FINAL
WIND DATA REPORT

Eastham

July 17, 2003 – August 27, 2004

Prepared for

Massachusetts Technology Collaborative
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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.

Wind monitoring equipment was first installed in Eastham on July 17, 2003. Anemometers and wind direction vanes are installed at 10 m, 30 m, and 39 m above the tower base. Redundant anemometers were installed at the 30 m and 39 m level. The equipment was taken down on August 27, 2004 after completing a full calendar year of measurements. Data collection for the period has been good except for the month of April when the data card arrived at RERL empty, apparently erased by mistake. The overall net data recovery percentage is 92.598 % due to the missing month of data.

This final data report summarizes the wind data collected between July 17, 2003 and August 27, 2004. The mean speed at 39 m over this time period was 5.29 m/s (10.65 mph). Wind speeds were found to be lower in the summer and highest in winter. Wind direction was predominantly from the south over the summer and from west northwest over the winter. The mean wind speed for a 365-day period between August 1, 2003 to July 31, 2004 was 5.36 m/s (10.49 mph) at 39 m.

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.

SECTION 1 - Station Location

The Eastham, MA station is located on town land next to privately owned dirt piles and a cell phone tower. Small (58 m [15-25 ft]) pine trees surround the site to the north, west, and south. Several trees were removed to create a clearing for the tower. The location of the tower base is 41^0- 52.026' North, 069^0- 58.922' West.

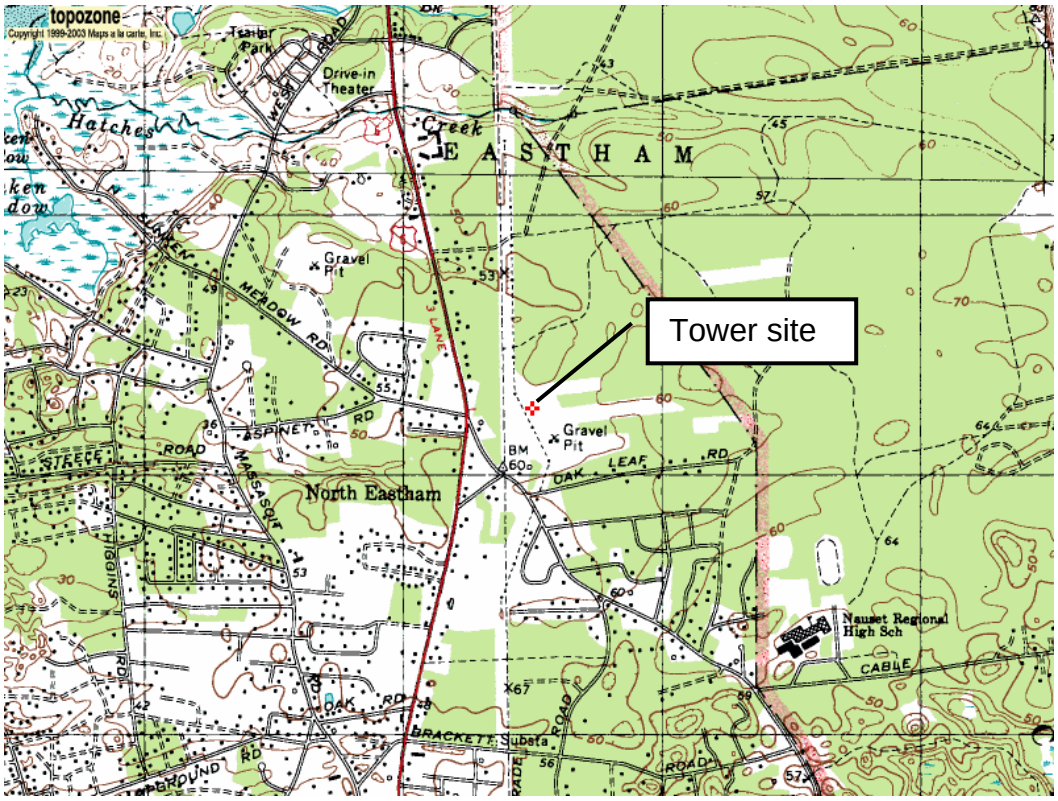

Figure 1 – Map of Eastham site.

Source: www.topozone.com.

