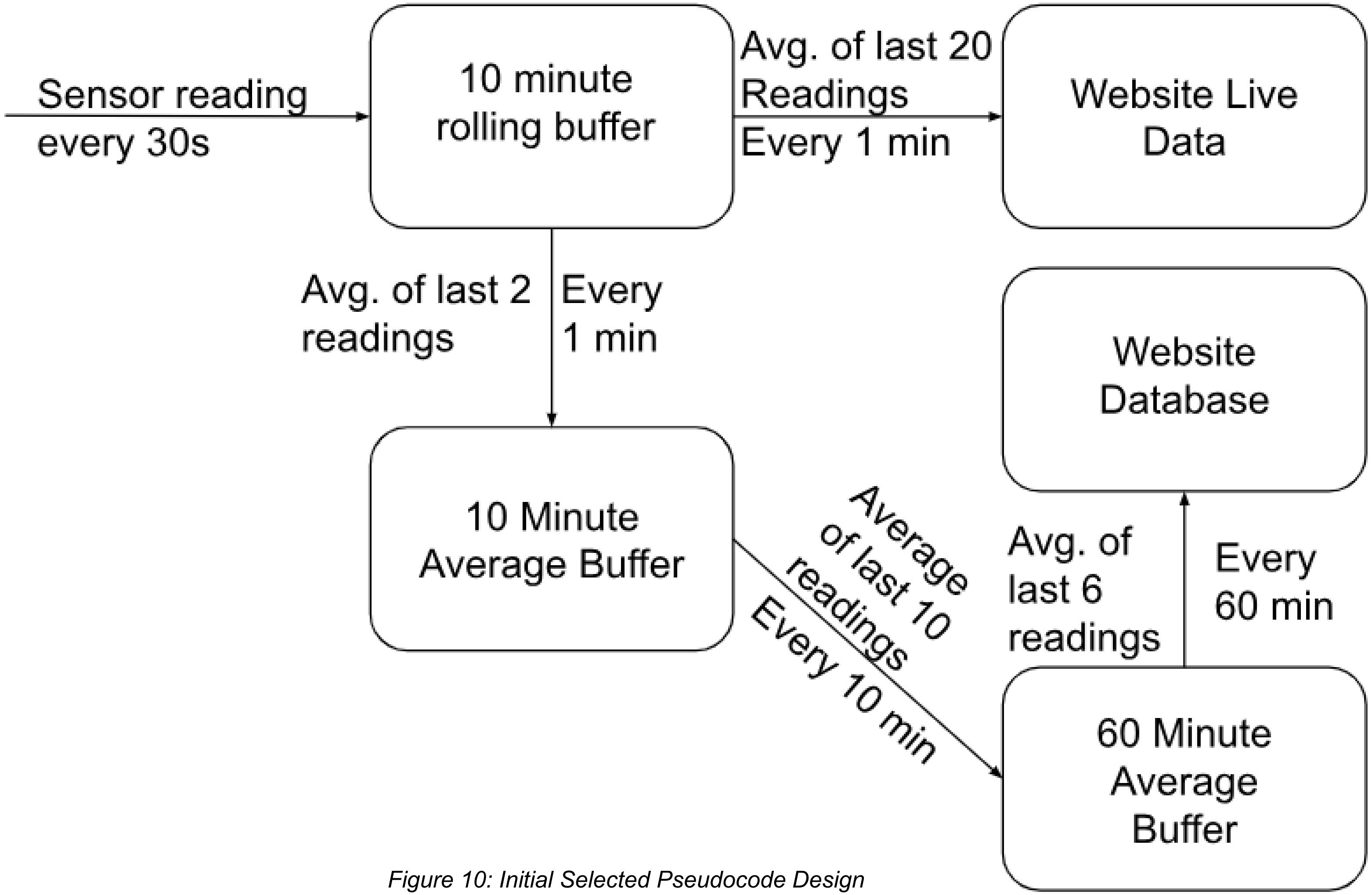


Figure 10: Initial Selected Pseudocode Design

Initial CAD

On the right are the top view and the overall view of our weather station. Our sensors will be deployed on the top of the tower, as shown in the Structure Design. The different colors in the picture represent different sensors.

