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A history of wind turbine noise regulations in the Netherlands

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Summary

The first professional guidance in the Netherlands for wind turbine noise assessment appeared in 1984 in the journal Geluid & Omgeving (Sound & Environment). The authors stated as a 'well-known fact' that most complaints occurred at times of warm weather and low (near ground) wind speeds when people were outdoors often or slept with open windows. Nevertheless it became customary to calculate wind turbine noise over a wide range of wind speeds and compare that to measured environmental noise levels (without wind turbine sound). The background sound measurements were made obsolete when the Ministry of the Environment introduced a fixed curve for sound level versus wind speed that represented a standard background level. In the last decade it became clear that wind speed near the ground was not a good predictor of wind turbine performance, especially not at night. In the present regulations a single limit is set for the long term averaged wind turbine sound level at a receiver, using the long term wind speed distribution at ground level. It look like most complaints still occur at warm summer evenings.

1. Introduction

In 1984 Geluid & Omgeving (Sound & Environment) was established as a journal mainly for professionals in environmental noise issues. It was only a few years after the Dutch Noise Act was published and the aim of the journal was to provide a platform for information and discussion for acoustic consultants, officials from all layers of government, researchers and others dealing with noise issues. The 30th year of publication was commemorated with an article in each issue of the quarterly magazine, addressing one of the articles published in the first year. One of these first articles was "Noise annoyance and windmills – Regulate or ignore windmill sound?" (of course it was in Dutch: "Geluidhinder en windmolens – Windmolengeluid reguleren of negeren?"), written by Van der Veen and Kok who then worked at a provincial authority.Wind turbine noise was a minor topic at that time, attracting little attention in contrast to the last decade. But the topic was gathering momentum in the early '80s after the '70s energy crises and the political wish to be less dependent on oil countries and exhaustible resources.

This paper is an English adaptation of my contribution to the jubilee of the journal now named Geluid (Sound) and titled "Windmolenhinder 30 jaar later" (""Windmill annoyance 30 years later") The name windmolen (windmill) is used for the historical constructions providing mechanical energy and wind turbine has become the more common name for an electricity generator -though windmill is still used to denote a wind turbine.

2. The take-off

In the mid-80s wind turbines were modest in size, measuring up to 20 or 30 m and producing up to perhaps 50 kW electrical power. The constant speed wind turbine was more usual then, followed up by a two speed turbine that was more efficient because of the optimization at two wind speeds instead of one. In the end the variable speed turbine was the most efficient, although this turbine also sheds efficiency at high wind speeds when the generator is at maximum power.

One of the directions in development was to reduce the number of blades to allow for higher speeds of revolution to simplify transmission (with a gearbox) to the generator. In the end this led to single blade wind turbines. Apart from mechanical problems a high tip speed of course leads to a higher noise level.

Early on it seemed logical to put the rotor behind the tower because it allowed the turbine to right itself: the wind would always push the rotor in the downwind direction. The change in blade load, when a blade passed behind the tower, proved to be a distinct disadvantage as it caused mechanical fatigue. Already in the '80s larger wind turbines were being developed. In 1983 in Germany the giant GROWIAN (Grosse Windanlage or Big wind generator) was erected: a test turbine with two 50 m blades meant to generate 3 MW. It was a complete failure, in part due to the downwind rotor construction and the associated variation in blade load . But perhaps the failure was also a consequence of non-commitment; the minister in charge said the test was done "so as to prove to wind energy proponents that it could not work". Apart from the mechanical problems a downwind rotor also produced sound pulses at blade passing frequency leading to complaints from residents. Downwind rotors were not developed further. Although other designs (such as vertical axis or small wind turbines) still exist, in the end they proved to be no match to the present triumph of technology, the three bladed, upwind, horizontal axis wind turbine.

