WIND DATA REPORT

Gardner NCCI

June 1, 2007 – August 31, 2007

Prepared for

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NOTICE AND ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

All the work presented in this Wind Data Report including installation and decommissioning of the meteorological tower and instrumentation, and the data analysis and reporting was preformed by the Renewable Energy Research Laboratory (RERL) at the University of Massachusetts, Amherst.

This report covers wind data measured at a 50 meter meteorological tower installed at the North Central Corrections Institution, in Gardner, MA. The tower has four anemometers, two at each height of 50 meters and 38 meters, respectively, as well as two wind vanes, one at each height. The data is collected by a NRG Symphonie data logger.

This quarter covers June 1, 2007 through August 31, 2007. The mean wind speed at 50 meters is 5.22 m/s (11.677 mph)* and the prevailing wind direction was from the west. The gross data recovery percentage (the actual percentage of expected data received) was 100.0% and the net data recovery percentage (the percentage of the expected data which passed all of the quality assurance tests) was 99.895%.

Additional information about interpreting the data presented in this report can be found in the Fact Sheet, "Interpreting Your Wind Resource Data," produced by RERL and the Massachusetts Technology Collaborative (MTC). This document is found through the RERL website:

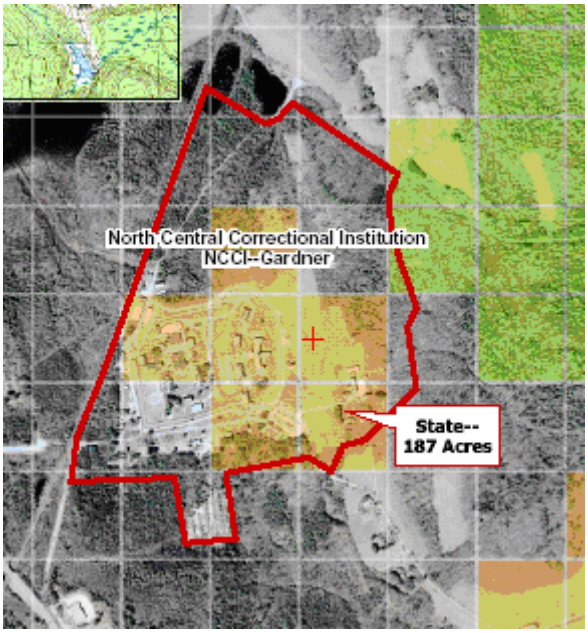
http://www.ceere.org/rerl/about_wind/RERL_Fact_Sheet_6_Wind_resource_interpretation.pdf

* 1 m/s = 2.237 mph.

SECTION 1

- Station Location

The station is located at Gardner North Central Correctional Institution, outside the prison on a grassy hill. The tower base is located at 42.581ºN, 71.939ºW. The red plus (+) denotes the approximate location of the tower.



SECTION 2 - Instrumentation and Equipment

The wind monitoring equipment is mounted on a NRG systems 50 meter (164') meteorological tower. The sensors include:

- NRG Symphonie Data Logger.
- 4 – Maximum # 40 Anemometers, standard calibration (Slope – 0.765 m/s, Offset – 0.350 m/s). Two anemometers are located at 50m (164') and two at 38m (124'8").
- 2 – NRG 200P Wind Vanes. One vane is at each height, 50m and 38m (164' and 124'8", respectively).
- 1 – NRG 110S Temperature Sensor, at 2m.
- 6 – Sensor booms, four 59" in length, two 43" in length.
- Lightning rod and copper ground cable.
- Shielded sensor cables.

SECTION 3- Data Summary

A summary of the wind speeds and wind directions measured during the reporting period is included in Table 1. Table 1 includes the mean wind speeds measured at each measurement height, the maximum instantaneous wind speed measured at each measurement height and the prevailing wind direction measured at each measurement height. These values are provided for each month of the reporting period and for the whole reporting period.

