WIND DATA REPORT

WBZ Tower, Hull, MA

9/1/06-11/30/06

Prepared for

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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) and Division of Energy Resources (DOER). 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 of the work presented in this Wind Data Report including installation and decommissioning of the meteorological tower, instrumentation, the data analysis and the reporting was preformed by the Renewable Energy Research Laboratory (RERL) at the University of Massachusetts, Amherst.

This report covers wind data measured at the WBZ AM radio tower in Hull, MA. Installed on August 28, 2006, the wind monitoring sensors have been in continuous operation to this day. Two sets of two anemometers and one wind vane are mounted at 118m (387 ft), 87m (285 ft), and 61m (200 ft).

The period covered by this report is September through November 2006 . The mean recorded wind speed for this period was 7.37 m/s (16.5 mph)[1] and the prevailing wind direction was from the southwest. The gross data recovery percentage (the actual percentage of expected data received) was 99.8% and the net data recovery percentage (the percentage of expected data which passed all of the quality assurance tests) was 99.2%.

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] 1m/s=2.237 mph

SECTION 1 - Station Location

Figure 1: Site Location: Hull, MA

The WBZ radio tower is located near the salt marsh on the west coast of the Hull isthmus that is located on the southern portion of the Boston Harbor. The site coordinates are 42° 16' 44.11" N by 70° 52' 34.39" W. These coordinates correspond to the NAD83 datum.

SECTION 2 - Instrumentation and Equipment

The wind monitoring equipment is mounted on an existing radio tower, known as the WBZ AM broadcast tower. All of the wind speed sensors come from NRG Systems, and consists of the following items:

- 6 – #40 Anemometers, standard calibration (Slope - 0.765 m/s, Offset – 0.350 m/s). Two anemometers are located at 118 m (387 ft), two at 87 m (285 ft) and one at a height of 61 m (200 ft).

- 3 - #200P Wind direction vanes. They are located at heights of 118m (387 ft), 87m (285 ft) and 61m (200 ft) each.
- Shielded sensor wire
- 2 - Climatronix aspirated temperature sensors mounted at ground level and at 118m (387 ft).
- Nomad2 SecondWind data logger box
- One Y-shaped sensor boom at each level that hosts two anemometers and one wind direction sensor. The booms face due east and the sensors are located approximately 14 feet away from the closest tower leg

The data from the SecondWind Nomad2 logger is emailed to the Renewable Energy Research Laboratory at the University of Massachusetts, Amherst on a daily basis. The logger samples wind speed and direction once every second. These data 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 Nomad2 software. These text files are then imported into a database software program where they are subjected to quality assurance (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 were taken:

- Several weeks of unsuccessful attempts to communicate via modem connection with the Nomad2 logger occurred before a special service trip was carried out that corrected the problem on Nov 12th, 2006. No data was lost during any part of the period before or after Nov 12th 2006.

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	Turbulence Intensity	Prevailing Wind Direction	Wind Shear Coeff
Height units	**118 m, [m/s]**	**118 m, [m/s]**	**118 m [ ]**	**118 m [ ]**	**87 m [m/s]**	**87 m [m/s]**	**87 m [ ]**	**87 m [ ]**	**61 m [m/s]**	**61 m [m/s]**	**61 m [ ]**	**61 m [ ]**	**Calc b/t 118 & 87m, [ ]**
Sep 2006	6.72	14.16	0.11	W	6.27	14.46	0.11	W	5.7	13.93	0.13	W	0.19
Oct 2006	8.11	15.29	0.11	WNW	7.82	16.17	0.11	WNW	7.27	15.59	0.12	WNW	0.17
Nov 2006	7.26	17.65	0.12	SW	6.86	16.54	0.12	WNW	6.34	15.86	0.13	SW	0.22
Sep '06 – Nov '06	**7.37**	**17.65**	**0.11**	**SW**	**6.99**	**16.54**	**0.12**	**W**	**6.45**	**15.56**	**0.13**	**SW**	**0.19**

Table 1: Data Statistics Summary

The wind data statistics in the table above are reported when more than 90% of the data during the reporting period are valid.

