WIND DATA REPORT

Russell Municipal Lighting Company

February 3, 2009 – March 31, 2010

Prepared for

Massachusetts Department of Energy Resources
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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 performed by the Wind Energy Center (WEC) at the University of Massachusetts, Amherst.

Wind monitoring equipment was installed at Holiday Hill, a privately owned, large wooded land in the town of Russell on February 3rd 2009. The base of the 40 meter meteorological tower was installed 370 meters above sea level. Anemometers were installed at 25 and 39 meters (82.02 and 127.95 feet) above the base of the tower. There are redundant anemometers at both the heights. Wind direction vanes were installed at 25 and 39 meters. A temperature sensor is installed near the base of the tower.

This report summarizes the wind data collected between February 3, 2009 and March 31, 2010. Annual statistics are derived from data between March 1, 2009 and February 28, 2010. The annual mean recorded wind speed was 5.14 m/s (11.5 mph*) at 39 meters, and the prevailing wind direction was from the north-northwest. The average annual wind shear component was 0.23.

Additional information about interpreting the data presented in this report can be found in the Fact Sheet, "Interpreting Your Wind Resource Data," produced by WEC and the Massachusetts Technology Collaborative (MTC). This document is found through the WEC 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 Russell Municipal Lighting Company monitoring tower is located on Holiday Hill, a large wooded private area. The 50 meter tower is located at 42°12’40.09” N, 72°52’15.35 W and the tower base is approximately 370 meters above sea level. The approximate tower location is marked by the white box shown in Figure 1.

Figure 1 – Site Location

SECTION 2 - Instrumentation and Equipment

The wind monitoring equipment is mounted on a 40 m (131 ft) meteorological tower. The wind monitoring equipment comes from NRG systems and consists of the following items:

- NRG Symphonie data logger
- 4 – NRG #40 Anemometers, standard calibration (Slope – 0.765 m/s, Offset – 0.350 m/s). Two anemometers are located at 39 m (127.95 ft), and another two anemometers are located at 25 m (82.02 ft).
- 2 – NRG #200P Wind direction vanes. The vanes are located at 39 m (127.95 ft) and 25 m (82.02 ft).
- NRG #110S temperature sensor
- NRG iPack battery pack

The data from the Symphonie logger is mailed to WEC via a data card on a monthly basis. The logger samples wind speed and direction once every two second. These samples are combined into 10-minute averages and are put into a binary file along with the maximum, minimum and standard deviation for each 10-minute interval. The binary files are converted to ASCII text files using NRG software. These text files are then imported into a database software program where they are subjected to quality assurance tests prior to data usage.

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 calendar year between March 2009 and February 2010.

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	**39 m [m/s]**	**39 m [m/s]**	**39 m [m/s]**	**25 m [m/s]**	**25 m [m/s]**	**25 m [m/s]**
Mar 2009	5.25	24.44	NNW	4.82	26.33	NW
Apr 2009	5.58	25.57	NW	5.12	24.05	NW
May 2009	4.86	22.92	NNW	4.42	21.39	NW
Jun 2009	3.69	14.87	SSE	3.33	14.14	SSE
Jul 2009	4.11	21.79	NW	3.75	19.85	NW
Aug 2009	4.04	13.73	NNW	3.67	13.73	NW
Sep 2009	4.41	17.94	NNW	3.96	16.79	NW
Oct 2009	4.96	23.29	NNW	4.35	22.14	NW
Nov 2009	5.08	26.76	NNW	4.56	26.76	NW
Dec 2009	6.61	29.78	NNW	5.98	29.07	NW
Jan 2010	6.41	27.93	NNW	5.84	27.12	NW
Feb 2010	6.77	25.57	NNW	6.13	25.57	NW
Mar 2010	6.06	25.57	NNW	5.48	24.05	NW
Mar 2006 -Feb 2006	**5.14**	**18**	**NNW**	**4.65**	**16.26**	**NW**

