

# **WIND DATA REPORT**

## **Camden Hills Regional High School, ME**

September 1<sup>st</sup> 2006 to November 30<sup>th</sup> 2006

Prepared for

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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 report covers wind data measured at the Camden Hills Regional High School site in Maine, which was installed on February 1, 2006. Two anemometers and one wind vane are mounted at both 39 m (127.9 ft) and 30 m (98.4 ft).

The period covered by this report is September 1, 2006 – November 30, 2006. The quarterly mean recorded wind speed at 39 m was 3.6 m/s (8.1 mph)\* and the prevailing direction was from the west. The gross data recovery percentage (the actual percentage of expected data received) for the quarter was 100 % and the net data recovery percentage (the percentage of expected data which passed all of the quality assurance tests) for the quarter was 99.1%.

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](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 station is located at the Camden Hills Regional High School. The tower base is located at 44.190° N, -69.100° W (WGS84/ NAD83) (Figure 1). The red cross indicates the approximate location of the tower.

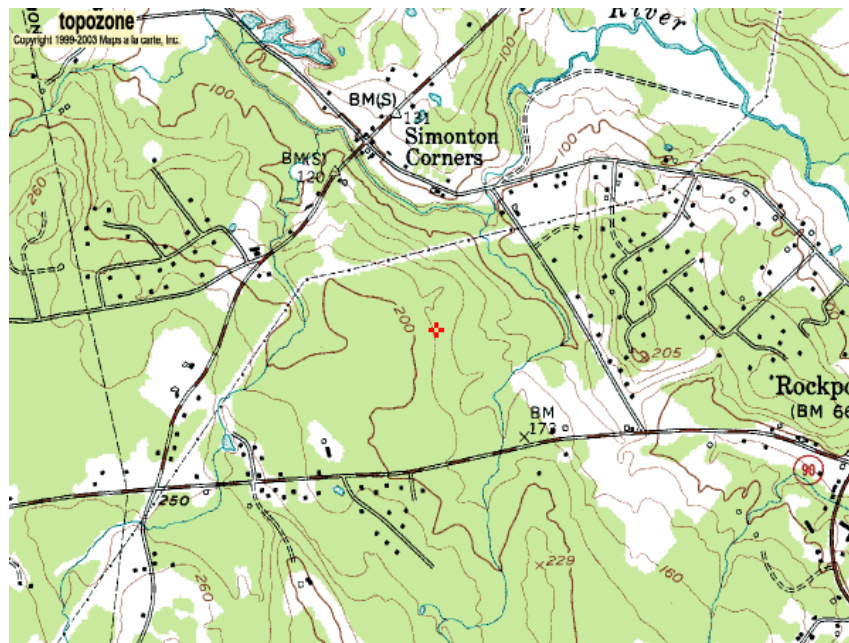


Figure 1 – Camden Hills Regional High School Site Location

Source: [www.topozone.com](http://www.topozone.com).

## SECTION 2 - Instrumentation and Equipment

The wind monitoring equipment is mounted on a 40 m (131.2 ft) meteorological tower. All the remaining monitoring equipment comes from NRG Systems, and consists of the following items:

- Symphonie Data Logger
- 4 – #40 Anemometers, standard calibration (Slope - 0.765 m/s, Offset – 0.350 m/s). Two anemometers are located at 39 m (127.9 ft), and two at 30 m (98.4 ft).
- 2 - #200P Wind direction vanes. They are located at heights of 39 m (127.9 ft) and 30 m (98.4 ft).

- 4 – 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:

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 | Wind Shear Coefficient |
|------------------------|-----------------|----------------|---------------------------|----------------------|-----------------|----------------|---------------------------|----------------------|------------------------|
| Heights, units         | 39 m, [m/s]     | 39 m, [m/s]    | 39 m, [ ]                 | 39 m, [ ]            | 30 m, [m/s]     | 30 m, [m/s]    | 30 m, [ ]                 | 30 m, [ ]            | 39 m, 30 m, [ ]        |
| 06-Jun                 | 3.06            | 8.1            | W                         | 0.29                 | 2.63            | 7.3            | W                         | 0.33                 | 0.58                   |
| 06-Jul                 | 4.18            | 14.1           | W                         | 0.29                 | 3.68            | 12.7           | W                         | 0.31                 | 0.49                   |
| 06-Aug                 | 3.56            | 10.8           | N                         | 0.28                 | 3.06            | 10.2           | N                         | 0.32                 | 0.58                   |
| <b>Jun 06 – Aug 06</b> | <b>3.60</b>     | <b>14.1</b>    | <b>W</b>                  | <b>0.29</b>          | <b>3.13</b>     | <b>12.7</b>    | <b>W</b>                  | <b>0.32</b>          | <b>0.53</b>            |

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  $\pm 0.2$  m/s, whichever is greater.

