Kokhanok, Alaska Wind Resource Report

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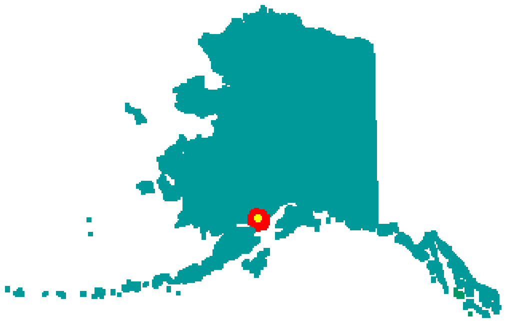
Photo © Doug Vaught



Summary Information

The wind resource in Kokhanok is superb by any measure – the winds are steady, smooth, low shear, highly directional and high power class. The selected wind site, near the tip of the spit of land jutting into Lake Iliamna (see photo above) is ideal for wind turbine installations as it is relatively far from the village but near an existing overhead power line, is comprised of stable rocky soil, and is in a location unlikely to be desired for other village uses (because of the wind).

Meteorological Tower Data Synopsis

Wind power class	Class 6 – Outstanding
Wind speed annual average (30 meters)	7.84 m/s
Maximum wind gust (2 sec. average)	40.1 m/s (Nov. 2004)
Mean wind power density (50 meters)	763 W/m^2 (calculated)
Mean wind power density (30 meters)	690 W/m^2 (measured)
Weibull distribution parameters	k = 1.64, c = 8.77 m/s
Turbulence intensity	0.0985 (low)
Roughness class	0.00 (smooth)
Power law exponent	0.0725 (very low wind shear)
Data start date	August 12, 2004
Data end date	June 14, 2006

Community Profile

Current Population:	179 (2005 State Demographer est.)
Pronunciation/Other Names:	(KOCK-hone-ack); alt. Kakhonak
Incorporation Type:	Unincorporated
Borough Located In:	Lake & Peninsula Borough
School District:	Lake & Peninsula Schools
Regional Native Corporation:	Bristol Bay Native Corporation

Location:
Kokhanok is located on the south shore of Iliamna Lake, 22 miles south of Iliamna and 88 miles northeast of King Salmon. It lies at approximately 59.441600° North Latitude and -154.755140° West Longitude. (Sec. 32, T008S, R032W, Seward Meridian.) Kokhanok is located in the Iliamna Recording District. The area encompasses 21.3 sq. miles of land and 0.1 sq. miles of water.

History:
This fishing village was first listed in the U.S. Census in 1890 by A.B. Schanz. The community was relocated to higher ground a few years ago when the rising level of Iliamna Lake threatened several community buildings.

Culture:
The village has a mixed Native population, primarily Alutiiq and Yup'ik. Subsistence activities are the focal point of the culture and lifestyle. The sale or importation of alcohol is banned in the village.

Economy:
The school is the largest employer in Kokhanok. Commercial fishing has declined since several limited entry permits were sold. Some residents travel to the Bristol Bay area each summer to fish; eight persons currently hold commercial fishing permits. People heavily rely on subsistence activities; many families have a summer fish camp near the Gibraltar River. Salmon, trout, grayling, moose, bear, rabbit, porcupine and seal are utilized.

Facilities:
Bedrock has made the development of water and sewer facilities difficult. The Village operates a piped water and sewer system that serves 35 households. The water treatment plant is currently being upgraded. The school operates its own well and water treatment facility. Kokhanok generates power only during the summer months; in winter, electricity is purchased from the School District.

Transportation:
Kokhanok is accessible by air and water. A State-owned 2,920' long by 60' wide gravel airstrip and a seaplane base serve scheduled and charter air services from Anchorage, Iliamna, and King Salmon. Supplies delivered by barge via the Kvichak River must be lightered to shore. There are no docking facilities. The community wants to develop a boat harbor and launch ramp. Skiffs, ATVs and trucks are common forms of local transportation.

Climate:
Kokhanok lies in the transitional climatic zone. Average summer temperatures range from 40 to 64 F; winter temperatures average 3 to 30 F. The record high is 84 F; the record low, -47 F. Precipitation averages 32 inches annually, including 89 inches of snowfall. Wind storms and ice fog are common during winter.

(Above information from State of Alaska Department of Commerce, Community, and Economic Development website, www.dced.state.ak.us)

Tower Sensor Information

Channel	Sensor type	Height	Multiplier	Offset	Orientation
1	NRG #40 anemometer	30 m	0.765	0.35	north
2	NRG #40 anemometer	21 m	0.765	0.35	north
7	NRG #200P wind vane	29 m	0.351	350	south
9	NRG #110S Temp C	2 m	0.136	-86.383	N/A

Site Information and Location

Site number	2257
Site Description	Near tip of spit jutting north into Lake Iliamna
Latitude/longitude	N 59° 26.907’ W 154° 45.835’
Site elevation	23 meters
Datalogger type	NRG Symphonie
Tower type	NRG 30-meter tall tower, 152 mm (6 in) diameter


L A K E
I A M N A
K A K H
Kokhanok Met Tower
Landing Strip
Kakhonak

Data Quality Control

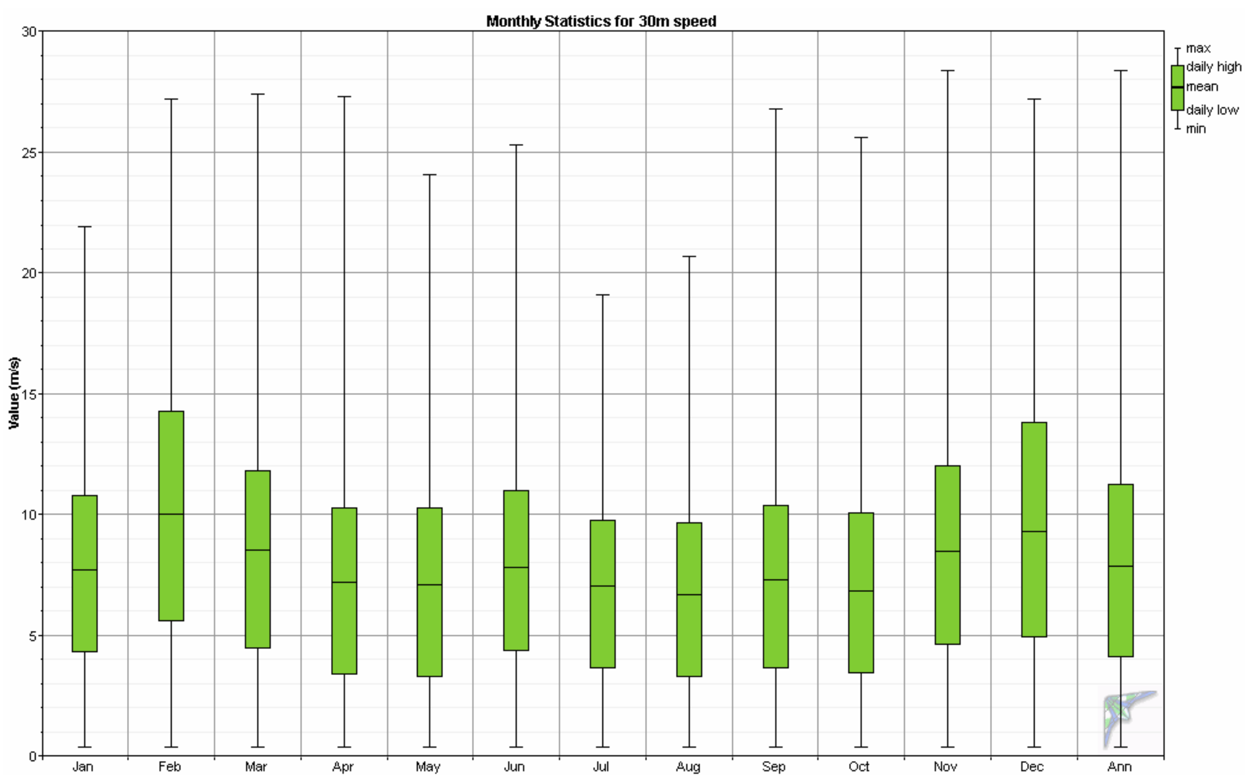
Data was filtered to remove presumed icing events that yield false zero wind speed data. Data that met the following criteria were filtered: wind speed < 1 m/s, wind speed standard deviation = 0, and temperature < 3 °C. Note that data recovery during the months of May through October was nearly 100%, but during the months of November through April some data was filtered. Temperature data recovery was 100 percent, indicating full functioning of the temperature sensor. Because data recovery was so good, data was not synthesized to replace data missing from icing events.

		30 m anemometer		21 m anemometer		Wind vane		Temperature	
Year	Month	Records	Recovery Rate (%)	Records	Recovery Rate (%)	Records	Recovery Rate (%)	Records	Recovery Rate (%)
2004	Aug	2,812	100.0	2,812	100.0	2,812	100.0	2,812	100.0
2004	Sep	4,320	100.0	4,320	100.0	4,320	100.0	4,320	100.0
2004	Oct	4,462	100.0	4,462	100.0	4,462	100.0	4,464	100.0
2004	Nov	4,291	99.3	4,295	99.4	4,291	99.3	4,320	100.0
2004	Dec	4,371	97.9	4,370	97.9	4,370	97.9	4,464	100.0
2005	Jan	4,357	97.6	4,353	97.5	4,353	97.5	4,464	100.0
2005	Feb	3,957	98.1	3,951	98.0	3,951	98.0	4,032	100.0
2005	Mar	4,427	99.2	4,428	99.2	4,427	99.2	4,464	100.0
2005	Apr	4,266	98.8	4,252	98.4	4,252	98.4	4,320	100.0
2005	May	4,463	100.0	4,463	100.0	4,463	100.0	4,464	100.0
2005	Jun	4,320	100.0	4,320	100.0	4,320	100.0	4,320	100.0
2005	Jul	4,464	100.0	4,464	100.0	4,464	100.0	4,464	100.0
2005	Aug	4,464	100.0	4,464	100.0	4,464	100.0	4,464	100.0
2005	Sep	4,320	100.0	4,320	100.0	4,320	100.0	4,320	100.0
2005	Oct	4,464	100.0	4,464	100.0	4,464	100.0	4,464	100.0
2005	Nov	4,285	99.2	4,288	99.3	4,285	99.2	4,320	100.0
2005	Dec	4,383	98.2	4,374	98.0	4,374	98.0	4,464	100.0
2006	Jan	4,275	95.8	4,237	94.9	4,232	94.8	4,464	100.0
2006	Feb	3,878	96.2	3,892	96.5	3,878	96.2	4,032	100.0
2006	Mar	4,213	94.4	4,179	93.6	4,166	93.3	4,464	100.0
2006	Apr	4,234	98.0	4,230	97.9	4,219	97.7	4,320	100.0
2006	May	4,453	99.8	4,458	99.9	4,453	99.8	4,464	100.0
2006	Jun	1,938	100.0	1,938	100.0	1,938	100.0	1,938	100.0
All data		95,417	98.8	95,334	98.7	95,278	98.6	96,622	100.0

