

WIND DATA REPORT

Nantucket, MA

December 1st 2005 to February 28th 2006

Prepared for

Massachusetts Technology Collaborative
75 North Drive
Westborough, MA 01581

by

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

March 30, 2006

Report template version 1.3

Renewable Energy Research Laboratory
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.

Further, MTC, the Commonwealth of Massachusetts, and RERL make no warranties or representations, expressed or implied, as to the fitness for particular purpose or merchantability of any product, apparatus, or service, or the usefulness, completeness, or accuracy of any processes, methods or other information contained, described, disclosed, or referred to in this report. MTC, the Commonwealth of Massachusetts, and the contractor make no representation that the use of any product, apparatus, process, method, or other information will not infringe privately owned rights and will assume no liability for any loss, injury, or damage directly or indirectly resulting from, or occurring in connection with, the use of information contained, described, disclosed, or referred to in this report.

TABLE OF CONTENTS

NOTICE AND ACKNOWLEDGEMENTS	1
Table of Contents	2
Table of Figures	3
Executive Summary	4
SECTION 1 - Station Location	5
SECTION 2 - Instrumentation and Equipment	5
SECTION 3 - Data Collection and Maintenance	6
SECTION 4 - Significant Meteorological Events	7
SECTION 5 - Data Recovery and Validation	7
Test Definitions	8
Sensor Statistics	9
SECTION 6 - Data Summary	9
SECTION 7 - Graphs	11
Wind Speed Time Series	11
Wind Speed Distributions	11
Monthly Average Wind Speeds	12
Diurnal Average Wind Speeds	12
Turbulence Intensities	13
Wind Rose	14
APPENDIX A – Sensor Performance Report	15
Test Definitions	15
Sensor Statistics	16
APPENDIX B - Plot Data	17
Wind Speed Distribution Data	17
Monthly Average Wind Speed Data	17
Diurnal Average Wind Speed Data	18
Wind Rose Data	19

TABLE OF FIGURES

Figure 1 - Nantucket Site Location.....	5
Figure 2 - Wind Speed Time Series, December 1, 2005 - February 28, 2006.....	11
Figure 3 - Wind Speed Distribution, December 1, 2005 - February 28, 2006.....	11
Figure 4 - Monthly average wind speeds, August 1, 2005 - February 28, 2006.....	12
Figure 5 - Diurnal Wind Speed, December 1, 2005 - February 28, 2006.....	12
Figure 6 - Turbulence Intensity vs. Wind Speed, December 1, 2005 - February 28, 2006.....	13
Figure 7 - Wind Rose, December 1, 2005 - February 28, 2006.....	14

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 a radio tower in Nantucket, MA, which was installed on July 21, 2005. Two anemometers and one wind vane are mounted at 99 m (324.8 ft), 68 m (223.1 ft), and 58 m (190.3 ft).

The season covered by this report is December 1, 2005 – February 28, 2006. The quarterly mean recorded wind speed at 99 m was 10.7 m/s (23.9 mph) and the prevailing direction was from the west-northwest. The gross data recovery percentage (the actual percentage of expected data received) was 99.9 % and the net data recovery percentage (the percentage of expected data which passed all of the quality assurance tests) was 99.7%.

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 Nantucket station is located at the town of Nantucket landfill. The tower base is located at 41.281° N, -70.169° W (WGS84) (Figure 1). The elevation at the station is approximately 3 m above sea level. The red cross indicates the approximate location of the tower.



Figure 1 - Nantucket Site Location

Source: www.topozone.com.

SECTION 2 - Instrumentation and Equipment

The wind monitoring equipment is mounted on a 142.6 m (467.8 ft) radio tower. All the remaining monitoring equipment comes from NRG Systems, and consists of the following items:

- 9300 Data Logger (Removed 8/10/2005)
- Symphonie Data Logger (Installed on 8/10/2005)
- 6 – #40 Anemometers, standard calibration (Slope - 0.765 m/s, Offset – 0.350 m/s). Two anemometers are located at 99 m (324.8 ft), two at 68 m (223.1 ft) and two at 58 m (190.3 ft).
- 3 - #200P Wind direction vanes. They are located at heights of 99 m (324.8 ft), 68 m (223.1 ft) and 58 m (190.3 ft).

- 6 – 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 Collection and Maintenance

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

Almost no data were missing (i.e. the logger reported values for nearly every 10-minute timestamp).

