Chapter 8: Noise

Appendix 8.1 Glossary of Acoustic Terms

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8.1.1 **Ambient Noise:** The ambient noise level is the overall level of noise present at a particular location, including both the background noise and any specific noise sources.

8.1.2 **Background Noise:** The background noise level is the under lying level of noise present at a particular location for the majority (usually 90 %) of a period of time. As such it excludes any short-duration noises, such as individual passing cars (but not continuous traffic), dogs barking or passers by. Sources of background noise typically include such things as wind noise, traffic and continuously operating machinery (e.g. air conditioning or generators).

8.1.3 **Specific Noise:** This term is used to refer to a particular noise source that is being discussed or investigated and that while it may form a component of the ambient noise, is distinct from the background noise. In the context of the preceding chapter, the noise from wind turbines could be considered as a specific noise source.

8.1.4 **Decibel (dB):** The decibel is the basic unit of noise measurement. It relates to the pressure created by the sound (Sound Pressure Level) and operates on a logarithmic scale, ranging upwards from 0 dB. 0dB is equivalent to the normal threshold of hearing at a frequency of 1000Hz. Each increase of 3 dB on the scale represents a doubling in the Sound Pressure Level, and is typically the minimum noticeable change in sound level under normal listening conditions. For example, while an increase in noise level from 32 dB to 35 dB represents a doubling in sound pressure level, this change would only just be noticeable to the majority of listeners.

8.1.5 **dB(A):** Environmental noise levels are usually discussed in terms of dB(A). This is known as the A-weighted sound pressure level, and indicates that a correction factor has been applied, which corresponds to the human ear's response to sound across the range of audible frequencies. The ear is most sensitive in the middle range of frequencies (around 1000-3000Hz), and less sensitive at lower and higher frequencies. The A-weighted noise level is derived by analysing the level of a sound at a range of frequencies and applying a specific correction factor for each frequency before calculating the overall level. In practice this is carried out automatically within noise measuring equipment by the use of electronic filters, which adjust the frequency response of the instrument to mimic that of the ear.

8.1.6 A scale of common noise sources compared to wind turbines is presented below (Source: PAN45).

Source/Activity	Indicative Noise Level dB(A)
Threshold of Pain	140
Jet aircraft at 250 m	105
Pneumatic drill at 7 m	95
Truck at 30 mph at 100 m	65
Busy general office	60
Car at 40 mph at 100 m	55
Wind farm at 350 m	35-45
Quiet bedroom	20

Source/Activity	Indicative Noise Level dB(A)
Rural night-time background	20-40
Threshold of hearing	0

8.1.7 **Free Field:** This term refers to a location where the propagation (movement) of sound is not affected by the presence of obstacles or surfaces which would cause reflections (echoes).

8.1.8 **Frequency:** The frequency of a sound is equivalent to its pitch in musical terms. The units of frequency are Hertz (Hz), which represents the number of cycles (vibrations) per second.

8.1.9 **$L_{A90,t}$:** This term is used to represent the A-weighted sound pressure level that is exceed for 90 % of a period of time, t. This is used as a measure of the background noise level.

8.1.10 **$L_{Aeq,t:}$** This term is known as the A-weighted equivalent, continuous sound pressure level for a period of time, t. It is similar to an average, and represents the sound pressure level of a sound of continuous intensity that would result in an equal quantity of sound energy as a sound which varies in intensity.

8.1.11 **Low frequency noise**: Noise at the lower end of the range of audible frequencies (20 Hz – 20 kHz). Usually refers to noise below 250 Hz. Should not be confused with infrasound, which is sound below the lowest audible frequency, 20 Hz.

8.1.12 **Noise:** Unwanted sound. May refer to both natural (e.g. wind, birdsong etc) and artificial sounds (e.g. traffic, noise from wind turbines, etc).

8.1.13 **Noise contour plot**: A diagram showing lines of equal sound levels in a similar manner to height contours on an Ordnance Survey map or isobars (lines of equal pressure) on a weather map.

8.1.14 **Noise sensitive receptors:** Locations that may potentially be adversely affected by the addition of a new source of noise. Can include residential properties, outdoor areas and sensitive species.

8.1.15 **Sound power (W):** The sound energy radiated per unit time by a sound source, measured in watts (W).

8.1.16 **Sound power level (L_w):** Sound power measured on the decibel scale, relative to a reference value (Wo) of 10-12W.

8.1.17 **Sound pressure (P):** The fluctuations in atmospheric pressure relative to atmospheric pressure, measured in Pascals (Pa).

8.1.18 **Sound pressure level (L_p):** Sound pressure measured on the decibel scale, relative to a sound pressure of 2 x 10-5 Pa.

8.1.19 **Tonal element:** A characteristic of a sound where the sound pressure level in a particular frequency range is greater than in those frequency ranges immediately above higher or lower. This would be perceived as a humming or whining sound.

8.1.20 **Vibration:** In this context, refers to vibration carried in structures such as the ground or buildings, rather than airborne noise.

Appendix 8.2 Background Information on Wind Turbine Noise

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Overview

8.2.1 Wind turbine noise is generated by the rotation of the turbine blades. This only occurs above the 'cut-in' wind speed and below the 'cut-out' wind speed. Below the cut-in wind speed there is insufficient energy in the wind to generate electricity and above the cut-out wind speed the turbine is automatically shut down to prevent any malfunctions or damage occurring. The cut-in wind speed at turbine hub height is normally around 4 metres per second (ms-1) and the cut-out wind speed is normally around 25 ms-1.

