Department for Energy Security & Net Zero

Assessment and Rating of Wind Turbine Noise

This draft guidance update does not represent a final position from government. It should not be used by local planning authorities during or after the consultation period in relation to ongoing planning applications. Following this consultation, we will analyse responses and issue a formal government response. Until this time, the current guidance remains suitable for assessing wind turbine noise. Planning authorities should continue to use existing guidance and are advised not to delay planning decisions on the basis of this consultation.

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Executive Summary

The Assessment and Rating of Wind Turbine Noise report provides technical guidance for assessing and controlling operational noise from wind turbines. It replaces the 1996 ETSU-R-97 document. It provides guidelines for the control of wind turbine noise, such that wind farm neighbours receive a reasonable degree of protection without placing unreasonable restrictions on wind farm development.

Noise assessment criteria are provided based on a combination of fixed levels and those based on a margin above existing sound levels (in the absence of wind turbines). The assessment criteria are determined on a site-specific basis with consideration of a range of factors. The cumulative levels from several wind farm sites need to be taken into account where relevant: in these cases, individual limits are defined for each separate site such that cumulative noise levels are suitably controlled to meet the assessment criteria. Individual site-specific noise limits can then be enforced through planning conditions, with example wording and technical clauses provided in the document.

Guidance is also provided on monitoring of noise from operational wind farms, to assess the noise levels produced against planning condition requirements, including the assessment of specific audible characteristics of the noise.

Contents

1 Introduction

1.1 The aim of this document is to provide technical guidance to developers, planners and other stakeholders on the environmental assessment and control of operational noise from wind turbines. This document is a targeted update and replacement for the original document, ETSU-R-97[1] *'The Assessment and Rating of Noise from Wind Farms'*. This targeted technical update was undertaken to reflect evolutions in turbine technology and developments in wind turbine noise assessment methodologies since 1996, as well as established best practice and the latest available evidence in the field. This update follows the scoping review commissioned by Government and published by WSP[2] in 2023.

1.2 The technical guidance has been prepared by specialists on wind turbine noise (the 'Project Team') from Noise Consultants Limited (part of Logika Group), Hoare Lea LLP and Hayes McKenzie Partnership Limited. The Project Team has also drawn on the experience of external peer reviewers.

Scope

1.3 The aim of this technical guidance is to provide a framework for assessing and rating operational noise from individual wind turbines and wind farms. It provides guidelines for the control of wind turbine noise, such that wind farm neighbours receive a reasonable degree of protection without placing unreasonable restrictions on wind farm development. Compliance with this technical guidance may therefore result in levels of noise that could be audible at noise sensitive receptor locations but are considered reasonable in the context of the need for renewable energy generation.

1.4 The noise assessment criteria are consistent with addressing the climate emergency and the need to achieve net zero carbon through the adoption of renewable energy sources, while limiting the potential impacts on people. The assessment and rating methods are presented in a manner suitable for use in the planning system and for controlling operational noise during the lifetime of the wind turbines. This includes a methodology for assessing operational wind turbine noise. An example planning condition is included, which could form the basis of consents or planning permissions for wind turbines or wind farms.

1.5 The noise assessment criteria defined in this technical guidance have been derived with reference to:

- Existing standards and guidance relating to noise emissions and control of wind turbine noise in the previous ETSU R 97[1] guidance, as well as the subsequent Institute of Acoustics (IOA) Good Practice Guidance[3] and proposed planning conditions for Amplitude Modulation.

- A scoping review on behalf of Government which was published in February 2023 (WSP report[2]), which included:
  - An extensive literature review;
  - Results of field measurements;
  - Engagement with stakeholders, including local authorities, government departments and professional associations.
- The societal need for renewable energy sources to reduce carbon dioxide emissions in line with Government energy policy.
- The ability of manufacturers and developers to meet these noise limits whilst delivering viable schemes.
- Advances in wind turbine technology since ETSU-R-97.
- Available research on responses to wind turbine noise and associated impacts including on health.
- Approaches and methodologies adopted internationally for the control of noise from wind turbines.
- The professional experience of qualified acousticians involved in the formal assessment and regulation of wind turbine noise emissions and other noise sources.

1.6 This technical guidance applies to noise from operational wind turbines and not to operational noise from related infrastructure. Other elements that may be incorporated into a wind energy development which can produce operational noise, such as battery storage systems, the substation(s) and solar installations are assessed through application of alternate assessment methods, which are not applicable to wind turbine noise.

1.7 The assessment of construction or decommissioning noise and vibration impacts also falls outside of the scope of these guidelines, as other applicable guidance and legislation exists.

1.8 This guidance does not prescribe the methodology for prediction of wind turbine noise[1]. This and other more detailed aspects of the assessment, such as equipment requirements, are addressed in good practice guidance maintained and published by the Institute of Acoustics.

1.9 This technical guidance applies to all types of wind turbines except those allowed under permitted development rights.

1 Except for advice relating to consideration of wind direction when assessing cumulative effects of more than one wind farm.

Periodic updates

1.10 It is recognised that wind turbine technology evolves and therefore there is a need for guidance that adequately reflects current wind turbine characteristics and the latest knowledge and practice. As such, it is anticipated that this technical guidance will be reviewed/updated as necessary.

Interaction with policy

1.11 Reference to ETSU-R-97 in UK planning policy or guidance should be interpreted to mean a reference to this technical guidance, which replaces ETSU-R-97.

Specific considerations relating to English Policy

1.12 The Noise Policy Statement for England (NPSE[4]) (2010) introduces the principles of a LOAEL (Lowest Observed Adverse Effect Level) and a SOAEL (Significant Observed Adverse Effect Level) for noise. The LOAEL identifies the exposure level where adverse effects of noise on health and quality of life can be detected (which should be mitigated and minimised). The SOAEL identifies the exposure level above which significant effects on health and quality of life occur (which should be avoided). The NPSE however notes that both of these general aims should be interpreted within the context of Government policy on sustainable development. The explanatory note to the NPSE also explains that the aim is to 'minimise' non-significant adverse noise impacts as far as reasonably practicable.

1.13 Since the publication of ETSU-R-97, wind turbine technology has advanced, leading to improvements such as variable speed operation[2], power regulation through turbine pitch[3], and use of Serrated Trailing Edges[4]. With these technologies applied, further reductions of noise from the wind turbines can generally only be achieved through design or operational changes that result in losses in renewable energy generation. For example, modern turbine models often allow the use of noise-reduced operation modes, but at the cost of some loss of electrical power generation. Increased setback distance from noise-sensitive receptors, when considering other design constraints or planning considerations, can often only be achieved through reduction in the number of proposed wind turbines.

1.14 ETSU-R-97 recognised the specific nature and operation of wind turbines and the noise they produce, and how this differs to many other sources of noise. It is necessary to balance the environmental impacts from a wind farm with the benefits

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2 The sound power output of a variable speed turbine varies considerably with wind speed, being quieter at the lower wind speeds when the blades are rotating more slowly. Older turbine models would operate at one or two fixed rotational speeds and therefore produce much more uniform noise at most wind speeds.

3 The alternative, power regulation through blade stall, would generate increasing levels of noise at higher wind speeds.

4 Blade additions which reduce noise emissions from the turbines at little or no energy cost.

that arise through the development of renewable energy sources. This general principle remains relevant for these guidelines.

1.15 Defining LOAELs and SOAELs for wind turbine noise, in the context of the NPSE guidelines in England, is outside the scope of the present technical guidance. However, based on the current state of knowledge, the noise assessment criteria derived in this document are not expected to exceed the SOAEL although they may be above the LOAEL in some cases.

1.16 When adverse but non-significant effects (above the LOAEL and below the SOAEL) are expected, through compliance with the present technical guidance, it is not necessary to further minimise noise levels from wind turbines in the context of sustainable development. It is considered that sufficient minimisation is already an inherent process through the usual iterative design of the wind turbine layout and use of readily available wind turbine technology that reduces noise emissions.

Considerations relating to Scottish, Welsh and Northern Irish policy

1.17 Like in England, there are references to ETSU-R-97 in planning policy and guidance for Scotland, Wales and Northern Ireland, however the concepts of LOAEL / SOAEL do not exist in national policies within these administrations. Nevertheless, national policies in these administrations are broadly similar, in that they support renewable energy generation (including from onshore wind) provided there are no significant adverse impacts including from noise. The same general comments as the previous section apply and compliance with the present technical guidance is considered a way of satisfying these requirements.

Potential effects which do not require assessment

1.18 There are a number of aspects of wind turbine acoustics that do not require assessment of their impact on humans at the planning stage due to their limited impact, as these effects can be considered negligible or suitably controlled by the proposed criteria. These include infrasound, ground borne vibration, and low frequency sound, which are considered in turn below.

Infrasound

1.19 The term infrasound refers to sound at frequencies below 20 Hz, and for wind turbines is often related to the blade passage frequency. Research has shown that, for modern upwind turbines (i.e. turbines where the rotor is positioned upwind of the tower when in operation), the levels of infrasound at typical receptor distances are well below the threshold of perception. The scoping review[2] (p114) concluded that ‘the findings from the existing evidence base indicate that infrasound from wind turbines at typical exposure levels has no direct adverse effects on physical or mental health’.

Ground borne vibration

1.20 The term ground-borne vibration refers to mechanical vibration from the operation of the wind turbine that is directly transferred to and propagates through the ground. Levels of ground-borne vibration from modern upwind turbines are very low and, although ground-borne vibration from wind turbines can be measured at large distances using sensitive equipment, they are significantly below the human perception threshold.

Low frequency

1.21 The term low frequency sound refers to sound occurring predominantly in the region below approximately 200 Hz. Noise-sensitive receptors are considered to be suitably protected from low frequency sound by the proposed noise criteria (which are based on A-weighted noise levels, see glossary for definition). In the absence of specific low frequency tonal noise (which is covered by the tonal assessment methodology below), no specific low frequency limits are necessary to control wind turbine noise.

2 Assessment method

Noise Assessment Criteria

Summary

Operational wind turbine noise assessment criteria for noise-sensitive receptors are defined as the greater of:

- a Lower Limiting Value (LLV); or
- 5 dB above the prevailing background $L_{A90,10min}$ sound levels determined in accordance with these guidelines.

