MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

Wind Turbine Noise Challenges in Sweden

Lagö, Thomas[1]
QirraSound Technologies Europe AB
Slagetorp 2, 576 92 Sävsjö, Sweden

Persson, Bertil[2]
Betongteknik AB
Daggpilsgränd 23, 233 63 Bara, Sweden

ABSTRACT

Wind turbines produce a lot of low frequency sound. The companies operating the turbines claim that they always comply with the legislation. MMÖD (Supreme Court) also says in its court decision 2017 that wind turbine noise cannot be measured when it is windy - only calculated with Nord2000 and summer data. It is possible to make proper wind turbine noise measurements, but this will pose a series of challenges that must be handled correctly. The Swedish Environmental Protection Agency has failed to handle its responsibility. This paper is outlining a measurements series of more than a week, where multiple measurements stations were used in conjunction with a weather station, plus measurements inside the house. The house in question is located at the country side and there are no other noise sources nearby, except a road where cars and trucks sometimes drive by. The paper will present the data collected and how, wind, background noise, trucks, cars and all other factors that could impact the measurement have been handled. Many parameters have been collected like dBA, dBZ, dBC, L_n and third octave bands. A selection of data over the 10 days are presented and a discussion in regard to measurement quality, the results and legal compliance will be presented. Knowing that sound level data can be trusted is key.

Keywords: Noise, Environment, Annoyance, Wind turbines, Health, Legal
I-INCE Classification of Subject Number: 55

1. INTRODUCTION

Wind turbine noise implies low frequency sound. Typically, we measure sound in the frequency range 20 - 20 000 Hz, but in too many situations, dBA is used as the pre-filter on the sound level meter. A dBA filter will reduce the low frequency content drastically. In the table below, this is presented. The reduction is as follows:

Frequency	**dBA attenuation**
100 Hz	19 dB
50 Hz	30 dB

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[1] thomas.lago@qirrasound.com
[2] sbertilmpersson@gmail.com

10 Hz	70 dB
1 Hz	150 dB

The fundamental frequency of the wind turbine is often in the range of 1 Hz. Hence, its fundamental is reduced by 150 dB. Therefore, it is possible to have huge infrasound levels (below 20 Hz) and still, the dBA level is moderate. This has been observed in research work around the world and health effects have been frequently reported. However, Sweden wants to present itself as a leader in environmental technology and hence, people that complain about sound levels have little or no chance to win a court case. This was well established in regard to the case in Småland, Sweden, where MMÖD (the Environmental Supreme Court) says in its court decision 2017 that wind turbine noise can only be calculated with the road traffic sound calculation model, Soundplan 7, but by the company instead called Nord2000, obviously in order to confuse. When using calculations together with input data that has been carefully selected and conditions to the wind turbine's advantage, it is possible to end up with 39.8 dB, and therefore the house dwellings will lose.

Important research and reports in regard to infrasound (inaudible, pulsating air waves < 20 Hz), are totally missed by the Swedish authorities. Interaction with ground vibrations increases the sound level indoors. Powerful ”dunking” sounds and echo effects occur when the wings are passing by the towers. Turbulence causes amplitude-modulated high noise level shocks. Infrasound show attenuated activity in the brain and respiratory center, pathological changes in the heart sac, lungs and blood vessels, degenerative effects on the brain, impaired heart muscle capacity by 20%, etc. American interconnection of public databases showed significant links between suicide frequency and wind power establishment up to 25 km, especially older individuals and those who lived in the prevailing wind direction, [8]. Finnish follow-up showed increasing disease symptoms up to 15 km, [9]. The German specialist medical group, Erzte für Immissionsschutz, states that the limit for health effects at infrasound exposure is at 60 dBZ and that this level is only below 10 km, from a single wind turbine, [10].