8.2.2 As the blades rotate in the air, aerodynamic noise is generated, which sounds like a swishing noise. Noise is also produced by the internal machinery, i.e. gearbox and, to a lesser extent, the generator (mechanical noise). The blades are aerodynamically efficient such they extract the maximum 'turning energy' from the wind, which means that any noise produced is minimised. The hub at the top of the tower is usually insulated to minimise noise radiation from the gearbox, generator and other components. The hub is also isolated from the tower and the blade assembly to prevent structure borne noise occurring, which in turn prevents any vibrations being transmitted to the ground.

The Assessment & Rating of Noise from Wind Farms – The Working Group on Noise from Wind Turbines (Report ETSU-R-97)

8.2.3 In 1993 a working group was established by the DTI to examine the difficulties experienced in applying various noise guidelines to wind farm noise assessments. The ETSU-R-97 report is the result of the group's work and the use of the methodology set out in ETSU-R-97 is recommended in PAN 1/2011.

8.2.4 In Scotland there have as yet been no decisions made by Scottish Ministers in relation to wind farm planning applications which have not applied the ETSU-R-97 assessment procedure or noise limits.

8.2.5 ETSU-R-97 recommends that noise limits should be applied to external locations used for relaxation or where a quiet environment is highly desirable. These limits should be set relative to prevailing background noise and should reflect the variation in both the wind turbine source noise and background noise with wind speed. Separate noise limits apply for daytime and for night time as during the night the protection of external amenity becomes less important and the emphasis should be on preventing sleep disturbance.

8.2.6 The noise limits proposed by ETSU-R-97 are based on the $L_{A90,10min}$ parameter, assuming free field conditions. Quiet daytime is defined as 1800 – 2300h every day, as well as 1300 – 1800h on Saturday and 0700 – 1800h on Sundays. Night time is 2300 – 0700h.

8.2.7 ETSU-R-97 proposes an operational noise limit ($L_{A90,10min}$) of 5 dB above the derived background noise level at each wind speed up to 12m/s. This is based on wide experience in environmental acoustics that noise from a new source is unlikely to cause annoyance where the predicted increase is less than 5 dB(A) above the existing background. In addition, an allowance is included for a fixed limit to be applied at wind speeds or locations where background noise levels are low. Where the quiet daytime background noise level is equal to or less than 30-35 dB $L_{A90,10min}$, the limit is defined as 35-40 dB $L_{A90,10min}$. The quiet daytime limit also applies to all other daytime periods, with the limits based on the quiet daytime background noise level.

8.2.8 A lower fixed limit of 43 dB $L_{A90,10min}$ (derived from World Health Organisation Guidelines on noise levels that can cause sleep disturbance) is recommended for night-time at wind speeds or locations where the background noise level is equal to or less than 38 dB $L_{A90,10min}$. This is relevant to the assessment as in rural areas the background can be significantly quieter at night. Where background noise levels exceed 38 dB $L_{A90,10min}$ the limit is set to 5 dB above the background noise level.

Prediction and Assessment of Wind Farm Noise Acoustics Bulletin Vol34 No2 (March / April 2009)

8.2.9 The technical paper *Prediction and Assessment of Wind Turbine Noise* was published in the Acoustics Bulletin in 2009. Written by an independent team of noise consultants, the paper considers additional aspects which should be addressed in the assessment of wind farm noise in addition to the requirements of ETSU-R-97. Although the paper has no particular status in planning terms, the recommendations are generally accepted to be good practice.

8.2.10 Specifically, two key issues are addressed: local wind shear and parameters for predicting noise immission levels.

8.2.11 The paper suggests a procedure for undertaking correction for local wind shear effects, including the appropriate heights of anemometers relative to hub height and methodology for correcting the measured levels to a standardised 10 m height using the reference roughness length of 0.05 m.

8.2.12 Recommended modelling parameters for the prediction of noise immission levels include assumptions for atmospheric conditions, ground factors in relation to the quality of the manufacturer’s test data and minimising assumed barrier attenuation relating to topography.

8.2.13 The paper also comments on vibration and low frequency noise levels, concluding that *there is no robust evidence that low frequency noise (including ‘infrasound’) or ground-borne vibration from wind farms generally has adverse effects in wind farm neighbours*.

Low Frequency Noise

8.2.14 Noise from modern wind turbines is essentially broadband in nature in that it contains similar amounts of noise energy in all frequency bands from low to high frequency. As the distance from a wind farm site increases, the noise level decreases as a result of the geometric spreading of the sound energy, but also due to air absorption which increases with increasing frequency. Accordingly, higher frequencies are attenuated more than lower frequencies.

8.2.15 A 2006 DTI study measured low frequency noise at three properties. The level of low frequency noise was below the criterion values recommended by Defra (2005). Therefore, low frequency noise levels from wind farms are not considered to be significant.

Infrasound

8.2.16 Infra-sound is defined as noise occurring at frequencies below 20Hz, which is considered to be the lowest frequency which is normally audible. In this frequency range, for sound to be perceptible, the amplitude of the sound has to be very high. It is generally considered that when such sounds are perceptible, then they can cause considerable annoyance.

8.2.17 Wind farms have often been cited as significant producers of infra-sound. Old technology wind turbines used to produce an audible low frequency thumping sound. These turbines were known as ‘downwind’ turbines and were common in the USA. Downwind turbines are configured with the blades downwind of the tower, such that the blades pass through the turbulent wake left in the wind stream by the tower resulting in a regular audible thump, with infra-sonic components, each time a blade passes the tower. Virtually all turbines installed in the UK nowadays are upwind turbines. In this configuration, the blades are upwind of the tower, such that this ‘thumping’ effect is eliminated.

