WIND DATA REPORT

Camden Hills Regional High School, ME

February 1, 2006 – July 29, 2007

Prepared for

Massachusetts Technology Collaborative
75 North Drive
Westborough, MA 01581

by

Matthew A. Lackner
James F. Manwell
Anthony L. Rogers
Anthony F. Ellis

July 31, 2007

Report template version 1.3

Renewable **E**nergy **R**esearch **L**aboratory
University of Massachusetts, Amherst
160 Governors Drive, Amherst, MA 01003
www.ceere.org/rerl • (413) 545-4359 • rerl@ecs.umass.edu

TABLE OF CONTENTS

TABLE OF FIGURES

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 Renewable Energy Research Laboratory (RERL) at the University of Massachusetts, Amherst.

This report covers wind data measured at the Camden Hills Regional High School site in Maine, which was installed on February 1, 2006. Two anemometers and one wind vane are mounted at both 39 m (127.9 ft) and 30 m (98.4 ft).

The period covered by this report is February 1, 2006 – July 29, 2007. The gross data recovery percentage (the actual percentage of expected data received) for the period was 99.9 % and the net data recovery percentage (the percentage of expected data which passed all of the quality assurance tests) was 98.2%.

Annual statistics are also provided in this report. All annual statistics are calculated from data between March 1, 2006 and February 28, 2007. The mean recorded wind speed at 39 m was 3.75 m/s (8.4 mph)* and the prevailing direction was from the west during this one year period. The gross data recovery percentage (the actual percentage of expected data received) for the period was 100 % and the net data recovery percentage (the percentage of expected data which passed all of the quality assurance tests) was 98.4%.

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 the Camden Hills Regional High School. The tower base is located at 44.190° N, -69.100° W (WGS84/ NAD83) (Figure 1). The red cross indicates the approximate location of the tower.

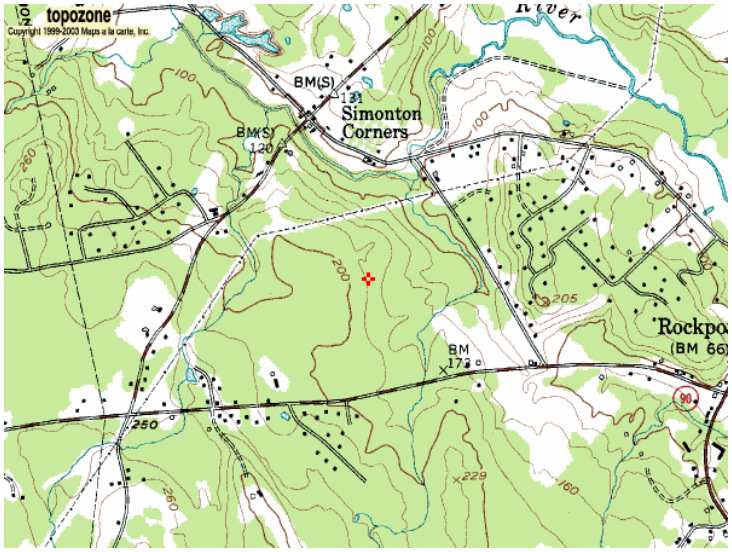

Figure 1 - Camden Hills Regional High School Site Location

Source: www.topozone.com.

SECTION 2 - Instrumentation and Equipment

The wind monitoring equipment is mounted on a 40 m (131.2 ft) meteorological tower. All the remaining monitoring equipment comes from NRG Systems, and consists of the following items:

- Symphonie Data Logger
- 4 – #40 Anemometers, standard calibration (Slope - 0.765 m/s, Offset – 0.350 m/s). Two anemometers are located at 39 m (127.9 ft), and two at 30 m (98.4 ft).
- 2 - #200P Wind direction vanes. They are located at heights of 39 m (127.9 ft) and 30 m (98.4 ft).
- 4 – Sensor booms, 12’ length
- Lightning rod and grounding cable

The data from the Symphonie logger is mailed to the University of Massachusetts, Amherst on a regular basis. The logger samples wind speed and direction once every two

seconds. These are then combined into 10-minute averages, and along with the standard deviation for those 10-minute periods, are put into a binary file. These binary files are converted to ASCII text files using the NRG software BaseStation®. These text files are then imported into a database software program where they are subjected to QA tests prior to using the data.

