WIND DATA REPORT

Orleans

1st December, 2004 –28th February, 2005

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

This wind measurement station is installed at the town watershed in Orleans, MA. Installed on October 27 of 2003, the station has been in continuous operation to this day. The two sets of two anemometers and one wind vane are mounted at 50 m (164.0 ft) and 40 m (131.2 ft), an additional vane and anemometer are mounted at 20 m (65.6 ft).

During the period covered by this report, December 2004 – February 2005, the mean recorded wind speed at 50 m (164.0 ft) was 6.25 m/s (13.7 mph); the prevailing wind direction at 40 m (131.2 ft) was NW. The gross data recovery percentage (the actual percentage of expected data received) was 100 % and the net data recovery percentage (the percentage of expected data which passed all of the quality assurance tests) was 88.608%. The net data recovery percentage is low because the 50 m (164.0 ft) wind vane had failed since November 2003.

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 Orleans site is located on the town watershed in Orleans, MA. The tower is on a cleared hilltop, surrounded by trees. The location of the tower base was measured to be at 41.7584° North, 69.9933° West referred to the NAD83.

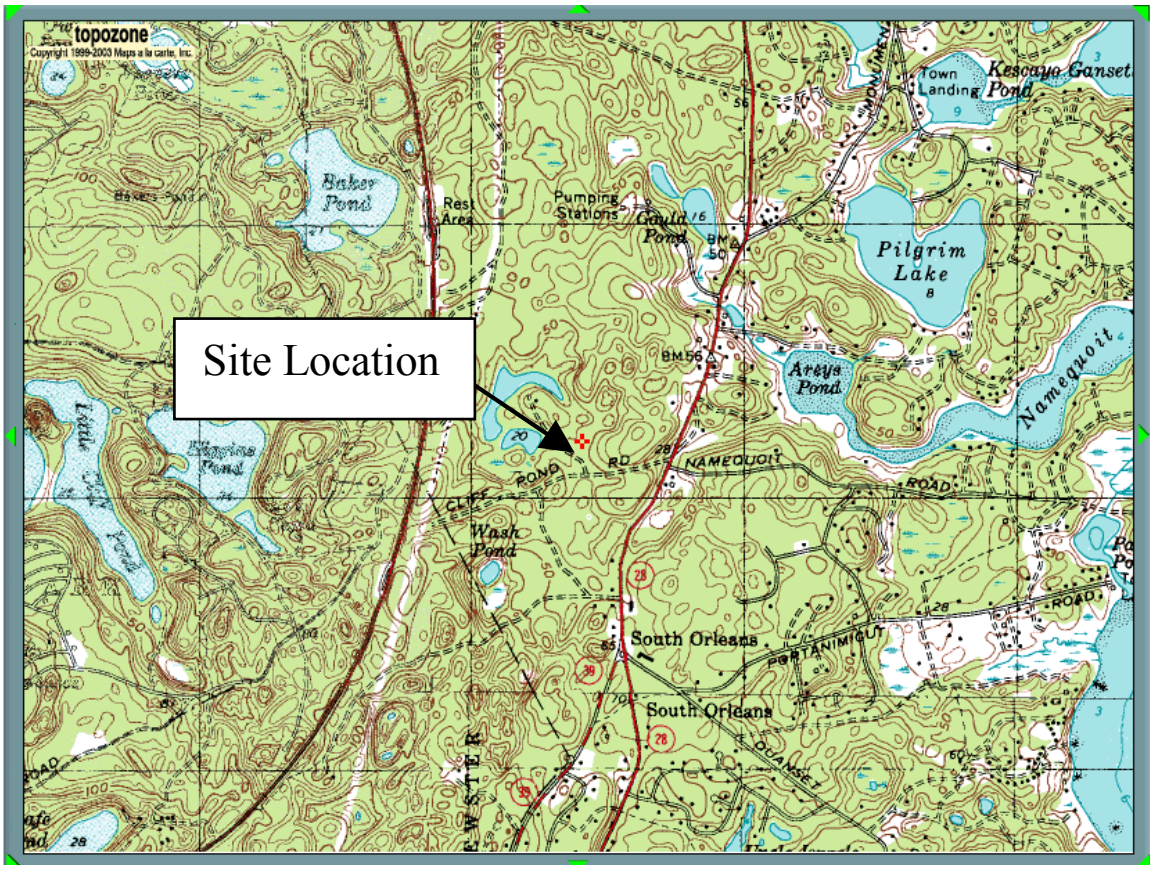

Figure 1 - Site location at Orleans site.
Source: www.topozone.com.

