Kaneohe, Hawaii Wind Resource Assessment Report

R. Robichaud, J. Green, and B. Meadows

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

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November 2011

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Executive Summary

The Department of Energy (DOE) has an interagency agreement to assist the Department of Defense (DOD) in evaluating the potential to use wind energy for power at residential properties at DOD bases in Hawaii. DOE assigned the National Renewable Energy Laboratory (NREL) to facilitate this process by installing a 50-meter (m) meteorological (Met) tower on residential property associated with the Marine Corps Base Housing (MCBH) Kaneohe Bay in Hawaii.

This report describes the wind resource measured at MCBH Kaneohe Bay. The data-set analyzed in this report includes a general validation and summarization of the 10-minute data taken from August, 2009 through September, 2010.

The mean annual wind speeds from the data collected at the MCBH Kaneohe Bay Met tower can be seen in the first row of Table 1. With the 20-m data at MCBH Kaneohe Bay normalized to the long-term wind speeds from the Marine Corps Air Station (MCAS) Kaneohe Bay airport. The vertical wind shear factors from the collected data at MCBH Kaneohe Bay were applied to the adjusted 20-m data to determine expected wind speeds at the 35 and 10.7-m heights at MCBH Kaneohe Bay from August 1998 through July 2010 in an average wind year. The overall net change in wind speeds at 20 m was a ~3.7% decrease in the mean wind speed of collected data at 20 m at MCBH Kaneohe Bay. The adjusted data was used as the basis for the subsequent economic analysis.

Table 1 shows the mean annual wind speed from the data collected at MCBH Kaneohe Bay from August 1, 2009 – July 31, 2010. The row labeled 'Kaneohe Estimated Long Term Mean Wind Speed' indicates the new mean annual wind speed at each anemometer height after applying the Measure Correlate Predict (MCP) method and the vertical wind shear factors from the Met tower at MCBH Kaneohe Bay to the long term data from MCAS Kaneohe Bay airport's 10-m data. The net change as a percentage is shown in the next row down.

Table 1. Mean Annual Wind Speed Before and After Long Term Correlation at MCBH Kaneohe Bay Met Tower

Measurement	Unit	10.7 m	20 m	35 m	50 m
Kaneohe Wind Speed as Collected	(m/s)	-	6.39	6.78	6.84
Kaneohe Estimated Long Term Mean Wind Speed	(m/s)	5.83	6.16	6.49	-
Percent Increase in Wind Speed	(%)	-	-3.6%	-4.3%	-
Kaneohe Estimated Long Term Mean Power Density	(W/m²)	182	213	253	-

The mean annual wind-power densities from both the collected data at MCBH Kaneohe Bay and the extrapolated data are also shown in Table 1. The mean annual wind power density is the average power per-unit area (i.e., power/m^2) over each time-step in the year. A wind power density of 182 W/m^2 at 10.7 m (expected height of a Skystream 3.7 wind turbine at this location) is considered a Class 1^+ wind resource. At the other heights of interest, 20 and 35 m, the wind power density is 213 and 253 W/m^2, or Class 2 winds.

It should be noted that though the wind-power densities are not high, and the power available in the wind is generally considered insufficient for an economic wind turbine project, the high cost of electricity in Hawaii (~$0.26/kWh) is a significant driver in overall wind turbine economics.

In this case, within the realm of current commercial rates, a simple payback of less than 20 years is estimated with several mid-size wind turbines. At a US average of ~$0.10/kWh, simple paybacks would increase to ~30-50 years.

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Station Location

The monitoring site is located on the southeastern side of the Mokapu Peninsula in Kaneohe Bay. The 50-m Met tower was installed adjacent to the school in MCBH Kaneohe Bay. Approximate grid coordinates are: N 21° 26' 32.5", W 157° 44' 16.7". The monitoring location is shown in Figure 1. The terrain in close proximity to the Met tower is generally flat and includes some vacant lots towards the ocean front, the school, 1-2 story buildings and residences, with some ground cover provided by grasses and bushes. The Met tower is ~130 m from the ocean with a relatively flat profile from the site to the ocean. The site is on the windward side of Oahu and is regularly exposed to the trade winds from the northeast.

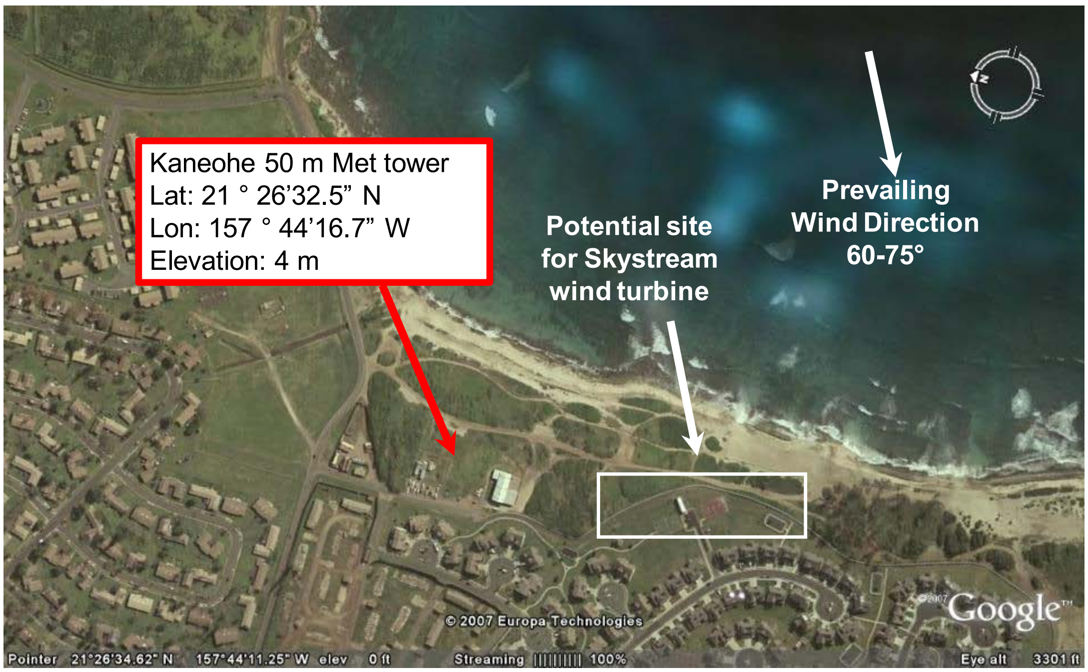


Figure 1. MCBH Kaneohe Bay 50-m Met tower location and potential Skystream wind turbine site.

Source: http://www.Googlemaps.com and with labels by Jim Green, NREL

The Met tower location relative to the Ulupau Crater is shown in Figure 2, with a view to the north-through-east arc. The crater ranges in height from ~1 - 200 m along its curved outer wall on the north-west-south arc. The crater will cause significant turbulence to the wind going through and over it. The MCBH Kaneohe Bay Met tower site is ~1,110 - 1,200 m (~0.7 mi) from the southern edge of the crater. Most of the energetic winds come from the 60-75° arc, and come into the Met tower site directly from the ocean, not over the crater. The full extent of the turbulent path caused by the crater is not known and cannot be discerned from the data at the Met tower site.

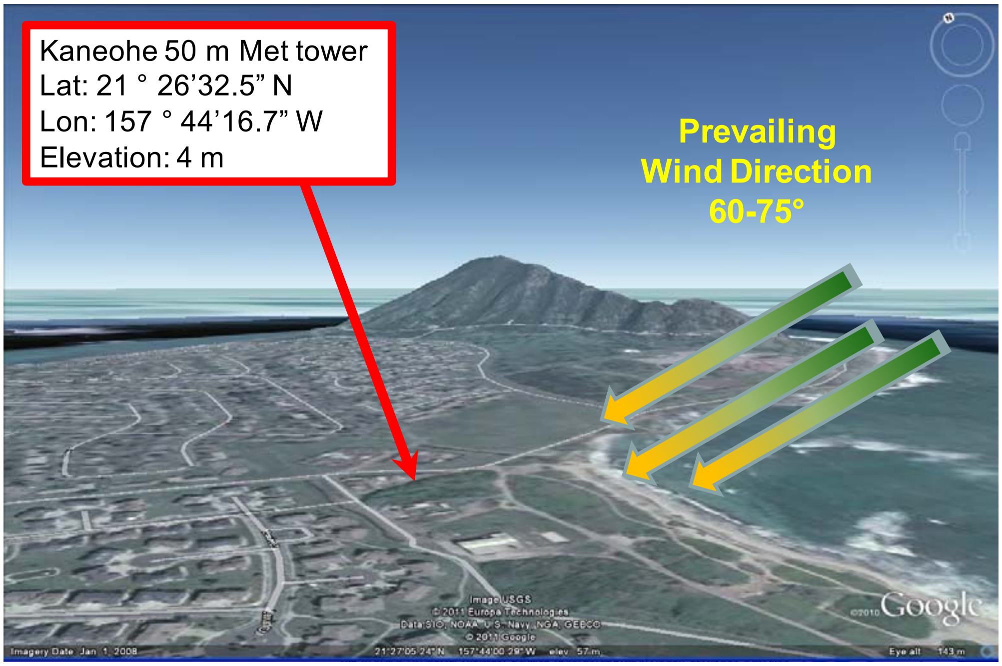


Figure 2. The view to the north-through-east arc (prevailing wind direction is from the northeast) from southwest of the Met tower site.

Source: http://www.GoogleEarth.com and with labels by Robi Robichaud, NREL

Table 2 summarizes the details of the monitoring station over the collection period July 23, 2009 through September 27, 2010. The data was processed using Windographer[1] software.

Table 2. Data Set Summary at MCBH Kaneohe Bay

Characteristic	Value
Latitude	N 21° 26' 32.500"
Longitude	W 157° 44' 16.700"
Elevation	4 m
Start date	8/1/2009 0:00
End date	7/31/2010 23:40
Duration	12 months
Length of time step	10 minutes
Calm threshold	3 m/s
Mean temperature	25.2 °C
Mean pressure	101.2 kPa
Mean air density	1.182 kg/m³
Power density at 50m	284 W/m²
Wind power class	2
Power law exponent	0.077
Surface roughness	0.0000693 m

[1] Web source: http://www.mistaya.ca/

Wind in Hawaii

There has been interest in wind energy applications on Hawaii since the 1980's. As can be seen in the 50-m wind speed map below, there is a considerable wind resource at particular locations on Oahu. Generally, the high ridges and some coastal areas have the best wind resource.

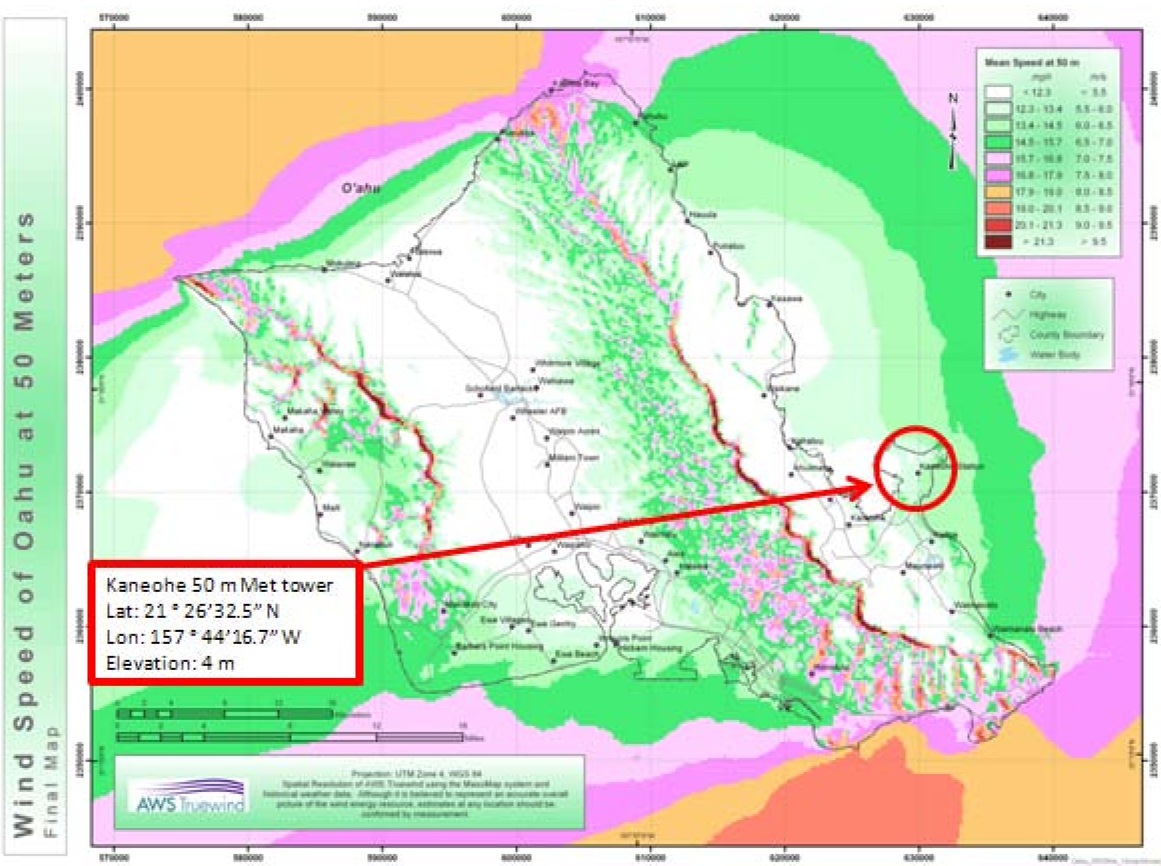


Figure 3. 50-m wind speed map of Oahu, HI.

Source: *Hawaii's Wind Energy Future*[2]

Wind resources are very site specific. Different sites in close proximity to each other, but with varying vegetation (i.e., tall trees vs. grassland or cropland), topographical features (ridges vs. valleys; canyons vs. mountains, etc), and surface roughness (i.e., city skyscrapers vs. flat or rolling farmland), may have entirely different wind regimes. One may prove to be economic, and another may not though reasonably close together. The Ulupau Crater provides a great example of a geographical/topographical feature that will cause a significant difference in the wind resource on different sides of and distances away from the crater. Wind maps are useful for

[2] Hawaii's Wind Energy Future, High resolution wind resource maps. Web site: http://www.hawaiisenergyfuture.com/Articles/Wind_Energy.html#WheresWind. Accessed 12/5/2011

determining from a high level view where the wind usually blows. Wind maps are not used to site large wind turbines/farms, as they are not that accurate. They are used to determine where it is merited to further investigate the wind with installation of an on-site wind monitoring station.

Figure 4 indicates a Class 1+ - Class 2 wind resource (100 – 300 W/m^2) in the MCBH Kaneohe Bay area.

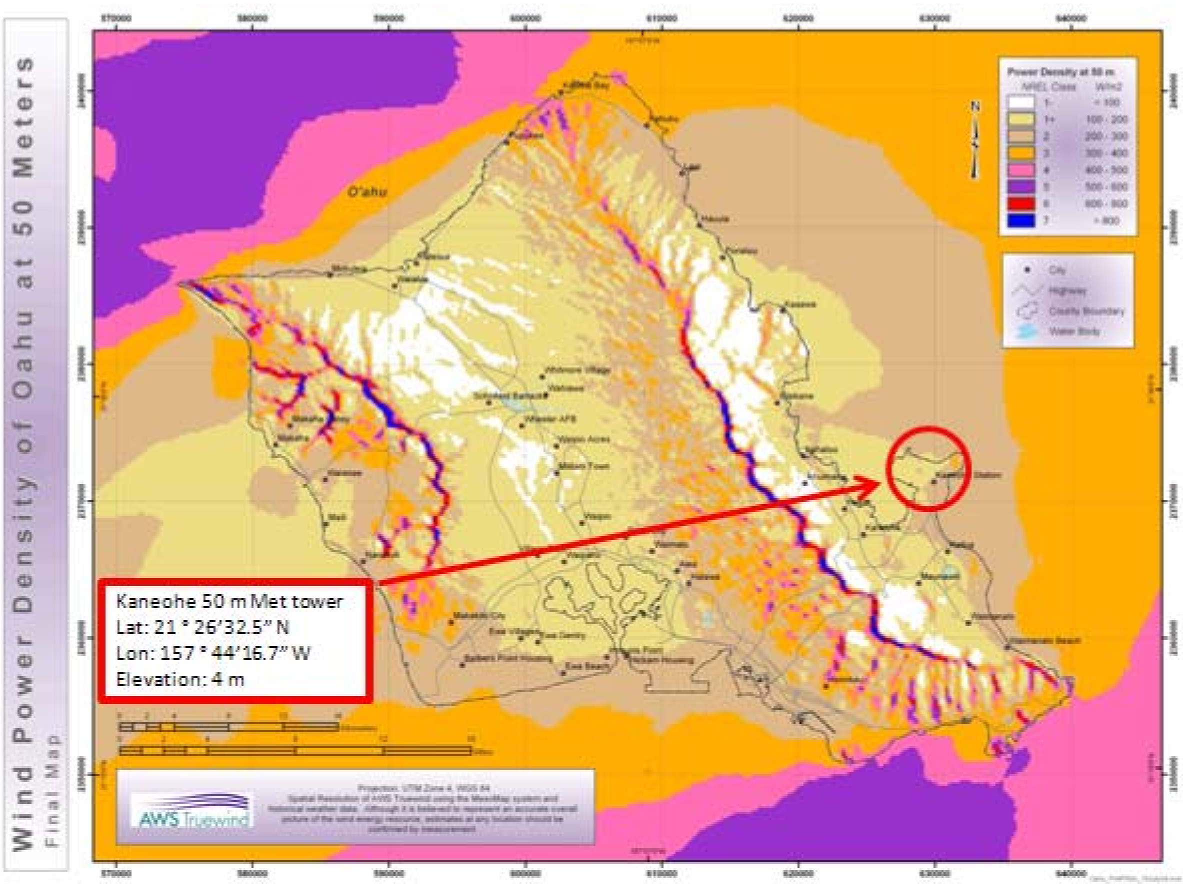


Figure 4. 50-m wind power density map of Oahu, HI.

Source: *Hawaii's Wind Energy Future*[3]

An enlargement of Figure 4 provides a better view of the mapped wind resource in Figure 5. The Met tower and the proposed location for the wind turbine are just to the right of the purple dot representing MCBH Kaneohe Bay. As shown, it appears to be in a Class 2 wind regime (200 – 300 W/m^2). It is interesting to note, that based on the wind map, parts of the Ulupau Crater to the north-by-northeast of the Met tower site, are considered to have a Class 3 (300 – 400 W/m^2) wind resource.

