KM Chng Environmental Inc.

MEMORANDUM

To: Aaron Kisicki (Vermont DPS)

From: Rich Letty and Martin Brien (KM Chng)

Subject: Vermont Public Service Department
Sheffield Wind Turbine Project - Supplemental Noise Measurements

Date: 24 May 2013

EXECUTIVE SUMMARY

The Sheffield Wind Project consists of 16 wind turbines located on the summit of Granby Mountain and Libby Hill, located within the boundaries of the Town of Sheffield, VT. At the request of the Vermont Department of Public Service, noise measurements were obtained over a three day period at the Therrien residence at 2924 New Duck Pond Road. The purpose of this noise study was:

- To obtain noise measurements at the Therrien residence over a 3-day period and compare the measured noise levels to the Vermont Public Service Board noise limit established for the facility, and
- To obtain 1/3rd-octave band noise measurements to determine if there are any tonal components to the noise at this location.

The results of the study indicate that:

- During the three days of measurements at this location, Leq A-weighted noise levels were obtained in 10-minute increments. During day 1 when the winds were relatively clam, the average daily (all of the 10-minute measurements averaged over the 24-hour period) was 30 dBA. The only audible noise on day 1 was from the traffic on I-91. On days 2 and 3, when the winds were significantly higher, the average daily Leq noise level was 47 dBA on day 2, and 45 dBA on day 3. The higher Leq noise levels on days 2 and 3 were due to the noise generated by the windy weather conditions, and not from the turbine facility. Any noise from the turbines was inaudible above the wind noise.
- Due to the relatively low level of turbine noise at the Therrien residence, it was not possible to isolate the wind turbine noise from other environmental noises in the area. It had been expected that the wind turbines would be audible at this location. However, from field observations regarding wind turbine audibility and from the noise measurements obtained at

the Therrien residence during the three day period, the noise levels from the wind turbine facility appeared to be below the 45 dBA Leq outdoor noise limit applied by the Vermont Public Service Board for other wind turbine projects. We were unable to gain access to the wind turbine facility to obtain noise measurements near the wind turbines where the wind turbine noise would be audible above the background wind noise. These noise measurements would have provided baseline reference source noise levels from the wind turbines.

- The 1/3rd-octave band noise measurements do not indicate any audible or measurable tonal component to the environmental noise at this location.

However, it should be noted that in conversations with the Therriens, the three-day measurement period was not representative of the worst-case noise conditions that they experience. They are most impacted by the wind turbine noise when the winds are from the east and the south, and their residence is directly downwind of the wind turbines. If measurements are to be made that demonstrate these worst-case noise conditions, it may be necessary to greatly extend the time of measurement period to catch the particular operating and atmospheric conditions that cause the level of annoyance claimed by the Therriens.

INTRODUCTION

The Sheffield Wind Farm is a 40 MW wind turbine facility operating in Sheffield, VT and is owned by First Wind. The facility includes 16 wind turbines atop Granby Mountain and Libby Hill. The facility is located in the Northeast Kingdom area of Vermont, which is a very quiet region, where background noise levels can be quite low. Since operations began at the facility over a year ago, there have been noise complaints from local residents.

The following noise measurement program was performed for the purpose of assessing the current noise environment at the Therrien residence in response to their noise complaints.

NOISE FROM WIND TURBINES – Background Information

The sources of noise emitted from operating wind turbines can be divided into two categories: mechanical and aerodynamic. Mechanical noise is transmitted along the structure of the turbine and is radiated from its surfaces. Aerodynamic noise is produced by the flow of air over the blades.

Mechanical noise originates from the relative motion of mechanical components and the dynamic response among them. Sources of such noise include the turbine gearbox, generator, yaw drives, cooling fans, and auxiliary equipment. Since the emitted noise is associated with the rotation of mechanical and electrical equipment, it tends to be tonal, although it may also have a broadband component. In addition, the hub, rotor, and tower may act as a loudspeaker, transmitting the mechanical noise and radiating it. The transmission path of the mechanical noise can be air-borne or structure-borne.

Aerodynamic noise originates from the flow of air around the blades. Aerodynamic noise generally increases with rotor speed. Aerodynamic broadband noise is typically the largest source of wind turbine noise. The various aerodynamic noise mechanisms can be divided into three groups:

(1) Low frequency noise generated when the rotating blade encounters localized flow disturbances due to the flow around a tower, wind speed changes, or wakes shed from other blades;

(2) Inflow turbulence noise that is generated by the amount of atmospheric turbulence that results in local force or local pressure fluctuations around the blade; and

(3) Airfoil self noise that is generated by the air-flow along the surface of the airfoil.

Turbines can be designed to minimize mechanical noise. This can include special finishing of gear teeth, using low speed cooling fans and mounting components in the nacelle instead of at ground level, adding baffles and acoustic insulation to the nacelle, using vibration isolation and soft mounts for major components, and designing the turbine to prevent noises from being transmitted into the overall structure. Efforts to reduce aerodynamic noise include the use of lower blade tip speed, lower blade angles of attack, upwind turbine design, variable speed operation and the use of specially modified blade trailing edges.

Recent improvements in mechanical design of large wind turbines have resulted in significantly reduced mechanical noise from both broadband and pure tones. As a result, the noise emission from modern wind turbines is dominated by broadband aerodynamic noise.

Wind turbine generated noise is a function of wind speed and of other aspects of the design of the wind turbine. Wind turbines may have blades that are rigidly attached to the rotor shaft and that always operate at a constant speed. Other designs may have blades that can be pitched (rotated around their long axis). Other designs might change the rotor speed as the wind changes. Wind turbine rotors may be upwind or downwind of the tower. Each of these design features might have different noise emissions because of the way in which they operate. In general, upwind rotors as opposed to downwind rotors, lower rotational speeds and pitch control result in lower noise generation.

The wind turbines at the Sheffield facility are of the modern design. They are Clipper Liberty 2.5 megawatt (MW) wind turbines with variable pitch and variable speed blades manufactured by Clipper Windpower at their facility in Cedar Rapids, Iowa.

Aerodynamic noise generation is very sensitive to speed of translation at the very tip of the blade. To limit the generation of aerodynamic noise, large modern wind turbines limit the rotor rotation speeds to keep the tip speeds under 65 meters/second. Large variable speed wind turbines often rotate at slower speeds in low winds, increasing in higher winds until the limiting rotor speed is reached. This results in much quieter operation in low wind conditions than a comparable constant speed wind turbine.

In general, as noise propagates without obstruction from a point source, the sound pressure level decreases. The initial energy in the noise is distributed over a larger and larger area as the distance from the source increases. With spherical propagation, the sound pressure is reduced by 6 dB per doubling of distance. This simple model of spherical propagation must be modified in the presence of reflective surfaces and other effects. For example, if the source of noise is on a perfectly flat and reflecting surface (such as an off-shore wind turbine), then hemispherical spreading will occur. Although this would also result is a 6 dB reduction per doubling of distance, given the reflective characteristics of the water, the sound level would be 3 dB higher at a given distance than with spherical spreading. The development of an accurate noise propagation model generally must include the following factors: source characteristics (wind turbine sound power level, directivity, height); distance from the source to the receptor; air absorption (which depends on frequency of the noise level); ground effects (reflection and absorption of sound on the ground, dependent on source height, terrain cover, ground properties, frequency of the noise levels); blocking of sound by obstructions and uneven terrain; and weather effects (such as wind speed, change of wind speed or temperature with height). In addition, the prevailing wind direction can cause considerable differences in sound pressure levels between upwind and downwind locations.

The ability to hear wind turbine noise depends on the ambient background noise levels. When the background noise and wind turbine noise are of the same magnitude, the wind turbine noise could be masked by the background noise. The ambient background sound levels will be a function of such things as local traffic, industrial noises, farm machinery, barking dogs, lawnmowers, insects, birds, other outdoor activities, and the interaction of the wind with ground cover, buildings, and trees. It will vary with the time of day, wind speed and direction, and the amount of human outdoor activity. Both the wind turbine sound level and the ambient sound level will be a function of wind speed. Thus whether a wind turbine exceeds the background sound level will depend on how each of these varies with wind speed. The wind-generated contribution to background noise tends to increase fairly rapidly with wind speed. For example, ambient background noise measurements obtained on another project in a quiet rural area was 25 dBA during calm wind conditions, and 40 dBA when the wind was 12 mph.

Wind turbine noise from large modern wind turbines during constant speed operation tends to increase more slowly with increasing wind speed than does ambient wind generated noise. As a result, noise issues are more commonly a concern at lower wind speeds and it is often difficult to measure sound from modern wind turbines above wind speeds of 15 mph because the background wind-generated noise masks the wind turbine noise. However, it should be remembered that just using sound pressure levels might not always indicate when a noise is detectable by a listener. For example, just as a dog's barking can be heard through other noise, sounds with particular frequencies or in an identifiable pattern may be heard through the background noise that is otherwise loud enough to mask those noises. Noise from wind turbines will also vary as the turbulence in the wind through the rotor changes. Turbulence in the ground level winds will also affect a listener's ability to hear other noises. Because fluctuations in ground level winds speeds will not exactly correlate with those at the height of the turbine, a listener might find moments when the wind turbine could be heard over the ambient noise.

