

## Low frequency noise near wind farms and in other environments



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## Executive summary

This report presents the findings of a study into low frequency noise levels within typical environments in South Australia, with a particular focus on comparing wind farm environments to urban and rural environments away from wind farms. This study is based on data collected during the recent infrasound study published by the Environment Protection Authority (Evans, Cooper & Lenchine, 2013).

Measurements were undertaken over a period of approximately one week at seven locations in urban areas and four locations in rural areas including two residences approximately 1.5 kilometres away from the wind turbines. Measured low frequency noise levels were compared to relevant assessment criteria, and shutdowns of the wind farms were organised to compare low frequency noise levels at those two residences with the wind farm both on and off.

### Urban environments

The measurement results collected at the seven urban locations suggest that the following factors can affect indoor low frequency noise levels at offices and residences:

- traffic from major and local roads, and aircraft
- mechanical plant (e.g. air-conditioning systems)
- daily activities of people within the office or home.

Excluding periods clearly affected by the daily activities of people, A-weighted low frequency noise levels at all locations were found to regularly exceed the night time residential criteria of 20dB(A) used in Denmark (between 16% and 86% of the time). Similarly, the DEFRA night time low frequency noise criteria were regularly exceeded at the urban locations.

It is important to recognise that, in urban areas, these low frequency noise levels are often accompanied by higher levels of broadband noise as well. Therefore, a direct comparison for the potential annoyance from low frequency noise with rural locations is difficult. However, it helps to place the low frequency noise levels measured near wind farms in context.

### Rural environments

The measurements at the four rural locations indicate that typically there is a lower level of low frequency noise in the environment relative to the seven urban locations. The measured night time  $L_{pA,LF}$  levels at the four locations only exceeded the 20dB(A) Danish criterion for 10% of the time or less. At one location, this 20dB(A) criterion was not exceeded. The levels of low frequency noise appeared to be correlated to wind speed at the site, but were also affected by the presence of people within a space at some locations.

The levels of low frequency noise at the two wind farm locations were low in comparison to the urban areas and were not noticeably higher than at the other two rural locations. The  $L_{pA,LF}$  levels at Location 8 remained below the Danish and DEFRA criteria at all

times, and the outdoor levels remained below 60dB(C) throughout the night time periods. The Danish 20dB(A) night time criterion was exceeded for 10% of the measurement time at Location 9 but this is believed to be due to the construction of the house rather than the contribution of noise from Clements Gap Wind Farm. There were very occasional exceedances of the night time DEFRA criteria at this site but the percentage of exceedances was no greater than at Location 10 and Location 11 (with no wind turbines within 10 kilometres).

Organised shutdowns of the two wind farms also found that the contribution of the Bluff Wind Farm to low frequency noise levels at Location 8 was negligible, while there may have been a relatively small contribution of low frequency noise levels from the Clements Gap Wind Farm at frequencies of 100Hz and above.

