Wind Turbine Annoyance - a clue from acoustic room modes

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Presented to
Acoustical Society of America Fall 2014
October 2014

Abstract - Wind Turbine Annoyance – A Clue from Acoustic Room Modes

When one admits that they do not know all the answers and sets out to listen to the stories of people annoyed by wind turbines, the clues can seem confusing. Why would some people report that they could get a better night's sleep in an outdoor tent, rather than their bedroom?

Others reported that they could sleep better in the basement recreation room of their home, than in bedrooms. That made little sense either.

A third mysterious clue came from acoustic measurements at homes nearby wind turbines. Analysis of the sound signature revealed low frequency spikes, but at amplitudes well below those expected to cause annoyance.

The clues merged while studying the acoustic room modes in a home, to reveal a remarkable hypothesis as to the cause of annoyance from wind turbines. In rooms where annoyance was felt, the frequencies flagged by room mode calculations and the low frequency spikes observed from wind turbine measurements coincided.

This paper will discuss the research and the results, which revealed a finding that provides a clue to the annoyance, and potentially even a manner of providing relief.

Listening to People – Lots About Sleep

- We could not sleep in our bedroom so we moved outdoors into a tent
- My husband has moved into the recreation room to sleep on the couch, he’s less comfortable, but sleeps somewhat better
- Sometimes I turn around from top to bottom in the bed and it seems to help
- When I cannot sleep at night I find myself falling asleep driving – I can’t tell my Doctor as he will take away my driving license. I’ll lose my job!

This presentation arose from listening to the sincere comments of people who live near wind turbine installations, and trying to make sense of what they honestly observed from their personal experience, and what they tried to do to address their observations. For most I listened to, large wind turbines have created a change in their environment, although in the case of some infants, they have known nothing but a wind turbine environment around their home. People may not be expert in knowing “why” they feel the way they do, but surely that must be the best expert in knowing “how” they do feel, and they deserve being listened to.

The first subject to be discussed usually is sleep - or lack thereof. People describe that they do not sleep as well as they had before turbines entered their environment.

Some observed that because they could not sleep in their bedroom, they even tried pitching a tent in their yard, and sleeping outside. This was interesting as the commonly held understanding is that sound is attenuated in going into a home, so outside the sound should be louder. Amplitude did not seem to be the only factor.

Others observed that sleep was better in a larger recreation room than in a bedroom, even without the benefit of a comfortable bed. How could room size matter?

Some described that out of desperation they tried anything, even trying to change their sleeping position from head to foot in bed. How does all this fit in?

Lack of rest produced consequences that were very troubling to listen to.

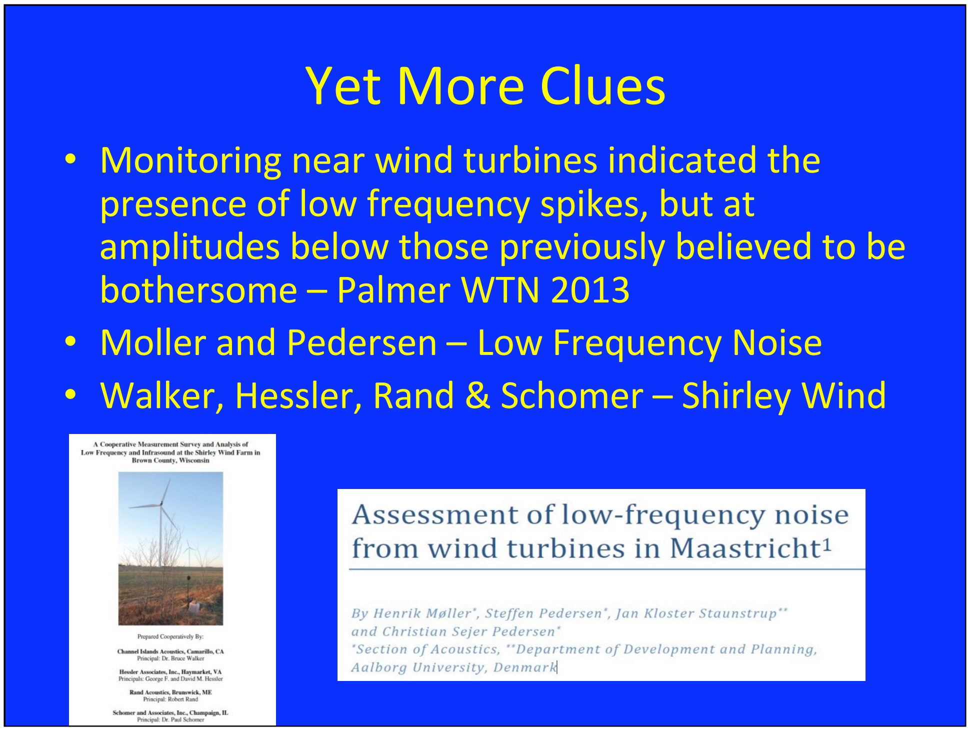
Listening More – It's Not Just Sleep

- Some mornings my head feels like it is three sizes too big
- I was nauseous most of the time when at home
- My diabetes used to be well controlled, but now my sugars are erratic, especially when I'm indoors
- I found I could not concentrate to do my job or anything after the turbines started up
- I started to be dizzy and fall, so needed a stick to walk with
- When I go away from home, I get much better
- We cannot live in our home anymore

As I continued to listen to people, in addition to the fairly common discussion about sleep, other subjects continued to arise. Here are some heard from more than one.

•Headaches, or a feeling of a throbbing sensation were often described. In the words of one, "Some mornings my head feels like it is three sizes too big."
•Nausea was often described. "I was nauseous most of the time when at home."
•Others described specific comments about diabetes – and blood sugar control for themselves or a family member. "My diabetes used to be well controlled, but even though I am not doing anything different, now my sugars are erratic, especially when I am indoors a lot in the winter."
•Difficulty to concentrate at work, or to use a computer were mentioned by several. "I found I could not concentrate to do my job after the turbine started up." Some described how they had made errors at work that could have impacted others.
•Dizziness and falling was mentioned by a number, changes that occurred over a fairly short period of a year or so, not simply as a general issue of ageing.
•Others described impacts on infants, livestock, or pets who had no preconceived opinions about wind turbines.