When data at multiple heights are available, shear coefficients,  $\alpha$ , 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 quarter are less than 15 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. The net data recovered is approximately 0.9% less than the gross data recovered. This is due to icing of the sensors, which causes some of the data points to fail the quality control tests.

|                          |      |
|--------------------------|------|
| Gross Data Recovered [%] | 100  |
| Net Data Recovered [%]   | 99.1 |

### 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. All graphs contain data from the period of September 1, 2006 – November 30, 2006. The following graphs are included:

- Time Series – 10-minute average wind speeds at a height of 39 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 39 m. The wind blows most frequently between 3 m/s and 4 m/s, for approximately 22.2% of the time. The wind speed distribution is shown in Figure 3.
- Monthly Averages - A plot of the monthly average wind speed at a height of 39 m from February 2005 - November 2006. This graph shows the trends in the

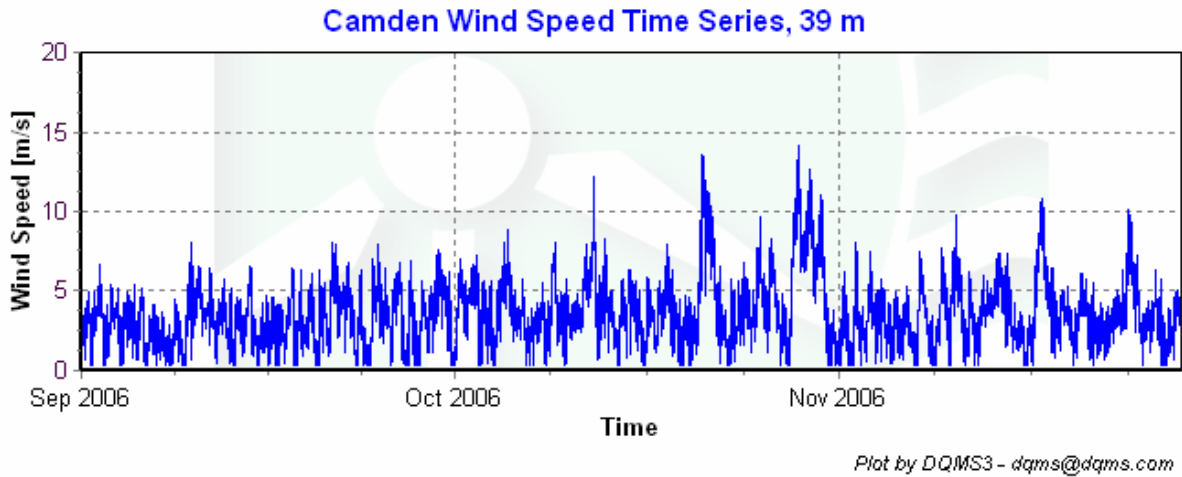
wind speed over the year. The monthly average wind speed plot is shown in Figure 4.

- Diurnal –A plot of the average wind speed for each hour of the day at a height of 39 m. The wind speeds are highest between 11 am and 12 pm, and lowest between 1 am and 2 am. 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 39 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 Camden, the average turbulence intensity was 0.29 at a height of 39 m. 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 39 m. This wind rose shows the prevailing direction from the west, and wind speeds are greatest from the northwest. The wind rose plot is shown in Figure 7.