These problems are well known in the work environment protection teams (like NIOSH, OSHA and Arbetsmiljöverket in Sweden), where so-called dose exchange rates are used. This typically implies a reduction by 3 dB per doubling of the exposure time. If this is converted to wind power, dangerous load can easily happen within a few years. After all, the risks are very serious for both younger and older people. There is also research that shows that infrasound can sometimes be reflected from atmospheric air layers. These waves can also go directly into the ground on slopes close to the turbine and are likely to generate vibrations. Ground vibrations can also be reflected from geological layers and reach ground levels from below. Since 2008, a high prevalence of front limb acquired flexural deformities was observed by the Faculdade de Medicina Veterinária de Lisboa, in a Lusitano stud farm, close to a wind park due to ground vibrations, [30].

As stated above, the dBA filtering is another factor that leads to wrong conclusion in regard to health effects. This filtration method is highly unfortunate. When people talk or shout, they are well within the filter range of dBA, but when machines with a more low frequency content make noise, they will be filtered by the dBA method. Often, the human hearing is referred to as a reason for dBA. However, Fletcher and Munson required a dBZ type measurement to determine the dB value first and then decide on the proper filter: dBA, dBB, or dBC. The typical approach is to use dBA even if the sound level is above about 50 dBZ as was described by Fletcher and Munson, [4]. That is not correct and leads to wrong conclusions in regard to the effects on humans when exposed to wind turbine noise, [6]. This is one of the reasons why low-frequency noise often causes greater health problems than what dBA indicates should be the case. This is discussed in more detail in several articles, [11-18]. WHO, Australia and many others have decided not to use dBA any longer. It is an outdated approach and should be obsoleted.

It is also important to understand that even the dBZ filter cuts below 10 Hz. Many of the microphones in an SLM (Sound Level Meter) starts rolling off at 5-8 Hz. It is possible to make a microphone that can measure down to 1 Hz and such a microphone was developed for the NASA Sonic Boom project. Gunnar Rasmussen from GRAS in Denmark designed the microphone for that project. However, that is not applicable to most SLM:s since the electronics and filters must also support 1 Hz. That is typically not the case.

2. THE SWEDISH ENVIRONMENTAL PROTECTION AGENCY

The Swedish Environmental Protection Agency organization has a clear responsibility for monitoring general environmental interests in cases and where the Environmental Code is applied and to participate in environmental trials that pertain to issues that are fundamentally important or is of great importance to the environment. This responsibility weighs lightly when there are other state interests. Hence, the financial interest in wind turbines weighs much higher than the environmental impact on humans. Also, there is a believe that with more wind turbines, the environmental impact is less. The scientific proof for that assumption is highly debatable.

The Swedish Environmental Protection Agency did not respond to the criticism in regard to the lack of noise calculations and evidence of the serious health effects of noise, which was submitted to the Environmental Testing Delegation and the District Court. The authority thus blocks the citizens' right to scientific assessment of comprehensive evidence, as well as two international reports on infrasound, which the local law with its own funds translated into Swedish, following the court's injunction;

1. The wind turbine's infrasound causes health problems in Finland, [9].
2. German specialist medical group Erzte für Immissionsschutz. [10].

2.1 The Swedish Environmental Protection Agency’s failures

The Swedish Environmental Protection Agency (SEPA) failed to pursue its own recommendation of 35 dBA at a wind turbine with tonal frequency 5 dB above the surrounding frequencies, or in areas with quiet background noise or respond to the criticism of the rigid “practice” of 40 dBA and the inconsistent application of daily average. An example is the wind turbine installation described and covered in the court case, [20]. SEPA Officials are very well aware the flaws:

- Calculation model Nord2000 provides eight (8) dBA too low dBA values in the low frequency range. The origin for Nord2000 is actually traffic noise, and with adjusted input data, it is possible to reach less than 40 dBA, over and over again.
- The Swedish Environmental Protection Agency's knowledge summary report, which states that health risks cannot be ruled out, and that the benchmark L_{night} should be reviewed (2012).
- The Swedish Environmental Protection Agency's research report 6241, “Sound from wind power plants” (2010), which shows that temperature inversion and cylindrical sound propagation result in multiplication of sound propagation.
- The Swedish Energy Agency's project 32437-1 (2014) from Uppsala university showed long-term measurements with frequent amplitude modulations of about 45

dBA. Calculation examples showed triple sound propagation in tailwind. Proposals to reduce the benchmark by 5 dBA were rejected by the Swedish Environmental Protection Agency's officials. Their current applied “practice” has such a weak legal force that it does not comply with the EU SME Directive, regarding the participation of the public and scientific expertise. The evidence presented is reinforced by the WHO's new report Environmental Noise Guidelines for the European Region 2018 (October), which for the first time handles noise pollution from wind power, [28].

