WIND DATA REPORT

Quincy Quarry Hills

December 2006 to February 2007

Prepared for

Massachusetts Technology Collaborative
75 North Drive
Westborough, MA 01581

by

Frederick W. Letson
James F. Manwell
Anthony L. Rogers
Anthony F. Ellis

April 18, 2007

Report template version 3.1

Renewable **E**nergy **R**esearch **L**aboratory
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). 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

TABLE OF FIGURES

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.

The sensors at the Quincy Quarry Hills site were installed on August 10th 2006, and have been in continuous operation until the present. The data are from two anemometers and one wind vane at each of 101 meters (330 ft) and 67 meters (220 feet). These sensors are mounted on a triangular lattice tower, and were installed by the tower owner in a position different from that given in the instructions from the RERL. The proximity of the sensors to the tower is a source of some uncertainty in wind speed measurements, as the wind speed close to a lattice tower is affected significantly by the tower's presence.

This report covers wind data collected at the Quincy Quarry Hills Site from December 2006 through February 2007. During these months, the average wind speed measured at 101 meters was 6.93 m/s (15.5 mph)[1] and the prevailing wind was from the west. 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 95.00%.

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] 1 m/s = 2.237mph

SECTION 1 - Station Location

The Quincy Quarry Hills Site is Located near the Granite Links Golf Club in Quincy, Massachusetts, off Ricciuti Drive. The tower stands at 42.2470° north and 71.0483° west, corresponding to the WGS 84 datum. The tower base is at an elevation of 50 meters above sea level.

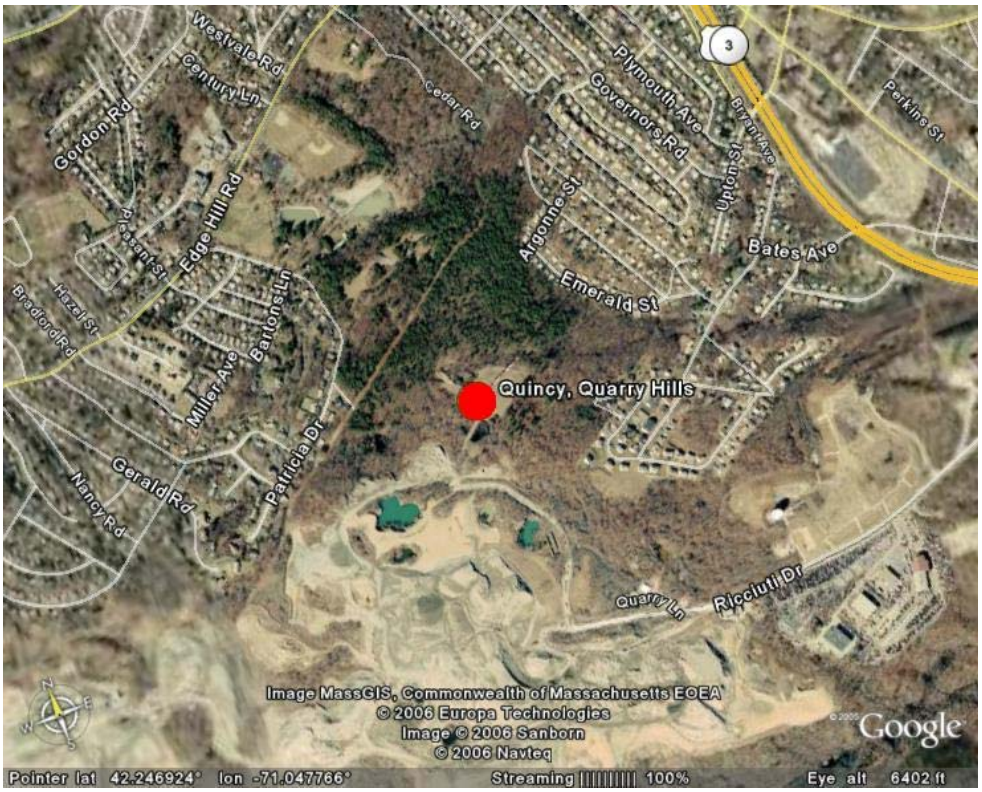

Figure 1 - Map showing the location of the Quincy Quarry Hills site

SECTION 2 - Instrumentation and Equipment

The Monitoring equipment at Quincy Quarry Hills is mounted on an existing triangular lattice tower owned by Industrial Communications. This equipment includes:

- Symphonie Data Logger
- Electrical enclosure box
- 4 – #40 Anemometers, standard calibration (Slope - 0.765 m/s, Offset – 0.350 m/s). Two anemometers are located at 101 m (330 ft)and two at 67 m (220 ft).
- 2 - #200P Wind direction vanes. They are located at heights of 101m (330 ft.) and 67m (220 ft.).
- Shielded sensor wire

These sensor heights are approximate.