SECTION 2 - Instrumentation and Equipment

The wind monitoring equipment is mounted on a 50 m (164.0 ft) Second Wind tower. All the remaining monitoring equipment comes from NRG Systems, and consists of the following items:

- Symphonie Data Logger
- Electrical enclosure box
- 5 – #40 Anemometers, standard calibration (Slope - 0.765 m/s, Offset – 0.350 m/s). Two anemometers are located at 50 m (164.0 ft), two at 40 m and one at a height of 20 m (65.6 ft).
- 3 - #200P Wind direction vanes. They are located at heights of 50, 40 and 20 m (164.0, 131.2 and 65.6 ft) each.
- 5 – Sensor booms, 54" length
- Lightning rod and grounding cable
- Shielded sensor wire

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

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.

Data Statistics Summary

Date	Mean Wind Speed	Max Wind Speed	Turbulence Intensity	Prevailing Wind Direction	Mean Wind Speed	Max Wind Speed	Turbulence Intensity	Prevailing Wind Direction	Mean Wind Speed	Max Wind Speed
Heights, units	**50 m, [m/s]**	**50 m, [m/s]**	**50 m, [ ]**	**40 m, [ ]**	**40 m, [m/s]**	**40 m, [m/s]**	**40 m, [ ]**	**20 m, [ ]**	**20 m, [m/s]**	**20 m, [m/s]**
December 2004	6.37	17.8	0.19	NW	5.78	16.6	0.21	NW	4.01	13.5
January 2005	6.47	19.6	0.21	NNW	5.81	17.9	0.24	NNW	4.19	13.4
February 2005	5.86	13.2	0.20	NW	5.15	11.8	0.23	NW	3.8	9.5
Dec 04 – Feb 05	**6.25**	**19.6**	**0.20**	**NW**	**5.59**	**17.9**	**0.23**	**NW**	**4.01**	**13.5**

No maintenance on the system was conducted in this quarter.

SECTION 4 - Significant Meteorological Events

The early part of this quarter continued the trend from last quarter with a slight increase in average wind speeds. This trend did not continue and the wind conditions were reported to be around the average values for this time of the year. The monthly average temperature , however, were constantly lower than normal and total snow fall was reported to be above average. 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 data recovered (ratio of raw data points which passed all QA control tests to data points expected) are shown below.

Gross Data Recovered [%]	100.000
Net Data Recovered [%]	88.608

The gross data recovered is low at 88.608% because of the failed 50 m (164.0 ft) wind vane. Disregarding the 50 m (164.0 ft) wind vane data, the gross data recovered is 99.684%.

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 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.

$$F1 > TF1 > F2$$

MinMax T 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. It should be noted that, while this test is tuned to detect sensor icing events, it is possible for the conditions that are representative of icing to occur at other times. The error due to this possibility is considered to be insignificant.

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 in Figure 2. The graph shows three distinct periods when the 10-minute mean wind speed exceed 15 m/s (33 mph).

- Wind Speed Distribution – A histogram plot giving the percentage of time that the wind is at a given wind speed. Figure 3 shows that the maximum percentage is between 5 and 6 m/s (10.95 and 13.14 mph).

- Monthly Average – A plot of the monthly average wind speed over a 16-month period is given in Figure 4. This graph shows the trends in the wind speed from November 2003 - February 2005. Data for the month of May is missing because the data card arrived at the lab empty.

- Diurnal – A plot of the average wind speed for each hour of the day is given in Figure 5. This graph shows a peak wind speed between 10 AM and 1 PM.

- 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. This graph is given in Figure 6.

