Comparison and Impacts of Air Temperature Measurements from Aspirated and Unaspirated Radiation Shields

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ABSTRACT

There are mechanical and thermodynamic differences between unaspirated and aspirated radiation shields that make each model useful for different environmental settings. This research explores the differences between both models of radiation shields compared to relative humidity, solar radiation, wind speed at two meters, and how seasonal changes affect temperature differences. Five years of Mesonet temperature data was collected between five models of solar radiation shields and compared against the data from the oldest model. This method will show the comparison of the new versus the older solar radiation shield model temperature differences. The results found represent the statistical analysis for the comparison of each solar radiation shield model and in which way the temperature data is skewed in relation to environmental changes.

1. Introduction

Without the use of a solar radiation shield, temperature sensors in direct solar radiation have been observed to register marginally inaccurate readings. These imprecise measurements can have many causes, but the issue originates from indirect and direct radiative heating (Johnson and Wilby 2013). Even though radiation shield use has been the solution to shielding the thermistor sensing equipment from direct solar radiation, dirt, and inclement weather, it is not the perfect resolution. The correlation between wind speed and solar radiation exposure is one of the primary sources of error when using a solar radiation shield. Calm winds (< 1 ms^{-1}) and high solar radiation conditions (> 800 Wm^2) attribute to insulation issues that impact the internal sensors (Brock et al. 1995).

Unaspirated radiation shields do not require a power source and can be placed in any remote location without an abundant amount of equipment. The absence of auxiliary instruments makes this type of radiation shield more economically advantageous for microscale uses and sites that do not have the means for electrical power (Thomas and Smoot 2013). With no additional shield maintenance, these devices can be placed in remote locations without the requirement of additional electrical power components such as batteries and solar panels. The original design of the naturally ventilated shields consisted of stacked metallic plates and a variety of different materials that could be used for the overall reflective coating (Fuchs and Tanner 1965). This type of radiation shield requires the natural aspiration of the wind to create ventilation for the inner core.

Aspirated radiation shields require an energy source that powers an attached small fan that creates a constant speed of aspiration within the device. These models are more costly with installations and equipment needed to operate (Thomas and Smoot 2013). Some fan models are outdoor adaptable with control units and can adjust their fan speed based on the outside wind speed. The main difference between aspirated and unaspirated models is that it can create its own mechanical air flow when the wind speeds are low. Outside of the high maintenance cost, “Mechanically aspirated shields may also introduce uncertainties due to turbulent eddies and the possible wet bulb effect during rainy days” (Sakalis 2022). For long-term operation use, these models are often swapped out for naturally ventilated shields to save on financial costs.

There are limitations to both the aspirated and unaspirated radiation shield models. Many factors are taken

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into consideration with inaccurate temperature readings, such as relative humidity, wind speed, solar radiation, seasonal changes, and location. It is an accepted conclusion throughout the scientific community that radiative errors are inversely proportional to airflow circulation throughout the inside encasement of the radiation shield (Yang et al. 2016); however, mechanically aspirated radiation shields do not always record temperatures more accurately compared to an unaspirated shield. It is known that having an aspirated or unaspirated shield, in general, will make a positive impact towards improving accurate temperature measurements, but this research will cover the comparison of newer models of radiation shields to older generations, temperature differences with unaspirated and aspirated radiation shields, how seasonal changes impacts temperature measurements, and to what margin of difference are the temperature measurements being recorded.

Mesonet History

The Oklahoma Mesonet was formed on 1 January 1994 and operates 120 surface observation stations. Each station collects data such as soil measurements, temperature, dew point, relative humidity, rainfall, and other variables. Its headquarters are at the Oklahoma Climatological Survey (OCS) located at the National Weather Center (McPherson et al. 2007). "The mission of its personnel is to operate a world-class environmental monitoring network; to deliver high-quality observations and timely value-added products to Oklahoma citizens; to support state decision makers [and more]" (McPherson et al. 2007). This network can provide real-world emergency, agriculture, meteorological, and hydrology data in 5-minute intervals (Brock et al. 1995).

