Renewable Energy Lab Weather Station

Final 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	N/A	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	Platinum RTD 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

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 sensor output will be calculated using the manufacturer‘s calibration equation.

Steps:

1. Convert to the sea level
2. Take reading from the barometer output using the manufacturer stated calibration equation.
3. Compare to Flagstaff Pulliam Airport’s most recent barometric 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.

EX2 - Convert to Sea Level

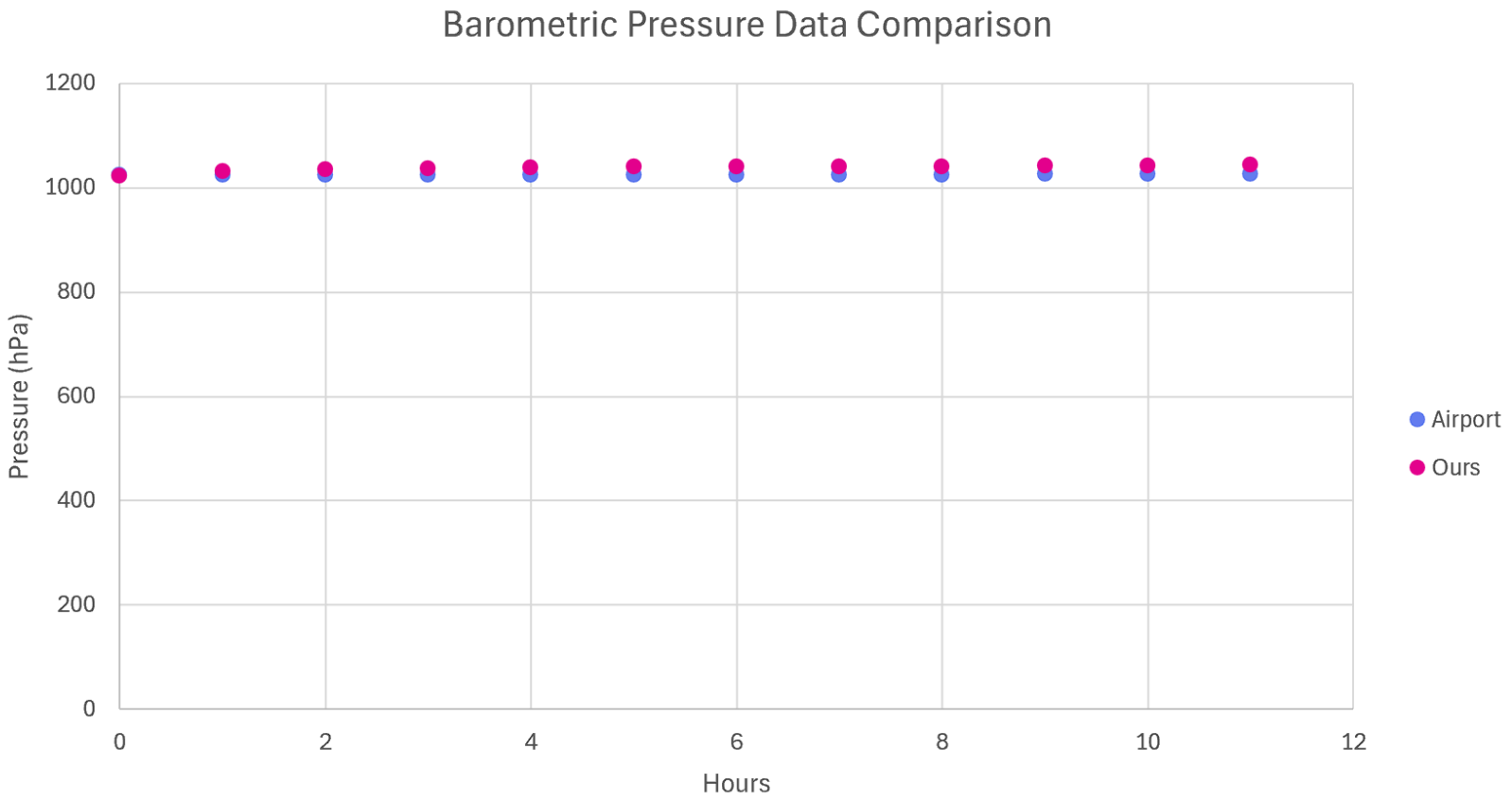
We use this formula below to convert to sea level. The actual pressure value will be affected by altitude and temperature. So, we found the precise altitude of the sensor's location on the website. Temperature was measured in real-time using the T60C sensor.