The LLV is set in the range of 37 – 40 dB L_{A90} for day periods (07:00 to 23:00). The actual value used within the range specified depends on several site-specific factors which are discussed at paragraphs 2.16 to 2.25. For night periods (23:00 to 07:00), the LLV is set to 43 dB. The relevant criteria are then determined as the minimum of the derived day and night criteria at each wind speed to apply at all times.

Background sound levels for the day (derived from the “quiet day” periods) and night, are related to standardised wind speeds determined from hub height wind speeds on the proposed wind farm site being assessed.

Alternatively, a simplified noise criterion of 37 dB L_{A90} (up to 10 m/s) can instead be applied regardless of background sound levels, during both day and night.

At noise-sensitive receptor locations where the occupiers are financially involved with the wind farm development the criteria can be increased to the greater of:

- 45 dB L_{A90}; or
- 5 dB above prevailing background sound levels.

The assessment and measurement of wind turbine noise is based on the L_{A90}. For the purposes of the prediction of turbine noise the L_{A90} is assumed to be 2 dB lower than the equivalent L_{Aeq}.

Noise-sensitive receptors

2.1 Noise sensitive receptor locations will normally comprise residential dwellings only. In some cases, additional receptors with sensitivity to noise, such as healthcare buildings providing inpatient services, nursing/retirement homes, educational establishments with residential elements, (e.g. boarding schools), etc. should also be included in the assessment. Additional receptors should be identified at the initial scoping stage of the assessment, in consultation with relevant stakeholders such as the relevant Planning Authority. It is not necessary to consider every potential noise-sensitive receptor within any study area provided that the receptors that are considered are representative of all relevant noise-sensitive receptors identified.

2.2 Although noise assessment criteria in this technical guidance are defined to protect the indoor and outdoor environment of the noise-sensitive receptor locations, they only apply to free-field[5] external areas closest to the noise-sensitive building. That is those areas which are frequently used for relaxation or for activities for which a quiet environment is highly desirable and use of which are directly connected with the noise-sensitive receptor location.

2.3 Protection of noise-sensitive receptors is based on the control of noise at locations free of acoustical reflections (other than the ground), excluding positions around the property which are acoustically reflective (such as locations near to walls of the dwelling) or unusually sheltered (such as enclosed spaces).

Noise criteria overview

2.4 **Noise limits vs noise assessment criteria**: the noise assessment criteria summarised above are the total noise assessment criteria which apply to cumulative operational noise levels of all acoustically relevant wind turbines (see Cumulative Noise paragraphs 2.34 to 2.38 below for further guidance) at a given receptor location. Wind turbine noise is controlled during its operation by the application of site-specific noise limits (SSNLs) at the nearest noise-sensitive receptor locations. These noise limits apply to the wind farm being considered through the use of site-specific noise limits in planning conditions. The SSNLs will be lower in some instances than the total noise assessment criteria.

2.5 **Wind speed references**: All wind speeds in this technical guidance refer to standardised[6] wind speeds. Noise assessment criteria apply for a range of standardised wind speeds from zero up to 10 m/s. Guidance is provided in section 3 on assessing noise effects at higher wind speeds in specific situations.

2.6 **Character corrections**: Noise assessment criteria to control wind turbine noise assume noise levels from the wind turbines are ‘rated’ by adding, where appropriate, a character correction to the noise from the wind turbines when compliance assessment measurements are undertaken for an operational wind farm. Character corrections are

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5 Free field means that the location is not significantly affected by acoustically reflective surfaces (except the ground), and in this case means at least 3.5 m from reflecting surfaces with a measurement height of 1.2 - 1.5 m.

6 The standardised wind speed V_s is based on the wind speed measured or extrapolated/interpolated at a height H_{hub} representative of the wind turbine hub height: V_{hub}, using the formula set out in the IEC 61400-11 standard with a notional height of 10-metres and a reference roughness length of 0.05 metres.
$V_s = V_{hub} \log(10/0.05) / \log(H_{hub}/0.05)$. This is consistent with the way wind turbine noise emissions levels as a function of wind speed are commonly reported according to the IEC 61400-11 standard.

to be applied for the presence of tones and elevated amplitude modulation (AM) during such compliance measurements.

2.7 It is, however, generally not possible to predict the occurrence of such noise characteristics at the planning stage. Tonal noise radiation from wind turbines, when it occurs, is usually associated with a specific design or component malfunction (combined with operational characteristics), rather than being an expected general characteristic of wind turbines. The occurrence of elevated levels of AM is a complex phenomenon due to a combination of turbine and site characteristics; the current consensus is that AM cannot be predicted. Tonal noise and AM are therefore best controlled through enforcement of planning conditions which include the application of character corrections as described in section 4. Consequently, character corrections should not be added at the planning/application assessment phase.

Noise assessment criteria definition

2.8 A single set of noise assessment criteria applies to control operational noise during both the day (07:00 to 23:00) and night (23:00 to 07:00) periods. The noise assessment criteria are based upon a combination of a Lower Limiting Value (LLV) and, optionally, a margin above typical baseline background sound levels. Typical baseline background sound levels and wind turbine noise both vary with wind speed. Accordingly, noise assessment criteria will generally be derived as values which change with wind speed, to reflect the variation in typical baseline background sound levels.

2.9 The $L_{A90,10min}$ measurement index is used when determining typical baseline background sound levels, determination of noise assessment criteria, setting of noise limits, and measurements completed during an assessment of compliance with noise limits. This is because compliance measurements at receptor locations made using the L_{A90} index provide a more reliable measure of wind turbine noise than measurement indices such as the L_{Aeq}, which can be affected by relatively loud, transitory noise events from other sources.

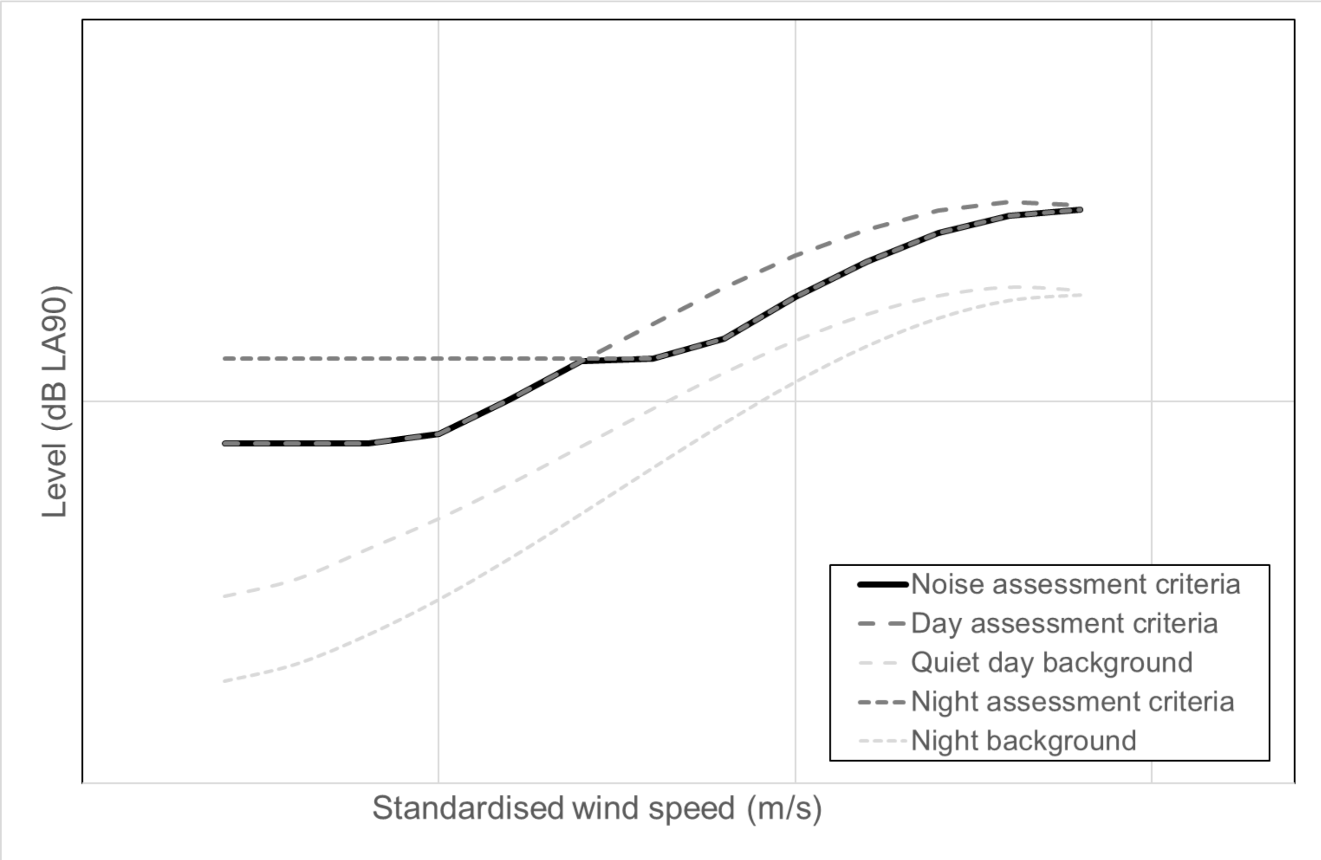
2.10 Wind turbine noise assessment criteria during both day and night periods shall be determined as the greater of either:

- 5 dB above typical background sound levels; or
- the relevant Lower Limiting Value (LLV) (see below).

2.11 Noise assessment criteria for day and night are derived separately based on the typical background sound levels during those periods (see section paragraphs 2.26 to 2.33 on background sound levels). The overall noise assessment criterion at each wind speed is set to the lower value of these two derived day and night noise assessment criteria and applies at all times. This means that noise is controlled consistently between day and night periods and that compliance monitoring can be completed at night (when sound levels from human activities decrease) and used to determine compliance during all periods. The lower value at each integer wind speed is used to avoid the situation where operational noise levels could increase at night as the night LLV is higher than the day LLV.

2.12 Figure 1 below represents an example where the noise assessment criteria is determined from the results of background sound measurements where the day and night assessment criteria are set relative to background.

Figure 1: Diagram illustrating the determination of the noise assessment criteria



2.13 It may be acceptable, where agreed between the developer and the relevant authority, to complete the above assessment process in absence of completing a survey of background sound levels. Such an approach would be based only upon the LLVs for the day periods, without reliance on relating the assessment criteria to a margin above background sound levels. Although the factors given below for justifying the choice of LLV during the day are to some extent determined by consideration of background sound levels, this can be determined based on the expected character of the area in a manner agreed with the relevant authority.