8.2.18 A study carried out for the DTI (Salford 2005) concluded that:

> *“Infrasound noise emissions from wind turbines are significantly below the recognised threshold of perception for acoustic energy within this frequency range. Even assuming that the most sensitive members of the population have a hearing threshold which is 12dB lower than the median hearing threshold, measured infrasound levels are well below this criterion”.*

8.2.19 The study goes on to state that based on information from the World Health Organisation:

> *“there is no reliable evidence that infrasounds below the hearing threshold produce physiological or psychological effects’ it may be concluded that ‘infrasound associated with modern wind turbines is not a source which may be injurious to the health of a wind farm neighbour.”*

Amplitude Modulation of Aerodynamic Noise

8.2.20 It is acknowledged in ETSU-R-97 that all wind turbines exhibit blade swish to a certain extent and that the noise limits specified in those recommendations take this into account without requiring any correction to be applied.

8.2.21 Work carried out to investigate the extent of low frequency and infrasonic noise received from three UK wind farms (DTI 2006) concluded that:

> *“the common cause of complaints associated with noise at all three wind farms is not associated with low frequency noise, but is the audible modulation of the aerodynamic noise, especially at night”.*

8.2.22 It suggests that:

> *“it may be appropriate to re-visit the issue of aerodynamic modulation and the means by which it should be assessed”.*

8.2.23 In 2007 the University of Salford investigated the amplitude modulation of aerodynamic noise (which essentially means ‘varying noise level’) on behalf of the DTI. The objectives of the study were:

- to establish the levels and nature of the reported noise complaints received across the UK relating to noise issues from wind farms, both historic and current, and determine whether AM is a significant effect;
- to review and understand the level of knowledge/understanding that exists throughout the world on AM, and whether AM can be predicted.

8.2.24 In July 2007 The Department for Business, Enterprise and Regulatory Reform (BERR formerly DTI) stated:

"The Salford University study has now been published. The study concluded that although AM cannot be fully predicted, the incidence of AM resulting from wind farms in the UK is low. Out of the 133 wind farms in operation at the time of the study, there were four cases where AM appeared to be a factor. Complaints have subsided for three out of these four sites, in one case as a result of remedial treatment in the form of a wind turbine control system. In the remaining case, which is a recent installation, investigations are ongoing.

8.2.25 Based on these findings, there is no compelling case for further work into AM and no further research will be carried out at this time; although the issue will remain under review.

A good practice guide to the application of ETSU-R-97 for the assessment and rating of wind turbine noise **Institute of Acoustics (IoA) May 2013**

8.2.26 In May 2013, the IoA launched their Good Practice Guide for the assessment noise from wind farms.

8.2.27 Essentially, the purpose of this document was to address the recommendations made in the Hayes McKenzie Partnership report *Analysis of how noise impacts are considered in the determination of wind farm planning applications* and to establish best practice in the application of ETSU-R-97.

8.2.28 The document does not seek to address the appropriateness of the day and night time limits for operational noise described in ETSU-R-97 as it considers that this is a matter for Government and not the IoA.

8.2.29 The recommendations of the Good Practice Guide have been adopted in the assessment of West Benhar Wind Farm, wherever possible, however it should be noted that its publication coincided with completion of the assessment.

References

- W/45/00656/00/00 The Measurement of Low Frequency Noise at Three UK Windfarms. Department of Trade and Industry 2006.
- DEFRA NANR45 Project Report Proposed Criteria for the Assessment of Low Frequency Noise Disturbance Moorhouse A., Waddington D, & Adams M. University of Salford 2005.
- University of Salford, 'Research into Amplitude Modulation of Wind Turbine Noise'. April 2007, NANR233.

Appendix 8.3 Noise Modelling and Assessment Details

Appendix 8.3 Noise Modelling and Assessment Details

Overview

8.3.1 There is no wind farm specific British or International Standard which prescribes the method to calculate wind turbine noise emissions.

8.3.2 However, it is generally accepted by UK acoustic consultants that wind farm noise is calculated according to ISO 9613-1 and ISO 9613-2 *Acoustics – Attenuation of sound during propagation outdoors*. Although there are other sound propagation methodologies, the ISO is regarded as a useful tool when calculating sound emission levels.

8.3.3 Due to the complexity of the equations contained within parts 1 and 2 of the ISO, it is standard practice to undertake these calculations using commercially available computer modelling software programmes. These programmes are fully quality assured and assuming that the correct input data is used then the results are highly unlikely to be subject to any user generated errors.

8.3.4 Parts 1 and 2 of ISO 9613 are incorporated within SoundPLAN sound modelling software. SoundPLAN was used to generate the scheme and cumulative operational noise levels at the identified NSR.

Wind Turbine Modelling

8.3.5 As with any noise modelling exercise there are a number of potential constraints which will influence the accuracy/uncertainty of any calculated sound levels and these are discussed below.

8.3.6 The ISO provides calculation procedures for the following physical effects:

- Geometric divergence (A_{div}) - reduction in sound level due to distance - (not frequency dependent);
- Atmospheric absorption (A_{atm}) - absorption of sound by the air (frequency dependent);
- Ground effect (A_{gr}) - absorption of sound by the ground (frequency dependent);
- Reflection from surfaces (not frequency dependent, rarely employed for wind farms);
- Screening by obstacles (A_{bar}) - shielding by a feature or the ground, this causes a reduction in the noise level (frequency dependent);
- Miscellaneous effects (A_{misc}) - such as propagation through trees.

8.3.7 These effects are combined with the sound power level of the turbine (Lw) in the following equation to derive the sound pressure level (Lp) for each turbine.

$$Lp = Lw - (A_{div} + A_{atm} + A_{gr} + A_{bar} + A_{misc})$$

8.3.8 For the purposes of modelling, a wind turbine is considered to have a single emission point at hub height. Within SoundPLAN the turbines are modelled as an industrial point source at the hub height of the proposed turbines and single spot receivers are used to calculate the combined noise emission level from all turbines at the closest NSRs. There are no corrections for the directivity of the sound emitted from the turbine.

8.3.9 The SoundPLAN model does not take into account the shielding effects of barriers or buildings or miscellaneous effects such as the influence of sound propagation through foliage.

