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Falmouth, Massachusetts wind turbine infrasound and low frequency noise measurements

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Falmouth, Massachusetts has experienced non-predicted adverse acoustic and health impacts from an industrial wind turbine (IWT) sited close to neighbors. The public response from this quiet rural area has been very vocal for a majority of homeowners living within 3000 feet. Complaints have ranged from the unexpectedly loud with constant fluctuations and the non-audible pressure fluctuations causing a real loss of public health and well-being. Early research indicates that both the IHC and OHC functions of the ear receive stimulation during moderate to strong wind speeds. This research presents a challenge to noise control and health professionals to determine the causal factors for the adverse public health impacts. This case study presents sound level and analyzed measurement data obtained while living in a house 1700 feet from an operating IWT during moderate to strong hub height wind speeds. There was a strong correlation with wind speed, power output and health symptoms.

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1 INTRODUCTION

Should "Soundscape" be an integral part for IWT community noise and public health assessments? Will this address, "Why are so many neighbors complaining about excessive noise and adverse public health impacts?" Leventhall in 2004[1] wrote that low frequency noise, the frequency range from about 10 Hz to 200 Hz, has been recognized as a special environmental noise problem, particularly to sensitive people in their homes. Conventional methods of assessing annoyance, typically based on A-weighted equivalent level, are inadequate for low frequency noise and lead to incorrect decisions by regulatory authorities. In 2006[2] Leventhall commented that fluctuating audible sounds or amplitude modulations are the routine characteristic of IWTs and may be disturbing and stressful to exposed individuals. Pierpont in 2009[3] describes symptoms reported by individuals living near wind turbines; "sleep disturbance, headache, tinnitus, ear pressure, dizziness, vertigo, nausea, visual blurring, tachycardia, irritability, problems with concentration and memory, and panic episodes associated with sensations of internal pulsation or quivering when awake or asleep". Leventhall also stated in 2009[4], "I am happy to accept these symptoms, as they have been known to me for many years as the symptoms of extreme psychological stress from environmental noise, particularly low frequency noise …". Salt stated in 2011, "The concept that an infrasonic sound that cannot be heard can have no influence on inner ear physiology is incorrect." [5]

This paper summarizes the results first presented in a white paper[6] titled "*The Bruce McPherson Infrasound and Low Frequency Noise Study*". The authors provided first-person experiences, measurements, recordings and analysis of ITW sounds measured inside a neighbor's home situated in a quiet environment (dBA nighttime L90 - mid 20s to low 30s). The best acoustic analyzer for determining human response is the human listening. This research shows that it is not appropriate to use unattended sound measurement instruments. It is important to be able to identify the noise source(s) by level, acoustic signature (broadband, tonal, variable …), and a judgment for intrusiveness to the ambient background without the noise under investigation.

The objective was to confirm or deny the presence of infrasound and low frequency noise (IFLN) produced by an IWT. If present, then evaluate IFLN; is it greater than or uniquely distinguishable from ambient background levels without IWT. High quality digital recordings were used to evaluate for ILFN spectral content and levels to determine if human detection thresholds could be exceeded.

2 HUMAN HEARING AND DETECTION

There are two types of hair cells in the cochlea where sound pressure converts to nerve impulses; the inner hair cells (IHCs) and the outer hair cells (OHCs). The IHCs are fluid-connected and velocity-sensitive, responding to minute changes in the acoustic pressure variations based on frequency, with sensitivity decreasing at a rate of -6 dB per downward octave. IHCs detect audible sounds and they are insensitive to low frequency and infrasonic acoustic energy. In contrast, the OHCs are mechanically connected, or DC-coupled, to movements of the sensory structure and respond to infrasound stimuli at moderate levels, as much as 40 dB below IHC thresholds. The approximate threshold for physiological response by OHCs to infrasound is 60 dBG (Salt, 2011[7]).

When A-weighted sound levels are low, the OHC responses to infrasound are maximal. Further, low frequency sounds produce a biological amplitude modulation of nerve fiber responses to higher frequency stimuli. This is completely different from the amplitude modulation detected by a sound level meter (Salt, 2011[8]). The OHC & IHC audibility curves are shown on Figure 2.

