Environment Protection Authority

Waterloo Wind Farm

Environmental noise study

South Australia

Waterloo Wind Farm environmental noise study

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Acknowledgments

The project was undertaken with the participation of volunteers from the community and with the active support of the wind farm operators. The EPA would like to thank all of the community volunteers and Energy Australia for their contributions.

We would also like to thank the New South Wales Environment Protection Authority (NSW EPA) who conducted a technical peer review of the methodology, data analysis and reporting and found the study to fundamentally be of a high technical standard. The peer review was advisory only, and the NSW EPA's role should not be misconstrued as an audit of the study or indicate agreement or otherwise with all of the findings or conclusions in the report.

Summary

In South Australia wind farm approvals are processed through the planning system, where planning approval requires assessment and management of noise impacts. The EPA provides advice (not direction) to planning authorities in accordance with the *EPA Wind Farms Environmental Noise Guidelines 2009* (the Guidelines).

The Guidelines were revised in 2009 following extensive consultation with community and industry groups, using the best information available. The Guidelines are among the strictest in the world and were predicated strongly on health advice from the National Health and Medical Research Council (NHMRC) and the Department for Health and Ageing.

Once approved, wind farms are not licensed by the EPA, but the EPA does retain regulatory power through the General Environmental Duty in Section 25 of the Environment Protection Act 1993. Every wind farm in SA has had a noise impact assessment undertaken at pre- and post-construction phases by independent acoustic consultants. Repeated short-term conventional measurements at receptor locations near SA wind farms have failed to show any signals that would not meet current criteria in the Guidelines. However, claims of serious health impacts persist in SA, nationally and internationally.

The Guidelines were utilised for the assessment of Waterloo Wind Farm, which was commissioned in 2011. Post-construction noise monitoring has confirmed compliance of the wind farm with conditions from the development approval (from the Clare and Gilbert Valleys Council).

In December 2012, EPA officers met with residents from Waterloo to discuss their concerns regarding the wind farm. Concerns included a rumbling noise and a variable pulsing noise that was dependent on wind direction. The residents spoke of various symptoms such as headaches, sleep disturbance and exhaustion, flu-like symptoms and tinnitus.

In January 2013, the Chief Executive of the EPA, Dr Campbell Gemmell and Operations Director of Science, Assessment and Planning, Mr Peter Dolan, visited the Central Local Government Region of SA to meet with a delegation of Mayors regarding wind farms in the area. They also met with members of the Waterloo and Districts Concerned Citizens Group on the matter.

What did the study set out to achieve?

Following the meeting with residents in December 2012, the EPA decided to undertake an independent study investigate the concerns of the community regarding noise from the Waterloo Wind Farm. In particular, the EPA sought answers to four primary questions, maintaining a particular focus on infrasound and low frequency noise:

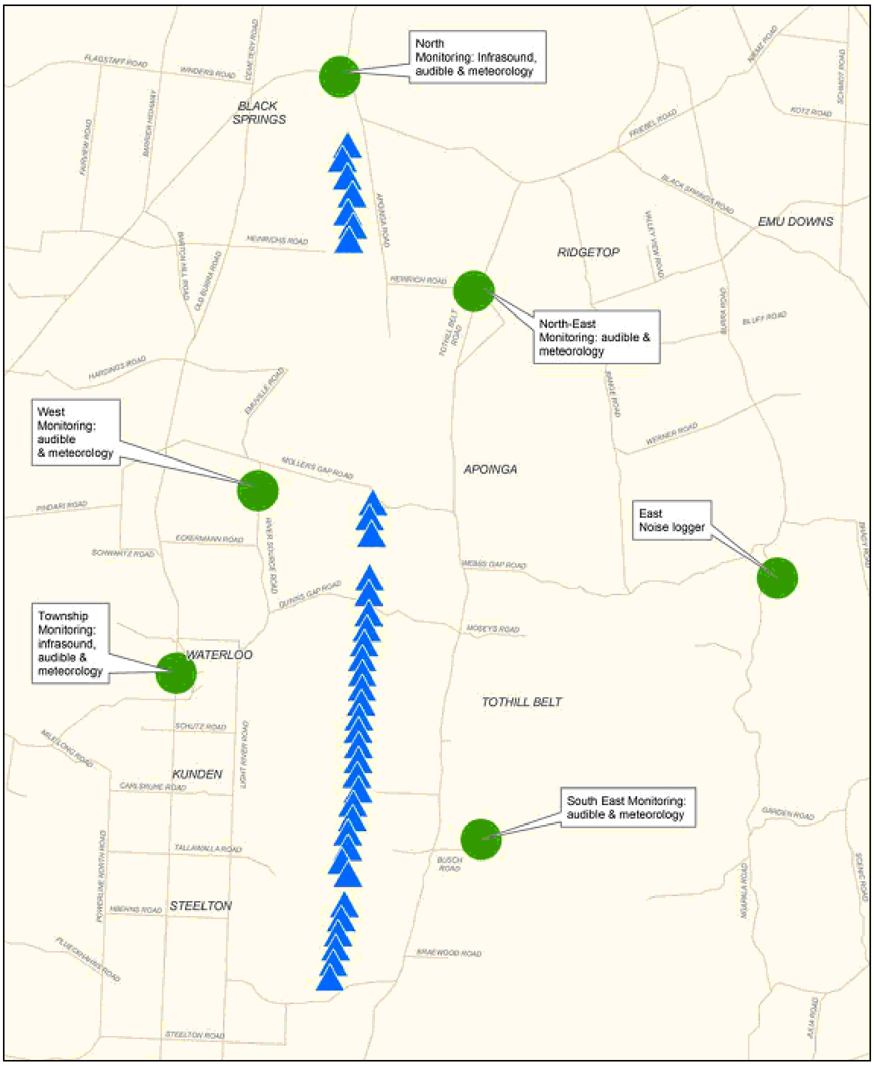
- Is there a physical basis for descriptions of noises supplied by members of the community?
- Are there particular environmental conditions that evoke complaints?
- Are low frequency and infrasound components present and do they contribute to these described effects and complaints?
- Do the criteria in the South Australian Wind Farm Environmental Noise Guidelines need to be reviewed?

The EPA's Waterloo Wind Farm Noise Study had two components; a noise and weather monitoring component, and a community diary component:

From April to June 2013, the EPA undertook noise and weather monitoring at six locations at distances of 1.3 to 7.6 km and a range of directions from the Waterloo Wind Farm (see map):

- At two locations, indoor and outdoor monitoring were undertaken for noise in both the infrasound (0.25Hz to 20Hz) and audio (20Hz to 20kHz) frequency ranges.
- At three locations, indoor and outdoor monitoring was undertaken for noise in the audio frequency range (~12Hz to 20kHz)
- At one further location, outdoor monitoring was undertaken for noise in the audio frequency range (~12Hz to 20kHz).

During the study, the EPA received weekly noise diaries from residents who volunteered to participate in the study.



Map showing monitoring areas around the Waterloo Wind Farm

Green circles ⇨ approximate location of stations; blue triangles ⇨ wind turbines

The owner and operator of the Waterloo Wind Farm, Energy Australia, also provided operational and meteorological information to the EPA, as well as organising, on request, six shutdowns of the wind farm under conditions when power would normally be generated.

The project design was based on a set of broad principles, including:

- A clear focus on houses where residents have expressed concerns about noise; and utilising descriptions supplied by residents to the EPA as a basis for investigation.
- Simultaneous acoustic and weather measurements, with concurrent noise measurements inside and outside the houses.
- A broad-based community noise diary program to supply essential data on perceived characteristics of noise.
- Full-scale wind farm shutdowns under typical power generating conditions.
- Detection and characterisation of noise from all sources that may contribute to the noise environment.
- Provision of as much information to the community as practical during the study period.

As the project aimed to investigate concerns expressed by residents, monitoring locations were selected according to where residents had identified concerns. This approach was chosen—rather than attempting to compare ‘affected’ and ‘non-affected’ locations—to maximise the focus on specific descriptions of noise around the wind farm, while optimising the utility of relatively limited resources.

An infrasound (centre) and audio noise (left) monitoring site, with the meteorological station to the rear

The diaries were essential in focusing analyses on particular events; and EPA is grateful for the willing participation of the community in providing this information. In fact at times, diary returns assisted EPA to understand some specific noise characters that were otherwise very difficult to detect,

What the study did not do …

The study was never intended to be either a comprehensive survey of the noise environment around the Waterloo Wind Farm, nor a health study.

The focus of available resources was specifically directed to whether a scientific basis could be found for descriptions of noise events by community members, rather than attempting to characterise the broad noise environment of the area.

Given this, a consideration of health effects was not part of the analysis.

However, community members were entirely free to provide information through the diary returns on the effects they felt during the study period, and any other factors that they considered important; and many have done so. Proper evaluation of these health-based descriptions falls more within the purview of health authorities, and EPA intends to refer the information to relevant authorities as soon as practical.

Noise and meteorological monitoring were continued over two months from mid-April to mid-June 2013. Noise diaries from the respondents living in the general Waterloo area were utilised for analysis of noise events. These were cross referenced to acoustical data, weather parameters and audio records.

What were the findings of the study?

- Noise events that could be attributed to the wind farm were periodically audible at four locations, but at very low levels, which did not dominate the noise environment; however, no attributable events were found at the two remaining houses.
- Where detectable, noise levels from the wind farm were found to comply with criteria in the EPA Wind Farm Environmental Noise Guidelines.
- Wind farm operation was shown to contribute to the low frequency content of noise under some operating and environmental conditions, resulting in an increase in relevant low frequency noise descriptors
- In those houses where infrasound was monitored, a 'blade pass frequency' component was found at levels significantly below the accepted perception threshold of 85dB(G).
- Background noise resulting from local winds and other noise sources, was shown to contribute to increases in low frequency noise that were comparable with, or higher than contributions from the wind farm.
- A 'rumbling' effect was found using diary records to focus the analysis, which could only be heard with amplification of audio records; however, in many cases, the EPA was unable to determine that described events could be attributed to the turbines; and at times reported events coincided with shutdowns of the plant.
- Some degree of modulation was detected, which may have been perceivable at times by residents.

- The rumbling and other low frequency characters found in this study would not generally be audible to a typical listener, but it is possible that sensitive people living within this very quiet area may hear them. This could cause annoyance to some people if exposed to the noise for prolonged time periods.

What are the implications of the study findings?

The Waterloo Wind Farm meets relevant South Australian and international standards and there is no evidence linking the noise from the wind farm to adverse impacts on residents.

On the basis of the physical results of this study, the EPA considers that noise from the wind farm may be audible to sensitive listeners at times, particularly under 'downwind' conditions. However, the EPA has does not consider that there is sufficient evidence from the physical measurements of noise, to warrant a review of the Wind Farm Guidelines.

The EPA relies on advice from health authorities in setting guidance for noise and other forms of environmental emissions, and notes that there is a review underway by the National Health and Medical Research Council into the possible health effects of wind farms.

If information becomes available to indicate that further review of the Wind Farm Guidelines may be needed, the EPA will of course consider that evidence in conjunction with relevant health authorities.

1 Introduction

The Waterloo Wind Farm Study was established with the specific purpose of investigating any physical basis for descriptions by members of the surrounding community of the noise around the wind farm. To that end, the focus was on the houses of volunteers who had expressed strong views about noise from the facility. The study was not therefore designed to be a comprehensive evaluation of the noise environment at all areas around the wind farm, and is not intended to be a study of health impacts. Measurements were supplemented by information supplied in weekly diaries, kindly submitted by volunteers in the community, both the hosts of monitoring equipment and other householders in the area.

In measuring noise and supporting meteorological parameters, the EPA aimed to provide the widest coverage of the noise spectrum with the available resources. Audio noise and infrasound (0.25Hz to 20 kHz) was measured inside and outside two houses; while audible noise, including the ‘Extended Low Frequency Band’ was measured at the remaining houses, covering 12.5Hz to 20kHz.

To further facilitate separation of wind farm noise signals from background noises, the wind farm operators cooperated in shutting the entire facility down on six occasions to provide periods when operation of the wind farm itself could be eliminated as a source of noise. On each occasion the wind farm was shutdown only under conditions established by the EPA, which would otherwise allow its normal operation; that is, when wind speeds were within the range at which electricity generation would have been viable.

For the purposes of this report, periods when wind speeds were less than threshold for operation of the turbines, that is under calm conditions or very low wind speeds were not considered to be ‘shutdowns’.

The report incorporates broad discussions of the design and implications of the study findings in Chapters 1 to 3, with detailed data and analyses presented in Section 4.

1.1 Wind power in South Australia

Wind power is a significant source of renewable energy within South Australia. To date, 15 wind farms have been constructed across the state, some of them are multi-stage developments. Total generating capacity of South Australian wind farms exceeds 1.2 GW which is equivalent to approximately 41% of the nation's installed wind capacity.

To date, wind farms have been installed in diverse regions across the state, especially the South East and Mid North regions.

Significant proposals to increase South Australia’s wind power generation capacity have been developed, most notably the CERES Project on the Yorke Peninsula.

1.2 The Mid North Region

The Mid North is a region of South Australia, north of the Adelaide Plains, but not including the Far North, or outback. It is generally accepted to extend from Spencer Gulf east to the Barrier Highway, including the coastal plain, the southern part of the Flinders Ranges, and the northern part of the Mount Lofty Ranges. Agriculture, viticulture and sheep farming are significant industries in the area.

The Mid North possesses significant wind resources and several wind farms have been built in the region. Wind farms constructed in the region are situated on top of high ridges, providing good opportunities for electricity generation, even when wind speeds in the surrounding valleys are not high.

Although the terrain is varied, it is particularly rugged only in the Southern Flinders Ranges. On the west is a coastal plain, narrowing north of Port Pirie. East of the plain a series of ridges of sandstones and quartzite run roughly north and south. Between them, on less resistant shales and slates, are wide valleys and flats. There is an intricate pattern of streams, but most flow only after heavy rain.

Annual rainfall varies between 350 mm and 500 mm, with falls up to 650 mm in a few areas in the Clare hills and South Flinders Ranges. Average monthly rainfalls and variations in the mean temperature are represented in Figure 1.

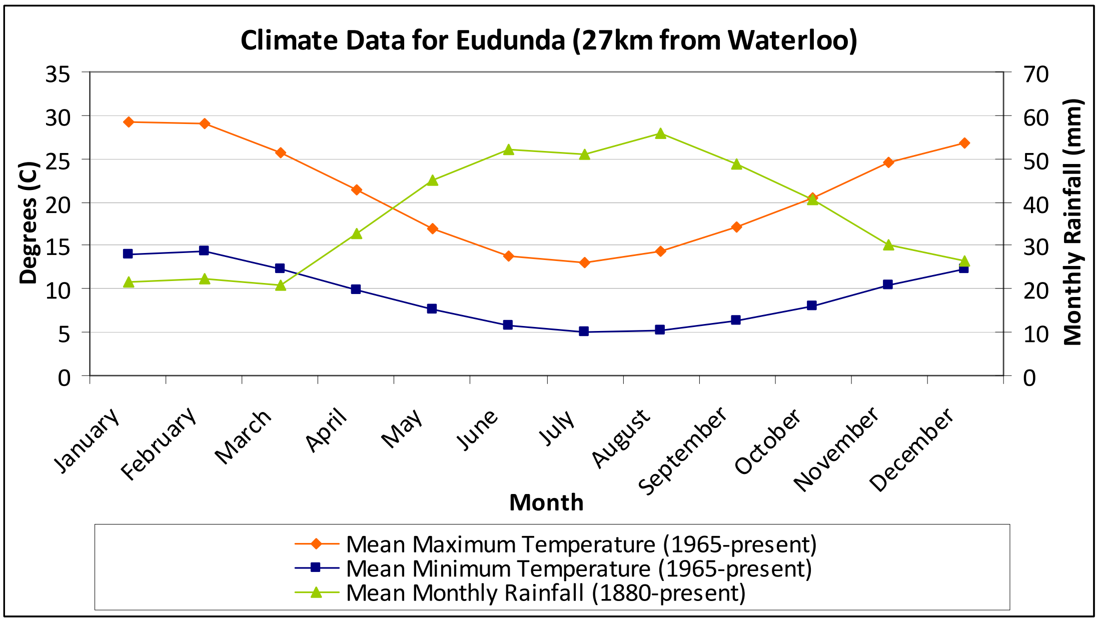


Figure 1 **Climate data for Eudunda (27 km from Waterloo Township)**

1.3 Waterloo Wind Farm

The Waterloo Wind Farm is located in the Mid North, approximately 100 km north of Adelaide, the state capital of South Australia. The facility lies approximately 20 km south of Burra (the nearest major town), and 3.5 km to the east of the small township of Waterloo (from which it derives its name). Situated atop a north–south ridge, and stretching for 18 km, the wind farm comprises 37 Vestas V90 3 Megawatt Wind Turbine Generators (wind turbine generators), each having a hub-height of 80 m, with the entire site having a rated generation capacity 111 Megawatts. Major technical parameters of the wind turbine generators are summarised in Appendix A [37]. The turbine does not exhibit any tonal characteristic in accordance with results of tonality tests [7, 23].

The Waterloo Wind Farm was commissioned and commenced operation in 2011, having gained development consent from the Clare and Gilbert Valleys District Council in 2009.

Following commissioning of the Waterloo Wind Farm, persistent complaints have been raised referencing noise issues, infrasound issues, health complaints, effect on livestock (most notably poultry), and effect on visual amenity among others.

A post-construction noise monitoring report [23] confirmed compliance of the wind farm with conditions of the development approval. Additional noise monitoring at other locations in the area was commissioned by the wind farm operator in response to complaints of some of the residents regarding noise from the wind farm.

The EPA conducted spot checks of reported noise levels using attended measurements at the North East site and other points near the wind farm (Figure 3). These tests were never intended to be comprehensive studies, but were aimed at providing some confirmation of whether figures recorded in consultants' reports could be reproduced under similar conditions. To provide some comparability of data, the days chosen for these tests were specifically based on forecasts of similar weather conditions.

For these exercises, the noise monitoring and data analysis were based on A-weighted levels. The investigations found no evidence that A-weighted noise levels from the wind farm might have been excessive.

As noted previously, the design of the current study included a broader range of acoustical descriptors, weather information and weekly diary returns from volunteer residents.

2 Goals and scope of the study

The project was established with the specific purpose of investigating four primary questions about effects of the wind farm:

- Is there a physical basis for descriptions of noises supplied by members of the community?
- Are there particular environmental conditions that evoke complaints?
- Are low frequency and infrasound components present and do they contribute to these described effects and complaints?
- Do the criteria in the *Wind Farm Environmental Noise Guidelines 2009* need to be reviewed?

In accordance with a commitment made to the Waterloo community, the project comprised continuous monitoring of noise at various strategically selected sites in the region surrounding the Waterloo Wind Farm, and subsequent data analysis.

Broadly, the approach adopted for the study is summarised as follows:

- Maintaining a clear focus on houses where residents have expressed concerns about noise; and utilising descriptions supplied by residents to the EPA as a basis for investigations.
- Undertaking simultaneous acoustic and weather measurements, with concurrent noise measurements inside and outside houses.
- Implementing a broad-based community noise diary program, in which both hosts of equipment and other community members could participate, to supply essential data on perceived impacts of noise.
- Inclusion of full-scale wind farm shutdowns under typical power generating conditions within the monitoring period.
- Using all available tools to detect noise from all sources in the area, including general wind-induced noise, other ambient sources (eg farm machinery, internal appliances, household activities), and the wind farm itself on a comparative basis, including amplification of audio records to facilitate analysis.
- Providing as much information to the community as practical during the study period.

As the project aimed to investigate concerns expressed by residents, monitoring sites were selected according to where those where residents had identified an impact. This approach was chosen—rather than attempting to compare 'affected' and 'non-affected' sites—to maximise the focus on specific descriptions of noise around the wind farm, and to optimise the use of relatively limited resources.

Furthermore, to ensure that information on the noise environment reflected as far as practical the experience of residents, noise measurements were undertaken concurrently inside and outside each of the residences selected for noise monitoring (except the East site). Weather data was also gathered at each site to facilitate analysis of the noise measurement data, as were diary records supplied by residents outlining times they were affected by the wind farm noise.

The scope of the study was expanded to explore potential for noise impact in the infrasound frequency range (down to 0.25Hz as defined in international standard ISO 7196 [14]) and the extended low frequency band, down to 12.5Hz.

The study was never intended to be a comprehensive survey of the noise environment around the Waterloo Wind Farm, or a health study.

The aim of the study was to investigate whether a physical, scientific basis could be shown for descriptions of noise by residents near the Waterloo Wind Farm, so the focus of available resources was specifically directed to answering that question, rather than attempting to characterise the broad noise environment of the area.

For similar reasons, a consideration of health impacts was not part of the analysis. However, community members were entirely free to provide information through the diary returns on the effects they felt during the study period, and any other factors that they considered important; and many have done so. Proper evaluation of these health-based descriptions under the purview of health authorities, and the EPA will refer the information to relevant authorities as soon as practical.

3 Methodology

The methodology selected for this study focused on examining whether a scientific basis could be found for community concerns about noise from the wind farm, in particular, whether during the study period:

1 Noise from the wind farm met established criteria, primarily the Wind Farms Environmental Noise Guidelines 2009 [32], or other appropriate criteria for infrasound and low frequency noise.

2 Noise from the wind farm was of a sufficient level to be audible and whether any particular noise characters were present.

3.1 Data acquisition

3.1.1 Noise and infrasound measurements

Regulatory documents typically require compliance measurements to be made within the audio frequency range, ie from 20Hz to 20kHz.

Additional requirements have been introduced by some authorities to address specific community concerns about low frequency and infrasound noise. In recognition of this, the current study incorporated measurements within ranges with lower limits, as described below.

The nature of noise

The frequency determines the 'pitch' of the sound we hear. Low frequencies are heard as low pitch sounds, while higher frequencies are heard as higher pitch sounds. Sounds with frequencies much above 20,000Hz, called 'ultrasound', are normally inaudible, but the exact range varies from person to person, and will vary for an individual over his or her lifetime, depending on factors such as age, health status and noise exposure patterns.

The range of frequencies in environmental noise is divided into octaves, in the same way as the range of sounds in music is divided up, for example on a piano keyboard. Two sounds are said to be an octave apart if the frequency of the higher pitch sound has double the frequency of the lower one.

For acoustic work, the smaller interval of a '1/3 octave' is often used to provide greater information about the frequency content of a sound. The range of frequencies that we can hear, from around 20 to 20,000Hz, covers many of these third-octave bands. Frequencies lower than most people can typically hear—called 'infrasound'—are also divided up in this way for acoustic measurements.

Humans can hear sounds over a very wide range of intensities, with the highest pressure level, called the 'pain threshold' being around a million times the lowest. Both Sound Pressure and Sound Power scales are used to characterise noise source. The scale which describes this huge range of intensities is the 'decibel' scale, which is a non-linear (logarithmic) scale with the unit of 'dB'. Very quiet conditions may have levels of 20dB(A) and a quiet bedroom around 30–35dB(A)

The Decibel scale is based on a lowest sound pressure level of 20 micro-Pascals (μPa); which is about the limit of human hearing sensitivity, generally found in younger people who have not been exposed to loud noises, such as loud music. A pressure change of 20 μPa is tiny—around 2 ten-billionths of normal atmospheric pressure—nevertheless some people can hear it.

Our perception of the intensity of sounds is not constant across this range, but decreases or 'rolls off' as the frequencies approach the upper and lower limits of our hearing. In contrast, microphones detect noise in a much more 'linear' way, according to the pressure of the sound waves they record; that is, the way sounds are recorded depends only on the characteristics of the microphone and measuring system. For this reason, acoustic readings from sound meters are usually adjusted or 'weighted' according to internationally accepted graphs of hearing sensitivity.

At low levels A-weighting approximates sensitivity of human ear to noise and is typically used for a wind farm noise assessment. The weighting shows a sharply decreasing sensitivity to sounds of frequencies less than around 250 Hz. However, for sound sources that have strong low frequency contents (eg music concerts, some industrial processes), C-weighting is used to reflect people's perception of those sounds, with the unit of dB(C).

Infrasound can be heard through our auditory systems, but only at high intensities. The G-weighting curve, with units of dB(G), describes this behaviour, with a generally accepted threshold of about 85dB(G).

As noted above, the directly recorded data depend only on the instrument characteristics; so they are often described as being 'non-weighted' or 'Z-weighted'. The characteristics of a microphone may become important at very low environmental noise levels, where 'self-noise' or the 'noise floor' may interfere with measurements. This is simply the level of electronic noise that characterises any measuring instrument. It is noted elsewhere in this report that the microphones used for infrasound measurements showed significant 'noise floors' for higher audio frequencies, which made calculation of A-weighted noise levels difficult for some indoor measurements. However, this was not so for the lower frequency and infrasound bands, so calculations of C-weighted and G-weighted levels were unaffected.

Instrumentation

For this study, two types of instruments were used, capable of recording sounds with lower frequency boundaries as described:

- Low frequency –12.5Hz (1/3 octave central frequency) for sites with deployed B&K Type 3639 noise monitoring stations;
- Infrasound – 0.25Hz (1/3 octave central frequency) for sites equipped with multi-channel Soundbook data acquisitions system.

Wind induced noise may have significant contribution to the reported values for outdoor measurements (refer to [12],[28],[35]). Therefore local wind speed was acquired simultaneously with the noise measurements.

Infrasound/low frequency content was measured and reported from microphones positioned approximately 1.2m above the ground and equipped with multi layer wind shields. The wind shields have been tested and engaged in previous comparative study on infrasound/low frequency noise (refer to the recent infrasound study [10] for details).

It is well understood that Infrasound measurements require specific techniques to minimise the wind noise influence; and other approaches were also considered. For example:

- Techniques utilising microphones placed on reflecting boards at ground level, as in IEC standard [13]), do not provide sufficient information on whether the +6dB correction for audible noise frequencies should also be applied to infrasound frequencies.
- Other studies have positioned microphones below ground level in fabric covered pits, however this is not always practical. For example the pit can be filled by water during rain periods and tends to attenuate higher frequencies of the infrasound range defined in ISO 7196 [14].

3.1.2 Wind farm operational data and shutdowns

The wind farm operator voluntarily provided data from sensors embedded into the wind turbine generator nacelle. The data are supplied for 10-minute intervals and include hub height, wind speed and wind direction, generated power, rotor rotations per minute (RPM) and other necessary parameters. They have been utilised for data analyses performed in accordance with regulatory documents and comparisons between noise levels during shutdown and operational conditions.

The wind farm operator advised that wind turbine generator on the site operated at the maximum electricity generation mode (noise mode '0'), which was confirmed later by operation data from the turbines.

The operator voluntarily agreed to arrange full operational shutdowns of all turbines on the site, under environmental conditions specified by the EPA; avoiding rain periods.

Shutdown periods are summarised in Table 1 and the time corresponds to Central Australian Standard Time (CAST). Shutdown periods mostly lasted for approximately up to 50 minutes of 'core' time. Transient periods right before and after the shutdowns were not taken into account for the comparative analysis of the shutdowns and similar operating periods.

Table 1 Periods of operational shutdowns of Waterloo Wind Farm

Reference	Date	Start time	End time
Shutdown 1	1 May 2013	20:10	21:00
Shutdown 2	30 May 2013	19:10	20:00
Shutdown 3	5 May 2013	20:40	21:30
Shutdown 4	10 May 2013	05:10	06:00
Shutdown 5	12 May 2013	20:10	21:00
Shutdown 6	14 May 2013	20:00	20:50

As noted previously, periods when wind speeds were less than threshold for operation of the turbines—that is, under calm conditions or very low wind speeds of less than 3.5 m/s—were not considered to be 'shutdowns' for this report.

Clearly, the turbines were not in energy generating mode under those conditions, so they were not useful for this analysis. The comparison needed to be undertaken under meteorological conditions that would normally allow operation of the turbines, so that the effect of the meteorological conditions on low frequency noise and infrasound could be established, in the absence of the wind turbine generators.

3.1.3 Noise diaries

Residents in the Waterloo region were invited to contribute information on their experiences of noise from the wind farm throughout the monitoring study, recording their assessments in weekly noise diaries. Participation in the diary component was open to anyone who wished to volunteer, in addition to householders who had agreed to host equipment. The aim was to ensure that as wide a sample of perceptions was available for comparison with monitored information.

The EPA is strongly appreciative of the effort and time put into the diaries, given the busy lives of residents in a farming community such as Waterloo.

EPA supplied diary templates and postage paid envelopes, for volunteers to return directly to the project communications officer, on a weekly basis. Respondents were advised that EPA could not accept any diaries received after posting of periodic summary reports (monitored data and diary summaries) on the EPA website for the previous week. This precautionary approach was designed to eliminate the risk of potential contamination of records by information already published.

Respondents were requested to record when they perceived noise that they attributed to operation of the wind farm, and provide brief descriptions of what the heard, and any other factors, such as wind conditions, that they felt were important. They were asked to indicate time corresponding to beginning and end of the noise events, environmental conditions, their sensations and other relevant information.

3.2 Analysis

3.2.1 Data acquisition and reporting

Sound power is the major parameter characterising wind turbine generator as a noise source. Sound power levels from a turbine increase as the wind speed at hub hight increases. The noise level at a distant receiver is defined mainly by the wind speed and direction, so analysis of noise levels for regulatory purposes is normally made in conjunction with meteorological data.

Environmental noise levels experienced by distant receivers depend on many environmental and operational factors. In general health organisations and authorities recommend assessment of noise impacts using relatively long-term averages, varying from a few minutes to 12 months [40].

Noise from a wind farm is typically steady with possible amplitude modulation, if audible. Equivalent sound pressure levels are normally utilised to assess impact from such sources. There are no grounds for applying other descriptors such as maximum or peak levels. These are more appropriate in situations where abrupt changes of noise occur, such as on construction sites, shooting ranges, mining operations, or where gas guns are employed as bird scarers in agriculture.

Turbine data acquisition systems typically supply data at 10-minute intervals, and was the case for this project. Intervals of 10-minute are also recommended in many regulatory procedures for analysis of wind farm noise, so this interval was chosen as the basic interval for data analysis in this project. The time stamp in this report corresponds to Australian Central Standard Time at the beginning of the integration period.

Data with shorter averaging periods were also gathered at some sites and were utilised for more thorough analysis where required. For example ISO 7196 [14] recommends integration time of 10 seconds for reporting G-weighting values. Ten-second data were acquired at the Township and North sites.

Wind induced noise is a potential problem for outdoor measurements [12, 35]. Acoustic data acquired outdoor at the local wind speed exceeding 5 m/s was disregarded for the current study. Periods of precipitation have also been identified from the local weather sensors and corresponding data was excluded from the data analysis.

Data also have been checked for potential presence of ambient noises, or noise from other sources, using analysis of acoustic descriptors and audio records where available. Typically, periods affected by such noises were not analysed.

3.2.2 Challenges of the data acquisition and data analysis

The original layout of the wind farm was designed to meet strict regulatory requirements. The noise monitoring equipment was deployed in a generally quiet rural area where the nearest monitoring site was about 1.3 km away from the nearest wind turbine generator. The low levels of noise characteristic of such areas and the potential of wind noise to overwhelm signals from the turbines under generating conditions, implies that noise from the wind farm may possibly be audible only under particular environmental conditions of low background or ambient noise levels at the houses.

Rain can be a particular interferent, and even where the rain sensor at a monitoring station does not show any rainfall, rain in adjacent areas may be heard in audio records, and may still dominate overall noise levels.

Agricultural activities may be performed at any or all times throughout the day, seven days per week during mid and late autumn. These activities need to be considered as potential contributors to the noise environment in the area.

Other noise sources may include flyovers of defence and civil aircraft, trucks and local traffic pass-bys.

Owners of the houses also utilise tools, pumps and agricultural equipment which are typical of farming activities in rural South Australia. Household activities in an occupied house can be a source of almost permanent interference for indoor noise measurements.

3.2.3 Audio and diary records

To ensure that the analysis was as objective as possible, acoustic descriptions recorded in diary returns were evaluated in conjunction with thorough analyses of audio records. To assist with the evaluations, audio records were amplified to facilitate identification of contributing noise sources and effects reported by the participants. The acoustic descriptors are reported as measured without amplification which may be required for process of the audio records replay.

Audio records were analysed to detect periods when wind farm noise may be audible and in conjunction with the respondents' records. Particular attention was paid to the noise diary entries of respondents living and attending the monitoring sites and nearest neighbourhood houses.

The noise monitoring equipment at the Township and North sites were acquiring audio records continuously when the equipment was in operation (both inside and outside of the house). Audio recording at other sites were collected when the sound power level reached the trigger level. The trigger levels have been adjusted during the monitoring period to provide a reasonable balance between the source identification and number of the records.

3.2.4 Instruments used

The noise monitoring program included data acquisition both inside and outside of the houses (except the East site):

- **Township and North sites**

Multichannel sound analysers Soundbook Mk2 which are also Class 1 instruments in accordance with IEC 61672 and has 1/3 octave filters Class 0 in accordance with ISO 61260. Factory calibration charts provide data down to 0.1Hz. They show negligible deviation of instrument frequency response. Four Brüel & Kjær Type 4193 microphones have been used for simultaneous multi-channel measurements with the Soundbook data acquisition systems. The microphone calibration charts also show negligible deviation of the instrument frequency response but are only reported to a frequency of 1Hz. To expand the frequency range over which the microphones had uniform frequency response, they have each been used in combination with a Brüel & Kjær Type UC-0211 low frequency adaptor and Type 2669 (North Site) or GRAS 26AK (Township Site) pre-amplifier. The sensitivity of the microphone assemblies system at 0.2Hz was calculated in accordance with information obtained from the manufacturer [4] and found to deviate by less than 1dB for any of the microphone/preamplifier combinations. Therefore, measured levels using this measurement system could be considered across the entire frequency range required by ISO 7196 (0.25 to 315Hz).

- **North East, West and South East sites**

The stations included B&K Type 2250 sound analysers which are capable of reporting data at the extended low frequency range. The analyser meets requirements for Class 1 instrument in accordance with IEC 61672-1 and Class 0 for the band filters in accordance with IEC 61260 and other national standards. Data from the monitoring stations have been supplied via GPRS connection utilising B&K Sentinel system which limits the lowest reported frequency down to 12.5Hz of 1/3 octave central frequency.

- **East site**

Outdoor noise levels at were measured with B&K noise logger based on Type 2250 sound analyser. The data have been acquired with extended low frequency range down to 6.3Hz of 1/3 octave central frequency.

Note that a side-effect of the extended low frequency range of the instruments used at Township and North Sites was an increase in the ‘self noise’ level (also known as the ‘noise floor’) at higher audio frequencies. Since typical noise levels at the monitoring sites were low, A-weighted and C-weighted levels from measurement channels engaged for infrasound/low frequency monitoring have not been reported, since their magnitudes can be compromised by this higher noise floor. For the same reason, spectral values for 1/3 octave central frequencies above 1kHz from the channels have not been included into this report.

Calibration information for acoustic instruments used is summarised in Appendix B. The equipment was periodically calibrated by B&K Type 4231 calibrator during the site visits. The results of calibrations were found to be consistent throughout the study. In addition to that, automatic Sentinel electric charge calibration was implemented on daily basis for the B&K Type 3639A stations.

Local wind speed/direction has been measured at all monitoring sites except the East site. Acoustic measurements at the North and South East sites were synchronised with data from Vaisala WXT520 sensor which also provides information about precipitation, temperature, pressure and humidity. A Davis Vantage Vue weather station deployed at the Township site also provided similar weather information in addition to the local wind speed/direction. Local wind speed/direction data were acquired from Vaisala WMT50 sensors at the North East and West sites.

Figure 2 Monitoring station layout, showing an infrasound microphone with wind shield (centre), audio microphone (left) and the meteorological sensor

3.2.5 Conventional descriptors and criteria

Most compliance checking procedures are based on A-weighted levels as an approximation for human sensitivities to noise at relatively low levels. In accordance with the development approval conditions, wind farms in South Australia should meet requirements in the Wind Farms Environmental Noise Guidelines which define baseline noise criteria of 35dB(A) for receivers in Rural Living zones and 40dB(A) for receivers in other zones. Alternative criteria may be based on pre-construction background levels plus 5dB(A) [32]. As noise impact have not been predicted at high levels before construction of the wind farm, pre-construction noise monitoring was not performed at the noise monitoring places. Default baseline criterion of 40dB(A) is applicable to the monitoring sites.

It is noted that regulatory documents do not require that noise from a wind farm should be inaudible; and further, the noise criteria should be met statistically, ie the approximating curve on the wind speed—sound power level chart should be below the applicable criteria (for the wind speeds between cut-in and speed of the rated power). Wind Farms Environmental Noise Guidelines indicate that compliance checking should be based on data collected under downwind conditions.

The Guidelines consider 5dB(A) penalty to be applied to the measured magnitudes if audible tone is present. Post-construction noise monitoring report (Marshall Day Acoustics 2011) contained tone assessment of wind turbine generator performed in accordance with IEC IEC61400-11:2006. No tones with audibility $\Delta L_{a,k}$ above 0dB were detected. Another test report [7] also did not indicate presence of audible tones in the wind turbine generator emission.

Tonal perception of sound was not a part of the respondents' diary information. However the possible presence of tones from the wind farm and other sources (eg electric substations) was explored where analysis of 1/3 octave data or audio records showed a potential that tones may be audible.

3.2.6 Criteria and data analysis for infrasound and low frequencies

International Standard ISO 7196

International standard ISO 7196 specifies separate weighting (G-weighting) for measurements and reporting of infrasound levels. Previous studies [26] found close relationship between G-weighted noise levels and annoyance from infrasound, indicating it is an appropriate weighting to use to assess infrasound in the environment. At the moment, the ISO standard is the only widely used tool to assess infrasound. The standard itself does not clearly set acceptable criteria, but indicates that 'weighted sound pressure levels which fall below about 90dB (meant G-weighted levels) will not normally be significant for human perception'. Multiple studies into perception threshold of infrasound indicate 85dB(A) as a conservative estimate (see report [10] for details) for the hearing threshold at infrasound frequencies. Typically 85dB(G) criterion is 5 to 10dB lower than the mean hearing threshold [2,15, 19, 24, 29, 39] and takes into account possible variations in individual hearing thresholds and any potential difference in the response to pure infrasonic tones and more broadband infrasonic noise.

Blade pass frequencies

Turbines may generate higher noise at the blade pass frequency, ie the frequency at which the rotating blades of a turbine passes the tower. During normal operating modes of the turbines, the blade pass frequency is expected to fall within 0.5–1Hz 1/3 octave bands. Respectively, the infrasound perception threshold can be utilised to explore whether the blade pass frequency component may be audible.

Low frequency noise

Another character that may potentially exacerbate perception of noise from a wind farm is excessive low frequency content. In spite of the fact that low frequency noise impact has been a matter of multiple research programs during last 50 years, it is difficult to indicate particular approach for assessment of low frequency noise which would have sufficient universality and worldwide applicability. Works [21] and [22] give a good overview of the low frequency and infrasound problem.

Some investigations in this area have resulted in additional sets of criteria specifically recommended for assessment of low frequency noise.

Danish EPA low frequency criteria

The Danish EPA low frequency noise criteria provide good correlation between objective and subjective assessments of low frequency noise when compared to other criteria applied in Europe [16,30]. This is a convenient way of assessing low frequency noise using a single number comparison. $L_{pA,LF}$ descriptor represents A-weighted level calculated for 1/3 octave frequencies between 10 and 160Hz [6]. A limit of 20dB(A) is recommended for evening and night time. The limit should be met inside of the houses and calculated as average of the microphone indications measured at three points.

In this study $L_{pA,LF}$ is reported based on indication of one microphone. As for practices utilised for wind farms, the low frequency noise criteria have been included in the Danish *Statutory Order on noise from wind turbines* (revised 15 December 2011). An indoor low frequency noise limit for night time periods of 20dB(A) $L_{pA,LF}$ is applied during calculations of wind turbine noise, and only for wind speeds of 6 m/s and 8 m/s at 10 m above ground level under standard conditions.

During this study, the low frequency levels were also reported for outdoor measurements to verify that the low frequency impact is caused by an external noise source. The Danish EPA criterion is used in the study as a conservative measure to explore possible reasons for complaints in a quiet rural area. However, it is noted that the results of a South Australian comparative environmental noise study in 2012 by Evans *et al* [11] showed that this criterion could barely be achieved in windy areas, without wind farms or any other significant noise sources being present in nearby areas.

UK DEFRA low frequency criteria

The UK Department of Environment, Food and Rural Affairs (DEFRA) recommended a set of frequency dependent criteria for the assessment of internal low frequency noise from 10 to 160Hz [8]. Low frequency criteria for non- steady noise at night time are represented in Table 2. It should be noted that limits in the table can be relaxed by 5dB for a steady noise and another 5dB increase can be applied for day time [8]. As with the Danish EPA criterion, DEFRA 1/3 octave criteria (as presented in Table 2) were utilised conservatively in this study, to accommodate for any possible variations in human perception.

Some regulatory documents and noise guidelines recommend using the difference between C-weighted and A-weighted equivalent sound power levels to assist in deciding whether low frequency character is present in the measured noise.

Table 2 Proposed DEFRA reference curve

Reference curve level in dB(Lin) at 1/3 octave band centre frequency (Hz)												
10	12.5	16	20	25	31.5	40	50	63	80	100	125	160
92	87	83	74	64	56	49	43	42	40	38	36	34

Other low frequency criteria

The *Guidelines for the use of the Environment Protection (Noise) Policy 2007* [33] suggest a difference of 15dB between the L_{Ceq} and L_{Aeq} levels may indicate a potential for a low frequency noise characteristic; however, other research indicate that the difference may need to be greater if it is to be used as an indicator of potential annoyance, although there is some controversy about this claim. Leventhall [21] suggests the difference should be greater than 20dB, while some authors indicate that the level may need to exceed 25dB when A-weighted noise levels are low (which is the expected situation in a quiet rural area). Given that this parameter may be useful in pointing to potential low frequency problems, it has been included in the analyses presented in this report.

Broner [3] has suggested a simple low frequency criterion, based on C-weighted measurements. Noise from a source which is operated 24/7 should meet a 60dB(C) criterion indoor during night time. However it is easier to specify this criterion outside from planning perspective. Apart from a desirable criterion of 60dB(C), he recommends a 65dB(C) (maximum) limit for the residential areas. However, this criterion is relatively new and does not have an extensive record of implementation.

Since previous monitoring programs could not clearly identify reasons for the residents' feedback, additional spectral analysis was undertaken for periods when specific descriptors were recorded in noise diaries. Vasudevan and Gordon [36] has shown that an unbalanced spectrum with a particular roll-off rate at low frequencies (about 7–8dB/octave) may cause increased annoyance of particular group of listeners. This may well be the case in the Waterloo area.

At the moment there is not sufficient information available on the applicability of low frequency noise criteria for wind farms; and their correlation with subjective assessments from sufficiently large and diversified groups of listeners. The above criteria were considered sufficiently comprehensive and conservative to explore low frequency impact in a quiet rural area in this study.

Refer to discussion in recent reports on low frequency assessment in other references [11, 21].

3.3 Monitoring locations

Unattended noise monitoring was undertaken over a period of approximately two months at a total of six monitoring sites. Sites were chosen specifically to address the concerns raised by the residents, and attempted to make best use of EPA's available suite of equipment by selecting:

- geographically, to obtain an appropriate spatial distribution of monitors around the wind farm
- structurally, aiming to select a mix of house construction types .

Each of the selected monitoring stations is detailed below, and Table 3 summarises their broad characteristics.

Two sites, designated as 'Township' and 'North' respectively (Figure 3), were selected for infrasound measurements in addition to monitoring of noise within the audio frequency range. These sites were selected for their proximity to the wind farm and severity of effects described by residents to be associated with the wind farm operation.

All stations had direct line of sight to the wind farm. Also, all sites were surrounded by trees and other vegetation. Where possible, the monitoring equipment was positioned to minimise influences of wind-induced noise from vegetation on the measured levels.

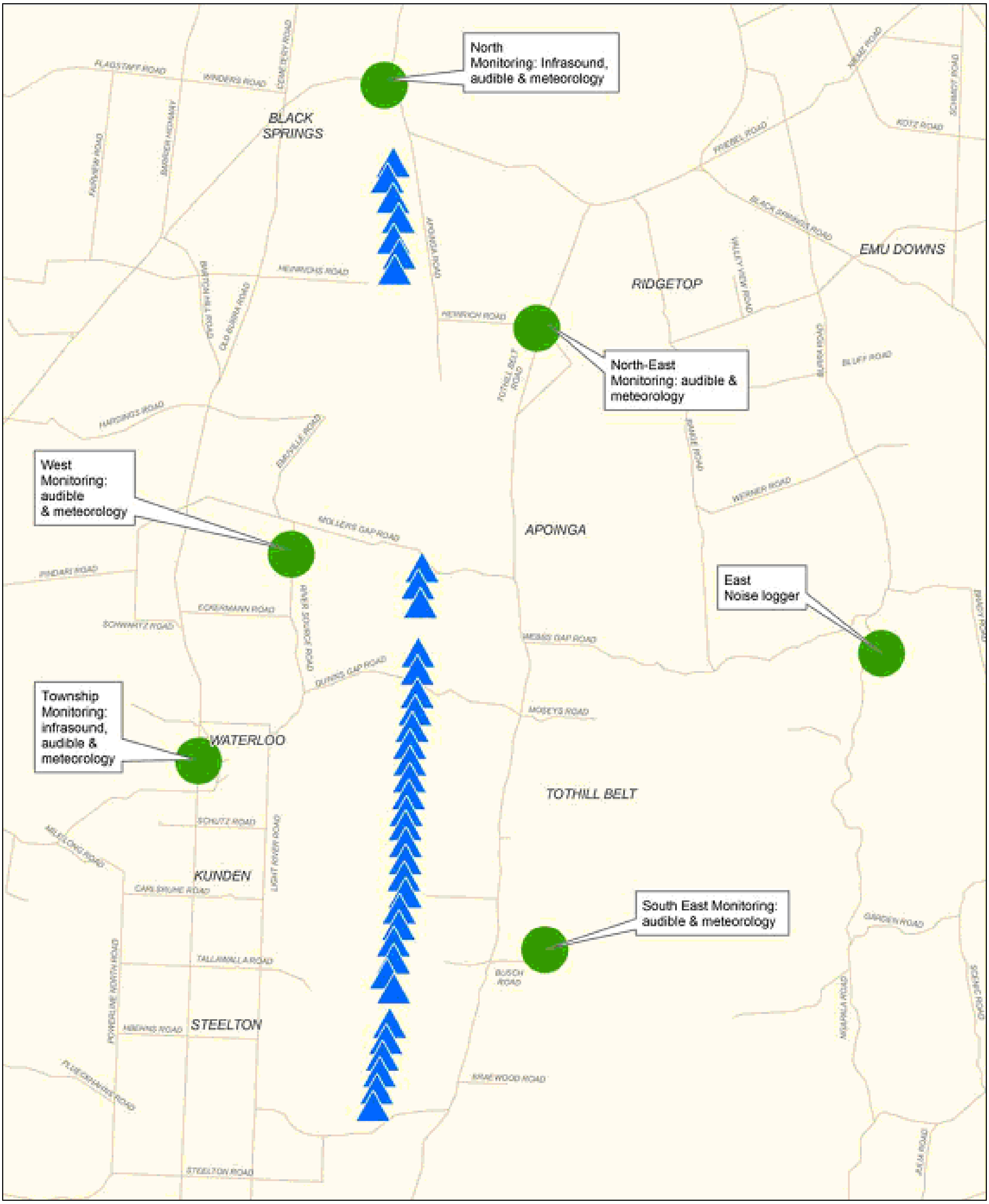


Figure 3 Turbine and noise monitoring locations, Waterloo area

Green circles ⇨ approximate location of stations; blue triangles ⇨ wind turbines

Table 3 Summary of acoustic measurements performed at the monitoring locations

Type of monitoring	Sites	Frequency range	Weather monitoring
Audio noise plus infrasound (indoors and outdoors)	Township, North	0.25Hz to 20kHz	Yes (6 parameters)
Audio noise only (indoors and outdoors)	North East, South East, West	12.5Hz to 20kHz	Yes*
Outdoor noise logging only	East	12.5Hz to 20kHz	No

*1 station monitoring with 6 weather parameters, and 2 stations monitoring with 2 weather parameters

3.3.1 Township site

Noise monitoring equipment at the locality included instruments indicated in Table 29 of Appendix B. Microphones for infrasound/low frequency measurements and standard audio frequency range measurements were deployed in the property which has a line of direct vision to the wind farm. The microphone was about 1.3 m above the ground. Microphones used for infrasound measurements were equipped with special multi-layer wind shields [10], and the GRAS microphone was fitted with the standard manufacturer wind shield. The outdoor equipment also comprised the weather monitoring station with a sensor positioned 2.2 m above the ground.