A common thread was that for most, the symptoms subsided when leaving home, but over time, returned more quickly when returning to their home.

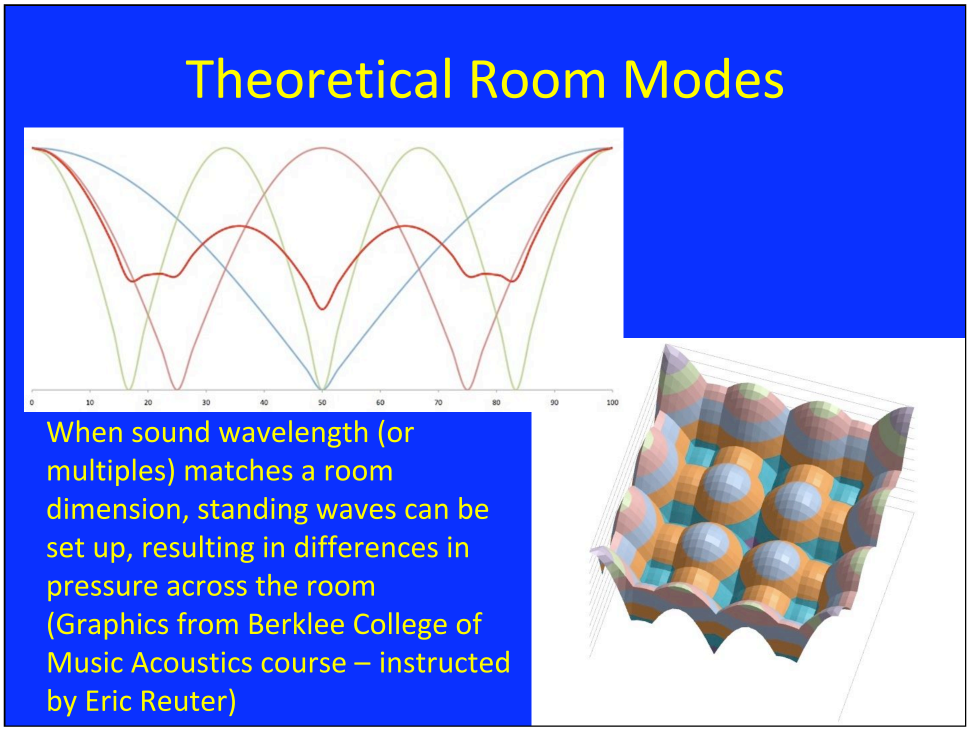


Added to the recurring observations made by those who live near wind turbine installations were clues that arose from other reported acoustical studies.

At the Wind Turbine Noise Conference in Denver last summer, I showed evidence from testing that wind turbines alter the soundscape, producing an easily identified repeatable change, exhibiting a higher amplitude of sound levels from 5 to 15 dB for frequencies below 2000 Hz, a more rapid rise and fall in sound level, a sharper transition, and distinct low frequency pulses not masked by wind and waves.

H. Moller and C.S. Pedersen from Aalborg University in Denmark reported in the JASA(129) June 2011, that the relative amount of low frequency noise is higher for larger wind turbines, and “It is thus beyond any doubt that the low-frequency part of the spectrum plays an important role in the noise at the neighbours.” They also noted that “Indoor levels of low-frequency sound in neighbor distances vary with turbine, sound insulation of the room, and position in the room.”

The Shirley Wind Study of 2012 documented in the 4 team consensus report of Walker, Hessler, Rand, and Schomer, (3 present) concludes, “The four investigating firms are of the opinion that enough evidence and hypothesis have been given herein to classify LFN and infrasound as a serious issue, possibly affecting the future of the industry. It should be addressed beyond the present practice of showing that wind turbine levels are magnitudes below the threshold of hearing at low frequencies.”



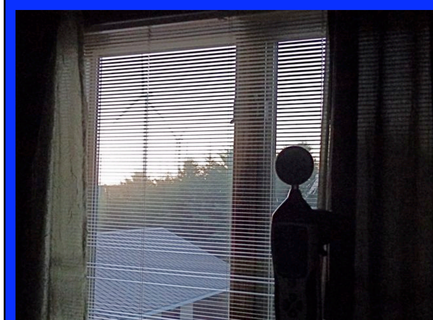
Earlier this year I took an acoustics course taught by Eric Reuter (present at session). During instructor / student "chat" sessions of the Berklee College of Music Acoustics course earlier this year, the subject of "room modes" was discussed as a potential factor that might explain conditions inside a home near wind turbines.

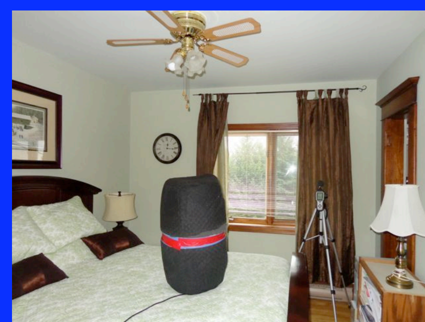
The two charts displayed here, used with permission from the course notes prepared by Eric Reuter, portray theoretical two and three dimensional variations that can occur across a room if the exciting wavelength or a multiple matches a room dimension. Combinations of harmonic waveforms show in theory that the waveform will be largest in the room corners, and smallest at the centre of the room. This suggests that taking a sound level reading in the centre of a room is not representative of the worst conditions.