SECTION 2 - Instrumentation and Equipment

Wind monitoring equipment is mounted on a standard NRG 40 m tall, 6 in diameter tilt-up guyed tower. Wind vanes and anemometers are located at three heights on the tower: 10 m, 30 m, and 39 m. Redundant anemometers exist at 30 m and 39 m. Additional equipment and models:

- NRG model Simphonie Cellogger®
- 5 – #40 Anemometers, standard calibration (Slope - 0.765 m/s, Offset – 0.350 m/s)
- 3 - #200P Wind direction vanes
- 3 – Sensor booms, 54" length
- Lightning rod and grounding cable
- Shielded sensor wire

Figure 2 – 40 m data tower in Eastham during installation.

SECTION 3 - Data Collection and Maintenance

Data collection began on July 17, 2003 and ended when the measurement tower was taken down on August 27, 2004. Data cards were manually removed from the logger by Fred Fenlon and mailed to staff at RERL at the beginning of each month except for the last month, which was removed by RERL staff.

Data collection during this period was good, with redundant wind speed sensors installed to cover for the primary ones if they failed. The only problem that arose was in April when the data card arrived at RERL empty, apparently erased by mistake. The data is summarized below.

Data Statistics Summary

Date	39 m Anemometer			30 m Anemometer			10 m Anemometer			10 m to 39 m	Vane 39 m	Vane 30 m	Vane 10 m
	Mean [m/s]	Max [m/s]	Turb. Int.[ ]	Mean [m/s]	Max [m/s]	Turb. Int.[ ]	Mean [m/s]	Max [m/s]	Turb. Int.[ ]	Shear [ ]	Prev. Dir.	Prev. Dir.	Prev. Dir.
Aug 2003	4.59	10.23	0.21	4.03	9.57	0.23	2.25	6.33	0.43	0.47	S	SW	S
Sep 2003	4.16	10.32	0.2	3.59	9.42	0.23	1.82	6.07	0.45	0.54	NNE	NE	NNE
Oct 2003	5.3	15.24	0.2	4.55	14.02	0.23	2.41	9.49	0.42	0.58	SSE	WNW	W
Nov 2003	5.73	17.05	0.21	4.99	14.86	0.24	2.83	9.88	0.4	0.53	WNW	NW	WNW
Dec 2003	7.23	18.11	0.2	6.35	15.78	0.22	3.69	12.35	0.38	0.48	WNW	NNW	WNW
Jan 2004	6.92	14.09	0.21	6.06	12.46	0.24	3.43	7.34	0.41	0.51	W	WNW	W
Feb 2004	5.49	14.22	0.2	4.79	12.58	0.23	2.69	8.1	0.4	0.52	WNW	NW	WNW
March 2004	6.08	13.79	0.21	5.44	12.76	0.23	3.43	8.97	0.37	0.43	NNE	NE	NNE
April 2004-	0	0	0	0	0	0	0	0	0	0	0	0	0
May 2004	4.62	12.96	0.23	4.18	11.4	0.25	2.56	7.48	0.42	0.4	S	SW	S
June 2004	4.61	10.4	0.21	4.05	9.55	0.24	2.21	6.2	0.46	0.51	S	SW	SSW
July 2004-	4.14	9.65	0.21	3.64	8.63	0.25	2	6.23	0.46	0.52	S	S	S

August 2004	4.59	10.23	0.21	4.03	5.16	0.23	2.25	2.98	0.43	0.47	S	S	S
July 2003 – August 2004	5.29	18.11	0.21	4.69	15.78	0.24	2.63	12.35	0.42	0.5	S	SW	S
August 2003 – July 2004	5.36	18.11	0.21	4.76	15.78	0.24	2.67	12.35	0.42	0	S	SW	S

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.

SECTION 4 - Significant Meteorological Events

The following significant meteorological events occurred during the measurement period:

- On Thursday, November 13 2003, strong winds hit much of the northeast. The winds gusted to more than 30 m/s (70 mph) in places on Thursday and gusts as high as 20 m/s (45 mph) swept over some areas Friday.
- Two nor'easters hit the area in December, one on the 7th and the other on the 15th bringing with it plenty of precipitation.

The wind conditions were close to average for the rest of the period.

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) for this quarter are shown below.