A microphone for infrasound/low frequency noise measurements was also positioned inside the house in a room facing the wind farm, on a tripod at approximately 1.3 m above the floor closer to the middle of the empty carpeted room measuring 4 x 4 x 3.6 m. The microphone was fitted with the manufacturer’s 90-mm wind shield to mitigate any possible influence of occasional air flows on the measurements (refer to Appendix B for details of the equipment).

The house is constructed of stone (estimated early 1900s) with small-medium single-pane wood-framed sash windows and corrugated iron roofing. The house was not permanently occupied during the monitoring period and was sporadically attended by the owners.

3.3.2 North site

Monitoring equipment was similar to that installed at the Township site (Table 29) and positioned in a similar manner. This site is closest to the wind farm, at a distance of about 1.3 km from the nearest wind turbine generator.

The house is of modern brick-veneer construction (estimated 1990s or later), with medium sized aluminium framed sash windows (panes divided into smaller lights) with corrugated iron roofing.

A set of outdoor equipment was placed in front of the garage on the gravel driveway. The microphones were mounted at the height approximately 1.2 m above the ground. A six-parameter weather monitoring station was mounted 2.2 m above the ground.

An indoor microphone was positioned at height of approximately 1.3 m in the front living room containing typical furnishings (sofas, carpeted floor, TV, etc.) directly under front window, in the corner of the room. The house has an open-plan layout, with several rooms directly off the living area. A window looks out onto a verandah. The wind farm was not clearly visible due to vegetation in the front garden. The residence was occupied during the monitoring period.

3.3.3 North East site

The house, situated at a significant distance from the wind farm, was estimated to be of 1900s construction, with small-medium windows and corrugated iron roofing. Two B&K Type 3639A noise monitoring stations were installed inside and outside the house (Table 29). Vegetation was growing close to the house.

A local wind speed/direction sensor was placed on a pole at 4 m above the ground. The outdoor station was positioned at a distance from the house on the side facing the wind farm. The microphones were fitted with the manufacturer’s wind shields. The outdoor microphone was set at a height of about 1.5 m, while an indoor microphone was placed in the main hallway of the original part of the dwelling (5 x 1.5 x 3.5 m), adjacent to the former (now disused) front door of solid wood with panel inserts, flanked by sidelights. The hallway had bare floor-boards was covered with fabric. The residence was occupied during the monitoring period.

3.3.4 West site

This house, of weatherboard construction with conventional large aluminium framed sliding windows and corrugated iron roofing, is located away from the wind farm by a significant distance. One side of the house (southeast corner) is enclosed by large gum trees and post-and-wire fencing. Information about instruments deployed at the site can be found in Table 29.

The outdoor monitoring station was deployed to the side of the house with local wind speed/direction sensor was placed on top of the pole at 4 m above the ground. Height of the outdoor microphone is approximately 1.5 m.

The indoor microphone was positioned in the front bedroom of the dwelling facing wind farm, dimensions approx. 3 x 3 x 3 m. Bedroom contains typical furnishings (bunk beds and single bed, built-in wardrobe, carpeted floor). Microphone was placed beneath window 1.3 m above floor level. The wind farm is visible through the window. The residence was occupied during the monitoring period.

3.3.5 South East site

This station was established at a house at a similar distance from the turbines as the North East and West sites. The instrumental deployment is the same as at the West and South East sites (Table 29). A six-parameter weather sensor placed at 4 m above the ground was able to supply precipitation and other environmental information in addition to the local wind speed/direction. The height of the outdoor microphone was about 1.5 m.

The house, of double brick construction, was estimated to have been built in the 1960s to 1980s, with conventional large aluminium framed sliding windows and a tiled roof. The indoor microphone was placed in the front living room facing the wind farm, linked by cable to the main station located outside. This configuration optimised power supply and reliability of data stream via a GPRS connection. In this region, reliable connection to mobile phone services was an important consideration.

The room contained typical furnishings (sofas, floor carpeting, TV, etc). The microphone was positioned close to a corner of the room near the window, at approximately 1.3 m above the floor level. The residence was occupied during the monitoring period.

3.3.6 East site

This is most distant site from the wind farm, at almost 8 km from the nearest wind turbine generator. Only external monitoring was undertaken at this house, using a noise logger based on a B&K Type 2250 sound analyser positioned outside of the house to acquire the data. The microphone was set at about 1.5 m above the ground. No weather station was available for this locality during the monitoring period.

The house is a solid brick or stone construction with average to large windows and corrugated iron roofing. The residence was occupied during the monitoring period.

4 Results and analysis

4.1 Township site

This station was installed at a house in the township of Waterloo approximately 3.5 km and wind direction from 43˚–133˚ as downwind from the nearest wind turbine generator (CD).

The house is close to a relatively busy road and small quarry to the east and southeast from the property (separation distance 200 m). An electrical substation is located in the township to the northwest at approximately 600 m away. It is understood that another substation is being built next to the existing one. The wind farm electrical substation is positioned to the east of the property at a significantly higher separation distance, approximately 3 km away. Private cars, trucks and quarry activities frequently affect noise impact at the property during day time.

The noise monitoring station was established in the backyard of the property, where local wind speeds were found to be low; not exceeding 5 m/s during the monitoring period. The site was therefore suitable for reporting low frequency and infrasound noise.

The data showed that noise associated with local turbulence was audible at very low local wind speeds, possibly generated by winds funnelling through the narrow passage between the house and shed, or interacting with the nearby tall TV antenna mast.

Two channels of the Soundbook measurement system were equipped with B&K Type 4193 microphones with low frequency adaptor to enable analysis in infrasound frequency range (refer to Table 29). The first microphone was positioned in a room facing the wind farm, while a second was deployed outside the house (see section 3.3.1 for additional details).

Influences of the relatively high noise floor for these microphones at higher frequencies became apparent under quiet conditions at this site. Overall A-weighted and C-weighted values measurement were not calculated for the infrasound channels, given potential interference from instrumental noise. For the same reason, spectral information have not been reported for 1/3 octave frequencies above 1000Hz.

The overall levels are reported using data from a third microphone positioned outside the house; a GRAS 40AL microphone with a low noise floor. The data acquisition system performed audio recording during the entire data acquisition period inside and outside the house (using GRAS microphone).

The owners were in residence sporadically, but the house was unoccupied most of the time. The building was found to have some structural problems that caused power outages during rain periods, resulting in interruptions to operation of the monitoring equipment.

It is noted that the pre-construction assessment of the wind farm did not predict high noise levels at this site, so monitoring of pre-construction background noise or post-construction noise were not performed at the house.

In the absence of any background data, a default criterion of 40dB(A) would be applicable at the site for the full range of wind speeds at the turbine from cut-in to the speed of the rated power .

One of the neighbours had previously complained about noise impact, which he believed is associated with the wind farm. The site operator commissioned an independent acoustical consultancy to investigate the noise complaints in 2011. The investigation was based on A-weighted levels monitoring and did not find evidence of excessive noise impact from the wind farm.

Extensive analysis of sound records was performed for this site. Generally noise levels were low and the audio records were analysed with significant amplification. No periods were detected when wind farm noise could be audible. The data analysis below is based on the data set not affected by other noise sources, rain periods and periods when the nearest turbines were not in the electricity generating mode.

4.1.1 Data analysis

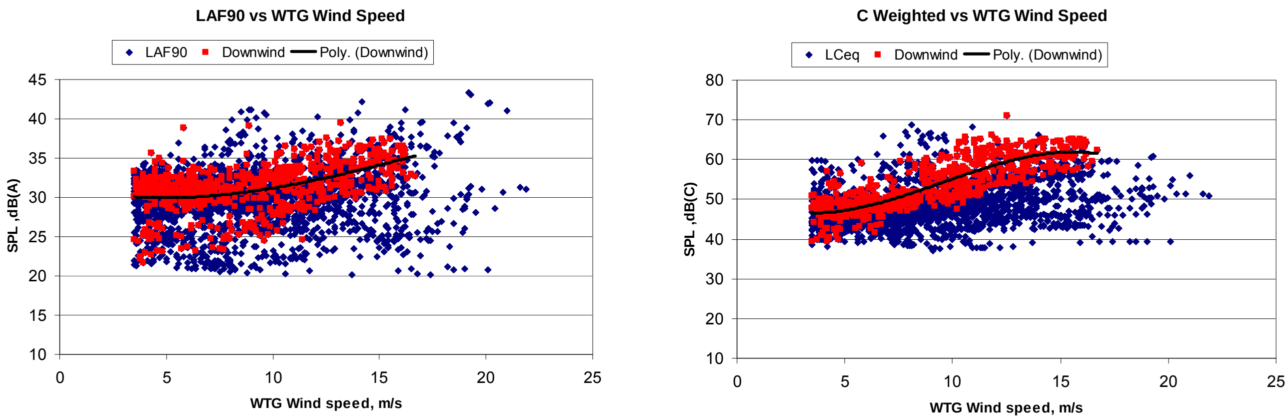
Collected data were frequently affected by ambient noise and noise from other sources, especially during the day time. Late evening and night time periods were more useful to characterise environment at the site without other noise sources. Of the full data set (8,741 averages for 10-minute intervals), about one-third remained after elimination of potential inference from ambient and other noise sources. Of these, 708 valid data pairs were collected under downwind conditions. These were used to evaluate noise levels and characteristics when winds were blowing towards the house from the direction of the wind farm.

A-weighted and C-weighted levels

The Wind Farms Environmental Noise Guidelines 2009 [32] recommend that compliance checking should be performed on the basis of A-weighted noise magnitudes collected for the downwind conditions (43˚–133˚ in this case). Data analysis performed in accordance with the recommendations for general information since wind farm noise was not detected at this location (Figure 4). The data is not corrected for the pre-construction background since it is not available for the monitoring location.

Figure 4a shows that environmental noise at the site meets 40dB(A) criterion recommended by the Wind Farms Environmental Noise Guidelines [32], however because of the absence of a detectable noise contribution from the wind farm, the criterion was not applied in this particular case.

C-weighted levels are also presented to explore potential low frequency noise problem. Figure 4b demonstrates that C-weighted levels, which can be utilised for simplified analysis of low frequency impact, may exceed 60dB(C) criterion recommended for quiet locations with 24/7 operation of noise source [3]. It may be generated by local turbulence or other sources present in the area.



(a) (b)

Figure 4 The statistical descriptor L_{AF90} (a) and equivalent C-weighted level (b) versus wind speed at wind turbine generator nacelle, Township site

Low frequency noise, infrasound levels and blade pass frequency components

This study maintained a specific focus on potential low frequency and infrasound problems, so infrasound levels (in accordance with ISO 7196) and the A-weighted low frequency descriptor $L_{pA, LF}$ were calculated for channels equipped with the special infrasound/low frequency microphones. Analysis of data against UK DEFRA 1/3 octave criteria was also performed for two channels.

It is emphasised that the Danish EPA and UK DEFRA criteria are applicable for indoor measurements. Magnitudes for the outdoor channel are reported for information purposes and the corresponding noise criteria would not have been expected to be achieved for outdoor measurements.

Infrasound levels acquired outside the house were typically below the widely accepted audibility threshold of 85dB(G) (Figure 5). Even noises from other sources resulted in the infrasound levels above the threshold on just few occasions during the monitoring period. Where there were no contributions from sources and human activities inside the house, internal levels were typically found to remain a few dB less than the outdoor levels.

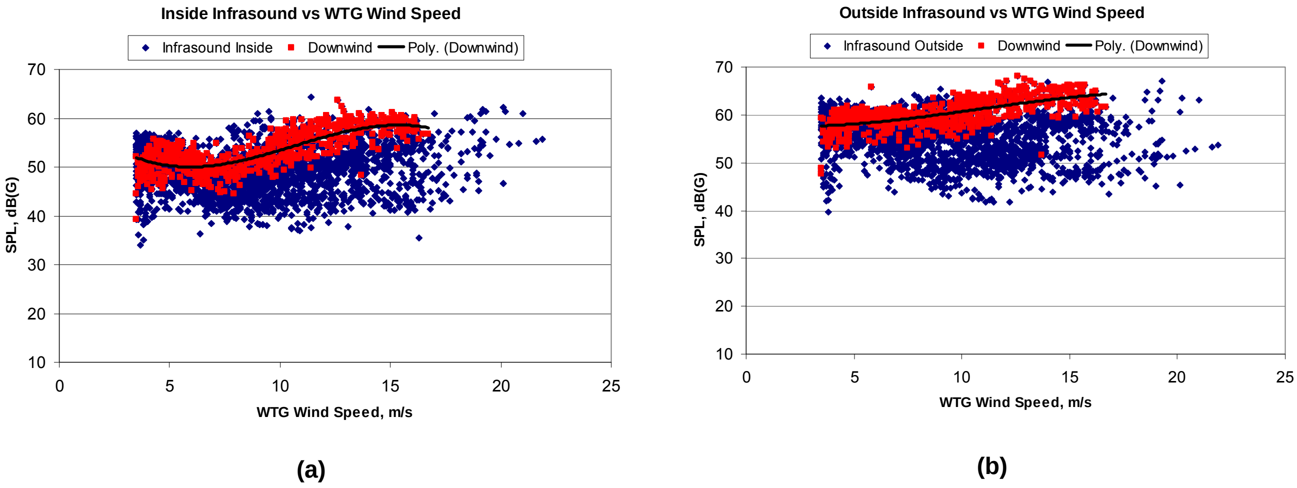
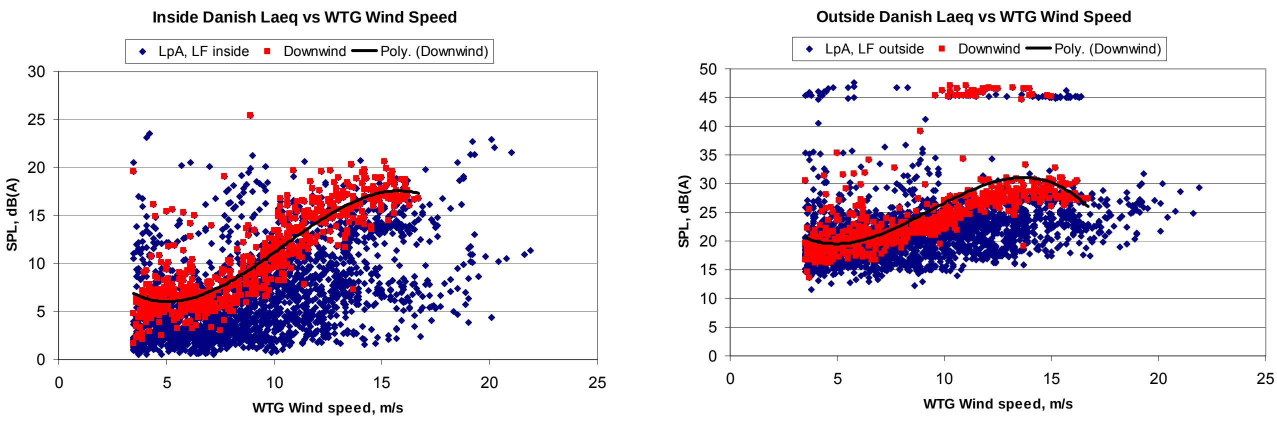


Figure 5 **G-weighted sound pressure level versus wind turbine generator wind speed at Township site: (a) inside and (b) outside**

The low frequency noise criterion recommended by Danish EPA is consistent with the subjective assessment of listeners exposed to noise [30]. The recommended evening and night time limit of 20dB(A) was met for 99% of the time (inside) when the wind turbines were in operation and other noise sources did not significantly affected the overall levels (refer to Figure 6b for typical levels). It includes all monitoring periods (not only evening and night).

To achieve the criteria recommended by UK DEFRA magnitudes must be less than the limits for all 1/3 octave bands within the frequency range 10–160Hz; so exceedences in one or more bands implies non-compliance. During this study, the strictest night time criterion was met for about 97% of the time inside the house when the wind farm was in its energy generating mode; and when total noise was not significantly affected by ambient noise or other noise sources. These conservative criteria were also met for a large part of the time outside of the house (about 55%).

Rotation of wind turbine generator blades is typically 10 to 18.4 rpm in normal operating modes when turbines produce viable amount of electricity and assumed to generate highest noise emission. Blade pass frequencies are within the 0.5–1Hz 1/3 octave frequency range. The spectrum information during periods of the diary returns was analysed for potential presence of the blade frequency component at high levels. Typically non-weighted spectrum has a general descending trend towards higher frequencies at the lowest available frequencies. No prominent components corresponding to the Blade Pass Frequency were detected either inside or outside of the house (see Figure 7, showing the blade pass frequency at 0.72Hz). Typically magnitudes corresponding to the Blade Pass Frequency are at least 50–60dB below the perception threshold for the relevant frequency bands. The 1/3 octave thresholds are equivalent to 128–149.3dB, based on 85dB(G) criterion.



(a) **(b)**

Figure 6 **A-weighted low frequency sound pressure level $L_{pA,\,LF}$ versus wind speed at the nearest wind turbine generator and local wind speed at the Township site: (a) inside and (b) outside**

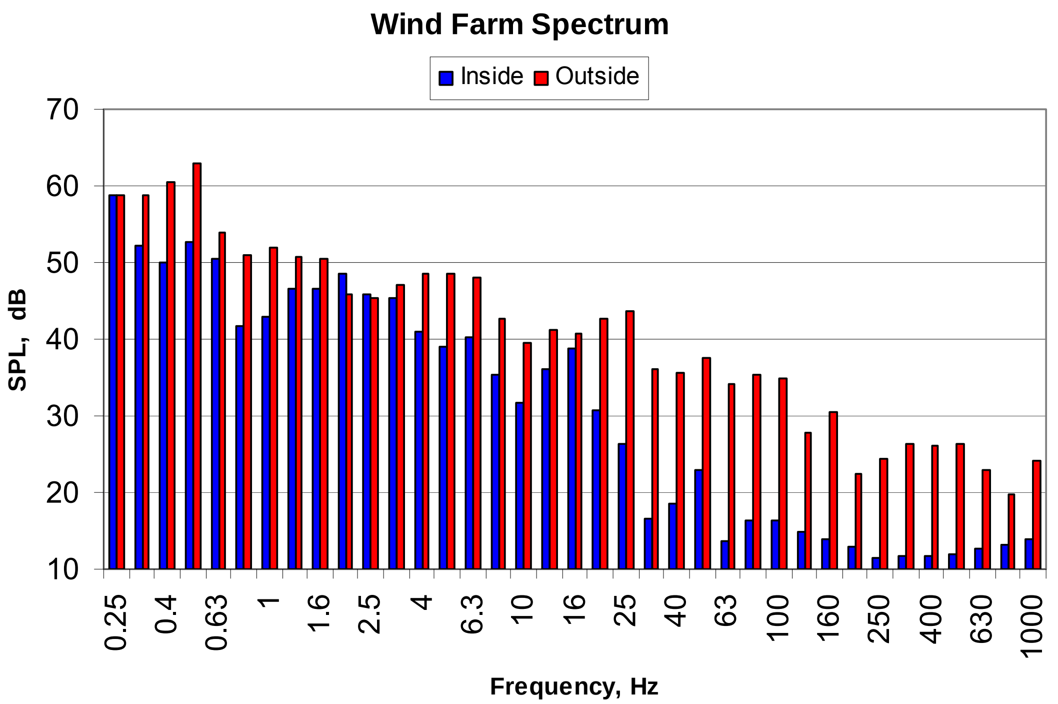


Figure 7 **1/3 Octave spectrum (10-second average, unweighted), downwind, turbine wind speed 8m/s, 14.4 rpm**

Shutdown and similar operating periods

Operating periods similar to the shutdowns were selected for the comparative analysis from the available data set. Wind speed and direction from the wind turbine generator are major parameters characterising the source and noise propagation from the source. Therefore the corresponding operating periods have been chosen to match these parameters (Table 4).

Overall estimates of the acoustic descriptors and information meeting DEFRA noise criteria are summarised in Table 5. Percentage in the DEFRA column of the table indicates fraction of time when 10-minutes averages of the spectral magnitudes meet the relevant criteria. Some of the periods were affected by other noise sources (Crosswind) and spectral analysis for them was not included into the report.

DEFRA and Danish EPA criteria (inside) are met for all of the comparative periods. It is difficult to find consistency in change of the descriptors since the noise impact is not controlled by the wind farm.

Table 4 Wind parameters for the comparative time periods, Township site

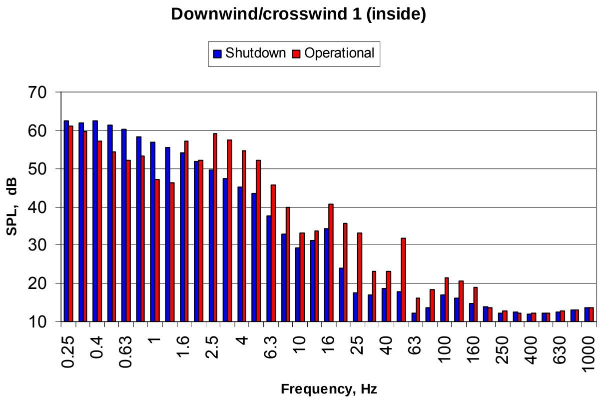
General conditions	Local wind speed		Wind turbine generator wind speed	
	Wind speed, m/s	Wind direction, deg	Wind speed, m/s	Wind direction, deg
Shutdown				
Shutdown 1: Downwind/crosswind 1	N/A	N/A	9.7–11.7	126–129
Shutdown 2: Downwind/crosswind 2	2.4–2.7	37–45	11.2–12.8	20–26
Shutdown 6: Crosswind	0–0.3	225–248	7.3–8.5	180–182
Shutdown 3: Upwind/crosswind 1	0.6–1.9	247–327	9.7–10.7	307–313
Shutdown 4: Upwind/crosswind 2	0	0	10.4–11.5	302–309
Shutdown 5: Upwind/crosswind 3	0–1.8	203–225	7.1–9.2	202–216
Operational				
Downwind/crosswind 1	0–1.9	113–121	9.8–11.6	129–131
Downwind/crosswind 2	0.1–2.3	41–56	11.3–12.8	21–25
Crosswind	0.3–0.6	236–253	7.5–8.5	176–187
Upwind/crosswind 1	0–1.3	249–23	9.9–10.7	309–313
Upwind/crosswind 2	0.5–1.5	268–358	10.7–11.5	300–309
Upwind/crosswind 3	1.1–2.7	223–225	7.9–9.2	203–208

An analysis of spectral information did not reveal any consistent trend in changes of 1/3 octave levels. Sometimes magnitudes during shutdown periods exceeded corresponding energy averages for similar operating periods (Figures 8 and 9); while other times, measured levels were affected by emissions from the electric substation, which may have resulted in higher 50, 100 and 160Hz components. Upwind/crosswind conditions 1 and 2 correspond to general downwind from the nearest substation. A relatively high magnitude at 50Hz is notable at Upwind/crosswind 1 shutdown (Figure 9a and b). A similar effect could be shown for the 100Hz component (outside) for environmental conditions Upwind/crosswind 2 (Figure 9c and d). However a general consistency in changes was not shown for shutdown and operating periods under environmental conditions Upwind/crosswind 1 and Upwind/crosswind 2. Noise levels may have been influenced by differences in local environmental parameters (for example local wind speed was 0 at Upwind/crosswind 2 and similar operating periods were characterised by higher wind speeds) and influences of sources other than the wind farm.

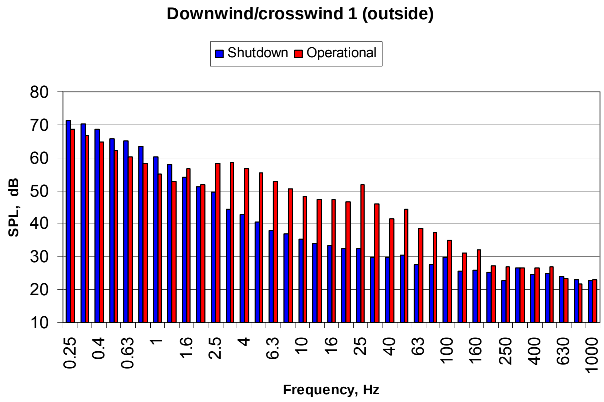
During operational periods used for the comparison, blade pass frequencies were within 0.63–0.8Hz 1/3 octave bands. No prominent blade pass frequency component was detected in the data records.

Table 5 Acoustic descriptors and meeting noise criteria information for shutdown and operational periods

General conditions	Inside			Outside					
	Infrasound, dB(G)	$L_{pA, LF}$	DEFRA	Infrasound, dB(G)	$L_{pA, LF}$	DEFRA	$L_{AF,90}$	L_{Ceq}	L_{Aeq}
Shutdown									
Downwind/ crosswind 1	41–47	4–16	100%	45–52	16–30	80%	25–32	49–52	28–36
Downwind/ crosswind 2	49–51	11–13	100%	54–57	25–28	0%	34-38	57	39–45
Crosswind Other noise sources	42–50	3–13	100%	52–61	18–30	80%	32-33	51–55	35–41
Upwind/ crosswind 1	52–53	9–11	100%	52–54	21–25	60%	32–34	48–49	34–37
Upwind/ crosswind 2	38–43	1–5	100%	47–50	21–23	0%	30	44–45	31–32
Upwind/ crosswind 3	41–46	3–5	100%	47–53	17–20	100%	32–34	48–57	33–40
Operational									
Downwind/ crosswind 1	51–58	9–16	100%	61–64	23–27	14%	32–37	51–63	34–40
Downwind/ crosswind 2	47–52	8–14	100%	53–57	23–26	0%	28–31	48–54	31–34
Crosswind	54–56	12–17	100%	59–63	24–29	33%	34–38	59–64	38–40
Upwind/ crosswind 1	42–52	2–10	100%	48–54	21–23	57%	24–32	44–53	26–34
Upwind/ crosswind 2	42–51	2–8	100%	47–52	19–23	83%	29–32	44–50	29–32
Upwind/ crosswind 3	45–50	1–3	100%	54–59	16–17	100%	30–33	42–55	31–37



(a)



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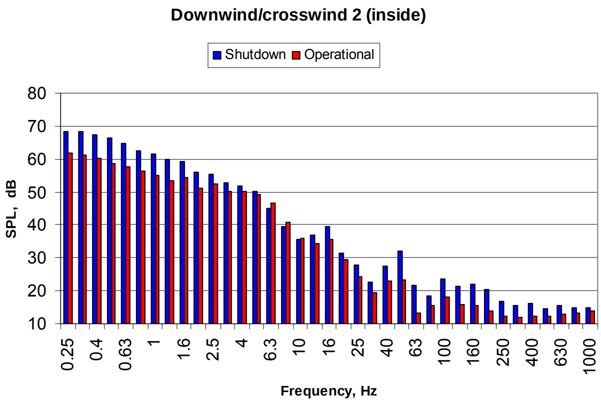

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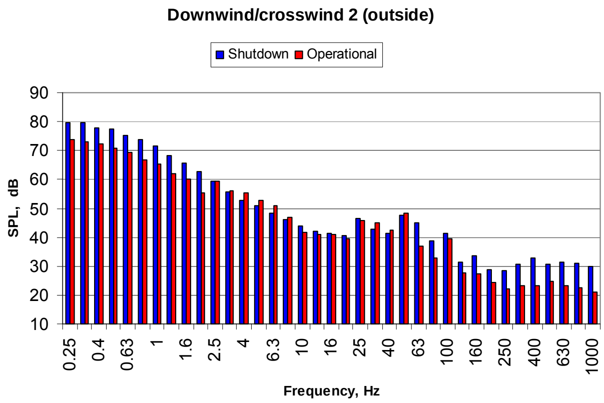


(d)

Figure 8 Comparison of unweighted spectral averages for shutdown and similar conditions at Township site: (a) and (b) Downwind/crosswind 1, (c) and (d) Downwind/crosswind 2

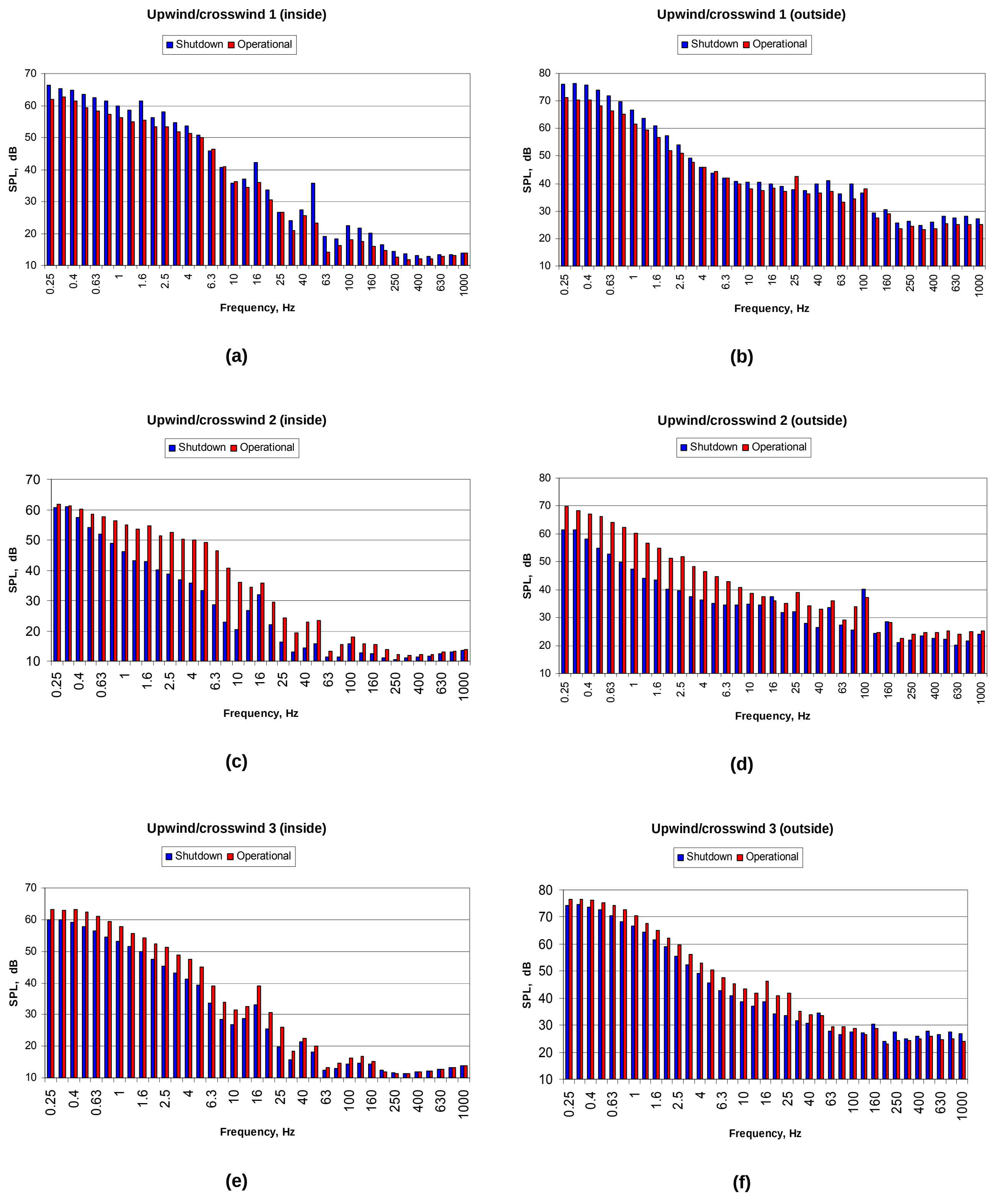


Figure 9 Comparison of unweighted spectral averages for shutdown and similar conditions at Township site: (a) and (b) Upwind/crosswind 1, (c) and (d) Upwind/crosswind 2, (e) and (f) Upwind/crosswind 3

4.1.2 Diary return periods and audio records

Noise diaries from the residence owner and two neighbourhood residences have been utilised to find possible links between the objective assessment and adverse effect records. Particular attention was paid to audio records when there were consistent responses from the neighbours.

Wind speed and directions for the checked diary returns records are summarised in Appendix C. The time stamp is adjusted in accordance with 10-minute data acquisition periods. Audio files corresponding with complaint records and other periods of potential wind farm audibility were reviewed; however the wind farm signal was not audible in records acquired either inside or outside the house (refer to Table 31).

Acoustic descriptors for the diary returns periods are summarised in Appendix C. Where start and end times of the noise events have not been specified in the diaries, the data is presented for the indicated 10-minute period. Indicator ‘0’ is entered if DEFRA low frequency noise criteria are met for all of the spectral components, ‘1’ means that the magnitudes exceed the limit in at least one 1/3 octave frequency band. If relevant data is analysed for longer time period, percentage of 10-minute intervals when the DEFRA criteria are met is entered into the corresponding field.

As noted previously, the residence is close to a relatively busy road, a small quarry and an electrical substation. Analysis of audio records indicated that machine, substation and other noises may have been present, but periods with characteristic wind farm noise were not detected during the monitoring periods. Descriptions such as ‘thumping’, ‘rumbling’ or ‘vibratory’ could not be confirmed by listening to the audio records.

Noise levels (including infrasound) are typically low and meet the strictest night-time Danish EPA and UK DEFRA criteria, where they are not affected by ambient noise and noise from other sources.

The data show that electric substation noise may have been sometimes audible outside the house during the monitoring period. Although a tonal character might have been expected if contributions from the substation had dominated the noise impact; noise levels attributable to the substation were generally found to be low. However the presence of the tone may increase annoyance for a sensitive person. This issue is discussed in more detail in the next section.

Noise spectra acquired during the reported periods were analysed for the presence of a prominent blade pass frequency component and resemblance to a specific spectrum shape within the low frequency range; on the basis (noted previously) of some evidence that a spectrum with smooth roll-off after 31.5Hz central frequency may underpin increased annoyance for some listeners [36]. The analysis did not indicate the presence of any of those spectral features.

Electric substation noise

The electrical substation is located approximately 600 m to the northwest of the property.

The study found that noise from the substation rarely dominated the environment outside the house due to the significant separation distance from the receiver. Analysis of the audio records did not detect events when the substation noise was audible inside of the house. The insertion loss of the house may be sufficient to mitigate noise from the source.

On those occasions when the substation dominated the overall noise during the study, A-weighted equivalent levels outside did not exceed 34dB(A) and were typically below 30dB(A). The noise levels also met the recommended simple low frequency criterion of 60dB(C) and the conservative Danish EPA and UK DEFRA low frequency criteria (inside).

According to the Clare and Gilbert Valleys Council development plan [5], the property and substation are situated in the Primary Production Zone which can be classified as Rural Industry zone under the Environment Protection (Noise) Policy 2007 [9]. The applicable noise criteria are 57dB(A) during the day and 50dB(A) at night, measured and adjusted in accordance with the Noise Policy. Noise from the substation would typically attract a 5dB(A) penalty for tonal character; however, even when adjusted, levels associated with the substation were found to be below 40dB(A) during this study and met the regulatory requirements.

The wind farm electric substation is situated to the west of the house. The existence of a noise contribution from the substation with a possible tonal character could not be excluded for all environmental conditions. However because of its significant distance from the house and a lack of evidence for attributable contributions to noise levels, the signal from the substation may be masked effectively by ambient noise and noise from other sources.

4.1.3 Summary for the Township site

The Township is centrally situated to the west from the wind farm within the Waterloo township and separated by a significant buffer from the site.

- It was not possible to detect noise that may be associated with the wind farm operation during the noise monitoring period.
- The data analysis details overall noise levels found at the site, which could be affected by the road traffic, operation of the small quarry, the electrical substation and other other noise sources.

- In absence of significant ambient noise and noise from other sources, noise levels at the site met the strictest indoor and outdoor criteria and complied with regulatory requirements. This may result not only from the inaudibility of noise from the wind farm, but also from the fact that the residence was not permanently occupied and the measured levels were less affected by household activities and operation of tools.
- Infrasound in the area during the monitoring period was typically detected at levels significantly below the accepted 85 dB(G) perception threshold.
- The blade pass frequency component was also not prominent and corresponding magnitudes were significantly below the perception threshold.
- The low frequency noise inside of the house generally met the strictest low frequency criteria.
- The recommended C-weighted criterion of 60dB(C) may have sometimes been exceeded during the study, due to natural factors and noise from other sources. C-weighted levels during the shutdowns and similar operating periods were found to be characterised by levels below the criterion.
- Noise from the nearest electrical substation was periodically detected at the site. On those occasions when noise from the substation dominated the environment, some evidence was found to suggest a tonal character which could increase annoyance. However levels attributable to the substation were found to be low and met the regulatory requirements.
- Substation noise was not generally found to be audible inside the house.
- The surrounding group of diary respondents recorded an extremely high number of occasions when they considered the wind farm to have had adverse impact on amenity in the area.
- Analysis of the relevant audio records did not indicate any periods when the wind farm noise was audible.

4.2 North site

The North site is the nearest to the wind farm at about 1.3 km from the nearest wind turbine generator. Downwind direction from the nearest wind turbine generator (wind turbine generator AG) is 172°±45°. The site is characterised by low local wind speeds which did not exceed 5 m/s during the monitoring period. Sound pressure levels relating to the natural background were found to be low. Some audibility of noise from the turbines was expected under particular environmental conditions. The site was found to be suitable for reporting low frequency and infrasound noise due to low local wind speeds and consequently a small wind induced component.

Local wind speeds appeared to be affected by local turbulence as they did not correlate well with wind speeds measured at wind turbine generator height.

On the other hand, local wind direction data were found to be consistent with the wind direction at the nacelle of the nearest wind turbine generator for the majority of the monitoring period.

Two channels of the Soundbook measurement system were equipped with two B&K Type 4193 microphones with low frequency adaptor to enable analysis of infrasound frequency range (see Appendix B). The first microphone was positioned inside an occupied living room and the second one was deployed outside the house (see section 3.3.2 for details).

As previously noted, influences of the relatively high noise floor for these microphones at higher frequencies became apparent under quiet conditions at this site, so overall A-weighted and C-weighted values measurement were not calculated for the infrasound channels, given potential interferences from instrumental noise. For the same reason, spectral information has not been reported for 1/3 octave frequencies above 1,000Hz.

The overall levels were reported using data from a third microphone positioned outside the house; a GRAS 40AL microphone with a low noise floor. The data acquisition system performed audio recording during the entire data acquisition period inside and outside the house.

It is noted that the pre-construction assessment of the wind farm did not predict high noise levels at this site, so monitoring of pre-construction background noise or post-construction noise were not performed at the house.

In absence of any background data, a default criterion of 40dB(A) would be applicable at the site for the full range of wind speeds at the turbine from cut-in to the speed of the rated power .

The site operator commissioned an independent acoustical consultancy to investigate the noise complaints (2012). The investigation was based on A-weighted levels monitoring and confirmed compliance with conditions of the development approval.

4.2.1 Data analysis

Data collection was frequently affected by ambient noise and noise from other sources, especially during the day time. Night-time periods were found to be more useful for analysing periods where the wind farm noise might be expected. Of the full data set about 30% remained after elimination of potential inference from ambient and other noise sources. Of these, 434 valid data pairs were collected under downwind conditions. These were used to evaluate noise levels and characteristics when winds were blowing towards the house from the direction of the wind farm.

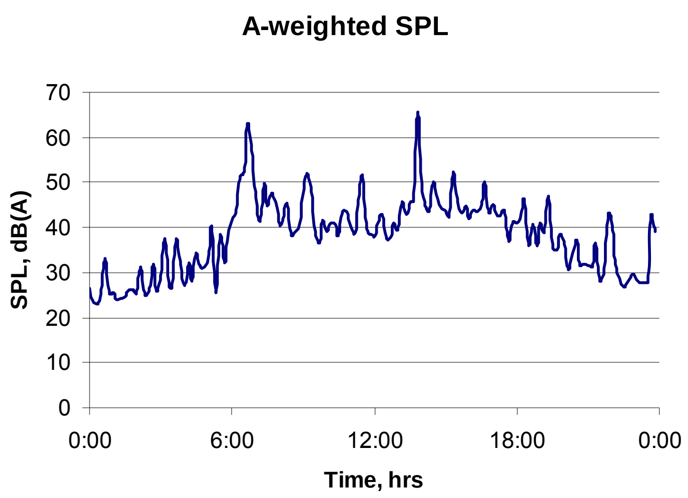


Figure 10 Typical daily A-weighted sound pressure level daily time history, outside at the North site

A-weighted and C-weighted levels

The Wind Farms Environmental Noise Guidelines recommend that compliance checking should be performed on the basis of A-weighted noise magnitudes collected for downwind conditions from a wind farm (172º±45º in this case). Data analysis performed in accordance with the Guidelines [32] recommendations is represented in Figure 11a. The data was not corrected for the background since background levels are not available for this monitoring site.

Figure 11a confirms compliance of the wind farm noise with 40dB(A) criterion. C-weighted levels are also presented to explore the low frequency noise.

The measured sound pressure levels (Figures 11 and 12) typically correlated better with local wind speed at the house, than with the wind speed measured at the nearest turbine. The summary of coefficients of determination R^2 is represented in Table 6 for the best second or third order regression curves. For majority of the cases, the overall levels (including infrasound levels) are better correlated with the local wind speed for both downwind and all wind directions. In spite of the fact that the wind farm noise can be audible, the overall levels may be significantly affected by the natural background which is better related to the local wind speed. The wind farm may not control noise impact at the site.

Work [3] recommends strictest criterion of 60dB(C) for quiet areas with 24/7 operation of a noise source. Figure 11c and d show that the noise levels can be higher than the low frequency criterion. It is difficult to identify whether it is associated with operation of the wind turbines since C-weighted levels are better correlated with local wind speeds. This issue is also explored in the next section.

