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Indoor low frequency noise from wind turbines

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Abstract

According to Swedish guidelines, noise from wind turbines close to residencies should not exceed the equivalent free field value of 40 dBA. Furthermore, low frequency noise is to be considered irrelevant if the difference between C-weighted and A-weighted levels is lower than 15 dB. There is a common concern when wind farms are established, that the low frequency noise has not been thoroughly investigated and could lead to disturbance. To further investigate the topic, a master thesis has been written on low frequency noise (20–200 Hz) from wind turbines in regards to sound propagation, sound generation and sound insulation.

The low frequency sound insulation of typical Swedish family houses is compared with the frequency spectra from several wind turbine noise measurements. The outdoor wind turbine levels in third octave band frequencies 20–200 Hz, belonging to an A-weighted equivalent level of approximately 40 dBA, is especially observed. The analysis indicates that wind turbine noise at low frequencies is close to outdoor background levels and the outdoors levels typically contain guidance values indoors och exceed with up to 10 dB. The thesis shows that very low facade sound insulation may be obtained at frequencies corresponding to the first room's resonances. In typical residencies these frequencies appear at approximately 30–60 Hz. Wind turbine noise levels in third octave bands 31.5–100 Hz are normally below recommended indoor levels why sound insulation at these frequencies most often are of minor concern. The conclusion of the thesis confirms that indoor low frequency sound level rules will be met if the outdoor sound is within the recommended level, i.e. the equivalent sound level of 40 dBA. So far this conclusion applies to wind farms with a maximum capacity of around 100 wind turbines up to 5 MW size.

Introduction

Swedish government authorities have established guidelines regarding indoor low frequency noise. Indoor sound level limits in third octave bands 31.5–200 Hz, due to external activity, have been defined in order to prevent annoyance, see *Table 1*. Research regarding human hearing on low frequencies has concluded that perception levels are close to annoying levels. Compiled limiting levels in the guidelines are therefore similar to normal human perception levels at low frequencies. This article concludes a master thesis on low frequency sound from

wind turbine contra indoor guidelines in regards to sound propagation and sound insulation [1].

Table 1 Swedish guidelines regarding indoor noise at low frequencies

Low frequency noise (indoor)	
Third octave band [Hz]	**Sound level [dB]**
31,5	56
40	49
50	43
63	41,5
80	40
100	38
125	36
160	34
200	32

Low frequency sound from wind turbines close to residencies

Sound from wind turbines is normally described with an A-weighted equivalent sound pressure level, which to some extent underestimates the loudness of low frequencies. Since high frequencies (>200 Hz) are more effectively absorbed by the atmosphere and the ground, it is possible that low frequency levels may cause disturbance despite an moderate A-weighted equivalent level, especially at long distances from the source.

In order to investigate the probability that low frequency wind turbine sound could lead to disturbances among residents, third octave band sound pressure levels between 31.5–200 Hz from outdoor wind turbine measurements were compared with indoor guidelines. The results in *Table 2* refer to four different outdoor measurements on wind turbine sound [1], [6], [7]. The purpose of *Table 2* is to display the minimum level of low frequency sound insulation needed to meet Swedish indoor guidelines, presuming that presented outdoor sound levels are wind turbine generated (three of four results are not corrected due to background noise). In resident areas where trees or some kind of shrubbery are present, wind generated background levels normally mask wind turbine sound at low frequencies effectively. Sounds from ocean waves or road traffic close to residencies could increase low frequency background levels even further. The results indicate that even though low frequency levels increase with an increased amount of wind turbines, sufficient sound insulation, to prevent annoying indoor low frequency wind turbine noise, is likely to be obtained in most types of resident constructions. In third octave bands 31.5–100 Hz wind turbine noise levels are normally below or very close to recommended indoor levels why sound insulation at these frequencies most often are of minor or no concern.

It has been observed that wind turbines generate a frequency spectrum that varies between models and manufactures. Calculations on sound propagation from large scale off shore wind farms (800-1000 turbines) made at ÅF-Sound & Vibrations, using prediction model Nord2000, indicate that significant differences in sound levels at low frequencies can occur due to the type of wind turbine used in the calculation. On great distances from the wind farm where the equivalent sound level touch upon 40 dBA, the choice of wind turbine type can be crucial when determining if indoor guidelines at low frequencies are met.

Table 2 Level difference between measured outdoor wind turbine noise (in three cases including background noise) and Swedish guidelines regarding indoor noise at low frequencies [1], [6], [7]

Measured low frequency sound from wind turbines compared with indoor guidelines				
Wind park capacity	1 turbine (1 MW)	1 turbine (2 MW)	17 turbines (2 MW)	60 turbines
Distance [m]	650	270	750	1000
Wind speed	8 m/s	8 m/s	Data missing	Data missing
Free field level [dBA]	40	41	50	Data missing
Background noise correction	Yes	-	-	-
Frequency [Hz]	**Level difference between outdoor wind turbine noise and indoor guidelines [dB]**			
31,5	-15	-9	1	7
40	-10	-4	5	10
50	-9	0	7	14
63	-0,5	1	7,5	13,5
80	6	1	12	11
100	7	2	16	11
125	5	2	14	9
160	3	3	15	7
200	11	4	14	7

Sound insulation at low frequencies

Separating walls with a double panel construction are frequently used in resident buildings in Sweden. The transmission loss decreases substantially at the mass-air-mass resonance frequency of the double panel. In order to avoid mass-air-mass resonance frequency influence on the weighted sound reduction index R_W (average of measured reduction levels at third octave band frequencies 100–3150 Hz) double panels are normally constructed with the mass-air-mass resonance frequency below 100 Hz, resulting in very poor sound insulation at frequencies below 100 Hz in many separating walls [2].