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 one-year period between March 1, 2006 and February 28, 2007.

Table 1. Wind Speed and Direction Data Summary

Date Height Units	Mean Wind Speed 39 m [m/s]	Max Wind Speed 39 m [m/s]	Prevailing Wind Direction 39 m	Mean Wind Speed 30 m [m/s]	Max Wind Speed 30 m [m/s]	Prevailing Wind Direction 30 m
Feb 2006	4.40	15.1	NW	4.10	13.9	NW
Mar 2006	4.28	11.4	NW	3.81	10.6	NNW
Apr 2006	4.41	13.5	N	3.93	11.3	N
May 2006	3.86	10.2	E	3.43	9.3	E
June 2006	3.05	9.0	SE	2.73	7.7	SE
July 2006	3.07	9.7	W	2.70	12.2	W
Aug 2006	3.29	10.9	NNW	2.81	9.6	W
Sep 2006	3.06	8.1	W	2.63	7.3	W
Oct 2006	4.18	14.1	W	3.68	12.7	W
Nov 2006	3.56	10.8	N	3.06	10.2	N
Dec 2006	3.98	12.3	W	3.48	11.0	W
Jan 2007	4.06	12.6	NW	3.70	11.3	NW
Feb 2007	4.34	13.9	WNW	3.83	12.8	WNW
Mar 2007	5.06	12.8	NNW	4.53	11.1	NW
Apr 2007	4.58	14.3	NNW	4.02	12.7	E
May 2007	3.90	10.6	NNW	3.42	9.7	NNW
June 2007	3.54	8.9	NW	3.08	8.3	NW
July 2007	2.74	8.0	N	2.35	7.4	N
Mar 2006 -Feb 2007	**3.75**	**14.1**	**W**	**3.31**	**12.8**	**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 a 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 one-year period between March 1, 2006 and February 28, 2007. 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 10 and 11 m/s. In many cases, there is not enough data between 10 m/s and 11 m/s to calculate the turbulence intensity. In these cases, no data is provided.

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 Height Units	Turbulence Intensity at 10 m/s 39 m [-]	Turbulence Intensity at 10 m/s 30 m [-]	Mean Wind Shear Coefficient, α Between 39 m and 30 m [-]
Feb 2006	-	-	0.27
Mar 2006	0.25	0.26	0.44
Apr 2006	0.27	0.30	0.44
May 2006	0.27	-	0.45
June 2006	-	-	0.42
July 2006	0.41	-	0.49
Aug 2006	0.27	0.27	0.60
Sep 2006	-	-	0.58
Oct 2006	0.27	0.27	0.49
Nov 2006	0.25	0.27	0.58
Dec 2006	0.27	0.28	0.51
Jan 2007	0.27	0.28	0.35
Feb 2007	0.25	0.28	0.48
Mar 2007	0.26	0.28	0.42
Apr 2007	0.27	0.30	0.50
May 2007	0.24	0.30	0.50
June 2007	-	-	0.53
July 2007	-	-	0.59
Mar 2006 -Feb 2007	**0.26**	**0.27**	**0.48**

SECTION 4- Capacity Factor

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 hub height of 80 m, a 1.8 MW wind turbine with a rotor diameter of 80 m and the mean wind speed at the highest measurement height and the mean wind shear at the site, in order to determine the mean hub height wind speed. The capacity factor (CF) is then estimated from (see G.M. Masters, Renewable and Efficient Electric Power Systems, Wiley, 2004):

$$CF = (0.087)U_{hub} - \frac{P_{rated}}{D^2}$$

where U_{hub} is the mean annual hub height wind speed in m/s, P_{rated} is the rated power of the wind turbine in kW and D is the diameter of the rotor in meters. Based on this equation, the estimated capacity factor of a wind turbine at this site would be about 4.5%.

SECTION 5- Graphs

This report contains several types of wind data graphs. Unless otherwise noted, each graph represents data from one calendar year (March 1, 2006 – February 28, 2007). The following graphs are included:

- Time Series – 10-minute average wind speeds at a height of 39 m are plotted against time. The wind speed time series is shown in Figure 2.

- Wind Speed Distribution – A histogram plot giving the percentage of time that the wind is at a given wind speed at a height of 39 m. The wind blows most frequently between 3 m/s and 4 m/s, for approximately 20.8% of the time. The wind speed distribution is shown in Figure 3.

