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PARTNERSHIP LTD



Prepared for:

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**Eoltec Scirocco 5.6 m/6 kW Wind Turbine
Source Noise Level Measurement**

**HM: 1820/R1
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SCIROCCO WIND TURBINE
SOURCE NOISE LEVEL MEASUREMENT
Report HM:1820/R1.1, 10th April 2007

1. Introduction

- 1.1 This report describes the results of measurements of the source noise level of an Eoltec Scirocco 5.6m/6 kW wind turbine. The Eoltec Scirocco is a 2 bladed, direct drive generator, passively orientated, upwind turbine, manufactured by Eoltec SAS of France.
- 1.2 Hayes McKenzie Partnership Ltd (formerly Hayes McKenzie Partnership) have been specialising in the measurement, assessment and control of noise from wind farm sites for over 15 years. During that time this has included work on well over 300 proposed, consented or completed sites both in the UK, Continental Europe, USA, New Zealand and Australia; source noise measurements on around 20 turbine types (with around 200 actual turbines measured in total), measurements of residential noise levels at around 20 existing wind farms and provision of expert witness evidence for 39 UK public inquiries. Our clients have included most of the major UK wind farm developers and have included many successful applications including those gained at Public Inquiry.
- 1.3 The noise measurements were carried out by Bryan J Rendall (Electrical) Ltd at a turbine site on the island of Westray in the Orkney Islands in consultation with Hayes McKenzie. The turbine at this site is mounted on a standard 12m tilt up freestanding tower, and is representational of a typical installation.
- 1.4 Hayes McKenzie have analysed the results in order to derive the sound power level at integer wind speeds from 4 - 10 m/s, a third octave band spectrum level for the reference wind speed of 8 m/s and an assessment of worst case tonal content over all measurements taken.

2. Noise Measurements

- 2.1 Noise measurements were made at the turbine site on the island of Westray in Orkney, Scotland, according to the requirements of BS EN 61400, *Wind Turbine Generator Systems - Part 11, Acoustic noise measurement techniques*. Figure 1 shows the relative positions of the



turbine tower/pole, the anemometer mast installed to record the wind speed and wind direction and the microphone and ground board assembly required by BS EN 61400-11.

- 2.2 Noise measurements were carried out between 20:30 on 02/03/2007 and 07:59 on 03/03/2007 using a Cirrus CR:831B sound level meter calibrated using Cirrus model 511E calibrator, serial number 034811. The turbine was operating normally during this time, except when it was shut down to monitor the background noise. The sound level meter was set up to record successive measurements of $L_{Aeq, 1 \text{ minute}}$. Any such periods containing potentially interfering background noise were noted so that these could be eliminated from the subsequent data analysis. Supplemental audio recordings were made on a Sony TCD-D7 DAT recorder from the A/C output of the sound level meter during the period 20:32 to 21:32 to allow post-processing to be carried out to derive one-third octave band spectra and narrow band spectra of the noise signal.
- 2.3 The turbine was shut down between 21:03 on 03/03/2007 and 05:31 on 04/03/2007 to allow an assessment of steady background noise at the site to be evaluated, such that the measured noise level from the turbine could be corrected to account for it.
- 2.4 Synchronised wind speed and wind direction measurements were made using an NRG #40 anemometer and an NRG #200P wind vane mounted at 10m height connected to an NRG 9200 - Plus data logger.
- 2.5 The noise data was filtered to include only such times when the wind direction were such that the relative locations of the anemometer and measurement microphone were within the tolerances allowed by BS EN 61400-11. The criteria are that the anemometer must be upwind of the turbine, +/- 30 degrees (in this case), and the microphone position is downwind +/- 15 degrees. In this case, the acceptable range of wind bearings were between 135 and 165 degrees, see Figure 1.

