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:

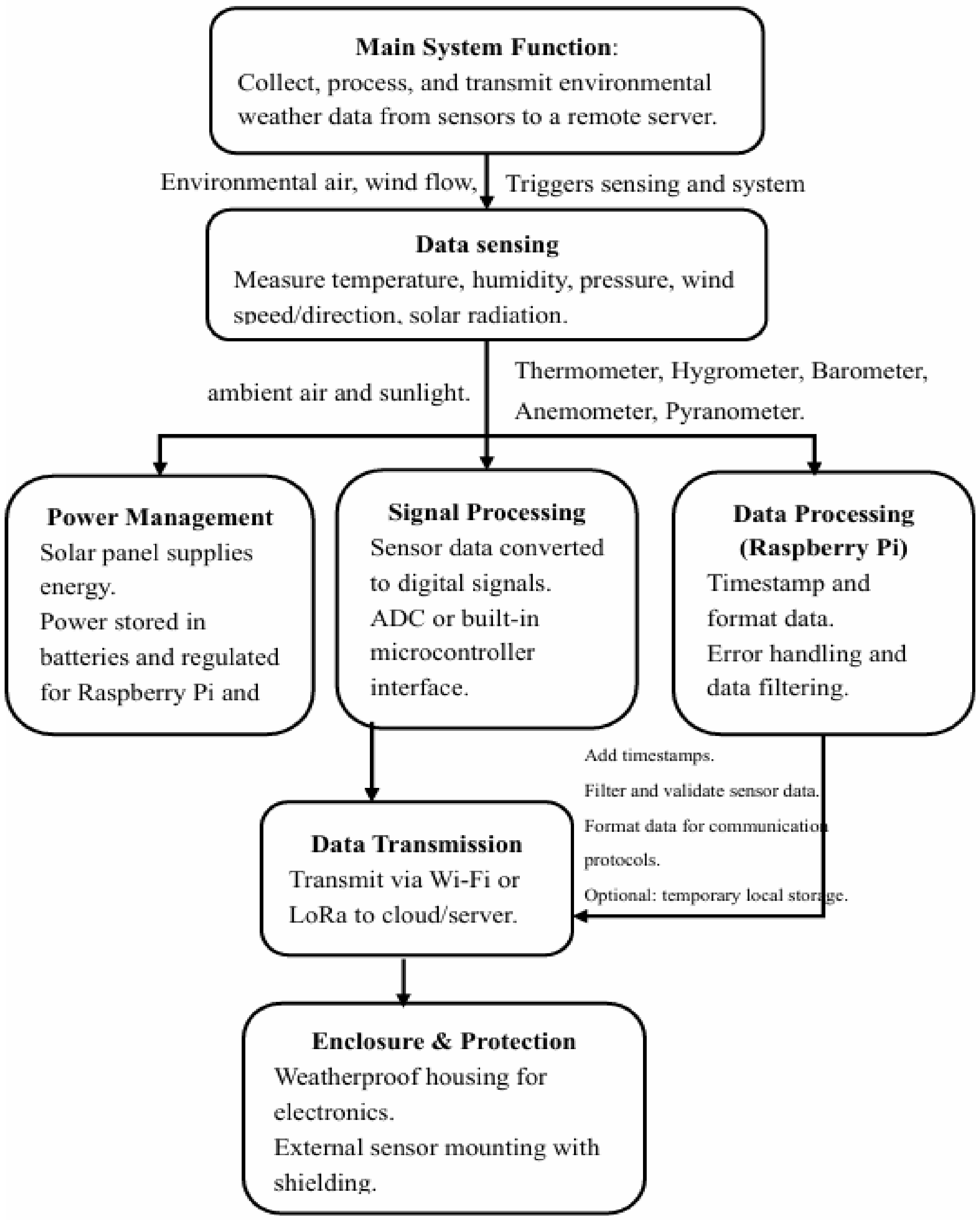
- Temperature
- Humidity
- Wind Speed/Direction
- Barometric Pressure
- Solar Irradiance

Purpose:

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

Design Description

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.



Design Description

This Python-based script enables real-time monitoring and visualization of environmental data from the BME280 sensor using a Raspberry Pi. The system captures temperature, humidity, and barometric pressure through the I2C interface.

The core functionality includes:

- Sensor Initialization: The I2C bus is initialized via , and calibration data is loaded using the library to ensure accurate readings.
- Data Acquisition Loop: The code continuously samples the sensor at 1-second intervals, capturing temperature (°C), relative humidity (%), and pressure (hPa) along with a timestamp.
- Live Plotting: The data is plotted in real time using , displaying three vertically stacked subplots for each variable. Interactive mode allows for continuous updates without restarting the graph.
- Data Logging: Sensor values and timestamps are stored in lists, which can be later saved or analyzed.
- Interrupt Handling: The loop gracefully exits when a key board interrupt is detected, ensuring a clean shutdown and final display of the plots.

