Wind turbine noise: practical immission measurements

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ABSTRACT

For 15 years the number of wind turbines installed in Europe has increased rapidly. In this framework many objections are expressed towards the sound emitted during the Wind Turbine (WT) working and its perception as a noise in the direct neighbourhood. The noise is due to aerodynamic interactions with the blades of WTs. After its propagation over several hundred meters, the noise is more or less stationary but can feature an amplitude modulation that can be very annoying for the human hearing. To understand the physical causes of this potential annoyance, some noise measurements were carried out. A lot of care is necessary to have relevant recordings of the WT noise. The measurement precautions are explained as well as the data processing to avoid the periods with a dominant background noise. Finally some results of measurement campaigns are exposed.

Keywords: Wind Turbine, Immission I-INCE Classification of Subjects Numbers: 14.5.4, 68.1

1. INTRODUCTION

A WT is a renewable device producing electricity with the help of wind. As Europe voted the 20 – 20 – 20 goal (decrease greenhouse gases by 20 %, enhancement of energy efficiency by 20 % and 20 % of utilized energy has to be renewable), wind farms are seen as one of the alternative source of electricity. For 15 years the wind energy production capacity in Europe has increased by four (1) as shown in Figure 1.

Year after year, WTs were constructed in places where high speed wind blew sufficiently like on the top of a hill or in the sea. With experience the constructors have improve their efficiency but also their size. So the development of a new WT project is currently often criticized. It can be about the hazard for birds, the devaluation of ground prices or also the changes in the landscape. Another important criticism concerns the sound emitted while the WTs rotate. This sound is a noise since unwanted by people living in the neighborhood but also by the constructors whose it is not their aim.

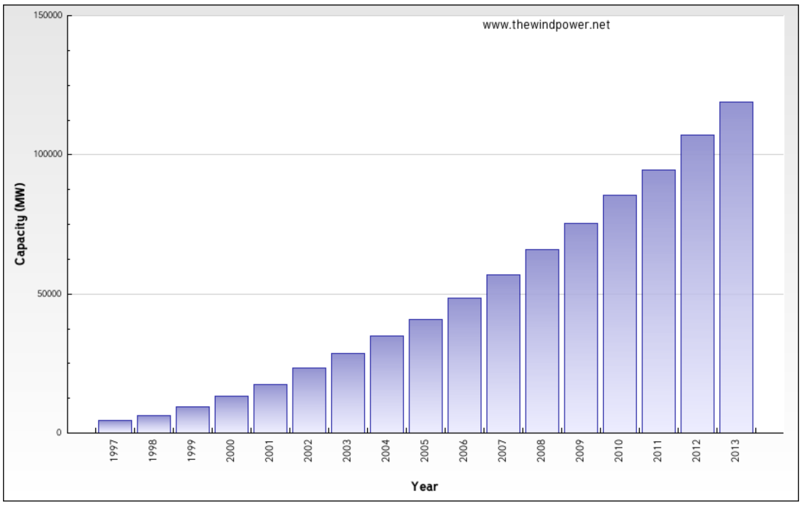

Figure 1: Evolution over the years of the wind energy production capacity in Europe (1)

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The WT noise is due principally to the interaction of blades with the wind. Many phenomena happen and depend on the wind speed, its gradients and eddies, and on the blade form and its completion. The most important noise sources are the trailing edge noise, the inflow turbulence noise and the tip noise (2). Globally, the WT noise is a broadband noise for which the sound power level L_W is higher than 95 dB(A) according to the wind speed and for high power WTs (> 1 MW). If we consider self-oriented WT, the emission is less important in the crosswind directions with regard to the upwind and downwind directions. Due to the directivity of the trailing edge noise and the Doppler amplification, an amplitude modulation can be detected near a wind turbine.

The WT noise propagates in the space and comes into the neighborhood where people can be present. After hundred meters of propagation, the sound pressure level L_p is low enough to avoid direct impact on human's ear but an annoyance can be developed leading to psychological distress and sleep disturbances (3). The annoyance is firstly correlated to the noise but also to others non-acoustical factors (see for example Review (4)).

The impact of a noise at a reception place is the immission of this noise. The immission measurements are important to understand why some people are annoyed by the WT noise and how it modifies their soundscape. At several hundred meters from a WT, measurements have to be made with a lot of care in order to have relevant results.