3. Results and Analysis

- 3.1 Figure 2 shows a plot of measured noise level against wind speed for periods when the turbine was operating and when it was shut down. Second order best fit regression lines are shown with each data series. For each integer wind speed, the background level was subtracted from



the turbine level, to give a corrected level, as per Equation 8 (page 18) in BS EN 61400 - 11. These results are summarised in Table 1, together with the calculated sound power level:

Table 1: Turbine Noise Levels

Wind Speed (m/s)	4	5	6	7	8	9	10
Measured Turbine noise dB L _{Aeq}	45.6	47.7	49.8	51.8	53.8	55.7	57.6
Measured Background Noise dB L _{Aeq}	42.5	42.2	42.4	43.0	43.9	45.2	46.9
Turbine noise corrected for background dB L _{Aeq}	42.8	46.3	48.9	51.2	53.3	55.3	57.2
Calculated Turbine Sound Power Level, dB L _{AWeq}	73.3	76.8	79.5	81.7	83.9	85.8	87.8

Third Octave Band Sound Power Level

3.2 The recorded audio samples were acquired into a notebook computer using the 01dB Symphony noise measurement software suite. This was used to provide a one third octave band spectrum of the turbine noise for the one minute sample period corresponding to the closest wind speed to the reference speed of 8 m/s shown in Table 2. The A-weighted spectrum is also shown, as is standard practice for wind turbine noise measurements. It is also shown normalised to a sound power level of 83.9 dB L_w, which corresponds to a wind speed 8 m/s.



Table 2: Turbine Third Octave Band Spectra

Third Octave Band Centre Frequency (Hz)	Octave Band Noise Level (dB L_{eq} 1 min) wind speed = 7.7 m/s	A-Weighted Octave Band Noise Level (dB L_{Aeq} 1min)	Sound Power Level (dB L_{Waeq} 1 min) Normalised to 8m/s wind speed
63	48.3	22.1	48.0
80	48.1	25.6	51.5
100	50.5	31.4	57.3
125	44.4	28.3	54.2
160	44.1	30.7	56.6
200	52.7	41.8	67.7
250	45.7	37.1	63.0
315	39.5	32.9	58.8
400	39.4	34.6	60.5
500	37.2	34.0	59.9
630	40.2	38.3	64.2
800	38.5	37.7	63.6
1000	40.1	40.1	66.0
1250	40.6	41.2	67.1
1600	40.8	41.8	67.7
2000	39.4	40.6	66.5
2500	37.1	38.4	64.3
3150	35.9	37.1	63.0
4000	35.7	36.7	62.6
5000	35.3	35.8	61.7
6300	37.2	37.1	63.0
8000	39.1	38.0	63.9



Tonal Analysis

- 3.3 The 01dB system was used to produce narrow band spectra of successive one minute samples over the duration of the audio recording. Tonal analysis in line with the requirements of BS EN 61400 – 11 was carried out on two of the samples considered to have the highest tonal content. The chosen worst case and second worst case narrow band spectra are shown in Figure 4 and Figure 5.
- 3.4 The analysis summarised in Figure 6 shows that the ‘broad’ tones centred on around 200 Hz have an audibility ($\text{dB } \Delta L_{a,k}$) of 20.2 and 19.7 in these two worst case samples. Although the band energy in any individual narrow band is not particularly high in itself, the combination of energy in all the bands making up the tonal element sum together to give a very high level of audibility when compared to the masking noise in the surrounding critical band. The spread of tonal energy is associated with the variation in speed, and hence frequency, over each one minute sample. If the speed were to be held constant then the tone peak would tend to be narrower and higher.



4. Conclusions

- 4.1 Bryan J Rendall (Electrical) Ltd have carried out noise measurements on an Eoltec Scirocco 5.6 m/6 kW Wind Turbine in accordance with BS EN 61400 part 11, in consultation with Hayes McKenzie. Hayes McKenzie analysed the data according to the same standard
- 4.2 The overall sound power level was calculated for 10 m height wind speeds of 4 to 10 m/s.
- 4.3 A third octave band spectrum was established using data for a one minute sample where wind speed was 7.7 m/s, and normalised to the overall sound power level for a wind speed of 8 m/s.
- 4.4 Narrow band spectra were established for each one minute interval of the recorded audio file. Analysis was carried out on two spectra with wind speeds of 6.9 and 6.4 m/s. The audibility ($\text{dB } \Delta L_{a,k}$) levels of the tonal content centred around 200 Hz tone during these intervals was 20.2 and 19.7.