- Wind Rose – A plot, by compass directions showing the percentage of time that the wind comes from a given direction and the average wind speed in that direction. The winter wind rose, in Figure 7, shows that the wind is predominantly from the NW at the 40 m height and that the mean wind speed is relatively even from all direction. (The 50 m (164.0 ft) wind data was used for the plot but 40 m wind direction data was used due to the failure of the vane at 50m.)

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

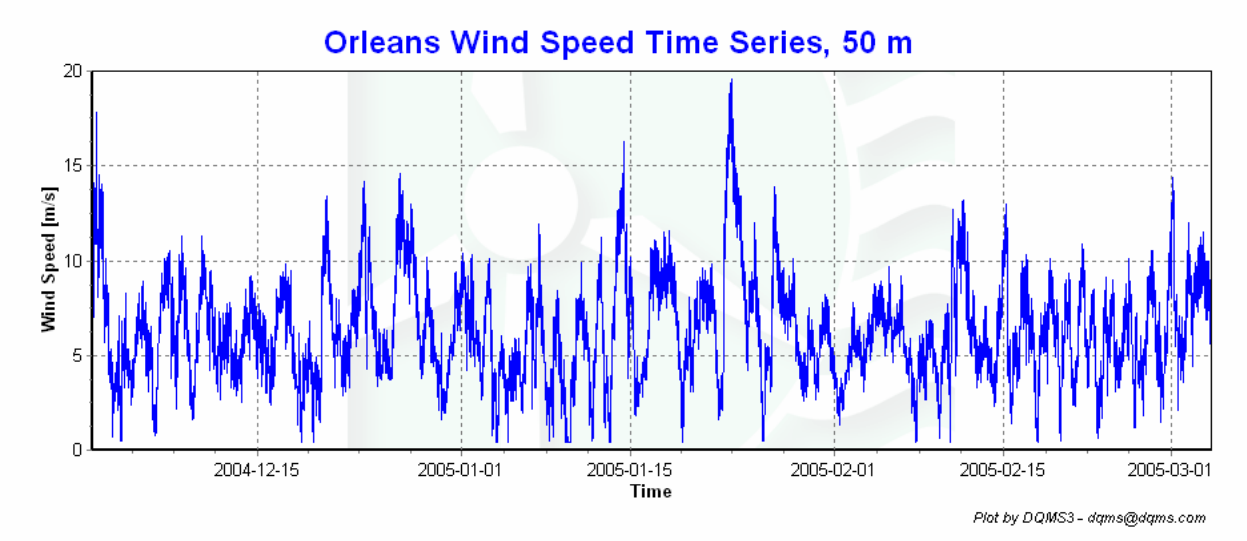

Figure 2 - Wind Speed Time Series, December 2004 - February 2005

Wind Speed Distributions