2.14 Where existing background sound surveys have already been completed (for adjacent schemes for example) it may be acceptable to use these data, provided these data have been gathered, and appropriately corrected for the reference wind speed height, in accordance with good practice.

2.15 Alternatively, a simplified noise criterion of 37 dB L_{A90} (up to 10 m/s) can be set regardless of background sound levels and applies during both day and night. This therefore does not require the measurement of background sound levels. These criteria may be particularly suitable for single or smaller scale turbines or cases where a large separation distance exists between the turbines and neighbouring properties.

Choice of LLV

2.16 Different lower limiting values (LLVs) apply during the day and night:

- The LLV applied for determining the day noise criteria is set in the range from 37 to 40 dB L_{A90} for noise-sensitive receptors without a financial involvement;
- The chosen LLV is applied to all noise sensitive receptors in the vicinity of the development, and not derived on a property-by-property basis.
- For night periods, the LLV is set to 43 dB for noise-sensitive receptors without a financial involvement.

2.17 The choice of the LLV for day periods within the range of 37-40 dB is to be determined based on the following site-specific factors which represent the planning impacts and merits of the wind farm scheme(s):

- The likely energy generation of the wind farm in the national context and the consequence the choice of LLV would have on the energy generating capacity of the proposed wind farm(s).
- The number of dwellings in the neighbourhood of the wind farm(s) and the magnitude of the levels to which these are exposed.
- The duration and level of exposure.

2.18 The factors considered in determining the LLV are presented in priority order, i.e. the largest weight should be given to the overall generating potential of the wind farm, with the number of dwellings and the duration and level of exposure being secondary and tertiary considerations.

2.19 The different LLV considerations should be evaluated where relevant within a national context (England, Wales, Scotland and Northern Ireland), as the range of wind energy projects, national policy priorities, and population density in practice can vary in each case.

2.20 **Energy generation:** the energy generation potential of the proposed site, evaluated in terms of the proposed installed generating capacity, should be considered in the context of the range of existing and proposed wind farm schemes.

- The higher the installed capacity of the project is, in the national context, the more the LLV should tend towards the upper end of the range.
- The lower the installed capacity is in the national context, the more the LLV should tend towards the lower end of the range.
- When determining a cumulative noise limit for several wind farms or the extension of an existing project (see cumulative noise section paragraphs 2.34 to

2.39), the total installed capacity from the relevant sites included in the assessment should be considered.

- The effect of the choice of LLV on energy generation should also represent a consideration. If the choice of LLV does not impact on energy generation of the wind development, for example because the nearest noise-sensitive receptors are relatively distant, then a lower LLV should be applied.

2.21 **Number of noise-sensitive receptors:** the more dwellings that are in the vicinity of a wind farm, the lower the limits should be, as the total environmental impact will be greater.

- When the turbines considered are located near a relatively large number of properties, for example a town or a village (or settlement as defined in relevant planning documents), the LLV should reduce or remain towards the lower end of the range.
- Conversely when located near a low number of properties, for example isolated individual dwellings, the LLV could increase or remain towards the upper end of the range.
- The neighbourhood of the turbines for this purpose can be considered as the region where predicted (cumulative) levels are 37 dB L_{A90} or above at any wind speed in the range of wind speeds considered.
- The magnitude of the predicted levels to which the different noise-sensitive receptors are exposed to also represents a consideration.

2.22 **Duration and level of exposure:** this aspect is more difficult to define precisely, but the proportion of the time and extent to which the wind turbine noise may be above existing background sound levels should be considered.

- Factors which will suggest the LLV would increase or remain high:
  - Most receptors are downwind of the turbines for a low proportion of the time, for example if located upwind of the turbines under the prevailing wind directions
  - Predicted noise levels are comparable to or lower than background sound levels, for example due to elevated background noise from other sources or an exposed location.
- Factors which will suggest the LLV would decrease or remain low:
  - Most receptors tend to be downwind of the turbines for a majority of the time (e.g. under prevailing wind conditions);
  - Predicted noise levels tend to be higher than background sound levels, for example due to relatively low background levels.

2.23 The different LLV considerations may also be inter-related and should therefore be evaluated holistically. For example, if a larger number of properties were located such that they would be exposed to the wind turbine noise for a minority of the time, this would attract less weight than if these were located such that they would have a higher duration of exposure. Some illustrative examples are set out in Appendix C.

2.24 The LLV should be evaluated in the prescribed range defined at 2.16 based on site-specific criteria that are considered in each case. A general presumption that a certain “standard value” should be used for all projects would be contrary to this principle.

2.25 The LLV used to define the noise assessment criteria can be increased to 45 dB L_{A90} where the occupier of the property has a financial involvement in the wind farm. A valid financial involvement applies at a property when the property resident receives a profitable (not merely compensatory) financial benefit associated with the wind farm over the life of that scheme. This definition of financial involvement applies to occupiers of residential properties, whether these are owner-occupiers or tenants.

Background sound levels

2.26 Where baseline background sound levels are to be measured, these are measured at noise-sensitive receptors and related to wind speeds experienced on the site being assessed. Wind speeds need to be representative of those experienced at the hub height of the wind turbines being considered and standardised to 10-metres height (see paragraph 2.5). Turbine noise predictions are also referenced in terms of standardised wind speeds so that they can be compared with the background sound levels at a dwelling in comparable conditions, on a like-for-like basis.

2.27 The range of wind speeds to be included in the survey of background sound levels needs to encompass a range from lower wind speeds (where the wind turbines begin to operate) up to higher wind speeds (where the wind turbines no longer have increasing noise emission levels), and within the range of wind speeds considered in these guidelines (see paragraph 2.5). For wind turbines currently being used for wind energy developments, which are based on variable speed operation and power regulation through blade pitch, this may only need to include standardised wind speeds up to 8 to 10 m/s at most.

2.28 Any measurements of background sound should not include noise from operational wind turbines, as these are not considered part of the baseline when determining the assessment criteria that applies to noise from all wind turbines. Where there remains a need to determine background sound levels that could be influenced by operational wind turbine noise, a suitable method needs to be selected to determine background sound levels without a substantial contribution from operational wind turbines, through reference to good practice guidance and in consultation with the relevant Planning Authority. It may be possible to reference historical data provided it is suitable, representative, and accords with good practice.

2.29 Measurements should normally be undertaken at a representative sample of noise-sensitive receptor locations where cumulative predicted noise levels exceed a level of

37 dB L_{A90} at any wind speed in the wind speed range considered. It is recommended to discuss the choice of representative background survey locations in consultation with the relevant Planning Authority where possible.

2.30 Typical background sound levels during the day (07:00 to 23:00) are determined from data for “quiet day” periods which are defined as comprising: all evenings from 18:00 to 23:00, plus Saturdays from 13:00 to 18:00, plus Sundays from 07:00 to 18:00. Typical background sound levels during the night are determined from data for the period 23:00 to 07:00 on any day of the week. All times are defined as local time including daylight savings where applicable.

2.31 The variation in background sound levels with wind speed is determined by relating multiple $L_{A90,10min}$ noise measurements with the average wind speeds measured over the same 10-minute intervals and then determining the average noise level as it varies with wind speed (e.g. by fitting a best fit curve to the data using a linear or polynomial regression). This process should be completed separately for the day and night and yield the relationship of the change of typical background sound levels with wind speed for both periods.

2.32 The aim of the monitoring is to determine reasonably representative data in conditions in which the noise-sensitive receptor locations would be exposed to noise from the wind turbines being assessed. For example, if some wind directions result in a noise-sensitive receptor location being relatively sheltered while downwind of the proposed wind turbines, consideration should be given to noise data collected for these wind conditions. Background sound measurements need to be carried out at locations representative of the nearest affected noise sensitive receptor locations (see paragraph 2.2) in a free field position. Whenever possible, the measurements should be made more than 3.5 metres from potentially significant acoustically reflective surfaces (except the ground).

2.33 Good practice guidance produced by the Institute of Acoustics is to be referenced to consider aspects of the background sound monitoring not covered in this technical guidance. For example; suitable equipment to use, including suitable windshields to undertake measurements in potentially windy conditions, placement of equipment, data analysis, survey duration and the exclusion of atypical sounds affecting the measurements.

Cumulative noise

2.34 The noise assessment criteria derived above apply to the cumulative effect of all wind turbines in the area contributing to the noise received at the noise-sensitive receptor locations in the vicinity of the proposed development.

2.35 Where noise levels from the proposed development are lower than 27 dB L_{A90}, or 10 dB or more below the total noise assessment criteria, a cumulative operational noise assessment is not necessary at that noise-sensitive receptor. All other wind farm developments must be considered in the cumulative assessment where their individual noise level contribution is greater than a level of 10 dB below the total noise assessment criteria.

2.36 When considering cumulative noise, financial involvement relates to a specific development. Accordingly, an additional test should be undertaken at each involved property by considering the total cumulative noise from all developments except the one to which it is financially involved. This specific cumulative level must not exceed a noise limit derived without assuming the financially involved status.

2.37 In some situations, a receptor may become exposed to noise from several different wind farm sites in different wind directions thereby increasing the duration of exposure, which is one of the factors relevant to determining the LLV. When assessing cumulative noise effects, if the contributions from each individual wind farm are combined assuming that the assessment location is downwind of all wind turbine developments simultaneously, this is considered to account for the increased duration of exposure.

2.38 Where more than one wind energy development is under consideration in the noise assessment, the total assessment criteria can be increased by 1 dB (increased tolerance), as long as the contribution from each wind turbine development in isolation does not exceed the total noise assessment criteria. This means that in a situation where existing operational noise levels are already consented at the assessment criteria (for example 40 dB L_{A90}) then the contribution from one proposed development with an operational noise level of 34 dB L_{A90} or below should be considered acceptable (or two schemes with a contribution of 31 dB L_{A90}). However, if another wind turbine development is proposed and the total cumulative wind turbine operational noise level is already 1 dB above the total assessment criteria, then the contribution from the new proposed development should be at least 10 dB below the total noise assessment criteria (excluding the 1 dB tolerance referenced above).

2.39 The above cumulative assessment criteria example is summarised in Table 1 below based on the example of a 40 dB L_{A90} assessment criterion applicable to cumulative levels, with other similar examples.