Figures

Figure 1

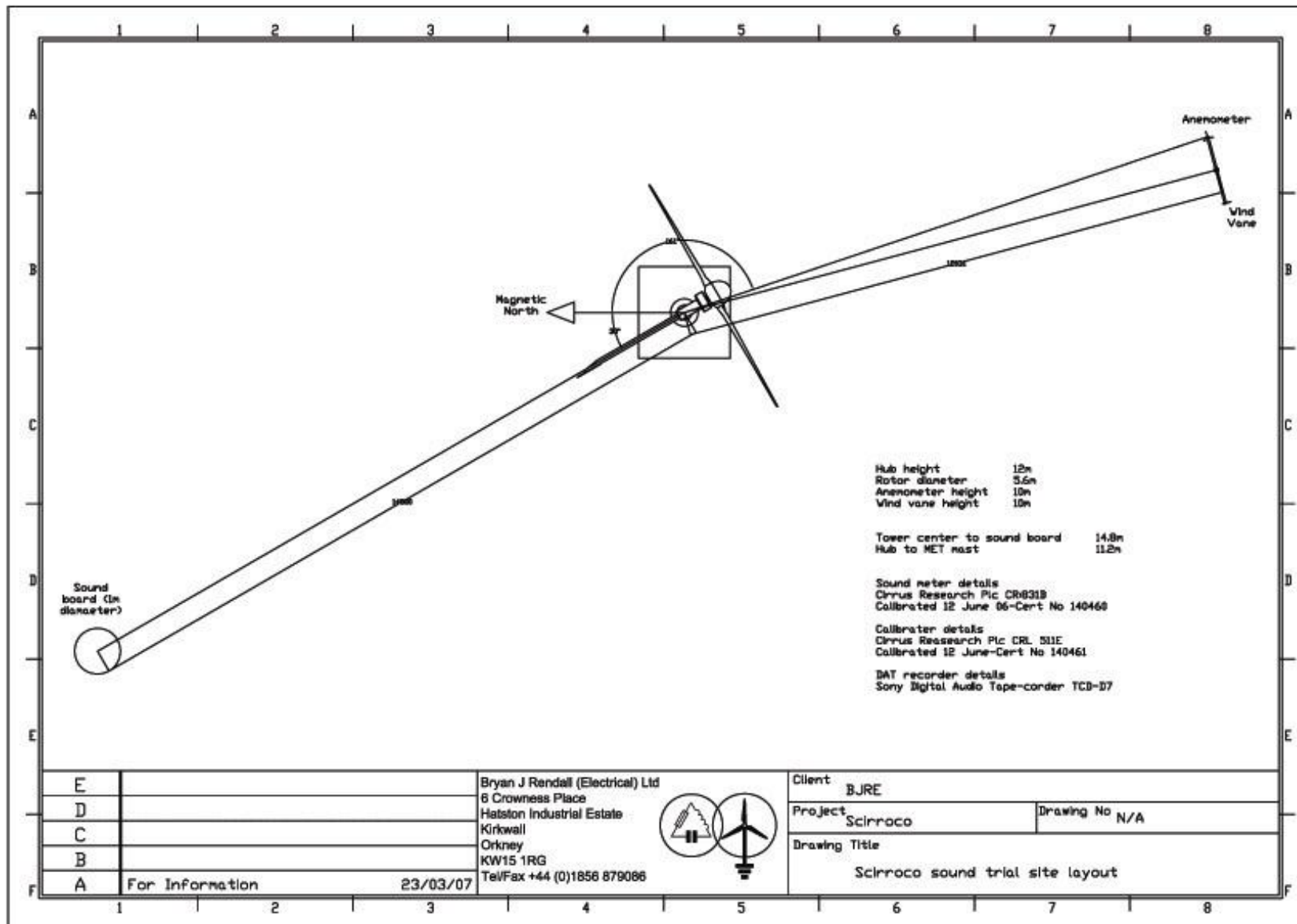


Figure 2

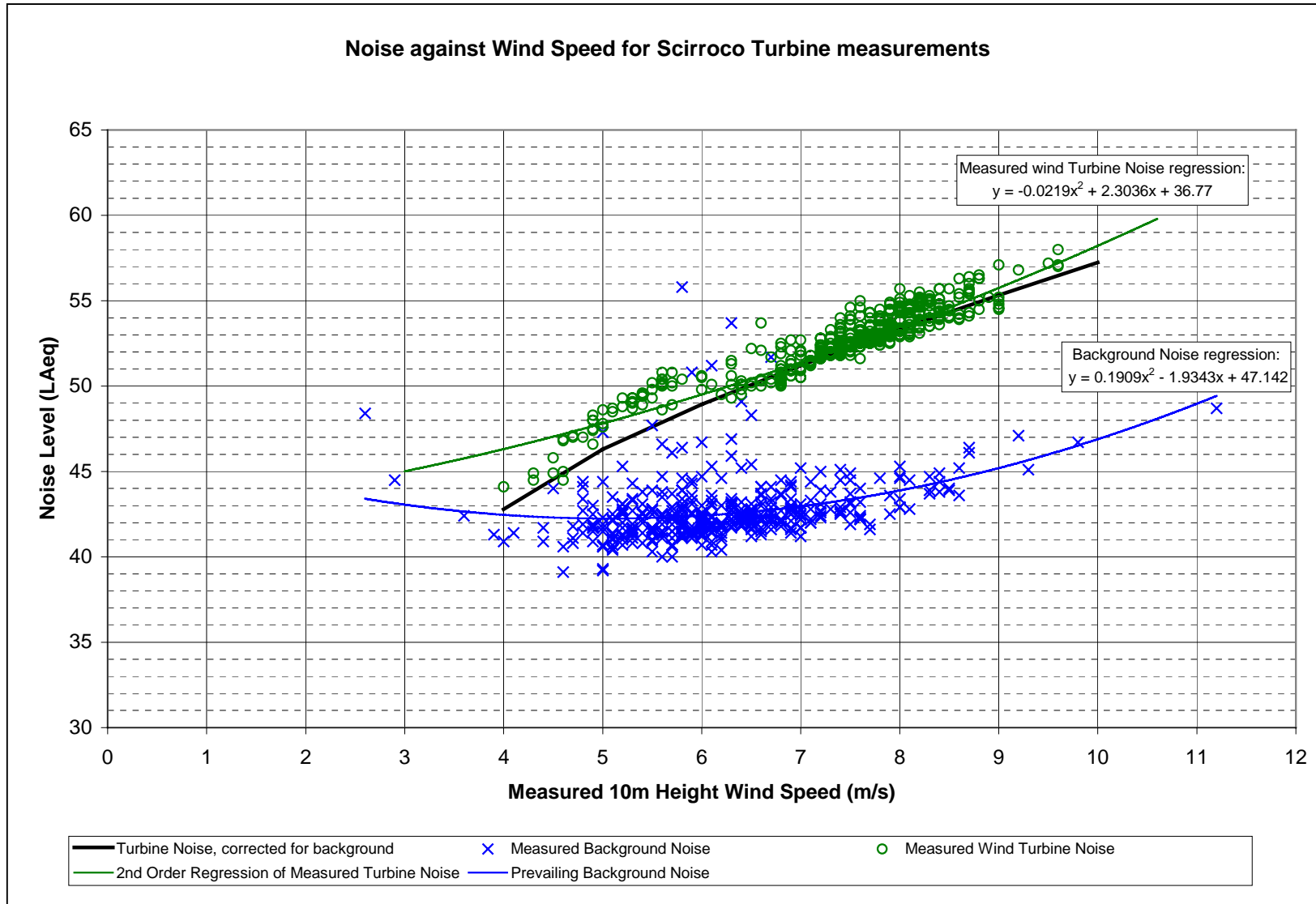


Figure 3: Third Octave band A-weighted Sound Power Level Spectrum

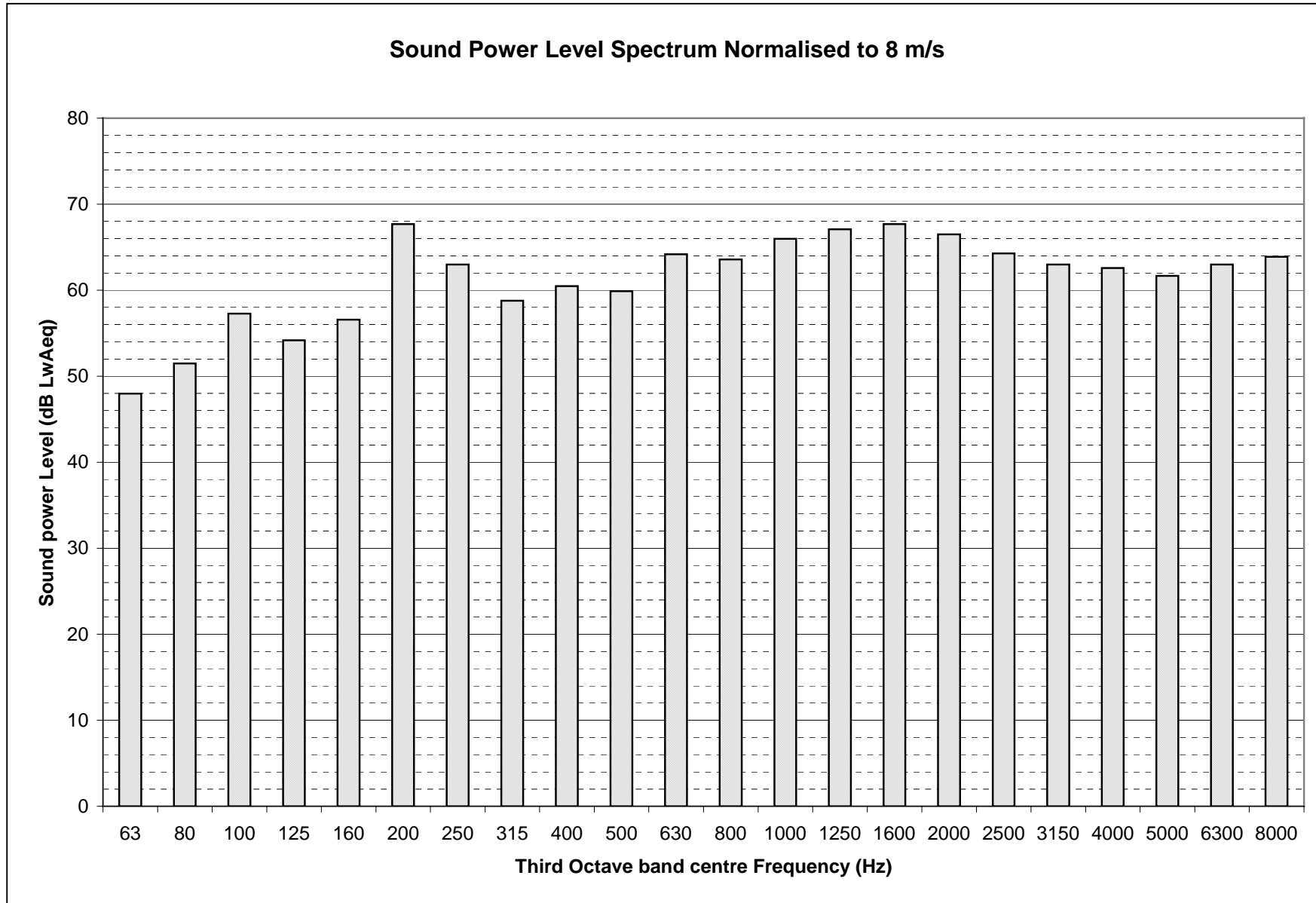


Figure 4

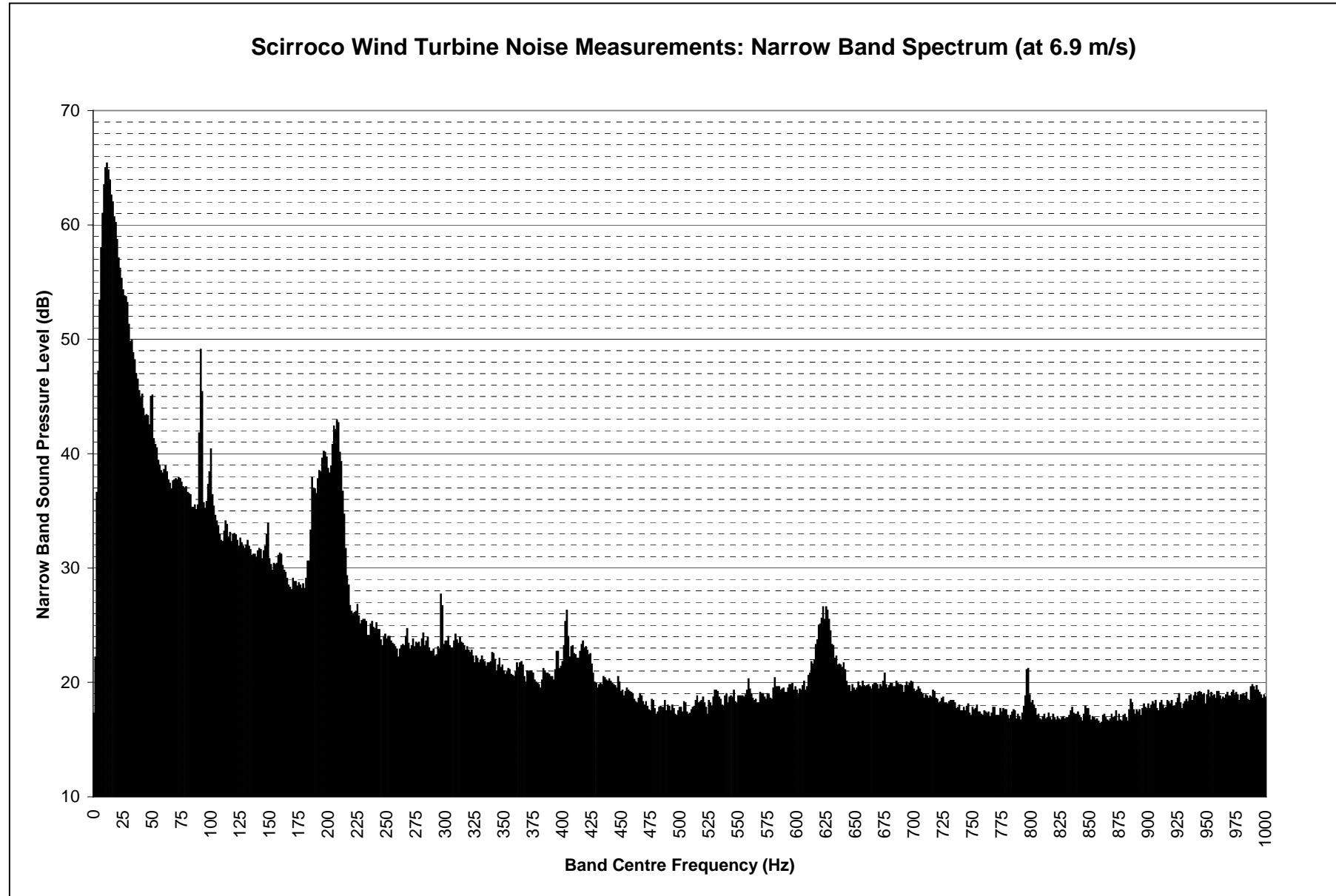