NOISE MEASUREMENT

Outdoor noise measurements were performed from 19-21 December 2012 at the Therrien residence located at 2924 New Duck Pond Road, primarily to assess the level of exterior noise at this location compared to the Vermont PSB noise limit established for wind turbine projects. In addition, 1/3rd-octave sound measurements were also obtained at this location to determine whether there were any significant discrete frequency components to the noise. Figure 1 shows an aerial view of the area indicating the location of the Therrien residence relative to the nearest wind turbines that are approximately 4500 feet from their residence.

Figure 1: Sheffield Wind Turbine Facility - Therrien Residence and Nearest Wind Turbines

Noise Metrics

Various sound level metrics were recorded digitally using a Rion NL-31 Type 1 integrating logging sound level meter contained in an environmentally protected case. The microphone for the meter was mounted above the case with a windscreen to reduce the effects of wind noise on the microphone. The microphone was set at approximately 1 meter above ground level to minimize the possibility of being dislodged by wind conditions. This system was set to record sound levels continuously in 10-minute intervals. In addition, a CEL Series 500 Type 1 sound level meter was used to record 1/3rd-octave sound spectrum levels. The microphone for this meter was placed at approximately the same position as the Rion measurement system.

Table 1 presents a chart showing typical general noise levels. The levels are stated in terms of maximum sound pressure level in A-weighted decibels (dBA). The decibel scale is logarithmic and allows a wide range of levels to be conveniently measured. The A-weighting refers to a filter used in the measurement of noise to emulate the frequency response of the human ear, which is less responsive to low frequency level sounds.

Table 1: Examples of Typical Noise Levels

dBA	Noise Example Description
20	Rustling Leaves
30	Whisper
40	Brook, Computer
50	Light Traffic, Refrigerator
60	Conversational Speech, Air Conditioner
70	Shower, Dishwasher
80	Alarm Clock, Garbage Disposal
85	Passing Diesel Truck, APTA Limit for Train Station Design
95	Belt Sander, Level at which Sustained Exposure May Result in Hearing Loss
105	Sporting Event, Table Saw
115	Emergency Vehicle Siren
125	Balloon Popping, Pain Begins
135	Air Raid Siren
145	Firecracker, Level at which Short Term Exposure Can Cause Permanent Hearing Damage
165	.357 Magnum Revolver
194	Sound Wave Transition to Shock Wave

During each 10-minute measurement interval, the Rion NL-31 recorded the Equivalent Continuous Sound Level (Leq). This is the preferred metric for sound levels that vary over time, resulting in a single number that takes into account the total sound energy during the 10-minute interval, and is the metric used for the project criteria. During each 10-minute interval, the sound level meter also recorded the maximum sound level (Lmax), and the sound level exceeded 90% of the time (L90). The L90 is often used to characterize the "background" ambient noise level that would exist without the effects of intermittent short-term noise sources such as car passbys and aircraft flyovers. It is also used as the baseline against which the effects of louder noise events can be compared. Typically, a difference of about 15 dB between the background level (L90) and certain noise events will result in complaints from people.

Noise Assessment Criteria

Noise emissions for the Sheffield Wind Turbine Facility are limited in Condition 8 of the Certificate of Public Good (CPG) issued to the project by the Vermont Public Service Board on August 8, 2007 and as amended by the "Order re Motions and Requests for Modification, Amendment, Clarification and Correction" (Order) dated October 1, 2007. The final condition is stated as follows:

> Condition 8. UPC (now First Wind) shall construct and operate the Project so that it emits no prominent discrete tones pursuant to ANSI standards at the receptor locations, and indoor sound levels at any existing King George School structure used for residential or instruction purposes and any existing surrounding residences do not exceed 30 dBA (Leq)(1 hour).

A "prominent discrete tone" as defined in ANSI standard S12.9/Part 3 1993 *Quantities and Procedures for Description and Measurement of Environmental Sound* is determined from the measurement of the 1/3 octave band frequency spectrum of sound. A tone is said to exist if the 1/3 octave band containing the suspected tone exceeds the arithmetic average of the two adjacent bands by:

15 dB - for all frequencies equal to or below 125 Hz

8 dB - for all frequencies between 160 and 400 Hz

5 dB - for all frequencies equal to or above 500 Hz

Since noise measurements were not obtained indoors at the Therrien residence, an outdoor noise limit of 45 dBA Leq(1 hour) was used to assess the noise impact from the wind turbines. This 45 dBA Leq outdoor noise limit is the level applied by the Vermont PSB on other wind turbine projects, and is the outdoor noise level used by other states and agencies to assess noise impact from wind turbines.

Weather Conditions

Weather conditions during the three days of measurements varied considerably. The first day of measurements, Wednesday 19 December, was a relatively calm day, where wind turbulence was not a factor. The noise environment was largely dominated by traffic noise from I-91. Although the traffic on this highway can be somewhat sparse at times, vehicles could still be heard from several miles away. Other localized noise events included dog barks, the sound of young children playing (inside or outside the residence), and sound from a diesel generator, which is occasionally used by the Therriens. During the measurements on this day, the observer was not able to clearly detect any audible sound from the wind turbines. This was largely due to the vehicle traffic on I-91 that dominated and masked the sound from the wind turbines.

On the second and third day of measurements, beginning Thursday and ending on Saturday, there were various storm conditions in northeastern Vermont. These conditions caused relatively high wind levels, with gusts that occasionally reached near 50 mph. Although the high level winds may have produced higher wind turbine noise, the effect could not be perceived because the noise caused locally by wind turbulence masked both the I-91 traffic noise and any possible wind turbine noise.

10-Minute Period Noise Monitoring Results

The noise levels recorded by the Rion NL-31 system are shown in Figures 2, 4, and 6, where each figure shows results for approximately one day of 10-minute noise measurements. Each figure shows the three measured noise metrics (Lmax, Leq, and L90). The figures also include a line to show the Vermont PSB outdoor noise limit of 45 dBA Leq. In addition, Figures 3, 5, and 7 show the corresponding wind speed data in 10-minute time intervals provided by First Wind from data obtained at the Sheffield Wind Turbine Facility. Other wind turbine operational data provided by First Wind for the three wind turbines closest to the Therrien residence (wind turbines 1, 2, and 3) included wind direction, turbine hub speed in rpm, and turbine power generation in kilowatts. The turbine hub speed and power generation data indicates when the wind turbines were not operating. The operational data from all three of the wind turbines was examined and found to be relatively similar. Appendix A contains the wind turbine operational data for the wind turbine (SF01) that is closest to the Therrien residence.

Figure 2 (Day 1) shows that, with the exception of one period, the Leq noise level never exceeds the criterion of 45 dBA. The one period where the criterion was exceeded (52 dBA @ 15:08) was probably due to the diesel electric generator, which is used occasionally by the residents. Except for events such as this, the Leq is primarily a measure of the noise from vehicles on I-91, which is typically about 35 dBA during daytime, and reduces to 25 dBA during late night. Although the turbine noise from the project may be a component in these noise levels, it was inaudible above the background traffic noise from I-91, and there is no means to determine this from the noise measurements obtained at the Therrien residence. The only way to determine if the wind turbines are a major component of the noise, is if they were audible above the background noise levels. From our observations while at the Therrien residence, the wind turbines were inaudible above the background noise levels.

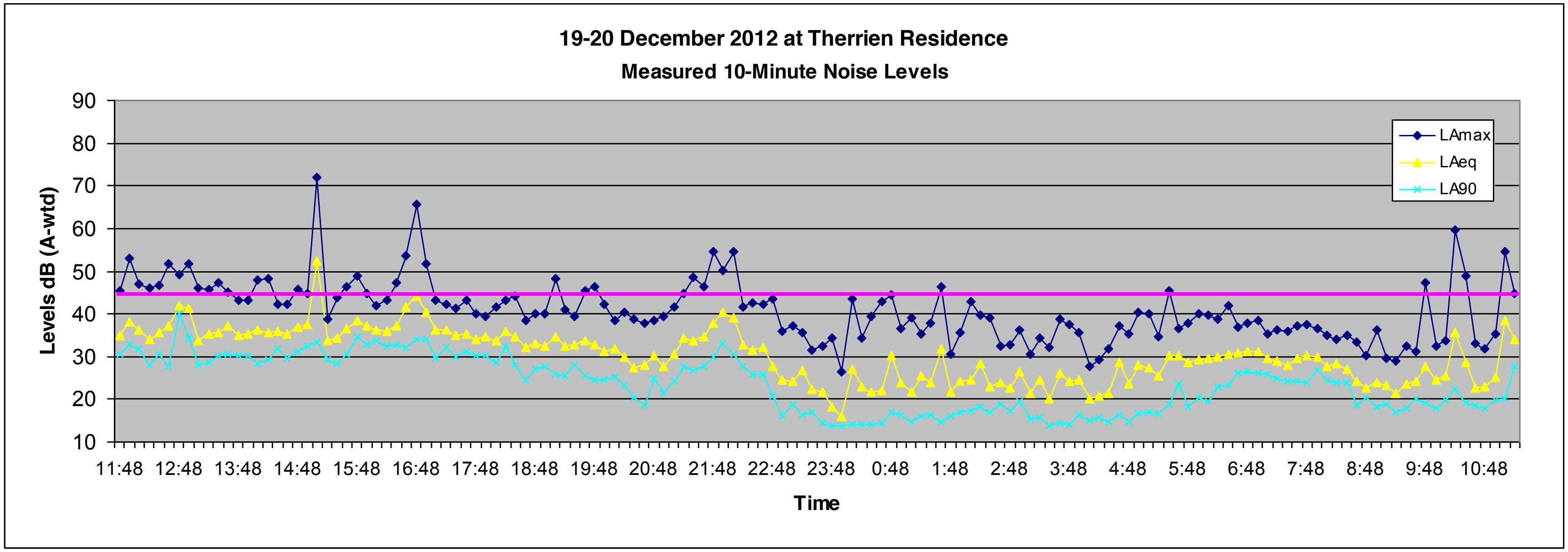


Figure 2: 10-Minute Noise Measurement Results at the Therrien Residence (Day 1)

