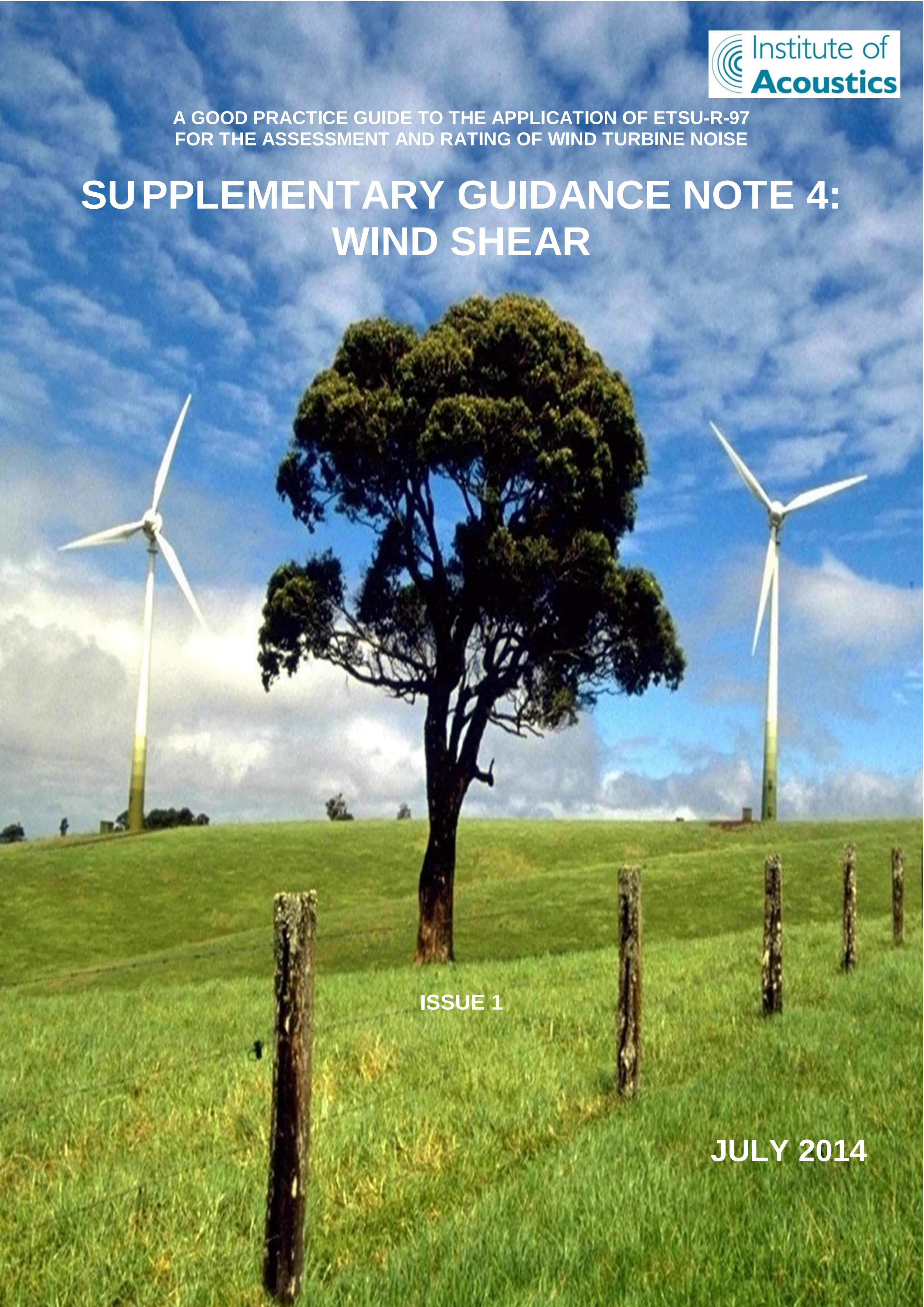
Institute of Acoustics

A GOOD PRACTICE GUIDE TO THE APPLICATION OF ETSU-R-97
FOR THE ASSESSMENT AND RATING OF WIND TURBINE NOISE

SUPPLEMENTARY GUIDANCE NOTE 4: WIND SHEAR



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PREFACE

This document has been produced by a working group on behalf of the Institute of Acoustics consisting of the following members:

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The working group gratefully acknowledges the assistance provided by Gavin Irvine from Ion Acoustics Ltd in the drafting of this note.

This supplementary guidance note has been produced to supplement the IOA document 'A GOOD PRACTICE GUIDE TO THE APPLICATION OF ETSU-R-97 FOR THE ASSESSMENT AND RATING OF WIND TURBINE NOISE' which is available on the IOA website at the following link: http://www.ioa.org.uk/publications/good-practice-guide (checked 06.04.14).

Prior to publication of this note, a peer review was undertaken by a separate group.

Any comments on this document should be sent to ETSUCONSULT@IOA.ORG.UK. The IOA will keep the document under review, and consider updating when significant changes to current good practice have occurred.

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Supplementary Guidance Notes

Number	Title	Information
1	**Data Collection**	Equipment specifications; measurement surveys: Practical considerations and set-up guidance and examples.
2	**Data Processing & Derivation of ETSU-R-97 background curves**	Data filtering, processing and regression analysis for different types of noise environments.
3	**Sound Power Level Data**	Manufacturer's data and warranties analysis.
4	**Wind Shear**	Wind speed references and long-term data analysis.
5	**Post Completion measurements**	Examples, considerations and strategies.
6	**Noise Propagation over water for on-shore wind turbines**	Noise propagation over large bodies of water.

