NAU NORTHERN ARIZONA UNIVERSITY

Renewable Energy Lab Weather Station

Initial Testing

By:

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Design Requirements

Customer Requirements:

CR1- Measurement of Key Weather Parameters - Station will measure temperature, humidity, wind speed and direction, barometric pressure and solar irradiance.

CR2- Data Transmission - Data collected will be transmitted via internet

CR3- Remote Data Access - Live and stored data should be accessible through a web interface

CR4- Renewable Power Supply - Any components which require power must run on solar energy means located at RE Lab

CR5- Weather Durability - Station must withstand outdoor weather conditions

CR6- Low Maintenance - Station should require less than 2 hours of maintenance per year

CR7- User Friendly - User interface should be easily navigable

CR8- Ease of Installation - Installation should require minimal tools or training

CR9- Low Cost - Station should be cost effective and within budget

CR10- Safety Compliance - Must comply with relevant electrical and operational safety standards

CR11- Data Storage - Data should be stored in an accessible and organized database for at least one year.

Design Requirements

Engineering Requirements:

ER1- Long Term Data Storage - Database should log data in an organized manner over the course of 4 years

ER2- Increased Data Accuracy - Sensor readings should be highly accurate, within 3% or less of Pulliam Airport reference data when applicable

ER3- Multiple Wind Speed Readings - Wind speed and direction should be measured at both standard height (~30ft) and atop the existing tower at the RE Lab (~90ft), providing at least 2 readings.

ER4- Measured at Industry Standards - Sensors should be properly positioned according to industry standards

ER5- Proper Calibration - Sensors should be properly calibrated to upload accurate data from raw readings within 3% of true values

ER6- Measurement of All Data Types - Station should record 6 data types including temperature, pressure, humidity, solar irradiation, wind speed and wind direction.

ER7- 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.

Testing Summary

Test:	Requirements Satisfied:	Equipment Needed:	Other Resources:
EX1 - Anemometer Calibration Test	CR1, ER2, ER3, ER5, ER6	Fan, Tripod, Handheld Anemometer, Tachometer	Manufacturer's Calibration Certificate
EX2 - Barometer Data Comparison	CR1, ER2, ER4, ER5, ER6	BME280 Sensor	Pulliam Airport Weather Database
EX3 - Pyranometer Test	CR1, ER2, ER4, ER5, ER6	Black Box	Pulliam Airport Weather Database, Sunny Day
EX4 - Temperature Sensor Calibration Test	CR1, ER2, ER4, ER5, ER6	BME280 Sensor	Pulliam Airport Weather Database
EX5 - Wind Vane Calibration Test	CR1, ER2, ER4, ER5, ER6	Compass, Ruler, Paper	N/A
EX6 - Boom Mount Stress Test	CR5, CR8, CR10, ER3, ER4	Weight, Strap	N/A
EX7 - Weather Database Test	CR2, CR3, CR7, CR11, ER1, ER6	Raspberry Pi	NAU Wi-Fi

EX1 – Anemometer Calibration Test

The goal of this test is to ensure the new anemometer is properly calibrated and produces accurate data. Essentially we will be ensuring the calibration certificate from the manufacturer, including the calibration equation, still upholds. In order to perform this test we will need a fan, handheld anemometer and a tachometer, which can be borrowed from Thermo Fluids Lab 111. The rotational speed of the anemometer will be adjusted using the fan settings and measured using the tachometer. This rpm measurement will be plugged into the calibration equation to ensure the voltage output reading results in the same wind velocity measurement. The handheld anemometer reading of the fan's wind speed will also be compared to the anemometer readings.