[3] Hawaii's Wind Energy Future, High resolution wind resource maps. Web site: http://www.hawaiisenergyfuture.com/Articles/Wind_Energy.html#WheresWind. Accessed 12/5/2011

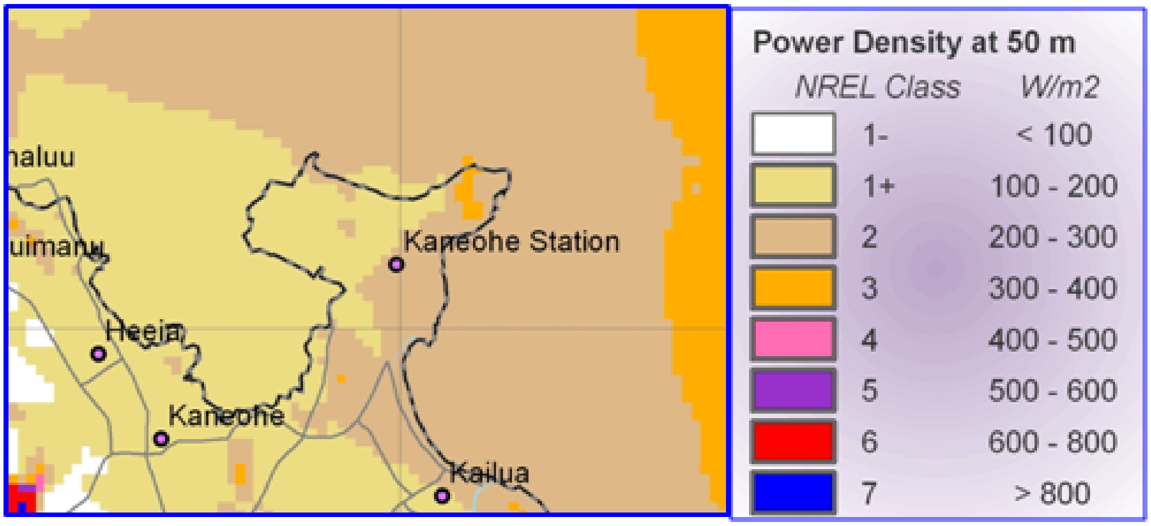


Figure 5. Enlarged 50m wind power density map of MCBH Kaneohe Bay Area on Oahu, HI.

Source: *Hawaii's Wind Energy Future*[4]

Instrumentation and Equipment

The project instrumentation consisted of an NRG 50 m XHD NRG Tall Tower, six anemometers, two wind vanes, temperature sensor, and a data logger. Details of the sensor configuration are summarized in Table 3 below. Three of the anemometers, at 50.15, 35.05, and 20.25 m, were aligned at 162° (labeled Southeast or SE hereafter) and a redundant anemometer at each height was oriented to 342° (labeled Northwest or NW). The nominal height and orientation were used for simplicity, so the anemometer at 50.2 m with orientation at 342° was labeled as 50 m NW.

Table 3. Instrumentation Summary at MCBH Kaneohe Bay

Sensor Type	Sensor Label	Measurement	Height	Boom Orientation
			[m]	[degrees - true]
NRG # 40 Calibrated Anemometer	50 m SE	Wind Speed (m/s)	50.15	162
NRG # 40 Calibrated Anemometer	50 m NW	Wind Speed (m/s)	50.15	342
NRG # 40 Calibrated Anemometer	35 m SE	Wind Speed (m/s)	35.05	162
NRG # 40 Calibrated Anemometer	35 m NW	Wind Speed (m/s)	35.05	342
NRG # 40 Calibrated Anemometer	20 m SE	Wind Speed (m/s)	20.25	162
NRG # 40 Calibrated Anemometer	20 m NW	Wind Speed (m/s)	20.25	342
NRG #200 Wind Direction Vane	Dir 50 m	Wind Direction (deg)	50.35	72
NRG #200 Wind Direction Vane	Dir 35 m	Wind Direction (deg)	35.25	72
NRG #110S Temperature Sensor	Temp	Temperature (deg C)	3	

[4] Hawaii's Wind Energy Future, High resolution wind resource maps. Web site: http://www.hawaiisenergyfuture.com/Articles/Wind_Energy.html#WheresWind. Accessed 12/5/2011

Data Recovery and Validation

The data logger sampled the sensors every two seconds and recorded the ten-minute average value for each sensor. The data was emailed daily to NREL for analysis. The data recovery rates were 100% for all sensors and the results are shown in Table 14 in Appendix A.

Wind Speed Sensor Summary

The collected data was analyzed and screened for anomalies and low-quality data. Table 4 provides an overview of a number of key parameters of the collected data.

One screen applied was to determine the effects of tower on the wind speeds recorded at each anemometer height. The tower can influence the wind speed that is measured by the anemometers through an effect known as tower shading. In some orientations, it has the effect of slowing down the free wind speed and in others it can accelerate the free wind speed. The effect can most easily be seen mathematically or graphically by comparing the wind speed ratios of the redundant anemometers at the same height. The wind speeds for two anemometers at the same height are expected to be the same or very close to the same. When they are not, it is cause for further investigation. The ratio of the wind speeds of these two anemometers should typically be 1 or very close to 1. Predictable impacts of the tower can be seen when the wind must go around the tower (aka, 'in the tower shadow') to reach one of the anemometers. When one anemometer is in the tower shadow, the data from the other one is typically used. The data recovery rate shown in the final row is after the screening, aka "flagging" has been applied. The data not used is "flagged."

Table 4. Wind Speed Sensor Summary at MCBH Kaneohe Bay

Variable	Units	Speed 50 m SE	Speed 50 m NW	Speed 35 m SE	Speed 35 m NW	Speed 20 m SE	Speed 20 m NW
Measurement height (m)	(m)	50.2	50.2	35	35	20.3	20.3
Mean wind speed (m/s)	(m/s)	6.9	6.9	6.7	6.8	6.4	6.4
MMM wind speed (m/s)	(m/s)	6.9	6.9	6.7	6.8	6.4	6.4
Median wind speed (m/s)	(m/s)	7.1	7.2	7	7.1	6.7	6.8
Min wind speed (m/s)	(m/s)	0.4	0.4	0.4	0.4	0.4	0.4
Max wind speed (m/s)	(m/s)	16.5	16.4	16	16.1	15.2	15
Weibull k		2.511	2.489	2.493	2.475	2.399	2.372
Weibull c (m/s)	(m/s)	7.687	7.666	7.484	7.587	7.141	7.136
Mean power density (W/m²)	(W/m²)	290	288	268	280	237	237
MMM power density (W/m²)	(W/m²)	290	288	268	280	237	237
Mean energy content (kWh/m²/yr)	(kWh/m²/yr)	2,539	2,525	2,349	2,454	2,074	2,078
MMM energy content (kWh/m²/yr)	(kWh/m²/yr)	2,539	2,525	2,349	2,454	2,074	2,078
Energy pattern factor		1.515	1.515	1.518	1.523	1.534	1.537
Frequency of calms (%)	(%)	12.29	12.72	12.94	13.37	14.21	14.59
Possible records	(#)	52,558	52,558	52,558	52,558	52,558	52,558
Valid records	(#)	51,902	49,224	51,928	49,417	51,939	50,533
Missing records	(#)	656	3,334	630	3,141	619	2,025
Data recovery rate (%)	(%)	98.75	93.66	98.8	94.02	98.82	96.15

Table 5 shows the data that was flagged for tower shadowing or other anomalies. Unless otherwise noted, all graphs and tables have the flagged data removed from the subsequent analysis.

Table 5. Flagged Data Summary at MCBH Kaneohe Bay for 8/1/2009 – 7/31/2010

Label	Unflagged - Valid Records	Flagged - Tower Shading
Speed 50 m SE	51,759	656
Speed 50 m NW	49,569	2,846
Speed 35 m SE	51,787	628
Speed 35 m NW	49,274	3,141
Speed 20 m SE	51,809	606
Speed 20 m NW	50,266	2,149
Direction 50 m	52,558	0
Direction 35 m	52,558	0
Temperature	52,558	0

Wind Resource Summary

Wind Speed Data

Wind speed data was collected at 50, 35, and 20 m with a redundant wind speed sensor at each height. The wind speed data from the anemometer designated as the Northwest (or NW) at 20 m is predominantly shown in the figures that follow as this was closest to the expected height of a wind turbine (e.g., the hub height of a Skystream 3.7 wind turbine is ~13.7 m or 45 ft) for this site. A box plot indicating the monthly maximum wind speed, the daily high, the monthly mean, the daily low and monthly minimum wind speed of the collected 20 m NW data is shown in Figure 6.

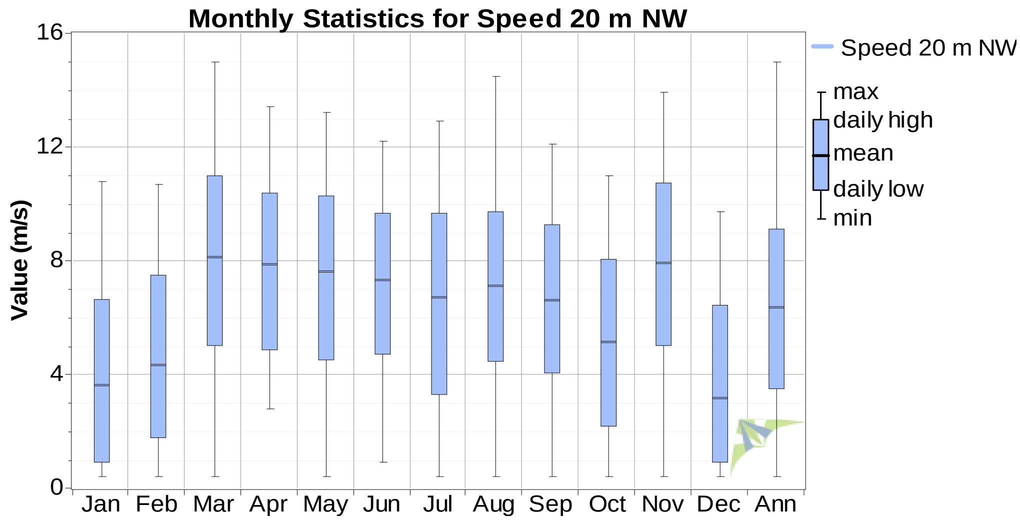


Figure 6. Box plot of the wind speed data at 20 m at MCBH Kaneohe Bay for 8/1/2009 – 7/31/2010

In Figure 7, the wind speeds at each anemometer height are plotted against time to depict the seasonal trends. Wind speed at a location typically increases with increased height above the ground. The collected data follows that pattern though the difference in wind speeds at 35 m vs. 50 m is relatively small.

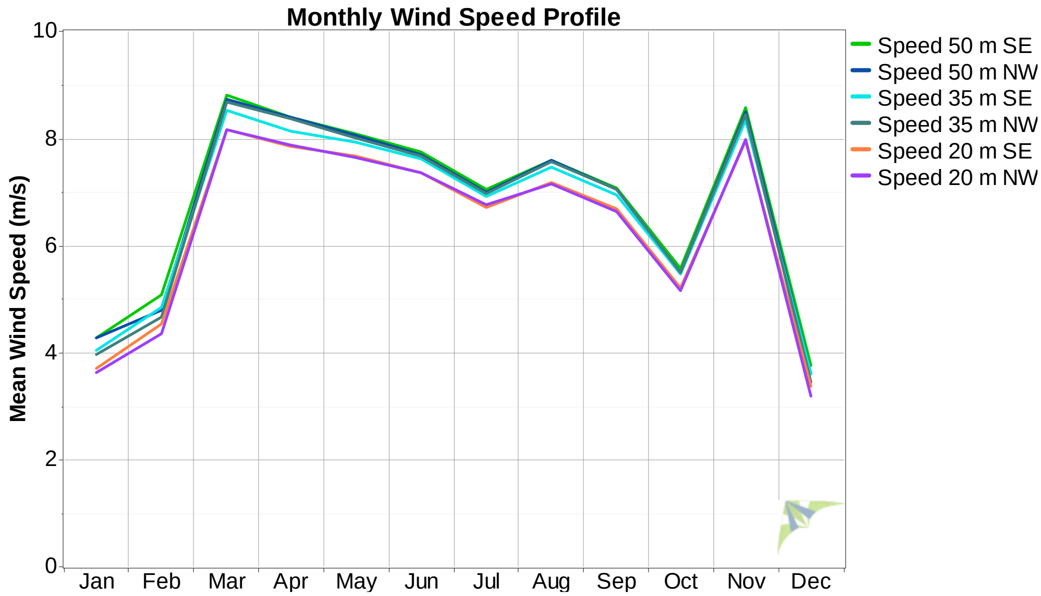


Figure 7. Seasonal Wind Speed Profile at MCBH Kaneohe Bay for 8/1/2009 – 7/31/2010

Figure 8 shows the annual average diurnal (daily) profile for the site. In general, the winds increase during the morning hours and decrease into early evening. Late evening through early morning tend to be the calmest. Overall, there is not a lot of difference between afternoon and nighttime winds. The wind is relatively steady throughout the day.

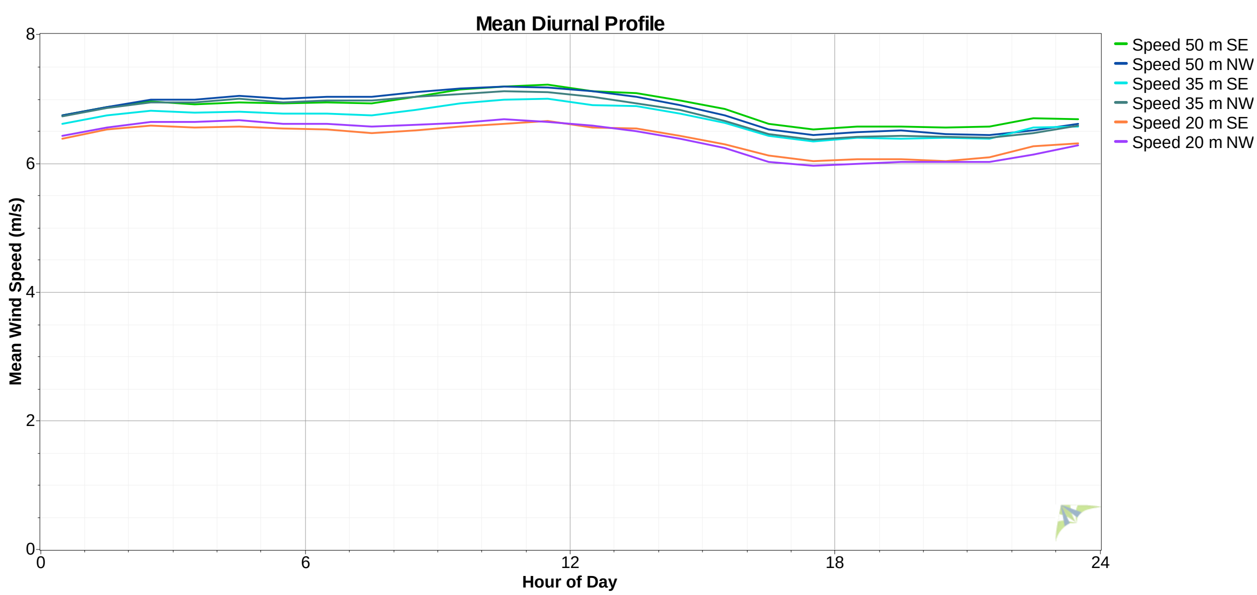


Figure 8. Diurnal wind speed profile at MCBH Kaneohe Bay for 8/1/2009 – 7/31/2010

Figure 9 depicts the diurnal (daily) wind pattern by month.

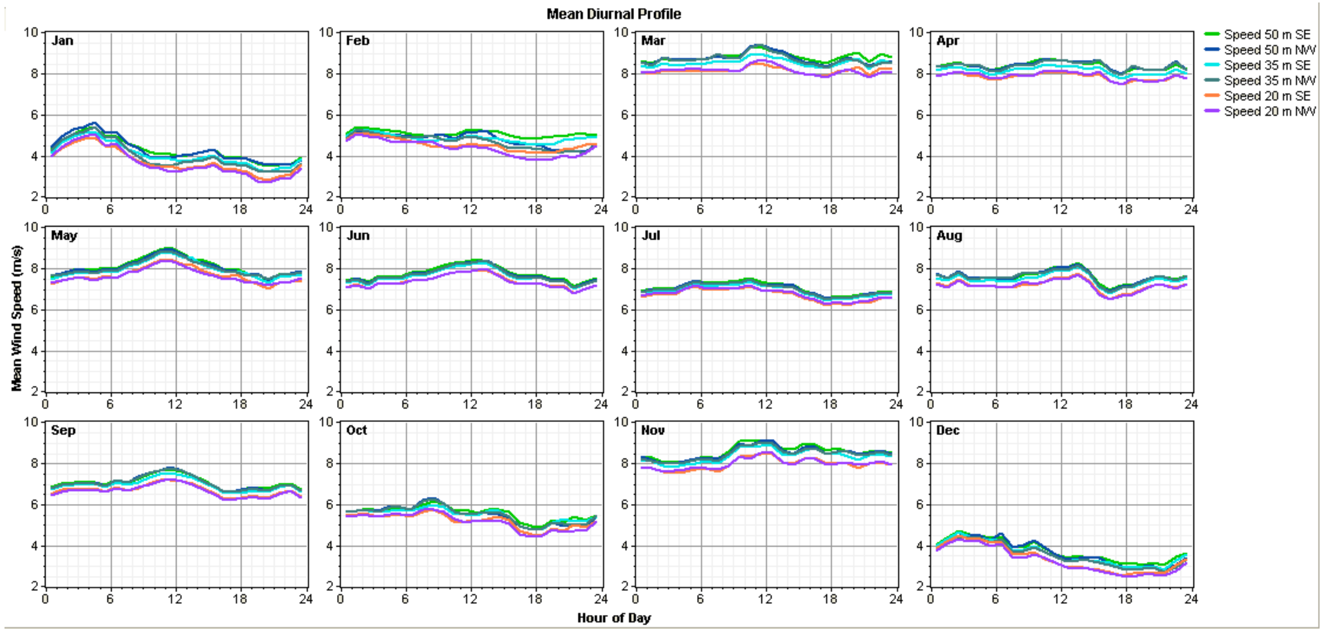


Figure 9. Diurnal wind speed profile by month at MCBH Kaneohe Bay for 8/1/2009 – 7/31/2010

Wind Direction Data

The Wind Frequency Rose in Figure 10 shows the frequency the wind blows from each direction as measured at 35 m. As shown, the winds most frequently come from the northeast-by-east sector. The Mean Wind Speed Rose on the right indicates the mean (average) wind speeds from all directions. As shown, the stronger winds tend to come from both the north-through-east sector.