The data from the Symphonie logger is mailed to the Renewable Energy Research Laboratory at the University of Massachusetts, Amherst on a regular basis. The logger samples wind speed and direction once every two seconds. 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 NRG software BaseStation®. 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 Summary

On February 6th, 2007 at 10:30 am, the wind vane at 101 meters stopped functioning. Wind direction data for that height are not available after that time. Wind directions at 67 meters are used in their place in this report.

Because of the incorrect sensor installation (see Section 6 for details), plans are being made to remount the sensors in the several weeks.

A summary of the wind speeds and wind directions measured during the reporting period is included in Table 1. Table 1 includes the mean wind speeds measured at each measurement height, the maximum instantaneous wind speed measured at each measurement height and the prevailing wind direction measured at each measurement height. These values are provided for each month of the reporting period and for the whole reporting period.

Table 1. Wind Speed and Direction Data Summary

Date	Mean Wind Speed	Max Wind Speed	Prevailing Wind Direction	Mean Wind Speed	Max Wind Speed	Prevailing Wind Direction
Height	**101m**	**101m**	**101m**	**67m**	**67m**	**67m**
Units	**[m/s]**	**[m/s]**	**[m/s]**	**[m/s]**	**[m/s]**	**[m/s]**
Dec-06	7.69	18.26	West	6.69	16.98	WSW
Jan-07	7.42	16.83	West	6.56	15.86	West
Feb-07	7.86	18.85	-	7.04	17.38	West
Dec 2006 - Feb 2007	**7.66**	**17.98**	**West**	**6.76**	**16.74**	**West**

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 or direction can be perfectly accurate. Wind speed measurement 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. Wind direction measurement errors occur due to sensor measurement uncertainty, tower effects, boom alignment measurement errors and twisting of pipe sections during the raising of a pipe tower. Efforts are also made to reduce these errors, but the reported wind directions are estimated to have an uncertainty of +/- 5 degrees.

A summary of the turbulence intensity and mean wind shear measured at each measurement height during the reporting period is included In Table 2. These values are provided for each month of the reporting period and for the whole reporting period. Turbulence Intensity is calculated by dividing the standard deviation of the wind speed by the mean wind speed and is a measure of the gustiness of a wind resource. Lower turbulence results in lower mechanical loads on a wind turbine. Turbulence intensity varies with wind speed. The average turbulence intensity presented in Table 2 is the mean turbulence intensity when the wind speed at each measurement height is between 10 and 11 m/s.

Shear coefficients provide a measure of the change in wind speed with height. 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 will not always 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.

The mean wind shear coefficient that is provided here is calculated based on the mean wind speeds in Table 1, where z_{high} and z_{high} are the heights of the higher and lower mean wind speeds used in the calculation and $U(z_{low})$ and $U(z_{high})$ are the mean wind speeds at the two heights.

$$\alpha = \log\left(\frac{U(z_{high})}{U(z_{low})}\right) \Big/ \log\left(\frac{z_{high}}{z_{low}}\right)$$

Table 2. Shear and Turbulence Intensity Data Summary

Date	Turbulence Intensity at 10.5 m/s	Turbulence Intensity at 10.5 m/s	Mean Wind Shear Coefficient, α
Height	101 m	67 m	Between 101 m and 67 m
Units	[-]	[-]	[-]
Dec-06	0.13	0.16	0.34
Jan-07	0.15	0.17	0.30
Feb-07	0.16	0.19	0.27
Dec 2006 - Feb 2007	**0.15**	**0.17**	**0.30**

SECTION 4- Graphs

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 – Figure 2: 10-minute average wind speeds are plotted against time. There were more winds over 15 m/s recorded in February than in the previous two months.

- Wind Speed Distribution – Figure 3: A histogram plot giving the percentage of time that the wind is at a given wind speed. Winds during this period were most often between 8 and 9 m/s. This occurred almost 13% of the time

- Monthly Average – Figure 4: A plot of the monthly average wind speed over a 6-month period. January was slightly less windy on average than either December or February.