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1 Context

1.1 Background

1.1.1 The Institute of Acoustics (IOA) published 'A GOOD PRACTICE GUIDE TO THE APPLICATION OF ETSU-R-97 FOR THE ASSESSMENT AND RATING OF WIND TURBINE NOISE' (GPG) in May 2013 to provide technical assistance for the undertaking of wind turbine noise assessments using the ETSU-R-97 document. In order to keep the GPG to a reasonable length, but not to lose clarifications and case studies, it was decided to produce a number of supplementary guidance notes which would support the GPG.

1.1.2 This guidance note will be of relevance to:

i. Acoustics consultants;
ii. Local Planning Authority (LPA) Environmental Health and Planning departments;
iii. Developers;
iv. The Planning Inspectorate or equivalent regulating authority;
v. The general public.

1.2 Scope of the Document

1.2.1 A series of six Supplementary Guidance Notes have been produced. This Supplementary Guidance Note 4 supports Section 4.5 of the GPG. It provides additional information on the influence of wind shear on wind turbine noise assessments and provides guidance on analysing anemometry data and correcting for wind shear. The guidance note provides information on the following:

- A short overview of the effect of wind shear on wind turbine noise assessments;
- Recommendations for analysing anemometry data;
- How to extrapolate the hub height wind speed from anemometry data at lower heights and;
- How data based on measured 10 m wind speed values can be corrected to account for wind shear.

1.3 Statutory Context

1.3.1 This Supplementary Guidance Note has been approved by the IOA Council for use by IOA Members and others involved in the assessment and rating of wind turbine noise using ETSU-R-97. It covers technical matters of an acoustic nature which the IOA-NWG believes represent current good practice.

2 Wind Shear

2.1 Wind Shear: Definitions

2.1.1 Wind shear is the variation in horizontal wind speed with height above ground level (agl). Under most conditions, wind speeds increase with height above ground and various equations can be used to describe this.

2.1.2 Turbine sound power levels determined in accordance with IEC 61400-11 are usually[1] reported with reference to 'standardised' wind speeds at 10m height which are calculated from the hub height wind speeds using a standard equation (rather than actually measured at 10m height). This is therefore the key reference wind speed for wind turbine noise.

2.1.3 The GPG requires careful consideration of the wind speed used and how it was measured and derived. The requirement to determine wind speeds for background noise surveys is described in Section 2.6 of the GPG. This section sets out three methods, A, B or C (see GPG 2.6.3). Methods A or B are preferred. However, the use of a 10 m mast to measure wind speed (Method C) is still considered good practice for small-scale developments provided that wind shear is accounted for with appropriate corrections.

2.1.4 When wind speed values are determined at hub height (Method A or B) it is necessary to standardise them to 10 m height, for consistency of referencing with sound power data. That way, the turbine sound power levels (and therefore the predictions) and the background noise data (and associated noise limits) both refer to standardised wind speed which is derived from the hub height wind speed using Equation 1 below.

[1] Please note that the 2012 edition 3 of IEC 61400-11 mainly requires sound power levels to be stated in relation to the hub height wind speed.

2.1.5 Standardising measured hub height (hh) wind speeds is done using the 'log-law' equation with a standard roughness length, z_0 of 0.05m. This is Equation 1 below. *As an example, if 6.7 m/s is measured at 80m height it would correspond to a standardised 10 m wind speed of 4.8 m/s.*

$$v_{10} = v_{hh} \times \left(\frac{\ln\left[10 / z_0 \right]}{\ln\left[hh / z_0 \right]} \right)$$

Equation 1

Where v_{10} is the standardised 10 m height wind speed, v_{hh} the hub height (hh) wind speed and z_0 the standard ground roughness length of 0.05m.

2.1.6 The ground roughness usually models the degree to which wind is slowed down by friction as it passes close to the ground: the rougher the ground (and the more obstacles such as trees, buildings *etc.*), the more the wind is slowed down and the larger the roughness length. For the standardisation process described in IEC 61400-11 and used therein, a fixed value of 0.05 is used in all cases for reference purposes.

2.1.7 Also relevant to wind farm noise assessments is the 'power law' shown below – Equation 2. Compared to Equation 1, this is an alternative mathematical representation used to model wind shear effects arising from differing atmospheric states. This model is now more frequently used when analysing long-term data as considered in the present SGN.

$$v_1 = v_2 \times \left(\frac{h_1}{h_2} \right)^m$$

Equation 2

Where v_1 is the wind speed at h_1 and v_2 is the wind speed at height h_2. The exponent m in the equation is known as the wind shear exponent.

2.2 Determining the Hub Height Wind Speed - general

2.2.1 Methods A and B involve determining the hub height wind speed data from an anemometry mast or from a LiDAR or SoDAR unit, for every 10 min data point recorded during the noise survey. Once hub height is established (with Methods A or B), as stated above, it should be standardised to 10 m height (Equation 1).

2.3 Method A: direct measurements

2.3.1 For method A, the hub height wind speed is obtained directly from measurements and no corrections are required, although the data should be checked for consistency and accuracy – see section 3.

2.4 Method B: calculations from other heights

2.4.1 Where there are no anemometers at or close to hub height, but measurements are available at two different heights (h1 and h2), hub height wind speeds can be estimated by extrapolation. The criteria for h_1 and h_2 for this to be applicable are set out in the GPG (2.6.3).

