WIND DATA REPORT

DARTMOUTH, MA

December 1st 2005 to February 28th 2006.

Prepared for

Massachusetts Technology Collaborative
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By

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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.

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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 at Dartmouth commenced on March 26th, 2005 and the station has been in continuous operation to this day. Wind speed and direction are measured at three heights: 50 m, 38 m and 20 m. This report covers data from December 1st 2005 through February 28th 2006. During the period covered by this report, the mean recorded wind speed at 50 meters was 5.4 m/s (12.1 mph) * and the prevailing wind direction at 50 m was WNW. The gross data recovery percentage (the actual percentage of expected data received) was 62.1 % and the net data recovery percentage (the percentage of expected data which passed all of the quality assurance tests) was 58.9%. These values are very low, due to a malfunction in the data logger at the site. The data logger has been replaced and is now operating normally.

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 site is located close to the drainage pits in the Dartmouth Water Treatment Facility premises. The site elevation is 9 m above sea level. The location of the tower base is at 41.590°N, 70.998°W (WGS84/NAD83).

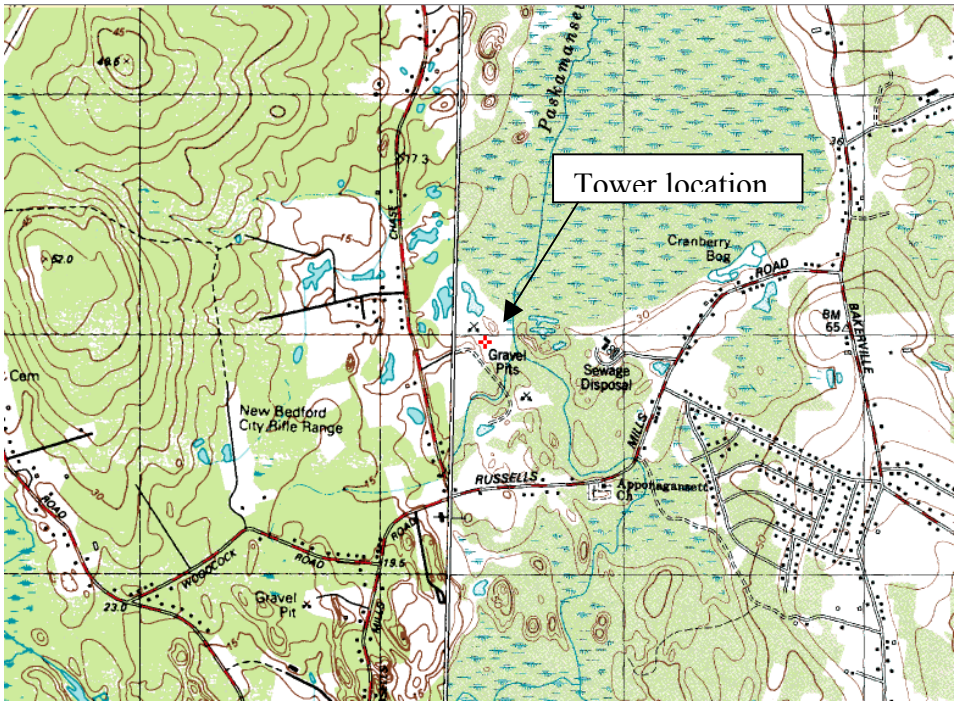

Figure 1 - Dartmouth Site Location

Source: www.topozone.com.

SECTION 2 - Instrumentation and Equipment

Wind monitoring equipment is mounted on a standard Second Wind 50 m tall 6-inch diameter tilt-up guyed tower. Wind vanes and anemometers are located at three heights on the tower: 50 m, 38 m, and 20 m. Redundant anemometers exist at 50 m and 38 m.

Additional equipment and models:

- NRG model Symphonie Cellogger
- 5 – #40 Anemometers, standard calibration (Slope - 0.765 m/s, Offset – 0.350 m/s)
- 3 - #200P Wind direction vanes
- Lightning rod and grounding cable

- NRG 11S temperature Sensor

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 Collection and Maintenance

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

On December 1, 2005 the logger at the Dartmouth, MA site ceased recording data. The logger was replaced and began recording data on January 4, 2006. The logger is now operating normally. Thus, there are approximately 35 days of missing data from this quarter.