Figure 1: early wind turbines; the Dutch 80 kW Lagerwey (left), the American test turbine 200 kW MOD-0A (middle) and the German 3 MW GROWIAN (right)

3. The 80s: the first Dutch wind turbine noise assessment

In the mid-80s wind turbine sound data were not readily available. 20 years later I found that it was still a problem to obtain sound power data of the older, smaller wind turbines that were present in the Netherlands. Spectral data were course even less available. Van der Veen and Kok mention sound power levels ranging from 95 dB(A) up to 105-110 dB(A) (as loud as a modern MW-turbine!).

Because of the constant speed, sound power level was relatively constant over a range of wind speeds. This made it easier to deal with a general requirement that applied to all industrial sources: sound measurements had to be performed at wind speeds not exceeding 5 m/s, so formally reliable data could only be obtained at wind speeds up to 5 m/s. However, Van der Veen and Kok also stated as a “well known fact” that “most complaints by far occur at warm weather and low wind speeds because that is when people stay outdoors and sleep with their windows open”. Therefore, it was sufficient to calculate receiver sound levels at 5 m/s wind speed and use these as the relevant exposure. At that time a near ground wind speed, anything between 2 and 10 m height, was implied and the vertical wind gradient was not considered relevant yet.

According to regulations for industrial noise at that time the limit for the average façade level at dwellings in the countryside, where wind turbines typically were erected, was 30 dB(A) at night. Van der Veen and Kok thought that for wind turbines this could be less severe and they mention that exceeding the limit up to 5 dB was “undoubtedly acceptable” so they advised an acceptable night time limit of 35 dB(A). This finally resulted in the recommendation to put a wind turbine at least 300 m from countryside dwelling. If wind turbines were put up near a ‘quiet residential area’ they advised 150 m (based on 40 dB(A)) and for an ‘urban residential area’ 100 m (45 dB(A)). To prevent noise components leading to added annoyance, they advised to make an assessment in each individual case of notable tonal noise from the gearbox or blade irregularities.

All this applied to a single wind turbine as wind farms were yet to appear in the Netherlands. The general view at that time was that wind turbine sound ought to be less loud than the existing ambient sound. Van der Veen and Kok were practical and preferred simplicity in noise assessment when justified: no more details in data then necessary for a professional assessment. They did not foresee the detailed acoustic characterization that is now common. However, they did see ominous signs from abroad concerning “very large wind turbines (rotor diameters above 25 m)”, probably referring to the MW downwind turbines that were then tested in several countries: “the scant information urges us to be aware of noise problems to be expected from these turbines”.

4. The 90s: growing numbers

In the 90s more and bigger wind turbines were erected in the Netherlands. With the lack of specific legal guidance an approach evolved from practice. At the end of the 90s it was generally accepted in the Netherlands that the limit was the existing ambient background. ‘Background’ according to Dutch guidance on background sound measurements when assessing the impact of industrial noise, implied the A-weighted 95-percentile sound level (L_{A95}) of all sound present -without the source to be assessed. The sound power levels of variable speed turbines, that became ever more common, strongly depended on wind speed over the range of moderate and strong wind speeds. As wind related background levels also increased with wind speed it seemed logical that both background level and wind turbine receiver level should be determined at every wind speed. To accomplish this, L_{A95} was measured at a location representative for one or more receivers over a one or two week period in 5 or 10 minute time slots. The L_{A95} values were collected in narrow wind speed ranges, usually 1 m/s wide, measured at 10 m height as customary in meteorology.

The measurements were preferably done in winter, when deciduous trees and shrubs were leafless. This was based on the idea that added ambient sound at high wind speeds was mostly due to rustling vegetation and winter would thus be a quieter period. Wind speeds exceeding 12 m/s were usually not included because such wind speeds did not occur often (and thus did often not show up in a sufficient number of data points) whereas wind turbine sound power did not further increase. In contrast to Van der Veen and Kok’s emphasis on a relatively low wind speed (5 m/s) high wind speeds were considered important, probably because they were related to the highest turbine sound levels. When the measurements

showed that the corresponding background sound levels were even higher, the highest wind turbine sound levels did not really constitute a problem. Of course this was a welcome (but wrong) insight for wind farm developers.