It has been determined that ANSI filters do not capture the fast peak pressure changes that occur in low and infrasonic frequencies (Bray & James, 2011[9]). ANSI Type 1 filter characteristics have a long impulse response time for the low frequency bands. At 1 Hz, the ANSI 1/3 octave band impulse response is close to 5 seconds.

3 SITE DESCRIPTION

The Town of Falmouth, Massachusetts went through an extensive permitting process for 3-IWTs. Two-IWTs are owned by the town; WIND1 & WIND2 located at the municipal wastewater treatment plant. The third is privately owned; NOTUS installed at the nearby industrial park west of the treatment facility. All three IWTs are manufactured by Vestas, model V82 rated at 1.65 MW. Their locations are shown on Figure 1.

WIND1 came online and neighbors began to complain. Months later the Town required noise surveys for WIND1; nighttime dBA levels ranged from the mid-30s to mid-40s. After NOTUS started, there were more complaints. In the spring of 2011, Falmouth required WIND1 to stop when hub-height wind speed exceeds 10 m/s.

4 INSTRUMENTS, OBSERVATIONS AND MEASUREMENTS

All sound level measurements were with Type 1 instruments with current calibration certificates. High quality 24-bit digital audio recorders were attached to the meter's analog output. Recordings were analyzed with PC software that enabled microphone/preamplifier frequency response corrections to flat (+/- 1 dB to 1 Hz). The measurement system was pre/post calibrated end-to-end. Field measurements were in general accordance with applicable standards, ANSI S12.18-1994[10] (Method 1), S12.9-1993/Part 3[11] (observer present), ASTM E966-02[12] (OILR) and ISO 7196:1995[13]. All measurements were witnessed with descriptions of IWT operations, weather conditions, audible sounds, observer activity, and observer physiological symptoms.

5 ANALYSIS SUMMARY

Significant findings are presented related the Falmouth IWT measurements and recordings. A detailed presentation and discussion is in The Bruce McPherson Study[6].

Figure 3 presents the daily time-history variations in wind speed, IWT output, observations and physiological symptoms experienced. There is a strong correlation between IWT power output and physiological symptoms. The graph shows that symptoms were strong the first day and moderated during the first night when power output and wind speed decreased. Power output and wind speed were low during the early morning hours of second day. Symptoms were somewhat better and improved while away for breakfast. Upon returning to the study house, wind speed and power output slowly increased and the symptoms quickly transitioned back to unpleasant. Strong winds continued and started to slow in the late afternoon. Leaving the area for dinner, the symptoms persisted and were strong enough to suppress appetite and affect clear thinking. Returning to the study house for rest, sleep was fitful with numerous awakenings. Late night and early morning winds fluctuated above and below 10 m/s. Near sunrise, the wind speed decreased to light; NOTUS stopped (520 meters) and WIND1 was slowly turning (1220 meters).

Figure 4 shows with a trend line that the outdoor IWT dBA sound levels decrease at about 6 dB per doubling of distance (dB/dd), whereas the trend line for dBL (controlled by IFLN) decreases at about 3 dB/dd. Noise levels measured at the study house show indoor levels were more than 20 dBA quieter than outdoors. However, the un-weighted dBL levels were several dB higher indoors than outdoors, indicating that the house was reinforcing (amplifying) portions of the ILFN.

Figures 5 and 6 compare the simultaneous outdoor and indoor IWT recordings with the OHC and IHC dBG thresholds. Outdoors, 22.9 Hz (at 45 dB) and 129 Hz both exceed the OHC threshold; however the latter also exceeds the IHC threshold (audible). Indoors, 22.9 Hz and 129 Hz exceed the OHC threshold. The amplitude-modulated spectrum is averaged, which does not represent the peaks detected by the human ear. The analyzer reported crest factors of 10-12 dB.