Table 1. Wind Speed and Direction Data Summary

Date	Mean Wind Speed	Max Wind Speed	Prevailing Wind Direction	Mean Wind Speed	Max Wind Speed	Prevailing Wind Direction
Height Units	**50 m [m/s]**	**50 m [m/s]**	**50 m**	**38 m [m/s]**	**38 m [m/s]**	**38 m**
June 2007	5.65	11.51	NW	5.20	10.76	NW
July 2007	5.11	15.89	W	4.67	14.94	W
Aug 2007	4.92	13.89	W	4.50	12.76	W
June 2007 -Aug 2007	**5.22**	**15.89**	**W**	**4.79**	**14.94**	**W**

Wind data statistics in the table are reported when more than 90% of the data during the reporting period are valid. In cases when larger amounts of data are missing, the percent of the available data that are used to determine the data statistics is noted.

No measurement of wind speed or direction can be perfectly accurate. Wind speed measurement errors occur due to anemometer manufacturing variability, anemometer calibration errors, the response of anemometers to turbulence and vertical air flow and due to air flows caused by the anemometer mounting system. Every effort is made to reduce the sources of these errors. Nevertheless, the values reported in this report have an expected uncertainty of about ± 2% or ± 0.2 m/s, whichever is greater. Wind direction measurement errors occur due to sensor measurement uncertainty, tower effects, boom alignment measurement errors and twisting of pipe sections during the raising of a pipe tower. Efforts are also made to reduce these errors, but the reported wind directions are estimated to have an uncertainty of +/- 5 degrees.

A summary of the turbulence intensity and mean wind shear measured at each measurement height during the reporting period is included In Table 2. These values are provided for each month of the reporting period and for the whole reporting period. Turbulence Intensity is calculated by dividing the standard deviation of the wind speed by the mean wind speed and is a measure of the gustiness of a wind resource. Lower

turbulence results in lower mechanical loads on a wind turbine. Turbulence intensity varies with wind speed. The average turbulence intensity presented in Table 2 is the mean turbulence intensity when the wind speed at each measurement height is between 10 and 11 m/s.

Shear coefficients provide a measure of the change in wind speed with height. When data at multiple heights are available, shear coefficients, α, have been determined. They can be used in the following formula to estimate the average wind speed, $U(z)$, at height z, when the average wind speed, $U(z_r)$, at height z_r is known:

$$U(z)=U(z_r)\left(\frac{z}{z_r}\right)^{\alpha}$$

The change in wind speed with height is a very complicated relationship related to atmospheric conditions, wind speed, wind direction, time of day and time of year. This formula will not always provide the correct answer at any given site. Nevertheless the calculated shear coefficient, based on measurements at two heights, can be used to characterize the degree of increase in wind speed with height at a site.

The mean wind shear coefficient that is provided here is calculated based on the mean wind speeds in Table 1, where z_{high} and z_{low} are the heights of the higher and lower mean wind speeds used in the calculation and $U(z_{low})$ and $U(z_{high})$ are the mean wind speeds at the two heights.

$$\alpha = \log\left(\frac{U(z_{high})}{U(z_{low})}\right) \Big/ \log\left(\frac{z_{high}}{z_{low}}\right)$$

Table 2. Shear and Turbulence Intensity Data Summary

Date	Turbulence Intensity at 10 m/s	Turbulence Intensity at 10 m/s	Mean Wind Shear Coefficient, α
Height Units	50 m [-]	38 m [-]	Between 50 m and 38 m [-]
June 2007	0.157	0.215	0.30
July 2007	0.212	0.239	0.34
Aug 2007	0.194	0.227	0.34
June 2007 -Aug 2007	**0.186**	**0.228**	**0.33**

SECTION 4- Graphs

This report contains several types of wind data graphs. Unless otherwise noted, each graph represents data from 1 quarter (3 months). The following graphs are included:

- Time Series – 10-minute average wind speeds are plotted against time. The plot is shown for June 1, 2007 through August 31, 2007.

- Wind Speed Distribution – A histogram plot giving the percentage of time that the wind is at a given wind speed. The plot is shown for June 1, 2007 through August 31, 2007, at a height of 50m.

- Monthly Average – A plot of the monthly average wind speed over a 12-month period. This graph shows the trends in the wind speed over the year, at a height of 50m for February 1, 2007 through August 31, 2007.

- Diurnal – A plot of the average wind speed for each hour of the day. The plot is shown for June 1, 2007 through August 31, 2007.

- Turbulence Intensity – A plot of turbulence intensity as a function of wind speed. Turbulence Intensity is calculated as the standard deviation of the wind speed divided by the wind speed and is a measure of the gustiness of a wind resource. Lower turbulence results in lower mechanical loads on a wind turbine. The plot is shown for June 1, 2007 through August 31, 2007.