3. TYPICAL MEASUREMENT CHALLENGES

When handling outdoor noise measurements for wind turbine applications, there are more factors to include than for most other sound level measurements. Some of these challenges are:

- Wind turbines run when there is wind. Wind can potentially contaminate the microphone and hence, proper wind protection must be used. Often, a single protection will protect the microphone, but for wind turbine applications over longer measurement times, it is recommended to use double protection.
- Large low frequency content and hence, proper filters and equipment with good low frequency handling must be used.
- All calibration factors must be included. This includes:
    - Weather- and wind protection units. Will rain and moist impact the microphone? How much damping is introduced due to the protection?
    - Where is the microphone placed? A house facade (or hard surface) will impose a 6 dB amplification factor that must be corrected. A microphone close to the ground will not properly measure low frequency unless a larger hard surface is used to extend the frequency range and nothing should hinder the sound waves. This must be thought of and handled properly. Low frequency implies large wave lengths and is more challenging.
- Cabling can pose challenges.
- Bird spikes are needed to avoid contamination from birds sitting on the microphones.
- Background noise and/or other noise sources that can impact the measurement must be considered. Controlling and documenting such sources is paramount.
- Other challenges should be thought of and handled.
- Use your ears and listen to how it sounds. If you can hear it, you can measure it.

It is also important to measure many parameters, enabling proper validation of data. One dBA value over a longer period of time is not possible to evaluate, even if Swedish wind noise experts claim that this is the standard. A single value, averaged over time, does not reveal enough information making sure that the data comes from a wind turbine. Since BMT (Best Possible Technology) is required, [26], a single dBA should never be used. L_n values are useful to get a good understanding of the distribution of the sound levels and e.g. third octaves can easily verify if the sound is tonal, [21].

L_n values are statistical noise levels (sometimes called percentiles) used to assess noise levels (sound pressure levels) from fluctuating noise sources over time. Any statistical value between 0.01% and 99.99% may be calculated where ‘n’ is the percent exceeded noise level over a timed measurement period (T). L_{90} is the level exceeded for 90% of the time. For 90% of the time, the noise level is above this level. It is generally considered to be representing the background or ambient level of a noise environment.

L_{90} is often used to quantify the background noise levels in assessments of noise pollution and nuisance noise from industrial sources.

4. MEASUREMENT DATA

Multiple measurement series over a period of almost 10 days were performed at a location in Småland, Sweden. Data was collected using Type-1 measurement equipment and many parameters were stored: dBA, dBC, dBZ, Max, Min, third octaves, L_n values etc. For easier reading, only partial data has been presented. Three (3) Sound Level Meters (SLM) was used and data was stored to the cloud. The dwelling location has four (4) wind turbines close to the property and two of them are really close. One turbine is as close as 650 m to the dwelling. The next closest turbine is located 730 m from the dwelling. The data below summarizes the results from these three data collectors. All factors mentioned above as “challenges” have been properly handled. The measurement series was carefully planned.

4.1 Measurement data, direction west

In Figure 1, data are presented, starting March 18 and ending March 27, end of the day, a total of 10 days data collection. The data show that the dBA and dBZ values follow each other most of the time, especially when there are larger sound levels. This implies that there is noise with a high level of low frequency. It is impossible to find an explanation to what could generate these sound levels in both dBA and dBZ, unless it is the wind turbine. It must be a noise source with large low frequency sound levels that is coherent in both dBA and dBZ.

As can be seen in the data, the wind turbine noise is over the legal limit most of the time. This correlates well to the perceived noise levels when visiting the location, using a trained human ear, by a sound expert. In some of the areas in the data, there are peaks and dBA/dBZ are closer to each other. That verifies that it is noise without large low frequency content. Hence, it can be determined that these peaks are not wind turbine related and therefore should be discarded.

