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Wind Turbines – A Changed Environment

William K.G. Palmer TRI-LEA-EM 76 Sideroad 33/34 Saugeen, RR5, Paisley, ON N0G 2N0 Canada.

E-mail: trileaem@bmts.com

Summary
This paper gives examples of the sound from wind turbines in the outdoor environment, and in the indoor environment. These are compared to other sounds occurring in the environment, such as road traffic or overhead aircraft, and to the sounds produced in a typical municipal library and by a typical refrigerator. In summary, the paper shows that wind turbines do alter the acoustic environment, both outside homes and inside homes presenting a greater difference at low frequencies than other sound sources normally met.

1. Introduction Classical problem solving for systems suggests that when a working system experiences a failure, look for changes in its environment. As an example, if an engine that has worked well for some time suddenly experiences distress, look for what has changed. Was the oil change schedule altered? Has a bearing reached end of life? This paper applies a similar approach to look for what has changed when distress occurs in the human system.

When wind turbines are installed in the environment of humans, a common finding based on face-to-face interviews conducted by the author, with many people, is that some report discomfort, at varying degrees, ranging from mild annoyance, to severe adverse health impacts. The healthy human system experiences distress. Interviews reveal when people leave the wind turbine environment, their distress diminishes, but when they return, so does the impact. What change is causing the distress?

Rather than trying to discount the discomfort, this paper looks for changes in the environment wind turbines create based on research into the sound and it's special characteristics as received where the humans live. The sound from wind turbines is compared to other sounds in the environment to examine the differences based on analyzing recordings of actual sound monitoring. We will look at sound from wind turbines, vehicular traffic, aircraft, wind, and people, to identify differences. We will look too at the way the sound is monitored, to see if that can have an impact.

Finally, through examination of the special characteristics of the sound generated by wind turbines that are different from the sound from other sources, a reason for the discomfort people experience is offered. The links between the changes in the environment wind turbines create and the human condition is explored.

2. Background

2.1 What do we mean by "the sound" from a wind turbine? Questions of how much sound wind turbines emit, and how that sound compares to other sound sources has been around for a long time. Almost everyone who has been following the information cloud surrounding wind turbines has heard the common expressions:

- The sound from wind turbines at your home is less than from your refrigerator or air conditioner.
- The sound from a wind turbine is comparable to a quiet library.
- The background noise of the wind "masks" the sounds emitted by wind turbines.
- The sound level produced by typical wind farms is so low that it would not be noticeable in most residential areas.

So, what does it mean when we speak of "the sound" from wind turbines? It is often represented by a single value, representing the amplitude in the range our hearing is most sensitive, the A-weighted value. But, should we not also consider the "quality" of the sound and it's special characteristics? The nature of human hearing is that we respond to a very wide range of sound inputs, and often it is differences in sound, and differences in the characteristics of the sound that gives them a recognizable signature. We can hear a whisper of a companion or a whimper from a restless baby. We can recognize the voice of someone we know in a crowded room. Most of us can whistle a familiar tune that sticks in our head. Our hearing responds better to differences than just to volume, and our mind responds to specific tones, or repetitive patterns more than to a random sound. Sound is far more than "volume."

2.2.What have we learned already? From previous work, we have learned that:

- At distances of more than 500 metres to a kilometer, the sound from wind turbines are rich in low frequency sound (sound less than 200 Hz) and infrasound (sound less than 20 Hz), while the higher frequencies are attenuated to be comparable to background,
- low frequency sound travels longer distances than high frequency sound
- low frequency easily passes through most building materials, even while higher frequency sounds are attenuated
- WHO states low frequency sound warrants special consideration
- the special characteristics of the sound from wind turbines makes them recognizable even when the volume is low

Further adding to the confusion is the fact that most regulators base sound level limits on A-weighted values, often found by considering only the octaves centred from 63 Hz to 8000 Hz. All this means sound levels at different octaves are adjusted as follows:

- sound from octaves at frequencies below 63 Hz is ignored
- 63 Hz – measured sound reduced by 26.2 dB
- 125 Hz – measured sound reduced by 16.1 dB

- 250 Hz – measured sound reduced by 8.6 dB
- 500 Hz – measured sound reduced by 3.2 dB
- 1000 Hz – measured sound considered as is
- 2000 Hz – measured sound augmented by 1.2 dB
- 4000 Hz – measured sound augmented by 1.0 dB
- 8000 Hz – measured sound reduced by 1.1 dB
- sound from octaves at frequencies above 8000 Hz is ignored