2.4.2 To obtain the wind speed at hub height, Equation 2 can be re-arranged to determine the wind shear exponent m based on the known data (v_1, v_2, h_1, h_2) for each 10 minute data period. Equation 2, re-arranged is shown below:

$$m = \log\left(\frac{v_2}{v_1}\right) / \log\left(\frac{h_2}{h_1}\right)$$

Equation 3

2.4.3 The wind shear exponent m is then used in Equation 2 to estimate the wind speed at hub height from the upper height measured. Where the wind speed at the lower anemometer (v_1 at h_1) is higher than the higher anemometer (v_2 at h_2) then this calculation should not be performed and it is suggested that the hub height wind speed is set to the higher reading (*i.e.* assumption of zero rather than negative shear).

2.4.4 *Example of GPG method B: In this example, the mast has anemometers at 70 and 50 m height. In one particular 10 minute interval, average wind speeds of 6.4 and 5.7 m/s were measured respectively. Using Equation 3, this corresponds to a shear exponent of m=0.32. If the proposed turbine hub height is 80 m, then the wind speed at 80 m can be estimated from the measured 70 m wind speed (6.4 m/s) and m=0.32 using Equation 2. This results in a value of 6.7 m/s at 80 m height, or 4.8 m/s standardised.*

2.4.5 The same formulae (Equations 2 and 3) can also be used to interpolate between two heights which are below and above the turbine hub height, such as for example with LiDAR/SODAR data. In all cases, the method used to determine the hub height wind speed should be clearly stated.

3 Anemometry Data

3.1 Checking Anemometry Data

3.1.1 On receiving anemometry data, either for relating to measured background noise levels directly, or for long-term wind shear analysis, a number of checks need to be carried out to verify the data, as errors and missing data can occur.

3.2 Time Stamps

3.2.1 Before carrying out the noise survey, a check should be made with the supplier/installer of the system regarding the operation of the anemometry system. In particular it will be necessary to establish that the time clock of the logger is accurately set and that anemometry system is functioning correctly and logging in 10-minute periods (see GPG 2.8).

3.2.2 The loggers for anemometry masts are usually set up with the clock set to GMT all year (no daylight savings). However, this should be verified with those responsible for providing the data. It is also necessary to check whether the time stamps correspond to the start of the period or at end of a 10 minute period. This will vary from logger to logger.

3.2.3 On receiving the data, it is necessary to correct the data for the local time at the time of survey. The ETSU-R-97 amenity hours daytime periods and night-time relate to the local time at the time of the survey and therefore it is necessary to correct the time stamps of the data to the local time. Care should be taken to ensure that the periods when the clocks go forward or back are taken into account.

3.3 Check of Data Set

3.3.1 The anemometry data must be checked for errors – ideally, in the first instance, by specialists providing the data and then by the acoustic engineer. It is not unusual for data to include error values or for samples to be omitted from the data set. Sometimes, data is provided with missing periods or periods removed when error values occur and data with missing periods, if not corrected, will lead to synchronisation errors. Ideally, the time series provided for the wind data should be continuous with no missing periods. A new time sequence can be added adjacent to the data to check this. Data should be checked for error report values. Data from anemometry masts also can in some cases "flat-line" (constant readings) at low wind speed values. Careful inspection of the noise and wind speed time history plots can also provide a check that the data is synchronised and can help determine periods when error values occur.

3.3.2 LiDAR and SoDAR will also have error values due to low cloud or rain or other conditions and therefore the data must be first checked ideally by those providing the data. Section 2.6.12 of the GPG describes the use of LiDAR and SoDAR data.

3.3.3 In addition, the anemometry mast data should be checked for errors or offsets in the wind direction. A mast installation report may specify any offsets that would need to be applied to the wind direction. Noting the wind direction whilst on site provides a check that the wind direction corresponds with that reported by the anemometry system.

3.4 Data from more than one anemometer or wind vane*.*

3.4.1 Anemometry masts will often have more than one wind sensor at some of the heights. In these cases, a choice must be made in carrying out any calculations, especially according to Method B.

3.4.2 Figure 1 below shows data from the ratio of wind speeds (v_1/v_2) for two anemometers plotted against wind direction. Anemometer v_1 was at 62.5 meters mounted on the top of the mast whereas v_2 was located at 60 metres. It can be seen that for most wind directions, the difference between the two anemometers is small, but at around 90° there is a dip as the v_1 wind speeds are reduced due to the presence of a lightning conductor rod. At approximately 0°, the mast tower shields anemometer v_2 and there is a larger disparity between the two readings.

3.4.3 When using such data for referencing background noise measurements, the resulting effects tend to be limited. But when undertaking wind shear analysis of long-term measurement data (see below), it is crucial to account for these shadowing effect or this can lead to unrealistic values which are spurious.

3.4.4 With large masts it is fairly common for several anemometers to be mounted on booms, *e.g.* with one orientated to the north and one orientated to the south. An analysis of the type shown in Figure 1 can allow the effects of the wind direction on the anemometer to be studied. In most cases, data from two anemometers at the same height can be averaged as reported in the GPG, but where shadowing effects occur, data from the unshaded anemometer can be used for the wind directions where this occurs. If one anemometer is present instead of a pair, an analysis of average wind shear exponent as a function of wind direction can highlight a similarly narrow wind sector with atypical and unrealistic values of wind shear, and this data should be excluded from the analysis.

3.4.5 Although this is not generally necessary, it is noted that wind direction data from wind vanes should not be arithmetically averaged[2], and vector averaging should be used. It is sufficient to report only the results of the wind vane closest to the proposed hub height as recommended in the GPG (2.6).