- Diurnal – Figure 5: A plot of the average wind speed for each hour of the day. There is slightly less wind on average around 9:30 in the morning and 5:00 in the evening than at other times during the day.

- Turbulence Intensity – Figure 6: 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. Turbulence intensities are highest for wind speeds between 0 and 3 m/s. The average turbulence intensity at this height is 0.17.

- Wind Rose – Figure 7: 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 winds during this quarter came almost entirely from the west. It should be noted that wind directions for this graph are taken from the 67 meter vane since the 101 meter vane stopped functioning on February 6^{th}.

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

Wind Speed Time Series

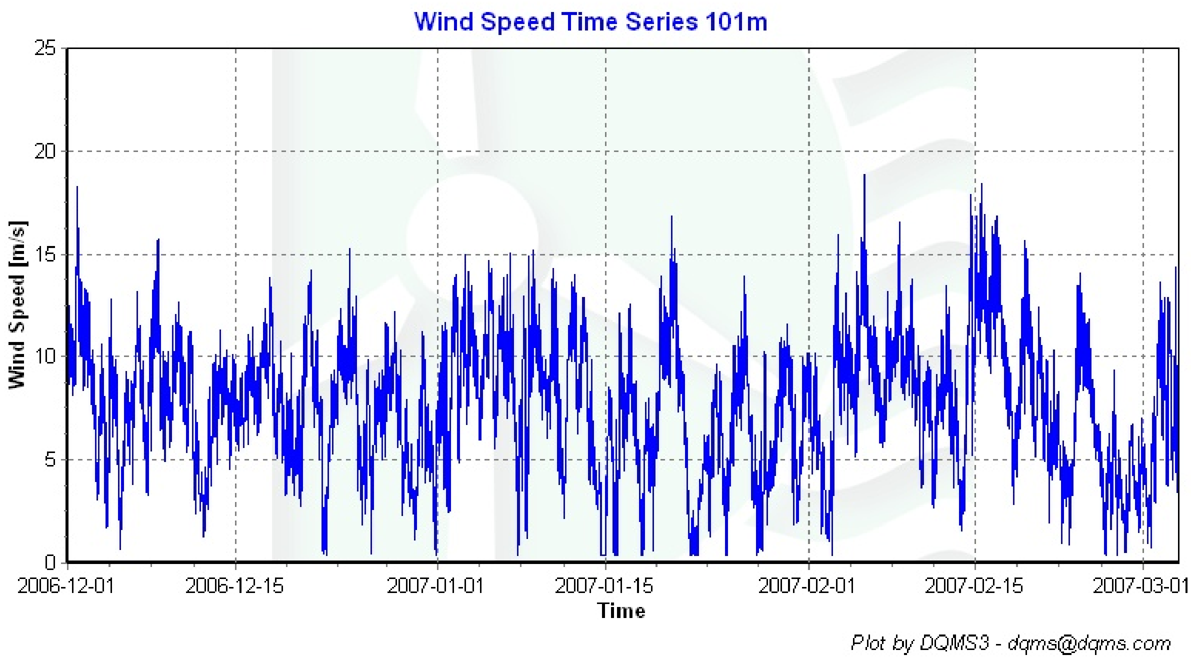

Figure 2 – Wind Speed Time Series December 2006 to February 2007

Wind Speed Distributions

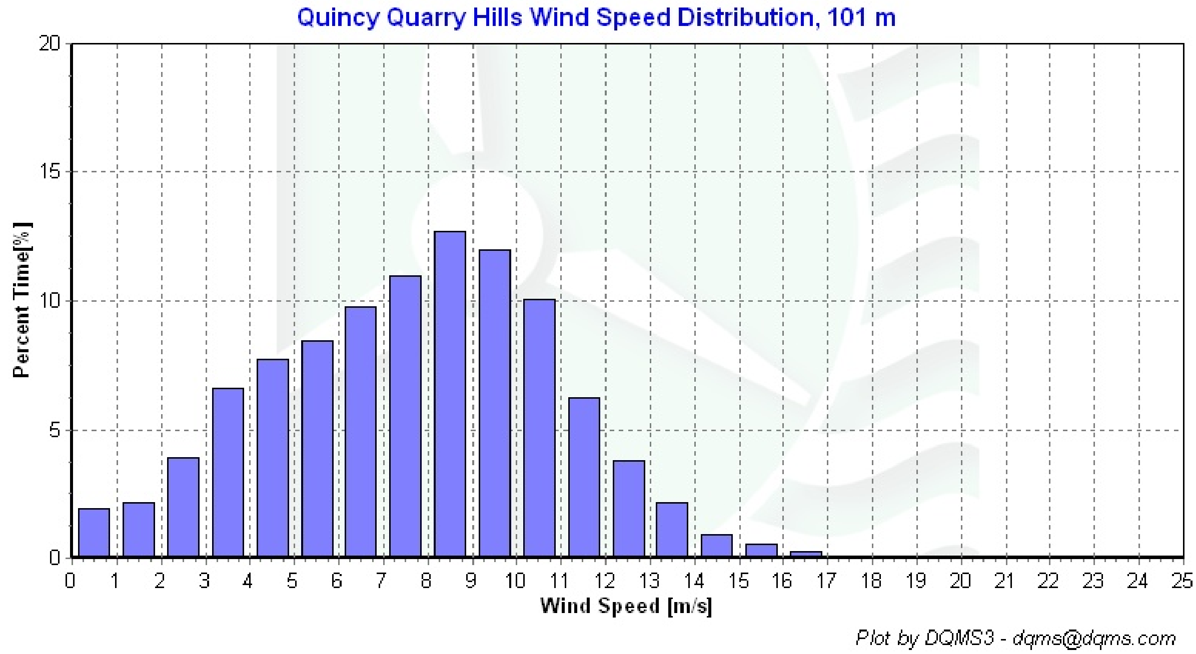

Figure 3 – Wind Speed Distribution December 2006 to February 2007

Monthly Average Wind Speeds

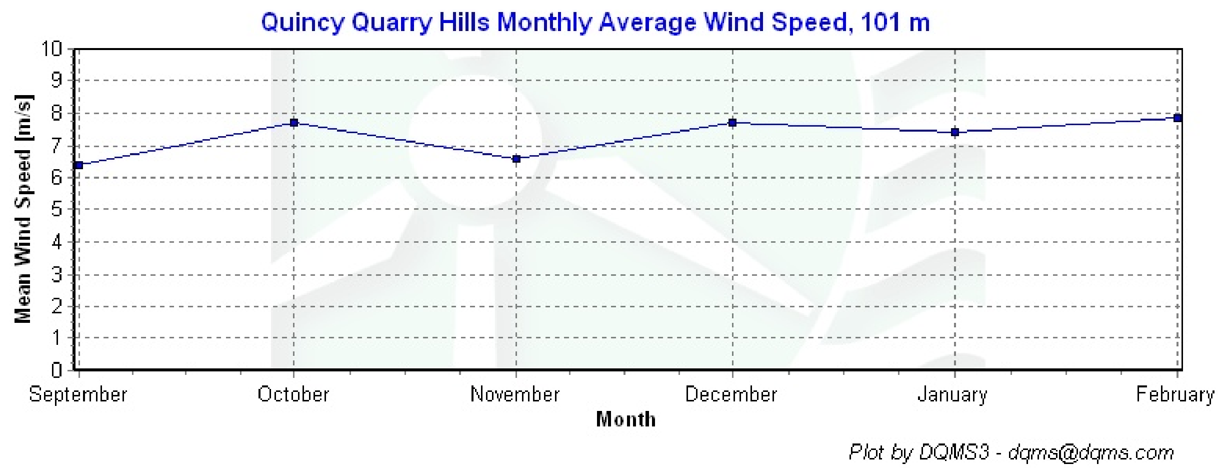

Figure 4 – Monthly Wind Speed Averages September 2006 to February 2007

Diurnal Average Wind Speeds

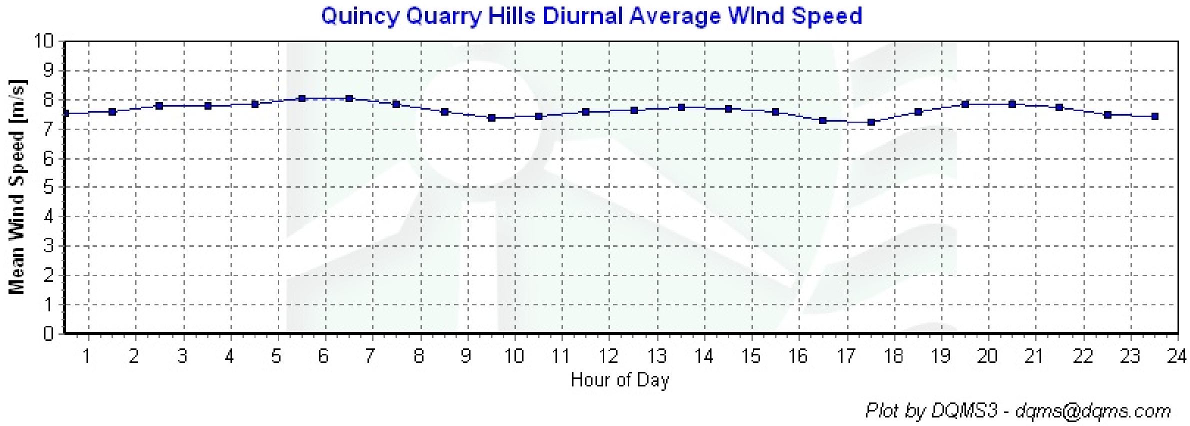

Figure 5 – Diurnal Average Wind Speeds December 2006 to February 2007

Turbulence Intensities

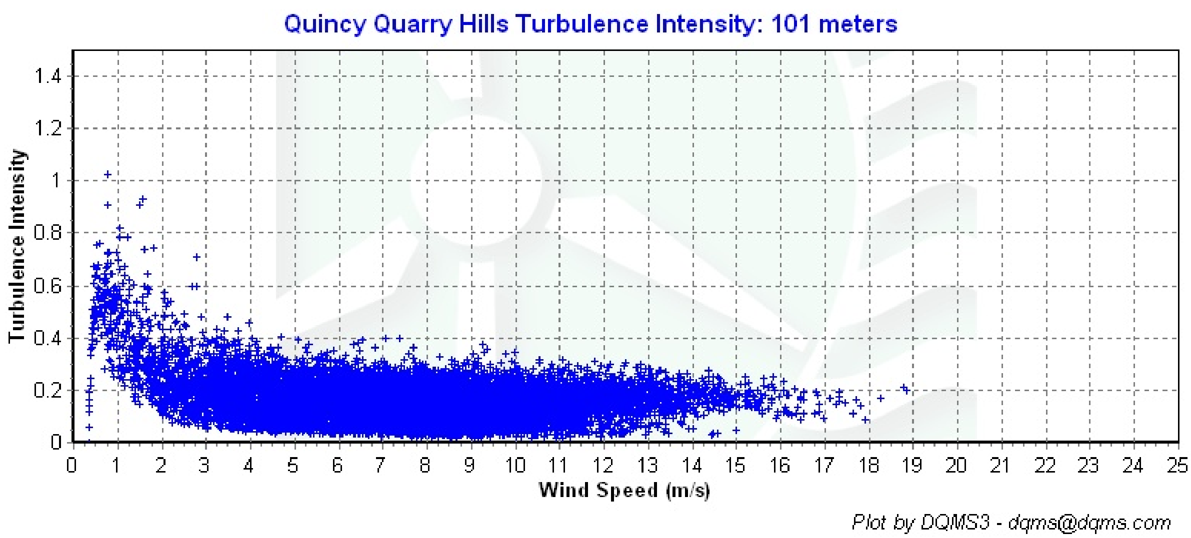

Figure 6 – Turbulence Intensities December 2006 to February 2007

