Title: Room modes – a predictor of wind turbine annoyance

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Running title: Room modes predict wind turbine annoyance

ABSTRACT

When one 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, 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 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 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 (presented first at the 168th Acoustical Society of America Fall 2014 Indianapolis Meeting) will discuss the research and the results that provide a clue to the annoyance caused by wind turbines.

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I. INTRODUCTION

This presentation did not arise from a position of knowing all the answers, and setting out to convince others. Instead, this presentation arose from knowing none of the answers, and from the author personally listening to the sincere comments of many people who live near wind turbine installations, then trying to make sense of what they observed from their personal experience or that of direct family members (spouses or children living with them). How those people tried to address their observations suggested clues to follow. The author's notes, compiled after face-to-face conversations with people in their kitchens, in coffee shops, during grocery store encounters, or after they had presented to officials, tribunals, or public meetings, identified repetitive themes. All are based on personal face-to-face encounters, not from literature searches, nor second-hand relation of stories. For most of the people listened to, wind turbines have created a change in their environment, except in the case of some infants, who have been brought up with wind turbines around their home.

II. COLLECTING BACKGROUND CLUES

A. First issue discussed – lack of sleep

The first subject discussed usually is change in sleep habits. People describe that they do not sleep as well as they had before turbines entered their environment. Some observed, "We could not sleep in our bedroom so we moved outdoors into a tent." This was interesting as the commonly held understanding is that sound is attenuated entering a home, so outside the sound should be louder. Was a different factor than amplitude of the sound responsible? Another observed, "My husband has moved from the bedroom into the recreation room to sleep on the couch. He's less comfortable than in bed, but sleeps somewhat better." How could room size matter? Some described that out of desperation they tried anything. "Sometimes I turn from top to bottom in the bed, and it seems to help." How could sleeping position in bed matter? More than a few individuals spoke that because they were not sleeping well at night, now they dozed off in the daytime. More than a few have mused, "Someday someone will peel me off the front of a truck, because I have dozed off at the wheel of my car." An individual presenting issues to representatives of the provincial Ministry of the Environment, broke into tears, to say, "I don't know what to do. I cannot tell my Doctor as he will take away my drivers license, and then I will not be able to get to work. I'll lose my job, and then we will lose our home when we cannot make the payments." Lack of rest produced consequences that were very troubling to listen to.

B. More issues – not just lack of sleep

In listening to people, in addition to the most common discussion about lack of sleep, other subjects continued to arise. Here are some recurring issues heard from more than one, of symptoms that came on gradually, but became worse over time.

- 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." This person also admitted to being quite hearing impaired, and as not wearing hearing aids at night, was not directly hearing anything.
- 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."
- The ability to concentrate at work, or to write using a computer was mentioned by several. "I found I

could not concentrate to do my job after the turbines started up." Some described how they had made errors at work that could have impacted others and had resulted in their leaving a caring position they loved for fear of hurting someone.

- Dizziness and falling was mentioned by a number, changes that occurred over a fairly short period of a year or so. "I fell in the bathroom, hit my head, and lay there until found," or, "I fell from the steps and injured my shoulder." or, "I started to feel dizzy, and fell. Now I need a stick *(cane)* to walk with."
- A number spoke of recurring nosebleeds that were a new development since the wind turbines had started up.
- Others described impacts on infants who would scream with earaches, of livestock that would stand "lathered up" in their stall, as if they had been running hard, or of pets that acted abnormally. None of these infants or livestock had preconceived opinions about wind turbines.

A common thread was that the symptoms subsided when people left their home for a few days, but came back upon returning. Over time, the symptoms came back faster on their return home, even though away for a number of days. Even to medically unqualified eyes, people encountered repeatedly seemed to progress in the space of a very few years from what appeared to be healthy normal individuals to unsteady ones, leaning on a cane. This did not give the indication of normal aging.