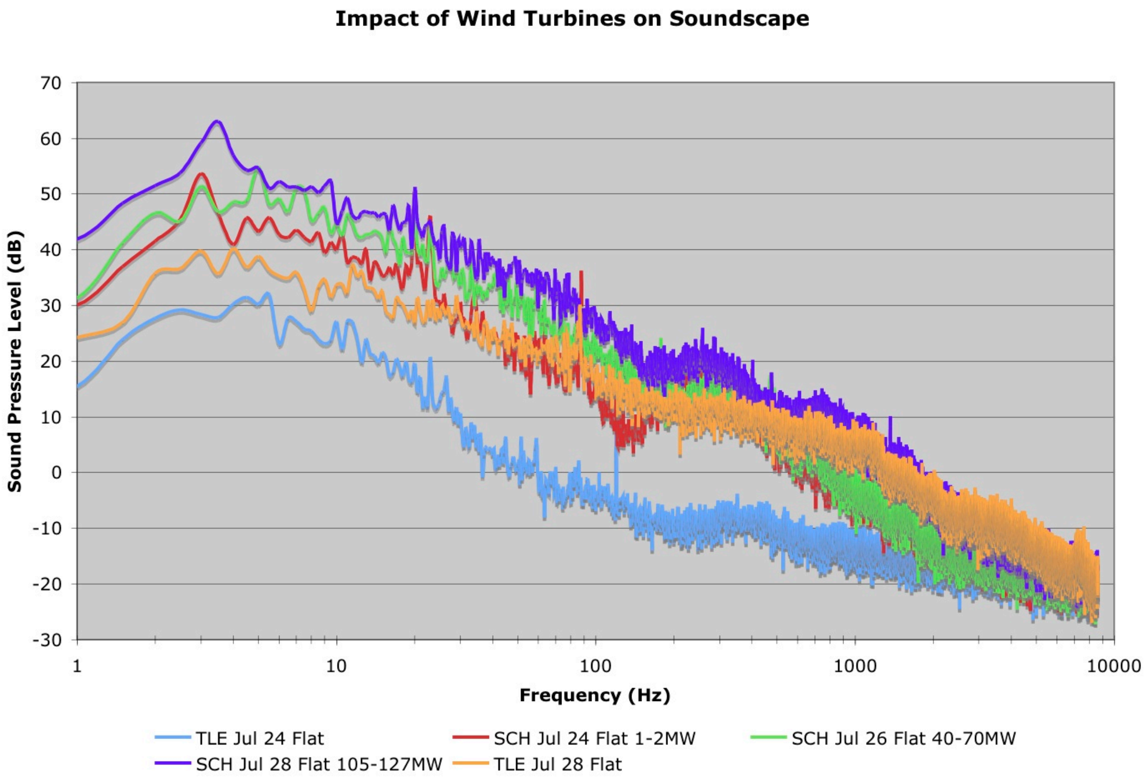
As a result low frequency and infrasound are reduced or ignored by most regulators, as are higher frequencies, on the assumption that those sounds are not considered part of the normal hearing range as used in spoken communication.

2.3 What will we not do? What this document will resist doing is to identify a single value of the sound intensity for any of the sources. Generating a single value by somehow adding together the octave contribution across the spectrum of sound produced by a source neglects the impact of the special characteristics of the sound. If a sound is cyclical (displaying a repeating pattern) or tonal (with a discernable pitch at one or more frequencies) it is more recognizable than a sound that is constant, and evenly distributed across all frequencies. Generally regulators recognize that if a sound has special characteristics of recognizable tonality, a cyclical nature, or impulsiveness (like a hammer blow or a gunshot) then the sound is penalized, yet, some regulators specifically do not consider sound from wind turbines which have a recognizable repetitive “swoosh” which modulates the sound at all frequencies as being cyclical. Yet, it is the cyclical, repetitive nature of sound from wind turbines that seems to make them most recognizable.

To those who hoped this document would produce a simple answer to the question about how the sound from a wind turbine compares to other sources, an apology must be given in advance. Instead, this document proceeds at a somewhat “pedestrian” rate, trying to give the reader a better understanding of why there is no simple answer, and why a response must be conditioned with “it depends.”

3.0 The Cases The cases have been selected from hundreds of sound samples recorded over the years, using the instrumentation and methodology described below. Although a visual representation of the sound as a function of frequency is displayed for each sound, the visual display cannot fully represent the full acoustic quality of each sample. The presentation first goes through a set of charts to show the impact of wind turbines or no wind turbines at different power levels at different locations in the same environment. Then, it goes through a set of charts to try to demonstrate a comparison of the impacts of wind turbines versus traffic, or overhead aircraft.