Table 6 Coefficient of determination (R^2) for polynomial best fits of the acoustic descriptors versus wind turbine generator and local wind speeds

Descriptor	Vs wind turbine generator wind speed		Vs local wind speed	
	Total	Downwind	Total	Downwind
L_{AF90}	0.08	0.30	0.21	0.19
L_{Ceq}	0.10	0.05	0.12	0.06
Infrasound (inside)	0.52	0.40	0.48	0.41
Infrasound (outside)	0.31	0.35	0.57	0.49

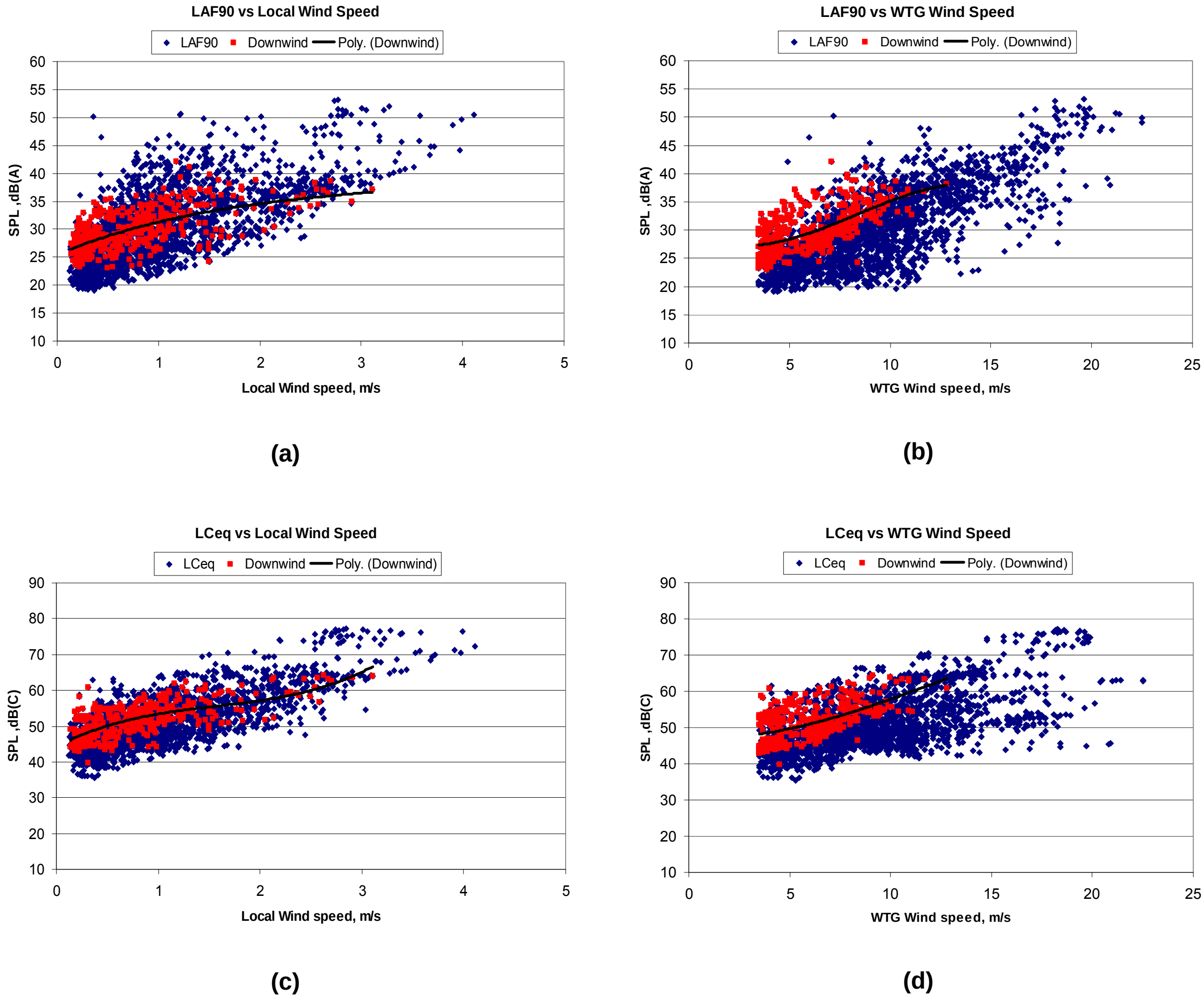
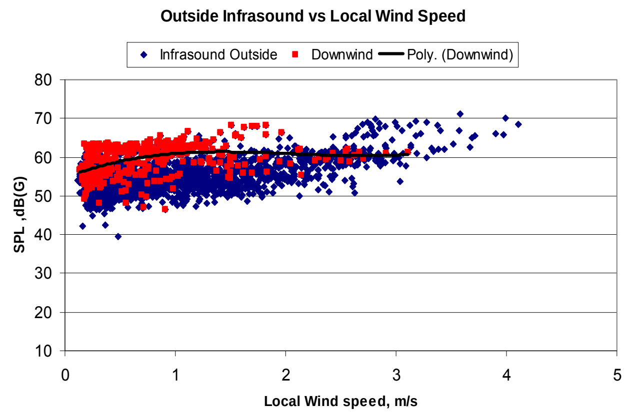


Figure 11 The statistical descriptor L_{AF90} and equivalent C-weighted level versus wind speed at wind turbine generator nacelle and local wind speed, outside at the North site

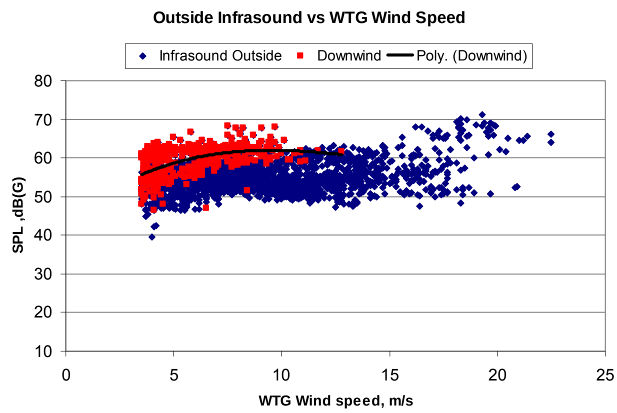
Low frequency noise, infrasound levels and blade pass frequency component

The current study has a specific focus on concerns about potential low frequency and infrasound problem. Accordingly, infrasound levels as defined in ISO 7196 and an A-weighted low frequency descriptor $L_{pA, LF}$ is reported for channels equipped with the special infrasound/low frequency microphones. Analysis of data versus UK DEFRA 1/3 octave criteria was also performed for two channels. As previously noted, the Danish EPA and UK DEFRA criteria are applicable for indoor measurements. Magnitudes for the outdoor channel are reported for information purposes and the corresponding noise criteria are not expected to be met for outdoor measurements.

Infrasound levels acquired outside of the house demonstrated a relatively high correlation with the local wind speed. The approximating curves for the infrasound measured outdoor versus the wind speed measured at the turbine showed lower R^2 magnitudes (Table 6). Generally infrasound levels were low and significantly below the widely accepted audibility threshold of 85dB(G) [10, 27]. It should be noted that the entire data set was shown to meet this criterion; that is the data included potential inference from ambient noise and other noise sources. If noise inside the house is not affected by household activities, internal levels are typically 3–5dB(G) less than the outdoor levels. The infrasound levels were similar to those measured at the Township site at which it was not possible to detect events associated with noise from the wind farm. This provides further support for the argument that infrasound measured during this study was more dependant on local wind conditions than other sources or factors.



(a)



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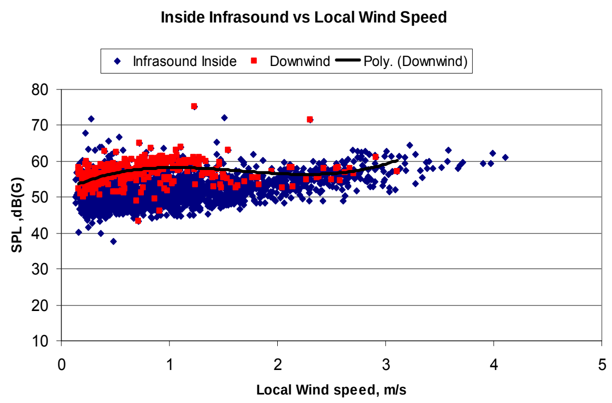

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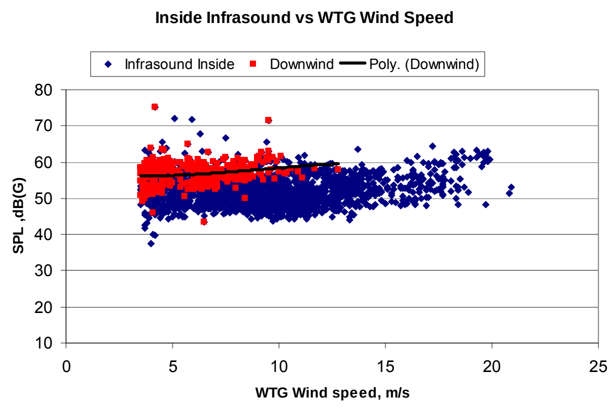


(d)

Figure 12 G-weighted sound pressure level versus local and wind turbine generator wind speed at North site: (a) and (b) outside; (c) and (d) inside

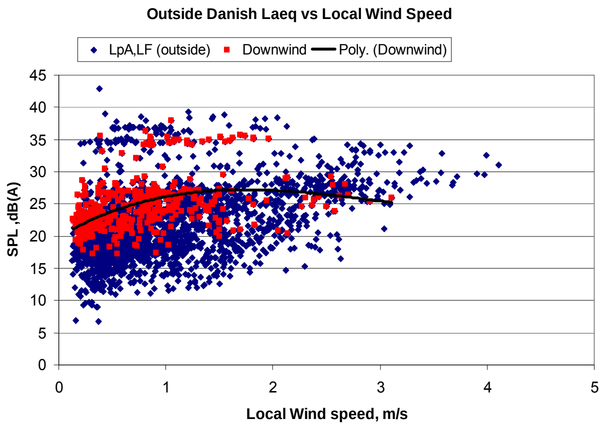
The low frequency noise criterion recommended by the Danish EPA typically is consistent with the noise perception of a typical listener. During this study, the recommended night time limit was met inside the house for 95% of the time, including at night and in the early evenings, when the wind farm was most likely to have been audible.

As noted previously, in order to achieve the criteria recommended by UK DEFRA, magnitudes must be less than the limits for all 1/3 octave bands within the frequency range 10–160Hz; so exceedences in one or more bands represent a non-compliance. During this study, the strictest night-time criterion was met for about 94% of the time inside the house when the wind farm was in its energy generating mode; and when total noise was not significantly affected by ambient noise or other noise sources. These conservative criteria were also met for a large fraction of the time outside of the house (about 67%).

Wind turbine generator blades typically rotate at 10–18.4 rpm when generating electricity at economic levels in normal operating modes; and when it is assumed that they generate their highest noise emissions. The consequent blade pass frequency is within a 0.5–1Hz 1/3 octave frequency range.

Spectral information obtained during periods of the wind farm noise audibility was analysed for the presence of significant blade pass frequency components. Non-weighted spectra typically showed a general roll-off towards higher frequencies at the lowest available frequencies. No prominent components corresponding to blade pass frequencies were detected either inside or outside the house.

The blade pass frequency magnitude was found to be marginally higher than adjacent components on some occasions (Figure 14), but the magnitude was typically around 60–70dB below the accepted perception threshold of 85dB(G).



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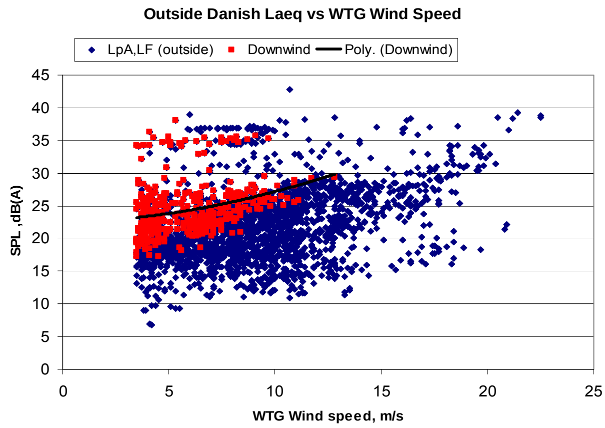

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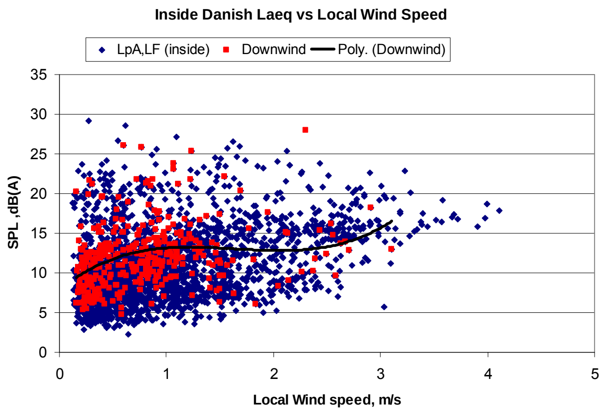

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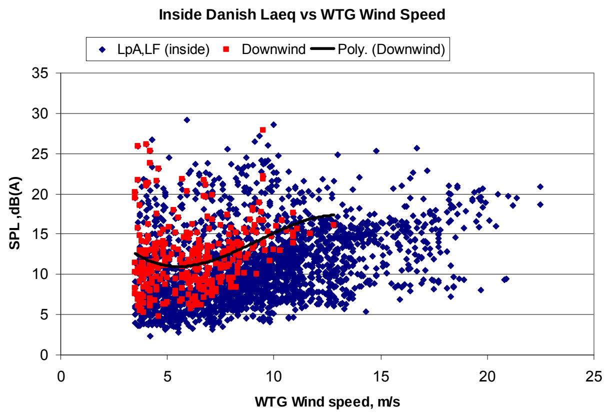


(d)

Figure 13 A-weighted low frequency sound pressure level $L_{pA,\,LF}$ versus local and wind turbine generator wind speed at North site: (a) and (b) outside; (c) and (d) inside

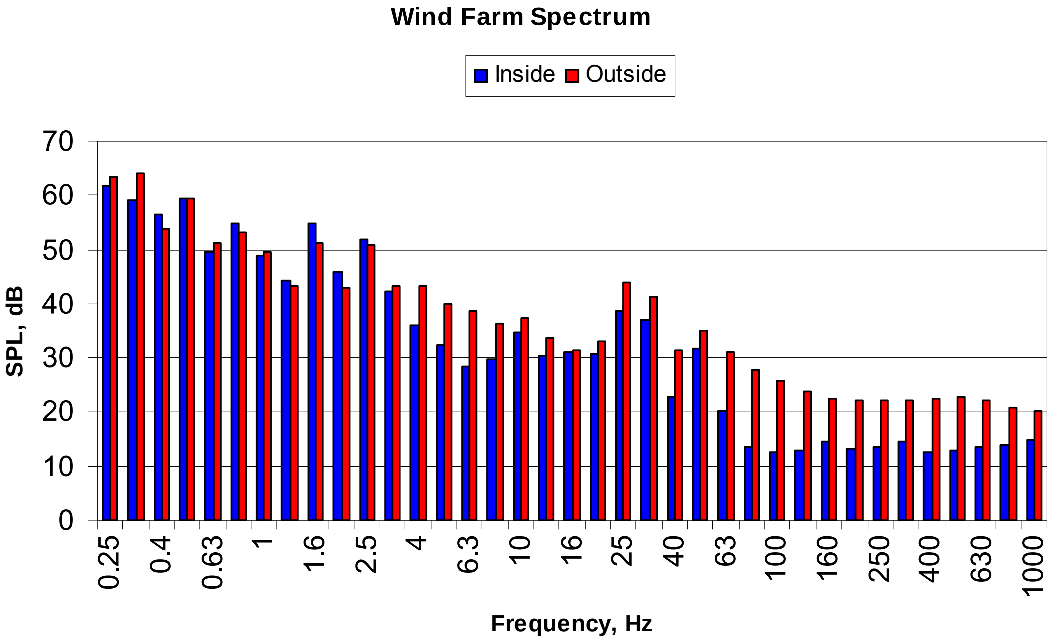


Figure 14 1/3-octave unweighted spectrum (10-second average), downwind/crosswind, wind turbine generator wind speed 9.7m/s, 16 rpm

Shutdowns and similar operating periods

Operating periods with similar conditions to those during the shutdowns were selected for the comparative analysis; with a particular on wind speed and direction from the wind turbine generator, given their critical importance in determining noise propagation from the source (see Table 7).

Table 7 Wind parameters for the comparative time periods at the North site

General conditions	Wind local		Wind turbine generator	
	Wind speed, m/s	Wind direction, deg	Wind speed, m/s	Wind direction, deg
Shutdown				
Shutdown 6: Downwind	0.7–1.3	171–198	6–7.3	172–180
Shutdown 1: Downwind/ crosswind 1	2.7–3.3	103–121	9–9.5	126–128
Shutdown 5: Downwind/ crosswind 2	0.3–0.6	220–276	8–8.8	207–214
Shutdown 2: Upwind	0.6	150–180	8.6–9.1	26–32
Shutdown 3: Upwind/crosswind 1	0.8–1.2	276–290	7.5–9.1	304–306
Shutdown 4: Upwind/crosswind 2	1.5–1.7	256–267	11.2–11.6	298–301
Operational				
Downwind	0.8–1.5	150–214	6–6.9	160–180
Downwind/ crosswind 1	0.6–2.8	105–125	9–9.3	111–136
Downwind/ crosswind 2	0.4–1.4	221–262	8–8.5	211–218
Upwind	0.3–0.6	77–194	8.5–9.7	20–35
Upwind/crosswind 1	0.6–1.2	251–288	7.8–9	303–308
Upwind/crosswind 2	0.9–1.3	270–328	11.2–11.8	297–300

Overall estimates of acoustic descriptors and information regarding meeting DEFRA noise criteria are summarised in Table 8. Percentages in the DEFRA column of the table indicates the fraction of time when 10min averages of the spectral magnitudes met the relevant criteria during the study.

As the measurements were performed in an occupied house at this site, sound pressure levels measured indoors during the shutdowns and adjacent periods were affected to some degree by household noises, with the exception of Shutdown 4 (Upwind/crosswind 2 conditions).

From a statistical perspective only comparisons of downwind and downwind/crosswind conditions may have indicated noise contributions from the wind farm, but this was also confirmed by comparison of spectral magnitudes averaged over the shutdown and corresponding operating periods (see Figures 15 and 16). It should be noted that a consistent trend for all of the available environmental conditions could not be detected by utilising variations in C-weighted levels. For example C-weighted magnitudes at Downwind/crosswind 1 environmental conditions were higher during the shutdown period than during similar operational time interval.

Comparisons of spectral information showed a significant contribution from the wind farm at low frequencies under downwind and downwind/crosswind operational conditions. Components at 25Hz and 31.5Hz are prominent for outdoor measurements at upwind and upwind/crosswind operational conditions, however it is unlikely that these would be perceived as conferring a tonal character on the noise.

It should be noted that outdoor spectral components were found to be below the threshold of audibility for the separate components up to 40Hz [15, 39]. As noted previously, internal noise levels are sometimes affected by household activities, which lead to greater spectral magnitudes measured inside of the house than outside.

Internal data records showed that DEFRA spectral criteria were met for 100% of time during the comparative operational periods. The Danish EPA low frequency criterion for night time was also met for the comparative operational and non-operational periods.

During operational periods used for the comparison, blade pass frequencies were within the 0.63–0.8Hz 1/3 octave bands. No prominent blade pass frequency component was detected in the data records.

Table 8 Acoustic descriptors and meeting noise criteria information for shutdown and operational periods

General conditions	Inside			Outside					
	Infrasound, dB(G)	$L_{pA, LF}$	DEFRA	Infrasound, dB(G)	$L_{pA, LF}$	DEFRA	$L_{AF,90}$	L_{Ceq}	L_{Aeq}
Shutdown									
Downwind	44–49	8–11	100%	47–49	18–23	80%	24–26	47–49	28–32
Downwind/ crosswind 1	50	9–10	100%	55–56	20–22	80%	34–38	61–65	40–43
Downwind/ crosswind 2	44–45	3–10	100%	48–50	17–21	100%	22–24	46–49	25–27
Upwind	48	18	100%	48–53	20–25	100%	32–34	53–54	35–38
Upwind/ crosswind 1	48–52	5–13	100%	48–55	15–18	100%	24–28	45–47	28–29
Upwind/ crosswind 2	50–52	7–9	100%	50–54	20–22	100%	36–38	49–50	38–39
Operational									
Downwind	53–61	9–14	100%	55–64	21–34	60%	30–34	48–57	29–39
Downwind/ crosswind 1	55–58	9–19	100%	59–60	25–27	40%	32–37	55–63	33–41
Downwind/ crosswind 2	52–60	8/16	100%	57–63	22–27	33%	28–34	51–62	31–39
Upwind	47–50	7–11	100%	50–54	15–27	80%	24–28	45–51	27–30
Upwind/ crosswind 1	48–53	6–19	100%	53–56	17–19	100%	21–30	45–50	26–33
Upwind/ crosswind 2	47–50	7–11	100%	51–53	18–21	100%	29–32	45–48	28–33

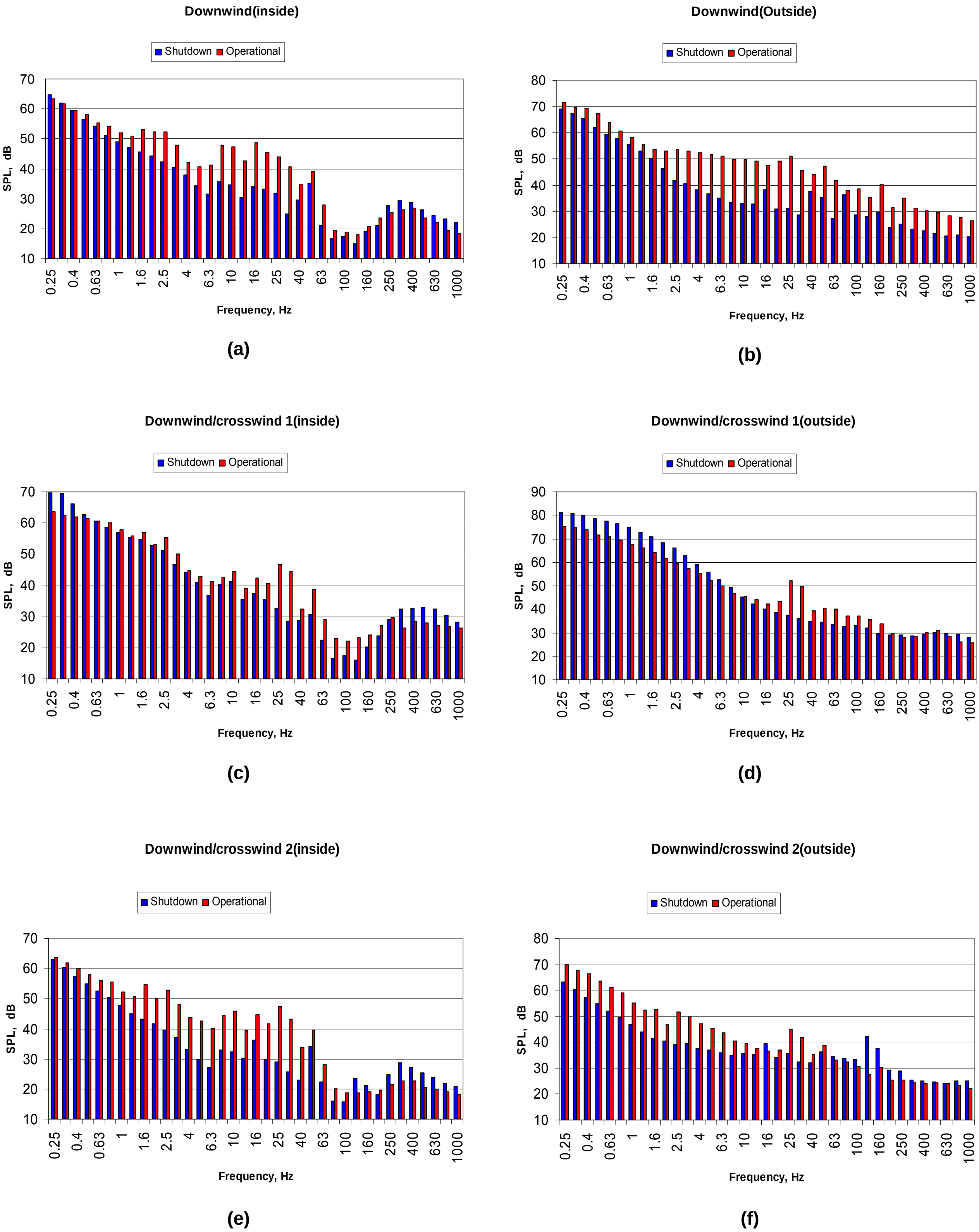


Figure 15 Unweighted sound pressure level versus local and wind turbine generator wind speed at the North site: (a) and (b) Downwind; (c) and (d) Downwind/crosswind 1; (e) and (f) Downwind/crosswind 2

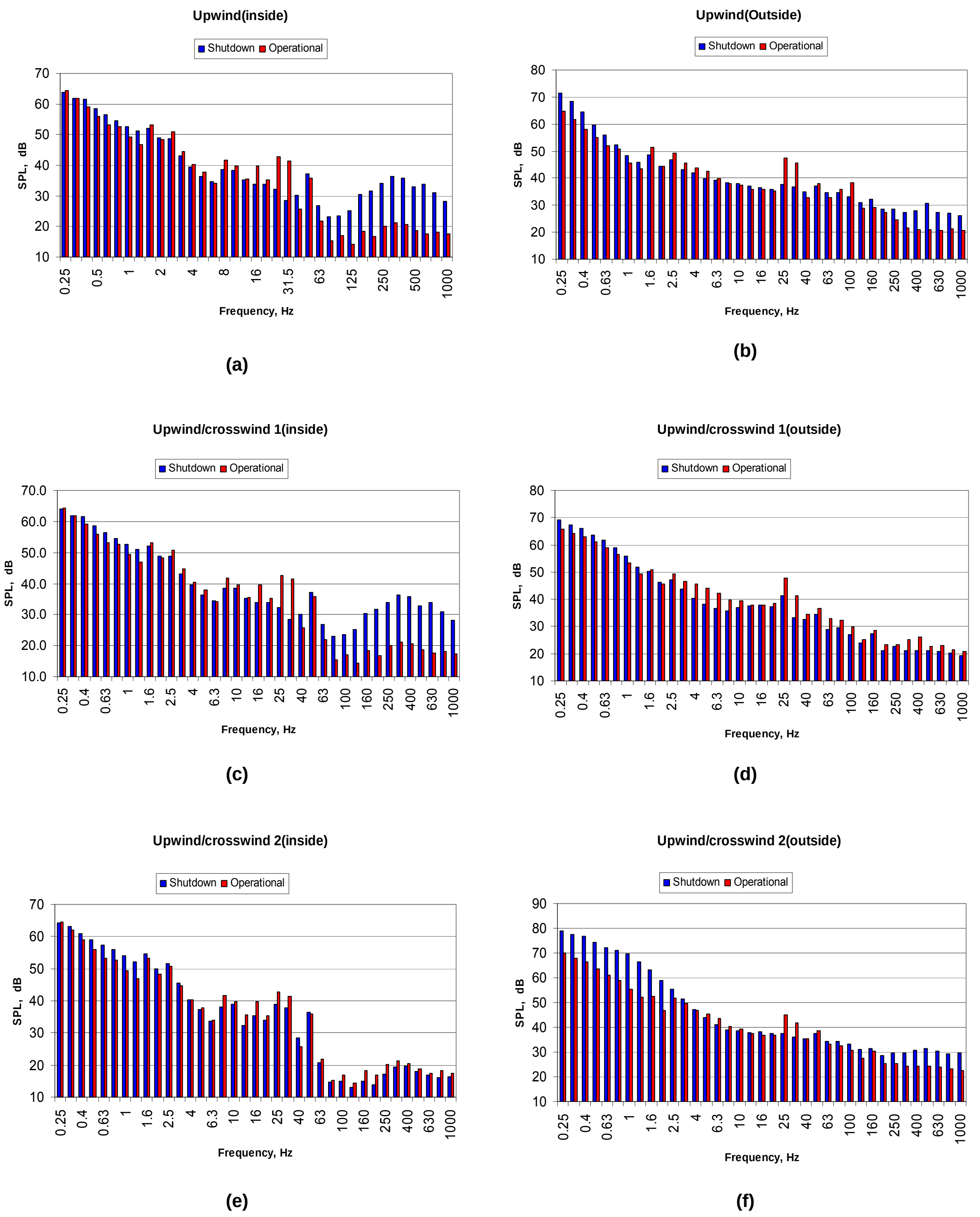


Figure 16 **Unweighted sound pressure level versus local and wind turbine generator wind speed at the North site: (a) and (b) Upwind; (c) and (d) Upwind/crosswind 1; (e) and (f) Upwind/crosswind 2**

Figure 17 Comparison of unweighted spectral averages for the shutdowns and adjacent periods at the North site

Some of the periods preceding the shutdowns were affected by ambient noise or noise from other sources; or are characterised by significant changes in wind speeds. Figure 17 shows the spectral content for similar environmental conditions and demonstrates insignificant influence of ambient noises measured during the adjacent periods. The figure also shows a notable increase in outdoor noise in the low frequency range for the downwind and downwind/crosswind conditions. It should be noted that there were slightly higher than average wind speeds before the downwind shutdown. Also wind speeds during the adjacent periods for Upwind and Upwind/crosswind 1 condition were on average higher than during the shutdowns.

There was only one shutdown period not affected by household noises inside the residence which could be utilised for comparison with a similar operating period; however, no conclusive spectral difference could be demonstrated for the relevant periods (Figure 17).

4.2.2 Diary return periods and audio records

Noise diaries from the residence occupant and two neighbourhood residences have been utilised for finding possible link between the objective assessment parameters and adverse effect records. The neighbours did not report noise associated issues from mid-May. Wind speed and directions for the diary returns records are summarised in Appendix D. The time stamp is adjusted in accordance with 10-minute data acquisition periods. Intervals when turbine noise is audible are highlighted in italics.

Acoustic descriptors for the diary returns periods are summarised in Table 33 of Appendix D. Where start and end times of the noise events have not been specified in the diaries, the data is presented for the time available. Indicator ‘0’ is entered if DEFRA low frequency noise criteria are met for all of the spectral components, ‘1’ means that the magnitudes exceed the limit in at least one 1/3 octave frequency band.

Analysis of sound records corresponding to the noise diaries required significant amplification. On those occasions when a wind farm signal could be detected in the amplified records, the character of the noise was continuous, with slight modulation. This may not be detectable by an average listener. The wind farm rarely dominated total noise at the North site. The amplified wind farm noise was mainly audible for downwind and downwind/crosswind conditions (refer to Table 33).

In many instances, the noise data did not provide evidence for wind farm noise associated with attributions in diary responses. There were occasions when noises were attributed to the wind farm when in fact the wind farm was not in operating mode, because of low wind speeds (see records No 2 and 4 in Appendix 4).

The diaries indicate that residents were clearly aware of noises during the monitoring program, which were often characterised as ‘thumping’, ‘rumbling’ or ‘vibratory’. However, analysis of audio records corresponding to the diary entries did not reveal periods of time when the wind farm noise was characterised by these effect.

Noise levels (including infrasound), that were clearly associated with wind farm noise, were typically low and met the strictest night-time Danish EPA and UK DEFRA criteria. Marginal exceedences of the criteria inside of the house were attributable to household activities. Time periods with marginal exceedence of C-weighted sound pressure level above the recommended 60dB(C) criterion were not dominated by the wind turbines and may be due to vegetation or other ambient sources.

Typical sound pressure levels associated with the wind farm impact outside of the house are very low and house structure provides additional attenuation. It was not possible to identify wind farm noise inside of the house in available audio records.

Noise spectra acquired during the reported periods were analysed for presence of a prominent blade pass frequency component and specific spectral shapes at low frequencies; noting (as previously discussed) that spectra with smooth roll-offs after 31.5Hz central frequency, may be associated with increased annoyance in some listeners [36]. However, the analysis did not indicate the presence of any such features.

4.2.3 Summary for the North site

The North site is situated at the north end of the wind farm and is the closest to the wind farm.

- Noise from the wind farm was detectable under particular environmental conditions, but rarely dominated environment at the measurement site and may not have been audible to an average listener.
- Typically wind farm noise was shown to meet relevant indoor and outdoor criteria and complied with the regulatory requirements during the monitoring period.
- From the monitoring data, it has been extremely difficult to demonstrate that wind farm noise inside of the house was audible; apart from any other factors, because of the very low levels of noise that could be associated with the wind farm noise levels outside the house.

- Infrasound in the area during periods of possible audibility of noise from wind farm was at levels significantly below the perception threshold. The blade pass frequency component was also not excessive and detected at levels significantly below the perception threshold.
- Low frequency noise data captured inside the house during the study period showed that noise levels generally met the strictest low frequency criteria. The recommended C-weighted criterion of 60dB(C) was occasionally exceeded; however there was no conclusive evidence to attribute those exceedences to contributions from the wind farm.
- It is noted that noise recorded during some shutdown periods was characterised by C-weighted levels above the criterion; and higher levels were affected by ambient noises during the diary return periods.
- It was not possible to detect any specific noise character (apart from slight modulation detected in amplified audio records) that could be attributed to wind farm operation.

4.3 North East site

The North Eastern monitoring site is estimated to be about 2.6 km away from the nearest wind turbine generator (wind turbine generator AA). This site was equipped with two long-term B&K monitoring stations to measure both inside and outside noise, using B&K type 4952 outdoor microphones. The weather station with sensor positioned 4 m above the ground was used to determine local wind condition.

The outside microphone was situated at about 25 m to the west of the house; while the inside microphone was placed in a long hallway (approximate 1.5x 5 x 3.6 m) within the house. For this site, wind direction from 245˚–335˚ (290˚±45˚) would be considered downwind from the nearest wind turbine generator.

The house is of double brick construction, built around the early 1900s. The house was occupied during the monitoring period.

4.3.1 Data analysis

Noise in the living area of the inhabited residence during day time was mostly dominated by other noise sources. After the rectification of most other noise sources levels, there were 2,983 valid data points for the outside measurements and 4,311 data points for inside measurements. There was also a large amount of downwind data points collected. Throughout the monitoring period, there were 986 and 1,412 downwind data points for outside and inside measurements respectively. A large fraction of data acquisition periods was characterised by high local wind speeds (5-10 m/s).

A-weighted and C-weighted levels

Where noise inside of the house was not affected by other noise sources and household activities, A-weighted and C-weighted levels inside the house are typically low (Figures 18a and b). C-weighted levels inside the house normally were below 60dB(C) during the monitoring period. Statistical trends for outdoor A-weighted levels versus wind turbine generator wind speed also remained below 40dB(A). Outside C-weighted levels were relatively high and exceeded the recommended 60dB(C) criterion for large fraction of the time (Figure 19). This was true both at lower speeds and at the increased speeds, suggesting contributions from noise-generating mechanisms other than the wind farm.

Sound pressure levels demonstrated high correlation with local and wind turbine generator wind speed (except C-weighted levels inside of the house against local wind speed during the monitoring period (refer to Table 9).

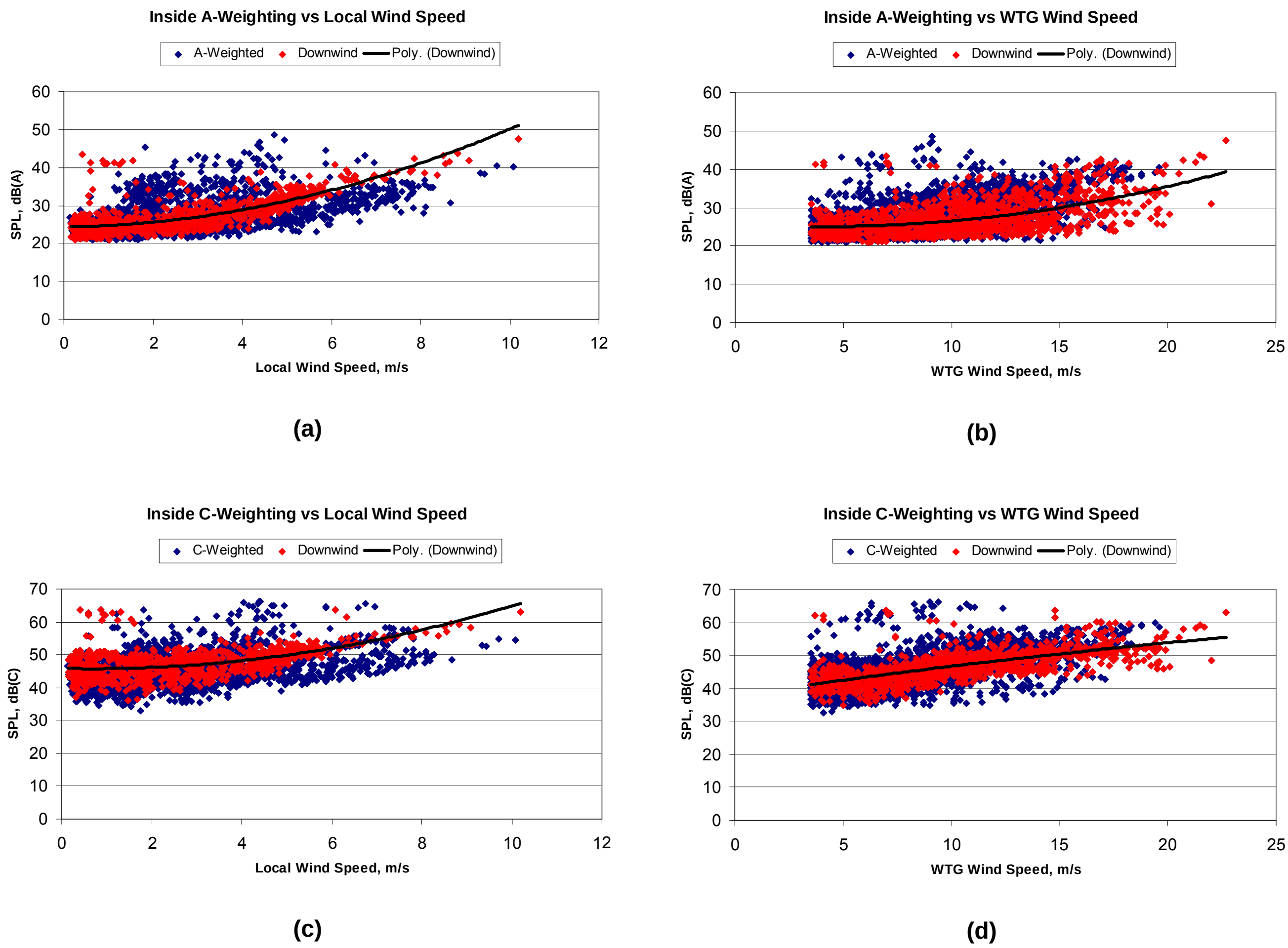


Figure 18 A-weighted and C-weighted levels versus local and wind turbine generator wind speed inside of the house, inside at the North East site

Figure 20b shows that noise at this site easily complied with the 40dB(A) default criterion and also met the requirement for quiet zones of 35dB(A). Noise outside the house demonstrated a relatively high correlation with the wind speed (Table 9) for sites separated by a significant buffer from the wind farm; with higher correlation coefficients for outdoor noise versus local wind speeds.

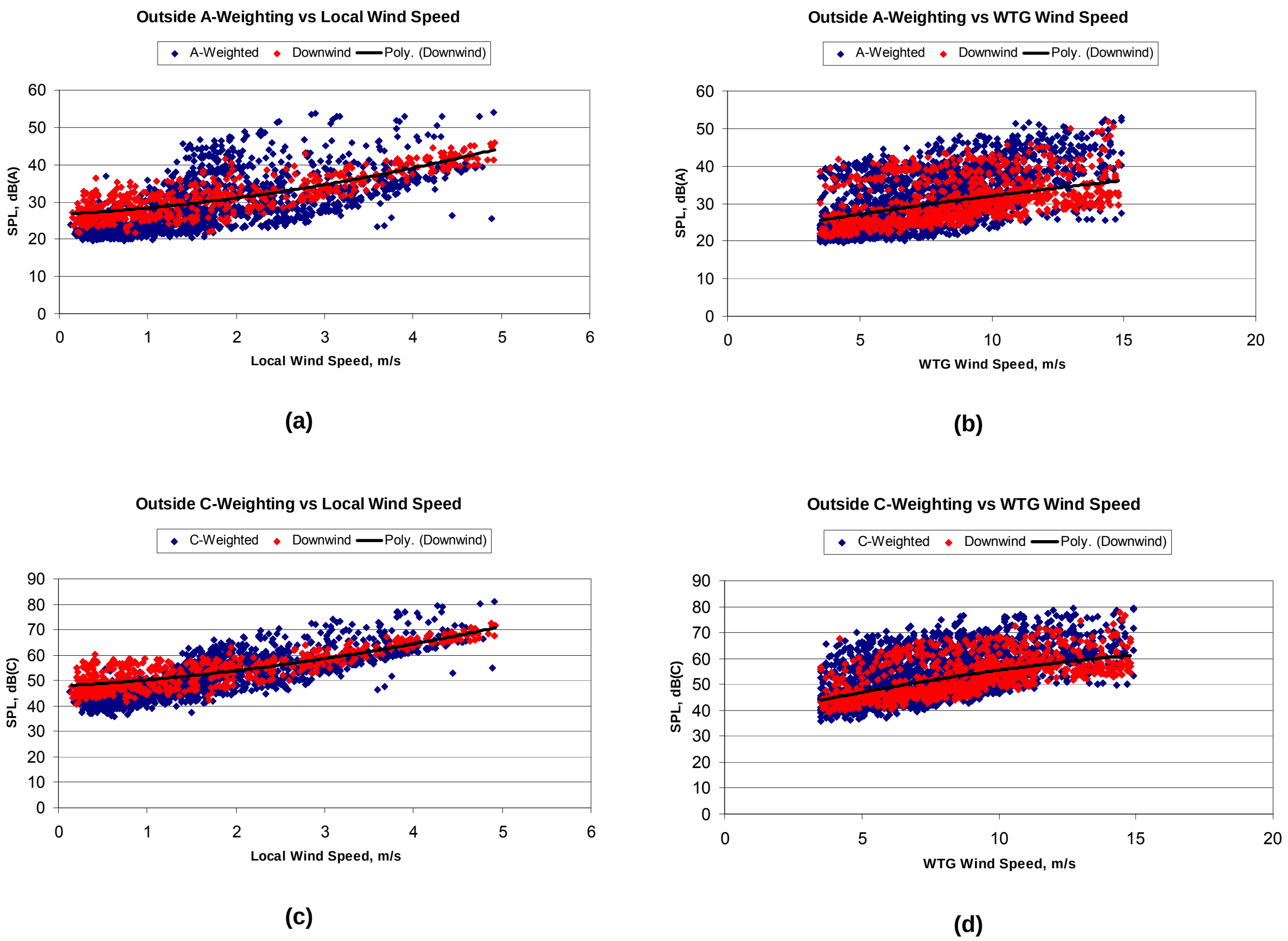


Figure 19 **A-weighted and C-weighted levels versus local and wind turbine generator wind speed outside the house, at the North East site**

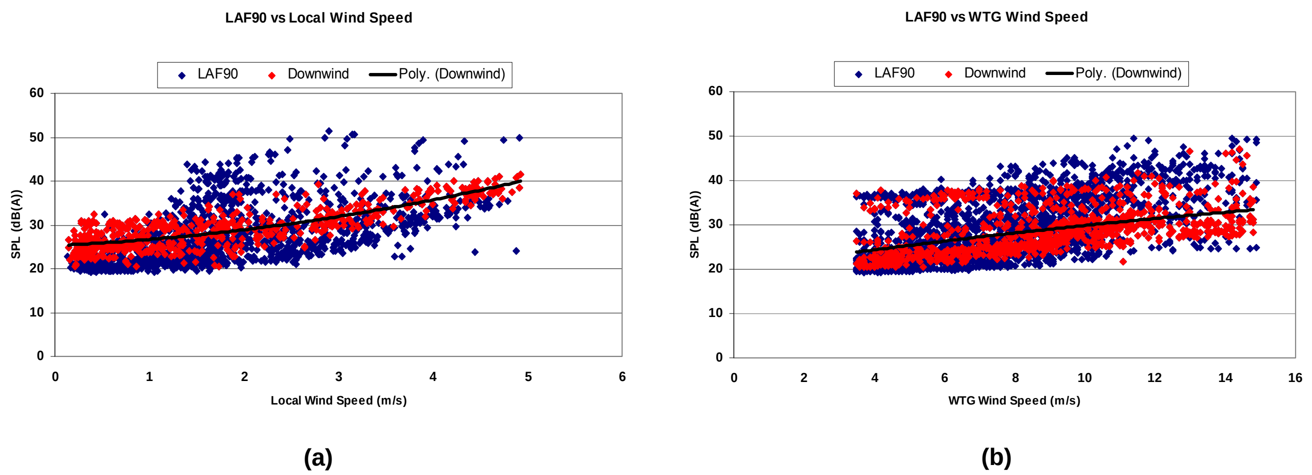


Figure 20 **Statistical descriptor LA_{90} versus (a) local and (b) wind turbine generator wind speed**

Table 9 Coefficient of determination R^2 for the approximating curves

Descriptor	vs wind turbine generator wind speed		vs local wind speed	
	General	Downwind	General	Downwind
L_{AF90} (outside)	0.317	0.429	0.361	0.755
L_{Ceq} (inside)	0.376	0.484	0.196	0.303
L_{Ceq} (outside)	0.323	0.505	0.638	0.730

Low frequency noise

Graphs of recommended Danish EPA low frequency noise descriptors against wind turbine generator wind speeds and local wind speeds demonstrated increasing trends (Figure 21a and b). $L_{pA,LF}$ magnitudes were shown to exceed 20dB(A) both inside and outside of the house, including periods with low wind speeds the turbines and low local wind speeds (refer to Figures 21 and 22). The difference between C-weighted and A-weighted levels was also high and frequently exceeded 20dB. Trends of the differences versus wind speeds reported inside the house indicated possible effects of attenuation provided by the house structure (Figure 21c and d).

High magnitudes of low frequency noise descriptors for low wind turbine generator wind speeds, combined with high variations in the measured levels appeared to indicate that the wind farm was not controlling low frequency impact at the North East site during the study.