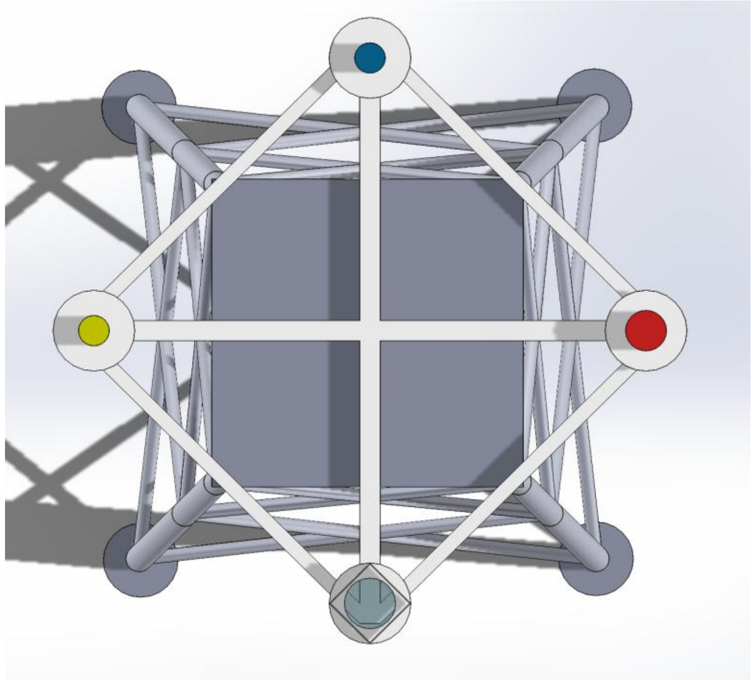


Figure 11: Crossbar Initial CAD Model

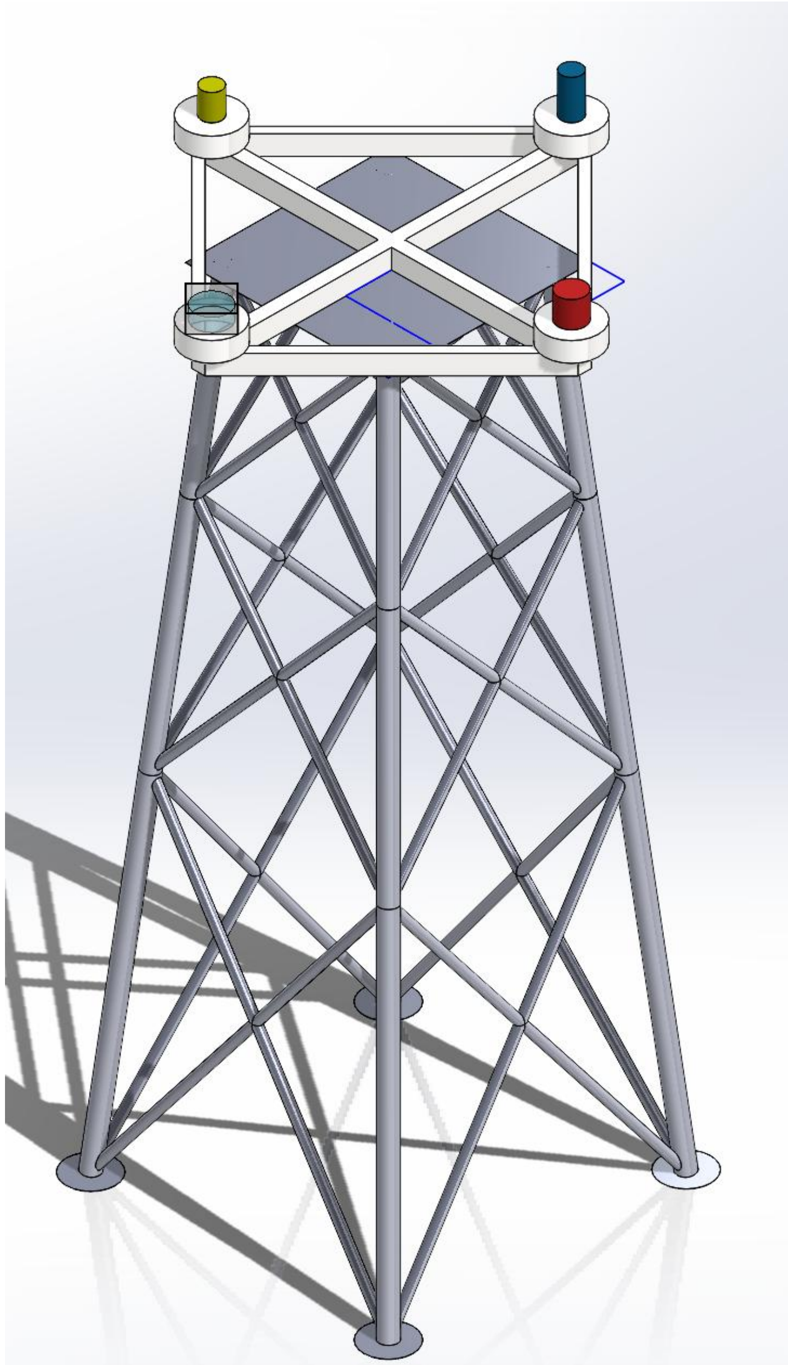


Figure 12:Initial CAD Model

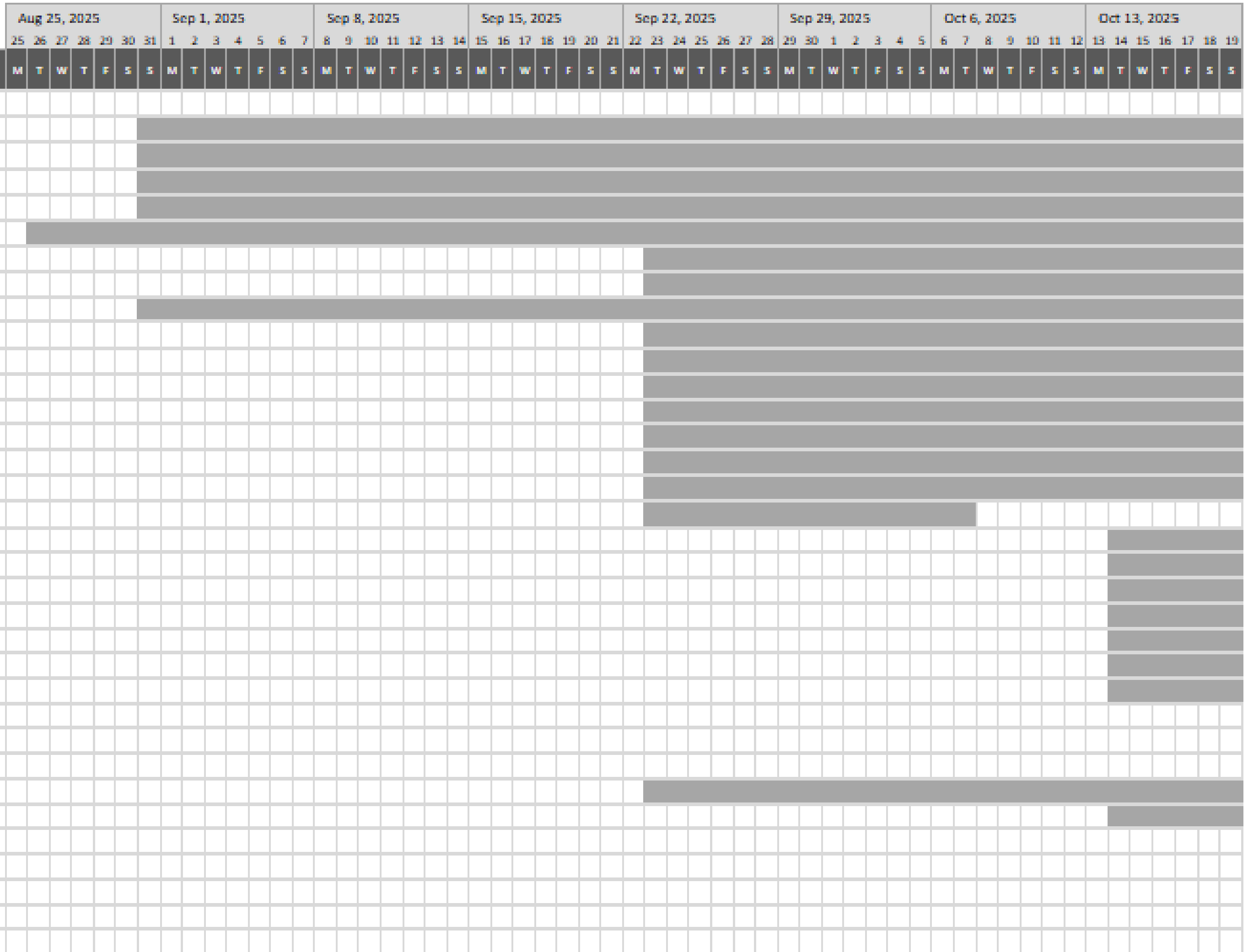
Gantt Chart

Weather Station

NAU Capstone

Project Start:	Tue, 8/26/2025
Today:	Sun, 11/16/2025
Display Week:	1

TASK	ASSIGNED TO	PROGRESS	START	END
FINAL				
Sensor connection and code	Ian	100%	8/31/25	11/16/25
Gantt Chart	Shutong	100%	8/31/25	11/16/25
Material purchase, order and assembly	Ian&Rowan	100%	8/31/25	11/16/25
Website Updates	Chenxi&Shutong	95%	8/31/25	11/16/25
Modification and improvement of CAD part	Chenxi	100%	8/26/25	11/4/25
Testing (Anemometer)	Rowan	50%	9/23/25	11/17/25
Testing (BME280)	Rowan	50%	9/23/25	11/17/25
Final PPT	Everyone	100%	8/31/25	11/16/25
Programming (Wind Vane)	Ian	100%	9/23/25	11/4/25
Physical Connection (Wind Vane)	Ian	100%	9/23/25	11/4/25
Programming (Pressure Sensor)	Chenxi	100%	9/23/25	11/4/25
Physical Connection (Pressure Sensor)	Shutong	100%	9/23/25	11/16/25
Testing (Pyranometer)	Rowan	50%	9/23/25	11/17/25
Testing (Wind Vane)	Rowan	100%	9/23/25	11/17/25
CAD	Chenxi	100%	9/23/25	11/18/25
Website Check #1	Chenxi&Shutong	100%	9/23/25	10/7/25
Programming (Thermometer)	Chenxi	100%	10/14/25	11/4/25
Connection (Thermometer)	Shutong	100%	10/14/25	11/4/25
Programming (Pyranometer)	Ian	100%	10/14/25	11/4/25
Connection (Pyranometer)	Ian	100%	10/14/25	11/4/25
Mounting	Rowan	95%	10/14/25	11/17/25
Testing (Thermometer)	Rowan	50%	10/14/25	11/17/25
Testing (Pressure Sensor)	Rowan	50%	10/14/25	11/17/25
Final Poster	Everyone	100%	10/30/25	11/16/25
Future				
Efest Registration	Ian	100%	10/21/25	10/21/25
Finalized Testing plan	Rowan	100%	9/23/25	10/31/25
Final CAD	Chenxi	100%	10/14/25	11/16/25
Product Demo/Final Testing	Rowan	50%	11/6/25	11/18/25
Final Report	Everyone	0%	11/6/25	11/28/25
Client Handoff	Everyone	0%	11/20/25	11/28/25
Final Website check	Everyone	0%	11/20/25	11/28/25
Efest	Everyone	0%	12/5/25	12/5/25



