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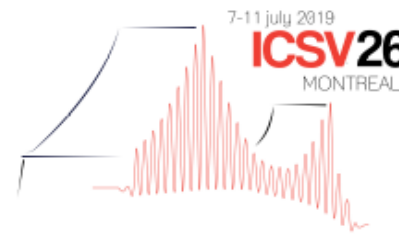


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## INFRASOUND AND LOW FREQUENCY NOISE GUIDE- LINES: ANTIQUATED AND IRRELEVANT FOR PROTECT- ING POPULATIONS

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**Background:** Over the past two decades, the increasing and unregulated production of infrasound and low frequency noise (ILFN,  $\leq 200$  Hz) has led to a considerable rise in associated noise complaints and health-related issues. The most recent of such ILFN sources are industrial wind turbines (IWT). Acoustical field-data was collected within a home located in the vicinity of IWT, to which the AUC Rule 012 and its requirements were applied. In Ontario, IWT noise complaints were gathered under the Freedom of Information legislation. **Goal:** To explore the usefulness of current noise control rules when protecting human populations against ILFN generated by IWT.

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Keywords: industrial wind turbines, residential exposure, health, dBA, acoustic signatures

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# 1. Background

The unbridled installation of industrial wind turbines (IWT) in different countries on different continents has brought a *very old problem* [1] to centre stage: the health effects induced by excessive exposure to anthropogenic (i.e., artificially generated, human-made) airborne pressure waves occurring within the lower ranges of the acoustical frequency spectrum (a.k.a. infrasound (<20 Hz) and low frequency noise ( $\leq 200$  Hz), or, ILFN, given the absence of a more precise nomenclature). The goal of this report is to (yet again) emphasize the long-standing problem of anthropogenic ILFN impacting human health, this time using IWT as a source-example.

## 2. Industrial wind turbine ‘noise’ in Canada

### 2.1 IWT ‘noise’ complaints in Ontario

The government of Ontario, Canada has a process for reporting environmental pollution that offers a pollution reporting “hotline,” managed by the Ministry of Environment, Conservation and Parks (MOECP), and which includes noise pollution complaints [2]. People living in proximity to IWT projects have used this service to submit Incident Reports/Complaints (IR/C) regarding environmental noise and associated adverse health effects. In order to evaluate the effectiveness of this process of reporting IWT ‘noise,’ government IR/C records were obtained through a request made under the province of Ontario’s Freedom of Information legislation [3] by the community group coalition Wind Concerns Ontario [4].

Findings were presented during a citizen appeal of an IWT project held before the Ontario Environmental Review Tribunal [4]. Testimony included factual evidence based on the official government IR/C records submitted by residents living in proximity to operating IWT [5]. The total number of Incidents filed officially with the MOECP between 2006 and the end of 2016 was 4,574. Only 1% of the reports received a “priority” response, another 30% were deemed as “deferred,” and records showed that in more than 50% of the Complaints, there was no ministry response [5]. Regarding health effects, notes by the Ministry’s Provincial Officers included statements from citizens reporting “headache, sleep deprivation, annoyance, and ringing or pressure sensation in the head and ears” [5]. These health effects were reported many times, and also included children [5].

### 2.2 Rule 012 for Noise Control in Alberta

In the Province of Alberta, the Utilities Commission has Rule 012 [6] dedicated to *Noise Control* that encompasses “an avenue for the submission of noise complaints relating to a facility and the process for addressing noise complaints” [7]. Rule 012 imposes a limit based on a minimum basic sound level to which various adjustments are made:

$$\text{Permissible Sound Level} = \text{Basic sound level} + \text{Daytime adjustment} + \text{Class A adjustment} + \text{Class B Adjustment} + \text{Class C adjustment}$$