Finally, a change perceived in some did not require their words. It is hard to describe how the eyes of people change, from showing hope with a twinkle in the eye, to a look of hopelessness with eyes that even seem to lose their shine, but this has been observed in a number of cases. It was with that look of hopelessness that more than a few have described that, "We just cannot live in our home anymore, and no one will listen to us." Without a pre-conceived idea of what is behind what is heard from these people, about the best that could be done by the author was to listen, and look for underlying clues from changes in their environment.

C. Yet more clues

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 Fifth International Meeting on Wind Turbine Noise in Denver, USA, the paper, "Perception Change of Soundscape as Wind Turbine Alters Community Sound Profile,"[1] showed wind turbines alter the soundscape, producing an easily identified repeatable change, exhibiting a higher amplitude of sound pressure levels for frequencies below 2000 Hz, a more rapid rise and fall in sound level, a sharper transition, and low frequency pulses not masked by wind and waves.
- Møller and Pedersen in JASA (129) June 2011, showed in "Low-frequency noise from large wind turbines,"[2] that the relative amount of low frequency noise is higher for larger wind turbines than for smaller ones, and stated, "It is thus beyond any doubt that the low-frequency part of the spectrum plays an important role in the noise at the neighbors." 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 4 team consensus report of Walker, Hessler & Hessler, Rand, and Schomer, in 2012, "A Cooperative Measurement Survey and Analysis of Low Frequency and Infrasound at the Shirley Wind Farm in Brown County, Wisconsin,"[3] entered into testimony before the Public Service Commission of Wisconsin concludes, "The four investigating firms are of the opinion that enough

> evidence and hypothesis have been given herein to classify LFN *(low frequency noise)* 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."

These are not the only reports of a changed environment in homes nearby wind turbines. Along with the insights gained from listening to people, they suggested that more study was needed to try to determine the link.

D. A final clue – theoretical room modes

Earlier this year, during the spring acoustics course of the Berklee College of Music, instructor / student "chat" sessions discussed work in progress, and 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 in Figure 1 and Figure 2, from the Berklee College of Music Acoustics course notes prepared by instructor Eric Reuter (used with permission), portray 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 center of the room. This suggests that taking a sound level reading in the center of a room as often a common practice is not representative of the worst conditions.

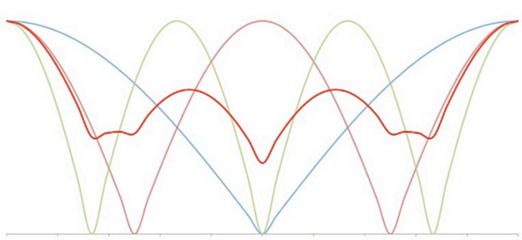

Figure 1 – A two-dimensional representation of sound pressure across a room, with 1% and 100% being opposite walls of the room.

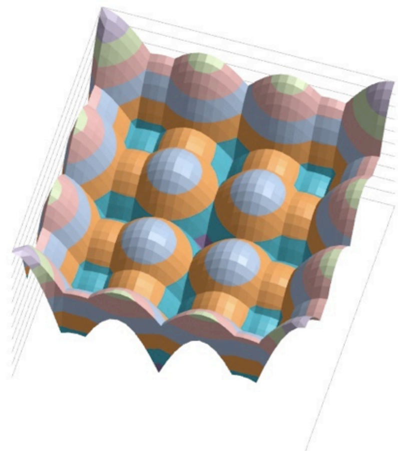
Figure 2 – A three-dimensional representation of sound pressure levels across a room.

In particular, exercises in calculating room modes as part of the course identified that the most significant variations would arise in a room that is nearly cubic. Ontario farm homes, in proximity to wind power developments are typified by small, square bedrooms with high ceilings, tending towards cubic. This suggested that research might confirm if measurement of conditions inside rooms where the residents had identified problems as previously discussed showed variations that could explain some of the observations.