In particular the exercises performed in calculating room modes as part of the course, identified that the most significant variations would arise in a room which is nearly cubic. Ontario farm homes, often in proximity to wind power developments located in the rural environment are typified by small, square bedrooms with high ceilings, tending towards cubic. This suggested that a useful subject for research might be to confirm if measurement of conditions inside rooms where the residents had identified problems of the nature identified previously showed variations which might explain some of the observations, and particularly if the room modes are set up by frequencies of the type identified previously near wind power developments.

The Research

- Monitor sound outside and inside a home, with windows open and closed, at different wind turbine powers
- Earthworks M30BX Measurement microphone, 9Hz-30kHz +1/-3 dB, 22 dBA SPL equivalent noise, recorded by Audacity at 44k, iBookG4
- Processed data using Electroacoustics Toolbox on MacBook 2.1





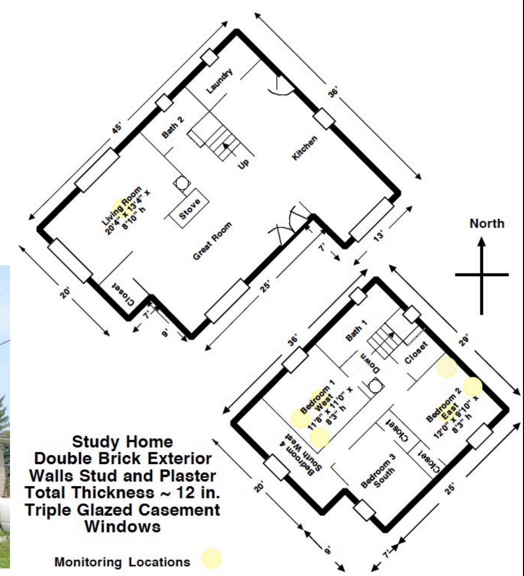
Permission was granted to monitor outside and inside a furnished home, which has been vacated by the owners who have identified some of the conditions previously identified. Measurements were conducted on a number of occasions, for various output levels for the nearby wind turbines. All of the turbines are at locations approved by the Ontario Ministry of the Environment based on a criteria of not exceeding 40 dBA outside the home for wind conditions of 6 m/s at a 10 metre height.

An Earthworks M30BX measurement microphone was used to collect the sound samples, which were digitized at a sampling rate of 44,100 samples per second by a Fast Track USB digitizer, and stored on a Macintosh iBook G4 computer using the Audacity digital recording software.

The Earthworks M30BX microphone has an omnidirectional response flat from 9 Hz to 30 kHz +1 / -3 dB, and a noise floor of 22 dB SPL equivalent (A Weighted). The microphone with a 90 mm primary windscreen was mounted on a vibration resistant mount in a secondary foam windscreen with a 450 mm minimum dimension to be compliant with Ontario Ministry of the Environment requirements. The microphone and monitoring array was calibrated before and after each sample data set.

The collected digital recording samples were processed using the Faber Acoustics Electroacoustics Toolbox software on a Macintosh MacBook 2.1 computer.

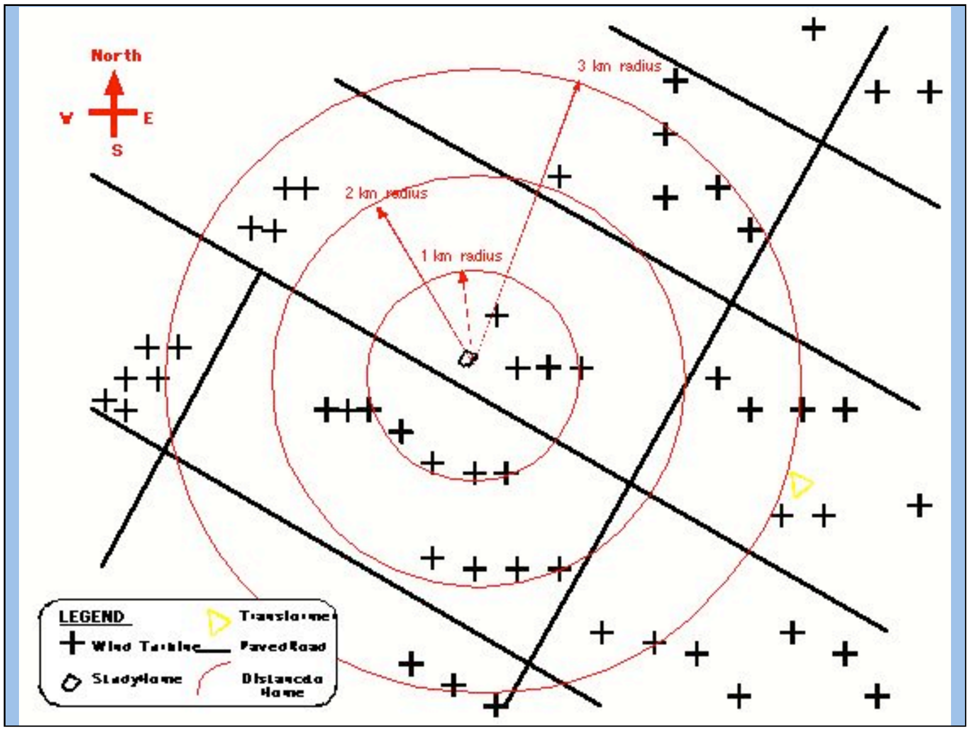
The Study Home



The study home where recordings were permitted (any hour of he day or night) is typical of a century Ontario Farmhouse, but with extensive upgrades. The home exterior walls are a double brick construction. Interior insulation, and a lath and plaster wall, in some cases with a further interior gypsum wallboard construction result in an overall wall thickness of some 12 inches (30 cm). Windows are upgraded modern design with triple glazed casement construction, and resilient gasket seals.

An exterior view of the study home, and the floor plans of the main floor and upper levels are shown here. Also shown on the floor plans are the locations where sound level monitoring was carried out, in the downstairs living room with the room window open and closed and in two upstairs bedrooms, in the centre of the room, the corner of the room, and the centre of a wall distant from the room window. Acoustical measurements were made with the bedroom windows fully open and fully closed for each case, and for some cases with the windows open only about 2 inches (5 cm.) to be typical of normal conditions.