2. Equipment

a. Solar Radiation Shield and Temperature Sensors

The five models of solar radiation shields and paired temperature sensors used throughout this study were provided by the Oklahoma Mesonet. Each model was installed at a different time and received standard maintenance at least three times a year.

3. Data

a. Location

Data instruments for this research project were housed in two locations at the North Campus of the University of Oklahoma. Both meteorological research sites were in the same grassy field, approximately 100 meters in separation. The Norman Oklahoma Mesonet (NRMN) site contained the two Norman solar radiation shields, as well as sensors to measure relative humidity, solar radiation, and wind speed at 2 meters. The nearby research tower (NEX5) site contained the Apogee and Barani solar radiation shields.

b. Weather Conditions

Every sensor, except the Barani aspirated, has been placed long enough to experience the different weather conditions for all four seasons. The climate of central Oklahoma has a range of weather conditions, such as hot and dry summers, cold winters with subzero temperature days, springs with high levels of rainfall, and autumns with average to brisk temperatures.

c. Time Frame

Each thermistor sensor used was installed at a different time, which is shown by an inconsistent amount of air temperature data with all 5 solar radiation shield observations. There are five years of relative humidity, solar radiation, wind speed at 2 meters, Norman, and Apogee temperature readings; three months of Barani aspirated, and two years of Barani Unaspirated data. Each sensor recorded its data in 5-minute intervals.

4. Methods

a. Finding the difference

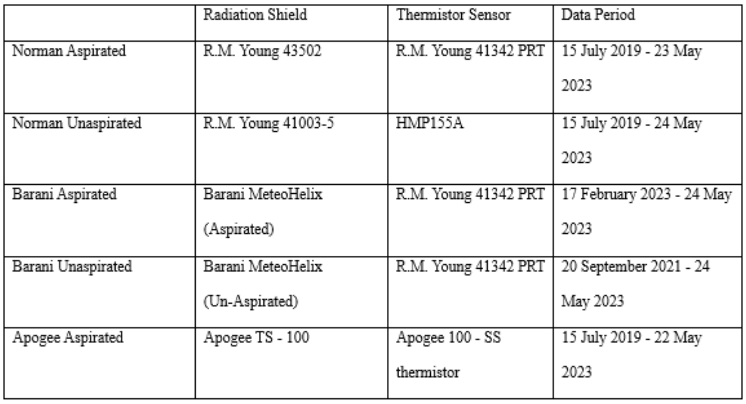
The Norman unaspirated shield is the oldest model of radiation shields used in this study and will represent the constant variable when calculating the difference between two temperature recordings. To calculate the difference, the other four radiation shield temperatures will be subtracted from the original Norman unaspirated temperature data. This will show the agreement of temperature measurements when compared to the wind speed at 2 meters, relative humidity, and solar radiation variables.

$$\text{Temperature Difference} = A\text{–}B \tag{1}$$

For each difference, A will represent the Norman unaspirated radiation shield data, and B will represent the data from the other four radiation shields. Once the temperature difference has been calculated, the visual data can be interpreted as anything above the zero-line representing a warmer temperature recorded by the original Norman data, and anything under the zero line represents a warmer temperature being recorded by the newer radiation shield.

b. Quality Assurance

Three processes of quality assurance were used to remove any sensor errors from the raw data imported. Upper and lower limit thresholds for each sensor were created and determined by what was realistically possible by meteorological standards for the sensor environment. The data were then converted to datetime to remove the dates of 27 October 2020 at 00:00UTC to 1 November



	Radiation Shield	Thermistor Sensor	Data Period
Norman Aspirated	R.M. Young 43502	R.M. Young 41342 PRT	15 July 2019 - 23 May 2023
Norman Unaspirated	R.M. Young 41003-5	HMP155A	15 July 2019 - 24 May 2023
Barani Aspirated	Barani MeteoHelix (Aspirated)	R.M. Young 41342 PRT	17 February 2023 - 24 May 2023
Barani Unaspirated	Barani MeteoHelix (Un-Aspirated)	R.M. Young 41342 PRT	20 September 2021 - 24 May 2023
Apogee Aspirated	Apogee TS - 100	Apogee 100 - SS thermistor	15 July 2019 - 22 May 2023

TABLE 1: Solar Radiation Shield with Paired Temperature Sensor and Installation Dates.