Budget

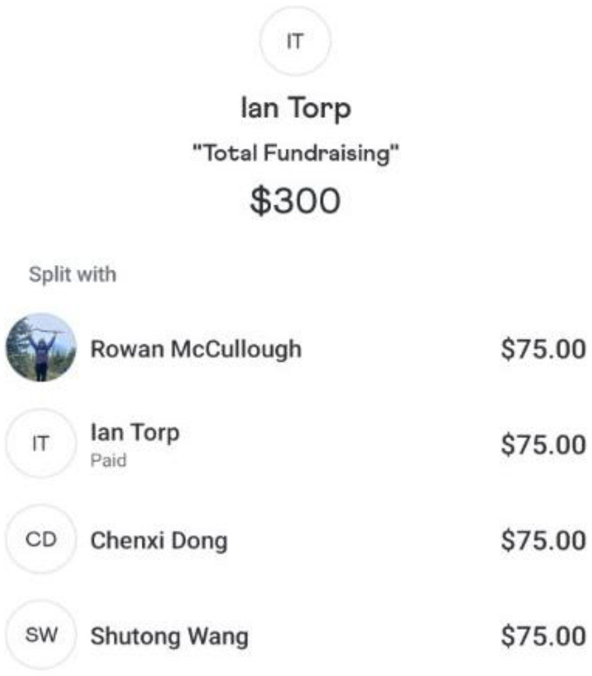


Figure 13: Fundraising from the Team

$250.41 Remaining

Client Funding Support: $500

Item	Total Cost:	Remaining Budget
Crossbar Aluminum	67.38	432.62
Hardware	14.19	418.43
Monitor	37.42	381.01
EKO Converter Cable	104.2	276.81
Replacement Raspberry PI	85.42	191.39
Home Depot Miscellaneous Items	53.96	137.43
Indoor Electrical Box	40.02	97.41
	Remaining Budget:	$97.41

Table 8: Client Funding

Total Spending Budget: $800

Total Remaining: $347.82

Bill Of Materials

Material	Quantity	Cost	Part Status	Make/Buy	Primary vender	Manufacturer	Lead Time	Link to Product
Onn MicroSD card 32gig	1	6.96	Arrived	Buy	Walmart	Onn	Same Day	https://www.wal
MCP3008 Analog to Digital Converter	2	15.3	Arrived	Buy	Amazon	Bridgold	Two Day	https://www.am
BME280 Sensor	2	14.1	Arrived	Buy	Amazon	Qoroos	Next Day	https://www.am
Model MS60 Pyranometer	1	3100	In house	Preowned	NRG	EKO	N/A	https://eko-instr
T60C Temperature NRG Sensor	1		In house	Preowned	NRG	NRG	N/A	https://www.nrg
Wind Vane NRG #200P	1		In house	Preowned	NRG	NRG	N/A	https://www.car
NRG #40C Anemometer	1		In house	Preowned	NRG	NRG	N/A	https://www.nrg
NRG BP60 Barometric Pressure Sensor	1		In house	Preowned	NRG	NRG	N/A	https://www.nrg
Raspberry Pi 3 model B+	1	35	In house	Preowned	Mouser	Raspberry Pi	N/A	https://www.mo
Wire/cabling	1	22c/ft	In house	Preowned	Home Depot	Syston	N/A	https://www.hor
3/4 emc tubing	18	N/A	In house	Preowned	N/A	N/A	N/A	N/A
36/1/(1/16) Angle Gage Aluminum	4	34.32	Arrived	Buy	Home Depot	Everbilt	Same Day	https://www.hor
1.5/36/(1/8) Flat Bar Aluminum	2	27.28	Arrived	Buy	Home Depot	Everbilt	Same Day	https://www.hor
2' Boom Mount	2	N/A	In house	Preowned	N/A	N/A	N/A	N/A
Voltage Amplifier (AD620)	1	13.23	Arrived	Buy	Amazon	Midzooparts	6-10 Day	https://www.am
Mounting Hardware	4	14.19	Arrived	Buy	Home Depot	Everbilt	Same Day	https://www.hor
EKO Converter Cable	1	104.2	Arrived	Replace	EKO	EKO	4-6 Day	https://eko-instr
Monitor	1	37.42	Arrived	Buy	NAU Surplus	Dell	Same Day	N/A
Backup Raspberry PI 4B	1	85.42	Arrived	Buy	ADA Fruit	Sony	4-6 Day	https://www.ada
Steel Fish Tape	1	29.97	Arrived	Buy	Home Depot	Klein Tools	Same Day	https://www.hor
UV Resistant Zip Ties	40	12.58	Arrived	Buy	Home Depot	CE	Same Day	https://www.hor
Hose Clamps	6	14.79	Arrived	Buy	Home Depot	SS	Same Day	https://www.hor
8x8x4 Electrical Enclosure Box	1	40.02	Arrived	Buy	Home Depot	Southwire	Same Day	Southwire 8 in. \
	Total Cost:	3487.42	100% ordered					
			100% Arrived					

Table 9: Bill of Materials

FMEA

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
Breadboard	Disconnection	Loss of connection	Outside Interference (Human)	35	Secure Connections
Sensors Wired Connection	Disconnection	Loss of connection	Outside Interference (Weather)	14	Secure Connections
PI Wire Connection	Disconnection, Electrical overload	Loss of connection, fried pins	Outside Interference (Human)	16	Secure Connections, no direct connections
Analog to Digital Converter	Disconnection	Loss of analog sensor data	Outside interference, product failure	14	Secure Connections
BME 280 Sensor	Disconnection	Loss of humidity data	Outside interference, product failure	12	Secure Connections, Housing
40C Anemometer	Disconnection	Loss of Windspeed data	Outside Interference, product failure	12	Secure Connections
T60C Temp. Sensor	Disconnection, snow buildup	Loss of temperature data	Outside Interference, Weather	18	Secure Connections, Housing
BP60C Barometer	Disconnection, snow buildup	Loss of pressure data	Outside Interference, Weather	18	Secure Connections, Housing
MS-60 Pyranometer	Disconnection, snow buildup	Loss of solar irradiance data	Outside Interference, Weather	36	Secure connections, Mounting
PI Data Conversion	Coding issue	Invalid data	Bug in coding, unrecognized input data	20	Extensive Code Testing
PI Data Upload	Loss of Internet	Missing data	Internet down, LAN connection failure	16	Database Check, Wired Connection
Truss Supports	Fatigue Failure	Broken Sensors	Poor mounting or durability	9	Secure mounting, strong material