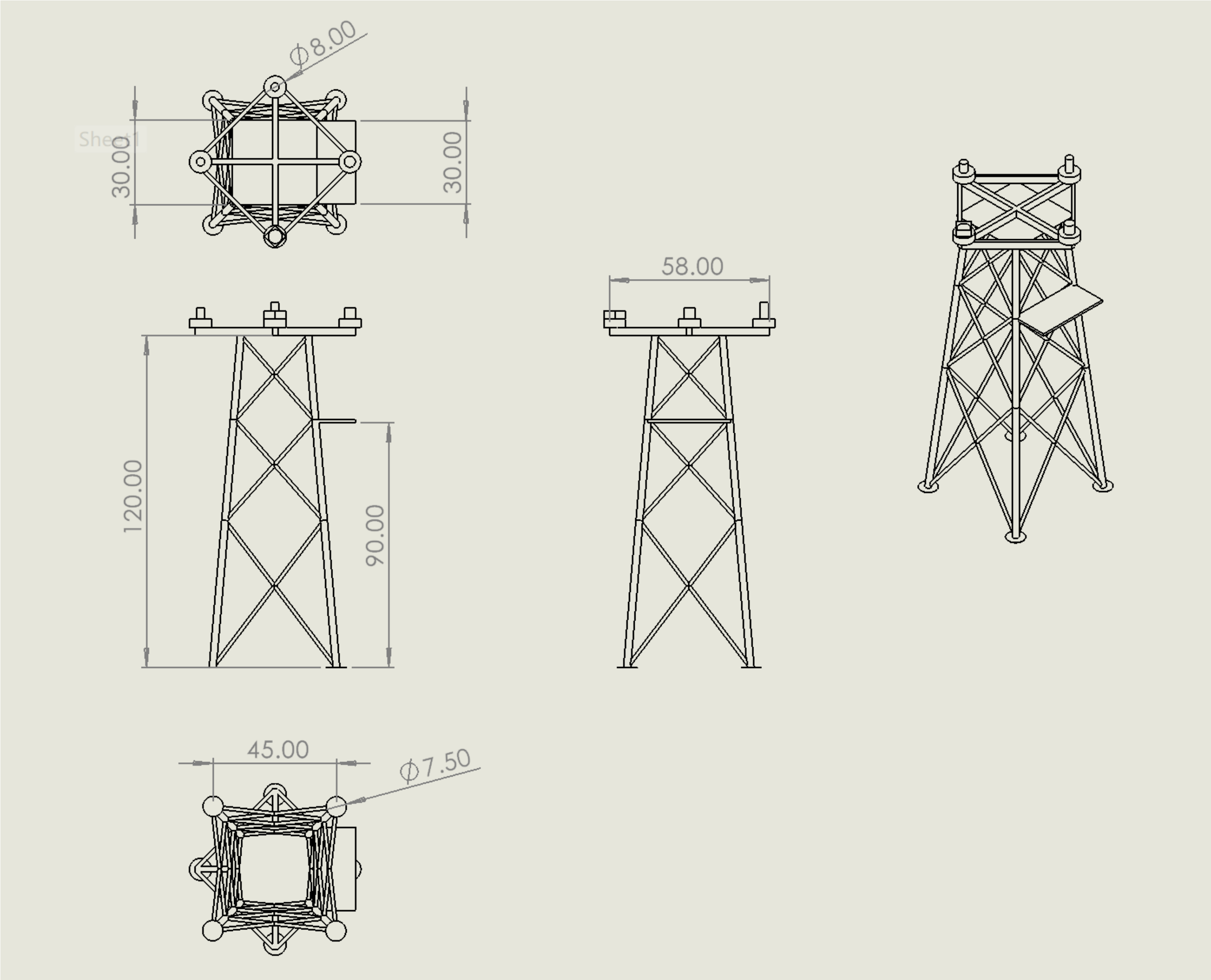
To run the script, the following Python libraries are used and must be installed in a virtual environment:

- smbus2 – for I2C communication
- bme280 – for sensor calibration and sampling
- matplotlib – for dynamic plotting

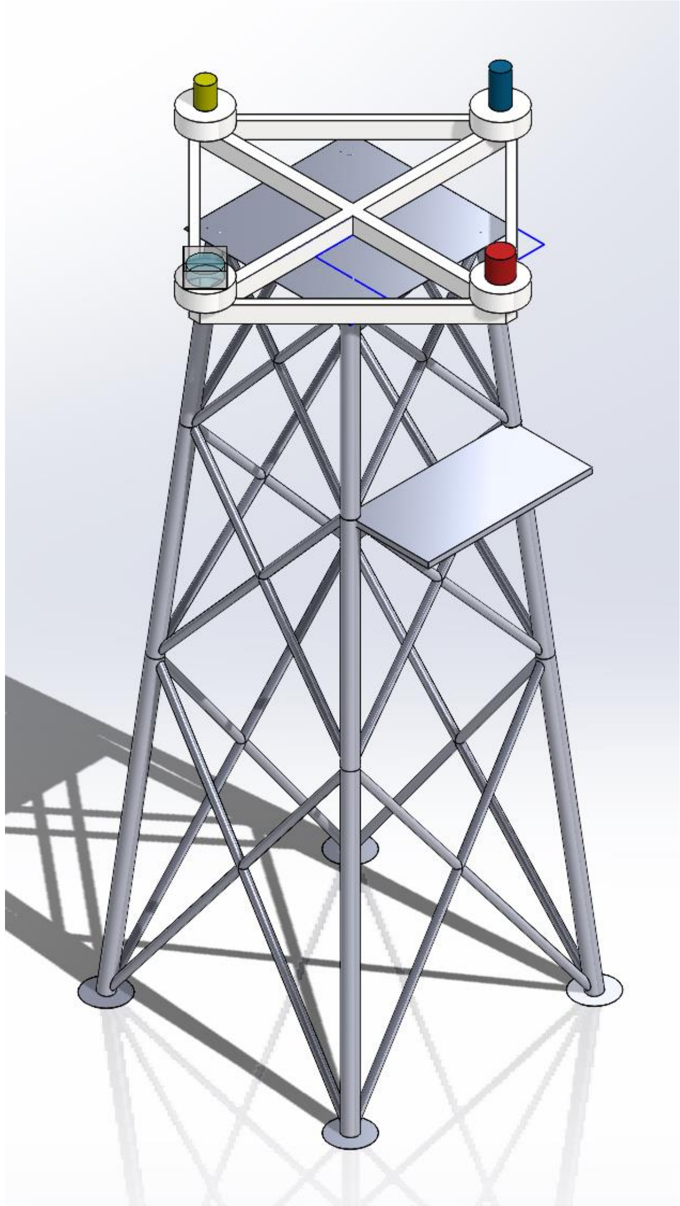
Design Description

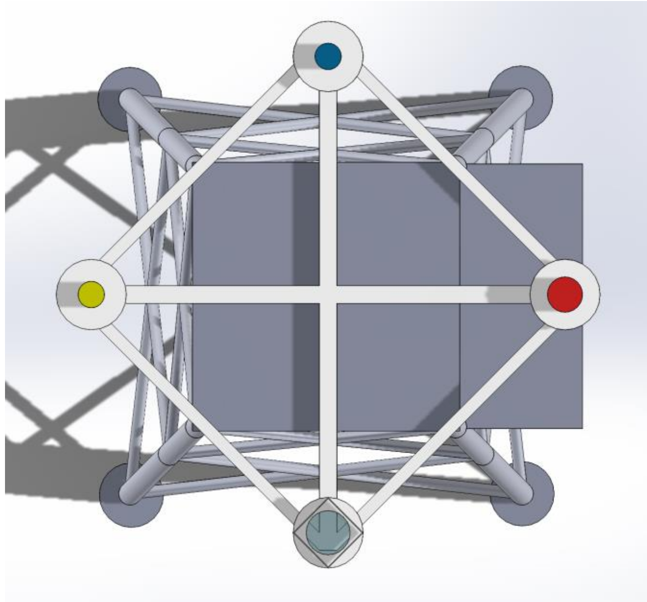
Main Tower

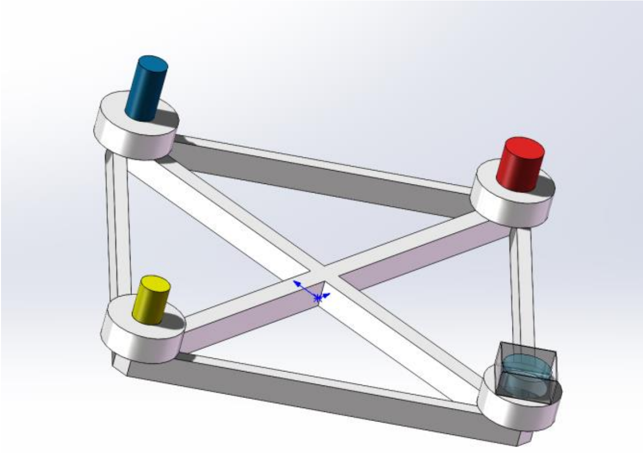
- Units in Inches
- Total height is 120 inches
- Top frame width is 58 inches (corner to corner)
- Base width is 45 inches