Table 1: Cumulative assessment - example scenarios of acceptable noise levels (all dB L_{A90})

Assessment Criteria	Site A	Site B	Site C	Total acceptable noise level
40	40	34	30	41
40	40	31	31	41
38	36	35	29	39
38	38	32	n/a	39
37	35	33	n/a	38
37	37	28	28	38

Site-specific noise limits

2.40 Site-specific noise limits (SSNLs) are derived for each receptor location at a level which is lower than or equal to the total noise assessment criteria. SSNLs should only be equal to the total noise assessment criteria where it is necessary, with supporting justification for this provided in the assessment. Cumulative noise limits that apply to noise sources outside of the control of the operator of the proposed development should not normally be applied.

2.41 Further information on setting appropriate SSNLs is set out at paragraphs 4.3 and 4.4.

3 Operational noise monitoring

3.1 Noise from wind farms should be controlled through planning conditions (or equivalent requirements) which direct the wind farm operator, at any time during the operation of the development, to undertake measurements at one or more specific properties following justified complaints related to noise. A condition requiring periodic monitoring, or post-completion monitoring at residences in the absence of complaints, is not required under this technical guidance.

3.2 Measurements should focus on periods where background sound levels are minimised (such as night periods) and where noise from the wind farm is maximised (for example, downwind conditions in which the wind blows from the wind turbines towards the noise-sensitive receptor) and/or with regards to specific conditions in which complaints occurred. This will define one or more data subset(s) in which the analysis will be undertaken.

3.3 Where it has been identified (e.g. through complaint records) that complaints specifically relate to operational wind turbine noise at wind speeds which are above those considered in the noise assessment and contained within the planning conditions, appropriate noise limits can be determined as part of the initial compliance assessment protocol to be submitted and agreed with the relevant Planning Authority.

3.4 Good practice guidance produced by the Institute of Acoustics is to be referenced to consider aspects of the monitoring not covered in this technical guidance, for example, equipment to use, including suitable windshields to undertake measurements in potentially windy conditions, placement of equipment, data analysis, survey duration and the exclusion of atypical noise sources affecting the measurements.

3.5 Values of the $L_{A90,10min}$ measurement index and other related data (wind speed, wind direction etc.), for each 10-minute interval, are separated (or 'binned') into 1 m/s wide wind speed bins centred on integer values of wind speed (i.e. 3, 4, 5 etc.). It is noted that baseline background sound levels are derived using a best-fit curve through the data to determine the typical background sound levels as they vary with wind speed, whereas operational noise measurements are concerned with defining noise levels under specific conditions (i.e. in wind speed and direction bins).

3.6 Data should also be filtered by wind direction, which may involve filtering data for only conditions where the assessment location is downwind of the wind turbines or separated into narrower wind direction data subsets (for example, separating data into 30° wind direction sectors). The relevant approach should reflect the following:

- Weather conditions in which complaints were received; or
- Weather conditions contained in the request from the relevant Planning Authority; or

- Should default to downwind conditions.

3.7 Where data are to be filtered to include only downwind conditions, the downwind sector is often considered to be the arc between the most dominant wind turbines and the noise-sensitive receptor position. This downwind direction arc may be expanded by up to +/- 45° to provide a suitable data subset size, but can be left more narrowly defined where considered appropriate.

3.8 For each wind speed bin and for each of the separate data subsets, a bin centre arithmetic average is calculated to represent the single value L_{A90} noise level. For each 10-minute interval a character correction is determined where relevant (see paragraphs 3.12 to 3.15), and the wind speed bin arithmetic average character correction calculated in each data subset. The bin average wind turbine rating level is the arithmetic sum of the L_{A90} noise level (corrected for background where appropriate) and the bin average character correction where applicable.

3.9 Where a correction for the contribution of other noise sources (i.e. not associated with the wind turbine(s) being assessed) is required, this is typically done by repeating the measurements with the assessed wind turbines shut down to determine a “residual” level. The wind turbine average residual noise level should normally be calculated for the relevant bins/subsets being considered; however, it may be appropriate for this correction to use an alternative method which must be justified.

3.10 The wind turbine development noise level is the average residual noise level logarithmically subtracted from the average measured overall noise level, within each bin, to obtain a corrected assessment level. The character correction is then applied to the corrected assessment level. It should be noted that, where the residual noise level is higher than, or within 3 dB of, the measured overall noise level it may no longer be appropriate to use this correction. This indicates that the turbine development noise level is equal to, or lower than the residual noise level.

3.11 Where it is not possible to determine compliance with the limits through measurements at the receptor locations (for instance where access to carry out measurements is refused or where residual noise levels are high relative to the total measured levels), it may be acceptable to determine compliance through proxy measurements and modelling, with agreement from the relevant Planning Authority.

Correcting measured noise for character

3.12 In cases where, based either on the description of the complaints, the opinion of the relevant authority or observations made on site, the character of the noise is likely to include specific character components that require assessment, then the compliance monitoring will assess these characteristics. Where no such descriptions or observations of the presence of these characteristics are made then the compliance assessment does not normally need to assess these characteristics.

3.13 Noise shall be ‘rated’ by adding a character correction which can be applied during assessment of compliance of a particular wind farm with its site-specific noise limits. These character corrections are to be added due to the presence of tones or discrete frequencies in the noise (tonal character correction) as well as amplitude modulation (AM character correction). During a compliance assessment, values of the $L_{A90,10min}$ measurement index will be determined for each 10-minute interval for one or more data subset(s) in which the analysis will be undertaken. For relevant subsets, values of the character correction shall be calculated for both tones and AM and the higher of these individual character corrections shall be applied (on the basis that it is the most dominant feature within that 10-minute interval that is relevant). If both tones and AM are being investigated, results are reported separately as well as reporting the applicable (highest) character correction.

3.14 Character corrections can only be determined at or close to the location assessed, as character and audibility can vary significantly between locations, i.e. character corrections from one measurement location cannot be applied to another location.

3.15 The character corrections may usefully also be assessed where relevant during shut-down periods, as it can allow identification of character in sounds not related to the wind farm being considered. Characters not related to the wind turbines being assessed should be excluded.

Tonal analysis

3.16 The tonal audibility and associated character correction shall be calculated for each 10-minute interval using the method shown in Appendix B. It should be noted that in order to perform narrowband analysis according to the method, it will be necessary to record audio data with a suitable resolution and sampling frequency to cover the frequency range of interest.

3.17 If the interval analysed is not considered valid[7], that data point is removed from the character analysis (no character correction calculated) and the data is not included in the bin averaging described below.

3.18 The associated character correction is calculated for each 10-minute interval. Where the tonal audibility is less than 2 dB the character correction is 0 dB, and where the tonal audibility is greater than or equal to 6.5 dB the character correction is 5 dB. Otherwise, the character correction is calculated using the following formula (as shown in Figure 2):

$$\underset{1.54\rightarrow 5}{\text{Character correction}} = \mathit{Tonal\ audibility} \times {}^{5}/_{6.5}$$

[7] This may be due to corruption from other sources of noise during the 10-minute interval or where the apparent tonality detected is unrelated to the wind turbines being assessed.

Figure 2: Tonal character correction curve

Amplitude modulation analysis

3.19 The modulation depth is calculated for each 10-minute interval using the method set out in the Institute of Acoustics document *A Method for Rating Amplitude Modulation in Wind Turbine Noise*[6]. The method is directly applicable to amplitude modulation (AM) for turbines with a blade passage frequency of up to 1.6 Hz, corresponding to a rotational speed of up to 32 rotations per minute (rpm) for a three-bladed turbine. It should be noted that in order to carry out the analysis, it is necessary to record A-weighted 1/3rd octave 100 ms data.

3.20 The Institute of Acoustics AM methodology requires the analysis to be undertaken in a choice of one of three frequency ranges (50 to 200 Hz, 100 to 400 Hz or 200 to 800 Hz). This should be determined by analysing the frequency range which tends to give the highest results, excluding outliers, as this provides the best representation of modulation associated with specific site and propagation characteristics. This analysis of the dominant band should be undertaken for each direction subset considered in the analysis, and in some cases at different wind speeds, as different bands may be relevant for different wind conditions.

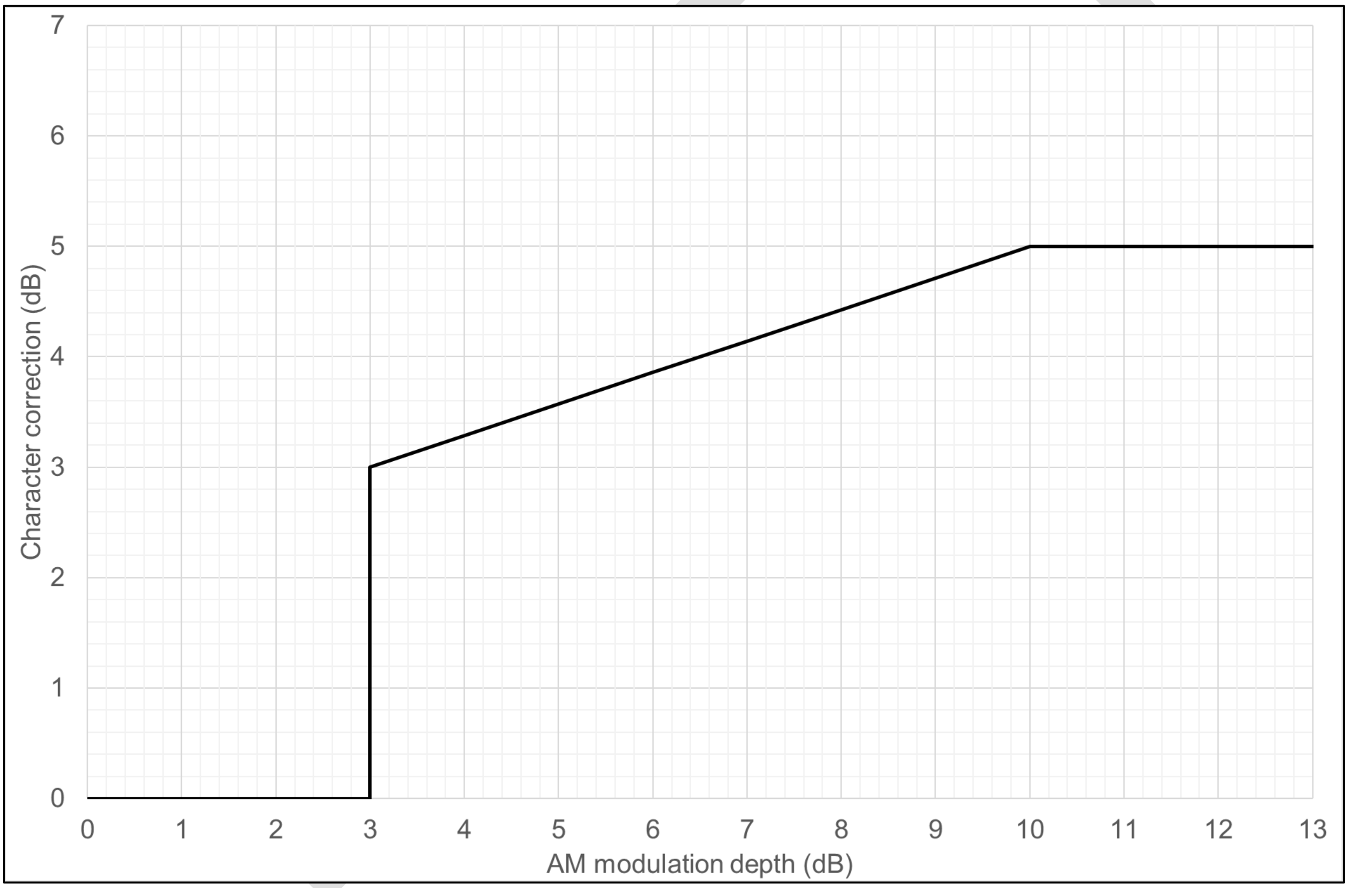
3.21 If the interval analysed is not considered valid, i.e. when corrupted due to other sources or the apparent modulation detected is not related to the wind turbines being measured but to other sources, that data point is removed from the character analysis (no character correction calculated and the period not included in the bin averaging described below).

