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

Wind Turbine Measurements in Sweden

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ABSTRACT

In Sweden, there are many wind turbines that have been placed too close to dwellings and creating a very noticeable low frequency disturbance, often above the legal limits. However, the wind turbine companies are allowed to continue their exceedance of legal limits since the authorities does not allow any external person making measurements, not even international specialists on measurement technology. In a pilot project, noise levels much above the legal limit of 40 dBA were documented over weeks of measurements for a lonely house on the country side. However, in a high court decision (MMÖD, Supreme Court), 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 predictions via simulations that can be used, and these can only be handled by the wind turbine company's experts. They always arrive at 39.5 or 39.8 dB. Knowledge in regard to measurements in windy conditions seems to be lacking. This will be covered and discussed, and data will be presented, plus comments from authorities and their experts and discussions in regard to why the authorities claim that the performed measurements cannot be used as evidence and proof that sound levels exceed the legal limits.

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

1. INTRODUCTION

In Sweden, its common to install wind turbines in direct conflict with the legal requirements. The financial remuneration is vast. The dwelling owners have little or no possibility to complain since the authorities lack knowledge and rely on the wind turbine owners for data and information. Since it is critical for them to continue their business, even if not legal, nothing will happen. This paper is covering a typical case in Sweden and how "impossible" it is to complain, but also how arguments are being used that lacks a foundation in science and technology.

The case presented is a house on the country side were four wind turbines are placed in close proximity to the property, as close as 650 m (the next closest on 730 m). The dwelling owners have been disturbed by noise since these turbines were installed and it has impacted their quality of life. It was a silent place before the wind turbines were erected. They have a tower height of 105 meters and a total height of 150 meters. Maximum power is 2 MW per unit. Regulatory authorities have not acted despite multiple claims from the house owners, for more than 8 years. This shows serious deficiencies in the system, in regard to the handling of noise from wind turbines. Figure 1 show the house and the proximity of the wind mills. The fourth wind turbine is just behind the camera to the left.

Figure 1. Photo showing how three of the four wind turbines are placed. They are very close the house. The left side of the house points in the western direction and the photo is facing north.

The property's noise exposure from the wind turbines shall not exceed 40 dBA, according to the legislation in Sweden, not taking into account the tonal part which is to be corrected by +5 dB in the measurements according to standard, which in turn gives a requirement of maximum 35 dBA. Consideration should also be given to the measurement accuracy which is approximately 2.5 dB, [5]. The measuring plate must be corrected, which gives - 6 dB on the measurement results. This has been corrected for in the measurements, including the effect of the wind protection.

Figure 2. Location of the wind turbine in the eastern direction.

Noise from wind turbines is extremely low frequency. The fundamental frequency is usually around 1 Hz, which creates sound waves that are about 345 meters long. In Figure 2, it is possible to see how close to the property one of these four wind turbines is placed, the eastern side of the house.

Three different measurement stations, complying to IEC 61672 and Type-1 standards was used, plus a weather station. Two of the measurement stations were placed outside (west and east), and one measurement station was placed inside, in the western direction. Double wind protection was used and properly calibrated microphones, paired with proper weather protection. A check of the data and system was performed almost daily, making sure that nothing bad disturbs or impacts the measurement.

Figure 3. Description of the wind and weather protection used for the measurement series. Calibration of the 6 dB for wall mount and calibration of damping for the wind- and weather protection have been properly handled.

One more measurement station was placed inside the house. This station handled both the wireless data collection from the weather station and an SLM (Sound Level Meter) placed in the room, located just to the left of the photo in Figure 4. This room was not occupied and hence, contamination from people living in the house was minimized. This room is facing west.

Figure 4. Data collection center placed in the house in the western direction. It is known that the noise impact will be largest in this direction and this room was not occupied.