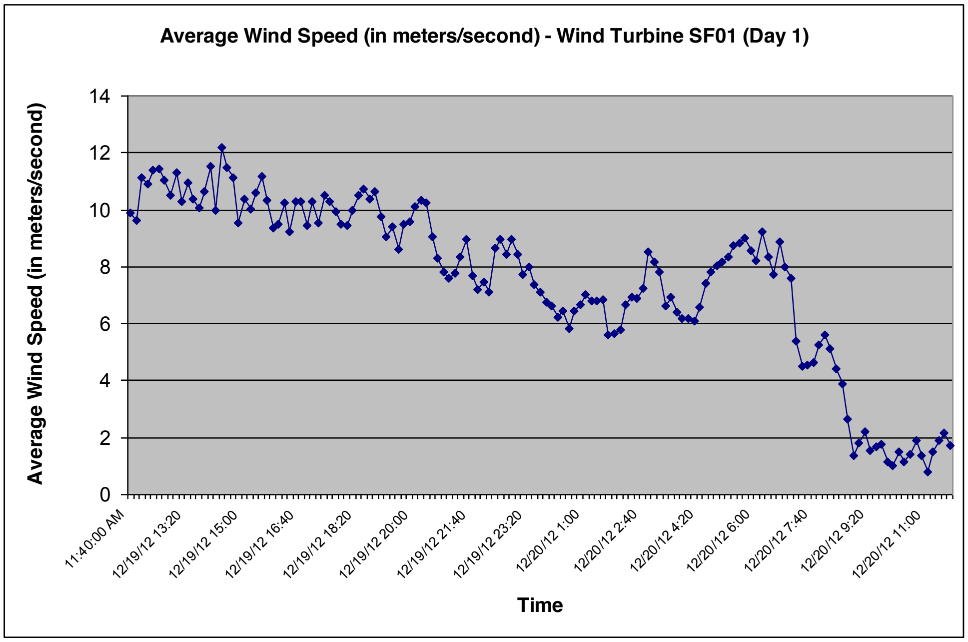


Figure 3: 10-Minute Average Wind Speed (in m/s) at the Wind Turbines (Day 1)

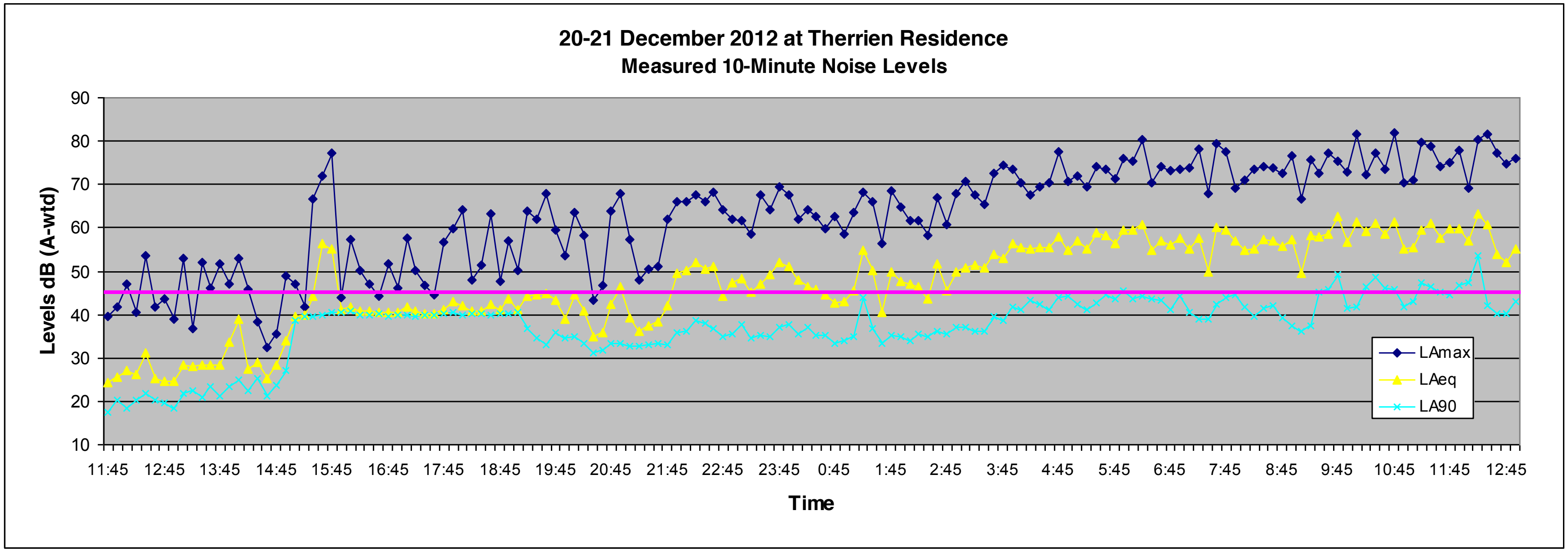


Figure 4: 10-Minute Noise Measurement Results at the Therrien Residence (Day 2)

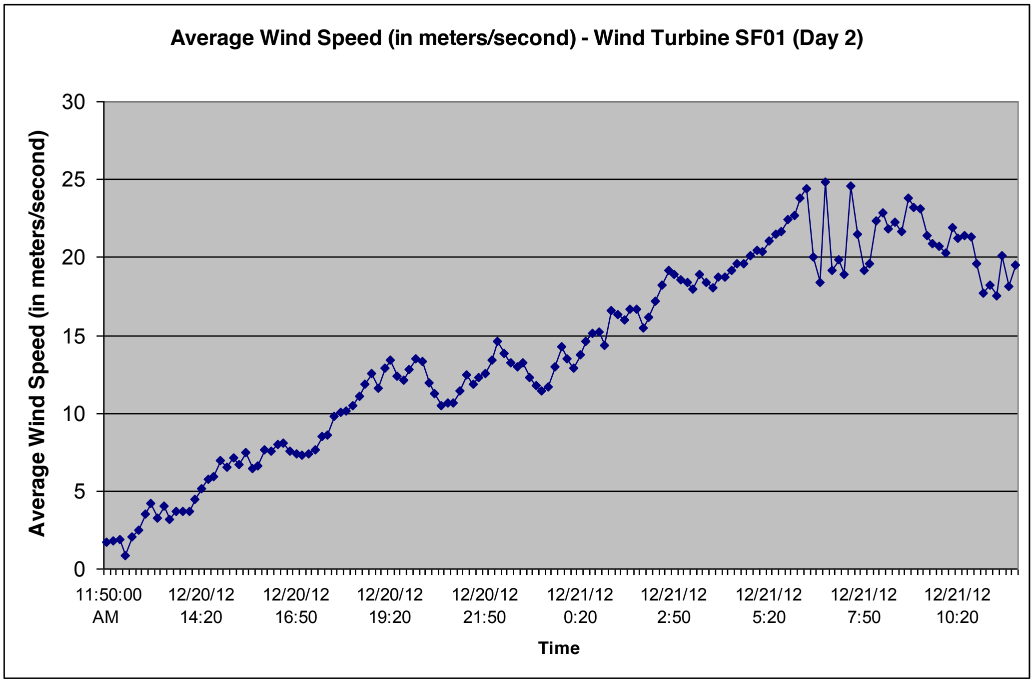


Figure 5: 10-Minute Average Wind Speed (in m/s) at the Wind Turbines (Day 2)

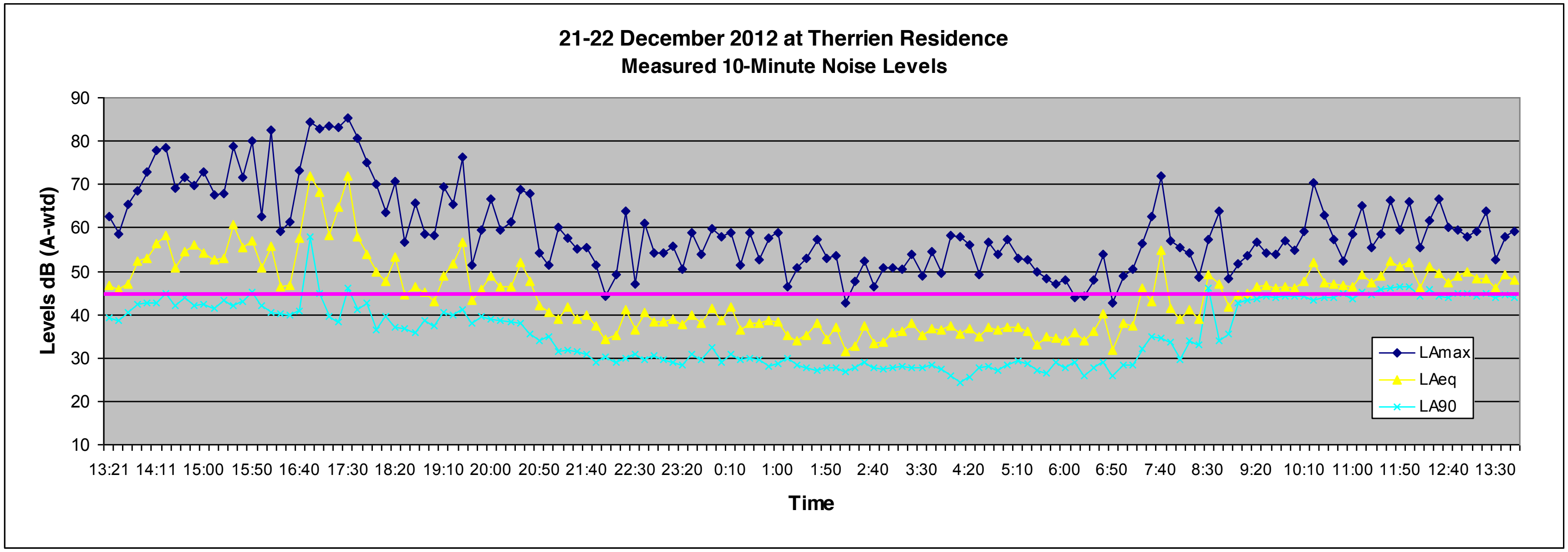


Figure 6: 10-Minute Noise Measurement Results at the Therrien Residence (Day 3)

