WIND DATA REPORT

Harwich

July 25, 2006 – August 31, 2006

Prepared for

Massachusetts Technology Collaborative
75 North Drive
Westborough, MA 01581

by

Meltem Duran
James F. Manwell
Anthony L. Rogers
Anthony F. Ellis

October 15, 2006

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

NOTICE AND ACKNOWLEDGEMENTS

This report was prepared by the Renewable Energy Research Laboratory (RERL) at the University of Massachusetts, Amherst in the course of performing work sponsored by the Renewable Energy Trust (RET), as administered by the Massachusetts Technology Collaborative (MTC), pursuant to work order number 05-1. The opinions expressed in this report do not necessarily reflect those of MTC or the Commonwealth of Massachusetts, and reference to any specific product, service, process, or method does not constitute an implied or expressed recommendation or endorsement of it.

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

The wind measurement station is installed at Harwich High School, Harwich, MA. Installed in July 2006, the wind monitoring station has been in operation for just over 2 months. The station consists of two anemometers at 50 m (164 ft) and at 38 m (125 ft), one anemometer at 20 m (66 ft) and wind vanes at the same heights.

During the interval covered by this report, July 25 – August 31 2006, the recorded mean wind speed was 4.85 m/s (10.85 mph) and the prevailing wind direction was from southwest. The gross data recovery percentage (the actual percentage of expected data received) was 99.919% and the net data recovery percentage (the percentage of expected data which passed all of the quality assurance tests) was 99.468%. These percentages are very high, which is an indication that the sensors and the data logger were performing well.

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 wind assessment station is located in an area mostly used for playing fields, behind the high school, about 4 miles away from the Chatham Municipal Airport. The anemometry is mounted on a 50-meter met tower. Relative to the Mean Low Water Level, the anemometry is mounted at a height of 15 m (49 ft).

Figure 1 – Site location at Harwich High School

SECTION 2 - Instrumentation and Equipment

The wind monitoring equipment is mounted on a met tower that is 164 feet tall, six inches in diameter, and held up by guy wires. This type of tower sits directly on the ground and no foundation is necessary. All the equipment comes from NRG Systems, and consists of the following items:

- Tower kit, height 50 m NRG tower
- Logger kit: NRG Symphonie Logger
- 5 - #40 Anemometers, standard calibration (Slope – 0.765 m/s, Offset – 0.350 m/s). One anemometer is located at 20 m (66 ft). Two anemometers are located at 38 m (125 ft) and two at 50 m (164 ft).

- 3 - #200P Wind direction vanes. The vanes are located at 20 m (66 ft), 38 m (125 ft), and 50 m (164 ft).

- 1 - #110S Temperature sensor located at 3 m (10 ft).

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 samples are combined into 10-minute averages and are put into a binary file along with the standard deviation for each 10-minute interval. The 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 quality assurance tests prior to data usage.

SECTION 3 - Data Collection and Maintenance

The following maintenance/equipment problems occurred during the report period, and the following corrective actions taken:

- The sensors started collecting data 17 hours after they were mounted and started.

- All sensors have been working without any problems since 5:50 pm on July 25, 2006.

- The wind monitoring station was mounted during this quarter. No maintenance operations were performed.

Data Statistics Summary

Date	Mean Wind Speed [m/s]	Max Wind Speed [m/s]	Turb. Intensity [ ]	Prevailing Wind Direction [ ]	Mean Wind Speed [m/s]	Max Wind Speed [m/s]	Turb. Intensity [ ]	Prevailing Wind Direction [ ]	Mean Wind Speed [m/s]	Max Wind Speed [m/s]	Turb. Intensity [ ]	Prevailing Wind Direction [ ]
Height [m]	50	50	50	50	38	38	38	38	20	20	20	20
July 2006	4.99	8.67	0.17	SW	4.54	9.61	0.19	SW	3.41	7.58	0.25	SW
Aug 2006	4.71	7.5	0.17	SWW	4.24	10.25	0.19	SWW	2.94	8.2	0.29	SW
July 06 – Aug 06	**4.85**	**8.09**	**0.17**	**SW**	**4.39**	**9.93**	**0.19**	**SW**	**3.18**	**7.89**	**0.27**	**SW**

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 is missing, the percent of the available data that are used to determine the data statistics is noted.