III. THE RESEARCH PROJECT

A. The subject home as monitoring site and the monitoring system

Permission was granted to monitor at a furnished home, vacated by the owners who have identified some of the conditions previously listed. Measurements were conducted outside and inside the home, for various output levels of the nearby wind turbines. An Earthworks M30BX measurement microphone collected sound samples, digitized at a sampling rate of 44,100 samples per second by a M-Audio Fast Track USB digitizer, 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. The microphone and array was calibrated before and after each sample data set. Figure 3 shows the monitoring microphone at a central point in a bedroom of the study home.

Figure 3: Microphone in windscreen monitoring room center in study home.

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

Figure 4: The study home is a typical Ontario farmhouse of double brick

An exterior view of the study home, is shown in Figure 4. It 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 layer result in an overall wall thickness of some 12 inches (30 cm). Windows are upgraded modern design triple glazed casement construction, with resilient gasket seals. The floor plan of the study home is shown in Figure 5. Shown on the floor plans are the locations where sound pressure level monitoring was carried out, in the downstairs living room with the room window open and closed and in two upstairs bedrooms, in the center of the room, the corner of the room, and the center of a wall distant from the room window. 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 rooms were normally furnished, with normal floor and wall covering materials present, there was little operating equipment in the home. No fans, refrigerator, or freezer were operating. Although electrical service was connected to the home, electrical loads were minimized, typically clocks or cube adapters for cordless telephones.

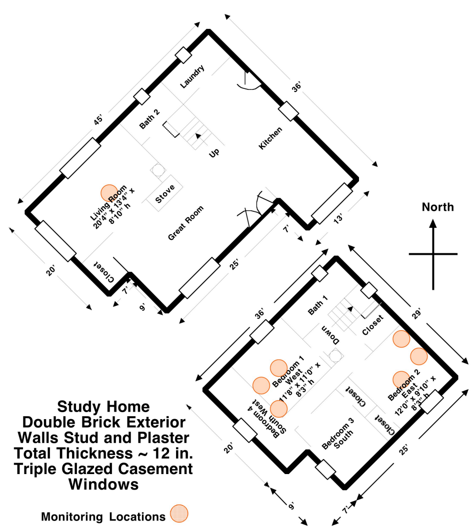

Figure 5: Floor plan of the study home

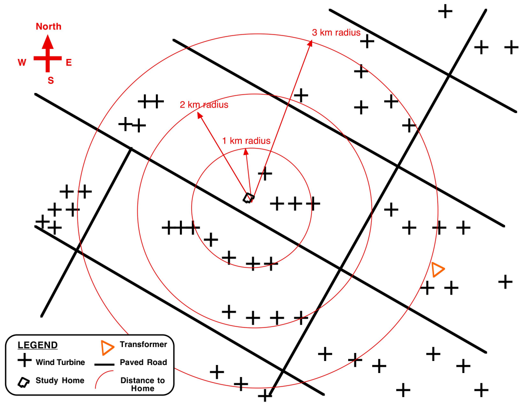

Figure 6: Study home surroundings.

Figure 6 shows the study home surroundings. The home has 9 – 1.65 MW wind turbines with 82 meter rotors on 80 meter hub height towers within 1000 meters, 6 more turbines from 1000 meters to 2000 meters, and 17 more turbines from 2000 meters to 3000 meters. The substation and step up transformers of the array are located just over 3000 meters from the home. The environmental noise report used to justify the array was based on an acceptability criteria of the sound level to be less than 40 dBA outside the home for wind speeds of 6 meters / second or less at a height of 10 meters. 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.

B. Sound characteristics outside study home

Before looking inside the study home, data was collected to provide an answer to the question, "Do wind turbines impact local sound pressure levels?" The data for a number of different cases were loaded into an Excel spreadsheet for display as shown in Figure 7.