Gross Data Recovered [%]	92.619
Net Data Recovered [%]	92.598

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

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 the following types of wind data graphs:

- Time Series – 10-minute average wind speeds are plotted against time. The highest 10 minute average peaks are shown to occur in the winter months.

- Wind Speed Distribution – A histogram plot giving the percentage of time that the wind is at a given wind speed. The distribution peak occurs between 4 and 5 m/s (9 – 11 mph).

- Monthly Average – A plot of the monthly average wind speed over a 13-month period. This graph shows the trends in the wind speed over the year. With twelve months of complete data, September shows the lowest average and December the highest. This is consistent with trends seen in other parts of the state. No average is reported for April due to missing data. The average for August 2004 was calculated based on 27 days worth of data because the site was decommissioned and the wind monitoring equipment was taken down on August 27, 2004.

- Diurnal Wind Speeds – A plot of the average wind speed for each hour of the day. This site has a fairly even diurnal distribution, with a slight increase in wind speeds in the early afternoon.

- 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 average trubulence intensity at 39 m is 0.21. The plot bottoms out around 5 m/s, suggesting that, under average wind conditions, this site experiences average turbulence.

- 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. This graph shows that average wind speed is slightly higher from the west and quite even from all other directions, with the clear prevailing direction being from the south.

SECTION 7 - Graphs

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

Wind Speed Time Series

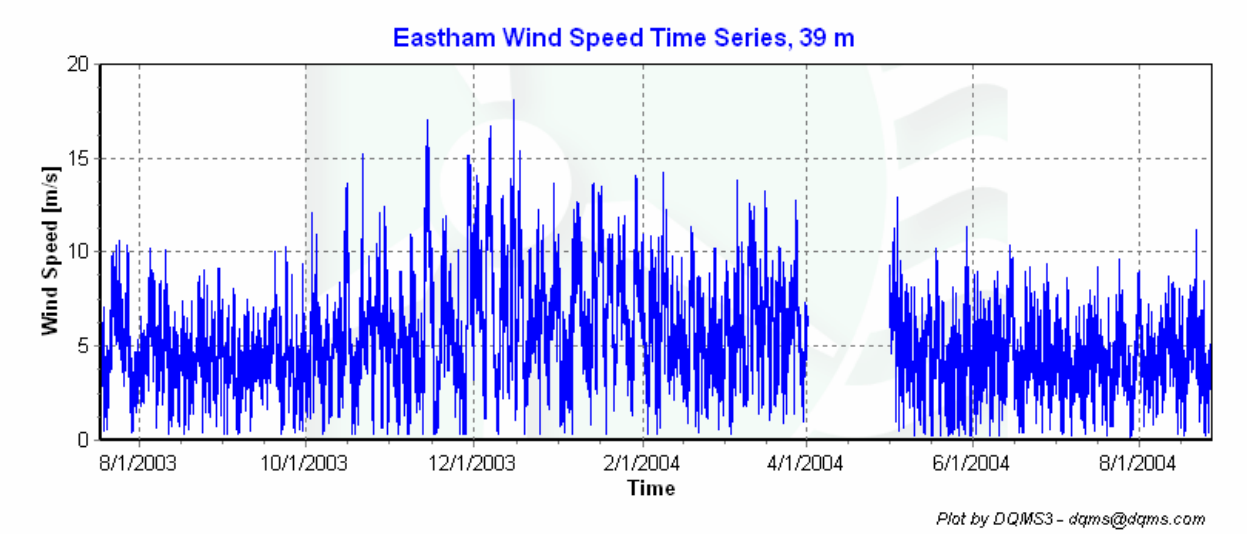

Figure 3 – Wind Speed Time Series, July 17, 2003 – August 27, 2004

Wind Speed Distributions

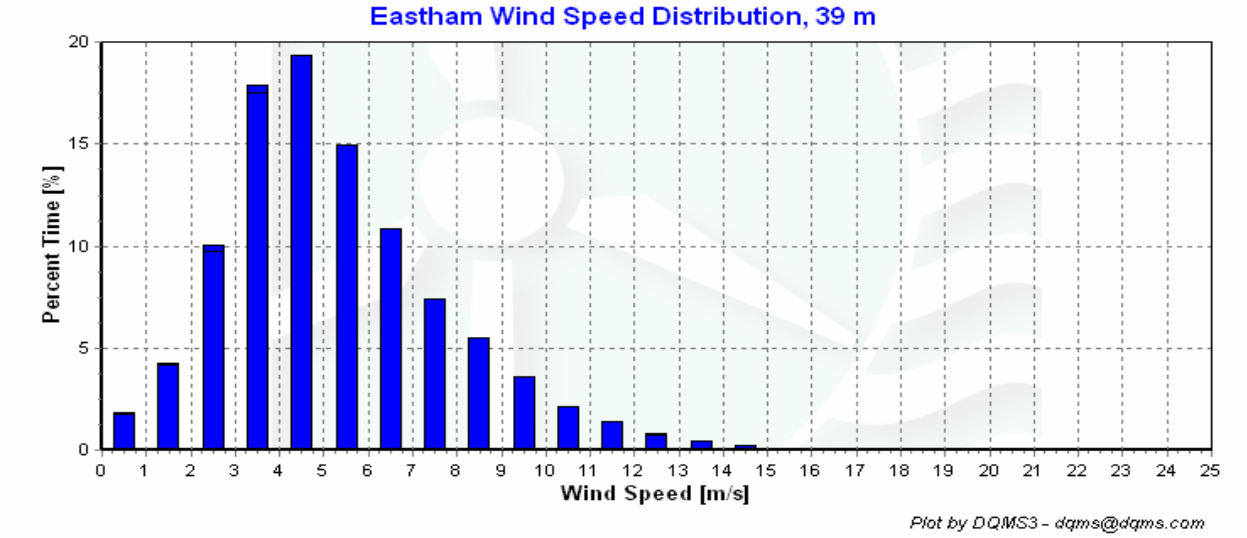

Figure 4 – Wind Speed Distribution, July 17, 2003 – August 27, 2004

Monthly Average Wind Speeds

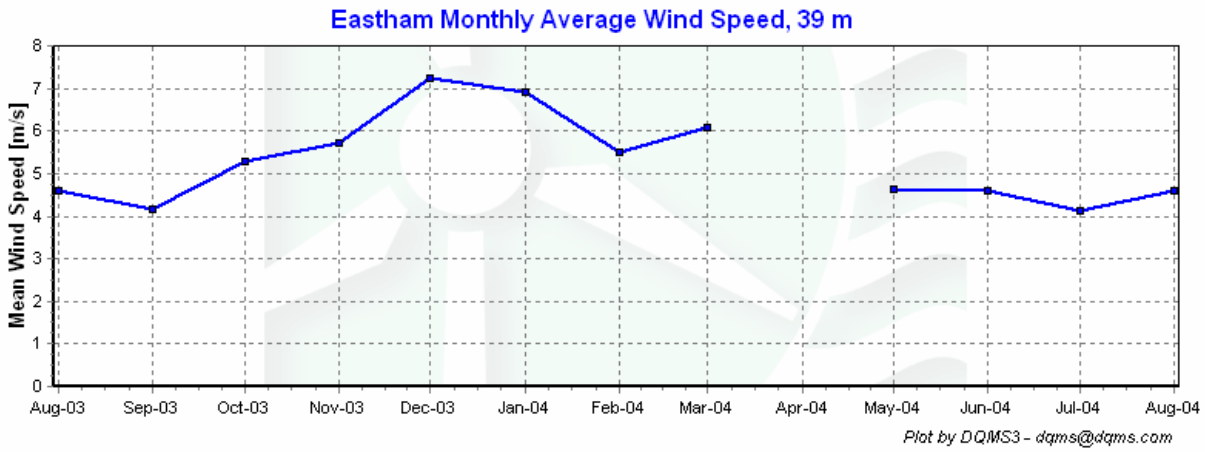