- Wind Rose – A plot, by compass direction showing the percentage of time that the wind comes from a given direction and the average wind speed in that direction. The plot is shown for June 1, 2007 through August 31, 2007.

Data for the wind speed histograms, monthly and diurnal average plots, and wind roses are included in APPENDIX B.

Wind Speed Time Series

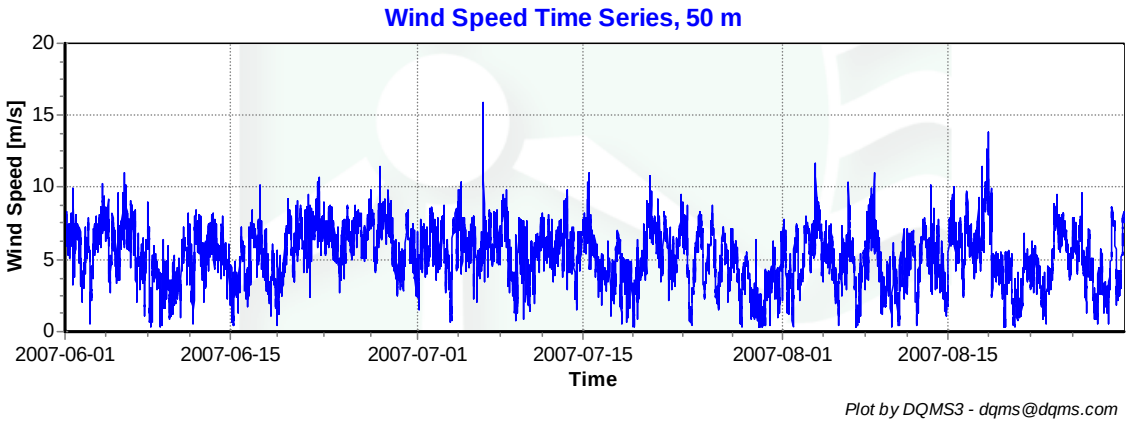


Figure 1 – Wind Speed Time Series, June 1, 2007 – August 31, 2007

Wind Speed Distributions

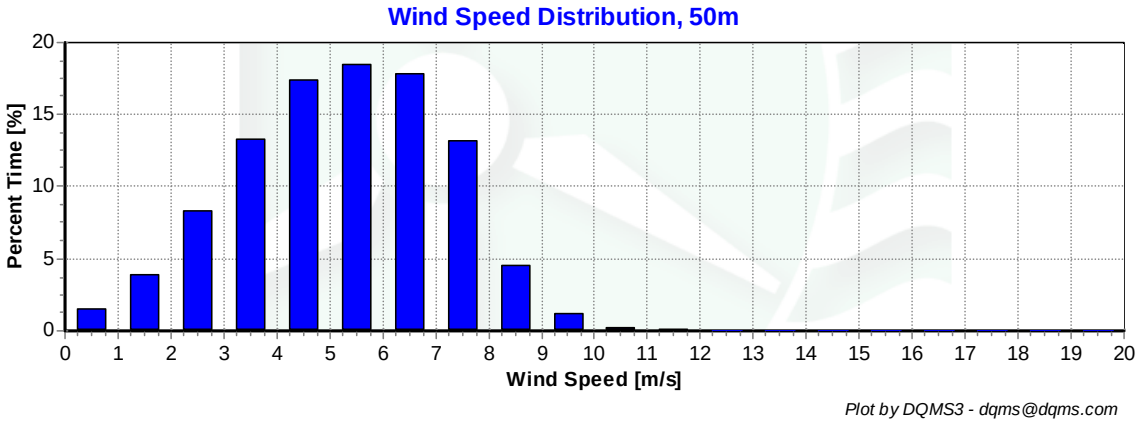


Figure 2 – Wind Speed Distribution, June 1, 2007 – August 31, 2007

Monthly Average Wind Speeds

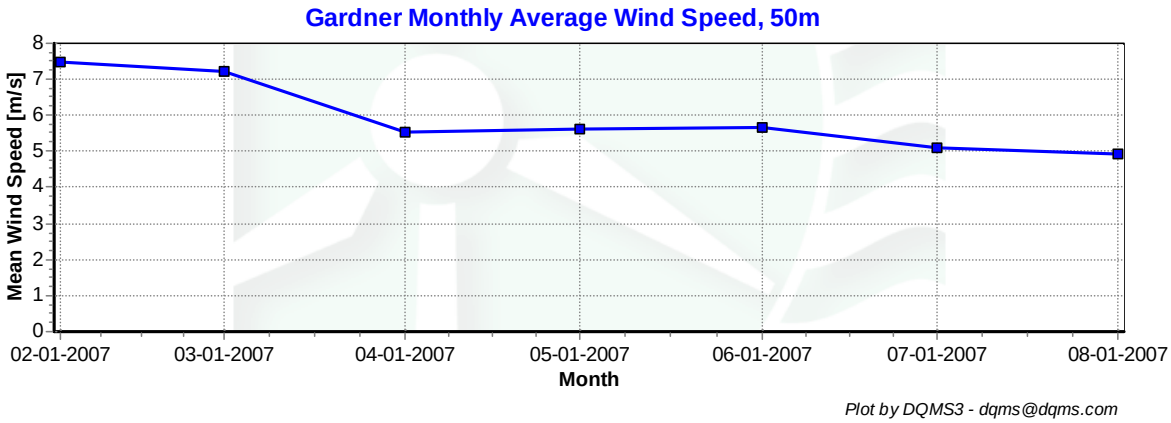


Figure 3 – Monthly Average Wind Speeds, February 1, 2007 – August 31, 2007

Diurnal Average Wind Speeds

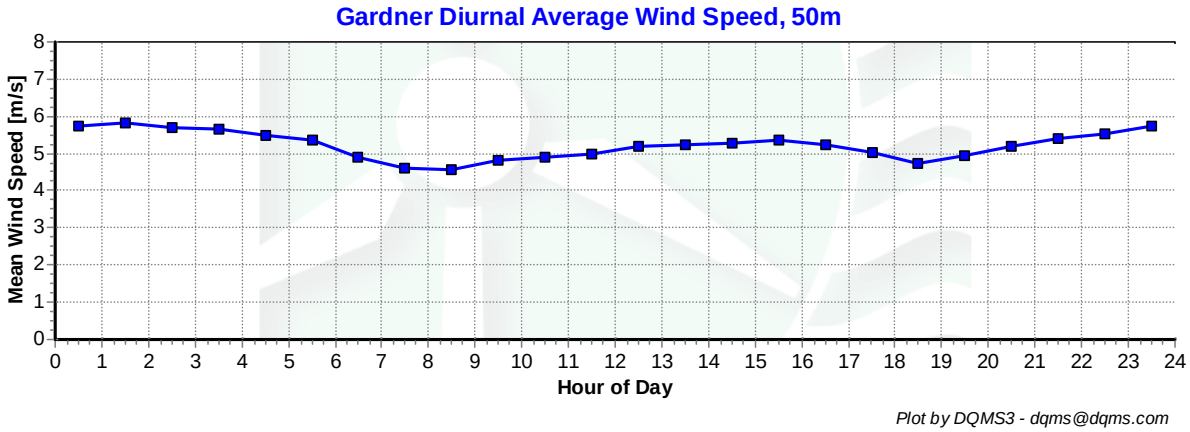


Figure 4 – Diurnal Average Wind Speed, June 1, 2007 – August 31, 2007

Turbulence Intensities

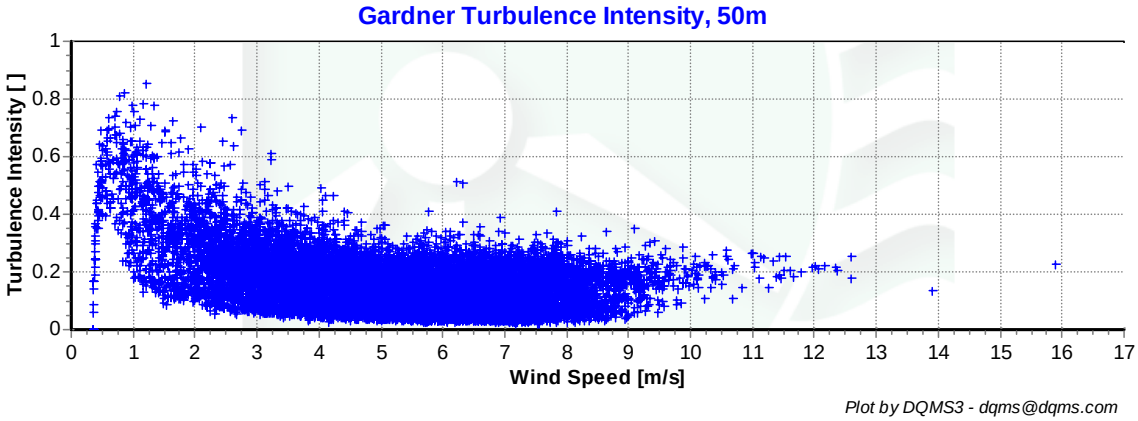


Figure 5 – Turbulent Intensity vs. Wind Speed, June 1, 2007 – August 31, 2007

Wind Roses

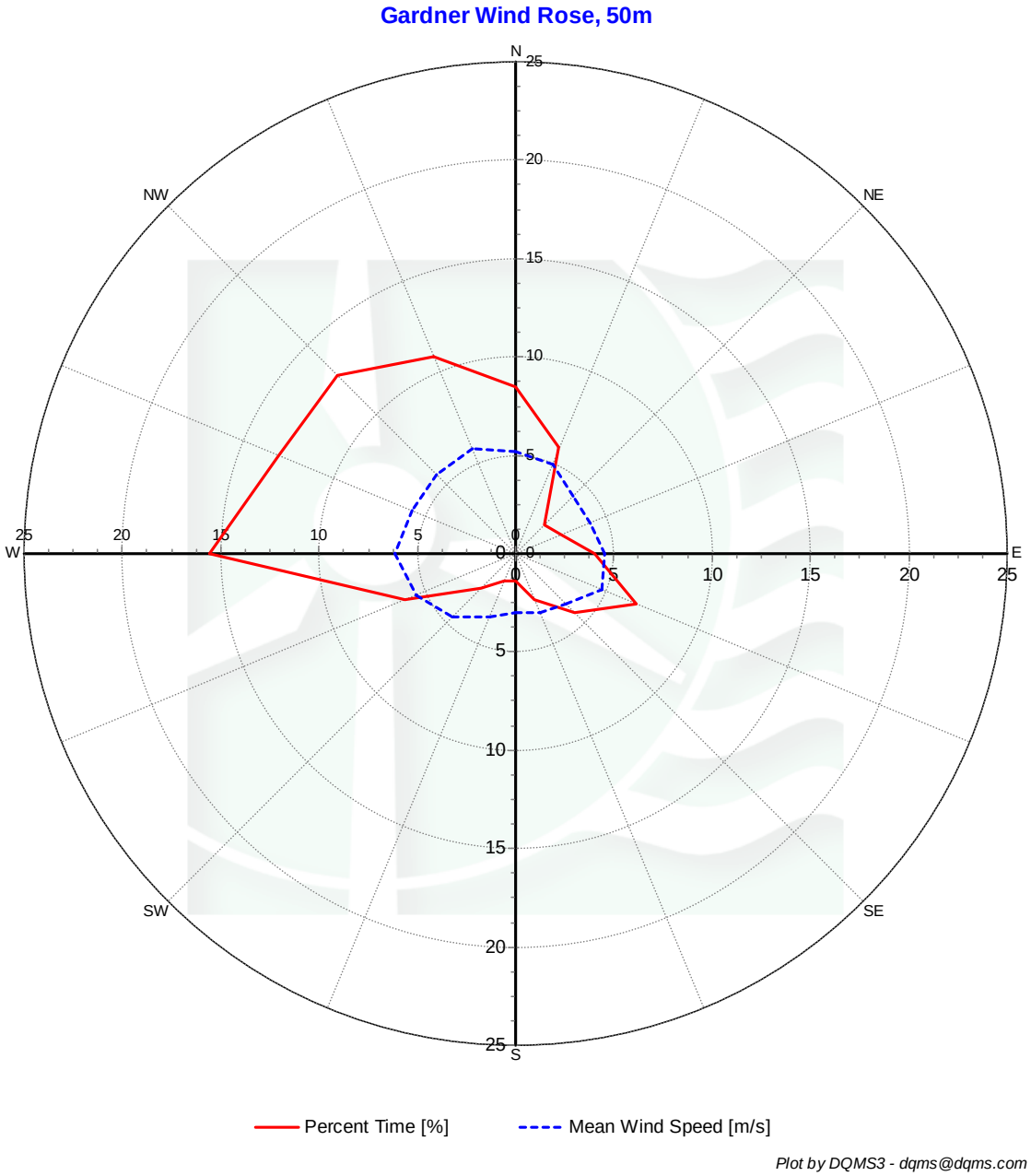


Figure 6 – Wind Rose, June 1, 2007 – August 31, 2007

SECTION 5 - Significant Meteorological Events

No significant meteorological events occurred within this quarter with affects on our wind data. This can be seen by no extreme fluctuations in the time series graph, Figure 1.