3.22 Where valid (uncorrupted) data allow the analysis to be undertaken, a decibel modulation depth (MD) is calculated in accordance with the Institute of Acoustics AM methodology for each 10-minute interval. Where the AM modulation depth is less than 3 dB, or no modulation was detected, the character correction is 0 dB, and where the modulation depth is greater than or equal to 10 dB the character correction is 5 dB. Otherwise, the character correction is calculated using the following formula (illustrated in Figure 3):

$$AM\ Character\ correction = 3 + {(2MD - 6)}/{7}$$

Where *MD* is the modulation depth.

Figure 3: Amplitude Modulation character correction curve



Combined character corrections and bin averaging

3.23 Where both tonal and AM character is being investigated, the highest character correction in each 10-minute interval is used when calculating the average character correction. The average character correction is then calculated for each wind speed bin and wind direction subset.

4 Planning conditions

Introduction

4.1 This section describes how noise limits shall be applied to wind turbine developments and includes the technical data that shall be recorded by the operator of the development and the way in which complaints should be investigated.

4.2 Where a complaint is made to the relevant Planning Authority about operational noise from the wind turbine(s), this can trigger a procedure for assessing compliance with the noise limits, which would normally involve measurements carried out at the expense of the operator of the wind turbine development. This can be secured via standard planning conditions.

Setting limits

4.3 Operational noise from wind turbine developments should be controlled through the application of Site-Specific Noise Limits (SSNLs) that apply to noise solely from the development being consented. The SSNLs should normally not be set equal to the total noise assessment criteria discussed in section 2 where it is not necessary to do so in order for the site to operate without unreasonable restriction (i.e. where there is a sufficient margin between operational noise levels and the assessment criteria).

4.4 The following additional guidance shall be followed when setting appropriate noise limits:

- The noise limit should normally follow the same profile as the total criteria (not the predicted noise levels), reduced by a fixed amount at all wind speeds[8];
- Noise limits that include the contribution from sources outside of the control of the operator/owner of the development should not be applied;
- The difference between the SSNL and the total noise assessment criteria may vary at different properties to account for the relative contribution of other cumulative sites considered, in such a manner that cumulative levels would remain below the total noise assessment criteria;
- In some cases, it may be appropriate to define a single value limit that applies at all wind speeds within a defined range (for example where the lowest limit across all wind speeds is met at all wind speeds);
- Limits defined at a level of more than 10 dB below the cumulative assessment criteria should be avoided.

[8] The limit for the proposed development could for example be set at the assessment criteria minus the minimum margin between the predicted operational noise level and the total criteria.

Example planning condition

4.5 The following section provides example text forming a suitable basis for inclusion in a planning condition (or similar requirement) to control operational noise levels. Planning Condition Technical Guidance Notes are also included in the following section and it is the intention of this technical guidance that planning conditions could reference these guidance notes without needing to include them in full, in the interest of conditions being concise. The text in square brackets in the following example is to be replaced by the appropriate text for the specific development being considered (e.g. references to noise limit values would be replaced by the appropriate noise limits for the consented development).

4.6 The rating level of noise from the combined effects of the wind turbines hereby permitted (including the application of any tonal and/or amplitude modulation (AM) character correction), when determined at relevant properties in accordance with the [Assessment and Rating of Wind Turbine Noise 2025 Guidance Notes], shall not exceed [either XX dB L_{A90} or] the values for the relevant integer wind speed set out in or derived from the Table attached to this condition and:

A) Within 21 days from receipt of a written request of the Planning Authority, following a complaint to it alleging noise disturbance at a dwelling, the wind farm operator shall, at its expense, employ an appropriately qualified and experienced consultant and provide a written Protocol to be approved by the Planning Authority. The Protocol shall confirm the applicable noise limit and describe the procedure to assess the level and character of noise from the wind farm at the complainant's property in accordance with the procedures described in the [ARWTN Technical Guidance Notes]. The written request from the Planning Authority shall set out as far as possible the time or meteorological conditions to which the complaint relates to and whether the character of the noise is likely to include tonal noise or AM components if applicable. Measurements to assess compliance with the noise limits shall be undertaken in accordance with the assessment Protocol which shall be approved in writing by the Planning Authority.

B) The wind farm operator shall provide to the Planning Authority the consultant's assessment of the rating level of noise at the complainant's property undertaken in accordance with the protocol within 2 months of the date of the approval of the protocol by the relevant Planning Authority unless otherwise agreed by the Planning Authority. The assessment shall include all data collected for the purposes of undertaking the compliance measurements and analysis, such data to be provided in a format to be agreed with the Planning Authority. Certificates of calibration of the equipment shall be submitted to the Planning Authority with the consultant's assessment report.

C) Where a further assessment of the rating level of noise from the wind farm at the complainant's property is required to correct for other noise sources pursuant to the [ARWTN Technical Guidance Notes], the wind farm operator shall submit a copy of the further assessment within 21 days of submission of the consultant's initial assessment unless otherwise agreed by the Planning Authority. The wind farm operator shall facilitate wind turbine shut-downs as required by the consultant to allow the other sources contribution to be determined if suitable data is not already available.

D) Wind farm operational and wind data logged by the operator, as defined in the [ARWTN Technical Guidance Notes], shall be supplied to the relevant Planning Authority on its request, within 14 days of receipt in writing of such a request.

Table [X]: Operational noise limits at receptor locations (dB L_{A90})

Receptor Location (easting, northing)	Standardised Wind Speed (m/s)									
	1	2	3	4	5	6	7	8	9	10

Planning condition technical guidance notes

4.7 These planning condition technical guidance notes are referenced in the planning condition, but do not need to be reproduced within the planning conditions attached to a development consent notice.

4.8 Values of the $L_{A90,10\ minute}$ noise index should be measured following good practice guidance issued and maintained by the Institute of Acoustics in terms of measurement positions and equipment used. Measurements shall be undertaken in such a manner to enable both a tonal and AM character correction to be calculated for selected periods where a tonal or AM assessment is required in the assessment Protocol, in line with the applicable assessment methods defined in Section 3 of this technical guidance.

4.9 The wind farm operator shall continuously log arithmetic mean nacelle anemometer wind speed, mean nacelle orientation, mean wind direction as measured at the nacelle, arithmetic mean rotor rotational speed and whether each wind turbine is running normally during each successive 10-minute interval for each wind turbine on the wind farm. The wind speed at wind turbine hub height shall be 'standardised' to a reference height of 10 metres as defined in paragraph 2.5. The resulting standardised wind speed data are synchronised with the noise measurements. All 10-minute intervals shall commence on the hour and in 10-minute increments thereafter synchronised with a common time reference such as Coordinated Universal Time (UTC). Data provided to the relevant Planning Authority in accordance with the noise condition shall be provided in electronic format using comma separated values or, in the case of audio recordings, WAV files (or similar accessible format). The assessment Protocol will define the wind reference to be used for the assessment of each location and how this will be determined from the wind turbine data recorded and/or any other suitable anemometry data available during the measurements.

4.10 Where a dwelling to which a complaint is related is not listed in the tables attached to the planning condition, the applicable noise limits included in the Protocol are to be justified by the consultant. The limits should be taken from the nearest listed location or, if the limits are set relative to background sound levels, based on the location likely to experience the most similar background sound environment to that experienced at the complainant's dwelling. In some cases, the noise limits for properties not listed in the noise limit table attached to the planning condition may require some adjustment to account for cumulative considerations in line with the original noise assessment. In these instances, the associated calculations should be clearly set out in the Protocol.

4.11 The Protocol should normally only specify an analysis of character (tonality and/or AM) if the description of the complaint, indications from the Planning Authority regarding the character of the noise or site observations suggest that the noise may potentially include specific tonal or AM components.

4.12 The assessment shall identify a subset of data having had regard to:

- the conditions (including time of day and corresponding wind directions and speeds) at times in which complaints were recorded;
- the nature/description recorded in the complaints if available;
- information contained in the written request from the relevant Planning Authority;
- likely propagation effects (downwind conditions or otherwise);
- the results of the tonality/AM analysis where relevant.

4.13 In cases where it is possible to identify patterns of clearly different conditions in which complaints have arisen, additional subsets may be considered provided this does not introduce unreasonable complexity in the analysis and can be justified by the assessor.

4.14 The $L_{A90,10\text{-minute}}$ measurements shall be synchronised with measurements of the 10-minute arithmetic mean wind and operational data logged in accordance with paragraph 4.9. Within each of the subset(s) of data identified, data shall be placed into separate 1 m/s wide wind speed bins.