Figure 5 – Monthly Average Wind Speed

Diurnal Average Wind Speeds

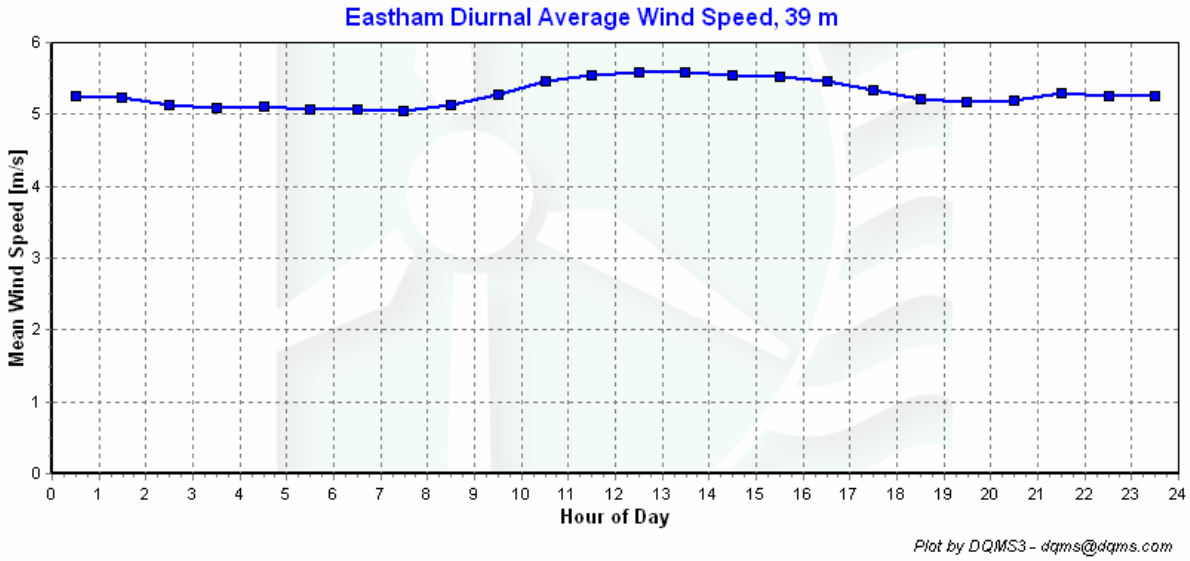

Figure 6 – Diurnal Wind Speed, July 17, 2003 – August 27, 2004

Turbulence Intensities

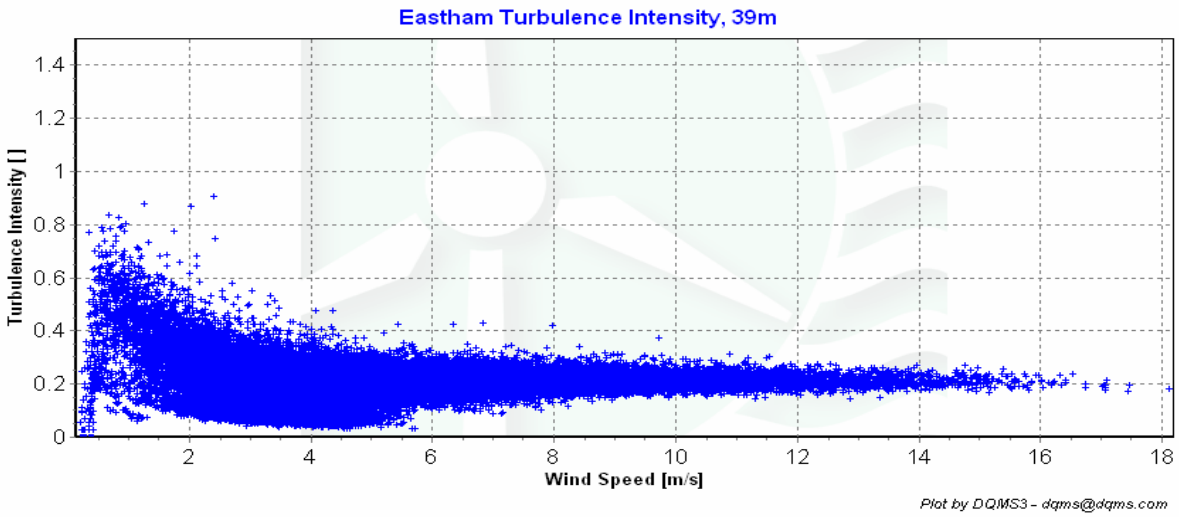

Figure 7 – Turbulence Intensity vs Wind Speed, July 17, 2003 – August 27, 2004

Wind Roses

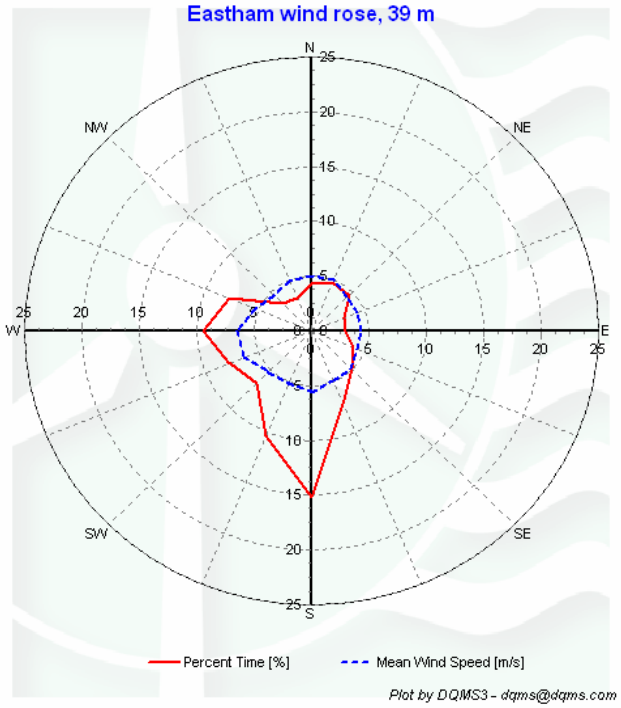

Figure 8 – Wind Rose, July 17, 2003 – August 27, 2004

APPENDIX A - Sensor Performance Report

Test Definitions

TestOrder	TestField1	TestField2	TestField3	CalcField1	CalcField2	TestType	Factor1	Factor2	Factor3	Factor4
1						TimeTest Insert				
4	Etmp2aDEGC					MinMax	-30	60		
5	EtmpSD2aDEGC					MinMax	-30	60		
10	Anem10aMS					MinMax	0	90		
11	Anem30aMS					MinMax	0	90		
12	Anem30bMS					MinMax	0	90		
13	Anem39aMS					MinMax	0	90		
14	Anem39bMS					MinMax	0	90		
20	AnemSD10aMS					MinMax	0	4		
21	AnemSD30aMS					MinMax	0	4		
22	AnemSD30bMS					MinMax	0	4		
23	AnemSD39aMS					MinMax	0	4		
24	AnemSD39bMS					MinMax	0	4		
30	Vane10aDEG					MinMax	0	359.9		
31	Vane30aDEG					MinMax	0	359.9		