8.3.10 Manufacturer's guaranteed noise emission data has been used in the prediction process and are reproduced in Chapter 8.

8.3.11 Where audible tones are present in the wind turbine noise spectrum, ETSU-R-97 recommends that a tonal penalty should be added, based on the level of the tone above the masking noise.

8.3.12 The manufacturer's data sheet for the RePower 3.4MW states that *RePower warrants that there is no tonal audibility >0dB*. No further correction is therefore considered necessary.

8.3.13 The sound power levels are based on the assessment approach stated in International Standard IEC-61400-11 *Wind turbine generator systems – Part 11: Acoustic noise measurement techniques*. The Standard enables the overall A-weighted sound power and one-third octave band spectrum to be obtained at normalised integer wind speeds. It also enables the directivity and the tonality of the noise emission to be determined.

Assessment Assumptions

8.3.14 The assessment was based on the methodology specified in ISO 9613. Conservative assumptions have been made in the modelling process and it is more likely that the model will over-predict than under-predict noise levels. The assumptions made were:

- Air Pressure = 1013.25 mbar;
- Relative Humidity = 70 %;
- Temperature = 10°C;
- Mixed-ground attenuation occurred between the turbines and the NSRs (G=0.5);
- Manufacturer's guaranteed sound power levels;
- Octave band frequency spectra has been used in the calculations;
- Receiver calculation height of 4.0 m.

8.3.15 Possible uncertainties in the modelling approach may arise from the use of the ground effect methods in section 7.3 of ISO9613-2. The ISO suggests two methods:

- Method 1 - spectral dependent term and is applicable to ground which is generally flat, either horizontally or with a constant slope;
- Method 2 - applicable to ground surfaces of any shape but is only used when the overall sound pressure level is of interest, i.e. not spectral dependent.

8.3.16 Method 1 was used to derive the wind turbine noise levels presented within the ES assessment since the ground is generally sloping with no significant changes in elevation across the sites and spectral data was available for the turbine sound levels.

8.3.17 The ISO 9613 method predicts noise levels likely to occur under conditions favourable to noise propagation, i.e. downwind or under a moderate ground-based temperature inversion that may occur at night. Additional meteorological conditions, as described in ISO 9613, were not considered further as charts in ISO 9613 show there is negligible change to the noise level and during extreme meteorological conditions background noise levels would raise inline with the turbine noise.

Site Specific Issues

8.3.18 In addition to the potential uncertainties that may be introduced by means of calculating the wind turbine noise level, there may also be uncertainties introduced by the method of deriving the location specific wind varying background noise level.

8.3.19 Appendix C of ETSU-R-97 provides commentary on the measurement of background noise data and the use of regression analysis to derive the prevailing wind varying background noise level. ETSU-R-97 notes that care must be taken when deriving background noise levels at the extremes of the data, i.e. at the low and high wind speed ends of the data. The situation could arise that at low wind speeds the derived line increases with decreasing wind speed or similarly the derived line decreases with increasing wind speed. These two situations are counterintuitive, i.e. the line should level off at the extremes of the data. Therefore the choice of regression analysis is important and it is often appropriate to use a combination of linear, 2nd or 3rd order polynomial 'data-fits' to ensure the highest correlation and most sensible regression analysis.

References

- ISO 9613-2, Acoustics - Attenuation of Sound During Propagation Outdoors. International Organization for Standardization, 1996.

Appendix 8.4 Wind Shear Assessment

Appendix 8.4 Wind Shear Assessment

8.4.1 As previously discussed, the IoA Bulletin Article *Prediction and Assessment of Wind Turbine Noise* recommends a methodology for the correction of local wind speed data to a standardised 10 m above local ground height which is endorsed in the IoA Good Practice Guide. This correction is considered to compensate for any local wind shear effects.

8.4.2 A wind shear analysis has been undertaken to inform the West Benhar Wind Farm technical assessment. The 10 minute average wind speed at proposed turbine maximum hub height (80m) was calculated using the ratio of wind speeds measured simultaneously at anemometer heights of 30 m and 70 m on the anemometry mast. A standardised extrapolation to 10 m was subsequently undertaken using a standard roughness length of 0.05 m. It should be noted that the relative heights of the anemometers in relation to maximum hub height do not match exactly the requirements of the methodology set out in the IoA Bulletin article, which requires one anemometer to be at 40-50 % of hub height and a second at greater than 60 % hub height. These specific requirements were not taken into account in the met mast design. It is considered, however, that the calculation undertaken provides adequate assessment of any local wind shear effects, given that the lower height (30m) is representative of 38% hub height, which is close to the requirement for 40%. The higher height (70m) meets the IoA Bulletin recommendation of greater than 60% of hub height.

8.4.3 Manufacturer's data on wind turbine sound power noise emissions are derived according to the International Standard IEC 61400:11. This requires that measured noise emissions are related to 10m height wind speeds calculated from hub height wind speeds using a standard equation of the form:

$$U_2 = U_1 \cdot \frac{\ln\left({H_2}/{z} \right)}{\ln\left({H_1}/{z} \right)}$$