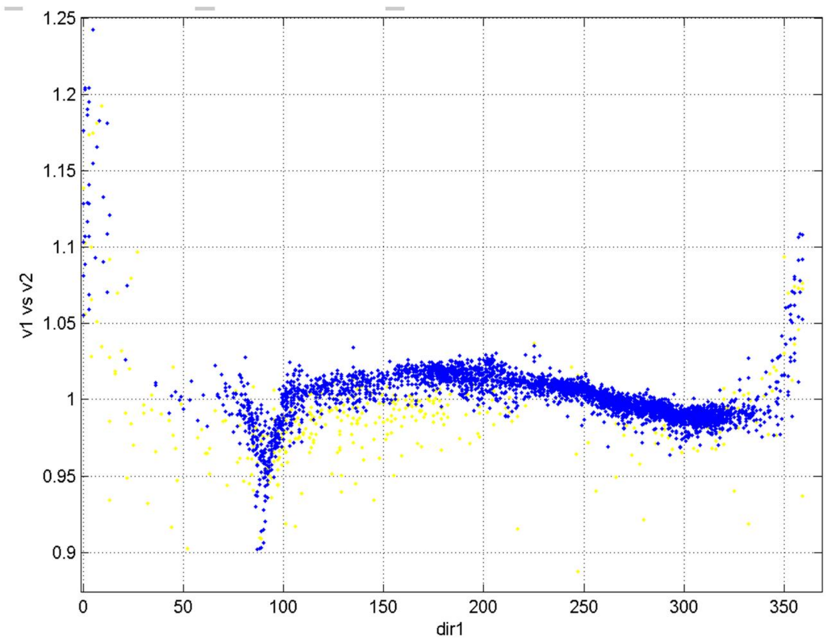


Figure 1 – Blue: ratio of wind speeds measured by two anemometers installed at similar heights on an anemometry mast as a function of wind direction, showing spurious values for two narrow arcs (around 0 and 90 degrees from north). *The yellow data samples correspond to low wind speeds (below 2.5 m/s) which have been removed to obtain a better correlation.*

4 Deriving corrections for data referenced against wind data measured at 10 m

4.1 10 m Measured Corrections

4.1.1 As noted in the GPG (2.6.6), when a baseline noise survey has been referenced to measured 10 m data, it is necessary to apply corrections to account for wind shear effects.

4.1.2 As described in the GPG, the cost of erecting a tall anemometry mast (or similar) during the baseline survey may not be justified for the smaller wind turbine projects. In this case, the long-term data necessary to derive site-specific wind shear may not be available either. A simplified wind shear correction is described in paragraph 4.5.4 of the IoA GPG. It involves shifting the turbine noise predictions to the “left” along the wind speed axis (i.e. at lower wind speeds than if direct predictions are used). This is an empirical method which should result in robust, that is conservative, noise assessments even in the absence of site-specific data. A tolerance of +5 m can be applied when considering the hub height thresholds in the GPG. The noise limits are then based on measured wind speeds at 10 m height.

4.1.3 However this method does not use actual site-specific wind shear conditions. In some cases, suitable site anemometry data may in fact be available: either from an anemometer on an adjacent (representative) site, or because historic data is available, or because a mast was erected after the noise assessment such that the original noise data can be re-analysed. In the case of using a nearby mast, it is suggested that this is within 5 km of the wind farm site, with careful consideration of factors such as topography and tree/ground obstacles cover, which have to be similar to the proposed site or significant differences can be observed. Note that use of longer-term data, typically at least one year duration, is considered good practice in this case.

[2] Arithmetically averaging 355° and 5° will lead to an erroneous result of 180°.

4.1.4 This section describes the associated methods of correcting for wind shear based on this data, which can be classified into two basic methods:

- Applying a correction to the turbine noise predictions – this involves shifting the turbine noise predictions to the left along the wind speed axis (decreased wind speeds for a given prediction). This method is similar to that described in the GPG Paragraph 4.5.4 but using derived site-specific wind shear values rather than a simple fixed correction.
- Alternatively, the background noise data can be corrected based on measured wind shear values – this involves shifting the background noise data to the right along the wind speed axis (increased wind speeds for a given background level).

4.1.5 Note that the former is used more often (see 4.4). Applying a correction to the noise predictions means that background noise values are still referenced to the measured wind speed at 10 m height. Alternatively, shifting the background noise data effectively results in noise limits set in relation to a specific hub height (for which the wind speed is standardised to 10 m). In each case, it is important that the noise conditions limits clearly set out the appropriate wind speed reference and that consistency of wind references is retained (see 2.6.7 of the GPG). Those responsible for preparing the noise assessment will have to justify firstly why a 10 m mast was used and secondly the wind shear correction method used.

4.1.6 At the end of this Supplementary Guidance Note, example wind shear exponents (Equation 3) are set out based on the analysis of long-term wind data from anemometry masts from various sites. This data is provided for reference only, so that the results of wind shear calculations can be compared with typical examples from other sites. It may be tempting to use such data to provide corrections required in some cases; however, this approach is not recommended because wind shear data is variable from site to site and the use of generic wind shear data would lead to arguments and inconsistencies. Therefore, unless a source of wind speed data is available for the actual turbine site or a similar site to it, the simplified approach advocated in the GPG Section 4.5.4 should be used.

