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Evidence Based Study of Noise Impacting Annoyance

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Abstract

The growth of large industrial wind turbines in the world, from less than 2,000 MW installed capability in 1990, to over 159,000 MW in 2009, led to a steady increase in complaints of noise annoyance. A few papers reported annoyance in the early 1990's while today sees a steady progression of papers recording complaints. Often reports of annoyance are dismissed citing they have only an anecdotal basis, rather than facts or research. This paper provides a factual evidence based examination of the special characteristics of the noise from wind turbines. The factual evidence is used to develop an explanation for the regularly reported anecdotal statement: "I just cannot get used to the sound from wind turbines." The evidence backed explanation gives a basis for change in regulations.

A calibrated microphone with a flat response over the audible spectrum protected by primary and secondary wind screens was used to collect a series of readings in all seasons. These were digitized and recorded for locations approved by regulators as meeting A-weighted sound level criteria. Measurements were also taken at locations under similar environmental conditions (wind speed, terrain, temperature and humidity) at a site about 5 km distant from wind turbines.

A spectral analysis was performed of the digitized measurements to compare the unweighted sound to the A-weighted sound for Leq calculations for the octaves from 16 Hz to 8000 Hz. Analysis of the recordings and spectral analysis examines the impact of the special characteristics of the cyclical sound from wind turbines to explore the impact of basing regulation of wind turbine sound on A-weighted sound levels.

Comparison is presented of the differences between the sound level, special characteristics, and pitch at locations approved under the regulations, to locations taken under similar environmental conditions distant from the turbines. The findings of the comparison are examined considering current medical research looking at impacts on the human body from sound to suggest a basis for revision of regulations to result in less impact on humans.

Introduction – Defining the Problem

It was their eyes that were most compelling.

Over the last 5 years, I have had the opportunity to sit down and talk to over 25 people with personal adverse experience in living near industrial wind turbines. I heard second hand, and read the stories of many more, but it was the people that I sat face to face with that impacted me the most. Many of them had never met a lot of the others I spoke with. Their words of their stories varied somewhat since some were more eloquent than others, but their eyes told a consistent story, that is haunting and compelling. These people are hurting. They do not fully understand why they are hurting, but they do know that something changed when industrial wind turbines started operating near where they live, and now they all suffer some form of discomfort ranging from annoyance to debilitation. The haunting message their eyes said wordlessly, was, “Cannot you do something to help me, please?”

So how am I personally impacted, and why should I care? Really, this need not matter to anyone else but it deserves an answer. I have to live my life striving to obey a master who tells me to love God, and to love my neighbour as myself. Then, the explanation of who my neighbour is was given, as being one I might not even know, but who was hurting. That may not matter to anyone else, but I note that nearly every culture in the world, whether Christian, Jew, Muslim, Hindu, Buddhist, or other, subscribes to basicly the same “Ethics of Reciprocity.” To show the multi-cultural basis for this statement, here is how the Dalai Lama expresses it, "Every religion emphasizes human improvement, love, respect for others, sharing other people's suffering. On these lines every religion had more or less the same viewpoint and the same goal." For me, it means using whatever talents I have, to try to meet this goal.

Over the years, the experience gained in a career of trying to determine the root cause of problems shows that a key component is to find out what changed, when a problem occurs. Rarely is it just “bad luck” that makes adverse impacts occur, often something has changed. As a result, the goal of this project was to investigate to determine what changed around the people whose eyes now haunt me. Once we know what changed, then, we can ensure that regulations are set appropriately to ensure that past problems are corrected, and future problems are avoided.

The goal had to be to determine the root cause in a transparent, reproducible manner, so that others could check the work done, and confirm the conclusions that arise. There is no magic to be used, and there needs to be a clear defensible path taken to derive the conclusions. I submit that this work helps to define the root cause of the problem experienced by those who are hurting.

1. Collecting Data in a Defensible, Reproducible Manner

Initial steps to try to determine the root cause started out by taking sound level readings using a calibrated IEC 651 Type 2 sound level meter, a CEM-DT-805, with a frequency range of 31.5 to 8 kHz, a measuring level of 30 to 130 dB, frequency weighting of A or C, time weighting of 125 ms (Fast) or 1 sec (Slow) and a rated accuracy of +/- 1.5 dB using a 5 cm wind screen. Several months later in the project,

that meter was supplemented by an IEC 61672-1 Type 2 data logging sound level meter, a CEM-DT-8852, with the same frequency range, and measuring levels.

Data was collected at homes at locations approved by regulators as meeting Ontario standards, and at a control site, a home located over 5000 metres from the nearest wind turbine yet, in a similar environment as the homes near the turbines. The results of the initial survey are shown in the table below. What the table shows is that at the homes near the turbines, not only is the A weighted sound level considerably higher than at the control home, but more significantly, the difference between the A and C weighted sound levels at the homes near the wind turbines is 5 to 15 dB more than at the control home, with an observed range from 17.5 to 33.5 dB.

	dBA	dBC	Δ dBA to dBC	Comment
Control Home	28	42 to 44	14 to 16	5000 m to turbine@24%
Home 1 Mar 8	39.5	60 to 65	20.5 to 25	620 m to turbine@32%
Home 2 Mar 12	40.5 to 42.5	58 to 70	17.5 to 27.5	560 m to turbine@72%
Home 1 Mar 12	40.5 to 41.5	60 to 75	19.5 to 33.5	620 m to turbine@72%
Home 3 Mar 14	41.5	60 to 72	18.5 to 30.5	450 m to turbine@50%
Home 4 Mar 14	41.5 to 42.5	60 to 72	18.5 to 29.5	450 m to turbine@50%
Home 5 Mar 14	40 to 41	60 to 68	20 to 27	650 m to turbine@35%

A literature review paper published by the Canadian province of Alberta's Energy Resources Conservation Board in 2008, *Incorporating Low Frequency Noise Legislation for the Energy Industry in Alberta Canada,* points out that a 15 to 20 dB difference between dBA and dBC sound level readings can indicate the need for a detailed investigation into the low frequency noise component.

