APPENDIX 11

Low Frequency Noise and Wind Turbines (Technical Annex)

British Wind Energy Association, 2005

Low Frequency Noise and Wind Turbines

Technical Annex

British Wind Energy Association

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Summary

To date, there is no scientific evidence which links the levels of low frequency noise emitted by wind turbines with impacts on human health. With over 68,000 wind turbines in operation around the world, some of which have been in place for over 20 years, there has been ample opportunity for any ill effects to have been identified; that none have is further proof of the benign nature of this technology.

Some earlier wind turbine designs in the 1980s had problems associated with low frequency noise. However, the vast majority of modern grid-connected wind turbines have a different configuration so problems associated with low frequency noise have been overcome with careful design and technological advances.

However, in light of recent public concern the Government has commissioned further independent research on low frequency noise and wind turbines, which is due to be published in February/March 2005. In the interim, BWEA have produced this document on research available to date which has examined low frequency noise from wind turbines.

1. Background

Concerns were raised in the UK at the beginning of 2004 regarding low frequency noise from wind turbines and their possible impact on human health, with suggested symptoms such as nausea, headaches and anxiety [*]. The issue was widely publicised in the national press and has consequently resulted in concern amongst some residents near both existing and proposed wind farm sites.

2. Low Frequency Noise – what is it?

Low frequency noise is not clearly defined but is generally regarded to mean noise in the range of 10 to 200 Hertz (Hz). Noise occurring at frequencies below 20Hz is often referred to as infrasound; this is also the type of noise that presents the most difficulties in its measurement and assessment.

According to research conducted for the Department for Environment, Food and Rural Affairs (Defra), frequencies below 20Hz can be audible, illustrating that there is some lack of clarity in the interpretations of infrasonic and audible noise[1]. The range of human hearing is 20 to 20,000 Hz, with 1dB being the smallest change that humans can detect in a noise. For the majority of people, the human ear is not very sensitive at low frequencies. A report for Defra specified the following "*At low levels of noise, the human ear attenuates sound by about 25 dB at 100 Hz, 40 dB at 50 Hz and 70 dB at 20 Hz (an*

[*] This was initiated by a letter written by a local GP in Plymouth, Dr Amanda Harry, based on a questionnaire given to 14 families living in the vicinity of Bears Down wind farm, Cornwall. Dr Harry published her letter in the Western Morning News at the end of January 2004. However, to date there is no scientific evidence to support her claims and neither have her findings been peer reviewed.

attenuation of 70 dB is less than 1/100th as loud), compared with the level at 1000 Hz. At higher levels, the effect is not so marked with the attenuation being about 5 dB at 100 Hz, 10 dB at 50 Hz and just under 25 dB at 20 Hz (i.e. less than 1/5th as loud). This means that frequencies in the region of 20 Hz may not be audible unless the level exceeds about 70 dB"[2].

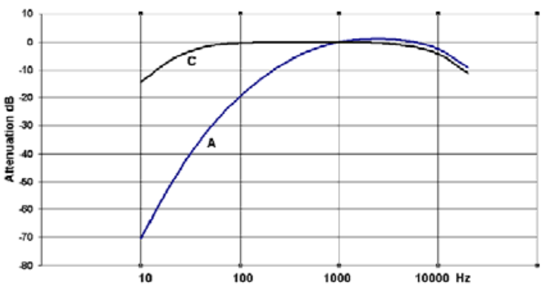
As a general rule, noise which is more than 20dB below the average threshold of ISO 226:2003 (*Acoustics. Normal equal-loudness-level contours*)[3] is unlikely to be a problem as, from the statistics of the threshold determination, this is below the threshold of the most sensitive person. In this brief the term low frequency noise will also include infrasound.

There is always low frequency noise present in any ambient quiet background and it can be produced by a variety of sources[4], such as:

- Machinery, including pumps, compressors, diesel and combustion engines, refrigerators and fans
- All forms of transport
- Structure-borne noise, which originates in vibration
- Neighbour-noise heard through a wall (blocks higher frequencies more than it blocks lower frequencies)
- Natural sources of such as the wind, the sea, thunder and vibration from low level ground movements

3. Measuring Low Frequency Noise

The majority of noise measurements are conducted using sound level meters, which give numeric representations of the noise. Sound level meter A-weighting is usually used for environmental noise. A-weighting gradually reduces the significance of frequencies below 1000Hz, until at 10Hz the attenuation is 70dB. The C-weighting, is flat to within 1dB down to about 50Hz and then drops by 3dB at 31.5Hz and 14dB at 10Hz. See Figure 1 for A and C-weighting curves.