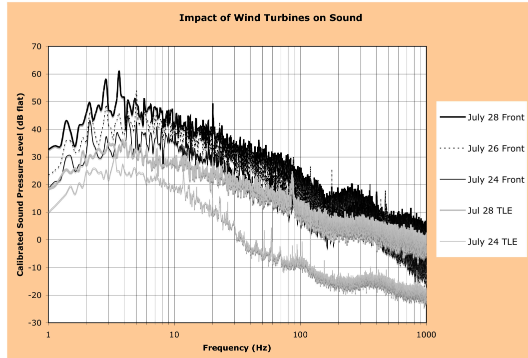

Figure 7: Excel chart showing the calibrated sound pressure levels for 5 outdoor cases.

The five cases of sound pressure level represented in Figure 7 are as follows (from the bottom of the chart):

- July 24 TLE – fine grey line – readings taken at a site 5 km from the nearest wind turbine, but within sight of the turbines of the array monitored on a day when turbines were rotating, but the array output for the entire 110 turbine array which has a rated output of 181.5 MW was only 1 to 2 MW, a very low power.
- July 28 TLE – medium grey line – readings taken at the same site 5 km from the nearest wind turbine monitored on a day when 110 turbine array operating at 105 to 127 MW, a moderate power.
- July 24 Front – fine black line – readings taken outside the study home within 45 minutes of the reading taken in the TLE sample. Both sites were subject to the same environmental conditions of wind (very light) vegetation proximity, and proximity to roadways (but with no road traffic in either case). Turbines rotating, but array at very low power of 1 to 2 MW.
- July 26 Front – fine black dashed line – readings taken outside study home when turbine array output was between 40 to 70 MW, a low power.
- July 28 Front – medium black line – readings taken outside study home when turbine output was between 105 to 127 MW, a moderate power,

the same day as the readings at the 5 km away site were recorded.

Observations:

Focusing first on the uppermost line for July 28, shows a typical calibrated FFT of a 60 second sample for the sound pressure level conditions outside the home, in this case for data collected at 0448 am (local time) on July 28, 2014, when there was no background noise from traffic, and little from insects or birds. The vertical axis shows calibrated sound pressure levels from -30 to +70 dB (flat, without weighting).

Clearly visible on the FFT analysis of the Jul 28 sample are the harmonics of the blade pass frequency. These are constant speed 3 bladed turbines, rotating at 14.4 rpm so the blade pass period is 1.39 second, or the frequency is 0.72 Hz. Note the peaks at 1.44 Hz, 2.16 Hz, 2.88 Hz, 3.6 Hz and so on. Since these are multiples of 0.72 Hz, they show that the fundamental frequency is indeed 0.72 Hz. Note also on the chart the strong tone at 20 Hz, which corresponds to the 1200 rpm rotation of the generator of these wind turbines.

For the hours bracketing the Jul 28 sample, the wind turbine array output was between 105 MWh / hour and 127 MWh / hour as shown by the Ontario Independent Electricity System Operator, 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).

This chart also shows that sound levels below 1000 Hz from FFT analysis at the study home (fine grey 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 (fine dark 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) shown on the fine grey line, to low power – 40 to 70 MW – shown on the medium shaded line, to a moderate power – 105 MW to 127 MW – shown on the dashed line) the sound level increases by about 10 to 15 dB per step. While the sound level at the site 5kM distant from the nearest operating wind turbine (medium dark line) also increases, it remains some 10 to 20 dB less than at the study home.

It is clear that sound levels, particularly at frequencies below 1000 Hz are significantly higher at a home 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.

C. Theoretical Room Modes in Bed Room 1 and Measured Results

Turning now to the case inside the study home, the theoretical room modes were calculated for the study home BR1 dimensions using a web-based calculator available at (Date last viewed Nov. 25, 2014) http://www.bobgolds.com/Mode/Room/RoomModes.htm. 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 degree of excitation at each frequency. In this example shown, the lowest frequency mode occurs at 48.5 Hz, the mode at 68.5 Hz. is strongly excited, and there is a clustering of 9 modes from 109 Hz to 145 Hz.