In cases No measurement of wind speed can be perfectly accurate. 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.

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 may not 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.

SECTION 4 - Significant Meteorological Events

July and August of 2006 experienced, on average, normal winds and precipitation. No major events are shown in the wind speed time series.

Source: http://www.erh.noaa.gov/box/MonthlyClimate2.shtml

SECTION 5 - 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 [%]	99.919
Net Data Recovered [%]	99.468

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 (F4).

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

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

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*.

SECTION 6 - Data Summary

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, starting on July 25, 2006, Figure 2. The graph represents data at 50 m.
- Wind Speed Distribution – A histogram plot giving the percentage of time that the wind is at a given wind speed. Figure 3 shows wind speeds ranged between 4 m/s

(8.9 mph) and 5 m/s (11.2 mph) about 23% of the time. The graph represents data at 50 m.

- Monthly Average – This is usually a plot of the monthly average wind speed over a 12-month period. This graph shows the trends in the wind speed over July and August 2006 as the wind measuring station became active on July 25, 2006 and has not yet collected data from a 12-month period. This plot is shown on Figure 4 and represents data collected at 50 m.

- Diurnal – A plot of the average wind speed for each hour of the day. Figure 5 shows that the wind speed varied between 5 m/s (11.2 mph) and 6 m/s (13.4 mph) throughout the day on average and the highest wind speeds were recorded in the early afternoon. The plot represents data collected at 50 m.

- 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. For Harwich, the turbulence intensity was well within the acceptable range. This plot is shown as Figure 6. The plot represents data at 50 m.

- 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 wind blew from the southwest approximately 15% of the time at an average speed of approximately 6 m/s (13.4 mph). This plot is shown on Figure 7 and represents data collected at 50 m.