4.15 A data logging rain gauge shall be installed for the duration of the noise measurements. The gauge shall record over successive 10-minute intervals synchronised with the noise measurements. Data affected by rainfall shall be excluded from the analysis.

4.16 The L_{A90} sound pressure level for each data subset and wind speed bin is the arithmetic mean of all the 10-minute sound pressure levels within that data subset and wind speed bin except where data has been excluded for reasons which should be clearly identified by the consultant.

4.17 The noise measurements shall be made so as to provide not less than 20 valid data points in each data subset(s) assessed, or provide clear explanations as to why this was not possible or necessary.

4.18 Where relevant in accordance with the Protocol, an assessment of tonality and/or amplitude modulation shall be undertaken for each 10-minute interval of the data subset(s) considered. The analysis shall be undertaken in accordance with the character analysis methodologies set out in in Section 3.

4.19 Where data for a 10-minute interval are corrupted such that the character rating is considered unlikely to be associated with the wind turbines being tested, that interval shall be removed from the character analysis. For all other valid data, the value of the tonal audibility and/or AM rating for each 10-minute interval shall be converted to a character correction in decibels in accordance with the procedure of Section 3 (Figure 2 and Figure 3). In cases where both tonal and AM character corrections are identified, the maximum value will be retained for each 10-minute interval as a character correction.

4.20 The resulting character correction shall be placed in the appropriate data sub-set and wind speed bin. Where a character correction is zero it should be placed in the bin in the same way. For each data subset considered, the character correction for each bin is the arithmetic mean of the character penalties in the bin. The assessment level in each bin is the arithmetic sum of the bin L_{A90} and the character correction in the bin.

4.21 If the assessment level in every bin lies at or below the limit(s) defined in the assessment Protocol then no further action is necessary. In the event that the assessment level is above the limit(s) defined in the assessment Protocol in any bin, the consultant shall undertake a further assessment of the rating level to correct for other noise sources so that the rating level relates to noise only from the wind turbine(s) being assessed. Correction for other noise sources need only be undertaken for those wind speed bins where the assessment level is above the limit.

4.22 The residual noise level (L_3) without the wind turbines operating is normally obtained through shut down of wind turbines[9]. If such data is required, the wind farm operator shall ensure that acoustically relevant wind turbines in the development are turned off for such periods as the consultant requires to undertake the further assessment. The further assessment shall then be undertaken by repeating the steps in paragraphs 4.14 to 4.16, with the wind farm switched off, and determining a residual noise level (L_3) at each integer wind speed within the wind speed bins and data subsets defined in paragraph 4.20. The corrected wind farm noise level (L_1) in each of these bins shall

[9] For large wind farm sites, the contributions of relatively distant turbines may be considered negligible and and therefore shutting down these turbines would not be considered necessary. The relevant turbines and the method used (e.g. through predictive modelling) should be agreed as part of the Protocol if relevant.

then be calculated as follows where L_2 is the measured level with wind turbines running but without the addition of any tonal character correction:

$$L_1 = 10\ \log\left[10^{L_2/10} - 10^{L_3/10}\right]$$

4.23 Where the residual noise level is higher than, or within 3 dB of, the measured overall noise level it may no longer be appropriate to use this correction. This indicates that the turbine development noise level is equal to, or lower than the residual noise level. In these circumstances where, the corrected wind farm noise level cannot be calculated using this method and, an alternative method of determining the corrected wind farm noise level (e.g. supplemented by alternative site-specific measurements and predictive modelling) should be agreed with the relevant Planning Authority.

4.24 The corrected assessment level shall be calculated by adding the character correction defined in paragraph 4.19 to the derived wind farm noise L_1 in that bin. If the corrected assessment level in every bin lies at or below the limit(s) defined in the assessment Protocol then no further action is necessary. If the corrected assessment level exceeds the limit(s) defined in the assessment Protocol in any wind speed then the development fails to comply with the planning condition in the circumstances represented by that bin.

5 References

1 ETSU R 97 'The Assessment and Rating of Noise from Wind Farms', The Working Group on Noise from Wind Turbines, Final Report, September 1996.

2 WSP for the Department for Business, Energy & Industrial Strategy (2022), A review of noise guidance for onshore wind turbines, report reference 70081416 001 03 03.

3 Institute of Acoustics, A Good Practice Guide to the Application of ETSU-R-97 for the Assessment and Rating of Wind Turbine Noise, May 2013.

4 Department for Environment, Food and Rural Affairs (2010), Noise Policy Statement for England (NPSE).

5 BS 4142:2014+A1:2019, Methods for rating and assessing industrial and commercial sound, British Standards Institute, 30 Jun 2019.

6 Institute of Acoustics (IOA), Noise Working Group (Wind Turbine Noise), Amplitude Modulation Working Group, Final Report, A Method for Rating Amplitude Modulation in Wind Turbine Noise, 9 Aug 2016, Version 1.

Appendix A – Glossary of Terms

Term	Description
Amplitude modulation (AM)	A sound is modulated in amplitude when its level exhibits periodic fluctuations.
A-weighted	A filter that represents the frequency response of the human ear.
Acoustically relevant	When two environmental sound sources are present, if one source is 10 dB greater in level than the other, it is generally accepted the source with the lower level does not make an acoustically relevant contribution to the total noise level. In theory this results in an additional 0.4 dB (e.g. 40 dB + 30 dB results in 40.4 dB).
Background sound levels	The level of sound rarely fallen below in any given location over any given time interval, often classed according to day, evening or night periods.
Bin	Subset or group into which data can be sorted; in the case of wind speeds, bins are often centred on integer wind speeds with a width of 1 m/s. For example the 4 m/s bin would include all data with wind speeds of 3.5 m/s to 4.5 m/s.
Blade passage frequency	Rate or frequency at which the blade passes the tower during its rotation.
Day	07:00 to 23:00 local time, including daylight savings where applicable.
dB	Abbreviation for 'decibel'.
Emission level	The noise level emitted by a source, often quantified as a sound power level.
Fast time weighting	An exponential time weighting applied to sound levels (defined in IEC 616721:2013 Electroacoustics - Sound level meters - Part 1: Specifications.
Free field	A location that is not significantly affected by acoustic reflections (other than from the ground).

Frequency	The number of acoustic pressure fluctuations per second occurring about the atmospheric mean pressure (related to the ‘pitch’ of a sound).
Frequency analysis	The analysis of a sound into its frequency components.
Hertz (Hz)	The unit normally employed to measure the frequency of a sound, equal to cycles per second of acoustic pressure fluctuations about the atmospheric mean pressure.
Hub height	The height of the centre of the rotor of a wind turbine above ground levels around the wind turbine.
Immission level	The level of noise at a receiver location quantified as a sound pressure level.
$L_{Aeq,T}$	The A-weighted energy average sound pressure level over the time interval, T
$L_{A90,T}$	A-weighted sound pressure level that is exceeded for 90% of a given time interval (T) measured using the fast time weighting, often used for the measurement of background sound. In the case of wind turbine noise assessment, the time interval T is 10 minutes.
LLV	Lower limiting value. This is the value of the fixed element of the noise limit and which is not related to a margin above background sound levels but is set at a fixed value irrespective of wind speed.
ms	Millisecond.
Night	23:00 to 07:00 local time, including daylight savings where applicable.
Noise	Sound that evokes a feeling of displeasure in the environment in which it is heard and is therefore unwelcomed by the receiver.
Planning Authority	The council/body responsible for local planning matters.

Quiet day	Consists of periods of the day when background sound levels are often lower than other periods of the day. The quiet day consists of the following periods: evenings from 18:00 to 23:00, Saturdays from 13:00 to 18:00, and Sundays from 07:00 to 18:00.
Rated noise level	The level of wind turbine noise plus any adjustments (‘penalties’ or ‘corrections’) for the presence of tones or amplitude modulation characteristics.
Residual level	The level of sound measured at the assessment location not associated with the wind turbines being assessed.
Sound	Physically: a regular and ordered oscillation of air molecules that creates fluctuating positive and negative acoustic pressure above and below atmospheric pressure. Subjectively: the sensation of hearing excited by the acoustic oscillations described above (see also ‘noise’).
Standardised wind speeds	Standardised wind speeds are wind speeds at turbine hub height, converted to a height of ten metres for standardisation purposes with a formula using a ground reference roughness length of 0.05 metres (in accordance with the IEC 61400-11 standard).
Tone	The concentration of acoustic energy into a very narrow frequency range.

Appendix B – Tonal Analysis

B.1. There are three main steps in the procedure:

- Narrowband FFT frequency analysis of the noise at receiver locations;
- Line classification determination of the sound pressure level of the tone(s) and the sound pressure level of the masking noise within the critical band;
- evaluation of the difference between the tone and the masking noise sound pressure levels (ΔLtm) by comparison with a criterion curve to determine the audibility of the most prominent tone and any related tonal character correction.

Frequency analysis

B.2. The analysis for tones shall be completed on audio recordings of 2-minutes duration within each overall assessment 10-minute interval. These 2-minute audio recordings shall each lie within each of the overall assessment 10-minute interval considered.

B.3. For each 10-minute interval where an audio recording is available, a recording shall be processed to yield a multi spectrum of sequential and contiguous individual narrow-band spectra using Fast Fourier Transform (FFT), sampled using the Hanning window, with a 50% overlap, with an FFT frequency resolution of 3 Hz ± 0.5 Hz and an analysis bandwidth of 2 kHz[10], with spectral line magnitudes in decibels. This will result in each individual short-term FFT having a window length of between 0.29 to 0.4 seconds. An overall average narrow-band spectrum of the same frequency resolution shall also be obtained for the whole 2-minute sample (‘average FFT’).

B.4. The tonal analysis shall be completed on ‘A’ weighted noise levels. This may be achieved using ‘A’ weighting applied when recording the audio, or post-processed to apply ‘A’ weighting to the audio before the FFT, or applied to the FFT spectra. Applying the A-weighting to the recordings as a post-processing step has the benefit of retaining the ability to listen to un-weighted recordings when interrogating the data.