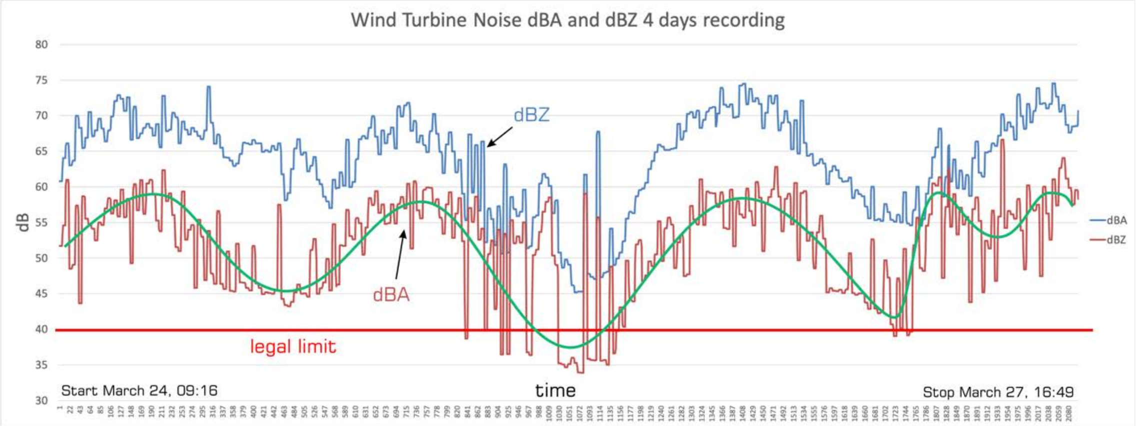

Figure 1. Wind Turbine Noise data collected from March 18 to March 23, 2017. Both dBA and dBZ are presented and the green line is an approximation of an average value over time. The red line represents the legal limit of 40 dBA, without the 5 dBA reduction due to tonal noise.

4.2 Measurement data, direction east

Data has also been collected in the eastern direction. Figure 2 show data over two (2) days where the levels often are over the limit value. The sound exposure on the eastern side of the house is typically less, since the house is shielding noise from the two western wind turbines. It is also possible to see that when the wind turbines are not making noise, it is a silent place. Typically, the background noise is 30-35 dBA and that is visible in the data recordings too.

The data show that the dBA and dBZ values follow each other most of the time, especially for larger sound levels. This implies that there is noise with a high level of low frequency.

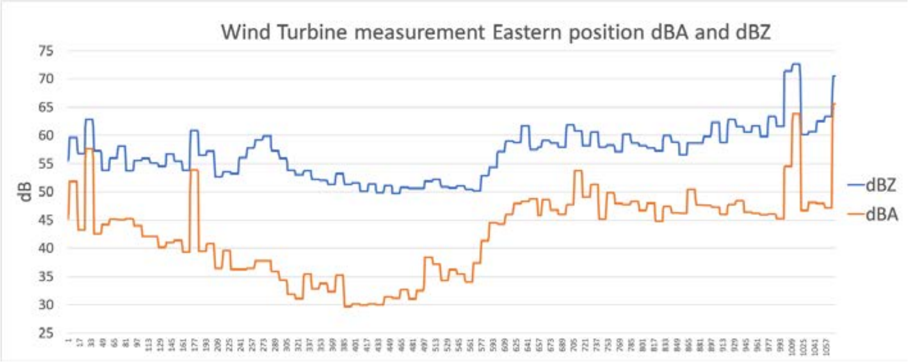

Figure 2. Wind Turbine Noise data collected from March 27 to March 29, 2017. Both dBA and dBZ are presented. Blue represent dBZ and orange represent dBA.