2. WT NOISE IMMISSION

2.1 WT noise

After emission, the noise coming from a WT is modified in its characteristics by propagation phenomena: geometrical divergence, atmospheric absorption, ground effect and turbulence diffusion principally. As a result, the noise has an average L_p (≤ 50 dB(A) near a house in the neighborhood) with a high-frequency attenuation and an amplitude modulation not always heard[2]. It greatly depends on the atmospheric conditions and especially on the wind direction and speed:

- at low speeds the WTs rotate barely, L_W is low and the background noise should be higher;
- at medium speeds comprised in the interval [4; 8] m/s referenced at 10 m high, the WT noise can be dominant due to a faster rotation and a wind not too high on ground (5);
- at higher speeds the WTs do not rotate faster after reaching their optimal speed whereas the background noise becomes more important.

Even if the WT noise is recorded when the second condition is met, it is absolutely not obvious that measurements will give the WT noise. The background noise can be the most important.

2.2 Background noise and wind-equipment noise

The background noise is defined as the noise at the receiving point when the WTs do not influence. The meaning is double: either the WTs do not rotate or they are not perceptible. The background noise can be subjectively separated in two groups.

The first group includes noises coming from human activities like means of transport (cars, trains, airplanes), places of specific activity (farms, industrial sites, parks) and neighbourhood noises. These noise sources change a lot with daytime and night time.

The second group contains the "natural" noises like thunder, rain or braking waves; but also animal noises (birds, dogs, cattle, frogs). When the wind blows strong it interacts with any solid object: the roof of a house, a park car but also the vegetation. This last one plays a particular part because wind farms are very often constructed in the countryside. WT noise exists only if there is wind so that vegetation noise will be almost always present.

Noises are also produced by the interaction of wind turbulences and microphone. These noises are always present even if a windscreen is installed on its microphone, but are reduced. If the wind blows stronger a correction can be applied to take these effects into account (see (2, 7)). If the wind-equipment noises are too high, the measurements have to be moved aside.

[2] the amplitude modulation can be heard again to when two or more WTs are synchronized with regards to the reception point or according to special atmospheric conditions

2.3 Measurements

In the framework of the WT noise immission measurements, it is important to carry out recordings of the WT noise near houses placed in the direct vicinity of a WT. The distance can be very small (300 m) or large (> 1 km). To have a relevant recording of the situation, with different wind speed or other atmospheric conditions, it is necessary to leave the instruments more than one week at the reception point. Why?

The wind has to blow but not too strong. A whole day of no wind or too-strong-wind condition is not unusual. Besides, two days of rain can disrupt or hide the WT noise, the clear days in summer are appreciated by birds, a change in the direction of wind and the noise from a motorway two kilometers away becomes dominant, etc.

Two instruments are desirable to carry out this kind of measurement: a sound level meter and a meteorological station. This last records wind speed, wind direction, temperature and other atmospheric data. The sound level meter has to provide different sound levels (equivalent with an integration time short enough to highlight the amplitude modulation, statistical levels), A-weighted or not, with the spectrum details (third-octave-band decomposition or FFT). A low-quality audio recording is recommended to listen to special events. The sound level meter has to be equipped with an “outdoor device” against the rain and the wind. For strong winds, both instruments have to be tied up. Their memory cards and batteries should be large enough to prevent too frequent operator’s intervention. The recording place has to be isolated or in a private propriety to avoid damages or thefts. The microphone does not have to be too close of solid vertical surfaces and too close of high density vegetation to avoid respectively secondary reflections and too vegetation noises. The picture in Figure 2 shows the instruments installed for a short measurement campaign of two weeks.

After a couple of weeks, a large collection of data is available and it is necessary to extract the pieces of interesting information: the WT noise.