Wind Roses

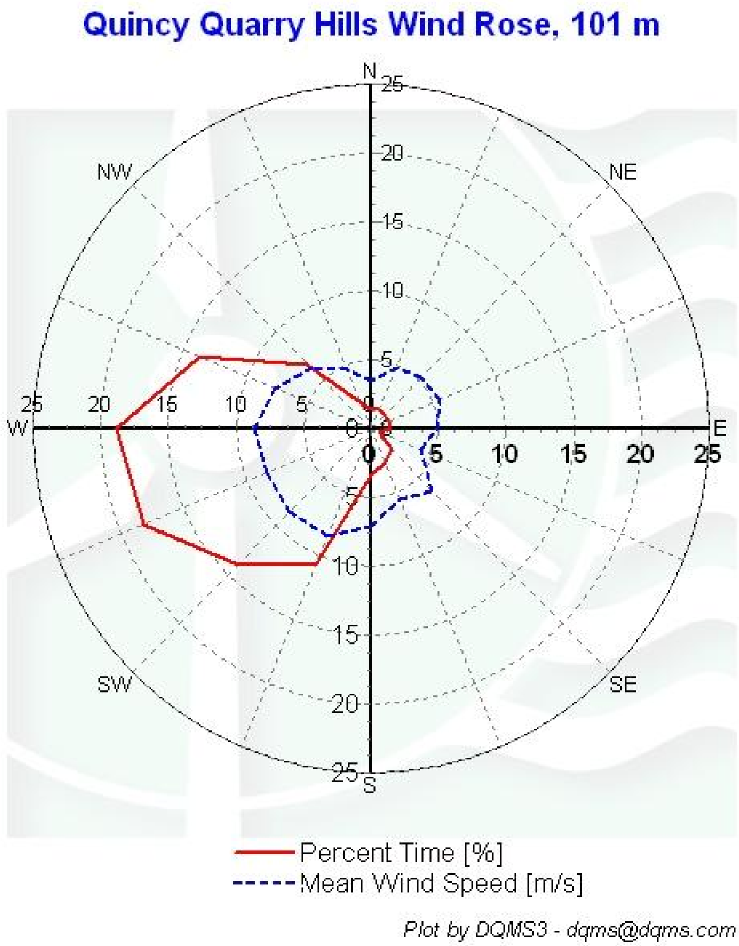

Figure 7 – Wind Roses December 2006 to February 2007

SECTION 5 - Significant Meteorological Events

There was a lengthy icing event from 6 pm on February 14th to 6 am on the 16th very little wind data was taken during this period.

SECTION 6 - Data Collection and Maintenance

Sensor Positions

The Quincy, Quarry Hills site has two anemometers and one wind vane at each of two heights: approximately 67 and 101 meters. These instruments are mounted north and south of the triangular lattice tower. The sensors mounted north of the tower are referred to as the A sensors, while those to the south are referred to as B sensors.

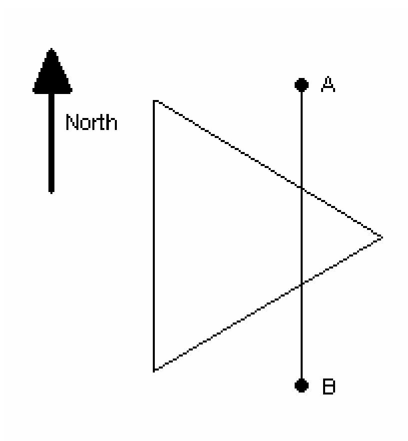

Figure 8 - Sensor Positions

Tower Effects on Measured Wind Speed

Since the sensors are mounted less than one tower-width from the tower (that is, the distance from the tower to the sensors is less than width of the tower), aerodynamic effects of the tower have a significant effect on the measured wind speeds. The measured wind speeds will be lower than free-stream velocity when an anemometer is in the wind shadow of the tower, and can be high when it is in an area where wind is accelerating around the tower.

Both of these effects and their magnitudes can be seen in the following graph for the difference in measured wind speeds between the A and B anemometers at 101 meters plotted against the measured wind direction.