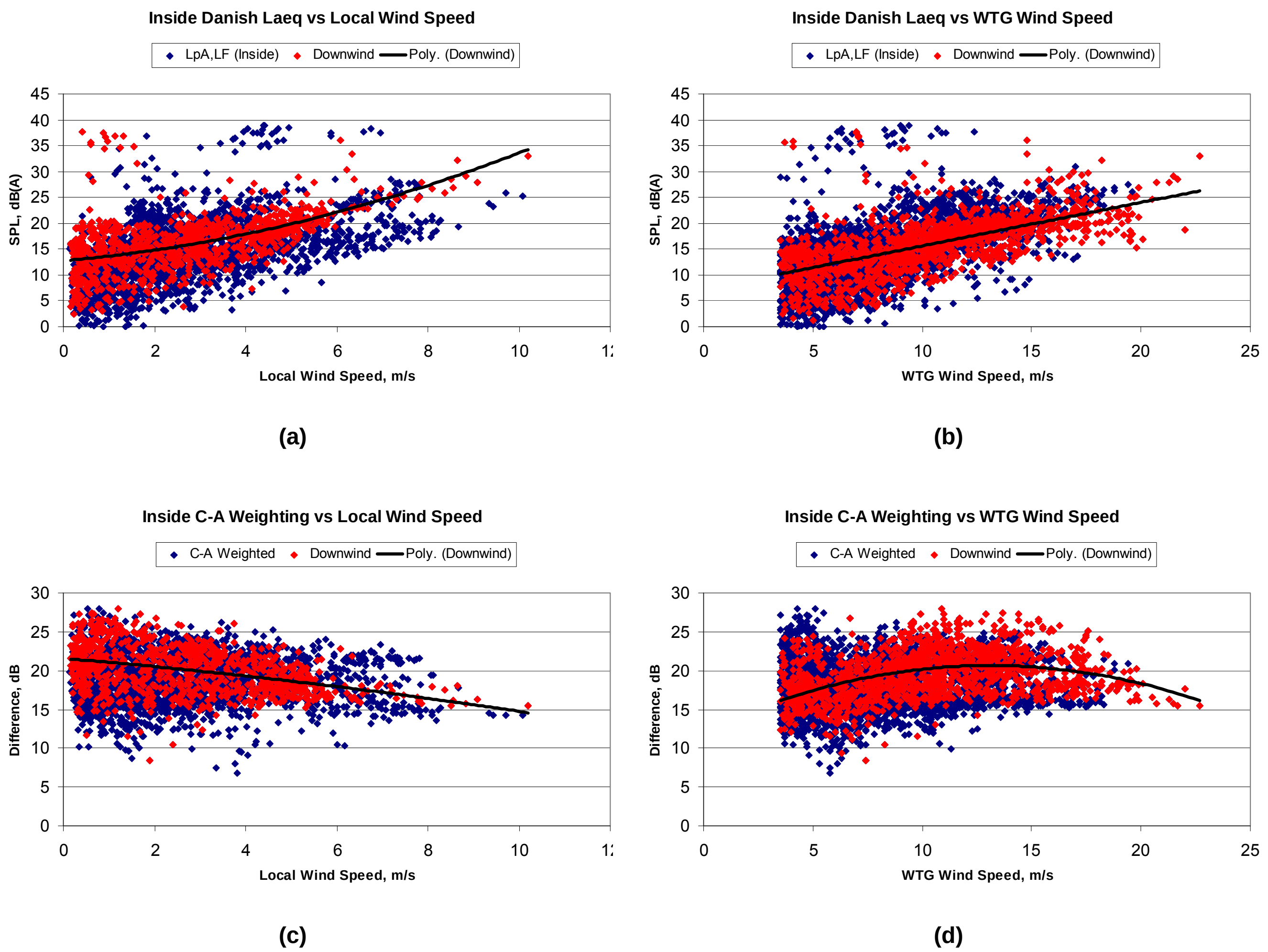
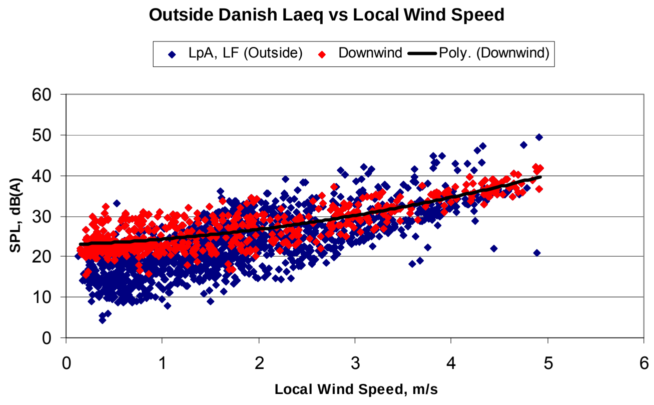
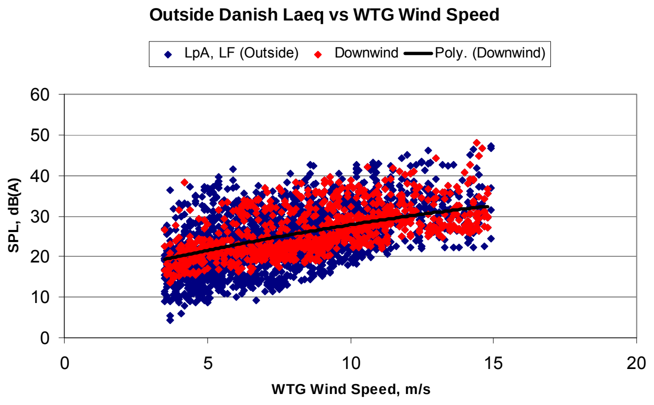


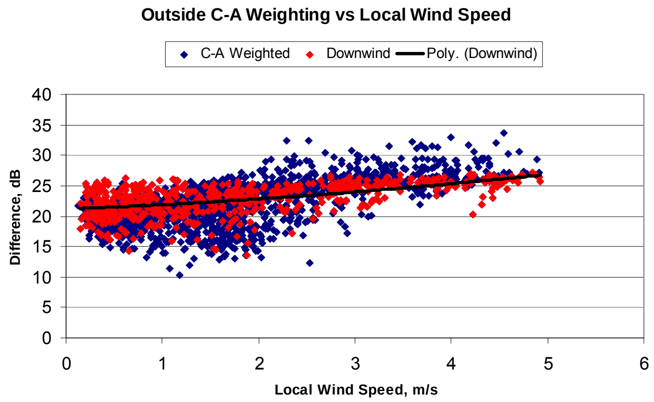
Figure 21 **$L_{pA,LF}$ descriptor and L_{Ceq}-L_{Aeq} difference versus wind turbine generator and local wind speed, inside at the North East site**



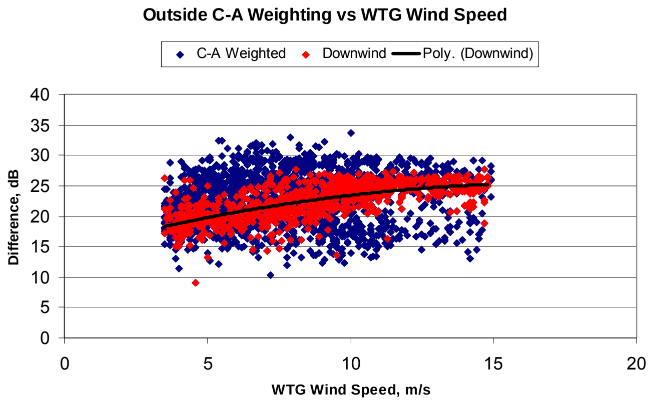
a)



b)



c)



d)

Figure 22 $L_{pA,LF}$ descriptor and L_{Ceq}-L_{Aeq} difference versus wind turbine generator and local wind speed, outside at the North East site

4.3.2 Comparative analysis of shutdown periods

The organised shutdown periods covered a range of wind speeds and directions, with two periods closely matching ideal downwind conditions (refer to Table 10). Some of the best matching periods were affected by ambient noise or noise from other sources, either inside or outside the house. Therefore the comparison was made separately for the levels measured indoors and outdoors.

Comparison of basic noise characteristics inside of the house can be found in Table 11. There were four shutdown periods where noise levels inside of the house were dominated by other noise sources. These periods were included into the table but further analysis was not undertaken. The range of variations of A-weighted levels for the period not affected by the other noise sources (Upwind and Downwind 2) was relatively high and did not indicate conclusive differences between noise levels during shutdowns which were not affected by other noise sources, and those during similar operating periods.

Similarly, analysis of the C-weighted descriptor and $L_{pA,\ LF}$, did not show significant differences. However the DEFRA criterion was met for a lesser fraction of the time when the wind farm was in operation, mainly because of a 50Hz 1/3 octave component most likely generated by the wind farm..

It should be noted that the conservative Danish EPA criterion of 20dB(A) was met for Downwind 2 conditions and was sometimes marginally exceeded under Upwind conditions, for both the shutdowns and operational periods. The prevalence of low frequency noise descriptors under upwind conditions compared with downwind parameters could not be considered typical; as higher low frequency content is normally expected under downwind conditions. Where this occurred under upwind conditions, other contributors may have been important.

Noise outside the house was affected by ambient noises for a lesser number of periods, than was apparent inside. Four shutdown periods were able to be utilised for the comparative analysis (Table 12). A-weighted sound power levels for were marginally higher for the selected operating periods that were not affected by other noise sources; with the exception of Downwind 1. A marginal increase of C-weighted levels and $L_{pA,\ LF}$ was demonstrated for the shutdown periods, except for Downwind 2 and Crosswind 2.

The inconsistency in the change in A- and C- weighted levels between operational and shutdown periods would suggest that the wind farm was not a significant or controlling component of the noise environment during the monitoring period.

Table 10 Wind speed and direction for shutdown and comparative operational periods, North East site

General conditions	Wind local		Wind turbine generator	
	Wind speed, m/s	Wind direction, deg	Wind speed, m/s	Wind speed, deg
Shutdown				
Shutdown 1: Upwind	3.1–4.6	141–158	9.3–9.9	119–122
Shutdown 2: Crosswind 1 Other noise sources	1.5–2.8	38–47	7.5–8.2	23–27
Shutdown 3: Downwind 1 Other noise sources	3.5–3.9	310–317	7.4–8.1	292–297
Shutdown 4: Downwind 2	0.9 – 2.7	17–74	10.9–11.3	288–290
Shutdown 5: Crosswind 2 Other noise sources	1.6–2.1	165–172	8.6–9.8	192–197
Shutdown 6: Crosswind/upwind Other noise sources	1.7–2.6	167 – 178	5.5 – 7.1	164–171
Operational (inside)				
Upwind	4.4–4.6	113–113	9.4–9.6	121–123
Crosswind 1	0.7–1.6	326–357	7.5–8.1	14–17
Downwind 1	0.5–1.2	150–185	7.1–8.4	295–299
Downwind 2	1.6–3.3	313–346	10.9–11.3	288–292
Crosswind 2	3.6–4.4	192–201	8.4–10.2	178–188
Crosswind/upwind	1.8–2.0	172–182	5.4–7.5	183–189
Operational (outside)				
Upwind	N/A	N/A	9–9.9	112–117
Crosswind 1	0.9–2.2	30–192	7.3–8.2	16–20
Downwind 1	1.2–2.0	37–42	7.6–8.1	295–298
Downwind 2	1.7–3.3	313–346	10.9–11.3	288–271
Operational (outside)				
Crosswind 2	1.7–2.8	203–224	8.0–9.8	201–205
Crosswind/upwind	0.4–1.2	71–162	5.8–7.3	178–190

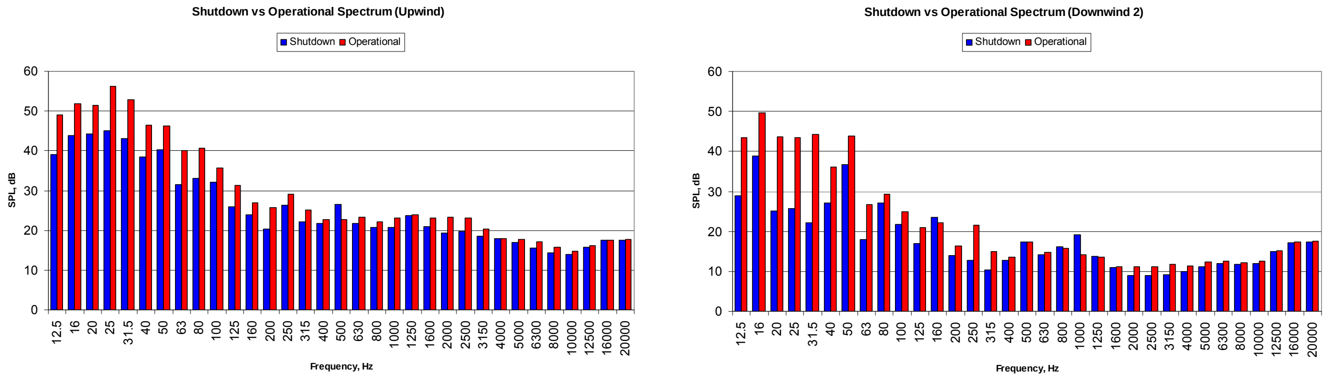
Table 11 Acoustic descriptors during shutdown and comparative operational periods, inside at the North East site

Shutdown period	Inside			
	$L_{Aeq,\ dB(A)}$	$L_{Ceq,\ dB(C)}$	$L_{pA,\ LF,\ dB(A)}$	DEFRA
Shutdown				
Shutdown 1: Upwind	28–37	44–51	15–21	80%
Shutdown 2: Crosswind 1 Other noise sources	47–57	65–66	37–38	0%
Shutdown 3: Downwind 1 Other noise sources	26–42	38–63	9–36	20%
Shutdown 4: Downwind 2	24–33	34–41	0.3–17	100%
Shutdown 5: Crosswind 2 Other noise sources	40–52	65–66	38–39	0%
Shutdown 6: Crosswind/upwind Other noise sources	53–64	57–64	26–30	0%
Operational				
Comparison 1: Upwind	34–35	55–57	23–26	0%
Comparison 2: Crosswind 1	22–24	38–40	4–10	100%
Comparison 3: Downwind 1	25–27	43–45	13–15	100%
Comparison 4: Downwind 2	25–27	47–48	16–18	20%
Comparison 5: Crosswind 2	24–25	44–48	9–14	100%
Comparison 6: Crosswind/upwind	24–26	41–43	3–15	100%

Table 12 Acoustic descriptors during shutdown and comparative operational periods, outside at the North East site

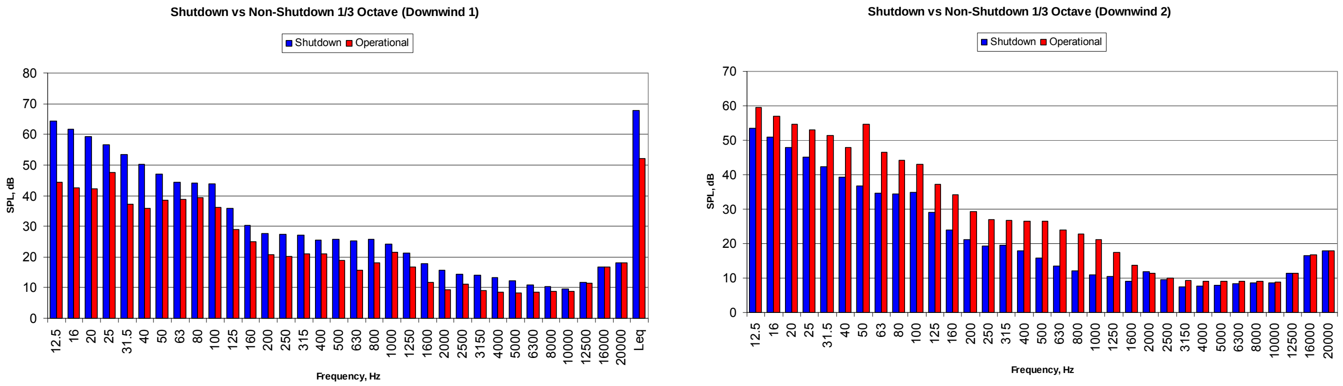
Shutdown period	Outside				
	$L_{Aeq,}$ dB(A)	$L_{Ceq,}$ dB(C)	L_{AF90} dB(A)	$L_{pA,\ LF,}$ dB(A)	DEFRA
Shutdown					
Shutdown 1: Upwind Other noise sources	36–46	68–75	29–41	32–40	0%
Shutdown 2: Crosswind 1 Other noise sources	34 – 40	54 – 64	31 – 33	27–33	0%
Shutdown 3: Downwind 1	32– 42	56 – 63	28 – 32	26–32	0%
Shutdown 4: Downwind 2	24– 27	38 – 53	22 – 23	14–23	100%
Shutdown 5: Crosswind 2	26 – 27	43 – 49	25 – 26	19–20	100%
Shutdown 6: Crosswind/upwind	23 – 24	48 – 54	21 – 22	14–18	100%
Operational					
Comparison 1: Upwind	41–42	64–71	37–39	29–36	0%
Comparison 2: Crosswind 1	27–29	46–54	26–28	20–25	60%
Comparison 3: Downwind 1	27–29	47–48	25–26	22–23	80%
Comparison 4: Downwind 2	32–35	57– 60	31–33	29–31	0%
Comparison 5: Crosswind 2	27–29	53–58	25–26	23–26	20%
Comparison 6: Crosswind/upwind	27	44–47	26	19–20	100%

A comparison of spectra measured inside the house during downwind periods, which were not affected by ambient noise and other noise sources (Upwind and Downwind 2), represented in Figure 23, showed a consistent increase in spectral magnitudes for both cases up to 125Hz. Changes in the spectral content for Downwind 2 conditions for frequencies above 125Hz are sporadic with some magnitudes being higher during the shutdown period.

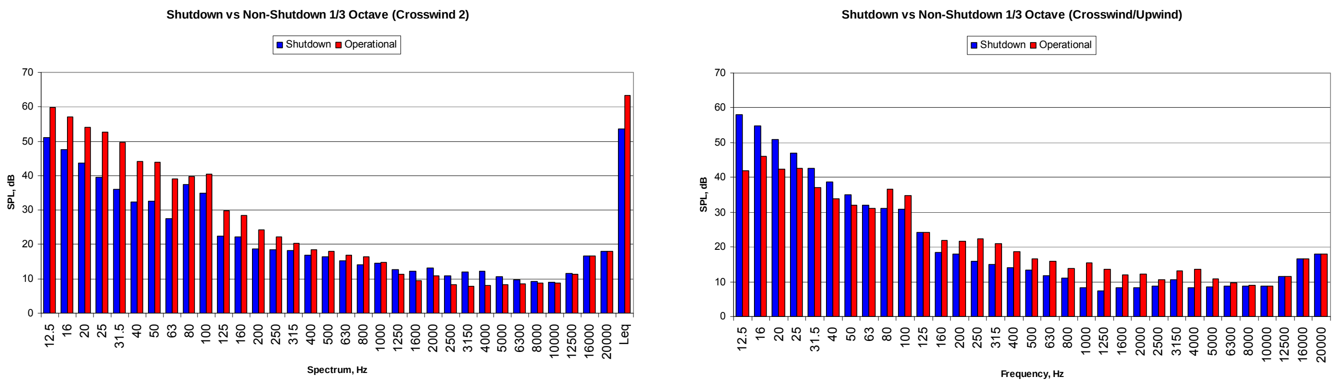


(a) (b)

Figure 23 Comparison of unweighted spectra during shutdowns and similar operating periods, inside the North East site



(a) (b)



(c) (d)

Figure 24 Comparison of averaged unweighted spectra for shutdown and similar operating periods, outside at the North East site

The 50Hz 1/3 octave central frequency component was prominent for Downwind 2 conditions during the shutdown and operational periods; however, it would not have been likely to confer a tonal character to the noise.

External

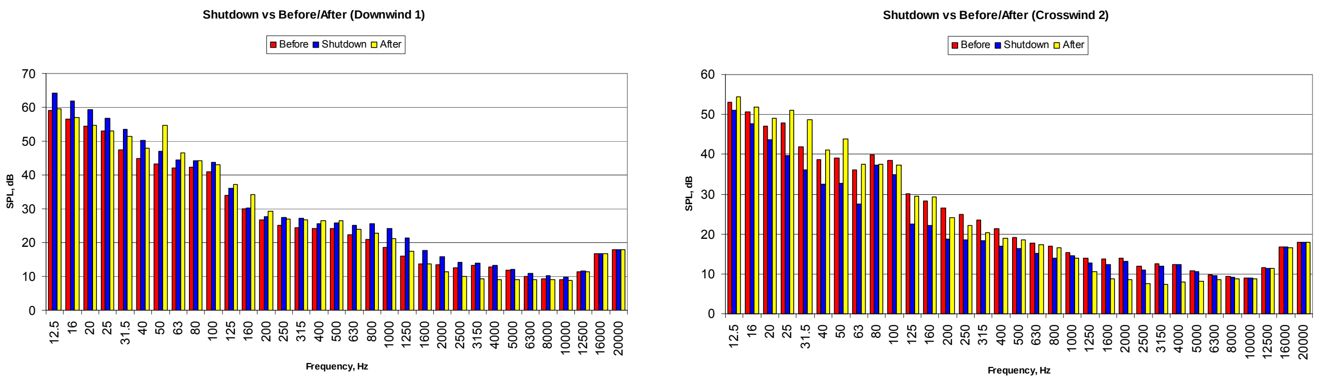
Fewer shutdown periods were affected by ambient noise and other noise sources for the outdoor measurements. There was no consistent change in the spectra for periods corresponding to the downwind conditions, with spectral components exceeding the operational values for Downwind 1 period and opposite effect for Downwind 2 conditions (Figure 24a and b).

Internal

Quite a notable increase for Crosswind 2 conditions in the low frequencies can be seen in Figure 24c. However data for the Cross/upwind period (Figure 24d) did not show a consistent change in spectral magnitudes, with the magnitudes being greater for the shutdown period at the lowest frequencies up to 63Hz.

Often, periods adjacent to the shutdowns were affected by ambient noises or noise from other sources noises, which was very much the case with noise measurements taken inside the house. Comparison of spectral components for periods preceding the shutdown and after normal operating modes are represented for only two events, Downwind 1 and Crosswind 2 (outside the house). Unweighted sound power level during Downwind 1 period is higher than before and after the shutdown (Figure 25a) in spite of the fact that the average wind speeds were higher during the operating periods (Table 13). Also 50Hz prominent (not tonal) component appeared after the wind farm was brought back to the operational mode after the shutdown. It was not observed before and during the shutdown.

The magnitude of the 80Hz component did not change for the Crosswind 2 shutdown and period after that. There was consistent increase of low frequency content for frequencies up to 800Hz, with exception of 80Hz (Figure 25b).



(a) (b)

Figure 25 Comparison of unweighted spectra during shutdown and adjacent operating periods, outside the North East site

Table 13 Wind speed and direction for the shutdown and adjacent periods, at the North East site

Shutdown	**Wind local**	**Wind turbine generator**		**General conditions**	
	Wind speed, m/s	**Wind direction, deg**	**Wind direction, deg.**	**Wind speed, m/s**	**Wind direction, deg**
Shutdown 3: Downwind 1	**Before**	2.7–3.3	313–320	7.6–8.5	289–291
	Shutdown	3.4–3.9	310–317	7.4–8.1	292–297
	After	1.6–3.3	313–346	10.9–11.3	289–292
Shutdown 5: Crosswind 2	**Before**	1.6–2.5	160–169	8.4–9.7	177–186
	Shutdown	1.6–2.1	165–172	8.6–9.8	192–197
	After	1.9–2.8	180–195	8.8–10.1	198–206

4.3.3 Diary return periods and audio records

The monitoring covered a part of period of active agricultural works. There was limited number of the diary entries made by the house occupants. Analysis of audio records and acoustic descriptors for the noise diaries entries is summarised in Appendix E. The entries correspond to downwind or crosswind propagation of noise from the wind farm. It was not possible to detect noise which may be associated with the turbines by analysis of the audio records corresponding to the noise diaries entries.

Additional analysis of amplified audio records was performed for downwind conditions, mainly for night time or early morning periods when the background noise is low. Wind farm noise was audible in the amplified records at times, under dominantly downwind conditions inside or outside of the house, sometimes accompanied by rumbling or thumping character although not as distinctly as shown in records for the South East Site (refer to Section 4.5). These periods were not indicated in the relevant diary returns.

4.3.4 Summary for the North East site

The North East site is at a distance similar to those for the West and South East sites, around 2.5 km. There were only a limited number of diary returns records regarding the wind farm noise during the monitoring period.

- Analysis of acoustic descriptors versus local and wind speeds at the nearest turbine showed relatively high correlations. However it was not possible to detect the wind farm noise by analysis of amplified audio records during the diary return periods.
- It was possible to detect the wind farm noise inside and outside the house by analysis of the amplified audio records during periods with low background levels and downwind propagation conditions which typically occur at nights or early mornings.
- A rumbling noise character that may have been associated with the wind farm was sometimes discernible in the amplified records during these periods.
- The data showed that contributions from the wind farm were most likely insignificant and would not have been detectable by a typical listener. The possibility that noise from the wind farm could have been audible under particular environmental conditions could not be excluded, but it is important to note that during the analysis of audio records, wind farm noise was not audible without amplification.

4.4 West site

The West monitoring site, estimated to be 2.5 km away from the nearest wind turbine generator (turbine BH), was equipped with two long-term B&K monitoring stations to measure both inside and outside noise (Appendix B). The microphone used was a B&K type 4952 outdoor microphone and a weather station was established at 4 metres above ground level. For this site, wind direction between 56˚–143˚ (98˚±45˚) was considered downwind from the nearest turbine. There were tall trees and other vegetation in the areas adjacent to the house and the site was found to be exposed to frequent high wind speeds.

In the absence of pre-construction background data, a 40dB(A) default criterion was applied at this site for WTG wind speeds at cut-in and rated power conditions.

The house was occupied most of the time during the monitoring period. Equipment for the indoor measurements was withdrawn from the site before the end of the monitoring period at the owner’s request.

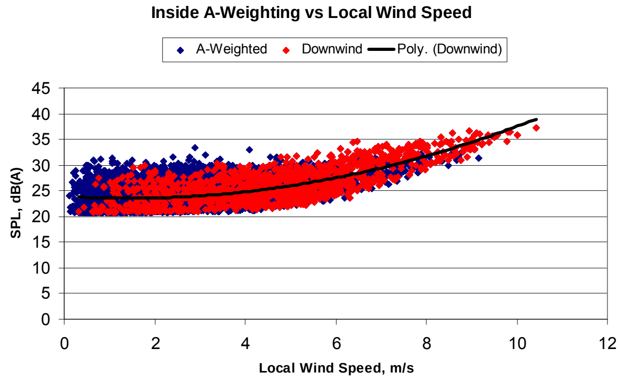
4.4.1 Data analysis

The inside microphone was placed within an empty bedroom next to a window facing the wind farm. The room was still used by the residents, but only rarely; so it provided a good site for monitoring indoor noise with reduced ambient noise and noise from other sources. Throughout the study, there were 5,347 valid data points, of which 1,451 pairs of internal records were available under downwind conditions.

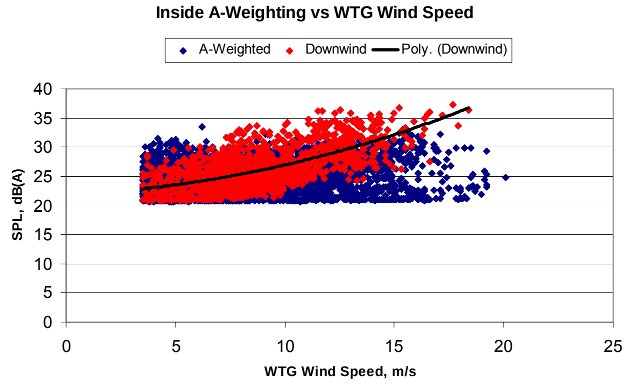
The outside microphone was about 10 m to the south of the house, and was surrounded by a few trees and other vegetation in the garden of the residence. After elimination of noise from other sources, 2,859 valid data points remained, of which 464 were recorded during downwind conditions.

4.4.2 A-weighted and C-weighted levels

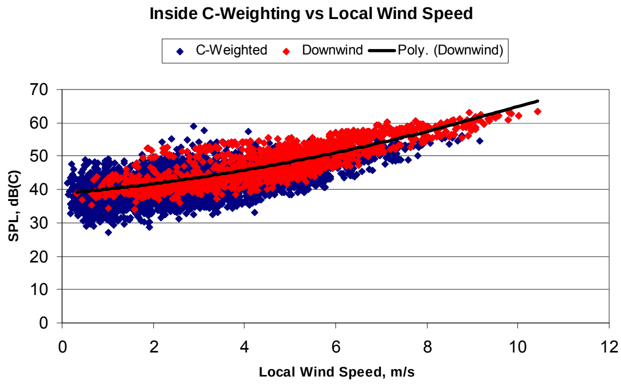
Where not affected by other noise sources, indoor A-weighted sound pressure levels were typically low (refer to Figure 26a and b). C-weighted levels were also low and but exceeded the adopted 60dB(C) limit occasionally at high local or wind turbine generator wind speeds (refer to Figure 26c and d).



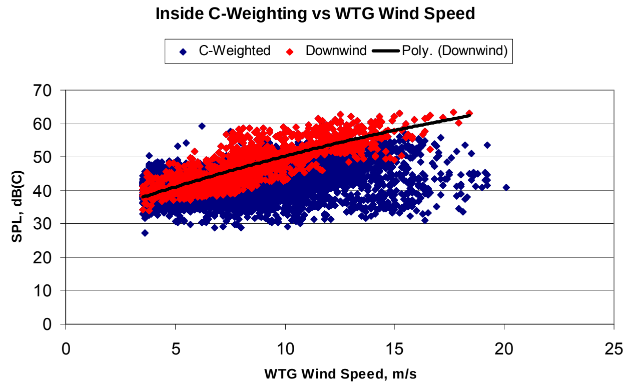
(a)



(b)



(c)



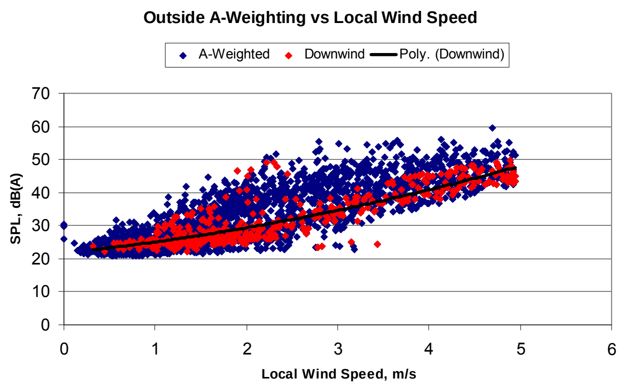
(d)

Figure 26 A-weighted and C-weighted levels versus local and wind turbine generator wind speed, inside the house at the West site

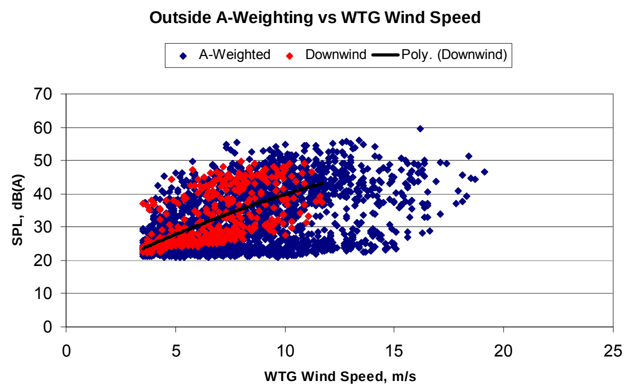
Statistical trends for A-weighted levels were typically higher for measurements outside the house than inside (Figure 27a and b). The simple low frequency criterion of 60dB(C) was exceeded for a large fraction of 10-minute intervals.

A-weighted and C-weighted descriptors were well correlated with local wind speeds (Table 14), possibly reflecting contributions from the surrounding trees and vegetation.

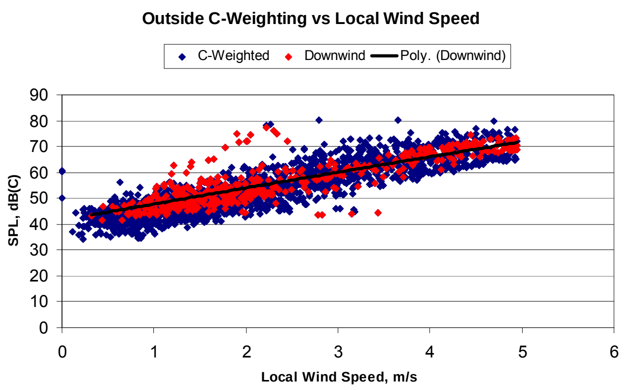
Total measured noise (without correction for background) met the baseline criterion of 40dB(A) in Figure 28a for the range of environmental conditions experienced during the study, except for downwind conditions with wind speeds close to the rated power.



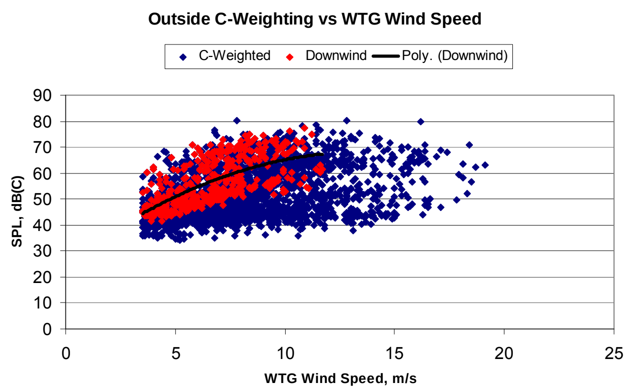
(a)



(b)



(c)

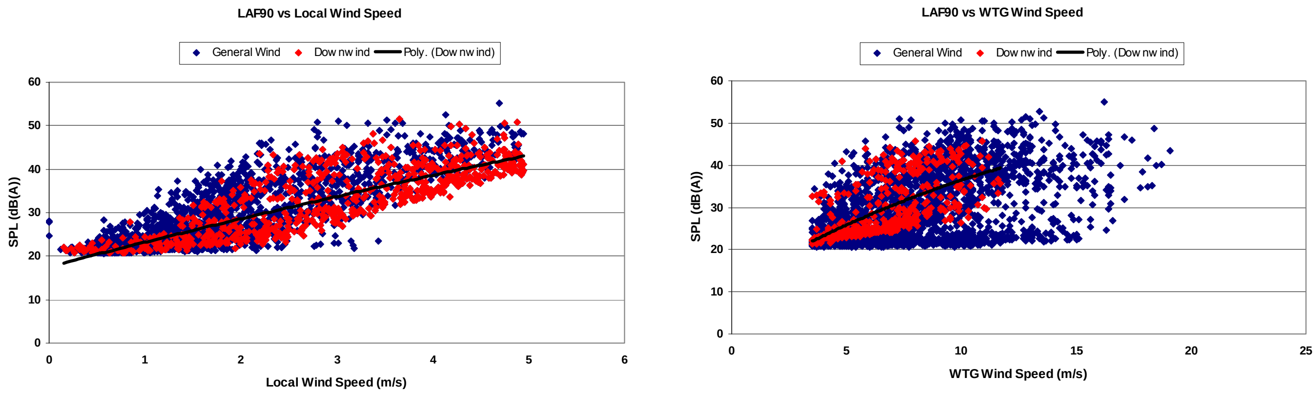


(d)

Figure 27 **A-weighted and C-weighted levels versus local and wind turbine generator wind speed, outside at the West site**

Table 14 **Coefficient of determination (R^2) for polynomial best fits of the acoustic descriptors versus wind turbine generator and local wind speeds, at the West site**

Descriptor	vs wind turbine generator wind speed		vs local wind speed	
	General	Downwind	General	Downwind
L_{AF90}	0.248	0.444	0.711	0.683
$L_{Ceq\ (Inside)}$	0.215	0.650	0.586	0.678
$L_{Ceq\ (Outside)}$	0.193	0.482	0.794	0.705



a) *b)*

Figure 28 Statistical descriptor L_{AF90} versus (a) local and (b) wind turbine generator wind speeds, outside at the West site

4.4.3 Low frequency noise

Graphs of recommended Danish EPA low frequency noise descriptors against wind speeds at the nearest turbine and local wind speeds demonstrate increasing trends (Figure 29a and b). A saturation zone is observed at high wind turbine generator wind speeds for the difference in C-weighted and A-weighted levels at high wind speeds (Figure 29d). Levels exceeding Danish EPA criterion of 20dB(A) and L_{Ceq}-L_{Aeq} differences above 15–20dB(A) are common for this location.

The increasing trend is also notable for the outdoor $L_{pA,LF}$ measurements (Figure 30a and b). From a statistical perspective, magnitudes outside of the house were higher than those recorded inside. Trends of the approximating curves for the C-weighted and A-weighted level differences outside were not similar to those inside the house. This suggests the presence of other mechanisms generating noise at higher frequencies; and possible influence of the house noise attenuation which becomes more effective at higher frequencies.

Relatively high magnitudes of low frequency noise descriptors for low wind turbine generator wind speeds, combined with high data scatter suggests that the wind farm may not be controlling low frequency impact at the location.

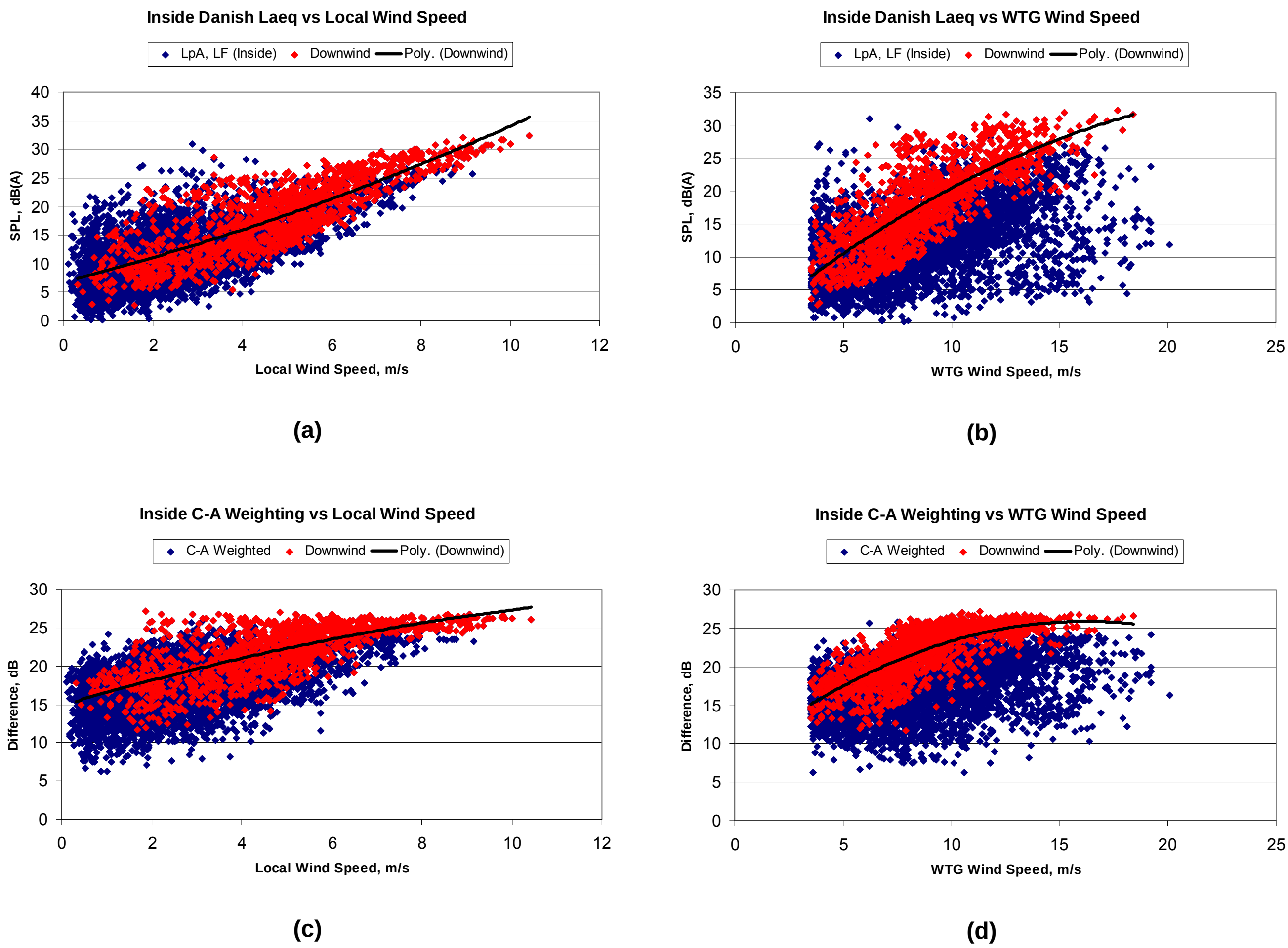


Figure 29 **Low frequency noise descriptors versus local and wind turbine generator wind speed, inside at the West site**

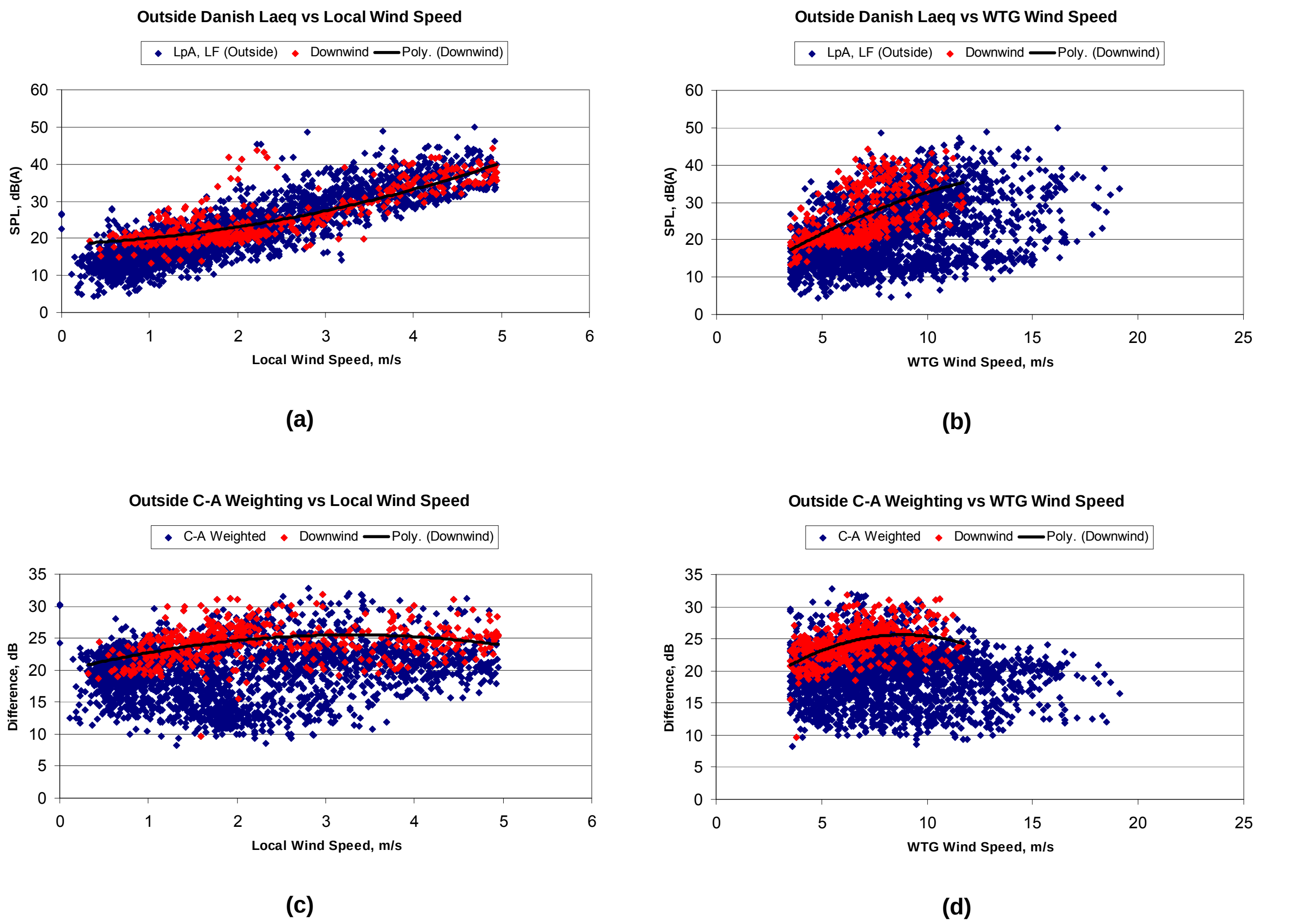


Figure 30 Low frequency noise descriptors versus local and wind turbine generator wind speed, outside at the West site

4.4.4 Shutdown period analysis

The organised shutdowns covered a range of environmental conditions (refer to Table 15). Influences of obvious noises from other sources during the shutdown periods for outdoor measurements were negligible. Since the internal measurement system had been withdrawn earlier, only one shutdown period was available (Shutdown 1: Downwind). Rather than decreased A-weighted levels; these were marginally higher during the shutdown (Table 16).

$L_{pA,\ LF}$ levels were below the conservative 20dB(A) criterion in both of the cases. C-weighted levels can be considered as marginally higher during the operation period; however they were still below 60dB(C) by a significant margin. DEFRA low frequency noise criteria were satisfied for a lesser fraction of the time during operation (80%) compared with the shutdown period (100%). It should be noted that local wind speeds for the comparative operating period were significantly higher. This may have increased background noise level significantly.

Periods before and after the shutdown were characterised by negligible changes in A-weighted levels and notable increase in C-weighted magnitudes, although they were still significantly less than the 60dB(C) limit (Table 17). There were significant variations in $L_{pA,\ LF}$ levels during the shutdown, but the upper limit of the range was marginally higher for the operating periods. It should be noted that the shutdown was characterised by wind speeds at the nearest turbine that were about 1 m/s lower than those measured within the adjacent operating periods. Lower wind speeds may have influenced these differences; and some local sources may also have contributed. In part, analysis of outdoor data during similar periods confirmed this view

Outdoor measurements indicated that values of the acoustic descriptors, including the low frequency noise parameters, were generally higher during the shutdown periods (Table 18). This may indicate that overall noise levels were not controlled by the wind farm during the study; and differences between them were too small to be detected by comparison of similar periods.

Table 15 Wind speed and direction for shutdown and comparative operation periods, at the West site

General conditions	Local wind		Wind turbine generator	
	Wind speed, m/s	Wind direction, deg	Wind speed, m/s	Wind direction, deg
Shutdown				
Shutdown 1: Downwind	1.9–2.3	155–170	8.2–9.1	131–135
Shutdown 2: Crosswind 1	3.6–3.9	60–62	9.3–10.3	26–29
Shutdown 3: Upwind 1	2.5–3.7	321–329	8.0–9.3	302–307
Shutdown 4: Upwind 2	0.8–2.7	338–11	10. –11.0	301–303
Shutdown 5: Crosswind 2	1.3–2.5	203–209	6.7–9.0	209– 217
Shutdown 6: Crosswind 3	2.0–2.0	184–190	5.8– 6.6	181–184
Operational (indoor)				
Comparison 1: Downwind	4.4–6.2	122–135	7.9–9.1	123–134
Operational (outdoor)				
Comparison 1: Downwind	1.3–2.7	184–204	7.9–9.1	148–151
Comparison 2: Crosswind 1	1.6–1.9	47–58	9.5–10.5	14–18
Comparison 3: Upwind 1	2.8–3.7	329–34	8.5–8.9	303–310
Comparison 4: Upwind 2	1.3–1.7	339–348	10.1–11.4	311–314
Comparison 5: Crosswind 2	0.9–2.4	177–211	8.1–8.6	222–223
Comparison 6: Crosswind 3	1.0–1.4	169–184	5.4–6.6	191–199

Periods adjacent to Shutdowns 5 and 6 (Crosswind 2 and Crosswind 3) were not affected by noises from other sources and a summary of wind and acoustic parameters for them can be found in Table 19. Generally the low frequency descriptors are greater during the adjacent operation periods. It should be noted that both the wind speeds at the nearest turbine and the local wind speeds were higher during the wind farm operation.

Only one shutdown period is available for measurements inside of the West site. Spectral content averaged over the shutdown periods shows decrease of low frequency content (up to 250Hz) compared to a similar operational period not affected by other noise sources (Figure 31a). There is a local maximum at 50Hz which is unlikely to add a tonal character to the noise. Increases in the low frequency content can be also seen by comparison of the averaged spectra for the periods adjacent to the shutdown (Figure 31b).