The house owners have for several years complained of high noise levels from the wind turbines, but no action has been taken despite health issues, appeals and processes. In this measurement series, large exceedances are recorded. Regulatory authorities, or those responsible, have not shown any interest in reducing the health concerns that accompany this grave overexposure and which have been allowed to last for more than 8 years. This is a violation of several paragraphs in e.g. the Environmental Code. In a court decision, it was decided that it is not possible to measure wind turbine noise since the wind will contaminate the measurement and hence, only theoretical calculations are valid. These theoretical predictions can only be made by the experts related to the wind turbine operator, and they claim less than 40 dBA. The company make calculations 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 humudity. The court decision can not be disputed or appealed in Sweden, [19].

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2. BACKGRUND TO THE WIND TURBINE NOISE MEASUREMENT

Wind turbine noise is low frequency and often modulated plus tonal in its character. The old dBA filtration method is highly unfortunate and Figure 5 illustrates typical frequency ranges for sound from different sources. 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. If the noise sources have a low frequency content below 300 Hz, the impact can be substantial. 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 and then decide on the proper filter: dBA, dBB, or dBC. The typical approach is to use dBA even if the dBZ sound level is above about 50 dB, as was described by Fletcher and Munson, [4]. That is wrong and leads to faulty conclusions in regard to the effects on humans when exposed to wind turbine noise, or other low frequency sounds, [6].

The fundamental frequency for a wind turbine is often around 1Hz. Noise from wind turbines is extremely low frequency. The fundamental around 1 Hz creates sound waves that are about 350 meters long. According to the Swedish principle, dBA must be used, which is a very unfortunate method because the noise is reduced due to the built-in filter in the measuring instrument so that only a fraction of the noise is recorded or visible. In Figure 5, it is obvious that the fundamental tone of 1 Hz is reduced by much more than 120 dB and the frequency of 10 Hz by as much as 70 dB. Fifty Hz is attenuated by 30 dB. This means that the real sound is much stronger than what dBA will show. 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, [7-17].

Swedish authorities and their experts claim that self noise from people living in the house is cited as the reason for high sound levels, not the wind turbines. When using e.g. a lawn mower there will be noise, and that could be the reason for high sound levels. These machines have a certain amount of low-frequency noise, but they have significantly lower levels of low frequency. Hence, they cannot be confused with the noise levels from the wind turbines. It is not possible for a lawn mower to produce high dBZ levels over longer periods of time. Hence, it is of interest to always compare dBA and dBZ to see if these conditions could be valid or not. However, in Sweden, the authorities can only look at dBA and an average over longer time periods, and hence, the value cannot be trusted:

it could have been contaminated by other noise sources. Therefore, theoretcial calculations must be used. It is interesting that the company in question (and other operators also) always come to theoretical predictions just below 40 dBA, often 39.5 dBA. When performing measurements, they are not even made at the house but some other strange location, enabling theoretical predictions to be performed from that location, then justifying a value just below 40 dBA. An abroad control centre of the wind turbine, from where all the turbines were handle, even has increased the effect of one turbine during the legal processes without information to the dwelling owner or the authorities. 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 the 15 years for the turbine in question.

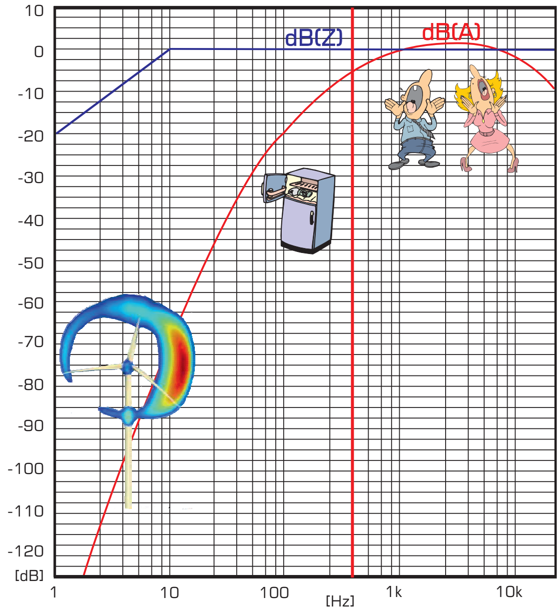


Figure 5. Description of the impact from the dBA filter on sound, relative to frequency content down to 1 Hz.