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 amount 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 the highest measurement height is between 9.5 and 10.5 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	39 m [-]	25 m [-]	Between 50 m and 40 m [-]
Mar 2009	0.23	0.23	0.19
Apr 2009	0.23	0.23	0.19
May 2009	0.22	0.24	0.21
Jun 2009	0.18	-	0.23
Jul 2009	0.21	0.22	0.21
Aug 2009	0.16	-	0.22
Sep 2009	0.19	0.22	0.24
Oct 2009	0.21	0.24	0.30
Nov 2009	0.21	0.23	0.24
Dec 2009	0.22	0.24	0.23
Jan 2010	0.2	0.23	0.21
Feb 2010	0.22	0.24	0.22
Mar 2010	0.21	0.24	0.23
Mar 2009 – Feb 2010	**0.22**	**0.24**	**0.23**

SECTION 4- Long Term Estimate and Capacity Factor

Wind speed varies year by year and the mean obtained over the measurement period may be less or more compared to what is seen over a longer time period. Therefore, the use of the long term mean at the site is preferred when projecting the performance of a wind turbine. The long term mean at a site may be estimated by using the Measure-Correlate-Predict (MCP) method.

The MCP method correlates wind speed measurements at the target site to a reference site which collects data over the same period of time and has been collecting data for a much longer period. Based on this correlation, the reference wind speed data is used to predict long term mean at the site.

Long term data from the Blandford tower between October 15th, 2006 and October 15th, 2009 is used as reference in the case of Russell. Correlation between the two sites are obtained from concurrent data between February 7th, 2009 and April 12th, 2010. The long term mean at Russell at 39 m is estimated to be 4.86 m/s with an uncertainty of 1.8% for the MCP process. This estimate may also be used to calculate the long term mean at different heights by using the mean wind shear at site and the equation described in the previous section. The long term mean wind speed at 70 m height is estimated at 5.56 m/s.

The capacity factor of a wind turbine at a given site depends on the hub height, wind speed distribution at the hub height, the wind turbine power curve and any assumptions about down time and losses due to wake effects from upwind wind turbines, etc. If the hub height wind speed is estimated from data at lower heights, then the capacity factor will also depend on the estimated wind shear and the wind speeds measured at lower heights. No simple estimate of capacity factor at a site could take all of these effects and choices into account. Nevertheless, an estimate of the capacity factor of a wind turbine at this site is provided here to help the reader understand the order of magnitude of the wind resource at this site.

The estimates assume a GE 1.5 sl turbine with a hub height of 80 m and the long term mean wind speed estimate at the highest measurement height and the mean wind shear at the site, in order to determine the mean hub height wind speed, in this case 5.73 m/s. The wind speed probability distribution is assumed to be given by a Rayleigh distribution. The average wind turbine power is then estimated from:

$$\overline{P_W} = \int_0^\infty P_W(U)\,p(U)\,dU$$

where $P_W(U)$ is the wind turbine power curve and $p(U)$ is the wind speed probability distribution. The capacity factor is then calculated from:

$$CF = \frac{\overline{P_W}}{P_{rated}}$$

where P_{rated} is the rated capacity of the turbine, i.e., 1500 kW. Based on this equation, the estimated capacity factor of a wind turbine at this site would be about 0.24.

SECTION 5- Graphs

This report contains several types of wind data graphs. Unless otherwise noted, each graph represents data from one calendar year (March 2009 to February 2010). The following graphs are included:

- Time Series – 10-minute average wind speeds are plotted against time. This graph includes all of the collected data. Peak 10-minute averages in the summer barely go beyond 10 m/s while they generally are between 12 m/s to 18 m/s in the winter.

- Wind Speed Distribution – A histogram plot giving the percentage of time that the wind is at a given wind speed. Nearly half of the time the wind speeds are between 3 m/s and 6 m/s.

- 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 whole period of data collection. The overall pattern of higher wind speeds in the winter compared to the summer can be easily seen.

- Diurnal – A plot of the average wind speed for each hour of the day. There is a slight increase of wind speed in the afternoon and early night. The lowest wind speeds occur in the mornings between 7 to 10 AM.

- 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.

- 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. There is a definite directional preference for the wind to come in from the north-northwest and northwest. Concurrently, the higher wind speed averages are coming in from the same direction.