Where:-

H_1 The height of the upper wind speed measurement

H_2 The height of the lower wind speed to be calculated

U_1 The measured wind speed at H_1

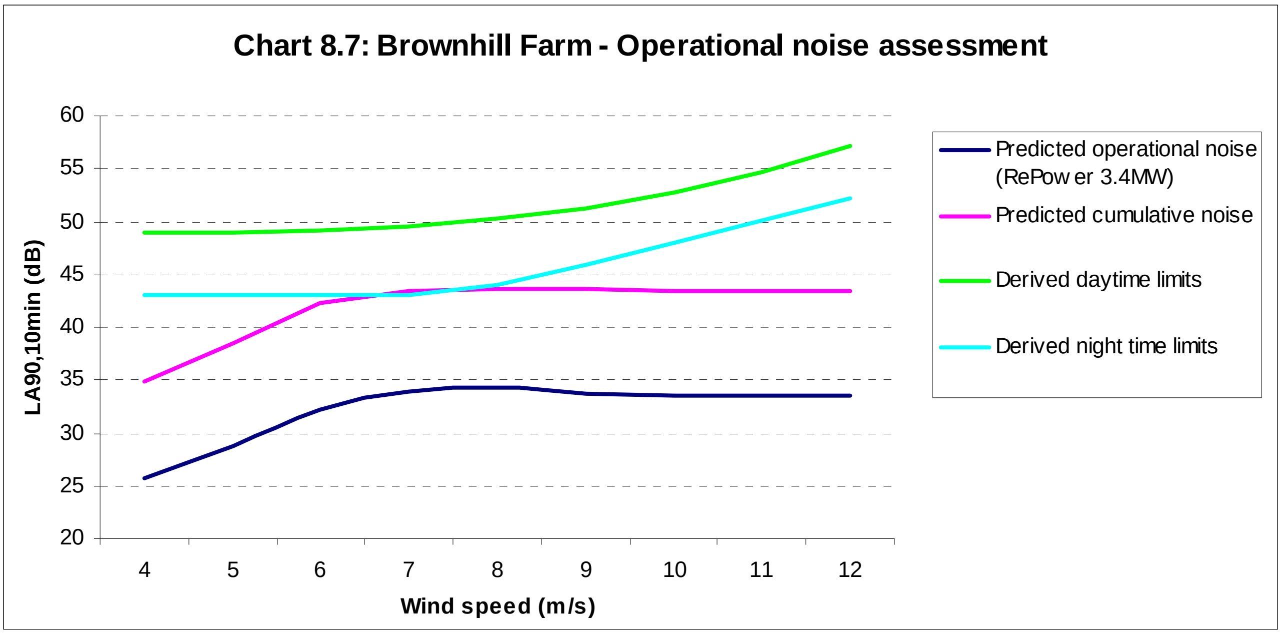
U_2 The calculated wind speed at H_2

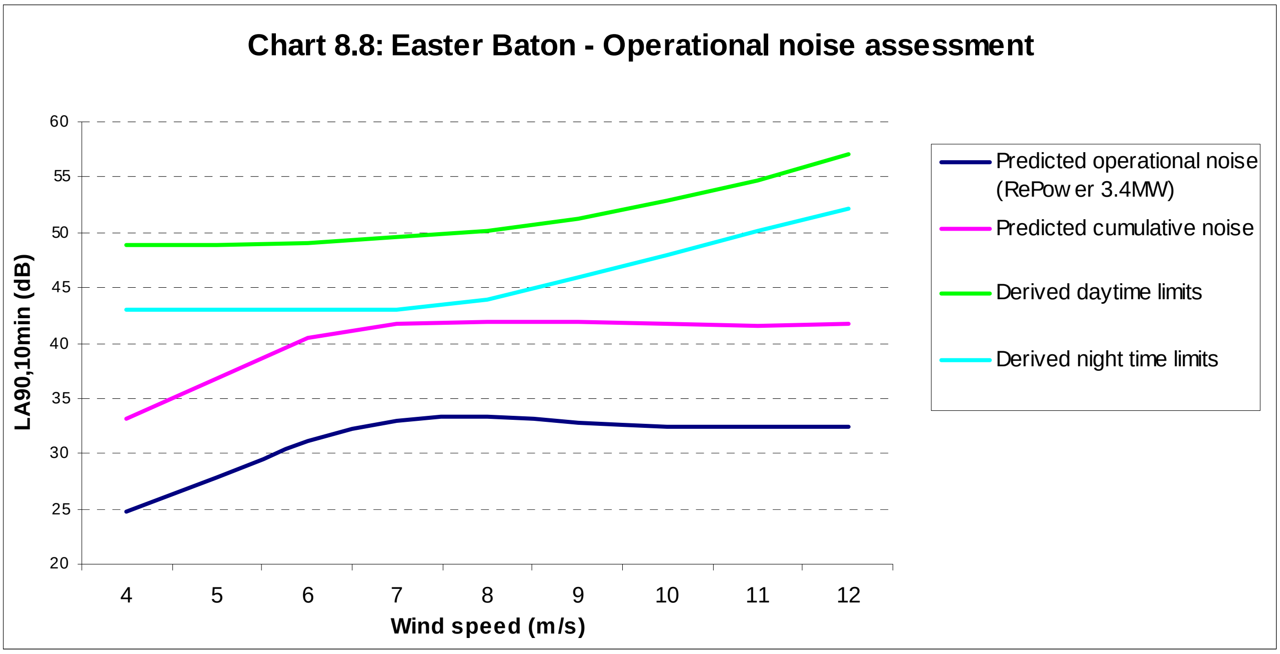
z The roughness length (m)

8.4.4 The equation uses a roughness length to calculate the wind speeds at other heights to the one measured. When used for provision of sound emission data, a standard, or reference, roughness length is used with a value of 0.05 m. The standard roughness length approximates to that found on open grassland. The local wind shear correction has been used to derive the wind speed at hub height, which in this case is 80m and then using the standard roughness of 0.05, the derived standardised wind speed at 10 m can then be calculated.