No measurement of wind speed can be perfectly accurate. Errors occur due to anemometer manufacturing variability, anemometer calibration errors, response of anemometers to turbulence and vertical airflow 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

During the period summarized in this report, there were no sustained aberrations in the behavior of the weather that would significantly skew the averages presented above in the data statistics summary.

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 [%]	99.8
Net Data Recovered [%]	99.2

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.

$$[\ TF1 \le F3 \text{ and } TF2 \le F3 \text{ and } abs(TF1 - TF2) > F1\ ]$$
$$\text{or } [\ (TF1 > F3 \text{ or } TF2 > F3) \text{ and } (abs(1 - TF1 / TF2) > F2 \text{ or } abs(1 - TF2 / TF1) > F2)\ ]$$

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 that 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 September 1 2006 to Nov 30th at a height of 118 meters**.** The following graphs are included:

- Time Series – 10-minute average wind speeds are plotted against time. Time series data 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 speed distribution data is shown below

in Figure 3. During the report summary period, the most commonly occurring wind speed bin was 7.5 m/s, occurring 12.8% of the time.

- Monthly Average – A plot of the monthly average wind speed over a 12-month period. This graph shows the trends in the wind speed over the year. This graph appears incomplete because only three months of data are summarized in this report. The monthly average wind speed data is shown below in Figure 4.

- Diurnal – A plot of the average wind speed for each hour of the day. The diurnal average wind speed data is shown below in Figure 5. During the report summary period, the WBZ site exhibited a slight dip in average wind speeds during the afternoon and early evening hours.

- 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. Typical turbulence intensities range from approximately 0.1-0.4. Lower turbulence results in lower mechanical loads on a wind turbine. The turbulence intensity values for the WBZ tower during this report period exhibit normal behavior until high wind speeds are recorded, during which time the standard deviation of the average wind speeds tends to increase. This abnormality is being studied so that the problem can be isolated and resolved. Turbulence intensity data is shown below 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 below in Figure 7. The prevailing wind direction for this period was from the southwest, occurring 13.9% of the time with an average wind speed of 7.9 m/s.