Table 10: FMEA

Prototype

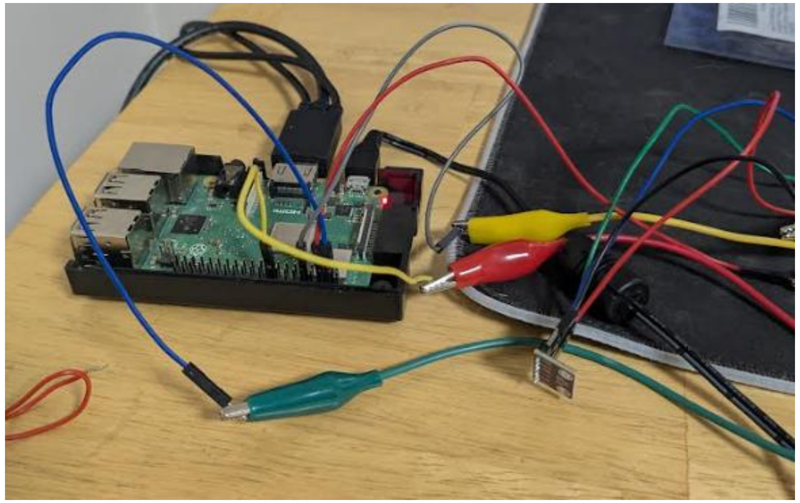


Figure 14: First Successful Sensor Connection

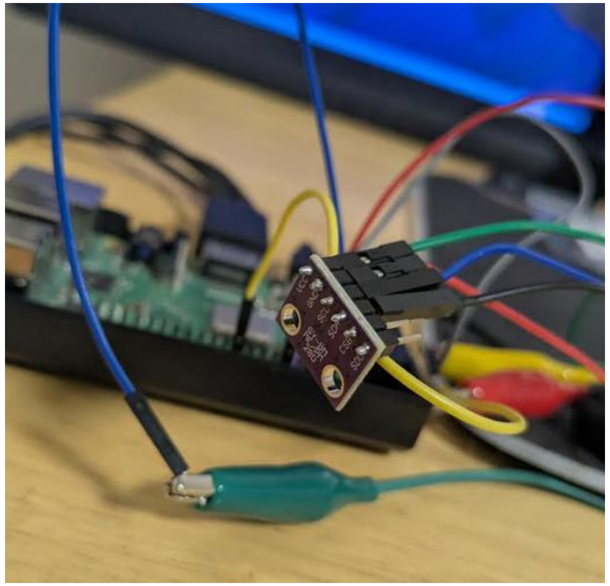


Figure 15: BME280 Humidity Sensor

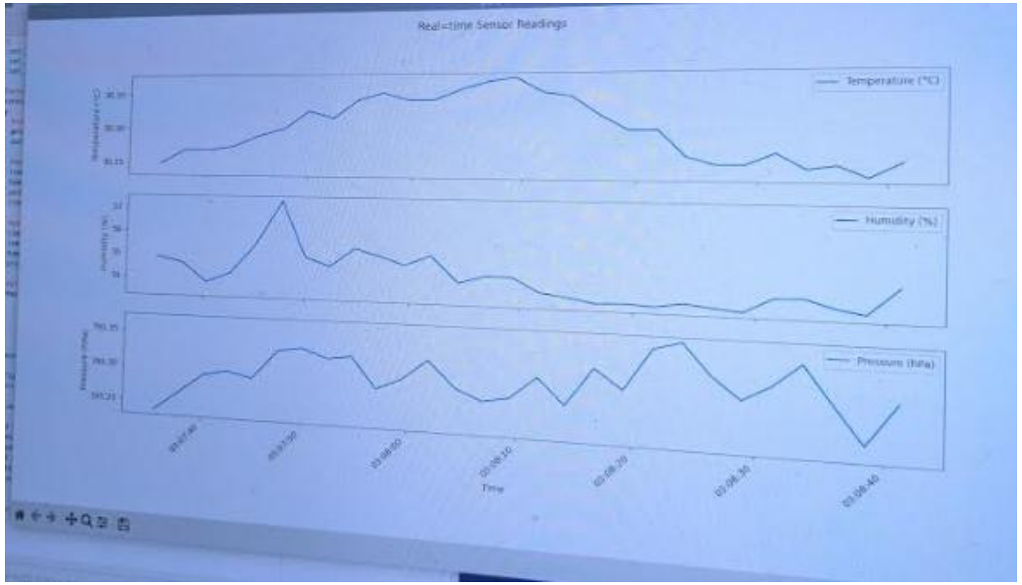