Appendix 8.5 Charts 8.7 to 8.14

Appendix 8.5 Charts 8.7 to 8.14





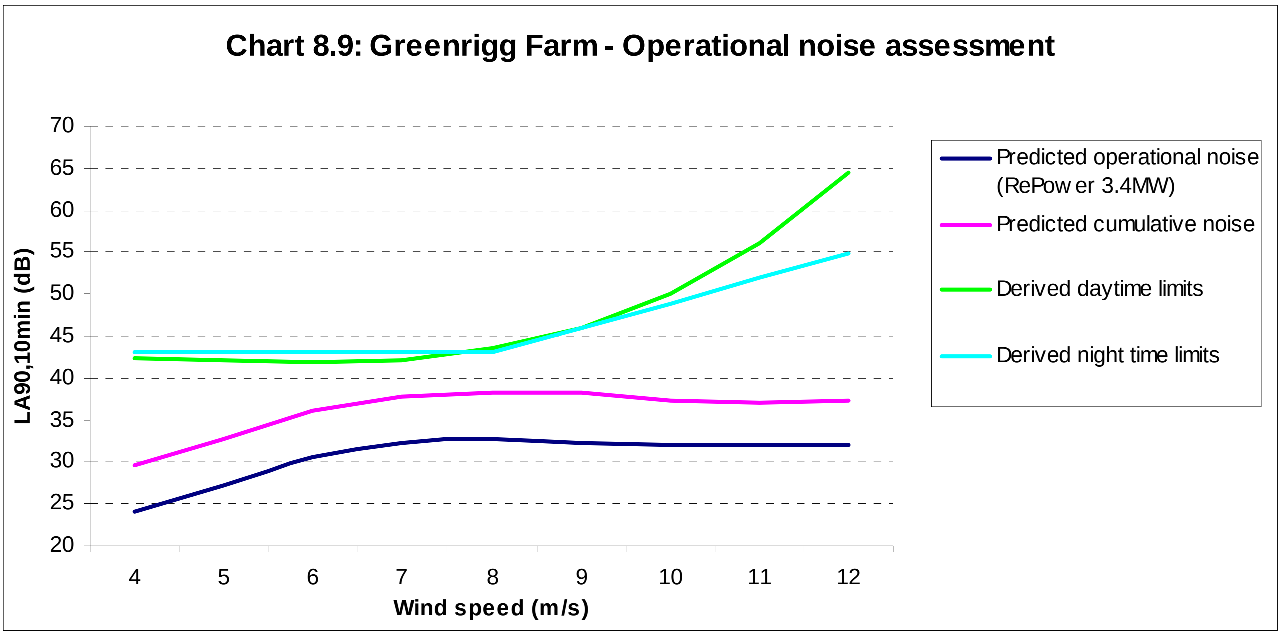


Chart 8.9: Greenrigg Farm - Operational noise assessment
LA90,10min (dB)
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Wind speed (m/s)
Predicted operational noise (RePower 3.4MW)
Predicted cumulative noise
Derived daytime limits
Derived night time limits

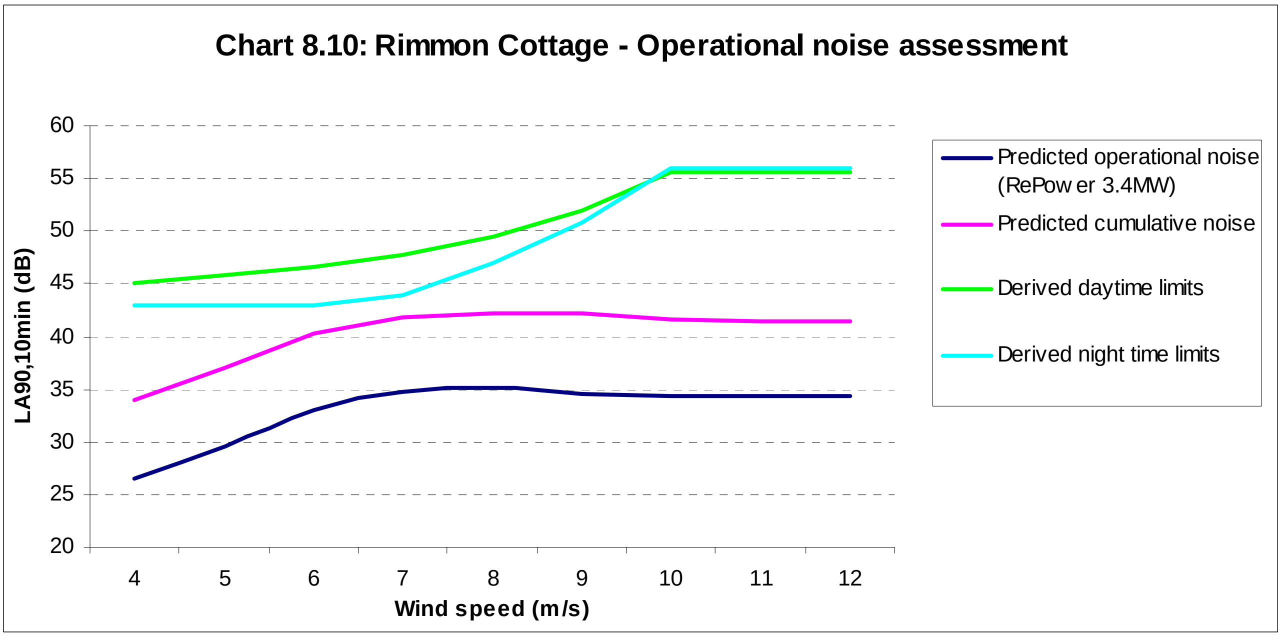
Chart 8.10: Rimmon Cottage - Operational noise assessment
LA90,10min (dB)
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Wind speed (m/s)
Predicted operational noise (RePower 3.4MW)
Predicted cumulative noise
Derived daytime limits
Derived night time limits