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

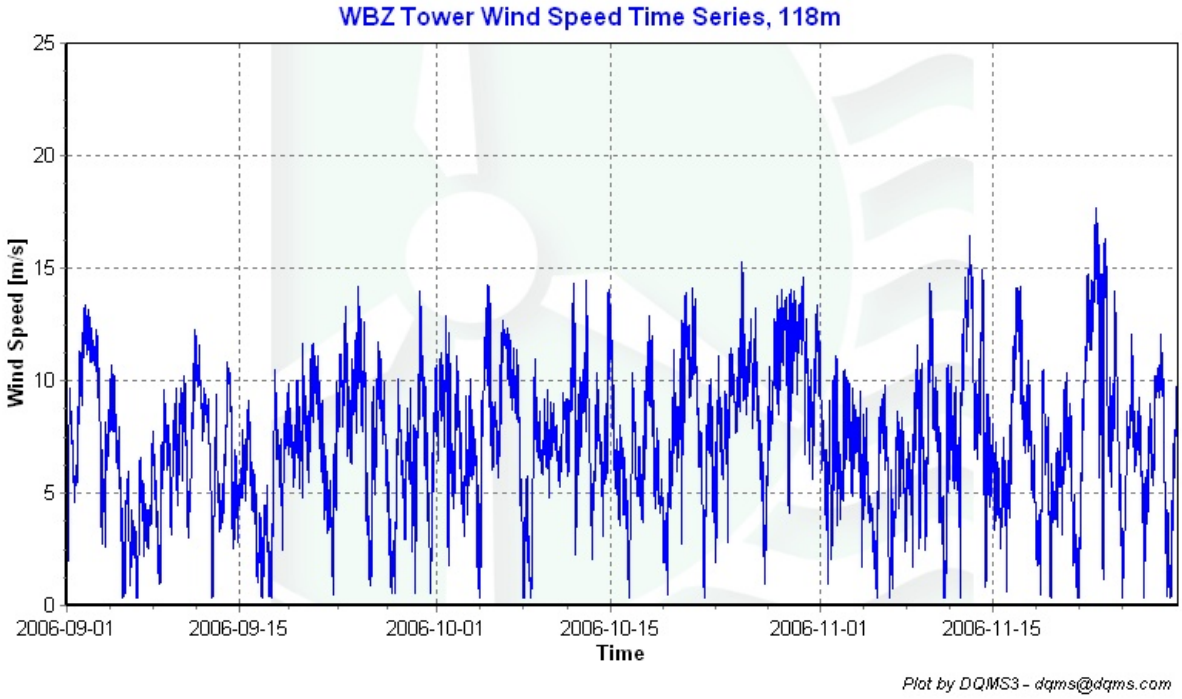

Figure 2 – WBZ Tower Wind Speed Time Series for Sep 1 to Nov 30

Wind Speed Distributions

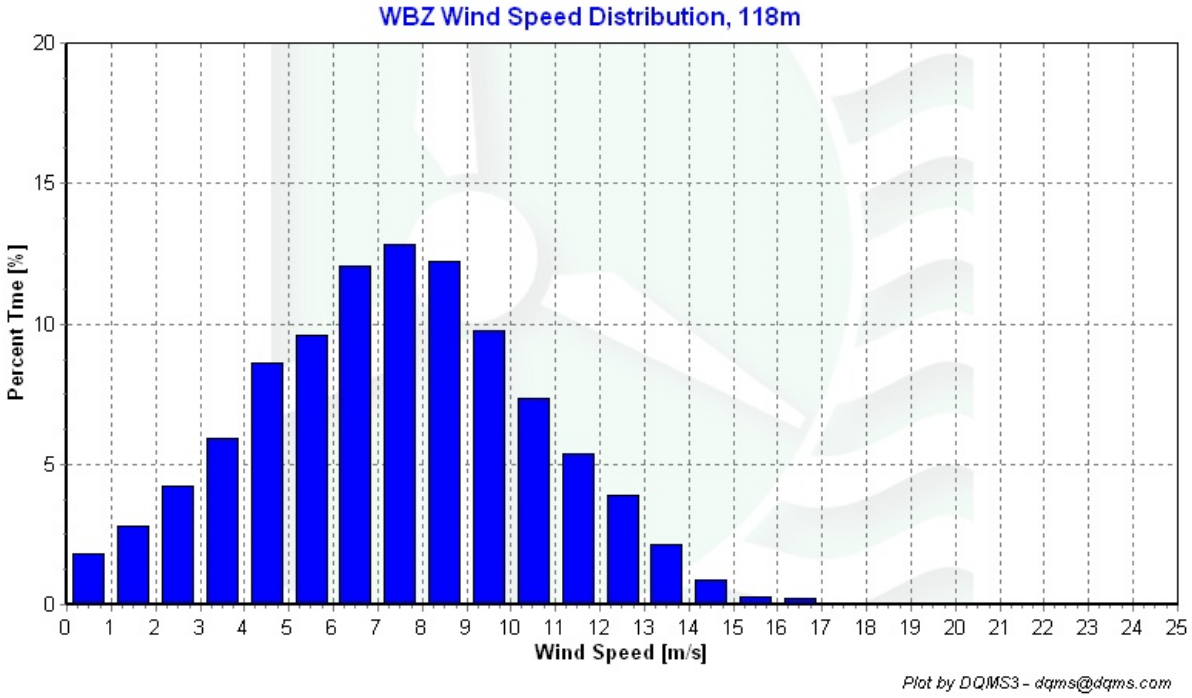

Figure 3 – WBZ Tower Wind Speed Distribution for Sep 1 to Nov 30

Monthly Average Wind Speeds

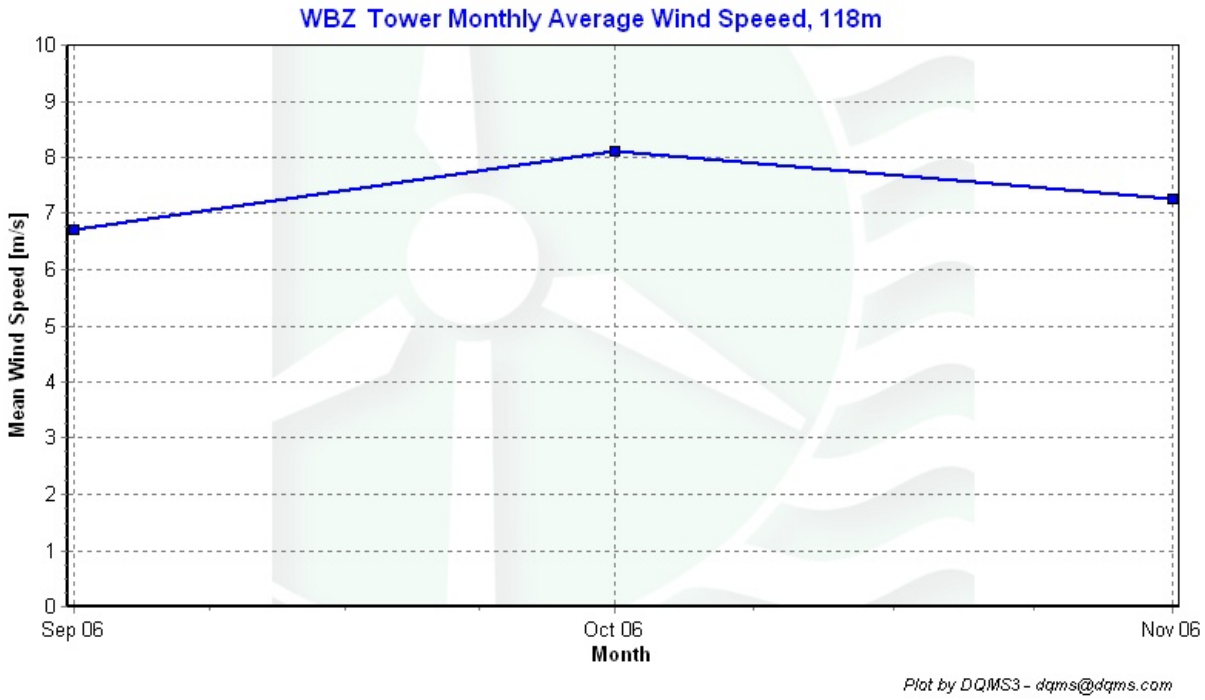

Figure 4 – WBZ Tower Monthly Average Wind Speed

Diurnal Average Wind Speeds

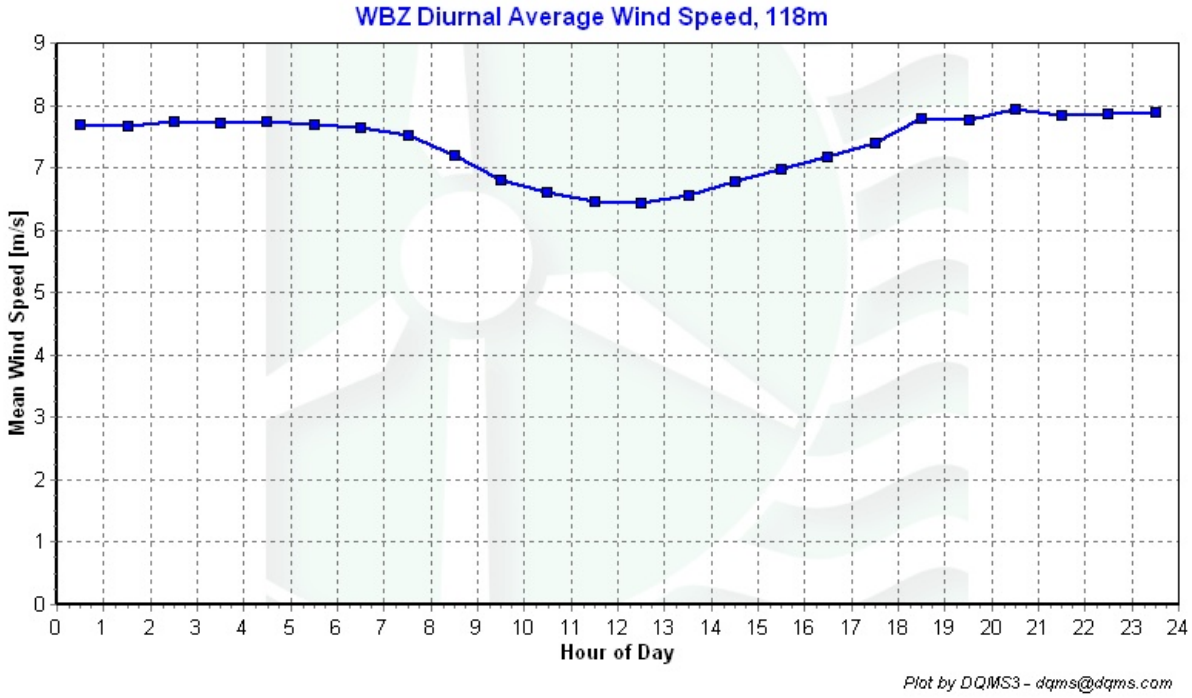

Figure 5 – WBZ Tower Diurnal Average Wind Speed for Sep 1 to Nov 30

Turbulence Intensities