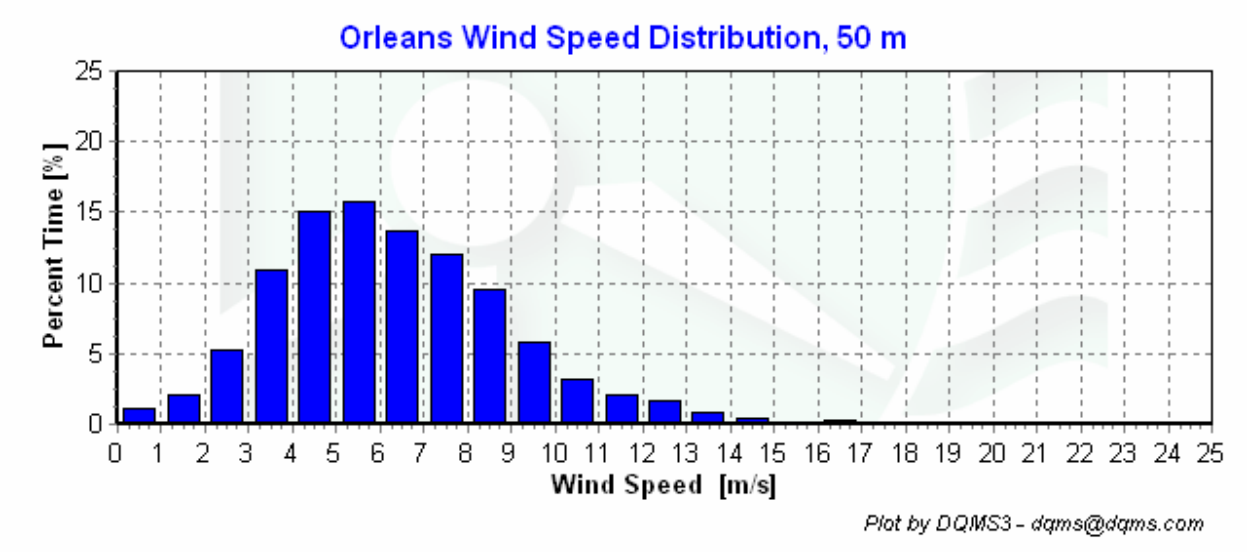

Figure 3 - Wind Speed Distribution, December 2004 - February 2005

Monthly Average Wind Speeds

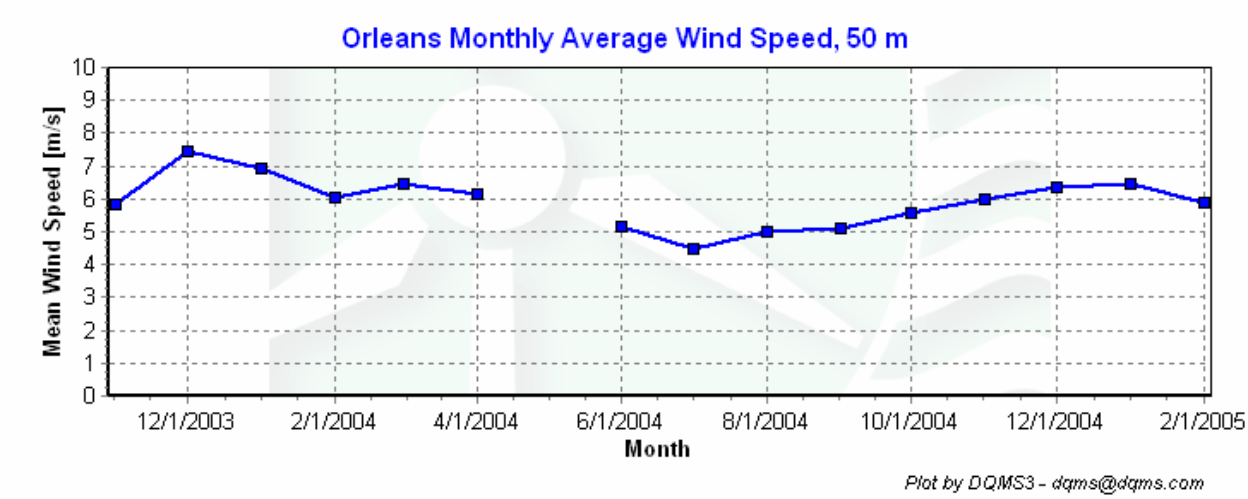

Figure 4 - Monthly average wind speed

Diurnal Average Wind Speeds

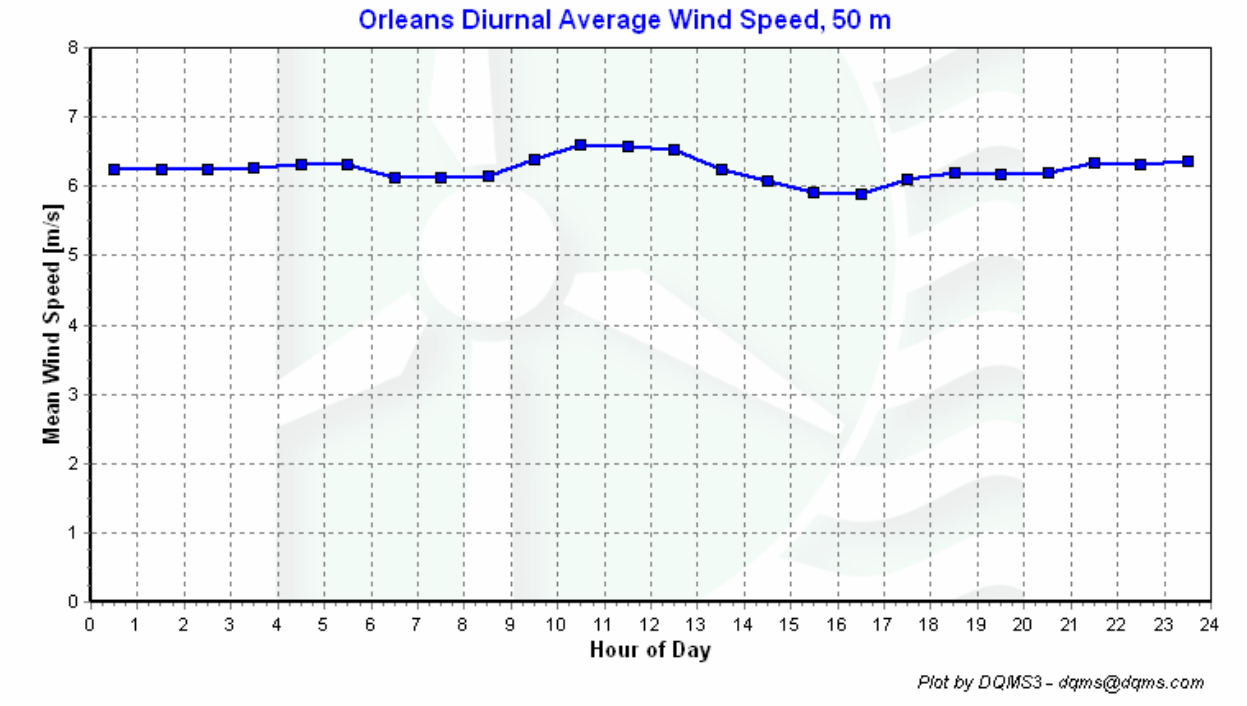

Figure 5 - Diurnal Wind Speed, December 2004 - February 2005

Turbulence Intensities

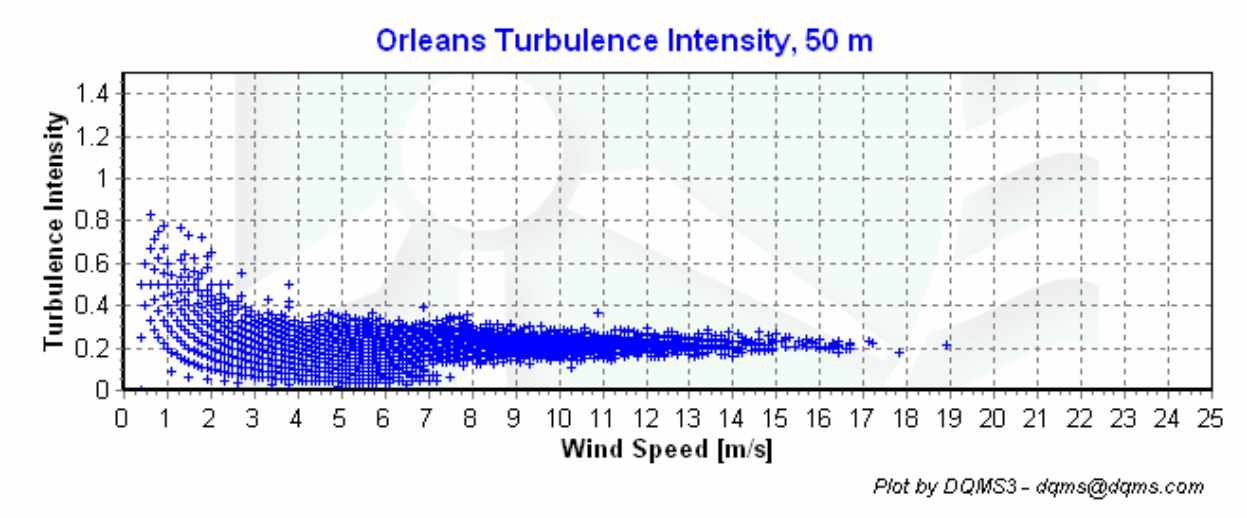

Figure 6 - Turbulence Intensity vs. Wind Speed, December 2004 - February 2005

Wind Roses

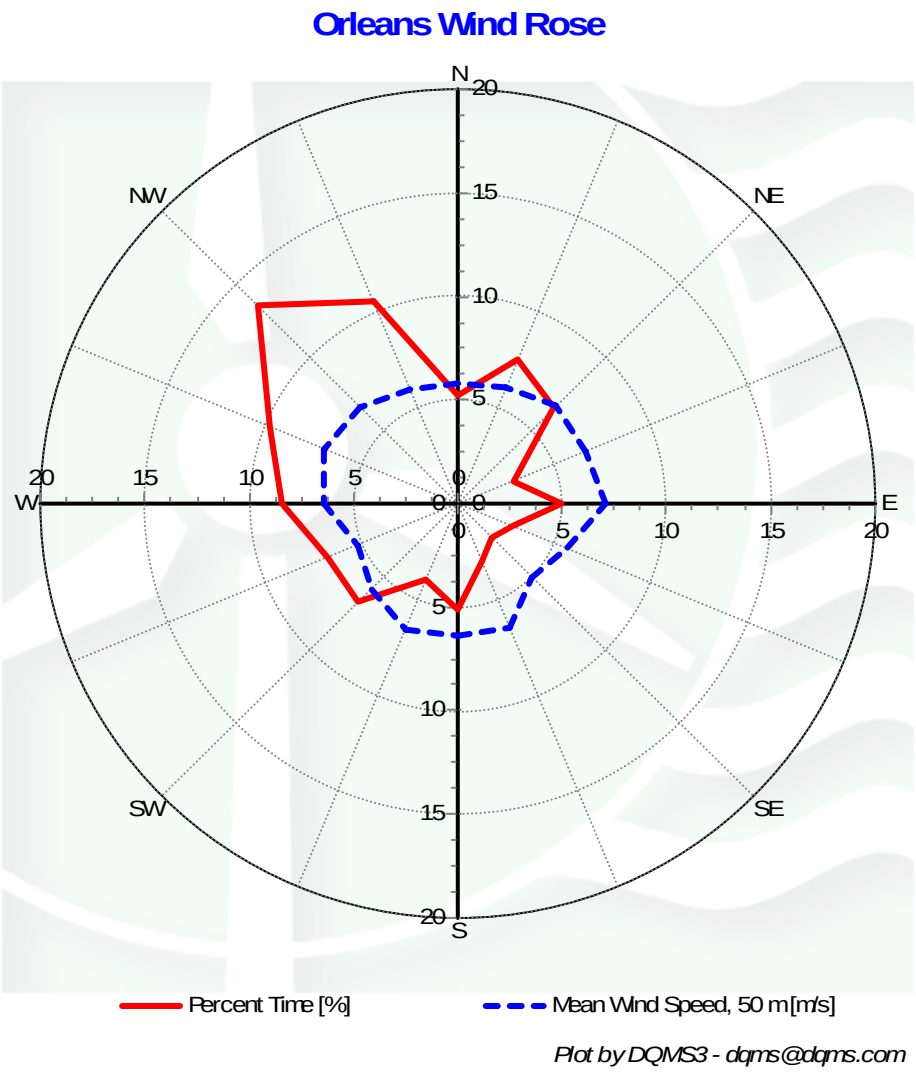

Figure 7 - Wind Rose, December 2004 - February 2005

APPENDIX A - Sensor Performance Report

Test Definitions