Data Statistics Summary

Date	Mean Wind Speed	Max Wind Speed	Prevailing Wind Direction	Turbulence Intensity	Mean Wind Speed	Max Wind Speed	Prevailing Wind Direction	Turbulence Intensity	Mean Wind Speed	Max Wind Speed	Prevailing Wind Direction	Shear Coefficient
Heights, units	**50 m, [m/s]**	**50 m, [m/s]**	**50 m, [ ]**	**50 m, [ ]**	**38 m, [m/s]**	**38 m, [m/s]**	**38 m, [ ]**	**38 m, [ ]**	**20 m, [m/s]**	**20 m, [m/s]**	**20 m, [ ]**	**50 m, 38 m**
05-Dec	-	-	-	-	-	-	-	-	-	-	-	-
06-Jan	5.2	14.8	SW	0.22	4.6	12.9	SW	0.25	3.4	10.6	SW	0.56
06-Feb	5.5	14	NW	0.22	4.9	13.2	NW	0.24	3.8	10.9	WNW	0.49
Dec 05 - Feb 06	**5.4**	**14.8**	**WNW**	**0.22**	**4.7**	**13.2**	**WNW**	**0.25**	**3.6**	**10.9**	**WNW**	**0.53**

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. For this quarter, only 88.1% of the January data were available, and these data were used to determine the January statistics. For December, only 1% of the data was available, and so no monthly statistics are given for December.

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

There were no extreme metrological events in the three months covered by this report. The highest wind speeds in the 3 months are less than 15 m/s as shown by the time series graph.

Source: http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwevent~storms

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 [%]	62.1
Net Data Recovered [%]	58.9

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 that is included in APPENDIX A. Data that 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. 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. The wind blows between 4-5 m/s for close to 18% of the time. Approximately 1 month's worth of data were missing when these quarterly statistics were calculated. The wind speed distribution is shown in Figure 3.

- Monthly Average – A plot of the monthly average wind speed from April 2005 - February 2006. 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. The hourly mean wind speed high occurs between 12 pm and 1 pm and the low occurs between 4 am and 5 am. Again, approximately 1 month's worth of data were missing when these quarterly statistics were calculated. The diurnal variation plot is shown in Figure 5.

- 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 turbulence intensity graph flattens out after 4 m/s. 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. The wind rose plot is shown in Figure 7.

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

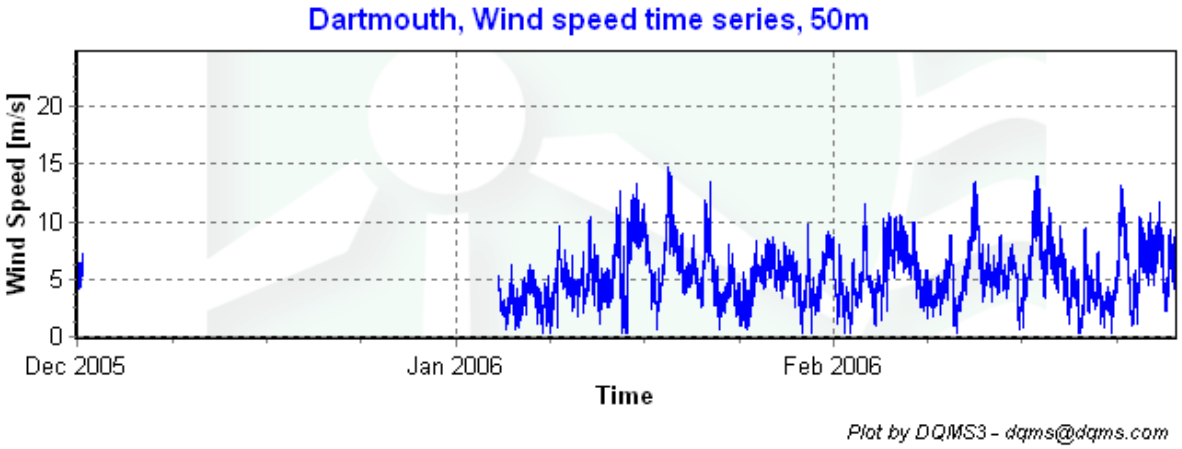

Figure 2 - Wind Speed Time Series, December 1, 2005 – February 28, 2006.