Measured Wind Speeds

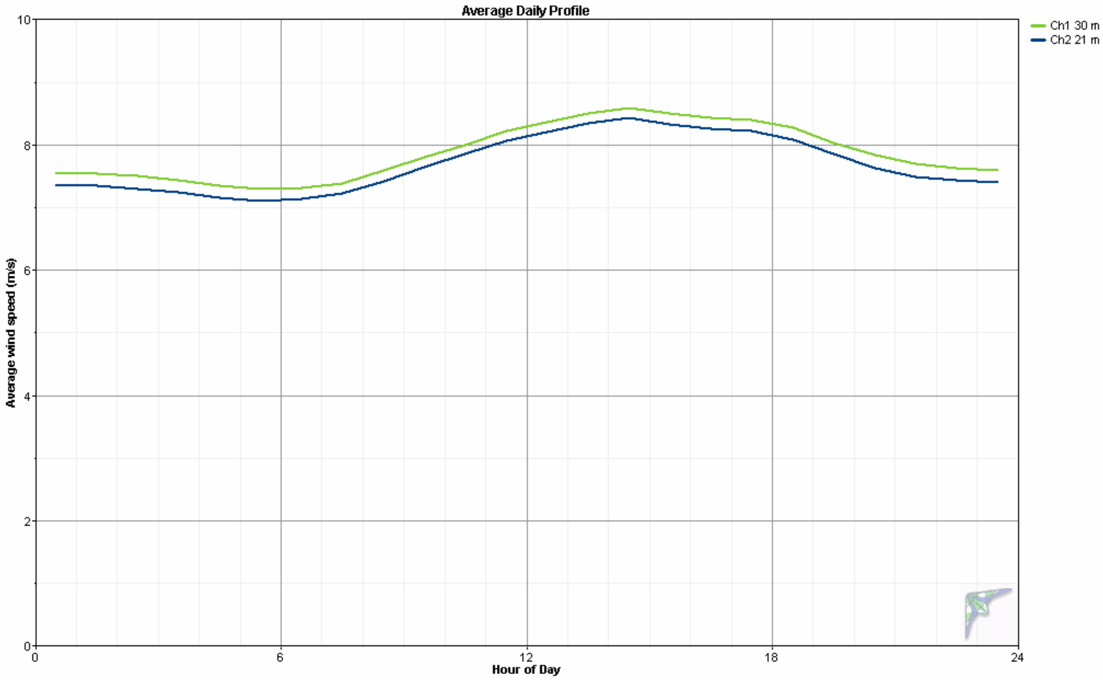
The Channel 1 (30-meter) anemometer annual wind speed average for the reporting period is 7.84 m/s and the Channel 2 (20-meter) anemometer wind speed average is 7.66 m/s.

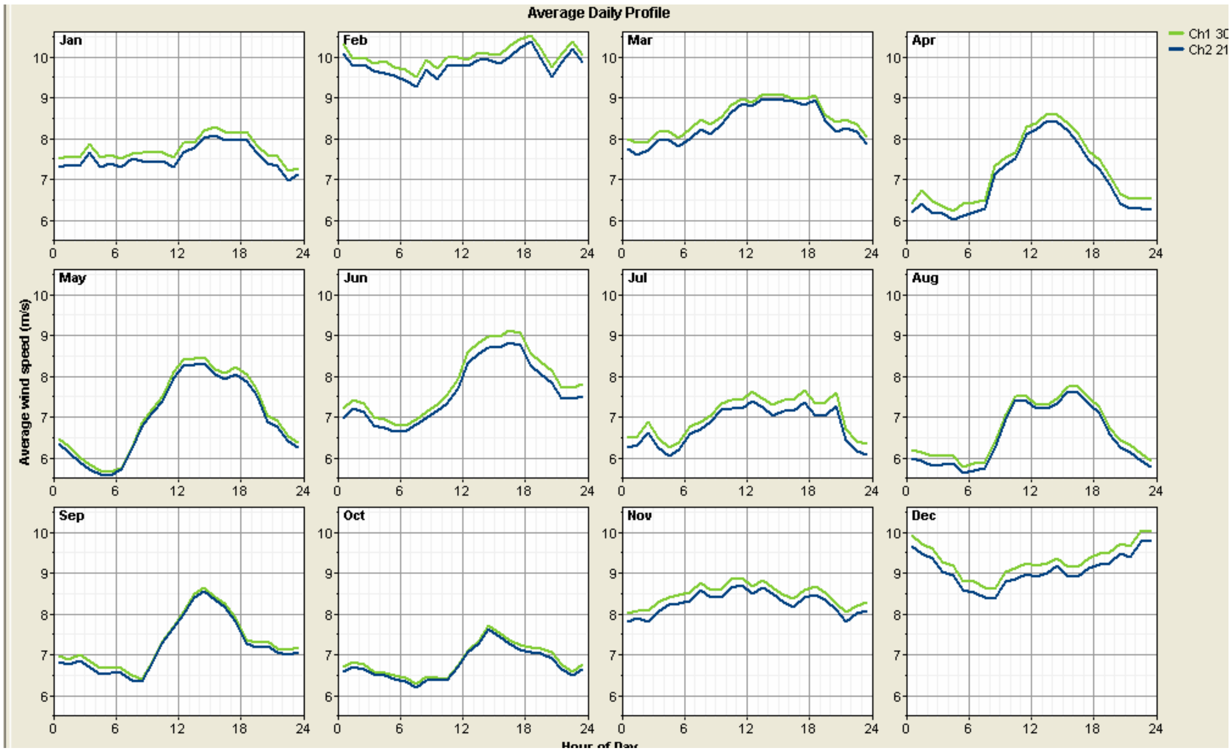
	30 m anemometer					21 m anemometer	
Month	Mean (m/s)	Max (m/s)	Std. Dev. (m/s)	Weibull k	Weibull c (m/s)	Mean (m/s)	Max (m/s)
Jan	7.73	21.9	4.51	1.72	8.64	7.53	21.7
Feb	10.01	27.2	6.08	1.61	11.11	9.81	26.8
Mar	8.53	27.4	4.86	1.77	9.55	8.35	26.9
Apr	7.22	27.3	4.46	1.64	8.05	7.00	26.7
May	7.09	24.1	4.81	1.41	7.74	6.97	23.6
Jun	7.84	25.3	5.01	1.49	8.60	7.60	24.7
Jul	7.03	19.1	3.49	2.04	7.87	6.79	18.6
Aug	6.68	20.7	3.60	1.86	7.48	6.53	20.2
Sep	7.33	26.8	3.85	1.93	8.22	7.23	26.1
Oct	6.86	25.6	4.22	1.63	7.63	6.77	25.0
Nov	8.46	28.4	4.63	1.87	9.51	8.27	27.4
Dec	9.32	27.2	5.62	1.61	10.34	9.08	26.5
Annual	**7.84**	28.4	4.79	1.64	8.77	**7.66**	27.4



Daily wind profile

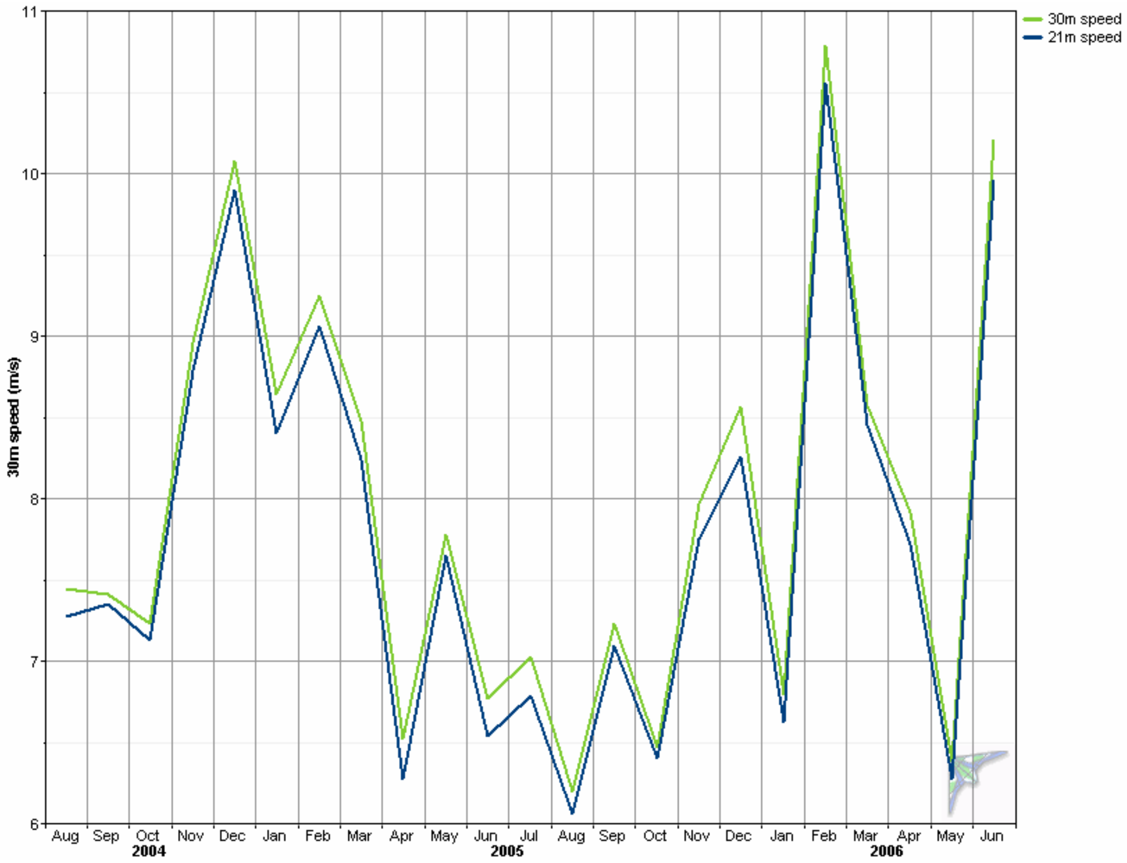
The daily wind profile indicates that the lowest wind speeds of the day occur in the morning hours of 5 a.m. to 7 a.m. and the highest wind speeds of the day occur during the afternoon hours of 1 p.m. to 4 p.m. The daily variation of wind speed is minimal on an annual basis but more pronounced on a monthly basis.