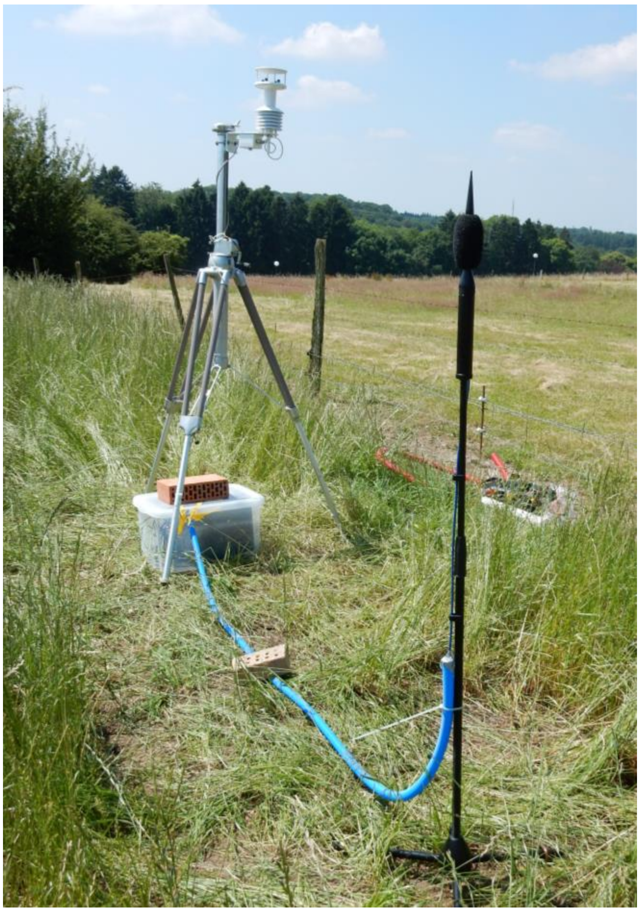

Figure 2: Installation of a sound level meter and a meteorological station for two weeks outdoor measurements

3. DATA PROCESSING

To reduce the quantity of data, it is common to analyse by 10 minute steps (2, 5, 8). It is not an obligation (see for example (9)) but experience of people working on the subject reveals that is a relevant value. Besides wind turbine data, like wind speed at hub height or rotation speed, are often given every 10 minutes. Based on the meteorological data and sound pressure level L_p and its third-octave-band spectrum, several simple and automatic analyses can be carried out:

- Loud events like close passages of train or car, a barking dog near the microphone or also a real shower exceed a level well higher than the WT level. Beyond 600 m, 60 dB(A) is reasonably forecast as a level never reached by the WT noise. If it is the case, the period is removed.
- During good weather, birds particularly sing in the early morning. The main contributions are situated above 1 kHz. High levels in these frequencies can be a removal criterion.
- For every 10 minute period it is possible to calculate the correction to take into account the contribution of the wind-equipment noise as noted before. The correction is determined from the wind speed and the diameter of the windscreen.
- If the wind speed on ground is higher than 5 m/s, the vegetation noise and the wind-equipment noise are too important. All third-octave-bands are saturated and the period can be removed.

After that, if too long parts are detected on 10 minute period, the whole period should be removed.

Unfortunately, even if other conditions are added, it is not sufficient to detect all periods with dominant background noise and to highlight the WT noise. Short events like distant cars or airplanes have a similar spectrum and not exceed the thresholds fixed for the sound pressure level. But similar does not mean identical. A distant road with many cars can give a L_p rather stationary with time as the WT noise but with a spectrum often slightly shift towards the high frequencies. The airplane noise, often used to describe the WT noise in absence of amplitude modulation, have not the same duration as the WT noise which can last several hours. Nevertheless the automatic detection is far to be easy to implement. Manual analysis has to be performed.

The manual detection is based on the observation of the L_p and its spectrum in parallel with the listening of the audio recording. It is a time-consuming work to review several weeks of measurement despite the preliminary processing. What else is necessary to do? Short events have to be removed and long constant part to be listened to. First is easy but repetitive. Second is sensitive to the experience of the person who performs the analysis: Is the WT what I heard? Is it the only noise or the dominant noise? Is it a motorway noise or a wind noise? Fast and short audio samples taken by chance over a great time characterized by a constant L_p allow us to be on the right track. It is due to the constant pitch and timber of the WT noise unlike the motorway noise (different cars and trucks) or the vegetation noise (highly dependent on the ground wind and its gusts).