3.1 Impact of Wind Turbine on Soundscape Outdoors at Rural Sites



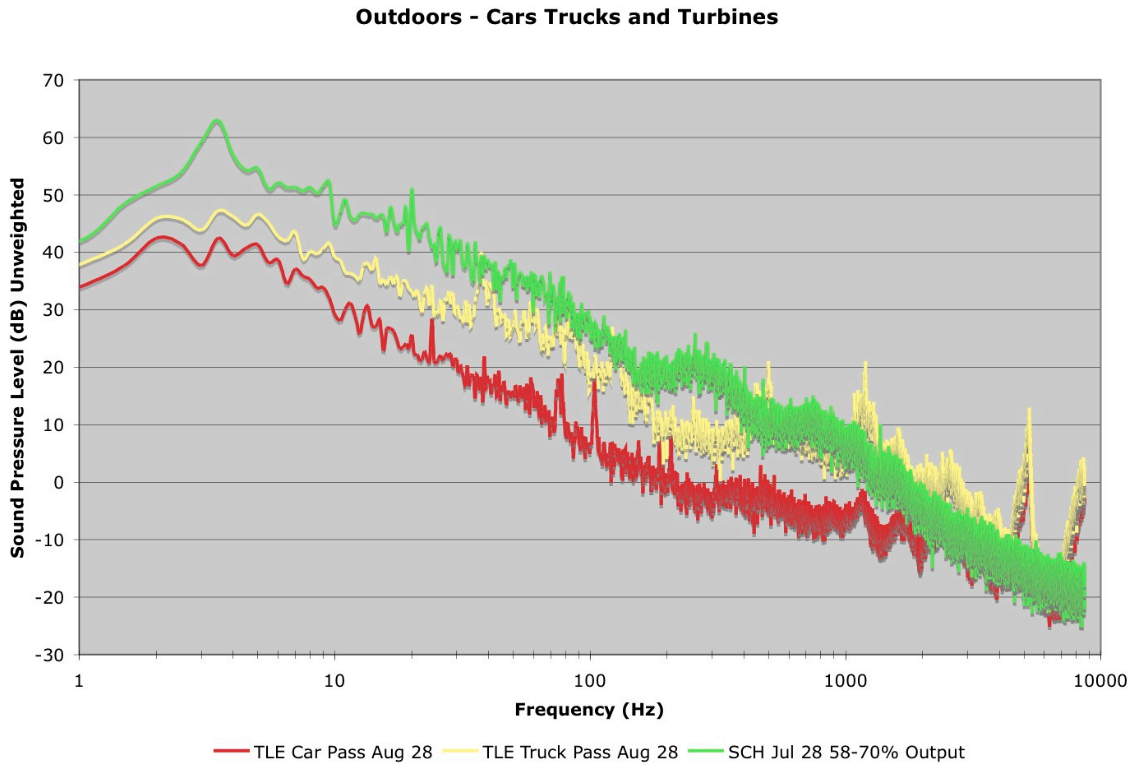
This chart demonstrates that low frequency sound is present in the environment at a higher level than in the normal audible range. The TLE site in the samples above is 5 km from the nearest wind turbine. However, the range of frequencies humans communicate at is typically in the rage of hundreds to thousands of Hz. Our hearing is generally considered to be insensitive to frequencies below about 20 Hz or above about 20,000 Hz, although this will vary among individuals. The 5 unweighted sound level readings shown in the chart show similar patterns. The sites are within a 7 km radius, and the turbines at any site are visible from the others.

The readings were taken using an Earthworks M30BX microphone mounted 1.5 metres above ground with a 90 mm diameter primary and 450 mm diameter secondary wind screen, digitized using a M-Audio Fast Track USB Audio Interface, and recorded on a Macintosh iBook G4 computer running the Audacity Digital Audio Editor program. The limiting feature in the system was the frequency response of the microphone, which is listed as 9 Hz to 30,000 Hz, with 3 dB down points at about 5 Hz and 40,000 Hz. The system was calibrated before and after each recording session using a Lutron 941 - 94 dB 1 kHz sound calibrator.

The signal processing was done using the Electroacoustics Toolbox version 3.5, which permits calculating and plotting calibrated FFT data at selected bandwidth and resolution. The FFT calculation averages 10 sets of calculations to derive the result plotted. These plots shown above used a 8613 Hz span, with 17,228 calculations to produce a 0.5 Hz resolution.