32	Vane39aDEG					MinMax	0	359.9		
200	VaneSD10aDEG	Anem10aMS				MinMaxT	0	100	100	10
201	VaneSD30aDEG	Anem30yMS				MinMaxT	0	100	100	10
202	VaneSD39aDEG	Anem39yMS				MinMaxT	0	100	100	10
300	Anem10aMS	AnemSD10aMS	Vane10aDEG	VaneSD10aDEG	Etmp2aDEGC	Icing	0.5	1	2	
301	Anem30aMS	AnemSD30aMS	Vane30aDEG	VaneSD10aDEG	Etmp2aDEGC	Icing	0.5	1	2	
302	Anem30bMS	AnemSD30bMS	Vane30aDEG	VaneSD30aDEG	Etmp2aDEGC	Icing	0.5	1	2	
303	Anem39aMS	AnemSD39aMS	Vane39aDEG	VaneSD39aDEG	Etmp2aDEGC	Icing	0.5	1	2	
304	Anem39bMS	AnemSD39bMS	Vane39aDEG	VaneSD39aDEG	Etmp2aDEGC	Icing	0.5	1	2	
400	Anem30aMS	Anem30bMS				CompareSensors	1	0.25	3	0
401	Anem39aMS	Anem39bMS				CompareSensors	1	0.25	3	0
500	Amax10aMS					MinMax	0	90		
501	Amin10aMS					MinMax	0	90		
502	Amax30aMS					MinMax	0	90		
503	Amin30aMS					MinMax	0	90		
504	Amax30bMS					MinMax	0	90		
505	Amin30bMS					MinMax	0	90		
506	Amax39aMS					MinMax	0	90		
507	Amin39aMS					MinMax	0	90		
508	Amax39bMS					MinMax	0	90		
509	Amin39bMS					MinMax	0	90		
540	Vmax10aDEG					MinMax	0	359.9		
541	Vmin10aDEG					MinMax	0	359.9		