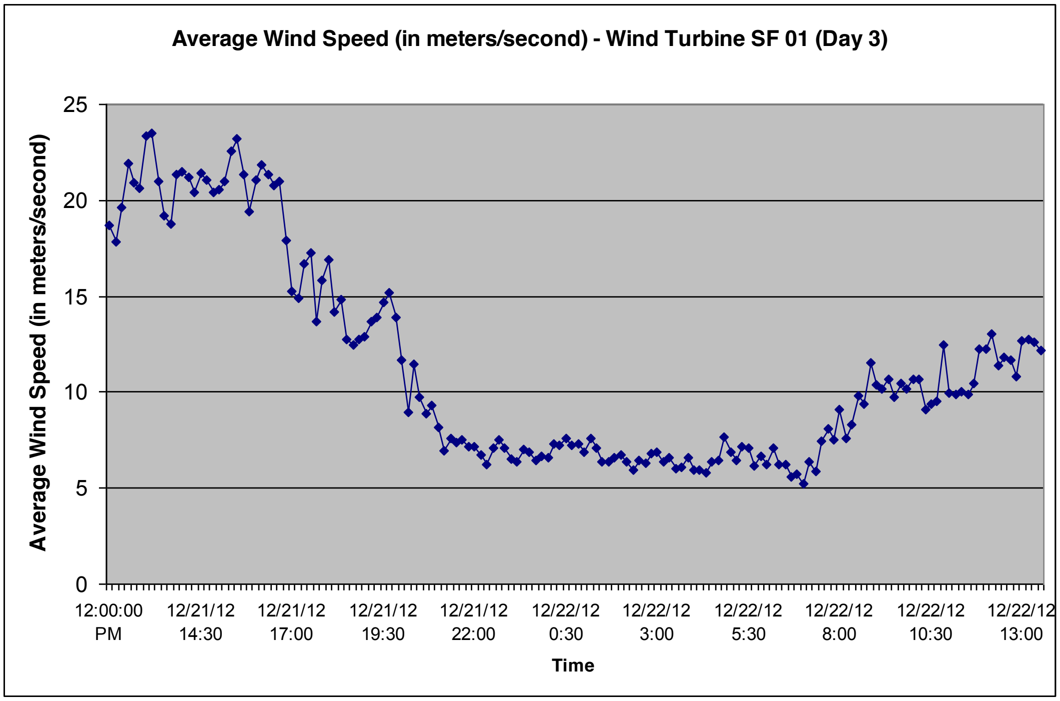


Figure 7: 10-Minute Average Wind Speed (in m/s) at the Wind Turbines (Day 3)

The levels obtained during the 2nd and 3rd day of measurements show quite a different noise environment. At approximately 13:00 hours in Figure 3, on 20 December, all the levels show a significant increase, compared to the previous day. With the exception of the peak at around 15:45, which is likely due to the operation of the diesel generator, wind turbulence is now the main noise source. The wind gusts, which weather reports indicated might reach 50 mph, are prominent in the Leq and Lmax noise levels. The L90, or background levels, have also increased, as the wind turbulence was always present to some degree. Although the higher winds might have increased the sound generated from the wind turbines, the level of the wind turbine component is not known, and is unlikely to be a significant contributor to the noise levels shown in the figures. As further evidence of this fact, spot measurements of localized wind noise from turbulence in nearby trees, showed levels in the same range as those shown in the figures. The sound generated by the wind turbines was not directly measureable using the equipment utilized for this project, nor was it audible to the observer.

On Thursday, 21 December, one of the storm systems subsided somewhat during the evening and nighttime periods. From approximately 22:00 hours to 06:00 hours the next day, the Leq levels are more indicative of the traffic on I-91. However, another storm system began to move into the area in the morning, and this weather system produced wind turbulence that persisted in dominating the noise up until the end of the measurement program.

To summarize the 10-minute measurement data, Table 2 presents the average noise levels for each day, and for the full three days of measurements. Since the average noise level is generally below 45 dBA Leq, it can be deduced that the contribution of noise from the project wind turbines did not exceed the Vermont PSB outdoor noise limit during the three days of measurement.

It should be noted that in discussing the measurement program with the Therriens, it was their opinion that the noise levels that they observed during the three days of measurements did not produce the high annoyance that they have perceived in the past from the wind turbines. The Therriens suggested that the higher level noise that they have experienced from the project occurs about 10-20% of the time primarily when the winds are from the east and the south and the Therrien residence is downwind of the wind turbines. Assuming that there is a particular set of circumstances, including wind direction, velocity, atmosphere conditions, etc. which would cause the higher perceived levels, it would be necessary to monitor for a much longer period than three days to make it likely that the higher level noise might be captured. Since the background L90 levels are so low in this area, it is reasonable to expect that during certain conditions noise from the wind turbines might be 15 dB greater than the background level, which can be expected to result in annoyance from some people. For example, at night the measurements on Wednesday often show Leq levels of approximately 20 dBA. If conditions occurred which resulted in wind turbine noise in the range of 35 dBA, it could be expected that some people will find the noise annoying, and a cause of concern.

Table 2: Summary of 10-Minute Noise Measurements

	19 December	**21 December**	**21 December**	**3-Day Average**
Lmax	40.9	62.0	59.4	54.1
Leq	**30.3**	**46.5**	**44.5**	**40.4**
L90	23.6	36.6	36.1	32.1

1/3rd-Octave Band Noise Measurement Results

Spot frequency spectrum measurements were made on two days, during the time that the 10-minute period broadband measurements were performed. The purpose of these measurements was to determine if the wind turbines might be emitting noise with a tonal component. The CEL Series 500 sound level meter was set to obtain 1/3rd-octave band un-weighted levels. The meter uses an electronic filter to separate the different frequency bands. This system provides an approximate method for locating tonal sound components. Even though the noise from the project wind turbines was not detectable during the three-day measurement program, if there were to be a very strong tonal component, such noise might be noticed in the frequency spectrum. The other environmental noises in the area, including vehicle noise and wind noise, rarely show a tonal component. The range of audible sound for the average person is in the frequency range of 20 – 20,000 Hz.

The results of the 1/3rd-octave band measurements are shown in Figure 8, for two different days. The measurements taken on Thursday, 21 December, may not contain any wind turbine activity. This is because during the drive back from the measurement site, approximately one-half hour after the 1/3rd-octave band measurement was taken, a glimpse of the some of the turbines from the southbound lanes of I-91 displayed no turbine blade movement. For the measurement on Friday, 22 December, a view of some of the turbines approximately one-half hour before the measurements verified that the turbines were in fact operating.

The frequency spectra shown in the Figure 8 does not show any evidence of discrete tonal sound as described in the Noise Assessment Criteria section of this report (page 7). The 1/3rd-octave band levels also indicate that there is a large amount of low frequency sound energy in the area. Low frequency sound is anything below 200 Hz. The levels seem to be greatest at frequencies that are at the lower limit of the human hearing range (20 Hz). “Infrasound” is a phenomenon that occurs at frequencies below 20 Hz. The instrumentation used for these 1/3rd–octave band noise measurements is not very sensitive to frequencies below 20 Hz, since noise in this range is generally inaudible and does not affect the A-weighted sound level. It should be noted that because the human ear is much less sensitive to very low frequency sound, the levels shown are essentially inaudible. Also, the low level sound spectrum is fairly typical for outdoor environments where traffic and other sounds predominate. The substantial difference in the levels between the two days is most likely due to the greatly increased wind turbulence during the second measurement.

SUMMARY ASSESSMENT

Based on the measurements obtained at the Therrien residence during the three-day period, it was difficult to find any measureable noise produced from the Sheffield Wind Turbine facility. The levels recorded are evidence of the traffic noise on I-91, and, during the later two days, various effects of high velocity wind turbulence. The measurements were mostly well below 45 dBA Leq, which is the outdoor noise limit for similar projects. Although indoor noise measurements were not obtained, typical sound attenuation through the buildings walls, closed windows, and closed doors would result in noise levels that are below the Vermont PSB indoor noise limit of 30 dBA Leq.