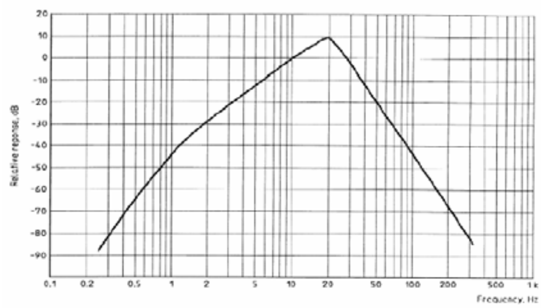


Figure 1: Sound Level Meter Weighting Curves A and C; **Figure 2: G-Weighting for Infrasound**

The G weighting is specifically designed for infrasound. This falls off rapidly above 20Hz and below 20Hz it follows assumed hearing contours with a slope of 12dB per octave down to 2Hz. See Figure 2 for the G-weighting curve.

3.1 National Criteria

Criteria for assessing low frequency noise levels vary from country to country; currently there are no British Standards that specifically refer to the assessment of low frequency noise. However, there is an international standard, *ISO7196:1995E Acoustics – Frequency-weighting characteristics for infrasound measurements*, which defines the G-weighting (see Figure 2) and used in assessments made in some countries, although not in the UK[5].

The tendency is that most European countries have specified their own measurement criteria. Figure 3 shows the Swedish criterion, which is used as a recommendation for assessing indoor low frequency noise.

Frequency 1/3 octave band Hz	Criterion dB	ISO 226 threshold dB
31.5	56	56.3
40	49	48.4
50	43	41.7
63	41.5	35.5
80	40	29.8
100	38	25.1
125	36	20.7
160	34	16.8
200	32	13.8

Figure 3*: Limits for Low Frequency Noise - Sweden

Figure 4: Limits for Low Frequency Noise - Netherlands

Low frequency hearing threshold for levels for 50% and 10% of the population.
(NSG reference curve in bold)

	Otologically Unselected Population 50 – 60 years		Otologically Selected Young adults (ISO 226)	
Freq Hz	**50% dB**	**10% dB**	**50% dB**	**10% dB**
10	103	92	96	89
12.5	99	88	92	85
16	95	84	88	81
20	85	**74**	78	71
25	75	**64**	66	59
31.5	66	**55**	59	52
40	58	**46**	51	43
50	51	**39**	44	36
63	45	**33**	38	30
80	39	**27**	32	24
100	34	**22**	27	19
125	29	18	22	15
160	25	14	18	11
200	22	10	15	7

Figure 4 shows the limits for low frequency noise in the Netherlands, which are based on audibility, using the hearing threshold for 10% of the population of 50-60 year olds. Thus, 10% of this population are more sensitive than these limits.

3.2 Impacts of Low Frequency Noise to humans

Several studies[6], including a review conducted in 2001 on 69 low frequency noise studies, confirm that the primary effect of low frequency noise to humans is annoyance, and no links have been shown to biological health effects[7]. Furthermore, noise annoyance can only be defined subjectively and is influenced by numerous non-acoustic personal, attitudinal, and situational factors in addition to the amount of noise *per se*. Sometimes a noise is heard by a complainant, but cannot be measured. In these situations a mechanism other than airborne sound can be responsible, known as false perception of noise.

* Fig shows the 1987 thresholds, which were current at the time the work was done, however, the 2003 thresholds are a few dB higher at the lowest frequencies.

These can include tinnitus, electromagnetic waves, synaesthesia, hypnagogic effects and the “cognitive itch”, a possible ongoing memory of a sound.

4. Research on Low Frequency Noise and Wind Turbines

Research and development has been carried out on both audible and inaudible noise from wind turbines in the UK.

The Wind Turbine Noise Working Group, established by the DTI in 1996, developed guidelines[8] for wind farm developers on noise from wind turbines. These have been adopted as part of the best practice standards set by the British Wind Energy Association and are consequently followed by the majority of the UK wind industry. Preliminary recommendations from the Wind Turbine Noise Working Group are that turbine noise levels should be kept to within 5 dB(A) of the average existing evening or night-time background noise level.