A considerable variety of reports, such as the review of literature published in 2004 for the Canadian Defence Research and Development titled, *"The Effect of Vibration on Human Performance and Health"* notes that "Human response to vibration is strongly frequency-dependent." Consistent with ISO 2631-1, it identifies that frequencies in the range from 1 to 80 Hz are generally of interest, and the concern depends on the intensity of the vibration, the duration of exposure, and the orientation of the affected human.

These source documents are not referenced with a goal of trying to identify specific limits being exceeded, but only to suggest that there is a basis for carrying out an investigation to determine if wind turbines do result in a significant change in the low frequency exposure to people living near the installations, as others have alleged.

To collect data on the change in sounds at homes near wind turbines compared to a site distant from wind turbines, in a reproducible manner, the following method was applied.

1. The sound level recordings were made using:
    a. 0.5 inch Knowles BL-21994 condenser microphone, mounted on a tripod 1.5 metres above ground protected by 2 inch (5 cm) primary and 7 inch (18 cm) secondary wind screens. The specification sheet for the Knowles BL-21994 microphone shows the response is effectively flat from about 2 Hz to 8 kHz. A voltage supply was provided to the condenser microphone as per the Knowles microphone specifications.
    b. supplying signal to a M-Audio Fast Track USB Audio interface
    c. recorded on a Macintosh iBook G4 portable computer
    d. using either the Audacity Digital Audio Editor recording program version 1.3.12 or a Record Pad digital audio sound recording program version 2_10 or 4_10
    e. calibration of the recording system was done before and after readings using a Lutron SC-941 1kHz / 94dB Sound Level Calibrator
    f. additional tracking was made using a CEM DT-8852 Data Logging Class 2 Sound Level Meter, calibrated before and after use.

Figure 1: Typical Monitoring Array Used to Collect Data

2. After monitoring of the digital recordings to ensure that they were not exhibiting extraneous sounds such as road traffic, aircraft, birds, or wind noise, a sample digital signal was created, as shown on the example below. (Calibrator Traces shown in examples.)

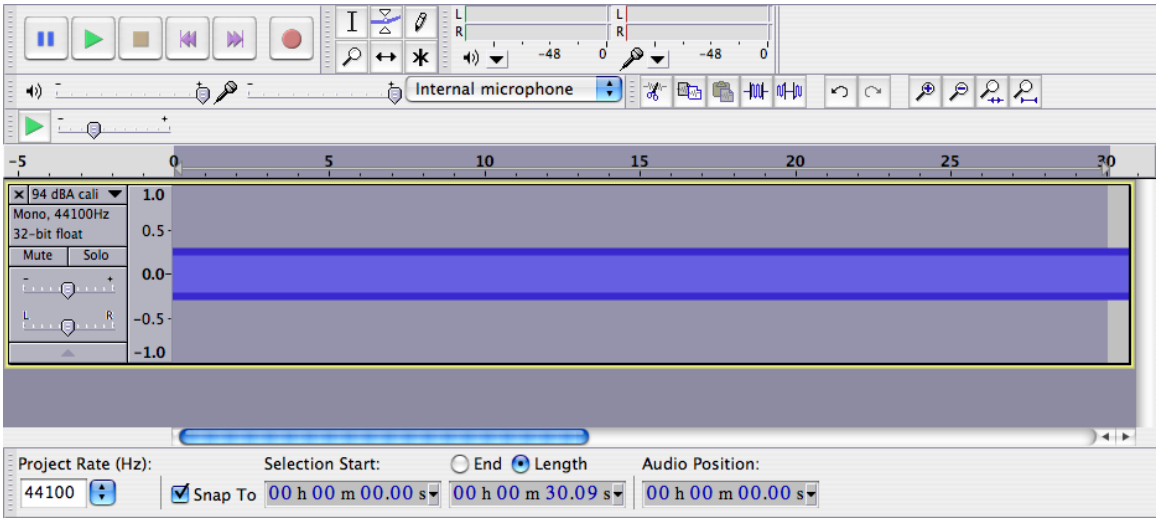


Figure 2: Audacity Trace of 94 dbA 1000 Hz Calibrator (30 second trace)