In order to be sure that the project is not significantly introducing annoyance to residents in the area of concern, a much longer-term measurement program would be necessary. Ideally, such a program would capture the measured Leq levels generated by the wind turbines during a period of time verified by the Therriens as producing significant disturbance/annoyance. In addition, simultaneous noise measurements obtained near the wind turbines, where the wind turbine noise dominates above the background noise levels, could be used as a control measurement for comparison with the noise levels measured at the Therrien residence. Also, this data could be used to determine the expected noise levels from the wind turbines at the Therrien residence by extrapolating the measured noise levels near the wind turbines to a distance of 4,500 feet (the distance from the Therrien residence to the nearest wind turbines) to obtain an estimate of the wind turbine noise as a component of the Leq noise levels measured at the Therrien residence.

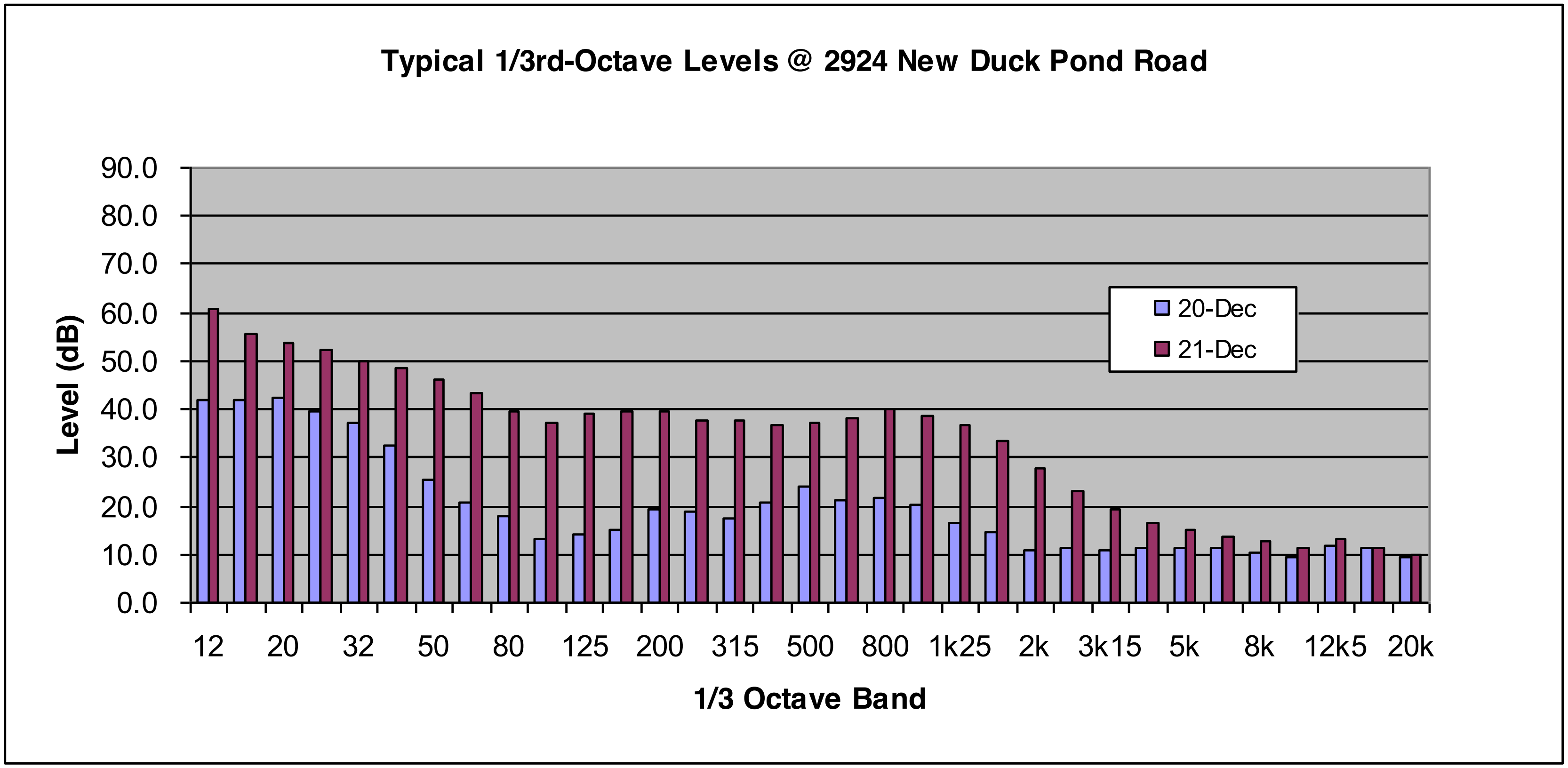
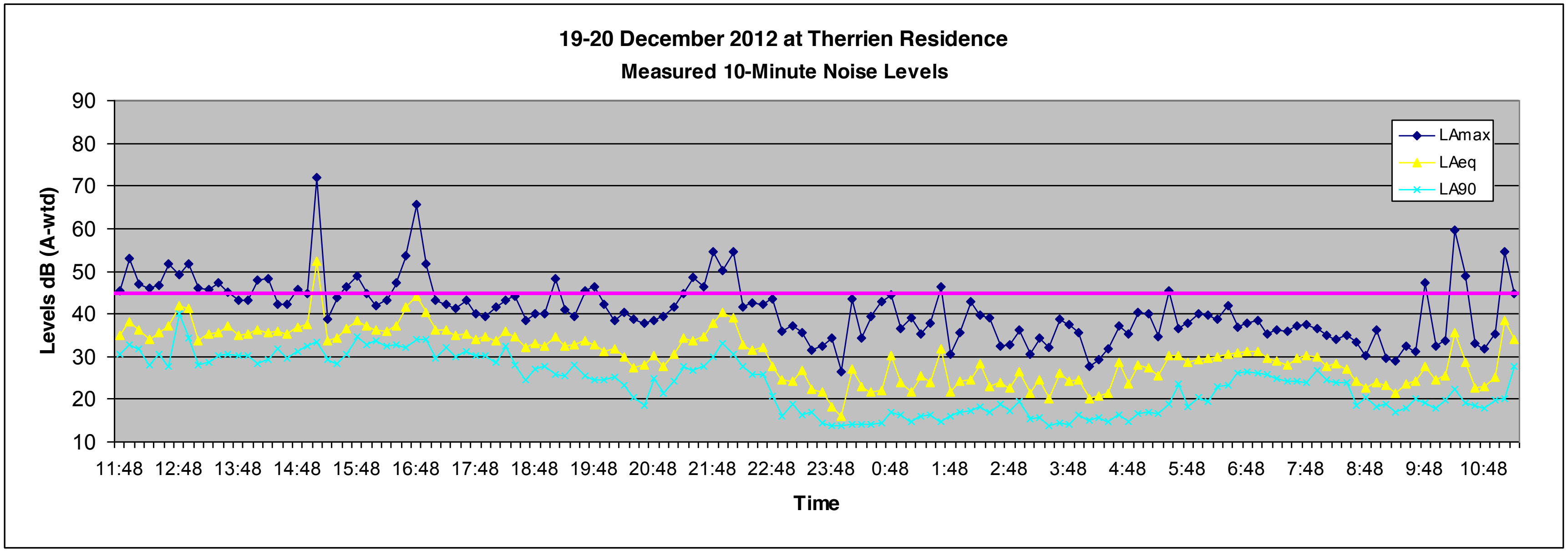


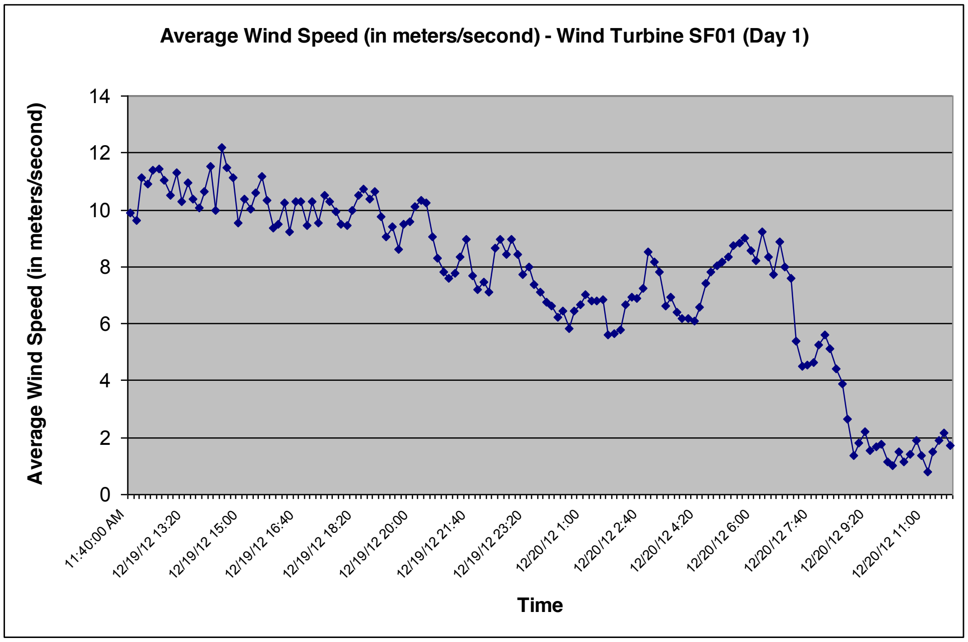
Figure 8 - 1/3rd-Octave Band Noise Frequency Spectra Obtained at the Therrien Residence