TestOrder	TestField1	TestField2	TestField3	CalcField1	CalcField2	TestType	Factor1	Factor2	Factor3	Factor4
542	Vmax30aDEG					MinMax	0	359.9		
543	Vmin30aDEG					MinMax	0	359.9		
544	Vane39aDEG					MinMax	0	359.9		
560	Emax2aDEGC					MinMax	-30	60		
561	Emin2aDEGC					MinMax	-30	60		
562	Vmax39aDEG					MinMax	0	360		
563	Vmin39aDEG					MinMax	0	360		
600	Anem30yMS					MinMax	0	50		
601	AnemSD30yMS					MinMax	0	6		
602	Anem39yMS					MinMax	0	50		
603	AnemSD39yMS					MinMax	0	6		
604	Turb10zNONE					MinMax	0	2		
605	Turb30zNONE					MinMax	0	2		
606	Turb39zNONE					MinMax	0	2		
607	Pwrd10zWMC					MinMax	0	1000		
608	Pwrd30zWMC					MinMax	0	1000		
609	Pwrd39zWMC					MinMax	0	1000		
610	Wshr0zNONE					MinMax	0	100		

Sensor Statistics

Sensor	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	% Data Good
Anem39aMS	58554	54234	92.622	0.333	0	1.833	92.6
AnemSD39aMS	58554	54234	92.622	0.333	0	1.833	92.6
Anem39bMS	58554	54234	92.622	0.167	0	0	92.62
AnemSD39bMS	58554	54234	92.622	0.167	0	0	92.62
Vane39aDEG	58554	54215	92.59	3	0	0	92.559
VaneSD39aDEG	58554	54215	92.59	3	0	0	92.559
Anem30aMS	58554	54234	92.622	0	0	0.667	92.615
AnemSD30aMS	58554	54234	92.622	0	0	0.667	92.615
Anem30bMS	58554	54234	92.622	0	0	2	92.602
AnemSD30bMS	58554	54234	92.622	0	0	2	92.602
Vane30aDEG	58554	54234	92.622	7.667	0	0	92.544
VaneSD30aDEG	58554	54234	92.622	1.167	0	0	92.61
Anem10aMS	58554	54234	92.622	0	0	0	92.622
AnemSD10aMS	58554	54234	92.622	0	0	0	92.622
Vane10aDEG	58554	54234	92.622	4.5	0	0	92.576
VaneSD10aDEG	58554	54234	92.622	7.667	0	0	92.544
Etmp2aDEGC	58554	54234	92.622	0	0	0	92.622
EtmpSD2aDEGC	58554	54234	92.622	0	0	0	92.622
Total	1053972	976174	92.619	28	0	9	92.598

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	Percent
0.5	1.75
1.5	4.15
2.5	9.75
3.5	17.51
4.5	19.37
5.5	14.97
6.5	10.88
7.5	7.44
8.5	5.5
9.5	3.6
10.5	2.1
11.5	1.4
12.5	0.77
13.5	0.46
14.5	0.22
15.5	0.1
16.5	0.03
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

Table B1: Wind Speed Distribution, July 2003 – August 2004

Diurnal Average Wind Speed Data

Hour of Day	Wind Speed [m/s]
0	5.26
1	5.23
2	5.13
3	5.08
4	5.11
5	5.08
6	5.07
7	5.04
8	5.12
9	5.27
10	5.47
11	5.54
12	5.59
13	5.59
14	5.55
15	5.52
16	5.46
17	5.34
18	5.22
19	5.18
20	5.19
21	5.29
22	5.25
23	5.26

Table B3: Diurnal Wind Speed, July 2003 – August 2004

Wind Rose Data

Direction	Percent Time [%]	Mean Wind Speed [m/s]
N	4.34	5.01
NNE	4.82	5.07
NE	4.63	4.33
ENE	3.09	4.32
E	2.91	4.28
ESE	3.98	4.31
SE	4.95	4.89
SSE	7.26	4.93
S	15.17	5.59
SSW	10.39	5.21
SW	6.83	5.34
WSW	7.68	6.4
W	9.43	6.51
WNW	7.74	5.32
NW	3.51	4.64
NNW	3.27	4.93

Table B4: Wind Rose Time Percentage and Mean Wind Speed, July 2003 – August 2004