Steps:

- Position fan at distance of 1ft from anemometer and start on highest setting.
- Record Wind Speed reading output from Raspberry Pi voltage conversion
- Record handheld anemometer reading at 1ft from fan.
- Record rotational speed in rpm from tachometer
- Convert RPM into wind speed based on geometry of anemometer
- Compare measured and calculated wind speed
- Adjust Calibration equation if needed until wind speeds are equivalent

Results: Outputs from converted Raspberry Pi voltage signal reading (read as Hz) using calibration equation 1 should be within 3% of handheld anemometer reading and converted RPM reading using equation 2.

$$v\ [\text{m/s}] = 0.75776 \cdot f\ [\text{Hz}] + 0.39322 \qquad (1)$$

$$v\ [\text{m/s}] = 0.75776 \cdot (\text{RPM})/60 + 0.39322 \qquad (2)$$

EX1 - Results

Measurement:	Average Reading:	%Difference:
Anemometer	3.2 m/s - 3.704 Hz	N/A
Handheld Anemometer	3.2 m/s	<1%
Tachometer	3.009 Hz	20.69%

EX2 - Barometer Data Comparison

This test verifies whether our barometric pressure sensor produces reasonable values by comparing its readings to Flagstaff Pulliam Airport data, as both locations should experience nearly identical pressure levels. The pressure reading from the BME280 sensor will also be referenced. The sensor output will be calculated using the manufacturer's calibration equation.

Steps:

1. Take reading from the barometer output using the manufacturer stated calibration equation.
2. Compare to Flagstaff Pulliam Airport's most recent barometric pressure reading
3. Compare to BME280 pressure reading
4. If our data is not within 3% of reference data, adjust the calibration equation and begin again from step 1.

Results:

Output from converted Raspberry Pi voltage signal should be within 3% of most recent Flagstaff Pulliam Airport and BME280 barometric pressure reading.

EX3 - Pyranometer Test

This test verifies that the pyranometer readings are accurate by comparing them to solar irradiance data from Flagstaff Pulliam Airport. Since we cannot create a controlled light environment, we will use a black-box test (no light) as the only control. The measured value is the solar irradiance calculated using the manufacturer’s calibration equation.

Steps:

1. Take reading from the pyranometer output using the manufacturer stated calibration equation.
2. Compare to Flagstaff Pulliam Airport’s most recent solar irradiance reading.
3. If our data is not within 3% of airport data, adjust the calibration equation and begin again from step 1.
4. Place the pyranometer inside a black box with lid sealed.
5. Ensure zero solar irradiance is measured.

Results:

Output from converted Raspberry Pi voltage signal should be within 3% of most recent Flagstaff Pulliam Airport solar irradiance reading. Zero solar irradiance should be measured from black box test.

EX4 - Temperature Sensor Calibration Test

This test checks whether the temperature sensor's readings and calibration equation are accurate. We will compare our data to Flagstaff Pulliam Airport temperatures, noting that slight differences may occur due to shade or cloud cover at the RE Lab. The converted temperature should be within 5% of the airport data under stable weather conditions. The BME280 temperature reading will also be compared.

Steps:

1. Record converted temperature sensor reading from manufacturer stated calibration equation.
2. Compare reading to BME280 temperature reading.
3. Compare temperature sensor reading in standard mounting position (ambient, 6ft off ground).
4. Compare to Flagstaff Pulliam Airport's most recent temperature data
5. Adjust calibration equation and repeat from step 1 until temperature reading is within 5% of controlled box temperature.

Results:

Temperature data should be within 5% of airport data and BME280 sensor data on a day with consistent weather conditions (sunny, low wind).

EX5 - Wind Vane Calibration Test

This test checks the voltage output of the wind vane and compares it to the expected voltage of the wind vane in 90 degree increments; these increments denote the cardinal directions. Important note: the degree output by the wind vane marks where the wind is blowing from, not the direction it is blowing to.

Steps:

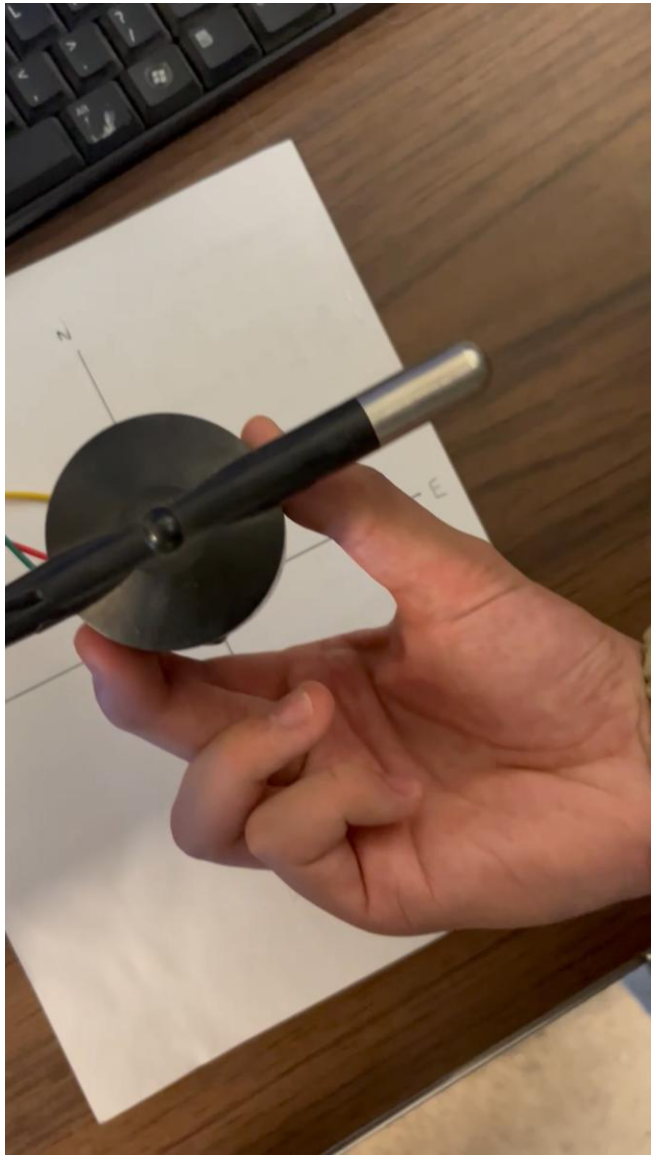
1. Sketch circle on paper and mark cardinal directions at increments of 90 degrees around the circle.
2. Align wind vane zero point (north) with north mark on paper. Adjust wind vane to align with each cardinal direction and log output at each mark.
3. Ensure wind vane output matches 90 degree increments on paper at each point.
4. If output does not match the degree mark on paper, adjust the calibration equation and start over from step 2.
5. Ensure degree reading resets to zero after passing 359.9 degree point

Results:

The degree output from the converted voltage signal through the Raspberry Pi should match the degree mark at which it was taken within 1 degree. These alignments will not be perfect as they will be done by eye, but the outputs should be extremely accurate. The output must reset to zero once the 359.9 degree point is crossed.

EX5 – Results

- **Each cardinal direction reads properly**
- **N = 0**° Voltage = 0V
- **E = 90**° Voltage = 0.825V
- **S = 180**° Voltage = 1.65V
- **W = 270**° Voltage = 2.475V
- **359.9**° Voltage = 3.2999V



EX6 – Boom Mount Stress Test

The goal of this test is to ensure the mounting strategy for attaching the boom mounts to the tower located at the RE Lab. These booms are designed for the mounting of the anemometer and wind vanes, so their attachment to the boom is not at risk of failure. The stress test will ensure the hose clamps used to mount the boom to the tower are capable of keeping the boom in place under heavy wind conditions. This will be tested by attaching weights on a rope to the end of the boom and swinging them to replicate heavy wind gusting.

Steps:

- Attach boom to tower 3 hose clamps at a height of ~5ft
- Thoroughly tighten hose clams until the boom is as secure as possible
- Tie rope with weight to the end of the boom rod.
- Swing and move weight in semi-random patterns to simulate heavy wind gusting
- Ensure the boom remains secure in place and hose clams do not loosen.
- If any major movement or failure of the hose clamps occurs, add additional mounting clamps or adjust mounting position then repeat steps 1-5.
- Repeat weight swinging trial to ensure the first trial did not lead to a weakening of the boom secure mounting.
- Repeat steps 1-7 with second boom arm

Results:

The boom arm is permitted to have slight movement during weight swinging but must remain equally secured as it was before the test. No loosening of the hose clamps are permitted. No bending of the boom arm is permitted. Boom must remain level after each trial. The second weight trial must maintain a similar result as the first to ensure fatigue does not lead to failure.