4.3 Tonal components

The data acquisition system allows for third octave analysis too. Hence, this analysis gives a great opportunity to see which sound components the noise consists of. Figure 3 depicts an example where the sound is dominated by a low frequency part and the band 40 Hz contains tonal components. There are also a 50 Hz tone. It is not a “hum component,” which must always be reviewed when 50 Hz is present. This peak decreases as the wind power plants' noise levels fall. A 50 Hz hum component would have maintained the same amplitude level. The 32 Hz component is stronger in amplitude than the 50 Hz component and the 40 Hz is the most dominant one. This is a typical result from a wind turbine and this frequency and amplitude shape is not the signum of wind noise in the microphones which the Swedish authorities and experts believe, [20].

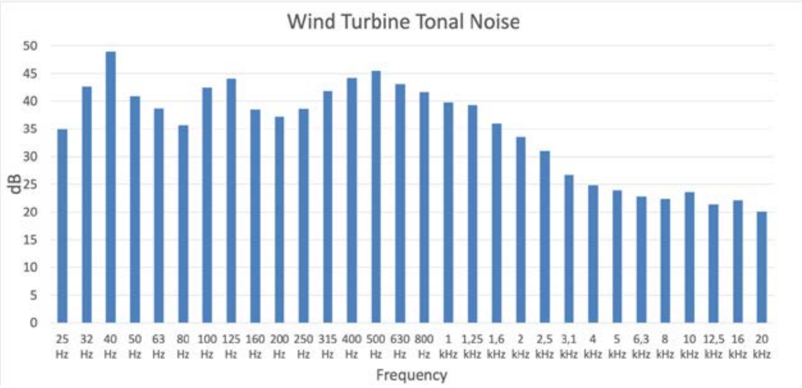

Figure 3. Wind Turbine Noise analyzed in third octave bands from the west measurement station. It is clear that the noise is tonal and should be corrected with +5 dB, or the legal limit lowered by 5 dB to 35 dBA.

The difference in frequency and amplitude in turn is dependent of the size of modern wind turbines (90 m in blade length, or even 150 m lately) as compared to the ones in present regulations, which cover 50 m in blade length. For large turbines the blades turn backwards before zenith by passive action of the dead weight of the blade, which give an catapult effect after zenith i.e. lower frequency before zenith of the blade and an increase in frequency after the blade passes zenith of its rotation. This is the news of the noise of large wind turbines as compared the 21-year-old turbine in the Swedish regulations and also coincide well which the rotation speed of the wind turbine blade passing zenith, about 1 Hz or even lower for a 150-m-blade.

The legal requirement for tonality, is that the tone should exceed by 5 dBA as compared to the frequency above and below, which is the case as shown in Figure 10. Therefore 40 – 5 = 35 dB applies legally at the dwelling in question.

The eastern measuring station has consistently lower values than the west station, which is coherent with the dwelling owner's subjective reports (typically 5-10 dB according to the measurements). However, there are continuous exceedances and since the distance between dBZ and dBA follows each other, it is proven that the sound consists of low-frequency noise from the wind turbines and not of any activity of the business owners. There are no other sources of noise on or near the property that can generate these low-frequency sound levels over long periods of time that dBA/dBZ reports.

The property is located in the forest and it is an extremely quiet environment, unless the wind turbines are spinning. This should also be taken into account and in “silent environments” the requirement should be 35 dBA and not 40 dBA, which the authorities correctly use, since the general plan of the community do not indicate a silent place at the dwelling in question. Still the legal component for tonal frequency applied i.e. in all 35 dB applies as a legal requirement. A silent environment is disturbed more psychologically, than one with a more noisy background, [11][12].

By measuring L_{eq} (1 second) over time (between 27-29 March) in both dBA and dBZ, it is evident when data contains noise from the wind turbines, and when there may be “other causes,” [21]. The short “peaks” contained in the data in Figure 1 and 2, should therefore not be used as a basis for exceedances, but other data must come from wind turbine noise. There are no other sources of noise on the property that can create these noise levels, or sounds in the background, with such high dBZ levels.