Figure 7 presents the indoor time-history for the 22.9 Hz IWT fluctuations exceeding the 45 dB OHC threshold. This graph shows amplitudes as high as 60 dB, which is 10 dB higher than the 50 dB average and 15 dB greater than the OHC 45 dB threshold. The total fluctuation, maximum to minimum exceeds 50 dB. The OHC is receiving pressure events every 43 milliseconds 50% of the time. This analysis used a 20 to 24 Hz 10th order digital bandpass filter, inserted between the digital recording output and the analysis input channel. Spectral analysis (FFT) used 23 millisecond intervals with Hamming weighting. This provided the band-limited tonal energy at 22.9 Hz free of the slower response ANSI filters.

Figure 8 shows the coherence relationship between ILFN outdoors and indoors. Neighbors have reported, "It's like living inside a drum". Strong frequency correlations range from 0.7 to 1.0 (highlighted band) that include the very low infrasonic frequencies, 22.9 Hz, and 129 Hz.

Figure 9 compares time-history measurements for dBA, dBC and dBL. The amplitude modulation of dBA was audible outdoors and the dBL has much stronger amplitude modulations. The indoor differences between dBL minus dBA is approximately 22 dB, whereas dBC minus dBA is closer to 15 dB. The dBA and dBC filters do not respond fast enough to measure the infrasound amplitudes produced by the blades.

Figure 10 illustrates the time-history difference between the indoor and outdoor measured dBL. This graph substantiates that the indoor dBL ranges from 2 to 8 dB higher than outdoors. The amplitude modulation was noticeably higher indoors, and the graph shows the modulation exceeding 10 dB per second.

Figure 11 reveals the difference outdoors with IWT “ON” and “OFF” in Pascal. There are significant amplitude modulation pressure pulsations with the ITW “ON” and very little when “OFF”**.**

6 CONCLUSION

This investigation was undertaken with no predetermined expectations for the outcome. Basic scientific methods and approaches were used as guideposts throughout this investigation. Accounting for the frequency response and sensitivity for human hearing (OHC and IHC detectors) were essential. Understanding instrument capabilities and limitations were critical for determining an appropriate scientific analysis for human hearing response. Personal experiences were supported by measurements, recordings and analysis.

This report presents evidence that supports neighbors' complaints about IWTs in quiet environments. The dBA measurement does not correlate directly to complaints; health symptoms were stronger indoors where dBA levels were significantly lower. Low frequency measurements with instruments conforming to ANSI filter standards are too slow and fail to mimic the response of human hearing. Witnessed measurements are mandatory with careful listening at distances greater than 300 meters. Acoustic measurements must have human involvement with the real-time data collection indoors and outdoors for more than an hour. There is a strong need to understand causal factors related to variations in human susceptibility to IWT ILFN and acoustic pressure pulsations. House construction, room dimensions and roof structure need to be considered as contributing factors.

This study should encourage acoustic and health professionals for more research related to the human response to IWT ILFN. This is especially applicable for rural environments where the public has a strong appreciation for quiet and natural "Soundscapes".

7 ACKNOWLEDGEMENTS

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Figure 1 – Falmouth Wind Turbine Environs