Appendix A

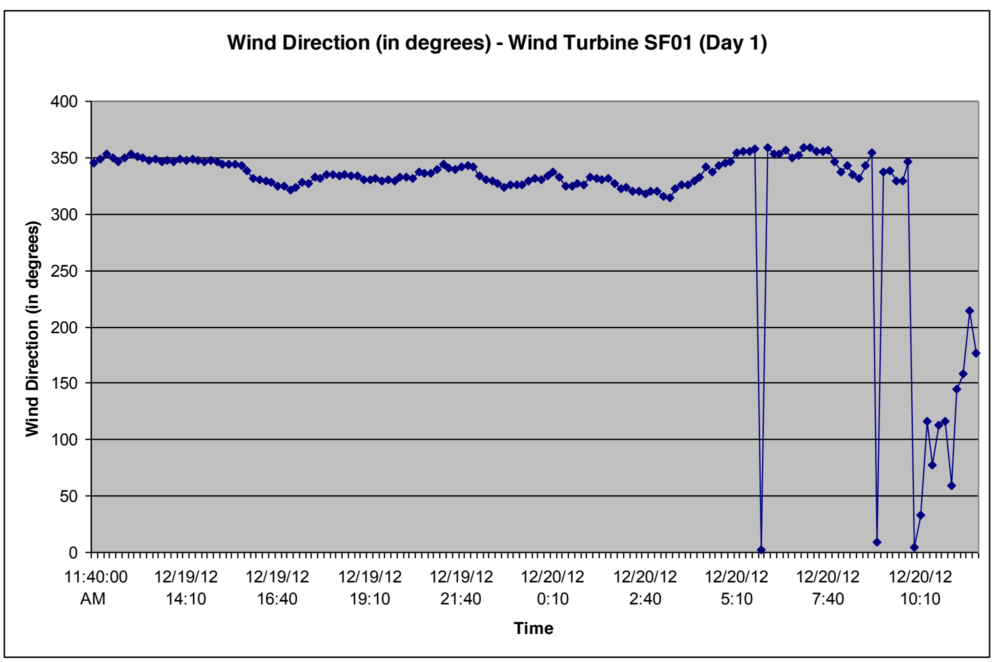
Wind Turbine Performance Data (SF01)



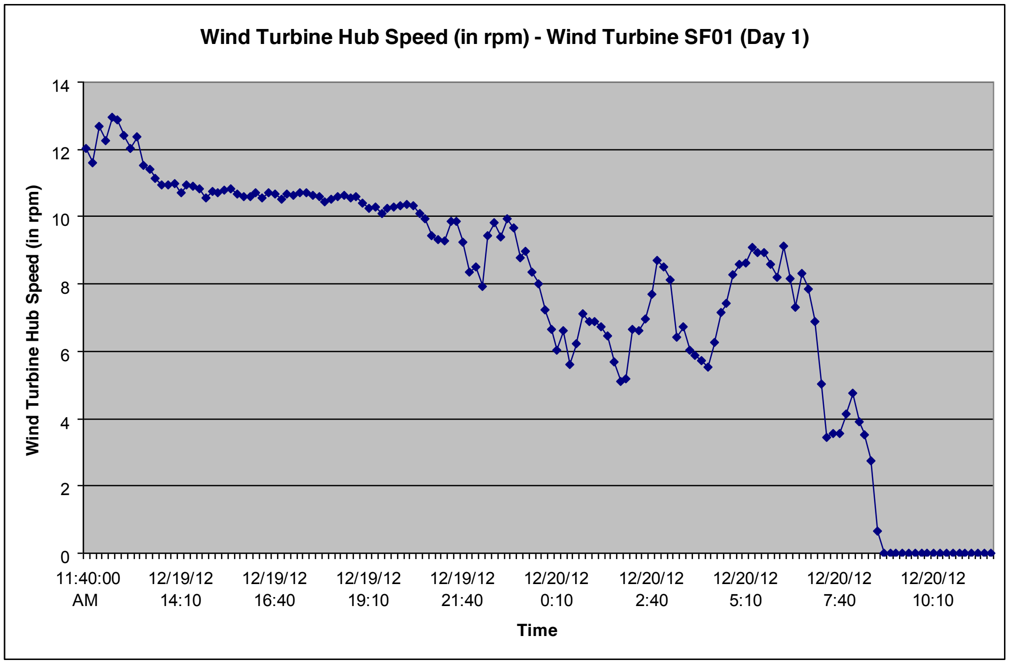
10-Minute Noise Measurement Results at the Therrien Residence (Day 1)



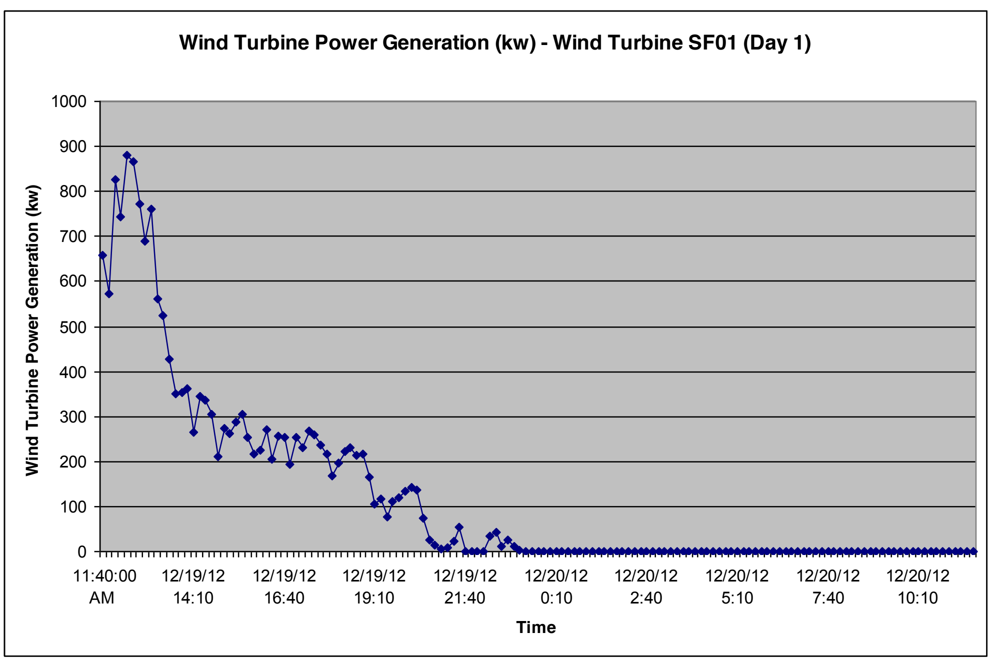
10-Minute Average Wind Speed (in m/s) at the Wind Turbines (Day 1)



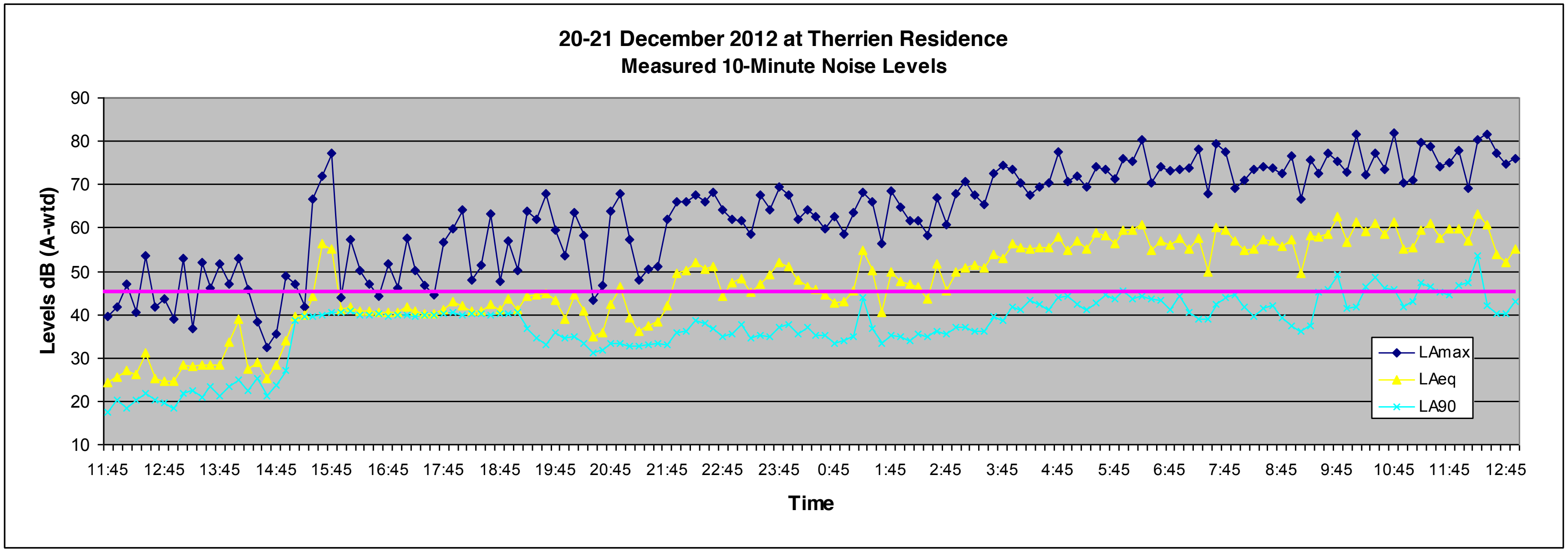
Average Wind Direction 10-Minute Intervals (Day 1)