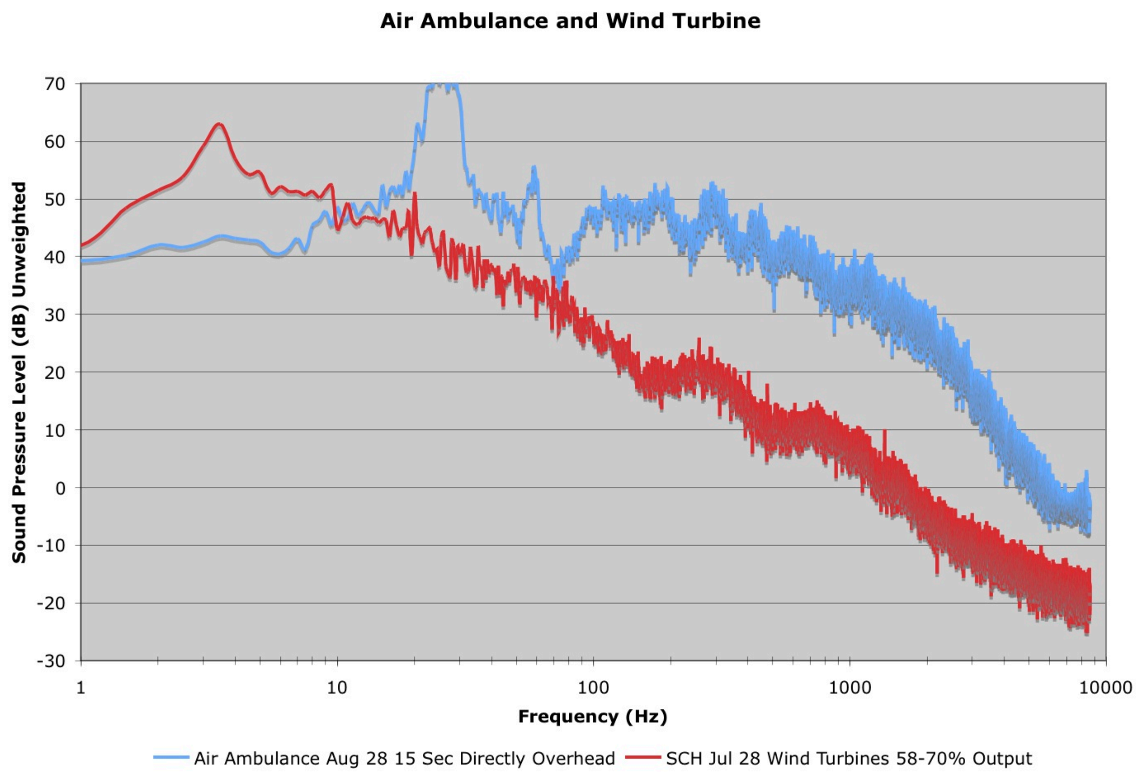
On a day the turbines were at a very low power (July 24 on the chart), with an output of 1 to 2 MW for the entire 110 turbine array (rated at 181 MW) the sound levels are similar at an outdoor recording site, (identified as SCH) a home at an approved setback distance from the turbines, as at the TLE site at frequencies above 1000 Hz. However, at lower frequencies, the sound at the SCH site, home of a "receptor", the sound levels are about 15 dB higher than at a TLE site 5 km from the turbines. At a day the turbines were at a moderately high power (July 28 on the chart) the array output ranged from 105 to 127 MW (58 to 70% of maximum) in the hour before and after the recording was taken. For this day even though the sound level had risen at the site remote from the turbines, the sound level at the approved receptor was now some 20 dB higher than the sound at the site 5 km from the turbines.

3.2 Cars, Trucks, and Turbines (Outdoor Sound)



This chart shows the plot of the FFT for a car and a truck passing the TLE site. The road is located about 75 metres from the sampling location. One feature the car and truck display makes clear is the necessity to actually listen to recordings taken to discern if there are other sounds present. Both the car and the truck recordings exhibit the presence of insects, and the traces show peaks at about 5244 Hz and 8564 Hz, which are likely due to the insect presence, as it is also present in background recordings. The traces show that the sound from the wind turbine at the SCH monitoring site, when the array was at a power level ranging from 58 to 70% output, exceed the sound of either the truck and car pass for all frequencies below about 400 Hz, and are about 10 dB higher than even the truck for frequencies below about 40 Hz.

3.4 Overhead Helicopter Air Ambulance (as heard outdoors)



Similarly, the Ornge helicopter air ambulance passes directly over our home as it flies from London en route to the local hospital. Recordings of the air ambulance overhead shows that it too has a significant amplitude for about 15 seconds as it passes overhead, a low frequency tonal characteristic, and yet, one would not want a regulation to prohibit air ambulance flights to save lives. The awakening it produces (on a rare night flyover) is usually the opportunity for a simple prayer of "God-speed, I wonder what happened?" Note that the wind turbine is louder than the air ambulance for frequencies below about 10 Hz.

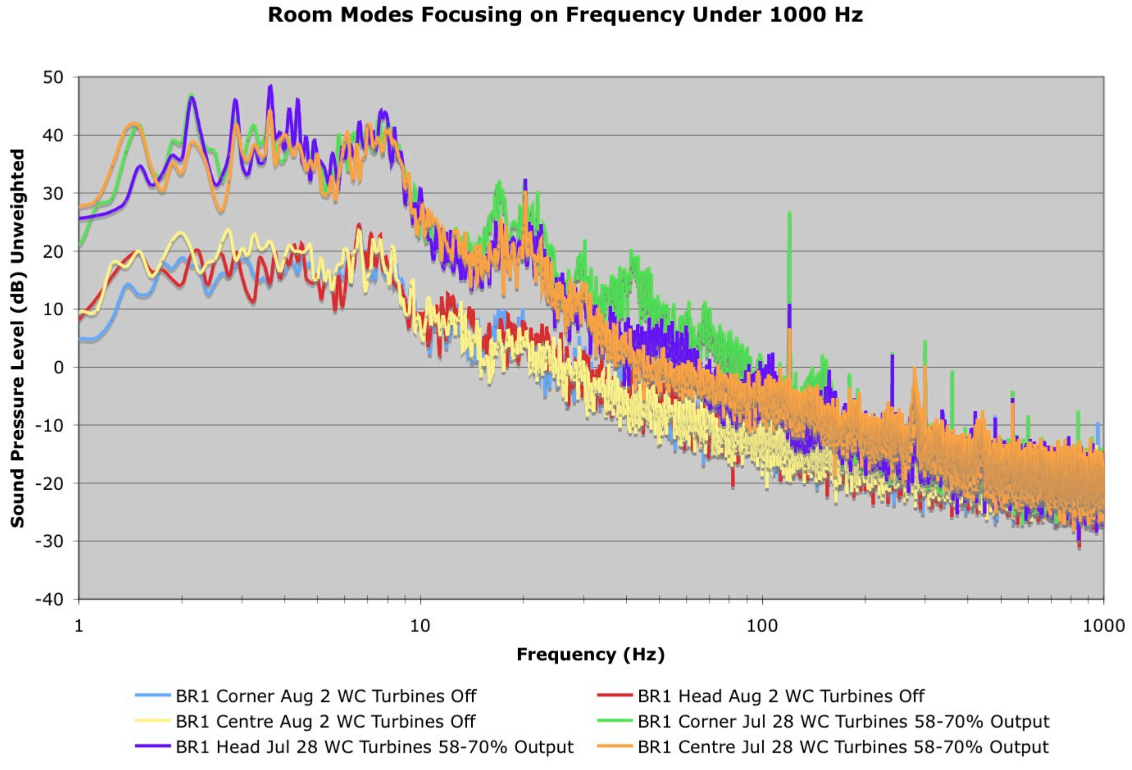
3.5 Impact of Wind Turbines on Sound Inside a Home