2020 at 23:55UTC from the Apogee aspirated temperature sensor due to a recording error. If left unremoved, these data points would have negatively skewed the data with all three variables. The third process of quality assurance was setting upper and lower limits to the temperature differences to -4 and +4. This function performed a double-check to ensure that no inaccurate outlier data points were being utilized in any statistical analysis.

c. Data Thresholds

The data for each comparison variable was categorized into three sections (low, moderate, and high) and was set based on the skewness of the data. The root mean squared difference and mean of the temperature differences were determined for each section and can be seen in Figures 1-3.

d. Statistical Analysis

Table 2-4 represents the overall statistical analysis measured for each temperature comparison graph. The root mean squared, and mean were calculated for the low, moderate, and high variable thresholds.

5. Results

a. Wind Speed at 2 Meters

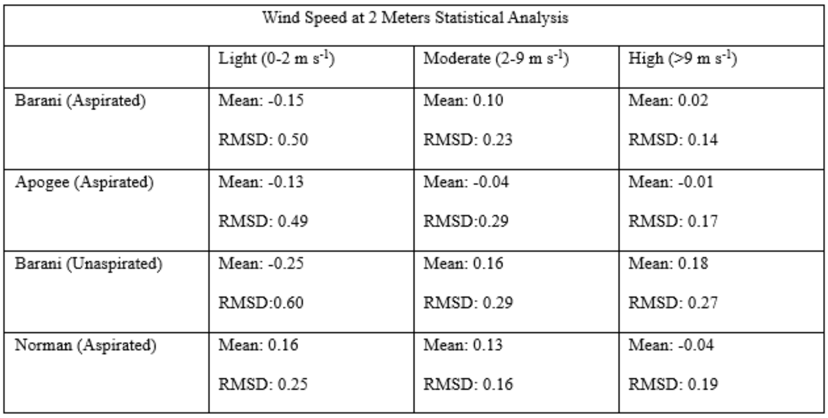
Out of the four radiation shield comparisons, each plot followed the same trend of decreasing temperature differences as the wind speed increased. The biggest difference in temperature alignment occurred in the light wind sections when the wind speeds were less than 2 ms^{-1}. The Apogee model took until 4 ms^{-1} to start having more of an overlap with the Norman unaspirated data. Once the wind speeds increased into the moderate range, the root mean squared decreased sharply in all four comparisons. High winds of > 9 ms^{-1} had the best temperature agreement apart from the Norman aspirated radiation shield. This radiation shield had a temperature difference mean of -0.04°C during high winds, but the root mean squared increased from 0.16°C to 0.19°C. The Barani aspirated was the newest model of radiation shields and had fewer data points, but the root mean squared was the second most aligned to the oldest Norman unaspirated radiation shield. This is a good representation of how the oldest 10 stack plate model is holding up to the helictical aspirated radiation shield design. With the temperature difference correlated to wind speed measurements, the increased wind speed has a direct correlation to improved temperature difference.

b. Relative Humidity

Relative humidity is "the ratio of the amount of water vapor in the air to the amount of water vapor air can hold at that temperature" (Elovitz 1995). Looking at the statistical analysis of the comparison of temperature differences to relative humidity, there are no significant changes to temperature measurement alignment. The means and root mean squared of each low, moderate, and high section follow no specific patterns. The lack of a specific finding indicates that relative humidity does not have a positive or negative impact on the usage of an aspirated or unaspirated radiation shield.