Table 16 Comparison of acoustical descriptors for the shutdown and similar period, inside the house at the West site

Shutdown period	Inside			
	$L_{Aeq,}$ dB(C))	$L_{Ceq,}$ dB(C)	$L_{pA, LF,}$ dB(A)	DEFRA
Shutdown				
Shutdown 1: Downwind	25–29	37–47	8–20	100%

Operational				
Comparison 1: Downwind	24–26	46–48	16–19	80%

Table 17 Comparison of acoustic descriptors for shutdown and adjacent periods, inside the house at the West Site

Shutdown period 1	**Descriptors (inside)**			
	$L_{Aeq,}$ dB(A)	**$L_{Ceq,}$ dB(C)**	**$L_{pA,\ LF,}$ dB(A)**	**DEFRA**
Before	25–27	46– 50	17–21	0%
Shutdown	25–29	37–47	8–20	100%
After	26–28	51–53	22–23	0%

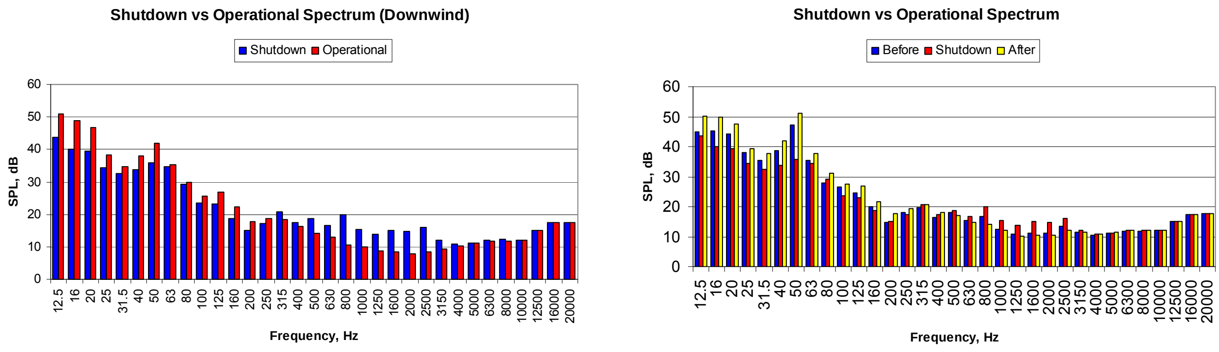
The variability of levels is different for measurements outside the house. Spectral components for the shutdown periods (measured outside) are consistently higher for almost the entire frequency range and wind conditions (Figure 33). Adjacent periods for Shutdown 5 and 6 were not affected by noises from other sources and the relevant spectra are presented in Figure 33. Low frequency components are greater for the operating periods adjacent to Shutdown 5, however this change is not obvious for Shutdown 6. As mentioned above, this effect may be caused by differences in wind speeds before and after the shutdown or possible influences of other noise sources.

Comparisons of adjacent shutdown and operating periods (Figure 33) indicated that spectral components for the shutdowns sometimes exceeded the magnitudes of records acquired during the electricity generating modes; which means that contributions from the wind farm at the measurement site were insignificant and the noise levels were controlled by other sources.

Table 18 Comparison of acoustical descriptors for the shutdown and similar period, outside at the West site

Shutdown period	**Outside**				
	$L_{Aeq,}$ dB(A)	**$L_{Ceq,}$ dB(C)**	**$L_{AF,90}$ dB(A)**	**$L_{A,\ LF}$,dB(A)**	**DEFRA**
Shutdown					
Shutdown 1: Downwind	43–49	74–78	37–44	38–45	0%
Shutdown 2: Crosswind 1	44–48	61–64	41–45	30–33	0%
Shutdown 3: Upwind 1	40–45	61–66	36–41	31–37	0%
Shutdown 4: Upwind 2	24–33	34–53	22–28	8–21	100%
Shutdown period	**Outside**				
	$L_{Aeq,}$ dB(A)	**$L_{Ceq,}$ dB(C)**	**$L_{AF,90}$ dB(A)**	**$L_{A,\ LF}$,dB(A)**	**DEFRA**
Shutdown 5: Crosswind 2	30–36	43–53	27–33	18–22	100%
Shutdown 6: Crosswind 3	24–26	54–56	23	17–19	100%
Operational					
Shutdown 1: Downwind	27–29	52–54	27–28	22–23	100%
Shutdown 2: Crosswind 1	34–35	46–49	32–33	20–21	100%

Shutdown 3: Upwind 1	34–42	56–65	30–37	27–36	0%
Shutdown 4: Upwind 2	23–25	46–47	22–24	14–17	100%
Shutdown 5: Crosswind 2	23	47–47	22	14–15	100%
Shutdown 6: Crosswind 3	22–24	46–48	22	14–17	100%

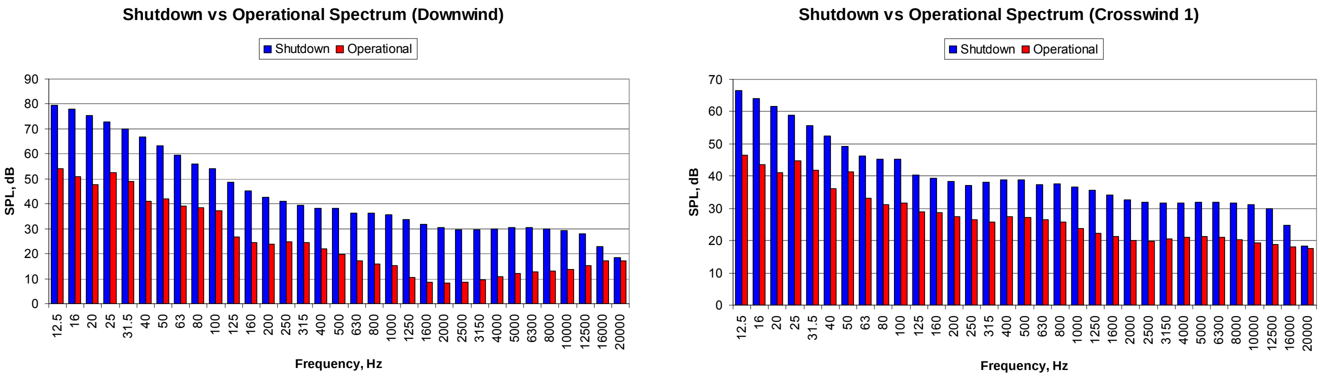


(a) **(b)**

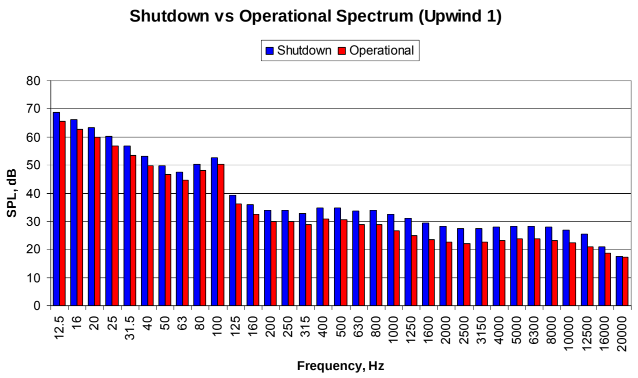
Figure 31 **Unweighted spectra for shutdowns under downwind conditions and adjacent operating periods, inside the house at the West site**

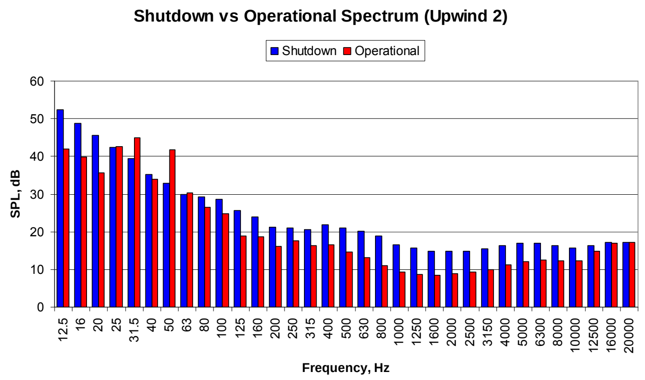
Table 19 **Comparison of acoustic descriptors for shutdown and adjacent periods, outside at the West site**

Shutdown	**Period**	**Descriptors (outside)**			
		L_{Aeq}, dB(A)	**L_{Ceq}, dB(C)**	**$L_{pA, LF}$, dB(A)**	**DEFRA**
Shutdown 5: Crosswind 2	Before	29–32	57–62	24–27	0%
	Shutdown	30–35	39–53	16–22	100%
	After	28–33	53–61	21–26	0%
Shutdown 6: Crosswind 3	Before	32–33	62	28–29	0%
	Shutdown	24–26	54–56	17–19	100%
	After	26–27	50–53	22–24	0%

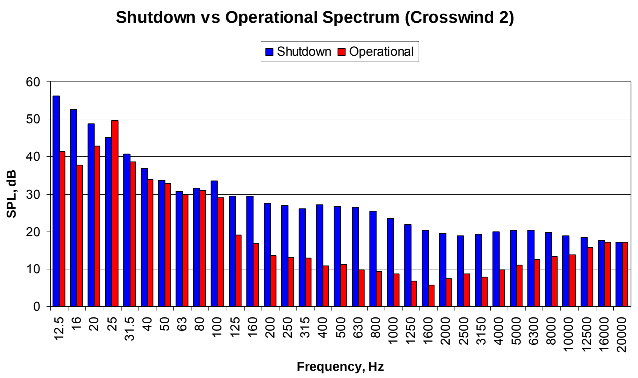


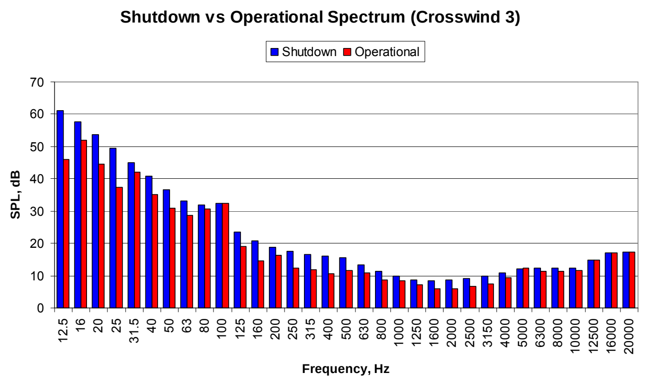
(a) (b)





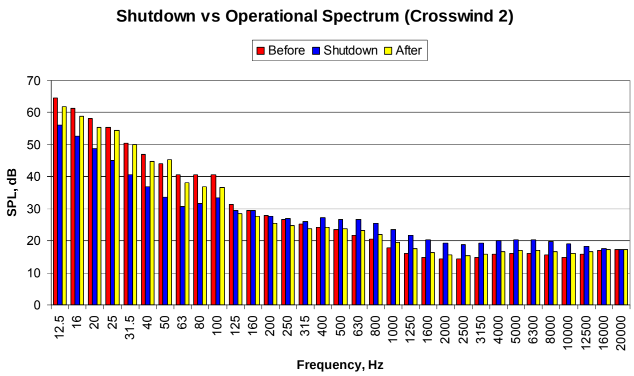
(c) (d)



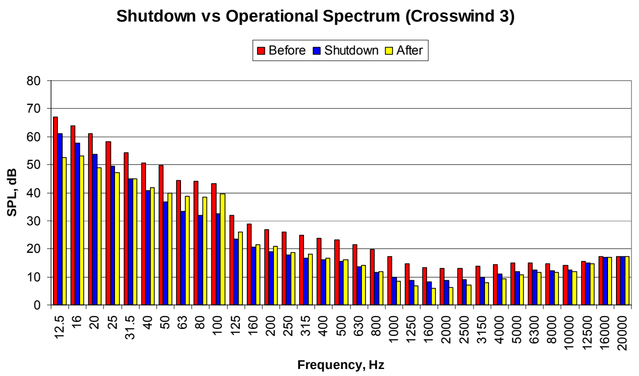


(e) (f)

Figure 32 Unweighted spectra for shutdowns and similar operating conditions, outside at the West site



(a)



(b)

Figure 33 Unweighted spectra for shutdown under downwind conditions and adjacent operating periods, outside at the West site

4.4.5 Diary return periods and audio records

Noise diaries from the local residents around the site were compiled to produce the tables in Appendix F. Table 36 is the compilation of weather conditions during the diary returns period while Table 37 contains a list of the acoustics descriptors during the same period. A significant number of entries attributed events to wind farm operation.

Audio recording commenced when sound pressure levels reached a set trigger. Monitoring equipment inside the house was withdrawn before the end of the monitoring program. Therefore internal audio records were not acquired to compare with all of the events noted in the diaries around this site. The time stamp in the tables is accords with the periods recorded in the diary returns. No end times were given in most of the diary entries. The diary entries were used to focus the analysis of audio records, including multiple audio records for periods before and after the given time, to ensure that any related events could be captured.

Analysis of audio records did not indicate the presence of wind farm noise at times corresponding with most of the diary entries. As noted previously, wind farm noise did not dominate the noise environment at this site during the monitoring period.

There were times where noise from the wind turbines could be heard in the external audio records when the local wind speeds were low. During the study, the site was characterised by relatively high wind speeds, which may have enhanced background noise, including noise with a low frequency content, as was demonstrated by the comparison of the shutdown and operating periods.

As also reported in the previous section, there were certain time periods where spectral analysis of noise within event periods identified in diaries showed a prominent 50Hz component inside the residence, generally under downwind conditions from the wind farm. To analyse the events, the audio records during these times were listened to with significant amplification.

This prominent 50Hz component did not appear to create a perception of a tonal character in the noise; and no other significant characters could be heard in the amplified audio records for those periods.

There were other periods where, after significant amplification of audio records, slight rumbling and modulation could be heard in the records acquired inside the house. The noise character was similar to that detected at times at the South East site (refer to section 4.5 for details) but was less distinct; and was likely to have been associated with the wind farm.

The West site was characterised by relatively high local wind speed and considerable vegetation around the house. Examination of outside audio records corresponding with events described in diary returns showed that the noise environment was generally dominated by noise generated by wind acting on vegetation and by noise from other sources.

4.4.6 Summary for the West site

The West site is situated in a quiet rural area at significant separation distance from the wind farm site.

Noise from the wind farm was detectable at times with low local wind speeds, when the masking noise is low.

- Typically the noise contribution from the wind farm was too insignificant to be detectable.
- Under some environmental conditions, the wind farm may have contributed to low frequency noise during the study. However local background low frequency noise was also found to be high, as demonstrated by analysis of the shutdown periods.
- A 'rumbling' effect, which may be associated with the wind farm operation, was detectable at times inside of the house with significant amplification of the audio records. The character of noise was similar to that detected at the South East site, but was less prominent. It is possible that such effects could cause increased annoyance to a sensitive listener if exposed for a long time period.
- Noise levels recorded at this site met current regulatory requirements, within the range of environmental conditions experienced during the monitoring period.

4.5 South East site

The South East monitoring site was about 2.4 km away from the nearest wind turbine generator (turbine DB). This site was equipped with two B&K Type 3639 monitoring terminals to measure both inside and outside noise, and B&K type 4952 outdoor microphones. The weather station used to determine local wind and other environmental parameters using Vaisala WXT520 6 parameter weather station mounted on 4 m pole. Observations showed high local wind speeds to be fairly common for this site. Because of the potential interference from wind interacting with the microphone wind shields, acoustic data gathered outdoor at wind speeds above 5 m/s were excluded from the analysis. For this site, the wind direction from 245˚–335˚ (290˚±45˚) would be considered downwind from the nearest turbine. The house was occupied during the monitoring period.

The baseline 40dB(A) criterion was applicable for this site in absence of the background data acquired before the wind farm construction.

4.5.1 Data analysis

As the house was occupied, data collected inside of the house was mostly affected by other noise sources, such as household activities. After elimination of noise from other sources, there were 4,081 valid data point for analysis of outdoor noise, 1,543 data points corresponded to downwind conditions. For internal noise analysis, there were 3,411 data points, including 1,177 data points recorded under downwind conditions.

4.5.2 A-weighted and C-weighted levels

Where noise inside the house were not affected by ambient sources and household activities, A-weighted and C-weighted levels inside of the house were typically found to be low; however sound pressure levels above 40dB(A) occurred fairly often (Figure 34). C-weighted levels were typically below 60dB(C) inside the house; exceedences are typically marginal, in the order of a few dB.

Outdoor A-weighted levels were typically below 50–60dB, but many data points were above 40dB(A) which may be due to contribution from vegetation noise and natural background.

C-weighted levels were relatively high and exceeded 60dB(C) at increased wind speeds (Figure 35). Sound pressure levels correlated reasonably well with local wind speeds and wind speeds at the nearest turbine, as shown in Table 20. The clear exception was the C-weighted levels measured inside the house, which when compared with local wind speed, exhibited a R^2 of only 0.004, indicating that virtually no statistical relationship existed between them.

Table 20 Coefficient of determination (R^2) for polynomial best fits of the acoustic descriptors versus wind turbine generator and local wind speeds, at the South East site

Descriptor	vs local wind speed		vs wind turbine generator wind speed	
	General	Downwind	General	Downwind
L_{AF90} (Outside)	0.360	0.612	0.528	0.712
L_{Ceq} (Inside)	0.004	0.341	0.446	0.797
L_{Ceq} (Outside)	0.435	0.572	0.482	0.769

Figure 36 shows the fitting curves calculated in accordance with the Wind Farms Environmental Noise Guidelines indicating that the 40dB(A) criterion was met during the study, for total noise, even without correction for background.

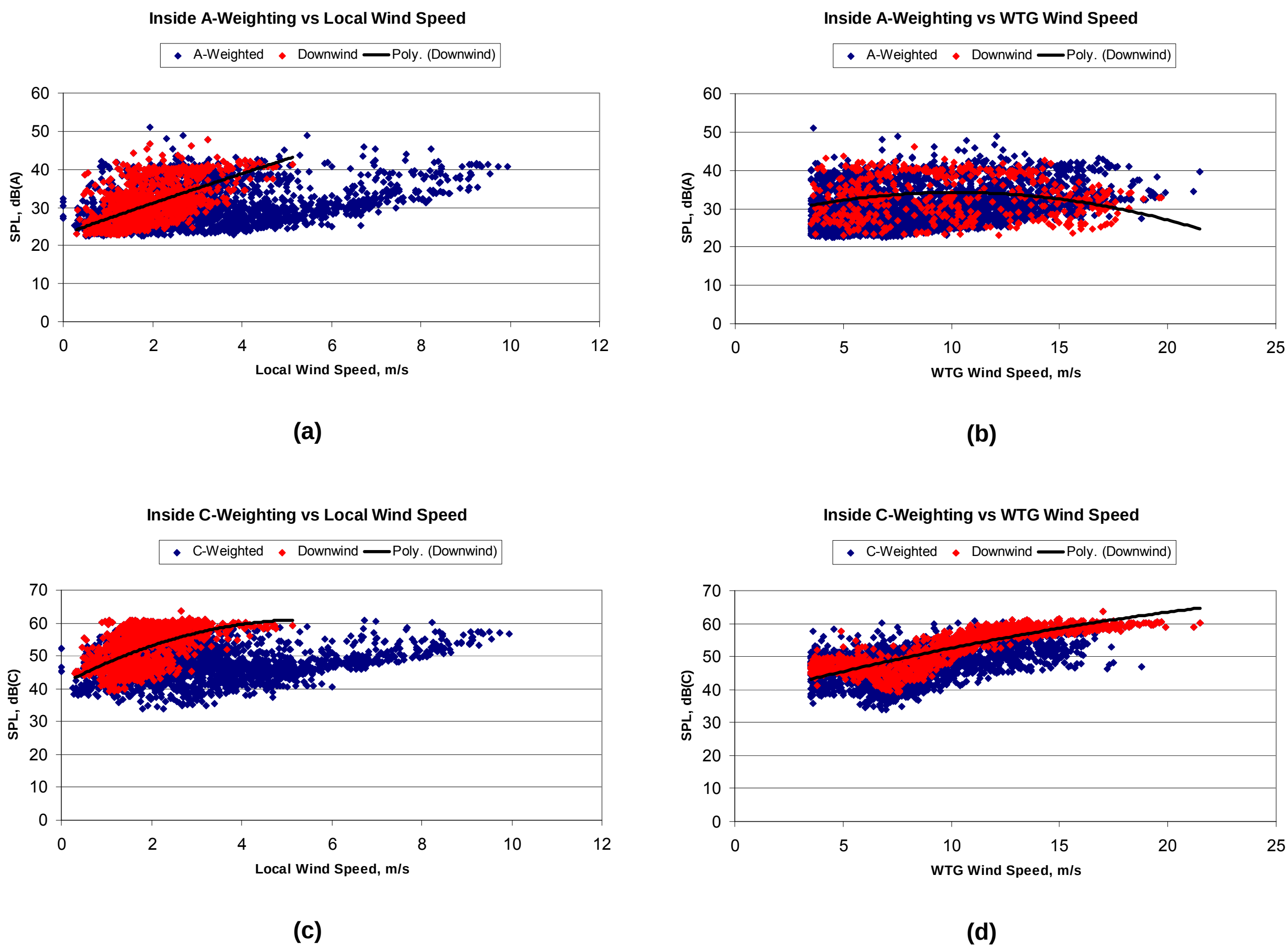


Figure 34 A-weighted and C-weighted levels versus local and wind turbine generator wind speed, inside the house at the South East site

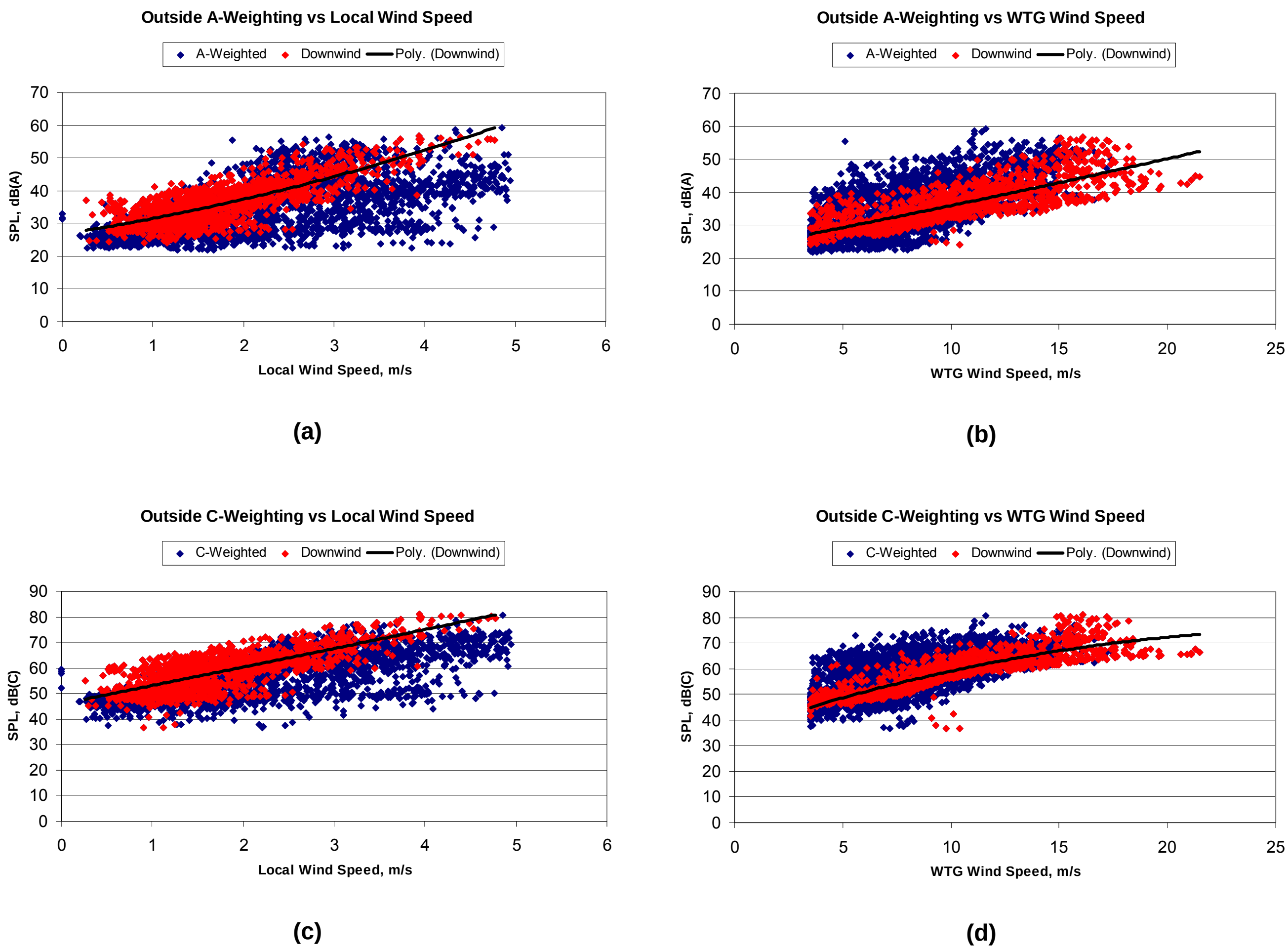


Figure 35 A-weighted and C-weighted levels versus local and wind turbine generator wind speed, outside at the South East site

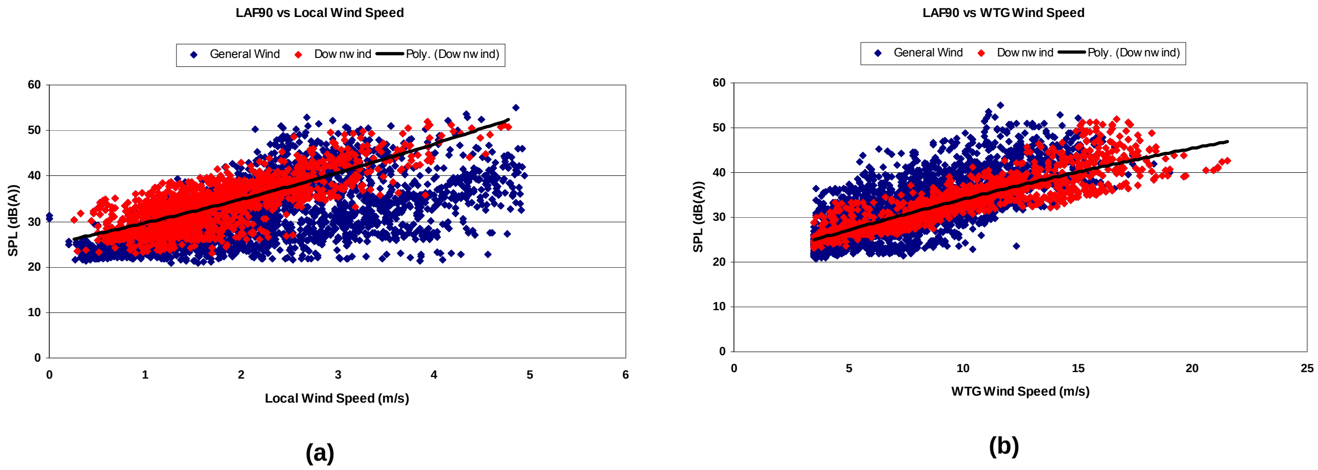


Figure 36 Statistical descriptor L_{AF90} versus local and wind turbine generator wind speeds, outside at the South East site

4.5.3 Low frequency noise

Calculated values of the low frequency noise descriptor recommended by the Danish EPA are presented in Figure 37a and b, against local wind speeds and wind speeds measured at the turbines. The graphs demonstrate increasing trends with increasing wind speeds. Levels above 20dB(A) $L_{pA,LF}$ were common for the indoor environment at this location and detected within a wide range of wind speeds measured both locally and at the turbines, not just high wind speeds; and a range of wind directions. The increasing trend is not explicit for differences in C-weighted and A-weighted levels (Figure 37c and d); however those differences are commonly greater than 15–20dB for this site.

An increasing trend is also notable for the outdoor $\mathbf{L_{pA,LF}}$ measurements (Figure 38a and b). $\mathbf{L_{Ceq}}$–$\mathbf{L_{Aeq}}$ differences outside the house are similar to those inside the house from a statistical perspective (Figure 38c and d). The statistical trends of the differences versus wind speeds were different from the $L_{pA,LF}$ trends and did not always demonstrate an expected link with the wind speeds. $L_{pA,LF}$ levels exceeded the conservative 20dB(A) criterion for a large fraction of the time both at wide range of local and wind turbine generator wind speeds including the lowest wind speeds (Figure 38c and d).

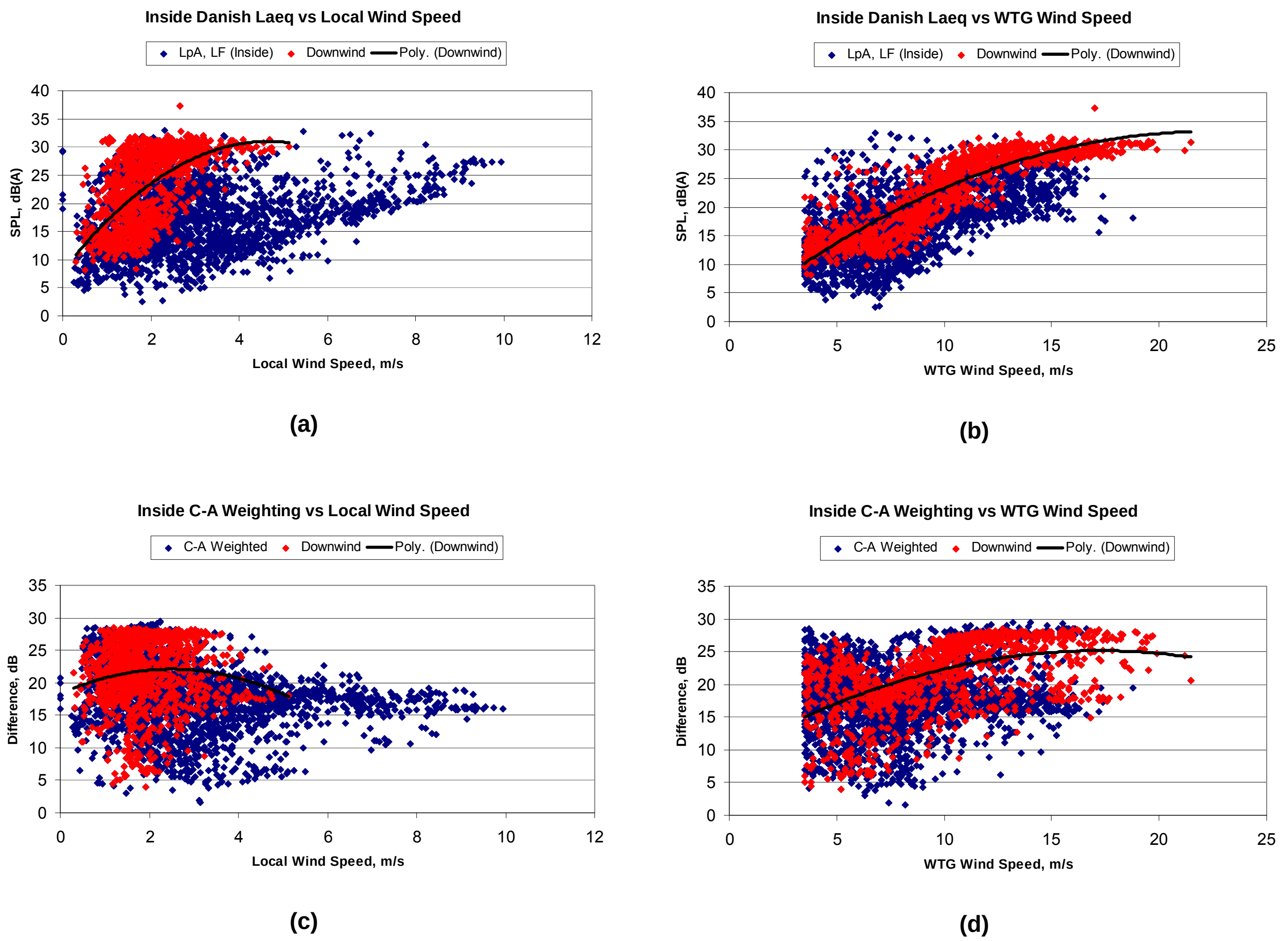


Figure 37 $\mathbf{L_{pA,LF}}$ **descriptor and** $\mathbf{L_{Ceq}}$**-**$\mathbf{L_{Aeq}}$ **difference versus wind turbine generator and local wind speed, inside the house at the South East site**

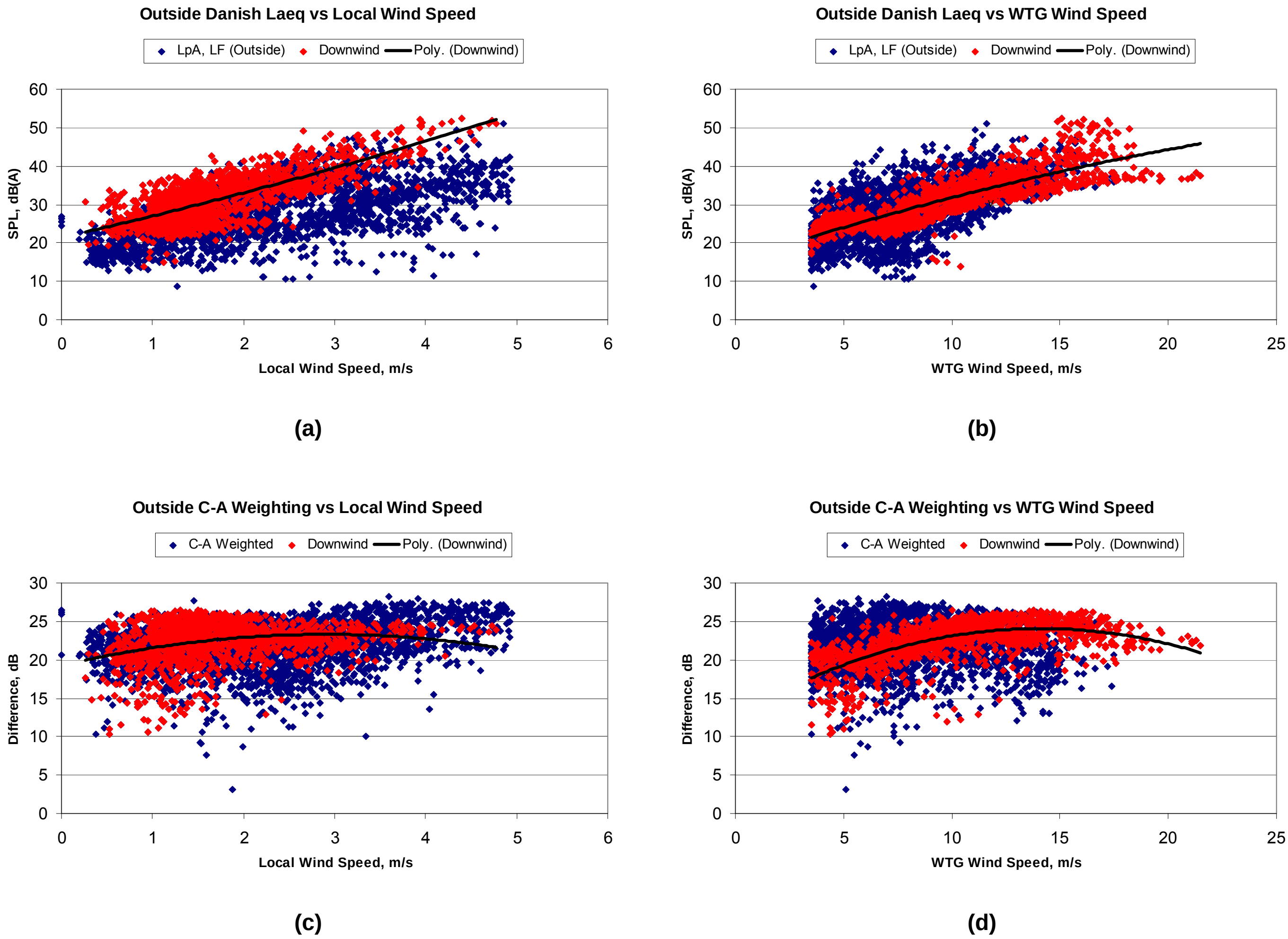


Figure 38 **$L_{pA,LF}$ descriptor and L_{Ceq}–L_{Aeq} difference versus wind turbine generator and local wind speed, outside at the South East site**

Shutdown period analysis

The organised shutdown periods covered a range of wind speed and directions with two periods closely matching ideal downwind conditions (refer to Table 21). Comparison of basic noise characteristics inside the house can be found in Table 22. There were four shutdown periods where noise levels inside of the house were dominated by noise from sources such as household activities; and for this reason, although these periods were included in the table, further analysis of them was not carried out. Only Shutdowns 4 and 6 were analysed for indoor noise impacts.

The data exhibited a range of variation in A-weighted levels for the shutdown periods for the selected periods were too high to show a conclusive difference. Low frequency noise descriptors showed significant increases for the operating period similar to Downwind 2 (Table 22). However, commensurate changes were not obvious for the Upwind/Crosswind environmental conditions.

If the data were referenced to a conservative interpretation of the Danish EPA criterion, it is likely that the criterion may have been met or marginally exceeded during wind farm operation; but was clearly met during the Downwind 2 shutdown.

The UK DEFRA criterion was also met for Downwind 2 shutdown and not satisfied for the operational period; but it was met for larger fraction of time when Crosswind/Upwind conditions prevailed.

Table 21 Wind parameters for the comparative time periods

General conditions	Local wind		Wind turbine generator	
	Wind speed, m/s	Wind direction, deg	Wind speed, m/s	Wind speed, m/s
Shutdown				
Shutdown 1: Upwind	3.1–4.2	113–129	8.5–10.2	115–121
Shutdown 2: Crosswind 1	2.6–3.5	17–26	9–11	8.1–19.7
Shutdown 3: Downwind 1	1.2–1.7	305–318	7.7–9.0	301–303
Shutdown 4: Downwind 2	0.9–1.3	2–63	9.7–10.4	295–303
Shutdown 5: Crosswind 2	1.1–2.2	114–162	7.6–8.3	194–206
Shutdown 6: Crosswind/upwind	2.2–2.7	155–172	6.9–8.2	170–176
Operational (inside)				
Upwind	5.6–6.1	90–95	8.8–10.2	102–109
Crosswind 1	1.7–2.2	17–28	10.2–11.7	18–23
Downwind 1	1.3–2.0	294–321	8.3–9.4	290–300
Downwind 2	1.4–1.5	357–15	9.9–10.7	313–317
Crosswind 2	3.3–3.9	184–194	6.9–9.2	196–203
Crosswind/Upwind	2.2–3.4	142–165	5.3–9.9	157–173
Operational (outside)				
Upwind	2.1–2.7	129–132	9.5–11.2	119–124
Crosswind 1	0.9–1.5	331–4	9.3–10.9	4–5
Downwind 1	0.9–1.7	8–70	7.9–8.8	309–323
Downwind 2	1.0–1.5	4–50	9.8–10.7	317–320
Crosswind 2	0.8–0.9	82–145	7.4–8.2	212–213
Crosswind/Upwind	2.2–3.4	142–165	5.3–9.9	157–173

Table 22 Acoustical descriptors for the comparative time periods, inside the house at the South East site

Shutdown period	Inside			
	L_{Aeq}, dB(A)	L_{Ceq}, dB(C)	$L_{pA, LF}$, dB(A)	DEFRA
Shutdown				
Shutdown 1: Upwind Other noise sources	52–64	60–68	31–42	0%
Shutdown 2: Crosswind 1 Other noise sources	49–56	52–63	25–34	0%
Shutdown 3: Downwind 1 Other noise sources	54–62	58–65	33–35	0%
Shutdown 4: Downwind 2	26–40	33–44	6–16	100%
Shutdown 5: Crosswind 2 Other noise sources	58–62	64–67	36–40	0%
Shutdown 6: Crosswind/upwind	26–35	41–49	19–27	60%
Operational (inside)				
Comparison 1: Upwind	28–30	46–48	17–18	100%
Comparison 2: Crosswind 1	25–28	47–49	18–20	0%
Comparison 3: Downwind 1	25–30	44–49	15–20	40%
Comparison 4: Downwind 2	25–26	48–52	18–22	0%
Comparison 5: Crosswind 2	27– 30	45–48	18–20	60%
Comparison 6: Crosswind/upwind	27–31	45–49	19–25	80%

Comparison of data for periods adjacent to the selected shutdowns showed that changes in A-weighted levels were marginal, and unlikely to be noticeable by a typical listener (Table 23). Increases in C-weighted levels were of the order of 20dB; the $L_{pA, LF}$ descriptor exceeded 20dB(A); and the DEFRA frequency dependent criteria were not met.

It should be noted that periods adjacent to the Downwind 2 shutdown were characterised by wind turbine generator wind speeds that on average were 1–2 m/s higher than those recorded during the shutdown.

Table 23 Comparison of the acoustic descriptors during shutdown and adjacent periods, inside the house at the South East site

Shutdown period	Inside			
	$L_{Aeq, dB(A)}$	$L_{Ceq, dB(C)}$	$L_{pA, LF, dB(A)}$	DEFRA
Before	28–30	55	25–26	0%
Shutdown 4	26–29	33–37	6–13	100%
After	28–31	54–56	25	0%

Noise outside the house was affected by noise from other sources for one shutdown period only, providing an opportunity for reliable comparison of operational and non-operational periods over a greater range of environmental conditions. A-weighted equivalent levels and the related $L_{AF,90}$ descriptor do not demonstrate any consistent change of magnitudes for the similar operational and non-operational periods. The most likely contribution of the wind farm to noise levels was too subtle; and the wind farm was not shown to control levels of A-weighted noise at the South East site during the study.

C-weighted levels were higher for Downwind 2 conditions; however no consistent increase in the levels could be found for all of the periods. For example, C-weighted levels during the Upwind shutdown exceeded not only the 60dB(C) criterion, but were notably higher than levels measured for similar operating periods, and would be attributable to the natural background..

Three of the shutdown periods were characterised by high levels of low frequency noise outside the house (Shutdowns 1–3). Significant increases in $L_{pA,\,LF}$ magnitudes were found for half of the operational periods. Relatively high values of acoustical descriptors acquired during some of the shutdown periods indicated that the natural environment and other unidentified sources were probably making significant contributions to noise levels during the study, including noise with substantial low frequency content. This suggested that the wind farm was not the dominant source.

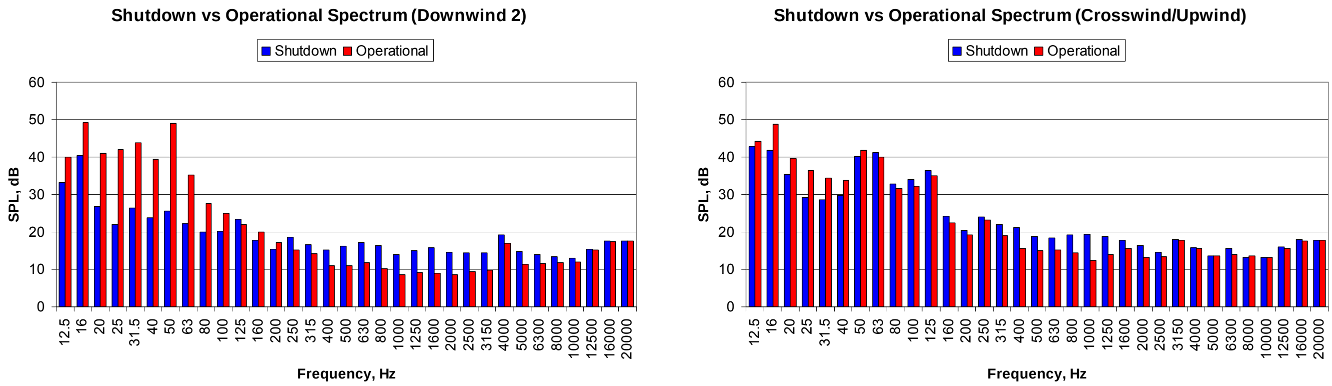
Table 24 Acoustical descriptors for the comparative time periods, outside the house at the South East site

Shutdown period	Outside				
	L_{Aeq}, dB(A)	L_{Ceq}, dB(C)	$L_{AF,90}$ dB(A)	$L_{pA,\,LF}$, dB(A)	DEFRA
Shutdown					
Shutdown 1: Upwind	39–43	61–68	36–39	29–35	0%
Shutdown 2: Crosswind 1 Other noise sources	44–46	63–69	41–44	35–40	0%
Shutdown 3: Downwind 1	36–41	56–66	29–37	28–36	0%
Shutdown 4: Downwind 2	24–29	37–42	23–24	14–22	100%
Shutdown 5: Crosswind 2	24–25	38–41	23	15–16	100%
Shutdown 6: Crosswind/upwind	23–24	37–41	22	11	100%
Operational					
Comparison 1: Upwind	31–36	51–61	28–33	23–28	0%
Comparison 2: Crosswind 1	27–32	51–53	25–31	23–25	0%
Comparison 3: Downwind 1	29–33	53–55	29–32	25–27	0%
Comparison 4: Downwind 2	32–34	57–58	32	28–29	0%
Comparison 5: Crosswind 2	28–29	51	27 -28	24–25	0%
Comparison 6: Crosswind/upwind	28–32	51–58	26–30	23–26	0%

Spectral comparisons were also made for operational periods with similar wind conditions as the shutdown periods. As previously noted, shutdown periods dominated by other sources were not included in the comparisons.

There were only two instances where shutdowns coincided with periods without interference from other noise sources inside the house; one of which was under Downwind conditions (Downwind 2, refer to Figure 39a).

Comparison of data from the periods when downwind conditions existed highlighted a low frequency range up to around 100Hz, where the difference in spectral content was significant, and included a prominent 50Hz component. Noise for adjacent periods was not affected by ambient sources for one period only (Shutdown 4). Figure 40 shows increases in magnitudes of low frequencies up to 200Hz, under downwind conditions, in addition to the prominent 50Hz component. The change was notable, even taking into account the observation that wind speeds measured at the nearest turbine were 1–2 m/s higher on average than those measured during the shutdown.