- L 11’0” x W 11’8” x Height 8’3”

Sample of predicted results:

- 48.5 Hz (0,1,0 Ax)
- 51.4 Hz 5.6% (1,0,0 Ax)
- 68.5 Hz 24.9% (0,0,1 Ax)
- 70.6 Hz 2.9% (1,1,0 Ta)
- 83.9 Hz 15.8% (0,1,1 Ta)
- 85.6 Hz 1.9% (1,0,1 Ta)
- 96.9 Hz 11.6% (0,2,0 Ax)
- 98.4 Hz 1.5% (1,1,1 Ob)
- 102.7 Hz 4.1% (2,0,0 Ax)
- 109.7 Hz 6.3% (1,2,0 Ta)
- 113.6 Hz 3.4% (2,1,0 Ta)
- 118.7 Hz 4.2% (0,2,1 Ta)
- 123.5 Hz 3.8% (2,0,1 Ta)
- 129.3 Hz 4.4% (1,2,1 Ob)
- 132.6 Hz 2.4% (2,1,1 Ob)
- 137.0 Hz 3.2% (0,0,2 Ax)
- 141.2 Hz 2.9% (2,2,0 Ta)
- 145.3 Hz 2.8% (0,1,2 Ta)
- and so on …

The test for the research was to see if these theoretical room modes are matched in reality for the actual room, with its furnishings.

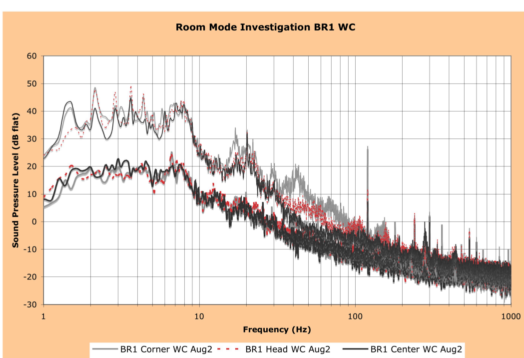

Figure 8: Calibrated sound pressure levels inside bedroom 1 (windows closed) as turbine power level changes.

Figure 8 shows the FFT display of the calibrated sound pressure levels (flat – not weighted) for frequencies between 1 and 1000 Hz at the three monitoring locations in BR1 - center 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.

Observations:

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. The case with the turbines off, on August 2 does not show the blade pass frequency peaks, nor does it show the significant increases in sound pressure levels at the predicted room modes.

The fine lines represent the data for Jul 28 when the wind turbine array was operating at a power level between 105 to 127 MW, a moderate power. The medium width lines represent the data for Aug 2, when the wind turbines were not in operation.

The charts for the July 28 cases confirm that the sound pressure level is highest in the corner of the room (grey line), of medium intensity at the head of the bed (middle point of the wall – dashed line) and lowest in the center of the room (solid black line) particularly if one looks between the frequencies of 10 to 100 Hz where the room modes are predicted to be concentrated. The clustering of room modes is evident as predicted.

Also visible on the chart 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 which had an audible hum was located in the room.

D. Theoretical Room Modes in Bedroom 2 and Measured Results

Looking now at the second sampling room on the second floor of the study home, BR2, the theoretical room modes are calculated as before by the web-based calculator for the room dimensions.

- L 12'0" x W 9'10" x Height 8'2"

Sample of predicted results:

- 47.1 Hz (1,0,0 Ax)
- 57.5 Hz 18% (0,1,0 Ax)
- 68.5 Hz 16% (0,0,1 Ax)
- 74.3 Hz 7.8% (1,1,0 Ta)
- 83.3 Hz 10.5% (1,0,1 Ta)
- 89.4 Hz 7% (0,1,1 Ta)
- 94.2 Hz 5% (2,0,0 Ax)
- 101.0 Hz 6.7% (1,1,1 Ob)
- 110.3 Hz 8.4% (2,1,0 Ta)
- 115.0 Hz 4.0% (0,2,0 Ax)
- 116.4 Hz 1.2% (2,0,1 Ta)
- 124.2 Hz 6.2% (1,2,0 Ta)
- and so on

The prediction shows a clustering of room mode impacts between 74.3 Hz and 94.2 Hz. and again between 110.3 Hz and 116.4 Hz.