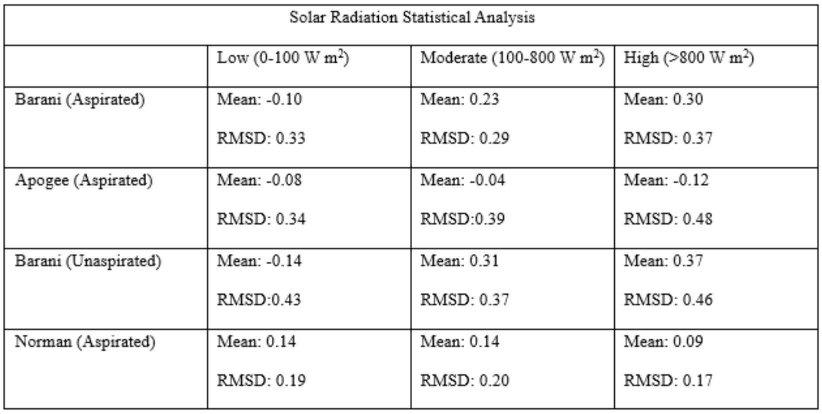
c. Solar Radiation

Without adequate coverage and ventilation, sensors are most affected by indirect and direct solar radiation. Most radiation shields are developed to protect their inner devices from high solar angles, but the 10 stacked plate design is not built to protect against the low solar angles of the early morning and late evening. This stacked design model has openings on the side that allows for direct solar radiation to peak through the device and cause overheating. The Barani aspirated and unaspirated models take each solar angle into account with their new helical



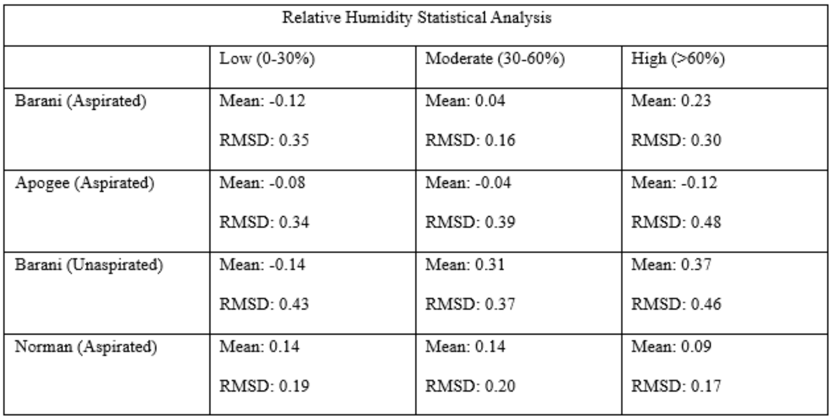
Wind Speed at 2 Meters Statistical Analysis			
	Light (0-2 m s^{-1})	Moderate (2-9 m s^{-1})	High (>9 m s^{-1})
Barani (Aspirated)	Mean: -0.15 RMSD: 0.50	Mean: 0.10 RMSD: 0.23	Mean: 0.02 RMSD: 0.14
Apogee (Aspirated)	Mean: -0.13 RMSD: 0.49	Mean: -0.04 RMSD:0.29	Mean: -0.01 RMSD: 0.17
Barani (Unaspirated)	Mean: -0.25 RMSD:0.60	Mean: 0.16 RMSD: 0.29	Mean: 0.18 RMSD: 0.27
Norman (Aspirated)	Mean: 0.16 RMSD: 0.25	Mean: 0.13 RMSD: 0.16	Mean: -0.04 RMSD: 0.19

TABLE 2: Temperature Difference Statistics based on Wind Speed at 2 Meters



Solar Radiation Statistical Analysis			
	Low (0-100 W m^2)	Moderate (100-800 W m^2)	High (>800 W m^2)
Barani (Aspirated)	Mean: -0.10 RMSD: 0.33	Mean: 0.23 RMSD: 0.29	Mean: 0.30 RMSD: 0.37
Apogee (Aspirated)	Mean: -0.08 RMSD: 0.34	Mean: -0.04 RMSD:0.39	Mean: -0.12 RMSD: 0.48
Barani (Unaspirated)	Mean: -0.14 RMSD:0.43	Mean: 0.31 RMSD: 0.37	Mean: 0.37 RMSD: 0.46
Norman (Aspirated)	Mean: 0.14 RMSD: 0.19	Mean: 0.14 RMSD: 0.20	Mean: 0.09 RMSD: 0.17

TABLE 3: Temperature Difference Statistics based on Solar Radiation.