No maintenance work was done in 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	Wind Shear Coefficient
Heights, units	99 m, [m/s]	99 m, [m/s]	99 m, []	99 m, []	68 m, [m/s]	68 m, [m/s]	68 m, []	68 m, []	58 m, [m/s]	58 m, [m/s]	58 m, []	[]
05-Dec	10.1	32.1	WNW	0.08	9.4	30.5	WNW	0.10	9.0	29.0	WNW	0.11
06-Jan	11.1	28.4	W	0.08	10.1	25.5	W	0.10	9.5	23.9	W	0.11
06-Feb	10.9	26.0	NW	0.09	10.1	24.7	NW	0.11	9.6	23.9	NW	0.12
Dec 05 – Jan 06	10.7	32.1	WNW	0.08	9.9	30.5	WNW	0.10	9.4	29.0	WNW	0.11

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 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 $\pm 2\%$ 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 meteorological events in the three months covered by this report. The highest wind speeds in the 3 months are less than 32 m/s as shown by the time series graph.

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 [%]	99.9
Net Data Recovered [%]	99.7

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.

$$\begin{aligned} & (TF1 < F1) \\ & \text{or } (TF2 < F4 \text{ and } TF1 > F2) \\ & \text{or } (TF2 \geq F4 \text{ and } TF1 > F3) \end{aligned}$$

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.

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

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 at a height of 99 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 99 m. The wind blows most often

between 12 m/s and 13 m/s, for approximately 8% of the time. The wind speed distribution is shown in Figure 3.

- Monthly Average – This graph shows the trends in the mean monthly wind speed at a height of 99 m from August 2005 - February 2006. This graph shows the trends in the wind speed over the year. To date, January has been the windiest month, with a mean wind speed of 11.1 m/s. 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 99 m. The wind speed was lowest between 7 am and 8 am, with a mean speed of 10.3 m/s. The wind speed was highest between 8 pm and 9 pm, with a mean speed on 11.1 m/s. 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 99 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 0.4; for Nantucket, the average turbulence intensity was 0.1. 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 99 m. This wind rose shows the prevailing direction from the west-northwest. The wind rose plot is shown in Figure 6.

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

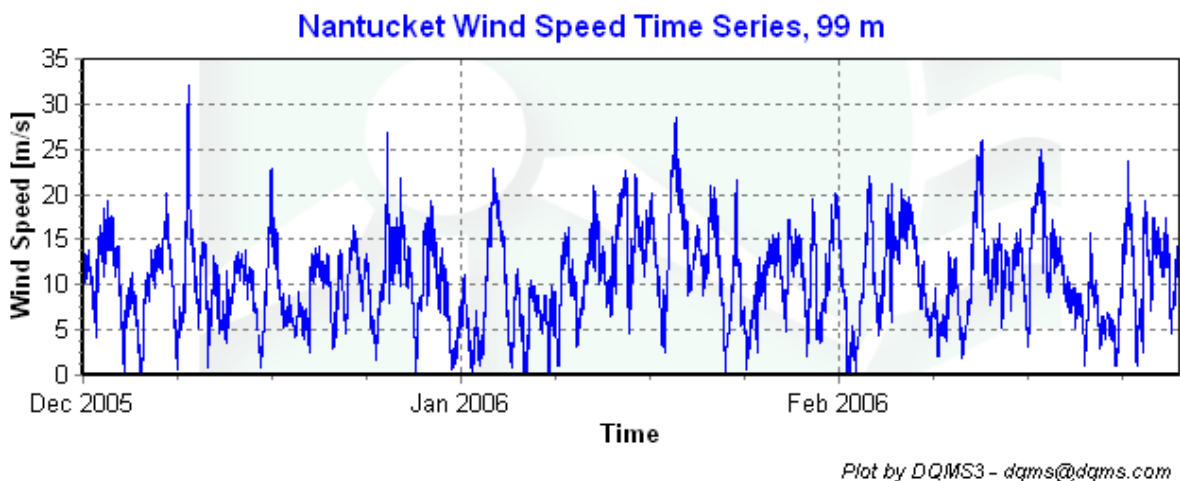


Figure 2 - Wind Speed Time Series, December 1, 2005 - February 28, 2006.