CAD







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 5 data types including temperature, pressure, humidity, solar irradiation and wind data
- 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

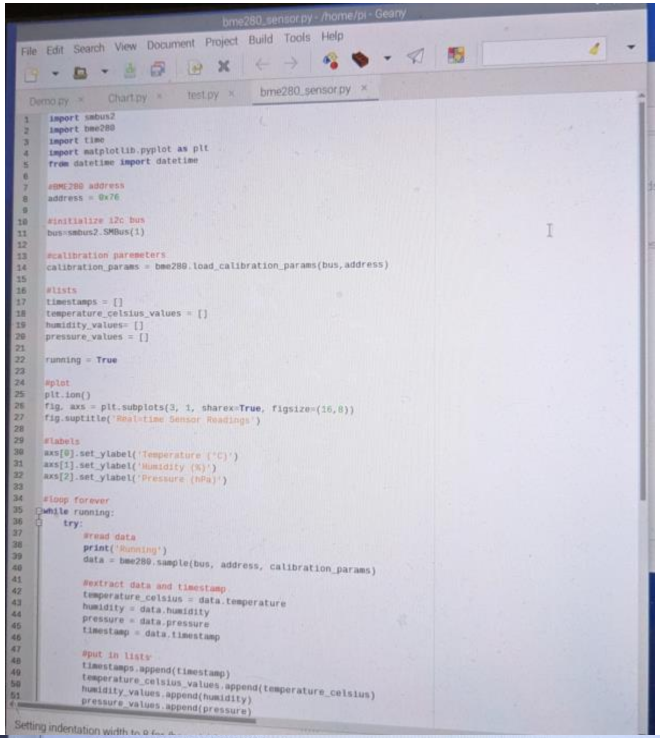
		1	2	3	4	5	6
1	Long Term Data Storage						
2	Increased Data Accuracy	1					
3	Multiple Windspeed Readings	1	3				
4	Measured at Industry Standards	1	9	9			
5	Proper Callibration	3	9	3	9		
6	Temp, Pressure, Humidity, Wind spd/dir, Solar Irradiance	3	9	3	9	9	
7	Low Power Requirement	3	1	1	1	1	9

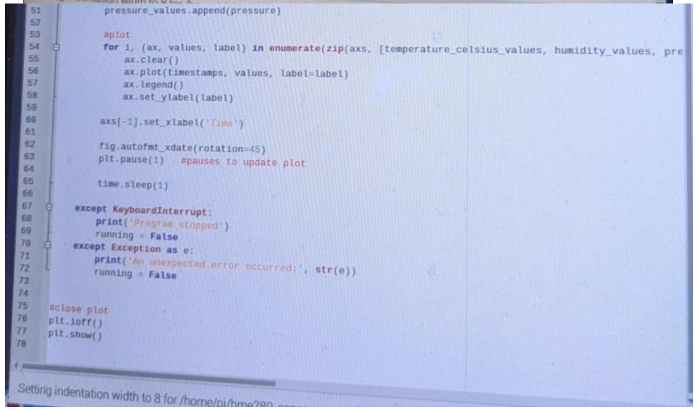
Legend

A	KFLG
B	Tempest
C	Davis Vantage

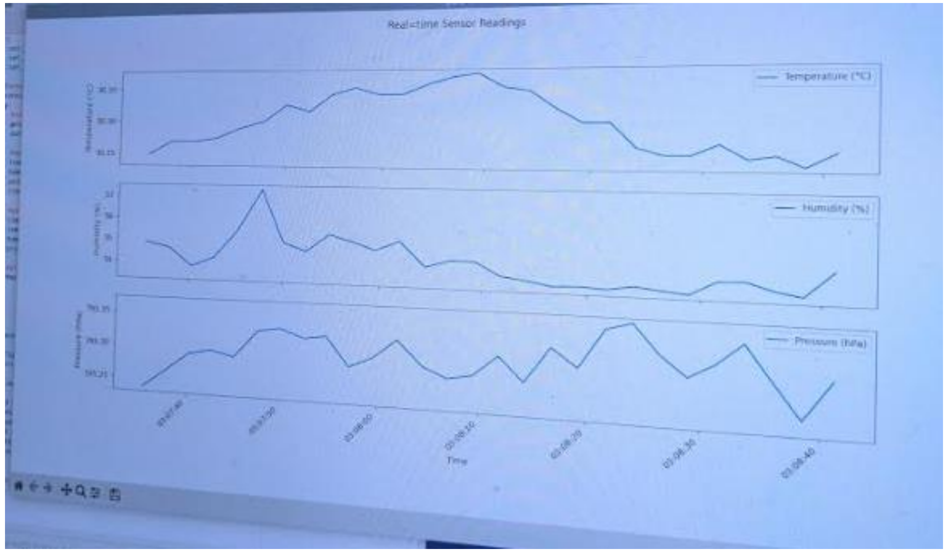
	Customer Needs	Customer Weights	Long Term Data Storage	Increased Data Accuracy	Multiple Windspeed Readings	Measured at Industry Standards	Proper Callibration	Temp, Pressure, Humidity, Wind spd/dir, Solar Irr	Low Power Requirement	1 Poor	2	3 Acceptable	4	5 Excellent
			Technical Requirements							Customer Opinion Survey				
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	3	5	0.2					
	Absolute Technical Importance		82	98	75	12	123	80	8					
	Relative Technical Importance		4	5	1	3	6	7	2					