This is in line with standard practice for assessment of most sources of noise except for transportation and some mineral extraction and construction sites when higher levels are usually permitted. A fixed low level of between 35 and 40 dB(A) may be specified when background noise is very low, i.e. less than 30 dB(A). In addition, there is a British Standard for measuring acoustic noise from wind turbines, *BS EN 61400-11:2003 Wind turbine generator systems. Acoustic noise measurement techniques*[9].

4.1.1 Research in the US

One study often referred to regarding low frequency noise and wind turbines, is the 1987 report by Kelley[10]. Kelley conducted research in the US on low frequency noise from wind turbines, examining the 2 megawatt (MW) MOD-1 type wind turbines, which had a stiff tower design and were known to have problems with sub-audible vibration. Kelley found that if the noise had an impulsive characteristic, then under the right set of circumstances, people could "hear" it within homes in nearby communities.

Kelley also found a difference between downwind and upwind wind turbines as regards to low frequency noise. According to Kelley, downwind wind turbines can produce impulsive noise due to wakes arising from tower structural elements, as was the case with the MOD-1 turbine and its pipe truss design with four cylindrical legs connected by cross-members. Subsequent US research reported in 1991[11] compared low frequency noise from downwind and upwind machines. This work confirmed the fact that low frequency noise is indeed a function of the downwind turbine configuration.

The majority, if not indeed all, wind turbines installed in the UK in recent years have been upwind machines, as has also been the case elsewhere in Europe. Therefore, low-frequency noise has been not considered to be an issue with the upwind design, and concern rather focuses on the much higher frequency broadband and discrete frequency noise associated with blade tips.

Kelley’s research was conducted in 1987 and advances in modern wind turbine technology have meant that in most cases problems with low frequency noise have been reduced to below detectable levels. In addition, wind turbine designs typical in the US at that time differ greatly to those used in the UK and Europe.

4.1.2 Research in Europe

Denmark

Denmark has a long history of wind energy and both the Danish Wind Industry Association[12] and the Danish Environmental Agency[12] confirm that low frequency noise from wind turbines has not been an issue and there have been very few complaints from the general public in the past 20 years. In fact, if anything, research by the Danish research institute DK Teknik found that perception of noise from wind turbines was governed more by people's attitude to the source of the noise rather than the actual noise itself [13].

Germany

Germany is another European country with a long history in wind energy and has by far and away the greatest installed capacity of onshore wind energy in the world. The German Wind Energy Association[12] has confirmed that no impacts to human health have been proved from low frequency noise from wind turbines in German studies.

Studies conducted in Germany found that wind turbines emit sound at extremely low levels in the infrasound range (below 20 Hz). However, this sound is far below detection threshold and far below levels which can cause any impacts[14]. Measurements on a turbine in the megawatt class at the DEWI Test Site showed levels of 58 dB at a distance of 100 meters to the turbine in the one-third octave band level at 10 Hz[15], which means more than 40 dB below the hearing threshold at this frequency. Furthermore, other year-long studies[16] have shown that low frequency noise which cannot be detected does not cause impacts upon human health and is therefore harmless.

Research by van der Berg[17] on a 17-turbine 30 MW wind farm in 2003 found that variable speed turbines were noisier than predicted due to the fact that the developer misjudged the wind speed at the turbine hub height of 98 meters. The developer did not consider night time propagation and therefore higher than expected wind speed at night resulted in higher audible sound levels. The wind turbines in this case study were generally operating at the same rotational speed, and were thought to go in and out of phase, resulting in fluctuation in the aerodynamic sound of the blades.

However, this case study is not applicable in all conditions as a wind farm of constant speed turbines should not show the same effect. Furthermore, it should be noted that 1dB is the smallest change humans can detect in a noise whilst in this case study the level changes were up to 3 to 5dB.

4.1.3 Research in the UK

The Snow Report 1997

Snow[18] undertook measurements in 1996 on a wind farm in the UK, which consisted of eleven 450 kilowatt (kW) machines. Noise and vibration measurements were taken at increasingly distant points up to 1 kilometre from the wind farm. Low frequency vibrations were determined down to 0.1Hz, taking into consideration variation with distance, wind speed and on/off load levels. During the experiment a wide range of wind speeds and directions were recorded.