Determination of tone and masking levels

B.5. The bandwidth of a critical band is 100 Hz for critical bands with a centre frequency of between 20 Hz and 500 Hz and 20% of the critical band centre frequency for critical bands with a centre frequency greater than 500 Hz. If a single tone is present within a critical band, the critical band is centred upon the tone. If two or more, closely spaced

[10] It may be necessary in some specific cases to identify tonality at higher frequencies and therefore consider a wider bandwidth, with a similar frequency resolution. If used, this should be clearly identified by the assessor.

tones are present within a single critical band, the critical band is placed so that it maximises the amount of tonal energy.

B.6. The 2-minute average FFT is used to look for potential tones (using an initial search for local maxima or peaks) in the average spectrum. This can be done for example by:

- Identifying any FFT line that is higher than the two adjacent lines; or
- Using a threshold test, where lines are tested by detecting a specified increase above a threshold followed later by a decrease of more than this threshold (when scanning the spectrum moving from left to right). This is confirmed by undertaking the same analysis scanning the spectrum moving from right to left. This specified threshold would typically be set relatively low in level (~1 dB). The peak is then identified as the maximum level in the interval identified.

B.7. Although this initial search can result in ‘false positives’, the method then determines whether each peak is a tone with sufficient magnitude to be classified as such, as well as determining the masking energy within each critical band.

B.8. For each of the local maxima identified in the average FFT from the initial search, a peak is classed as a tone if its level is more than 6 dB above the logarithmic average of the sound pressure levels of the rest of the lines in the critical band centred on the peak, but excluding one FFT line each side of the peak (these are initially classed as neither tone nor masking).

B.9. An iterative procedure is undertaken to classify all other lines in the critical band. The general process is that if the peak line qualifies as tone, the adjacent lines are also classified as tone if their level is within 10 dB of the peak and greater than 6 dB above the logarithmic average masking level (excluding lines either side of the initial peak). If an FFT spectral line is more than 6 dB above the logarithmic average masking level and more than 10 dB below the peak level it is classified as neither tone nor masking.

B.10. Because classifying a line as a tone means it can no longer be counted as masking, an iterative procedure is required for the proper identification of tones and masking. This is described by reference to the two worked examples shown in Section B.22 to B.24. This classification process should be repeated and the logarithmic average masking level re calculated following re classification of any spectral lines within the critical band. Once no lines are re-classified the next peak in the average FFT is then considered and so forth. The process is repeated for every critical band centred around peaks in the spectrum. The result is that within each critical band every spectral line is classified as tone energy, masking energy or neither. Having identified the lines in the average FFT contributing to tonal levels, masking levels or neither, the tonal analysis can continue.

B.11. The masking energy within a critical band is calculated from the average FFT. Calculate the masking level in the critical band (L_{pm}) correcting for a reduction in the number of lines due to the exclusion of tones and for use of the Hanning window:

$$L_{pm} = 10\ Log_{10}\sum 10^{\frac{L_m}{10}} + \frac{10\ Log_{10}(critical\ bandwidth)}{(N_m\,.\,\Delta f)} + 10\ Log_{10}({}^{1}/_{1.5})$$

Where: L_m = sound pressure level of each line containing masking noise.

N_m = number of lines within the critical band containing the masking noise.

B.12. Having identified the tonal lines, if several distinct tones are present in a critical band, the critical band should be adjusted to maximise the tonal audibility. This process may need to be repeated where there are multiple tones and different critical bands. Once all critical bands have been determined, the process can continue.

B.13. For each of the individual FFT spectra of 0.29 to 0.4 seconds duration, calculate the tone energy within each critical band, L_{pt}', using those lines classified as ‘tone’ from the 2-minute average FFT spectrum. Where more than one line in the average FFT is classified as ‘tone’ within a critical band then the tone level for each of these short-term spectra is calculated as the energy sum of lines classified as ‘tone’ to yield L_{pt}' for each short-term spectra.

$$L_{pt}' = 10\ Log_{10}\sum 10^{\left({}^{L_t}/_{10}\right)}$$

Where: L_t is the sound pressure level of each line containing tonal noise.

B.14. The tone level used in the assessment, L_{pt}, is the arithmetic mean of the top 10% of the tone levels (L_{pt}'), from all the individual short-term FFTs constituting the 2-minute average FFT.

Evaluation of the audibility of the tone(s)

B.15. The audibility of a tone is dependent upon the tone level difference (ΔL_{tm}) and the frequency (f) of the tone:

$$\Delta L_{tm} = L_{pt} - L_{pm}$$

B.16. The audibility criterion is defined as follows:

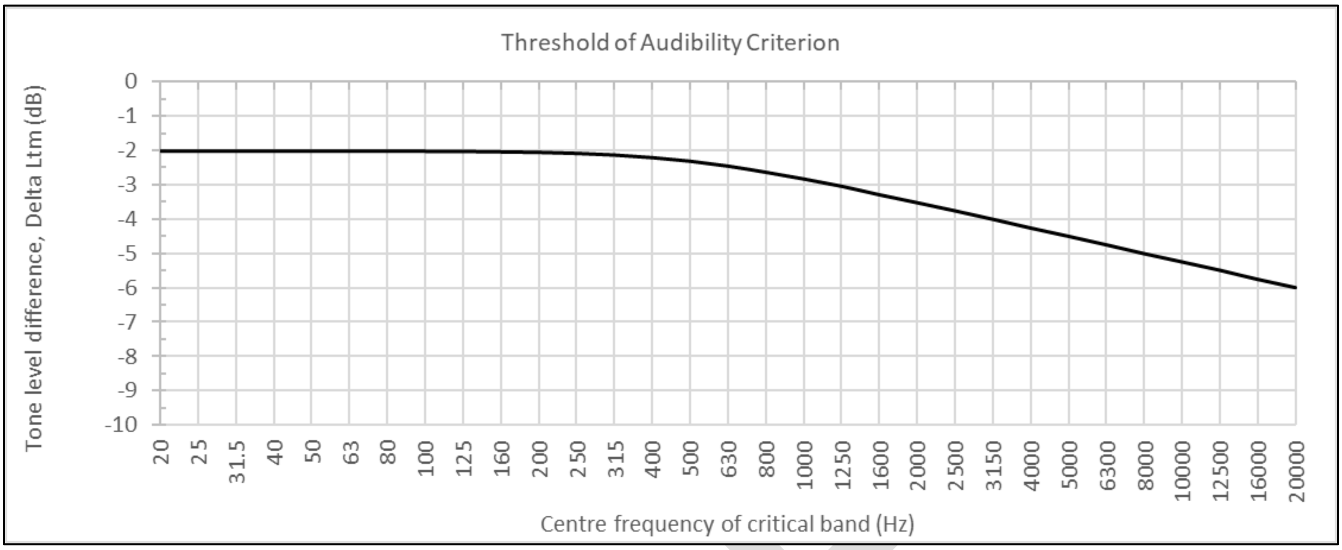
$$\Delta L_{tm,crit} = -2 - Log\left[1 + \left(\frac{f}{502}\right)^{2.5}\right]$$

B.17. This is the level at which the average listener will be just able to hear the tone. Figure 4 details the audibility criterion based upon the above equation. It can be seen from the figure that the audibility criterion is related to the frequency (f) which is the centre frequency of the critical band. For a single tone, the critical band centre frequency and the tone frequency will be similar. Where multiple tones are found within a critical band, the critical band centre frequency may differ from the frequency of the individual tones within the critical band.

B.18. The tonal audibility (ΔL_a) can be calculated from the audibility criterion as follows:

$$tonal\ audibility = \Delta L_{tm} - \Delta L_{tm,crit}$$

Figure 4: Audibility criterion for tonal noise assessment



B.19. The resulting tonal audibility is used to calculate the associated character correction in the following section. The critical band with the greatest tonal audibility should be identified and used for calculating any related tonal character correction.

B.20. In cases where tones appear at low frequencies, it is advisable to investigate if the total tone level is above the hearing threshold (e.g. BS EN ISO 389-7 or BS ISO 28961:2012). If the total absolute tone level in a critical band, when correctly weighted and calibrated, is below the hearing threshold, this critical band is to be disregarded in the assessment of tonal audibility.

Tonal analysis outputs

B.21. Suggested analysis outputs for each 2-minute interval analysed:

- average FFT and classification of all lines (tone, neither or masking);
- each critical band containing tones and for this critical band, the centre frequency, total masking energy, total tonal energy, tone level difference, audibility criterion, tonal character correction, number of tones within critical band and the frequency and levels of the tone(s).

Tonal analysis worked examples

B.22. Figure 5 and Figure 6 show the stages in the tone identification and classification process. These are:

- Find peaks in the spectrum (line 23) using the initial search for local maxima.
- Calculate the average masking level in the critical band centred on each peak (28.8 dB), not including the peak and the two lines adjacent to the peak (line 22 & 24). This is the 'initial classification'.
- If the peak is more than 6 dB above the average masking level then the line is classed as 'tone' (line 23). Lines either side of the 'tone' are classed as 'neither' and the remainder are classed as 'masking'.

B.23. Reclassify spectral lines:

Pass 1

- Calculate new average masking level centred around the peak, for those lines classified as 'masking'.
- Compare spectral lines above and below the peak to the average masking level.
- If a line is more than 6 dB above the average and less than 10 dB below the peak then it is classed as 'tone', therefore lines 22, 24 and 25 are also classified as 'tone'.

Pass 2

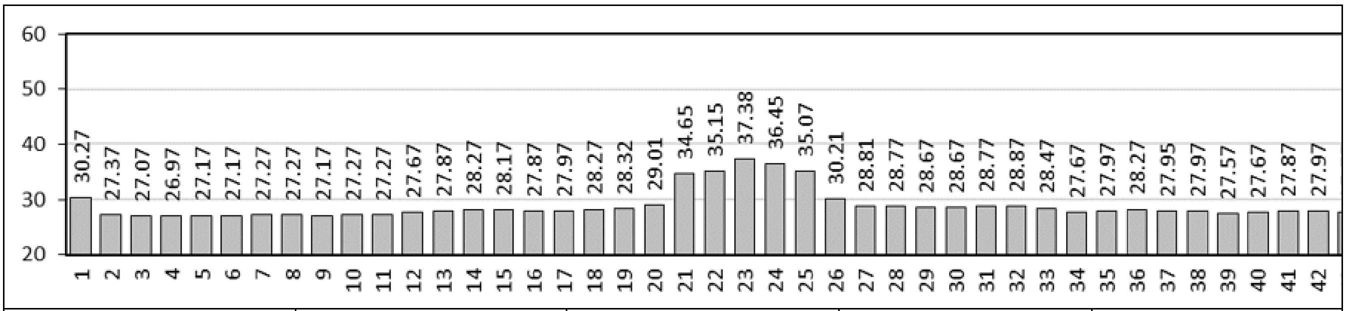
- Calculate new average masking level centred around the peak, for those lines classified as 'masking'.
- Compare spectral lines above and below the peak to the average masking level.
- If a line is more than 6 dB above the average and less than 10 dB below the peak then it is classed as 'tone', therefore line 21 is also classified as 'tone'.