(a) (b)

Figure 39 Comparison of unweighted spectra for the shutdown and similar operational periods, inside the house at the South East site

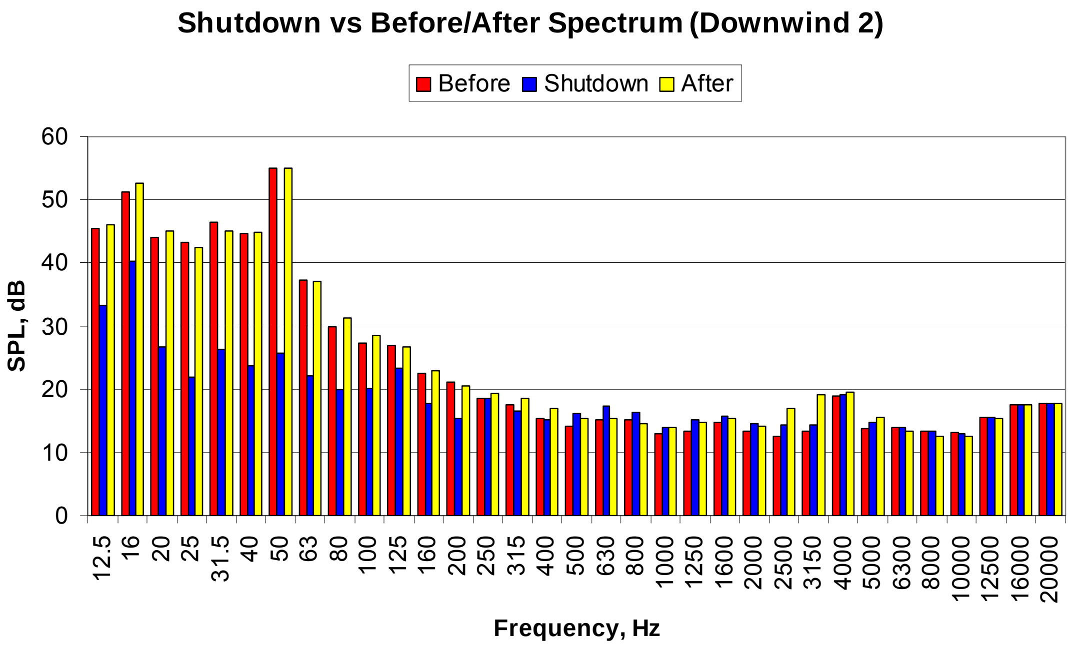


Figure 40 The averaged unweighted spectrum for the shutdown and adjacent periods, inside the house at the South East site

It is notable that low frequency components below 50Hz were still insignificant during the adjacent operating periods, and were lower than suggested hearing thresholds [15, 24, 25, 39, 42].

Noise levels outside the house were affected by noise from other sources for one period only. Comparative spectra for the rest of the periods are summarised in Figure 41.

Significant differences in the low frequency part of the spectrum (up to about 160Hz) were apparent for Downwind 2 and Crosswind conditions (Shutdowns 4–5); however the difference was not obvious for another downwind period (Shutdown 3), and noise levels were even higher for the Upwind shutdown (Figure 41a).

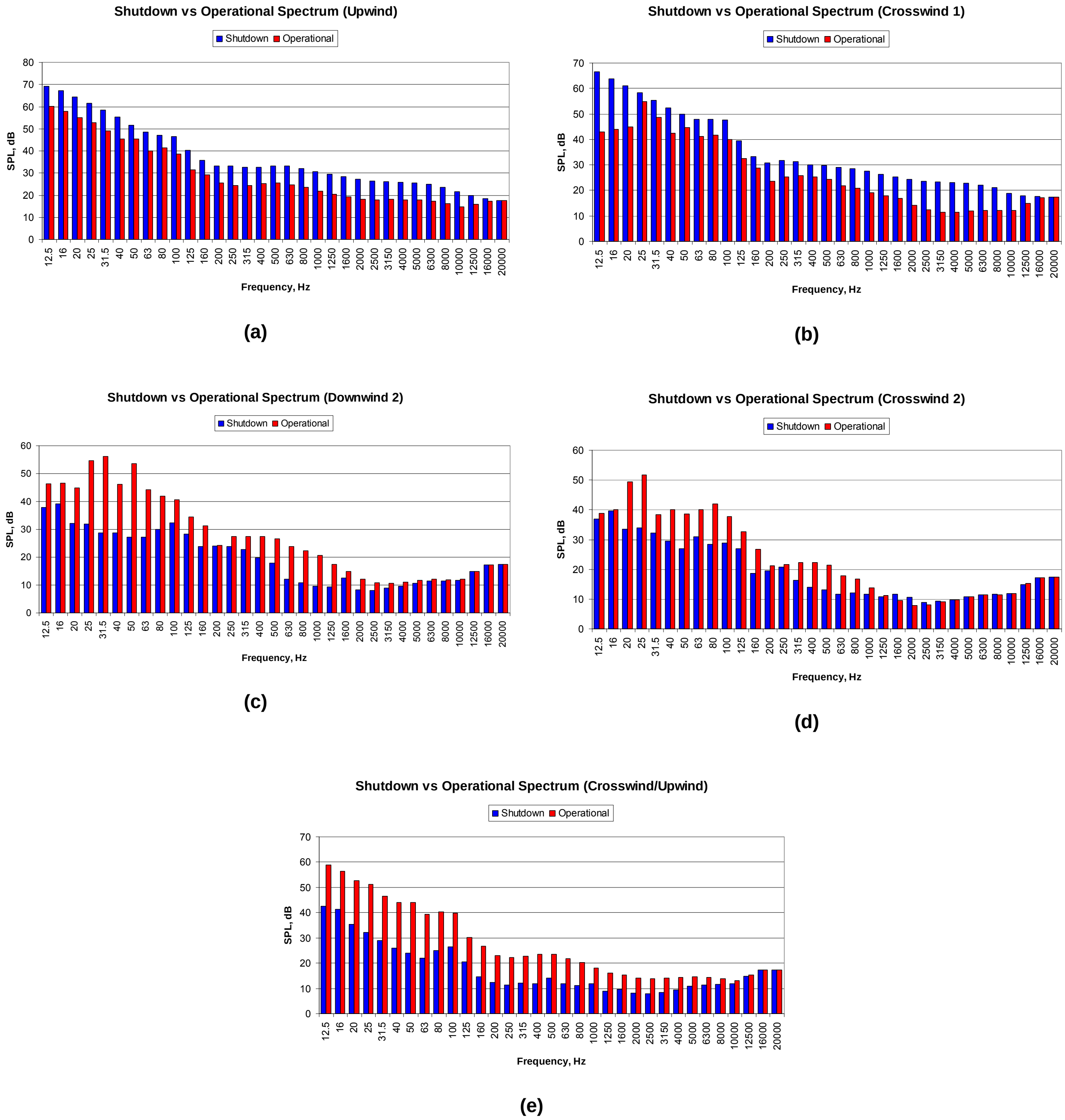
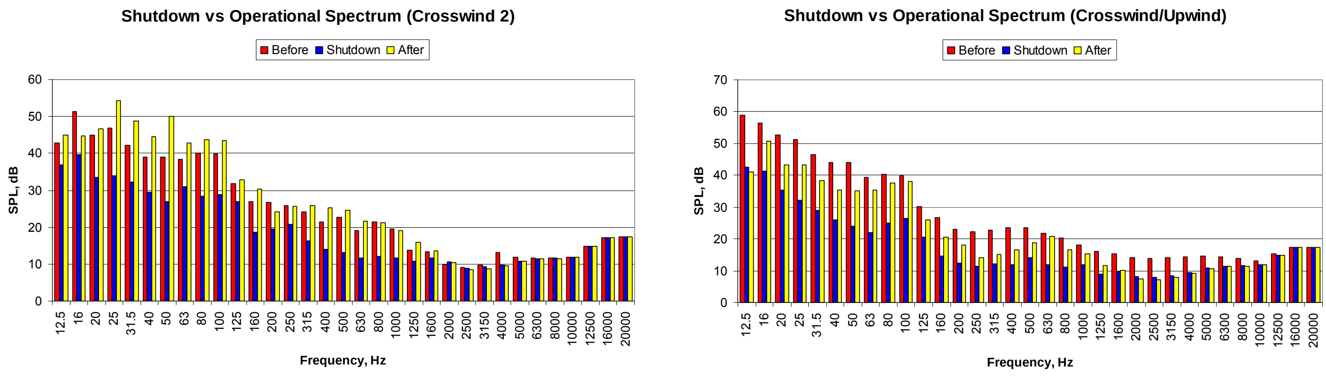


Figure 41 Comparison of averaged unweighted spectra for shutdown and operating periods outside at the South East site

Detailed analyses of spectra measured outdoors were performed for periods adjacent to Shutdown 5 and 6, since the noise was not affected by ambient sources. Notable differences were seen for a broad range of frequencies including low and mid frequencies (Figure 42).



(a) (b)

Figure 42 Comparison of unweighted spectra for shutdown and adjacent periods, outside at the South East site

A local spectral maximum was detected at 50Hz during some operational periods. No prominent tones were identified for this type of wind turbine generator, using the tonality test performed after commissioning of the wind farm [7, 23]; however, the 1/3 octave component appeared to be rather prominent, from the results of acoustic testing [23]. The effect may be supplemented by the emission from the electric substation constructed on the wind farm site, which is likely to generate a 50Hz component. At this site, downwind propagation from the nearest turbines also corresponds to a downwind direction from the electric substation.

It is noted that NZS 6808:2010 [34], ANSI S12.9- Part 4 [1] and other regulatory procedures recommend objective testing of the tonal audibility, requiring a 15dB difference between the possible tone and adjacent 1/3 octave components, for a frequency range from 25 to 125Hz.

Despite the prominence of a 50Hz component for some of the operating regimes, it did not meet the definition of a tone, based on the results of the objective and subjective tests. Amplified sound records were analysed for some of the downwind operational conditions. The character of noise can be described rather as ‘rumbling’ or ‘thumping’ which coincides with descriptions in some of the diary return records; noting, however, that sound power levels during these events were typically low [total noise is around 35dB(A) or below].

4.5.4 Diary return periods and audio records

Noise diaries from the surrounding area were utilised to focus the search for possible links between the acoustic data and events described by residents. Wind speeds and directions for the diary return records are summarised in Appendix G. The time stamp was adjusted in accordance with 10-minute data acquisition periods. Intervals when turbine noise was audible are highlighted in italics. Since the house was occupied during the monitoring period, many records were affected by the operation of home appliances and household activities. The majority of noise diary entries were not found to be related to noise emission from the wind farm.

Acoustic descriptors for the diary return periods are summarised in the table of Appendix G. Where start and end times of the noise events were not specified in the diaries, the data is presented for the time available. The percentages in the DEFRA field shows the percentage of time when DEFRA low frequency noise criteria were met for all of the spectral components.

Analysis of sound records corresponding to the noise diaries required significant amplification. When emission from the wind farm was audible in these amplified records, the character of noise was continuous, sometimes with rumbling character. The wind farm was rarely the dominant noise source at the West site; and was mainly audible for downwind and downwind/crosswind conditions (refer to tables in Appendix G).

Where the relevant audio records were reproduced at the actual levels, the rumbling effect was not discernible. The rumbling effect was more distinct inside the house when household noises do not interfere. The character may have related to contrast, since the house structure provides better attenuation of higher frequencies than the lower frequencies.

The majority of events described in diary returns for the site were associated with downwind wind direction from the turbines (Table 38). Noise levels that could be attributed to wind farm noise were typically low, if not affected by other noise sources. The conservative Danish EPA and UK DEFRA criteria were generally not met for periods identified in diary records. However many of those periods (especially inside of the house) were found to have been affected by other noises; and it has been difficult to tell what contribution of the wind farm into the low frequency descriptors may have been.

Annoyance from the wind farm noise may increase inside the house during periods when there is no noise from household activities and operation of home appliances, ie when the internal background is low.

4.5.5 Summary for the South East site

The South East site is situated in a quiet rural area east from the Waterloo ridge at a significant distance from the wind farm site.

- Noise from the wind farm was detectable under downwind environmental conditions outside the house.
- A 'rumbling' effect and wind farm noise were identified both inside and outside the house in analyses of amplified audio records, but these may not have been detectable to a typical listener, if reproduced at actual levels recorded. These noise characters were the most prominent at this site, of the three sites where they were found; that is the North East, West and South East sites.
- Comparison of data from wind farm shutdowns with data from operating periods with similar conditions indicate that the wind farm contributed to low frequency noise under particular environmental conditions (downwind, crosswind), during the study. This may have caused non-compliances with the conservative Danish EPA and UK DEFRA low frequency criteria.
- It should be noted that similar low frequency noise levels were detected during half of the shutdown periods; and the low frequency descriptors were found to be high even during periods of low wind speeds. Differences between operational and non-operational periods were not discernible when listening to audio records reproduced at the actual levels; that is, without amplification. Neither were rumbling nor low frequency characters discernible.
- It is possible that operation of the wind farm may cause increased annoyance to a sensitive listener at this site, if exposed for a long time period, possibly exacerbated by the presence of some degree of amplitude modulation.
- Analyses of spectral data indicated a prominent component at 50Hz 1/3 octave central frequency at times. Objective testing and analysis of audio records did not indicated the likelihood that a tonal character may be detectable in the noise; however, it is possible that the 50Hz component could increase annoyance to a sensitive listener, in conjunction with potential modulation of noise at this 1/3 octave band.
- The noise impact at the site met current regulatory requirements, even without correction for background noise.

4.6 East site

The East site is the most distant monitoring place established during this study, approximately 7.6 km from the nearest turbine, at a downwind direction of 268 º±45º (nearest turbine BF). Only external noise was monitored using a conventional outdoor noise logging approach, based on descriptions of wind farm impacts at this site.

The house, of solid brick or stone construction, average-large windows with corrugated iron roofing was occupied during the monitoring period. The logger was deployed in a field to south of the dwelling, separated from it by a row of trees and a driveway. The house was occupied during the monitoring period.

The baseline criterion of 40dB(A) could be applicable in case wind farm noise was detectable at the house.

4.6.1 Data analysis

The logger was powered by a battery and some continuous data was lost at a time when it was not possible to replace the battery. However, data are available for 35 days between 10 April and 9 June 2013.

The basic logging period was 15 minutes as prescribed by the Environment Protection (Noise) Policy 2007, for reporting noise data for general environmental noise sources. The data were reprocessed into 10-minute averages where possible.

Very quiet periods were found to occur frequently at the East site, and at times noise levels were so low that measured values may have been influenced by the noise floor of the instrument, about 17dB(A).

The data set for the analysis comprised 1,531 valid data pairs, of which 190 corresponded to downwind conditions.

Weather monitoring equipment was not available for this site, so the data analysis was referenced against wind speeds measured at the nearest turbines.

No noise was detected that could be attributed to wind farm operation, in available audio records. Given that, the results of the data analysis below reflected the character of the ambient or background noise environment at the site during the study, rather than that of noise from the wind farm.

A-weighted and C-weighted levels

As expected, A-weighted sound power levels did not exhibit a good correlation with wind speeds measured at the turbines, since the noise was not controlled by the wind farm. Both A-weighted and C-weighted data showed a large scatter (Figure 43) which may have been due to the absence of any contribution from the wind farm.

Under such circumstances, any significant correlation with wind speeds measured at the turbines would not have been expected. A limited number of data points were collected under downwind conditions (Figure 44a). The statistical trend remained below 40dB(A) as recommended by the Guidelines [32].

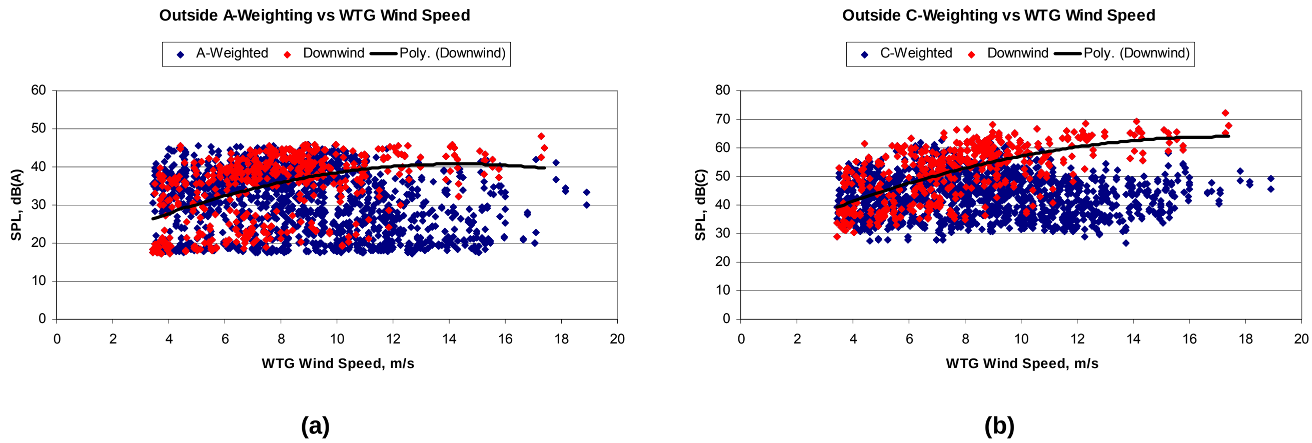
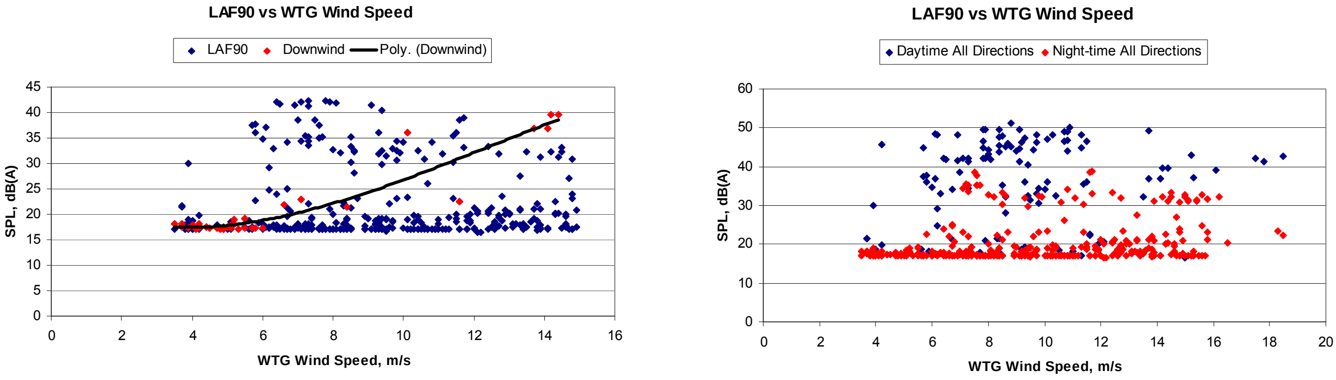


Figure 43 A-weighted and C-weighted levels versus wind turbine generator wind speed, outside at the East site

From the graph in Figure 43b, it appears that downwind data points represented significantly higher noise levels than other directions; however it is noteworthy that only 53 of the 190 downwind data points occurred during the night-time period of 10 pm to 7 am [as defined in the Environment Protection (Noise) Policy 2007], and noise levels at night typically did not exceed 35dB(A) (L_{AF90}) under downwind conditions (Figure 44a). Analysis of audio records for day-time periods at low wind speeds demonstrated that in the majority of cases measured noise levels were significantly affected by other noise sources.



(a) (b)

Figure 44 (a) Background vs wind turbine generator wind speed (b) Day and night time noise levels, outside at the East site

Analysis of audio records confirmed that the majority of the highest recorded noise levels (particularly those at lower wind speeds) could be attributed to periods of ambient noise, rather than operation of the wind farm.

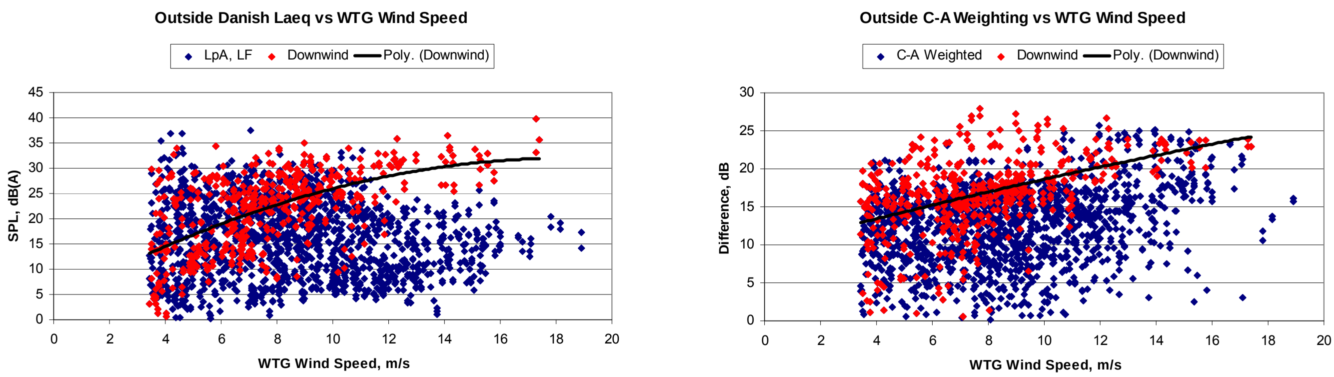
C-weighted levels sometimes exceeded the recommended 60dB(C) criterion, possibly due to wind-induced noise on the microphone from local wind conditions.

Low frequency noise

A large degree of scatter in the low frequency data was typical for this site. Outdoor magnitudes were also relatively high, which most likely reflected influence of wind induced noise, wildlife and other sources (Figure 45).

Frequency analysis of spectra for logging periods in the early morning and early evening hours typically indicated a peak in the spectrum in the 4kHz 1/3 octave band. Typically, the L_{Ceq} minus L_{Aeq} parameter was negative during these two periods, due to the large amount of energy in the mid-high frequency range, compared with the amount of energy in the low frequency range. Filtering the noise logging data to only show periods where the L_{Ceq}–L_{Aeq} parameter was negative demonstrated that the overwhelming majority of such occurrences were during the early morning and early evening periods. Analysis of audio records associated with these periods indicated that bird noise was the most likely cause of the elevated noise levels at the measurement site, and these events have not been included into the graphs in Figure 50.

Analysis of audio records indicated that samples where L_{Ceq}–L_{Aeq} exceeded 25dB were dominated by the wind noise of extremely high wind speeds in the vast majority of cases.



(a) (b)

Figure 45 $L_{pA,LF}$ descriptor and difference between C-weighted and A-weighted levels, outside at the East site

4.6.2 Analysis of shutdowns periods

Shutdown data was available for one shutdown only, which occurred on 30 May 2013 (Shutdown 2). Wind speeds at the nearest turbine were 10.7–11m/s and wind directions were within 24–25°, corresponding to crosswind conditions. The noise levels during this shutdown were compared with the noise levels recorded during a similar operational period; and with acoustic descriptors acquired immediately before and following the shutdown, to ascertain whether any difference in the noise environment existed as a result of the turbines having stopped operation.

The results (Table 25) did not indicate any conclusive difference between the parameters acquired during similar operational and non-operational periods. Sound pressure levels were low and the low frequency noise descriptors met the strictest limits.

Table 25 Comparison of shutdown and operational periods, outside at the East site

Period	$L_{Aeq, dB(A)}$	$L_{Ceq, dB(C)}$	$L_{pA, LF, dB(A)}$	DEFRA
Shutdown				
Shutdown 2: Crosswind	27–29	42–43	17–20	100%
Operational				
Comparison 2: Crosswind	26–35	34–42	10–20	100%
After Shutdown 2	26–30	39–41	16–18	100%

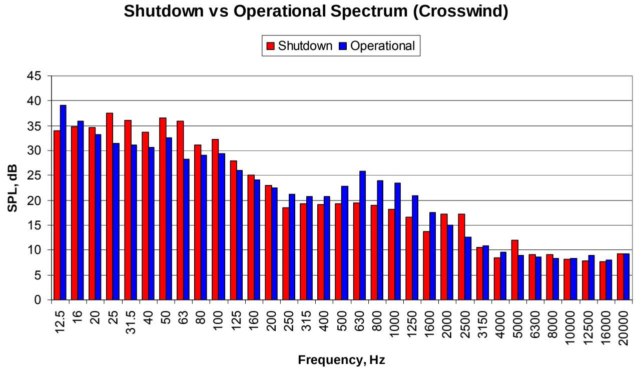
Periods before the shutdown and within the first half of the shutdown period were affected by ambient noises. Resuming operation of the wind farm after the shutdown did not bring any significant change in the magnitudes of acoustical descriptors (Table 26).

Table 26 Acoustic descriptors before and after the shutdown period, outside at the East site

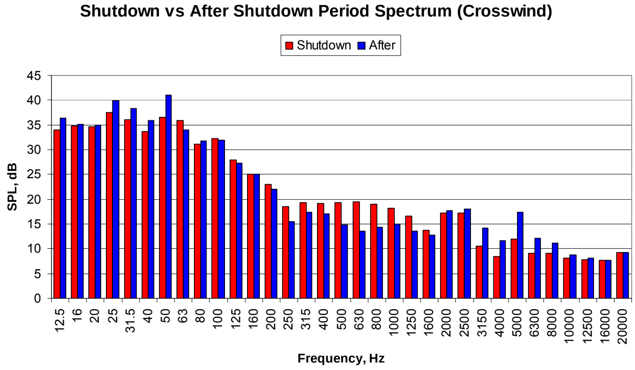
Time	Wind turbine generator (wind direction)	Wind turbine generator (wind speed)	L_{Aeq}, dB(A)	L_{Ceq}, dB(C)	$L_{pA, LF}$, dB(A)	DEFRA
30/05/2013 18:30 Other noise sources	23	11	43	54	34	1
30/05/2013 18:45 Other noise sources	23	11	42	48	26	1
30/05/2013 19:00 Other noise sources	24	10.7	35	42	17	0
30/05/2013 19:15 Other noise sources	24	10.7	36	48	27	1
30/05/2013 19:30	25	11	29	43	20	0
30/05/2013 19:45	25	11	27	42	17	0
30/05/2013 20:00	22	12	27	41	17	0
30/05/2013 20:15	22	12	26	39	16	0

Analysis of the spectral components for periods not affected by other noise sources indicated that there was no conclusive difference. As demonstrated in Figure 46a, some of the components were higher for the shutdown period.

Wind speeds measured at the nearest turbine following Shutdown 2 were also found to have increased; as had some of the spectral components shown in Figure 46b. The acoustic descriptors did not show any notable variations indicating that the shutdown had little effect on reducing noise levels at this location.



(a)



(b)

Figure 46 Comparison of unweighted noise spectra for shutdown and similar periods, outside at the East site

4.6.3 Diary return analysis

There was a significant amount of diary returns from the resident and neighbours, the data from which are summarised in Appendix H. Analysis of amplified records focused on diary records did not allow identification of noise events that may have been attributable to the operation of the wind farm.

4.6.4 Summary for the East site

Only outdoor noise logging was performed at the East site, which was the most distant at almost 8 km from the wind farm.

- Analysis of available audio records did not indicate any noise events that could be attributable to the wind farm.
- Noise due to high local wind speed, interactions of winds with vegetation and other sources frequently resulted in relatively high magnitudes of relevant acoustic descriptors for low frequencies, which may cause annoyance to a listener with a sensitivity to low frequency noise.
- Due to the large separation distance, the wind farm noise was not detectable at the East site; and there was no evidence that the noise levels from the wind farm may have been excessive during the study.

4.7 Notes on the rumbling noise character

A particular noise character, which diary returns described as 'rumbling' or 'thumping', was detected in amplified audio records at three sites (North East, West and South East sites), with the most prominent effects at the South East site. All of these monitoring sites are situated at similar separation distances from the wind farm (approximately 2.5km). It must be noted that the rumbling was only discernible when listening to amplified audio records, not in records replayed at actual levels. Analysis of shutdown and adjacent periods at the South East site indicated a direct link between operation of the wind farm and this particular noise character. It was present during periods adjacent to the shutdown and was not detectable during the shutdown by analysis of the amplified audio records.

Typically the effect was recorded under downwind conditions when the local background noise was low, notably at low local wind speeds. Spectral analysis showed that the effect could have been linked to a prominency 50Hz 1/3 octave component. The component was not that prominent at the North site and noise did not exhibit the rumbling character. As noted previously, results of the acoustics tests did not show the presence of tones in turbine emission; however the spectral content of the wind turbine generator noise contains prominent 50Hz component (not tonal) at the mid to high wind turbine generator wind speeds [7].

A rumbling effect was typically associated with a high degree of modulation. It was not identified at the North site, which was closer. Sometimes variations in environmental conditions can cause effect similar to the amplitude modulation [20], and amplification of the modulation effect due to changes of environmental parameters over a larger distance was considered plausible. The noise character was not detectable at a large distance (for example at the Township site) during the monitoring period, because of the greater attenuation of wind farm noise with increasing distance.

It is emphasised that in analysing monitoring data for the Township site, the ‘rumbling’ could be heard only when the audio records were amplified.

5 Conclusion

This report presents results of noise monitoring program performed at six sites in the vicinity to Waterloo Wind Farm over approximately two months, at distances ranging between 1.3 and 7.6 km, covering a broad range of directions.

Measurements of noise inside and outside of houses were undertaken at five sites.

Additional monitoring equipment was deployed at two houses (Township and North sites) to acquire data in infrasound frequency range both inside and outside of the houses.

No evidence was found for the presence of excessive infrasound within the infrasound frequency range. The blade pass frequency component, which falls within the infrasound frequency range, was found to be below the perception threshold by significant margin, and typical levels were consistent with results of other relevant studies. G-weighted levels were also found to be below the perception threshold.

Analysis of acoustic data and audio records measured at the Township and East sites did not show evidence for noise that may have been associated with wind farm operations.

Wind farm noise was found to be audible at very low levels at the other sites, with a slight degree of modulation; but rarely dominated the noise environment during the monitoring period. Where it could be identified, wind farm noise was generally only discernible with substantial amplification of audio records. A ‘rumbling’ character could be identified in amplified audio records at three residences (North East, West and South East sites), typically under downwind conditions.

The data showed that operation of the wind farm may have contributed to the low frequency content of noise under some operating and environmental conditions during the period, resulting in increases of relevant low frequency noise descriptors. As with the rumbling effect, the low frequency content was not discernible subjectively when replaying audio records at actual levels, but could be detected with amplification.

Analysis of data for the sites showed that high level of low frequency noise is typical for some of the sites, most likely due to natural background or ambient noise sources, for which low frequency descriptors were found to be comparable with those from the wind farm, or at times even higher.

The noise diaries were essential to the study in focusing the acoustic analyses on events and descriptions recorded by the community. In particular, the identification of the rumbling effect and other noise characters associated with the wind farms was facilitated by diary returns. However, it is noted that in analysing audio records acquired during the study, amplification was generally necessary to hear these effects; and where detectable, noise levels recorded during the study complied with the conditions of the development approval and the baseline criterion of 40dB(A).

Nevertheless, it is possible that people who have a higher sensitivity to the lower frequencies in particular may detect these characteristics, and they may cause increased annoyance for those who have been aware of them for a prolonged period.

Noise impact from the wind farm, where detectable, was found to comply with the conditions of the development approval and the baseline criterion of 40dB(A).

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7 Glossary

A-weighting	Frequency weighting as specified in Standard IEC 61672–1 Electroacoustics–Sound level meters–Part 1: Specifications or its equivalent
Amplitude modulation	A sound which is clearly perceived as rising and falling. It has varying, fluctuating noise character that is clearly audible above everything else.
Audio frequencies	Noise most audible to the general human ear, normally lies within the frequency range between 20Hz to 20kHz.
Blade pass frequency	Frequency of which the blade of a wind turbine generator passes the tower.
C-weighting	Frequency weighting as specified in Standard IEC 61672–1 Electroacoustics–Sound level meters–Part 1: Specifications or its equivalent
Decibel [dB or dB(Lin)]	Unit of sound pressure level, referenced to 20 µPa. Where dB is used in this report, it refers to the level in decibels with no frequency weighting applied.
L_A, dB(A)	Unit of sound pressure levels which have had the A-weighting applied to them
L_C, dB(C)	Unit of sound pressure levels which have had the C-weighting applied to them
L_G, dB(G)	Unit of sound pressure levels which have had the G-weighting applied to them.
Low frequency noise	Noise perceptible and definite content in the audible noise frequency range below 250Hz
Equivalent noise level $L_{Aeq, T}$	The equivalent continuous A-weighted sound pressure level obtained using the 'Fast' time weighting, over the measurement time interval. Expressed as $L_{Aeq, T}$, where T refers to the measurement time interval.
Frequency	Rate of sound pressure variations – noise or sound is composed of energy across a wide range of frequencies including 20Hz or lower (infrasound).
G-weighting	Frequency weighting as defined in ISO 7196:1995, used to approximate how the human ear responds to infrasonic noise levels.
Hertz (Hz)	Unit of frequency – one Hz is equivalent to one cycle per second.
Infrasound	Sound or noise where the energy lies mainly in the frequency range below 20Hz.
$L_{pA,LF}$, $L_{Aeq(LF)}$	Low frequency noise descriptor based on the A-weighted noise level calculated for the 1/3 octave band levels from 10Hz to 160Hz inclusive.
L_{90}	Noise level which was equalled or exceeded for 90% of the measurement period. Typically used to represent the background noise level in an environment.
Leq	Equivalent noise level – energy averaged noise level over the measurement period. Most common descriptor used to quantify noise sources.
$L_{eq,10min}$	Equivalent noise level over a 10-minute measurement period.
$L_{eq,15min}$	Equivalent noise level over a 15-minute measurement period.
Noise floor	The minimum noise level which can be recorded by a specific measurement instrument.
Sound pressure	A logarithmic measure of effective sound pressure relative to a reference value (normally

level (SPL)	20µPa). Measured in dB.
Tonal noise	Noise with perceptible and definite pitch or tone.
Wind farm	A group of wind farm turbines installed in the same region and all operated by the same operator. It is not necessary that all wind turbine generators are located in the same premises.
Z-weighting	Unweighted noise levels. Sometimes called 'linear' levels.

Appendix A Wind turbine generator parameters

Technical parameters of the wind turbine generator

Table 27 Extract from technical specification for Vestas V90-3MW wind turbine generator

Make and model	Vestas V90 3MW
Rotor diameter, m	90
Hub height, m	80
Orientation	Upwind
Rotor speed, rpm	8.6–18.4
Cut-in wind speed (hub height, m/s)	3.5
Rated power wind speed (hub height, m/s)	15
Cut-out wind speed (hub height, m/s)	25
Sound power L_{WA} at 8m/s (10 m AGL, dBA), Mode 0	107.0

Table 28 Sound power levels [dB(A)] versus wind turbine generator wind speed for Vestas V90–3MW turbine

Wind speed at 10 m AGL, m/s	4	5	6	7	8	9	10	11	12	13
Sound power level (Noise Mode 0)	97.9	100.9	104.2	106.1	107.0	106.9	105.6	105.2	105.3	105.4

Appendix B Instruments used

Instruments used for the acoustic measurements

Table 29 Serial numbers and calibration information for the acoustic instruments

Site	Measurement parameters	Equipment	Serial numbers	Due for calibration
1	Indoor and outdoor infrasound, and conventional audio frequencies noise monitoring outdoor	Sinus Soundbook Mk1 4-channel Analyser with Samurai software installed	06364	Oct. 2014
		Outdoor Infrasound Microphone: Brüel & Kjær 4193L with low-frequency adapter GRAS Type 26AK Pre-amplifier	2751414 96875	March 2014 March 2015
		Outdoor Conventional Microphone (type 41AL): GRAS 40AJ microphone GRAS Type 26AK Pre-amplifier	83193 20710 96877	March 2015 March 2015
		Indoor Infrasound Microphone: Brüel & Kjær 4193L with low-frequency adapter GRAS Type 26AK Pre-amplifier	2751415 165280	March 2014 January 2015
2	Indoor and outdoor infrasound ,and conventional audio frequencies noise monitoring outdoor	Sinus Soundbook Mk2 4-channel Analyser with Samurai software installed	07109	March 2015
		Outdoor Infrasound Microphone: Brüel & Kjær 4193L with low-frequency adapter Brüel & Kjær 2669L Pre-amp	2774944 2751425 2818624	March 2014 December 2014
		Outdoor Conventional Microphone (Type 41AL): GRAS 40AJ microphone GRAS Type 26AK Pre-amplifier	83190 20697 96873	March 2015 March 2015
		Indoor Infrasound Microphone: Brüel & Kjær 4193L with low-frequency adapter Brüel & Kjær 2669L Pre-amp	2774943 2751424 2818623	March 2014 December 2014

Site	Measurement parameters	Equipment	Serial numbers	Due for calibration
3	Indoor and outdoor conventional noise monitoring	Outdoor (NMT6):		
		Brüel & Kjær 3639A NMT	2769912	June 2013
		Brüel & Kjær 2250 SLM	2750956	June 2013
		Indoor (NMT1):		
		Brüel & Kjær 3639A NMT	2769911	June 2013
		Brüel & Kjær 2250 SLM	2763455	June 2013
4	Indoor and outdoor conventional noise monitoring	Outdoor (NMT5):		
		Brüel & Kjær 3639A NMT	2769916	June 2013
		Brüel & Kjær 2250 SLM	2763469	June 2013
		Indoor (NMT2):		
		Brüel & Kjær 3639A NMT	2769914	June 2013
		Brüel & Kjær 2250 SLM	2763471	June 2013
5	Indoor and outdoor conventional noise monitoring	Outdoor (EPA3):		
		Brüel & Kjær 3639A NMT	2769915	June 2013
		Brüel & Kjær 2250 SLM	2763470	June 2013
		Indoor (EPA4):		
		Brüel & Kjær 3639A NMT	2769913	June 2013
		Brüel & Kjær 2250 SLM	2750955	June 2013
6	Conventional noise logging	Brüel & Kjær Noise Logger based on Type 2250 Sound Level Meter	2764923	March 2015

Appendix C Township site records

Audio record analysis for the Township site

Table 30 Wind speed and direction corresponding to diary return records, Township site

No.	Resident	Neighbours	Date	Start time	End time	Wind			
						Local		Wind turbine generator	
						Speed, m/s	Direction, deg	Speed, m/s	Direction, deg
1	No	Yes	11/04/2013	23:30	5:00	N/A	N/A	7.4–14.8	54–113
2	No	Yes	12/04/2013	7:30	N/A	N/A	N/A	10.1	37.1
3	Yes	No	12/04/2013	10:00	N/A	N/A	N/A	6.4	22.6
4	Yes	No	12/04/2013	13.20	N/A	N/A	N/A	1.9	310.2
5	No	Yes	13/04/2013	12.30	N/A	N/A	N/A	17.7	299.8
6	Yes	No	13/04/2013	13:30	N/A	N/A	N/A	15.2	295.5
7	Yes	Yes	19/04/2013	13:40	23.50	N/A	N/A	5.8–15.6	68.2–94.1
8	No	Yes	20/04/2013	8:00	N/A	N/A	N/A	7.5	57.1
9	No	Yes	25/04/2013	8:00	N/A	N/A	N/A	11	281.3
10	Yes	No	25/04/2013	22:30	N/A	N/A	N/A	7.6	244.6
11	Yes	No	26/04/2013	4:30	N/A	N/A	N/A	9.2	265.2
12	No	Yes	26/04/2013	15:40	N/A	N/A	N/A	5.5	278
13	Yes	No	27/04/2013	8:00	N/A	N/A	N/A	18.7	325.3
14	No	Yes	27/04/2013	9:40	N/A	N/A	N/A	13.9	317.7
15	No	Yes	28/04/2013	9:00	N/A	N/A	N/A	6.4	243.4
16	No	Yes	28/04/2013	10:30	N/A	N/A	N/A	5.8	260.8
17	Yes	No	29/04/2013	N/A	8:00	N/A	N/A	4.9	135.3
18	Yes	No	30/04/2013	N/A	0:00	N/A	N/A	9.2	71.8
19	Yes	No	30/04/2013	N/A	6:50	N/A	N/A	5.7	49.8
20	No	Yes	30/04/2013	15:30	N/A	N/A	N/A	4.8	235.8
21	Yes	No	30/04/2013	N/A	23:50	N/A	N/A	4.8	116.6
22	Yes	No	1/05/2013	N/A	6:40	N/A	N/A	6.9	205.2

No.	Resident	Neighbours	Date	Start time	End time	Wind			
						Local		Wind turbine generator	
						Speed, m/s	Direction, deg	Speed, m/s	Direction, deg
23	Yes	No	1/05/2013	10:00	N/A	N/A	N/A	7.1	159.4
24	Yes	No	1/05/2013	10:30	N/A	N/A	N/A	8.5	158.3
25	Yes	No	1/05/2013	11:50	N/A	N/A	N/A	6.1	142.8
26	Yes	No	1/05/2013	18:00	N/A	N/A	N/A	7.7	139.4
27	Yes	No	1/05/2013	19:30	N/A	N/A	N/A	10.5	133.1
28	No	Yes	1/05/2013	21:30	N/A	N/A	N/A	12.7	122.6
29	No	Yes	2/05/2013	2:40	N/A	N/A	N/A	14.3	94.3
30	No	Yes	2/05/2013	4:00	N/A	N/A	N/A	15.5	72.1
31	No	Yes	2/05/2013	7:40	N/A	N/A	N/A	21.2	54.1
32	Yes	No	2/05/2013	9:00	9.20	N/A	N/A	15.6–16.1	47.8–50.8
33	Yes	No	2/05/2013	18:10	18.30	1.8–2	40.6–45	11.3–13.7	44.1–47.7
34	Yes	Yes	3/05/2013	10:00	N/A	3.1	346.8	14.8	323.4
35	Yes	No	4/05/2013	6:00	N/A	0.0	0.0	6.7	101.6
36	Yes	No	4/05/2013	19:00	N/A	1.9	83.2	11.2	84.8
37	Yes	No	4/05/2013	20:30	N/A	2.4	81.1	12.2	90.1
38	Yes	No	5/05/2013	8:30	N/A	3.8	56.3	11.8	58.1
39	Yes	No	6/05/2013	4:30	N/A	2.6	48.9	14.1	50.9
39	Yes	No	6/05/2013	7:00	N/A	1.8	20.8	14.6	45.9
40	No	Yes	6/05/2013	17:40	N/A	0.9	35.8	10	43.7
41	Yes	No	6/05/2013	19:20	N/A	0.4	4.5	10.7	42
42	Yes	No	7/05/2013	2:00	N/A	0.6	5.8	10.8	331.6
43	Yes	No	7/05/2013	19:00	N/A	0.3	318.2	9.3	22.8
44	Yes	No	8/05/2013	20:30	N/A	0.8	56.6	12	50
45	Yes	Yes	9/05/2013	8:00	8:20	3–3.1	41.5–46.6	13–16.5	11.1–15
46	Yes	Yes	9/05/2013	17.30	18:30	0.7–1.6	38–53.1	9.4–9.9	24.4–32.2
47	No	Yes	9/05/2013	23.50	N/A	0.8	59.0	9.8	45.6

No.	Resident	Neighbours	Date	Start time	End time	Wind			
						Local		Wind turbine generator	
						Speed, m/s	Direction, deg	Speed, m/s	Direction, deg
48	No	Yes	10/05/2013	7:10	N/A	2.1	36.8	5.5	0.2
49	No	Yes	10/05/2013	8:10	N/A	1.6	43.8	6.2	3.7
50	No	Yes	10/05/2013	11:50	N/A	2.9	29.9	11.4	21.7
51	No	Yes	10/05/2013	17:30	N/A	1.9	47.5	9.1	41
52	Yes	No	10/05/2013	22:30	N/A	1.2	42.7	14.5	13.6
53	No	Yes	10/05/2013	23:50	N/A	2.2	32.6	14.9	17.2
54	Yes	No	11/05/2013	4:30	5:00+	1.7–2.2	351.2–2.9	9.9–13.3	3.9–8.0
55	Yes	No	12/05/2013	5:30	N/A	0.4	263.9	10.8	308.7
56	Yes	No	13/05/2013	6:10	N/A	0.3	185.2	14.7	251.8
57	No	Yes	13/05/2013	10:30	N/A	0.9	137.6	10.8	236.9
58	No	Yes	13/05/2013	13:00	N/A	1.1	210.7	7.9	232.8
59	No	Yes	13/05/2013	16:50	N/A	0.2	128.7	10.3	250.7
60	No	Yes	15/05/2013	9:30	N/A	1.0	157.8	12.6	242.6
61	No	Yes	17/05/2013	13:00	N/A	1.2	223.4	3.3	184.9
62	No	Yes	18/05/2013	11:10	N/A	0.8	280.8	3.5	285.1
63	No	Yes	19/05/2013	15:30	N/A	0.7	307.8	8.9	299
64	No	Yes	19/05/2013	16:30	N/A	0.7	292.4	9.2	295.2
65	Yes	Yes	21/05/2013	N/A	18:00	2.8	42.6	14	33.1
66	Yes	Yes	22/05/2013	N/A	00:30	2.5	65.9	8.8	62.2
67	Yes	No	22/05/2013	N/A	5:30	2.2	64.8	9.3	69.4
68	Yes	No	22/05/2013	17:50	N/A	1.1	208.2	7.9	229.4
69	Yes	No	23/05/2013	22:00	N/A	0.0	0.0	8.4	142.9
70	Yes	Yes	24/05/2013	7:00	N/A	0.0	0.0	7.9	148.1
71	Yes	No	25/05/2013	00:00	N/A	0.0	0.0	8.1	223.8
72	Yes	Yes	26/05/2013	21:40	N/A	2.6	108.2	8.8	114.2
73	Yes	No	27/05/2013	2:30	N/A	0.5	88.1	10.6	84.9
74	No	Yes	27/05/2013	9:10	N/A	2.9	56.0	8.2	52.7