The research found that the absolute level of the vibration signals measured at any frequency at 100m from the nearest wind turbine were significantly below criteria for 'critical working areas' given by British Standard *BS6472:1992 Evaluation of human exposure to vibration in buildings (1Hz to 80 Hz)*[19], and were even lower than limits specified for residential premises.

Vibration levels in the range of 0.5 to 1.0 Hz remained at comparable levels even during non-operation of the wind farm and during low wind speed conditions. At these frequencies there was little attenuation with distance, so that the source of vibration may not be local to the site. The research also found that frequencies above 3.0 Hz attenuated rapidly with distance and higher frequencies attenuated at a progressively increasing rate. There was no clear trend of increasing vibration levels with wind speed. Low frequency noise and vibration levels were both found to comply with recommended residential criteria, even on the wind farm site itself. The acoustic signal, below 20Hz, was well below accepted thresholds of perception[**].

Hayes 2004

According to Hayes[20], from noise consultants Hayes McKenzie Partnership, low frequency noise was found to be below recognised thresholds of perception, even when measured close to wind turbines. Furthermore, Hayes found that noise from wind turbines was generally not an infrasonic issue as most of the sound was in the 250Hz region and therefore above low frequency noise level.

This research also found that audibility was likely to be dependent upon several factors, including building construction, room dimensions and the sensitivity of occupants.

[**] The hearing threshold at 20Hz is given in ISO 226:2003 as 78.5dB. This is the median, for which 50% are less sensitive and 50% more sensitive. Standard deviations are such that, out of the 50%, 34% of more sensitive people are within approximately 6dB of the threshold and practically everybody else within a further 6dB.

Geoff Leventhall uses an absolute cut off as 20dB below average threshold, which is greater than approximately three standard deviations. In Snow's work the levels at 20Hz were generally about 50dB or lower, which meets Leventhall's cut off of greater than 20dB below 78.5dB

Furthermore, Hayes concluded from his findings that low frequency noise is not really an issue for sites with 10-20 wind turbines, the issue is of audibility of higher frequencies and acceptability of those sounds.

Leventhall 2004

Dr Geoff Leventhall[21], Consultant in Noise Vibration and Acoustics and author of the Defra Report on Low Frequency Noise and its Effects, predicted levels at a proposed wind farm using a calibrated tape recording of noise from a 1.3 megawatt (MW) wind turbine. The tape was analysed in order to investigate any presence of low frequency noise.

Leventhall's analysis confirmed the presence of tonal peaks in the low frequency region. However, their levels were found to be below the hearing threshold of most people, and therefore the research concluded that noise from the proposed wind farm installation in the low frequency (10Hz to 200Hz) range was unlikely to be a problem.

In fact, Dr Leventhall has since said in personal communication that *"I can state quite categorically that there is no significant infrasound from current designs of wind turbines. To say that there is an infrasound problem is one of the hares which objectors to wind farms like to run. There will not be any effects from infrasound from the turbines.*

The turbines produce a modulated higher frequency - the swish, swish - which people may not like, but this is not infrasound. There is no low frequency in it.

There is negligible infrasound and very little low frequency noise from wind turbines - a few low level tones from the gearbox. Whatever might be making people ill it is not low frequency noise - there just isn't enough of it from modern wind turbines.[22] "

5. Conclusion

Low frequency noise is not clearly defined but is generally regarded to mean noise in the range of 10 to 200 hertz (Hz). There is no British Standard for measuring low frequency noise and most European countries tend have their own criterion.

Low frequency noise is almost always present in an ambient quiet background, produced by for instance machinery, transport and natural sources such as the wind, sea and thunder. Older downwind wind turbines in the 1980s had associated problems with low frequency noise. This was taken into consideration by the wind industry and most modern turbines designed thereafter have been upwind turbines, particularly in the UK.

The main impact of low frequency noise to humans is that of annoyance, however, research to date has not shown any biological health effects at the levels normally associated with operational wind turbines. Furthermore, research conducted in low frequency noise on modern wind turbines has shown that the levels of low frequency noise have been below accepted thresholds, and is therefore not considered to be a problem.

References

[1] Defra (2003), A Review of Published Research on Low Frequency Noise and its Effects, Report for Defra by Dr Geoff Leventhall Assisted by Dr Peter Pelmear and Dr Stephen Benton. Available online at: http://www.defra.gov.uk/environment/noise/lowfrequency/pdf/lowfreqnoise.pdf.