It is always important to consider background noise, especially in connection with outdoor measurements. To facilitate analysis of background noise versus wind power noise, a comparison between dBA and dBZ is the foundation. The a-priori information that exists indicates that background noise on the property is not in the same frequency range and will therefore be filtered differently by the dBA filter. This comparison is therefore important to understand, assuring that the wind power noise has been measured correctly. This is one method that can be used as a first step.

The purpose of the measurement is to document how the actual sound levels look over time. That is why a long-term measurement was carried out in the period 18 - 29 of March. Parallel to this, the house owner filled in a standardized document that reports their degree of disturbance so that a correlation between actual sound data, exceedances and their experiences can be accomplished, [3]. The coherence between their completed documents and noise levels measured, is very good and can be used as a basis for this type of reporting.

Since the house could net get any attention for their claims, they contacted an international expert team on sound and vibration measurements. Multiple measurements stations, both inside the house and outside were placed, together with a weather station. In the measurement series, double windshields have been used, one inner and one outer, together with a weather protection on the inner windshield. Data have been stored continuously to the cloud and can be used for various calculations later.

A separate measurement series showed that background noise typically was below 35 dBA. This is also verified in the measurement series that took place during the 10 days. Before the measurement series took place, a listening with human ears were performed, to get a feel for "how loud is the sound" and can it be heard above the background noise. The "swooshing" was loud and clear and days when the wind turbine was not in action, it was very silent. The "swooshing" from the wind turbines is very noticeable, especially the turbines to the west, when the wind comes from the west. However, this depends on how the four turbines interact. Therefore, the wind situation will have a rather large inpact on the actual sound levels at the property.

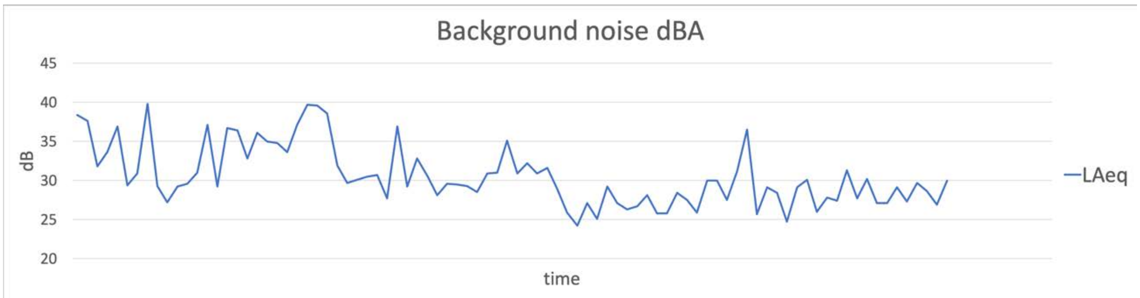


Figure 6. Typical background noise at the house location when no cars are passing by, not frequently happening. It is a remote location.

The L_{90} values also verifies the background noise levels, [20]. L_n values are statistical noise levels (sometimes called percentiles) used to assess noise levels (sound pressure levels) from fluctuating noise sources over time. If we sample any fluctuating noise levels and store the results once a second, then at the end of an hour we would have 3600 samples. We can then use these samples to determine some helpful statistics. For example, if all samples are added up and divided by 3600, then an average will be accomplished, or an L50% value of the noise over the hour. 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.

This is a parameter that Swedish authorities and their experts is not privy to. They claim that background noise cannot be measured at all, since when there is a windy situation (needed for the turbines to run), background noise could possibly be "the measurement". With L_{90}, it is possible to still see what the actual background noise is since the turbines has a "swooshing sound." When this has been brought up in court, it has been discarded as "we are not privy to that method and hence, it cannot be used".