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

<u>Wind Speed Time Series</u>

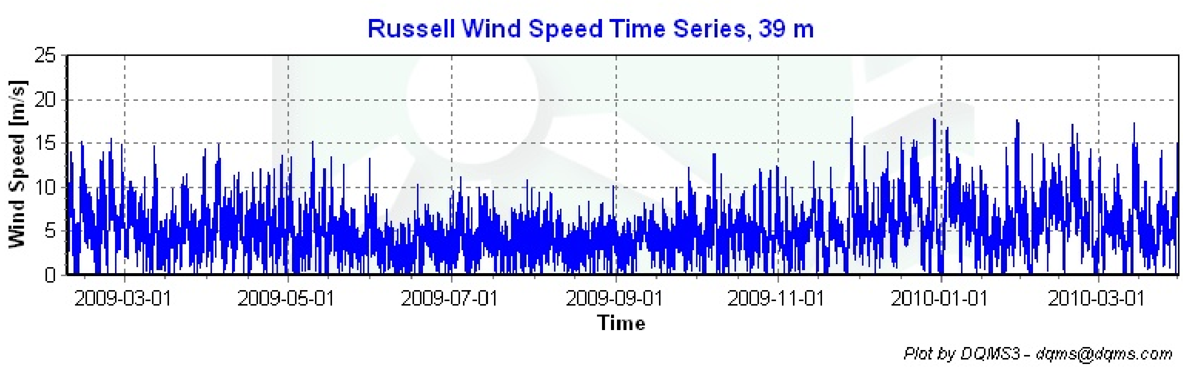

Figure 2 - Wind Speed Time Series, February 3, 2009 – March 31, 2010

Wind Speed Distributions

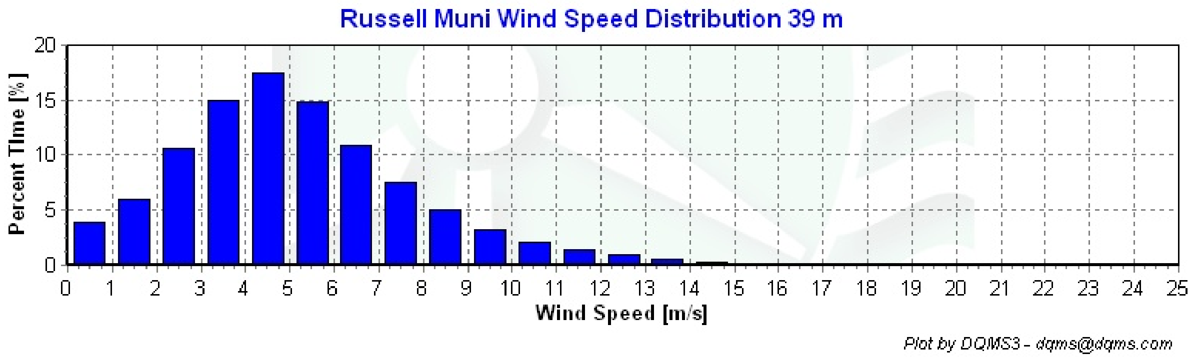

Figure 3 - Wind Speed Distribution, March 1, 2009 – February 28, 2010

Monthly Average Wind Speeds