- Monthly Average – A plot of the monthly average wind speed at a height of 39 m from February 2006 - June 2007. This graph shows the trends in the wind speed over the year. The monthly average wind speed plot is shown in Figure 4.

- Diurnal – A plot of the average wind speed for each hour of the day at a height of 39 m. The wind speeds are highest between 12 pm and 1 pm, and lowest between 3 am and 4 am. The diurnal variation plot is shown in Figure 5.

- Turbulence Intensity – A plot of turbulence intensity as a function of wind speed at a height of 39 m. 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. In general, turbulence intensities range from 0.1 to 0.5; for Camden, the average turbulence intensity was 0.26 at a height of 39 m. The turbulence intensity plot is shown in Figure 6.

- 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 at a height of 39 m. This wind rose shows the prevailing direction from the west, and wind speeds are greatest from the northwest. The wind rose plot is shown in Figure 7.

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

Wind Speed Time Series

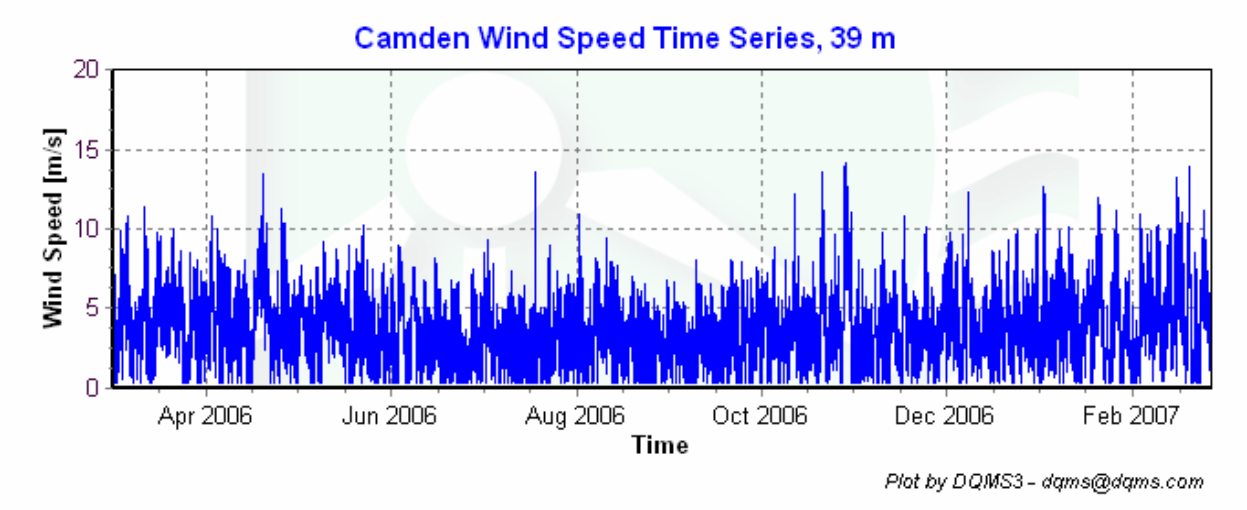

Figure 2 - Wind Speed Time Series, March 1, 2006 - February 28, 2007.