Wind Speed Distributions

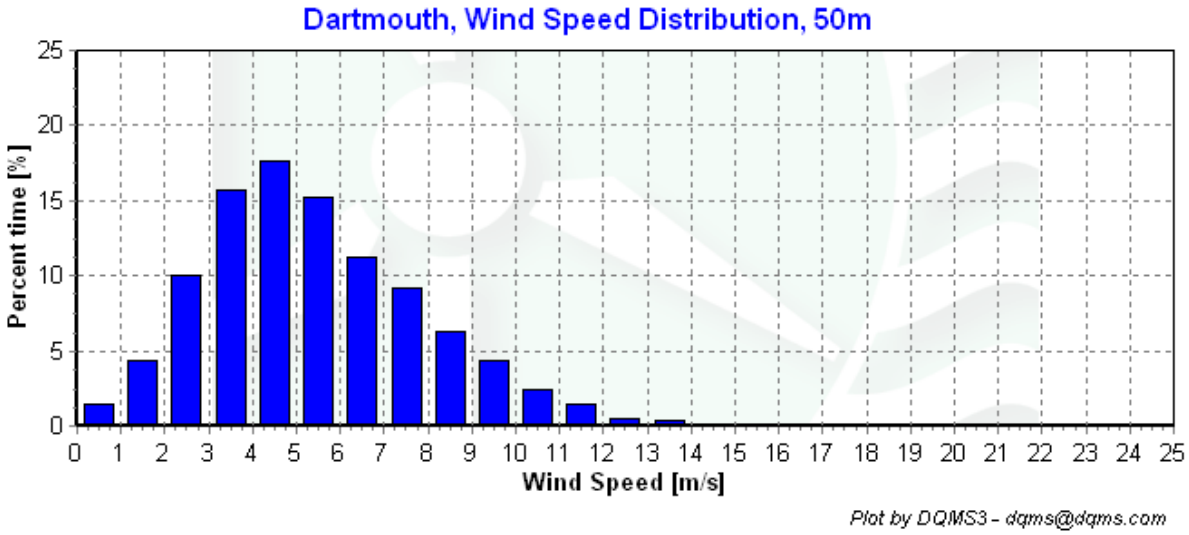

Figure 3 - Wind Speed Distribution, December 1, 2005 – February 28, 2006.

Monthly Average Wind Speeds

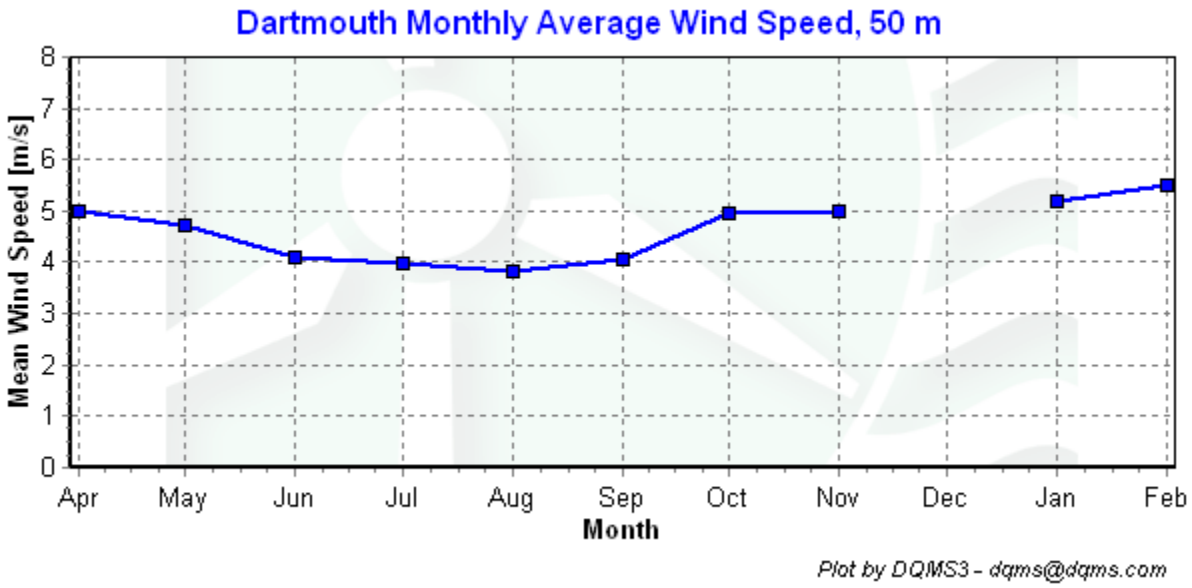

Figure 4 - Monthly average wind speeds, April 1, 2005 – February 28, 2005.