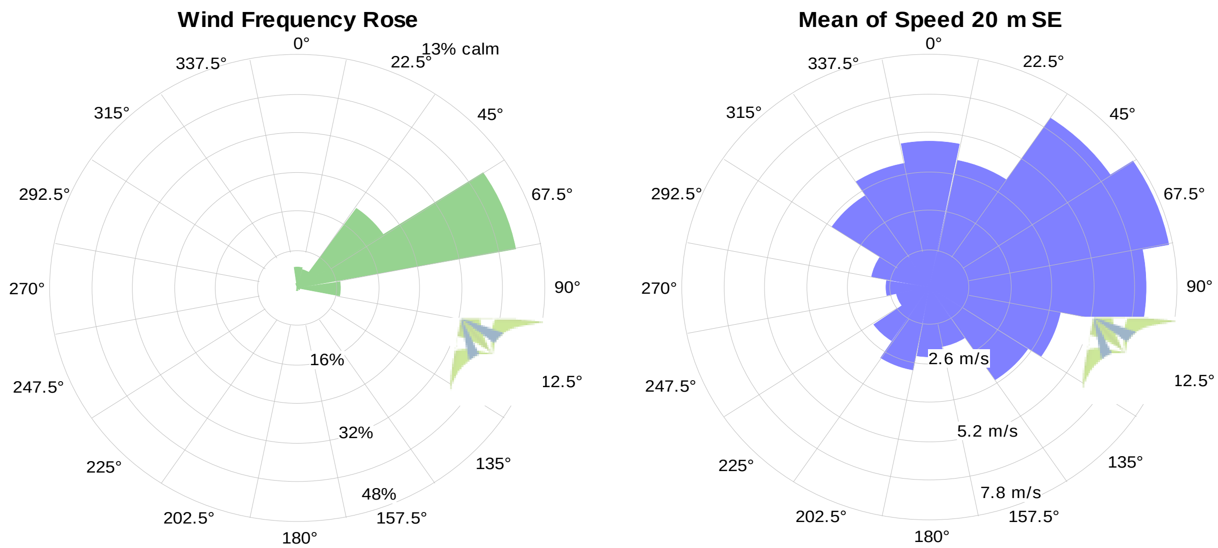


Figure 10. Wind Frequency Rose and Mean of Speed Rose at MCBH Kaneohe Bay for 8/1/2009 – 7/31/2010

The Total Wind Energy Rose in Figure 11 indicates that most of the wind energy during the course of the year comes from the northeast-by-east. The Met tower site itself, or the proposed wind turbine site, are well-situated to take advantage of the high wind power density in the prevailing winds. In siting a wind turbine near the Met tower site at MCBH Kaneohe Bay, relatively low surface roughness or obstructions between the wind turbine and the shore should be a priority. Siting a turbine(s) close to the water will help to maximize the availability of the wind resource while minimizing turbulence. Surface obstructions (trees or buildings) between the turbine(s) and the water should be avoided as they will increase the turbulence intensity and decrease the overall wind resource the wind turbine will experience.

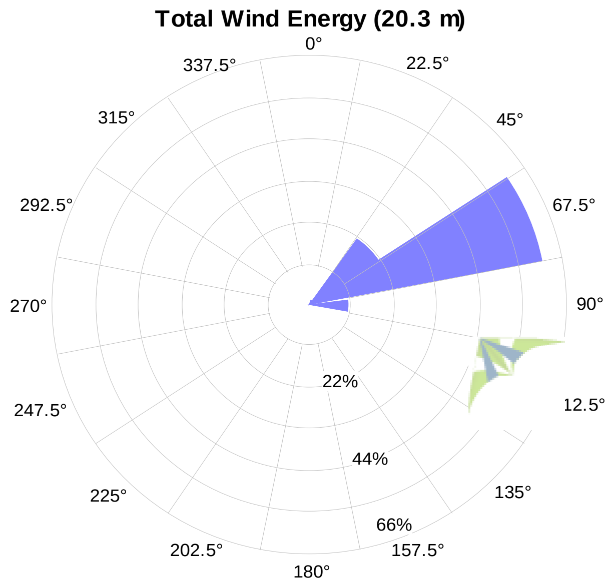


Figure 11. Total Wind Energy Rose at MCBH Kaneohe Bay for 8/1/2009 – 7/31/2010

The graphic below shows how the Total Wind Energy Rose varies by month. A “common scale” is used in this analysis which means the relative size of the wind resource in January, February, and December is considerably smaller than the other months. There is also a considerable variance in the prevailing wind direction during both January and December with a significant portion of the wind coming from directions other than the northeast. As these winds in these months are much less energetic than the winds during the rest of the year, minimizing surface obstructions in these other directions are not nearly as critical as minimizing surface obstructions in the northeast-by-east sector.

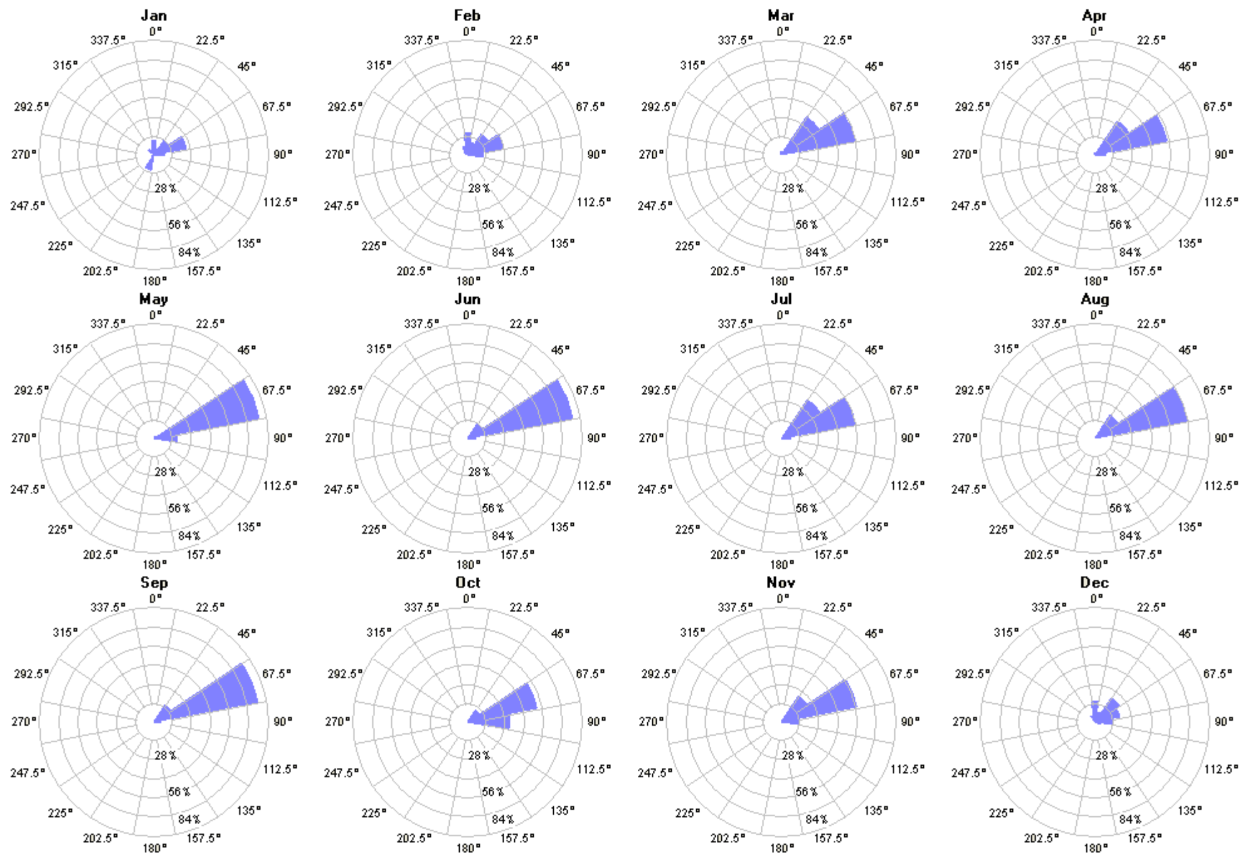


Figure 12. Wind Power Density Rose at 20 m by month at MCBH Kaneohe Bay for 8/1/2009 – 7/31/2010

Wind Frequency (Probability) Distribution

Figure 13 illustrates the frequency (%) of time that the wind (at 20 m) is at a given wind speed. This probability distribution function is called a Weibull distribution. There are two commonly used factors to describe the characteristics of the distribution function, the Weibull c and Weibull k factors. The Weibull c is the scale factor for the distribution related to the annual mean wind speed. The Weibull k value is a unitless measure indicating how narrowly/widely the wind speeds are distributed about the mean with values ranging from 1.0 – 3.0.

The best fit Weibull distribution parameters for the measured data are k = 2.37 and c = 7.13 m/s. The distribution below shows that the most frequent winds, or mode of the data set, are between 5-7 m/s as measured by the wind sensor at 20 m.

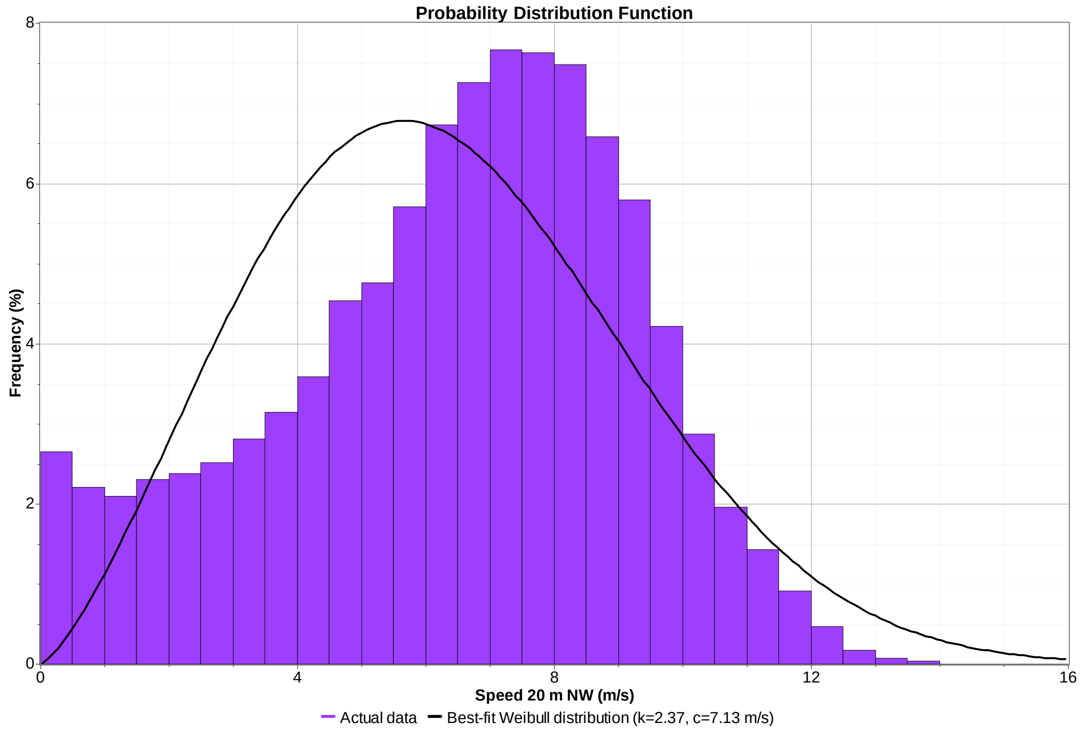


Figure 13. Wind Speed Frequency Distribution at 20 m at MCBH Kaneohe Bay for 8/1/2009 – 7/31/2010

The figure below illustrates how the wind speed distribution varies throughout the year.

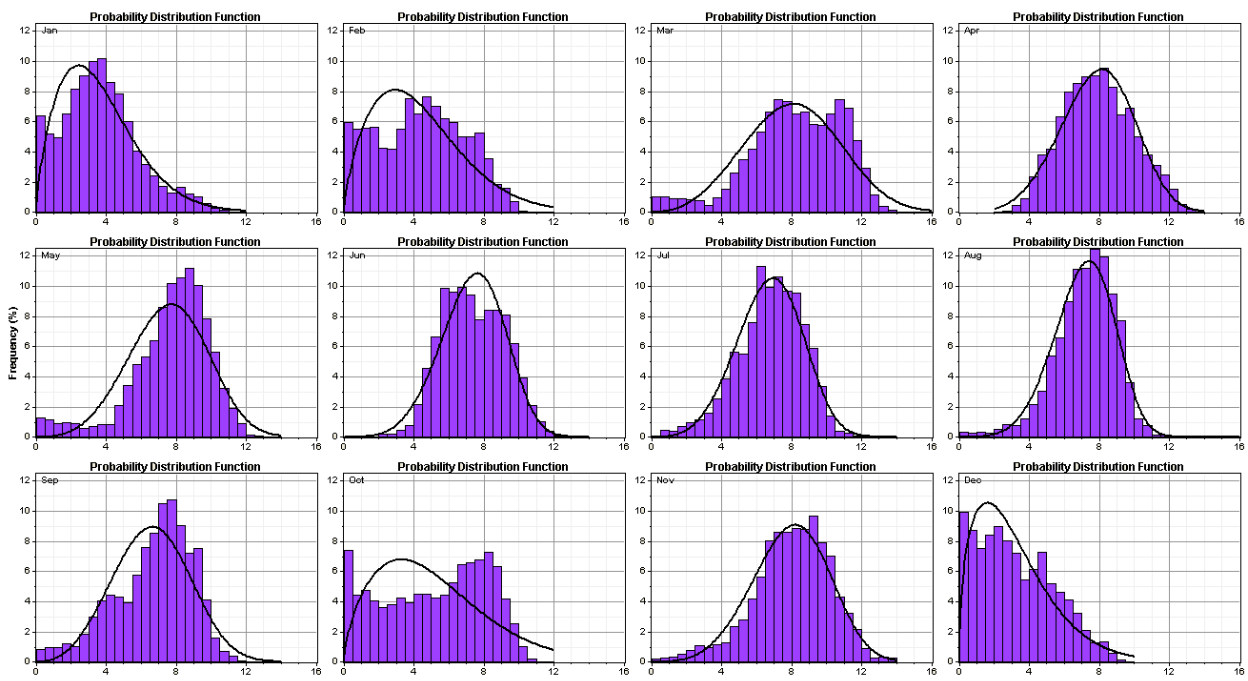


Figure 14. Monthly Wind Speed Distributions at 20 m at MCBH Kaneohe Bay for 8/1/2009 – 7/31/2010

Vertical Wind Shear

Vertical wind shear is defined as the change in wind speed with the change in height. Typically, wind speed increases as the height above the ground increases. This variation of wind speed with elevation is called the vertical profile of the wind speed, or vertical wind shear. In wind turbine engineering, the determination of vertical wind shear is an important design parameter, since it directly determines the productivity of a wind turbine on a tower of certain height, and it can strongly influence the lifetime of a turbine rotor blade as it provides an indication of different wind speeds acting on different parts of the rotor (i.e., turbulence).

Analysts typically use one of two mathematical relations to characterize the measured wind shear profile:

- Power law profile, aka *power law*
- Logarithmic profile, aka *log law*

The power law equation is shown below. Depending upon what data is known and what is sought, the equation can be manipulated to solve for any of the variables.

Power Law Equation

$$V = V_{ref}\left(\frac{Z}{Z_{ref}}\right)^{\alpha}$$

V = wind speed at height of interest (e.g., hub height)
V_{ref} = wind speed measured at height Z_{ref}
Z = height of interest (e.g., hub height)
Z_{ref} = height of measured data
α = wind shear exponent

The wind shear exponent, α, is often referred to as the vertical wind shear factor. It defines how the wind speed changes with height. When the actual wind shear value is not known, a typical value used to estimate the wind shear exponent is 0.14 (aka $1/7^{th}$ power law). When wind speed readings are available at multiple heights, the wind shear factor can be calculated using the power law equation. That is what was done with the collected data at MCBH Kaneohe Bay. Table 6 shows the calculated wind shear values between the various anemometer heights.

The vertical wind shear factors from several heights with known wind speeds are used to estimate both the vertical wind shear factor and wind speed at other heights of interest above the measured data (e.g., turbine hub height). Depending upon the type of terrain and surface roughness features, the wind shear factor may vary from 0 to 0.4.

The Logarithmic Law uses a parameter known as the surface roughness length (measured in meters) in predicting the wind shear profile. Smooth surfaces, such as calm, open sea have very low wind shear values (e.g., 0.0002 m); crops are a little higher at 0.05 m of surface roughness length. Areas with a few trees have surface roughness of about 0.1 m while cities with tall buildings would be about 3.0 m.

The surface roughness parameter is ‘solved for’ from the existing wind speed data at various heights. The resultant surface roughness characterization may not always match the actual surface conditions, but it serves as a descriptor of the vertical wind shear profile. The resultant surface roughness lengths have been calculated for MCBH Kaneohe Bay and are shown in the tables below. The low surface roughness aligns well with the bulk of the wind coming across the waters of Pearl Harbor.

The figures shown for both the power law exponent and surface roughness were calculated between valid data for all anemometer heights. In this location, it is assumed that 20 m may be near the maximum tower height for this location, so calculations represent a conservative approach to the vertical wind shear factor.

Table 6. Power Law Exponent and Surface Roughness Length at MCBH Kaneohe Bay for 8/1/2009 – 7/31/2010

Speed Sensor	Actual Height	Mean Wind Speed	Power Law Exponent	Surface Roughness
	(m)	(m/s)	(unitless)	(m)
50 m SE	35	7.009	0.0738	0.0000394
50 m NW	35	6.947		
35 m SE	35	6.836		
35 m NW	35	6.883		
20 m SE	20.3	6.548		
20 m NW	20.3	6.520		

Figure 15 is a graph of the vertical wind shear profile includes anemometer data from all heights as the more realistic and conservative profile. As is often the case with ocean winds or winds very close to the shore, the vertical wind shear factor is relatively low, meaning that the wind speed increases relatively slowly with increased distance above the ground. Using only the wind speed readings from the 20.3 and 35 m anemometers results in a higher calculated vertical wind shear factor than is actually the case, which is not fully representative of site characteristics. Using the higher vertical wind shear factor to extrapolate wind speeds at 50, 60, or 80 m would result in estimates being higher than the wind speeds actually are at those heights.