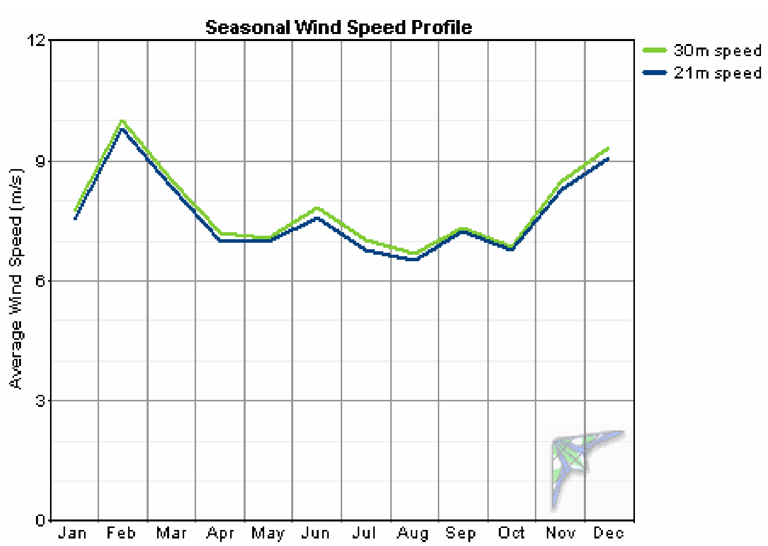




Time Series of Wind Speed Averages

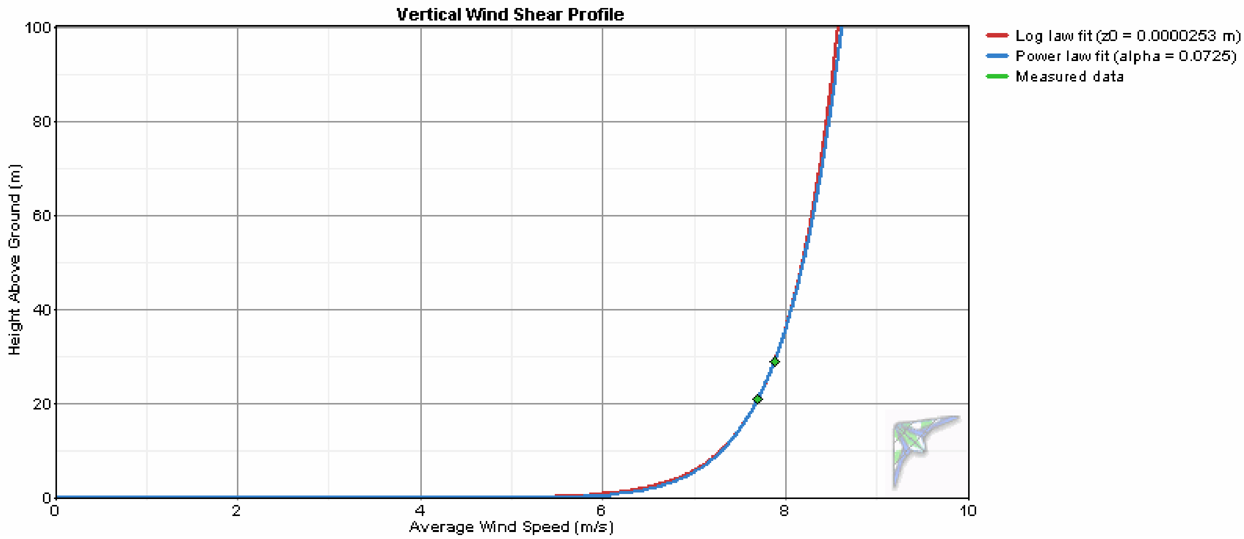
As expected, the highest winds occur during the winter months and the lowest winds during spring, summer and early autumn, but in the case of Kokhanok, this is relative as the monthly average wind speeds are very good all year round. The unusually low winds measured in January 2006 were due to a persistent high pressure system over Alaska that month that yielded calm winds and extremely cold weather Statewide.

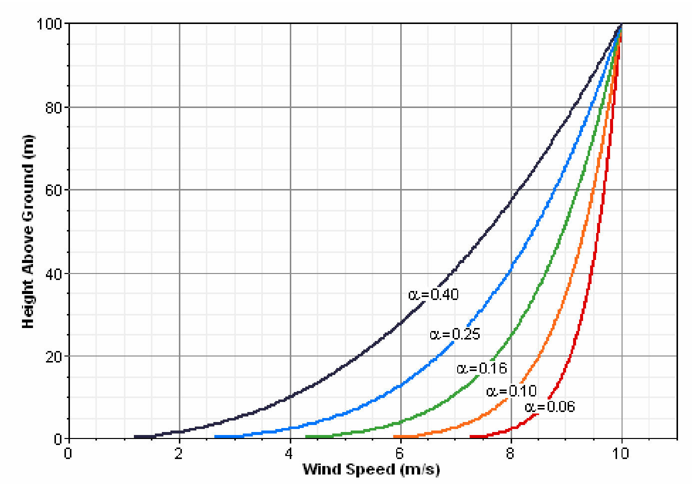


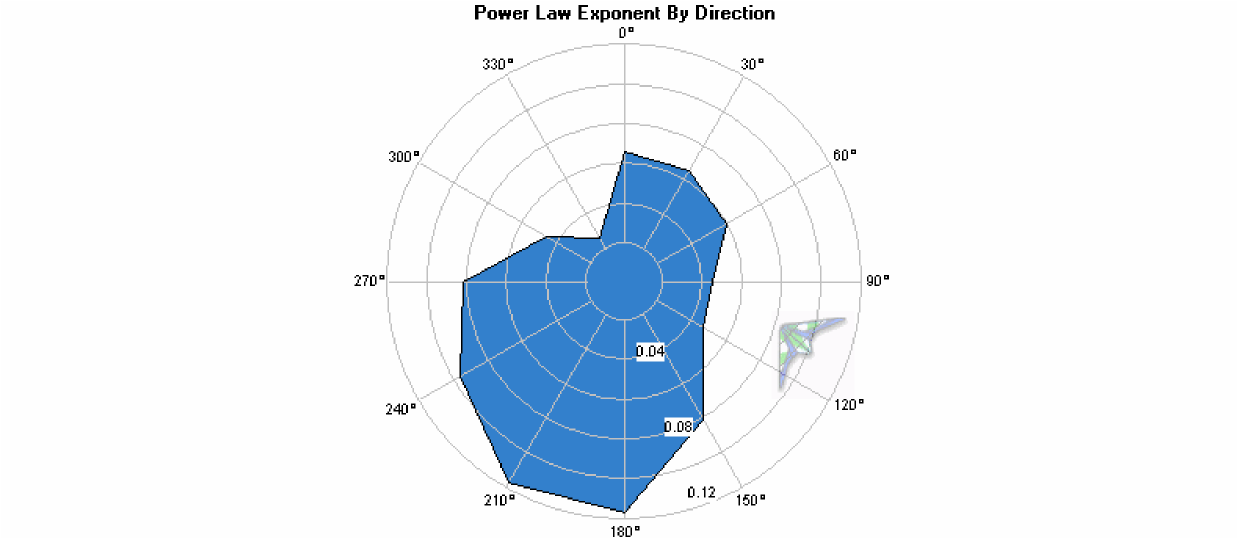


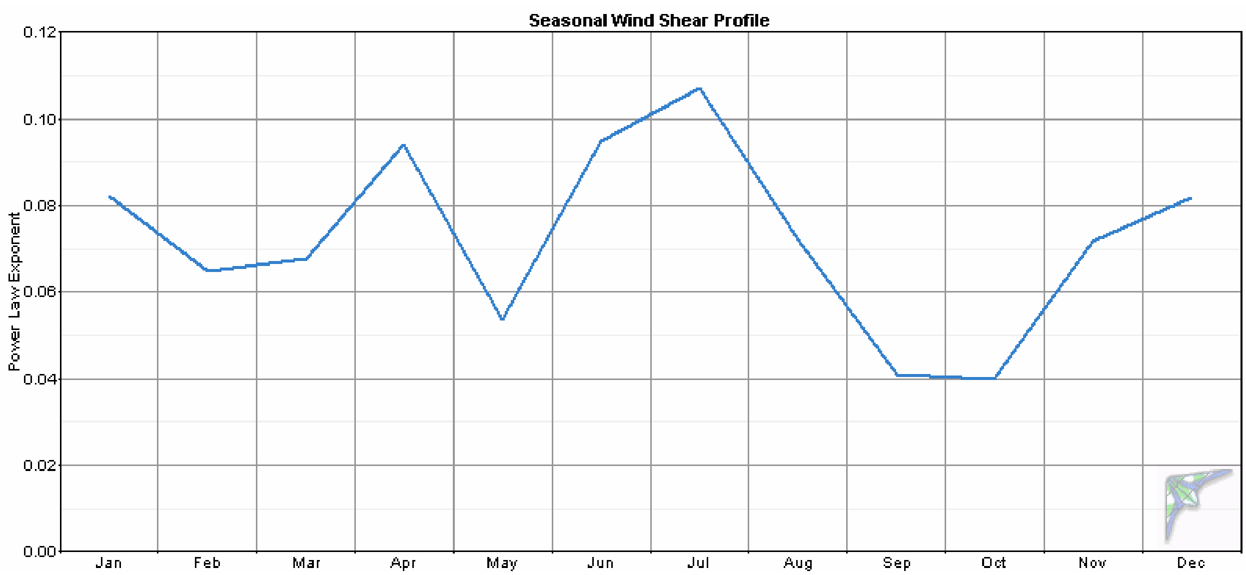
Wind Shear Profile

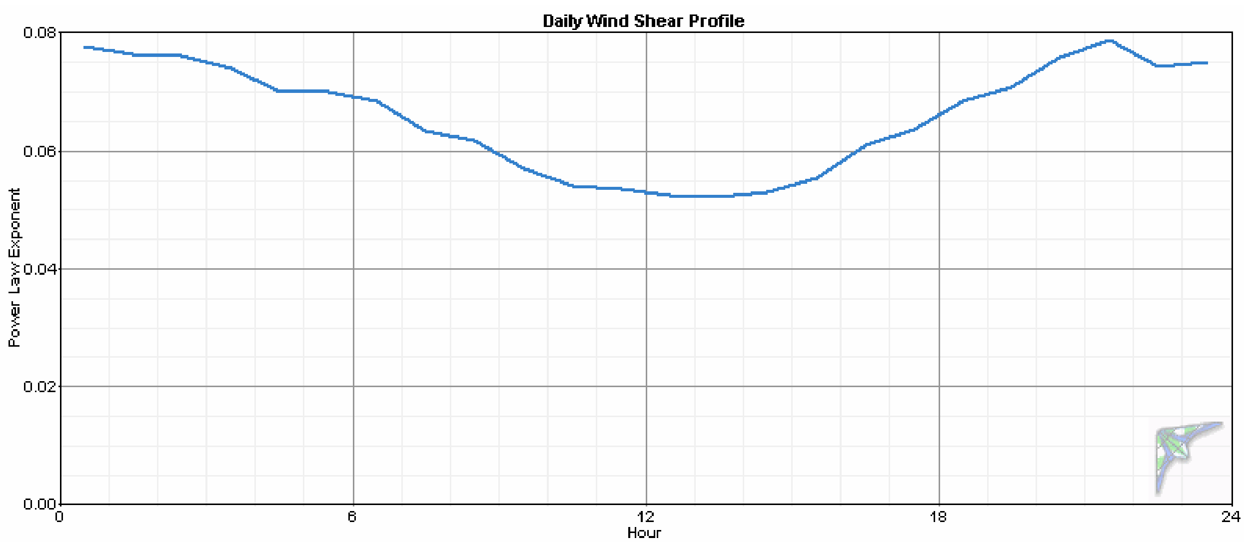
The power law exponent was calculated at 0.0656 indicating very low wind shear at the Kokhanok test site. The seasonal wind shear profile graph indicates that higher wind shear occurs in the summer months and lower wind shear in the winter months and that shear is lowest to the east and slightly higher to the southwest, although in all directions the wind shear is very low. The practical application of this data is that a low turbine tower height is possible as there will be only a marginal gain in wind speed/power recovery with additional height. A tower height/power recovery/construction cost tradeoff study is advisable.