Wind Speed Distributions

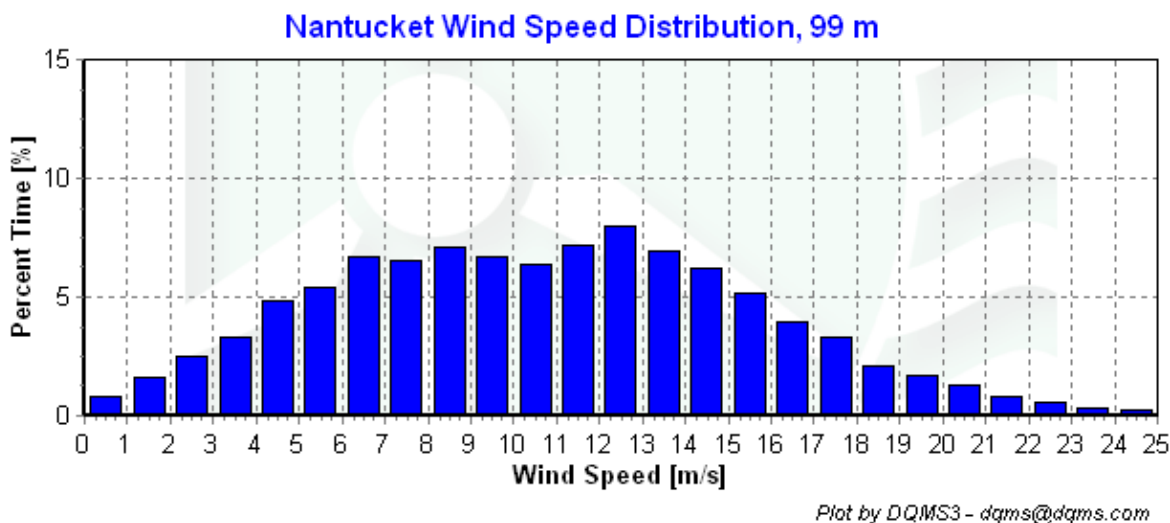


Figure 3 - Wind Speed Distribution, December 1, 2005 - February 28, 2006.

Monthly Average Wind Speeds

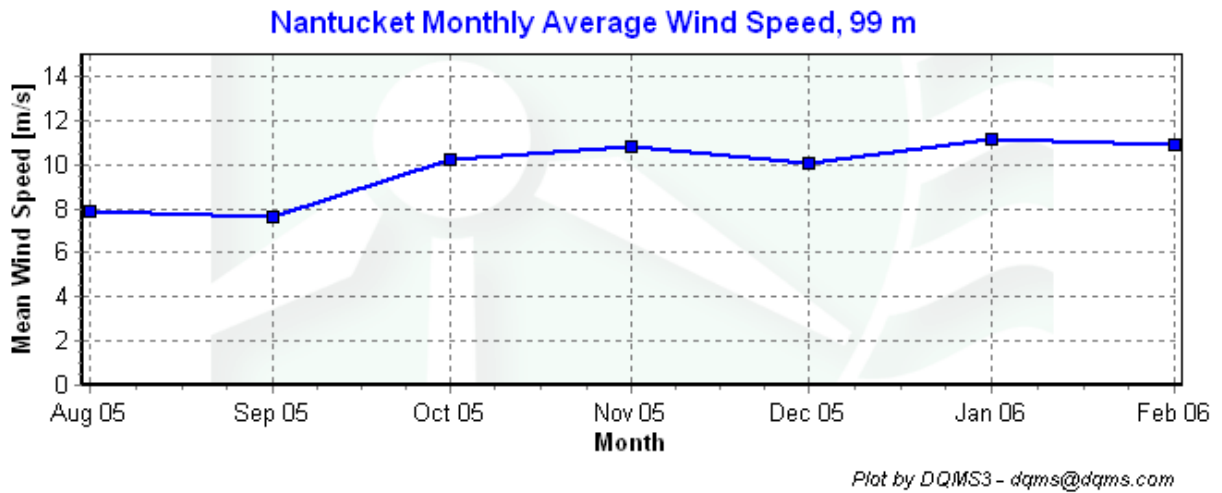


Figure 4 - Monthly average wind speeds, August 1, 2005 - February 28, 2006.