## SECTION 7- Graphs

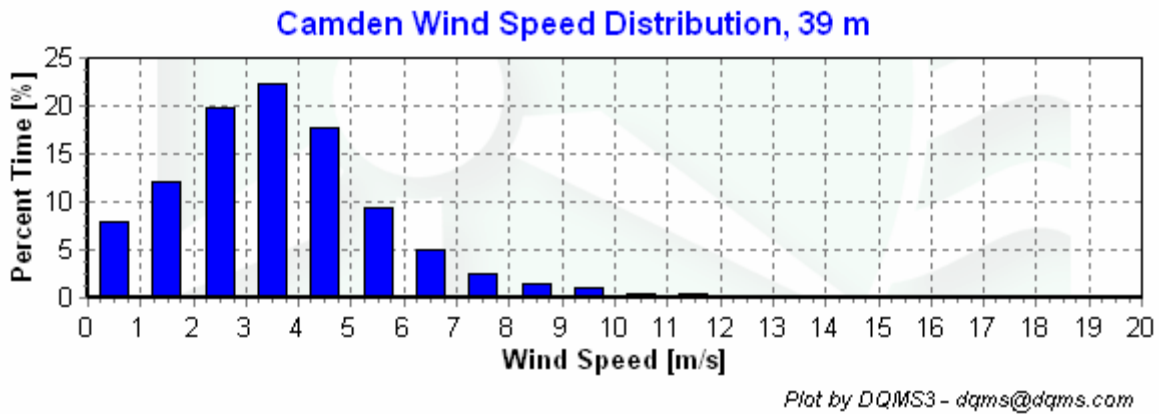
Data for the wind speed histograms, monthly and diurnal average plots, and wind roses are included in APPENDIX B.

### Wind Speed Time Series



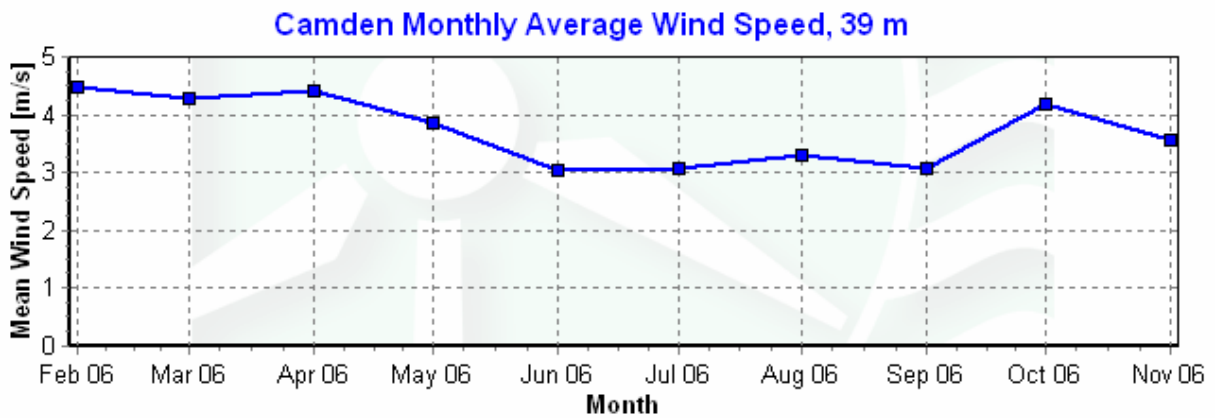
**Figure 2 - Wind Speed Time Series, September 1, 2006 - November 30, 2006.**