Figure 16: Readings from Prototype, Temperature, Humidity, and Pressure

Final CAD – Weather Tower

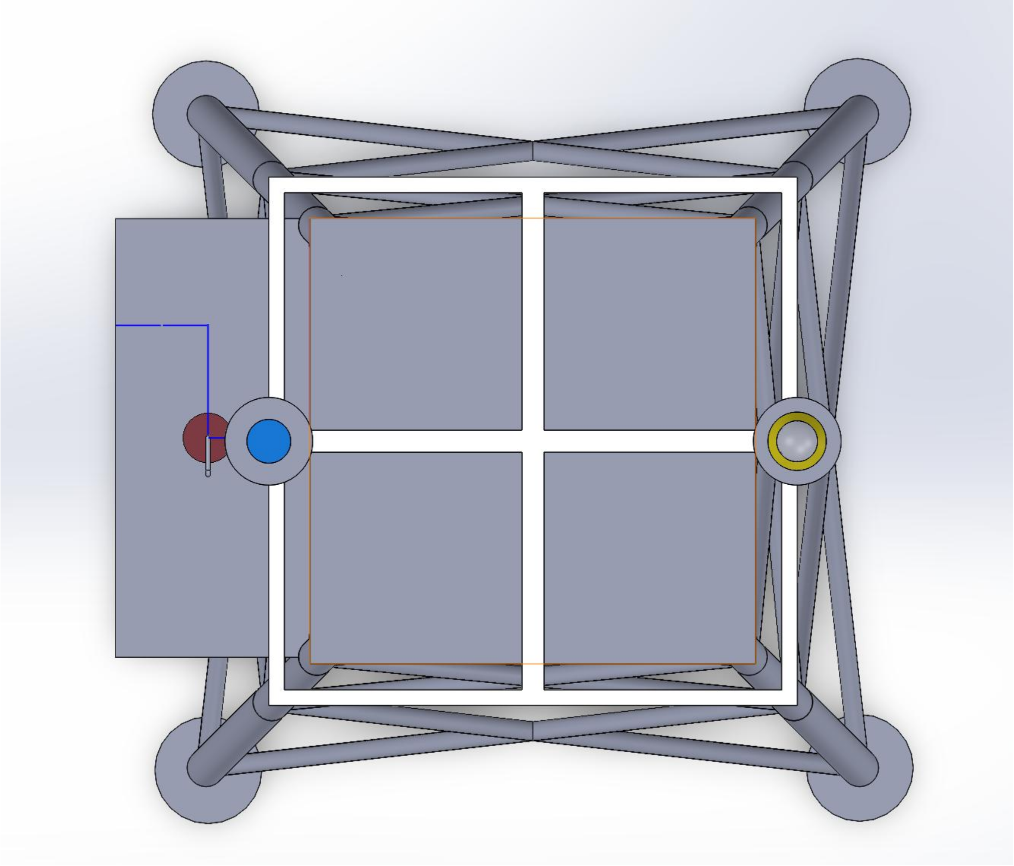


Figure 17: Final CAD Model Top View

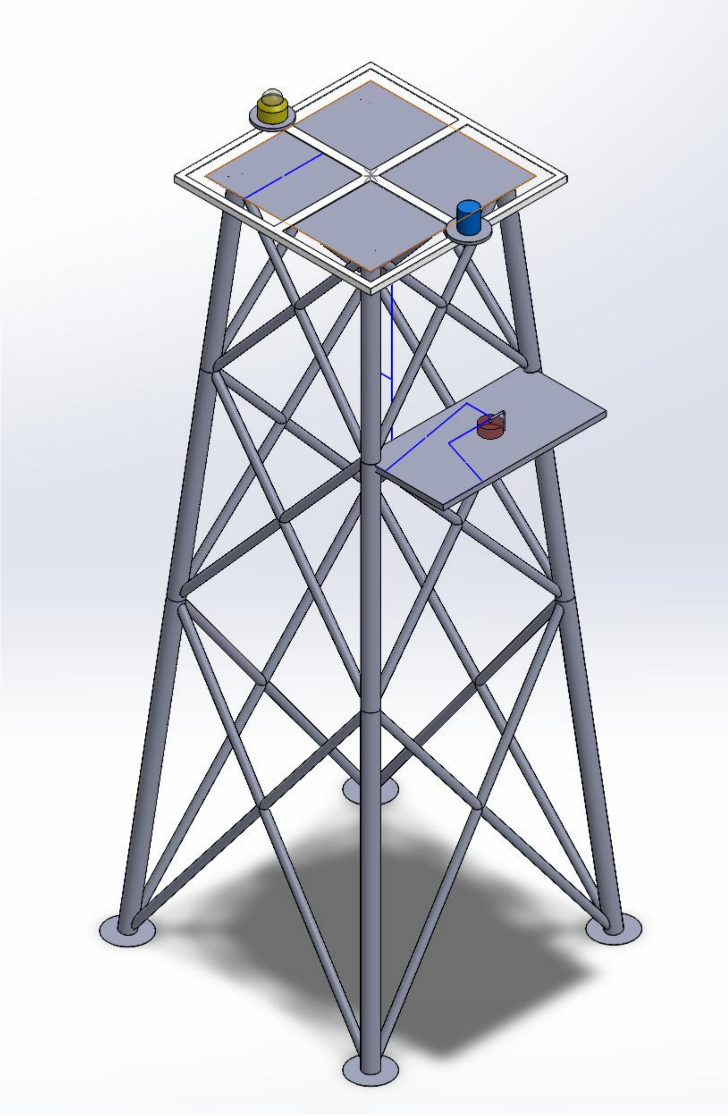
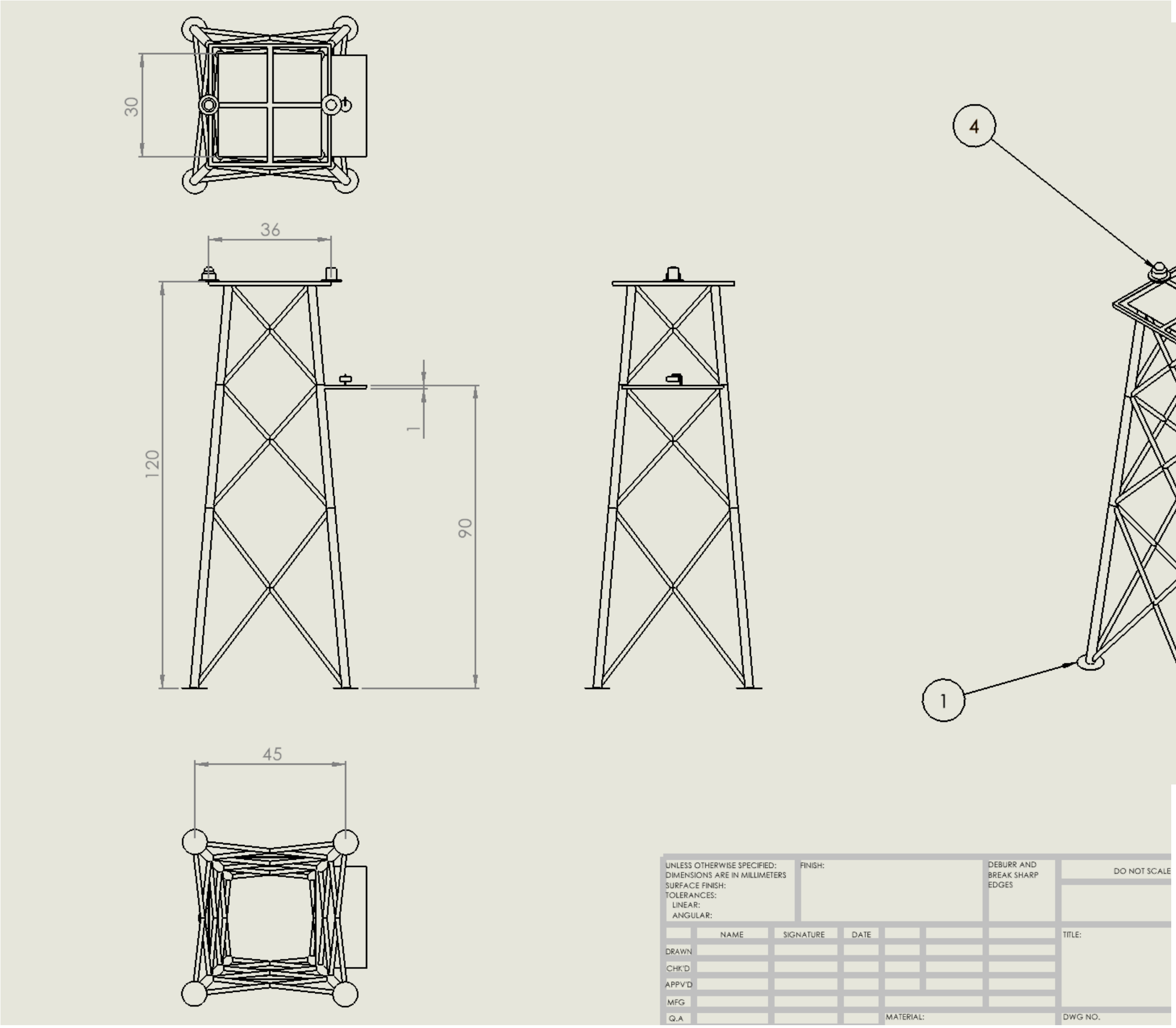
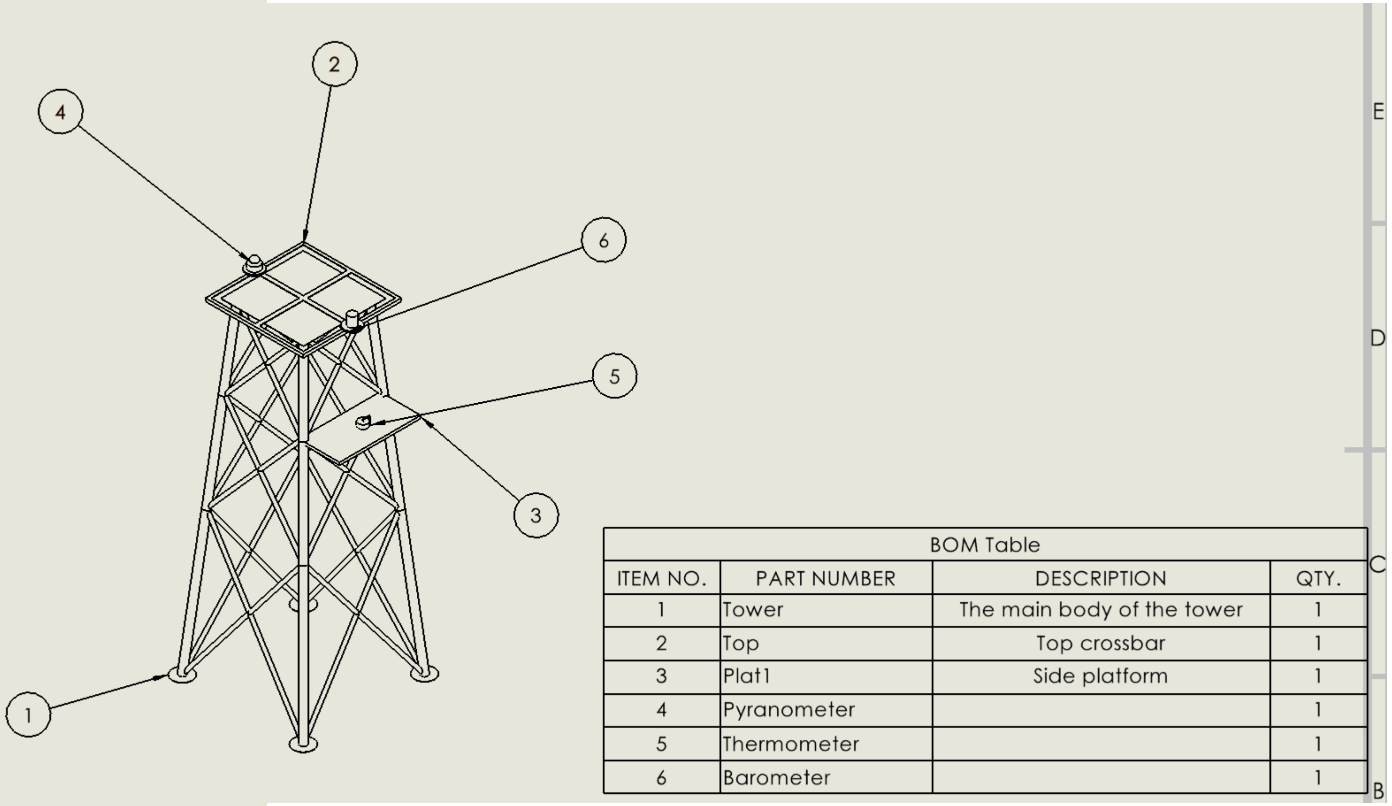