[2] Defra (2001), Low Frequency Noise, Technical Research Support for DEFRA Noise Programme, Casella Stanger. Available online: http://www.defra.gov.uk/environment/noise/casella/pdf/lowfrequencynoise.pdf.

[3] See www.bsi-global.com for British Standards.

[4] Defra (2001), Low Frequency Noise, Technical Research Support for DEFRA Noise Programme, Casella Stanger. Available online: http://www.defra.gov.uk/environment/noise/casella/pdf/lowfrequencynoise.pdf.
Defra (2003), A Review of Published Research on Low Frequency Noise and its Effects, Report for Defra by Dr Geoff Leventhall Assisted by Dr Peter Pelmear and Dr Stephen Benton. Available online at: http://www.defra.gov.uk/environment/noise/lowfrequency/pdf/lowfreqnoise.pdf.

[5] Defra (2003), A Review of Published Research on Low Frequency Noise and its Effects, Report for Defra by Dr Geoff Leventhall Assisted by Dr Peter Pelmear and Dr Stephen Benton. Available online at: http://www.defra.gov.uk/environment/noise/lowfrequency/pdf/lowfreqnoise.pdf.

[6] Defra (2000), Health Effect Based Noise Assessment Methods: A Review and Feasibility Study;
WHO (1980), WHO Environmental Health Criteria 12 - Noise, World Health Organisation;
Infrasound, Brief Review of Toxicological Literature, 2001.

[7] Mirowska, M. (1998): An investigation and assessment of low frequency noise in dwellings. Jnl Low Freq Noise Vibn 17, 119-126;
Lundin, A., and Ahman, M. (1998): Case report: Is low frequency noise from refrigerators in a multi-family house a cause of diffuse disorders? Jnl Low Freq Noise Vibn 17, 65-70.

[8] ETSU (1996), The Working Group on Wind Turbine Noise, The Assessment and Rating of Noise from Wind Farms, ETSU-R-97.

[9] See the British Standards Institute (BSI) website for more information on British Standards: http://www.bsi-global.com.

[10] Kelley, N., (1998) Is Low Frequency Noise a Problem for Wind Turbines? U.S. National Renewable Energy Laboratory, http://www.awea.org/faq/noise-lf.html;
Kelley (1987), A Proposed Metric for Assessing the Potential of Community Annoyance from Wind Turbine Low-Frequency Noise Emissions, Presented at the Windpower '87 Conference and Exposition, October 5-8, 1987, San Francisco, California.

[11] Physical Characteristics and Perception of Low Frequency Noise From Wind Turbines' K P Shepherd, H H Hubbard, Noise Control Engineering Journal, Jan-Feb 1991, Vol.36, No.1.

[12] Personal communication, Feb-March 2004

[13] Danish Wind Industry Association, Sound from Wind Turbines, http://www.windpower.org/en/tour/env/sound.htm, "Genepåvirkninger af støj fra vindmøller" (ISBN 87-77-16-028-2, report 150/1994).

[14] Klug, H., (2002), DEWI, Infrasound from wind turbines: A ‚German' Problem?, DEWI Magazin Nr. 20, February 2002. Infraschall von Windenergieanlagen: Realitat oder Mythos?

[15] Messbericht: Messung der Infraschall-Abstrahlungeiner WEA des Typs Vestas - 1,65 MW; ITAP-Institut fur technische und angewandte Physik GmbH, Oldenburg, 26. Juni 2000.

[16] Ising, Makrert, Schenoda, Schwarze (1982), Infraschallwirkungen auf den Menschen, Dusseldorf, VDI-Verlag.

[17] van der Berg, G.P. (2003), Effects of the Wind Profile at Night on Wind Turbine Sound, Journal of Sounds and Vibration, Article in Press. Received 22 January 2003, accepted 22 September 2003.

[18] ETSU (1997), Low Frequency Noise and Vibrations Measurement at a Modern Wind Farm, prepared by D J Snow.

[19] See also ANSI S3.29-1983 (R1996): Guide to the Evaluation of Human Exposure to Vibration in Buildings.

[20] Hayes, M. (2004) Low Frequency Noise and Wind Turbines, presented at the BWEA26 Conference, 8th July 2004, Manchester.

[21] Leventhall, G. (2004), Assessment of Low Frequency Noise from the Proposed West Mill Wind Farm Watchfield, A Report to Vale of White Horse District Council.

[22] Personal communication, September 2004.