EX 6 – Results

Estimated Bucket Weight: 15-18 lbs

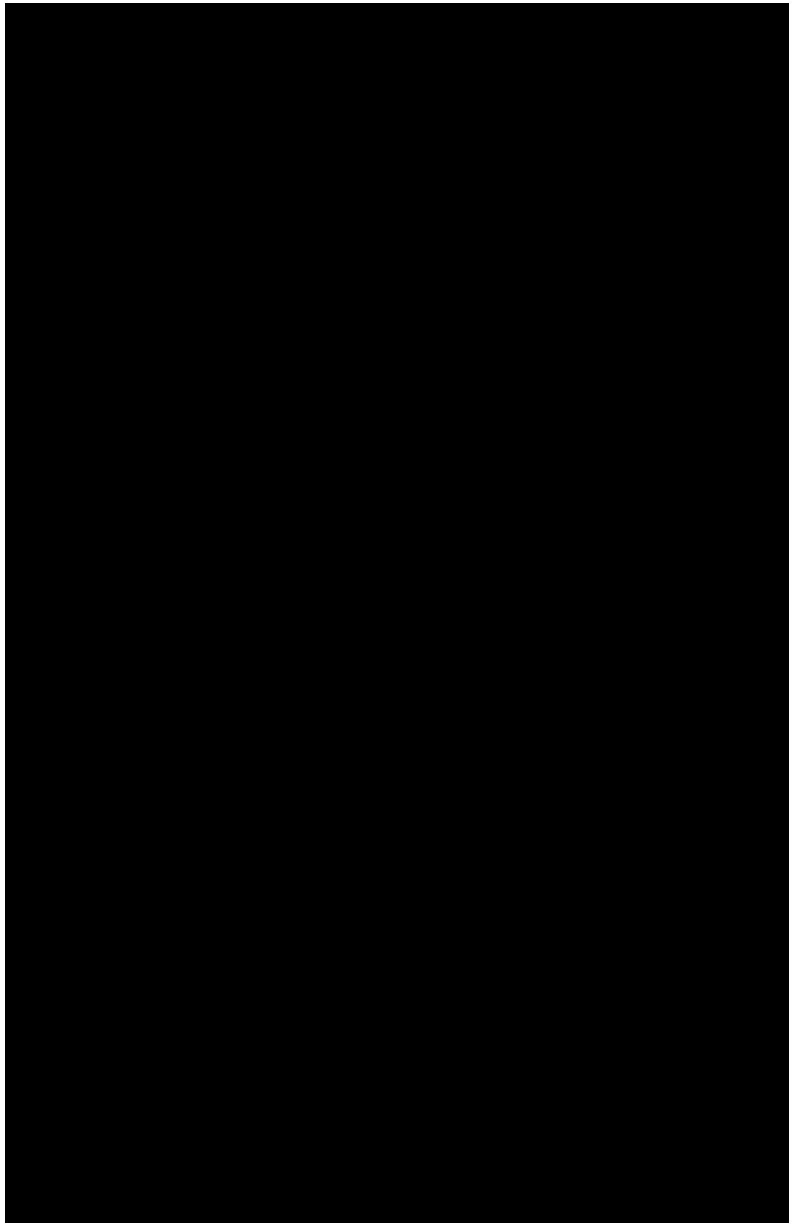
Moment: M = (15 lbs) * (4 ft) = 60 ft-lbs