Wind Speed Distributions

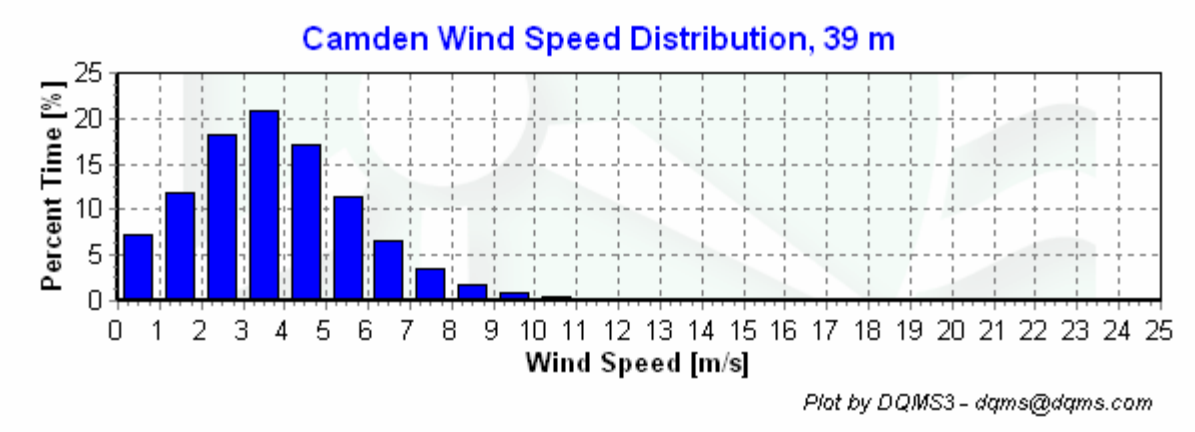

Figure 3 - Wind Speed Distribution, March 1, 2006 - February 28, 2007.

Monthly Average Wind Speeds

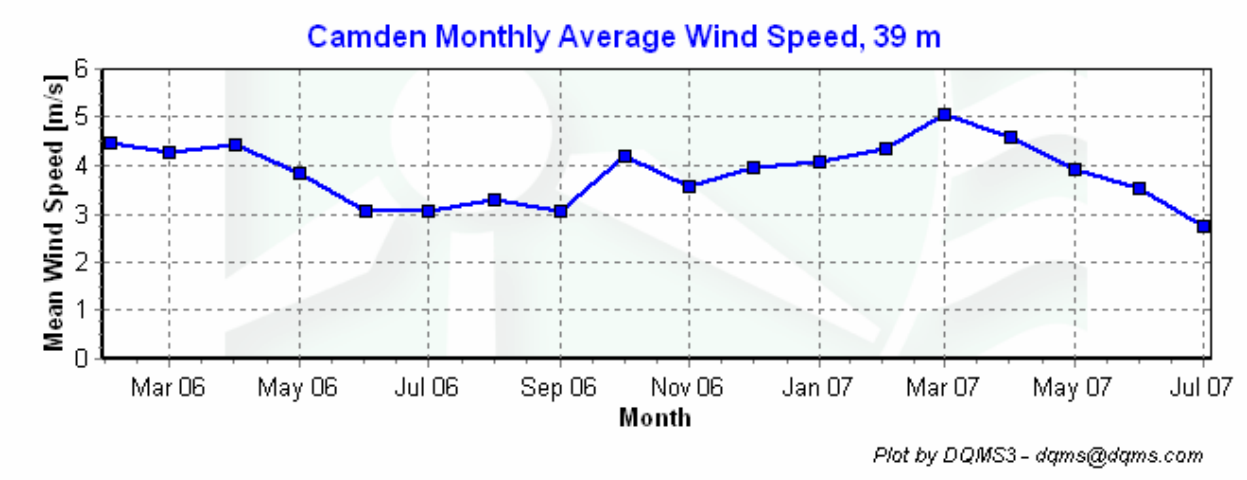

Figure 4 - Monthly Average Wind Speed, February, 2006 – July, 2007

Diurnal Average Wind Speeds

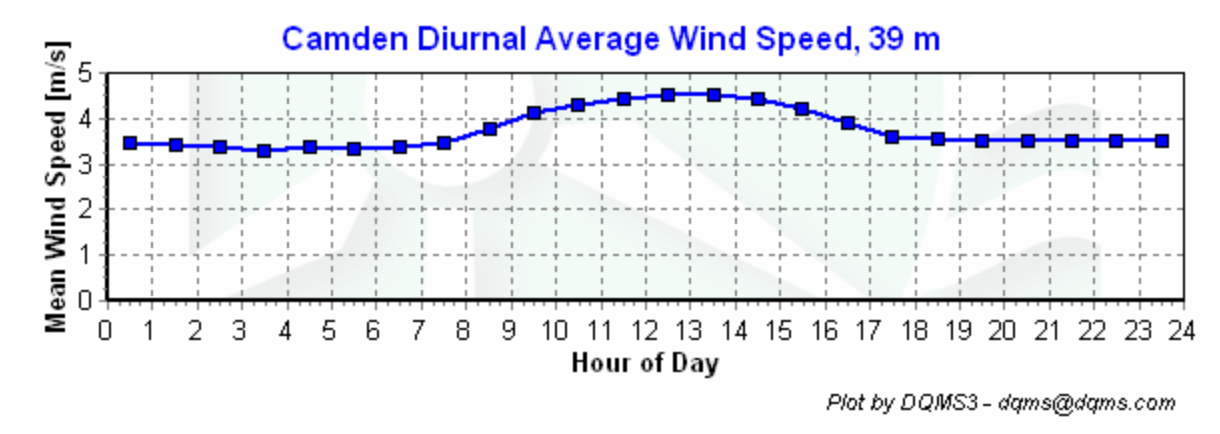

Figure 5 - Diurnal Wind Speed, March 1, 2006 - February 28, 2007.