Test Order	TestField1	TestField2	TestField3	CalcField1	CalcField2	TestType	Factor1	Factor2	Factor3	Factor4
1						TimeTest Insert				
2	Etmp2aDEGC					MinMax	-30	60		
3	Etmx2aDEGC					MinMax	-30	60		
4	Etmn2aDEGC					MinMax	-30	60		
5	EtmpSD2aDEGC					MinMax	-30	60		
10	Anem50aMS					MinMax	0	90		
11	Anem50bMS					MinMax	0	90		
12	Anem40aMS					MinMax	0	90		
13	Anem40bMS					MinMax	0	90		
14	Anem20aMS					MinMax	0	90		
15	Anem50yMS					MinMax	0	90		
16	Anem40yMS					MinMax	0	90		
20	AnemSD50aMS					MinMax	0	4		
21	AnemSD50bMS					MinMax	0	4		
22	AnemSD40aMS					MinMax	0	4		
23	AnemSD40bMS					MinMax	0	4		
24	AnemSD20aMS					MinMax	0	4		
25	AnemSD50yMS					MinMax	0	4		
26	AnemSD40yMS					MinMax	0	4		
30	Vane50aDEG					MinMax	0	359.9		
31	Vane40aDEG					MinMax	0	359.9		
32	Vane20aDEG					MinMax	0	359.9		
50	Turb50zNONE					MinMax	0	2		
51	Turb40zNONE					MinMax	0	2		
60	Wshr0zNONE					MinMax	-100	100		
70	Pwrd50zWMS					MinMax	0	5000		
71	Pwrd40zWMS					MinMax	0	5000		
200	VaneSD50aDEG	Anem50yMS				MinMaxT	0	100	100	10
201	VaneSD40aDEG	Anem40yMS				MinMaxT	0	100	100	10
202	VaneSD20aDEG	Anem20aMS				MinMax	0	100	100	10
300	Anem50aMS	AnemSD50aMS	Vane50aDEG	VaneSD40aDEG	Etmp2aDEGC	Icing	0.5	1	2	10
301	Anem50bMS	AnemSD50bMS	Vane50aDEG	VaneSD40aDEG	Etmp2aDEGC	Icing	0.5	1	2	10
302	Anem40aMS	AnemSD40aMS	Vane40aDEG	VaneSD40aDEG	Etmp2aDEGC	Icing	0.5	1	2	10
303	Anem40bMS	AnemSD40bMS	Vane40aDEG	VaneSD40aDEG	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	Anem40aMS	Anem40bMS				CompareSensors	1	0.25	3	0
500	Amax50aMS					MinMax	0	90		
501	Amax50bMS					MinMax	0	90		
502	Amax40aMS					MinMax	0	90		
503	Amax40bMS					MinMax	0	90		
504	Amax20aMS					MinMax	0	90		
510	Amin50aMS					MinMax	0	90		
511	Amin50bMS					MinMax	0	90		
512	Amin40aMS					MinMax	0	90		
513	Amin40bMS					MinMax	0	90		
514	Amin20aMS					MinMax	0	90		
520	Vmax50aDEG					MinMax	0	359.9		
521	Vmax40aDEG					MinMax	0	359.9		
522	Vmax20aDEG					MinMax	0	359.9		
530	Vmin50aDEG					MinMax	0	359.9		
531	Vmin40aDEG					MinMax	0	359.9		
532	Vmin20aDEG					MinMax	0	359.9		