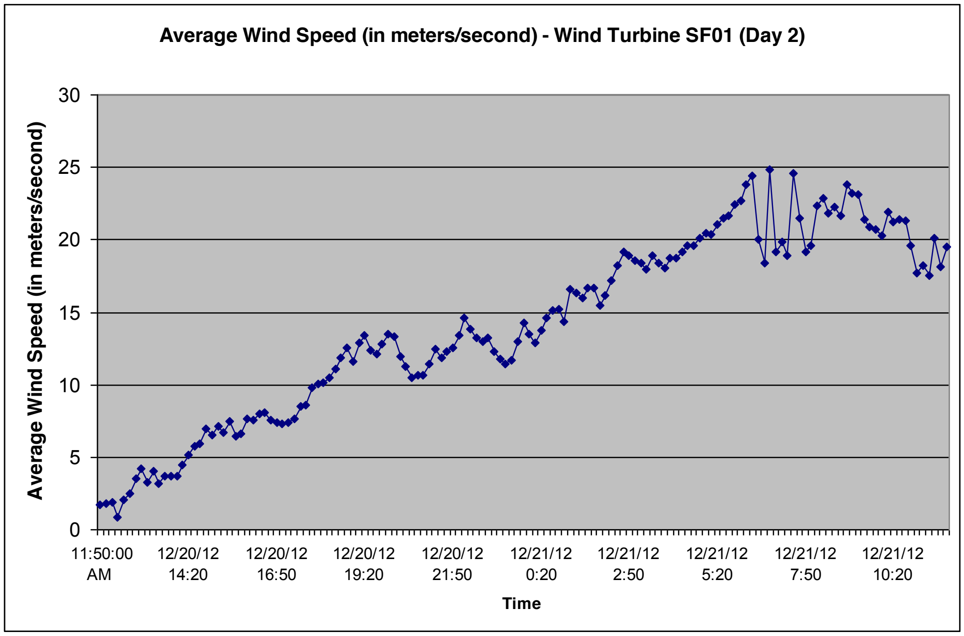
Wind Turbine Hub Speed (Day 1)



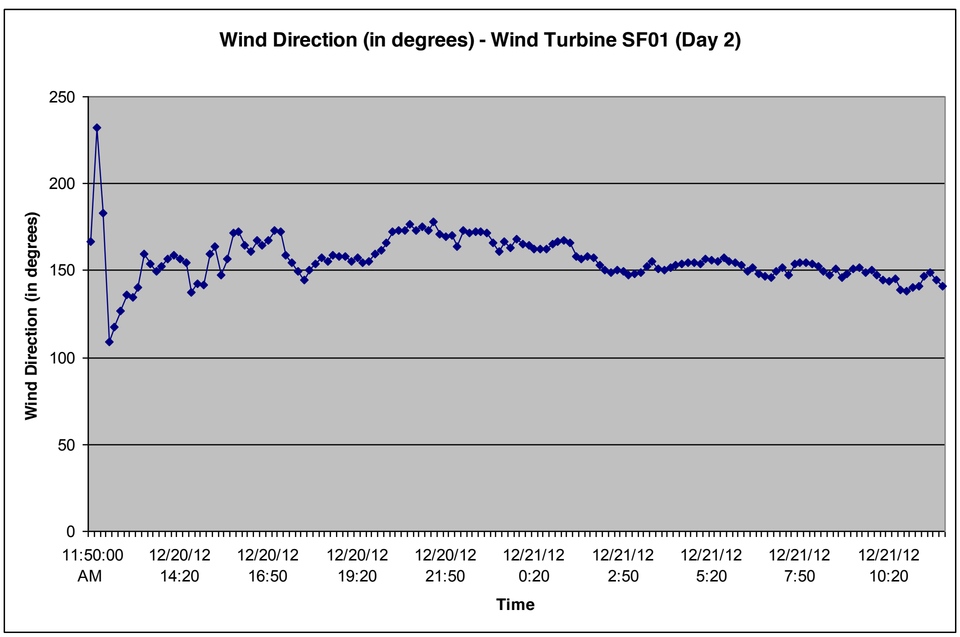
Wind Turbine Power Generation (Day 1)



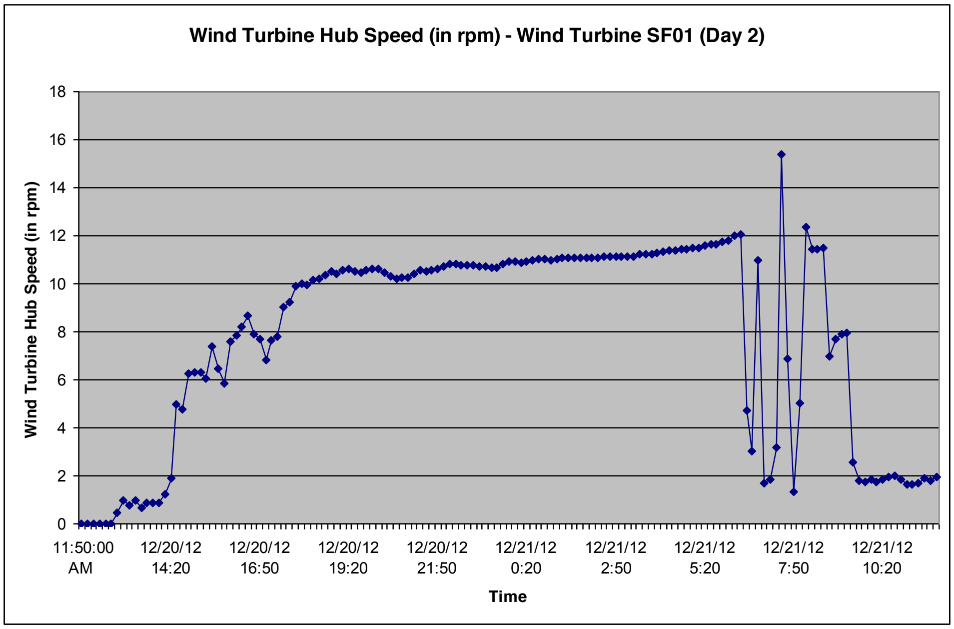
10-Minute Noise Measurement Results at the Therrien Residence (Day 2)



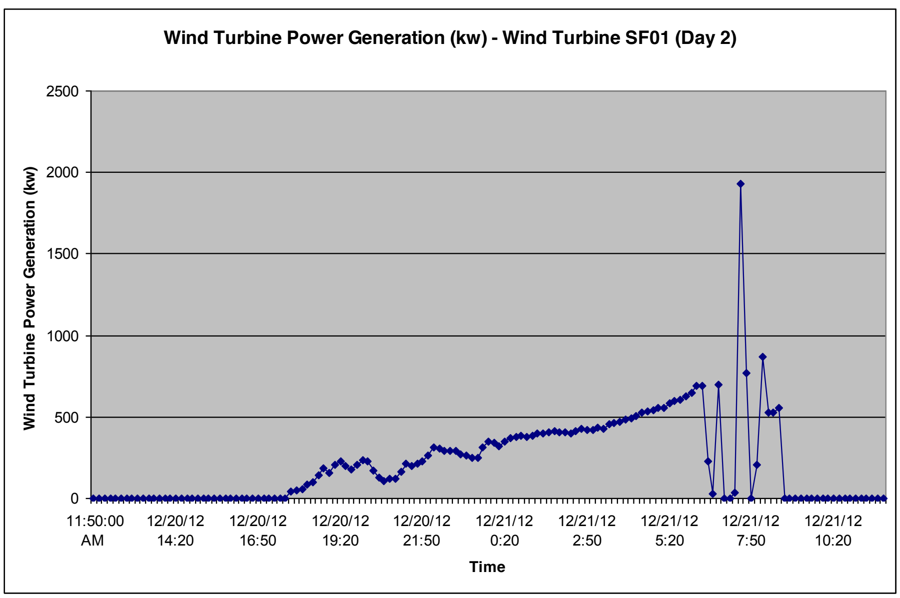
10-Minute Average Wind Speed (in m/s) at the Wind Turbines (Day 2)



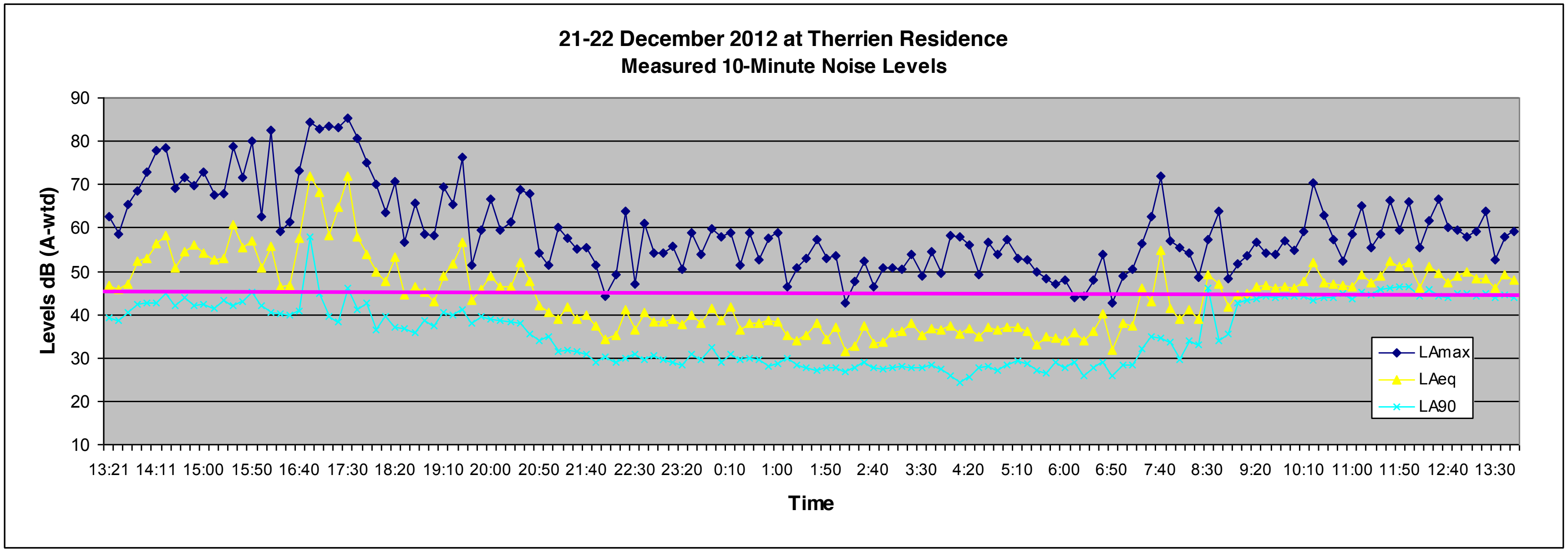
Average Wind Direction 10-Minute Intervals (Day 2)