4.4 Measurement station inside, west

Measurement data from this measuring station reports a large contribution from the low frequency in the sound, as depicted in Figure 4. Since the house wall is good at filtering higher frequencies, only the low frequency goes through. That is normal since walls often have a challenge stopping low frequency. This also show clearly that the low frequency measured is not wind noise, but wind turbine noise. The sound level meter is placed inside the house and there is no wind. Despite that, it is possible to see how the wind turbine’s low frequency sound changes with wind direction and size.

The measurement has been done night time, making sure that activities from the family is minimized (not cutting grass which the court often refers to). The short “peaks” in the data come from vehicles driving past. It is common that some trucks use the night time for timber transport. These peaks are not wind turbine noise, which is also verified if comparing dBA with dBZ for these peaks. It is interesting that is very visible that around 5am, traffic and activities start. Despite that, it is also visible in the data that there is wind turbine noise in parallel.

No one is in this bedroom which is an “extra bedroom” for visitors. Hence, “self-sound” can be ruled out. The bedroom is located in the west direction which makes it more exposed to wind turbine noise and hence, a good measurement location.

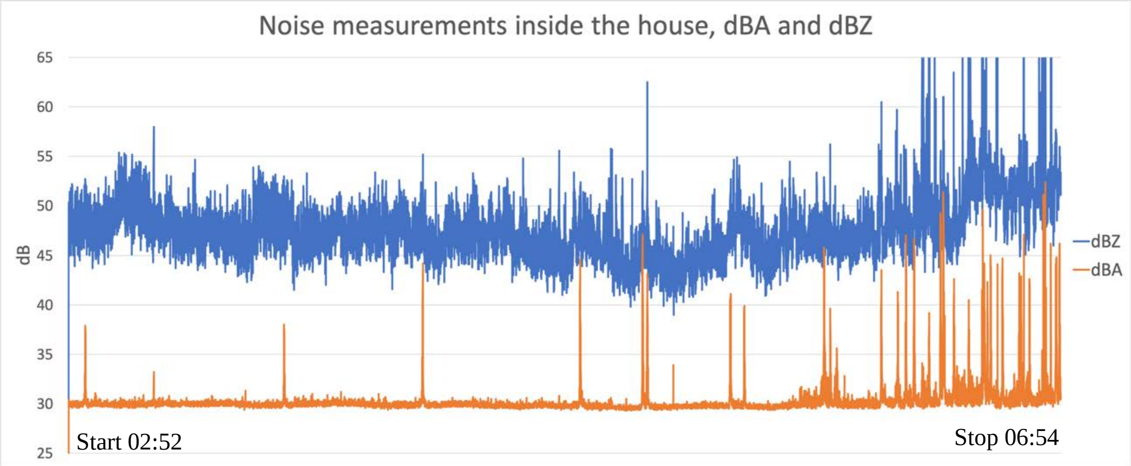

Figure 4. Wind Turbine Noise data collected during night time inside the dwelling, in one of the bedrooms, typically used for visitors.

4.5 Background noise

A measurement series at the house location showed that background noise typically was below 35 dBA. This is also verified in the measurement series that took place during 10 days.

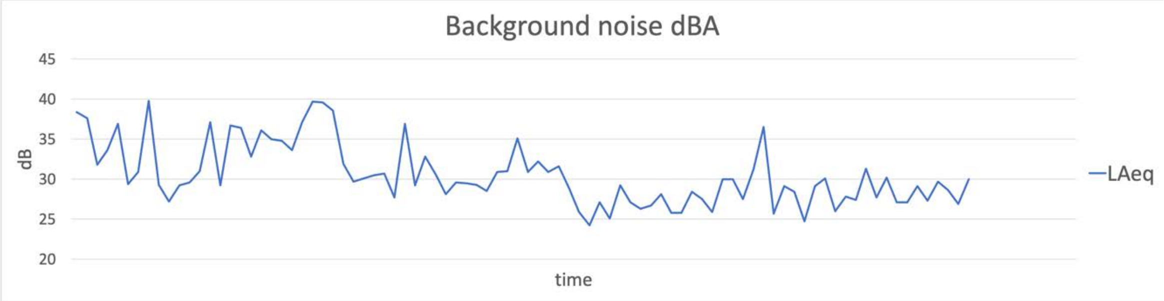

Figure 5. Typical background noise at the house location when no cars are passing by, not frequently happening. It is a remote location.