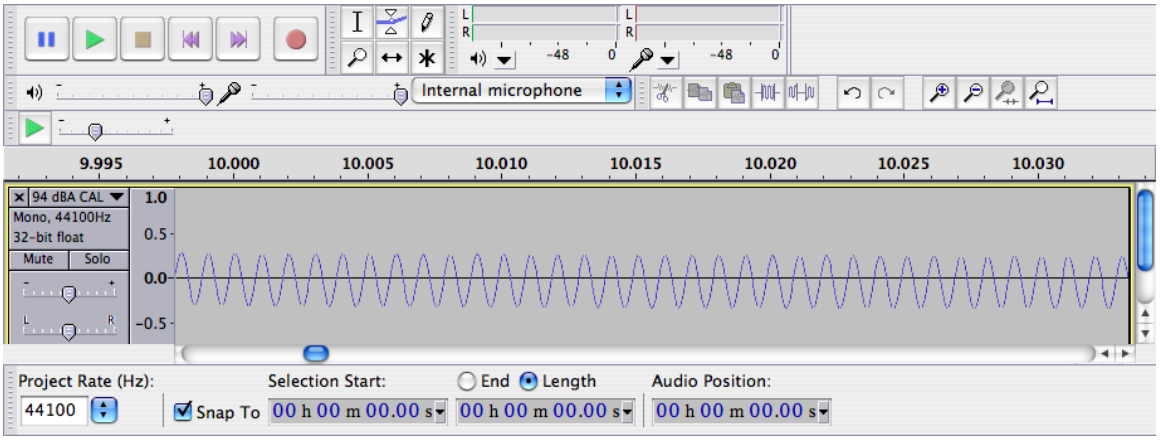


Figure 3: Audacity Trace of 94 dBA 1000 Hz Calibrator (expanded to 0.03 second trace to show calibrator output signal clearly)

3. The digital signal trace was analyzed using the Audacity Digital Audio Editor fast fourier transformation to create a frequency spectrum analysis, using a Hanning Window, with a window size of 16,384 samples. (Calibrator example shown on next page). The Audacity program also permits generating a table of 8191 values of the output every 2.69 Hz from 2.69 Hz to 22,047 Hz.

4. The output table for the monitoring system was adjusted using the 94 dBA calibrator output at the peak value. For example in the figure shown the 94 dBA calibrator signal has an output of -10.2 dB, so the adjustment factor to be added to all readings to come to the correct 94 dB calibrator value was 10.2 dB + 94 dB. This was added to all the values on the table of outputs to produce the Adjusted Sound Level versus Frequency Plot on the next page.

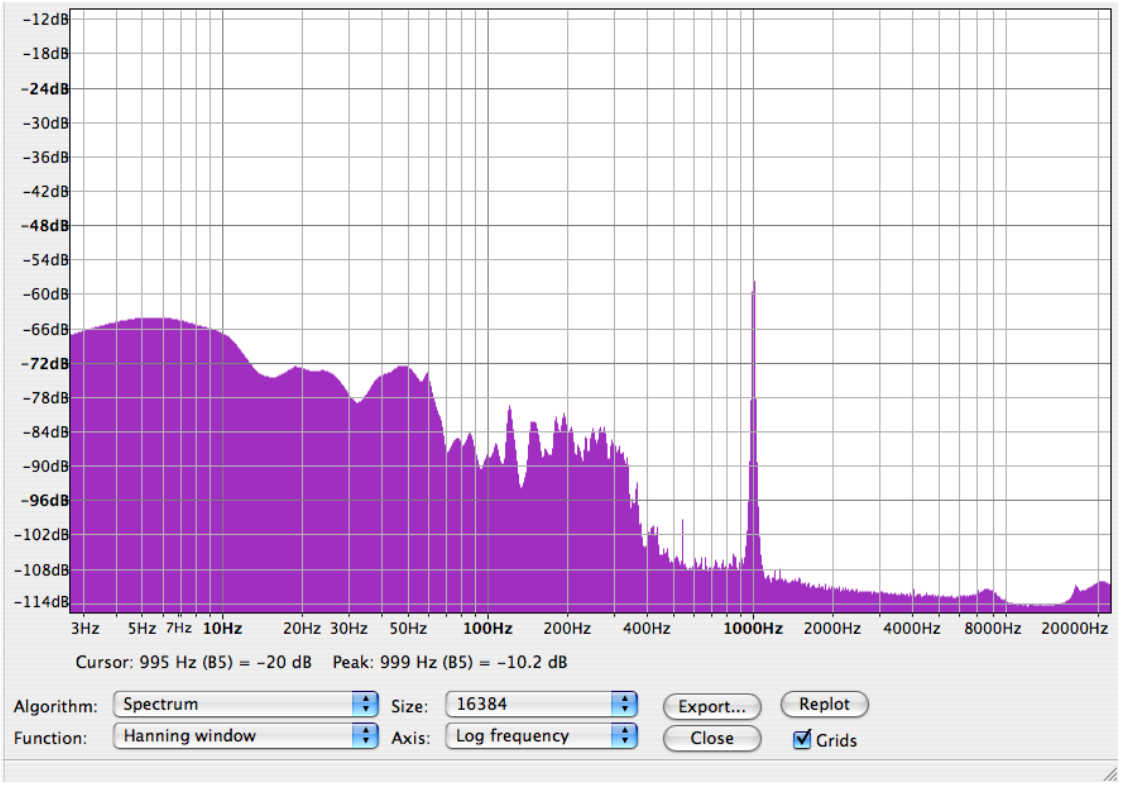


Figure 4: Audacity Frequency vs. Sound Level Plot for 94 dBA 1000 Hz Calibrator (Shows Peak Output of -10.2 dB at 999Hz)