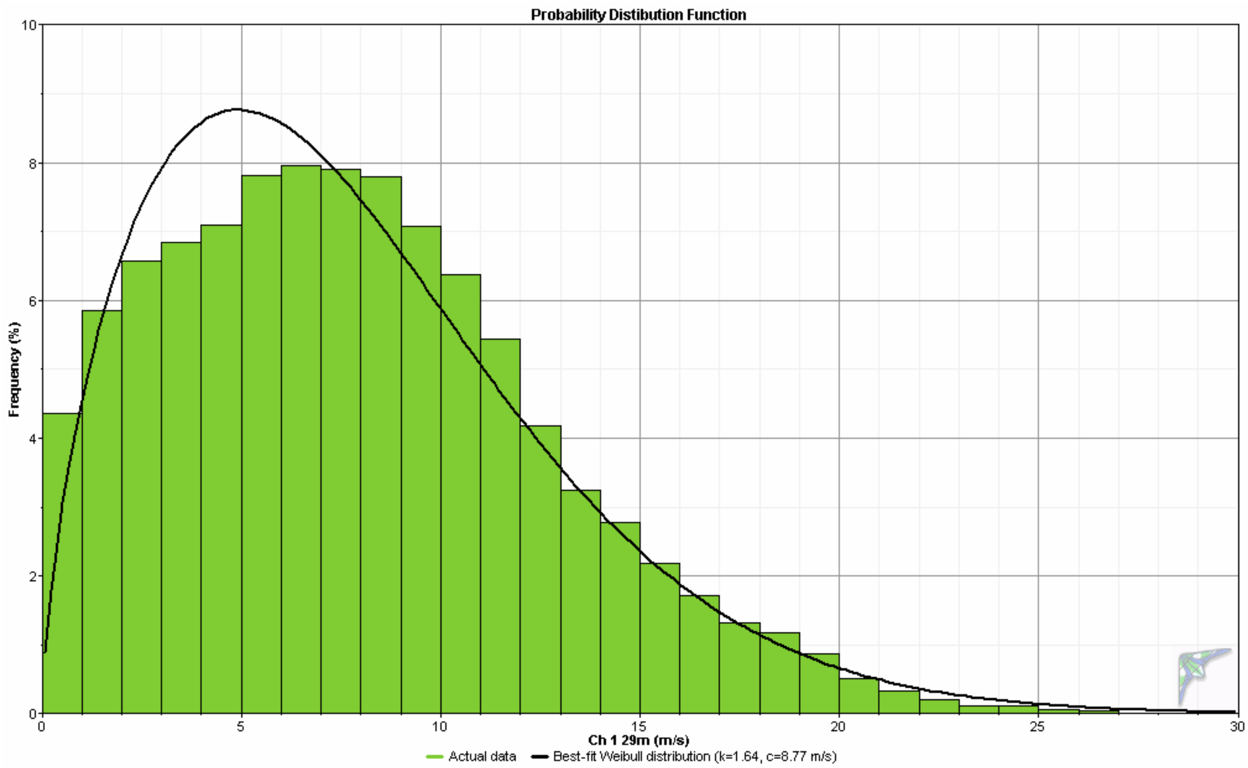

Power Law Exponent By Direction
0°
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
0.04
0.08
0.12

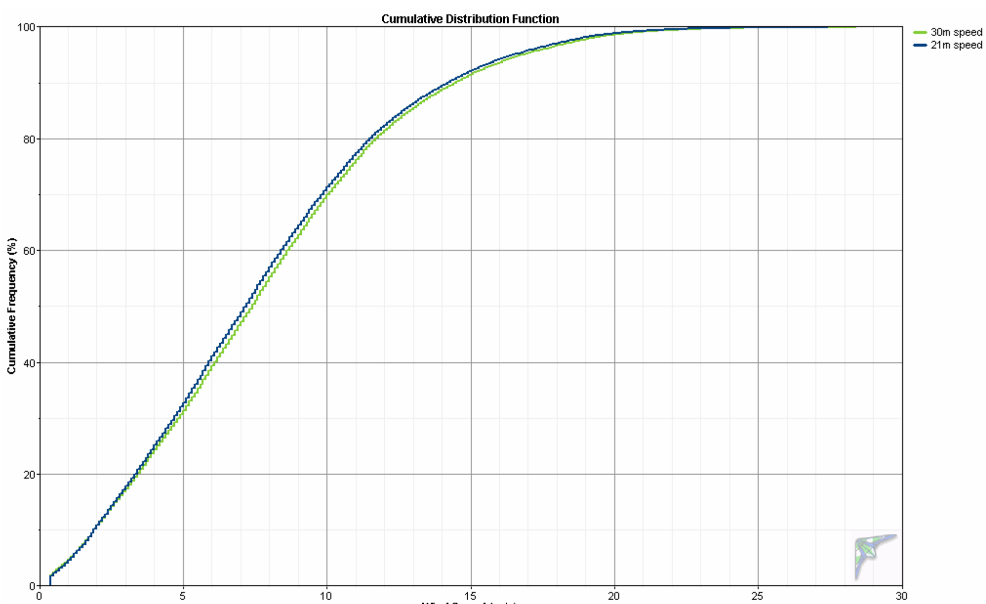

Seasonal Wind Shear Profile
Power Law Exponent
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


Daily Wind Shear Profile
Power Law Exponent
0.08
0.06
0.04
0.02
0.00
0
6
12
18
24
Hour

Probability Distribution Function

The probability distribution function provides a visual indication of measured wind speeds in one meter per second “bins”. Note that most wind turbines do not begin to generate power until the wind speed at hub height reaches 4 m/s. The black line in the graph is a best fit Weibull distribution. Weibull parameters are k = 1.64, c = 8.77 m/s. The PDF information is shown visually in another manner in the second graph, the Cumulative Distribution Function.

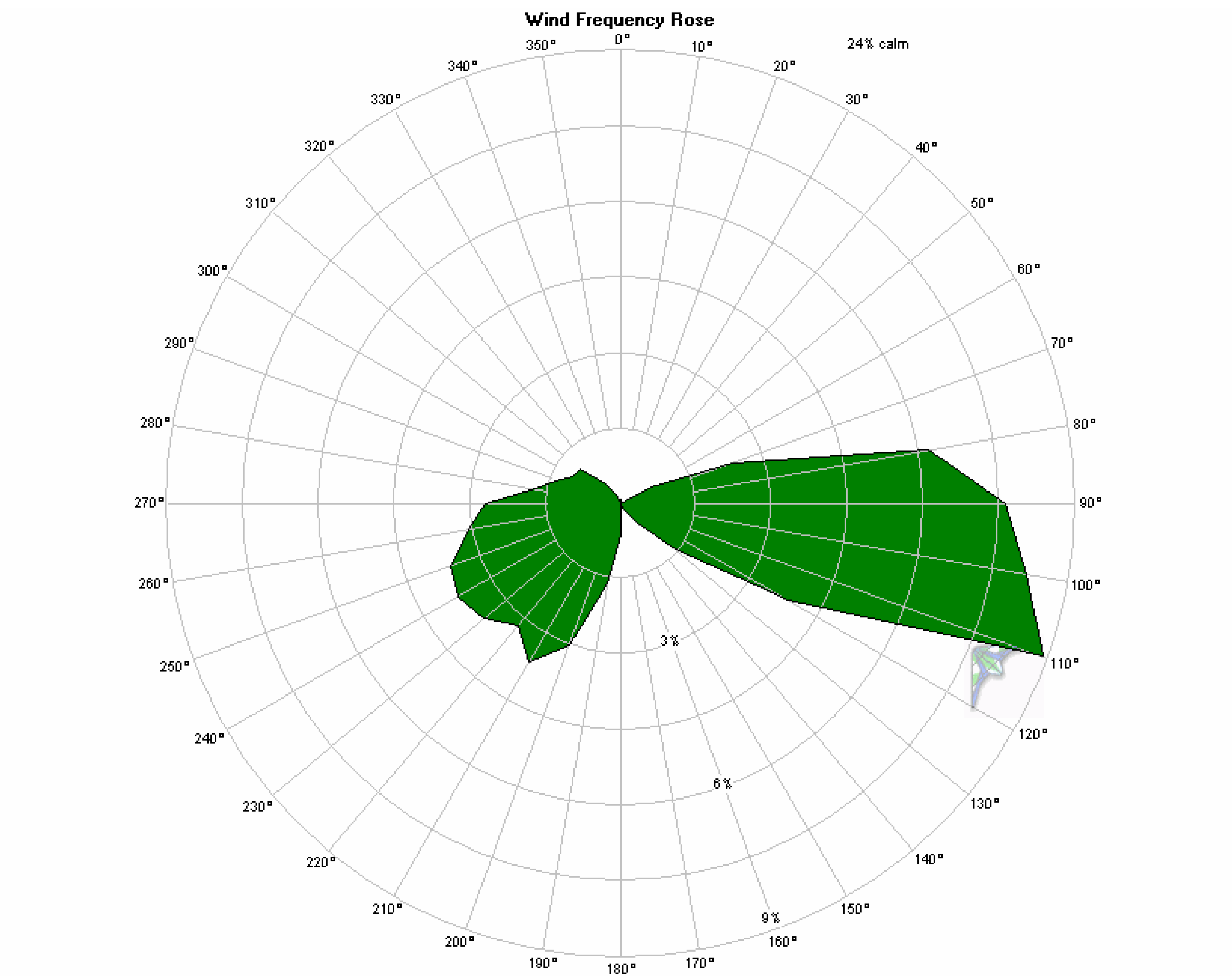




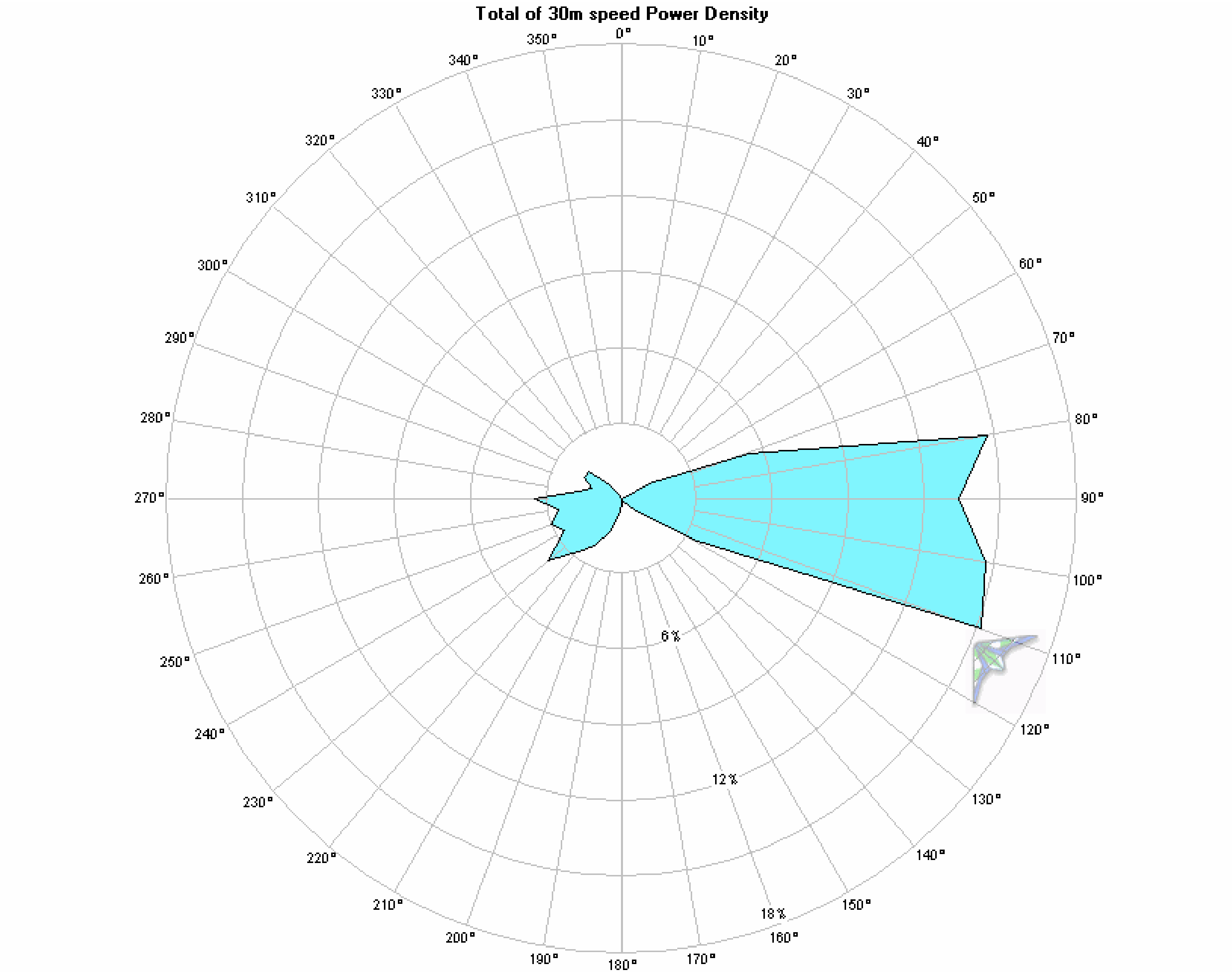
Wind Roses

Kokhanok winds are highly directional; the wind frequency rose indicates exclusively easterly and southwesterly winds. This observation is strongly reinforced with reference to the power density rose below. Power producing winds are almost entirely easterly. The practical application of this information is that the test site on the spit (the location of the Kokhanok's old airport) is ideal in that easterly winds travel a long fetch of water before traversing the site. If more than one turbine were to be placed in Kokhanok, they should be oriented north-south with a minimum 1.5 rotor diameter placement hub-to-hub. The indication below of 24 percent calm winds is calculated with a 4 m/s wind speed threshold, the typical cut-in speed of wind turbines.