Turbulence Intensities

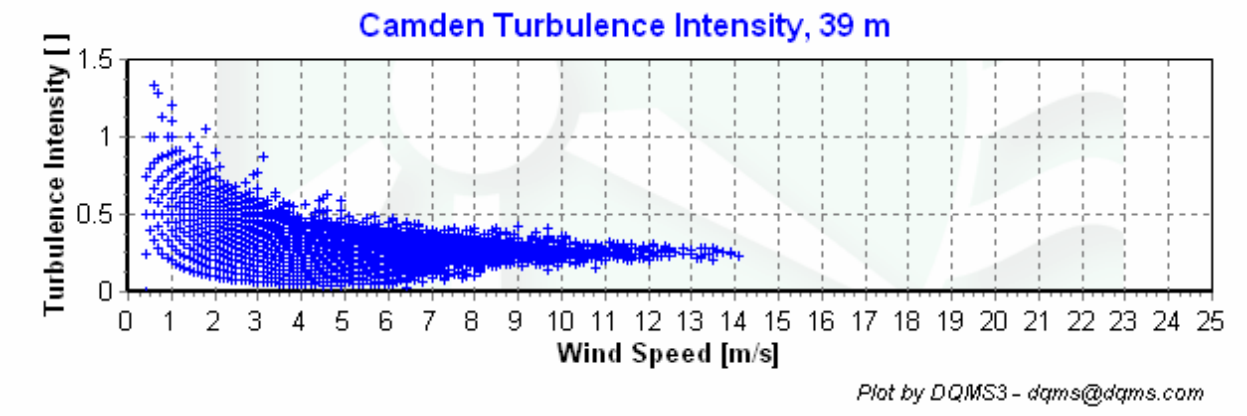

Figure 6 - Turbulence Intensity vs. Wind Speed, March 1, 2006 - February 28, 2007.