In Chapter 2, Section 3, of the Environmental Code, it is required that the person who conducts professional activities apply BMT, Best Possible Technology. Larger time periods for data acquisition, as well as the use of more tools for the analysis, are crucial in knowing that the analysis is correct. It is also important to be able to separate other possible background sounds and/or the business owners' possible activity. By making multi-dimensional measurements with several types of analysis tools, this challenge is avoided, and that has been handled properly in this project.

3. MEASUREMENT RESULTS

Multiple measurement series over a period of almost 10 days were performed at the 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 in this paper.

3.1 Measurement data, direction west

In Figure 7 and 8, data are presented, starting March 18 and ending March 27, end of the day, a total of 10 days of data collection. In March also frozen ground exist with lower absorption than during summer time, with high vegetation on the ground.

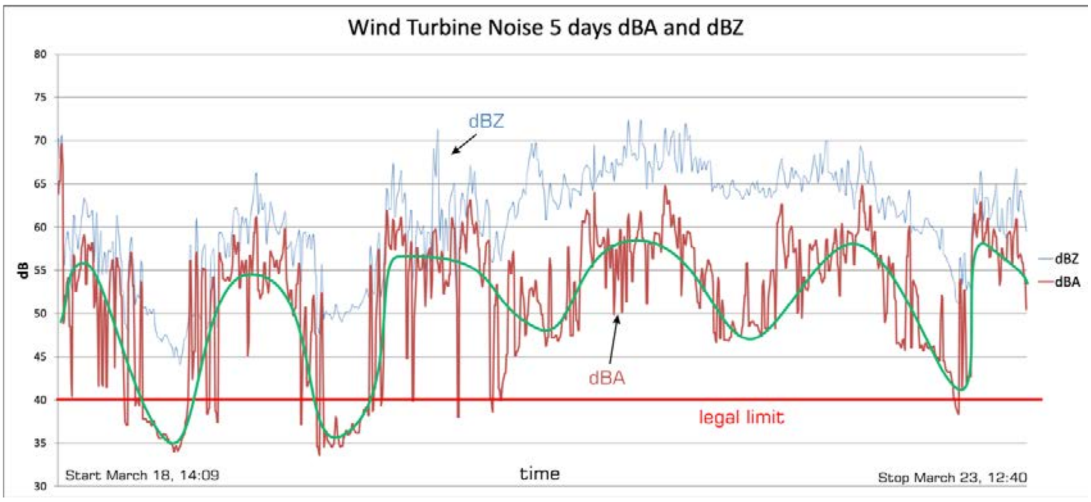


Figure 7. Wind Turbine Noise data collected from March 18 to March 23, 2017. Both dBA and dBZ are presented and the green line is an approximation of an average value over time. The red line represents the legal limit of 40 dBA, without the 5 dBA reduction due to tonal noise.

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.