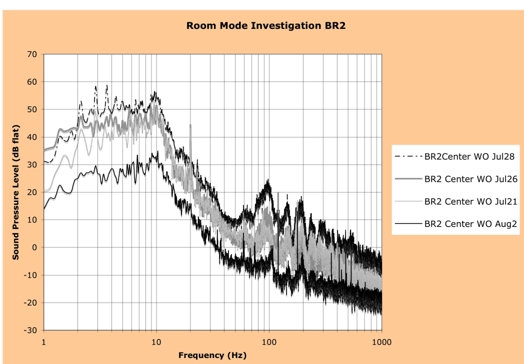

Figure 9: Calibrated sound pressure levels in bedroom 2 with window open.

In Figure 9, only the center of the room data is shown for bedroom 2, to show the comparison of measured conditions inside BR2 at different turbine power levels. The cases are as follows:

- Aug 2 – fine black line – no turbines in array operational, power 0 MW
- Jul 21 – fine grey line - array power levels between 9 MW and 6 MW for 181.5 MW array, thus very low power
- Jul 26 – medium grey line – array power levels between 23 MW and 53 MW for 181.5 MW array, thus low power
- July 28 – dashed fine line – array power levels between 127 MW and 97 MW for 181.5 MW array, thus moderate power

Observations:

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 the home (see Figure 7), 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.

E. Tabular comparison of dBC minus dBA and discussion of results

Date – Output	Room/Window	dBA	dBC - dBA	dBC
Jul 28 – 70%	BR1CenterWO	29.7	**22.2**	51.9
Jul 28 – 70%	BR1CornerWO	29.2	**24.9**	54.1

Jul 28 – 70%	BR2CenterWO	36.7	**15.9**	52.6
Jul 28 – 70%	BR2CornerWO	33.5	**20.6**	54.1
Aug 2 – 0%	BR1CenterWO	24.3	9.8	34.1
Aug 2 – 0%	BR1CornerWO	24.4	8.3	32.7
Aug 2 – 0%	BR2CenterWO	24.5	8.4	32.9
Aug 2 – 0%	BR2CornerWO	24.5	13.8	38.3

Table I: The impact of wind turbines on dBC – dBA, as an indication of low frequency proportion of sound

Up to now, this paper has presented a graphical representation of the low frequency proportion of sound outside and inside a home. Recognizing that some prefer a tabular listing to a graphical view, Table I presents the dBA and dBC readings in the center and corner of Bedroom 1 and Bedroom 2 of the subject home for the case when the turbines in the array around the home are operational at a moderate power level of about 70% on July 28, and when the turbines are shut down on August 2.

Observations:

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 center, 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. A consideration in comparing dBC and dBA readings on Aug 2, when no turbines were operating, is that the dBA values recorded, at about 24 dBA, are near the noise floor for the Earthworks microphone used with the Fast Track digitizer. However, for the same dBC to dBA differential to be maintained as for the case when the turbines were operating, the dBA value would have needed to be as low as 32.7 – 24.9 = 7.8 dB.

Many references suggest that a difference between dBC and dBA readings of greater than 15 to 20 dB will result in increased annoyance. A paper by Desgagne, D.C. and Lapka, S.D., *"Incorporating Low Frequency Noise Legislation for the Energy Industry in Alberta Canada,"*[4] published in the Journal of Low Frequency Noise, Vibration and Active Control, September 2008, provides an extensive listing of technical papers related to low frequency noise, and concludes in this manner, *"The conclusions were clear: the metric LAeq fails to properly account for the presence of LFN (low frequency noise) in CSL (comprehensive sound level) survey data, and LFN can have serious negative effects on an individual's quality of life."* The conclusions of Desgagne and Lapska go on to state the final position of the Alberta Energy Resources Conservation Board. *"In order to be classified as an LFN problem, the isolated (i.e., nonfacility noise, wind noise, etc., removed) LCeq minus LAeq value for the measured nighttime period must be equal to or greater than 20 dB, and a clear tonal component must exist at a frequency below 250 Hz, using appropriate spectrum analysis."*