4.2 Analysing long-term wind data

4.2.1 With a source of wind data, an analysis of the wind shear corrections can be determined. Typically datasets of 1 year or more are used, and it is recommended that at least six months of wind data[3], comprising both winter and summer months, is obtained. The use of database software is particularly suitable for the analysis of such large datasets. The requirements for the anemometry source (measurement heights etc.) should be as set out in the GPG (2.6.3).

4.2.2 Firstly, both the hub height wind speed and actual 10 m wind speed need to be calculated for each 10 minute period. The hub height wind speed can be determined in the way set out in the GPG (2.6.4), and then standardised using Equation 1.

4.2.3 Some masts will have an anemometer at 10 m height and therefore this information can be used directly. If there is no 10 m anemometer, the 10 m wind speed should be calculated by extrapolation from the nearest (i.e. lowest) anemometer using the power law (Equation 2 and 3), in a similar way to that set out in section 2.4 above (Method B, but h1 and h2 being the two lowest anemometers). The same applies if hub height is not directly measured by the mast.

4.2.4 When performing this kind of analysis, the data must be filtered to remove erroneous or unrepresentative data as described in Section 3. See in particular the comments above on mast shadowing which can lead to erroneous shear coefficients. Data with negative wind shear, *i.e.* where the wind speed at the higher height is not greater than measured at the lower height, can also be excluded from the averaging or alternatively, a value of zero wind shear is assumed (constant wind speed with height). This provides a more conservative analysis.

4.2.5 The wind shear is then calculated either through:

- The exponent (m) between the hub height and 10 m wind speeds, using the average wind speed for the 10 minute periods considered (see 4.2.8) and Equation 3.

[3] Ray, M. L., A. L. Rogers, and J. G. McGowan. "Analysis of wind shear models and trends in different terrains." University of Massachusetts, Department of Mechanical and Industrial Engineering, Renewable Energy Research Laboratory (2006).

- The difference (subtraction) between the actual/extrapolated 10 m wind speed and that obtained from standardising the hub height wind speed (using Equation 1) for each of the 10 minute periods considered.

4.2.6 *<u>Example1 :</u> In this example, the mast has anemometers at hub height (64 m) and 10 m height directly. In one particular 10 minute interval, wind speeds of 5.1 and 3.0 m/s are measured respectively. This corresponds to a wind shear exponent of 0.29 (Equation 3) between 64 m and 10 m. Alternatively, the difference between the measured 10 m wind speed and the standardised 64 m height wind speed (3.8 m/s) is calculated as 0.8 m/s.*

<u>Example 2:</u> Same as above but there are no measurements at 10 m height. However the mast has anemometers at 30 and 20 m height in addition to 64 m height. From the measurements at 30 and 20 m (4 and 3.4 m/s respectively), an exponent of 0.4 is determined and used to calculate a wind speed of 2.6 m/s at 10 m by extrapolation (Equation 2) from the 20 m measurements. This represents an exponent of 0.37 (between 64 and 10 m/s) or a shift of -1.2 m/s with the standardised wind speed of 3.8 m/s.

4.2.7 It can be seen from the illustrative examples at the end of this SGN that wind shear can be strongly dependant on wind speed, as increased winds tend in particular to disturb stable atmospheric conditions. High shear exponents may be apparent in conditions in which no turbines would operate. Averaging data for all wind speeds may therefore result in unrealistic values. The data should therefore be binned into 1 m/s wide bins for each integer wind speed value. If the purpose of the data analysis is to find appropriate corrections to measured 10 m wind speeds, the data should be binned according to this reference. If the intent is to correct emission or predictions values (which are based on standardised wind speeds), the binning should be made according to standardised wind speeds.

4.2.8 The wind shear data (exponents or direct wind speed difference values) are then averaged for different key periods: ETSU-R-97 evening periods (18.00 to 23.00) and ETSU-R-97 night-time periods (23.00 – 07.00). During these periods, wind shear due to atmospheric effects tends to be highest and seasonal effects are more limited. The standard deviation of the variations around the average should also be determined to evaluate variability; it is typically of the order of 50% of the average values.

4.3 Correcting the Turbine Noise Predictions

4.3.1 This method involves shifting the turbine noise predictions to the left along the wind speed axis. The calculated wind shear correction values are applied to the wind speed reference used for predictions of wind turbine noise. This can be done either by adjusting the source levels (emissions) or the predictions at each location (immissions). An interpolation is then required to obtain values at integer wind speeds.

4.3.2 An example calculation of corrections applied to manufacturer sound power data is shown in Figure 2. The correction is shown for average wind shear values, determined as a function of standardised wind speed bins, and the same process can be undertaken for the average +/- one standard deviation.It can be seen from this example that, for a variable speed turbine, the effects of wind shear only significantly affect the effective emission levels at lower wind speeds, below the maximum noise output of the turbine. The sound power data for integer wind speeds can then be determined for example by linear interpolation (as shown in Figure 2). In addition to the average shear correction, consideration of plus and minus one standard deviation provides a reasonable account of what may occur during less frequent periods. The assessment will then be based on the values with the highest shift, *i.e.* including the standard deviation.

<u>For example</u>: from the standardised wind speed of 4 m/s, the corresponding hub height (80 m) wind speed is determined (5.6 m/s) using Equation 1. At this standardised wind speed, an exponent of 0.3 was determined as representative of the average shear at the site. This is used to calculate a wind speed of 3.1 m/s at 10 m height from the hub height wind speed using Equation 2, or a shift of 4 - 3.1 = 0.9 m/s. If a variation of one standard deviation around the average shear is considered (approximately 50 % more in this example), this corresponds to a worst-case shift of 1.3 m/s to 2.7 m/s. The sound power at the standardised wind speed (99 dB(A)) is expressed at the shifted wind speed of 2.7 m/s.

