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Outdoor to indoor reduction of wind farm noise for rural residences

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ABSTRACT

Compliance limits for wind farm noise are usually based on allowable outdoor levels. Since these limits are designed to protect the amenity of the people residing indoors, the outdoor to indoor noise reduction is an important consideration. World Health Organisation recommendations for outdoor noise are based on outdoor to indoor noise reductions for traffic noise. However, traffic noise is dominated by mid-frequency energy, whereas wind farm noise is dominated by low-frequency energy for which expected noise reductions are much less. This paper investigates typical noise reductions for residences near wind farms that are located in rural areas in Australia. It is found that during the night, when the wind farm is operating and the local wind speed is low, the A-weighted outdoor to indoor noise reductions with closed windows are less than 20 dB, which is at least 10 dB lower than the value generally assumed for traffic noise in urban areas. Furthermore, the C-weighted, G-weighted and low-frequency A-weighted (10 Hz – 160 Hz) noise reductions are lower still, indicating that A-weighted noise reduction values are not representative for noise dominated by low-frequencies. Outdoor to indoor noise reduction generally decreases with frequency, however, there are some variations to this trend which are related to housing construction. Structural resonances, room modes and coupling between the air volume inside the residence and the stiffness of the walls, roof and ceiling can contribute to reducing the noise reduction, sometimes to negative values. Below 2.5 Hz, the outdoor to indoor noise reduction is zero.

1. Introduction

Renewable energy has become an important investment as society moves towards reducing greenhouse gas emissions and securing future renewable energy supplies. Of the available technologies, wind energy has many advantages that include high efficiency, cost effectiveness, low emissions and availability. On the other hand, worldwide concerns have been raised about the potential for adverse health effects that arise as a result of long-term exposure to wind farm noise. To address these concerns, numerous countries have developed regulations to assess wind farm compliance. While the specific parameters for assessment vary between different countries and states and counties within the same country, noise limits are generally expressed as outdoor limits based on overall A-weighted values [1]. In a large number of cases, there are different noise limits for daytime versus night-time, where the latter are generally lower to account for reduced background noise levels as well as increased sensitivity to noise when people are trying to sleep.

To establish meaningful outdoor limits, it is necessary to determine acceptable levels of indoor noise as well as to make conservative assumptions on the attenuation properties of typical housing structures. Several guidelines for wind farm noise refer to recommendations specified by the World Health Organisation (WHO) [2–4]. According to the WHO guidelines [5,6], “if negative effects on sleep are to be avoided the equivalent sound pressure level should not exceed 30 dB(A) indoors for continuous noise.” The WHO night noise for Europe guidelines [6] also specify that typical noise reductions for European houses are 15 dB with windows open and 30 dB with windows closed. These guidelines refer to traffic noise, where the noise source is relatively continuous and the frequency content is predominantly mid-frequency. WHO [5] recommends that special attention should be given to cases where the noise source contains low-frequency components and where the background levels are low and that in such cases, sleep disturbance may occur for noise levels below 30 dB(A). It is also anticipated that the noise reduction from outdoors to indoors would be less when the spectra are dominated by low-frequency components.

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Despite meeting the relevant compliance criteria, wind farms continue to invoke adverse community response in a large number of areas worldwide. Many residents who live near wind farms report annoyance even when the measured noise levels are relatively low. One reason for this is that wind turbines are often located in rural areas where background noise levels are very low, particularly at night time. The contrast between ambient noise and noise due to wind farm operation is further exacerbated during the evening and night-time due to stable atmospheric conditions [7]. During these conditions, the wind turbines continue to operate, while the wind speed at the residence is negligible, resulting in very low levels of background noise. Stable atmospheric conditions also give rise to high wind shear, which has been identified as a contributing factor to amplitude modulation of wind farm noise [8] [9], which makes it even more intrusive. Listening tests have shown that for a given noise level, the presence of amplitude modulation significantly contributes to perceived annoyance [10].

In contrast to traffic noise, which consists of energy distributed over the mid-frequency range, wind farm noise at distances exceeding about 1.5 km from the nearest turbine is dominated by low-frequency energy. This is because low-frequency noise is poorly absorbed by the atmosphere and ground, resulting in it being detected at much greater distances from the source than mid-to high-frequency noise [11]. In addition, acoustic refraction arising from atmospheric wind and temperature gradients leads to reduced attenuation of low-frequency noise in the downwind direction but little change for high-frequencies [12]. Therefore, low-frequency noise can propagate over large distances due to a combination of downward refraction (in downwind and/or temperature inversion conditions), small atmospheric absorption and insignificant losses on reflection from the ground. At a typical residence, noise in the mid-to high-frequency range is selectively attenuated by the walls and roof, resulting in the house structure behaving as a low-pass filter [13]. As a consequence, the spectrum of sound inside the house is even more heavily weighted towards lower frequencies, which is perceived as more annoying than a well-balanced spectrum of equal loudness [14]. Resonances in an average-sized room are well separated at low frequencies, causing a variation in sound pressure level of up to 20–30 dB as a function of location in the room [15]. Control of low-frequency noise and infrasound is also problematic with standard acoustic treatment.