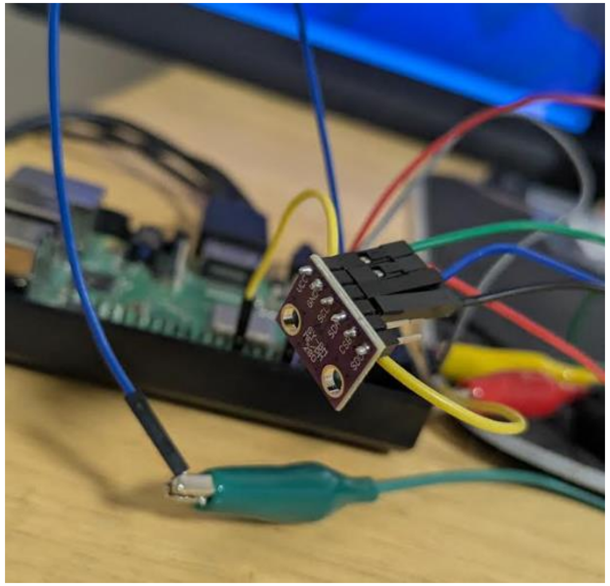
Engineering Calculations





Functional Code for the BME280 humidity, temperature, and pressure sensor used in Prototype 2. [28]





Engineering Calculations

Parameter	Value
Ambient Temperature Ta	35°C (typical summer)
Solar Irradiance G	800 W/m² (clear sky, noon)
Enclosure Absorptivity α	0.85 (black plastic)
Surface Area A	0.015 m² (top of enclosure)
Conv. Coefficient h	10 W/m²·K (natural convection)
Emissivity ε	0.9

Thermal Durability Analysis
We simulate how the outer surface of a small electronics enclosure heats up under constant solar irradiance of 800 W/m²

Component	Max Safe Temp	Est. Internal Temp	Risk Level
Raspberry Pi 3B	85°C	~75°C	Medium
NRG BP-20 Sensor	80°C (est.)	~70–75°C	Low–Medium
MCP3008 ADC	85°C	~73°C	Low

Qsolar =α*G*A=0.85×800×0.015=10.2 W

$$Q_{\text{loss}} = Q_{\text{conv}} + Q_{\text{rad}}$$

$$Q_{\text{conv}} = h \cdot A \cdot (T_s - T_a) = 10 \cdot 0.015 \cdot (65 - 35) = 4.5\ \text{W}$$

$$Q_{\text{rad}} = \varepsilon \cdot \sigma \cdot A \cdot (T_s^4 - T_a^4)$$

$$= 0.9 \cdot 5.67 \times 10^{-8} \cdot 0.015 \cdot (338^4 - 308^4) \approx 4.0\ \text{W}$$

$$Q_{\text{loss,total}} \approx 8.5\ \text{W} < Q_{\text{solar}} = 10.2\ \text{W}$$

- Net heat gain ≈ 1.7 W
- Enclosure surface temperature may rise above 65°C
- Inside enclosure, electronics may reach >75°C

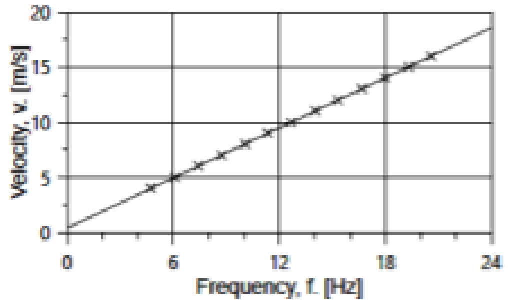
Through research, sensors can reach 75 degrees Celsius in a short period of time.

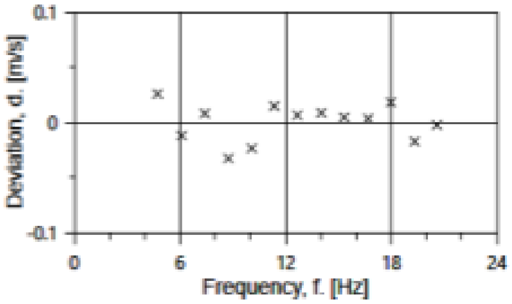
Conclusion : The enclosure is at moderate thermal risk under summer conditions. Recommend adding ventilation openings or applying reflective coating to reduce solar absorption.

Engineering Calculations

Obtained Calibration Certificates with specific calibration constants using Serial Numbers from NRG and LI-COR Websites.

Succession	Velocity pressure, q. [Pa]	Temperature in wind tunnel [°C]	Temperature in d.p. box [°C]	Wind velocity, v. [m/s]	Frequency, f. [Hz]	Deviation, d. [m/s]	Uncertainty u_c (k=2) [m/s]
1-first	9.44	24.2	26.6	4.008	4.7364	0.026	0.023
13-last	14.67	24.3	26.6	4.998	6.0929	-0.012	0.026
2	21.29	24.1	26.6	6.018	7.4131	0.008	0.030
12	28.73	24.4	26.6	6.995	8.7559	-0.033	0.034
3	37.69	24.1	26.6	8.008	10.0803	-0.024	0.038
11	47.68	24.4	26.6	9.012	11.3552	0.015	0.043
4	58.77	24.1	26.6	10.001	12.6703	0.006	0.047
10	71.47	24.4	26.6	11.035	14.0322	0.008	0.051
5	84.76	24.2	26.6	12.012	15.3269	0.004	0.056
9	99.77	24.5	26.6	13.038	16.6832	0.003	0.060
6	115.72	24.2	26.6	14.038	17.9826	0.018	0.064
8	132.48	24.4	26.6	15.025	19.3327	-0.018	0.069
7	150.16	24.3	26.6	15.994	20.5917	-0.003	0.073





Reference Pressure (hPa)	Sensor Output (V)	Slope (hPa/V)	Offset (hPa)	Linearity R^2
552.130000	0.236063	243.8566	494.6673	1.000000
756.910000	1.074680			
1048.660000	2.272093			

To Scale to.....	Slope enter Scale Factor	Offset enter Offset
°C	**44.6894**	**-40.7170**
°F	**80.4409**	**-41.2906**

Calibration Constant(s):

Output: 71.12 microamps per 1000 watts m^{-2}

For use with LI-COR handheld meters and loggers:

Multiplier: -14.06 watts m^{-2} per microamp

If this is an LI-200-BL (3-wire bare leads):

Multiplier: 14.06 watts m^{-2} per microamp

For use with LI-COR 2220 (147 ohm) millivolt Adapter:

Multiplier: -95.65 watts m^{-2} per millivolt

If this is an SL or SMV sensor:

Multiplier: -100 watts m^{-2} per millivolt

Engineering Calculations

Sampling Frequency & Total Samples

- Sampling interval = 30 s
- Samples per year:

$$\frac{60}{30} \times 60 \times 24 \times 365 = 1051200 \ samples/year$$

Based on this frequency of use, check manufacturer information and community resources.