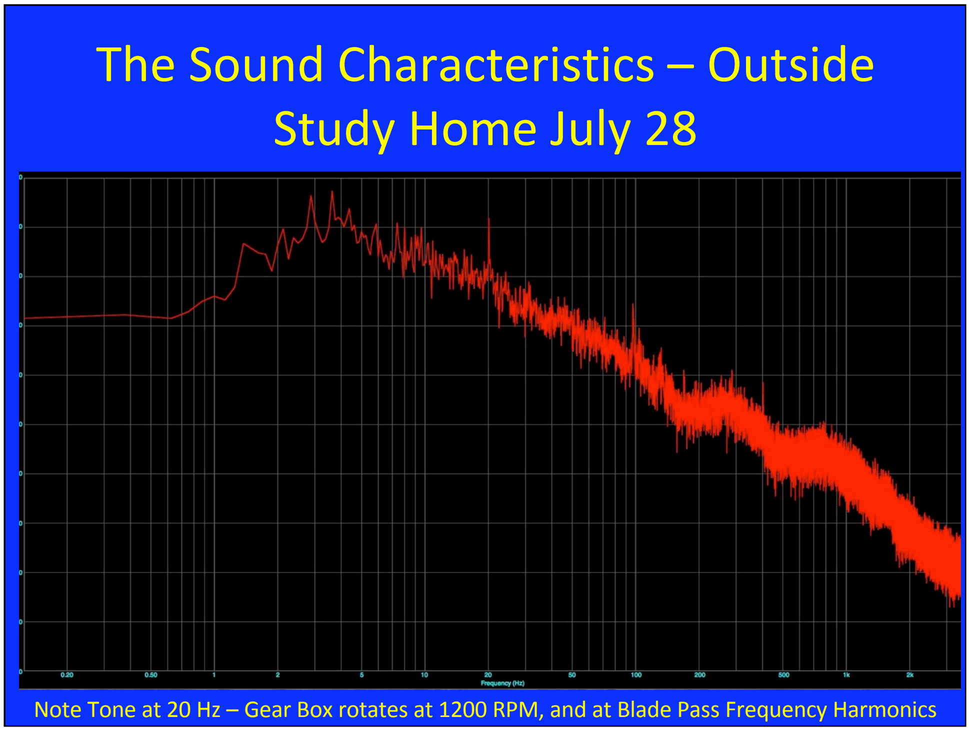
Although the home rooms were normally furnished, and normal flooring and wall covering material was present, there was little operating equipment in the home. No fans, no refrigerator or freezer compressors were operating. Although electrical service was connected to the home, electrical loads were minimized, typically clocks or cube adapters for cordless telephones.



This drawing shows the study home surroundings, typical of others approved by the Ontario Ministry of the Environment. The home has 9 – 1.65 MW wind turbines with 82 metre rotors on 80 metre hub height towers within 1000 metres, 6 more turbines from 1000 metres to 2000 metres, and 17 more turbines from 2000 metres to 3000 metres. The substation and step up transformers of the array are located just over 3000 metres from the home.

The Ontario Ministry of the Environment accepted this array density, and the accepted environmental noise report based on an acceptability criteria of the sound level to be less than 40 dBA outside the home for wind speeds of 6 metres / second or less at a height of 10 metres. Although the wind turbines first started up some 6 years ago in November, and complaints were filed with the operator and the Ontario Ministry of the Environment regarding the noise and adverse health impacts observed soon after startup, and many times since, at this time, 6 years later, a Ministry called for audit of the acoustic conditions still has not been completed. The turbines continue to operate.

The residents of this home, and of some others in the array, have vacated their homes.

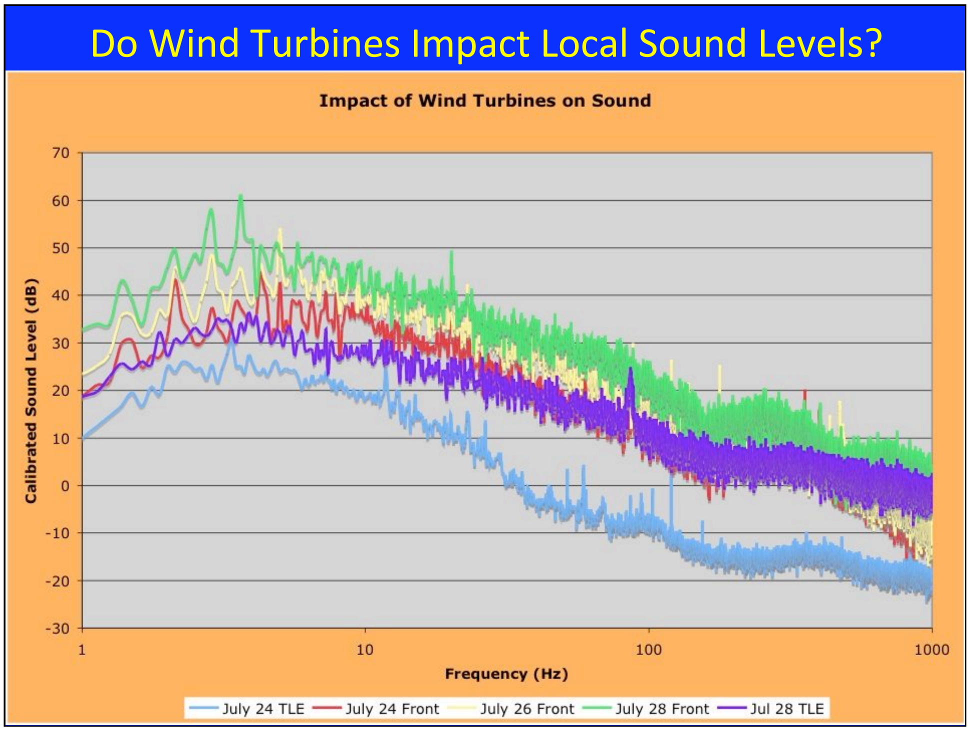


This shows a typical FFT for the conditions outside the home, in this case for data collected at 0448 am (local time) on July 28, 2014, when there was no other background noise from traffic, and little from insects or birds.