Diurnal Average Wind Speeds

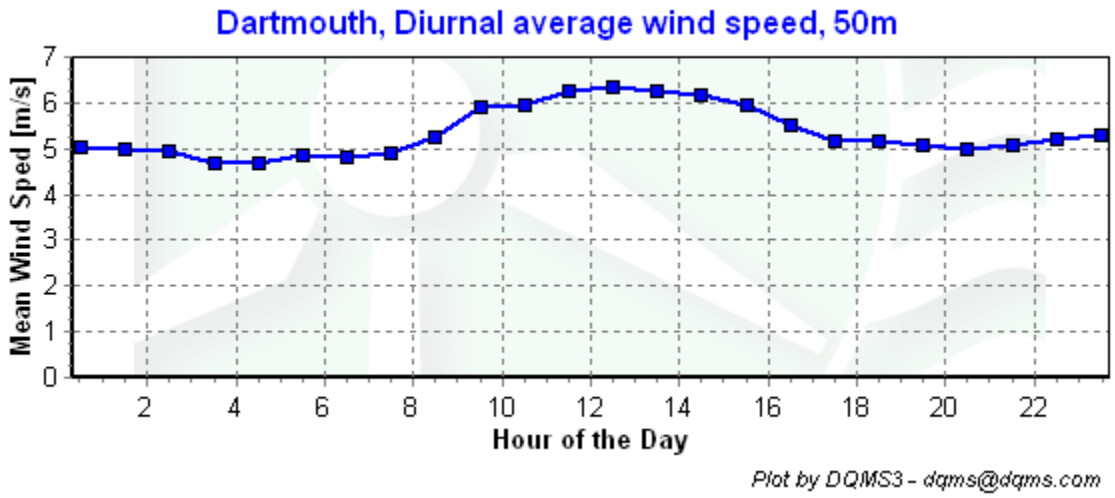

Figure 5 - Diurnal Wind Speed, December 1, 2005 – February 28, 2006.

Turbulence Intensities

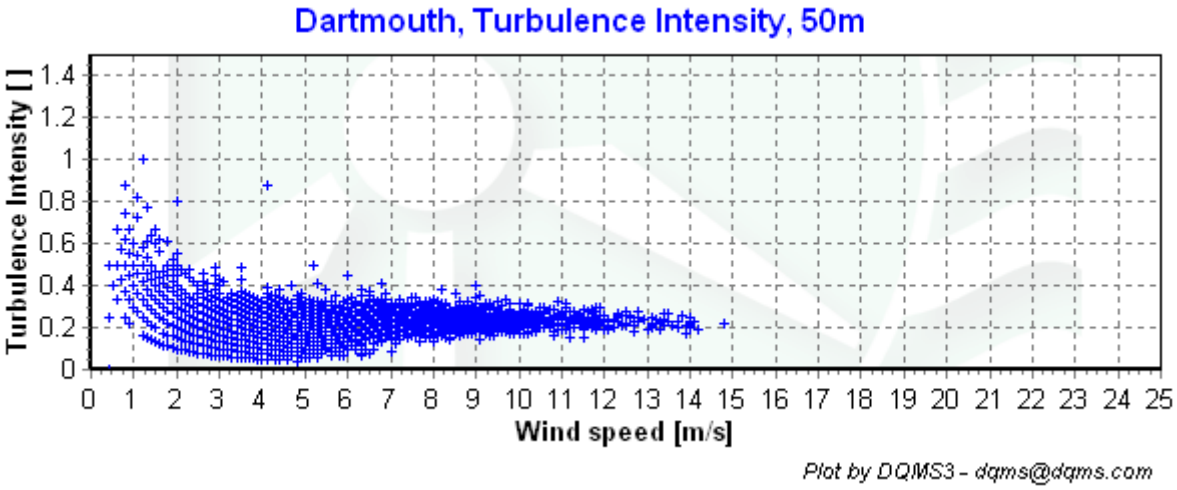

Figure 6 - Turbulence Intensity vs. Wind Speed, December 1, 2005 – February 28, 2006.