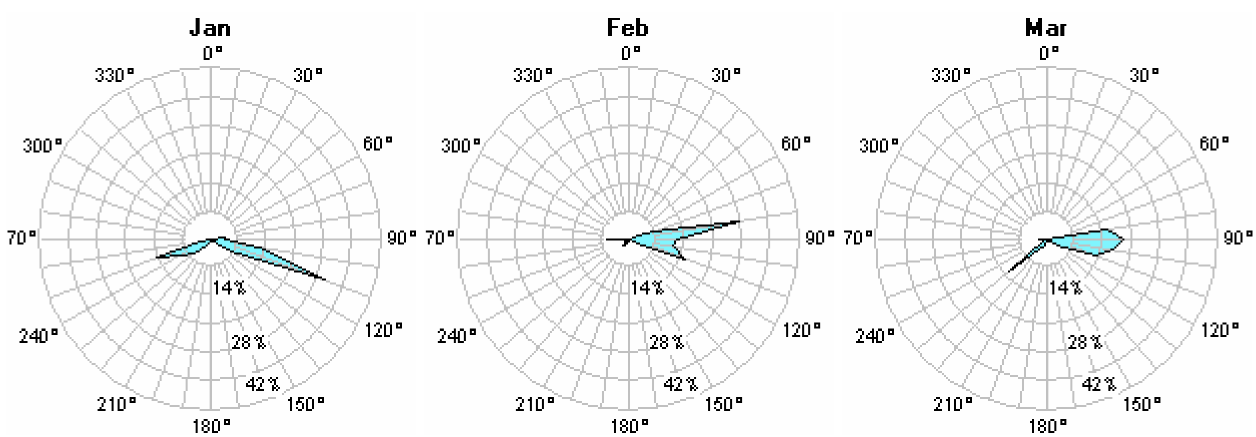
Wind Frequency Rose (30 meters)

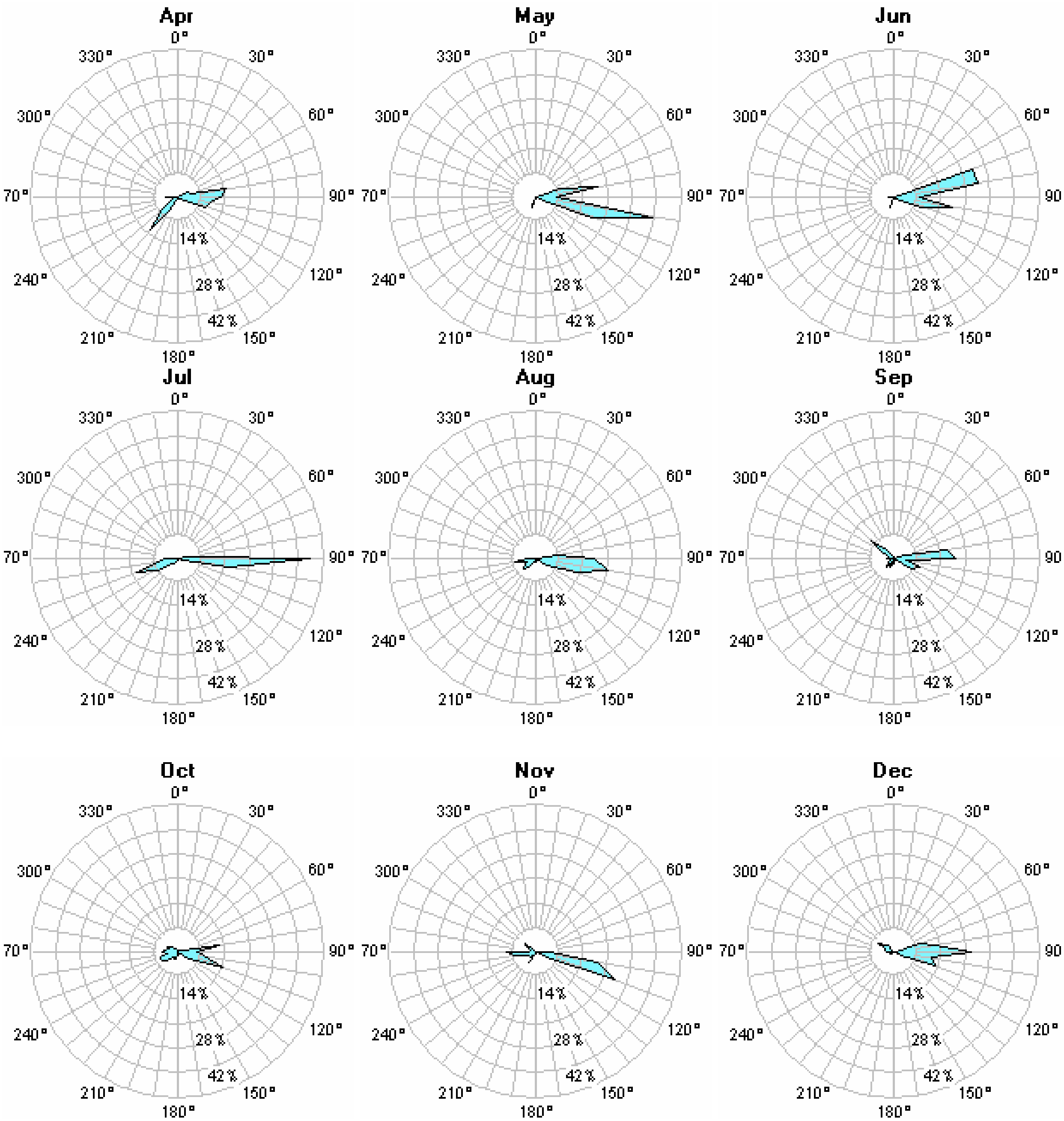


Wind Power Density Rose (30 meters)



Wind Power Density Rose by Month (30 meters)

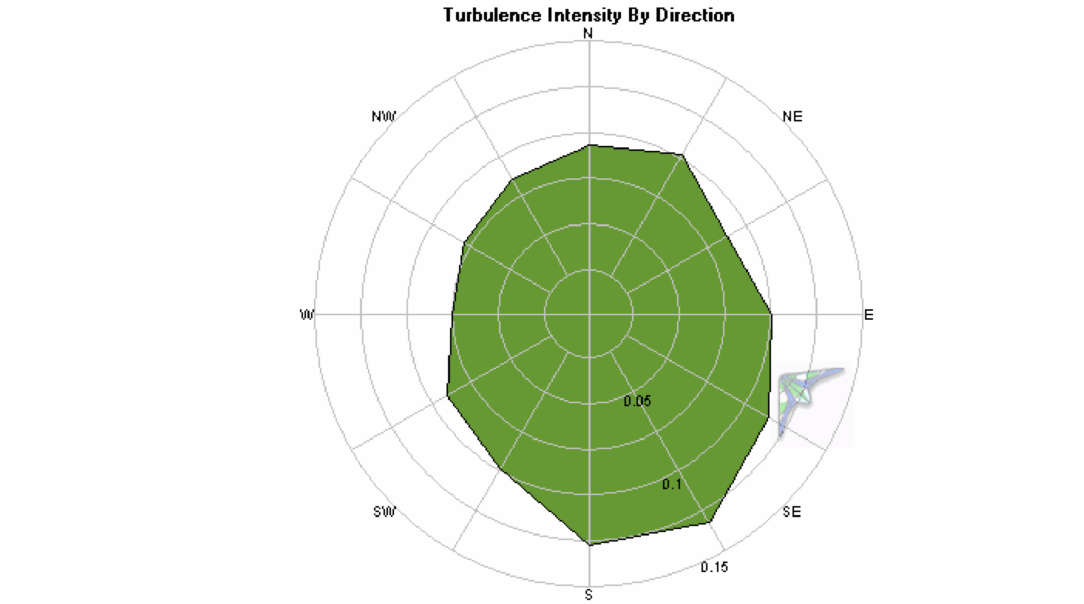



Apr
0° 30° 60° 90° 120° 150° 180° 210° 240° 70° 300° 330°
14% 28% 42%
May
0° 30° 60° 90° 120° 150° 180° 210° 240° 70° 300° 330°
14% 28% 42%
Jun
0° 30° 60° 90° 120° 150° 180° 210° 240° 70° 300° 330°
14% 28% 42%
Jul
0° 30° 60° 90° 120° 150° 180° 210° 240° 70° 300° 330°
14% 28% 42%
Aug
0° 30° 60° 90° 120° 150° 180° 210° 240° 70° 300° 330°
14% 28% 42%
Sep
0° 30° 60° 90° 120° 150° 180° 210° 240° 70° 300° 330°
14% 28% 42%
Oct
0° 30° 60° 90° 120° 150° 180° 210° 240° 70° 300° 330°
14% 28% 42%
Nov
0° 30° 60° 90° 120° 150° 180° 210° 240° 70° 300° 330°
14% 28% 42%
Dec
0° 30° 60° 90° 120° 150° 180° 210° 240° 70° 300° 330°
14% 28% 42%

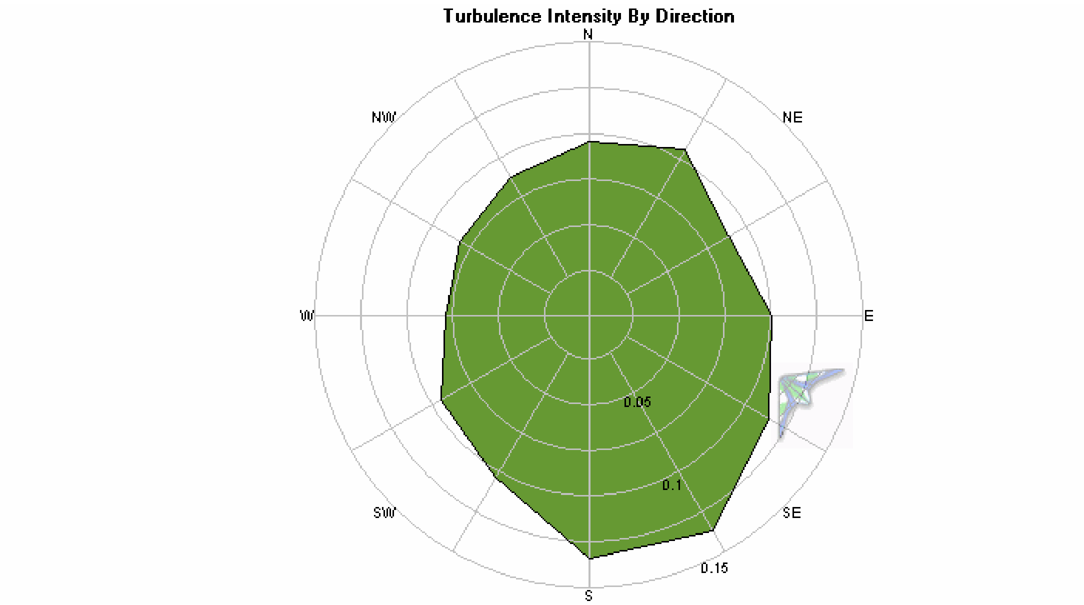
Turbulence Intensity

The turbulence intensity (TI) is quite acceptable for all wind direction, with a mean turbulence intensity of 0.0985 (30 meters) and 0.100 (20 meters), indicating very smooth air. These TIs are calculated with a threshold wind speed of 4 m/s. The spike of relatively high turbulence to the south and southeast in both graphs is due to the infrequent winds from these sectors. The most important TI is for winds from the east.