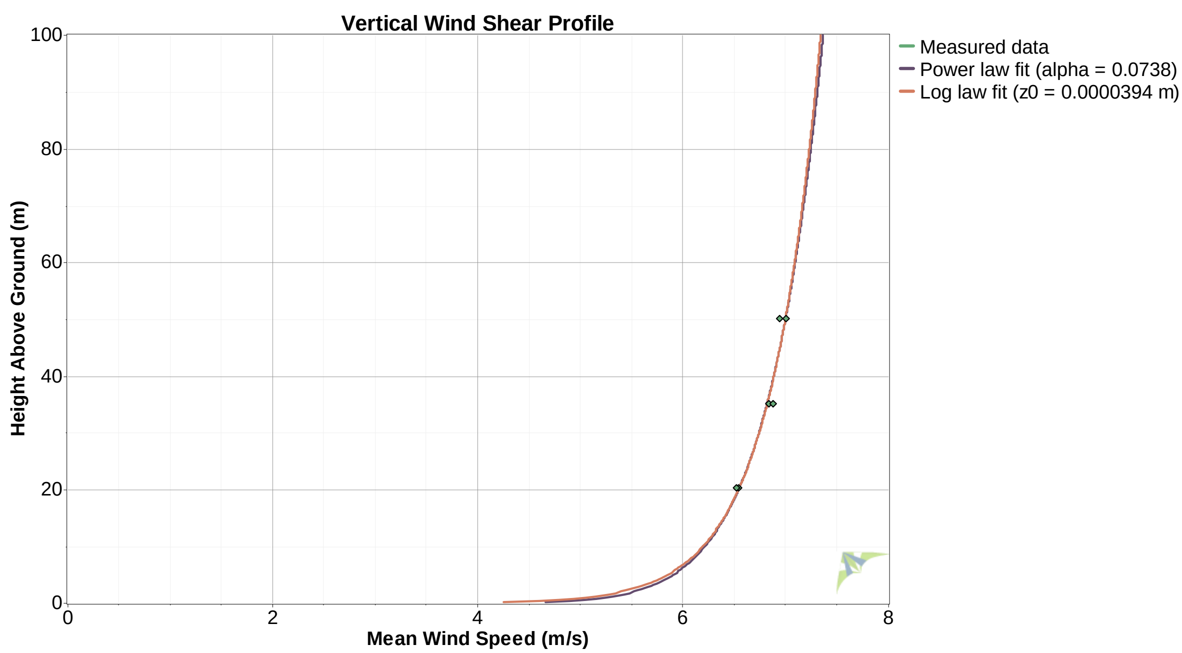


Figure 15. Vertical Wind Shear Profile at MCBH Kaneohe Bay for 8/1/2009 – 7/31/2010

In Table 7, the mean wind speeds at each height, power law exponent, and surface roughness calculation are shown for each direction sector taken from the wind vane at 35 m. It is worth noting for the direction sectors 22.5 - 67.5 and 67.5 - 112.5, which comprise 87.1% of the data points, the power law exponent is quite low at 0.068 and 0.059 respectively indicating a low vertical wind shear factor for winds coming from these directions. The low surface roughness lengths for these same direction sectors also speak to winds with low turbulence coming from these directions. Both of these factors are good in terms of being an indicator that this site will generally have less turbulence than other sites at the height of the wind turbine at ~20 - 30 m and above.

Table 7. Power Law Exponent and Surface Roughness Length by direction at MCBH Kaneohe Bay for 8/1/2009–7/31/2010

Direction Sector	Time Steps	Mean Wind Speed						Best-Fit	
		@ 50 m SE	@ 50 m NW	@ 35 m SE	@ 35 m NW	@ 20 m SE	@ 20 m NW	Power Law Exponent	Surface Roughness
[°]	[#]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]		[m]
337.5° - 22.5°	1,202	5.569	5.415	5.370	5.256	5.089	5.025	0.0910	0.0005
22.5° - 67.5°	18,757	7.274	7.170	7.064	7.139	6.796	6.802	0.0680	0.0000
67.5° - 112.5°	22,402	7.884	7.841	7.751	7.786	7.490	7.427	0.0590	0.0000
112.5° - 157.5°	689	4.329	4.423	4.289	4.352	4.137	4.149	0.0620	0.0000
157.5° - 202.5°	495	3.458	3.525	3.227	3.260	2.635	2.687	0.3050	1.1261
202.5° - 247.5°	1,882	3.072	3.092	2.784	2.793	2.254	2.262	0.3470	1.6965
247.5° - 292.5°	1,722	1.834	1.818	1.730	1.777	1.266	1.282	0.4130	2.5364
292.5° - 337.5°	886	3.713	3.710	3.390	3.451	2.878	2.877	0.2830	0.8935

The daily wind shear profile for each month of the year can be seen in Figure 16. January and December have the highest daily wind shear factors with large swings overnight. Generally, the other months show much smaller to minimal wind shear variation during the day.

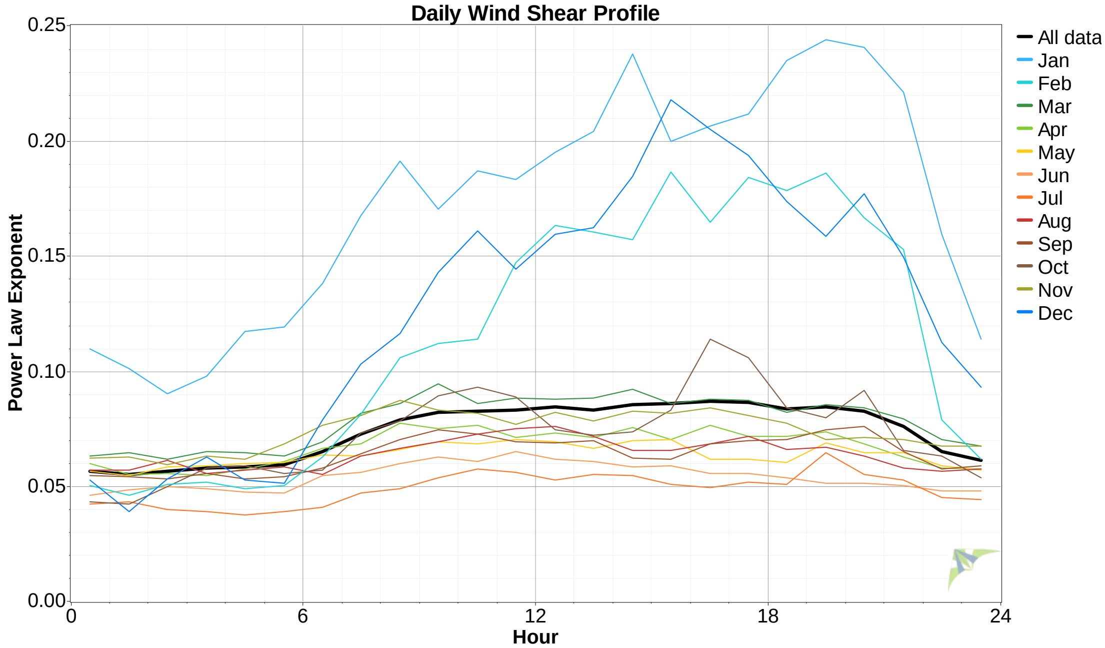


Figure 16. Daily Wind Shear Profile by month at MCBH Kaneohe Bay for 8/1/2009 – 7/31/2010

In Table 8, the mean wind speeds at each height, power law exponent and surface roughness calculation are shown for each month with the 35 m wind vane as the reference.

Table 8. Power Law Exponent and Surface Roughness Length by month at MCBH Kaneohe Bay for 8/1/2009 – 7/31/2010

Month	Time Steps	Mean Wind Speed						Best-Fit	
		@ 50 m SE	@ 50 m NW	@ 35 m SE	@ 35 m NW	@ 20 m SE	@ 20 m NW	Power Law Exponent	Surface Roughness
[mon]	[#]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]		[m]
Jan	3,442	4.27	4.34	4.04	4.03	3.71	3.68	0.167	0.0781
Feb	3,201	4.85	4.81	4.65	4.71	4.38	4.34	0.114	0.0046
Mar	4,187	8.96	8.81	8.68	8.76	8.29	8.28	0.079	0.0001
Apr	3,944	8.55	8.42	8.31	8.39	8.02	7.98	0.067	0.0000
May	4,403	8.17	8.12	8.00	8.06	7.73	7.67	0.064	0.0000
Jun	4,310	7.76	7.69	7.62	7.67	7.37	7.35	0.054	0.0000
Jul	4,433	7.07	7.02	6.94	6.99	6.73	6.76	0.049	0.0000
Aug	4,289	7.70	7.64	7.56	7.61	7.27	7.22	0.064	0.0000
Sep	4,259	7.13	7.06	7.00	7.04	6.74	6.67	0.064	0.0000
Oct	4,167	5.72	5.64	5.61	5.64	5.35	5.32	0.072	0.0000
Nov	4,028	8.69	8.60	8.48	8.53	8.10	8.09	0.074	0.0000
Dec	3,372	3.63	3.65	3.52	3.54	3.27	3.25	0.123	0.0089

Turbulence Intensity

The figure below shows the representative and mean turbulence intensities (TI) as a function of wind speed at 20 m. The TI is defined as the standard deviation of the wind speed within a time-step divided by the mean wind speed over that time step and is a measure of the gustiness of the wind. High turbulence can lead to increased turbine wear and potentially increased operations and maintenance (O&M) costs. At lower wind speeds, the calculated turbulence intensity is often higher as can be seen in Figure 17. At low wind speeds, the turbulence is of little consequence to the wind turbine itself as the power in the wind is low. Turbulence at higher winds speeds is of greater interest and concern to wind turbine manufacturers as it causes increased component fatigue which can result in increased O&M costs.

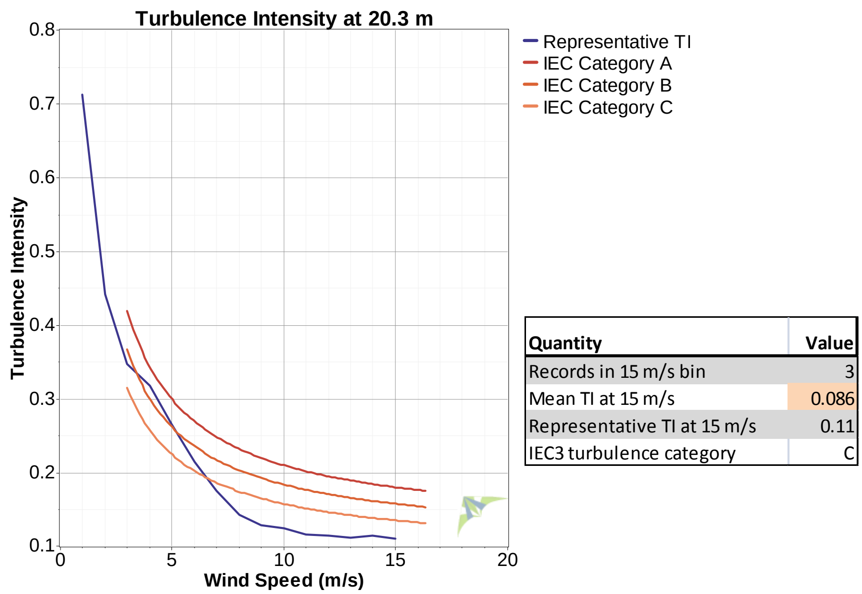


Figure 17. Turbulence Intensity at 20 m at MCBH Kaneohe Bay for 8/1/2009 – 7/31/2010

Table 9 displays the relevant turbulence parameters per wind speed bin. The orange-shaded box indicates that the mean TI at 15 m/s, is below the IEC Category rating for categories A, B, and C.

Table 9. Turbulence Analysis at 20 m at MCBH Kaneohe Bay for 8/1/2009 – 7/31/2010

Bin (#)	Bin Midpoint (m/s)	Bin Endpoints (m/s)	(m/s)	Records in Bin	Mean TI	Standard Deviation of TI	Representative TI	Peak TI
1	1	0.5	1.5	2,167	0.498	0.168	0.713	1.222
2	2	1.5	2.5	2,356	0.278	0.128	0.442	0.870
3	3	2.5	3.5	2,676	0.213	0.105	0.347	1.077
4	4	3.5	4.5	3,382	0.188	0.101	0.317	0.762
5	5	4.5	5.5	4,673	0.153	0.087	0.265	0.644
6	6	5.5	6.5	6,260	0.122	0.072	0.214	0.484
7	7	6.5	7.5	7,527	0.102	0.057	0.175	0.492
8	8	7.5	8.5	7,664	0.090	0.041	0.142	0.506
9	9	8.5	9.5	6,247	0.086	0.033	0.129	0.461
10	10	9.5	10.5	3,569	0.087	0.029	0.124	0.396
11	11	10.5	11.5	1,708	0.085	0.024	0.116	0.288
12	12	11.5	12.5	698	0.086	0.022	0.114	0.267
13	13	12.5	13.5	127	0.089	0.017	0.111	0.155
14	14	13.5	14.5	18	0.090	0.019	0.114	0.145
15	15	14.5	15.5	3	0.086	0.019	0.110	0.107
16	16	15.5	16.5	0	0.000	0.000	0.000	0.000

The scatterplot in Figure 18 provides a visual display of the array of data that are averaged to produce the discrete curves in Figure 17 above.

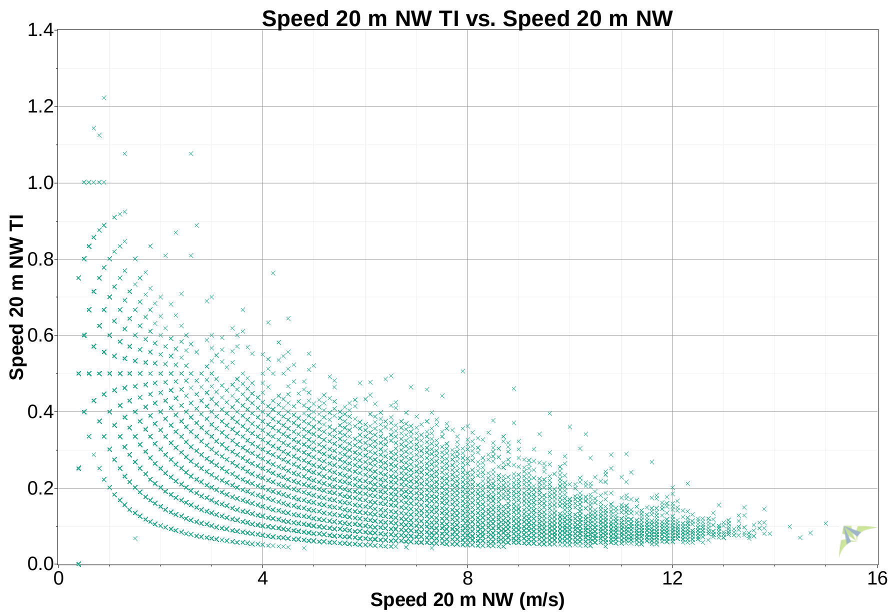


Figure 18. Turbulence Intensity vs. Wind Speed at 20 m at MCBH Kaneohe Bay for 8/1/2009 – 7/31/2010

The monthly TI factors are displayed in Figure 19. The fall/winter months of December through February experienced the most turbulence during the period of collected data.

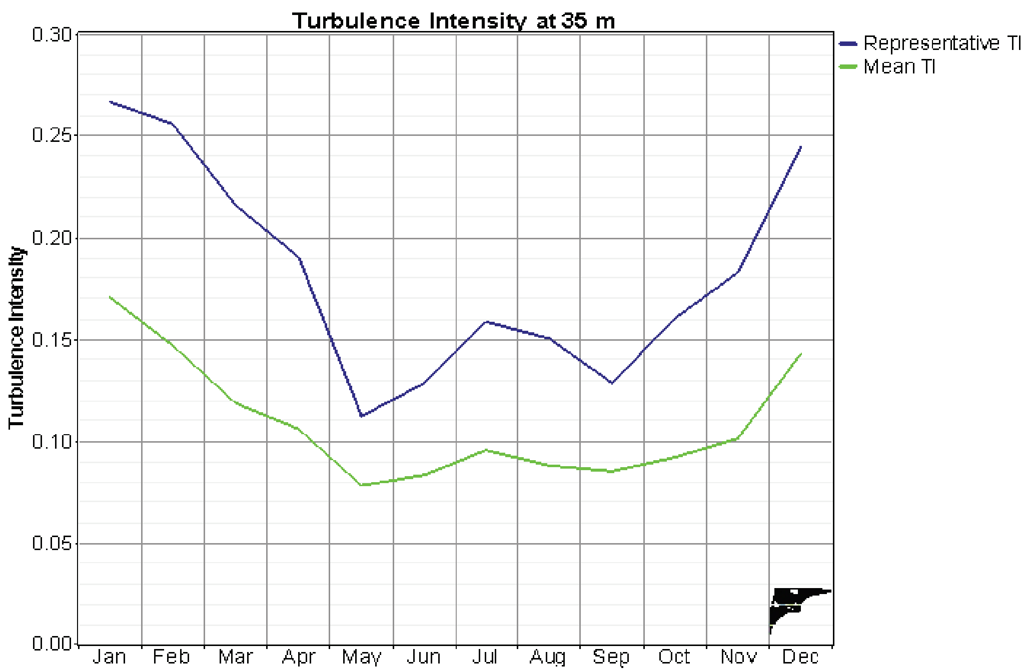
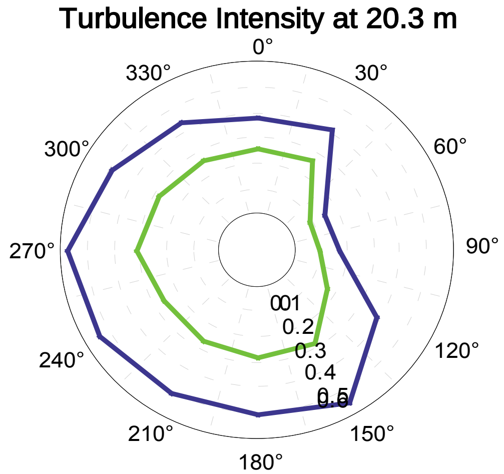


Figure 19. Turbulence Intensity by month at 35 m at MCBH Kaneohe Bay for 8/1/2009 – 7/31/2010

The turbulence intensity rose in Figure 20 illustrates that the representative and mean turbulence comes typically comes from directions (i.e., west-northwest and southeast) other than the primary wind direction (northeast – east). This provides evidence that the source of the turbulence is not from the energetic winds from the primary wind direction which is good.