Considering the various characteristics of low-frequency noise that have been outlined above, it is evident that it may not be appropriate to apply guidelines to wind farm noise that are derived from studies on traffic noise. Use of the A-weighting metric in wind farm noise guidelines is questionable due to the heavy penalties that are applied to low-frequency noise and the inability of the A-weighted noise level to correlate with annoyance and disturbance when the noise spectrum is dominated by low frequencies. Specification of an overall A-weighted allowable noise level assumes outdoor to indoor housing noise reductions that are typical for road traffic noise and this is not appropriate for spectra dominated by low frequencies.

WHO guidelines are particularly applicable to urban and suburban Europe, where general background noise levels are much higher than in rural areas where many wind farms are found. It would be expected that people living in regions with higher background noise levels would have a higher tolerance to noise than people living in low-noise environments. In addition, the higher background noise masks the more annoying noise due to traffic and other industrial sources such as wind farms.

The main aim of the work described in the following sections is to investigate typical outdoor to indoor noise reduction values for residences near wind farms in rural Australia, with a view to providing guidance on appropriate allowable outdoor noise levels resulting from one or more wind farms. Two residences have been investigated in detail and outdoor to indoor noise reductions have been considered as a function of frequency as well as for overall wind farm noise levels with various weightings that are commonly applied in analysis of wind farm noise. The typical noise reduction values are then compared with the WHO guidelines for both windows open and windows closed cases to determine the applicability of the stated noise reduction values to wind farm noise in rural Australia. A comparison is made between the third-octave band outdoor to indoor noise reductions for nine different residences located at varying distances from two different wind farms to determine if the observed trends are consistent for different housing constructions and locations.

2. Instrumentation

Continuous indoor and outdoor measurements were carried out for periods of several weeks at two residences located near the Hallett wind farm, which is made up of 167 Suzlon S88 turbines, each rated at 2.1 MW. The turbines are clustered into four separate areas that are considered as different stages of the wind farm and therefore each area has its own operational data. For the indoor acoustic measurements, three B&K 4955 microphones were located at various positions around an unoccupied room. These microphones have a low noise floor of 6.5 dB(A) and a flat frequency response down to 6 Hz, although they are still capable of indicating the blade-pass frequency and harmonics [16]. The microphones were connected to LAN-XI hardware and continuous 10-min recordings were made using Pulse software. The average sound pressure level of the three microphones was calculated based on the Danish guidelines for indoor low-frequency noise measurements [17]. This average includes one microphone positioned in the room corner and two microphones at a height of 1.5 m, which were located at possible receptor locations within the room. The corner microphone was positioned at a room vertex, 50 mm from each wall and the floor. In this corner position, the maximum sound pressure level was measured since this is an anti-node for all room response modes. At House 1, third-octave indoor noise measurements were also made using a G.R.A.S. 40HL microphone connected to a SVAN 979 sound level meter, measuring continuously over 10-min intervals. This microphone has a noise floor of 6.5 dB(A) and a flat frequency response down to 6 Hz. At House 2, the microphone used in this set-up was instead a G.R.A.S. 40AZ/SV 17, which has a noise floor of 17 dB(A) and a flat frequency response down to 0.8 Hz. Data from this microphone were used to determine a suitable correction for the B&K 4955 microphones for third-octave frequencies below 6 Hz.

The outdoor third-octave noise measurements were made using G.R.A.S. 40AZ/SV 12L microphones connected to a SVAN 958 sound level meter, which measured continuously over 10-min intervals. The microphones have a noise floor of 17 dB(A) and a flat frequency response down to 0.8 Hz. The microphones were mounted on the ground and 450 mm diameter hemispherical secondary wind shields in addition to the 900 mm diameter primary wind shields were used to minimise the wind-induced noise. The wind shields were designed according to the IEC 61400-11 standard [18], which specifies the use of these secondary wind shields for sound power measurements close to a wind turbine. In the 1 Hz–125 Hz frequency range, the difference in results obtained for a ground mounted microphone compared to one mounted at a height of 1.5 m is small due to the long wavelengths involved and the small absorption coefficient of the ground at these frequencies. However, the overall A-weighted noise reduction results reported later may be 1–2 dB higher than reported here for an exterior noise measurement at 1.5 m rather than at ground level. The reason for the