$$P_0 = P_{\text{station}} \left(1 - \frac{Lh}{T + 273.15}\right)^{-5.255}$$

- P_{station}: Measured atmospheric pressure at sensor height (hPa)
- h: Altitude (m), here **2106 m**
- T: Local temperature (°C), measured from the **T60C sensor**
- $L = 0.0065$ K/m: Standard temperature lapse rate
- The exponent **5.255** is an approximation of $\frac{gM}{RL}$

EX2 - Results

Airport	Pressure	%diff
1024.044	1022.073	0.192475473
1023.705	1032.123	0.822268335
1023.705	1034.857	1.089337358
1023.705	1036.58	1.2576475
1023.705	1038.43	1.438363554
1023.705	1039.94	1.585866929
1024.383	1040.75	1.597774732
1024.721	1041.168	1.604991369
1025.399	1041.397	1.560213849
1025.737	1042.06	1.591320998
1025.737	1042.967	1.679745205
1025.737	1043.536	1.735217501
	avg	1.346268567



- Average of 1.35% difference from airport barometric pressure measurements over 12-hour period
- Average of 1041.36 hPa while airport reported average of 1039.94 hPa (1.74% max difference)

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:

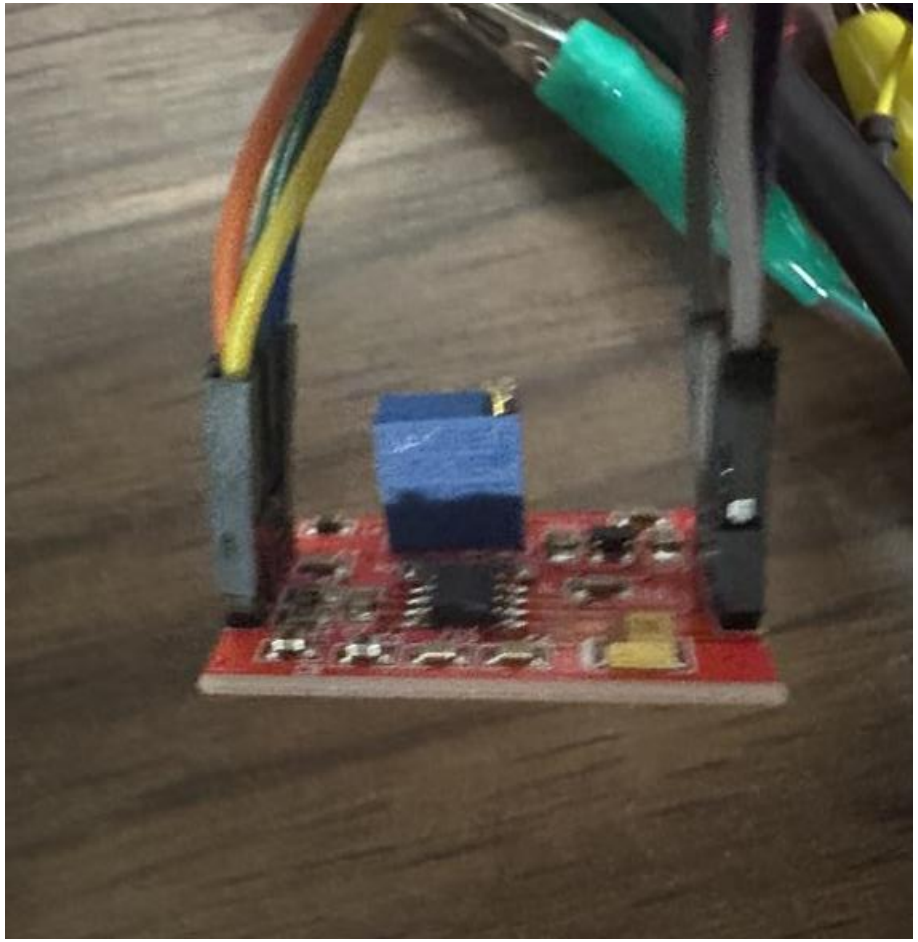
1. Take reading from the pyranometer output using the manufacturer stated calibration equation.
2. Compare
3. to Flagstaff Pulliam Airport's most recent solar irradiance reading.
4. If our data is not within 3% of airport data, adjust the calibration equation and begin again from step 1.
5. Place the pyranometer inside a black box with lid sealed.
6. 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.

EX3 - Results

- The sensor outputs in mV
  - .2mV to 4mV
- Sensor responds to black box
  - 0mV output
- Raspberry Pi cannot read output
- Amplification device AD623 not functioning
- Raspberry Pi cannot receive readable solar irradiance data



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 Platinum RTD temperature reading will also be compared.