Figure 5

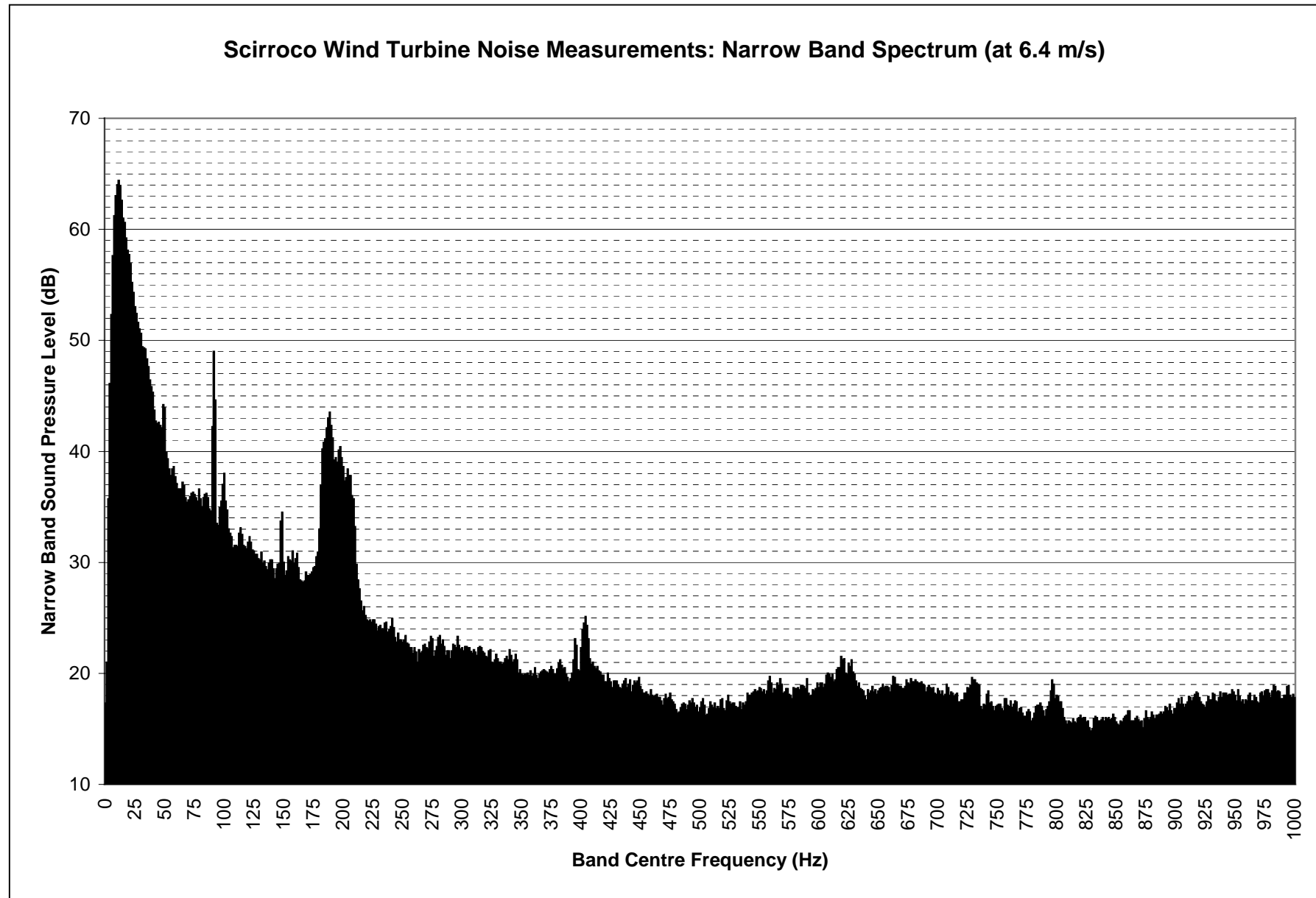


Figure 6: Tonality Calculation According to BS EN 61400-11

Centre Frequency (Fc)	205	The frequency of the centre of the tone (eyeballed from graph)
Critical Bandwidth:	103.0	$25+75*(1+1.4*(Fc/1000)^2)^{0.69}$