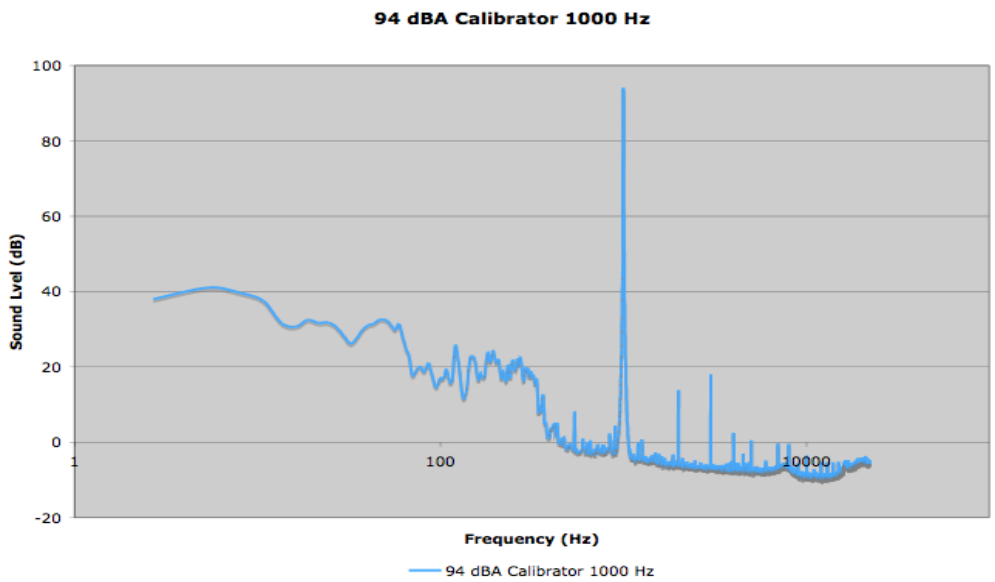


Figure 5: Adjusted Audacity Frequency vs. Sound Level Plot for 94 dBA 1000 Hz Calibrator (Adjusted for Calibrator Output of 94 dB at Peak)

5. From the adjusted values of sound level by frequency, a surrogate 10 octave analysis was created by using the values closest to 15.875 Hz, 31.75 Hz, 62.5 Hz, 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz and 8000 Hz. An A weighted value for the sound was also calculated by adding the A-Weighting adjustment factor to each octave to produce the A-weighted values for each octave, which were again summed to produce the 10 octave A-weighted value.

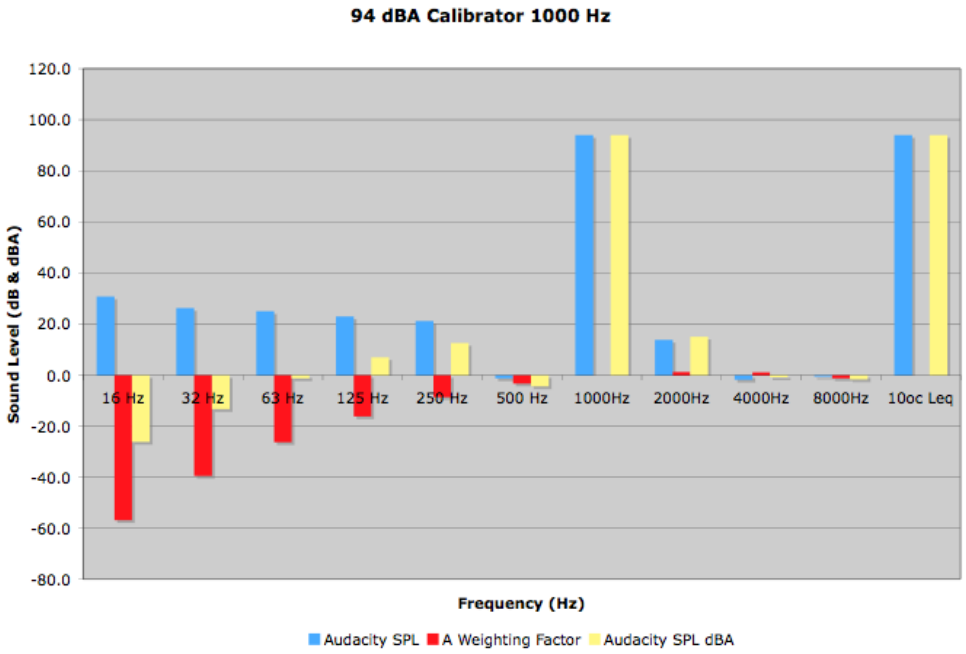


Figure 6: 10 Octave Band Calculation of Unweighted Sound Level and A-Weighted Sound Level. Note that in this case for the calibrator, the Unweighted and the A-Weighted Sound Levels are the same since the 1000 Hz signal value is predominant, and the 1000 Hz value has a “0” change applied when converting to A-weighting.

2. Interrogating the Collected Data

Data collection commenced using the method described in Section 1 in March 2010. At the time of writing (Jan. 2011) data collection has been underway for over 10 months, and over 225 data sample recordings have been made on over 30 separate days in winter, spring, summer, and autumn conditions. Recordings have been made with turbines ranging from low power to high power (with power levels available from the hourly data provided by the Independent Electricity System Operator [IESO] of Ontario), and a variety of downwind, upwind, and crosswind conditions. Readings have been taken at several different wind power developments, incorporating 4 different varieties of turbines. In a number of cases, readings were taken over a 2-hour period at both the control location (over 5000 metres to the nearest wind

turbine) and at a variety of homes located closer to wind turbines, so that the turbine output power and environmental conditions stayed very similar. All of the homes are located in similar open, relatively flat terrain, and are subject to similar environmental conditions. In fact, from the control location the wind turbines located near many of the other monitored homes are visible, although some 6 to 10 km distant. While there are not a sufficient number of data samples to perform a detailed statistical analysis, it was possible to use the samples to perform a number of comparisons some of which are described in this paper.