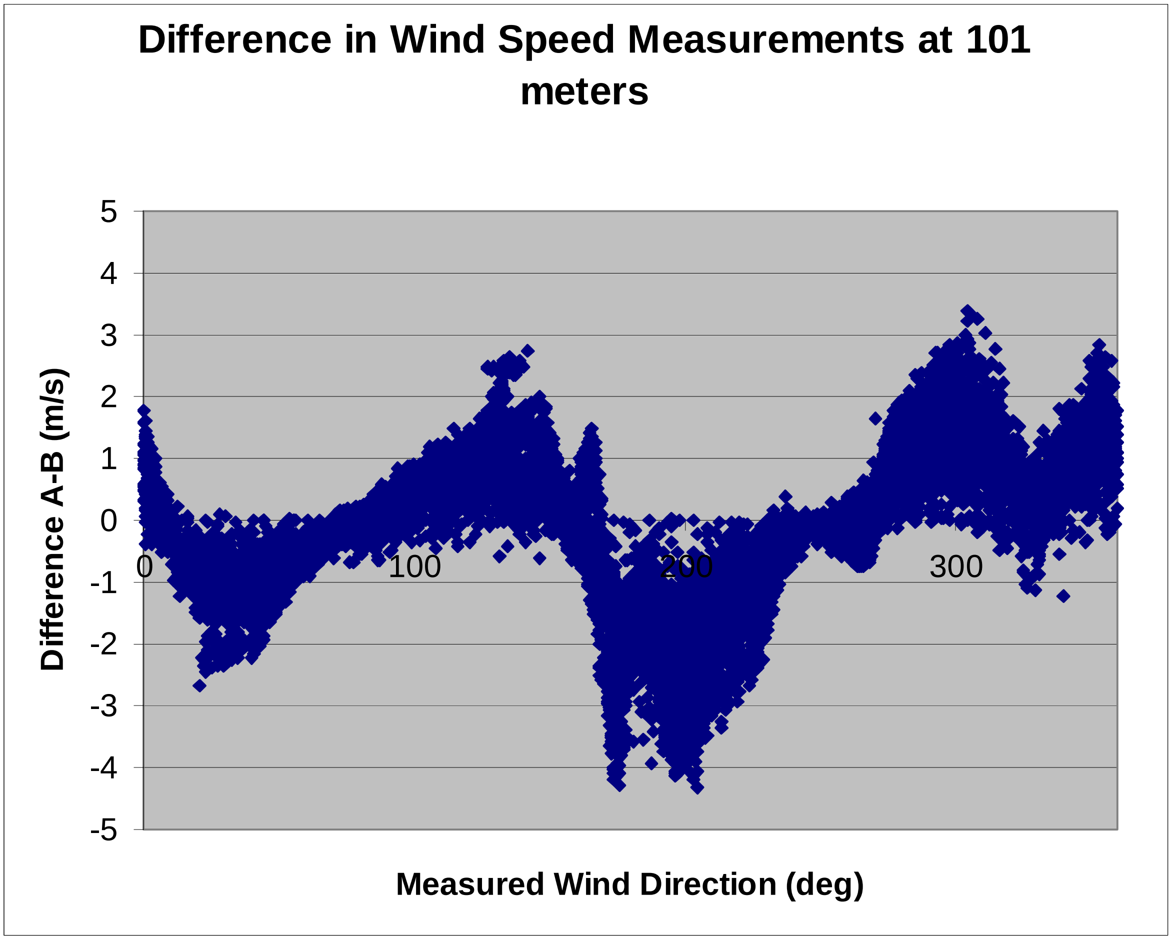

Figure 9 - Difference in measured wind speeds

A positive speed on this graph indicates a wind direction for which the A anemometer reads higher that the B anemometer. A negative speed indicates a direction for which the B anemometer reads higher. These discrepancies are due to a combination of the slow down in wind speed down wind of the tower and the speed up that can occur to either side.

With a tubular tower, and sensors placed far from it, it is preferable to choose the data from the anemometer that is reading higher, when two instruments disagree. An instrument in the tower shadow read significantly lower than the actual wind speed. Other speed-up and slow-down effects are generally minor and contribute to the uncertainty. This is the method that was also used in analyzing data from the Quincy Quarry Hills site as well, since it is the most effective method available with the information at our disposal. In the case of data from this tower, the wind speeds selected by this method may be as much as 2 meters per second above the actual wind speed. Westerly wind directions could put both anemometers in the tower shadow, leading to readings notably below the actual wind speed.

SECTION 7 - 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 [%]	100
Net Data Recovered [%]	95.0

Most of the data that failed quality assurance tests was from the 101 meter wind vane, which gave no good data after February 6th. There was also an icing event starting of February 14th that led to several hours of bad data.

<u>Test Definitions</u>

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

A summary of the results of the data collection and filtering are given in the Sensor Performance Report which is included in APPENDIX A. The following categories of information, tabulated for each sensor, are included in that report.

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*.