Diurnal Average Wind Speeds

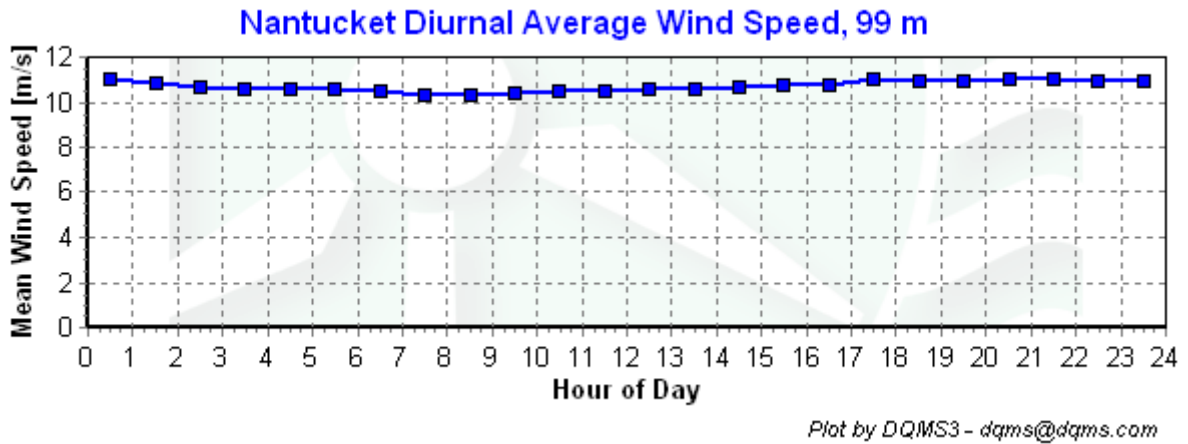


Figure 5 - Diurnal Wind Speed, December 1, 2005 - February 28, 2006.

Turbulence Intensities

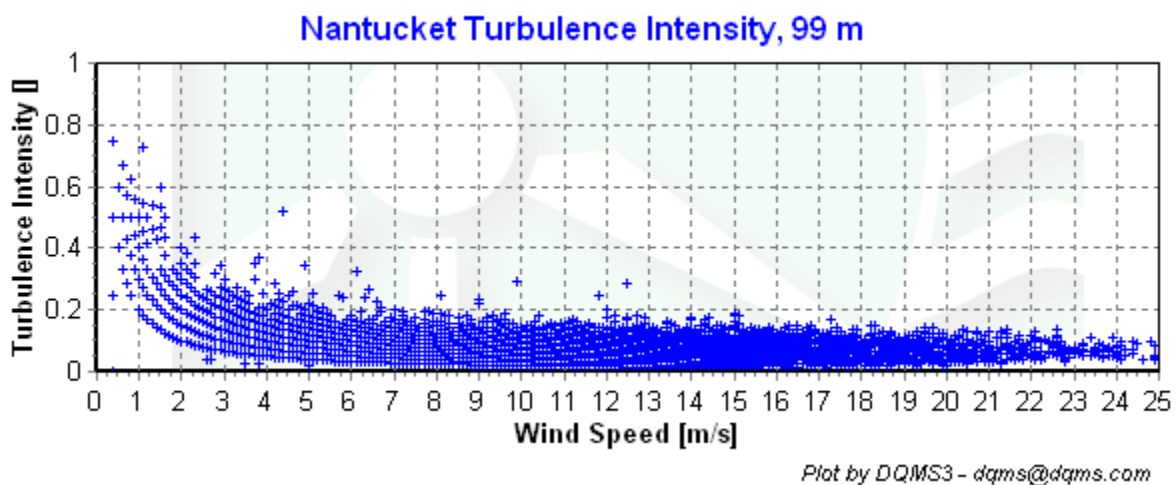
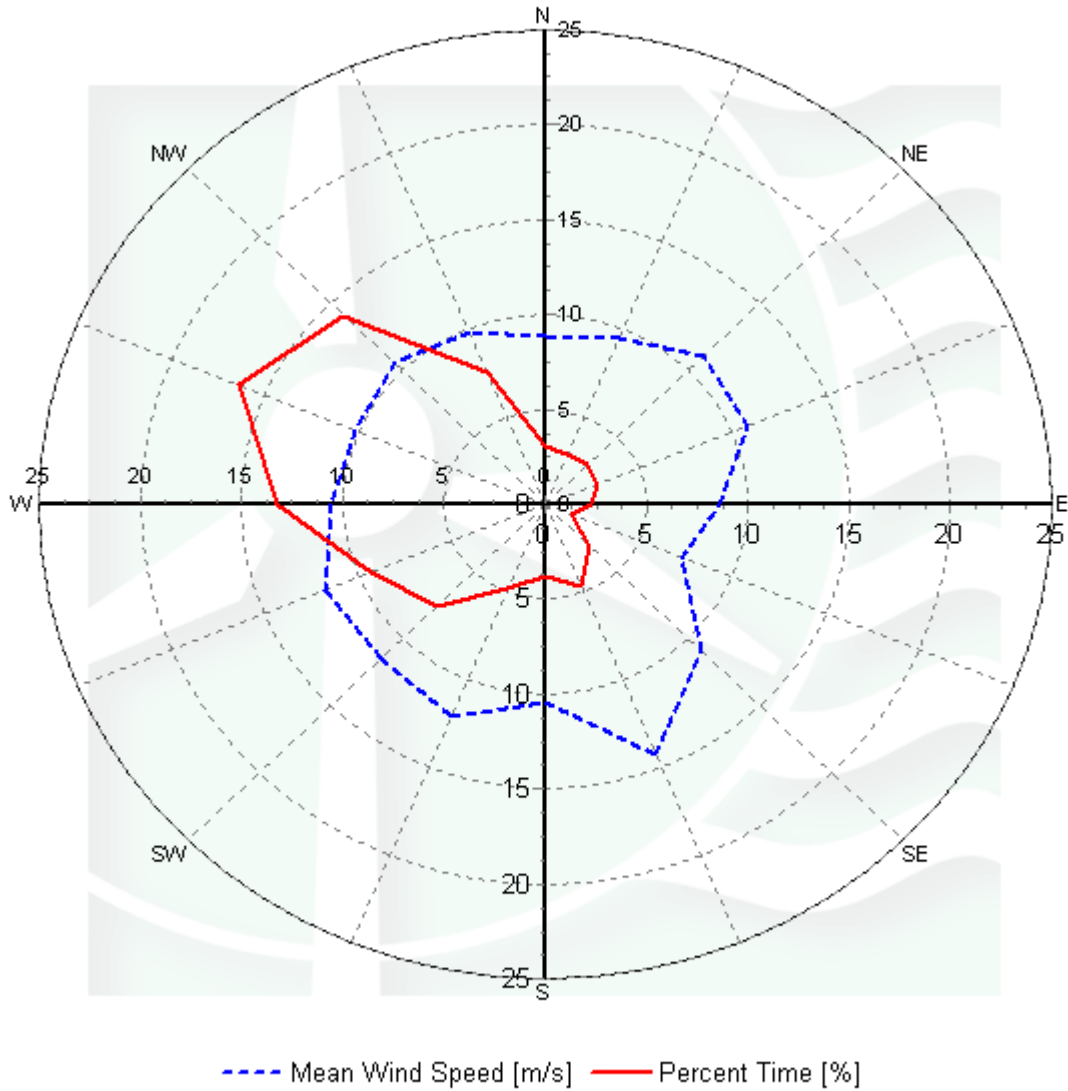