Wind Rose

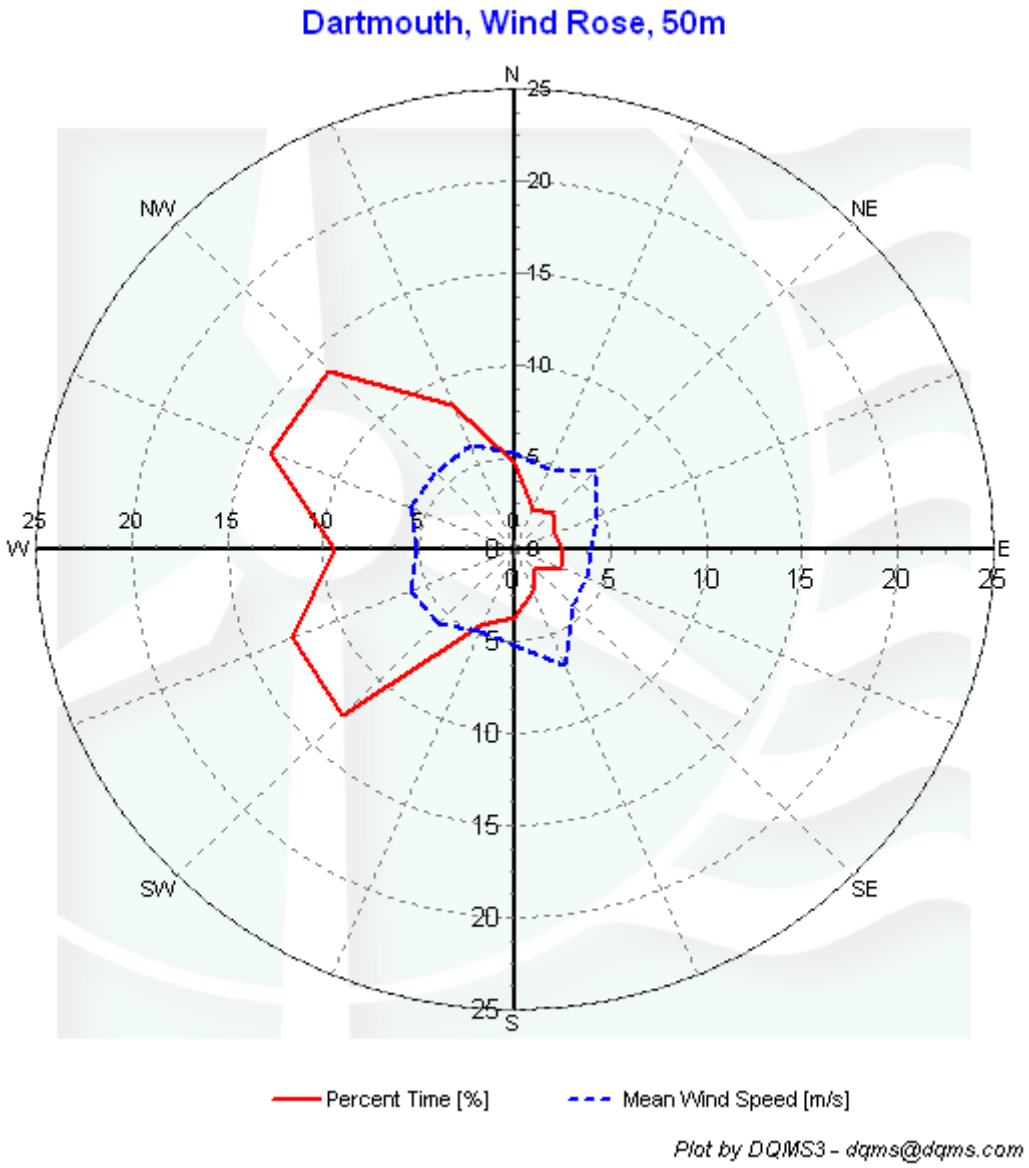

Figure 7 - Wind Rose, December 1, 2005 – February 28, 2006.