Wind Roses

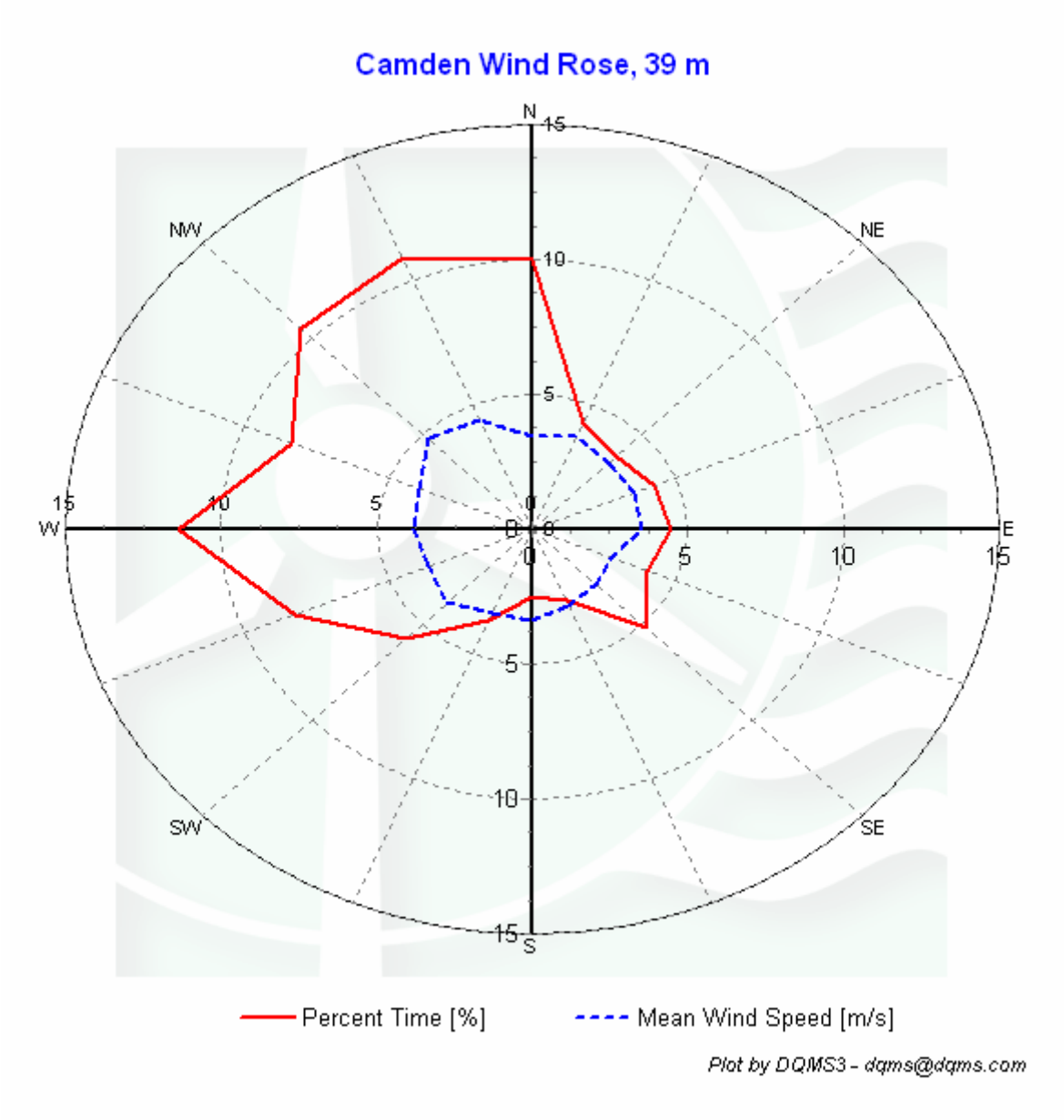

Figure 7 - Wind Rose, March 1, 2006 - February 28, 2007.

SECTION 6 - Significant Meteorological Events

There were no significant meteorological events during this period.

SECTION 7 - Data Collection and Maintenance

No maintenance was performed during this 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. This data is calculated from the one-year period between March 1, 2006 and February 28, 2007.

Gross Data Recovered [%]	100
Net Data Recovered [%]	98.4

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

Test Order	TestField1	TestField2	Test Field3	Calc Field1	Calc Field2	Calc Field3	TestType	Factor1	Factor2	Factor3	Factor4
1							TimeTest Insert				
4	Etmp2adegc						MinMax	-30	60	0	0
5	EtmpSD2adegc						MinMax	-30	60	0	0
10	Anem39ams						MinMax	0	90		
11	Anem39bms						MinMax	0	90		
12	Anem30ams						MinMax	0	90		
13	Anem30bms						MinMax	0	90		
14	Anem39yms						MinMax	0	90		
15	Anem30yms						MinMax	0	90		
20	AnemSD39ams						MinMax	0	4		
21	AnemSD39bms						MinMax	0	4		
22	AnemSD30ams						MinMax	0	4		
23	AnemSD30bms						MinMax	0	4		
24	AnemSD39yms						MinMax	0	4		
25	AnemSD30yms						MinMax	0	4		
30	Vane39adeg						MinMax	0	359.9		
31	Vane30adeg						MinMax	0	359.9		
50	Turb39zNONE						MinMax	0	2		
51	Turb30zNONE						MinMax	0	2		
60	Wshr0zNONE						MinMax	-100	100		
70	Pwrd39zWMS						MinMax	0	5000		
71	Pwrd30zWMS						MinMax	0	5000		
200	VaneSD39adeg	Anem39yms					MinMaxT	0	100	100	10
201	VaneSD30adeg	Anem30yms					MinMaxT	0	100	100	10
300	Anem39ams	AnemSD39ams	Vane39adeg	VaneSD39adeg	Etmp2adegc		Icing	0.5	1	2	10
301	Anem39bms	AnemSD39bms	Vane39adeg	VaneSD39adeg	Etmp2adegc		Icing	0.5	1	2	10
302	Anem30ams	AnemSD30ams	Vane30adeg	VaneSD30adeg	Etmp2adegc		Icing	0.5	1	2	10
303	Anem30bms	AnemSD30bms	Vane30adeg	VaneSD30adeg	Etmp2adegc		Icing	0.5	1	2	10
400	Anem39ams	Anem39bms					CompareSensors	1	0.25	3	0
401	Anem30ams	Anem30bms					CompareSensors	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
Anem39ams	52560	52560	100	0.167	125.333	7.333	98.484
AnemSD39ams	52560	52560	100	0.167	125.333	7.333	98.484
Anem39bms	52560	52560	100	0.167	128.833	46.833	97.993
AnemSD39bms	52560	52560	100	0.167	128.833	46.833	97.993
Anem39yms	52560	52560	100	0.167	125.333	0.667	98.56
AnemSD39yms	52560	52560	100	0.167	125.333	0.667	98.56
Vane39adeg	52560	52560	100	4.5	134	0	98.419
VaneSD39adeg	52560	52560	100	4.5	134	0	98.419
Anem30ams	52560	52560	100	0	157.833	0.333	98.194
AnemSD30ams	52560	52560	100	0	157.833	0.333	98.194
Anem30bms	52560	52560	100	0	120.833	117.5	97.279
AnemSD30bms	52560	52560	100	0	120.833	117.5	97.279
Anem30yms	52560	52560	100	0	127	0	98.55
AnemSD30yms	52560	52560	100	0	127	0	98.55
Vane30adeg	52560	52560	100	4.833	157.833	0	98.143
VaneSD30adeg	52560	52560	100	4.833	157.833	0	98.143
Etmp2adegc	52560	52560	100	0	0	0	100
EtmpSD2adegc	52560	52560	100	0	0	0	100
Total	**946080**	**946080**	**100**	**19.667**	**2154**	**345.333**	**98.402**