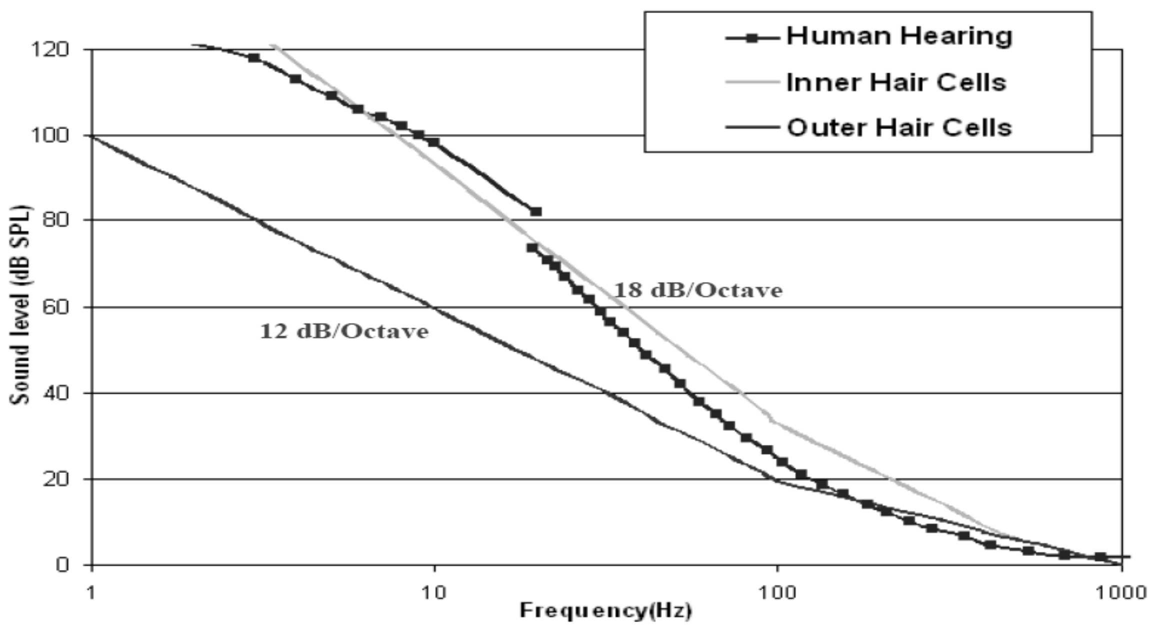


Figure 2 – Human Audibility Curves; IHC and OHC response compared with ISO 2003 and Moller & Pederson 2004 audibility measurements. Adapted with permission, from figure at http://oto2.wustl.edu/cochlea/romesalt.pdf