4.3.3 It is equally valid to correct the turbine noise predictions instead of adjusting the source levels. In the example below in Figure 3, turbine noise predictions are shifted for an average wind shear value. As above, this can be calculated from the derived exponent values, or directly from the calculated differences between actual and standardised 10 m wind speeds, and using corrections for average shear plus one standard deviation.

Standardised wind speed	3	4	5	6	7	8	9	10	11	12
Hub Height (m)	80									
Sound power		99.0	102.3	105.5	106.7	107	107	107	107	107
Corresponding hub height wind speed		5.6	7.0	8.4	9.7	11.1	12.5	13.9	15.3	16.7
Site Shear Exponent (average)		0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.1	0.1
10 m height wind speed, using average shear		3.1	4.1	5.2	6.4	7.7	8.8	10.0	11.4	12.8
10 m height wind speed, using average+stdev shear		2.7	3.7	4.8	6.1	7.5	8.7	10.0	11.4	12.8
Interpolated at integer 10 m wind speed	100.1	103.2	105.7	106.6	106.8	107.0	107.0	107.0	107.0	107.0

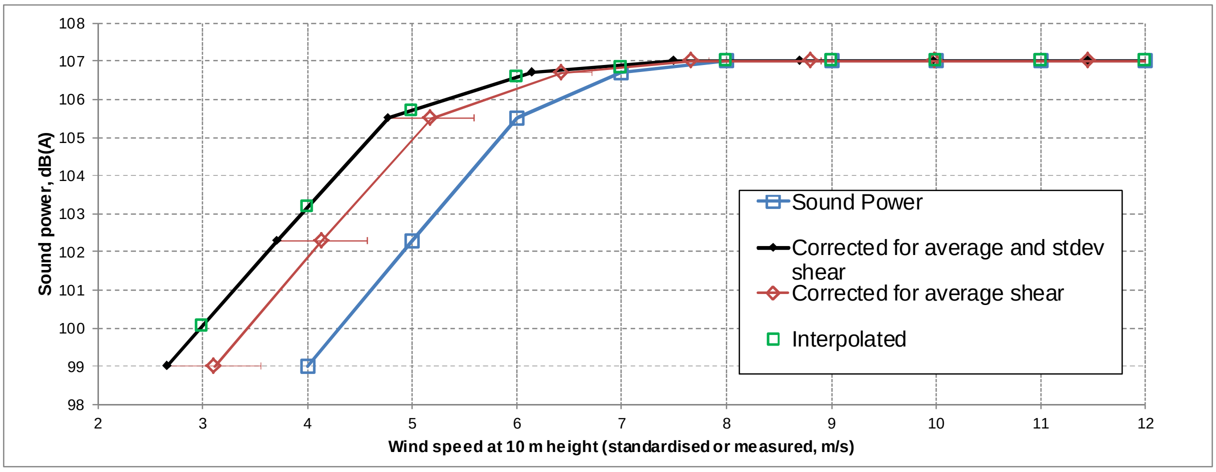


Table 1 & Figure 2 – turbine sound power adjusted for derived wind shear values at different wind speeds – values at integer wind speeds are then determined by linear interpolation (green squares)