### Wind Speed Distributions



**Figure 3 - Wind Speed Distribution, September 1, 2006 - November 30, 2006.**

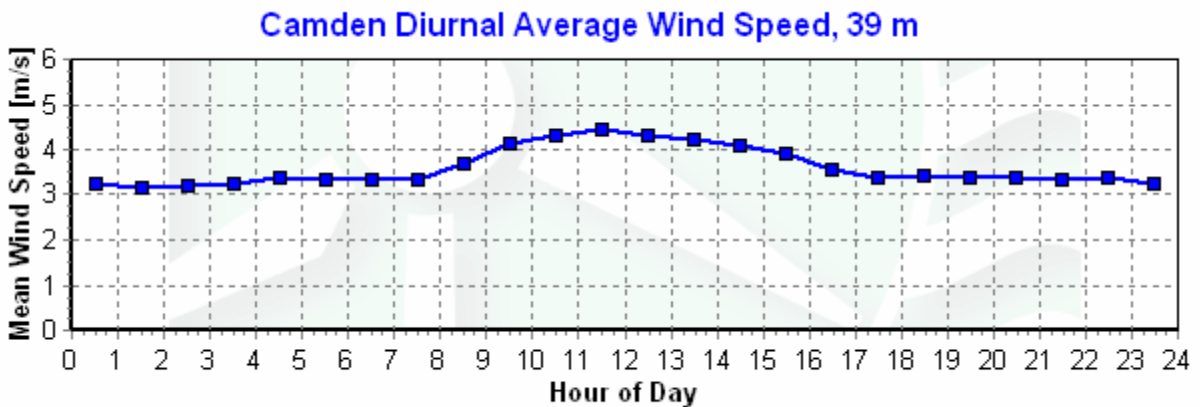
### Monthly Average Wind Speeds



Plot by DQMS3 - dqms@dqms.com

Figure 4 – Monthly Average Wind Speed, February, 2006 - November, 2006

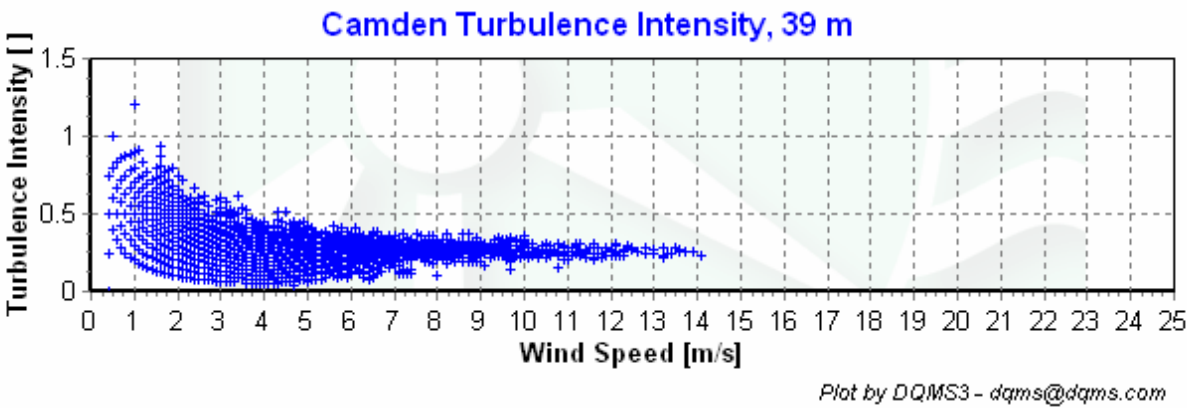
### Diurnal Average Wind Speeds



Plot by DQMS3 - dqms@dqms.com

Figure 5 - Diurnal Wind Speed, September 1, 2006 - November 30, 2006.