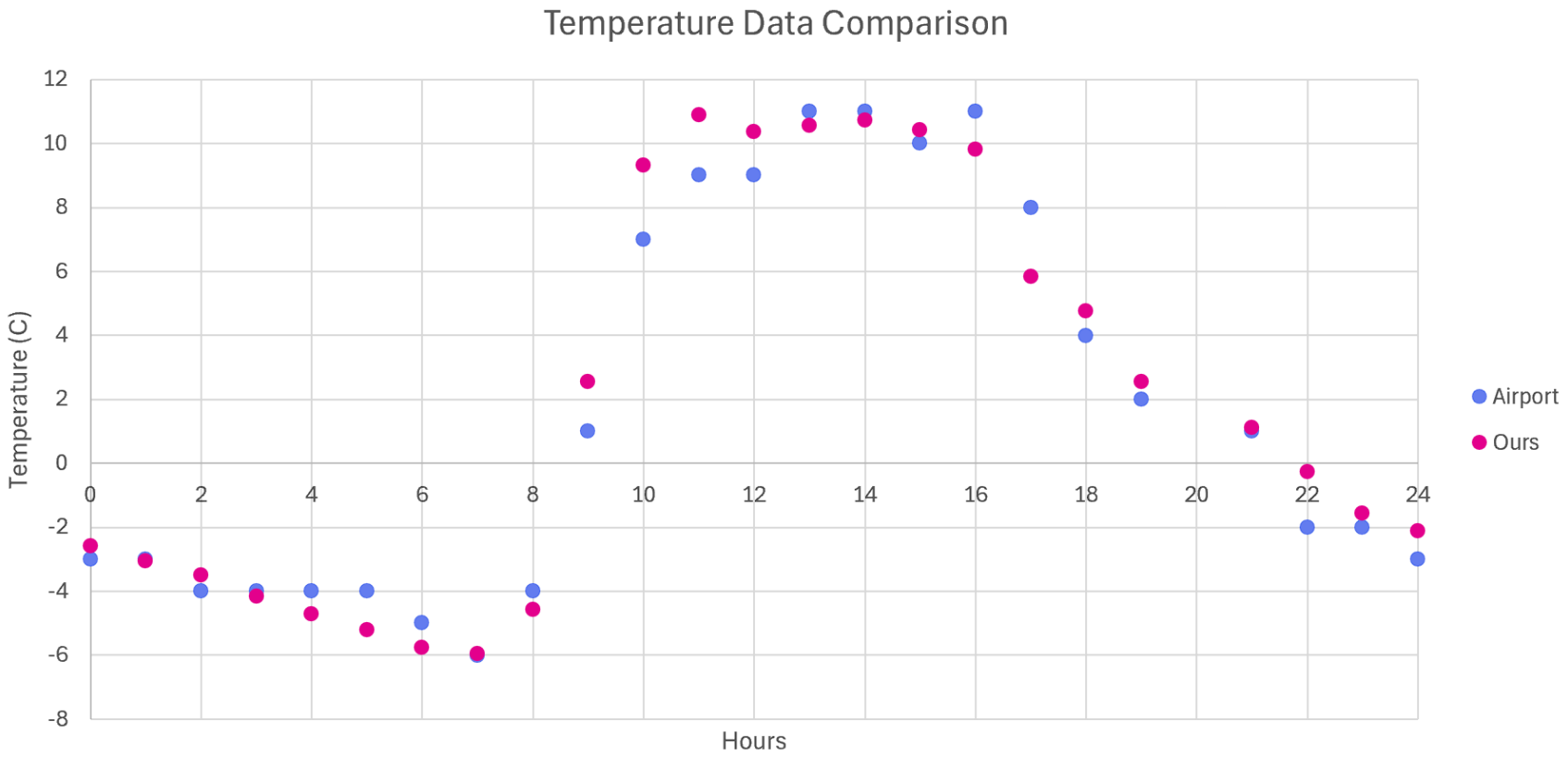
Steps:

1. Record converted temperature sensor reading from manufacturer stated calibration equation.
2. Compare reading to RTD 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).