Quantity	Value
Records in 15 m/s bin	3
Mean TI at 15 m/s	0.086
Representative TI at 15 m/s	0.11
IEC3 turbulence category	C

Figure 20. Turbulence Intensity Rose at 20.3 m at MCBH Kaneohe Bay for 8/1/2009 – 7/31/2010

Comparison of MCBH Kaneohe Bay Anemometer Data with Long Term Reference Data

It is important to consider if the monitoring period data reflects a high, low, or average year in terms of wind resource. Different techniques are used to estimate the long term wind resource from a short term Met tower study. One common method is Measure Correlate Predict (MCP), where the measured data is correlated to a nearby monitoring station (aka the reference site) with long term wind data. The correlation relationship is then applied to the long term data set to arrive at a comparable long term data set at the site of interest. The MCP method was applied in this analysis.

Marine Corps Air Station Kaneohe Bay

The Marine Corps Air Station (MCAS) Kaneohe Bay airport runway is approximately ~2.5 - 4.0 km (~1.5 - 2.5 mi) away from the MCBH Kaneohe Bay 50-m Met tower, depending upon which part of the runway is being measured to. The terrain between the two sites is relatively flat with the notable exception of a 100-m hill with a circular base directly between the runway and the Met tower which can be seen Figure 21. The area in between the runway and the 50-m Met tower has numerous 1 - 2 story commercial, airport, and military buildings, and is heavily built with residential housing. The residential areas have heavy tree cover while the more commercial and airport sites have few trees.

Northeast-by-east of the airport is the Ulupau Crater which rises ~1 - 200 m (~330 - 660 ft) above sea level and is ~3 - 5 km (~2 - 3 mi) away from the MCAS Kaneohe Bay airport. The wind at the airport is likely a combination of wind that goes around and/or over the Ulupau Crater as it comes in off the ocean. The wind speed and direction data is collected at a single height, so it is not possible to determine the extent of the turbulence and the relative influence of these two different wind patterns. The relative location of the Met tower for each site is shown in Figure 21 below.

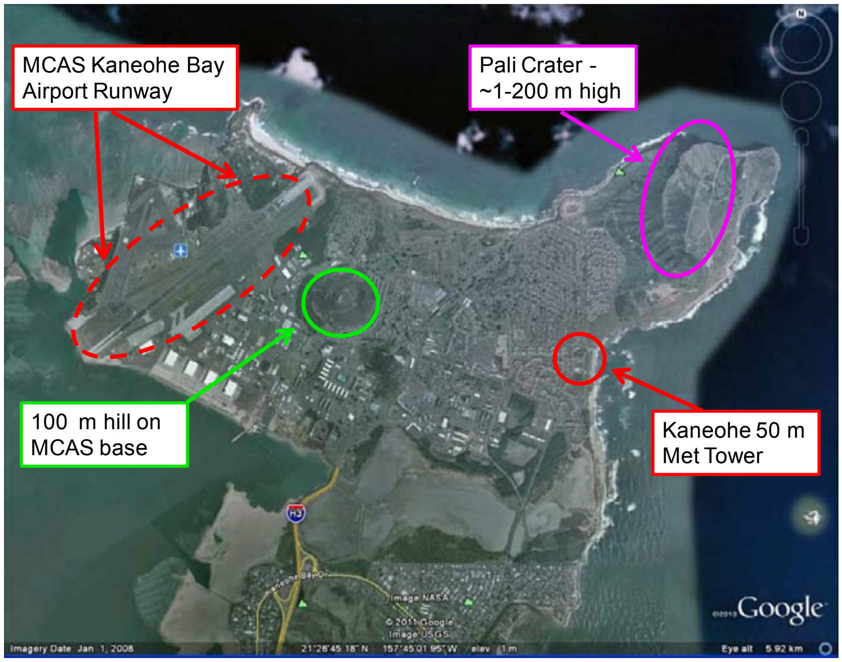


Figure 21. MCAS Kaneohe Bay airport and MCBH Kaneohe Bay 50-m Met tower sites.

Source: http://www.earth.google.com

MCAS Kaneohe Bay Airport Long Term Data

Wind speed and direction data has been collected at ~7.6 m (25 ft) on an hourly basis at MCAS Kaneohe Bay airport from January 1973 through January 1998. It is not known exactly which part of the runway hosts the Met tower. The Met tower was updated in February 1998 and the data began being collected at 10 m (~33 ft). This ~12.7 year period (1998 – 2010) at 10 m, is sufficient for long term correlation and it represents wind speeds at a consistent height, which is preferred. The mean annual wind speed from January 1, 1998 – July 31, 2010 at 10 m was 3.66 m/s and the mean of the monthly wind speeds during this time period was 3.67 m/s. This wind data set was used as the long-term data set for comparison and correlation purposes with the data collected at the MCBH Kaneohe Bay 50-m Met tower site. Long-term data and resultant wind profile parameters from MCAS Kaneohe Bay airport Met tower can be seen in Table 10. The monthly means have been combined into monthly annual means and can be seen in the column labeled “Mean” in the middle of the table.

Table 10. MCAS Kaneohe Bay airport long term wind data at 10 m (3/1/1998 - 9/30/2010)

Month	Possible Records	Valid Records	Recovery Rate	Mean	Median	Max	Std. Dev.	Weibull k	Weibull c
			(%)	(m/s)	(m/s)	(m/s)	(m/s)		(m/s)
Jan	8,928	8,222	92.1	3.46	3.6	18.0	2.39	1.701	4.0641
Feb	8,136	7,298	89.7	3.63	3.6	13.4	2.26	1.931	4.2637
Mar	8,928	7,919	88.7	3.74	4.1	11.8	2.25	2.013	4.3947
Apr	8,640	7,518	87.0	4.06	4.1	22.6	1.95	2.523	4.6745
May	8,928	8,246	92.4	3.34	3.6	8.8	1.78	2.432	3.9231
Jun	8,640	8,053	93.2	3.94	4.1	18.5	1.49	3.205	4.4470
Jul	8,928	8,273	92.7	4.10	4.1	12.0	1.39	3.580	4.5896
Aug	9,672	8,855	91.6	3.95	4.1	11.8	1.52	3.283	4.4676
Sep	9,360	8,664	92.6	3.56	3.6	39.6	1.68	0.402	3.4229
Oct	9,205	8,431	91.6	3.48	3.6	10.8	1.87	2.397	4.0867
Nov	8,640	7,985	92.4	3.46	3.6	10.8	2.14	1.983	4.0868
Dec	8,928	8,265	92.6	3.29	3.6	13.4	2.30	1.722	3.9075
	106,933	97,729	91.4	3.66	4.1	39.6	1.96	2.291	4.2683
Mean of monthly means				3.67					

The graph in Figure 22 below, on an enlarged y-axis scale, shows the long-term wind speed data at MCAS Kaneohe Bay airport. The annual mean wind speeds from 8/1/1998 – 7/31/2010 at MCAS Kaneohe Bay airport can be seen graphically in the green curved line. The annual mean wind speeds displayed here have been segmented to match the time period used for correlation with MCBH Kaneohe Bay from August 1st through July 31st each year. The long-term mean at MCAS Kaneohe Bay airport for 8/1/1999 – 7/31/2010, segmented as described, is 3.67 m/s as shown with the red line. The mean wind speed of 3.77 m/s during 8/1/2009-7/31/2010 is shown as the solid blue line and it has been extended as a dashed line for ease of comparison. Overall, the August 1, 2009 – July 31, 2010 time period represents a wind year above, by 0.098 m/s or 2.67%, the average wind year at MCAS Kaneohe Bay airport. Consequently, the MCBH Kaneohe Bay wind data should be correspondingly adjusted downward by 2.67% to reflect the expected annual wind speeds on a long-term basis. The approach taken for correlation with a long term reference site, as explained in the next section, and the subsequent adjustment inherently includes the long term data and accounts for the variation in wind speeds during the 8/1/2009 - 7/31/2010 time period.

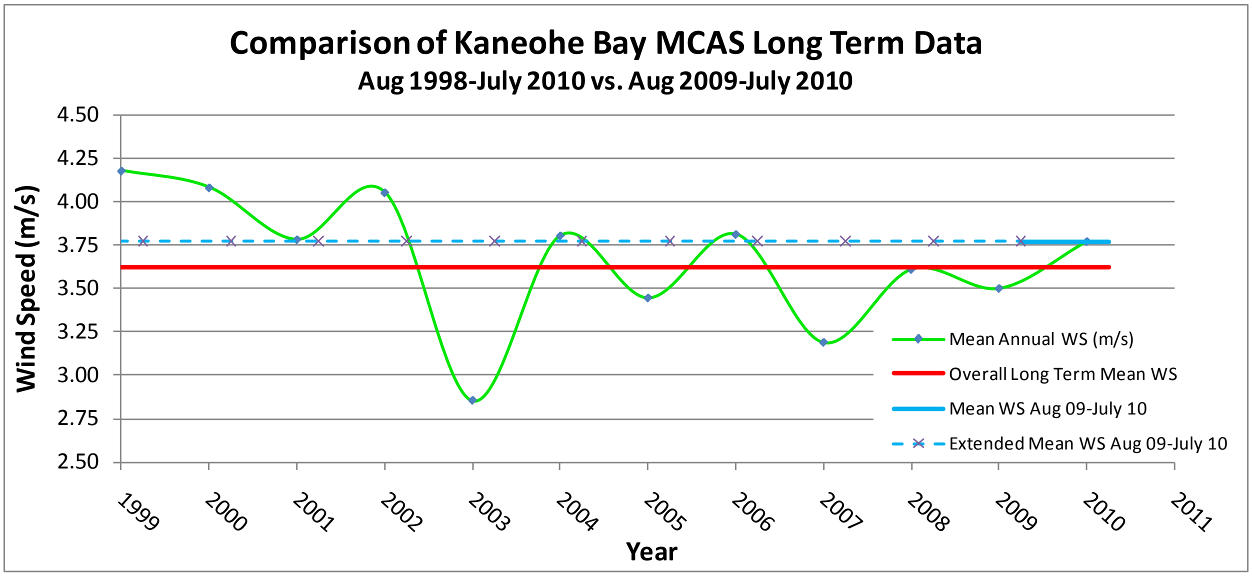


Figure 22. Long and short term mean wind speeds at MCAS Kaneohe Bay airport Met Tower

Correlation of MCBH Kaneohe Bay 20m Met to MCAS Kaneohe Bay Airport Met

The period of time used for correlation is August 1, 2009 – July 31, 2010 as there is concurrent quality wind data from both sites during this time. The wind speed data from the 10-m Met tower at MCAS Kaneohe Bay airport was compared to the 20-m data from the MCBH Kaneohe Bay 50-m Met tower as correlation is generally strongest with comparable heights. The mean hourly wind speed from each site was used for consistency. The mean of the collected data at the MCBH Kaneohe Bay 20-m Met tower from August 1, 2009 – July 31, 2010 at 20 m NW was 6.39 m/s. The mean of the MCAS Kaneohe Bay airport data at 10 m during the same time period was 3.77 m/s.

The hourly wind speed data collected at 20 m at the MCBH Kaneohe Bay Met tower from August 1, 2009 – July 31, 2010 was compared to the hourly MCAS Kaneohe Bay airport wind speed data during the same period to determine the degree of correlation between these two sites. The data was graphed in a scatterplot and a linear regression run to find both the resultant linear equation and the relative "goodness of fit" of the line to the data. The goodness of fit is typically measured by the r^2 value of the regression analysis. The higher the r^2 value, the higher the confidence that the predictions made using the linear regression equation are valid. Generally speaking, r^2 values greater than 0.8 provide confidence that the two wind sites "see the same wind" and hence long term correlation will be valid. Values between 0.7-0.8 and even lower are sometimes used as the resultant regression equation still represents the best available predictor of future wind speeds. Overall, the r^2 value for this data comparison is 0.1824, which is not considered high enough to have confidence the predictive results will be valid.

There can be any number of reasons for the low r^2 values. Possible explanations for the low r^2 value in comparing these two data sets include:

- The two sites are far enough apart in an area with complex terrain. For the MCAS Kaneohe Bay airport Met tower, the wind must flow over or around the ~1 - 200 m Ulupau Crater to the northeast-by-east and the ~100 m hill to the east. The prevailing winds for the MCBH Kaneohe Bay 50-m Met do not have to contend with either feature.
- Non-uniform exposure to buildings and other surface roughness features. All of the energetic wind that MCAS Kaneohe Bay sees comes across dense residential building zones, military buildings and other ground-cluttering features whereas the energetic winds that the MCBH Kaneohe Bay 50-m Met sees come off of the ocean with very low surface roughness.

To find a regression equation with a better correlation, a longer time period can be used – daily instead of hourly. With this approach, the r^2 value was 0.5831 indicating a stronger correlation than with the hourly comparison, though still not in the preferred range. This correlation is between daily average wind speeds, not the more specific hourly mean wind speed. However, as the MCAS Kaneohe Bay data represents the best available long term data for comparison to the MCBH Kaneohe Bay Met tower, it was used.

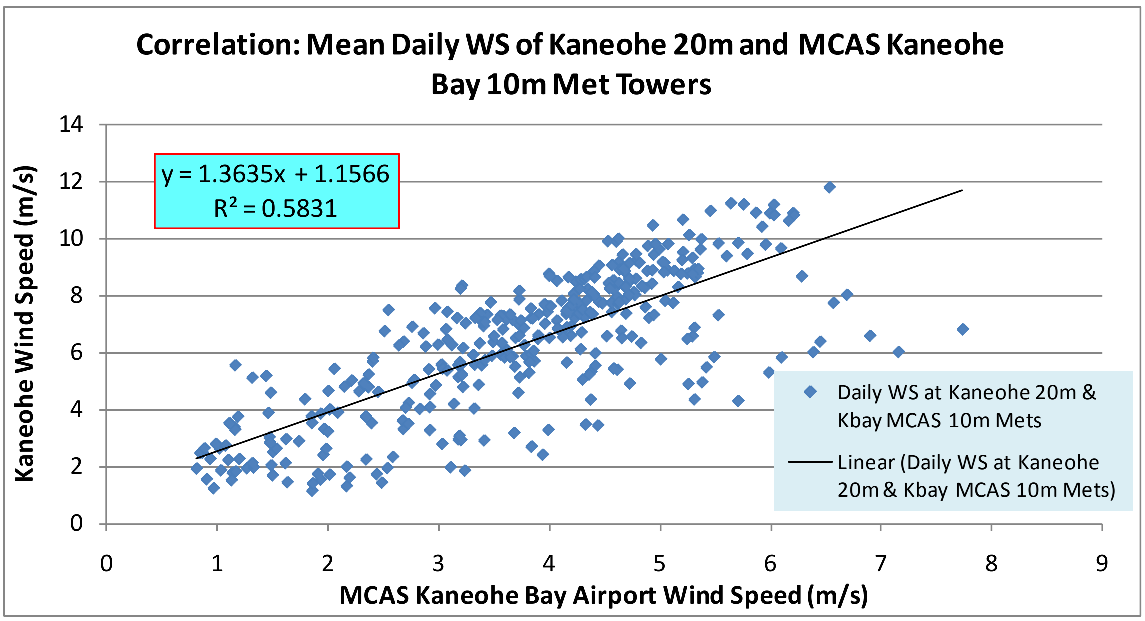


Figure 23. Correlation of mean daily wind speed for MCAS Kaneohe Bay airport and MCBH Kaneohe Bay Met Towers

The trendline in the figure above is in the form of: Y = mx + b

The correlation equation relates wind speeds at the long term wind data site, MCAS Kaneohe Bay airport at 10 m, to the MCBH Kaneohe Bay site at 20 m during the same period.

Equation 1 Correlation equation for normalizing the long term data (MCAS Kaneohe Bay airport) to short term data (MCBH Kaneohe Bay).

Y = 1.3635x + 1.1566
Y = Expected wind speed at 31
m = 1.3635x = Slope of correlation trendline

x = wind speed at 10m reference site
b = 1.1566= Y intercept of correlation trendline
$r^2 = 0.5831$

With an acceptable correlation, the equation above was applied to all the daily data from MCAS Kaneohe Bay airport at 10 m from August 1, 1998 – July 31, 2010 to MCBH Kaneohe Bay at 20 m to derive an equivalent 20 m long term data set for MCBH Kaneohe Bay. The long term mean wind speed at 20 m was estimated to be ~6.16 m/s. The vertical wind shear factors for MCBH Kaneohe Bay from August 1, 1998 – July 31, 2010 were applied to this equivalent long term data set to create a full equivalent long term data set at 35 m and 10.7 m for performance and economic modeling of wind turbines.

Adjusting the Collected Wind Speed Data at MCBH Kaneohe Bay

With the 20-m data at MCBH Kaneohe Bay normalized to the long term wind speeds from MCAS Kaneohe Bay airport, the vertical wind shear factors from the collected data at MCBH Kaneohe Bay were applied to the adjusted 20-m data to determine expected wind speeds at the 35 and 10.7-m heights at MCBH Kaneohe Bay from August 1998 through July 2010 in an average wind year. The overall net change in wind speeds at 20 m was a ~3.7% decrease in the mean wind speed of collected data at 20 m at MCBH Kaneohe Bay.

It should be recalled from the graphic in Figure 22 that Aug 2009 – July 2010 represented a wind year that was 2.7% above the average wind year and the wind speed data should be adjusted downward to do this. The 3.7% represents that downward adjustment. As applied, it is 1% over-adjusted. This discrepancy implies the long term wind speed estimate at 20 m at MCBH Kaneohe Bay might be 0.06 m/s slower than expected. This may be the result of the low r^2 value. Due to the small magnitude of this adjustment relative to the mean wind speed, no further adjustment was made. The adjusted data was used as the basis for the subsequent economic analysis.

Table 11 shows the mean annual wind speed from the data collected at MCBH Kaneohe Bay from August 1, 2009 – July 31, 2010. The row labeled ‘Kaneohe Estimated Long Term Mean Wind Speed’ indicates the new mean annual wind speed at each anemometer height after applying the MCP method and the vertical wind shear factors from the Met tower at MCBH Kaneohe Bay to the long term data from MCAS Kaneohe Bay airport’s 10 m data. The net change as a percentage is shown in the next row down. Below that are the calculated wind power densities at the heights of interest for a wind turbine at this site.