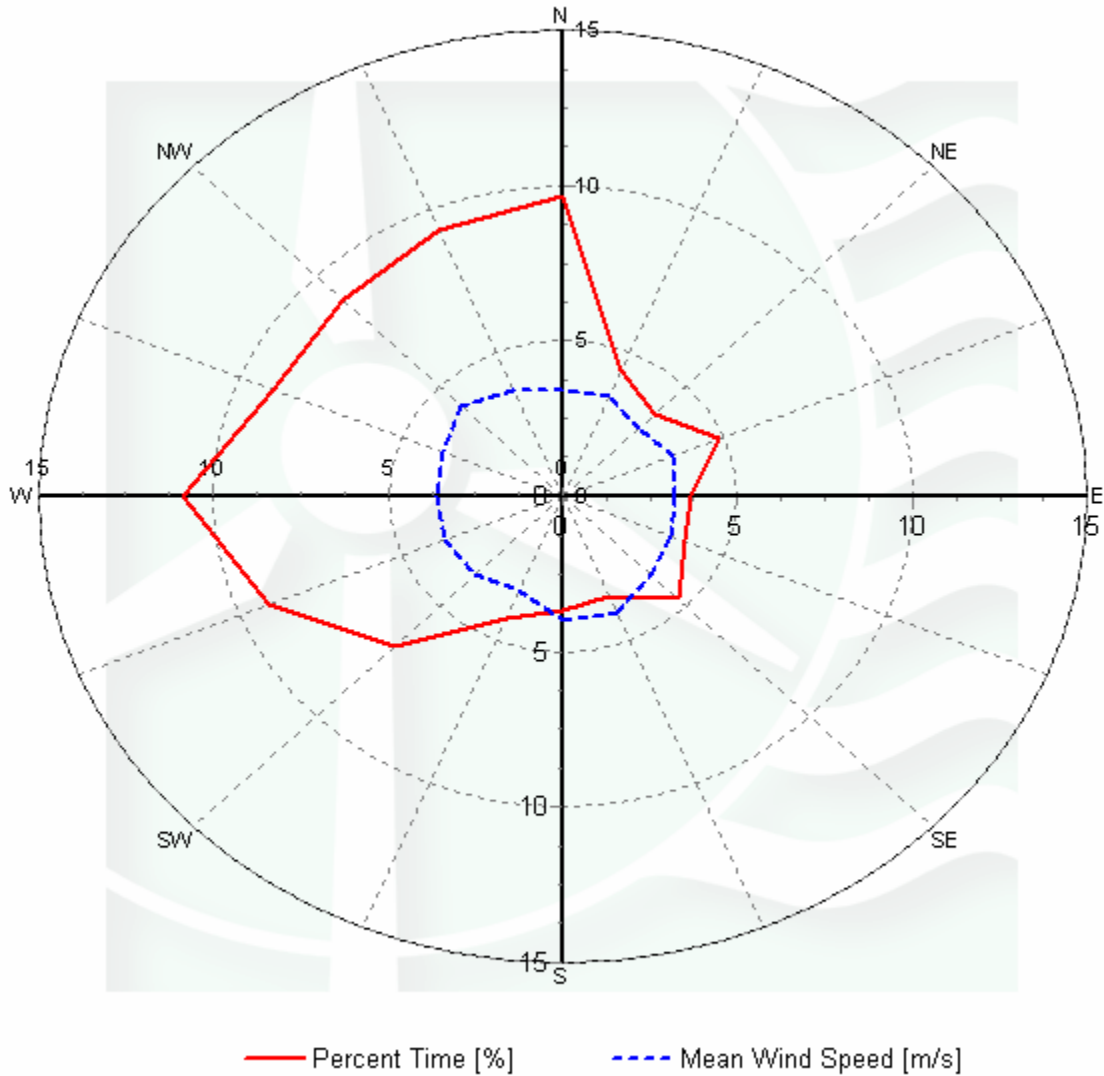
**Turbulence Intensities**



**Figure 6 - Turbulence Intensity vs. Wind Speed, September 1, 2006 - November 30, 2006.**

# Wind Rose

Camden Wind Rose, 39 m



Plot by DQMS3 - dqms@dqms.com

Figure 7 - Wind Rose, September 1, 2006 - November 30, 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 |         |         |         |         |
| 4          | Etmp2adegc   |             |             |              |             |             | MinMax          | -30     | 60      | 0       | 0       |
| 5          | EtmpSD2adegc |             |             |              |             |             | MinMax          | -30     | 60      | 0       | 0       |
| 10         | Anem39ams    |             |             |              |             |             | MinMax          | 0       | 90      |         |         |
| 11         | Anem39bms    |             |             |              |             |             | MinMax          | 0       | 90      |         |         |
| 12         | Anem30ams    |             |             |              |             |             | MinMax          | 0       | 90      |         |         |
| 13         | Anem30bms    |             |             |              |             |             | MinMax          | 0       | 90      |         |         |
| 14         | Anem39yms    |             |             |              |             |             | MinMax          | 0       | 90      |         |         |
| 15         | Anem30yms    |             |             |              |             |             | MinMax          | 0       | 90      |         |         |
| 20         | AnemSD39ams  |             |             |              |             |             | MinMax          | 0       | 4       |         |         |
| 21         | AnemSD39bms  |             |             |              |             |             | MinMax          | 0       | 4       |         |         |
| 22         | AnemSD30ams  |             |             |              |             |             | MinMax          | 0       | 4       |         |         |
| 23         | AnemSD30bms  |             |             |              |             |             | MinMax          | 0       | 4       |         |         |
| 24         | AnemSD39yms  |             |             |              |             |             | MinMax          | 0       | 4       |         |         |
| 25         | AnemSD30yms  |             |             |              |             |             | MinMax          | 0       | 4       |         |         |
| 30         | Vane39adeg   |             |             |              |             |             | MinMax          | 0       | 359.9   |         |         |
| 31         | Vane30adeg   |             |             |              |             |             | MinMax          | 0       | 359.9   |         |         |
| 50         | Turb39zNONE  |             |             |              |             |             | MinMax          | 0       | 2       |         |         |
| 51         | Turb30zNONE  |             |             |              |             |             | MinMax          | 0       | 2       |         |         |
| 60         | Wshr0zNONE   |             |             |              |             |             | MinMax          | -100    | 100     |         |         |
| 70         | Pwr39zWMS    |             |             |              |             |             | MinMax          | 0       | 5000    |         |         |
| 71         | Pwr30zWMS    |             |             |              |             |             | MinMax          | 0       | 5000    |         |         |
| 200        | VaneSD39adeg | Anem39yms   |             |              |             |             | MinMaxT         | 0       | 100     | 100     | 10      |
| 201        | VaneSD30adeg | Anem30yms   |             |              |             |             | MinMaxT         | 0       | 100     | 100     | 10      |
| 300        | Anem39ams    | AnemSD39ams | Vane39adeg  | VaneSD39adeg | Etmp2adegc  |             | Icing           | 0.5     | 1       | 2       | 10      |
| 301        | Anem39bms    | AnemSD39bms | Vane39adeg  | VaneSD39adeg | Etmp2adegc  |             | Icing           | 0.5     | 1       | 2       | 10      |
| 302        | Anem30ams    | AnemSD30ams | Vane30adeg  | VaneSD30adeg | Etmp2adegc  |             | Icing           | 0.5     | 1       | 2       | 10      |
| 303        | Anem30bms    | AnemSD30bms | Vane30adeg  | VaneSD30adeg | Etmp2adegc  |             | Icing           | 0.5     | 1       | 2       | 10      |
| 400        | Anem39ams    | Anem39bms   |             |              |             |             | CompareSensors  | 1       | 0.25    | 3       | 0       |
| 401        | Anem30ams    | Anem30bms   |             |              |             |             | CompareSensors  | 1       | 0.25    | 3       | 0       |