Interesting as the study of sound outside a home might be, as previously presented in this paper, the truth is that people tend to live indoors, and that is generally where they go to seek rest, and sleep. As I spoke to people about wind turbines in their environment, many puzzling statements led to a study of the conditions inside a home, instead of just focusing outside. The results were presented in a paper presented to the Acoustical Society of America, fall 2014 session, and the paper is currently undergoing peer review prior to consideration for issuance in the Journal of the Acoustical Society of America.

Briefly, the puzzling statements included ones such as:

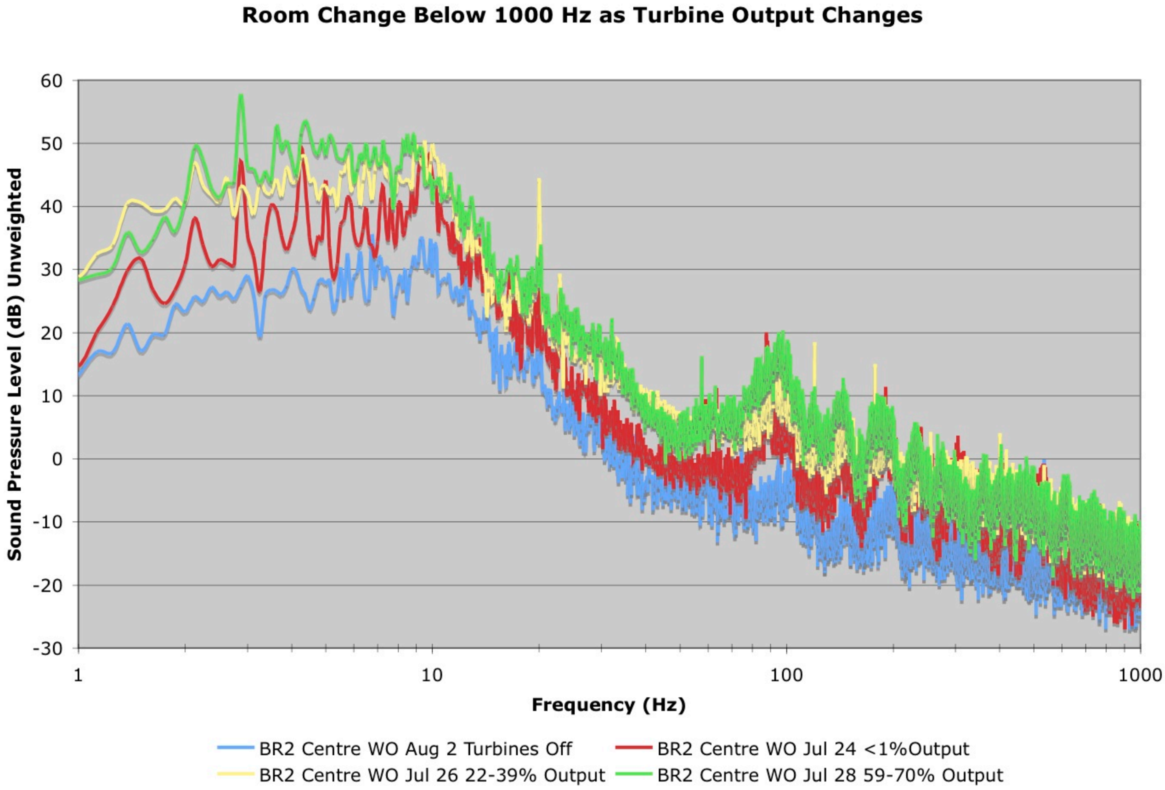
- we were unable to sleep in our bedroom, but when we moved out of doors into a tent, we were able to sleep better.
- My husband is unable to sleep in our bedroom, but when he moved downstairs into a recreation room, he gets a bit more sleep.
- I've tried everything, even lying in bed with my head at the footboard, and my feet at the headboard, to try to get some sleep.

In summary, the paper presented explains that what was found was that room conditions exist inside homes, particularly ones with rooms that tend to be cubic, typical of older Ontario farm homes (which have smaller square rooms with high ceilings) resulting in preferred frequencies matching wavelength and the room dimensions. These generate peaks in waves inside homes.