Here in the study home, a difference above 20 dB in the center of one room is seen, as in the corners of both Bedroom 1 and Bedroom 2 when wind turbines are operational. As well, a tonal component from both blade pass and the generator, exist, again predicting annoyance will be experienced more with wind turbines operational than shut down.

F. Third octave analysis – amplitude and frequency variation

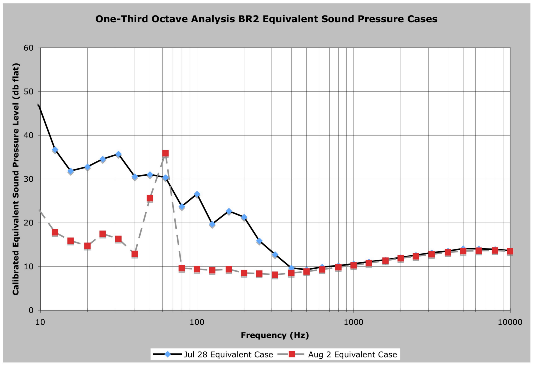

Figure 10: Third octave analysis showing the difference between wind turbines at moderate power level, or not operating.

An alternative representation of the difference between the case of the equivalent sound pressure level monitored in the corner of BR2 with the window closed on Jul 28 when the adjacent wind turbines were operating at a moderate power level, and on Aug 2, when the turbines were not operating was shown by the third octave analysis of the Electroacoustics Toolbox. Figure 10 shows that at third octaves above 400 Hz, the results of the conditions with or without wind turbines are very close, and as a result, the A-weighted sound levels will be very close as values above 400 Hz are dominant in the calculation. However, at third octaves below 400 Hz, the difference is as high as 20 dB in the same third octave.

IV. CONCLUDING - WHAT HAS BEEN LEARNED?

Finally, looking at what was learned:

- Room modes have been shown to exist inside buildings, consistent with the predictions – and result in significant variation in sound pressure levels across a room. The difference from the center of a room (the lowest value) to the mid point of a side wall, or the room corner is a detectable magnitude.
- Changes displayed at the room mode cluster frequencies are more significant inside a home, varying some 10 to 15 dB at the room mode cluster frequencies, while outside that variation is less, even though it may be sound from outside that excites the room.
- Sound levels below 100 Hz can be 20 dB higher inside a home with wind turbines operating than when the wind turbines are shutdown.

What is seen is that there are real reasons for the observations people living near wind turbines are making.

- Conditions have changed a lot in the environment where the people live since the wind turbines came into operation, but A-weighting of the sound does not portray the magnitude of the change.
- Conditions within a room vary significantly when there is excitation from an outside wind turbine source, and can explain why turning from top to bottom in a bed can make a change.
- 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 center of the room.
- Room modes, and the change in sound level across a room can explain why a person might sleep better outside in a tent than in their bedroom, or better in a rectangular recreation room with a lower ceiling than in a farmhouse bedroom that approaches a cube in shape.

V. POSTLUDE – COMMENTS RECEIVED AFTER PRESENTATION

These comments were received following the conference presentation, along with the disposition of each.

1. The first comment from Dr. Brigitte Schulte-Fortkamp of the Technical University of Berlin was a thank-you for a valuable contribution to the field of knowledge about wind turbine acoustics. The author is grateful for this comment. It is an incentive to continue the work.