Range (lower limit)	153.5	The centre frequency - 0.5 Critical bandwidth
Range (upper limit)	256.5	The centre frequency + 0.5 Critical bandwidth
Energy of band:	32.1	$10*\log(\text{sum}(10^{(\text{each band level})}/10))$
L70	27.3	$10*\log(\text{sum}(10^{(\text{band levels up to 70th percentile})}/10))$
L70+6	33.3	
Lpn,avg	27.6	$10*\log(\text{average}(10^{(\text{bands with level less than L70+6 value})}/10))$
Lpn,avg+6	33.6	
Tone level (Lpt,j,k)	63.1	$10*\log(\text{sum}(10^{(\text{bands with level greater than Lpn+6})}/15))$
Masking line sum (Lpn,j,k)	27.6	$10*\log(\text{sum}(10^{(\text{bands with level less than L70+6})}/10))$
Lpnjk	45.0	$L_{pn,avg,j,k}+10*\log(\text{critical bandwidth}/1.5*\text{frequency resolution})$
Tonality ($\Delta L_{tn,j,k}$)	18.1	$L_{pt,j,k} - L_{pn,j,k}$
Audibility ($\Delta L_{a,k}$)	20.2	$DL_{tn,j,k}-(-2*\log(1+(Fc/502)^{2.5}))$