30-meter Turbulence Intensity

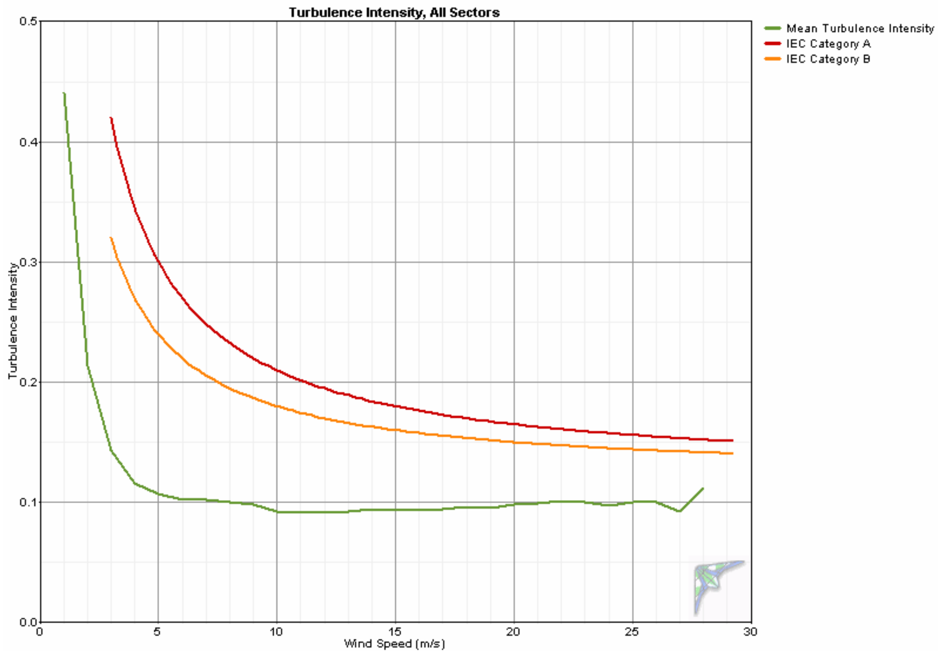


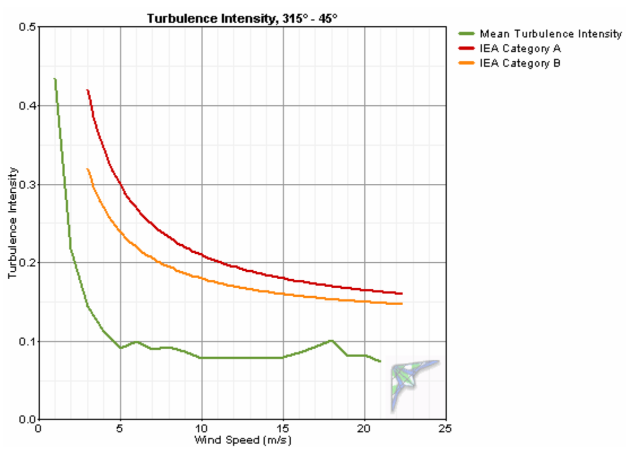
21-meter Turbulence Intensity

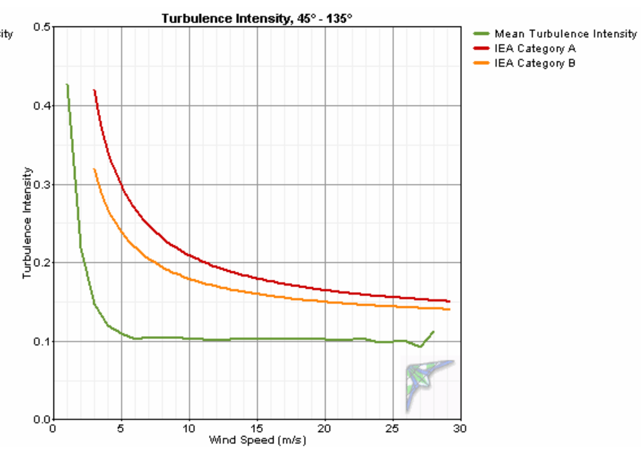


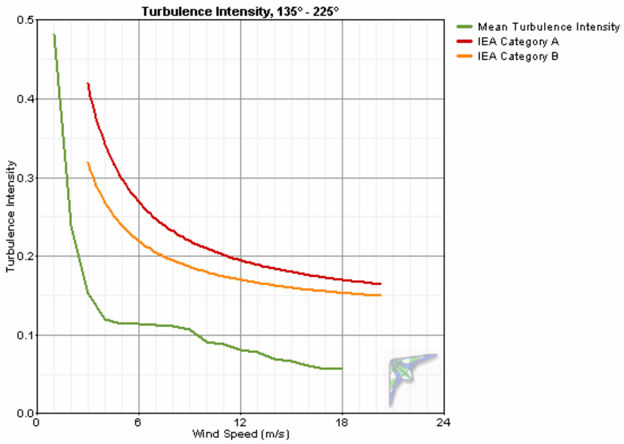
IEC Turbulence Intensity Standards

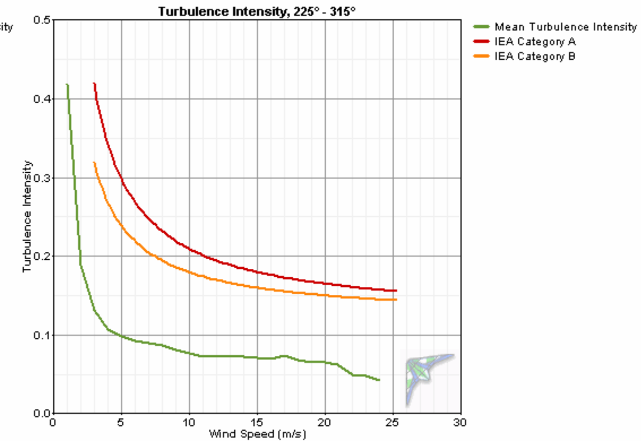
Turbulence at the Kokhanok project test site is well within International Electrotechnical Commission (IEC) standards at all measured wind speeds and from all four quadrants of the wind rose.











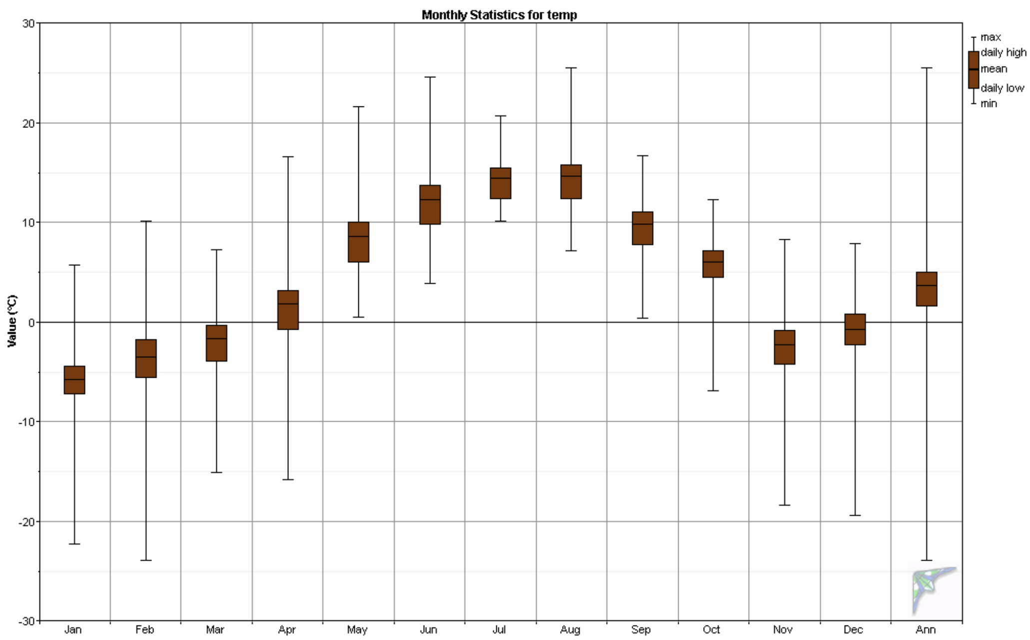
Turbulence Table

Bin Midpoint (m/s)	Bin Endpoints Lower (m/s)	Bin Endpoints Upper (m/s)	Records In Bin	Standard Deviation of Wind Speed (m/s)	Mean Turbulence Intensity	Standard Deviation of Turbulence Intensity	Characteristic Turbulence Intensity
1	0.5	1.5	4729	0.400	0.441	0.180	0.620
2	1.5	2.5	6175	0.409	0.214	0.121	0.335
3	2.5	3.5	6396	0.421	0.144	0.079	0.222
4	3.5	4.5	6665	0.456	0.116	0.059	0.174
5	4.5	5.5	7029	0.529	0.107	0.047	0.154
6	5.5	6.5	7605	0.607	0.102	0.041	0.144
7	6.5	7.5	7526	0.707	0.102	0.038	0.140
8	7.5	8.5	7705	0.798	0.100	0.035	0.136
9	8.5	9.5	7016	0.875	0.098	0.035	0.133
10	9.5	10.5	6397	0.922	0.093	0.035	0.127
11	10.5	11.5	5770	1.005	0.092	0.031	0.123
12	11.5	12.5	4517	1.096	0.092	0.030	0.121
13	12.5	13.5	3511	1.200	0.093	0.028	0.121
14	13.5	14.5	2814	1.317	0.094	0.026	0.120
15	14.5	15.5	2410	1.394	0.093	0.026	0.119
16	15.5	16.5	1882	1.489	0.093	0.025	0.119
17	16.5	17.5	1380	1.604	0.095	0.025	0.120
18	17.5	18.5	1231	1.726	0.096	0.025	0.121
19	18.5	19.5	954	1.811	0.096	0.024	0.119
20	19.5	20.5	638	1.945	0.098	0.023	0.121
21	20.5	21.5	404	2.066	0.099	0.021	0.120
22	21.5	22.5	261	2.212	0.101	0.023	0.124
23	22.5	23.5	167	2.303	0.101	0.021	0.122
24	23.5	24.5	90	2.326	0.097	0.020	0.117
25	24.5	25.5	96	2.484	0.100	0.022	0.122
26	25.5	26.5	55	2.598	0.100	0.022	0.122
27	26.5	27.5	28	2.500	0.093	0.014	0.107
28	27.5	28.5	2	3.150	0.112	0.020	0.133
29	28.5	29.5	0	3.150	0.112	0.020	0.133