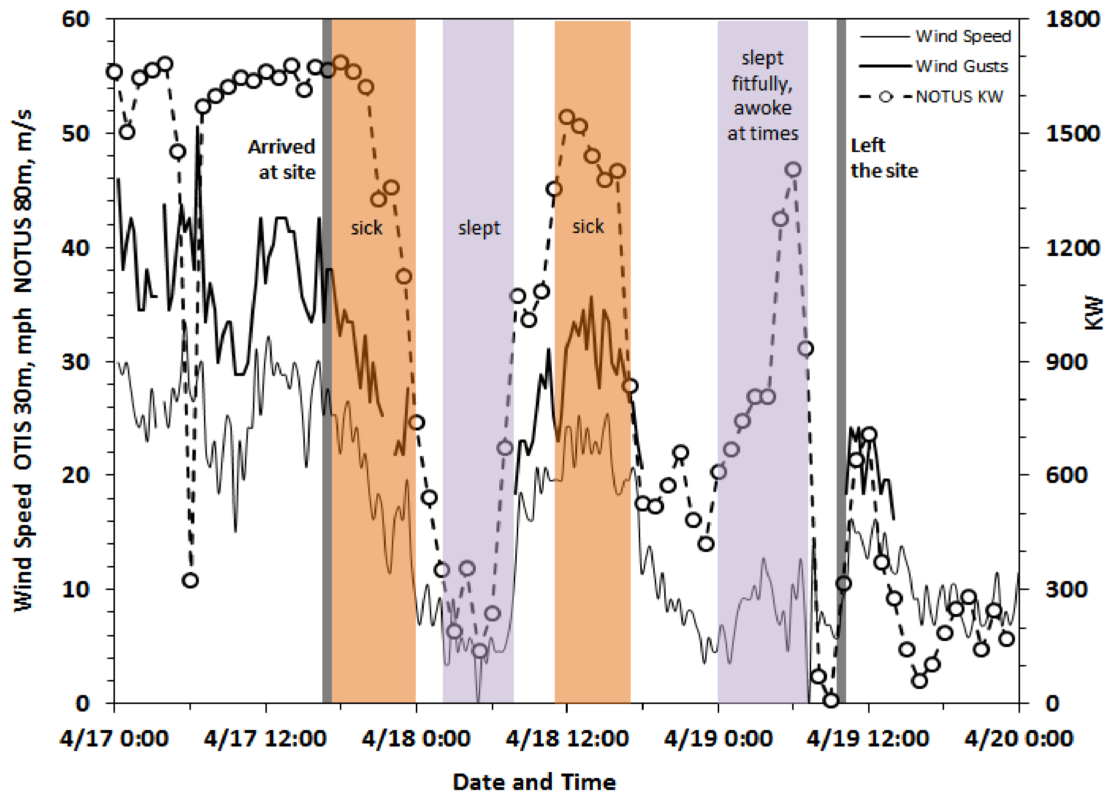
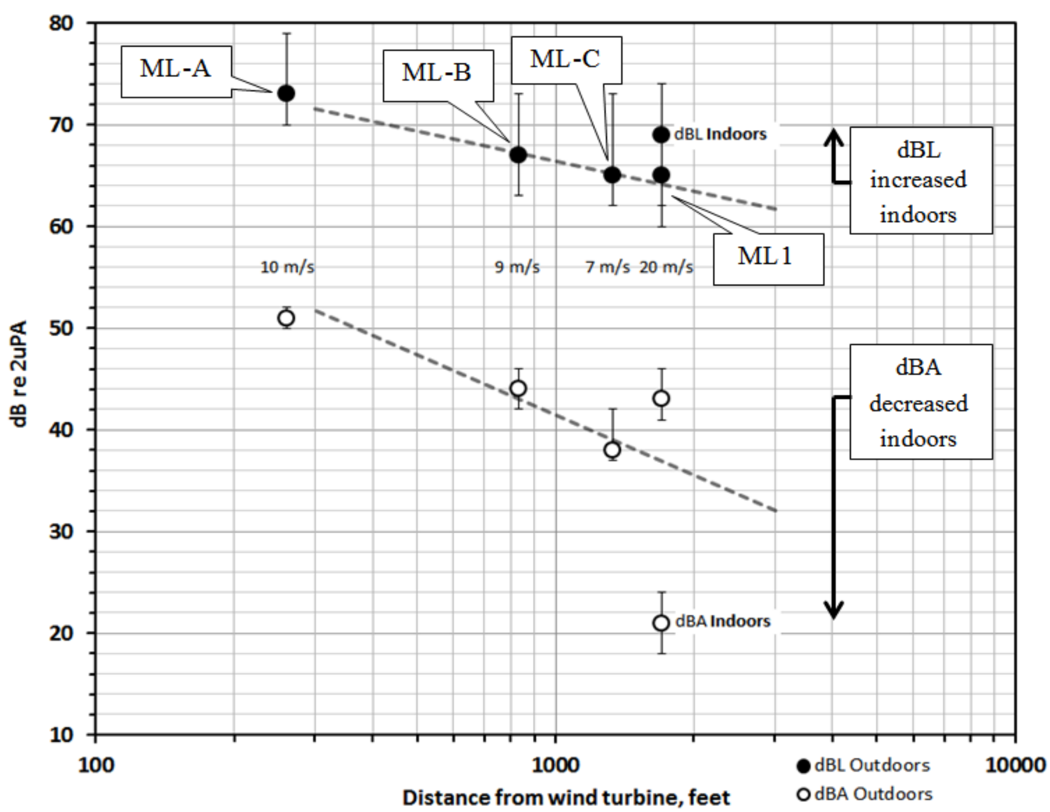