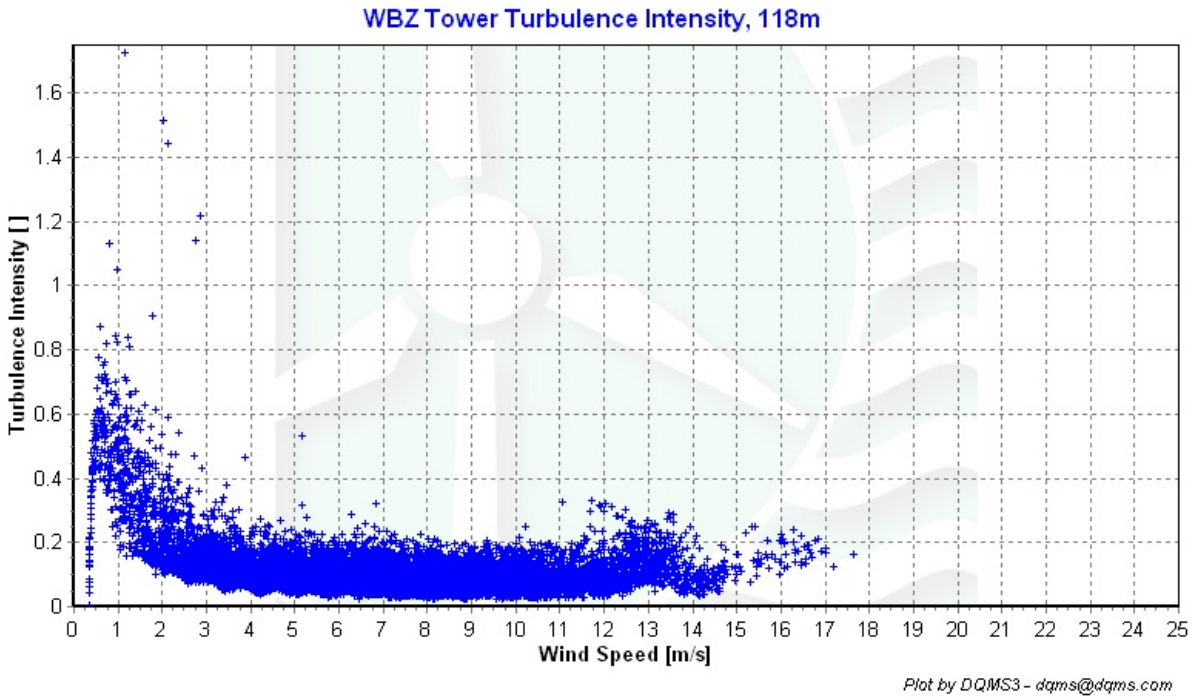

Figure 6 – WBZ Tower Turbulence Intensity for Sep 1 to Nov 30

Wind Roses

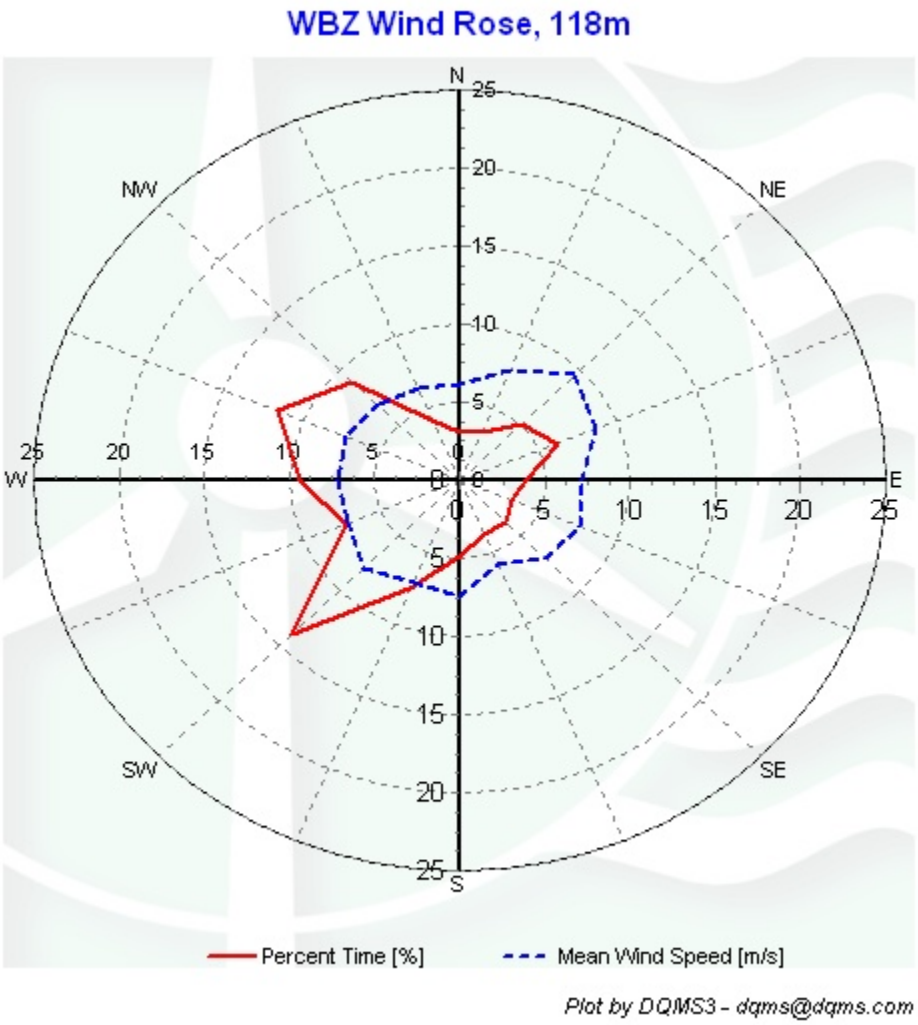

Figure 7 – WBZ Tower Wind Rose for Sep 1 to Nov 30

APPENDIX A - Sensor Performance Report

Test Definitions

TestOrder	TestField1	TestField2	TestField3	CalcField1	CalcField2	TestType	Factor1	Factor2	Factor3	Factor4
2	ETemp2DEGC					MinMax	-25	40	0	0
3	ETempSD2DEGC					MinMax	-25	40	0	0
4	ETemp118DEGC					MinMax	-25	40	0	0
5	ETempSD118DEGC					MinMax	-25	40	0	0
6	ITtemp2aDEGC					MinMax	-25	40	0	0
7	Batt1aV					MinMax	5	14	0	0
8	Batt1bV					MinMax	5	14	0	0