SECTION 7- Graphs

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

Wind Speed Time Series

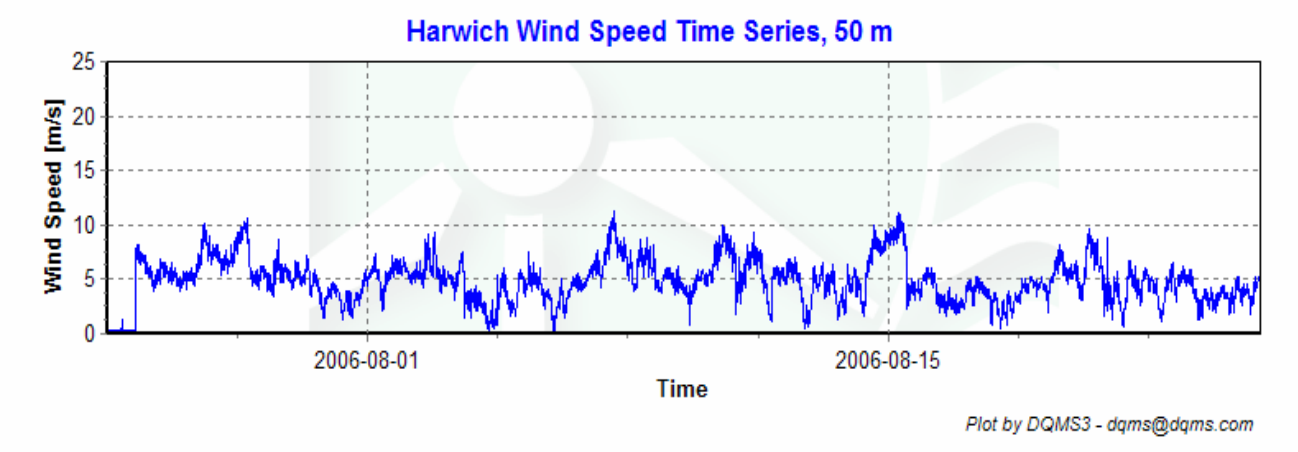

Figure 2 – Wind Speed Time Series, July 2006 – August 2006

Wind Speed Distributions

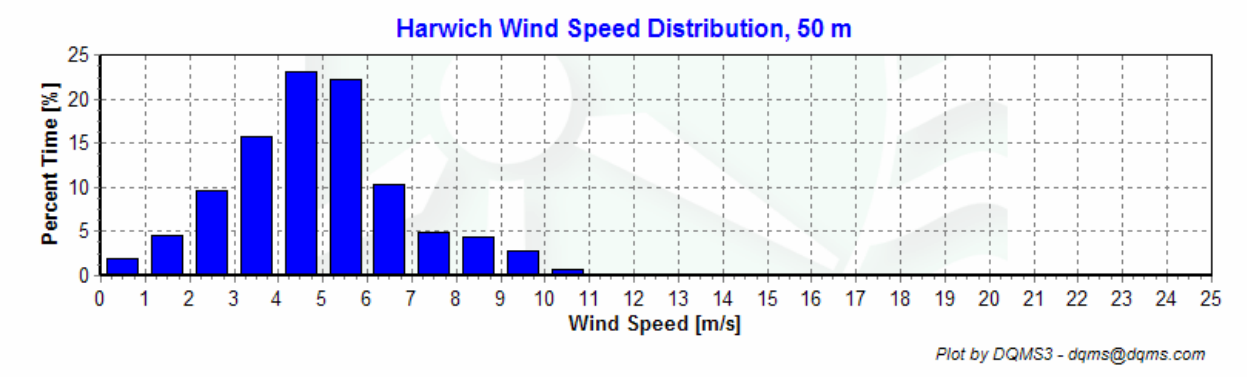

Figure 3 – Wind Speed Distribution, July 2006 – August 2006

Monthly Average Wind Speeds

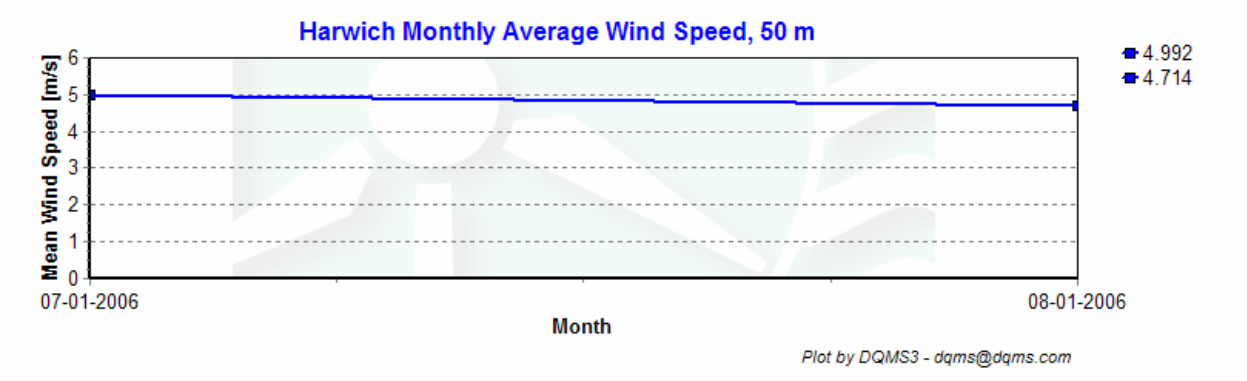

Figure 4 – Monthly Average Wind Speeds, July 2006 – August 2006

Diurnal Average Wind Speeds

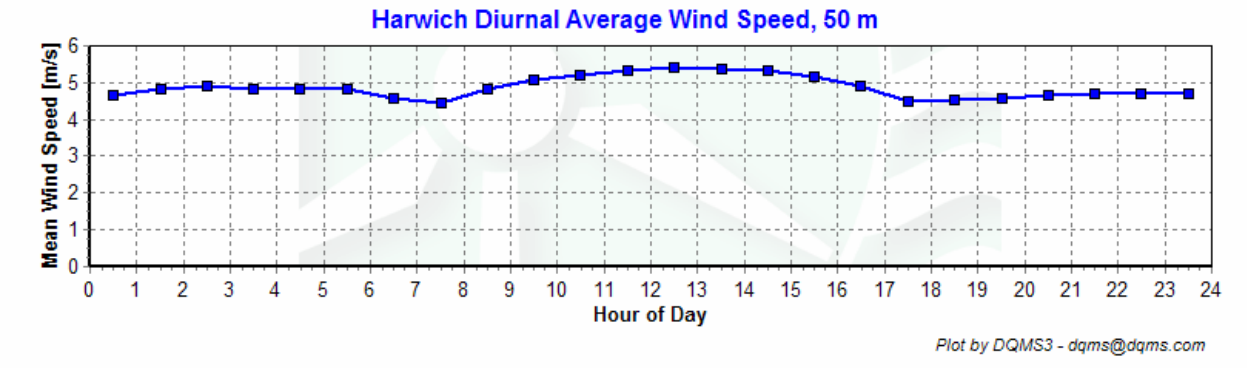

Figure 5 – Diurnal Wind Speed, July 2006 – August 2006

Turbulence Intensities

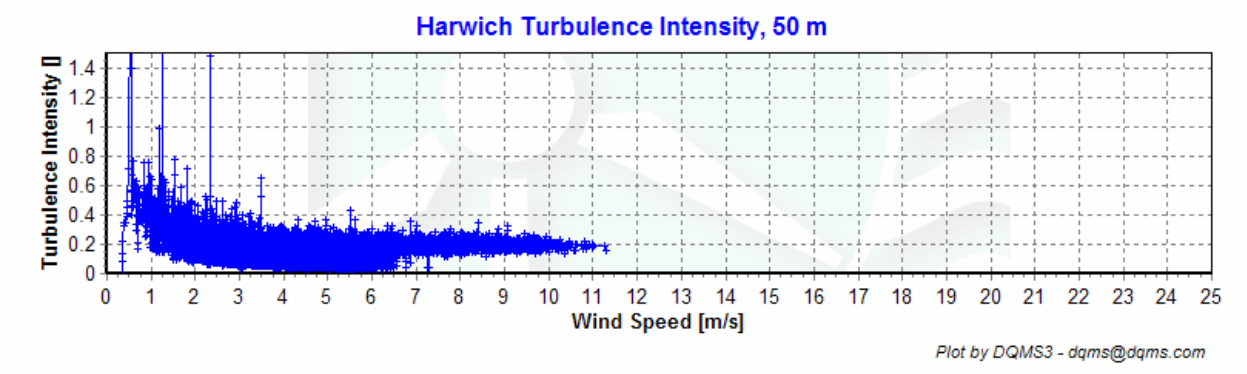

Figure 6 – Turbulence Intensity vs. Wind Speed, July 2006 – August 2006

Wind Roses

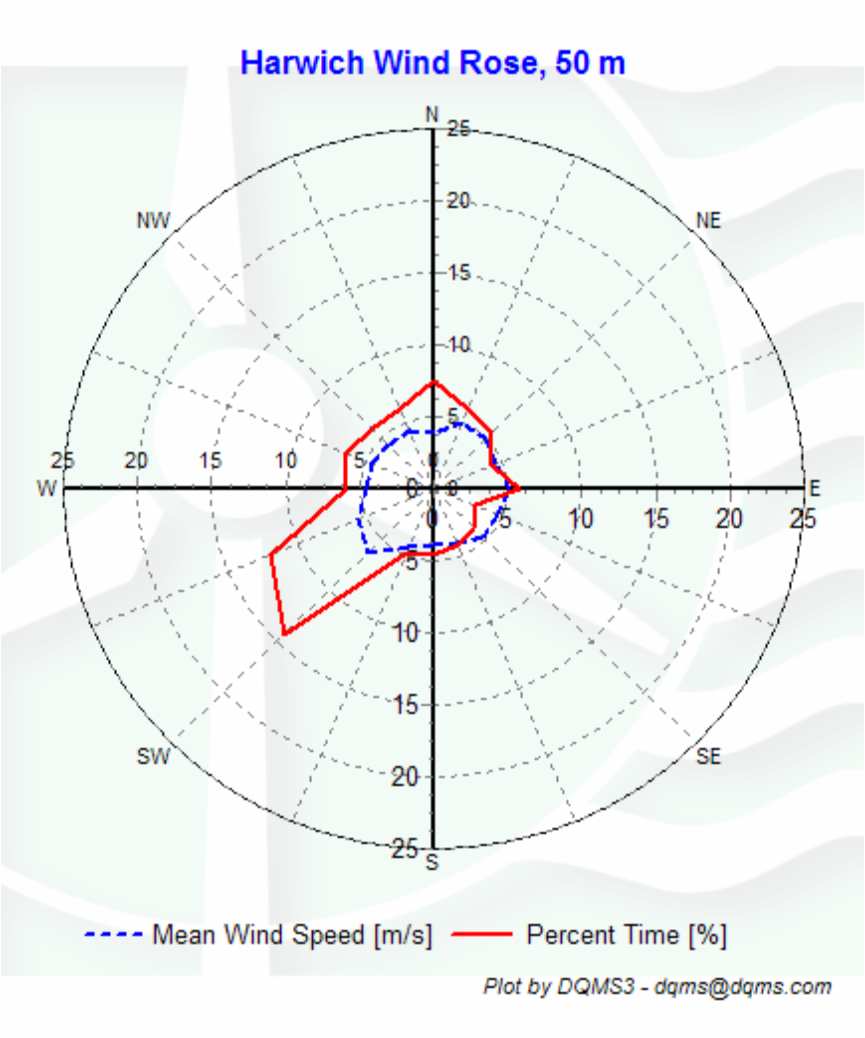

Figure 7 – Wind Rose, July 2006 – August 2006

APPENDIX A - Sensor Performance Report

Test Definitions