Relative Humidity Statistical Analysis			
	Low (0-30%)	Moderate (30-60%)	High (>60%)
Barani (Aspirated)	Mean: -0.12 RMSD: 0.35	Mean: 0.04 RMSD: 0.16	Mean: 0.23 RMSD: 0.30
Apogee (Aspirated)	Mean: -0.08 RMSD: 0.34	Mean: -0.04 RMSD: 0.39	Mean: -0.12 RMSD: 0.48
Barani (Unaspirated)	Mean: -0.14 RMSD: 0.43	Mean: 0.31 RMSD: 0.37	Mean: 0.37 RMSD: 0.46
Norman (Aspirated)	Mean: 0.14 RMSD: 0.19	Mean: 0.14 RMSD: 0.20	Mean: 0.09 RMSD: 0.17

TABLE 4: Temperature Difference Statistics based on Relative Humidity.

design. The spiral design shape is angled to create constant airflow and solar shielding from each angle. Out of the four temperature differences, the Barani aspirated and unaspirated were the coolest in correlation to the Norman unaspirated with the low, moderate, and high solar radia-

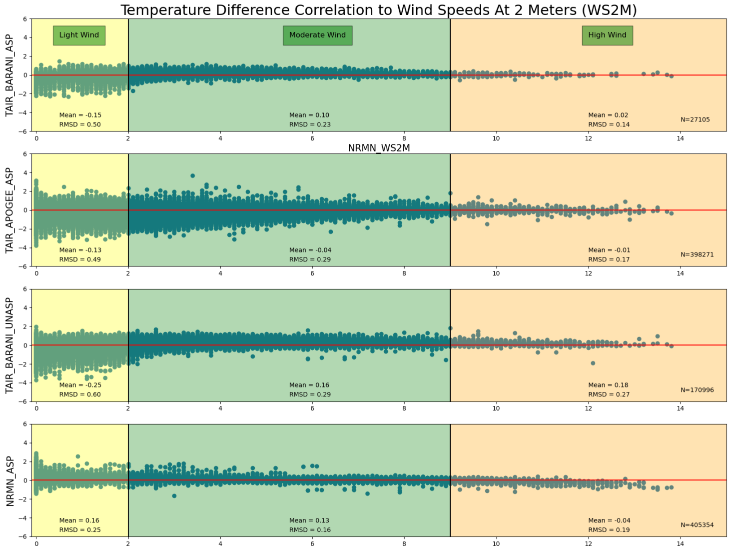


FIG. 1: Temperature Difference Correlation to Wind Speed Measurements at 2 Meters.

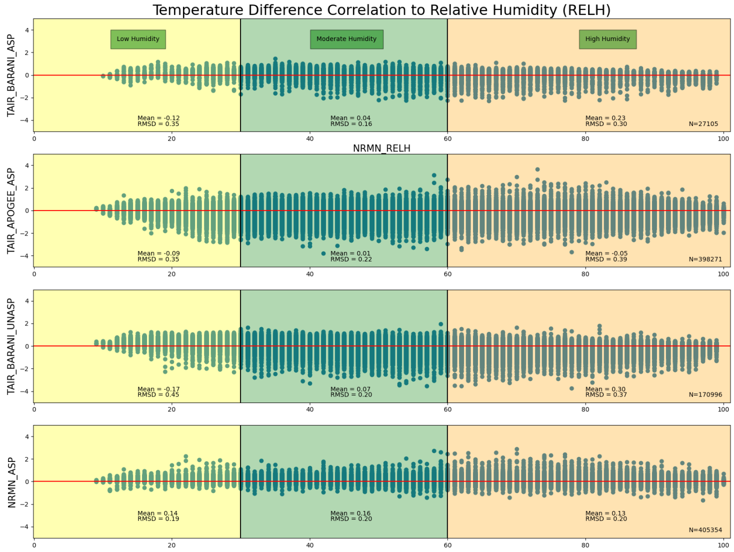


FIG. 2: Temperature Difference Correlation to Relative Humidity.

tion. This shows that the Barani helical design is working against the issue of direct sunlight from lower solar angles.

d. Effects of Season Changes

The Barani aspirated device was not included with this variable because the equipment did not have enough history for the statistical analysis of all four seasons. Each season was broken into three-month increments, with Winter being December through February, Spring being March through May, Summer being June through July, and Fall being August through November. The temperature difference for the four radiation shields were consistent throughout each season. Out of each temperature difference, there was no outlier that indicated that one season was reporting different temperature measurements more precisely than the other. This result is what was expected for the properly functioning sensor and radiation shield pair. If there had been any significant difference, then that would have signified that further research needed to be done to find the reason for the outlier difference.