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	Percent of Time [%]
0.5	7.15
1.5	11.94
2.5	18.1
3.5	20.76
4.5	17.19
5.5	11.31
6.5	6.65
7.5	3.55
8.5	1.8
9.5	0.89
10.5	0.4
11.5	0.17
12.5	0.08
13.5	0.03
14.5	0
15.5	0
16.5	0
17.5	0
18.5	0
19.5	0
20.5	0
21.5	0
22.5	0
23.5	0
24.5	0

Table 3 - Wind Speed Distribution, 39 m, March 1, 2006 - February 28, 2007.

Monthly Average Wind Speed Data

Date	10 min Mean [m/s]
Feb-06	4.48
Mar-06	4.28
Apr-06	4.41
May-06	3.86
Jun-06	3.05
Jul-06	3.07
Aug-06	3.29
Sep-06	3.06
Oct-06	4.18
Nov-06	3.56
Dec-06	3.98
Jan-07	4.06
Feb-07	4.34
Mar-07	5.06
Apr-07	4.58
May-07	3.90
Jun-07	3.54
Jul-07	2.74

Table 4 - Monthly Average Wind Speeds, 39 m, February, 2006 - July, 2007.

Wind Rose Data

Direction	Percent Time [%]	Mean Wind Speed [m/s]
N	9.97	3.44
NNE	4.27	3.72
NE	3.82	3.48
ENE	4.24	3.55
E	4.47	3.5
ESE	3.99	2.76
SE	5.18	2.91
SSE	2.87	3.07
S	2.47	3.39
SSW	3.63	3.4
SW	5.74	3.86
WSW	8.25	3.62
W	11.38	3.81
WNW	8.35	3.94
NW	10.51	4.76
NNW	10.86	4.4

Table 5 - Wind Rose, Time Percentage and Mean Wind Speed by Direction, 39 m, March 1, 2006 – February 28, 2007.

Diurnal Average Wind Speed Data

Hour of Day	Average Wind Speed [m/s]
0.5	3.45
1.5	3.41
2.5	3.39
3.5	3.31
4.5	3.36
5.5	3.35
6.5	3.38
7.5	3.46
8.5	3.75
9.5	4.14
10.5	4.31
11.5	4.44
12.5	4.52
13.5	4.50
14.5	4.44
15.5	4.23
16.5	3.92
17.5	3.60
18.5	3.54
19.5	3.52
20.5	3.53
21.5	3.52
22.5	3.52
23.5	3.49

Table 6 - Diurnal Average Wind Speeds, 39 m, March 1, 2006 - February 28, 2007.