Although acoustic consultants did a lot of noise assessments, it was not always clear what the assessment results meant in the real world. Several issues were not really solved or even discussed. One of these was the influence of wind direction, which was usually not analysed separately. E.g., L_{A95} levels from one direction with a highway, were averaged with levels from the opposite direction that could be much quieter. Also seasonal variations in sound production and propagation were disregarded. Another issue was wind induced noise on the microphone which was not separated from real sound caused by wind in vegetation. With a microphone at 1.5 up up to 4 m height, L_{A95} values contained unknown and disregarded amounts of microphone noise.
One of the rare occasions that a measurement issue was discussed (in the December 1998 issue of the journal Geluid) was the way L_{A95} values in a wind speed bin were aggregated in a single value. It was proposed to measure L_{A95} in very short, 5 second intervals. The agreed procedure was to determine a best polynomial fit based on the L_{A95} data points. Figure 2 gives an example for a case in the UK (hence the 10 minute L_{A90} values). The result is not the long term L_{A95}, but the best estimate for the expected short term (5/10 minute) value. The difference between both is that over a longer period of time, L_{A95} may be very different from the short term average. This is certainly the case when 5 s periods are chosen. The author in fact acknowledged this, by stating the short periods 'prevented the L_{A95} level from being determined by short periods with a low background sound level". Figure 3 illustrates some results: there are prolonged periods (such as the first days in figure 4) when the 10 minute background sound level is higher than the best fit or average value. But there are also periods (those with the red dots) when most of the actual $L_{A90,10min}$ values are below the average.

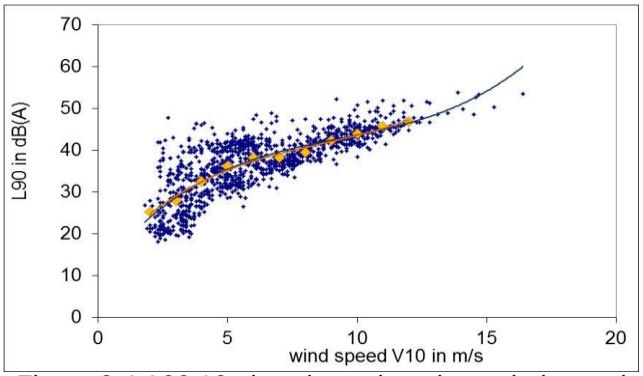

Figure 2: LA90,10min values plotted vs. wind speed (small blue dots) and arithmetic average of these values per bin of 1 m/s (larger yellow dots); lines are best third power polynomial fits