The first comparison was made between the home greater than 5000 metres from turbines (identified as TLE in the Figure 7 below), a home some 620 metres from the nearest Vestas V-82 turbine (identified as SMI below) and another home some 450 metres from the nearest Vestas V-82 turbine (identified as CSK below). In this case, the turbines were rotating, at a very low power (identified by the IESO as less than 2% output for the array). The sound levels are shown both in the unweighted format, and in an A-weighted format, as shown Figure 8 on the next page. Figure 8 also identifies the Leq calculated from the 10 octaves from 16 Hz to 8000 Hz (within the flat response range of the microphone) in both the unweighted format and the A-weighted format.

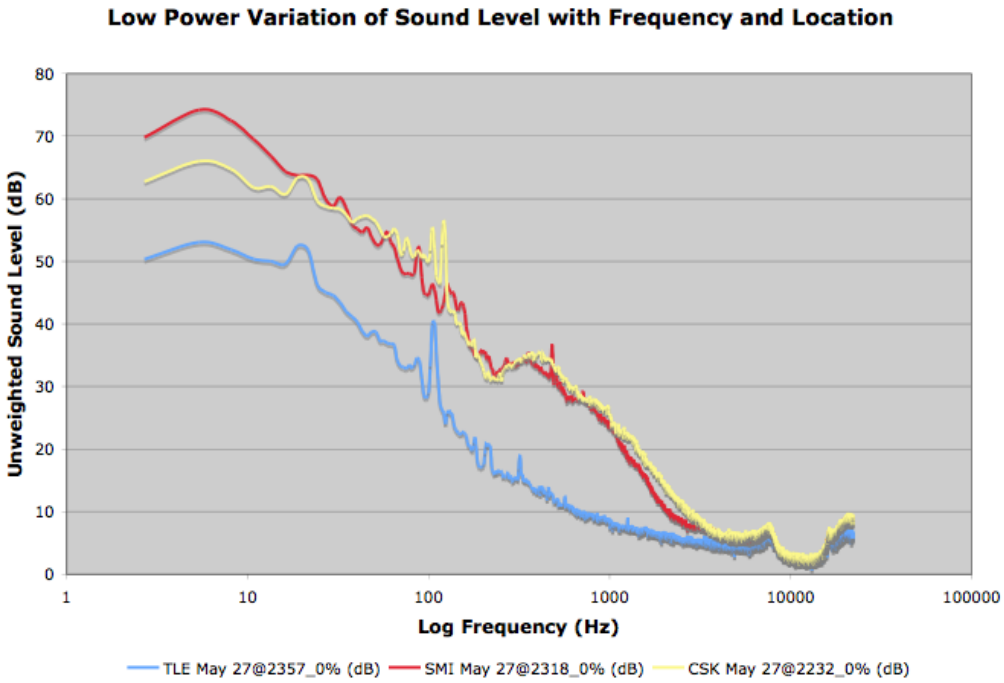


Figure 7: The frequency distribution of the Unweighted Sound Power as Calculated by the FFT Routine of the Audacity Program for recordings taken at the control location (TLE) and homes approved by the regulators (SMI and CSK).

Both Figure 7 and Figure 8 show that the sound levels at all frequencies below 1000 Hz are about 15 dB higher at homes near the wind turbines than at the distant home. Above 1000 Hz, the sound levels are closer in magnitude as a result of the attenuation of sound at higher frequencies in air.