~3 inch horizontal oscillation at end of boom arm during heavy swinging

No movement observed at mounting point

Hose clamps remained secure across all trials

Boom arms remained level after trials



EX7 – Weather Database Test

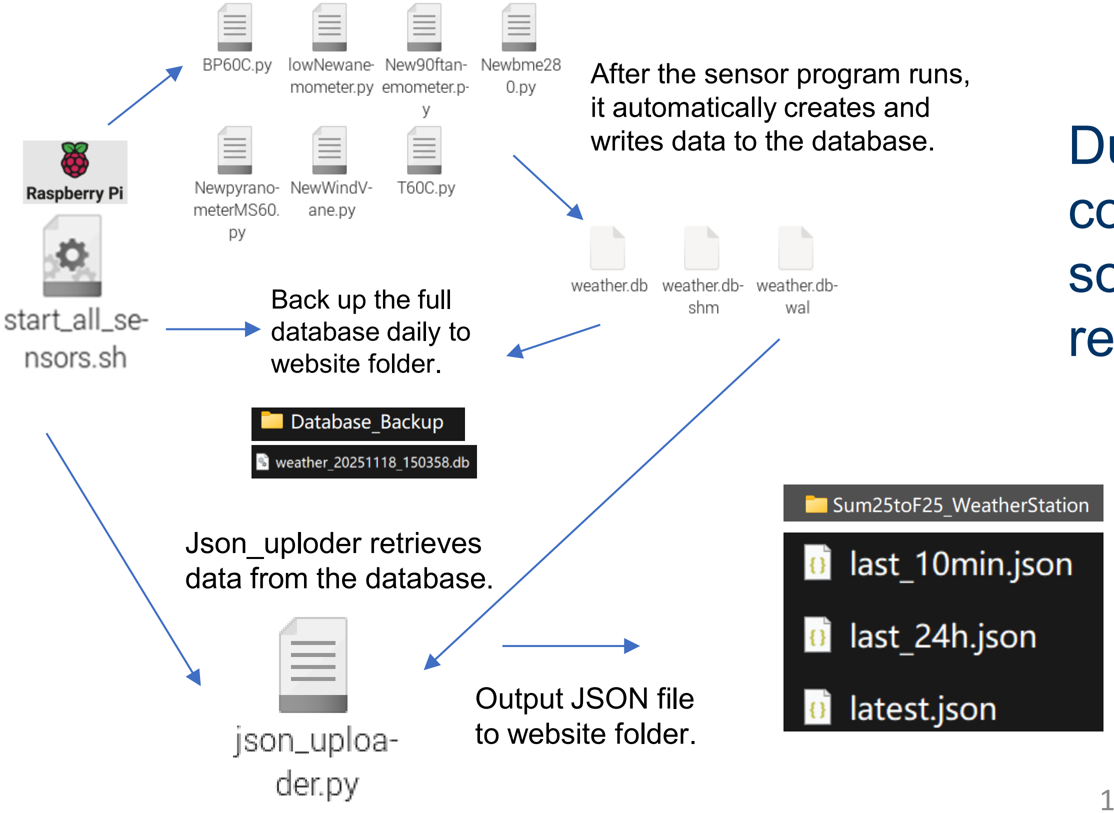
The goal of this test is to ensure the weather database is working correctly. This includes timely upload of most recent data, proper display of past data, proper display updates when new data comes in, proper labeling of data and no gaps or cut-outs in data collection. No tools or materials will be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

Steps:

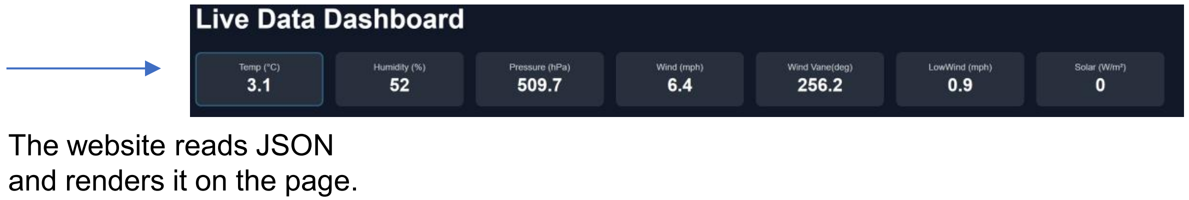
- The Raspberry Pi data collection is activated, and data from all seven sensors is first saved to a local database. Then, a separate program extracts the data from the database and exports a .json file to the NAU website folder for display. Simultaneously, the database .db file is uploaded to the NAU 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	TBD	TBD
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	TBD	TBD
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

Customer Requirement Table

	Customer Requirement: Met? (Y/N)	Client Satisfied? (Y/N)
CR1 - Key Weather Parameters	TBD	TBD
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

QFD

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	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	12	80	8					
	Relative Technical Importance		4	5	1	3	6	7	2					

Thank You
& Questions?