Great low frequency sound insulation is normally obtained in heavy, stiff constructions, e.g. concrete or brick walls. Even multiple layers of gypsum boards can obtain relatively decent low frequency sound insulation, provided that the mass-air-mass resonance frequency is set very low, e.g. by adjusting the air gap.

Sound transmission through windows is partially area dependent where an increase in window area significantly decreases sound insulation at low frequencies, which probably is caused by lower stiffness when window area is increased. According to calculation experiments, using the modeling program *Insul*, reduction levels decreases with 5 dB at third octave band frequencies below 160 Hz when window area is doubled (calculations refer to 4 mm double glazed window with 12 mm air gap). With the intention to reduce low frequency sound transmission through doubled glazed windows, a method has been developed using optimally tuned Helmholtz resonators, [3]. A 10 dB improvement is achieved at the mass-air-mass resonance frequency by placing 4-6 resonators along the frame in between the glasses.

The sound insulation, at the frequencies 20-200 Hz, within separating walls may vary substantially depending on e.g. fastener properties, the receiving room's dimensions and leakage through cavities etc. At some frequencies the collaboration between room resonances and wall modes can result in a very low sound insulation. The reduction level at low frequencies in the separating wall between two rooms does not solely depend on wall properties, but also the dimension of the room, the position of the source and the reverberation time. This means the reduction level, especially at low frequencies, is defined as the coupling between room-wall-room.

In a Danish study of low frequency wind turbine sound in residencies, the sound insulation of five typical family houses was measured [4]. The results show that façade sound insulation at low frequencies varies greatly between different types of houses. Below approximately 50 Hz the sound reduction in some façades was very low. This could be explained by the receiving room's first resonance frequencies collaborating with the wall modes in such a way that the sound insulation strongly deteriorates. The average of the sound level difference outdoors/indoors measured in 10 different rooms is shown in *Table 3*. The measurements were performed in two rooms per house. No room correction has been made. Merely corner microphone positions have been used, which gives approximately 3-4 dB lower sound reduction as in comparison with using a large number of microphone positions equally spread out in the receiving room.

Table 3 The average of 10 sound insulation measurements, expressed as the level difference indoor/outdoor [5]

Frequency [Hz]	20	25	31,5	40	50	63	80	100	125	160	200
ΔL [dB]	16,7	15,5	19,1	13,3	12,0	15,2	16,1	18,3	15,9	16,1	16,7

Measurement methods

Reliable low frequency measurements in ordinary rooms are difficult to achieve due to the presence of a non-diffuse sound field below the Schroeder frequency. Standing wave patterns creates a sound field where the sound levels at different

positions vary significantly. Maximum levels appear in room corners and close to walls and minimum levels occur in the centre of the room. In typical rooms in residencies (30-50 m^3) the Schroeder frequency appears at approximately 200-300 Hz, somewhat lower in well-furnished rooms. Levels between different positions vary the most at frequencies close to approximately the first, second and third room modes. At subsequent modes the variation between positions are less explicit due to high modal overlap. The first room mode appears between approximately 30-50 Hz.

There are many methods and theories on low frequency measurements in room. The choice of microphone positions and the number of microphones distinguishes the methods mostly. International Standard ISO 140-5 and ISO 140-4 requires a minimum of five microphone positions to be used in the receiving room and a minimum distance between microphone positions of 0.7 m, with 0.5 m between any microphone position and the room boundaries. Annex D in ISO 140-4 (guidance on measurements at low frequencies) states that there should be a minimum distance of 1.0–1.2 m between any microphone position and the room boundaries and that the number of microphone positions should be increased. In typical rooms in dwellings (30-50 m^3) these restrictions implies that only a very narrow area in the middle of the room is suitable for microphone positions, which on the other hand should be avoided due the presence of anti-modes.

Simmons guidance on measurements at low frequencies, SP INFO 1996:17 [5], requires relatively few microphone positions where the purpose is to find the maximum disturbance level in a typical resident. The method requires one microphone corner position and two microphone positions where the resident normally is positioned. The method normally presents a room average level that is 1-2 dB higher than a level based on a great number of microphone positions.