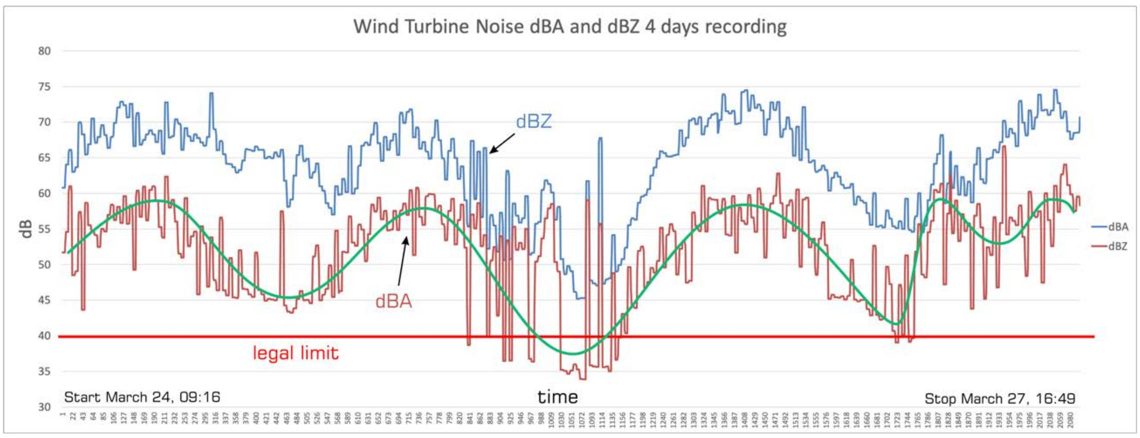


Figure 8. Wind Turbine Noise data collected from March 18 to March 23, 2017. Both dBA and dBZ are presented and the green line is an approximation of an average value over time. The red line represents the legal limit of 40 dBA, without the 5 dBA reduction due to tonal noise.

3.2 Measurement data, direction east

Data has also been collected in the eastern direction. Figure 9 show data over two (2) days and the levels 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, when the turbines are not spinning.

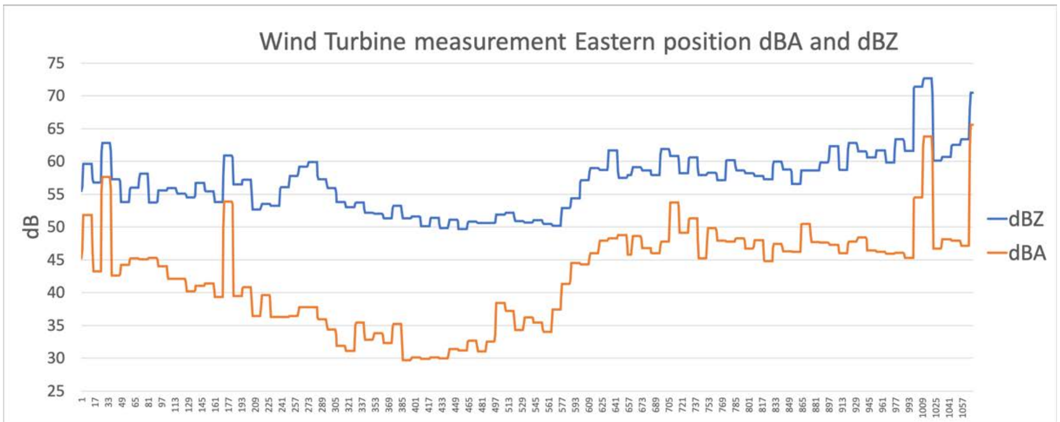


Figure 9. Wind Turbine Noise data collected from March 27 to March 29, 2017. Both dBA and dBZ are presented. Blue represent dBZ and orange represent dBA. The red line represents the legal limit of 40 dBA, without consideration of the 5 dBA reduction due to tonal noise.

The data acquisition system allows for third octave analysis too. Hence, this analysis gives a great opportunity to see which sound components the sound consists of. Figure 10 shows an example where the levels are typically far too high and it is clear that the sound is dominated by a low frequency part and that the band 40 Hz contains high levels of low frequency sounds.

There is 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 decrease. 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.