10	Anem118aMS					MinMax	0	90	0	0
11	Anem118bMS					MinMax	0	90	0	0
12	Anem87aMS					MinMax	0	90	0	0
13	Anem87bMS					MinMax	0	90	0	0
14	Anem61aMS					MinMax	0	90	0	0
15	Anem61bMS					MinMax	0	90	0	0
16	Anem118yMS					MinMax	0	90	0	0
17	Anem87yMS					MinMax	0	90	0	0
18	Anem61yMS					MinMax	0	90	0	0
20	AnemSD118aMS					MinMax	0	4	0	0
21	AnemSD118bMS					MinMax	0	4	0	0
22	AnemSD87aMS					MinMax	0	4	0	0
23	AnemSD87bMS					MinMax	0	4	0	0
24	AnemSD61aMS					MinMax	0	4	0	0
25	AnemSD61bMS					MinMax	0	4	0	0
26	AnemSD118yMS					MinMax	0	4	0	0
27	AnemSD87yMS					MinMax	0	4	0	0
28	AnemSD61yMS					MinMax	0	4	0	0
30	Vane118aDEG					MinMax	0	359.9	0	0
31	Vane87aDEG					MinMax	0	359.9	0	0
32	Vane61aDEG					MinMax	0	359.9	0	0
50	Turb118zNONE					MinMax	0	2	0	0
51	Turb87zNONE					MinMax	0	2	0	0
52	Turb61zNONE					MinMax	0	2	0	0
70	Pwrd118zWMS					MinMax	0	5000	0	0
71	Pwrd87zWMS					MinMax	0	5000	0	0
72	Pwrd61zWMS					MinMax	0	5000	0	0
200	VaneSD118aDEG	Anem118yMS				MinMaxT	0	100	100	10
201	VaneSD87aDEG	Anem87yMS				MinMaxT	0	100	100	10
202	VaneSD61aDEG	Anem61yMS				MinMax	0	100	100	10
300	Anem118aMS	AnemSD118aMS	Vane118aDEG	VaneSD118aDEG	ETemp2DEGC	Icing	0.5	1	2	10
301	Anem118bMS	AnemSD118bM	Vane118aD	VaneSD118	ETemp2DE	Icing	0.5	1	2	10

		S	EG	aDEG	GC					
302	Anem87aMS	AnemSD87aMS	Vane87aDEG	VaneSD87aDEG	ETemp2DEGC	Icing	0.5	1	2	10
303	Anem87bMS	AnemSD87bMS	Vane87aDEG	VaneSD87aDEG	ETemp2DEGC	Icing	0.5	1	2	10
304	Anem61aMS	AnemSD61aMS	Vane61aDEG	VaneSD61aDEG	ETemp2DEGC	Icing	0.5	1	2	10
305	Anem61bMS	AnemSD61bMS	Vane61aDEG	VaneSD61aDEG	ETemp2DEGC	Icing	0.5	1	2	10
400	Anem118aMS	Anem118bMS				Compare Sensors	1	0.25	3	0
401	Anem87aMS	Anem87bMS				Compare Sensors	1	0.25	3	0
402	Anem61aMS	Anem61bMS				Compare Sensors	1	0.25	3	0
500	Wshr0zNONE					MinMax	-100	100	0	0