APPENDIX A – Sensor Performance Report

Test Definitions

Test Order	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
14	Anem20aMS					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
24	AnemSD20aMS					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
32	Vane20aDEG					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
202	VaneSD20aDEG	Anem20aMS				MinMax	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
304	Anem20aMS	AnemSD20aMS	Vane20aDEG	VaneSD20aDEG	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
504	Amax20aMS					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
514	Amin20aMS					MinMax	0	90	0	0
520	Vmax50aDEG					MinMax	0	359.9	0	0
521	Vmax38aDEG					MinMax	0	359.9	0	0
522	Vmax20aDEG					MinMax	0	359.9	0	0
530	Vmin50aDEG					MinMax	0	359.9	0	0
531	Vmin38aDEG					MinMax	0	359.9	0	0
532	Vmin20aDEG					MinMax	0	359.9	0	0

Sensor Statistics

Sensors	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	% Data Good
Anem50aMS	12960	8049	62.106	0	105.333	0	57.23
AnemSD50aMS	12960	8049	62.106	0	105.333	0	57.23
Anem50bMS	12960	8049	62.106	0	100.5	0	57.454
AnemSD50bMS	12960	8049	62.106	0	100.5	0	57.454
Anem38aMS	12960	8049	62.106	0	49.167	6.833	59.514
AnemSD38aMS	12960	8049	62.106	0	49.167	6.833	59.514
Anem38bMS	12960	8049	62.106	0	75	0	58.634
AnemSD38bMS	12960	8049	62.106	0	75	0	58.634
Anem20aMS	12960	8049	62.106	0	53.5	0	59.63
AnemSD20aMS	12960	8049	62.106	0	53.5	0	59.63
Vane50aDEG	12960	8049	62.106	0	105.333	0	57.23
VaneSD50aDEG	12960	8049	62.106	0	105.333	0	57.23
Vane38aDEG	12960	8049	62.106	0.167	75	0	58.627
VaneSD38aDEG	12960	8049	62.106	0.167	75	0	58.627
Vane20aDEG	12960	8049	62.106	0.167	53.5	0	59.622
VaneSD20aDEG	12960	8049	62.106	0.167	53.5	0	59.622
Etmp2aDEGC	12960	8049	62.106	0	0	0	62.106
EtmpSD2aDEGC	12960	8049	62.106	0	0	0	62.106
Total	**233280**	**144882**	**62.106**	**0.667**	**1234.667**	**13.667**	**58.894**

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	Percent of Time [%]
0.5	1.4
1.5	4.3
2.5	10.05
3.5	15.73
4.5	17.63
5.5	15.2
6.5	11.19
7.5	9.14
8.5	6.25
9.5	4.34
10.5	2.39
11.5	1.47
12.5	0.47
13.5	0.35
14.5	0.1
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, December 1, 2005 – February 28, 2006.

Monthly Average Wind Speed Data

Date	10 min Mean [m/s]
Apr-05	4.99
May-05	4.7
Jun-05	4.1
Jul-05	3.98
Aug-05	3.82
Sep-05	4.04
Oct-05	4.96
Nov-05	5.01
Dec-05	-
Jan-06	5.2
Feb-06	5.5

Table 2 - Wind Speed Averages, 50m

Diurnal Average Wind Speed Data

Hour of Day	Average Wind Speed [m/s]
0.5	5.04
1.5	5
2.5	4.95
3.5	4.68
4.5	4.67
5.5	4.84
6.5	4.81
7.5	4.91
8.5	5.27
9.5	5.9
10.5	5.96
11.5	6.25
12.5	6.34
13.5	6.25
14.5	6.16
15.5	5.96
16.5	5.53
17.5	5.16
18.5	5.16
19.5	5.06
20.5	4.99
21.5	5.07
22.5	5.21
23.5	5.29

Table 3 - Diurnal Average Wind Speeds, December 1, 2005 – February 28, 2006.

Wind Rose Data

Direction	Percent Time [%], 50 m	Mean Wind Speed [m/s], 50 m
N	4.64	5.26
NNE	2.37	4.74
NE	2.8	5.96
ENE	2.29	4.68
E	2.48	3.93
ESE	2.57	4.1
SE	1.52	4.31
SSE	2.48	6.77
S	3.72	5.26
SSW	4.53	4.77
SW	12.69	5.66
WSW	12.52	5.91
W	9.38	5.13
WNW	13.76	5.94
NW	13.72	5.88
NNW	8.51	6.13

Table 4 - Wind Rose, Time Percentage and Mean Wind Speed by Direction, December 1, 2005 – February 28, 2006.