4. RESULTS

The results come from a measurement campaign carried out during February and March 2014 in the small village of Tourpes situated in the west of Belgium. At 1 km for the nearest WT of a wind farm containing nine 2 MW WTs, the instruments were placed in a private garden respecting the pieces of advice described in point 2. The data processing follows the process of point 3. An example of an automatic detection of wrong events are presented in Figure 3 where the equivalent A-weighted sound pressure level $L_{A,eq,T}$ (integration time T = 500 ms) is plotted on 25 minutes. The first set of peaks comes from a rooster. Then, it is respectively the passage of one train and two cars closed to the point of measurement. For all these events, it is a criterion on frequencies higher than 1 kHz that allowed the detection.

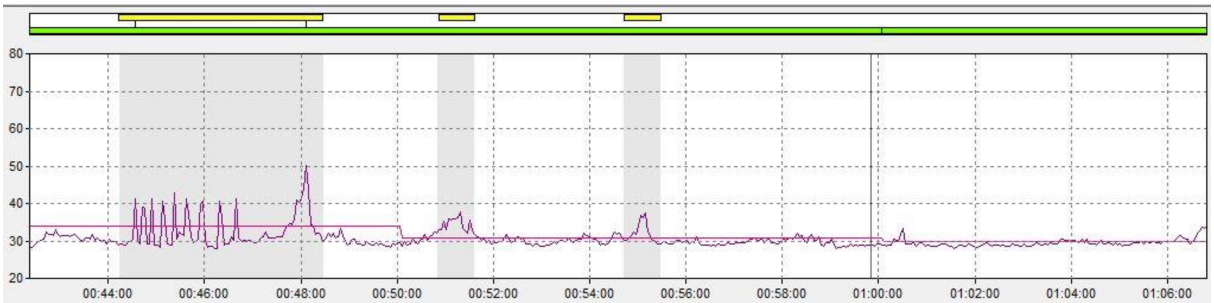

Figure 3: $L_{A,eq,T}$ in dB(A) according to time

The results shown below try to highlight the difficulties appearing during the measurement analysis, i.e. the events that are not automatically detected.

The $L_{A,eq,T}$ and its third-octave-band spectrum at one period in Figure 4 are the signature of WT noise. The $L_{A,eq,T}$ is relatively constant for half an hour. The spectrum is rather wide with a major contribution in the 400 Hz third-octave-band and the two or three before and after mainly. The total level is not perfectly constant with time for two reasons. On one hand the wind at hub height changes or an amplitude modulation can occur; on the other hand a vegetation noise is always present due to the wind and its gust on ground level.

If a distant motorway is added, it also leads to a constant $L_{A,eq,T}$ as the first graph in Figure 5 shows it for 10 minutes. But the spectrum is a little bit different: the motorway component is also wide but shifted towards the 800 Hz - 1 kHz bands. Despite an audio recording characterized by two close dominant noises, changes regularly happen regarding the pitch and the timber.