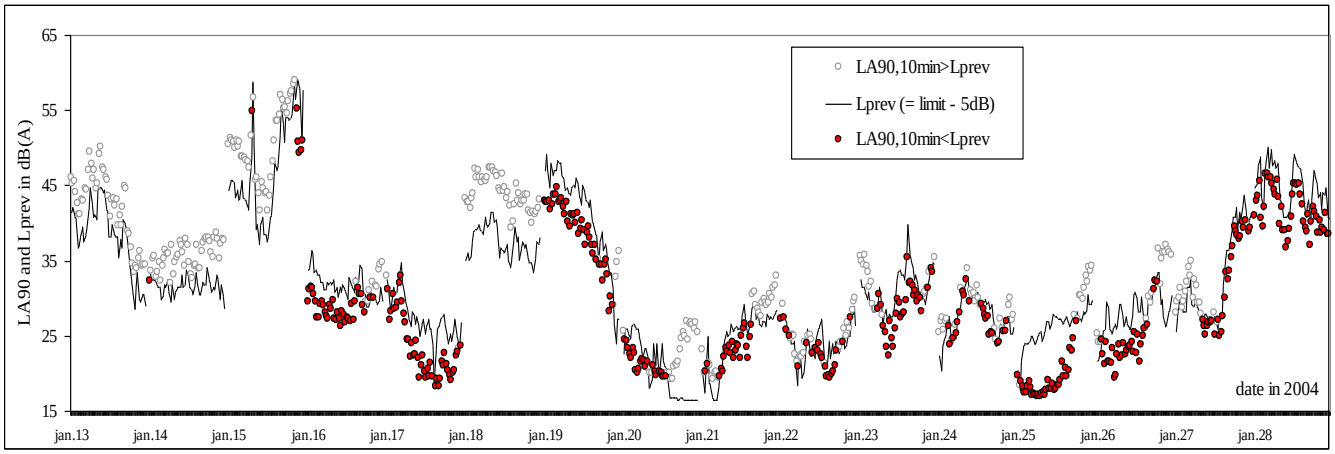

Figure 3: $L_{A90,10min}$ above (open grey dots) and below (filled dots) average background sound level obtained from 'best fit'; line is estimated $L_{A90,10min}$ based on wind speed at time of measurement

5. The ‘00s: legal regulations

The Ministry of the Environment in 2001 made background sound measurements for wind developments obsolete by introducing the WindNormCurve (WNC; ‘Wind Standard Curve’), a stylized representation of measured background sound levels at increasing wind speed. The WNC was a wind speed dependent limit value, built from two elements:

1. A fixed threshold of 40 dB(A) at low wind speeds and

2. A variable limit increasing from 40 dBA at 2 m/s V10 (wind speed at 10 m height) up to 50 dBA at 12 m/s V10.

It was implied, though not clearly stated, that this was applied to ‘the’ wind turbine sound receiver level. It was understood by consultants this was the level calculated from the manufacturer’s specifications at every wind speed, although maximum levels or average levels plus one standard deviation could have been possible candidates. It was also understood that the WNC should be valid at any diurnal period, including the night as most sensitive period.

The threshold level was higher than the limit proposed by Van der Veen and Kok (35 dBA for the night time period). At their representative wind speed (5 m/s) the WNC limit was 42 dB(A). As shown in a fairly typical example in figure 4, the assessment procedure often showed sound levels at about 6 m/s V10 were closest to the WNC and thus most critical. When later it was shown that the hub height wind speeds related to 6 m/s V10 could occur at 2 m/s V10 in a night with a stable atmosphere, this seems to echo the 1984 observation: “most complaints by far occur at warm weather and low wind speeds ….”.

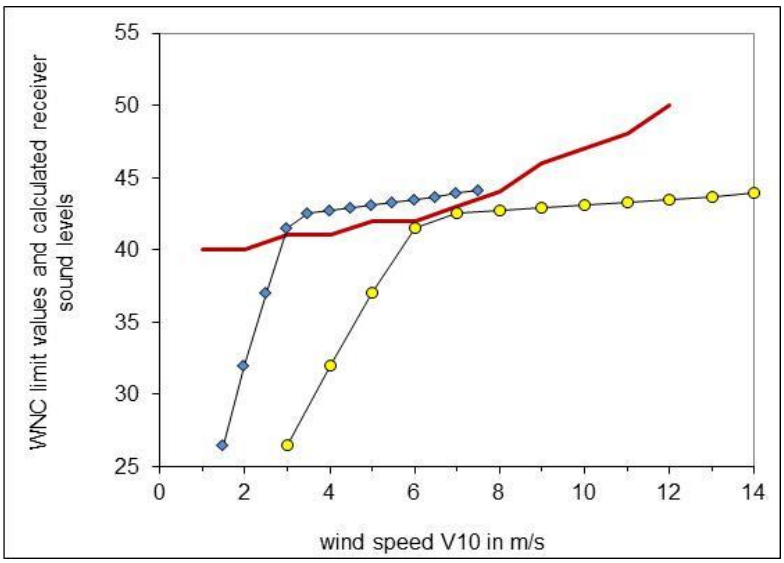

Figure 4: receiver level of a wind turbine in a neutral (yellow markers) and very stable atmosphere (blue markers), compared to the WNC limit curve (red line)