This is the calibrated FFT analysis of a 60 second sample performed using the Electroacoustics Toolbox using an upper frequency cutoff of 4306 Hz, to give 34,454 spectral lines and a minimum resolution of 0.125 Hz.

Clearly visible on the FFT analysis are pulses at 1.44 / 2.16 / 2.88 / and 3/60 Hz. These are the 2nd, 3rd, 4th, and 5th the harmonics of the blade pass frequency of 0.72 Hz. These are constant speed 3 bladed turbines, rotating at 14.4 rpm so the blade pass frequency is 0.72 Hz. Since peaks seen are multiples of 0.72 Hz, they show that the fundamental frequency is indeed 0.72 Hz, although not evident in the FFT display. Note also on the chart the strong tone at 20 Hz, which corresponds to the 1200 rpm rotational speed of the generator of these wind turbines.

For the hours bracketing the sample, the wind turbine array output was between 105 MWh / hour and 127 MWh / hour, corresponding to an array output from 58% to 70% of rated output, so not at full power. (These stall regulated turbines increase in noise level as the output increases).

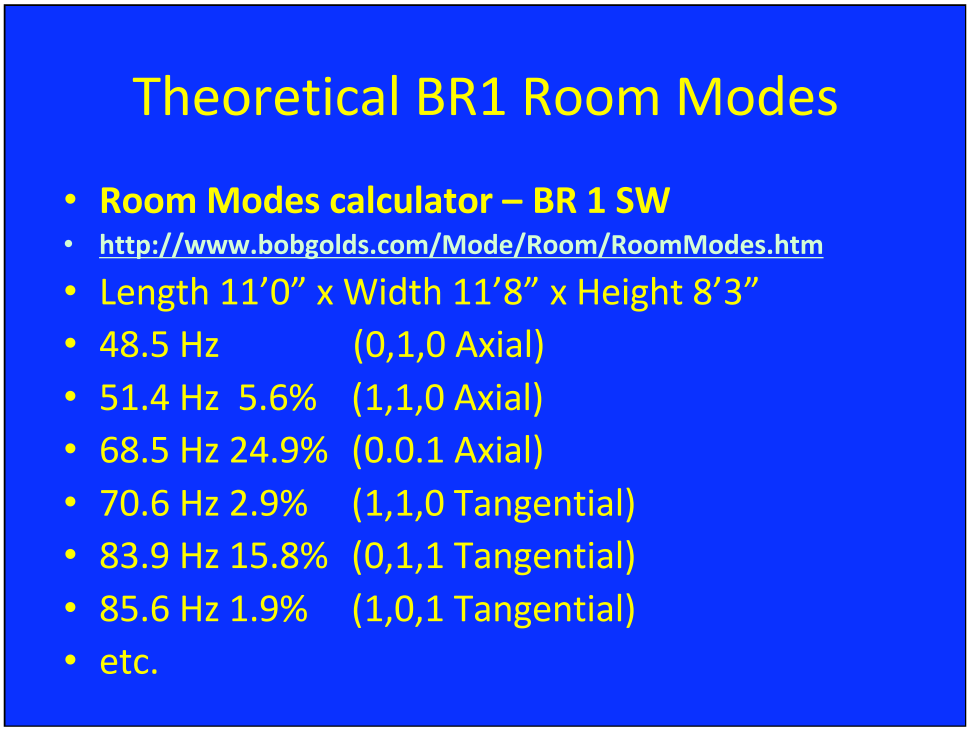


Briefly, before looking inside a home, this chart addresses the question, “Does proximity to wind turbines impact sound levels below 1000 Hz outside a home?”

This chart shows that sound levels below 1000 Hz from FFT analysis at the study home (red line) on a day wind turbines are at a very low power (1 to 2 MW for a 181 MW array) are 10 to 15 dB higher than at a location 5 kM from the nearest wind turbine (blue line) even though the turbines are within sight, and other conditions of wind speed, nearby road impacts, terrain and vegetation are very similar.

The chart also shows as the wind turbine output increases for the 181 MW array, (progressing from very low power – 1 to 2 MW - say 0%) shown on the red line, to low power – 40 to 70 MW – say 30% shown on the yellow line, to a moderate power – 105 MW to 127 MW – say 65% shown on the green line) the sound level increases by a further 10 to 15 dB. While the sound level at the site 5kM distant from the nearest operating wind turbine (purple line) increases, being nearly the same for frequencies above 1000 Hz, it remains some 10 to 20 dB less than at the study home.