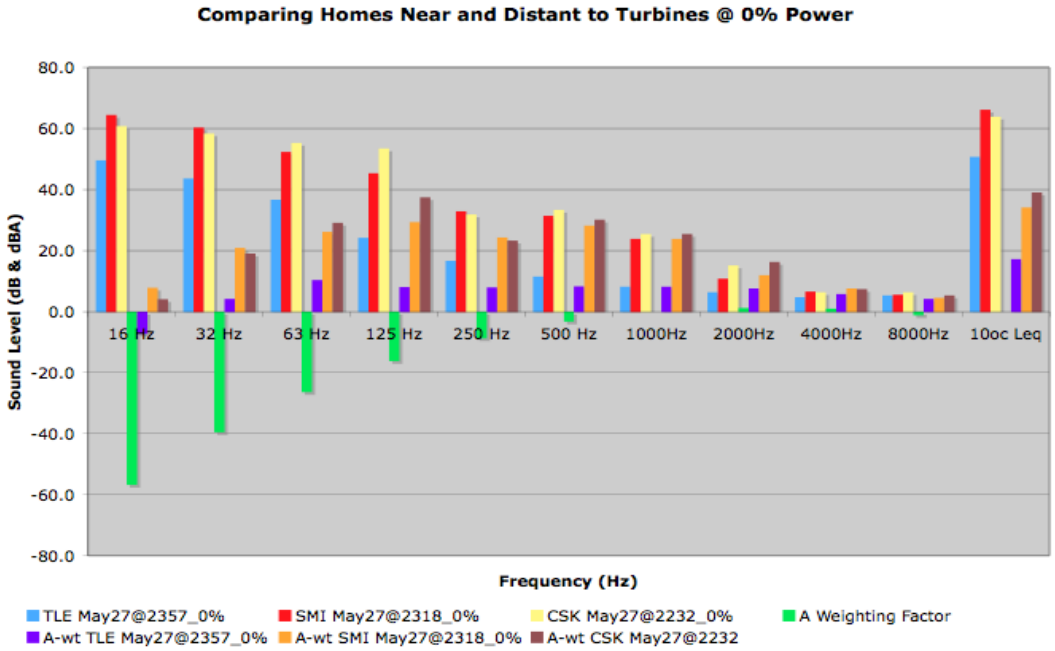
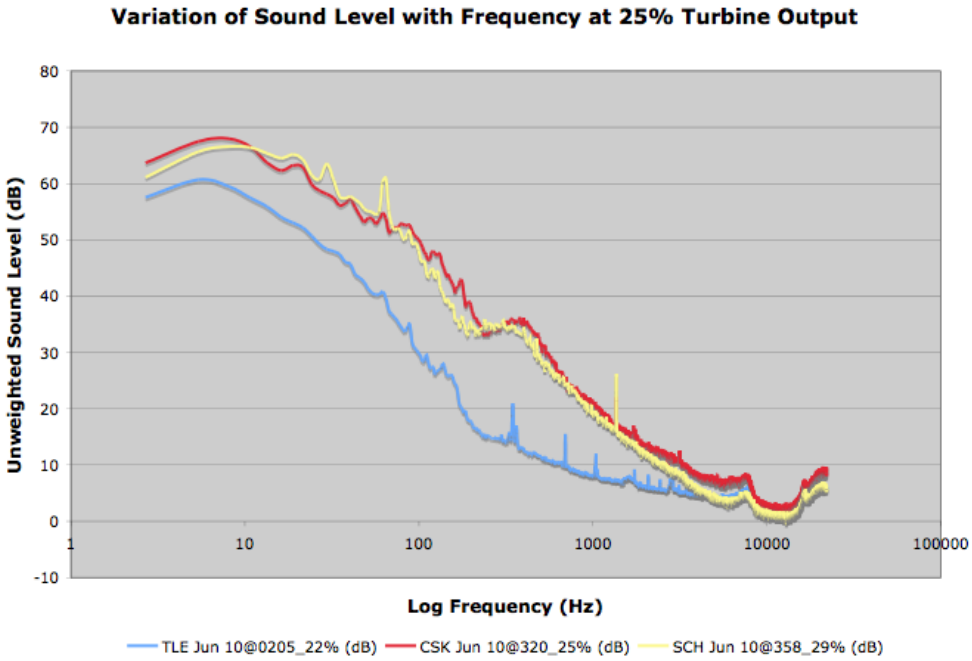


Figure 8: Comparing Sound Level at Homes at very low Turbine Power – Developed from FFT Output as described in the Text.

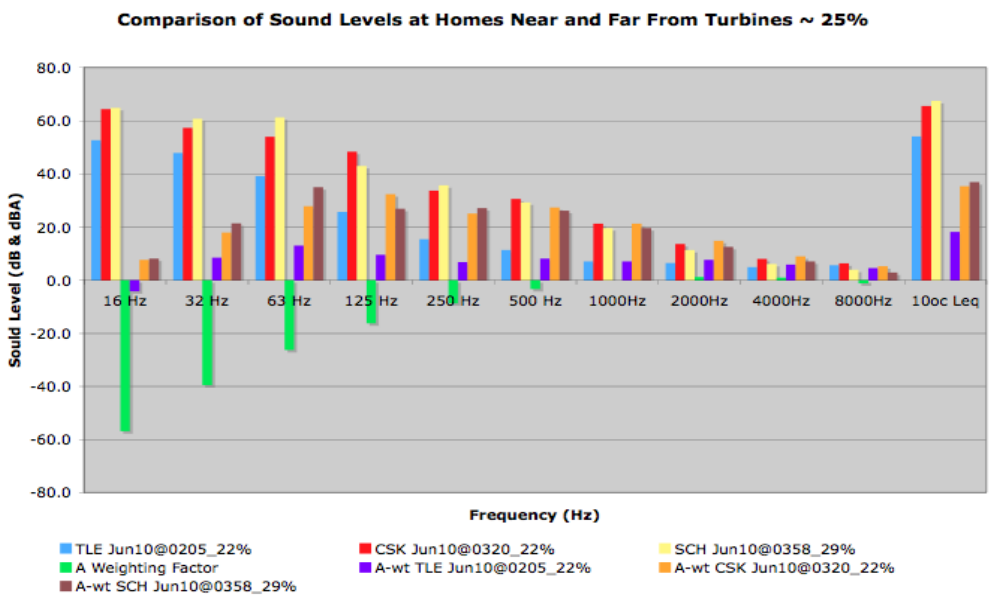
The second comparison was made between the home greater than 5000 metres from turbines (identified as TLE), and two homes (identified as CSK and SCH) located at distances of about 450 metres from the nearest Vestas V-82 turbine for the case of turbine power about 25% as shown by the IESO – both predicted to have sound level readings of 40 BA or lower in the Environmental Noise Assessment prepared for the wind power development.

Figure 9 (first figure on the next page) shows that the sound level at the homes near the wind turbines remains some 10 to 15 dB higher than at the control home, but as the turbine power rose, a greater increase in the difference to over 20 dB is apparent at a “knee” in the curve between frequencies between about 200 and 500 Hz.