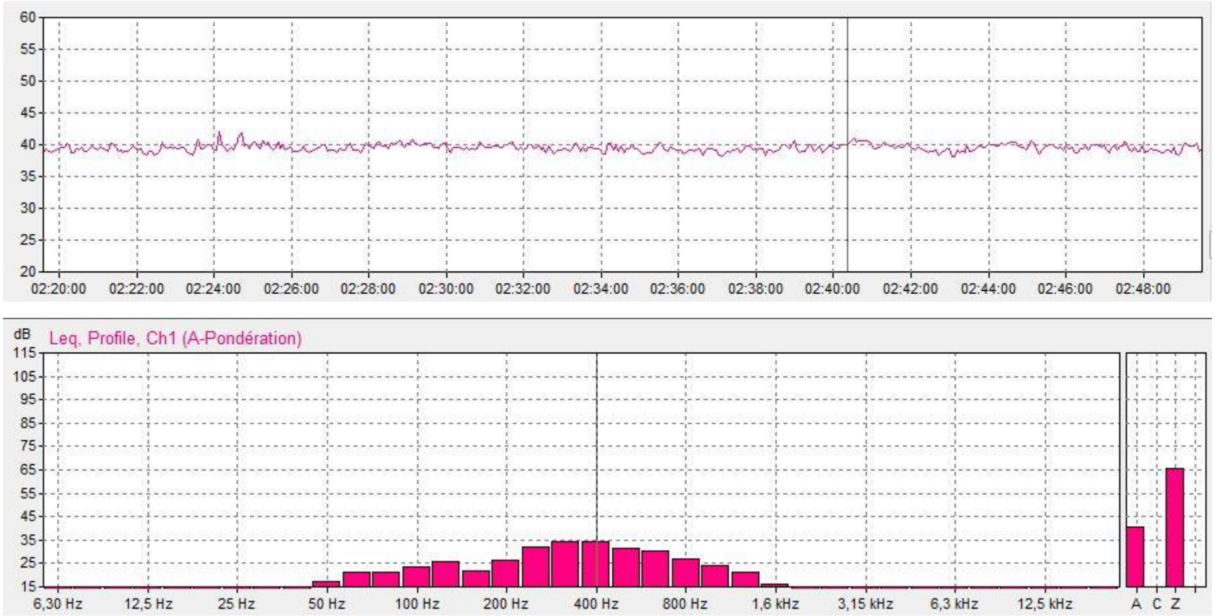

Figure 4: $L_{A,eq,T}$ of WTs (above) and its third-octave-band spectrum (under). Both are in dB(A)

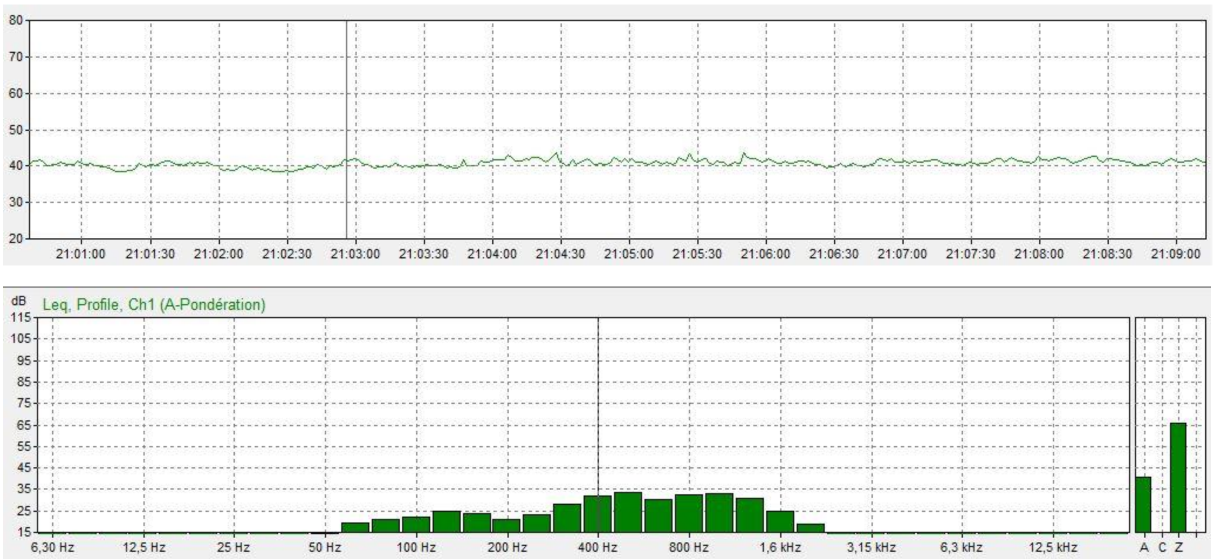

Figure 5: $L_{A,eq,T}$ of WTs and a distant motorway (above) and their third-octave-band spectrum (under) in dB(A)

Still more subtle, a distant airplane has the same spectrum as the WT noise. In this case, the total level increases during a finite time. But as it can be seen in Figure 6, the increase of $L_{A,eq,T}$ is low (the blue area). It is why a final integration time of 10 minutes is suggested in order to avoid a great influence of this kind of events if there are not detected.