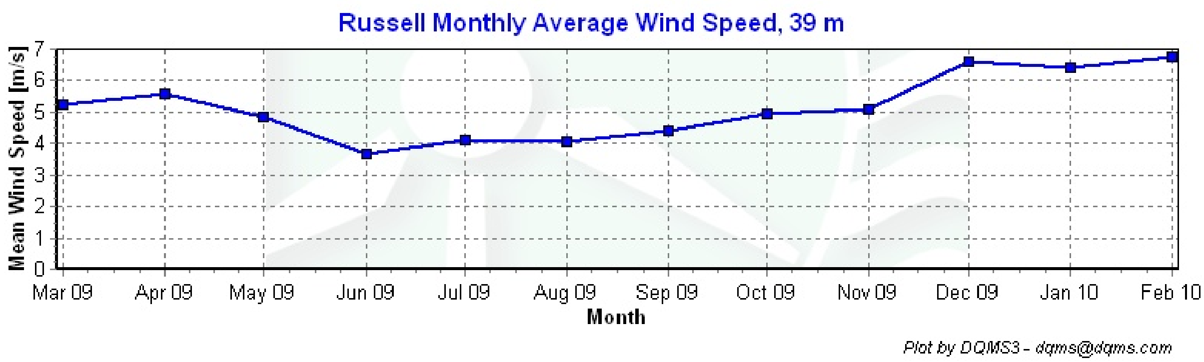

Figure 4 – Monthly Average Wind Speed, March 2009 – February 2010

Diurnal Average Wind Speeds

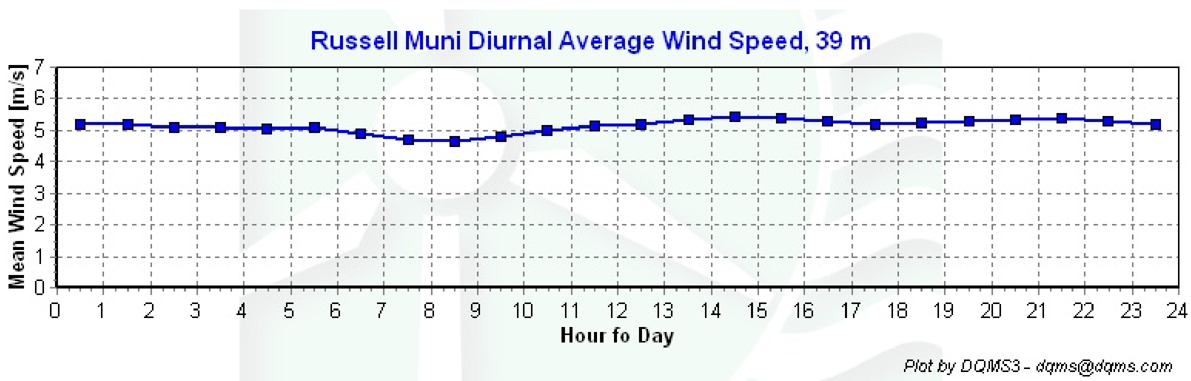

Figure 5 - Diurnal Average Wind Speeds, March 1, 2009 – February 28, 2010

Turbulence Intensities

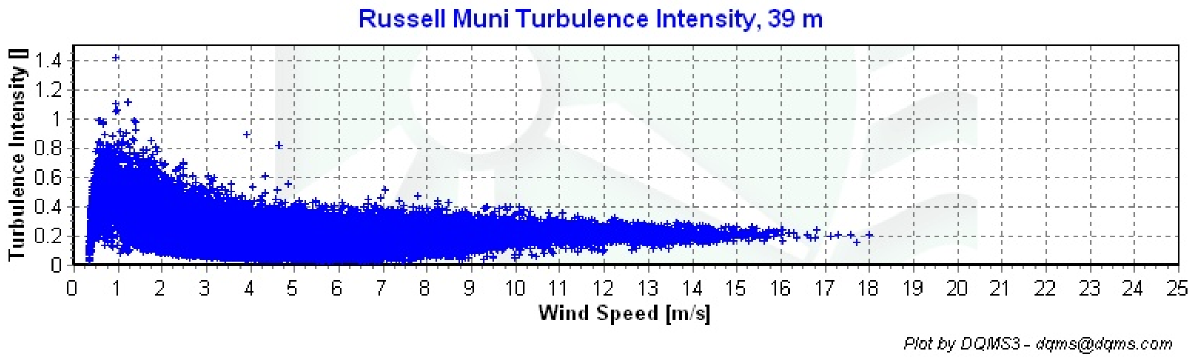

Figure 6 - Turbulence Intensity vs. Wind Speed, March 1, 2009 – February 28, 2010