The basic sound level begins at 40 dBA  $L_{eq}$  and increases depending on the number of houses nearby and proximity of heavily travelled roads. The Daytime adjustment is an increase of 10 dBA between 7 am and 10 pm. Class A adjustments address seasonal variation and non-representative ambient monitoring. Class B adjustments are made for temporary increases in noise generation. Class C adjustments are made when the ambient wind increases to a level that masks the generated noise. On the matter of low-frequency components, Section 3.2 states: “If available, C-weighted sound pressure level (dBC) minus the A-weighted sound pressure level (dBA) is to be considered in the noise model...to identify the potential for low frequency noise impacts.” The procedure then described in

Section 4.5 and Appendix 5 is required only when low frequency noise is identified subsequent to the complaint investigation. Therefore, the difference between the overall C-weighted sound level and the A-weighted sound level must be calculated for all pertinent recordings and the periodograms analysed for sharp peaks in the 20–250-hertz region. Only if both the dBC – dBA difference is greater than 20 dB *and* sharp peaks are identified, is a more comprehensive investigation of ILFN required.

### 3. IWT in Germany – Case Report

#### 3.1 Background

Beginning in 2014, the Hogeveen family residing in Schleswig-Holstein, Germany, described the symptoms (to the media) that they and their children had been developing after 20 IWT were commissioned within a 2-km radius of their home [8-10]. The children—who exhibited increased aggressiveness and unexplained nosebleeds—were promptly sent to boarding school to avoid further health deterioration. The Hogeveens had to remain in the home since it is also their place of work (sports medicine and physical therapy centre), while persistently enduring dizziness, headaches, sensations of pressure on the chest and lungs, ear-aches, swollen tonsils, and ocular and oral inflammations [8-10]. But, they abandoned their upstairs bedroom and constructed a bunker-bedroom deep in the basement of the home. This has provided some respite, except when winds are easterly. Acoustical recordings were conducted simultaneously in both abandoned and bunker bedrooms, taking wind conditions into account.

#### 3.2 Materials and methods for acoustic capture

Data were captured with a SAM Scribe FS (Full Spectrum) system (Model: Mk1, Atkinson & Rappley, Palmerston North, New Zealand) [11,12]. This two-channel recorder measures at sampling rates up to 44.1 kHz, and delivers data streams via USB to a Windows notebook computer, storing it as uncompressed wav files to hard disk. GPS information is also stored as metadata in the files, and this includes a digital signature. The manufacturer’s frequency response curve shows a microphone capsule very close to linear over the 1-1000 Hz range used in this study (0.5-1000 Hz: ± 0.5 dB; 1-10 kHz: ± 2dB; 10-20 kHz: ± 4dB) (custom-made Model No.: EM246ASS’Y, Primo Co, Ltd, Tokyo, Japan) [13]. Acoustic data was processed in Matlab (The MathWorks, USA) using narrow-band filters complying with the ANSI® S1.11-2004 and IEC 61260:1995 standards. All data presented herein were captured a sampling rate of 11.025 kHz and recorded as uncompressed WAV files, including the required reference calibration tone (Type I Calibrator, 1000 Hz/94 dB). Windshields were placed on both microphones during the entire measurement periods. Microphones were attached to tripods at approximately 1.5 m above the ground. The recordings selected for analysis and presentation herein were chosen on their educational value, and are shown in Table 1.

Table 1: Samples selected for analysis and presentation herein.