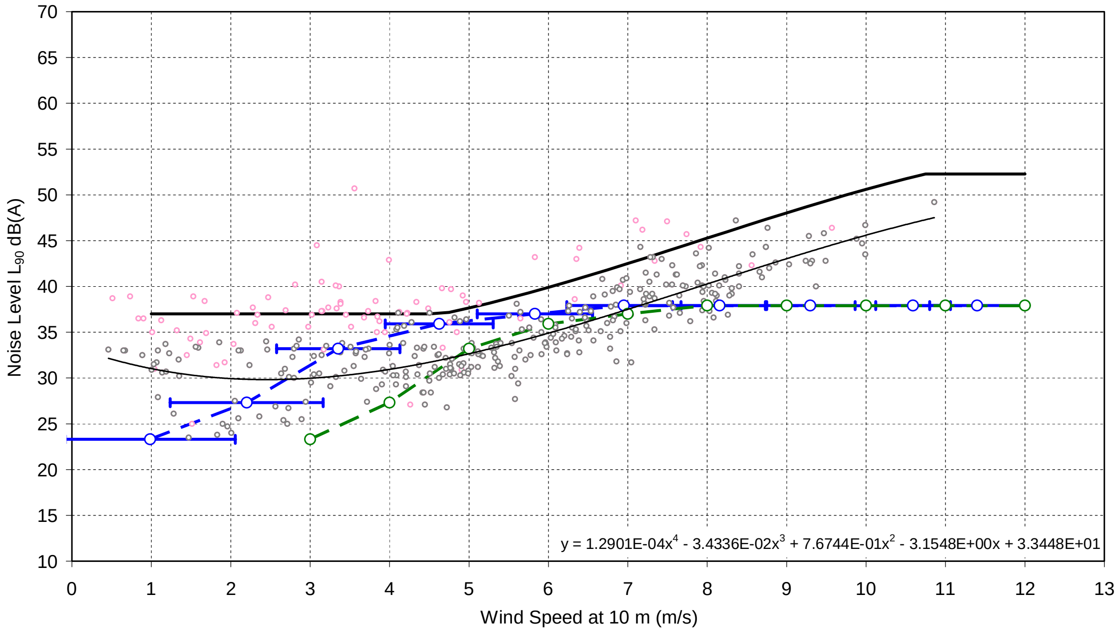


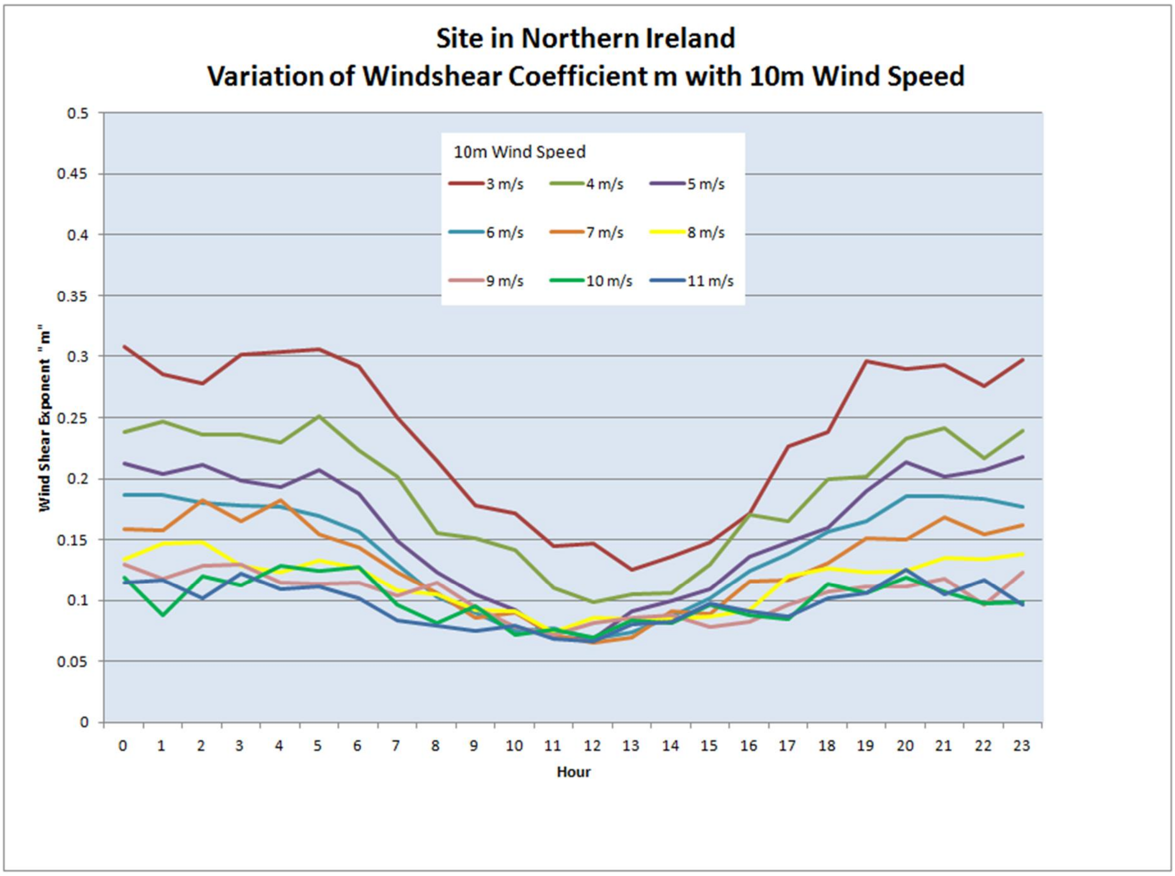
Figure 3 – Chart of background noise levels against measured 10 m wind speeds (open grey circles), the best fit curve (thin black line) to this data, the derived noise limit curve (thick black line) during amenity hours day time periods. Predicted immission noise levels (thick dashed lines with open circles): standard shear conditions (green) and corrected for specific average shear (blue, error bars represent 1 standard deviation from the average).