One of the reasons for the choice of the WNC limit value was to leave sufficient space for wind energy development: choosing a lower limit would imply more distance to dwellings. At that time tonal sound from the gearbox was effectively reduced and there was a general belief, professed by developers and consultants, that wind turbine sound was relatively soft and without specific characteristics and therefore hardly annoying. It was sometimes presented as almost benign, “like a rustling brook”. Based on calculated sound levels, I shared the opinion then that the sound of a wind turbine was only an issue within at most 400 m from the turbine. At around the year 2000 I tried to check when a turbine became audible every time I was close to a turbine and it was within 300 to 400 m. I could not understand rumours that wind turbines could be audible up to several kilometers. The penny dropped only when a resident told me that on calm summer evenings he sometimes sat in his garden with a big wind turbine nearby

rotating at full speed. Of course, I thought, in a stable atmosphere there are big vertical differences in wind speed. I had lectured this in a course! A stable atmosphere originates at sundown when the wind is not too strong and the ground cools under a sufficiently clear sky. The important thing is that at higher altitudes the wind keep on blowing, often even stronger, while the wind at ground level abates. I thought immediately that this could explain why complaints arose mostly at evening and night time. And it also could explain how wind turbines could be audible at larger distances: most other sounds abate at night and thus had less masking potential.

It took a few years before the penny dropped in the heads of most acoustic consultants. Or perhaps they saw it earlier but they felt they had to protect their clients rather than residents. The regulations were changed in 2010 and are based on hub height wind speeds without any reference to ambient background sound. From then on it seemed as if big consultancies had always known the atmosphere changes at night and of course the hub height wind speed is the relevant wind speed. Long-term averaged receiver levels are now calculated from the distribution of wind speeds at hub height at the location of the wind turbine, separately for the three diurnal periods. The result has to comply with the limit of 47 dB L_{den}. It also has to comply with a separate night time limit of 41 dB L_{night}, but for a free running wind turbine (no stopping or low noise mode) in the Dutch wind climate both limits in practice are equivalent. In the preparations for the new regulations the National Institute for Public Health and the Environment (RIVM) investigated the onshore area available to wind farm developments depending on the height of the noise limit. Based upon survey results, RIVM proposed a preferred limit of 40 dB L_{den}, reflecting a low level of noise annoyance. (in Dutch noise legislation there is for the main noise sources a preferred limit and a higher maximum allowable limit). For a wind turbine operating without restrictions 40 dB L_{den} corresponds to 34 dB L_{night}, so this would be very close to the limit proposed in 1984. However, the 47 dB L_{den} and 41 dB L_{night} were chosen as the legal limits, which was in practice nearly equivalent to the WNC limit for unrestricted, free running wind turbines.

6. The present

Onshore wind energy developments now include turbines of several MW and hub heights up to 120 m with blade lengths up to 60 m on top of that and we are not at the end of this development. After about 35 years large machines like the 2 MW American MOD-2 or the 3 MW GROWIAN have become almost standard (but now with an upwind orientation) and 10 MW machines are the next generation. Due to their size they do not blend in with the landscape, but dominate it. The impact on landscape is (still) the first and most important objection coming from residents. Sound is the next and it seems to be gaining weight because of the fear (strategically kindled by wind farm opponents) it will cause serious health effects.

Wind turbine noise has become a far more complex issue than anticipated in the early days. It is not a soft, rustling sound, but in contrast a swishing/beating, relatively annoying sound. It has to do with place attachment, with being taken seriously, with energy policy and dependable authorities, with fear and maybe with habituation. We will need (more) acoustical knowledge but this will not solve the problems; non-acoustical factors dominate the debate. In the Netherlands there is now an attempt to involve all stakeholders, including residents and their representatives, to find common ground as a basis for measures and procedures to guide further developments.

Acknowledgment

The Lagerwey picture in Figure 1 is from the website www.wind-turbine-models.com, the others from an “Illustrated history of wind power development” (www.telosnet.com/wind/govprog.html).