Figure 7: Tonality Calculation According to BS EN 61400-11

Centre Frequency (Fc)	188.8	The frequency of the centre of the tone (eyeballed from graph)
Critical Bandwidth:	102.6	$25+75*(1+1.4*(Fc/1000)^2)^{0.69}$
Range (lower limit)	137.5	The centre frequency - 0.5 Critical bandwidth
Range (upper limit)	240.0	The centre frequency + 0.5 Critical bandwidth
Energy of band:	32.6	$10*\log(\sum(10^{(each\ band\ level)/10}))$
L70	28.2	$10*\log(\sum(10^{(band\ levels\ up\ to\ 70th\ percentile)/10}))$
L70+6	34.2	
Lpn,avg	28.4	$10*\log(\text{average}(10^{(bands\ with\ level\ less\ than\ L70+6\ value)/10}))$
Lpn,avg+6	34.4	
Tone level (Lpt,j,k)	63.4	$10*\log(\sum(10^{(bands\ with\ level\ greater\ than\ Lpn+6)/15}))$
Masking line sum (Lpn,j,k)	28.4	$10*\log(\sum(10^{(bands\ with\ level\ less\ than\ L70+6)/10}))$
Lpnjk	45.7	$Lpn,avg,j,k+10*\log(\text{critical\ bandwidth}/1.5*\text{frequency\ resolution})$
Tonality ($\Delta L_{tn,j,k}$)	17.7	$L_{pt,j,k} - L_{pn,j,k}$
Audibility ($\Delta L_{a,k}$)	19.7	$DL_{tn,j,k}-(-2-\log(1+(Fc/502)^{2.5}))$

Indicative Receiver Levels for a Range of Wind Speeds and Separation Distances: results shown in dB LAeq.

Separation Distance (m)	Wind Speed (m/s)						
	4	5	6	7	8	9	10
25	34.0	37.6	40.2	42.5	44.6	46.6	48.6
50	28.4	32.0	34.6	36.9	39.0	41.0	43.0
75	24.8	28.4	31.0	33.3	35.4	37.4	39.4
100	22.1	25.7	28.3	30.6	32.7	34.7	36.7
125	20.0	23.6	26.2	28.5	30.6	32.6	34.6
150	18.3	21.9	24.5	26.8	28.9	30.9	32.9
175	16.8	20.4	23.0	25.3	27.4	29.4	31.4
200	15.5	19.1	21.7	24.0	26.1	28.1	30.1
225	14.4	18.0	20.6	22.9	25.0	27.0	29.0
250	13.3	16.9	19.5	21.8	23.9	25.9	27.9
275	12.4	16.0	18.6	20.9	23.0	25.0	27.0
300	11.5	15.1	17.7	20.0	22.1	24.1	26.1
325	10.7	14.3	16.9	19.2	21.3	23.3	25.3
350	10.0	13.6	16.2	18.5	20.6	22.6	24.6
375	9.3	12.9	15.5	17.8	19.9	21.9	23.9
400	8.6	12.2	14.8	17.1	19.2	21.2	23.2
425	8.0	11.6	14.2	16.5	18.6	20.6	22.6
450	7.4	11.0	13.6	15.9	18.0	20.0	22.0
475	6.8	10.4	13.0	15.3	17.4	19.4	21.4
500	6.3	9.9	12.5	14.8	16.9	18.9	20.9

These values have been calculated in accordance with ISO9613-2, Acoustics – Attenuation of sound during propagation outdoors, using worst-case assumptions throughout. The following points should be borne in mind when interpreting these results:

- The results are calculated for a single turbine operating in isolation. A group of turbines will be noisier by up to 3 dB for each doubling in the number of turbines.
- The data only extends up to 10 m/s wind speed
- The actual audibility of noise from the wind turbine is highly dependant on the existing background noise at any given location and time.