SECTION 6 - Data Collection and Maintenance

There were no significant problems with data acquisition or processing. No maintenance was done during this quarter.

SECTION 7 - Data Recovery and Validation

All raw wind data are subjected to a series of tests and filters to weed out data that are faulty or corrupted. Definitions of these quality assurance (QA) controls are given below under Test Definitions and Sensor Statistics. These control filters were designed to automate the quality control process and used many of the previous hand-worked data sets made at UMass to affect a suitable emulation. The gross percentage of data recovered (ratio of the number of raw data points received to data points expected) and net percentage (ratio of raw data points which passed all QA control tests to data points expected) are shown below.

Gross Data Recovered [%]	100
Net Data Recovered [%]	99.895

Test Definitions

All raw data were subjected to a series of validation tests, as described below. The sensors tested and the parameters specific to each sensor are given in the Sensor Performance Report which is included in APPENDIX A. Data which were flagged as invalid were not included in the statistics presented in this report.

MinMax Test: All sensors are expected to report data values within a range specified by the sensor and logger manufacturers. If a value falls outside this range, it is flagged as invalid. A data value from the sensor listed in Test Field 1 (TF1) is flagged if it is less than Factor 1 (F1) or greater than Factor 2. This test has been applied to the following sensors (as applicable): wind speed, wind speed standard deviation, wind direction, temperature, and solar insolation.

$$F1 > TF1 > F2$$

MinMaxT Test: This is a MinMax test for wind direction standard deviation with different ranges applied for high and low wind speeds. A wind direction standard

deviation data value (TF1) is flagged either if it is less than Factor 1, if the wind speed (TF2) is less than Factor 4 and the wind direction standard deviation is greater than Factor 2, or if the wind speed is greater than or equal to Factor 4 and the wind direction standard deviation is greater than Factor 3.

$$(TF1 < F1)$$
$$\text{or } (TF2 < F4 \text{ and } TF1 > F2)$$
$$\text{or } (TF2 \geq F4 \text{ and } TF1 > F3)$$

Icing Test: An icing event occurs when ice collects on a sensor and degrades its performance. Icing events are characterized by the simultaneous measurements of near-zero standard deviation of wind direction, non-zero wind speed, and near- or below-freezing temperatures. Wind speed, wind speed standard deviation, wind direction, and wind direction standard deviation data values are flagged if the wind direction standard deviation (CF1) is less than or equal to Factor 1 (F1), the wind speed (TF1) is greater than Factor 2 (F2), and the temperature (CF2) is less than Factor 3 (F3). To exit an icing event, the wind direction standard deviation must be greater than Factor 4.

$$CF1 \leq F1 \text{ and } TF1 > F2 \text{ and } CF2 < F3$$

CompareSensors Test: Where primary and redundant sensors are used, it is possible to determine when one of the sensors is not performing properly. For anemometers, poor performance is characterized by low data values. Therefore, if one sensor of the pair reports values significantly below the other, the low values are flagged. At low wind speeds (Test Fields 1 and 2 less than or equal to Factor 3) wind speed data are flagged if the absolute difference between the two wind speeds is greater than Factor 1. At high wind speeds (Test Fields 1 or 2 greater than Factor 3) wind speed data are flagged if the absolute value of the ratio of the two wind speeds is greater is greater than Factor 2.

$$[\ TF1 \leq F3 \text{ and } TF2 \leq F3 \text{ and } abs(TF1 - TF2) > F1\ ]$$
$$\text{or } [\ (TF1 > F3 \text{ or } TF2 > F3) \text{ and } (abs(1 - TF1 / TF2) > F2 \text{ or } abs(1 - TF2 / TF1) > F2)\ ]$$

Sensor Statistics

A summary of the results of the data collection and filtering are given in the Sensor Performance Report which is included in APPENDIX A. The following categories of information, tabulated for each sensor, are included in that report.