The chart was prepared using a higher resolution in the Electroacoustics Toolbox, to give a resolution of 0.125 Hz, which permits a more detailed low frequency examination and a clearer display of tonality. The chart shows that comparing the sound conditions in the same room on days when neighbouring wind turbines are off, compared to being at moderate power, result in peaks in sound level at the room mode frequencies, and accentuating the forcing function presented by the sound from wind turbines entering the home. Note also the strong peaks in the high power case representing the blade pass frequency for these turbines. As a result, conditions in side the home are actually more changed and peaked than the conditions outside. As expected for room conditions, the corner of the room displays a higher sound level than the centre of the wall, and the lowest sound level in the room is actually in the centre of the room.

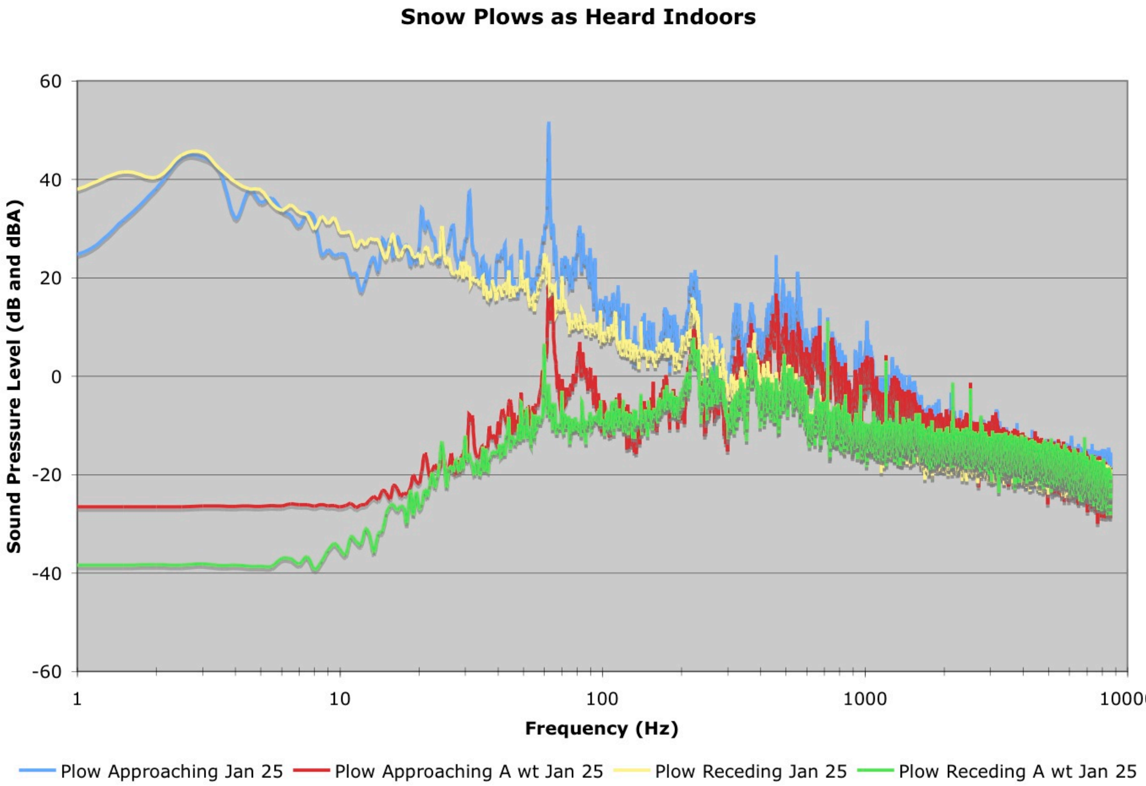
The room modes study went further to examine the conditions inside the same room as surrounding turbine output changed, in particular as the room window was cracked open only about 2 inches (5 cm) for ventilation, as would be typical in the summer time. The results are shown in the chart below.



The chart shows that although the variation above about 500 Hz is minor, as the frequency falls, the difference caused with rising turbine power continues to grow. Also, the presence of the room condition variations is more noticeable as the turbine power rises.

For more details on the difference caused by the room mode variations, the reader is referred to the paper planned for issuance in for the Journal of the Acoustical Society of America. Copyright restrictions prevent going into more detail here.