6. Conclusion

The results that came out of this study were mostly expected but beneficial to compare. The statistical analysis

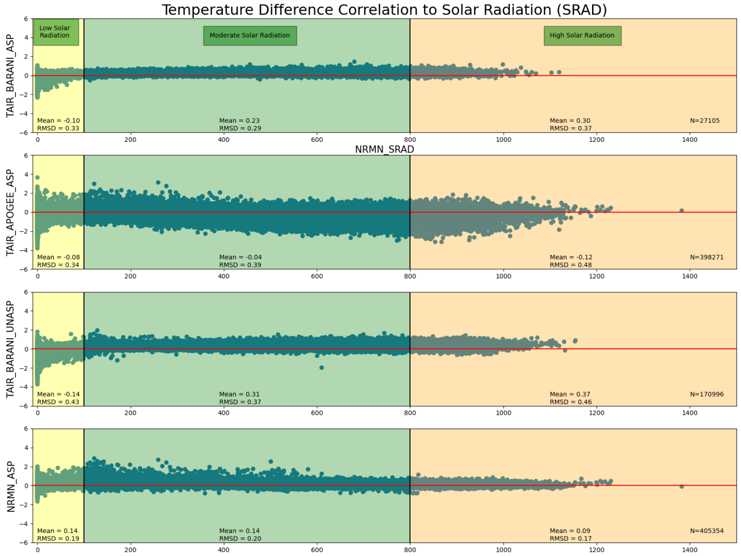


FIG. 3: Temperature Difference Correlation to Solar Radiation.

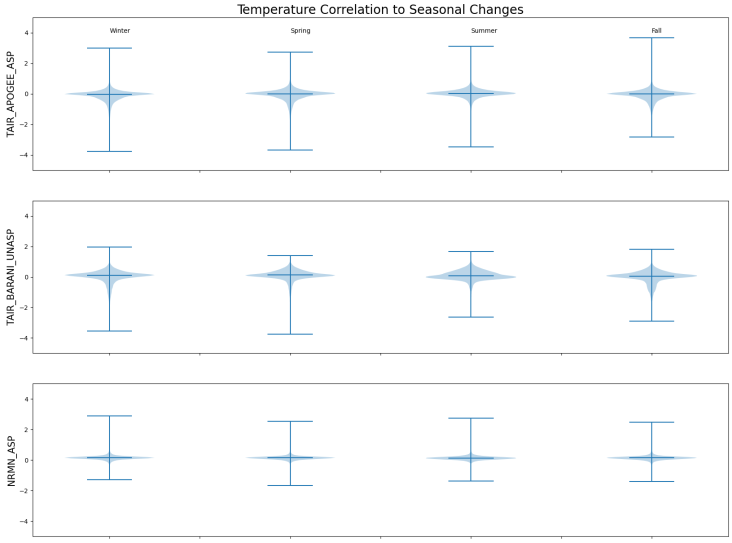


FIG. 4: Temperature Difference in Correlation to Seasonal Changes.

has confirmed that there was a direct correlation to wind speeds at 2 meters and temperature difference alignment, the Barani helical design is defensive against low solar radiation angles, and that there was no correlation with relative humidity to temperature differences. Although the Barani aspirated shield did not have as much temperature measurements, the difference to the 10-plate stacked model was relatively close and consistent. The Norman aspirated model was also close in location to the Norman unaspirated device, and that could be a reason as to why the data was similar in each comparison model. It was also found that the seasonal changes did not affect the temperature difference of each sensor, and that the bulk of the data was relatively aligned and fell within the range of -2°C and + 2°C. Each radiation shield displayed consistent results throughout each month, which is important as it shows that there was no seasonal bias to the temperature differences.

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