Figure 10 (the second figure on the next page) shows little difference in the sound levels between the low power case and the 25% power case, perhaps showing that the very low power case is surprisingly higher in noise level than expected.



Figures 9 (above) and 10 (below) for Sound Levels at ~ 25% Turbine Power



The third comparison was made for the case when the turbines were operating at high power, in the order of 88% of rated output. At the time these recordings were made, the wind speed at ground level, measured with a hand held anemometer some 2 metres above the ground, and confirmed by a mast mounted anemometer at about 7 metres above the ground was measured at 8 metres per second. This is an appreciable wind, typically described as Force 5 on the Beaufort Scale, which will make small trees sway, and raise whitcaps. The point to note, is that it required this appreciable wind, for the sound level at the control home to approach the sound level measured at homes near the wind turbines for the zero power case for frequencies below about 1000 Hz. Mean time, the sound level at the homes near the wind turbines had climbed a further 20 dB.

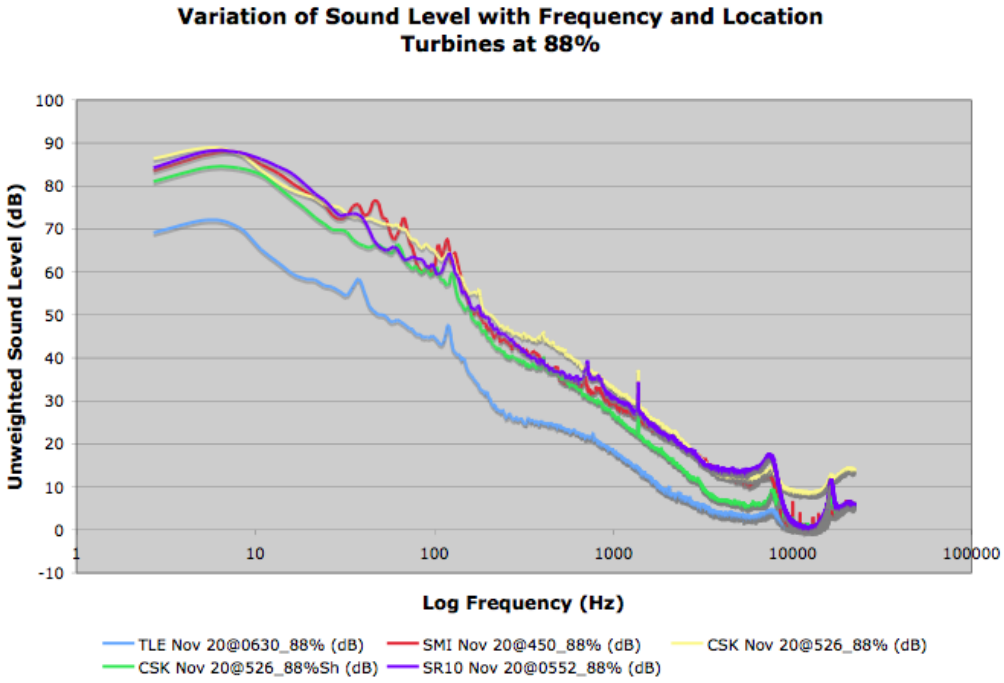


Figure 11: The FFT Calculated Sound Levels as a Function of Frequency calculated by the Audacity Program for Recordings of Sound Made at control location (TLE) over 5000 metres from wind turbines, and at locations SMI, CSK, and SR10, located 620, 450, and 550 metres from the nearest Vestas V82 Turbine.

Figure 12 (next page) shows the ground level wind speed has not masked the noise level from the wind turbines, as the sound level at homes near the turbines has risen a further 20 dB above the noise from the wind.