3.6 Snow Plow on Highway (As Heard Indoors)



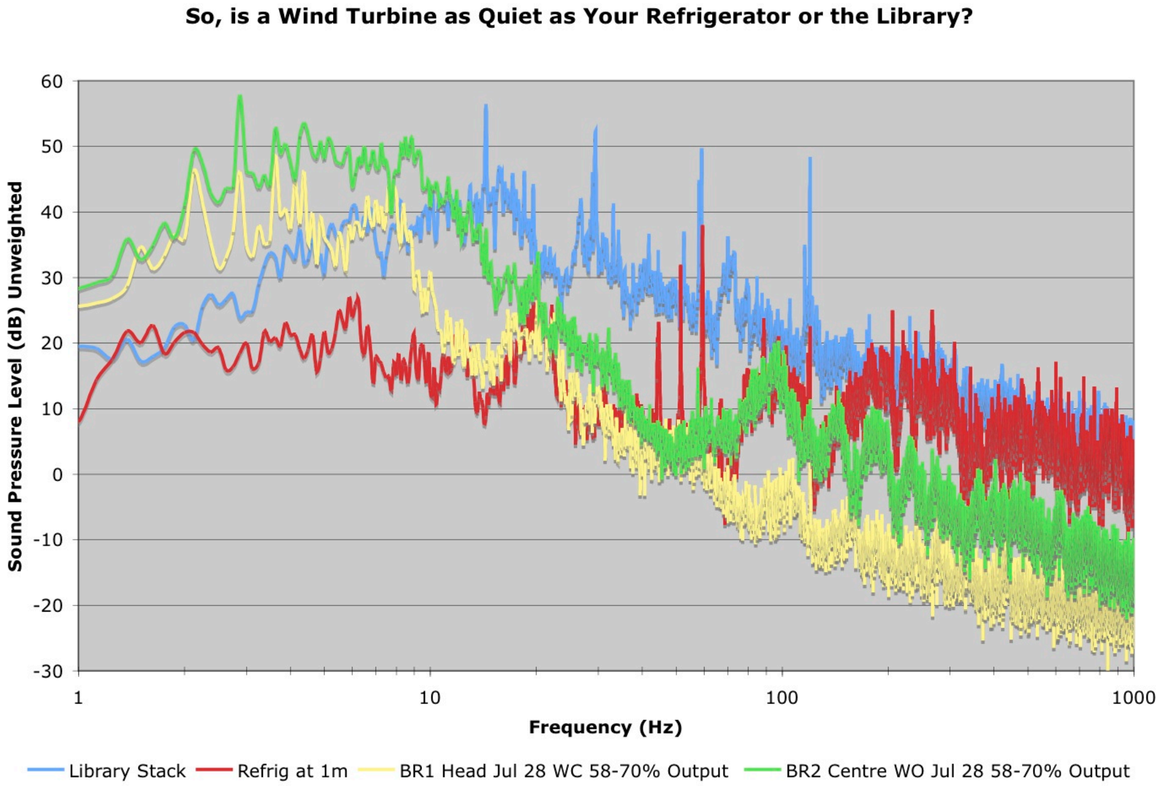
This chart has little to do with wind turbines, but was recorded using the same technique as the previous wind turbine profiles. What this chart shows is a recording of a snow plow scraping snow from a paved highway, recorded from a distance from about 75 metres to about 600 metres as the plow passed the house. The intent of presenting this record is to show that there are other sound sources in the environment that have a similar low frequency amplitude as do wind turbines. This is a caution to anyone who might be inclined to want to see a restriction passed that simply limits the emission of low frequency noise.

Snow Plow Approaching and Receding (behind a sound absorbing cloud of snow)

Any restriction needs to consider the frequency of the sound, the duration of the sound intrusion, and special characteristics of the sound. While the snow plow may have a frequency distribution amplitude similar to wind turbines, and a tonal peak, a restriction from plowing the roads would not be desirable to most rural dwellers. It may be true that when the snow plow passes our home (generally at about 5:30 AM) it will often awaken sleepers, but the duration of the pass by is short, less than 5 minutes in the night, and it is a reassuring sound, as it means that the roadway is open and safe for travel.

Comparison of this chart and the previous room conditions chart shows that the sound from the snow plow is less than that produced by the wind turbines at powers above 1% output for most frequencies below about 30 Hz.

3.7 Library, Refrigerator, or Wind Turbines



Finally we get to the beginning question, are wind turbines really as quiet as a public library, or your refrigerator, or other sounds in your environment? The intent of this chart is to answer the question. To provide a response, recordings were made of the sound:

- in the stacks of the Port Elgin Branch of the Bruce County Library below a ventilating diffuser (a busy spot with folks chatting, going up and down stairs, and moving chairs),
- 1 metre away (that’s close!) from an operating Whirlpool Energy Star Frost Free refrigerator, with everything else off in our kitchen
- inside two bedrooms of a home in a bedroom with wind turbines at approved setbacks, in once case with the window closed, with then cracked open 2 inches (5 cm) typical of a summer night.

And the answer? Well, sort of, if you A-Weight the sound, and neglect octaves below 63 Hz, as the Ontario regulations do. In fact, what the recording showed is how noisy the refrigerator or library actually are. Few would sleep in the library routinely as a matter of choice. Fewer still would sleep with their head 1 metre away from a full sized refrigerator. Looking at the chart, the busy library, with a sound level of some 44 dBA-Leq, and some very tonal points from the air conditioning system is indeed noisy. The library is noisier than the wind turbines at frequencies above about 20 Hz. The refrigerator, at 1 m, is noisier than the wind turbines at frequencies above about 200 Hz.

However inside the home with wind turbines as neighbours, the sound level in the bedroom at the pillow end of the bed, where the occupant’s head would lie, or even in the centre of the room if the window is cracked open, becomes some 25 dB higher than the refrigerator at frequencies below 20 Hz, and noisier than the library at frequencies below about 10 Hz.