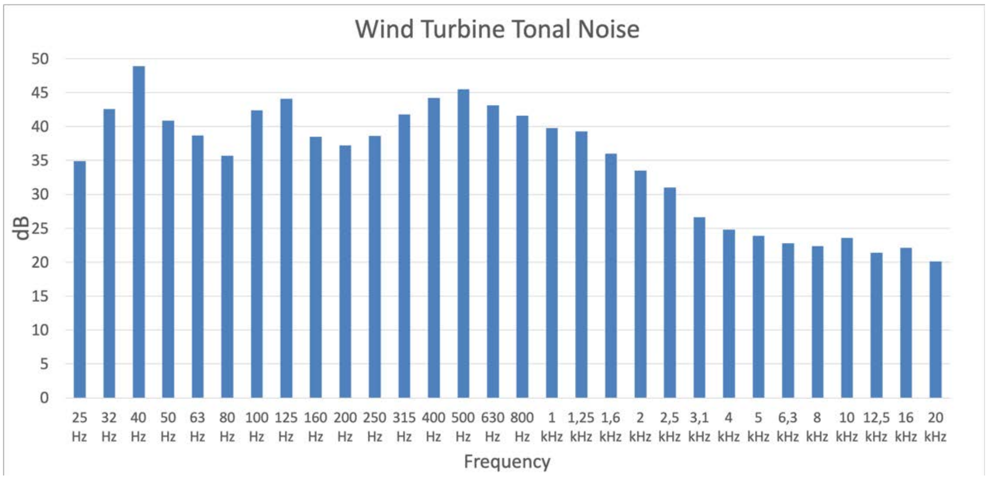


Figure 10. Wind Turbine Noise analyzed in third octave bands from the west measurement station. It is clear that the noise is tonal and should be corrected with +5 dB, or the legal limit lowered by 5 dB to 35 dBA.

The requirement for tonal frequency, legally exceeded 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.

In the picture below, another measuring period is analyzed which reports L_{eq} in dBA and dBZ in the same image. As can be seen clearly, dBZ is typically 15 dB higher than dBA, which indicates that the sound is composed of low frequency sounds. The short peaks that are seen are vehicles that pass by or other sounds generated on the property and these should not be considered as an exceedance. It is the more continuous measurement values when dBA/dBZ follow each other, that relate to exceedances.

The eastern measuring station has consistently lower values than the west, which is coherent with the house owner's subjective reports (typically 5-10 dB according to the measurements). However, there are 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 noise sources on or near the property that can generate these low-frequency sound levels over long periods of time, that dBZ reports. The property is located in the forest and it is an extremely quiet environment unless the wind turbines are spinning. No trees are located close to the measurement location, giving high background noise. A silent environment is disturbed more psychologically than one with a more noisy background, [11][12]. 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.

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 wind turbine, and when there may be "other causes". The short "peaks" contained in the data in the picture below should therefore not be used as a foundation 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 for a longer period of time.

3.3 Measurement station inside, west

Measurement data from this measuring station reports a clear contribution from low frequency, in the sound. Since the house wall is good at filtering higher frequencies, 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 size and direction. The measurement has been performed night time, making sure that activities from the family is minimized (not cutting grass which the court 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 by 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 that there is wind turbine noise in parallel.

No one is in this bedroom which is an “extra bedroom” for visitors so “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.

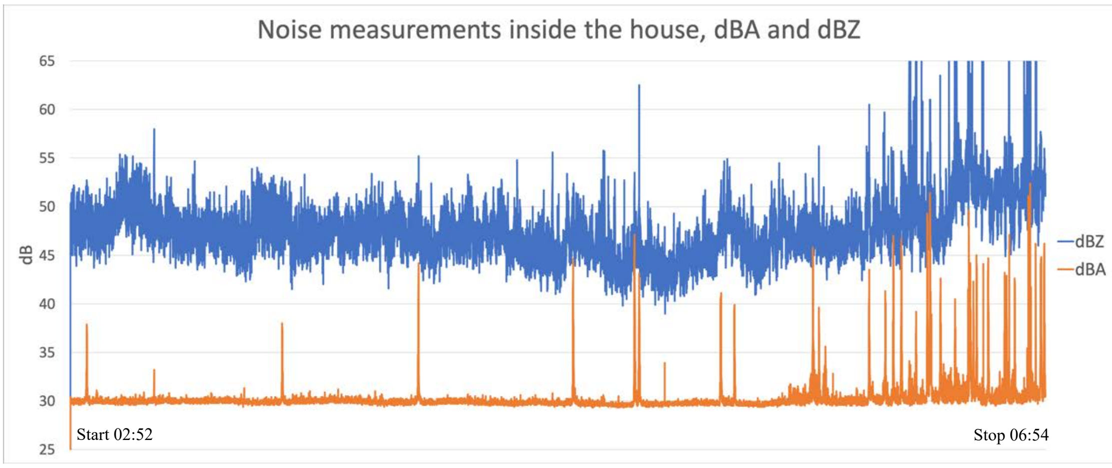


Figure 11. Wind Turbine Noise data collected during night time inside the dwelling, in one of the bedrooms, typically used for visitors.