Wind Roses

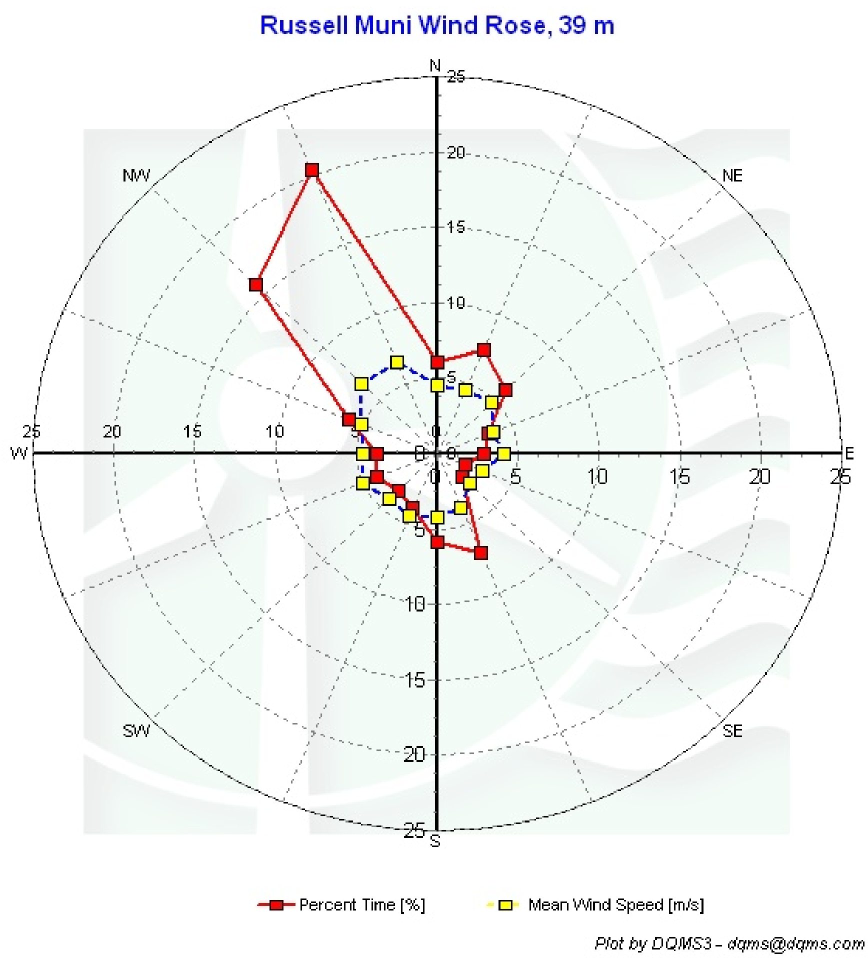

Figure 7 - Wind Rose, March 1, 2009 – February 28, 2010

SECTION 6 - Significant Meteorological Events

There were no significant meteorological events for the year except for some winter snow storms that caused some damage to the area but the met tower and equipment were unaffected except for some icing events.

SECTION 7 - Data Collection and Maintenance

All sensors and equipment functioned properly throughout the monitoring period. No maintenance was performed throughout the period.

SECTION 8 - 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 [%]	99.1

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.

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

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

Test Order	Test Field 1	Test Field 2	Test Field 3	Calc Field 1	Calc Field 2	Test Type	Factor 1	Factor 2	Factor 3	Factor 4
1						TimeTest Insert	0	0	0	0
2	Anem39aMS					MinMax	0	90	0	0
3	Anem39bMS					MinMax	0	90	0	0
4	Anem25aMS					MinMax	0	90	0	0
5	Anem25bMS					MinMax	0	90	0	0
6	Anem39yMS					MinMax	0	90	0	0
7	Anem25yMS					MinMax	0	90	0	0
8	Vane39aDEG					MinMax	0	359.9	0	0
9	Vane25aDEG					MinMax	0	359.9	0	0
10	Etemp3aDEGF					MinMax	-30	60	0	0
11	Batt3aVDC					MinMax	10.5	15	0	0
12	Turb39zNONE					MinMax	0	2	0	0
13	Turb25zNONE					MinMax	0	2	0	0
14	AnemSD39aMS					MinMax	0	4	0	0
15	AnemSD39bMS					MinMax	0	4	0	0
16	AnemSD25aMS					MinMax	0	4	0	0
17	AnemSD25bMS					MinMax	0	4	0	0
18	AnemSD39yMS					MinMax	0	4	0	0
19	AnemSD25yMS					MinMax	0	4	0	0
21	EtempSD3aDEGF					MinMax	-30	60	0	0
22	BattSD3aVDC					MinMax	0	5	0	0
200	VaneSD39aDEG	Anem39yMS				MinMaxT	0	100	100	10
201	VaneSD25aDEG	Vane25yMS				MinMaxT	0	100	100	10
300	Anem39aMS	AanemSD39aMS	Vane39aDEG	VaneSD39aDEG	Etemp3aDEGF	Icing	0.5	1	2	4
301	Anem39bMS	AanemSD39bMS	Vane39aDEG	VaneSD39aDEG	Etemp3aDEGF	Icing	0.5	1	2	4
302	Anem25aMS	AanemSD25aMS	Vane25aDEG	VaneSD25aDEG	Etemp3aDEGF	Icing	0.5	1	2	4
303	Anem25bMS	AanemSD25bMS	Vane25aDEG	VaneSD25aDEG	Etemp3aDEGF	Icing	0.5	1	2	4
400	Anem39aMS	Anem39bMS				Compare Sensors	1	0.25	3	0
401	Anem25aMS	Anem25bMS				Compare Sensors	1	0.25	3	0