Sensor Statistics

Sensor	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	% Data Good
Anem50aMS	12961	12961	100	5.333	14.5	0.333	99.066
AnemSD50aMS	12961	12961	100	5.333	14.5	0.333	99.066
Amax50aMS	12961	12961	100	0	0	0	100
Amin50aMS	12961	12961	100	0	0	0	100
Anem50bMS	12961	12961	100	5.167	7.5	7.333	99.074
AnemSD50bMS	12961	12961	100	5.167	7.5	7.333	99.074
Amax50bMS	12961	12961	100	0	0	0	100
Amin50bMS	12961	12961	100	0	0	0	100
Anem40aMS	12961	12961	100	5	7.5	7.667	99.066
AnemSD40aMS	12961	12961	100	5	7.5	7.667	99.066
Amax40aMS	12961	12961	100	0	0	0	100
Amin40aMS	12961	12961	100	0	0	0	100
Anem40bMS	12961	12961	100	6.167	7.5	3.5	99.205
AnemSD40bMS	12961	12961	100	6.167	7.5	3.5	99.205
Amax40bMS	12961	12961	100	0	0	0	100
Amin40bMS	12961	12961	100	0	0	0	100
Anem20aMS	12961	12961	100	0	6.833	0	99.684
AnemSD20aMS	12961	12961	100	2.167	6.833	0	99.583
Amax20aMS	12961	12961	100	0	0	0	100
Amin20aMS	12961	12961	100	0	0	0	100
Vane50aDEG	12961	12961	100	0	0	2160.167	0
VaneSD50aDEG	12961	12961	100	0	0	2160.167	0
Vmax50aDEG	12961	12961	100	0	0	2160.167	0
Vmin50aDEG	12961	12961	100	0	0	2160.167	0
Vane40aDEG	12961	12961	100	1.833	14.5	0	99.244
VaneSD40aDEG	12961	12961	100	1.833	14.5	0	99.244
Vmax40aDEG	12961	12961	100	0.333	0	0	99.985
Vmin40aDEG	12961	12961	100	0	0	0	100
Vane20aDEG	12961	12961	100	0	6.833	0	99.684
VaneSD20aDEG	12961	12961	100	0.667	6.833	0	99.653
Vmax20aDEG	12961	12961	100	0	0	0	100
Vmin20aDEG	12961	12961	100	0	0	0	100
Etmp2aDEGC	12961	12961	100	0	0	0	100
EtmpSD2aDEGC	12961	12961	100	0	0	0	100
Etmx2aDEGC	12961	12961	100	0	0	0	100
Etmn2aDEGC	12961	12961	100	0	0	0	100
Total	466596	466596	100	50.167	130.333	8678.333	88.608

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	Percent of Time [%]
0.5	1.17
1.5	2.14
2.5	5.22
3.5	10.89
4.5	15.07
5.5	15.77
6.5	13.65
7.5	12.07
8.5	9.53
9.5	5.75
10.5	3.15
11.5	2.14
12.5	1.64
13.5	0.85
14.5	0.36
15.5	0.13
16.5	0.25
17.5	0.12
18.5	0.09
19.5	0.02
20.5	0
21.5	0
22.5	0
23.5	0
24.5	0

Table 1 - Wind Speed Distribution, December 2004- February 2005

Monthly Average Wind Speed Data

Date	10 min Mean [m/s]
November 2003	5.84
December 2003	7.47
January 2004	6.95
February 2004	6.02
March 2004	6.46
April 2004	6.12
May 2004	
June 2004	5.15
July 2004	4.48
August 2004	5.01
September 2004	5.08
October 2004	5.58
November 2004	6.00
December 2004	6.37
January 2005	6.47
February 2005	5.86

Table 2 - Wind Speed Averages

Diurnal Average Wind Speed Data

Hour of Day	Average Wind Speed [m/s]
0	6.23
1	6.25
2	6.26
3	6.27
4	6.31
5	6.32
6	6.12
7	6.13
8	6.16
9	6.38
10	6.61
11	6.57
12	6.53
13	6.25
14	6.09
15	5.92
16	5.9
17	6.11
18	6.2
19	6.17
20	6.2
21	6.33
22	6.32
23	6.36

Table 3 - Diurnal Average Wind Speeds, December 2004- February 2005

Wind Rose Data

Direction	Percent Time [%], 40 m	Mean Wind Speed [m/s], 50 m
N	5.25	5.75
NNE	7.53	6.1
NE	6.56	6.64
ENE	2.88	6.67
E	4.96	7.06
ESE	2.86	5.66
SE	2.26	5.05
SSE	3.06	6.49
S	5.1	6.35
SSW	3.93	6.56
SW	6.72	5.87
WSW	6.75	5.18
W	8.46	6.44
WNW	9.69	6.91
NW	13.47	6.62
NNW	10.53	5.95

Table 4 - Wind Rose, Time Percentage and Mean Wind Speed by Direction, December 2004 - February 2005