Table 11. Mean Annual Wind Speed Before and After Long Term Correlation

Measurement	Unit	10.7 m	20 m	35 m	50 m
Kaneohe Wind Speed as Collected	(m/s)	-	6.39	6.78	6.84
Kaneohe Estimated Long Term Mean Wind Speed	(m/s)	5.83	6.16	6.49	-
Percent Increase in Wind Speed	(%)	-	-3.6%	-4.3%	-
Kaneohe Estimated Long Term Mean Power Density	(W/m^2)	182	213	253	-

Estimated Wind Turbine Performance

The normalized and correlated wind speed data, with slightly decreased wind speeds overall, was used to estimate the performance of several small-size wind turbines. Some of the key outputs are shown in Table 12. Note the rated power for the turbines varies from 1.8 kW to 10 kW, so the output should likewise vary by comparable ratios. The hub height for the Skystream was realistic for use in this project. All of the other models have comparable output at 20 and 30 m.

Table 12. Comparison of Wind Turbine Sizes and Output at Several Hub Heights

Turbine Model Turbine	Rated Power (kW)	Hub Height (m)	Hub Height WS (m/s)	Time At Zero Output (%)	Mean Net Power Output (kW)	Mean Net Energy Output (kWh/yr)	Net Capacity Factor (%)
Southwest Skystream 3.7	1.8	10.7	5.83	14.66	0.5	4,638	29.4
Southwest Skystream 3.7	1.8	20	6.16	12.97	0.6	5,229	33.2
Southwest Skystream 3.7	1.8	30	6.39	13.01	0.6	5,621	35.6
Bergey Excel-S	10	18	6.10	12.97	2.0	17,743	20.3
Bergey Excel-S	10	20	6.16	12.97	2.1	18,151	20.7
Bergey Excel-S	10	30	6.39	12.99	2.3	19,867	22.7
Endurance S-250	5	20	6.16	16.44	1.0	9,056	20.7
Endurance S-250	5	30	6.39	16.29	1.1	10,034	22.9

Economic Analysis of Wind Turbine Performance

The economics of any particular wind turbine depend upon a number of factors and costs – not all of which can be known accurately a priori. Items such as the: wind turbine cost, geotechnical requirements and excavation costs, installation costs, tower height, shipping/freight costs, permitting, etc. are all important cost components and specific costs may not be publically available. Costs estimates were made to conduct the analyses with an added ~20% factor to account for a generally higher cost of living in Hawaii. The request for proposal (RFP) will yield more concrete pricing for installed turbine costs at MCBH Kaneohe Bay.

Commercial electricity rates from the DOE's Energy Information Agency[2] (EIA) were used to determine the expected annual value of the electricity produced and the estimated years to payback. The average retail rate for electricity in the commercial sector was \$0.2665/kWh in November 2010 vs. \$0.1007/kWh in the US as a whole. The EIA data indicated that Hawaiian electricity rates increased by ~10.2% from November 2009 to November 2010 vs. an overall increase of 2.2% across the country, a nearly five-fold increase in Hawaii. As electricity prices are subject to change, rather than analyze with a single static price, a range of prices were used to provide greater insight to the effect of price on simple payback in years in Table 13.

[2] Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State, http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_a.html

Table 13. Representative Turbine Annual Output, Cost Savings and Simple Payback

Turbine Model	Rated Power	Hub Height	WS at Hub	Energy Output	Capacity Factor	Installed Cost Estimate	Cost Savings/Year Electricity Cost Range			Simple Payback in Years Electricity Cost Range		
Turbine	(kW)	(m)	(m/s)	(kWh/yr)	(%)	($)	$0.20	$0.25	$0.30	$0.20	$0.25	$0.30
Southwest Skystream 3.7	1.8	10.7	6.58	5,435	34.5	$22,000	$1,087	$1,359	$1,631	20.2	16.2	13.5
Southwest Skystream 3.7	1.8	20	7.00	6,217	39.4	$22,000	$1,243	$1,554	$1,865	17.7	14.2	11.8
Bergey Excel-S	10	10	6.53	18,130	20.7	$75,000	$3,626	$4,533	$5,439	20.7	16.5	13.8
Bergey Excel-S	10	18	6.93	21,124	24.1	$75,000	$4,225	$5,281	$6,337	17.8	14.2	11.8

The economics of small wind turbines are challenging – they do not align with the utility-competitive megawatt-scale turbines that comprise large wind farms. However, the high cost of electricity is a significant driver in overall wind turbine economics. In this case, within the realm of current commercial rates, a simple payback of less than 16 years is estimated. At an average rate of ~$0.10/kWh, simple paybacks would increase to the ~25 - 40 year range.

The economics would improve with larger wind turbines and taller towers.

Summary and Conclusions

The wind resource assessment for a 50-m Met tower at MCBH Kaneohe Bay has been completed using collected wind data at the site, adjusting it to long term trends from the MCAS Kaneohe Bay airport at 10 m, then normalizing it to concurrent data from the airport using the MCP method.

The Met tower location has very good exposure to the wind with minimal surface roughness and other impediments to the prevailing wind. Siting a wind turbine at the proposed site or at the Met tower site would provide good exposure to the energetic winds off of the ocean. The long-term mean adjusted wind speed at 20 m at MCBH Kaneohe Bay is ~6.16 m/s corresponding to a mean power density of 253 W/m^2. This is considered a solid Class 2 wind resource.

The overall turbulence at the site is low which helps to minimize component fatigue issues and repairs. The vertical wind shear factor is low which indicates it is not necessary to have a really tall tower to access better winds. There is a smaller advantage to going higher than at site with a high vertical wind shear factor.

For this site, a "behind-the-meter" wind turbine application with a small-size wind turbine aimed at reducing the amount of electricity purchased annually from the utility can provide a simple payback of less than 20 years when the retail cost of electricity is greater than $0.26/kWh.

The wind resource assessment provides the framework for the subsequent economic analysis. There may be other factors to consider for a wind turbine project beyond purely economics. Considerations of factors such as base operations, visual impacts, environmental impacts, etc. are necessary in scoping a wind turbine project, but are beyond the scope of this wind resource assessment.

Next Steps

NREL will work with MCBH Kaneohe Bay to develop an RFP and review submitted proposals in selecting a contractor for installing a Skystream wind turbine at the MCBH Kaneohe Bay site already selected for one. NREL will, once all necessary permits and permissions are in place, contract for the installation of a Skystream at MCBH Kaneohe Bay.

Appendix A – Other Wind Data from MCBH Kaneohe Bay Met Tower

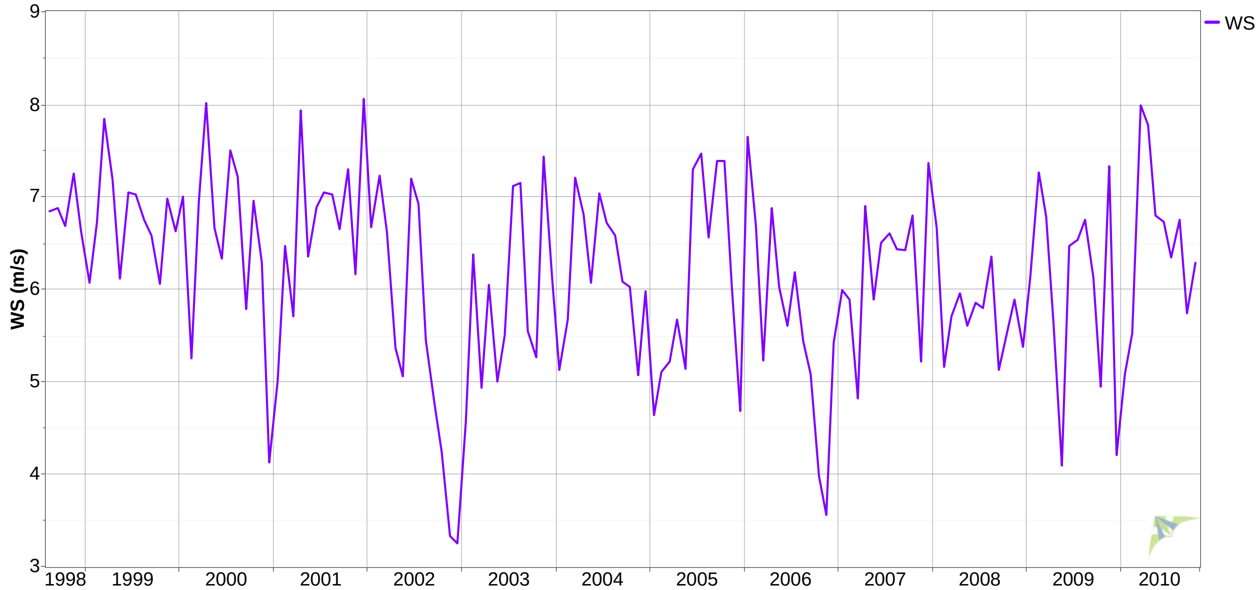


Figure 24. Estimated long term mean monthly wind speeds at MCBH Kaneohe Bay at 20 m

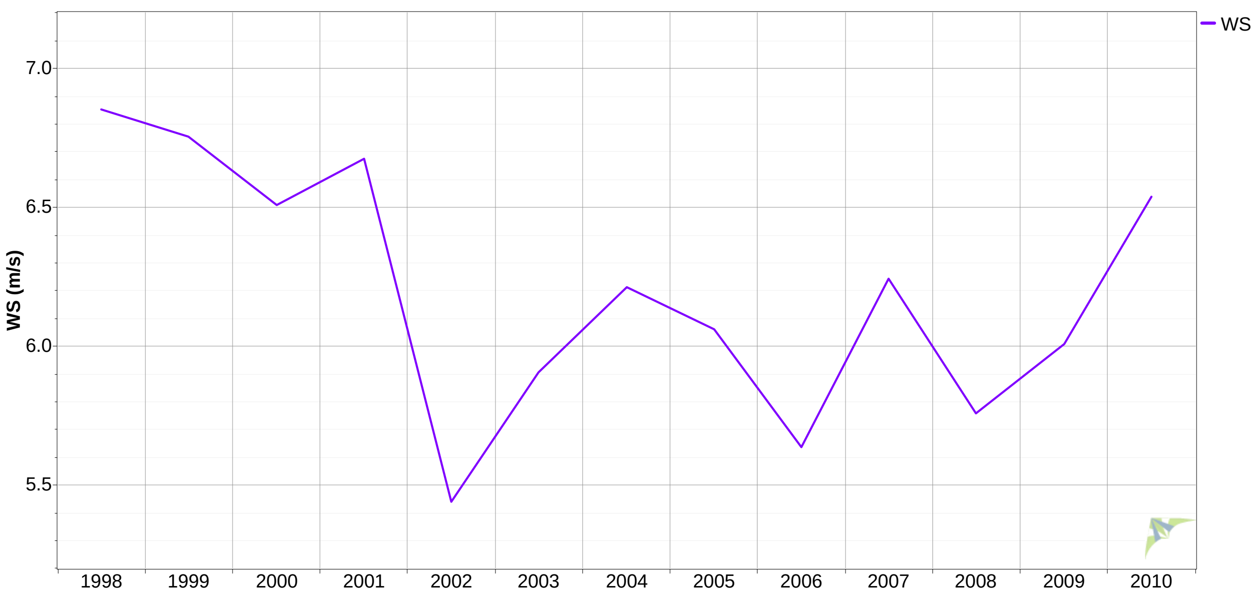


Figure 25. Estimated long term mean annual wind speeds at MCBH Kaneohe Bay at 20 m

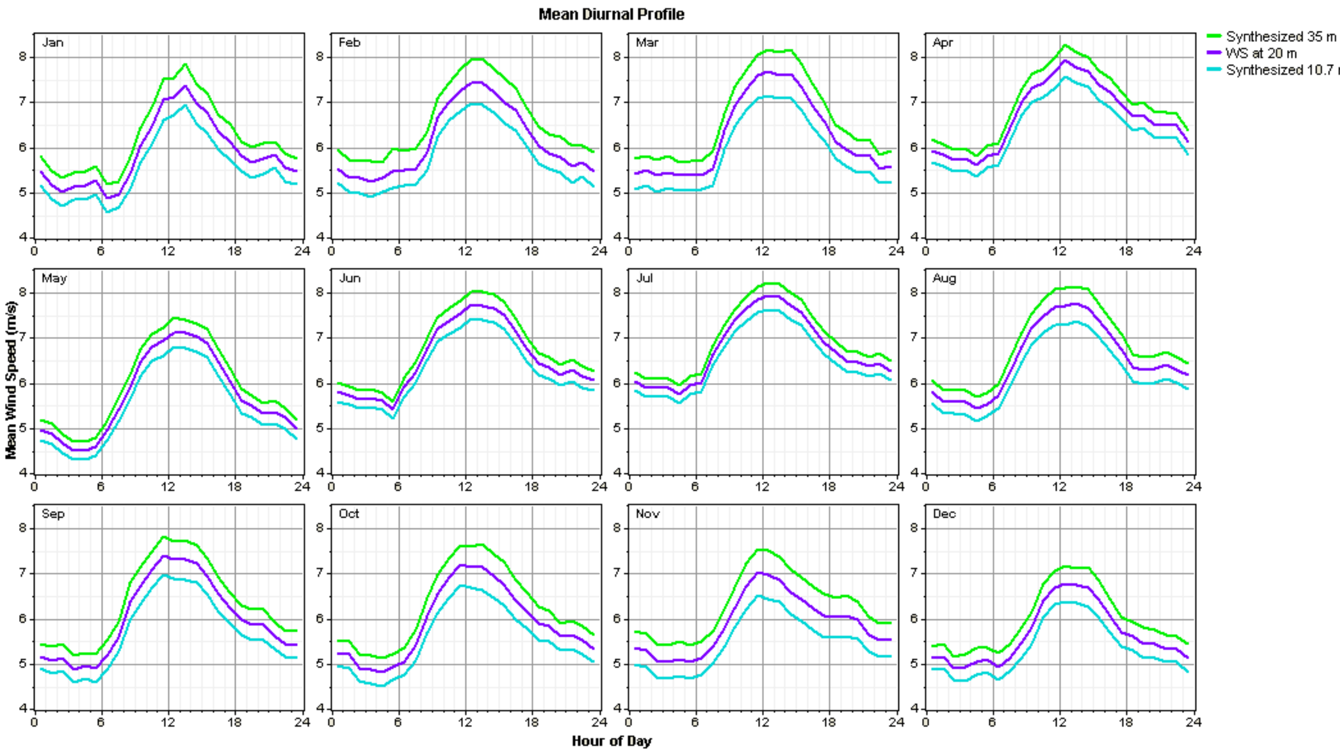
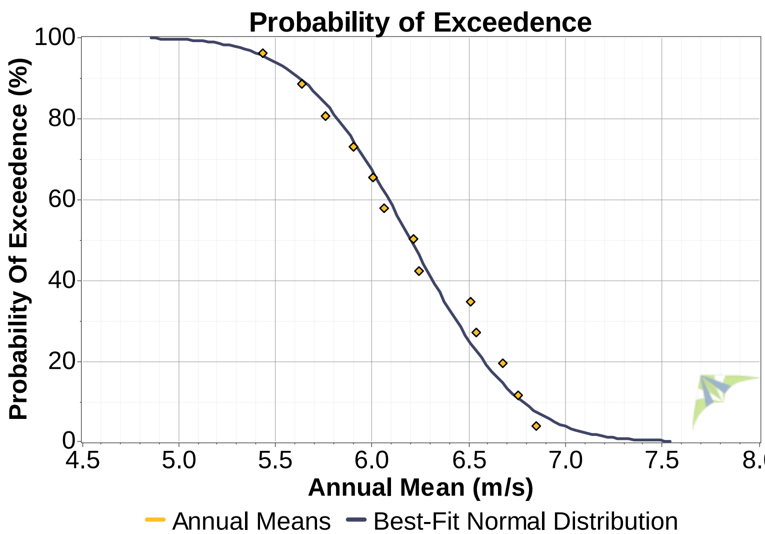


Figure 26. Long term monthly mean diurnal profile at MCBH Kaneohe Bay at 20 m

The Probability of Exceedence graph in Figure 27 analyzes long term data and estimate the probability that the annual mean speed will exceed certain values in a given year. The results can be seen graphically and in the table below.



Percentile	Actual Distribution (m/s)	Normal Distribution (m/s)
P99		5.156
P95	5.467	5.462
P90	5.595	5.624
P75	5.869	5.896
P50	6.211	6.199
P25	6.573	6.501
P10	6.773	6.773
P5	6.837	6.936
P1		7.241

Figure 27. Probability of Exceedence graph and Probability Table for Long Term at 20 m at MCBH Kaneohe Bay

Table 14. Raw Data Recovery Rates at MCBH Kaneohe Bay from 8/1/2009 – 7/31/2010

Label	Units	Height	Possible Records	Valid Records	Recovery Rate (%)	Mean	Min	Max	Std. Dev
Speed 50 m A	m/s	50.2 m	52,558	52,558	100.0	6.81	0.4	16.5	2.93
Speed 50 m A SD	m/s	50.2 m	52,558	52,558	100.0	0.69	0	4.5	0.374
Speed 50 m A Max	m/s	50.2 m	52,558	52,558	100.0	8.47	0.4	20.2	3.31
Speed 50 m A Min	m/s	50.2 m	52,558	52,558	100.0	5.02	0.4	13.7	2.65
Speed 50 m B	m/s	50.2 m	52,558	52,558	100.0	6.73	0.4	16.4	2.9
Speed 50 m B SD	m/s	50.2 m	52,558	52,558	100.0	0.704	0	4.5	0.374
Speed 50 m B Max	m/s	50.2 m	52,558	52,558	100.0	8.41	0.4	19.5	3.28
Speed 50 m B Min	m/s	50.2 m	52,558	52,558	100.0	4.9	0.4	13.3	2.58
Speed 35 m A	m/s	35 m	52,558	52,558	100.0	6.63	0.4	16	2.86
Speed 35 m A SD	m/s	35 m	52,558	52,558	100.0	0.701	0	4.5	0.375
Speed 35 m A Max	m/s	35 m	52,558	52,558	100.0	8.34	0.4	20.6	3.26
Speed 35 m B SD	m/s	35 m	52,558	52,558	100.0	0.706	0	4.5	0.377
Speed 35 m B Max	m/s	35 m	52,558	52,558	100.0	8.38	0.4	19.9	3.28
Speed 20 m A SD	m/s	20.3 m	52,558	52,558	100.0	0.724	0	4.1	0.378
Speed 20 m A Max	m/s	20.3 m	52,558	52,558	100.0	8.13	0.4	20.2	3.22
Speed 20 m B SD	m/s	20.3 m	52,558	52,558	100.0	0.719	0	4.1	0.381
Direction 35 m Max	°	35.3 m	52,558	52,558	100.0	311.6	72	429	141.2
Direction 35 m Min	°	35.3 m	52,558	52,558	100.0	72.0	72.0	72.0	0.0
Temperature	°C		52,558	52,558	100.0	25.2	16.8	31.0	2.0
Temperature SD	°C		52,558	52,558	100.0	0.023	0	1.5	0.069
Temperature Max	°C		52,558	52,558	100.0	25.5	17.0	31.4	2.1
Temperature Min	°C		52,558	52,558	100.0	25.0	16.7	31.0	2.0
Speed 50 m A TI			52,558	52,558	100.0	0.126	0	1.167	0.103
Speed 50 m B TI			52,558	52,558	100.0	0.129	0	1.167	0.103
Speed 35 m A TI			52,558	52,558	100.0	0.132	0	1.143	0.109
Speed 35 m B TI			52,558	52,558	100.0	0.132	0	1.125	0.105
Speed 20 m A TI			52,558	52,558	100.0	0.144	0	1.25	0.118
Speed 20 m B TI			52,558	52,558	100.0	0.145	0	1.222	0.123
Speed 50 m A WPD	W/m²		52,558	52,558	100.0	287	0	2678	282
Speed 50 m B WPD	W/m²		52,558	52,558	100.0	277	0	2629	273
Speed 35 m A WPD	W/m²		52,558	52,558	100.0	265	0	2442	259
Speed 35 m B WPD	W/m²		52,558	52,558	100.0	270	0	2488	266
Speed 20 m A WPD	W/m²		52,558	52,558	100.0	234	0	2093	225
Speed 20 m B WPD	W/m²		52,558	52,558	100.0	231	0	2012	223

Figure 28 on the next page provides an indication that in the 2001 - 2003 timeframe, the MCAS Kaneohe Bay airport Met station was not recording wind speed data as consistently and reliably as usual over the past 12 years. The cause for this is unknown at this time, but the result may be lower wind speeds reported (as averages) during some of that time than was actually the case.