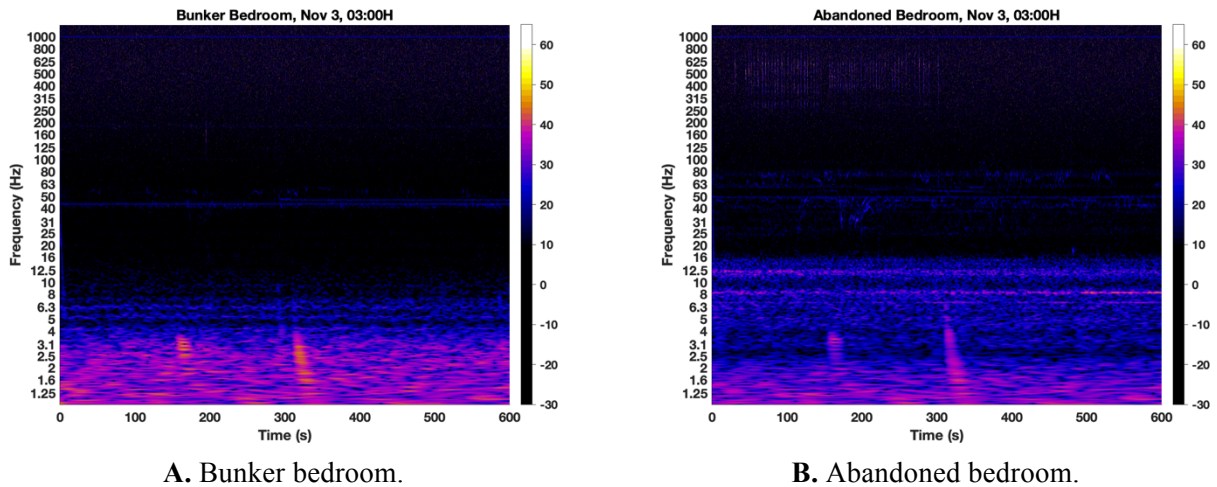
Sample	Date	Time	Wind Speed (m/s)	Wind Direction
Lo wind	03NOV17	03:00	0.9	290°
Hi wind	01NOV17	14:00	7.6	290°

#### 3.3 Abandoned vs. Bunker bedrooms

Significant and distinctive differences were found between the two environments that survived changes in wind speed and wind direction. Figure 2A-D compares the sonograms of the simultaneous recordings captured in both locations, under both wind speeds. All disclose some tonal components (horizontal lines) although these appear more prominent in the abandoned bedroom than in the bunker bedroom. The abandoned bedroom discloses larger SPL values between approximately 5-40 Hz in low wind conditions (0.9 m/s, Fig. 2B), and between 6.3-40 Hz in the high-wind conditions (7.6 m/s,

Fig. 2D). Within those frequency bands, distinct peaks at 8 and 12 Hz, as well as a peak at 80 Hz, are present in the abandoned bedroom, but absent from the bunker bedroom. Apart from some wind-gust noise—seen as vertical features broadening and moving to the right with decreasing frequency—the sonograms tend to show that the character of the sound does not change throughout the 10-minute periods and so the periodograms, shown in Figure 3, are representative of the sound over those intervals. (The continuous, 1000-Hz tone seen in the quieter recordings is due to electronic noise within the SAM Scribe Mk1, eliminated in the more recent SAM Scribe models.)