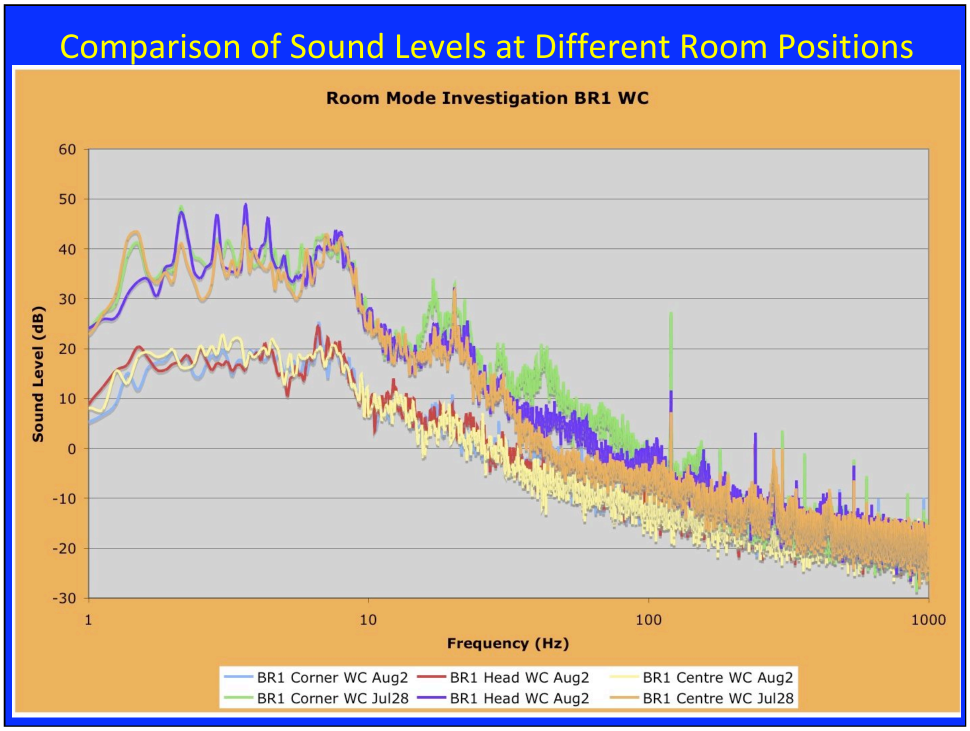
It is very clear that sound levels, particularly at frequencies below 1000 Hz are significantly higher near wind turbines than away from them, show the presence of tones of the blade pass harmonics and the generator rotation, and furthermore increase in difference near the turbines compared to distant from the turbines as the turbine power level increases.



Turning now to the case inside the study home, the theoretical room modes were calculated for the study room BR1 dimensions using a web based calculator shown here. Room modes are created due to the reflection of sound between room surfaces. Although it is possible to calculate the theoretical room modes for the axial modes - sound waves reflecting between two parallel surfaces – such as the opposite walls of the room, or the floor and ceiling, or for tangential modes - sound waves reflecting between four surfaces, or oblique modes – sound waves reflecting between all surfaces – floor, ceiling, and walls, the theoretical calculation will apply fully only to an empty room, while in reality rooms have furnishings, floor coverings, and wall coverings that change the precise values. However, the room mode calculator gives a beginning place.

The calculator returns the value of the frequency based on the room dimensions, and gives an evaluation of the magnitude of the impact at each frequency. In this example shown, the room modes below 86.5 Hz cover nearly 50% of the impact, and higher frequencies are lower in magnitude.

The test will be to see if these theoretical room mode are matched in reality for the actual room, and its furnishings.



Here we see the FFT display of the sound levels for frequencies between 1 and 1000 Hz at the three monitoring locations in BR1 - centre of room, head of bed = middle of wall, and corner of the room, on two separate dates, when the turbines are not operating (on August 2nd) and when turbines are at moderately high power (on July 28th). Note that these readings were performed with all windows closed, on this solid home with casement windows including tight seals.

The data shows that broad peaks in the sound levels are seen, on the higher power July 28 case, at frequencies in the same range as the room mode predicted peaks. The presence of the blade pass frequency when the turbines are operating is clearly visible.

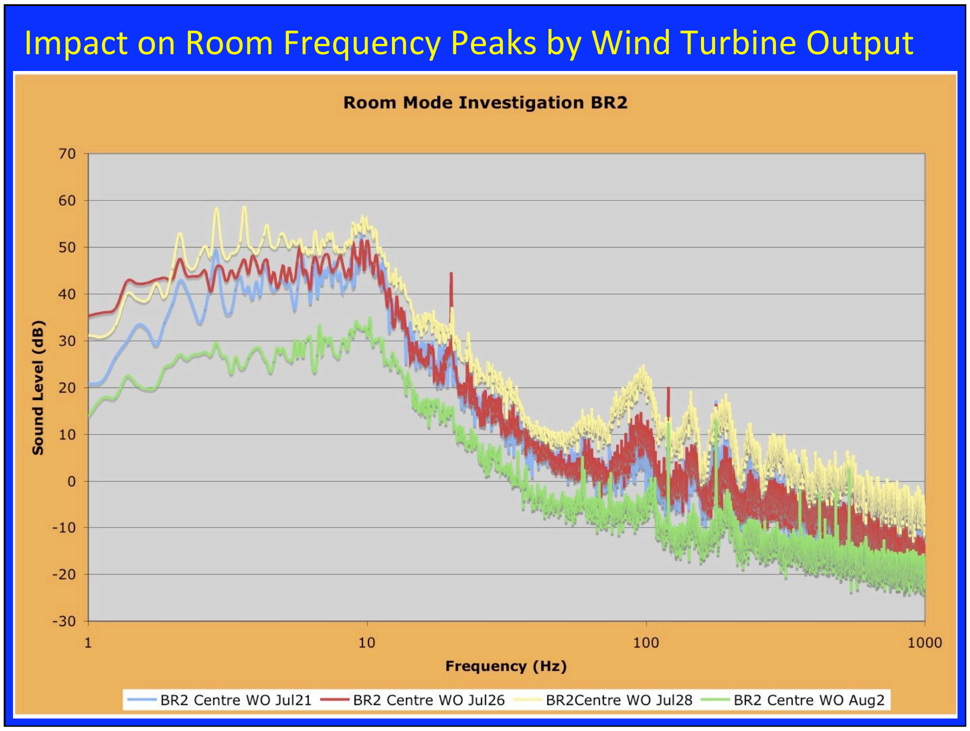
Also visible are sharp peaks at 120 Hz and harmonic multiples of 60 Hz. It was noted that a cube tap power supply for a cordless telephone was located in the room.