Sensor	Samples/day	Samples/year	Calibration Interval	Replacement Cycle
BME280	2,880	1,051,200	—	12 months
NRG #40C	—	—	12 months	3–5 years
LI-200R / MS-60	2,880	1,051,200	1–2 years	5 years
BP60C	2,880	1,051,200	1 year	3–5 years

Sensor	Model	Manufacturer	Datasheet / Industry Note
Humidity	**BME280**	Bosch Sensor tec	Designed for long-term operation, but MEMS sensors show performance drift after 1 year of continuous high-frequency use.
Anemometer	**NRG #40C**	NRG Systems	Calibrated annually; field use up to 5+ years with proper lubrication and bearing maintenance.
Pyranometer	**LI-200R / MS-60**	LI-COR / EKO	Manufacturer recommends calibration every 1–2 years; replacement after ~5 years.
Barometer	**BP60C**	NRG Systems	Annual calibration recommended; typical lifespan 3–5 years.

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

Design Validation

FMEA Table

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

Design Validation

Test Methods:

- Comparison of our data against Pulliam airport weather data
- Calibration tests using controlled conditions such as ice water at 0 degrees to test temperature sensor
- Visualization of data to spot outliers
- Measure energy usage
- Secure wire connections and make sure they are not easily disconnected by weather or tampering
- Ensure proper sensor housing which aligns with industry standards
- Ensure snow buildup will not pose a threat to sensor data collection
- Analyze data difference between 10m anemometer and 30m anemometer.

Design Validation

Testing Equipment and Resources:

- Reference Weather Data: Pulliam Airport historical weather records (public data access)
- Power Supply: Rechargeable batteries and regulated USB-C output for Raspberry Pi
- Data Logger: Raspberry Pi 3B with SD card for data storage
- Thermal Chamber / Freezer (optional): For extreme temperature tests
- Multimeter & Voltage Logger: To monitor energy usage and wire integrity
- Spare Sensors: For redundancy and comparison
- Outdoor Testing Space: Open area to mount weather station at different elevations (10m and 30m poles)
- Weatherproof Mounting Kits: To simulate snow or wind loading on sensors
- Coding & Visualization Tools: Python/MATLAB for plotting and regression
- Internet Access: To test upload reliability and simulate failure conditions

Schedule

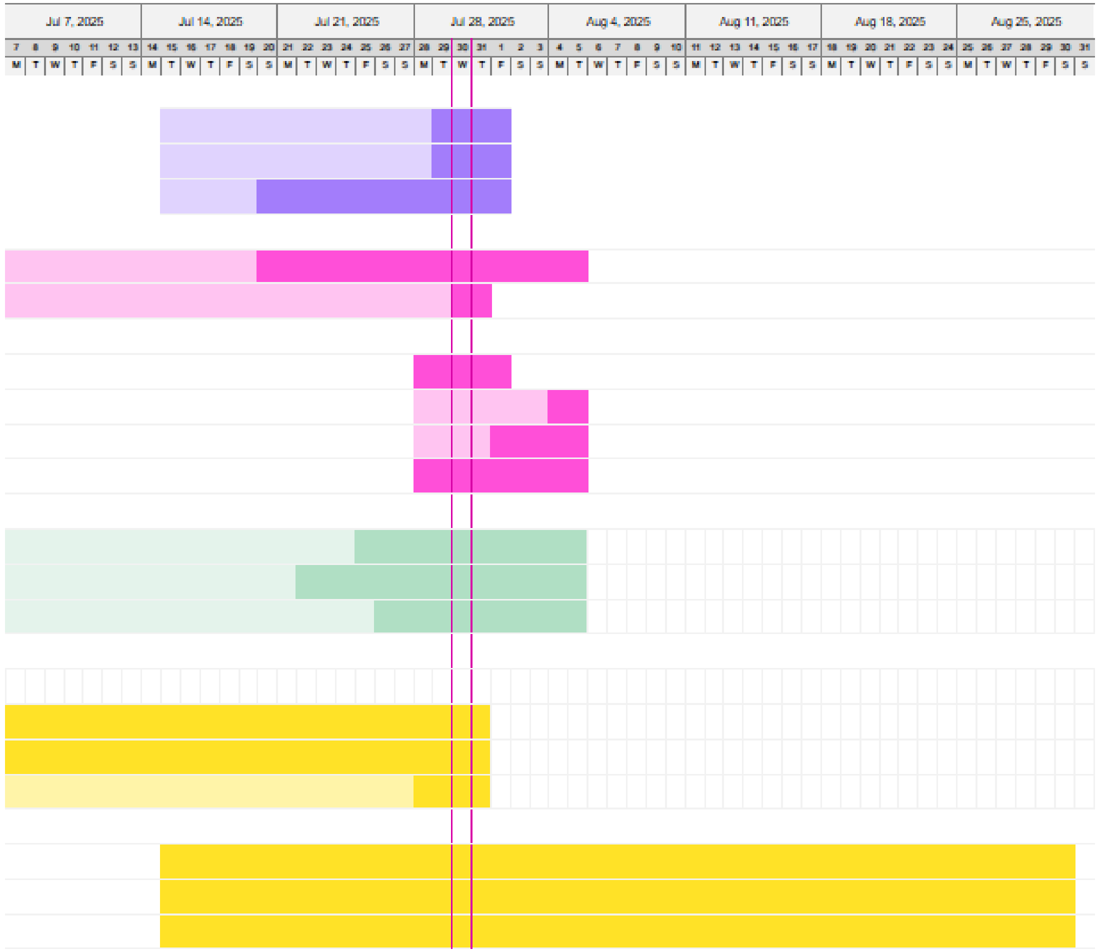
Weather Station

NAU Capstone

SIMPLE GANTT CHART by Vertex42.com
https://www.vertex42.com/ExcelTemplates/simple-gantt-chart.html