### Sensor Statistics

| Sensor       | Expected Data Points | Actual Data Points | % Data Recovered | Hours Out of Range | Hours of Icing | Hours of Fault | % Data Good  |
|--------------|----------------------|--------------------|------------------|--------------------|----------------|----------------|--------------|
| Anem39ams    | 13104                | 13104              | 100              | 0                  | 15.5           | 1.167          | 99.237       |
| AnemSD39ams  | 13104                | 13104              | 100              | 0                  | 15.5           | 1.167          | 99.237       |
| Anem39bms    | 13104                | 13104              | 100              | 0                  | 16.833         | 11.667         | 98.695       |
| AnemSD39bms  | 13104                | 13104              | 100              | 0                  | 16.833         | 11.667         | 98.695       |
| Anem39yms    | 13104                | 13104              | 100              | 0                  | 15.5           | 0              | 99.29        |
| AnemSD39yms  | 13104                | 13104              | 100              | 0                  | 15.5           | 0              | 99.29        |
| Vane39adeg   | 13104                | 13104              | 100              | 1.333              | 16.833         | 0              | 99.168       |
| VaneSD39adeg | 13104                | 13104              | 100              | 1.333              | 16.833         | 0              | 99.168       |
| Anem30ams    | 13104                | 13104              | 100              | 0                  | 18.167         | 0              | 99.168       |
| AnemSD30ams  | 13104                | 13104              | 100              | 0                  | 18.167         | 0              | 99.168       |
| Anem30bms    | 13104                | 13104              | 100              | 0                  | 17.333         | 34.333         | 97.634       |
| AnemSD30bms  | 13104                | 13104              | 100              | 0                  | 17.333         | 34.333         | 97.634       |
| Anem30yms    | 13104                | 13104              | 100              | 0                  | 17.333         | 0              | 99.206       |
| AnemSD30yms  | 13104                | 13104              | 100              | 0                  | 17.333         | 0              | 99.206       |
| Vane30adeg   | 13104                | 13104              | 100              | 0.667              | 18.167         | 0              | 99.138       |
| VaneSD30adeg | 13104                | 13104              | 100              | 0.667              | 18.167         | 0              | 99.138       |
| Etmp2adegc   | 13104                | 13104              | 100              | 0                  | 0              | 0              | 100          |
| EtmpSD2adegc | 13104                | 13104              | 100              | 0                  | 0              | 0              | 100          |
| <b>Total</b> | <b>235872</b>        | <b>235872</b>      | <b>100</b>       | <b>4</b>           | <b>271.333</b> | <b>94.333</b>  | <b>99.06</b> |