No.	Resident	Neighbours	Date	Start time	End time	Wind			
						Local		Wind turbine generator	
						Speed, m/s	Direction, deg	Speed, m/s	Direction, deg
75	Yes	Yes	27/05/2013	22:30	N/A	0.0	0.0	6.8	36.3
76	Yes	Yes	28/05/2013	0:00	N/A	0.0	0.0	8.5	45.7
77	No	Yes	28/05/2013	17:10	N/A	0.0	0.0	3.7	53.1
78	Yes	No	28/05/2013	22:00	N/A	0.3	342.4	9.9	24.1
79	No	Yes	29/05/2013	8:30	N/A	0.7	357.1	15.4	339.3
80	No	Yes	29/05/2013	9:00	N/A	0.7	5.6	14	340.4
81	Yes	No	30/05/2013	16:50	N/A	2.2	31.8	10.4	22.5
82	Yes	No	31/05/2013	1:10	N/A	2.3	357.4	9.3	351
83	No	Yes	31/05/2013	9:30	N/A	0.0	0.0	4	352.8
84	No	Yes	5/06/2013	11:50	17.10	0.2–2.8	245.2–357.6	7.8–15.0	304.8–318.8
85	No	Yes	6/06/2013	13:50	14:30+	0.3–1.5	266.3–331.1	10.6–13.8	288.4–294.7
86	Yes	No	8/06/2013	5:30	N/A	0.0	0.0	6.3	42
87	No	Yes	8/06/2013	15:30	N/A	0.8	356.6	4.5	315.5
88	Yes	No	9/06/2013	3:30	N/A	0.0	0.0	3.7	356.2
89	No	Yes	9/06/2013	10:30	N/A	1.0	348.4	6.1	326.4
90	No	Yes	12/06/2013	11:10	13:40+	0.4–3.7	223.8–262.4	5.4–11.9	183.9–201.0
91	No	Yes	14/06/2013	13:30	24:00	0–2.8	0–247.5	4.0–9.9	8.9–24.0

Table 31 Acoustic descriptors and analysis of audio records for diary return entries, Township site

No.	Inside			Outside							Spectrum shape/blade pass frequency	Audio records (inside/outside where available)
	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	$L_{AF,90}$	L_{Ceq}	L_{Aeq}	L_{Ceq}–L_{Aeq}		
1	51.3–59.6	7.9–17.1	97%	56.2–64.6	45.1–47.1	1	24.1–33.6	57.1–64.4	29.8.1–38.8	3.8–7.0	Negative	Inside – not audible Outside – wildlife, wind, other noise sources
2	48.2	8.2	0	53.9	45.4	1	27.8	54.1	34.3	19.8	Negative	Inside – other noise sources, music Outside – machine noise, cars, wind
3	58.3	22.2	1	58.1	45.4	1	29.5	57.6	46.3	11.3	Negative	Inside – not audible Outside – not audible
4	44.9	13.6	0	48.1	45.0	1	21.2	54.0	29.4	24.6	Negative	Inside – not audible Outside – not audible, turbines not in operation
5	60.5	18.9	0	59.6	46.1	1	43.0	62.5	40.6	21.9	Negative	Inside – wind noise Outside – wind noise, other noise sources
6	63.8	22.1	0	64.0	46.2	1	38.4	61.8	45.5	16.3	Negative	Inside – other noise sources Outside – wind, cars, wildlife, machine noise
7	49.9–62.4	7.1–28.5	61%	56.2–65.9	18.2–44.2	19%	23.3–42.7	48.2–68.1	24.9–48.6	9.3–28.7	Negative	Inside and outside – wind noise

No.	Inside			Outside							Spectrum shape/blade pass frequency	Audio records (inside/outside where available)
	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	$L_{AF,90}$	L_{Ceq}	L_{Aeq}	L_{Ceq}–L_{Aeq}		
8	51.2	16.2	0	55.3	32.2	1	n/a	59.2	39.9	19.3	Negative	Inside – other noise sources Outside – wildlife, wind gusts, other noise sources
9	50.7	11.5	0	52.8	21.6	1	30.0	50.8	32.1	18.7	Negative	Inside and outside – car/machine noise
10	38.9	2.7	0	46.4	17.3	0	23.1	42.0	25.1	16.9	Negative	Inside – other noise sources Outside – cars, machines (most likely agricultural), wildlife
11	38.2	4.4	0	44.5	19.0	0	21.1	37.7	22.6	15.1	Negative	Inside – not audible Outside – machine noise with modulation
12	49.5	10.2	0	50.3	23.9	0	22.2	55.7	37.3	18.4	Negative	Inside – not audible Outside – mainly wind noise
13	55.1	11.6	0	50.6	22.9	1	32.7	49.1	43.1	6.0	Negative	Inside – other noise sources Outside – other noise sources, wildlife, wind noise

No.	Inside			Outside							Spectrum shape/blade pass frequency	Audio records (inside/outside where available)
	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	$L_{AF,90}$	L_{Ceq}	L_{Aeq}	L_{Ceq}–L_{Aeq}		
14	64.9	22.9	0	62.4	29.4	1	38.3	60.2	43.7	16.5	Negative	Inside – wind other noise sources Outside – wind, other noise sources
15	48.7	5.5	0	52.5	15.2	0	26.9	55.9	35.2	20.7	Negative	Inside – not audible Outside – machine, wind wildlife noise
16	51.3	12.7	0	53.6	19.3	0	28.1	56.1	40.7	15.4	Negative	Inside – mainly not audible, other noise sources Outside – wildlife, car, wind noise
17	52.4	14.1	0	60.2	29.3	1	43.6	53.3	48.3	5.0	Negative	Inside – rain noise Outside– rain, cars, wildlife
18	51.1	8.1	0	57.1	22.4	1	25.8	55.5	28.2	27.3	Negative	Inside – not audible Outside – natural background, may be substation noise occasionally
19	50.9	14.8	0	56.5	29.2	1	34.2	49.6	44.0	5.6	Negative	Inside – cars, other noise sources Outside – wildlife, cars and other noise sources

No.	Inside			Outside							Spectrum shape/blade pass frequency	Audio records (inside/outside where available)
	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	$L_{AF,90}$	L_{Ceq}	L_{Aeq}	L_{Ceq}–L_{Aeq}		
20	53.5	25.3	1	56.2	38.6	1	30.3	59.4	45.4	14.0	Negative	Inside – not audible most of the time or other noise sources Outside – wildlife, cars and other noise sources
21	50.7	6.0	0	55.6	21.5	1	23.0	48.3	24.4	24.3	Negative	Inside and outside – machine noise
22	49.5	6.2	0	57.7	22.6	0	31.3	44.6	38.0	6.6	Negative	Inside – not audible Outside – other noise sources, substation may be audible in previous periods
23	61.7	31.2	1	57.5	26.7	1	34.5	56.7	38.7	18	Negative	Inside – household activities Outside – cars, machine and other noise sources
24	62.5	37.9	1	59.2	40.6	1	38.5	61.7	46.0	15.7	Negative	Inside – household activities, machine noise Outside – cars, machine and other noise sources

No.	Inside			Outside							Spectrum shape/blade pass frequency	Audio records (inside/outside where available)
	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	$L_{AF,90}$	L_{Ceq}	L_{Aeq}	L_{Ceq}–L_{Aeq}		
25	57.0	18.8	0	63.58	34.78	1	34.6	59.8	43.0	16.8	Negative	Inside – car, other noise sources Outside – car, machine, beeper, other noise sources
26	47.2	23.0	0	55.5	35.3	1	27.1	51.4	39.7	11.7	Negative	Inside – inaudible Outside – machine, other noise sources
27	50.9	11.3	0	58.8	24.1	1	29.8	49.6	35.7	13.9	Negative	Inside – inaudible Outside – machine, other noise sources
28	55.7	15.2	0	62.9	29.1	1	33.1	57.5	36.1	21.4	Negative	Inside – other noise sources Outside – wind, natural background
29	59.8	18.9	1	65.8	30.3	1	36.4	65.1	40.4	24.7	Negative	Inside– not audible; Outside – wind, natural background
30	59.5	18.4	1	66.2	30.5	1	34.4	61.4	38.2	23.2	Negative	Inside – not audible Outside – wind, natural background
31	64.2	22.5	1	68.4	37.4	1	40.8	70.3	48.7	21.6	Negative	Inside – not audible Outside – natural background

No.	Inside			Outside							Spectrum shape/blade pass frequency	Audio records (inside/outside where available)
	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	$L_{AF,90}$	L_{Ceq}	L_{Aeq}	L_{Ceq}–L_{Aeq}		
32	62.6–64.4	23.3–25.3	1	68.5–72.9	37.1–40.4	1	44–46.1	66.2–68.6	48.5–50	17.5–18.7	Negative	Inside –other noise sources Outside – other noise sources, natural background
33	51.9–52.8	15.1–21.6	1	58.6–60.5	28.8–36.7	1	31.5–31.9	56.8–57.6	36.2–44.7	12.9–21.3	Negative	Inside – inaudible Outside– natural background
34	64.5	28.1	1	65.0	41.9	1	38.9	62.6	53.8	8.8	Negative	Inside – other noise sources Outside – wind, cars other noise sources
35	47.7	7.0	0	56.3	17.8	0	27.0	43.8	30.9	12.9	Negative	Inside – inaudible Outside – natural background, machine noise
36	56.3	14.2	0	62.0	26.3	1	31.2	57.4	37.0	20.4	Negative	Inside – inaudible Outside – natural background, wind
37	59.7	17.9	0	63.9	27.5	1	33.5	67.3	41.0	26.3	Negative	Inside – inaudible Outside – dominated by wind noise
38	59.9	18.0	0	67.4	28.9	1	38.8	67.4	44.5	22.9	Negative	Inside – quiet periods interrupted by other noise sources Outside – wildlife, wind

No.	Inside			Outside							Spectrum shape/blade pass frequency	Audio records (inside/outside where available)
	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	$L_{AF,90}$	L_{Ceq}	L_{Aeq}	L_{Ceq}–L_{Aeq}		
39	57.5	16.5	0	63.6	28.0	1	34.5	62.0	40.5	22.5	Negative	Inside – mainly inaudible Outside – wind, natural background
40	56.2	14.3	0	61.3	27.4	1	35.5	56.3	48.7	7.6	Negative	Outside – mainly inaudible Outside – wildlife, cars, other noise sources
41	53.0	9.9	0	58.6	23.6	1	29.9	62.4	35.1	17.3	Negative	Inside – inaudible Outside – quiet background, may be machine/substation noise
42	44.0	4.3	0	49.9	23.6	1	25.9	44.1	27.8	16.3	Negative	Inside – inaudible Outside – substation noise
43	50.0	24.1	0	55.0	39.6	1	25.6	50.3	48.0	2.3	Negative	Inside and outside – truck and other noise sources, may be substation
44	52.7	12.8	0	59.5	26.2	1	28.4	53.6	30.6	23	Negative	Inside – inaudible Outside – natural background, cars

No.	Inside			Outside							Spectrum shape/blade pass frequency	Audio records (inside/outside where available)
	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	$L_{AF,90}$	L_{Ceq}	L_{Aeq}	L_{Ceq}–L_{Aeq}		
45	56.1–61.9	17.7–20.6	0	60.2–63.3	32.4–37.5	1	36.6–37.5	61.3–62.4	43.0–46.8	23.8–26.1	Negative	Inside – quiet periods interrupted by household activities Outside – wildlife, natural background, other noise sources
46	47.0–48.9	6.6–12.1	0	53.7–54.8	21.6–28.3	1	26.3–30.5	47.2–55.2	31.2–38.4	8.8–23.3	Negative	Inside – quiet periods interrupted by other noise sources Outside – natural background, wind, machine noise (may be substation)
47	48.1	7.2	0	54.9	19.4	0	25.3	48.8	26.6	22.2	Negative	Inside – other noise sources Outside – wind, background, faint machine noise
48	53.9	11.8	0	59.8	26.9	1	35.8	55.3	44.8	10.5	Negative	Inside – other noise sources Outside – wildlife, wind, trucks, other noise sources

No.	Inside			Outside							Spectrum shape/blade pass frequency	Audio records (inside/outside where available)
	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	$L_{AF,90}$	L_{Ceq}	L_{Aeq}	$L_{Ceq}–L_{Aeq}$		
49	58.5	21.1	0	62.1	37.3	1	32.5	58.4	43.7	14.7	Negative	Inside – inaudible; Outside – wildlife, wind, cars, beeper alarm, other noise sources
50	59.7	16.7	0	60.0	28.6	1	37.8	63.0	42.5	20.5	Negative	Inside – inaudible Outside – wind, other noise sources
51	51.5	13.1	0	55.6	26.6	1	45.9	58.0	44.0	14.0	Negative	Inside and outside – wildlife, other noise sources
52	50.7	9.0	0	56.9	24.6	1	28.0	50.3	29.4	20.9	Negative	Inside – inaudible Outside – substation noise
53	52.4	18.3	0	57.7	32.2	1	32.9	53.4	34.8	18.6	Negative	Inside – inaudible Outside – wind, faint substation noise
54	53.3–57.3	11.4–14	0	58.6–59.8	25.5–26.1	1	29.2–32.4	55.1–56.1	32.1–38.6	17.3–23.0	Negative	Inside – mainly inaudible Outside– wind, wildlife
55	54.6	12.9	0	55.4	23.2	0	32.1	47.8	38.3	9.5	Negative	Inside – rain noise Outside – rain and faint substation noise
56	49.5	5.9	0	53.1	18.4	0	30.7	57.5	33.1	24.4	Negative	Inside – inaudible Outside – wind, natural background

No.	Inside			Outside							Spectrum shape/blade pass frequency	Audio records (inside/outside where available)
	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	$L_{AF,90}$	L_{Ceq}	L_{Aeq}	L_{Ceq}–L_{Aeq}		
57	55.4	14.0	0	59.1	31.2	1	38.2	63.4	43.0	20.4	Negative	Inside – wind Outside – wind, natural background, other noise sources
58	50.2	7.0	0	55.5	17.2	0	28.6	61.3	38.8	22.5	Negative	Inside – inaudible Outside – wind, other noise sources
59	55.4	25.8	1	53.7	19.3	0	31.1	58.0	47.2	10.8	Negative	Inside – quiet periods interrupted by other noise sources Outside – wildlife, other noise sources
60	58.5	16.5	0	57.2	26.9	1	40.7	62.0	48.0	14.0	Negative	Inside – quiet periods interrupted by other noise sources Outside – rain, other noise sources
61	48.0	6.8	0	52.6	28.0	1	26.4	51.5	36.7	14.8	Negative	Inside – inaudible Outside – wind, natural background
62	47.9	7.3	0	51.0	22.0	0	27.9	52.6	36.5	15.6	Negative	Inside – inaudible Outside – machine noise (may be substation)

No.	Inside			Outside							Spectrum shape/blade pass frequency	Audio records (inside/outside where available)
	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	$L_{AF,90}$	L_{Ceq}	L_{Aeq}	$L_{Ceq}–L_{Aeq}$		
63	53.0	10.6	0	54.9	25.0	1	29.6	53.1	37.6	15.5	Negative	Inside – quiet periods interrupted by other noise sources Outside – cars, wildlife, natural background
64	49.9	6.3	0	51.7	35.5	1	27.8	51.2	36.9	14.3	Negative	Inside – mainly inaudible Outside – wildlife, machine noise, other noise sources
65	56.6	16.2	0	60.6	27.7	1	36.2	63.0	42.0	21.0	Negative	Inside – other noise sources Outside – wildlife, wind, other noise sources
66	56.9	23.3	0	64.5	31.7	1	50.5	60.3	55.3	15.0	Negative	Inside and outside – rain, wind noise
67	52.1	9.9	0	59.1	22.5	0	31.5	54.3	34.0	20.3	Negative	Inside – quiet periods interrupted by other noise sources Outside – wind, natural background.
68	47.9	12.1	0	56.3	25.8	1	32.8	57.0	41.3	15.7	Negative	Inside – inaudible Outside – wind, background, substation noise

No.	Inside			Outside							Spectrum shape/blade pass frequency	Audio records (inside/outside where available)
	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	$L_{AF,90}$	L_{Ceq}	L_{Aeq}	L_{Ceq}–L_{Aeq}		
69	47.6	6.9	0	58.6	23.1	0	29.3	48.2	29.9	18.3	Negative	Inside – other noise sources Outside – machine or substation noise
70	47.3	10.1	0	61.2	25.8	1	34.9	54.0	50.5	3.5	Negative	Inside – quiet or wildlife noise Outside – wildlife, machine and other noise sources
71	44.2	7.0	0	54.3	15.6	0	28.9	48.4	36.0	12.4	Negative	Inside – typically inaudible Outside – cattle, substation, other noise sources
72	55.8	13.9	0	62.0	27.4	1	35.5	56.5	39.5	17.0	Negative	Inside – quiet periods interrupted by other noise sources Outside – wind, wildlife
73	56.8	10.8	0	63.9	24.6	1	32.5	54.0	34.5	19.5	Negative	Inside – inaudible Outside – machine noise
74	54.2	16.1	0	61.5	29.2	1	33.8	62.8	43.3	19.5	Negative	Inside – mainly inaudible Outside – wind noise, wildlife

No.	Inside			Outside							Spectrum shape/blade pass frequency	Audio records (inside/outside where available)
	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	$L_{AF,90}$	L_{Ceq}	L_{Aeq}	L_{Ceq}–L_{Aeq}		
75	49.8	5.8	0	59.7	19.3	0	29.8	48.6	30.5	18.1	Negative	Inside – inaudible Outside – substation noise
76	48.9	12.1	0	57.4	27.2	1	29.2	50.6	38.7	11.9	Negative	Inside – inaudible Outside – substation noise, other noise sources
77	51.1	11.9	0	58.9	26.8	1	31.6	57.9	41.4	16.5	Negative	Inside – mainly inaudible Outside – wildlife, cars, machine and other noise sources
78	49.0	6.1	0	57.4	20.9	0	30.1	48.2	30.6	17.6	Negative	Inside – inaudible Outside – other noise sources and substation noises
79	50.2	16.1	0	58.8	34.2	1	35.2	58.2	46.0	18.2	Negative	Inside – other noise sources Outside – beeper alarm, wildlife
80	48.6	14.3	0	57.6	31.2	1	36.2	58.1	41.8	15.9	Negative	Inside – other noise sources Outside – cars, wildlife, beeper alarm, other noise sources

No.	Inside			Outside							Spectrum shape/blade pass frequency	Audio records (inside/outside where available)
	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	$L_{AF,90}$	L_{Ceq}	L_{Aeq}	L_{Ceq}–L_{Aeq}		
81	50.3	16.8	0	56.7	33.0	1	36.5	58.0	44.7	12.3	Negative	Inside – mainly inaudible Outside– wildlife, wind, cars
82	52.0	10.4	0	59.2	25.6	1	31.8	54.4	34.1	20.3	Negative	Inside – quiet periods or wind noise Outside – quiet periods, wind noise
83	55.0	18.9	0	61.8	35.3	1	32.7	54.4	45.2	9.2	Negative	Inside – mainly inaudible Outside – wildlife, beeper alarm, cars, substation
84	48–71.1	7.1–33.1	88%	53.2–84.0	21.0–46.8	3%	31.4–46.2	52.2–65.7	36–67.5	20–29.6	Negative	Inside – mainly inaudible Outside – wildlife, cars, beeper alarm, other noise sources
85	53.4–59.5	14.2–20.0	0	56.8–60.1	28.2–33.6	1	35.6–39.5	56.9–63.5	404.–47.9	9.6–23.2	Negative	Inside – other noise sources Outside – wildlife, wind, cars, other noise sources
86	51.5	4.2	0	58.8	18.2	0	31.9	46.1	33.4	12.7	Negative	Inside – inaudible Outside – dominated by substation noise

No.	Inside			Outside							Spectrum shape/blade pass frequency	Audio records (inside/outside where available)
	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	$L_{AF,90}$	L_{Ceq}	L_{Aeq}	L_{Ceq}–L_{Aeq}		
87	48.1	13.6	0	56.3	32.1	1	31.3	52.8	35.8	17.0	Negative	Inside – mainly inaudible Outside – wildlife, substation, other noise sources
88	56.1	2.0	0	61.9	20.3	0	29.9	46.7	31.2	15.5	Negative	Inside – mainly inaudible Outside – machine, substation noise
89	46.3	5.4	0	55.5	29.8	1	31.7	48.5	42.8	5.7	Negative	Inside – wildlife, other noise sources Outside – wildlife noise, cars
90	52.2–58.5	10.8–20.5	0	59.1–68.2	23.8–33.4	18%	33.6–43.7	60.5–68.5	42.0–51.5	12.3–24.1	Negative	Inside – quiet periods interrupted by other noise sources Outside – wind, wildlife, rain periods, other noise sources
91	42.2–59.6	3.2–23.1	0	52.1–73.2	18.4–35.9	62%	31.4–42.2	48.6–66.2	32.7–51.5	8.9–24.0	Negative	Inside – quiet periods interrupted by other noise sources Outside – wildlife, cattle, other noise sources

Appendix D North site records

Audio record analysis for the North site

Table 32 Wind speed and direction corresponding to diary return records, North site

No.	Resident	Neighbours	Date	Start time	End time	Wind			
						Local		Wind turbine generator	
						Speed, m/s	Direction, deg	Speed, m/s	Direction, deg
1	No	Yes	8/04/2013	13:10	15:20	1–1.7	81–108	8.3–10.6	81–112
2	No	Yes	12/04/2013	21:30	N/A	0.3	96	2.7	327
3	No	Yes	13/04/2013	10:00	N/A	1.9	293	14.8	306
4	No	Yes	15/04/2013	09.20	N/A	0.5	69	2.8	65
5	*Yes*	*Yes*	*16/04/2013*	*Neighb–17:30 Res–21:00*	*N/A*	*1.3;2.6*	*103;108*	*4.4;10.2*	*135;116*
6	*Yes*	*Yes*	*17/04/2013*	*17:30*	*N/A*	*1.0*	*92*	*8.5*	*118*
7	*Yes*	*No*	*18/04/2013*	*21:00*	*N/A*	*1.2*	*90*	*12.1*	*122*
8	Yes	No	19/04/2013	7:00	N/A	2.8	88	18.2	96
9	Yes	No	21/04/2013	22:30	N/A	0.4	241	10.2	258
10	Yes	No	22/04/2013	7:10	N/A	0.6	258	11.3	272
11	Yes	No	22/04/2013	18:00	19:00	0.5–0.6	215–239	9.4–10.9	280–282
12	Yes	No	23/04/2013	6:40	N/A	0.4	239	3.4	211
13	Yes	No	24/04/2013	21:00	N/A	0.2	241	8.6	236
14	*Yes*	*No*	*1/05/2013*	*23:30*	*N/A*	*2.1*	*116*	*11.2*	*116*
15	Yes	No	2/05/2013	6:00	N/A	0.8	123	8.6	53
16	Yes	No	5/05/2013	2:30	N/A	1.3	56	15.6	72
17	No	Yes	5/05/2013	15:30	N/A	1	56	9	67
18	Yes	No	6/05/2013	7:00	N/A	0.5	112	10.8	64
19	Yes	No	9/05/2013	1:30	N/A	0.7	131	11.2	34
20	*Yes*	*No*	*26/05/2013*	*N/A*	*24:00*	*1.7*	*90*	*11.1*	*100*

No.	Resident	Neighbours	Date	Start time	End time	Wind			
						Local		Wind turbine generator	
						Speed, m/s	Direction, deg	Speed, m/s	Direction, deg
21	*Yes*	*No*	*1/06/2013*	*19:00*	*N/A*	*1.5*	*201*	*7.8*	*186*
22	*Yes*	*No*	*2/06/2013*	*8:00*	*N/A*	*0.6*	*212*	*3.3*	*179*

Table 33 Acoustic descriptors and analysis of audio records for diary return entries, North site

No.	Inside			Outside							Spectrum shape/blade pass frequency	Audio records (inside/outside where available)
	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	$L_{AF,90}$	L_{Ceq}	L_{Aeq}	$L_{Ceq}–L_{Aeq}$		
1	53.0–65.4	5.1–16.9	0	52.6–59.9	16.5–35.3	0	23.6–30.0	52.0–60.1	32.1–42.2	14.9–23	Negative	Inside – household noise Outside – other noise sources
2	38.6	5.4	0	41.1	6.2	0	23.4	40.4	29.3	11.2	Negative	Inside – not audible Outside – other noise sources
3	66.4	22.0	0	56.4	33.1	1	43.0	59.8	47.6	12.2	Negative	Inside– not audible Outside – wildlife, other noise sources
4	46.3	17.1	0	43.0	21.8	1	26.2	47.8	43.8	4.0	Negative	Inside – household activities Outside – wildlife, other noise sources
5	*55.2; 61.0*	*9.8; 15.3*	*0*	*54.2; 57.3*	*22.9; 28.4*	*0; 1*	*28.4; 34.3*	*56.3; 57.6*	*50.2; 42.4*	*4.1; 15.2*	*Negative*	*Inside – household activities, other noise sources* *Outside – wildlife, other noise sources during day time, turbine noise with slight modulation in the evening*

No.	Inside			Outside							Spectrum shape/blade pass frequency	Audio records (inside/outside where available)
	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	$L_{AF,90}$	L_{Ceq}	L_{Aeq}	L_{Ceq}–L_{Aeq}		
6	*66.5*	*21.6*	*0*	*56.0*	*21.9*	*0*	*28.9*	*55.4*	*38.4*	*17*	*Negative*	*Inside – household noises Outside – wildlife, other noise sources, periodically turbine noise with slight modulation is audible*
7	*55.7*	*13.5*	*0*	*58.7*	*27.7*	*1*	*33.0*	*53.6*	*38.8*	*14.6*	*Negative*	*Inside – household noises Outside– turbine noise with slight modulation*
8	61.3	19.2	1	67.7	33.3	1	50.2	76.7	57.9	18.8	Negative	Inside – other noise sources Outside – wildlife, wind gusts, other noise sources
9	50.7	11.5	0	52.8	21.6	1	30.0	50.8	32.1	18.7	Negative	Inside– not audible Outside– other noise sources, natural background
10	47.5	11.7	0	52.5	26.3	1	35.2	54.7	48.5	6.2	Negative	Inside – not audible Outside – dominated by wildlife, other noise sources, airplane noise

No.	Inside			Outside							Spectrum shape/blade pass frequency	Audio records (inside/outside where available)
	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	$L_{AF,90}$	L_{Ceq}	L_{Aeq}	L_{Ceq}–L_{Aeq}		
11	46.4–62.1	10.7–18.1	0	51.4–60.6	20.0–34.4	0–1	31.2–35.7	52.3–55.8	38.6–51.5	4.3–9.2	Negative	Inside – household and other noise sources Outside – wildlife, shower in the adjacent area
12	57.7	6.5	0	53.3	19.1	0	53.8	54.6	59.5	N/A	Negative	Inside – wildlife noise Outside – wildlife and other noise sources
13	59.4	12.6	0	55.5	21.4	0	28.7	49.2	31.4	17.8	Negative	Inside – household noise Outside – other noise sources (most likely agricultural machine)
14	59.6	20.1	1	61.0	28.1	1	36.9	64.4	38.1	26.3	Negative	Inside – pump or other domestic machine noise Outside – dominated by vegetation noise, wind farm may be audible occasionally
15	53.4	11.5	0	56.4	24.1	0	36.1	50.2	43.5	16.8	Negative	Inside – not audible Outside – dominated by wildlife

No.	Inside			Outside							Spectrum shape/blade pass frequency	Audio records (inside/outside where available)
	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	Infrasound, dB(G)	$L_{pA,LF}$, dB(A)	DEFRA	$L_{AF,90}$	L_{Ceq}	L_{Aeq}	L_{Ceq}–L_{Aeq}		
16	55.1	20.6	0	56.0	25.9	1	42.6	58.2	44.1	14.1	Negative	Inside – other noise sources Outside – vegetation, wind noise
17	50.4	10.8	0	53.3	26.2	1	38.9	57.2	39.8	17.4	Negative	Inside – household activities Outside – other noise sources
18	51.0	12.8	0	54.8	27.9	1	32.5	56.0	59.1	N/A	Negative	Inside – other noise sources Outside – wildlife, other noise sources
19	53.5	18.9	0	52.8	20.1	0	33.9	55.0	36.8	18.2	Negative	Inside – pump or home appliances noise Outside – wildlife, other noise sources
20	*54.7*	*15.4*	*0*	*59.0*	*26.5*	*1*	*37.3*	*63.7*	*40.1*	*23.7*	*Negative*	*Inside – not audible* *Outside– vegetation noise, wind gusts, wind farm noise with slight modulation*

No.	**Inside**			**Outside**							**Spectrum shape/blade pass frequency**	**Audio records (inside/outside where available)**
	Infrasound, dB(G)	**$L_{pA,LF}$, dB(A)**	**DEFRA**	**Infrasound, dB(G)**	**$L_{pA,LF}$, dB(A)**	**DEFRA**	**$L_{AF,90}$**	**L_{Ceq}**	**L_{Aeq}**	**L_{Ceq}–L_{Aeq}**		
21	*63.9*	*20.3*	*1*	*66.5*	*34.1*	*1*	*40.0*	*61.7*	*41.6*	*20.1*	*Negative*	*Inside – household activities* *Outside – wind turbines with slight modulation, sound of rain in adjacent area*
22	*57.4*	*11.2*	*0*	*60.1*	*33.1*	*1*	*44.2*	*53.3*	*44.5*	*8.8*	*Negative*	*Inside – not audible* *Outside – wildlife noise with possible turbine noise as background*

Appendix E North East site records

Audio record analysis for the North East site

Table 34 Wind speed and direction corresponding to diary return records, North East site

No.	Resident	Neighbours	Date	Start time	End time	Wind			
						Local		Wind turbine generator	
						Speed, m/s	Direction, deg	Speed, m/s	Direction, deg
1	Yes	No	14/04/2013	04:00	11:00	N/A	N/A	3.2– 8.0	227.0– 331.0
2	No	Yes	22/04/2013	17:30	N/A	4.6	265.5	13.7	270.8
3	Yes	No	02/05/2013	12:30	21:15	1.9– 6.5	25.4– 47.6	8.7– 11.5	21.3– 44.1
4	Yes	No	03/05/2013	19:30	N/A	0.3	119.6	11.8	286.4

Table 35 Acoustic descriptors and analysis of audio records for diary return entries, North East site

No.	Inside				Outside						Spectrum shape/blade pass frequency	Audio records (inside/outside where available)
	L_{Aeq}, dB(A)	L_{Ceq}, dB(C)	$L_{pA,LF}$, dB(A)	DEFRA	L_{Ceq}, dB(C)	DEFRA	L_{Ceq}– L_{Aeq}	$L_{AF,90}$, dB(A)	$L_{pA,LF}$, dB(A)	DEFRA		
1	24.2–61.7	36.3 –63.4	4.6–39.0	86%	21.8–55.4	40.3–72.2	–1.3–26.7	20.9–34.7	14.9–53.3	69%	Negative	Inside – other noise sources, household noise Outside – wildlife, vehicle, wind nose
2	61.9	62.4	29.2	0%	46.4	70.3	23.9	37.3	40.6	0%	Negative	Inside – other noise sources, household noise Outside – wind noise
3	27.3–67.9	41.9–67.2	11.4–36.5	45%	35.7–51.4	59.0–76.4	13.0–26.6	28.8–43.8	29.7–47.3	0%	Negative	Inside – other noise sources, household noise Outside – wildlife, high wind, flyover noise
4	31.4	47.0	17.4	0%	41.7	56.8	15.2	30.7	31.6	0%	Negative	Inside – other noise sources, household noise Outside – flyover, wind noise

Appendix F West site records

Audio record analysis for the West site

Table 36 Wind speed and direction corresponding to diary return records, West site

No.	Resident	Neighbours	Date	Start time	End time	Wind			
						Local		Wind turbine generator	
						Speed, m/s	Direction, deg	Speed, m/s	Direction, deg
1	Yes	No	11/04/2013	1:16	N/A	2.3	167.2	10.3	111.3
2	Yes	No	11/04/2013	5:26	N/A	5.0	94.1	8.3	93.5
3	Yes	No	11/04/2013	17:40	18:30	3.0–3.8	110.6–117.6	7.2–7.7	113.4–116.9
4	Yes	Yes	11/04/2013	21:00	N/A	5.4	125.6	7.3	130.2
5	No	Yes	11/04/2013	21:30	N/A	5.4	126.8	10.0	126.8
6	Yes	No	12/04/2013	1:20	N/A	6.6	100.7	13.9	102.2
7	Yes	No	12/04/2013	5:11	N/A	4.8	76.7	8.7	55.4
8	Yes	No	14/04/2013	21:57	N/A	1.0	178.5	3.6	184.7
9	Yes	Yes	15/04/2013	21:30	N/A	3.0	134.5	6.1	141.3
10	Yes	Yes	16/04/2013	7:00	N/A	2.0	131.2	6.2	111.7
11	Yes	No	16/04/2013	17:45	N/A	1.8	127.6	4.4	108.1
12	Yes	Yes	16/04/2013	21:30	N/A	5.2	112.3	7.6	109.6
13	Yes	No	17/04/2013	7:00	N/A	5.0	91.4	6.0	85.3
14	Yes	Yes	17/04/2013	19:30	N/A	4.6	128.1	9.0	121.4
15	Yes	No	18/04/2013	6:26	N/A	6.6	96.6	9.5	96.9
16	Yes	Yes	18/04/2013	20:00	6:30	3.7–10.4	78.3–121.5	7.1–18.4	86.1–123.7
17	Yes	No	19/04/2013	17:40	N/A	0.7	122.7	8.0	90.1
18	Yes	Yes	19/04/2013	19:00	8:00	2.2– 8.5	32.6– 76.6	4.7 – 15.8	46.3– 76.5
19	Yes	Yes	20/04/2013	8:00	10:30	2.7– 6.4	32.4– 64.5	8.9– 15.9	44.0– 54.0
20	Yes	No	20/04/2013	23:13	N/A	4.1	42.4	10.8	31.4

No.	Resident	Neighbours	Date	Start time	End time	Wind			
						Local		Wind turbine generator	
						Speed, m/s	Direction, deg	Speed, m/s	Direction, deg
21	Yes	No	21/04/2013	22:49	N/A	3.6	253.4	10.3	256.7
22	Yes	No	22/04/2013	2:26	N/A	3.4	252.5	13.5	251.7
23	Yes	No	23/04/2013	6:28	N/A	2.6	176.8	5.2	201.9
24	Yes	No	23/04/2013	19:20	N/A	0.2	202.0	3.5	254.9
25	Yes	No	26/04/2013	7:15	N/A	0.6	331.3	5.5	286.2
26	Yes	No	29/04/2013	6:26	N/A	1.0	66.2	4.9	323.5
27	Yes	Yes	29/04/2013	20:00	N/A	4.6	108.5	9.4	70.2
28	Yes	No	30/04/2013	6:33	N/A	2.8	97.2	6.1	52.4
29	Yes	No	01/05/2013	5:06	N/A	1.7	206.2	3.4	200.9
30	Yes	No	01/05/2013	6:45	N/A	0.9	187.1	7.2	203.0
31	Yes	Yes	01/05/2013	18:30	10:00	1.0– 9.3	75.2–171.1	7.5–17.6	49.9–142.6
32	Yes	No	04/05/2013	11:27	N/A	7.3	114.4	10.4	102.4
33	Yes	No	04/05/2013	18:02	N/A	3.5	109.2	7.2	88.9
34	Yes	Yes	04/05/2013	19:00	7:00	5.1–8.6	83.5–116.1	9.0–14.6	58.8–99.1
35	No	Yes	05/05/2013	09:00	N/A	6.3	88.7	7.6	60.1
36	Yes	No	05/05/2013	19:50	N/A	4.2	94.5	9.8	77.5
37	Yes	No	06/05/2013	1:03	N/A	7.0	81.5	9.9	54.2
38	Yes	No	06/05/2013	5:06	N/A	8.6	80.5	13.8	51.4
39	Yes	No	06/05/2013	17:20	N/A	7.2	77.4	14.2	48.2
40	Yes	No	06/05/2013	18:00	N/A	7.9	81.2	9.1	47.4
41	Yes	No	07/05/2013	12:08	N/A	3.7	310.9	6.8	308
42	Yes	No	07/05/2013	21:48	N/A	3.5	69.9	7.4	38.1
43	Yes	No	08/05/2013	4:06	N/A	1.8	57.8	6.1	356.7
44	No	Yes	08/05/2013	6:30	N/A	1.5	345.3	13	347.2
45	Yes	No	08/05/2013	12:01	N/A	4.1	64.3	8.2	30.6

No.	Resident	Neighbours	Date	Start time	End time	Wind			
						Local		Wind turbine generator	
						Speed, m/s	Direction, deg	Speed, m/s	Direction, deg
46	Yes	No	08/05/2013	18:25	N/A	4.1	76.0	10.3	52.7
47	Yes	Yes	08/05/2013	19:00	9:00	2.4–5.6	60.8–83.3	4.8–13.5	17.1–56.3
48	Yes	Yes	09/05/2013	21:00	N/A	2.4	55.3	10.2	24.9
49	Yes	No	10/05/2013	1:06	N/A	4.5	75.4	7.6	33.3
50	Yes	No	10/05/2013	5:06	N/A	1.9	31.5	4.6	0.2
51	No	Yes	10/05/2013	21:00	N/A	1.4	34.6	4.5	9.6
52	Yes	No	10/05/2013	21:33	N/A	2.0	61.2	4.3	17
53	Yes	No	11/05/2013	1:08	N/A	2.9	61.3	9.7	18.4
54	Yes	No	15/05/2013	5:26	N/A	4.5	270.0	11.7	255.5
55	No	Yes	15/05/2013	10:00	N/A	2.8	259.4	11.5	245.4
56	No	Yes	16/05/2013	21:00	N/A	1.4	240.9	6.5	222.7
57	Yes	No	19/05/2013	2:26	N/A	0.5	29.6	6.1	326.9
58	No	Yes	19/05/2013	3:00	4:30	0.5–0.9	344.4–29.8	7.7–12.0	304.0–316.2
59	Yes	No	19/05/2013	5:56	N/A	0.7	14.6	12.8	300.1
60	Yes	Yes	20/05/2013	0:30	2:30	4.3–6.3	306.8–316.9	9.6–12.1	289.1–298.5
61	Yes	No	20/05/2013	4:46	N/A	1.6	349.9	9.9	323.0
62	Yes	No	20/05/2013	6:47	N/A	2.6	340.6	16.1	316.7
63	Yes	No	21/05/2013	7:28	N/A	1.2	48.8	6.5	349.8
64	Yes	No	21/05/2013	19:20	N/A	5.0	60.8	16.2	31.1
65	No	Yes	22/05/2013	3:00	4:00	3.5–4.3	90.7–99.9	6.7–8.3	63.9–72.6
66	Yes	No	22/05/2013	5:56	N/A	3.9	88.5	7.6	63
67	*Yes*	*No*	*23/05/2013*	*1:54*	*N/A*	*5.1*	*155.8*	*12.7*	*128.3*
68	*Yes*	*No*	*23/05/2013*	*4:56*	*N/A*	*4.7*	*162.0*	*10.6*	*137.5*
69	*Yes*	*Yes*	*23/05/2013*	*6:00*	*7:30*	*3.0–4.4*	*149.2–165.3*	*10.3–12.9*	*117.6–130.1*

No.	Resident	Neighbours	Date	Start time	End time	Wind			
						Local		Wind turbine generator	
						Speed, m/s	Direction, deg	Speed, m/s	Direction, deg
70	Yes	No	23/05/2013	10:00	N/A	4.3	182.4	6.1	152.1
71	Yes	No	24/05/2013	0:00	N/A	2.1	184.9	8.0	150.7
72	*Yes*	*No*	*24/05/2013*	*3:58*	*N/A*	*2.2*	*199.3*	*7.5*	*144.5*
73	*Yes*	*No*	*24/05/2013*	*5:56*	*N/A*	*0.9*	*166.5*	*6.7*	*140.3*
74	Yes	No	24/05/2013	8:45	N/A	1.8	194.0	3.3	150.5
75	Yes	No	24/05/2013	10:35	N/A	2.8	197.4	2.9	166.3
76	Yes	No	24/05/2013	12:35	N/A	3.1	187.4	4.8	185.9
77	Yes	No	24/05/2013	18:10	N/A	1.9	201.3	4.3	205.5
78	Yes	No	25/05/2013	17:40	N/A	0.8	225.4	4.5	222.1
79	Yes	No	26/05/2013	5:56	N/A	1.1	178.9	2.5	176.8
80	Yes	No	26/05/2013	8:05	N/A	1.6	191.8	2.8	148.5
81	Yes	No	26/05/2013	17:30	N/A	1.9	140.6	4.8	122.9
82	Yes	No	26/05/2013	19:30	N/A	2.8	127.0	5.9	119.9
83	Yes	Yes	26/05/2013	21:00	22:30	3.3–5.3	125.7–138.4	6.8–10.9	110.4–132.4
84	*Yes*	*No*	*27/05/2013*	*1:18*	*N/A*	*5.0*	*106.6*	*9.1*	*99*
85	Yes	No	27/05/2013	5:56	N/A	4.8	79.3	7.8	55.6
86	Yes	No	27/05/2013	8:45	N/A	4.5	81.3	7.2	56.2
87	Yes	No	27/05/2013	12:45	N/A	4.1	79.5	5.1	46.4
88	Yes	No	27/05/2013	17:40	N/A	3.3	87.5	7.1	60.3
89	No	Yes	27/05/2013	20:30	22:15	1.8–3.1	76.1–106.2	5.8–8.7	51.9–79.3
90	No	Yes	28/05/2013	0:00	7:00	1.1–3.9	38.4–84.3	4.1–9.6	17.9–55.8
91	Yes	No	28/05/2013	17:40	N/A	2.1	70.3	5.7	43.4
92	No	Yes	28/05/2013	23:00	0:00	1.3–2.2	27.2– 42.9	4.7–5.1	355.9–13.5
93	Yes	No	30/05/2013	5:56	N/A	1.2	35.7	7.8	326.6

No.	Resident	Neighbours	Date	Start time	End time	Wind			
						Local		Wind turbine generator	
						Speed, m/s	Direction, deg	Speed, m/s	Direction, deg
94	No	Yes	01/06/2013	4:00	6:30	3.1–6.3	306.3–326.1	13.3–17.8	296.6–307.7
95	No	Yes	01/06/2013	20:00	N/A	9.3	196.7	10.6	184.6
96	No	Yes	02/06/2013	20:00	N/A	1.3	181.6	5.9	183.2
97	No	Yes	05/06/2013	6:00	9:00	0.9–4.2	159.1–190.9	2.4–3.8	163.5–190.7
98	No	Yes	12/06/2013	17:30	N/A	5.3	199.8	9.7	193.6
99	No	Yes	14/06/2013	6:00	N/A	2.6	199.0	10.4	191.5
100	No	Yes	14/06/2013	21:00	N/A	1.2	180.7	5.4	178.3

Table 37 Summary of acoustic descriptors and audio record analysis for diary return entries, West site

No.	Inside				Outside						Spectrum shape	Audio records (inside/outside where available)
	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{pA,LF}$, dB(A)	DEFRA	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{Ceq} - L_{Aeq}$	$L_{AF,90}$	$L_{pA,LF}$, dB(A)	DEFRA		
1	24.7	45.3	15.8	0%	31.6	60.3	28.6	29.0	25.9	0%	Negative	Inside – no noise heard Outside – wind noise
2	23.2	44.3	15.2	100%	44.2	69.7	25.5	40.9	36.9	0%	Negative	Inside – no audio recording Outside – high wind noise
3	25.5–40.5	41.1–44.8	13.5–21.6	80%	39.8–67.5	57.9–69.9	2.4–24.0	30.3–40.3	26.1–39.2	0%	Negative	Inside and outside – dog barking
4	23.7	47.3	17.4	0%	47.8	75.7	27.9	42.8	42.3	0%	Negative	Inside – no audio recording Outside – wind noise
5	24.8	50.1	20.0	0%	47.5	75.8	28.3	43.1	42.3	0%	Negative	Inside – no noise heard Outside – high wind noise
6	27.4	52.5	23.0	0%	52.8	77.3	24.5	48.5	45.8	0%	50Hz peak inside	Inside – no noise heard Outside – wind noise
7	22.9	44.6	15.2	100%	45.7	68.9	23.2	43.1	34.9	0%	Negative	Inside – no noise heard Outside – wind noise
8	24.6	44.6	14.1	100%	24.1	46.4	22.4	22.1	14.8	100%	Negative	Inside and outside – no audio recordings
9	22.8	41.6	12.0	100%	31.7	61.7	30.0	28.7	26.2	0%	Negative	Inside and outside – no audio recordings
10	24.6	42.4	13.3	100%	29.6	53.0	3.3	37.0	24.3	0%	Negative	Inside – household noise Outside – wildlife noise

No.	Inside				Outside						Spectrum shape	Audio records (inside/outside where available)
	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{pA,LF}$, dB(A)	DEFRA	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{Ceq} - L_{Aeq}$	$L_{AF,90}$	$L_{pA,LF}$, dB(A)	DEFRA		
11	23.9	42.7	10.8	100%	34.3	49.5	15.3	23.5	19.5	100%	Negative	Inside – no audio recordings Outside – wind noise
12	27.0	48.5	18.9	100%	47.9	74.2	26.3	41.1	41.4	0%	Negative	Inside – no audio recordings Outside – high wind noise
13	23.6	43.0	13.8	100%	51.5	68.8	17.3	41.8	36.1	0%	Negative	Inside – no noise heard Outside – high wind noise
14	26.1	48.0	17.7	0%	44.4	74.6	30.2	38.2	39.9	0%	Negative	Inside – household noise Outside – high wind noise
15	25.9	50.4	20.5	0%	54.6	77.8	23.2	46.8	47.2	0%	Negative	Inside – Wind noise Outside – high wind noise
16	24.4–37.3	50.4–63.4	20.6–32.4	0%	46.1–68.1	73.8–87.8	19.6–27.5	43.3–60.7	40.7–59.2	0%	50Hz peak inside	Inside – no noise heard Outside – high wind noise
17	26.2	43.0	11.1	100%	32.7	48.9	16.1	26.1	20.7	100%	Negative	Inside – no noise heard Outside – machinery noise
18	22.8–34.0	39.4–60.7	9.3–29.9	10%	29.5–61.9	53.5–83.5	18.8–25.5	25.6–56.8	21.2–53.5	1%	50Hz peak inside	Inside – wind noise Outside – high wind noise
19	24.4–37.5	47.7–60.9	18.1–31.8	7%	46.1– 64.6	64.9–83.0	18.3–22.3	45.1– 59.6	33.2– 52.5	0%	Negative	Inside – wind noise Outside – high wind noise
20	39.6	51.0	24.3	0%	47.3	71.1	23.8	43.5	38.9	0%	Negative	Inside – no noise heard Outside – wind noise