Project start: **Tue, 6/10/2025**
Display week: **5**

TASK	ASSIGNED TO	PROGRESS	START	END
Prototype 2				
Sensor connection	Shutong	80%	7/15/25	8/1/25
Calibration Code	Ian Torp & Rowan Mc(	80%	7/15/25	8/1/25
Website Link	Shutong & Chenxi	30%	7/15/25	8/1/25
Report 2 & PRES 3				
Report 2	Everyone	50%	7/3/25	8/5/25
Pres 3	Everyone	95%	6/24/25	7/31/25
Future				
PM 486C	Everyone	0%	7/28/25	8/1/25
FINAL CAD	Chenxi Dong	80%	7/28/25	8/5/25
Final BOM	Rowan B McCullogh	50%	7/28/25	8/5/25
Peer Eval 4	Everyone	0%	7/28/25	8/5/25
Website Check				
Begin Website	Chenxi Dong	80%	6/10/25	8/5/25
Access Website	Everyone	60%	7/1/25	8/5/25
Build	Everyone	70%	7/1/25	8/5/25
Future				
Establish Technical Advisor	Everyone	0%	6/10/25	6/30/25
Track expenses	Rowan B McCullogh	30%	6/10/25	7/31/25
Evaluate progress	Ian Torp	30%	6/10/25	7/31/25
CAD design	Chenxi Dong	90%	6/22/25	7/31/25
Next Semester Big Dates				
Hardware Status 100%	Everyone	0%	7/15/25	10/24/25
Final Report	Everyone	0%	7/15/25	11/17/25
Client Handoff	Everyone	0%	7/15/25	11/28/25
				7/4/25



(dates estimated using spring schedule in the 486C assignment)

Budget

~$3000 worth of existing equipment.

Around ~$500 from client for expected additional costs.

$300 have been contributed by the team to meet the fundraising goal

Additional expenses:

- Construction of diamond crossbar for mounting
- Additional sensor parts i.e. voltage amplifiers,

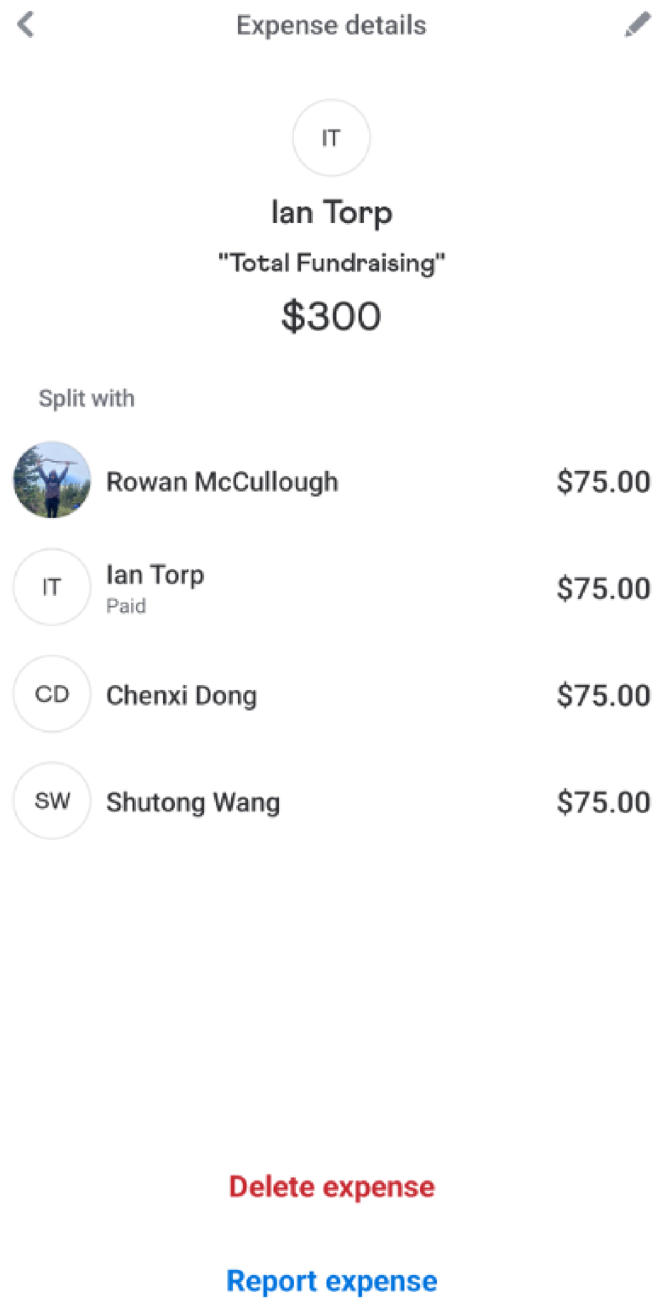
Fundraising

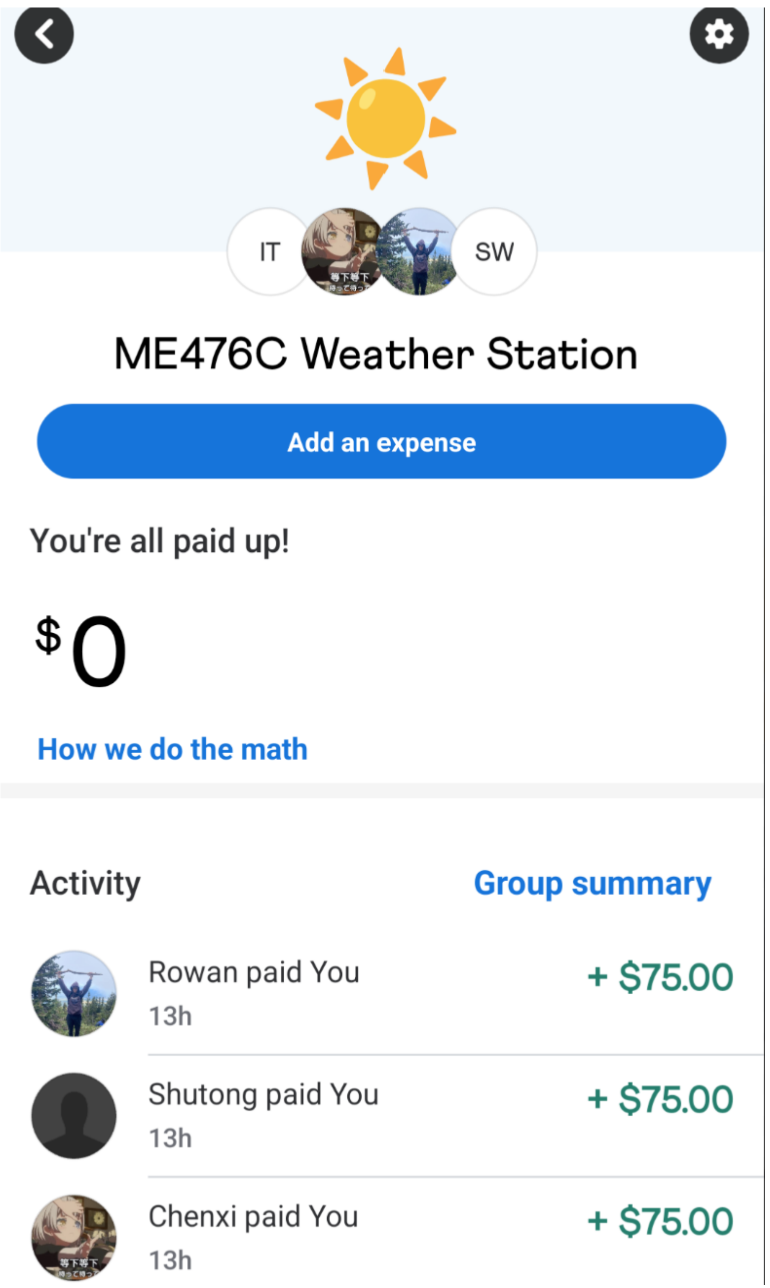
$300 total from the team

$75 from each person

Total remaining to spend:

$263.64





Bill of Materials

Material	Quantity	Price $	Link to Product
Onn MicroSD card 32gig	1	6.96	https://www.walmart.co
MCP3008 Analog to Digital Converter	2	15.3	https://www.amazon.co
BME280 Sensor	2	14.1	https://www.amazon.co
	Total Cost:	36.36	

Works Cited

[1] Setra Systems, Inc, “Barometric Pressure Sensors | Setra Systems,” *Setra.com*, 2025. https://www.setra.com/product/pressure/barometric (accessed Jun. 18, 2025).

[2] N. US Department of Commerce, “Standards and Policy,” *www.weather.gov*. https://www.weather.gov/coop/standards

[3] World Meteorological Organization, *Guide to meteorological instruments and methods of observation.*, Volume 1. Geneva, Switzerland: World Meteorological Organization, 2008.

[4] ISO-CAL, “What is a Pyranometer? 10 Important Points to Consider.,” *isocalnorthamerica.com*, Jan. 16, 2023. https://isocalnorthamerica.com/what-is-a-pyranometer/

[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/

[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

[7] US, “National Weather Service,” *Weather.gov*, 2025. https://forecast.weather.gov/MapClick.php?lat=35.19814000000002&lon=-111.65112499999998 (accessed Jun. 18, 2025).

[8]Ambient Weather, “Ambient Weather Station Installation Guide,” Online Product Documentation, 2023. [Non-peer-reviewed]

[9] “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).

[10] 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

[11] Wisconsin DNR, “Calibration & barometric pressure | | Wisconsin DNR,” *dnr.wisconsin.gov*. https://dnr.wisconsin.gov/topic/labCert/BODCalibration2.html

[12] 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

[13]Çengal, Y.A. and A.J. Ghajar, 2014: Heat and Mass Transfer: Fundamentals and Application. Fifth edition. New York, McGraw-Hill Education.

Works Cited

[14] "Printed humidity sensors", Encyclopedia.pub. https://encyclopedia.pub/entry/7493

[15] MDPI Sensors – Review of Printed Humidity Sensors – https://www.mdpi.com/2079-4991/13/6/1110

[16] Encyclopedia.pub – Capacitive vs Resistive Humidity Sensors – https://encyclopedia.pub/entry/7493

[17] BOMS Review – Comparison of sensing layers – https://www.ias.ac.in/article/fulltext/boms/045/0238

[18] "Humidity and Dew Point", National Weather Service. https://www.weather.gov/media/epz/wxcalc/dewpoint_rh.htm

[19] Ma, H. et al., "Graphene-Based Humidity Sensors" (arXiv) – https://arxiv.org/abs/2410.02255

[20] NOAA Sensor Siting Standards – https://www.weather.gov/coop/standards

[21] WMO Guide to Meteorological Instruments – https://library.wmo.int/index.php?lvl=notice_display&id=12407

[22] 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=AfmBOopea9LGqjBDOoZJngG3fUaw1xYyltpGe5olf4VLMBsv2Ow8Cz9z# (accessed Jul. 15, 2025).

[23] 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).

[24] J. Portilla, "Python Bootcamps: Learn Python Programming and Code Training," Udemy, 2019. https://nau.udemy.com/course/complete-python-bootcamp (accessed Jun. 22, 2025)

[25] 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)

[26] Raspberry Pi, "Raspberry Pi Documentation - Getting Started," www.raspberrypi.com

[27] Raspberry Pi, "Raspberry Pi OS," Raspberry Pi, 2025.

[28] 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).

Works Cited

[29] Bosch Sensortec. BME280 Combined Humidity and Pressure Sensor Datasheet. https://www.bosch-sensortec.com

[30] NRG Systems. NRG #40C Anemometer Specifications. https://www.nrgsystems.com

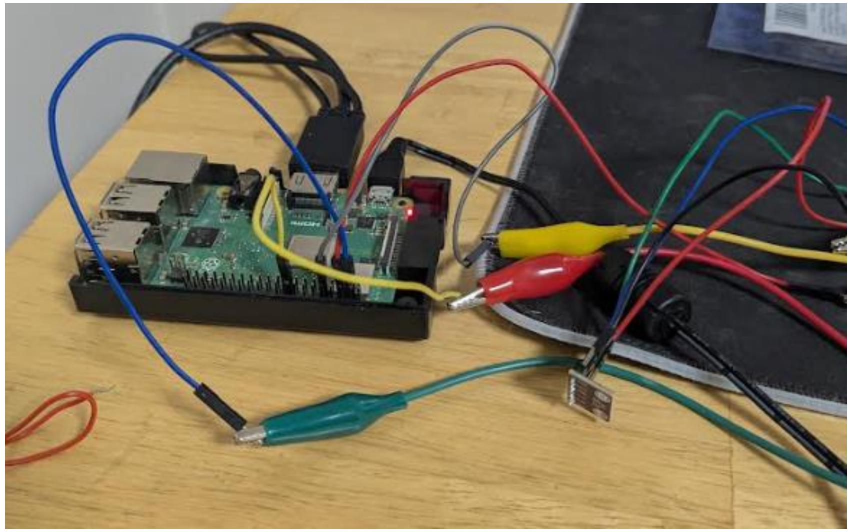
[31] LI-COR Biosciences. LI-200R Pyranometer Specifications and Calibration Guidelines. https://www.licor.com