Figure 3 - Survey Operations at Study House



ML1

Figure 4 – ITW Sound Level versus Distance

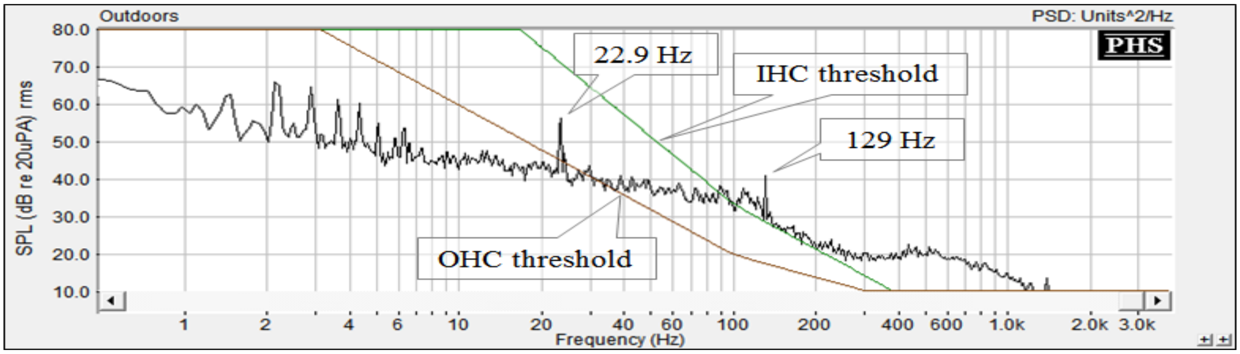


Figure 5 - Outdoor NOTUS sound levels (rms averaged) vs OHC & IHC Thresholds

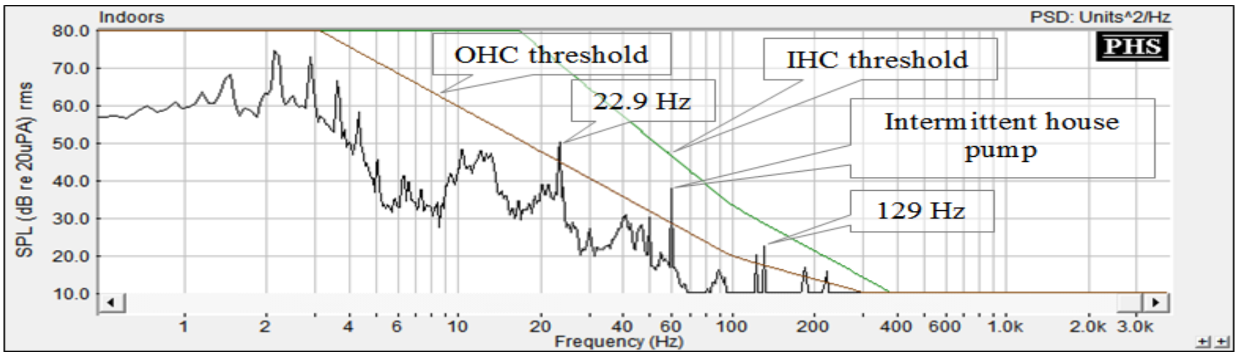