*Wind speed 0.9 m/s and westerly wind (290°) on 03 Nov 2017, at 03:00H.*



*Wind speed 7.6 m/s and westerly wind (290°) on 01 Nov 2017, at 14:00H.*

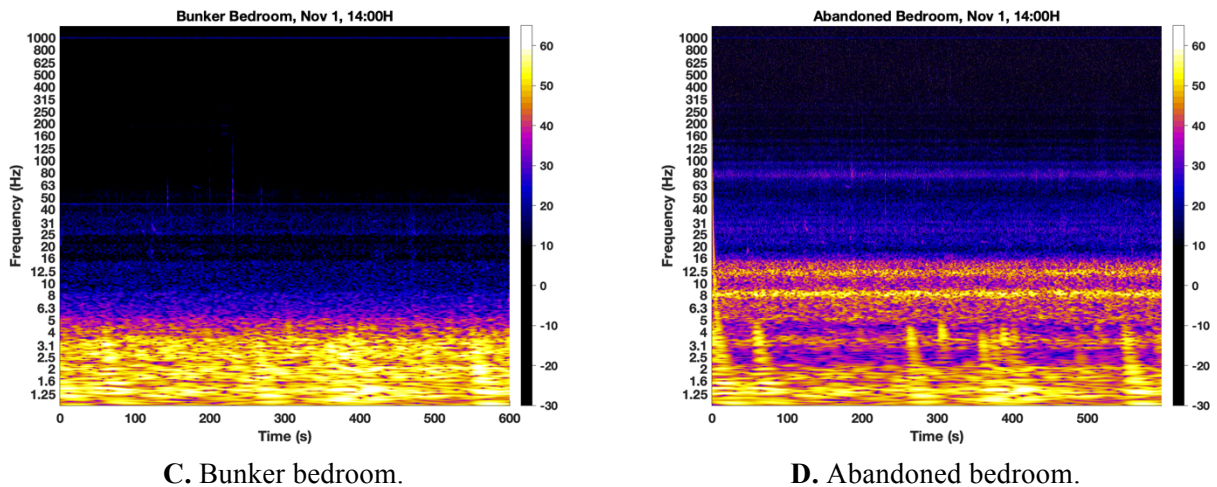
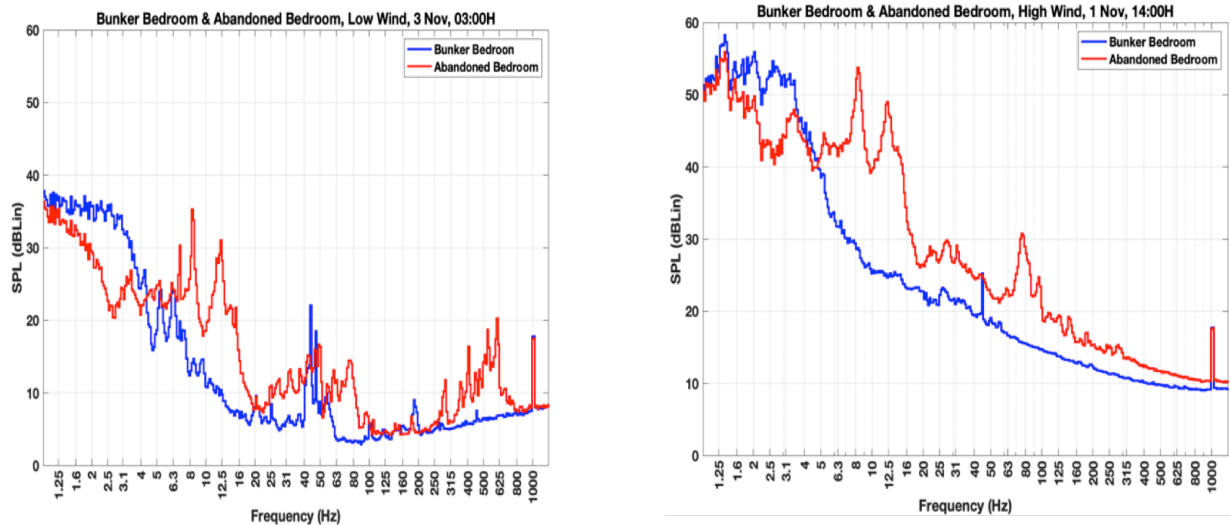


Figure 2: Sonograms covering a 10-min interval (600 s) and analyzed between 1–1250 Hz. The color-coded bar on the right indicates SPL in dBLin.

In the abandoned bedroom, the shapes and positions of the peaks at the three frequencies (8, 12 and 80 Hz, Fig. 3) are quite distinct, are clearly identifiable and independent of wind speed. Particularly visible in Fig. 3 is the similarity in the profile, occurring simultaneously in both locations, at the lower limiting frequencies of these measurements, i.e., approximately from 0.1 Hz to 2.5 Hz or to 4.5 Hz. The acoustical events responsible for these readings seem to impact both locations in the same manner, independent of wind conditions. The wavelengths corresponding to the airborne acoustical events at

these frequency values are, approximately, 76 m (4.5 Hz) to 3430 m (at 0.1 Hz). The source of these phenomena remains unclear.