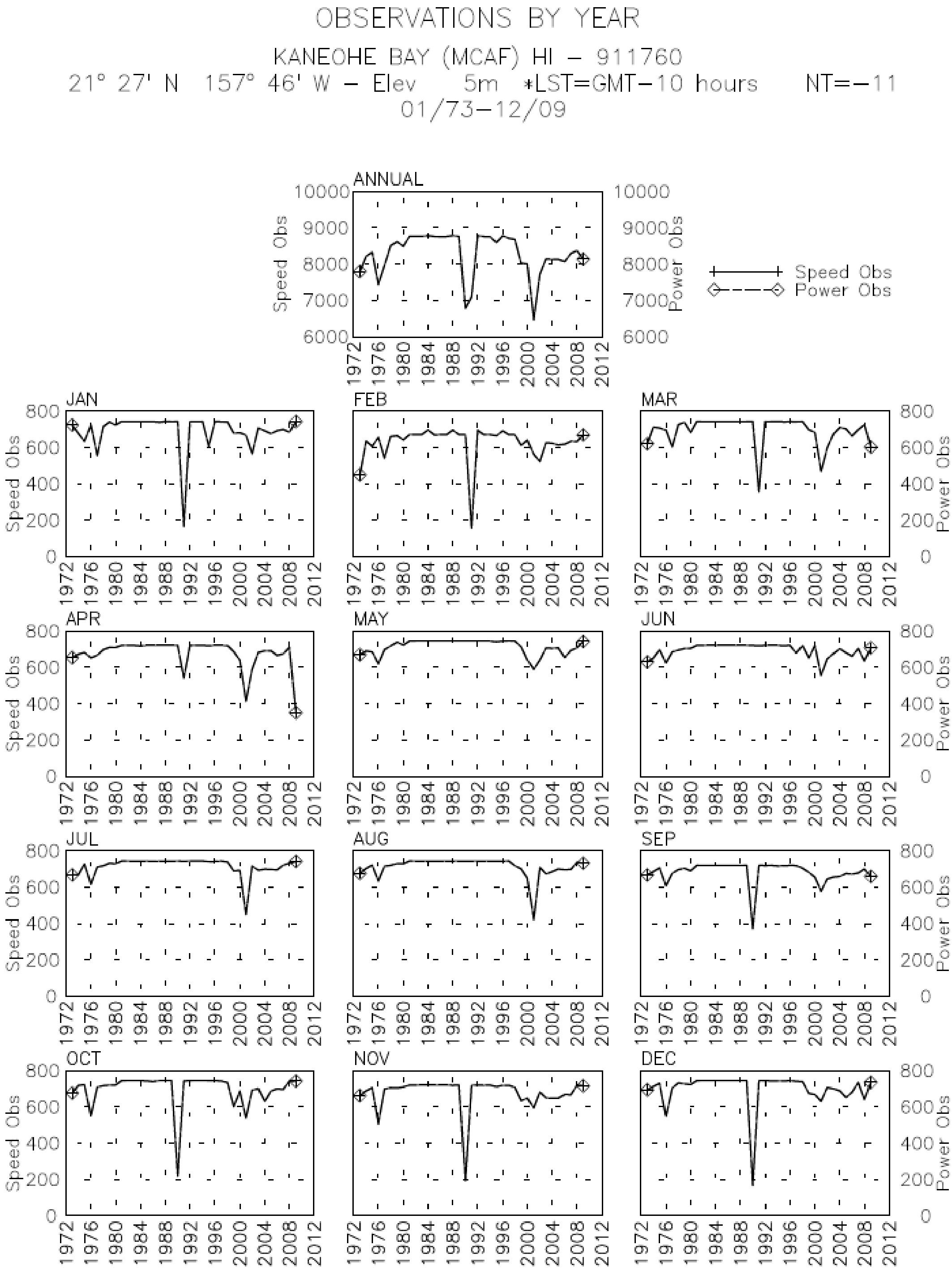


Figure 28. Wind speed data from MCAS Kaneohe Bay airport Met tower

Appendix B – Commissioning Report

Relevant excerpts from the commissioning report are shown below.

DATE	6/17/2009

SITE INFORMATION

SITE#	2
SITE NAME	Kaneohe Bay
LATITUDE	N 21 26.542
LONGITUDE	W 157 44.279
TIME ZONE	Hawaii-Aleutian Standard (GMT -10:00)
SITE DESCRIPTION	Simi flat rolling bumps, on sandy beach with scrub vegiatation

DATUM
WGS84

TOWER

TOWER MAKE & MODEL	NRG 50m XHD w/out tower extension
TOWER DIAMETER	8-10in

UNITS

FIELD INSTALLER CONTACT INFO

COMPANY	Harmer Communications
CONTACT PERSON	Mark Harmer
ADDRESS	310-9 Alamaha Street, Kahului, Hawaii, 96732
PHONE NUMBER	808-877-8082
FAX NUMBER	808-877-8084
EMAIL ADDRESS	harmer@flex.com

CREW MEMBERS	MS, MH, PT, JP
SCF QC'd BY	Mark Harmer

SUMMARY OF SERVICES PERFORMED (use the box below) - entry required

Guidelines

If a *new tower has been installed*, please explicitly state this.

If a pre-existing *tower has been dropped to perform any services on it*, please clearly describe the services performed.

If a pre-existing *tower has been decommissioned*, please explicitly state this. Additionally, please:

1) indicate if the tower has failed requiring wreckage to be cleared
2) indicate storage plans of tower and components (e.g. where, or with whom)
3) indicate whether any tower parts or components have been left on site and why
4) note damaged tower sections or components identified during decommissioning (for a tower which had not failed)

Install new tower with marker balls and bird diverters on guy wires

ANEMS - all anem calibration certification sheets must be supplied to UPC

							UNITS
LOGGER CHANNEL NUMBER	1	2	3	4	5	6	
SENSOR MAKE & MODEL	NRG #40C	NRG #40C	NRG #40C	NRG #40C	NRG #40C	NRG #40C	
ACTUAL MONITORING HEIGHT	50.15 m	50.15 m	35.05 m	35.05 m	20.25 m	20.25 m	
PRIMARY OR REDUNDANT	Primary	Primary	Primary	Primary	Primary	Primary	
BOOM ORIENTATION twr raised (GOT) / twr lowered	342 / 342	162 / 162	342 / 342	162 / 162	342 / 342	162 / 162	degrees TRUE
BOOM HEIGHT	49.9	49.9	34.8	34.8	20	20	meters

BOOM MAKE & MODEL	NRG 3752	NRG 3752	NRG 3752	NRG 3752	NRG 3991	NRG 3991	
BOOM LENGTH	1.53m	1.53m	1.53m	1.53m	1.93	1.93	meters
BOOM DIAMETER	0.5in	0.5in	0.5in	0.5in	0.75	0.75	inches
OFFSET HEIGHT	8in	8in	8in	8in	8	8	inches

ANEM SERIAL NUMBER	53338	53341	53342	53339	53336	53331

PASS FUNCTIONAL TEST?	Yes	Yes	Yes	Yes	Yes	Yes
COMMENTS	West ano	East ano	West ano	East ano	West ano	East ano

BASE HEIGHT	2	inches
BASE PLATE DISPLACEMENT	0	inches

VANES & OTHER SENSORS - any calibration sheets for non-vane sensors must be supplied to UPC

							UNITS
LOGGER CHANNEL NUMBER	7	8	9				
SENSOR TYPE	Vane	Vane	Temperature				
SENSOR MAKE & MODEL	NRG #200P	NRG #200P	NRG #110S				

VANES								UNITS
	ACTUAL MONITORING HEIGHT	50.35 m	35.25 m					
	BOOM ORIENTATION twr raised (GOT) / twr lowered	72 / 72	72 / 72					degrees TRUE
	DEADBAND ORIENTATION	AWAY from tower	AWAY from tower					
	BOOM HEIGHT	50.1	35					meters
	BOOM MAKE & MODEL	NRG 3752	NRG 3752					
	BOOM LENGTH	1.53m	1.53m					inches
	BOOM DIAMETER	0.5in	0.5in					inches
	OFFSET HEIGHT	8in	8in					inches

OTHER								UNITS
	MOUNTING HEIGHT			3				meters
	MOUNTING ORIENTATION			N				
	SERIAL NUMBER (if available)							

PASS FUNCTIONAL TEST?	Yes	Yes	Yes			
COMMENTS						

Appendix C – Met Tower Configuration & Components

Met tower components for MCBH Kaneohe Bay

50m tower:

- 6- NRG #40 anemometers (item 1899)
- 2- #200P wind vanes (item 1904)
- 1- #110S temperature sensor (item 1906)
- 2- 2C cables for 50m level (item 1934)
- 1- 2C cable for 40m level (item 1933)
- 1- 2C cable for 30m level (item 1932)
- 1- 3C cable for 50m level (item 1939)
- 1- 3C cable for 40m level (item 1938)
- 12- Hose clamps for side mount booms (item 2712)

NRG #40 Anemometer (item: 1899) – The NRG #40 Maximum anemometer is the industry standard anemometer used worldwide. NRG #40 anemometers have recorded wind speeds of 96 m/s (214 mph). Their low moment of inertia and unique bearings permit very rapid response to gusts and lulls. Because of their output linearity, these sensors are ideal for use with various data retrieval systems. A four-pole magnet induces a sine wave voltage into a coil producing an output signal with a frequency proportional to wind speed. The #40 is constructed of rugged Lexan cups molded in one piece for repeatable performance. A rubber terminal boot is included.

Figure 29. Anemometer #40 (item 1899)

Photo Courtesy of NRG Systems http://www.nrgsystems.com/

NRG #200P Wind Direction Vane, 10K (item: 1904) – The NRG #200P wind direction vane is the industry standard wind direction vane used worldwide. The thermoplastic and stainless steel components resist corrosion and contribute to a high strength-to-weight ratio. The vane is directly connected to a precision conductive plastic potentiometer located in the main body. An analog voltage output directly proportional to the wind direction is produced when a constant DC excitation voltage is applied to the potentiometer. A rubber terminal boot is included.

Figure 30. Wind vane NRG #200P (item 1904)

Photo Courtesy of NRG Systems *http://www.nrgsystems.com/*

NRG Mounting Booms – NRG side mounting booms allow you to easily mount sensors to your tower or mast at any height. Mounting hardware is included.

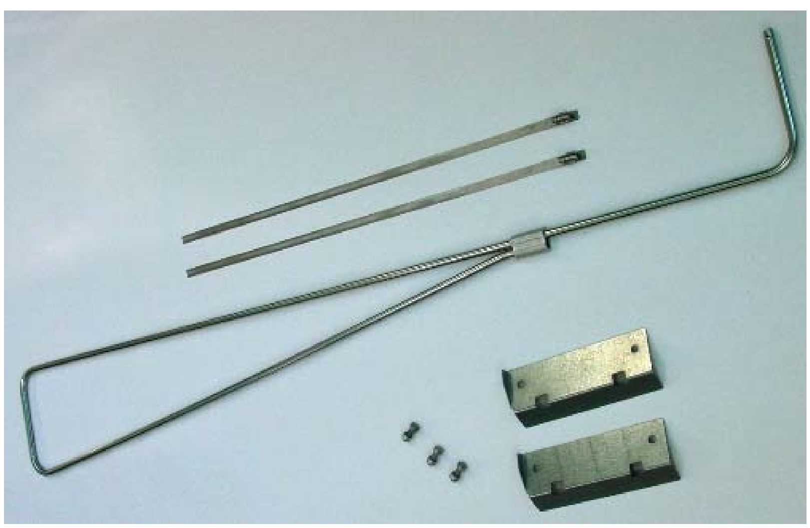
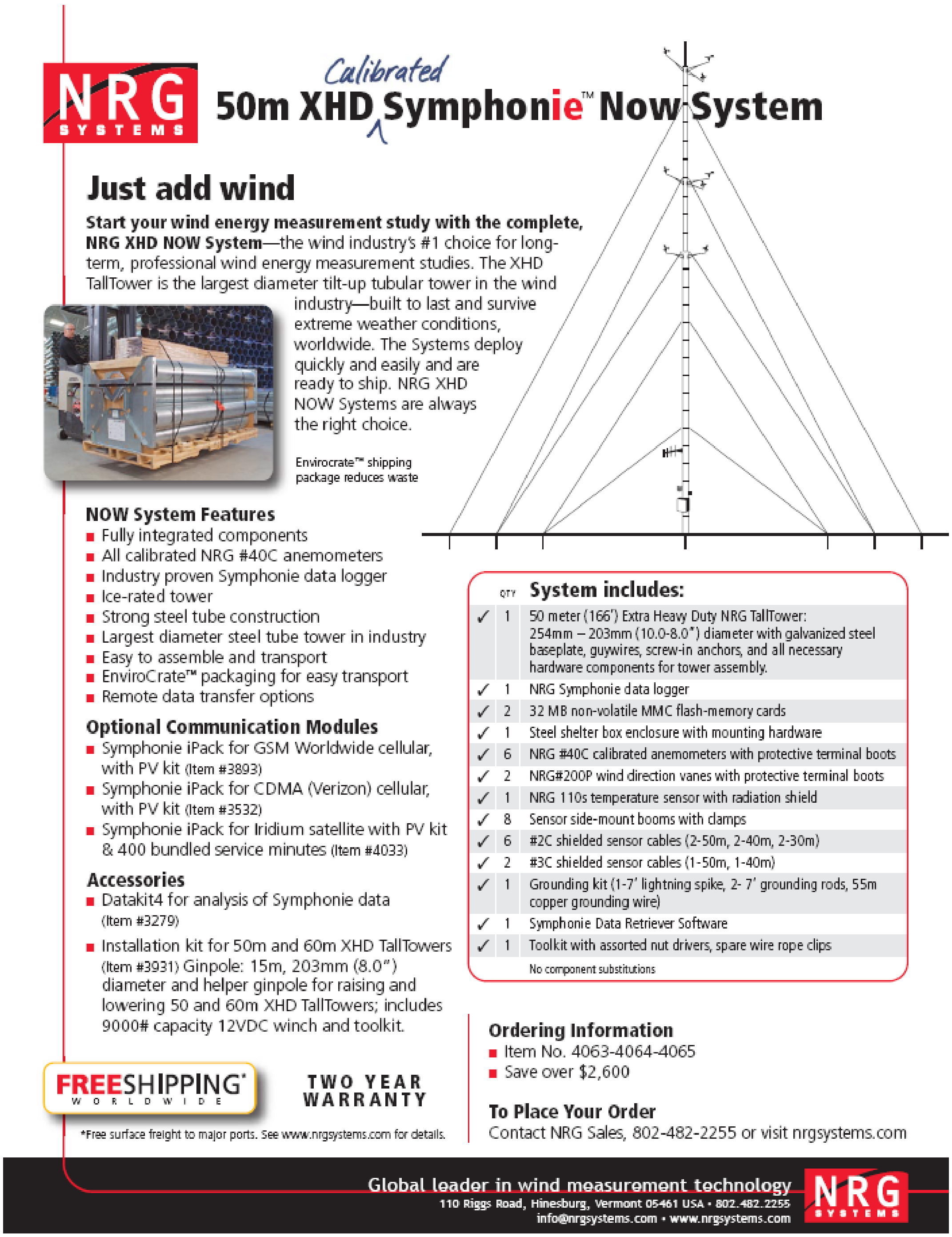


Figure 31. Boom, Side, 1.53m (60.5"), Galv, with clamps (item: 3390)

Photo Courtesy of NRG Systems *http://www.nrgsystems.com/*



Calibrated 50m XHD Symphonie™ Now System

NRG SYSTEMS

Just add wind

Start your wind energy measurement study with the complete, NRG XHD NOW System—the wind industry's #1 choice for long-term, professional wind energy measurement studies. The XHD TallTower is the largest diameter tilt-up tubular tower in the wind industry—built to last and survive extreme weather conditions, worldwide. The Systems deploy quickly and easily and are ready to ship. NRG XHD NOW Systems are always the right choice.

Envirocrate™ shipping package reduces waste

NOW System Features

- Fully integrated components
- All calibrated NRG #40C anemometers
- Industry proven Symphonie data logger
- Ice-rated tower
- Strong steel tube construction
- Largest diameter steel tube tower in industry
- Easy to assemble and transport
- EnviroCrate™ packaging for easy transport
- Remote data transfer options

Optional Communication Modules

- Symphonie iPack for GSM Worldwide cellular, with PV kit (Item #3893)
- Symphonie iPack for CDMA (Verizon) cellular, with PV kit (Item #3532)
- Symphonie iPack for Iridium satellite with PV kit & 400 bundled service minutes (Item #4033)

Accessories

- Datakit4 for analysis of Symphonie data (Item #3279)
- Installation kit for 50m and 60m XHD TallTowers (Item #3931) Ginpole: 15m, 203mm (8.0") diameter and helper ginpole for raising and lowering 50 and 60m XHD TallTowers; includes 9000# capacity 12VDC winch and toolkit.