The L_{90} values also verifies the background noise levels, [21]. This is a parameter that Swedish authorities and their experts is not privy to. The court claim that background noise cannot be measured at all, since when there is a windy situation (needed for the turbines to operate). The background noise would be contaminated by the turbine noise, but it is impossible state how much. It is a clear Catch 22 for the authorities and their experts and actually, they seem to appreciate that. However, with L_{90}, it is possible to still see what the actual background noise is since the turbines has a “swooshing sound,” [21]. When this has been brought up in court it has been discarded as “we are not privy to L_n and hence offering information in regard to L_{90} is hence rejected.” They continue to state that background noise cannot be measured when turbines are in operation. However, analysis of the L_{90} values over the measurement time in this project, show a rather steady value of about 40 dB.

As a comparison, a measurement series has been performed when it is rather windy, readings between 8-16 m/s on the Oregon weather station. The data has been collected using double protection and the sound has also been recorded as a wav file. When listening to the file, the wind protection is doing its job. The background noise comes from the trees, birds and some remote activities that can be heard in the recording. It is of special interest to compare the difference in between the sound when the turbines are in operation and the background noise collected at a location without any wind turbines nearby, but windy conditions. Absolute levels cannot be compared since these two measurement series are done at different locations and different circumstances, but the intent is to demonstrate that the wind is not contaminating the microphones. Microphones are reading the sound that they are exposed to, and the “frequency shape” is different compared to the turbine sound, as can be seen in Figure 6.

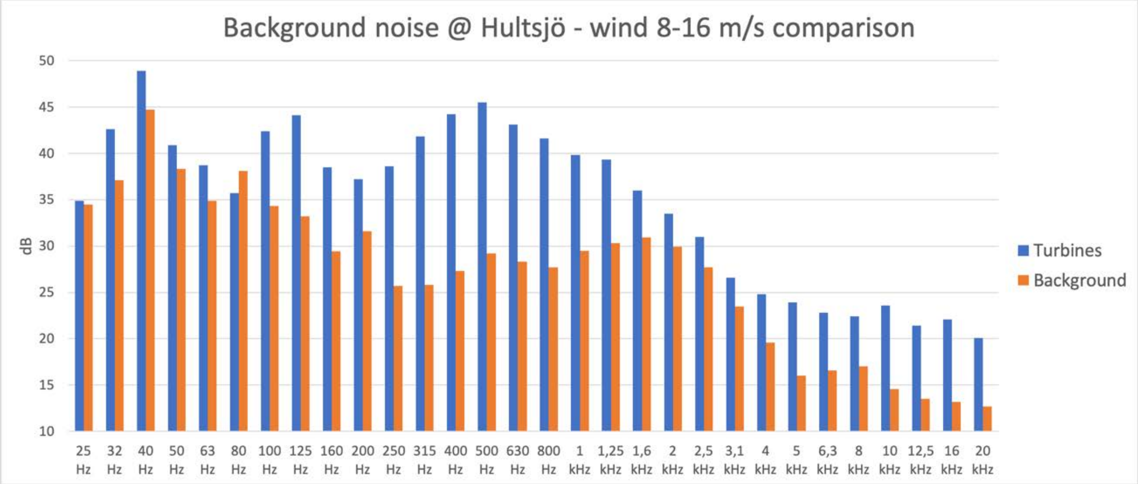

Figure 6. Background noise compared with the turbine noise measured at the dwelling location. The background noise is measured at a location without any wind turbines nearby, but windy conditions.

In Figure 6, the 40 Hz component is about 8 dB larger than the 32 Hz component and about 10 dB larger than the 50 Hz component. In measurement technology, 3 dB is typically used when determining if the SNR (Signal to Noise Ratio) is enough to measure the signal. However, when handling Type-1 measurements, 3 dB is not enough. The signal is visible, but the accuracy is not good enough. For Type-1, the needed SNR number is 7 dB, if the error should be below the 1 dB margin, required by Type-1. However, many SLM (Sound Level Meter) manufacturers use 5 dB as the foundation for the SNR in their equipment (what is lowest signal that can be measured). Given the data presented, accuracy in the readings versus possible contamination via the background noise or other components, is not a topic, since the SNR dB value is large enough. Analyzing the background noise data over time, for dBA and dBZ, show that they are not correlated, like with the wind turbine data. They do not “follow each other”.