Pass 3

- Calculate new average masking level centred around the peak, for those lines classified as 'masking'.
- Compare spectral lines above and below the peak to the average masking level.
- If a line is more than 6 dB above the average and less than 10 dB below the peak then it is classed as 'tone'. There are no lines re-classified as 'tone' or 'neither' therefore the process stops.

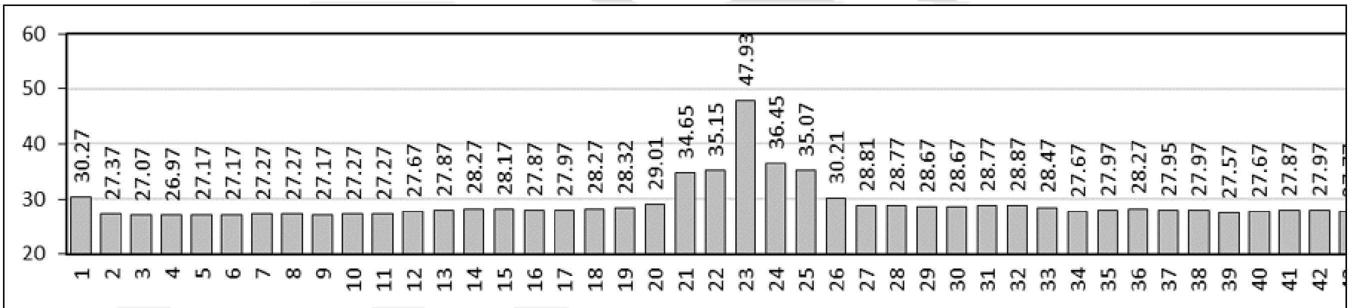
B.24. This process repeats for each pass until no lines are re classified and the process terminates. The number of passes required will vary depending on the spectrum shape. Figure 6 shows a further example of the stages in the tone identification and classification process using the same data as Figure 5 but where the tone is larger in magnitude leading to reclassification of adjacent lines as 'neither' in subsequent passes, terminating after the third pass does not identify any further lines to be 'neither'.

Figure 5: Tonal analysis worked example 1



	Pass:	**Initial**		**1**		**2**		**3 (STOP)**	
Average Masking Level:		*28.81*		*28.46*		*28.10*		*28.10*	
Line	SPL	Class	Level above average masking	Class	Level above average masking	Class	Level above average masking	Class	Level above average masking
19	28.32	Masking	-0.49	Masking	-0.14	Masking	0.22	Masking	0.22
20	29.01	Masking	0.20	Masking	0.55	Masking	0.91	Masking	0.91
21	34.65	Masking	5.84	Masking	6.19	Tone	6.55	Tone	6.55
22	35.15	Neither	6.34	Tone	6.69	Tone	7.05	Tone	7.05
23	37.38	Tone	8.57	Tone	8.92	Tone	9.28	Tone	9.28
24	36.45	Neither	7.64	Tone	7.99	Tone	8.35	Tone	8.35
25	35.07	Masking	6.26	Tone	6.61	Tone	6.97	Tone	6.97
26	30.21	Masking	1.40	Masking	1.75	Masking	2.11	Masking	2.11
27	28.81	Masking	0.00	Masking	0.35	Masking	0.71	Masking	0.71
28	28.77	Masking	-0.04	Masking	0.31	Masking	0.67	Masking	0.67

Figure 6: Tonal analysis worked example 2



	Pass:	**Initial**		**1**		**2**		**3 (STOP)**	
Average Masking Level:		*28.81*		*28.46*		*28.10*		*28.10*	
Line	SPL	Class	Level above average masking	Class	Level above average masking	Class	Level above average masking	Class	Level above average masking
19	28.32	Masking	-0.49	Masking	-0.14	Masking	0.22	Masking	0.22
20	29.01	Masking	0.20	Masking	0.55	Masking	0.91	Masking	0.91
21	34.65	Masking	5.84	Masking	6.19	Neither	6.55	Neither	6.55
22	35.15	Neither	6.34	Neither	6.69	Neither	7.05	Neither	7.05
23	47.93	Tone	19.12	Tone	19.47	Tone	19.83	Tone	19.83
24	36.45	Neither	7.64	Neither	7.99	Neither	8.35	Neither	8.35
25	35.07	Masking	6.26	Neither	6.61	Neither	6.97	Neither	6.97
26	30.21	Masking	1.40	Masking	1.75	Masking	2.11	Masking	2.11
27	28.81	Masking	0.00	Masking	0.35	Masking	0.71	Masking	0.71
28	28.77	Masking	-0.04	Masking	0.31	Masking	0.67	Masking	0.67

Appendix C – Day LLV Examples

C.1 The following examples are intended to illustrate how the different factors affecting the appropriate choice of day LLV should be accounted for when determining the day LLV for a specific site. Note that the examples below are provided for purely illustrative purposes and are by necessity not exhaustive. The appropriate choice of day LLV needs to be determined by taking into account the relevant factors for the particular site under consideration and is therefore by definition site-specific.

Table 2: Case Study 1 – Large wind farm affecting relatively low number of properties under prevailing conditions

	Energy generation	**Number of dwellings**	**Duration and level of exposure**
Factor to be considered	100 MW generating capacity	8 isolated properties where predicted operational noise levels are above 37 dB L_{A90}	Most of these properties located such that they are downwind in the prevailing wind direction.
Weight given to factor	Large generating capacity in the national context	Relatively low number of properties in relatively close proximity	Elevated proportion of the properties likely to be affected by noise under prevailing wind conditions

Resulting LLV	
A large-scale development with a handful of properties in the vicinity, mostly downwind for the prevailing wind direction. The large generating capacity and relatively small number of properties affected indicates a higher LLV would be appropriate, whereas the relatively frequent duration of noise exposure for the properties affected by noise would suggest a reduced LLV. Considering all the factors in combination, a day LLV at the upper end of the range is appropriate.	Example resultant day LLV: 39-40 dB L_{A90} (depending on site constraints)

Table 3: Case Study 2 – Small to mid-sized wind farm affecting relatively low number of properties under prevailing conditions

	Energy generation	**Number of dwellings**	**Duration and level of exposure**
Factor to be considered	10 MW generating capacity	8 properties where predicted operational noise levels are above 37 dB L_{A90}	Most of the properties are located such that they are downwind in the prevailing wind direction. No elevated background (rural).
Weight given to factor	Relatively low generating capacity in the national context	Relatively low number of properties in relatively close proximity	Elevated proportion of the properties likely to be affected by noise under prevailing wind conditions

Resulting LLV	
A smaller scale development with a handful of properties in the vicinity, mostly downwind for the prevailing wind direction. The relatively low generating capacity and the relatively frequent duration of exposure for the properties affected by noise would suggest a reduced LLV, whereas the relatively low number of properties affected would suggest an increased LLV. Considering all the factors in combination, a day LLV at the lower end of the range is appropriate.	Example resultant day LLV: 37-38 dB L_{A90} (depending on site constraints)

Table 4: Case Study 3 – Small wind farm affecting low number of properties under prevailing conditions or with existing elevated noise levels

	Energy generation	**Number of dwellings**	**Duration and level of exposure**
Factor to be considered	1 MW generating capacity	2 non-involved properties where predicted operational noise levels are above 37 dB L_{A90}	Both properties are upwind in the prevailing wind direction OR exposed to substantial existing water noise
Weight given to factor	Low generating capacity in the national context	Only 2 properties in relatively close proximity	Both properties unlikely to be downwind for a significant period of time

Resulting LLV	
A small-scale development with 2 properties in the vicinity, likely to be upwind for the majority of the time. The low generating capacity would strongly suggest an LLV towards the bottom end of the range, whereas the small number of properties and the relatively low duration of effect at these properties would indicate an increased LLV. Considering all the factors in combination, a day LLV at the lower end of the range is appropriate.	Example resultant day LLV: 37 dB L_{A90}

Table 5: Case Study 4 – Moderate capacity wind farm affecting large number of properties under prevailing conditions

	Energy generation	Number of dwellings	Duration and level of exposure
Factor to be considered	20 MW generating capacity	One village with 30 properties where predicted operational noise levels are above 37 dB L_{A90}	The village is located in a direction which is downwind in the prevailing wind direction
Weight given to factor	Moderate capacity in the national context	Relatively high number of properties.	A village likely to be affected by noise under prevailing conditions

Resulting LLV	
A moderate scale development with a relatively large number of properties in the vicinity, downwind for the prevailing wind direction. The moderate generating capacity would indicate an increased LLV, but the relatively large number of properties affected by noise and the relatively high duration of exposure for these properties would indicate a reduced LLV. Considering all the factors in combination, a day LLV towards the lower end of the range is appropriate.	Example resultant day LLV: 37-38 dB L_{A90} (depending on site constraints)

Table 6: Case Study 5 – Large capacity wind farm affecting small number of properties under non-prevailing conditions

	Energy generation	**Number of dwellings**	**Duration and level of exposure**
Factor to be considered	100 MW generating capacity	6 properties where predicted operational noise levels are above 37 dB L_{A90}	Most of the properties located such that they are not downwind in the prevailing wind direction. No elevated background (rural).
Weight given to factor	Large generating capacity in the nation context	Relatively low number of properties in relatively close proximity	Most properties likely to be affected by noise under infrequent weather conditions

Resulting LLV	
A large-scale development with a relatively small number of properties in the vicinity, not downwind for the prevailing wind direction. The large generating capacity, relatively low number of properties expected to be affected by noise and the relatively low duration of exposure would all indicate an increased LLV is appropriate. Considering all the factors in combination, a day LLV towards the upper end of the range is appropriate.	Example resultant day LLV: 39-40 dB L_{A90} (dependant on site constraints)

This publication is available from: www.gov.uk/government/consultations/assessment-and-rating-of-wind-turbine-noise-guidance-proposed-updates

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