Test Order	Test Field1	Test Field2	Test Field3	Calc Field1	Calc Field2	Calc Field3	TestType	Factor 1	Factor 2	Factor 3	Factor 4
1							TimeTest Insert				
10	Anem50aMS						MinMax	0	90		
11	Anem50bMS						MinMax	0	90		
12	Anem38aMS						MinMax	0	90		
13	Anem38bMS						MinMax	0	90		
14	Anem20aMS						MinMax	0	90		
20	AnemSD50aMS						MinMax	0	4		
21	AnemSD50bMS						MinMax	0	4		
22	AnemSD38aMS						MinMax	0	4		
23	AnemSD38bMS						MinMax	0	4		
24	AnemSD20aMS						MinMax	0	4		
30	Vane50aDEG						MinMax	0	359.9		
31	Vane38aDEG						MinMax	0	359.9		
32	Vane20aDEG						MinMax	0	359.9		
50	Turb50zNONE						MinMax	0	2		
51	Turb38zNONE						MinMax	0	2		
52	Turb20zNONE						MinMax	0	2		
60	Wshr0zNONE						MinMax	0	20		
70	Amax50aMS						MinMax	0	90		
71	Amin50aMS						MinMax	0	90		
72	Amax50bMS						MinMax	0	90		
73	Amin50bMS						MinMax	0	90		
74	Amax38aMS						MinMax	0	90		
75	Amin38aMS						MinMax	0	90		