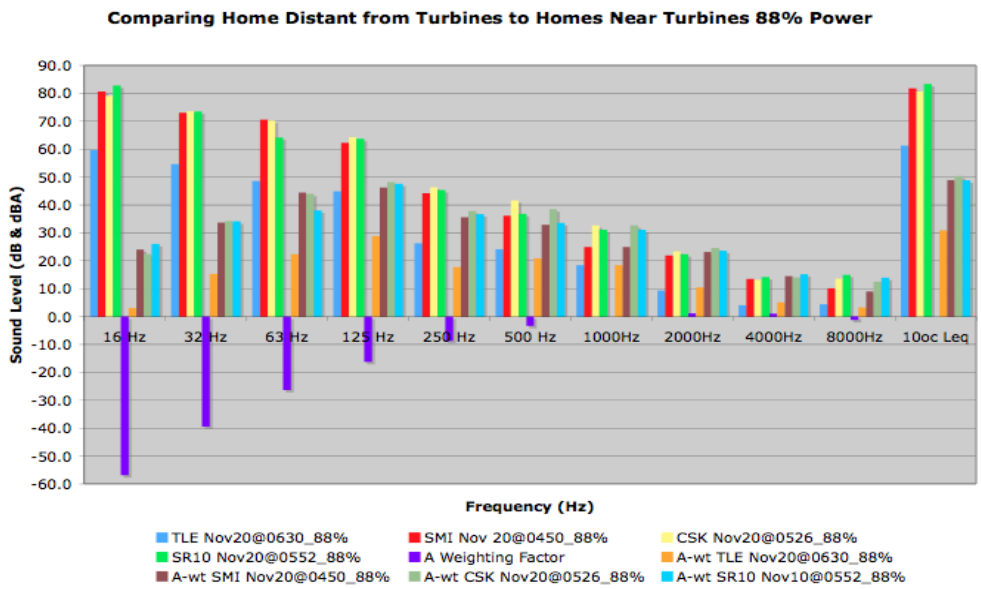
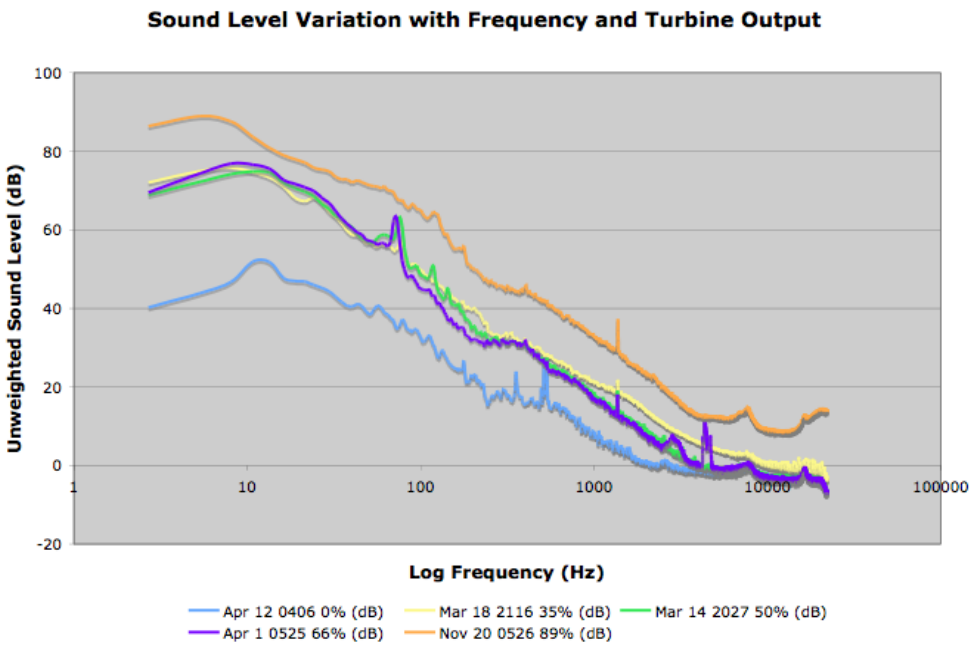


Figure 12 (above) – The High Power Case at Different Locations, and
Figure 13 (below) Different Powers at one Home Location Near Wind Turbines.



The final comparison was shown in Figure 13 (second figure on the previous page) made to plot the change in sound level at a home located at an approved distance (450 meters) from the nearest Vestas V-82 wind turbines as the turbine power changes. As noted in the last charts, even at the zero power case, the sound level at the home near wind turbines is comparable to the sound at the control location distant from wind turbines when a force 5 Beaufort wind is blowing at the control home, a relatively rare occurrence. At all times, the sound level at frequencies of 1000 Hz or less are 15 to 20 dB higher than at the home distant fro the turbines. Ground level winds are not masking the wind turbine noise emissions.

3. Summary of Observations

Discussion with people living near where wind turbines have been installed shows that a significant number of individuals are suffering, yet are unable to identify an exact reason for the discomfort they feel. Initial steps taken to monitor the sound levels near the homes occupied by the sufferers showed a pattern of C weighted sound levels being from 17.5 to 33.5 dB higher than A weighted sound levels, a considerably higher spread than observed at locations distant from wind turbines.

Literature review shows that a spread between C weighted and A weighted sound between 15 and 20 dB suggests the need for an investigation of the low frequency noise component.

A method of making recordings of sound levels and then processing these into their frequency components was described. Using the described method over 225 recordings have been made. Analysis of the recordings show that at homes near the wind turbines approved by the regulator with predicted sound levels of 40 dBA or less, the sound level at all octaves below 1000 Hz is between 15 and 20 dB higher than at a control location distant from the turbines, with a particular “knee” in increased sound levels between about 200 and 500 Hz. The nature of the cyclical nature of the sound which is known to cause annoyance is not even considered in this evaluation.

The sound levels observed at homes at approved distances from wind turbines when the turbines are just synchronized, but at very low load, when ground level wind speeds are very low (or zero) is equal to or greater than the sound levels observed at the control location when a force 5 wind is present. At that time, the sound level at the homes near the wind turbines are some 20 dB higher yet.

Conclusions

A repeatable manner of assessing the frequency spectrum of the sound levels experienced by people living in homes at distances approved by regulators, with predicted sound levels of 40 dBA or less shows that the sound levels at octaves below 1000 Hz are consistently 15 to 20 dB higher than experienced at homes remote from the wind turbines.

Sound levels at homes near turbines for all octaves below 1000 Hz are shown to be greater than the sound level experienced at a home distant from wind turbines when the wind there exceeds a Beaufort Force 5 wind.

Research presented in this paper shows that wind turbines introduce a change into the environment at homes approved by regulators as having an A-weighted sound level of 40 dBA or less, such that the sound levels at frequencies below 1000 Hz are 15 to 20 dB higher than the sound level at a home in a similar environment but distant by 5000 metres from wind turbines.

Research by others (notably A.N. Salt) notes that low frequency sound which might be emitted by wind turbines needs further study. This work confirms the presence of low frequency sound at homes near wind turbines.

References

Audacity, Free Audio Editor and Recorder, available for Mac OS X, Windows, GNU/Linux, and other operating systems from http://audacity.sourceforge.net/

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