At low wind speed (0.9 m/s), the bunker bedroom displays a continuous tone at approximately 50 Hz. This can be seen as a horizontal line in the sonograms (Fig. 2A and 2C), as peaks in the classical analysis (Fig. 4), and as narrow peaks in the corresponding periodogram (Fig. 3). Usually, these tones are attributed to electrical appliances that may be present in the environment, and that do not vary with wind conditions. This is much less obvious in the abandoned bedroom (Fig. 2B and 2D) since no appliances are currently present. In the abandoned bedroom, tones that are not present in the bunker bedroom can be identified at 8 Hz, 12.5 Hz and 80 Hz (Fig. 3). These tones are present at low wind speed and increase in sound pressure level with higher wind speeds, while maintaining the consistency of their shape.



**A.** Bunker vs. Abandoned bedrooms. Wind speed 0.9 m/s, westerly wind (290°), 03 Nov 2017, at 03:00H.

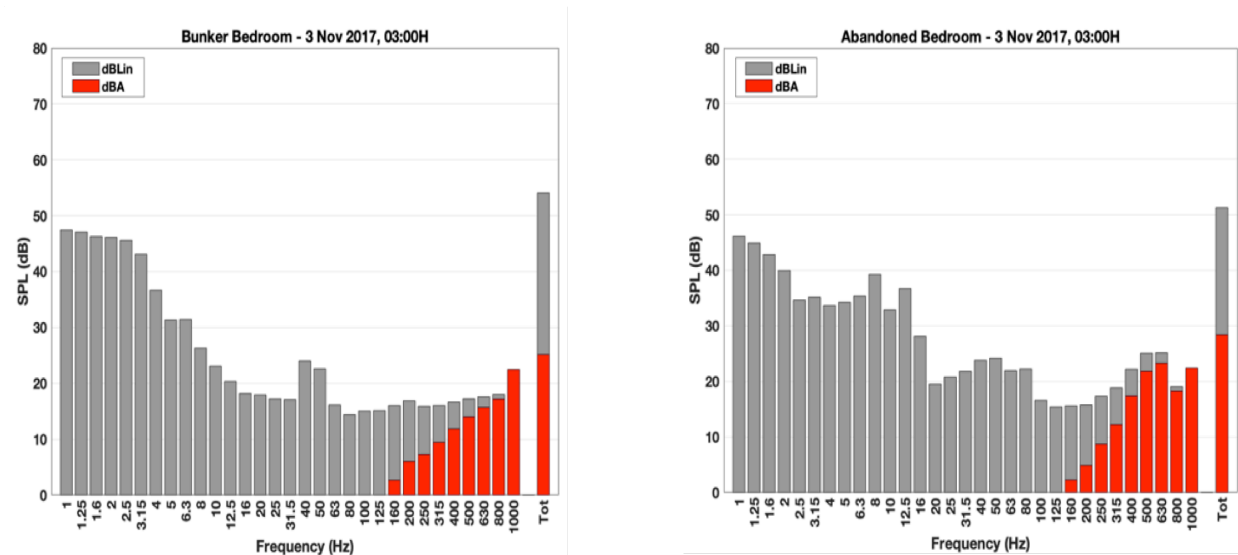
**B.** Bunker vs. Abandoned bedrooms. Wind speed 7.6 m/s, westerly wind (290°), 01 Nov 2017, at 14:00H

Figure 3: Periodograms covering the same 10-min intervals as in Figure 2 (analyzed between 1–1250 Hz), comparing the bunker and abandoned bedrooms at low and high wind speeds. The abandoned bedroom has consistently higher SPL levels than the bunker bedroom within the 4-40 Hz range, with very distinct shapes. At the lowest frequencies ( $\leq 2$  Hz), SPL variations in both rooms have similar shapes and positions.