Figure 6 - Turbulence Intensity vs. Wind Speed, December 1, 2005 - February 28, 2006.

Wind Rose

Nantucket Wind Rose, 99 m



Plot by DQMS3 - dqms@dqms.com

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

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				
10	Anem99ams						MinMax	0	90	0	0
11	Anem99bms						MinMax	0	90	0	0
12	Anem68ams						MinMax	0	90	0	0
13	Anem68bms						MinMax	0	90	0	0
14	Anem58ams						MinMax	0	90	0	0
15	Anem58bms						MinMax	0	90	0	0
16	Anem99yms						MinMax	0	90	0	0
17	Anem68yms						MinMax	0	90	0	0
18	Anem58yms						MinMax	0	90	0	0
20	AnemSD99ams						MinMax	0	4	0	0
21	AnemSD99bms						MinMax	0	4	0	0
22	AnemSD68ams						MinMax	0	4	0	0
23	AnemSD68bms						MinMax	0	4	0	0
24	AnemSD58ams						MinMax	0	4	0	0
25	AnemSD58bms						MinMax	0	4	0	0
26	AnemSD99yms						MinMax	0	4	0	0
27	AnemSD68yms						MinMax	0	4	0	0
28	AnemSD58yms						MinMax	0	4	0	0
30	Vane99aDEG						MinMax	0	359.9	0	0
31	Vane68aDEG						MinMax	0	359.9	0	0
32	Vane58aDEG						MinMax	0	359.9	0	0
50	Turb99zNONE						MinMax	0	2	0	0
51	Turb68zNONE						MinMax	0	2	0	0
52	Turb58zNONE						MinMax	0	2	0	0
60	Wshr0zNONE						MinMax	-100	100	0	0
200	VaneSD99aDEG	Anem99yms					MinMaxT	0	100	100	10
201	VaneSD68aDEG	Anem68yms					MinMaxT	0	100	100	10
202	VaneSD58aDEG	Anem58yms					MinMaxT	0	100	100	10
400	Anem99ams	Anem99bms					CompareSensors	1	0.25	3	0
401	Anem68ams	Anem68bms					CompareSensors	1	0.25	3	0
402	Anem58ams	Anem58bms					CompareSensors	1	0.25	3	0