4.0 Concluding Observations

The charts in this document show the sound from wind turbines is indeed rich in low frequency, exceeding the low frequency contribution received from the wind in the environment, of a helicopter flying directly overhead, of refrigerators, or libraries, and of most highway traffic. The charts show that the sound from wind turbines shows tonal characteristics. The charts also show that inside homes, room conditions cause a greater variation across a room than in the outdoor environment, and result in intensity increases at room mode frequencies, a function of the room size, and exciting source.

What the charts cannot show is the duration of the wind turbine sound, which can continue for hours at a time, particularly at night, when meteorological conditions favour higher wind turbine output, and be significantly greater than other sound sources in the environment. Neither do the charts properly identify the cyclical nature of the sound, rising and falling repeatedly, which makes them particularly recognizable. These durations and repetitive patterns (amplitude modulation) are apparent from the audio recordings that form the basis for this document though, which were made in a rigorous manner.

It is suggested that the information displayed in these charts provides a firm argument that use of A-weighting and of considering only octaves from 63 Hz to 8000 Hz does not provide an adequate regulatory environment for wind turbines.

Some regulators recognize that special audible characteristics of wind turbines should be addressed. New Zealand Standard NZS6808-2010 states, *“5.4.2. Wind turbine sound levels with special audible characteristics (such as, tonality, impulsiveness, and amplitude modulation) shall be adjusted by arithmetically adding up to +6dB to the measured noise at a noise sensitive location. This adjustment is a penalty to account for the adverse subjective response likely to be aroused by sounds containing such characteristics.”*

While the issues are identified, the regulations do not necessarily deal effectively with the issue. For example New Zealand Standard NTZ-6808-2010 states, *“C5.5.2 The World Health Organization recognizes that adverse noise effects can be increased by sound with a large proportion of low frequency components.”* However, all stakeholders, including the wind turbine industry, influence development of regulations.

The Standard goes on to diminish the issue. *“Measurements show that wind turbine sound does not contain a large proportion of low frequency components. As sound propagates from a wind farm (or any other source) the higher frequency components are attenuated quicker than the low frequency components. At a distance from any sound source it is often lower frequency components that are audible, albeit at a low sound level, Wind farm low frequency sound at a noise location which is tonal or has amplitude modulation would be penalized for special audible characteristics.”*

This document does give evidence that the wind turbine contribution to the environmental noise at low frequencies particularly is indeed above other sound sources, suggesting that they provide a basis for recognition in the New Zealand Standard.

The Ontario Noise Guidelines for Wind Farms (2008) state, *“the information (for acoustic emission of wind turbines) must include the sound power levels, frequency spectra in octave bands (63 to 8000Hz), and tonality at integer wind speeds from 6 to 10 m/s.”* The guidelines go on to note, *“Should the manufacturer’s data indicate that the wind turbine acoustic emissions are tonal, the acoustic emissions must be adjusted by 5 dB for tonality … otherwise the prediction should assume that the wind turbine noise requires no adjustments for special quality of sound.”* This document shows that measurement confirms that tonal acoustic emissions do occur; even if they are not indicated by the manufacturers data, suggesting that they may develop over time due to blade wear as an example.

The Ontario guidelines specifically exclude cyclical sound from wind turbines, noting, *“No special adjustments are necessary to address the variation in wind turbine sound level (swishing sound) due to the blade rotation, see Section 4. This temporal characteristic is not dissimilar to other sounds to which no adjustments are applied. It should be noted that the adjustments for special quality of sound described in Publication NPC-104, Reference [1], were not designed to apply to sounds exhibiting such temporal characteristic.”*

This document shows that using only the octave bands from 63 to 8000 Hz as well as A-weighting those sounds results in a regulatory environment that is not protective, as both A-weighting, and restricting the octave bands does not address the large proportion of low frequency components that is specifically identified by the World Health Organization as a source of adverse noise effects, which is noted in the New Zealand Standard. The audio recordings made to support this document demonstrate that the cyclical nature of the wind turbines is not similar to other sounds to which no adjustments are applied, it is indeed a “signature” quite specific to wind turbines, and the cyclical penalty from Publication NPC-104 should apply. The exclusion of the variation in sound from wind turbines should be revisited.

This document demonstrates that a revision to the regulatory environment for wind turbines is justified. The basis for neglecting the low frequency components and the cyclical (or amplitude modulation) nature of the sound by regulators that they are minimal has been proven to be faulty. The document also provides a part of the information called for by the Conclusion on Page 10 or the report of the Ontario Chief Medical Officer of Health, which states, *“The review also identified that sound measurements at residential areas around wind turbines and comparisons with sound levels around other rural and urban areas, to assess actual ambient noise levels prevalent in Ontario, is a key data gap that could be addressed.”*

This fact that thousands of complaints have been filed with the Ontario Ministry of the Environment regarding noise from wind turbines and adverse impacts on scores of citizens have been reported is confirmation of the result of regulations that are not protective. This document is provided in good faith, as a demonstration of the evidence that shows there are reasons of changed conditions brought about by wind turbines that are not addressed by current regulations, which call for their review.

References

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