Theoretical BR2 Room Modes

- Length 12’0” x Width 9’10” x Height 8’2”
- 47.1 Hz (1,0,0 Axial)
- 57.5 Hz 18% (0,1,1 Axial)
- 68.5 Hz 16% (0,0,1 Axial)
- 74.3 Hz 7.8% (1,1,0 Tangential)
- 83.3 Hz 10.5% (1,0,1 Tangential)
- 89.4 Hz 7% (0,1,1 Tangential)
- 94.2 Hz 5% (2,0,0 Axial)
- etc.

Looking now at the second sampling room on the second floor of the study home, BR2, the theoretical room modes are calculated as before.

It’s noted that the prediction is that over 30% of the room mode impact will be seen between 74.3 Hz and 94.2 Hz.



In this chart only the centre of the room data is shown, for 4 different cases to show the comparison of room mode values with no turbines, and with turbines operating at powers of 0% / 30% / 65%

The presence of the wide peak just below 100 Hz confirms that the prediction of the room mode calculator that over 30% of the impact will be between 74 and 94 Hz is borne out. Some presence of a room mode increase is seen even on the day the turbines are not operating (August 2nd) but the peak is much less pronounced, perhaps 5dB above ambient, compared to the increase of some 15dB above ambient when the turbines are operating. It is important to note that this large a variation was not visible in the conditions outside, but it is enhanced inside the room.

Again, in the case when the turbines were not operating on August 2nd there is neither sign of the blade pass harmonics, nor of the 20 Hz peak corresponding to the generator speed of rotation.

A narrow peak at 120 Hz is visible in all cases. It is noted as was seen in the photograph of the study home that the main electrical supply feeder is directly outside this room wall.

A Tabular Comparison

Date - Output	Room / Window	dBA	Delta dBC - dBA	dBC
Jul 28 – 70%	BR1 – Cent - WO	29.7	22.2	51.9
Jul 28 – 70%	BR1 – Corn - WO	29.2	24.9	54.1
Jul 28 – 70%	BR2 – Cent – WO	36.7	15.9	52.6
Jul 28 – 70%	BR2 – Corn – WO	33.5	20.6	54.1
Aug 2 – Off	BR1 – Cent – WO	24.3	9.8	34.1
Aug 2 – Off	BR1 – Corn – WO	24.4	8.3	32.7
Aug 2 – Off	BR2 – Cent – WO	24.5	8.4	32.9
Aug 2 – Off	BR2 – Corn – WO	24.5	13.8	38.3

Now, some folks prefer a tabular listing to a graphical view.

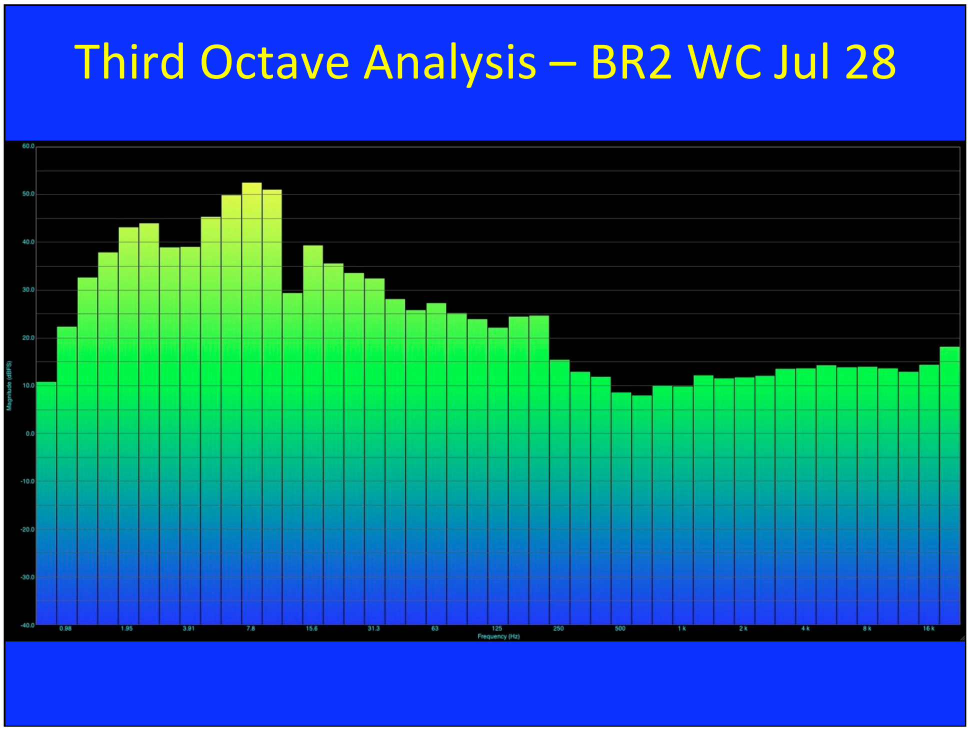
For those folks, here is a table comparing the dBA and dBC values for the July 28 and August 2 cases,

You can see that on the July 28 date, when the turbines are at about 70% output, the difference between dBC and dBA ranges from 15.9 to 24.9, and the difference is higher in the corner of the room than the centre, showing the effect of the Room modes and the low frequency component.

In contrast, on the Aug 2 date, when no turbines were operating, the difference between the dBC and dBA readings ranged from 8.3 to 13.8

It is fairly generally considered that a difference between dBC and dBA readings of greater than 15 dB will result in increased annoyance.

Here we have a difference of nearly 25 dB in the corner of one room.



Wrapping up, one particular factor that was noticed when watching the real time third octave analysis of the conditions inside the rooms of the study home, was the amplitude variation in each frequency allocation.

This chart shows the output of the Electroacoustics Toolbox Third Octave Analysis for BR2 with the room window closed on July 28th.