#### 4. Discussion and Conclusions

Figure 4 shows  $\frac{1}{3}$ -octave analyses obtained from a 10-min average, corresponding to the period shown in Figure 2A-B. In the bunker bedroom, the unweighted SPLs (Fig. 4A, grey bars) show a broad peak at about 50 Hz (or two narrower peaks on slightly either side). The highest SPLs are recorded below about 4 Hz. Unweighted SPLs in the abandoned bedroom (Fig. 4B, grey bars) show peaks at 8 and 12.5 Hz. There is relatively more energy in the abandoned bedroom above 4 Hz, but less below this. In both cases A-weighted SPLs (red bars) merely reflect that which humans would *hear* if present. As per Rule 012, this is the type of data required to establish permissible exposure levels.

Rule 012 was informally applied to the data obtained from the Hogeveen home. No recordings were made outside of the residence so the interior recordings used would a) be quieter than outside recordings and b) have a higher proportion of ILFN. The basic sound level is the lowest, 40 dBA, since it has less than 9 nearby dwellings within a 451-metre radius and is further than 500 m from a heavily travelled road. (Since outside night-time levels in the absence of IWT were impossible to measure, a 35-dBA level is assumed for the remainder of these calculations.)



A. Bunker Bedroom.

B. Abandoned bedroom.

Figure 4: These 1/3-octave frequency histograms cover the same 10-min interval as shown in Fig. 2A and B, wind speed 0.9 m/s and westerly wind (290°) on 03 Nov 2017, at 03:00H.

Two Class A adjustments are required. Assuming that a complaint is made in wintertime (the season during which these recordings were made), there is a +5 dBA adjustment. The ambient sound level with operational IWT is already 5 dBA below the basic sound level of 40 dBA, therefore, the adjustment is the maximum of +10 dBA. Since the sum of these two is +15 dBA, the maximum possible of +10 dBA is taken. For the Class B adjustment, two cases were considered: no increase occurs and one increase occurs for up to 60 days. This will give an adjustment of 0 dBA for the first case and +5 dBA for the second. The night time limit is therefore 40 dBA + 10 dBA + 0 dBA = 50 dBA for the base case, and 55 dBA is permissible for one period a year of up to 60 days. The daytime limit is the night-time value + 10 dBA = 60 dBA. The C-weighted and A-weighted overall sound levels for the 10-minute intervals captured on 01 and 03 November are shown in Table 2.

Table 2: dBC-dBA applied to the German data

	dBA Leq 10-min	dBC Leq 10-min	Difference
Bunker bedroom (01Nov)	35.7	56.2	20.5
Abandoned bedroom (01 Nov)	39.4	60.9	21.5
Bunker bedroom (03 Nov)	30.9	39.9	9.0
Abandoned bedroom [03 Nov)	33.7	42.7	9.0

Since these aspects of Rule 012 are stipulated in A-weighted sound levels, and the controversial features of IWT emissions are all in the ILFN regions, it is not surprising to find that these thresholds would very rarely be breached by IWT. The conclusion is that these aspects of Rule 012 are largely irrelevant. Moving, then, to the sections of Rule 012 dealing with ILFN, the question of whether significant components exist is determined by section 3.2 [7]. The difference in C-weighted and A-weighted sound levels must be 20 dB or more *and* there must be prominent, sharp peaks between 20 and 250 Hz. Figure 3 shows that there are prominent, sharp peaks in the bunker bedroom (blue lines) between 40 and 50 Hz. The abandoned bedroom does not show sharp peaks, therefore, they are not considered tonal, even though they are prominent. From the differences in the C-weighted and A-weighted sound levels, it can be seen that only the recording made on November 1, with high wind speeds, exceeds the 20-dB threshold. Ironically, this is because of the increased wind noise in the

ILFN regions. Section 4.5 (4) however, states that measurements should not be taken during high-wind-speed conditions for exactly this reason. Therefore, this aspect of the Rule also fails to catch the important soundscape features. Had it done, and the requirements of section 4.5 were met, the maximum penalty would be the addition of 5 dBA to the measured sound levels. If these then exceeded the limits (between 50 dBA and 60 dBA as above) then the operator would be required to implement noise attenuation measures and confirm that ILFN was no longer an issue.