Expected Data Points: the total number of sample intervals between the start and end dates (inclusive).

Actual Data Points: the total number of data points recorded between the start and end dates.

% Data Recovered: the ratio of actual and expected data points (this is the *gross data recovered percentage*).

Hours Out of Range: total number of hours for which data were flagged according to MinMax and MinMaxT tests. These tests flag data which fall outside of an expected range.

Hours of Icing: total number of hours for which data were flagged according to Icing tests. This test uses the standard deviation of wind direction, air temperature, and wind speed to determine when sensor icing has occurred.

Hours of Fault: total number of hours for which data were flagged according to CompareSensors tests. These tests compare two sensors (e.g. primary and redundant anemometers installed at the same height) and flag data points where one sensor differs significantly from the other.

% Data Good: the filter results are subtracted from the gross data recovery percentage to yield the *net data recovered percentage*.

APPENDIX A - Sensor Performance Report

Test Definitions

TestOrder	TestField1	TestField2	TestField3	CalcField1	CalcField2	TestType	Factor1	Factor2	Factor3	Factor4
1						TimeTest Insert	0	0	0	0
2	Etmp2aDEGC					MinMax	-30	60	0	0
3	Etmx2aDEGC					MinMax	-30	60	0	0
4	Etmn2aDEGC					MinMax	-30	60	0	0
5	EtmpSD2aDEGC					MinMax	-30	60	0	0
10	Anem50aMS					MinMax	0	90	0	0
11	Anem50bMS					MinMax	0	90	0	0
12	Anem38aMS					MinMax	0	90	0	0
13	Anem38bMS					MinMax	0	90	0	0
15	Anem50yMS					MinMax	0	90	0	0
16	Anem38yMS					MinMax	0	90	0	0
20	AnemSD50aMS					MinMax	0	4	0	0
21	AnemSD50bMS					MinMax	0	4	0	0
22	AnemSD38aMS					MinMax	0	4	0	0
23	AnemSD38bMS					MinMax	0	4	0	0
25	AnemSD50yMS					MinMax	0	4	0	0
26	AnemSD38yMS					MinMax	0	4	0	0
30	Vane50aDEG					MinMax	0	359.9	0	0
31	Vane38aDEG					MinMax	0	359.9	0	0
50	Turb50zNONE					MinMax	0	2	0	0
51	Turb38zNONE					MinMax	0	2	0	0
60	Wshr0zNONE					MinMax	-100	100	0	0
70	Pwrd50zWMS					MinMax	0	5000	0	0
71	Pwrd38zWMS					MinMax	0	5000	0	0
200	VaneSD50aDEG	Anem50yMS				MinMaxT	0	100	100	10
201	VaneSD38aDEG	Anem38yMS				MinMaxT	0	100	100	10
300	Anem50aMS	AnemSD50aMS	Vane50aDEG	VaneSD50aDEG	Etmp2aDEGC	Icing	0.5	1	2	10
301	Anem50bMS	AnemSD50bMS	Vane50aDEG	VaneSD50aDEG	Etmp2aDEGC	Icing	0.5	1	2	10
302	Anem38aMS	AnemSD38aMS	Vane38aDEG	VaneSD38aDEG	Etmp2aDEGC	Icing	0.5	1	2	10
303	Anem38bMS	AnemSD38bMS	Vane38aDEG	VaneSD38aDEG	Etmp2aDEGC	Icing	0.5	1	2	10
400	Anem50aMS	Anem50bMS				CompareSensors	1	0.25	3	0
401	Anem38aMS	Anem38bMS				CompareSensors	1	0.25	3	0
500	Amax50aMS					MinMax	0	90	0	0
501	Amax50bMS					MinMax	0	90	0	0
502	Amax38aMS					MinMax	0	90	0	0
503	Amax38bMS					MinMax	0	90	0	0
510	Amin50aMS					MinMax	0	90	0	0
511	Amin50bMS					MinMax	0	90	0	0
512	Amin38aMS					MinMax	0	90	0	0
513	Amin38bMS					MinMax	0	90	0	0
520	Vmax50aDEG					MinMax	0	359.9	0	0
521	Vmax38aDEG					MinMax	0	359.9	0	0
530	Vmin50aDEG					MinMax	0	359.9	0	0
531	Vmin38aDEG					MinMax	0	359.9	0	0