Figure 18: Final CAD Model Isometric View

Final CAD





BOM Table			
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Tower	The main body of the tower	1
2	Top	Top crossbar	1
3	Plat1	Side platform	1
4	Pyranometer		1
5	Thermometer		1
6	Barometer		1

Figure 19: Final CAD Drawings

Wiring

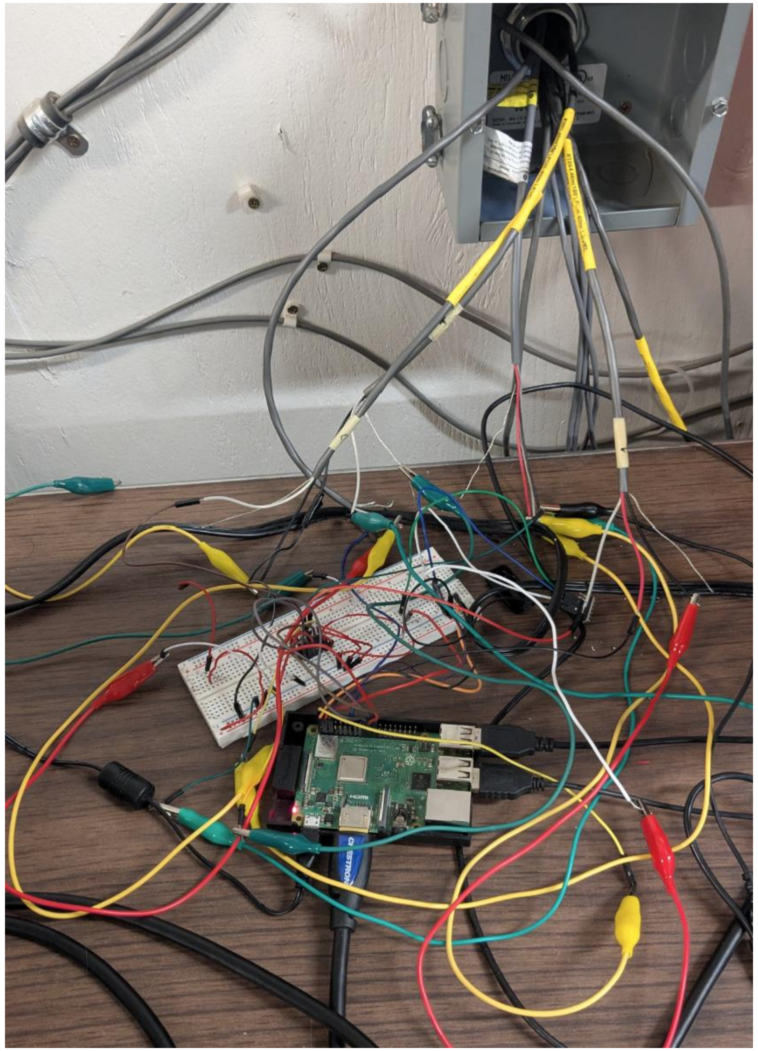


Figure 20: Wiring Connections During Testing

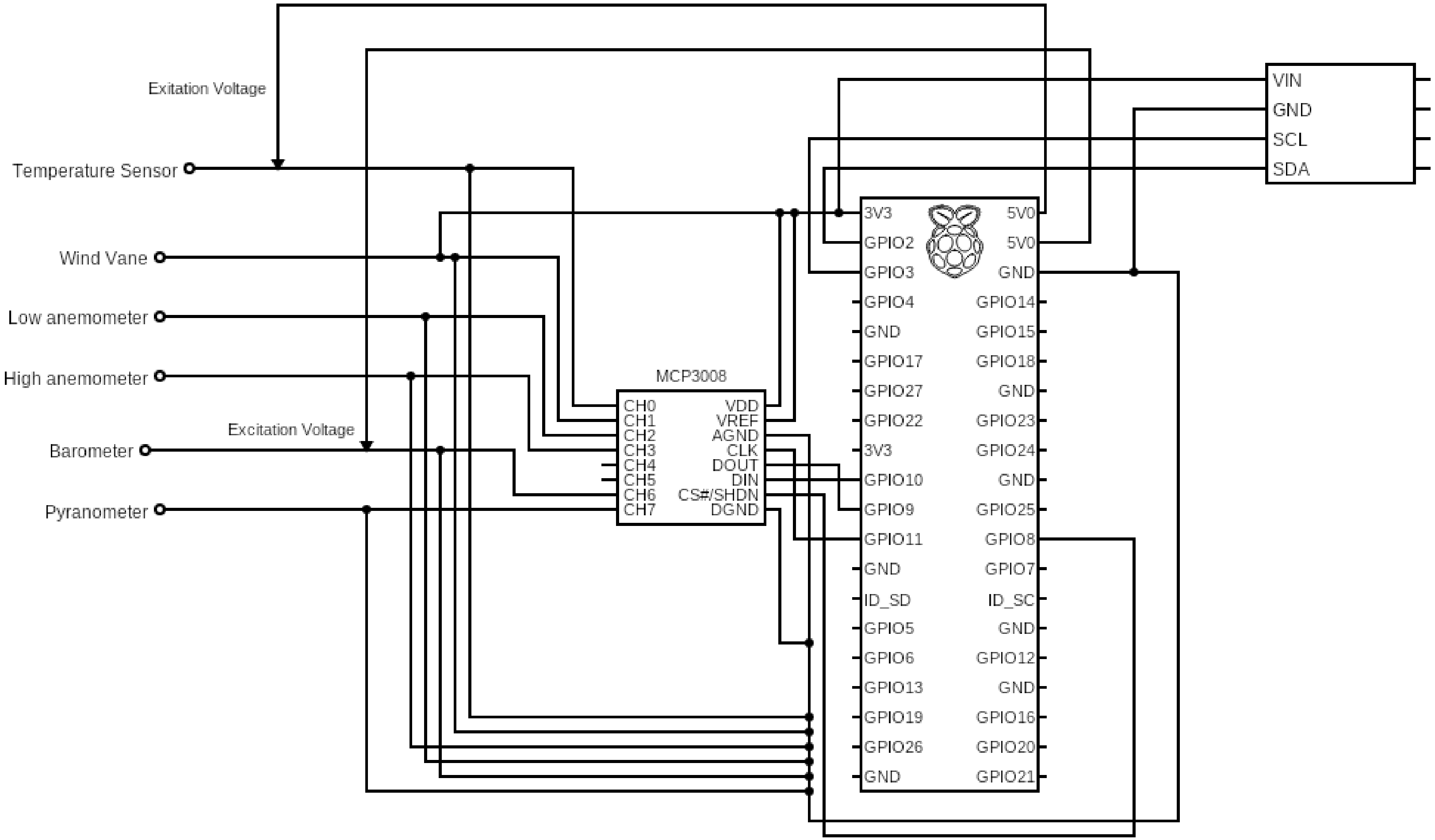


Figure 21: Wiring Diagram for the Full System

Weather Tower

Figure 21: Barometric Pressure Sensor (left) and Pyranometer (right)

Figure 22: Wind Vane (top) and Anemometer (bottom)

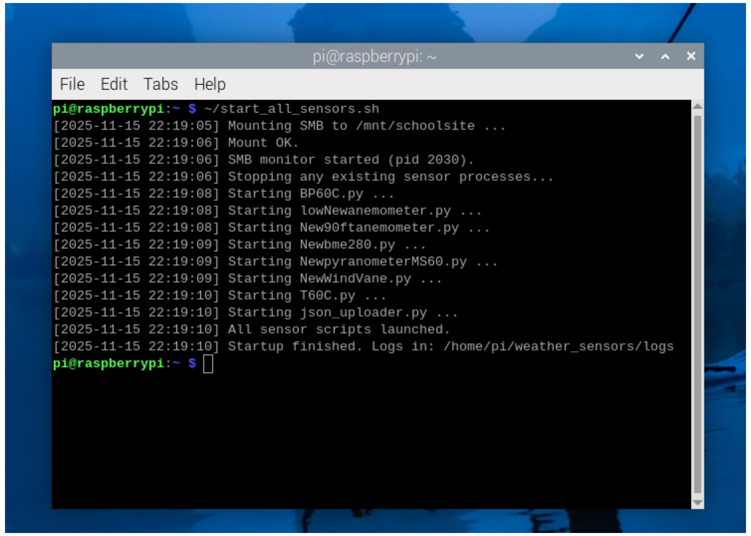
Figure 23: Thermometer

Data Stream

Raspberry Pi

start_all_sensors.sh

The script runs automatically when the Raspberry Pi boots up. First, it automatically connects to the NAU website folder. Then, it starts the seven sensor programs. Next, it starts the JSON upload program.



Back up the full database daily to website folder.

Database_Backup

weather_20251118_150358.db

Start 6 sensors and JSON upload program.

BP60C.py, lowNewanemometer.py, New90ftanemometer.py, Newbme280.py, NewpyranometerMS60.py, NewWindVane.py, T60C.py

After the sensor program runs, it automatically creates and writes data to the database. It also exports the runtime log.