When IWT are the source of ILFN, the rotating blades generate a series of pressure pulses at the ‘blade pass frequency’ (BPF), which is seen as a harmonic frequency series called *wind turbine signature* [14]. When synchronous IWT rotate at a constant rate, regardless of the wind speed, they will share a common harmonic series [15]. The IWT near the Hogeveen home are asynchronous, their BPF changes with wind speed. Given the sheer number of these IWT at the site, a single (‘clean’) IWT signature was not a reasonable expectation. Nevertheless, an analysis of the existence of harmonic series was conducted on the recordings of the abandoned bedroom, at low and high wind speeds.

Figure 5 shows the 1–100-Hz region of Fig. 3 with the harmonic series starting at 1.36 Hz added as dashed lines. The two main peaks at 8 and 12 Hz appear on this harmonic series as the 6<sup>th</sup> and 9<sup>th</sup> harmonics (H6 and H9). There is a large peak at 1.36 Hz for the higher wind speed. The 8 and 12 Hz peaks also appear on the harmonic series starting at 2.04 Hz; there is a small peak at 2.04 Hz. There is also a peak at 6.8 Hz on this series for the lower wind speed. A further harmonic series starting at 0.68 Hz includes these three peaks (1.36 Hz, 2.04 Hz and 6.8 Hz) as well as the broad peak at 3.45 Hz. There is no suggestion that peaks have moved between the two wind speeds although neither of the peaks (1.36 and 2.04 Hz) is seen at the lower wind speed. Note that the resonant frequencies of the bedroom are in the order of 60 Hz and upwards, with the peak just below 80 Hz likely being one such. The peaks discussed above are therefore less than  $1/10$  of the cavity resonant frequencies and are not likely to be attributable to these phenomena.

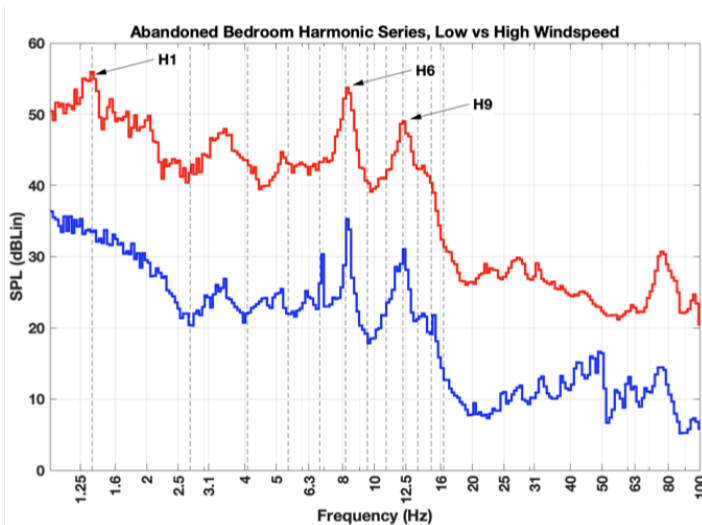


Figure 5: Comparison of data captured in the abandoned bedroom, at low (0.9 m/s-blue) and high (7.6 m/s-red) wind speeds, and same wind directions (290°). Harmonics of 1.36 Hz are shown as vertical, dashed lines.

A re-evaluation of legislation regarding population exposure to ILFN has been urgently required for decades [1]. The Canadian regulations here applied are similar to other regulations worldwide, and equally unsuitable *if* the goal is to protect human health against chronic ILFN exposures. Symptomatic complaints currently being ignored and/or misdiagnosed will predictably lead to a burden on future healthcare costs. Although the proliferation of IWT is bringing this agent of disease [16] to centre stage, the biases regarding how human health is impacted by airborne pressure waves (audible or not and whatever the source) continue to impede a proper scientific investigation [17], and consequently, proper protection of human populations and their offspring.

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