Air Temperature and Density

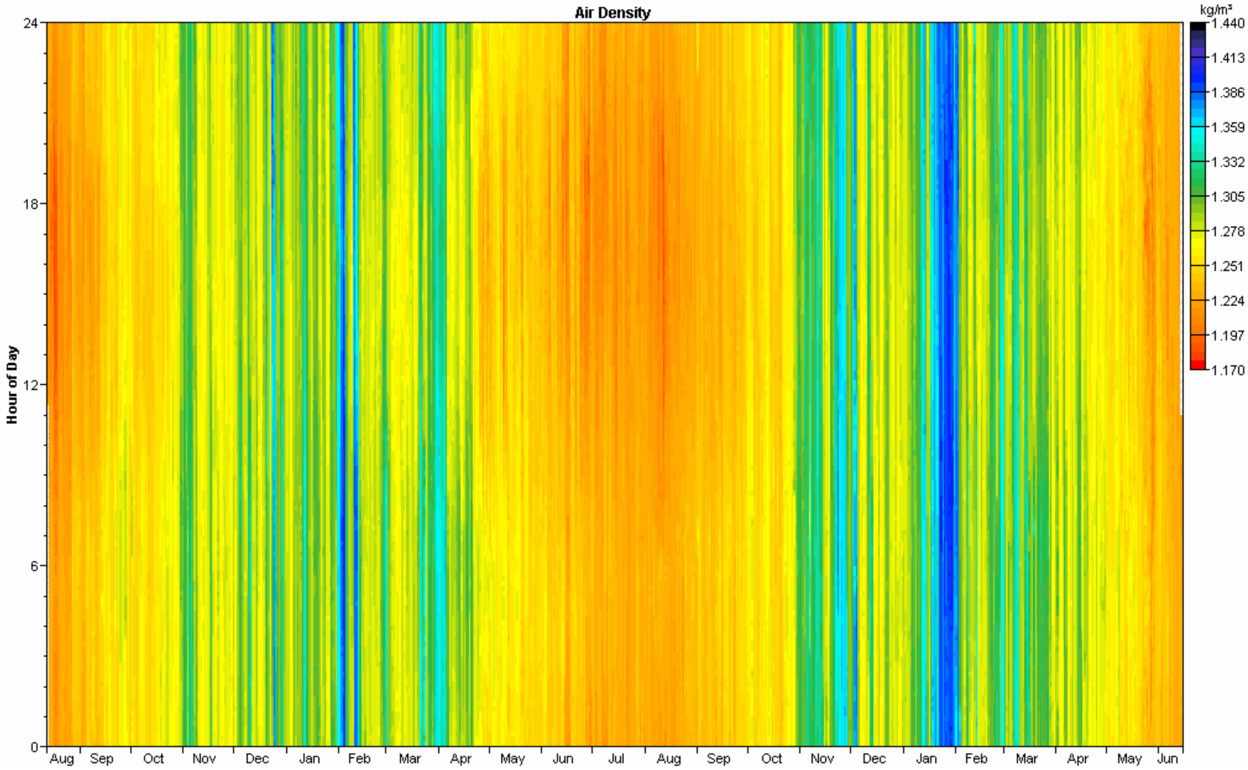
Over the reporting period, Kokhanok had an average temperature of 4.5° C. The minimum recorded temperature during the measurement period was -23.9° C and the maximum temperature was 25.5° C, indicating a wide variability of an ambient temperature operating environment important to wind turbine operations. Consequent to Kokhanok's cool temperatures, the average air density of 1.268 kg/m^3 is approximately four percent higher than the standard air density of 1.2223 kg/m^3 (14.8° C and 101.02 kPa at 23 m elevation), indicating that Kokhanok, due to its cool annual temperature average and low elevation, has denser air than the standard air density used to calculate turbine power curves. This density variance from standard *is* accounted for in turbine performance predictions in this report.

	Temperature				Density			
Month	Mean (°C)	Min (°C)	Max (°C)	Std. Dev. (°C)	Mean (kg/m³)	Min (kg/m³)	Max (kg/m³)	Std. Dev. (kg/m³)
Jan	-5.78	-22.3	5.7	7.81	1.317	1.262	1.403	0.0393
Feb	-3.47	-23.9	10.2	7.33	1.306	1.242	1.412	0.0366
Mar	-1.66	-15.1	7.3	5.02	1.297	1.255	1.364	0.0243
Apr	1.89	-15.8	16.6	4.93	1.280	1.215	1.367	0.0233
May	8.59	0.5	21.6	2.89	1.249	1.194	1.286	0.0127
Jun	12.34	3.9	24.6	2.76	1.233	1.182	1.270	0.0119
Jul	14.42	10.2	20.7	1.83	1.224	1.198	1.242	0.0078
Aug	14.67	7.2	25.5	2.58	1.223	1.178	1.255	0.0109
Sep	9.89	0.4	16.7	2.83	1.243	1.214	1.286	0.0125
Oct	6.10	-6.9	12.3	3.45	1.260	1.233	1.322	0.0158
Nov	-2.21	-18.4	8.3	5.99	1.299	1.250	1.381	0.0291
Dec	-0.68	-19.4	7.9	5.50	1.292	1.252	1.387	0.0269
Annual	**4.51**	-23.9	25.5	8.38	**1.268**	1.178	1.412	0.0394



Air Density DMap

The DMap below is a visual indication of the daily and seasonal variations of air density (and hence temperature). Air densities higher than standard will yield higher turbine power than predicted by turbine power curves, while densities lower than standard will yield lower turbine power than predicted. Density variance from standard is accounted for in the turbine performance predictions.



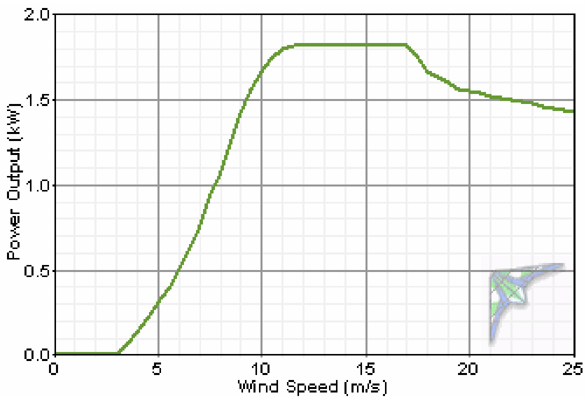
Wind Turbine Performance

The turbine performance predictions noted below are based on 100 percent and 90 percent turbine availabilities. The 100 percent data is for use as a baseline of comparison, but it is realistic to expect ten percent or more of losses or downtime for wind turbines located in a small, remote community.

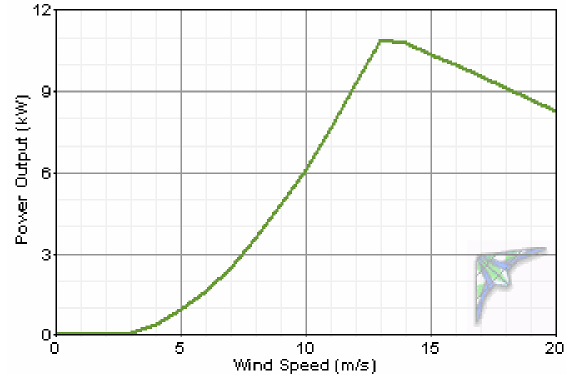
Note that these performance estimates were predicted with use of Windographer® wind analysis software; power curves provided by manufacturers are not independently verified and are assumed to be accurate. The power curves are presented for a standard air density of 1.225 kg/m^3 at 15° C temperature and 101.3 kPa pressure at sea level. However, the predictions of power production are density compensated by multiplying the standard density power output by the ratio of the measured air density to standard air density, accounting for the site elevation.

A number of smaller village-scale grid-connected turbines are profiled in this report for comparison purposes. These turbines were selected because they have market availability and they are deemed to be within a suitable range for consideration of wind power development in a village the size of Kokhanok.

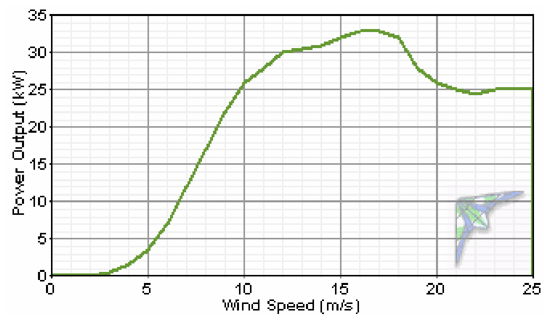
Southwest Skystream 3.7: 1.8 kW rated power output, 3.7 meter rotor diameter, stall-controlled. Available tower heights: 10.7 and 33.5 meters. Additional information is available at www.skystreamenergy.com.



Bergey Excel-S: 10 kW rated power output, 6.7 meter rotor diameter, stall-controlled. Available tower heights: 18, 24, 30, 37 and 43 meters. Additional information is available at www.bergey.com.

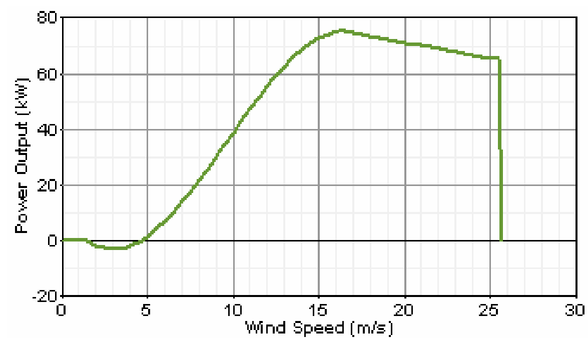


Fuhrländer FL30: 30 kW rated power output, 13 meter rotor, stall-controlled (power curve provided by Lorax Energy, LLC). Available tower heights: 26 and 30 meters. Additional information is available at http://www.fuhrlaender.de/ and http://www.lorax-energy.com/.

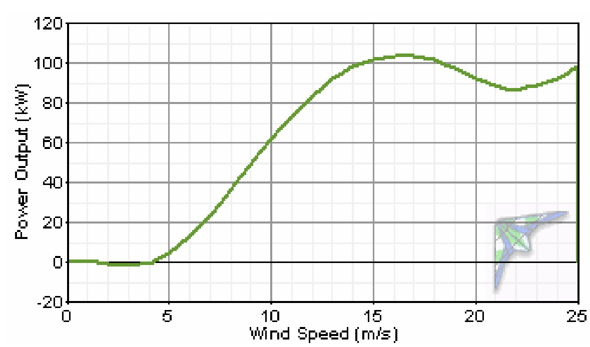


Entegrity eW-15: 65 kW rated power output, 15 meter rotor, stall-controlled (power curve provided by Entegrity Energy Systems). Available tower heights: 25 and 31 meters. Additional information is available at http://www.entegritywind.com/.

Vestas V15: 75 kW rated power output, 15 meter rotor, stall-controlled (power curve provided by Powercorp Alaska LLC). Available tower heights: 25, 31 and 34 meters. Additional information is available at http://www.pcorpalaska.com/.



Northwind 100/20: 100 kW rated power output, 20 meter rotor (19 meter rotor blades with 0.6 meter blade root extensions added), stall-controlled (power curve provided by Northern Power Systems). Available tower heights: 25 and 32 meters. Additional information is available at http://www.northernpower.com/.