The sound insulation of a typical Swedish resident, located on the country side, was measured in the project. The separating wall was built of timber and gypsum boards with a double glazed window in the centre. The results in *Figure 1* refer to measurements with microphone positions in the receiving room according to ISO 140-5 and SP INFO 1996:17. As predicted, somewhat lower reduction levels was measured following SP INFO 1996:17. To investigate room mode influence on sound insulation, the receiving room eigenfrequencies was estimated with a simple calculation model, assuming acoustically hard walls and a sound speed of 340 m/s. The first room mode was calculated to 29 Hz which coincide with the decrease in reduction level at the 31.5 Hz third octave band. The second and third room modes, at 45 Hz and 54 Hz, coincide with the decrease in reduction level at the 50 Hz third octave band. The increase in reduction level at the 40 Hz third octave band could be explained by the presence of an anti-mode between the first and second room mode.

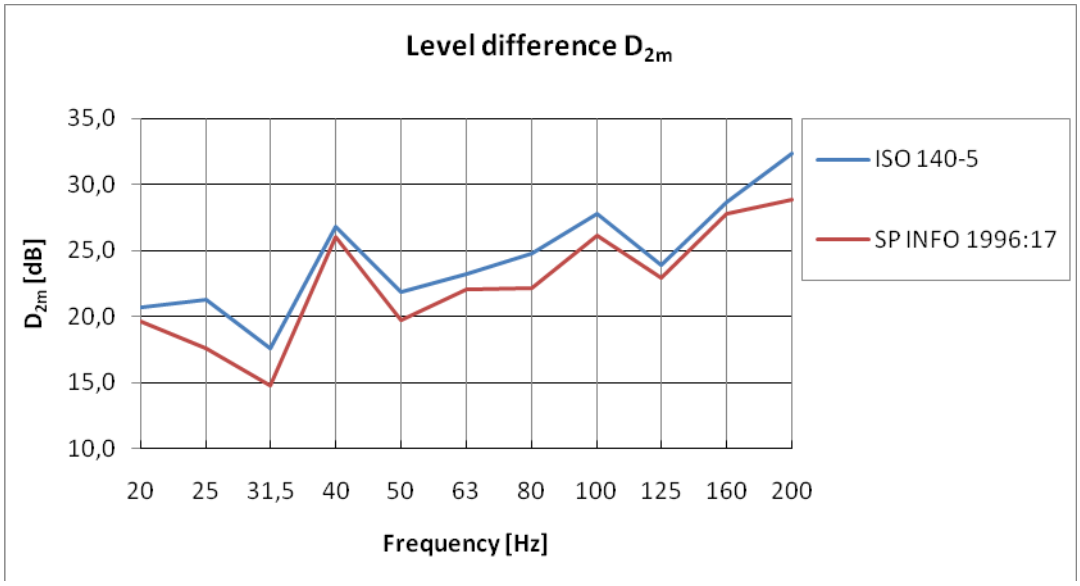

Figure 1 Measured sound level difference using microphone positions according to ISO 140-5 and SP INFO 1996:17

Conclusions

The sound insulation in ordinary residencies is considered sufficient; not exceeding the indoor guidelines for low frequency noise, provided the outdoor wind turbine excited A-weighted equivalent sound pressure level comes to approximately 40 dBA. It has been shown that very low façade insulation can be obtained from the frequencies corresponding to the receiving room's first resonance frequencies. The first eigenfrequencies in typical residences occur between approximately 30-60 Hz. In third octave bands 31,5-100 Hz wind turbine noise levels may be several decibels below indoor guidelines. Therefore the façade insulation at these frequencies in most cases is of no concern.

On low frequency measurements in rooms, a method which acknowledges the standing wave pattern appearing at low frequencies is recommended. By including corner microphone positions when measuring in rooms a more representative room average is obtained.

References

[1] Lindkvist, P. *Lågfrekvent buller från vindkraftverk – Mätning och modellering i bostadsrum med avseende på ljudutbredning och ljudisolering*. KTH, TRITA-AVE 2010:15.

[2] Åkerlöf, L. *Byggnadsakustik - En praktisk handbok.* AB Svensk Byggtjänst, ISBN 91-7332-917-7, 2001.

[3] Qibo, M and Stanislaw, P. *Experimental study for control of sound transmission through double glazed window using optimally tuned Helmholtz resonators.* 2009. Empa, Swiss Federal Laboratories for Materials Testing and

Research, Ueberlandstrasse 129, CH-8600 Duebendorf, Switzerland. www.elsevier.com/locate/apacoust.

[4] *Low frequency noise from large wind turbines. Measurement of sound insulation of facades.* 2008. DELTA EFP-06, Report AV1097/08. Client: Danish Energy Authority.

[5] Simmons, C. *SP INFO 1996:17. Vägledning för mätning av ljudnivå i rum vid låga frekvenser - fältprovning.* 1996.

[6] van den Berg, G P. *Do wind turbine produce significant low frequency sound levels .* 11th International meeting on low frequency noise and vibration and its control, Maastricht, The Netherlands, 2004.

[7] Hepburn, Howard G. *Acoustic and geophysical measurement of infrasound from wind farm turbines.* Canadian Acoustics, special issue. Vol. 34 No. 2 p.51, 2006.