weather.db, weather.db-shm, weather.db-wal

logs

BP60C.log, json_uploader.log, lowNewanemometer.log, mount_monitor.log, New90ftanemometer.log, Newbme280.log, NewpyranometerMS60.log, NewWindVane.log, T60C.log

Json_uploder retrieves data from the database.

json_uploader.py

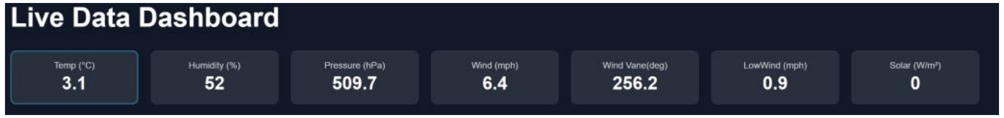
Output JSON file to website folder. Back up the full database daily.

Sum25toF25_WeatherStation

last_10min.json

last_24h.json

latest.json



The website reads JSON and renders it on the page.

Testing

EX1 - Anemometer Calibration Test	CR1, ER2, ER3, ER5, ER6
EX2 - Barometer Data Comparison	CR1, ER2, ER4, ER5, ER6
EX3 - Pyranometer Test	CR1, ER2, ER4, ER5, ER6
EX4 - Temperature Sensor Calibration Test	CR1, ER2, ER4, ER5, ER6
EX5 - Wind Vane Calibration Test	CR1, ER2, ER4, ER5, ER6
EX6 - Boom Mount Stress Test	CR5, CR8, CR10, ER3, ER4
EX7 - Weather Database Test	CR2, CR3, CR7, CR11, ER1, ER6

Table 11: Testing Summary

EX1 - Anemometer Test

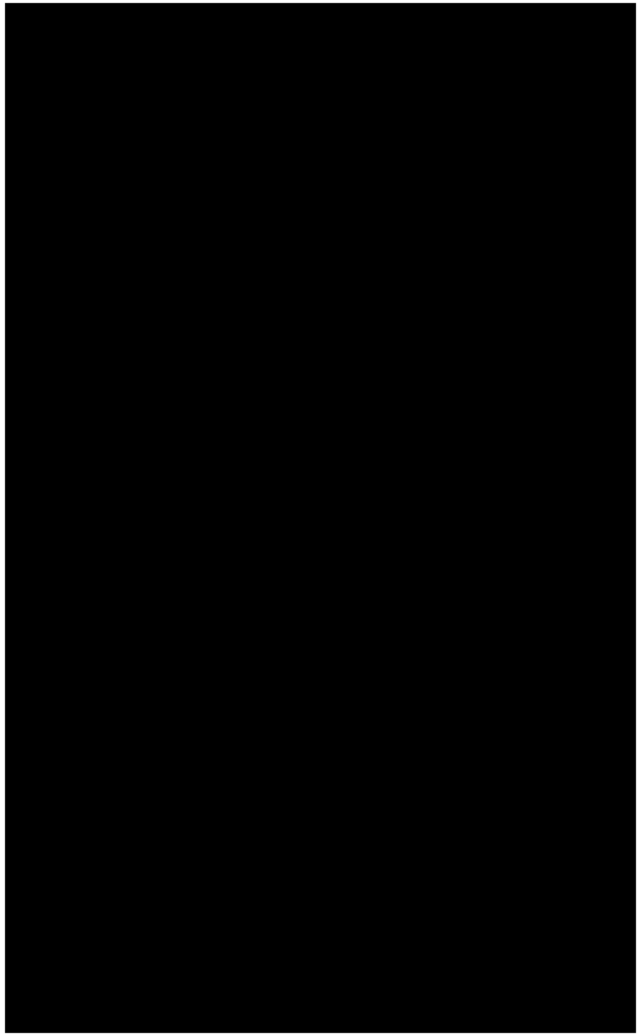


Figure 24: Fixed Wind Speed Setup

Figure 25: Handheld Anemometer Calibration Test

Figure 26: Rotation Speed Measurement Test

EX5 – Wind Vane Test

- **Outputs match direction**
- **Cardinal directions mapped**
- **Installed level and aligned with North**