Table 2: Test Definitions

Sensor Statistics

Sensor	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	% Data Good
ITtemp2aDEGC	13104	13096	99.939	0	0	0	99.939
Anem118yMS	13104	13096	99.939	0	0	0	99.939
Anem87yMS	13104	13096	99.939	0	0	0	99.939
Anem61yMS	13104	13096	99.939	0	0	0	99.939
AnemSD118yMS	13104	13096	99.939	33	0	0	98.428
AnemSD87yMS	13104	13096	99.939	11	0	0	99.435
AnemSD61yMS	13104	13096	99.939	9.5	0	0	99.504
Vane118aDEG	13104	13096	99.939	0.333	0	0	99.924
Vane87aDEG	13104	13096	99.939	0.667	0	0	99.908
Vane61aDEG	13104	13096	99.939	0.5	0	0	99.916
VaneSD118aDEG	13104	13096	99.939	0.333	0	0	99.924
VaneSD87aDEG	13104	13096	99.939	0.667	0	0	99.908
VaneSD61aDEG	13104	13096	99.939	0.5	0	0	99.916
ETemp2DEGC	13104	13096	99.939	25	0	0	98.794
ETempSD2DEGC	13104	13096	99.939	0	0	0	99.939
ETemp118DEGC	13104	13096	99.939	11	0	0	99.435
ETempSD118DEGC	13104	13096	99.939	0	0	0	99.939
Turb118zNONE	13104	12898	98.428	0	0	0	98.428
Turb87zNONE	13104	13030	99.435	0	0	0	99.435
Turb61zNONE	13104	13039	99.504	0	0	0	99.504
Batt1aV	13104	13096	99.939	0	0	0	99.939
Anem118aMS	13104	13096	99.939	33	0	9.5	97.993
Anem118bMS	13104	13096	99.939	30.5	0	84.833	94.658

Anem87aMS	13104	13096	99.939	11	0	0.667	99.405
Anem87bMS	13104	13096	99.939	39	0	44.333	96.123
Anem61aMS	13104	13096	99.939	9.5	0	8.667	99.107
Anem61bMS	13104	13096	99.939	19.667	0	23.5	97.962
Total	**353808**	**353271**	**99.848**	**235.17**	**0**	**171.5**	**99.159**

Table 3: Sensor Statistics

APPENDIX B - Plot Data

Wind Speed Distribution Data

Wind Speed [m/s]	Percent Time [%]
0.5	1.79
1.5	2.81
2.5	4.23
3.5	5.94
4.5	8.61
5.5	9.59
6.5	12.05
7.5	12.82
8.5	12.22
9.5	9.75
10.5	7.34
11.5	5.34
12.5	3.91
13.5	2.15
14.5	0.89
15.5	0.28
16.5	0.24
17.5	0.03
18.5	0
19.5	0
20.5	0
21.5	0
22.5	0
23.5	0
24.5	0

Table 4: Wind Speed Distribution Data

Monthly Average Wind Speed Data

Date	10 min Mean [m/s]
Nov 2006	7.26
Dec	-----
Jan 2007	-----
Feb	-----
Mar	-----
Apr	-----
May	-----
Jun	-----
Jul	-----
Aug	-----
Sep	6.72
Oct	8.11

Table 5: Monthly Average Wind Speed Data

Diurnal Average Wind Speed Data

hr	Mean Wind Speed [m/s]
0.5	7.7
1.5	7.68
2.5	7.74
3.5	7.73
4.5	7.75
5.5	7.7
6.5	7.65
7.5	7.53
8.5	7.21
9.5	6.82
10.5	6.6
11.5	6.45
12.5	6.44
13.5	6.56
14.5	6.78
15.5	6.99
16.5	7.19
17.5	7.4
18.5	7.78

19.5	7.77
20.5	7.94
21.5	7.83
22.5	7.86
23.5	7.88

Table 6: Diurnal Average Wind Speed Data

Wind Rose Data

Direction	Mean Wind Speed [m/s]	Percent Time [%]
N	6.11	3.08
NNE	7.62	3.3
NE	9.53	5.09
ENE	8.58	6.19
E	7.11	3.84
ESE	7.58	3.27
SE	7.08	3.82
SSE	5.86	3.77
S	7.38	4.86
SSW	7.14	7.54
SW	7.92	13.94
WSW	7.16	7.24
W	7.21	9.34
WNW	7.22	11.58
NW	6.82	8.97
NNW	6.38	4.17

Table 7: Wind Rose Data