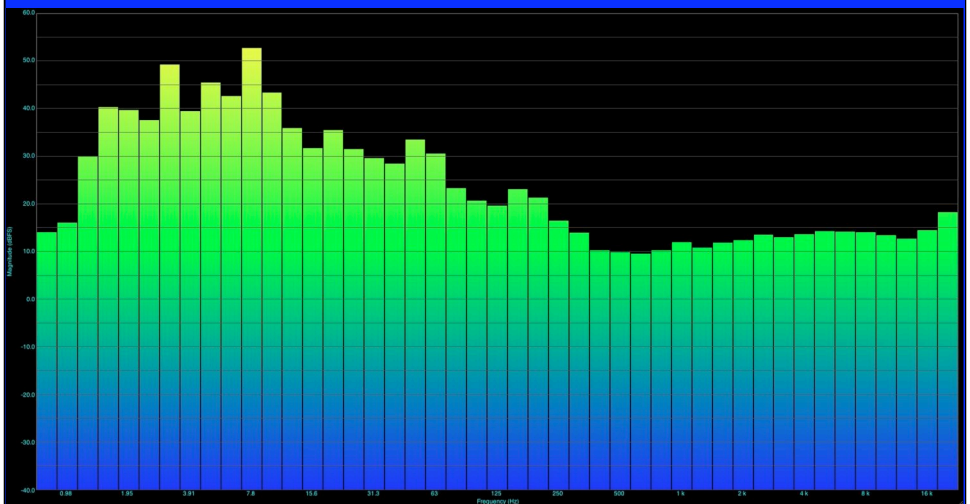
It is noticed that the third octaves above about 250 Hz are quite similar in magnitude, while there is much higher variation in the extended frequency analysis for the lower frequencies.

However, what this static picture does not show is the variation that is occurring in the low frequencies, where the analyzer shows that there is a rapid up and down change of greater than 15 dB.

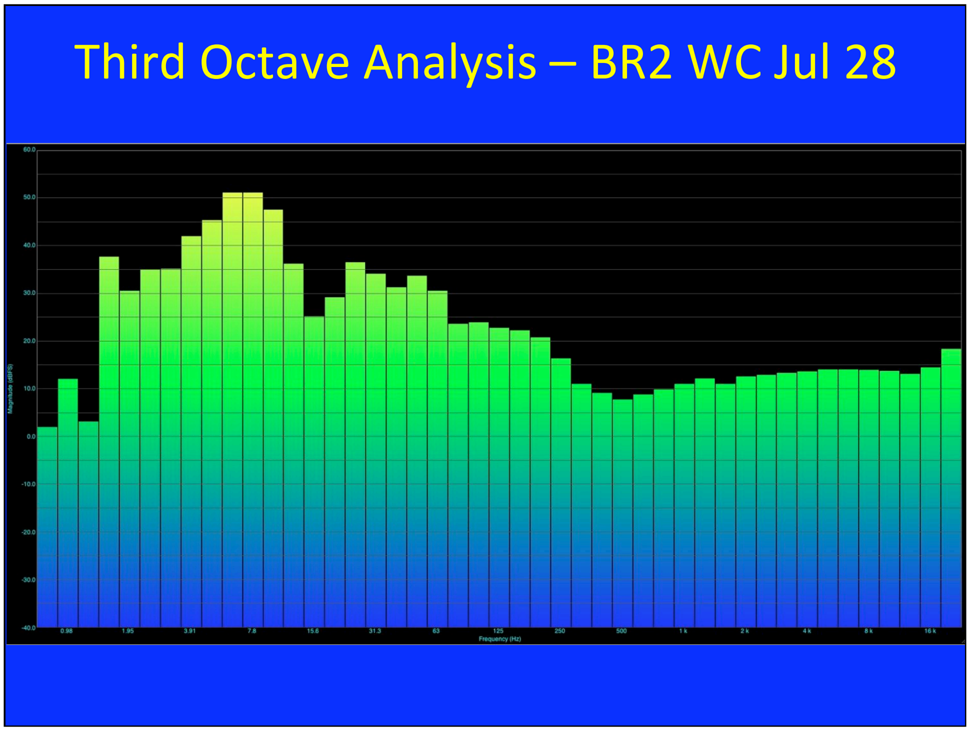
If we click quickly through this and the next two slides we see that the low frequency cases below 20Hz vary up and down in amplitude by some 20 dB, and that the higher value case shifts back and forth in frequency.

It reminds one of a European police siren that alternates “wee / woo / wee / woo” rising and falling in frequency - and done deliberately to be more noticeable.

Third Octave Analysis – BR2 WC Jul 28



Here's a second screen shot of the Third Octave Analysis



And, here is a third screen shot.

You can see that above 250 Hz there is very little variation in amplitude, while below 100 Hz the amplitude of each bin is varying by +/- some 15 to 20 dB.

What We Have Learned

- Room Modes inside buildings can result in significant sound distribution changes
- Changes inside a home are more significant than outside
- Sound levels below 100 Hz can be some 20 dB higher with wind turbine operating
- Low frequency sound from WTs shifts both in dB (+/- 10 -20 dB) and Hz making it noticeable
- There are legitimate reasons for observations of people living near wind turbines

Finally, we can look at what we have learned.
•Room modes have been shown to exist inside buildings, consistent with the predictions – and show significant variation across a room. The difference from the centre of a room to the mid point of a side wall, or the room corner can be high.
•Changes displayed at the room mode frequencies are more significant inside a home than outside, even though it is sound from outside that excites the room.
•Sound levels below 100 Hz can be 20 dB higher with wind turbines operating.
•Low frequency sound from the wind turbines shifts both in amplitude measured in dB by + / - 10 to 20 dB, and in frequency as measured in Hz. Both combine to make wind turbines more noticeable.
•we see is that there are real reasons for the observations people living near wind turbines are making.

- Conditions have changed a lot since the wind turbines came into operation, and generally when a problem occurs, we look for what has changed
- Conditions across a room vary significantly, and can explain why turning from top to bottom in a bed can matter
- It also can explain why a person sleeping with their head in a room corner is more impacted than a person with their head in the centre of the room.

To protect the public, regulations need to consider low frequency conditions inside the home, not just A weighted sound outside as they do now.

Thanks for Your Attention

Questions?