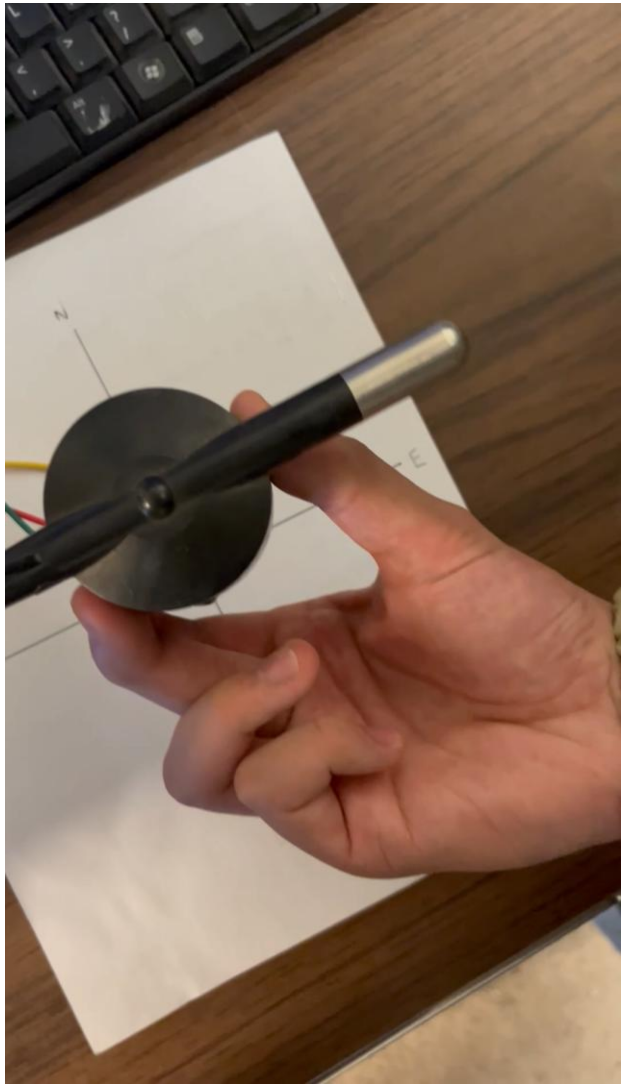


Figure 27: Rotation Speed Measurement Test

EX7 – Weather Database Test

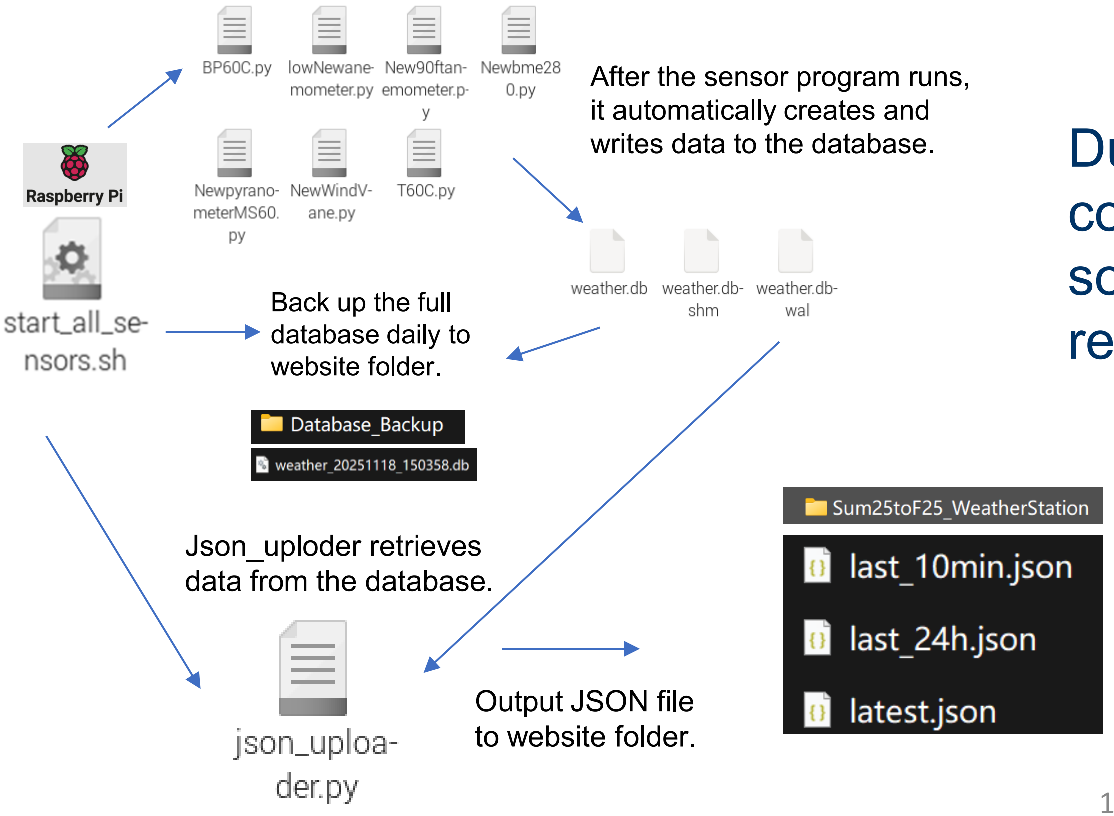
The goal of this test is to ensure the weather database is working correctly. This includes timely upload of most recent data, proper display of past data, proper display updates when new data comes in, proper labeling of data and no gaps or cut-outs in data collection. No tools or materials will be needed to perform this test.

Steps:

- The Raspberry Pi data collection is activated, and data from all seven sensors is first saved to a local database. Then, a separate program extracts the data from the database and exports a .json file to the NAU website folder for display. Simultaneously, the database .db file is uploaded to the NAU website folder daily as a backup.
- Leave the system running, checking data daily.
- After one week, check for missing data points and compare data points to Flagstaff Pulliam Airport weekly data.
- If data is not uploaded consistently and/or is outside a reasonable range to airport data, troubleshoot cause of error.

EX7 – Results

Observations show that the database runs stably. json_uploader reliably retrieves data from the database and uploads it to the NAU website folder. Information on the website is also updated promptly.



During testing, we also found that the connection to the NAU website folder would sometimes be lost, so we added an automatic reconnection function to the code.

Specification Table

Engineering Requirement	Target	Tolerance	Measured or Calculated Value	ER Met (Y/N)	Client Satisfied (Y/N)
ER1 - Long Term Data Storage	4 years	±1 year	9+ years	Y	Y
ER2 - Increased Data Accuracy	Airport	± 3%	testing		
ER3 - Multiple Wind Speed Readings	2	N/A	2	Y	Y
ER4 - Meets Industry Standards	Yes	2 sensors	Yes	Y	Y
ER5 - Proper Calibration	Yes	± 3%	testing		
ER6 - Measurement of All Data Types	5	N/A	5	Y	Y
ER7 - Low Power Requirement	<0.2 kWh	N/A	.0174 kwh/day	Y	Y

Table 12: Specification Table

Customer Requirement Table

	Customer Requirement: Met? (Y/N)	Client Satisfied? (Y/N)
CR1 - Key Weather Parameters	Y	Y
CR2 - Data Transmission	Y	Y
CR3 - Remote Data Access	Y	Y
CR4 - Renewable Power Supply	Y	Y
CR5 - Weather Durability	Y	Y
CR6 - Low Maintenance	Y	Y
CR7 - User Friendly	Y	Y
CR8 - Ease of Installation	Y	Y
CR9 - Low Cost	Y	Y
CR10 - Safety Compliance	Y	Y
CR11 - Data Storage	Y	Y

Table 13: Customer Requirement Table

Thank You
& Questions?