## APPENDIX B - Plot Data

### Wind Speed Distribution Data

| Bin Center Wind Speed<br>[m/s] | Percent of Time<br>[%] |
|--------------------------------|------------------------|
| 0.5                            | 7.82                   |
| 1.5                            | 12.16                  |
| 2.5                            | 19.88                  |
| 3.5                            | 22.27                  |
| 4.5                            | 17.63                  |
| 5.5                            | 9.36                   |
| 6.5                            | 4.93                   |
| 7.5                            | 2.46                   |
| 8.5                            | 1.39                   |
| 9.5                            | 0.98                   |
| 10.5                           | 0.51                   |
| 11.5                           | 0.33                   |
| 12.5                           | 0.17                   |
| 13.5                           | 0.1                    |
| 14.5                           | 0.01                   |
| 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, 39 m, September 1, 2006 - November 30, 2006.

### Diurnal Average Wind Speed Data

| Hour of Day | Average Wind Speed<br>[m/s] |
|-------------|-----------------------------|
| 0.5         | 3.26                        |
| 1.5         | 3.17                        |
| 2.5         | 3.2                         |
| 3.5         | 3.23                        |
| 4.5         | 3.37                        |
| 5.5         | 3.35                        |
| 6.5         | 3.35                        |
| 7.5         | 3.35                        |
| 8.5         | 3.68                        |
| 9.5         | 4.12                        |

|      |      |
|------|------|
| 10.5 | 4.33 |
| 11.5 | 4.44 |
| 12.5 | 4.31 |
| 13.5 | 4.22 |
| 14.5 | 4.09 |
| 15.5 | 3.9  |
| 16.5 | 3.55 |
| 17.5 | 3.38 |
| 18.5 | 3.4  |
| 19.5 | 3.38 |
| 20.5 | 3.39 |
| 21.5 | 3.35 |
| 22.5 | 3.38 |
| 23.5 | 3.24 |

**Table 2 - Diurnal Average Wind Speeds, 39 m, September 1, 2006 - November 30, 2006.**

**Monthly Average Wind Speed Data**

| <b>Date</b> | <b>10 min Mean<br/>[m/s]</b> |
|-------------|------------------------------|
| Feb-06      | 4.48                         |
| Mar-06      | 4.28                         |
| Apr-06      | 4.41                         |
| May-06      | 3.86                         |
| Jun-06      | 3.05                         |
| Jul-06      | 3.07                         |
| Aug-06      | 3.29                         |
| Sep-06      | 3.06                         |
| Oct-06      | 4.18                         |
| Nov-06      | 3.56                         |

**Table 3 - Monthly Average Wind Speeds, 39 m, September 1, 2006 - November 30, 2006.**

### Wind Rose Data

| <b>Direction</b> | <b>Percent Time<br/>[%]</b> | <b>Mean Wind Speed<br/>[m/s]</b> |
|------------------|-----------------------------|----------------------------------|
| <b>N</b>         | 9.67                        | 3.4                              |
| <b>NNE</b>       | 4.37                        | 3.49                             |
| <b>NE</b>        | 3.7                         | 3.07                             |
| <b>ENE</b>       | 4.82                        | 3.42                             |
| <b>E</b>         | 3.64                        | 3.22                             |
| <b>ESE</b>       | 3.78                        | 3.36                             |
| <b>SE</b>        | 4.66                        | 3.6                              |
| <b>SSE</b>       | 3.49                        | 4.04                             |
| <b>S</b>         | 3.64                        | 3.99                             |
| <b>SSW</b>       | 4.26                        | 3.27                             |
| <b>SW</b>        | 6.83                        | 3.58                             |
| <b>WSW</b>       | 9.13                        | 3.68                             |
| <b>W</b>         | 10.88                       | 3.59                             |
| <b>WNW</b>       | 8.98                        | 3.72                             |
| <b>NW</b>        | 8.88                        | 4.09                             |
| <b>NNW</b>       | 9.27                        | 3.7                              |

**Table 4 - Wind Rose, Time Percentage and Mean Wind Speed by Direction, 39 m, September 1, 2006 - November 30, 2006.**