No.	Inside				Outside						Spectrum shape	Audio records (inside/outside where available)
	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{pA,LF}$, dB(A)	DEFRA	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{Ceq} - L_{Aeq}$	$L_{AF,90}$	$L_{pA,LF}$, dB(A)	DEFRA		
21	22.6	38.8	9.1	100%	45.1	69.1	24.0	37.4	43.2	0%	100Hz peak outside	Inside – no noise heard Outside – wind noise
22	23.2	42.3	12.7	100%	49.9	72.9	23.0	42.9	47.8	0%	Negative	Inside – no noise heard Outside – high wind noise
23	25.1	44.2	13.0	100%	44.8	56.3	11.6	32.9	25.6	0%	Negative	Inside – no noise heard Outside – wildlife noise
24	26.1	44.5	14.4	100%	23.2	39.2	16.0	21.5	12.4	100%	Negative	Inside – household noise Outside – dog barking
25	24.1	39.7	12.3	100%	51.9	51.6	-0.3	34.5	19.2	100%	Negative	Inside – no audio recordings Outside – wildlife noise
26	24.2	33.7	7.0	100%	39.7	42.7	3.0	27.1	17.7	100%	Negative	Inside – no noise heard Outside – wildlife noise
27	24.3	47.1	17.4	100%	46.5	71.7	25.3	40.0	40.4	0%	Negative	Inside – no audio recordings Outside – wind noise
28	25.1	43.7	14.4	100%	54.2	58.3	4.1	31.8	26.5	0%	Negative	Inside – no audio recordings Outside – wind, wildlife noise
29	20.8	33.9	2.7	100%	29.4	58.3	28.9	21.8	26.4	0%	Negative	Inside and outside – no audio recordings

No.	Inside				Outside						Spectrum shape	Audio records (inside/outside where available)
	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{pA,LF}$, dB(A)	DEFRA	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{Ceq} - L_{Aeq}$	$L_{AF,90}$	$L_{pA,LF}$, dB(A)	DEFRA		
30	26.1	42.8	13.4	100%	57.8	56.8	-0.8	42.0	17.7	100%	Negative	Inside – no audio recordings Outside – wildlife noise
31	23.8–41.8	36.7–66.6	8.1–36.9	10%	27.7–70.3	51.9–87.9	16.2–31.1	26.7–65.8	22.1–58.8	2%	50Hz peak inside	Inside – no noise heard Outside – wind noise
32	31.1	56.7	26.0	0%	59.7	82.3	22.6	50.4	53.2	0%	Negative	Inside – wind noise Outside – High wind noise
33	29.4	46.7	16.7	100%	41.1	64.6	23.5	32.8	31.5	0%	Negative	Inside and outside – wind noise
34	28.7–36.8	53.1–60.7	23.4–31.4	0%	49.0–64.0	74.0–85.0	21.0–25.0	43.0–57.8	42.1–55.9	0%	Negative	Inside – no noise heard Outside – nigh wind noise
35	29.9	55.2	25.4	0%	55.6	78.3	22.7	50.5	47.4	0%	Negative	Inside – wind noise Outside – high wind noise
36	26.6	49.6	19.7	0%	47.4	71.2	23.8	41.2	38.4	0%	Negative	Inside – no audio recordings Outside – wind noise
37	28.3	52.8	23.6	0%	55.0	78.1	23.1	48.8	48.1	0%	Negative	Inside – no noise heard Outside – high wind noise
38	32.6	57.0	27.8	0%	60.6	81.9	21.3	55.2	52.7	0%	Negative	Inside – wind noise Outside – high wind noise
39	30.1	52.1	22.9	0%	54.2	76.3	22.0	49.4	46.1	0%	Negative	Inside – wind noise Outside – high wind noise

No.	Inside				Outside						Spectrum shape	Audio records (inside/outside where available)
	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{pA,LF}$, dB(A)	DEFRA	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{Ceq} - L_{Aeq}$	$L_{AF,90}$	$L_{pA,LF}$, dB(A)	DEFRA		
40	32.2	54.8	26.4	0%	58.8	80.2	21.5	53.1	50.8	0%	Negative	Inside – wind noise Outside – high wind noise
41	22.6	38.4	11.6	100%	42.7	67.4	24.7	33.8	35.9	0%	Negative	Inside –household noise Outside – wind Noise
42	32.1	38.0	5.9	100%	33.7	54.5	20.8	31.5	23.4	100%	Negative	Inside and outside – no audio recordings
43	21.0	37.6	6.4	100%	32.6	46.7	14.1	30.1	18.6	100%	Negative	Inside and outside – no audio recordings
44	26.1	43.0	14.2	100%	38.5	50.4	11.8	28.3	20.8	0%	Negative	Inside –household noise Outside – flyover noise, wildlife noise
45	40.2	51.8	30.3	0%	59.8	70.7	10.9	40.7	48.6	0%	Negative	Inside – household noise Outside – wind noise
46	23.7	44.5	15.0	100%	38.5	61.2	22.7	35.1	29.9	0%	Negative	Inside – household noise Outside – no audio recordings
47	23.2–34.4	40.0–47.6	10.5–18.6	60%	30.9–53.3	52.5–68.8	15.5–24.2	29.0–47.4	22.5–37.4	0%	50Hz peak inside	Inside – no noise heard Outside – wind noise
48	28.7	42.5	14.2	100%	42.9	54.3	11.4	39.2	26.9	0%	Negative	Inside – no audio recording Outside – truck noise
49	29.2	40.5	11.8	100%	40.5	63.7	23.2	37.0	32.1	0%	Negative	Inside and outside – no noise heard

No.	Inside				Outside						Spectrum shape	Audio records (inside/outside where available)
	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{pA,LF}$, dB(A)	DEFRA	L_{Aeq} dB(A)	L_{Ceq} dB(C)	L_{Ceq} – L_{Aeq}	$L_{AF,90}$	$L_{pA,LF}$, dB(A)	DEFRA		
50	24.3	42.8	13.4	100%	37.4	51.2	13.8	32.2	22.7	0%	Negative	Inside – no noise heard Outside – wind noise
51	22.7	38.2	8.8	100%	29.7	45.0	15.3	26.9	16.5	100%	Negative	Inside and outside – no audio recordings
52	23.7	42.5	13.6	100%	35.5	49.5	13.9	29.5	21.0	100%	Negative	Inside and outside – no audio recordings
53	23.4	45.2	14.8	100%	43.3	58.8	15.5	39.4	29.1	0%	Negative	Inside – no noise heard Outside – wind noise
54	23.0	38.8	10.4	100%	46.7	71.1	24.4	39.3	45.6	0%	Negative	Inside and outside – No noise heard
55	29.6	47.0	17.7	100%	51.7	74.6	22.9	43.5	49.9	0%	Negative	Inside and outside – No noise heard
56	27.4	38.4	13.0	100%	32.8	51.8	19.1	21.8	25.7	0%	Negative	Inside –household noise Outside – no audio recordings
57	23.0	38.4	8.3	100%	32.7	41.7	9.0	21.4	9.4	100%	Negative	Inside and outside – dog barking
58	20.7–24.6	32.1–38.1	2.4–9.4	100%	21.8–24.4	42.6–47.6	20.9–24.6	21.0–22.6	9.0–17.8	60%	Negative	Inside and outside – no audio recordings
59	22.3	40.8	12.8	100%	25.3	49.2	23.9	23.2	19.7	0%	Negative	Inside –household noise

No.	Inside				Outside						Spectrum shape	Audio records (inside/outside where available)
	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{pA,LF}$, dB(A)	DEFRA	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{Ceq} - L_{Aeq}$	$L_{AF,90}$	$L_{pA,LF}$, dB(A)	DEFRA		
60	28.4–39.6	46.7–52.5	18.2–27.0	62%	51.6–56.8	74.5–81.4	22.6–25.5	46.0–51.0	43.7–51.4	0%	Negative	Inside and outside – no audio recordings
61	20.8	34.6	4.0	100%	28.7	47.3	18.6	27.4	16.1	100%	Negative	Inside – household noise Outside – wind noise
62	24.4	41.7	12.3	100%	49.5	56.7	7.2	35.6	26.2	0%	Negative	Inside – no audio recordings Outside – wind, rain, wildlife noise
63	23.3	36.5	6.9	100%	44.3	46.1	1.8	29.9	16.3	100%	Negative	Inside – no audio recordings Outside – wildlife noise
64	29.8	50.5	21.5	0%	57.7	72.3	14.6	51.8	43.2	0%	Negative	Inside – no noise heard Outside – wind noise
65	23.5–26.6	42.7–48.2	13.3–18.1	100%	40.6–46.9	65.0–71.7	23.9–24.8	36.4–41.7	33.5–42.5	0%	Negative	Inside – no noise heard Outside – wind noise
66	24.4	44.6	15.4	100%	44.5	69.0	24.5	38.6	40.1	0%	Negative	Inside – no noise heard Outside – wind noise
67	*28.3*	*52.1*	*22.5*	*0%*	*55.6*	*68.2*	*27.7*	*49.7*	*51.2*	*0%*	*50Hz peak inside*	*Inside – slight rumbling at very high amplification. Possible wind turbine generator noise.* *Outside – wind noise*

No.	Inside				Outside						Spectrum shape	Audio records (inside/outside where available)
	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{pA,LF}$, dB(A)	DEFRA	L_{Aeq} dB(A)	L_{Ceq} dB(C)	L_{Ceq} – L_{Aeq}	$L_{AF,90}$	$L_{pA,LF}$, dB(A)	DEFRA		
68	*27.8*	*51.6*	*22.0*	*0%*	*54.8*	*83.0*	*28.2*	*48.3*	*50.4*	*0%*	*50Hz peak inside*	*Inside – slight rumbling at very high amplification. Possible wind turbine generator noise. Outside – high wind noise*
69	*27.9–29.2*	*51.5–54.4*	*21.5–24.9*	*0%*	*48.1–55.1*	*70.6–79.6*	*15.5–29.1*	*40.5–45.4*	*37.4–47.7*	*0%*	*50Hz peak inside*	*Inside – slight rumbling/modulation at high amplification. Possible wind turbine generator noise Outside – high wind noise*
70	27.3	45.2	16.1	100%	52.7	77.4	24.7	43.0	41.4	0%	Negative	Inside – household noise Outside – wind noise
71	22.7	42.7	12.5	100%	28.7	54.6	25.8	27.8	23.3	0%	Negative	Inside – no noise heard Outside – no audio recordings
72	*22.3*	*39.2*	*8.6*	*100%*	*26.5*	*50.9*	*24.4*	*25.7*	*20.4*	*100%*	*Negative*	*Inside – slight modulation at high amplification. Possible wind turbine generator noise. Outside – no audio recordings*
73	*23.0*	*42.5*	*11.1*	*100%*	*25.5*	*49.8*	*24.3*	*24.3*	*19.5*	*100%*	*Negative*	*Inside – slight modulation at high amplification. Possible wind turbine generator noise Outside – wildlife noise*

No.	Inside				Outside						Spectrum shape	Audio records (inside/outside where available)
	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{pA,LF}$, dB(A)	DEFRA	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{Ceq} - L_{Aeq}$	$L_{AF,90}$	$L_{pA,LF}$, dB(A)	DEFRA		
74	25.4	44.4	14.0	100%	46.1	53.5	7.3	31.2	22.2	100%	Negative	Inside – household noise Outside – wildlife noise
75	24.4	40.8	9.8	100%	47.6	61.8	14.2	34.4	25.5	0%	Negative	Inside – household noise Outside – wildlife noise
76	40.9	52.8	27.6	0%	43.6	68.7	25.0	32.6	31.6	0%	Negative	Inside – household noise Outside – wildlife, wind noise
77	30.0	46.7	17.3	100%	26.7	48.1	21.3	24.2	17.5	100%	Negative	Inside – household noise Outside – no audio recordings
78	32.4	50.5	29.8	0%	49.4	62.9	13.5	33.8	43.5	0%	63Hz peak Outside	Inside – mechanical noise. Outside – mechanical noise, sounds like a motor
79	20.8	28.2	-0.6	100%	36.4	38.1	1.7	20.8	4.5	100%	Negative	Inside – household noise Outside – wildlife noise
80	24.1	35.7	6.2	100%	47.8	49.2	1.4	34.1	15.1	100%	Negative	Inside – grinding sound Outside – wildlife noise
81	24.1	43.8	13.3	100%	37.8	57.8	20.0	25.9	24.2	0%	Negative	Inside – household noise Outside – wildlife noise
82	27.6	39.9	10.1	100%	34.8	61.8	26.9	29.8	28.5	0%	Negative	Inside – household noise Outside – no audio recordings

No.	Inside				Outside						Spectrum shape	Audio records (inside/outside where available)
	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{pA,LF}$, dB(A)	DEFRA	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{Ceq} - L_{Aeq}$	$L_{AF,90}$	$L_{pA,LF}$, dB(A)	DEFRA		
83	23.7–27.5	47.0–50.2	17.0–20.1	44%	44.9–54.5	72.3–79.2	24.6–27.4	40.4–50.4	39.1–48.2	0%	Negative	Inside – household noise Outside – wind noise
84	*24.7*	*49.7*	*19.3*	*0%*	*46.5*	*71.9*	*25.4*	*43.1*	*38.9*	*0%*	*50Hz peak inside*	*Inside – slight modulation heard at high amplification. Possible wind turbine generator noise.* *Outside – wind noise*
85	22.3	44.3	14.4	100%	42.9	68.4	25.4	38.4	36.3	0%	Negative	Inside – no noise heard Outside – wind noise
86	52.8	56.9	29.0	0%	47.3	59.8	22.6	37.8	37.8	0%	Negative	Inside – household noise Outside – wind noise
87	27.5	44.7	15.3	100%	53.1	65.7	12.6	36.6	33.2	0%	Negative	Inside – household noise Outside – wildlife, wind noise
88	27.4	43.2	13.0	100%	43.1	64.1	21.0	34.9	30.6	0%	Negative	Inside – household noise Outside – wildlife, wind noise
89	21.1–28.1	41.3–47.0	8.0–17.1	100%	26.2–37.1	48.2–62.1	17.4–25.7	24.6–31.5	18.5–24.6	73%	Negative	Inside – household noise Outside – flyover noise?
90	20.8–24.0	36.3–44.4	4.3 –13.6	100%	27.6–46.2	46.3–63.5	2.0–25.6	26.0–35.9	17.1–31.2	71%	Negative	Inside – no noise heard Outside – wind noise
91	N/A	N/A	N/A	N/A	35.2	47.2	11.9	24.0	17.7	100%	Negative	Outside – wildlife noise
92	N/A	N/A	N/A	N/A	30.4–37.4	49.3–51.9	14.5–19.9	27.7–31.0	20.2–23.0	0%	Negative	Outside – wind noise

No.	Inside				Outside						Spectrum shape	Audio records (inside/outside where available)
	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{pA,LF}$, dB(A)	DEFRA	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{Ceq} - L_{Aeq}$	$L_{AF,90}$	$L_{pA,LF}$, dB(A)	DEFRA		
93	N/A	N/A	N/A	N/A	35.9	42.4	6.5	24.7	14.5	100%	Negative	Outside – rain
94	N/A	N/A	N/A	N/A	47.9–60.7	67.1–82.7	18.7–22.5	43.7–54.4	38.1–56.5	0%	Negative	Outside – mostly high wind noise
95	N/A	N/A	N/A	N/A	64.0	90.8	26.8	58.6	59.2	0%	Negative	Outside – very high wind noise
96	N/A	N/A	N/A	N/A	25.4	48.5	23.1	24.4	20.8	100%	Negative	Outside – no audio recordings
97	N/A	N/A	N/A	N/A	31.8–50.4	47.8–63.0	1.0–31.2	23.6–39.2	15.5–26.3	61%	Negative	Outside – wildlife, wind noise
98	N/A	N/A	N/A	N/A	48.0	75.8	27.9	43.9	40.7	0%	Negative	Outside – wind noise
99	N/A	N/A	N/A	N/A	32.0	60.1	28.1	30.2	27.7	0%	Negative	Outside – wind noise
100	N/A	N/A	N/A	N/A	26.4	51.4	24.9	25.4	23.4	0%	Negative	Outside – no audio recordings

Appendix G South East site records

Audio record analysis for the South East site

Table 38 Wind speed and direction corresponding to diary return records, South East site

No.	Resident	Neighbours	Date	Start time	End time	Wind			
						Local		Wind turbine generator	
						Speed, m/s	Direction, deg	Speed, m/s	Direction, deg
1	Yes	No	12/04/2013	13:30	15:00	1.4–2.7	35.7–110.0	2.9–3.6	53.6–115.2
2	Yes	Yes	13/04/2013	1:00	6:00	1.2–2.4	335.9–352.7	12.3–15.4	309.3–327.6
3	Yes	Yes	13/04/2013	8:00	N/A	2.5	332.7	12.5	307.9
4	Yes	No	13/04/2013	17:00	N/A	2.3	288.6	9.1	284.5
5	Yes	No	14/04/2013	11:00	N/A	2.2	241.3	9.6	245.9
6	No	Yes	14/04/2013	12:00	18:00	1.5–3.4	187.3–258.5	6.2–11.0	202.5–251.8
7	*Yes*	*No*	*21/04/2013*	*4:00*	*N/A*	*2.1*	*353.2*	*8.5*	*332.4*
8	*Yes*	*No*	*21/04/2013*	*6:00*	*N/A*	*1.5*	*39.5*	*11.1*	*312.8*
9	Yes	No	21/04/2013	11:00	N/A	4.6	314.9	17.4	309.3
10	Yes	No	21/04/2013	18:00	N/A	2.7	228.0	17.5	241.6
11	Yes	No	21/04/2013	21:00	N/A	1.9	195.9	9.4	13.5
12	*Yes*	*No*	*22/04/2013*	*3:30*	*N/A*	*1.5*	*220.8*	*8.3*	*239.0*
13	Yes	No	22/04/2013	5:30	N/A	1.6	259.1	10.0	262.7
14	Yes	Yes	22/04/2013	9:00	N/A	2.3	260.1	10.7	261.7
15	Yes	No	22/04/2013	12:00	N/A	3.5	264.2	12.0	265.9
16	Yes	No	22/04/2013	18:00	N/A	2.1	276.8	10.8	273.1
17	Yes	No	22/04/2013	21:00	N/A	2.4	228.3	13.6	255.9
18	Yes	No	22/04/2013	21.40	23:00	2.1–5.2	174.9–209.0	9.7–12.0	216.3–246.2
19	Yes	No	24/04/2013	13:00	N/A	2.1	240.1	7.9	261.7

No.	Resident	Neighbours	Date	Start time	End time	Wind			
						Local		Wind turbine generator	
						Speed, m/s	Direction, deg	Speed, m/s	Direction, deg
20	Yes	No	24/04/2013	18:30	N/A	1.8	190.6	7.9	230.1
21	Yes	No	24/04/2013	21:00	N/A	1.5	183.1	6.1	226.2
22	Yes	No	24/04/2013	23:30	N/A	1.0	88.1	6.6	240.0
23	Yes	No	25/04/2013	8:00	N/A	2.5	267.3	11	272.8
24	Yes	No	25/04/2013	12:00	N/A	2.6	226.5	10.2	251.7
25	Yes	No	25/04/2013	20:30	N/A	0.8	54.2	7.6	231.0
26	*Yes*	*Yes*	*27/04/2013*	*6:00*	*N/A*	*1.8*	*357.9*	*16.7*	*313.3*
27	Yes	Yes	27/04/2013	8:30	N/A	2.8	321.1	14.7	315.3
28	Yes	Yes	27/04/2013	12:30	N/A	3.7	304.3	15.4	296.2
29	Yes	Yes	27/04/2013	17:00	N/A	1.8	311.8	13.2	298.6
30	*Yes*	*Yes*	*27/04/2013*	*19:00*	*23:30*	*2.0–3.3*	*317.1–337.7*	*15.1–19.6*	*302.9–313.4*
31	Yes	No	28/04/2013	8:00	N/A	1.5	223.3	4.8	236.1
32	Yes	No	28/04/2013	14:00	N/A	1.6	245.0	8.0	251.3
33	Yes	No	29/04/2013	8:00	N/A	2.4	63.1	4.1	107.1
34	Yes	No	29/04/2013	17:00	N/A	4.5	78.7	6.1	80.1
35	Yes	No	30/04/2013	13:00	17:00	0.8–2.2	189.6–8.3	2.1–5.8	225.9–21.2
36	No	Yes	02/05/2013	12:00	N/A	3.1	10.9	12.2	36.0
37	*No*	*Yes*	*03/05/2013*	*7:00*	*N/A*	*3.2*	*343.2*	*18.9*	*310.7*
38	Yes	No	03/05/2013	8:00	N/A	4.9	94.3	4.6	156.6
39	Yes	No	03/05/2013	18:00	N/A	1.8	126.8	7.7	125.6
40	Yes	No	03/05/2013	21:00	N/A	4.0	115.5	11.7	114.7
41	No	Yes	04/05/2013	11:30	N/A	6.8	78.5	9.6	87
42	No	Yes	06/05/2013	7:30	N/A	3.1	5.6	13.5	26.4
43	*Yes*	*No*	*07/05/2013*	*6:00*	*N/A*	*1.5*	*2.3*	*11.5*	*318.6*
44	Yes	No	08/05/2013	20:00	N/A	1.8	17.6	9.5	36.1

No.	Resident	Neighbours	Date	Start time	End time	Wind			
						Local		Wind turbine generator	
						Speed, m/s	Direction, deg	Speed, m/s	Direction, deg
45	No	Yes	11/05/2013	7:00	N/A	2.0	346.1	11.4	338.6
46	Yes	No	12/05/2013	16:00	N/A	1.9	266.4	10.5	267.5
47	No	Yes	19/05/2013	7:30	10:00	1.7–2.3	297.0–305.7	7.7–14.8	292.3–306.6
48	No	Yes	20/05/2013	7:00	N/A	1.4	317.7	15.8	306.1
49	No	Yes	22/05/2013	6:00	N/A	1.7	47.5	8.2	51.4
50	*No*	*Yes*	*29/05/2013*	*5:00*	*N/A*	*2.2*	*5.4*	*15.3*	*329.7*
51	*No*	*Yes*	*31/05/2013*	*7:00*	*N/A*	*1.5*	*294.8*	*11.3*	*289.9*
52	No	Yes	31/05/2013	10:30	N/A	1.3	29.7	5.6	346.7
53	No	Yes	01/06/2013	N/A	10:00	1.9	304.1	12.3	286.3
54	No	Yes	05/06/2013	7:00	N/A	1.6	350.3	6.4	18.8
55	No	Yes	05/06/2013	9:00	N/A	1.1	345.8	8.3	309.8
56	No	Yes	06/06/2013	9:00	N/A	2.8	299.5	11.7	292.2
57	*No*	*Yes*	*10/06/2013*	*6:00*	*10:00*	*0.8–1.9*	*8.3–336.5*	*9.9–13.1*	*292.3–297.9*

Table 39 Summary of acoustic descriptors and audio record analysis for complaint entries, South East site

No.	Inside				Outside						Spectrum shape	Audio records (inside/outside where available)
	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{pA,LF}$, dB(A)	DEFRA	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{Ceq} - L_{Aeq}$	$L_{AF,90}$	$L_{pA,LF}$, dB(A)	DEFRA		
1	33.5–51.0	45.5–54.3	18.3–23.2	57%	32.7–42.6	45.0–58.3	7.0–23.8	27.6–31.3	15.8–34.3	29%	Negative	Inside – household noise Outside –wildlife noise
2	27.6–55.5	55.0–59.8	25.1–29.3	0%	33.5–39.5	59.4–63.6	20.9–26.5	32.1–36.2	30.6–35.3	0%	50Hz peak inside	Inside – household noise Outside – possibly wind turbine noise
3	52.8	60.0	31.1	0%	41.0	63.3	22.3	38.8	35.1	0%	50Hz peak inside	Inside – household noise Outside – wildlife noise
4	54.0	61.0	29.8	0%	41.9	59.1	17.3	33.6	30.6	0%	Negative	Inside – household noise Outside – wildlife noise
5	49.6	61.8	34.3	0%	44.3	61.4	17.1	36.6	32.6	0%	Negative	Inside – household noise Outside – strong wind noise
6	32.8–63.0	50.9–65.6	20.1–38.5	0%	34.3–44.2	52.0–69.5	14.1–25.9	29.1–39.2	25.4–38.4	0%	Negative	Inside – household noise Outside – wind noise
7	*29.1*	*53.5*	*21.6*	*0%*	*38.0*	*63.6*	*25.7*	*34.9*	*34.9*	*0%*	*50Hz peak inside*	*Inside – rumbling can be heard at high amplification. Possible wind turbine generator noise.* *Outside – wind noise*

No.	**Inside**				**Outside**						**Spectrum shape**	**Audio records (inside/outside where available)**
	L_{Aeq} dB(A)	**L_{Ceq} dB(C)**	**$L_{pA,LF}$, dB(A)**	**DEFRA**	**L_{Aeq} dB(A)**	**L_{Ceq} dB(C)**	**L_{Ceq} – L_{Aeq}**	**$L_{AF,90}$**	**$L_{pA,LF}$, dB(A)**	**DEFRA**		
8	*32.2*	*56.2*	*26.8*	*0%*	*41.8*	*60.9*	*19.1*	*37.2*	*33.6*	*0%*	*50Hz peak inside*	*Inside – rumbling can be heard at high amplification. Possible wind turbine generator noise.* *Outside – rain noise*
9	69.2	71.5	44.5	0%	56.1	76.9	20.8	52.9	50.8	0%	Negative	Inside – household noise Outside – strong wind noise
10	58.6	65.1	38.1	0%	49.6	69.6	20.1	46.0	43.2	0%	Negative	Inside – household noise Outside – strong wind noise
11	39.7	51.4	22.3	0%	35.5	57.8	22.4	33.3	32.0	0%	Negative	Inside – household noise Outside – rain noise
12	*25.3*	*48.2*	*19.3*	*0%*	*35.0*	*56.5*	*30.9*	*33.1*	*30.9*	*0%*	*50Hz peak inside*	*Inside – rumbling can be heard at high amplification. Possible wind turbine generator noise.* *Outside – wind noise*
13	32.8	53.8	24.5	0%	36.8	59.8	23.0	34.8	33.9	0%	Negative	Inside – household noise Outside – wind noise

No.	Inside				Outside						Spectrum shape	Audio records (inside/outside where available)
	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{pA,LF}$, dB(A)	DEFRA	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{Ceq} - L_{Aeq}$	$L_{AF,90}$	$L_{pA,LF}$, dB(A)	DEFRA		
14	54.7	59.9	31.4	0%	50.8	64.9	14.1	39.1	40.6	0%	50Hz peak inside	Inside – household noise Outside – wind and wildlife noise
15	53.1	64.4	36.0	0%	50.2	72.3	22.1	42.2	44.8	0%	Negative	Inside – household noise Outside – wind noise
16	60.9	63.4	33.1	0%	39.3	63.6	24.3	35.1	35.7	0%	Negative	Inside – household noise Outside – wind noise
17	54.2	61.0	31.4	0%	44.5	67.5	22.9	38.6	43.0	0%	50Hz peak inside	Inside – household noise Outside – wind noise
18	30.2–53.7	53.3–60.9	24.5–31.1	0%	36.0–42.8	59.9–66.9	20.8–24.1	34.2–36.1	33.5–37.9	0%	50Hz peak inside	Inside – household noise Outside – wind noise
19	32.2	49.7	20.7	0%	43.5	59.5	16.0	35.3	31.0	0%	Negative	Inside – household noise Outside – wildlife noise
20	53.2	55.8	28.2	0%	31.7	52.5	20.7	30.4	26.4	0%	Negative	Inside – household noise Outside – car, tractor noise
21	58.7	61.5	31.7	0%	28.3	48.5	20.2	27.0	25.1	0%	Negative	Inside – household noise Outside – no audio recordings
22	23.1	41.9	12.8	100%	28.2	48.5	20.3	27.0	23.7	0%	Negative	Inside – household noise Outside – wildlife noise

No.	Inside				Outside						Spectrum shape	Audio records (inside/outside where available)
	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{pA,LF}$, dB(A)	DEFRA	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{Ceq} - L_{Aeq}$	$L_{AF,90}$	$L_{pA,LF}$, dB(A)	DEFRA		
23	48.0	55.7	26.8	0%	49.7	63.5	13.8	38.4	35.8	0%	Negative	Inside – household noise Outside – wildlife noise
24	54.5	60.9	31.2	0%	46.1	65.3	19.2	40.2	34.9	0%	Negative	Inside – household noise Outside – wildlife, wind, vehicle noise
25	52.8	55.4	25.4	0%	29.4	50.9	21.5	28.4	24.3	0%	Negative	Inside – household noise Outside – no audio recordings
26	*30.9*	*58.0*	*29.0*	*0%*	*40.8*	*62.8*	*22.0*	*35.4*	*34.6*	*0%*	*50Hz peak inside and Outside*	*Inside and outside – rumbling can be heard at high amplification. Possible wind turbine generator noise.*
27	59.2	68.3	41.0	0%	55.2	68.6	13.4	49.2	38.8	0%	Negative	Inside – household noise Outside – wind noise
28	41.4	59.0	29.8	0%	54.5	78.3	23.8	49.4	49.5	0%	Negative	Inside – no audio recordings Outside – wind noise

No.	Inside				Outside						Spectrum shape	Audio records (inside/outside where available)
	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{pA,LF}$, dB(A)	DEFRA	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{Ceq} - L_{Aeq}$	$L_{AF,90}$	$L_{pA,LF}$, dB(A)	DEFRA		
29	32.5	58.3	29.2	0%	44.2	67.5	23.3	40.8	37.9	0%	Negative	Inside – household noise Outside – wildlife noise
30	*32.7–65.9*	*60.3–70.0*	*31.0–42.3*	*0%*	*40.8–48.4*	*64.6–69.9*	*21.3–23.8*	*39.2–45.6*	*35.7–39.6*	*0%*	*Negative*	*Inside – rumbling can be heard when no other noise sources present. Possible wind turbine generator noise.* *Outside – wind noise*
31	55.8	58.7	30.9	0%	48.7	52.0	3.4	30.8	24.7	0%	Negative	Inside – household noise Outside – wildlife noise. Wind farm could be heard at high amplifications
32	56.5	58.3	26.6	0%	40.6	56.7	16.1	32.2	30.3	0%	Negative	Inside – household noise Outside – truck noise
33	45.7	54.4	24.8	0%	45.0	53.3	8.3	32.0	29.7	0%	Negative	Inside – household noise Outside – truck noise
34	60.3	62.5	33.3	0%	41.4	62.9	21.5	34.1	35.3	0%	Negative	Inside – household noise Outside – truck noise, wildlife noise
35	26.6–55.5	47.7–58.6	13.8–26.9	72%	31.1–53.1	47.1–54.8	1.7–19.7	25.6–31.2	23.1–30.2	0%	Negative	Inside – household noise Outside – wildlife noise
36	39.0	51.5	23.5	0%	47.3	67.6	20.3	41.7	38.8	0%	Negative	Inside – no audio recordings Outside – high wind noise

No.	Inside				Outside						Spectrum shape	Audio records (inside/outside where available)
	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{pA,LF}$, dB(A)	DEFRA	L_{Aeq} dB(A)	L_{Ceq} dB(C)	L_{Ceq} – L_{Aeq}	$L_{AF,90}$	$L_{pA,LF}$, dB(A)	DEFRA		
37	*53.8*	*63.6*	*34.8*	*0%*	*51.9*	*69.5*	*17.6*	*43.0*	*41.0*	*0%*	*50Hz peak inside*	*Inside – rumbling can be heard at high amplification when no other noise sources present. Possible wind turbine generator noise Outside – wind noise*
38	53.8	59.5	29.3	0%	51.2	56.5	5.3	33.4	30.9	0%	Negative	Inside – no audio recordings Outside – wind noise
39	54.9	62.3	35.0	0%	36.7	49.5	12.9	26.6	27.3	0%	Negative	Inside – household noise Outside – truck noise
40	50.4	57.5	28.6	0%	42.8	67.8	25.1	39.3	35.1	0%	Negative	Inside – household noise Outside – no audio recordings
41	31.5	49.8	19.8	0%	51.1	76.2	25.1	44.8	47.8	0%	Negative	Inside – no audio recordings Outside – high wind noise
42	54.7	59.8	30.4	0%	47.4	69.2	21.8	41.8	39.5	0%	Negative	Inside – household noise Outside – wind and wildlife noise

No.	Inside				Outside						Spectrum shape	Audio records (inside/outside where available)
	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{pA,LF}$, dB(A)	DEFRA	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{Ceq} - L_{Aeq}$	$L_{AF,90}$	$L_{pA,LF}$, dB(A)	DEFRA		
43	*33.4*	*57.5*	*28.9*	*0%*	*42.6*	*62.0*	*19.4*	*36.2*	*34.5*	*0%*	*50Hz peak inside and Outside*	*Inside – rumbling can be heard at high amplification with no other noise sources. Possible wind turbine generator noise.* *Outside – possibly wind turbine noise*
44	53.8	59.0	28.8	0%	33.6	54.0	20.5	28.0	27.5	0%	Negative	Inside – household noise Outside – no audio recordings
45	31.3	55.1	23.2	0%	41.9	60.7	18.8	35.0	32.6	0%	Negative	Inside – no audio recordings Outside – wind and wildlife noise
46	57.4	59.7	28.6	0%	42.8	62.2	19.4	36.0	34.2	0%	50Hz peak inside	Inside – household noise Outside – wind and wildlife noise
47	44.4–66.8	56.6–69.5	25.8–42.7	0%	44.6–58.2	63.8–70.0	6.9–23.3	37.3–41.7	34.9–40.6	0%	50Hz peak inside	Inside – household noise Outside – wind and wildlife noise
48	45.6	61.4	31.6	0%	45.3	63.8	18.5	38.8	35.2	0%	Negative	Inside – household noise Outside – wind and wildlife noise
49	26.6	40.9	12.9	100%	38.7	57.6	18.9	34.2	32.2	0%	Negative	Inside – no noise Outside – wind noise

No.	Inside				Outside						Spectrum shape	Audio records (inside/outside where available)
	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{pA,LF}$, dB(A)	DEFRA	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{Ceq} - L_{Aeq}$	$L_{AF,90}$	$L_{pA,LF}$, dB(A)	DEFRA		
50	*28.6*	*57.1*	*26.7*	*0%*	*39.6*	*64.4*	*24.8*	*38.1*	*36.1*	*0%*	*50Hz peak inside*	*Inside – rumbling can be heard at high amplification. Possible wind turbine generator noise* *Outside – low frequency noise can be heard at high amplification. Possibly wind turbines.*
51	*49.6*	*58.4*	*29.2*	*0%*	*44.8*	*62.0*	*17.2*	*36.0*	*33.3*	*0%*	*50Hz peak inside*	*Inside – rumbling can be heard at high amplification with no other noise sources. Possible wind turbine generator noise.* *Outside – truck/ machinery noise*
52	46.3	50.6	16.9	100%	38.9	52.7	13.8	30.0	25.7	0%	Negative	Inside – household noise Outside – wildlife noise
53	64.9	65.7	31.3	0%	46.7	68.8	22.1	41.2	43.3	0%	50Hz peak inside	Inside – household noise Outside – high wind noise
54	60.2	64.4	33.3	0%	47.7	57.1	9.3	28.6	29.8	0%	Negative	Inside – household noise Outside – wildlife noise, possible machinery noise
55	56.7	58.8	30.8	0%	48.3	65.5	17.2	35.1	45.9	0%	100Hz peak Outside	Inside – household noise Outside – possible machinery noise

No.	Inside				Outside						Spectrum shape	Audio records (inside/outside where available)
	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{pA,LF}$, dB(A)	DEFRA	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{Ceq} - L_{Aeq}$	$L_{AF,90}$	$L_{pA,LF}$, dB(A)	DEFRA		
56	41.9	57.9	28.7	0%	56.1	72.8	16.7	42.8	43.5	0%	Negative	Inside – no audio recordings Outside – wind noise
57	*28.0–44.0*	*53.5 58.7*	*24.3–29.0*	*0%*	*33.0–54.4*	*58.7–65.5*	*11.3–25.7*	*23.6–39.0*	*30.2–36.6*	*0%*	*50Hz peak inside*	*Inside and outside – rumbling can be heard at high amplification and no other noise sources. Possible wind turbine generator noise.*

Appendix H East site records

Audio record analysis for the East site

Table 40 Wind turbine generator wind speed and direction for diary return records, East site

No.	Resident	Neighbours	Date	Start time	End time	Wind speed at the nearest wind turbine generator	
						Speed, m/s	Direction, deg
1	Yes	No	13/4/2013	04:00	N/A	14.8	321.2
2	No	Yes	13/4/2013	08:00	11:00	9.6–16.1	303.1–315.5
3	No	Yes	13/4/2013	19:30	N/A	7.7	286.1
4	No	Yes	14/4/2013	05:00	5:30	4.8	279.7
5	No	Yes	14/4/2013	08:30	09:30	4.9	266.8
6	No	Yes	14/4/2013	20:30	22:00	3.0–6.3	171.7–200.3
7	No	Yes	16/4/2013	7:00	9:00	6.1	108.1
8	No	Yes	16/4/2013	21:15	N/A	6.0	108.4
9	No	Yes	17/4/2013	08:00	N/A	6.7	67.4
10	No	Yes	17/4/2013	17:50	N/A	7.6	109.6
11	No	Yes	20/4/2013	07:00	10:30	9.0–16.5	46.5 – 56.6
12	Yes	No	24/4/2013	05:00	N/A	10.9	282.9
13	Yes	No	26/4/2013	04:30	08:15	5.4–8.9	263.5–290.7
14	No	Yes	27/4/2013	04:30	08:15	15.0	328.0
15	Yes	Yes	27/4/2013	07:00	N/A	18.0	323.6
16	No	Yes	27/4/2013	17:30	N/A	15.9	311.1
17	Yes	No	27/4/2013	21:00	N/A	18.5	317.5
18	No	Yes	28/4/2013	20:45	N/A	4.7	232.4
19	No	Yes	29/4/2013	21:35	N/A	8.0	79.4
20	Yes	No	30/4/2013	02:00	03:30	5.4–8.8	49.3–60.1
21	No	Yes	10/5/2013	0:00	N/A	10.3	42.6
22	No	Yes	11/5/2013	22:30	N/A	9.0	308.6
23	No	Yes	12/5/2013	19:05	N/A	14.6	250.0
24	No	Yes	12/5/2013	19:55	20:05	12.5	262.9
25	No	Yes	12/5/2013	20:30	21:00	10.5	264.5

No.	Resident	Neighbours	Date	Start time	End time	Wind speed at the nearest wind turbine generator	
						Speed, m/s	Direction, deg
26	No	Yes	12/5/2013	21:30	N/A	13.0	258.8
27	Yes	Yes	13/5/2013	07:00	N/A	13.3	248.4
28	No	Yes	13/5/2013	10:20	10:30	6.7	237.8
29	No	Yes	13/5/2013	20:00	N/A	11.7	262.4
30	Yes	Yes	14/5/2013	08:15	10:30	9.7–14.9	286.7–297.1
31	Yes	No	14/5/2013	11:30	N/A	13.9	274.6
32	No	Yes	14/5/2013	20:50	N/A	11.8	267.4
33	No	Yes	14/5/2013	22:10	N/A	12.2	261.6
34	Yes	No	15/5/2013	07:00	N/A	12.6	252.9
35	No	Yes	15/5/2013	07:30	09:30	11.9	252.7
36	Yes	Yes	15/5/2013	19:00	N/A	8.3	256.1
37	No	Yes	29/5/2013	0700	10:00	12.4–14.7	338.3–343.4
38	No	Yes	29/5/2013	11:45	N/A	7.2	339.1
39	No	Yes	29/5/2013	21:30	N/A	8.9	24.7
40	No	Yes	30/5/2013	07:30	12:00	5.9	31.9
41	No	Yes	30/5/2013	14:00	N/A	7.1	343.3
42	No	Yes	30/5/2013	22:30	N/A	11.7	355.7
43	No	Yes	31/5/2013	13:30	N/A	9.8	299.8
44	No	Yes	31/5/2013	21:00	N/A	10.2	342.1
45	No	Yes	01/6/2013	08:00	09:00	15.5–20.8	300.0–305.3
46	No	Yes	01/6/2013	21:00	N/A	9.0	172.8
47	No	Yes	02/6/2013	07:00	N/A	8.4	190.5
48	No	Yes	06/6/2013	13:40	N/A	13.8	292.2
49	No	Yes	06/6/2013	15:00	N/A	11.0	296.1
50	No	Yes	06/6/2013	18:15	N/A	13.7	299.6
51	No	Yes	06/6/2013	22:00	N/A	16.2	294.1
52	No	Yes	07/6/2013	06:00	06:15	13.5–14.3	221.7– 22.4
53	No	Yes	07/6/2013	7:00	9:00	9.4	218.2
54	No	Yes	08/6/2013	12:00	N/A	3.5	9.0

Table 41 Acoustic descriptors and audio records analysis for diary return records, East site

No.	Outside					Spectrum shape	Audio records (inside/Outside where available)
	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{Ceq} - L_{Aeq}$	$L_{pA,LF}$, dB(A)	DEFRA		
1	39.0	64.0	25.0	31.4	0%	Negative	Rain noise
2	41.7–56.6	59.8–70.1	8.6–22.0	27.2–49.8	0%	Negative	Wildlife, rain noise
3	43.0	66.6	23.6	33.9	0%	Negative	Rain, wind noise
4	18.4–19.0	34.7–35.5	15.6–17.1	9.9–10.0	100%	Negative	No audio recordings
5	41.7–45.3	42.3–56.3	0.6–12.0	13.6–26.8	80%	Negative	Bird, high wind noise
6	28.4–31.8	41.2–45.6	10.7–20.8	14.4–21.6	100%	Negative	Dog barking
7	34.5–52.8	36.4–51.2	–1.6–8.5	7.2–22.1	100%	Negative	Wind, tree, and bird noise
8	28.4	41.6	13.2	12.1	100%	Negative	No audio recordings
9	48.2	47.0	-1.2	11.9	100%	Negative	Bird noise
10	46.9	51.6	4.7	18.8	100%	Negative	Wind, bird noise. Pulsing not evident
11	33.0–53.1	38.9–55.1	–1.3–16.5	9.2–23.7	71%	Negative	Wildlife noise
12	24.2	48.1	23.9	17.0	100%	Negative	No audio recordings
13	22.2–54.2	45.1–53.1	–1.4–26.9	16.3–22.0	73%	Negative	No audio recordings
14	20.7–54.0	39.4–54.1	–0.9–23.2	11.2–23.0	80%	Negative	No audio recordings
15	36.6	48.4	11.8	18.3	100%	Negative	No audio recordings
16	45.4	68.3	22.8	35.7	0%	Negative	No audio recordings
17	47.2	63.8	16.6	30.9	0%	Negative	No audio recordings
18	35.3	46.2	10.9	18.5	100%	Negative	No audio recordings
19	31.9	43.1	11.2	14.3	100%	Negative	No audio recordings
20	22.5–27.2	45.4–48.0	20.8–23.3	15.7–18.1	100%	Negative	No audio recordings

No.	Outside					Spectrum shape	Audio records (inside/Outside where available)
	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{Ceq} - L_{Aeq}$	$L_{pA,LF}$, dB(A)	DEFRA		
21	24.7	34.0	9.4	14.4	100%	Negative	No audio recordings
22	49.2	68.9	19.7	35.9	0%	Negative	No audio recordings
23	50.8	70.4	19.7	37.6	0%	Negative	No audio recordings
24	49.8–49.8	68.0–68.1	18.2–18.3	34.4–34.5	0%	Negative	No audio recordings
25	47.0–48.0	65.8–67.5	17.8–20.5	33.5–34.5	0%	Negative	No audio recordings
26	47.7	66.8	19.1	33.8	0%	Negative	No audio recordings
27	47.7	65.3	17.5	31.9	100%	Negative	No audio recordings
28	47.6	63.2	15.6	29.8	0%	Negative	No audio recordings
29	37.2	56.6	19.4	24.2	0%	Negative	No audio recordings
30	40.1–52.3	61.9–72.5	11.2–25.0	29.3–40.0	0%	Negative	No audio recordings
31	51.0	76.2	25.2	44.0	0%	Negative	No audio recordings
32	38.9	57.0	18.2	25.3	0%	Negative	No audio recordings
33	43.4	64.1	20.7	31.7	0%	Negative	No audio recordings
34	61.7	80.6	18.8	48.1	0%	Negative	No audio recordings
35	52.2–62.6	69.9–81.4	16.0–19.1	37.1–50.3	0%	Negative	No audio recordings
36	41.8	58.7	16.9	26.9	0%	Negative	No audio recordings
37	32.5–54.7	42.3–55.2	–0.6–9.8	13.9–27.1	25%	Negative	Wildlife noises
38	54.3	64.3	10.0	44.4	0%	Negative	Truck, machinery, wildlife noise

No.	Outside					Spectrum shape	Audio records (inside/Outside where available)
	L_{Aeq} dB(A)	L_{Ceq} dB(C)	$L_{Ceq} - L_{Aeq}$	$L_{pA,LF}$, dB(A)	DEFRA		
39	25.5	36.9	11.4	14.8	100%	50Hz and 100Hz peak	Flyover, machinery noise
40	63.0–58.9	45.8–66.1	–1.0–14.1	15.1–45.2	56%	Negative	Wind, tree noise. Human activities and light rain
41	36.9	55.0	18.1	29.5	0%	Negative	Engine noise, bird noise and livestock
42	28.3	49.9	21.6	22.6	0%	Negative	Rain noise, ringing telephone
43	43.4	63.0	19.6	31.9	0%	Negative	Rain noise
44.	33.5	44.6	11.1	18.9	100%	Negative	Rain noise
45	55.7–60.6	78.2–83.9	21.4–23.3	47.9–54.2	0%	Negative	Very heavy rains, strong winds
46	58.9	77.5	18.5	45.6	0%	Negative	Rain noise
47	39.3	54.4	15.1	22.4	100%	Negative	Rain noise
48	51.2	74.4	23.3	42.7	0%	Negative	No audio recordings
49	44.8	67.3	22.5	36.6	0%	Negative	Wind noise
50	43.3	65.6	22.3	33.2	0%	Negative	Strong wind, wildlife noise
51	55.4	79.5	24.1	48.5	0%	Negative	Rain, wind noise
52	55.3	71.9	16.5	39.5	0%	Negative	Rain, wind noise
53	46.0	59.6	13.6	28.4	0%	Negative	Wind noise
54	42.9	47.5	4.6	24.4	0%	Negative	Wildlife noise, mechanical engine noise