FREESHIPPING* WORLDWIDE

TWO YEAR WARRANTY

*Free surface freight to major ports. See www.nrgsystems.com for details.

	QTY	System includes:
✓	1	50 meter (166') Extra Heavy Duty NRG TallTower: 254mm – 203mm (10.0-8.0") diameter with galvanized steel baseplate, guywires, screw-in anchors, and all necessary hardware components for tower assembly.
✓	1	NRG Symphonie data logger
✓	2	32 MB non-volatile MMC flash-memory cards
✓	1	Steel shelter box enclosure with mounting hardware
✓	6	NRG #40C calibrated anemometers with protective terminal boots
✓	2	NRG#200P wind direction vanes with protective terminal boots
✓	1	NRG 110s temperature sensor with radiation shield
✓	8	Sensor side-mount booms with clamps
✓	6	#2C shielded sensor cables (2-50m, 2-40m, 2-30m)
✓	2	#3C shielded sensor cables (1-50m, 1-40m)
✓	1	Grounding kit (1-7' lightning spike, 2- 7' grounding rods, 55m copper grounding wire)
✓	1	Symphonie Data Retriever Software
✓	1	Toolkit with assorted nut drivers, spare wire rope clips

No component substitutions

Ordering Information

- Item No. 4063-4064-4065
- Save over $2,600

To Place Your Order

Contact NRG Sales, 802-482-2255 or visit nrgsystems.com

Global leader in wind measurement technology
110 Riggs Road, Hinesburg, Vermont 05461 USA • 802.482.2255
info@nrgsystems.com • www.nrgsystems.com

NRG SYSTEMS

Figure 32. 50m and XHD Tower configuration[3]

[3] http://www.nrgsystems.com/FileLibrary/3bd448ea64fa4f38b624e694f9229453/NRG%2060m%20and%2050m%20XHD%20TallTower%20Installation%20Manual%20-%20Rev%202.03.pdf

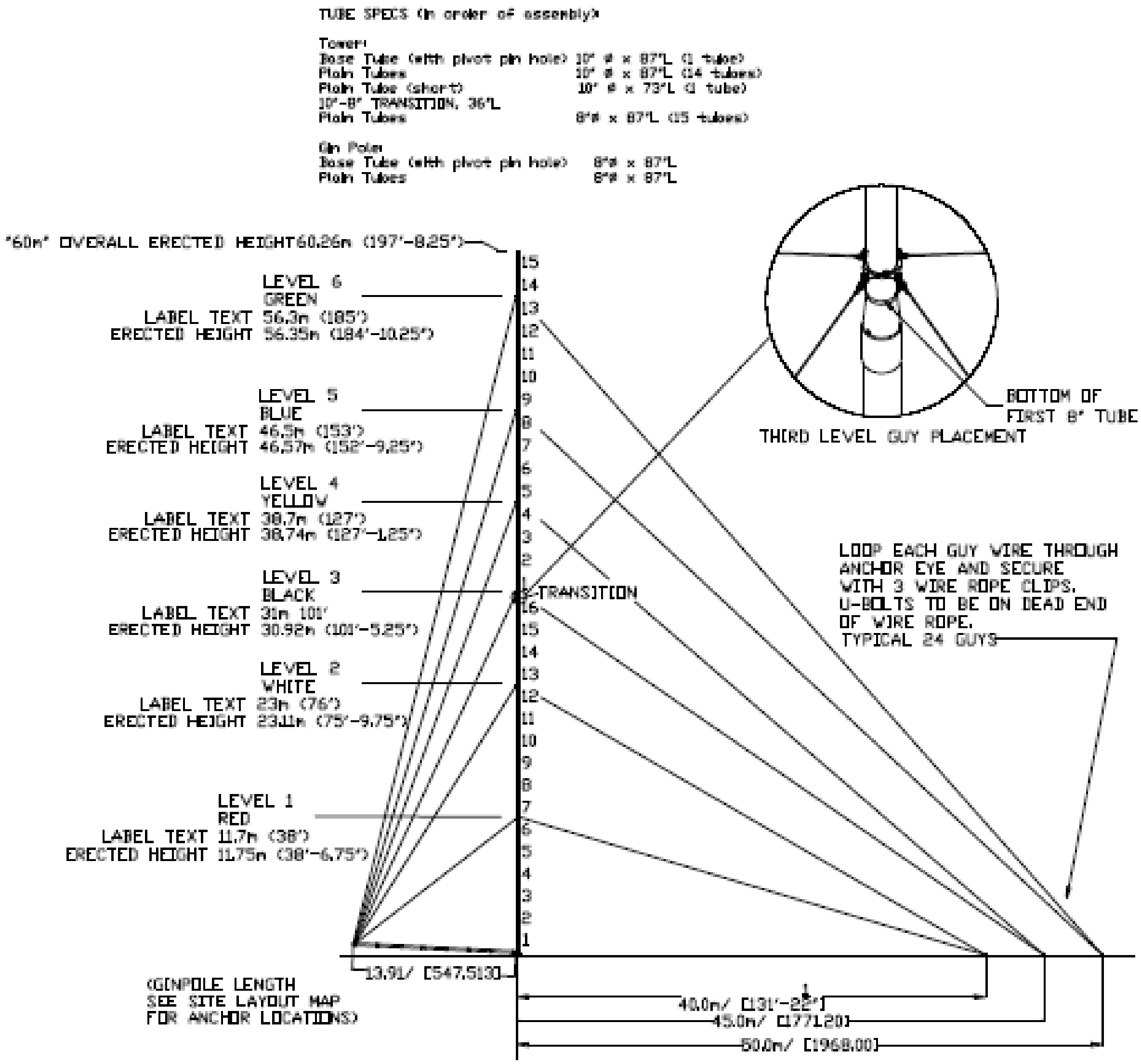


Figure 33. 60m XHD Tower configuration[4]

[4] http://www.nrgsystems.com/FileLibrary/3bd448ea64fa4f38b624e694f9229453/NRG%2060m%20and%2050m%20XHD%20TallTower%20Installation%20Manual%20-%20Rev%202.03.pdf (pg 88)

Figure 34. Guy wire degradation due to marine effects at MCBH Kaneohe Bay.

Source: Mark Harmer, Harmer Communications

Appendix D – Wind Turbine Spec Sheets

Southwest WindPower: Skystream 3.7

Source: http://www.windenergy.com/documents/spec_sheets/3-CMLT-1338-01_Skystream_spec.pdf

Technical Specifications

Rated Capacity	2.4 kW
Rotor Diameter	12 ft (3.72 m)
Weight	170 lb (77 kg)
Swept Area	115.7 ft² (10.87 m²)
Type	Downwind rotor with stall regulation control
Direction of Rotation	Clockwise looking upwind
Blades	(3) Fiberglass reinforced composite
Rated Speed	50 - 330 rpm
Maximum Tip Speed	216.5 ft/s (66 m/s)
Alternator	Slotless permanent magnet brushless
Yaw Control	Passive
Grid Feeding	120/240 VAC Split 1 Ph, 60 Hz 120/208 VAC 3 Ph compatible, 60 Hz (Check with dealer for other configurations)
Battery Charging	Battery Charge Controller kit available for battery charging systems
Braking System	Electronic stall regulation with redundant relay switch control
Cut-in Wind Speed	8 mph (3.5 m/s)
Rated Wind Speed	29 mph (13 m/s)
User Monitoring	Wireless 2-way interface
Survival Wind Speed	140 mph (63 m/s)
Warranty	5 year limited warranty

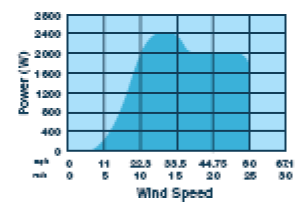
SKYSTREAM 3.7®

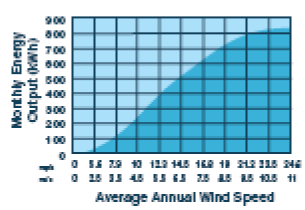
2.4 KW DISTRIBUTED WIND ENERGY SYSTEM

Take Control of Your Energy Needs

Designed for homes and small businesses, the Skystream 3.7® converts wind into clean electricity you can use. It's the first compact, user-friendly, all-inclusive wind generator (with controls and inverter built in) designed to provide quiet, clean electricity in very low winds.

With a rated capacity of 2.4 kW, Skystream can help offset a household or small business's total energy needs.[1] And because it operates at a low RPM, Skystream is as quiet as the trees blowing in the wind.





FIVE YEAR WARRANTY

Southwest Windpower
1801 W. Route 66
Flagstaff, AZ 86001 USA
928.779.9463
www.skystreamenergy.com

Makers of Skystream 3.7® / AIR / Whisper

[1] Actual savings is based on wind speed at the site and monthly energy consumption.
[2] Data measured and compiled by USDA-ARS Research Lab, Bushland, TX.

Printed on recycled paper with vegetable inks using 100% new wind energy.

Bergey Wind Power: BCW Excel-S 10 kW

Source: http://www.bergey.com/pages/technical

WindCad Turbine Performance Model

BWC EXCEL-S, Grid - Intertie

Tier/neo-SH3055-23-BWC

Prepared For:	**SWCC**
Site Location:	**Reference**
Data Source:	**AWEA Standard**
Date:	**3/8/2011**

10 kW

Inputs:

Ave. Wind (m/s) =	5
Weibull K =	2
Site Altitude (m) =	0
Wind Shear Exp. =	0.200
Anem. Height (m) =	30
Tower Height (m) =	30
Turbulence Factor =	0.0%

Results:

Hub Average Wind Speed (m/s) =	5.00
Air Density Factor =	0%
Average Output Power (kW) =	1.51
Daily Energy Output (kWh) =	36.2
Annual Energy Output (kWh) =	**13,227**
Monthly Energy Output =	1,102
Percent Operating Time =	67.9%

Weibull Performance Calculations

Wind Speed Bin (m/s)	Pow er (kW)	Wind Probability (f)	Net kW @ V
1	0.00	6.14%	0.000
2	0.00	11.17%	0.000
3	0.14	14.29%	0.020
4	0.43	15.27%	0.066
5	0.88	14.35%	0.126
6	1.51	12.15%	0.183
7	2.35	9.39%	0.221
8	3.43	6.67%	0.229
9	4.80	4.38%	0.210
10	6.42	2.67%	0.171
11	8.21	1.51%	0.124
12	10.02	0.79%	0.080
13	11.37	0.39%	0.044
14	11.76	0.18%	0.021
15	12.06	0.08%	0.009
16	12.14	0.03%	0.004
17	12.15	0.01%	0.001
18	12.10	0.00%	0.000
19	11.92	0.00%	0.000
20	11.44	0.00%	0.000
2008, BWC	Totals:	99.47%	1.510

Weibull Calculations: Wind speed probability is calculated as a Weibull curve defined by the average wind speed and a shape factor, K. To facilitate piece-wise integration, the wind speed range is broken down into "bins" of 1 m/s in width (Column 1). For each wind speed bin, instantaneous wind turbine power (W, Column 2)) is multiplied by the Weibull wind speed probability (f, Column 3). This cross product (Net W, Column 4) is the contribution to average turbine power output contributed by wind speeds in that bin. The sum of these contributions is the average power output of the turbine on a continuous, 24 hour, basis.
Best results are achieved using annual or monthly average wind speeds. Use of daily or hourly average speeds is not recommended.

Instructions:

Inputs: Use annual or monthly **Average Wind** speeds. If **Weibull K** is not known, use K = 2 for inland sites, use 3 for coastal sites, and use 4 for island sites and trade wind regimes. **Site Altitude** is meters above sea level. **Wind Shear Exponent** is best assumed as 0.18. For rough terrain or high turbulence use 0.22. For very smooth terrain or open water use 0.11. **Anemometer Height** is for the data used for the **Average Wind** speed. If unknown, use 10 meters. **Tower Height** is the nominal height of the tower, eg.: 24 meters. **Turbulence Factor** is a derating for turbulence, site variability, and other performance influencing factors -- typical turbulence has already been incorporated into the model. Use 0.00 (0%) for level sites with limited obstructions. Use -0.10 (negative 10%) for flat, clear sites on open water. Use 0.05 to 0.15 (5% to 15%) for rolling hills or mountainous terrain.

Results: Hub Average Wind Speed is corrected for wind shear and used to calculate the Weibull wind speed probability. **Air Density Factor** is the reduction from sea level performance. **Average Power Output** is the average continuous equivalent output of the turbine. **Daily Energy Output** is the average energy produced per day. **Annual** and **Monthly Energy Outputs** are calculated using the Daily value. **Percent Operating Time** is the time the turbine should be producing some power.

Limitations: This model uses a mathmatical idealization of the wind speed probability. The validity of this assumption is reduced as the time period under consideration (ie, the wind speed averaging period) is reduced. This model is best used with annual or monthly average wind speeds. Use of this model with daily or hourly average wind speed data is not recommended because the wind will not follow a Weibull distribution over short periods. The data used in creating the power curve was generated at the BWC test site in Norman, OK. Consult Bergey Windpower Co. for special needs. ***Your performance may vary.***

Endurance Wind Power

Source: http://www.endurancewindpower.com/s343.html

SPECIFICATIONS

TURBINE	
Configuration	3 blades, horizontal axis, upwind
Rated power @ 11 m/s	5.2 kW
Applications	Direct grid-tie
Rotor speed	166 rpm
Cut-in wind speed	4.1 m/s (9.2 mph)
Cut-out wind speed	24 m/s (54 mph)
Survival wind speed	52 m/s (116 mph)
Overall weight	300 kg (661 lbs)

ROTOR	
Rotor diameter	6.37m (20.9 ft)
Swept area	31.9m² (343 ft²)
Blade length	3.08m (10.1 ft)
Blade material	Fiberglass / Epoxy
Power regulation	Stall control (constant speed)

GENERATOR	
Type	Induction Generator
Configuration	1 Φ, 120/240 VAC split-phase @ 60 Hz, patented dual-voltage generation

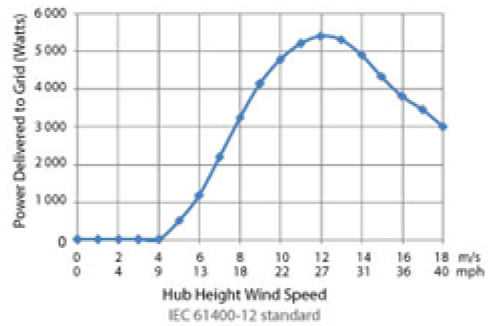
BRAKE & SAFETY SYSTEMS	
Main brake system	Rapid fail-safe mechanical brake on rotor shaft
Secondary safety	Redundant fail-safe mechanical brake on rotor shaft
Automatic shut down triggered by :	- High wind speed - Grid failure - Over speed - All other fault conditions

CONTROLS	
Control system	Field-programmable embedded controller
User interface	Wireless or wired networked software interface for remote monitoring and control

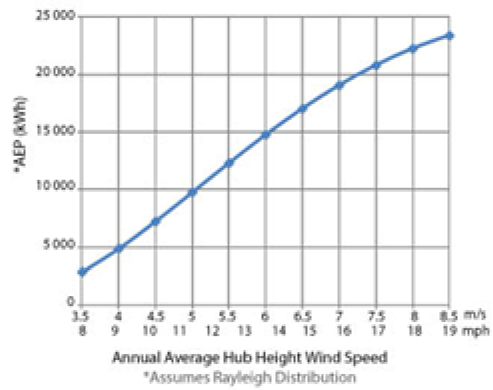
WARRANTY	
Turbine & controls	5 years parts and labour

TOWERS	
Types	Guyed, 31.1 m (102 ft) or 36.6 m (120 ft) Freestanding monopole, 27.5 m (90 ft)[1]

Power Curve



Annual Energy Production (AEP)



Annual Average Hub Height Wind Speed (m/s)	Annual Energy Production (kWh)
3.5	2 800
4.0	4 900
4.5	7 200
5.0	9 700
5.5	12 300
6.0	14 800
6.5	17 000
7.0	19 100
7.5	20 800
8.0	22 200
8.5	23 400

Wind Speed Conversion Table

m/s	4	5	6	7	8	9	10	11	12	14
km/h	14	18	22	25	29	32	36	40	43	50
mph	9	11	13	16	18	20	22	25	27	31

Appendix E – Electricity Rates

Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State

Electric Power Monthly with data for November 2010

Report Released: February 14, 2011

Table 5.6.A. Average **(Cents per kilowatthour)**

Census Division	Residential		Commercial[1]		Industrial[1]		Transportation[1]		All Sectors	
and State	10-Nov	9-Nov	10-Nov	9-Nov	10-Nov	9-Nov	10-Nov	9-Nov	10-Nov	9-Nov
Pacific Noncontiguous	**23.69**	**22.21**	**21**	**19.41**	**20.36**	**18.89**	**--**	**--**	**21.66**	**20.15**
Alaska	16.76	16.73	14.54	14.27	14.08	15.14	--	--	15.22	15.29
Hawaii	28.91	26.23	26.65	23.92	22.56	20.15	--	--	25.81	23.24
U.S. Total	**11.7**	**11.33R**	**10.07**	**9.85R**	**6.59**	**6.44R**	**10.42**	**11.13R**	**9.62**	**9.43R**

[1] See Technical notes for additional information on the Commercial, Industrial, and Transportation sectors.

R = Revised

Notes: • See Glossary for definitions. • Values for 2009 are final. Values for 2010 are preliminary estimates based on a cutoff model sample. See Technical Notes for a
discussion of the sample design for the Form EIA-826. • Utilities and energy service providers may classify commercial and industrial customers based on either NAICS codes or demands or usage falling w ithin specified limits by rate schedule. • Changes from year to year in consumer counts, sales and revenues, particularly involving the commercial and industrial consumer sectors, may result from respondent implementation of changes in the definitions of consumers, and reclassifications. • Retail sales and net generation may not correspond exactly for a particular month for a variety of reasons (i.e., sales data may include imported electricity). • Net generation is for the calendar month w hile retail sales and associated revenue accumulate from bills collected for periods of time (28 to 35 days) that vary dependent upon customer class and consumption occurring in and outside

Source: U.S. Energy Information Administration, Form EIA-826, "Monthly Electric Sales and Revenue Report w ith State Distributions Report."