EX4 - Results



- Average of 3.42% difference from airport temperature measurements over 24hr period
- Sensor read 8.26 C while RTD Measured 8.667 C (4.7% difference)

EX7 – Weather Database Test

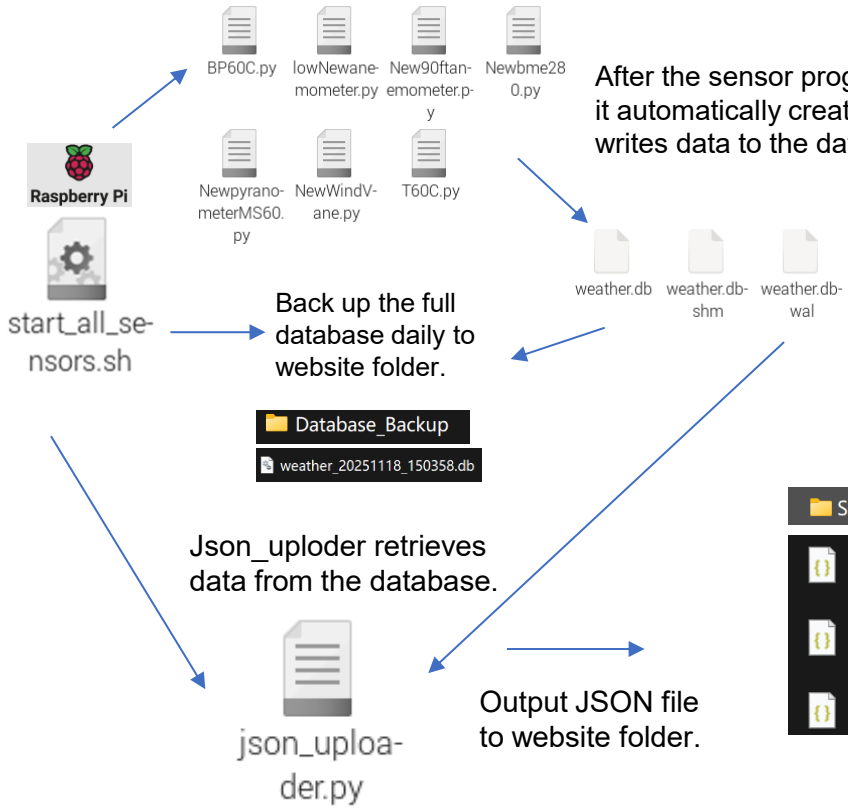
The goal of this test is to ensure the weather database is working correctly. This includes timely upload of most recent data, proper display of past data, proper display updates when new data comes in, proper labeling of data and no gaps or cut-outs in data collection. No tools or materials will be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

Steps:

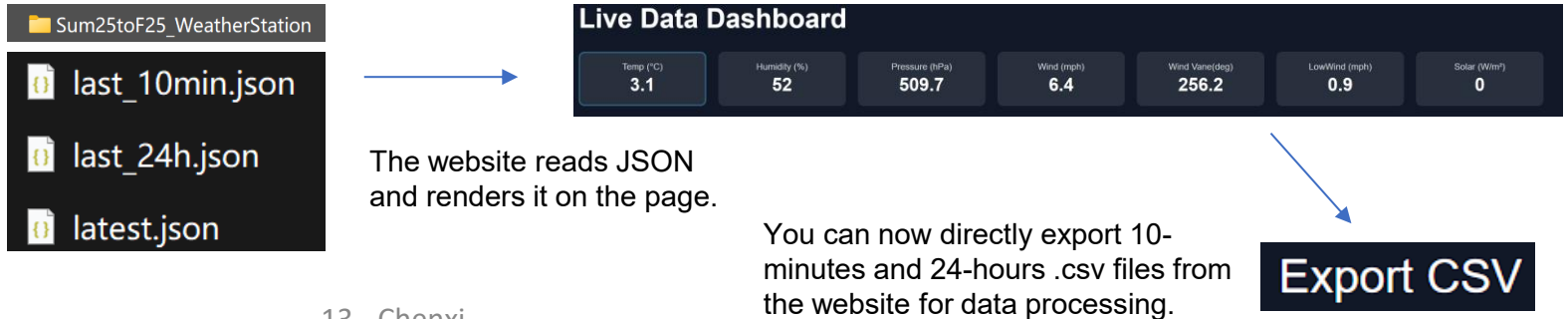
- The Raspberry Pi data collection is activated, and data from all seven sensors is first saved to a local database. Then, a separate program extracts the data from the database and exports a .json file to the NAU website folder for display. Simultaneously, the database .db file is uploaded to the NAU 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	Y	Y
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	Y	Y
ER6 - Measurement of All Data Types	5	N/A	5	N	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	N	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

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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	https://forecast.weather.gov/MapClick
B	Tempest	Tempest Home Weather S
C	Davis Vantage	https://www.davisinstrum

			Technical Requirements							Customer Opinion Survey				
	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
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 to 5	2	N/A	3	5	0.2					
	Absolute Technical Importance		82	sb	75	12	122	80	8					
	Relative Technical Importance		4	5	1	3	6	7	2					

Thank You & Questions?