76	Amax38bMS						MinMax	0	90		
77	Amin38bMS						MinMax	0	90		
78	Amax20aMS						MinMax	0	90		
79	Amin20aMS						MinMax	0	90		
80	Vmax50aDEGC						MinMax	0	359.9		
81	Vmin50aDEGC						MinMax	0	359.9		
82	Vmax38aDEGC						MinMax	0	359.9		
83	Vmin38aDEGC						MinMax	0	359.9		
84	Vmax20aDEGC						MinMax	0	359.9		
85	Vmin20aDEGC						MinMax	0	359.9		
200	VaneSD50aDEG	Anem50aMS					MinMaxT	0	100	100	10
201	VaneSD38aDEG	Anem38aMS					MinMaxT	0	100	100	10
202	VaneSD20aDEG	Anem20aMS					MinMaxT	0	100	100	10
300	Anem50aMS	AnemSD50aMS	Vane50aDEG	VaneSD50aDEG	Etmp3aDEGC		Icing	0.5	1	2	2
301	Anem50bMS	AnemSD50bMS	Vane50aDEG	VaneSD50aDEG	Etmp3aDEGC		Icing	0.5	1	2	2
302	Anem38aMS	AnemSD38aMS	Vane38aDEG	VaneSD38aDEG	Etmp3aDEGC		Icing	0.5	1	2	2
303	Anem20aMS	AnemSD20aMS	Vane20aDEG	VaneSD20aDEG	Etmp3aDEGC		Icing	0.5	1	2	2
400	Anem50aMS	Anem50bMS					CompareSensors	1	0.25	3	
401	Anem38aMS	Anem38bMS					CompareSensors	1	0.25	3	