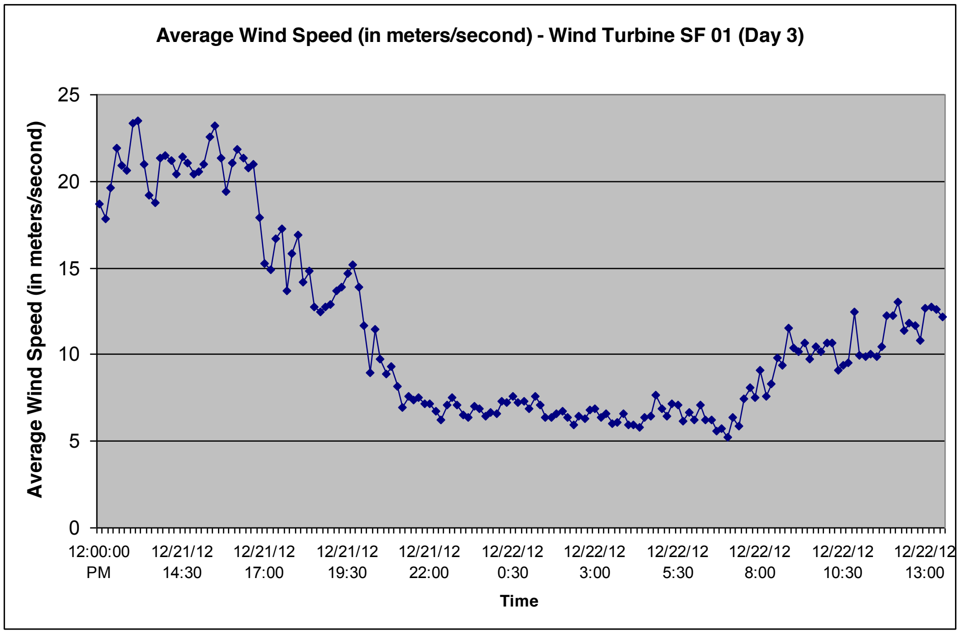
Wind Turbine Hub Speed (Day 2)



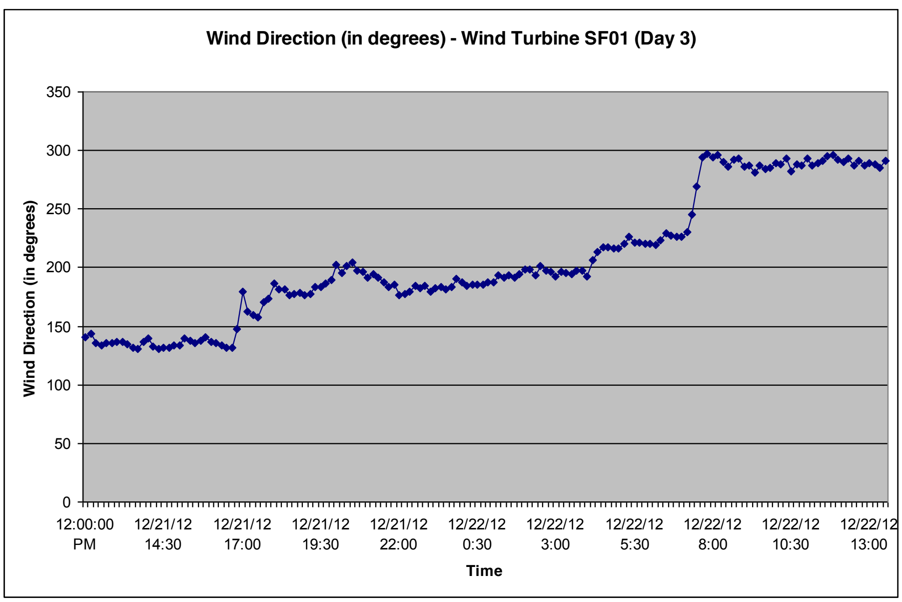
Wind Turbine Power Generation (Day 2)



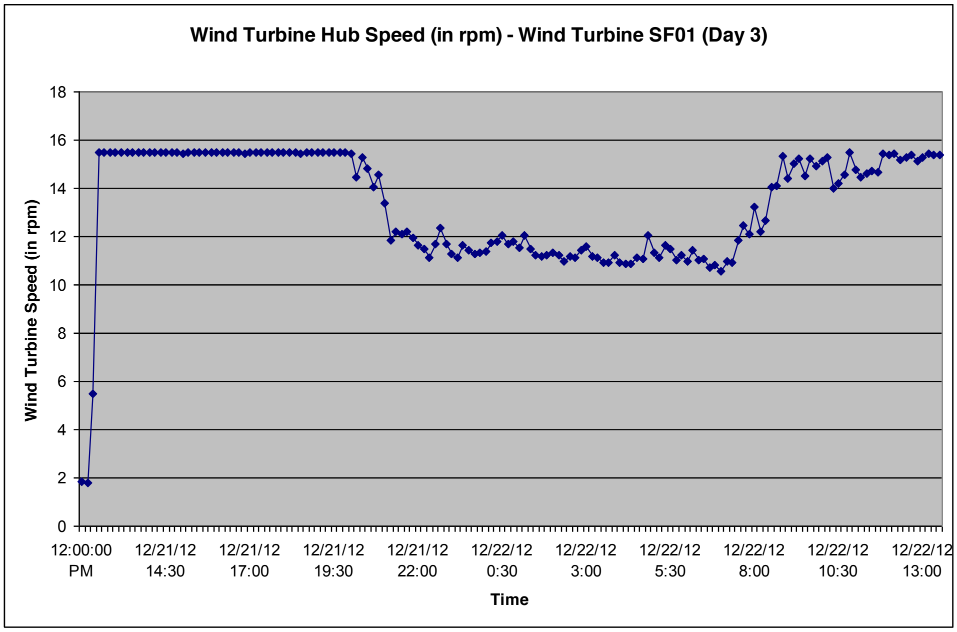
10-Minute Noise Measurement Results at the Therrien Residence (Day 3)



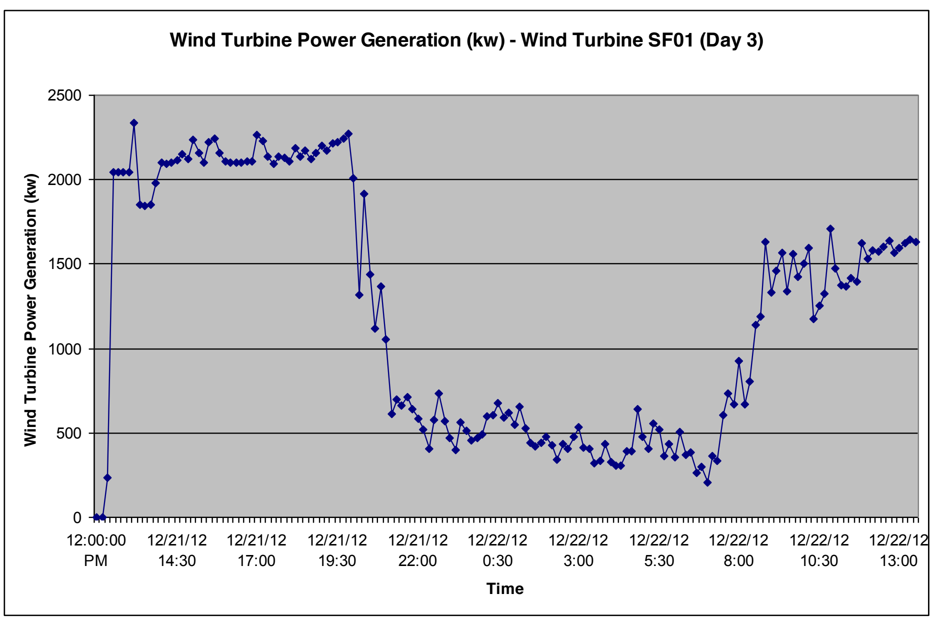
10-Minute Average Wind Speed (in m/s) at the Wind Turbines (Day 3)



Average Wind Direction 10-Minute Intervals (Day 3)



Wind Turbine Hub Speed (Day 3)



Wind Turbine Power Generation (Day 3)