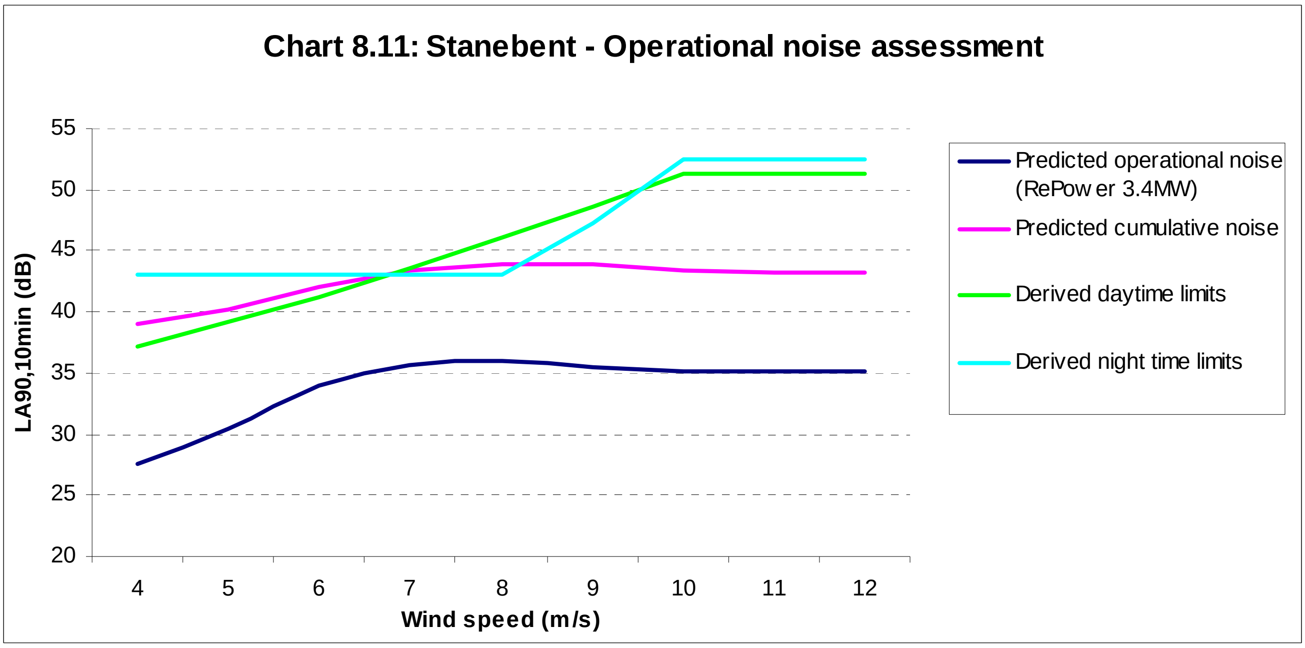
Chart 8.11: Stanebent - Operational noise assessment
LA90,10min (dB)
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Wind speed (m/s)
Predicted operational noise (RePow er 3.4MW)
Predicted cumulative noise
Derived daytime limits
Derived night time limits

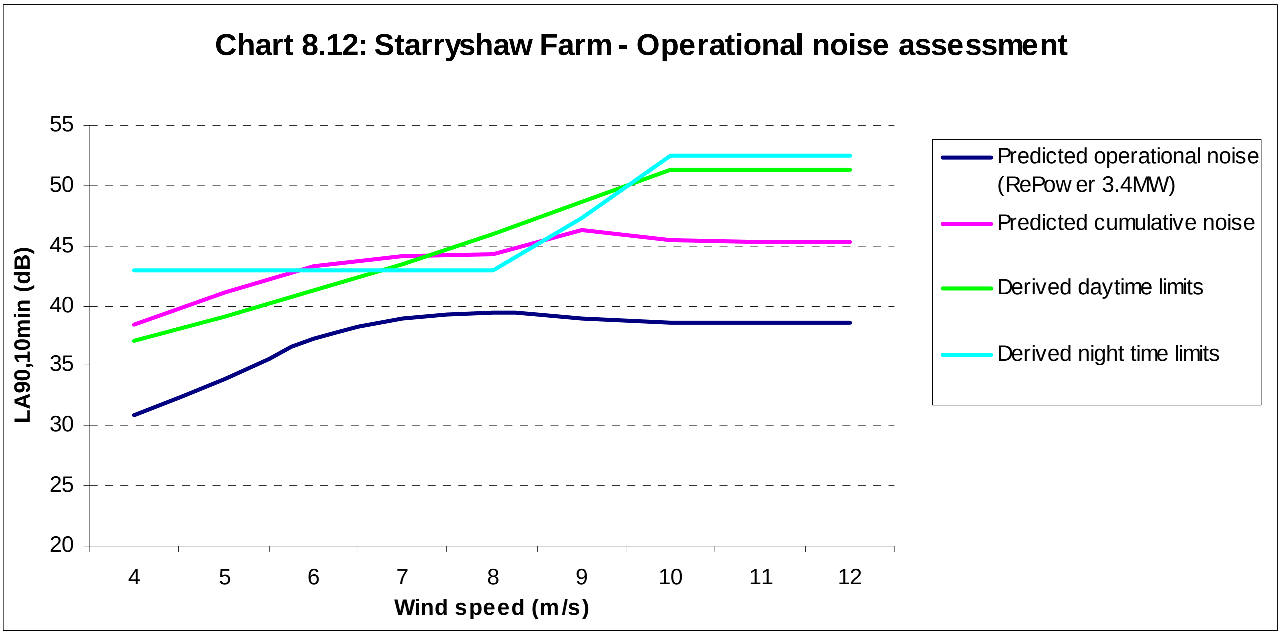
Chart 8.12: Starryshaw Farm - Operational noise assessment
LA90,10min (dB)
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Wind speed (m/s)
Predicted operational noise (RePow er 3.4MW)
Predicted cumulative noise
Derived daytime limits
Derived night time limits