Table 3 – Gardner Test Definitions

Sensor Statistics

Sensor	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	% Data Good
Anem50aMS	15162	15162	100	0.5	0	0	99.98
AnemSD50aMS	15162	15162	100	0.5	0	0	99.98
Anem50bMS	15162	15162	100	0.5	0	1.167	99.934
AnemSD50bMS	15162	15162	100	0.5	0	1.167	99.934
Anem38aMS	15162	15162	100	0.333	0	0.5	99.967
AnemSD38aMS	15162	15162	100	0.333	0	0.5	99.967
Anem38bMS	15162	15162	100	0.333	0	13.667	99.446
AnemSD38bMS	15162	15162	100	0.333	0	13.667	99.446
Vane50aDEG	15162	15162	100	0.833	0	0	99.967
VaneSD50aDEG	15162	15162	100	0.833	0	0	99.967
Vane38aDEG	15162	15162	100	0.667	0	0	99.974
VaneSD38aDEG	15162	15162	100	0.667	0	0	99.974
Etmp2aDEGC	15162	15162	100	0	0	0	100
EtmpSD2aDEGC	15162	15162	100	0	0	0	100
Total	212268	212268	100	6.333	0	30.667	99.895

Table 4 – Sensor Statistics, 50m and 38m, June 1, 2007 – August 31, 2007

APPENDIX B - Plot Data

Wind Speed Distribution Data

Wind Speed [m/s]	Percent
0.5	1.55
1.5	3.86
2.5	8.31
3.5	13.32
4.5	17.41
5.5	18.44
6.5	17.81
7.5	13.16
8.5	4.54
9.5	1.15
10.5	0.26
11.5	0.14
12.5	0.05
13.5	0.01
14.5	0.00
15.5	0.01
16.5	0.00
17.5	0.00
18.5	0.00
19.5	0.00
20.5	0.00
21.5	0.00
22.5	0.00
23.5	0.00
24.5	0.00

Table 6 – Wind Speed Distribution, 50m, June 1, 2007 – August 31, 2007

Monthly Average Wind Speed Data

Date	Average Wind Speed [m/s]
February 2007	7.46
March 2007	7.21
April 2007	5.56
May 2007	5.62
June 2007	5.65
July 2007	5.11
August 2007	4.92

Table 7 – Monthly Average Wind Speed, 50m, June 1, 2007 – August 31, 2007

Diurnal Average Wind Speed Data

Hour of Day	Average Wind Speed [m/s]
0.5	5.75
1.5	5.81
2.5	5.71
3.5	5.65
4.5	5.50
5.5	5.36
6.5	4.92
7.5	4.60
8.5	4.54
9.5	4.81
10.5	4.92
11.5	5.00
12.5	5.21
13.5	5.24
14.5	5.26
15.5	5.34
16.5	5.24
17.5	5.02
18.5	4.72
19.5	4.93
20.5	5.21
21.5	5.39
22.5	5.51
23.5	5.72

Table 8 – Diurnal Average Wind Speeds, 50m, June 1, 2007 – August 31, 2007

Wind Rose Data

Direction	Mean Wind Speed [m/s]	Percent of Time [%]
N	5.22	8.50
NNE	4.92	5.82
NE	4.13	2.07
ENE	4.08	2.51
E	4.53	3.99
ESE	4.75	6.63
SE	3.66	4.24
SSE	3.21	2.51
S	2.98	1.38
SSW	3.50	1.49
SW	4.50	2.51
WSW	5.46	6.13
W	6.12	15.55
WNW	5.67	13.06
NW	5.65	12.77
NNW	5.74	10.84

Table 9 – Wind Rose Data, 50m, June 1, 2007 – August 31, 2007