Turbine Power Output Comparison (100% availability)

Turbine	Hub Height (m)	Hub Height Wind Speed (m/s)	Time At Zero Output (%)	Time At Rated Output (%)	Average Net Power Output (kW)	Annual Net Energy Output (kWh/yr)	Average Net Capacity Factor (%)
Southwest Skystream 3.7	10.7	7.37	18.8	20.9	0.88	7,711	48.9
Southwest Skystream 3.7	33.5	7.92	17.6	23.6	0.96	8,422	53.4
Bergey Excel-S	18	7.63	11.5	10.1	3.81	33,376	38.1
Bergey Excel-S	30	7.86	12.4	10.5	3.96	34,702	39.6
Fuhrländer FL30	26	7.80	10.9	6.8	15.1	132,559	45.9
Fuhrländer FL30	30	7.86	11.2	7.0	15.3	134,061	46.4
Entegrity eW-15 60 Hz	25	7.78	24.6	10.3	25.3	221,978	39.0
Entegrity eW-15 60 Hz	31	7.88	24.3	10.6	25.9	226,844	39.8
Vestas V15	25	7.78	28.7	6.8	25.3	221,585	33.7
Vestas V15	31	7.88	28.2	7.0	25.9	226,996	34.6
Northern Power NW 100/20	25	7.78	24.6	9.2	37.4	327,963	37.4
Northern Power NW 100/20	32	7.90	24.3	9.4	38.4	336,193	38.4

Capacity Factor <20%
Capacity Factor >20%, <30%
Capacity Factor >30%, <40%
Capacity Factor >40%, <50%
Capacity Factor >50%

Assumed turbine losses for predictions of average power output, annual energy output, and average capacity factor:

Downtime (%)	0
Array (%)	0
Icing/soiling (%)	0
Other (%)	0
Total (%)	0

Note: Calculated for the data period 8/12/04 to 6/14/06

Turbine Power Output Comparison (90% availability)

Turbine	Hub Height (m)	Hub Height Wind Speed (m/s)	Time At Zero Output (%)	Time At Rated Output (%)	Average Net Power Output (kW)	Annual Net Energy Output (kWh/yr)	Average Net Capacity Factor (%)
Southwest Skystream 3.7	10.7	7.37	18.8	20.9	0.80	6,963	44.2
Southwest Skystream 3.7	33.5	7.92	17.6	23.6	0.87	7,606	48.2
Bergey Excel-S	18	7.63	11.5	10.1	3.44	30,141	34.4
Bergey Excel-S	30	7.86	12.4	10.5	3.58	31,338	35.8
Fuhrländer FL30	26	7.80	10.9	6.8	13.7	119,710	41.4
Fuhrländer FL30	30	7.86	11.2	7.0	13.8	121,067	41.9
Entegrity eW-15 60 Hz	25	7.78	24.6	10.3	22.9	200,461	35.2
Entegrity eW-15 60 Hz	31	7.88	24.3	10.6	23.4	204,856	36.0
Vestas V15	25	7.78	28.7	6.8	22.8	200,107	30.5
Vestas V15	31	7.88	28.2	7.0	23.4	204,993	31.2
Northern Power NW 100/20	25	7.78	24.6	9.2	33.8	296,173	33.8
Northern Power NW 100/20	32	7.90	24.3	9.4	34.7	303,606	34.7

Capacity Factor <20%
Capacity Factor >20%, <30%
Capacity Factor >30%, <40%
Capacity Factor >40%, <50%
Capacity Factor >50%

Assumed turbine losses for predictions of average power output, annual energy output, and average capacity factor:

Downtime (%)	5	
Array (%)	0	
Icing/soiling (%)	3	
Other (%)	2	
Total (%)	9.69	(factors are multiplicative)

Note: Calculated for the data period 8/12/04 to 6/14/06

Annual Fuel Cost Avoided for Energy Generated by Wind Turbine vs. Diesel Generator

Turbine	Annual Energy Output (kW-hr/yr)	Fuel Quantity Avoided (liters)	Fuel Quantity Avoided (gallons)	Fuel Price (USD/gallon) $1.75	$2.00	$2.25	$2.50	$2.75	$3.00	$3.25	Turbine Hub Height (m)
Southwest Skystream 3.7	6,963	2,109	557	$975	$1,114	$1,253	$1,393	$1,532	$1,671	$1,810	10.7
Southwest Skystream 3.7	7,606	2,303	608	$1,065	$1,217	$1,369	$1,521	$1,673	$1,825	$1,978	33.5
Bergey Excel-S	30,141	9,128	2,411	$4,220	$4,823	$5,425	$6,028	$6,631	$7,234	$7,837	18
Bergey Excel-S	31,338	9,490	2,507	$4,387	$5,014	$5,641	$6,268	$6,894	$7,521	$8,148	30
Fuhrländer FL30	119,710	36,252	9,577	$16,759	$19,154	$21,548	$23,942	$26,336	$28,730	$31,125	26
Fuhrländer FL30	121,067	36,663	9,685	$16,949	$19,371	$21,792	$24,213	$26,635	$29,056	$31,477	30
Entegrity eW-15 60 Hz	200,461	60,706	16,037	$28,065	$32,074	$36,083	$40,092	$44,101	$48,111	$52,120	25
Entegrity eW-15 60 Hz	204,856	62,037	16,388	$28,680	$32,777	$36,874	$40,971	$45,068	$49,165	$53,263	31
Vestas V15	200,107	60,599	16,009	$28,015	$32,017	$36,019	$40,021	$44,024	$48,026	$52,028	25
Vestas V15	204,993	62,078	16,399	$28,699	$32,799	$36,899	$40,999	$45,098	$49,198	$53,298	31
Northern Power NW 100/20	296,173	89,691	23,694	$41,464	$47,388	$53,311	$59,235	$65,158	$71,082	$77,005	25
Northern Power NW 100/20	303,606	91,942	24,288	$42,505	$48,577	$54,649	$60,721	$66,793	$72,865	$78,938	32

Notes:

1. Kokhanok electrical energy production efficiency assumed to be 12.5 kW-hr/gal
2. Assumes 90% wind turbine availability with no diversion of power to a thermal or other dump load
3. Assumes linear diesel generator fuel efficiency (i.e., 1:1 tradeoff of wind turbine kW-hr to diesel genset kW-hr)
4. Calculated for the data period 8/12/04 to 6/14/06

Temperature Conversion Chart °C to °F

°C	°F	°C	°F	°C	°F
-40	-40	-10	14	20	68
-39	-38.2	-9	15.8	21	69.8
-38	-36.4	-8	17.6	22	71.6
-37	-34.6	-7	19.4	23	73.4
-36	-32.8	-6	21.2	24	75.2
-35	-31	-5	23	25	77
-34	29.2	-4	24.8	26	78.8
-33	-27.4	-3	26.6	27	80.6
-32	-25.6	-2	28.4	28	82.4
-31	-23.8	-1	30.2	29	84.2
-30	-22	0	32	30	86
-29	-20.2	1	33.8	31	87.8
-28	-18.4	2	35.6	32	89.6
-27	-16.6	3	37.4	33	91.4
-26	-14.8	4	39.2	34	93.2
-25	-13	5	41	35	95
-24	-11.2	6	42.8	36	96.8
-23	-9.4	7	44.6	37	98.6
-22	-7.6	8	46.4	38	100.4
-21	-5.8	9	48.2	39	102.2
-20	-4	10	50	40	104
-19	-2.2	11	51.8	41	105.8
-18	-0.4	12	53.6	42	107.6
-17	1.4	13	55.4	43	109.4
-16	3.2	14	57.2	44	111.2
-15	5	15	59	45	113
-14	6.8	16	60.8	46	114.8
-13	8.6	17	62.6	47	116.6
-12	10.4	18	64.4	48	118.4
-11	12.2	19	66.2	49	120.2

Wind Speed Conversion Chart, m/s to mph

m/s	mph	m/s	mph	m/s	mph	m/s	mph	m/s	mph
0.5	1.1	10.5	23.5	20.5	45.9	30.5	68.2	40.5	90.6
1.0	2.2	11.0	24.6	21.0	47.0	31.0	69.3	41.0	91.7
1.5	3.4	11.5	25.7	21.5	48.1	31.5	70.5	41.5	92.8
2.0	4.5	12.0	26.8	22.0	49.2	32.0	71.6	42.0	93.9
2.5	5.6	12.5	28.0	22.5	50.3	32.5	72.7	42.5	95.1
3.0	6.7	13.0	29.1	23.0	51.4	33.0	73.8	43.0	96.2
3.5	7.8	13.5	30.2	23.5	52.6	33.5	74.9	43.5	97.3
4.0	8.9	14.0	31.3	24.0	53.7	34.0	76.1	44.0	98.4
4.5	10.1	14.5	32.4	24.5	54.8	34.5	77.2	44.5	99.5
5.0	11.2	15.0	33.6	25.0	55.9	35.0	78.3	45.0	100.7
5.5	12.3	15.5	34.7	25.5	57.0	35.5	79.4	45.5	101.8
6.0	13.4	16.0	35.8	26.0	58.2	36.0	80.5	46.0	102.9
6.5	14.5	16.5	36.9	26.5	59.3	36.5	81.6	46.5	104.0
7.0	15.7	17.0	38.0	27.0	60.4	37.0	82.8	47.0	105.1
7.5	16.8	17.5	39.1	27.5	61.5	37.5	83.9	47.5	106.3
8.0	17.9	18.0	40.3	28.0	62.6	38.0	85.0	48.0	107.4
8.5	19.0	18.5	41.4	28.5	63.8	38.5	86.1	48.5	108.5
9.0	20.1	19.0	42.5	29.0	64.9	39.0	87.2	49.0	109.6
9.5	21.3	19.5	43.6	29.5	66.0	39.5	88.4	49.5	110.7
10.0	22.4	20.0	44.7	30.0	67.1	40.0	89.5	50.0	111.8

Distance Conversion m to ft

m	ft	m	ft
5	16	35	115
10	33	40	131
15	49	45	148
20	66	50	164
25	82	55	180
30	98	60	197

Selected definitions (courtesy of Windographer® software by Mistaya Engineering Inc.)

Wind Power Class

The wind power class is a number indicating the average energy content of the wind resource. Wind power classes are based on the average wind power density at 50 meters above ground, according to the following table. Source: Wind Energy Resource Atlas of the United States (http://rredc.nrel.gov/wind/pubs/atlas/tables/A-8T.html)

Wind Power Class	Description	Power Density at 50m (W/m^2)
1	Poor	0-200
2	Marginal	200-300
3	Fair	300-400
4	Good	400-500
5	Excellent	500-600
6	Outstanding	600-800
7	Superb	800-2000

Windographer classifies any wind resource with an average wind power density above 2000 W/m^2 as class 8.

Probability Distribution Function

The probability distribution function f(x) gives the probability that a variable will take on the value x. It is often expressed using a frequency histogram, which gives the frequency with which the variable falls within certain ranges or bins.

Wind Turbine Power Regulation

All wind turbines employ some method of limiting power output at high wind speeds to avoid damage to mechanical or electrical subsystems. Most wind turbines employ either stall control or pitch control to regulate power output.

A stall-controlled turbine typically has blades that are fixed in place, and are designed to experience aerodynamic stall at very high wind speeds. Aerodynamic stall dramatically reduces the torque produced by the blades, and therefore the power produced by the turbine.

On a pitch-controlled turbine, a controller adjusts the angle (pitch) of the blades to best match the wind speed. At very high wind speeds the controller increasingly feathers the blades out of the wind to limit the power output.