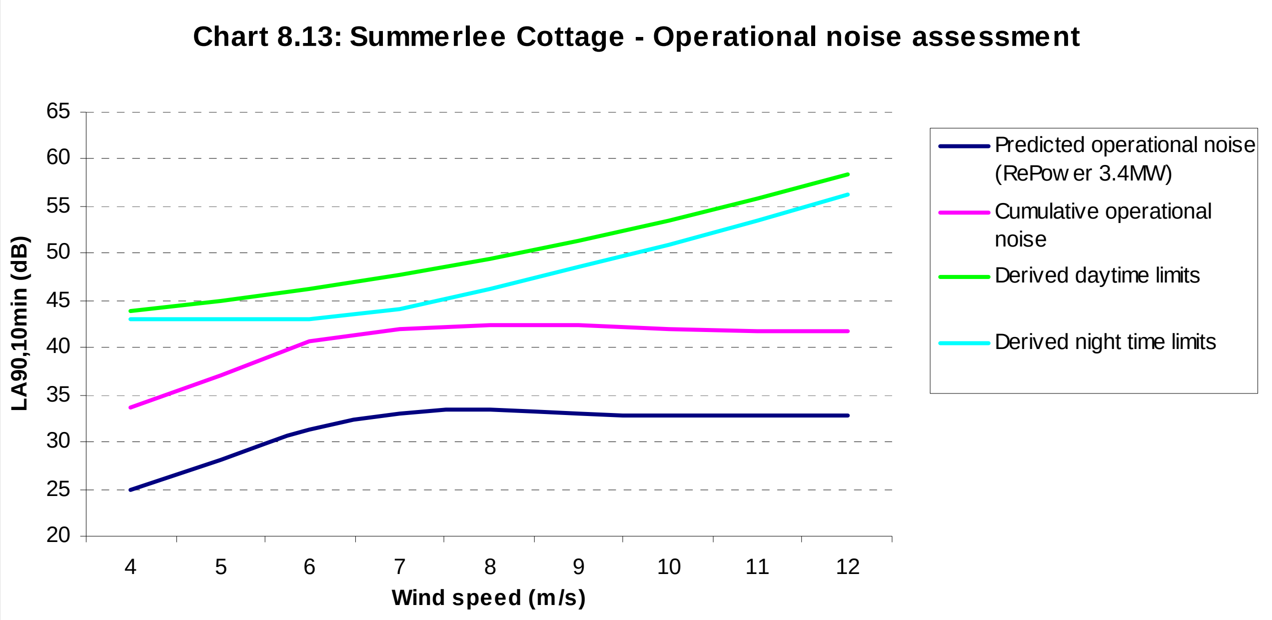
Chart 8.13: Summerlee Cottage - Operational noise assessment
LA90,10min (dB)
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Wind speed (m/s)
Predicted operational noise (RePower 3.4MW)
Cumulative operational noise
Derived daytime limits
Derived night time limits

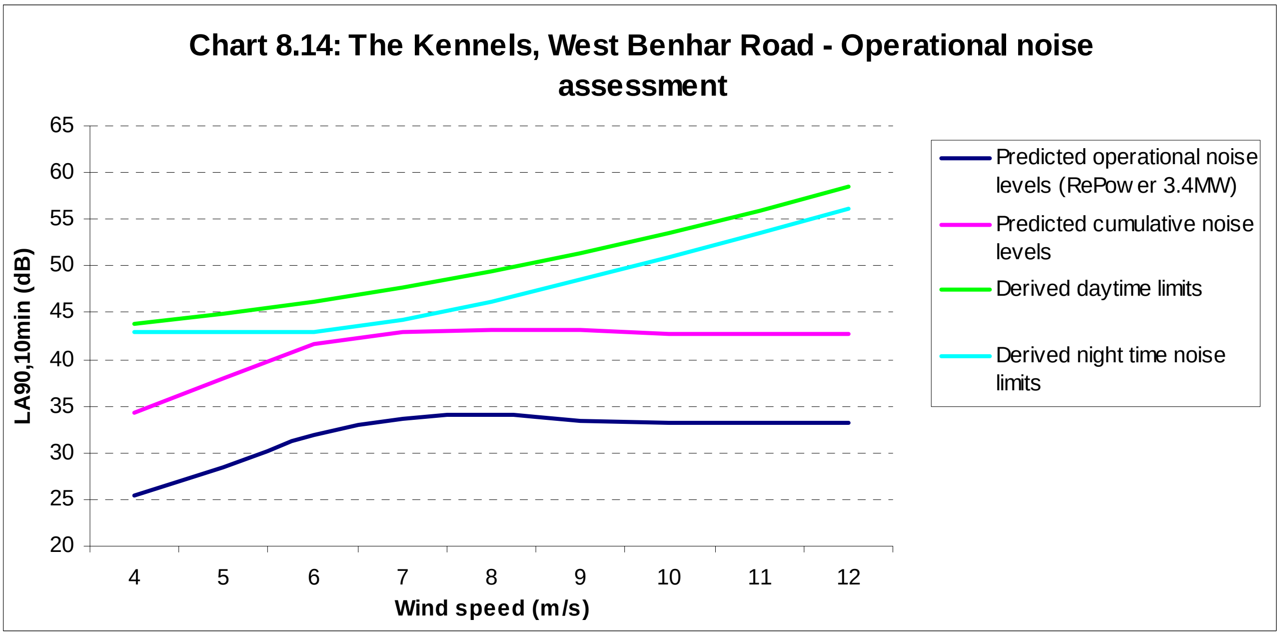
Chart 8.14: The Kennels, West Benhar Road - Operational noise assessment
LA90,10min (dB)
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Wind speed (m/s)
Predicted operational noise levels (RePower 3.4MW)
Predicted cumulative noise levels
Derived daytime limits
Derived night time noise limits