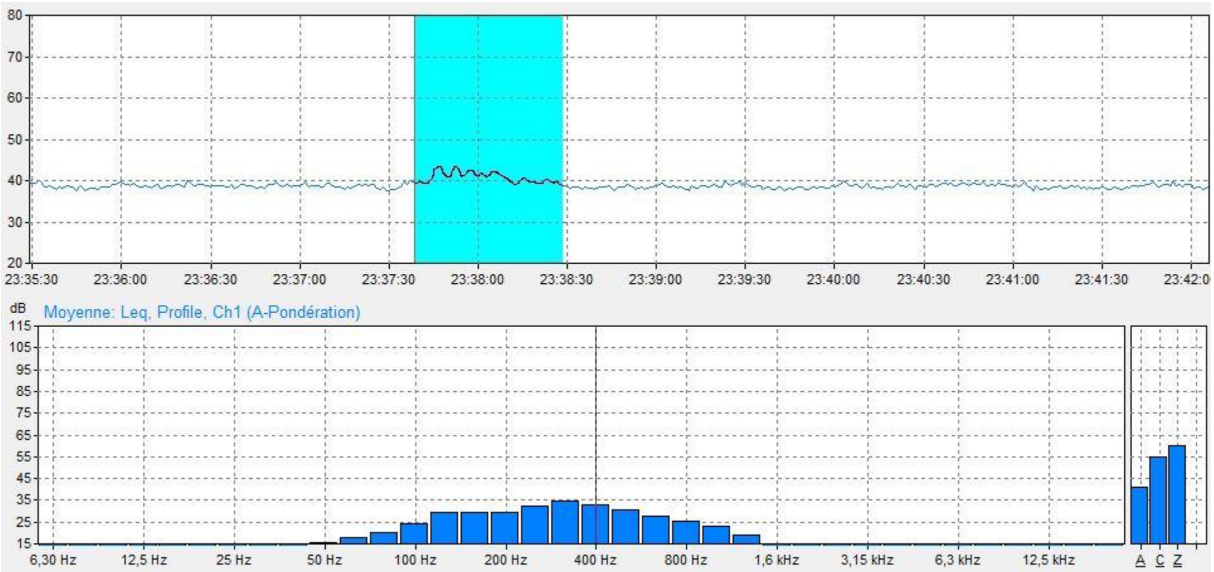

Figure 6: $L_{A,eq,T}$ of WTs and a distant airplane (above) and their third-octave-band spectrum (under) in dB(A)

5. FINAL REMARKS

A wind farm emits some noise that can be recorded. At several hundred meters, the sound levels are often close or below to the background noise which included different kinds of events. Some are easily detected, other are too close (according to time or frequencies) to the WT noise. Future development has to be carried out to improve the automatic detection of wrong events. A track could be the analysis of correlations between small samples of the audio recording. However the noise coming from the interaction between the wind and the environment will be almost always present when the WTs will rotate.

Finally, what is the impact of a wind farm distant of 1 km of a small village? In Figure 7, $L_{A,eq,T}$ and $L_{A,90}$ (often used to represent the back ground noise) values are calculated every 10 minutes over one day. Loud events are removed. The wind speed is closed to 0 m/s during the morning and after oscillates between 1.5 m/s and 2.2 m/s at microphone height. The beginning of the night does not present a decrease of sound levels. The levels are not excessively high but the background noise reaches no more the levels of a quiet night, which can be a source of annoyance.

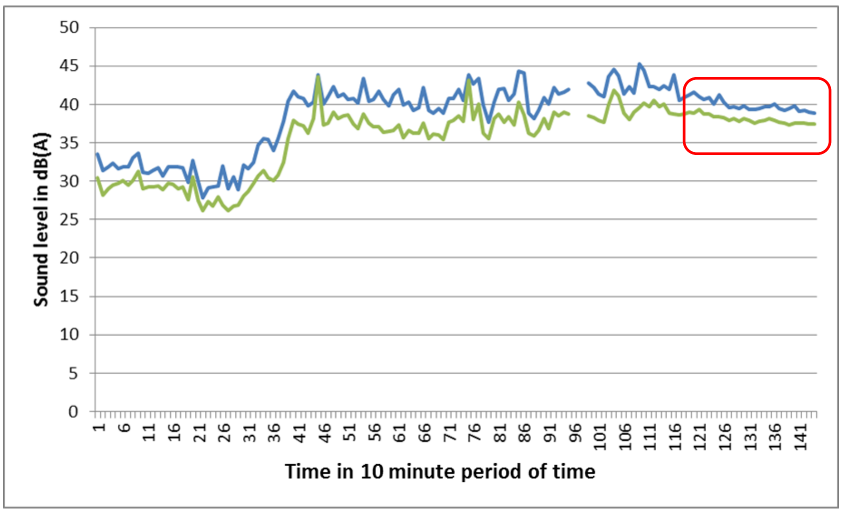

Figure 7: $L_{A,eq,T}$ and $L_{A,90}$ values plotted every 10 minutes for a whole day

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