Figure 6 - Indoor NOTUS sound level (rms averaged) vs OHC & IHC Thresholds

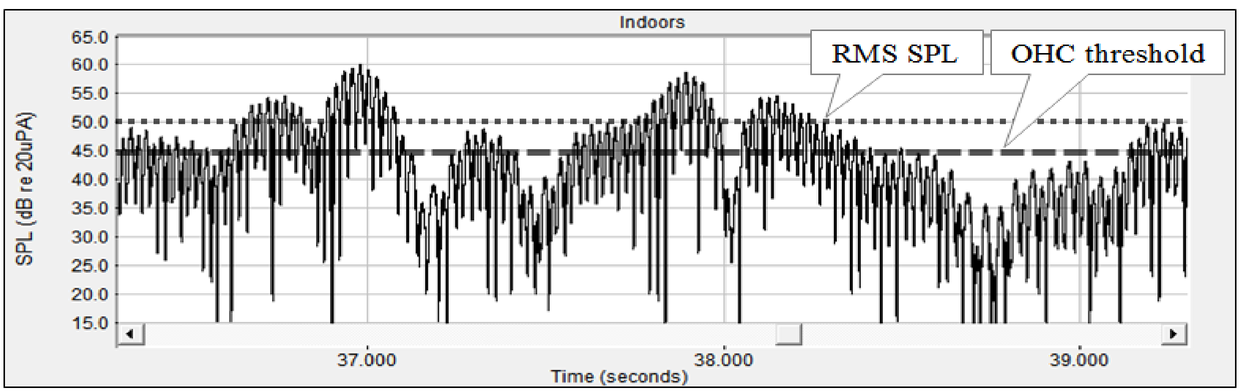


Figure 7 – 22.9 Hz tone fluctuation and OHC threshold

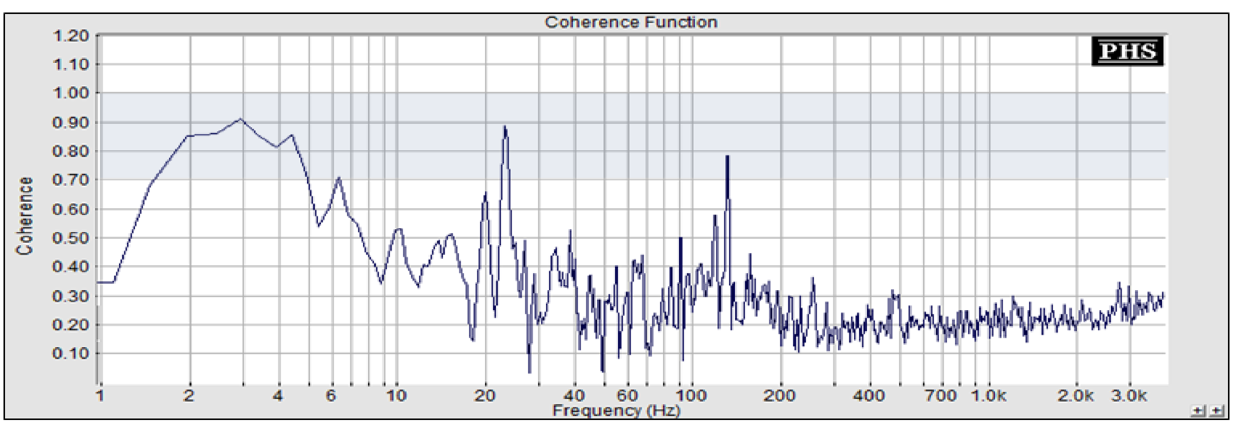


Figure 8 - Coherence, Outdoors to Indoors

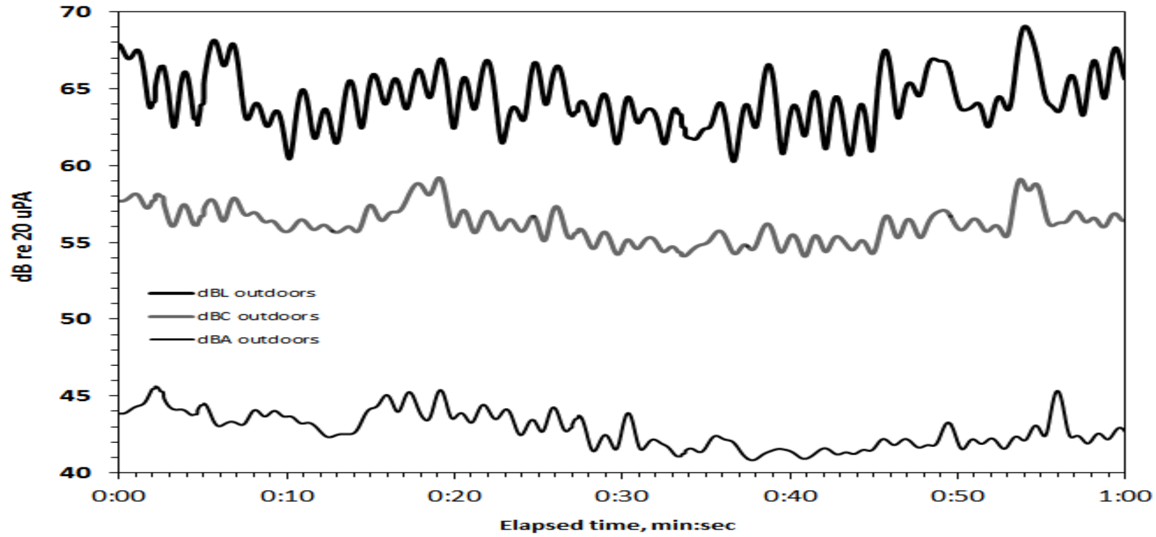