Sensor Statistics

Sensor	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Fault	% Data Good
Anem99ams	12960	12954	99.954	0.167	3.167	99.799
AnemSD99ams	12960	12954	99.954	0.167	3.167	99.799
Anem99bms	12960	12954	99.954	0.167	0.5	99.923
AnemSD99bms	12960	12954	99.954	0.167	0.5	99.923
Vane99aDEG	12960	12954	99.954	0.167	0	99.946
VaneSD99aDEG	12960	12954	99.954	0.167	0	99.946
Anem68ams	12960	12954	99.954	0.167	42.667	97.971
AnemSD68ams	12960	12954	99.954	0.167	42.667	97.971
Anem68bms	12960	12954	99.954	0.5	0.167	99.923
AnemSD68bms	12960	12954	99.954	0.5	0.167	99.923
Vane68aDEG	12960	12954	99.954	0	0	99.954
VaneSD68aDEG	12960	12954	99.954	0	0	99.954
Anem58ams	12960	12954	99.954	0.5	0	99.931
AnemSD58ams	12960	12954	99.954	0.5	0	99.931
Anem58bms	12960	12954	99.954	0.5	1.833	99.846
AnemSD58bms	12960	12954	99.954	0.5	1.833	99.846
Vane58aDEG	12960	12954	99.954	0	0	99.954
VaneSD58aDEG	12960	12954	99.954	0	0	99.954
Total	233280	233172	99.954	4.333	96.667	99.694

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	Percent of Time [%]
0.5	0.84
1.5	1.61
2.5	2.51
3.5	3.34
4.5	4.84
5.5	5.4
6.5	6.68
7.5	6.55
8.5	7.09
9.5	6.68
10.5	6.35
11.5	7.16
12.5	8.02
13.5	6.95
14.5	6.19
15.5	5.15
16.5	3.91
17.5	3.29
18.5	2.12
19.5	1.72
20.5	1.33
21.5	0.82
22.5	0.56
23.5	0.36
24.5	0.23

Table 1 - Wind Speed Distribution, 99 m, December 1, 2005 - February 28, 2006.

Monthly Average Wind Speed Data

Date	10 min Mean [m/s]
Aug-05	7.9
Sep-05	7.7
Oct-05	10.2
Nov-05	10.8
Dec-05	10.1
Jan-06	11.1

Feb-06	10.9
--------	------

Table 2 - Wind Speed Averages, 99 m

Diurnal Average Wind Speed Data

Hour of Day	Average Wind Speed [m/s]
0.5	11.05
1.5	10.81
2.5	10.68
3.5	10.6
4.5	10.55
5.5	10.54
6.5	10.53
7.5	10.32
8.5	10.33
9.5	10.39
10.5	10.5
11.5	10.53
12.5	10.58
13.5	10.59
14.5	10.66
15.5	10.71
16.5	10.76
17.5	10.99
18.5	10.93
19.5	10.93
20.5	11.07
21.5	11.01
22.5	10.98
23.5	10.95

Table 3 - Diurnal Average Wind Speeds, 99 m, December 1, 2005 - February 28, 2006.

Wind Rose Data

Direction	Percent Time [%]	Mean Wind Speed [m/s]
N	3.1	8.83
NNE	2.89	9.44
NE	2.97	10.99
ENE	2.81	10.78
E	2.29	8.61
ESE	1.38	7.32
SE	3.13	10.91
SSE	4.69	14.24
S	3.76	10.48
SSW	4.8	12.05
SW	7.58	11.42
WSW	9.35	11.72
W	13.19	10.56
WNW	16.4	10.2
NW	14.1	10.53
NNW	7.55	9.82

**Table 4 - Wind Rose, Time Percentage and Mean Wind Speed by Direction, 99 m,
December 1, 2005 - February 28, 2006.**