Sensor Statistics

Sensor	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	% Data Good
ETemp	52560	52560	100	279.167	0	0	96.813
BatteryVolt	52560	52560	100	1.333	0	0	99.985
Vane25	52560	52560	100	0	24.5	0	99.72
Anem25a	52560	52560	100	2.333	24.5	1.167	99.68
Anem25b	52560	52560	100	0.833	10	32.167	99.511
Vane39	52560	52560	100	0	49.667	0	99.433
Anem39a	52560	52560	100	3.667	49	28.667	99.148
Anem39b	52560	52560	100	1.5	43.333	87	98.499
Total	420480	420480	100	288.833	201	149	99.099

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	Mar. 2009 – Feb. 2010 [%]
0.5	3.86
1.5	6.05
2.5	10.63
3.5	15.01
4.5	17.51
5.5	14.88
6.5	10.92
7.5	7.49
8.5	5.09
9.5	3.16
10.5	2.09
11.5	1.42
12.5	0.92

Bin Center Wind Speed [m/s]	Mar. 2009 – Feb. 2010 [%]
13.5	0.56
14.5	0.29
15.5	0.1
16.5	0.02
17.5	0.01
18.5	0
19.5	0
20.5	0
21.5	0
22.5	0
23.5	0
24.5	0

Monthly Average Wind Speed Data

Month	Mean Wind Speed [m/s]
Mar 2009	5.25
Apr 2009	5.58
May 2009	4.86
Jun 2009	3.69
Jul 2009	4.11
Aug 2009	4.04
Sep 2009	4.41
Oct 2009	4.96
Nov 2009	5.08
Dec 2009	6.61
Jan 2010	6.41
Feb 2010	6.77
Mar 2010	6.06

Diurnal Average Wind Speed Data

Hour of Day	Mar. 2009 – Feb. 2010 Mean Wind Speed [m/s]
0.5	5.21
1.5	5.17
2.5	5.11
3.5	5.09
4.5	5.06
5.5	5.07
6.5	4.88
7.5	4.7
8.5	4.66
9.5	4.78
10.5	4.98
11.5	5.14
12.5	5.18
13.5	5.33
14.5	5.41
15.5	5.38
16.5	5.27
17.5	5.18
18.5	5.23
19.5	5.28
20.5	5.34
21.5	5.4
22.5	5.28
23.5	5.17

Wind Rose Data

Direction	Mar. 2009 – Feb. 2010	
	Percent Time [%]	Mean Wind Speed [m/s]
N	6.08	4.52
NNE	7.42	4.52
NE	5.9	4.76
ENE	3.45	3.74
E	2.85	4.1
ESE	1.85	3.06
SE	2.22	2.83
SSE	7.08	3.86
S	5.86	4.24
SSW	3.94	4.5
SW	3.44	4.16
WSW	4.03	5.03
W	3.72	4.62
WNW	5.89	5.08
NW	15.9	6.59
NNW	20.38	6.57