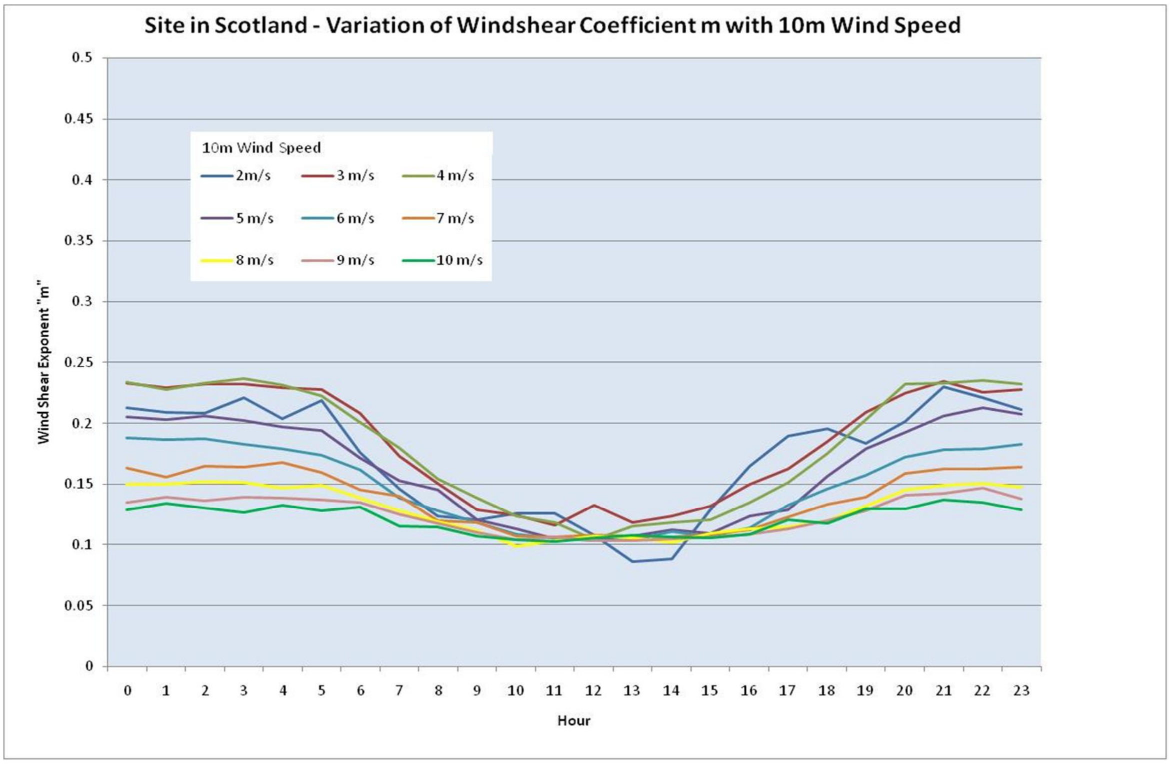
4.4 Correcting background noise data

4.4.1 Although the above correction to predictions (section 4.3) is used more often, noise data measured in relation to 10 m height wind speed during the survey can be adjusted to hub height (standardised), to account for wind shear. Using this method, the background noise is corrected based on measured wind shear exponents obtained from the analysis of long-term anemometry data obtained as set out above. In this case, the derived background noise curve is adjusted to a specific hub height wind speed and therefore the noise limits derived from this data, using the ETSU-R-97 method, will be set relative to a specific hub height, which is then standardised for referencing. The method is as follows:

4.4.2 As noted above in 4.2.7, in this case the analysis of long-term shear data is made by binning data according to measured (or extrapolated) 10 m wind speed (rather than standardised wind speeds). For each 10-minute value, determine the hub-height wind speed from the measured wind speed at 10 m height using either the derived shift or wind shear exponent (m) (Equation 2), for the corresponding wind speed bin and time of day. For consistency with the method of 4.3 and to obtain a conservative result, it is recommended that the wind shear used for the correction is the average value plus one standard deviation for each of the wind speed bins. The hub height wind speed is then standardised to 10 m height for referencing. A trend-line to this adjusted data can then be produced in the usual way. If the full dataset is not available, the derived trend-line is corrected directly.

Illustrative Examples of Wind Shear Analysis (Figures 4 & 5)





***** NB: Examples shown for qualitative and illustrative purposes *****

The example data below is shown for comparative reference but should not be used directly for corrections in the absence of site-specific data. The values shown are averaged wind shear exponents (Equation 3) obtained following analysis of long-term measured mast data. The standard deviation around the average is typically around 50% of the average at lower wind speeds.

		Standardised wind speed Wind Speed at 10 m									
		3	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Central England Location; Yearly Average; Moderate tree cover in relatively flat location Buildings located within 600m.	All Data	0.40	0.37	0.35	0.32	0.28	0.28	0.28	0.27	0.26	0.25
	Amenity	0.45	0.43	0.38	0.32	0.29	0.29	0.28	0.28	0.27	0.27
	Night	0.59	0.53	0.44	0.39	0.34	0.29	0.29	0.28	0.26	0.26
High Ridgeline/Tall Hill Location; Yearly Average; Clear Hill Top.	All Data	0.16	0.16	0.16	0.16	0.15	0.15	0.15	0.15	0.14	0.13
	Amenity	0.25	0.24	0.22	0.20	0.18	0.17	0.15	0.15	0.14	0.13
	Night	0.29	0.28	0.25	0.23	0.20	0.18	0.17	0.16	0.14	0.13
UK East Coast Flat Landscape; Yearly Average; Limited Tree cover.	All Data	0.33	0.35	0.31	0.26	0.23	0.22	0.20	0.20	0.20	0.19
	Amenity	0.43	0.41	0.37	0.30	0.24	0.22	0.21	0.19	0.19	0.19
	Night	0.45	0.47	0.41	0.32	0.26	0.23	0.21	0.20	0.21	0.20
Coastal Location; Yearly Average; End of Long Harbour Wall: >1km from Coast.	All Data	0.12	0.12	0.13	0.13	0.13	0.13	0.12	0.12	0.11	0.11
	Amenity	0.05	0.06	0.08	0.09	0.09	0.08	0.07	0.08	0.08	0.08
	Night	0.17	0.16	0.16	0.18	0.17	0.17	0.16	0.15	0.15	0.15
Coastal Plain; Yearly Average; Western Side UK: No trees or buildings.	All Data	0.20	0.21	0.20	0.18	0.17	0.15	0.14	0.13	0.12	0.11
	Amenity	0.19	0.21	0.20	0.18	0.16	0.15	0.15	0.14	0.13	0.12
	Night	0.28	0.28	0.25	0.23	0.21	0.18	0.16	0.15	0.13	0.12
East Anglia; Yearly Average; Rural tree lined boundaries.	All Data	0.29	0.24	0.22	0.20	0.19	0.18	0.18	0.17	0.17	0.16
	Amenity	0.35	0.39	0.38	0.32	0.28	0.25	0.24	0.23	0.21	0.21
	Night	0.55	0.60	0.56	0.50	0.42	0.31	0.32	0.34	0.19	0.23

Table 2: Typical a*veraged* wind shear exponents

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