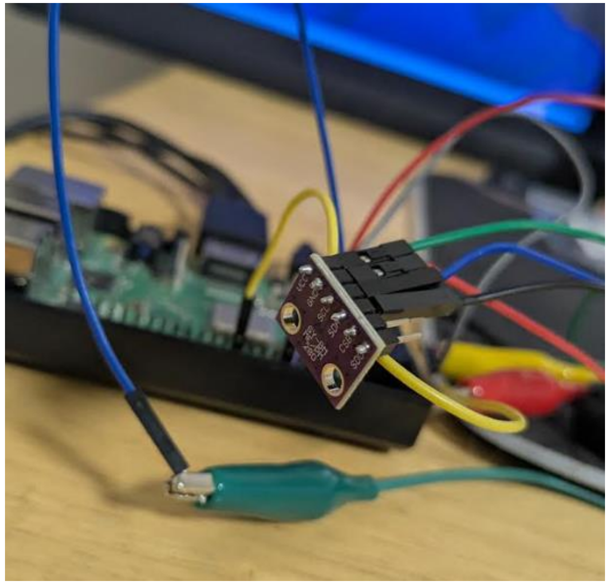
[32] EKO Instruments. MS-60 Pyranometer Datasheet. https://eko-instruments.com

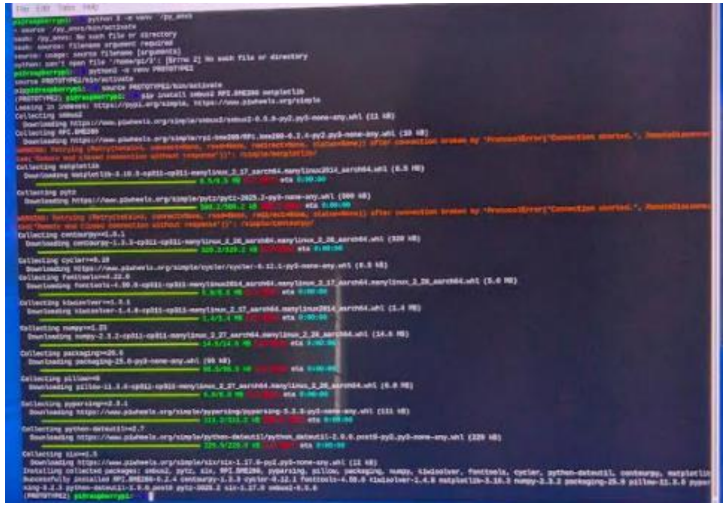
[33] NRG Systems. BP60C Barometric Pressure Sensor Datasheet. https://www.nrgsystems.com

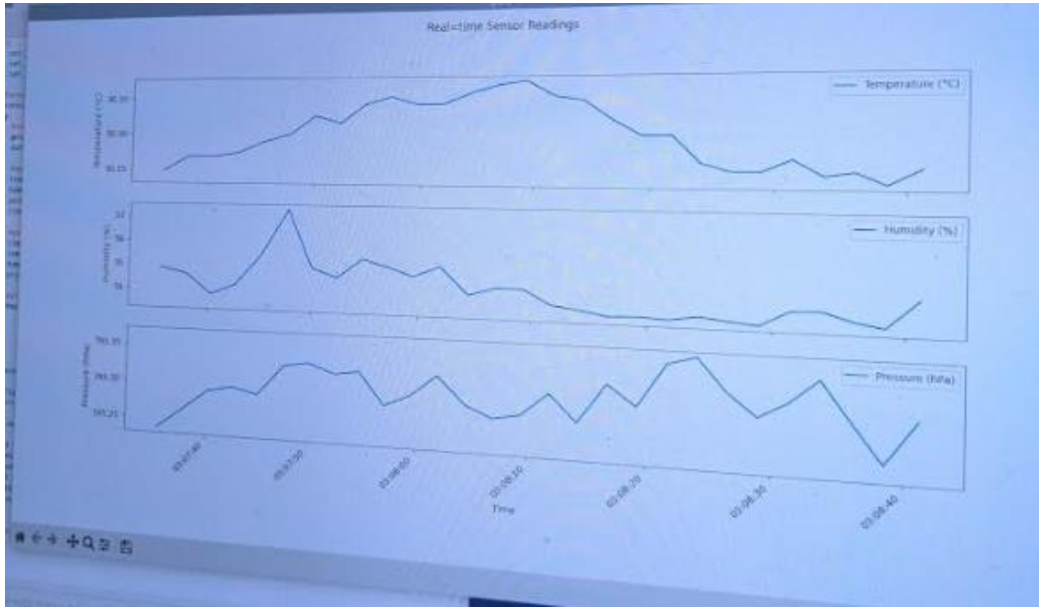
Thank You
& Questions?

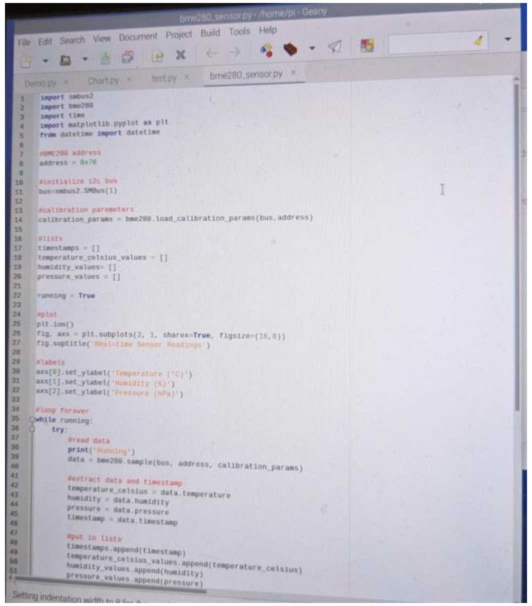
Prototype 2

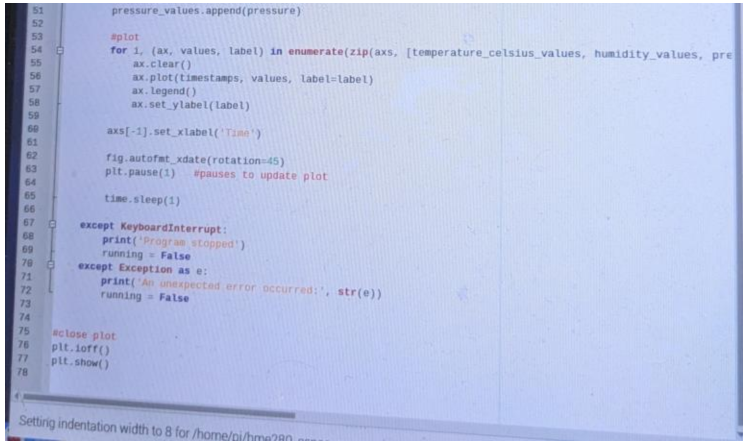












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