Figure 9 - Outdoors IWT sound levels

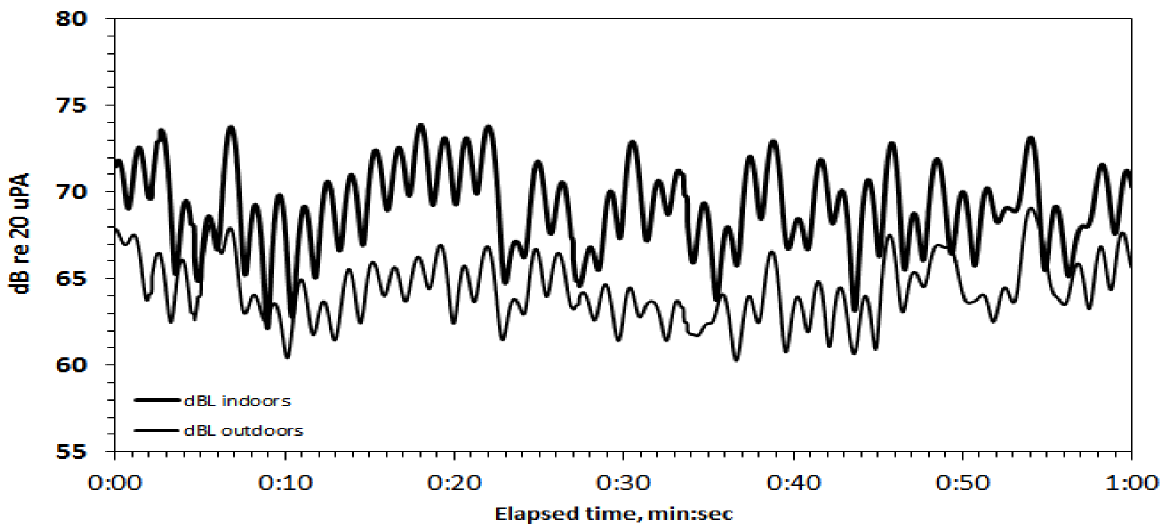


Figure 10 - dBL fluctuation time-history; indoors vs outdoors; April 18, 2011, 3:22 pm

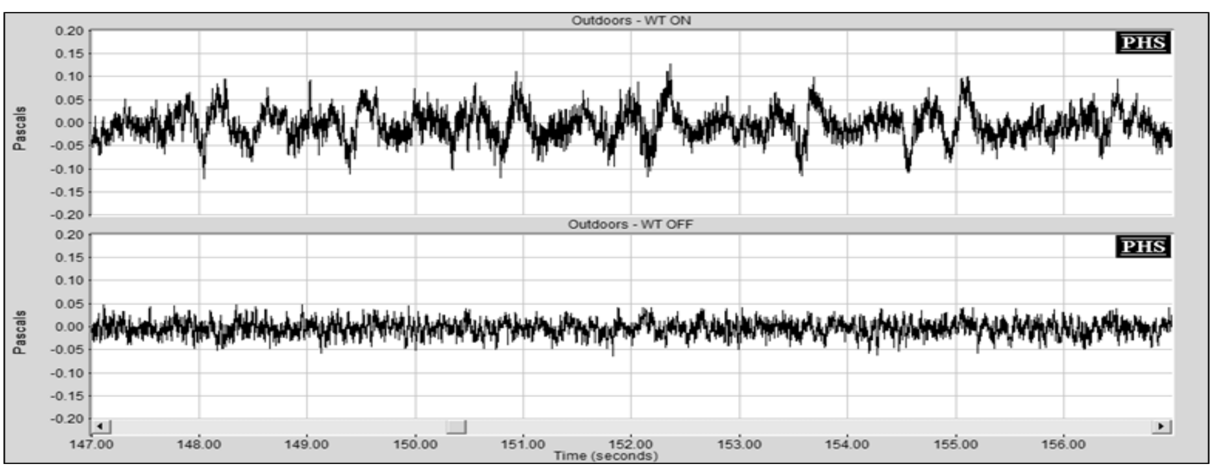


Figure 11 – Outdoors ITW "ON" & "OFF" at the study house