4.6 Comments in regard to wind contamination

The MMÖD court (Supreme Court) has decided that it is not possible to make physical measurements. When the wind turbines are operating, it implies that it is windy, and the measurement will then be contaminated with wind noise. This is an interesting comment since reporters can make sound recordings outside in really bad weather and it is very possible to hear what they say. Also, our expert team has performed many long-term outdoor measurements and never seen a bad wind contamination, if using proper weather- and wind protection. When using double protection, it is even better.

4.7 Comments in regard to the operator’s violation of legal requirements

The company shows that turbine 1 was run in Mode 1 between 2012-12-12 to 2015-12-15 i.e. also during their own sound measurement (not performed at the house property, but in a field, far away from the house), and then changed to Mode 0 thereafter. Down regulation was therefore not followed at all. On December 20, 2017, the company incorrectly certifies that no changes have been made to the turbine, since the building permit was granted, but at the same time paradoxically attaches a certificate stating that turbine 1, from the measurement date 2013-07-04 to December 20, 2017, changed to Mode 0, from having been suspended in Mode 1 at the measurement. Hence, Mode 0 has not been measured for turbine 1, which is a legal requirement. An increase of sound level of the turbine is following by increasing the effect of the turbine. This handling fault was discovered after several years on demand of the legal court. The motive of increasing the effect was solely an increase in profit, about 125 000 USD during 15 years for the turbine in question. No action was taken from the authorities in regard to the the mis-leading statement from the company.

5. CONCLUSIONS

A larger measurement series was performed, documenting sound levels during many days, including weather data. The measurement data clearly show amplitude exceedances. Despite that, in a Supreme court decision (MMÖD), it was decided that it is not possible to measure low frequency sound from wind turbines when there is wind, since wind noise will contaminate the measurement and it is therefore not possible to know what the real dBA value is. Hence, it is only calculations via Nord2000 and summer data as input that can be used as the foundation for sound level predictions, and these calculations can only be performed by the wind turbine company’s experts, [20]. These, experts, always arrive at 39.5 or 39.8 dB and they claim that it is impossible that the sound data collected, can be right. They never report any confidence interval or uncertainty since computer calculations are “always correct”.

The Swedish Environmental Protection Agency have failed to pursue its own recommendation of 35 dBA at a wind turbine with tonal frequency 5 dB above the surrounding frequencies, or in areas with quiet background noise or respond to the criticism of the rigid “practice” of 40 dBA and the inconsistent application of daily average. The Nord2000 software allows for manipulation without external consultants being able to validate and verify that the predictions are correct. The company make calculation for day hours with ideal summer conditions with low relative humidity and high green fields, but the dwelling owner is mainly disturbed in the winter time with frozen ground, free from vegetation and night conditions connected to high relative humidity. Since it is only these certified experts, in cohort with the wind turbine industry, that are allowed to do the calculations in Sweden, it really poses questions about bias and hence should disqualify their results. Another authority, Swedac, that certifies companies to make noise measurements, states, that no certified company exists to make certified measurements of Wind Turbine noise since a certified method to make this measurement is lacking in Sweden.

This paper clearly show that the sound levels collected are above the legal limit. Data that has been collected using professional equipment and expert sound engineers, with multiple methods for validation and error checking. All critical factors involved has been handled and documented in this paper. The end result is that theoretical predictions (by the wind turbine owners and their experts) and professional measurements performed at the house location are in clear contrast to each other. Despite that, the house owners cannot prove that the noise levels from the wind turbines exceed the legal limit.

6. ACKNOWLEDGEMENTS

We acknowledge gratefully the support from the family in regard to this measurement series which assumes their involvement and help, but also an intrusion in their home.

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