Sensor Statistics

Sensor	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	% Data Good
Etmp3aDEGC	5472	5472	100	0	0	0	97.478
EtmpSD3aDEGC	5472	5472	100	0	0	0	100
Anem50aMS	5472	5472	100	0	0	3.333	99.635
AnemSD50aMS	5472	5472	100	0	0	3.333	99.635
Anem50bMS	5472	5472	100	0	0	6.667	99.269
AnemSD50bMS	5472	5472	100	0	0	6.667	99.269
Anem38aMS	5472	5472	100	0	0	0.833	99.909
AnemSD38aMS	5472	5472	100	0	0	0.833	99.909
Anem38bMS	5472	5472	100	0	0	13.167	98.556
AnemSD38bMS	5472	5472	100	0	0	13.167	98.556
Anem20aMS	5472	5472	100	0	0	0	100
AnemSD20aMS	5472	5472	100	0	0	0	100
Vane50aDEG	5472	5432	99.269	0.333	0	0	99.232
VaneSD50aDEG	5472	5432	99.269	0.333	0	0	99.232
Vane38aDEG	5472	5472	100	0.5	0	0	99.945
VaneSD38aDEG	5472	5472	100	0.5	0	0	99.945
Vane20aDEG	5472	5472	100	0.667	0	0	99.927
VaneSD120aDEG	5472	5472	100	0.667	0	0	99.927
Total	**98496**	**98416**	**99.918**	**3**	**0**	**48**	**99.468**

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	Percent of Time [%]
0.5	1.91
1.5	4.48
2.5	9.59
3.5	15.74
4.5	23.09
5.5	22.12
6.5	10.4
7.5	4.82
8.5	4.32
9.5	2.73
10.5	0.75
11.5	0.04
12.5	0
13.5	0
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 1 - Wind Speed Distribution

Monthly Average Wind Speed Data

Date	10 min Mean [m/s]
July 2006	4.99
Aug 2006	4.71

Table 2 - Wind Speed Averages at 50 m

Diurnal Average Wind Speed Data

Hour of Day	Average Wind Speed [m/s]
0.5	4.67
1.5	4.83
2.5	4.91
3.5	4.83
4.5	4.84
5.5	4.84
6.5	4.55
7.5	4.45
8.5	4.82
9.5	5.07
10.5	5.22
11.5	5.31
12.5	5.4
13.5	5.35
14.5	5.32
15.5	5.18
16.5	4.91
17.5	4.5
18.5	4.54
19.5	4.56
20.5	4.64
21.5	4.7
22.5	4.71
23.5	4.69

Table 3 - Diurnal Average Wind Speeds, 50 m

Wind Rose Data

Direction	Percent Time [%]	Mean Wind Speed [m/s]
N	5.73	5.15
NNE	4.28	4.57
NE	5.49	4.90
ENE	6.01	4.97
E	7.53	3.84
ESE	5.98	4.35
SE	5.95	4.36
SSE	6.47	4.54
S	5.9	4.62
SSW	11.89	5.56
SW	14.26	6.21
WSW	4.85	4.43
W	4.55	3.94
WNW	4.17	4.11
NW	3.85	4.67
NNW	3.08	4.65

Table 4 - Wind Rose, Time Percentage and Mean Wind Speed by Direction, 50 m