APPENDIX A - Sensor Performance Report

Test Definitions

TestOrder	TestField1	TestField2	TestField3	CalcField1	CalcField2	CalcField3	TestType	Factor1	Factor2	Factor3	Factor4
1							TimeTest Insert				
4	Etmp2aDEGC						MinMax	-30	60		
5	EtmpSD2aDEGC						MinMax	-30	60		
10	Anem101aMS						MinMax	0	90		
11	Anem101bMS						MinMax	0	90		
12	Anem67aMS						MinMax	0	90		
13	Anem67bMS						MinMax	0	90		
20	AnemSD101aMS						MinMax	0	4		
21	AnemSD101bMS						MinMax	0	4		
22	AnemSD67aMS						MinMax	0	4		
23	AnemSD67bMS						MinMax	0	4		
30	Vane101aDEG						MinMax	0	359.9		
31	Vane67aDEG						MinMax	0	359.9		
50	Turb101zNONE						MinMax	0	2	0	0
51	Turb67zNONE						MinMax	0	2	0	0
60	Wshr0zNONE						MinMax	-100	100	0	0
70	Pwrd101zWMS						MinMax	0	5000	0	0
71	Pwrd67zWMS						MinMax	0	5000	0	0
200	VaneSD101aDEG	Anem101yMS					MinMaxT	0	100	100	10
201	VaneSD67aDEG	Anem67yMS					MinMaxDa	0	100	100	10
300	Anem101aMS	AnemSD101aMS	Vane67aDEG	VaneSD67aDEG	Etmp2aDEGC		Icing	0.5	1	2	
301	Anem101bMS	AnemSD101bMS	Vane67aDEG	VaneSD67aDEG	Etmp2aDEGC		Icing	0.5	1	2	
302	Anem67aMS	AnemSD67aMS	Vane67aDEG	VaneSD67aDEG	Etmp2aDEGC		Icing	0.5	1	2	
303	Anem67bMS	AnemSD67bMS	Vane67aDEG	VaneSD67aDEG	Etmp2aDEGC		Icing	0.5	1	2	

Sensor Statistics

Sensor	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	% Data Good
Etmp2aDEGC	12960	12960	100	0	0	100
EtmpSD2aDEGC	12960	12960	100	0	0	100
Anem101aMS	12960	12960	100	0	37.5	98.264
AnemSD101aMS	12960	12960	100	0	37.5	98.264
Anem101bMS	12960	12960	100	0.167	40	98.14
Anem67aMS	12960	12960	100	0	51.833	97.6
AnemSD67aMS	12960	12960	100	0	51.833	97.6
Anem67bMS	12960	12960	100	0.333	31.5	98.526
Vane101aDEG	12960	12960	100	0	1.333	74.869
VaneSD101aDEG	12960	12960	100	0	1.333	74.869
Vane67aDEG	12960	12960	100	0.167	54.5	97.469
VaneSD67aDEG	12960	12960	100	0.167	54.5	97.469
Anem101yMS	12960	12960	100	0	37.5	98.264
Anem67yMS	12960	12960	100	0	30	98.611
Total	181440	181440	100	0.833	429.333	94.99

APPENDIX B - Plot Data

Wind Speed Distribution Data

Wind Speed [m/s]	Percent of time [%]
0.5	1.9
1.5	2.14
2.5	3.86
3.5	6.59
4.5	7.74
5.5	8.44
6.5	9.77
7.5	10.98
8.5	12.67
9.5	11.96
10.5	10.04
11.5	6.23
12.5	3.76
13.5	2.13
14.5	0.93
15.5	0.51
16.5	0.24
17.5	0.08
18.5	0.02
19.5	0
20.5	0
21.5	0
22.5	0
23.5	0
24.5	0

Monthly Average Wind Speed Data

Month	Average Wind Speed [m/s]
Sep-06	6.41
Oct-06	7.69
Nov-06	6.48
Dec-06	7.69
Jan-07	7.42
Feb-07	7.86

Diurnal Average Wind Speed Data

Hour of day	Wind Speed [m/s]
0.5	7.53
1.5	7.6
2.5	7.78
3.5	7.81
4.5	7.85
5.5	8.02
6.5	8.02
7.5	7.86
8.5	7.56
9.5	7.4
10.5	7.45
11.5	7.56
12.5	7.65
13.5	7.72
14.5	7.69
15.5	7.61
16.5	7.31
17.5	7.24
18.5	7.58
19.5	7.82
20.5	7.83
21.5	7.75
22.5	7.5
23.5	7.46

Wind Rose Data

Wind Direction [deg]	Percent of time [%]	Average Speed [m/s]
0	1.4	3.44
22.5	1.48	4.8
45	1.42	5.27
67.5	1.43	5.51
90	1.42	4.85
112.5	0.63	3.97
135	2.13	6.37
157.5	2.7	5.5
180	3.4	7.13
202.5	10.55	8.49
225	13.99	8.59
247.5	18.2	8.4
270	18.83	8.63
292.5	13.78	7.66
315	6.63	6.22
337.5	2	4.62