3.4 Weather station

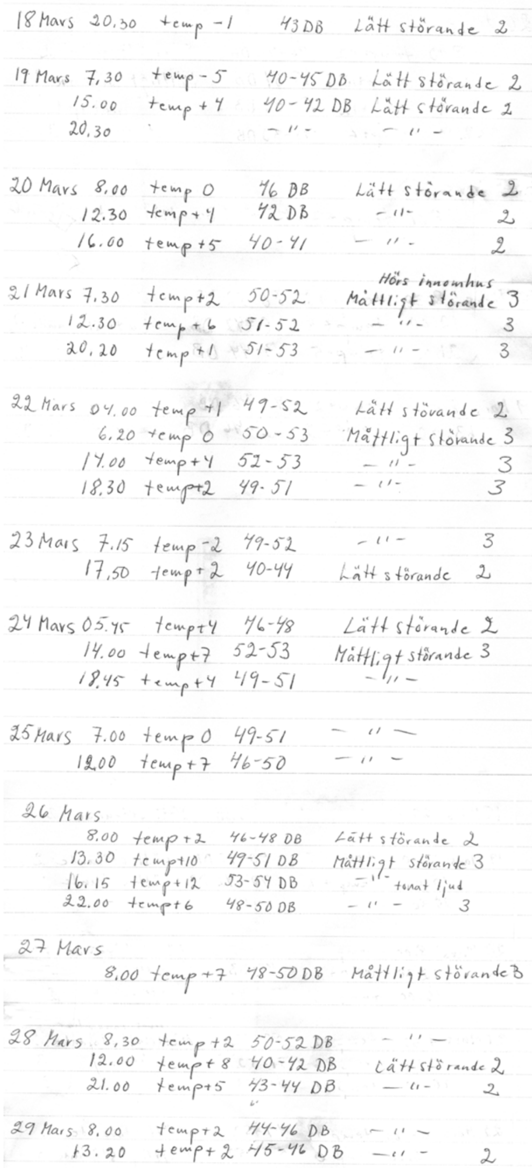
An Oregon WMR88 weather station was located at the boundary of the lot. Temperature was also recorded by the house owner. With the help of a computer, the information was stored and a small "data center" was established in the bedroom, with location to the west. Data has been stored and transferred as Excel files to a PC daily.

Figure 12. Location of the weather station in an open area, west of the house.

The weather can affect the extent of the sound exposure and how the noise of the four wind turbines interacts on the property. However, there is nothing in the statutory noise requirements that refer to "weather situation" and the turbine operator has to relate to the maximum possible noise impact that can occur during the worst weather conditions. However, the long-term measurements show that it is an overexposure during basically the entire time that the measurement was carried out (March 18 - March 29) and the two meters (west and east) have coherent results. The western side has a greater exposure since the wind usually comes from the west according to SMHI (The Swedish Meteorological and Hydrological Institute).

3.5 Documentation by the owners

The house owners have documented their own experiences of the sound exposure during the period 18 March - 29 March, and also documented the readings they made on the sound level meters at this time. This report complements the more detailed measurements and shows large exceedances and disturbing noise from the wind turbines.