2. The second comment again received from Dr. Brigitte Schulte-Fortkamp was a question if the cases of the individuals discussed in the presentation were based on personal knowledge, or from review of the work of others. The response was that in each case, the comments recorded were based on personal face-to-face contact by the author with the individuals.
3. The third comment received privately from another who had attended the conference presentation, was that while the communications from individuals listed are interesting, they are none-the-less anecdotal evidence, thus of little value, and the requirement is to continue the research to identify specific dose response relationships between the observed acoustic conditions and adverse health effects. While it is acknowledged that the information presented in this paper cannot prove a direct adverse health link, it would appear to fit the same place as that of a patient giving their history to a medical professional, as the history does not prove a condition exists, but it provides the clue for the medical professional to focus attention. Indeed medical practitioners with experience in listening to such patients tell the author that the most important part of making an accurate diagnosis in medicine especially with unusual or "new" presentations is to listen very carefully to what the patient is describing is happening to them - because it is that careful listening to "the history of the presenting complaint" which leads to accurate diagnosis.

   The Ethical Principles of the Acoustical Society of America specifically require, “If authors were aware that research procedures have harmed a participant, they must have taken reasonable steps to have minimized the harm.” Based on an understanding of that principle, and knowing the face-to-face disclosures of harm suffered in the environment that the research is monitoring, it is difficult to ethically request people to stay in their homes until they became sick, so that monitoring could confirm the point that occurred. Many will also acknowledge a higher need to comply with principles that require “do no harm” to others (as in Psalm 105:15) and feel a personal obligation (as from Micah 6:8, and John 15:12) to go well beyond “doing no harm.” Accordingly, this comment is acknowledged, but the author feels conflicted about proceeding along this path. However, potentially others may think of ways of extending the research compliant with ethical principles that the author may not have considered.

REFERENCES

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2. H. Møller and C.S. Pedersen, “Low frequency noise from large wind turbines,” reported in the J. Acoust. Soc. Am. (129), 3727 – 3744 (2011)
3. B. Walker, G.F. & D.M. Hessler, Rand, and P. Schomer, “A Cooperative Measurement Survey and Analysis of Low Frequency and Infrasound at the Shirley Wind Farm in Brown County, Wisconsin,”

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4. D.C. Degagne and S.D. Lapka, "Incorporating Low Frequency Noise Legislation for the Energy Industry in Alberta, Canada," J. Low Freq. Noise, Vib., Act. Control, **27**(2), 105-120 (2008).

TABLE I

Date – Output	Room/Window	dBA	dBC - dBA	dBC
Jul 28 – 70%	BR1CenterWO	29.7	**22.2**	51.9
Jul 28 – 70%	BR1CornerWO	29.2	**24.9**	54.1
Jul 28 – 70%	BR2CenterWO	36.7	**15.9**	52.6
Jul 28 – 70%	BR2CornerWO	33.5	**20.6**	54.1
Aug 2 – 0%	BR1CenterWO	24.3	9.8	34.1
Aug 2 – 0%	BR1CornerWO	24.4	8.3	32.7
Aug 2 – 0%	BR2CenterWO	24.5	8.4	32.9
Aug 2 – 0%	BR2CornerWO	24.5	13.8	38.3

Table I: The impact of wind turbines on dBC – dBA, as an indication of low frequency proportion of sound

Figure Captions

Figure 1 – A two-dimensional representation of sound pressure across a room, with 1% and 100% being opposite walls of the room.

Figure 2 – A three-dimensional representation of sound pressure levels across a room.

Figure 3: Microphone in windscreen monitoring room center in study home.

Figure 4: The study home is a typical Ontario farmhouse of double brick construction.

Figure 5: Floor plan of the study home showing sound pressure level monitoring locations.

Figure 6: Study home surroundings.

Figure 7: Excel chart showing the calibrated sound pressure levels for 5 outdoor cases.

Figure 8: Calibrated sound pressure levels inside bedroom 1 (windows closed) as turbine power level changes.

Figure 9: Calibrated sound pressure levels in bedroom 2 with window open.

Figure 10: Third octave analysis showing the difference between wind turbines at moderate power level, or not operating.