18 Mars	20.30	temp -1	43 DB	Lätt störande	2
19 Mars	7.30	temp -5	40-45 DB	Lätt störande	2
	15.00	temp +4	40-42 DB	Lätt störande	2
	20.30		— " —	— " —	
20 Mars	8.00	temp 0	46 DB	Lätt störande	2
	12.30	temp+4	42 DB	— " —	2
	16.00	temp+5	40-41	— " —	2
				Hörs inomhus	
21 Mars	7.30	temp+2	50-52	Måttligt störande	3
	12.30	temp+6	51-52	— " —	3
	20.20	temp+1	51-53	— " —	3
22 Mars	04.00	temp+1	49-52	Lätt störande	2
	6.20	temp 0	50-53	Måttligt störande	3
	17.00	temp+4	52-53	— " —	3
	18.30	temp+2	49-51	— " —	3
23 Mars	7.15	temp -2	49-52	— " —	3
	17.50	temp+2	40-44	Lätt störande	2
24 Mars	05.45	temp+4	46-48	Lätt störande	2
	14.00	temp+7	52-53	Måttligt störande	3
	18.45	temp+4	49-51	— " —	
25 Mars	7.00	temp 0	49-51	— " —	
	12.00	temp+7	46-50	— " —	
26 Mars					
	8.00	temp+2	46-48 DB	Lätt störande	2
	13.30	temp+10	49-51 DB	Måttligt störande	3
	16.15	temp+12	53-54 DB	— " — tonat ljud	
	22.00	temp+6	48-50 DB	— " —	3
27 Mars					
	8.00	temp+7	48-50 DB	Måttligt störande	3
28 Mars	8.30	temp+2	50-52 DB	— " —	
	12.00	temp+8	40-42 DB	Lätt störande	2
	21.00	temp+5	43-44 DB	— " —	2
29 Mars	8.00	temp+2	44-46 DB	— " —	
	13.20	temp+2	45-46 DB	— " —	2

Figure 13. Copy of the notes that the house owners have performed during the measurement period, including their "annoyance level".

The owners also recorded temperature and their experienced annoyance level. This report complements the more detailed measurements. Their documentation has been done according to: Bertil Persson, "Form for disturbance in wind turbines," according to ICBEN and according to Rohrmann, [3]. Sweden does not acknowledge this as "valid documentation," as described in the court decision, [19]. Despite the massive documentation and their own documentation, the court has decided that there is no wind turbine noise above 40 dBA at the property. However, a wind turbine installation next to the one in questions went into bankruptcy and the CEO then confessed in media that they had been lying about the sound levels, [18]. The court decision cannot be appealed.

3.4 Comments in regard to wind contamination

The MMÖD court (Supreme Court, Court of Appeal) has decided that it is not possible to make measurements since when the wind turbine is operating, it is windy. In the court decision from 2017, MMÖD also claims 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. 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 wind contamination that has impacted the data, if using proper weather protection. When using double protection, it is even better.

4. CONCLUSIONS

A measurement series have been performed in Småland, Sweden, where four wind turbines have been placed in proximity to a house. Hence, the owners have had to live with a disturbed life and despite multiple complaints, nothing has been done. A larger measurement series was performed, documenting sound levels for almost two weeks, including weather data. The measurement data show amplitude exceedances. Despite that, in a high court decision (MMÖD, Supreme Court), 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 simulations (road traffic sound calculation model Soundplan 7, but here called Nord2000) that can be used as the foundation for sound levels. These calculations can only be performed by the wind turbine company's experts, [19]. These, experts, always arrive at 39.5 or 39.8 dB and they claim that it is impossible that sound data collected by measurements can be right. They never report any confidence interval or uncertainty since calculations are "always right".

Knowledge is evidently lacking in regard to sound measurements in windy conditions, amongst the cohort of certified and authorized companies and teams that the wind turbine industry uses. The MMÖD Supreme court also claims that if you are not a certified body by the Swedish authorities, the measurement cannot be valid. In order to be certified, you typically need to be part of the companies that have huge wind turbine contracts and then, there is no financial interest to show that that wind turbines are more noisy than they claim. However, 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.

This paper show clearly that the sound levels are above the legal limit. The data has been collected using professional equipment and expert sound engineers, with multiple methods for validation and error checking. The end result is that theoretical predictions (by the wind turbine owners and their experts) and measurements performed at the house location are in clear contrast to each other. The court believes calculations since they have no variance and hence must be trusted. Hence, the dwelling owners lose in court, despite clear evidence.

5. 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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