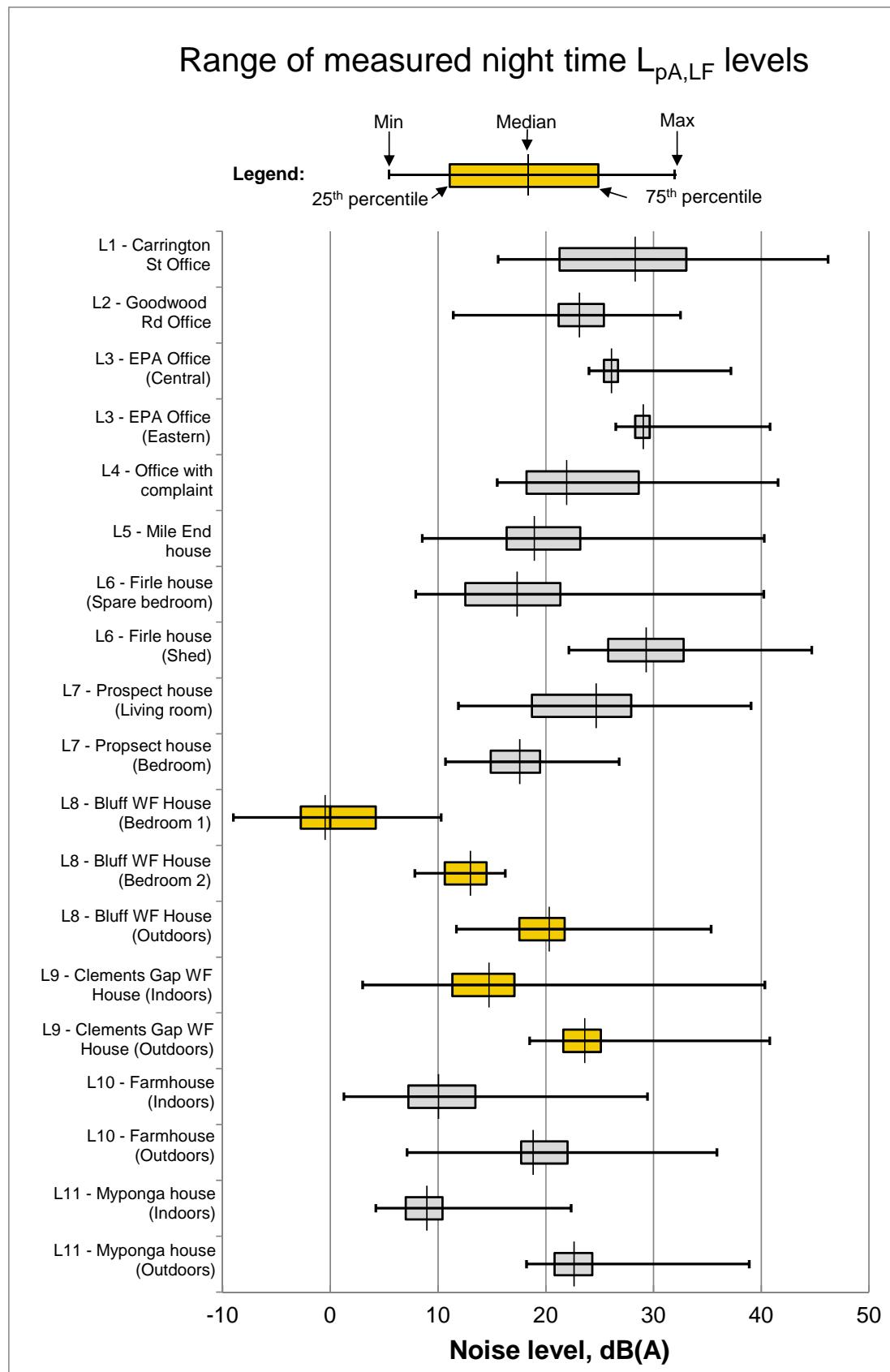
## Summary

The range of measured  $L_{pA,LF}$  low frequency noise levels at each of the measurement locations is presented in Figure 1, with the lines corresponding to the minimum, 25<sup>th</sup> percentile, median, 75<sup>th</sup> percentile and maximum  $L_{pA,LF}$  levels from left to right at each location.

It is clear from the results that the measured levels at the two residential locations near wind farms (Location 8 and Location 9) are within the range of levels measured at the other rural locations. The measured levels at Location 8, 1.5 kilometres from the Bluff Wind Farm, represent some of the lowest levels measured at any of the locations in this study.

Overall, this study demonstrates that low frequency noise levels near wind farms are no greater than levels in urban areas or at comparable rural residences away from wind farms. Organised shutdowns of the wind farms also found that the contribution of the Bluff Wind Farm to low frequency noise levels at Location 8 was negligible, while there may have been a relatively small contribution of low frequency noise levels from the Clements Gap Wind Farm at frequencies of 100Hz and above.

This provides a point of contrast to the infrasound study, which identified an insignificant contribution from wind farms to the infrasound levels at the two houses. In this low frequency noise study, it appears that operation of the wind farm may affect low frequency noise levels at frequencies of 100Hz and above. However, based on the data collected as part of this study, low frequency noise levels from the two wind farms did not exceed relevant assessment criteria.



**Figure 1 – Range of measured night time  $L_{pA,LF}$  low frequency noise levels at each measurement location**

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## 1 Introduction

In January 2013, the Environment Protection Authority published the findings of a study into the levels of infrasound are exposed to within typical environments in South Australia (Evans, Cooper & Lenchine, 2013).

Infrasound levels were measured over a period of days (typically one week) inside eleven buildings, including each of the following environments:

- urban areas:
  - offices in the Adelaide CBD and on major roads
  - residences in suburban areas
  - residences near transport routes
- rural areas:
  - residences near to wind farms
  - residences away from wind farms.

During the collection of data for the infrasound assessment, noise levels were also measured across the frequency range defined as low frequency noise. The frequency ranges covered by low frequency noise and infrasound partially overlap but that of low frequency noise extends higher than that considered to be infrasound.

This report presents the low frequency noise levels measured at the 11 locations selected for the original infrasound study. The measured low frequency noise levels have been compared both between the 11 locations as well as to relevant assessment criteria for low frequency noise available from national and international authorities and studies.

The current study is not focused on possible variations in human perception of noise, health effects of low frequency noise on people or a detailed review of technical assessment methods for low frequency noise. It is intended to provide a comparison of low frequency noise levels for different locations in different environments, including residences at distances from wind farms typical of the nearest receivers. Objective methods for quantifying low frequency noise are used to determine any differences in low frequency noise levels that may occur at houses adjacent to wind farms relative to other locations where people live, work and sleep.

For information on the indoor and outdoor measurement procedures employed during this study, refer to Appendix A of the original infrasound study available on the EPA website ([http://www.epa.sa.gov.au/xstd\\_files/Noise/Report/infrasound.pdf](http://www.epa.sa.gov.au/xstd_files/Noise/Report/infrasound.pdf)).

## 2 Background information

### 2.1 Overview

Low frequency noise refers to unwanted sound occurring within the lower region of the frequency range. People are often exposed to low frequency noise in the environment, as it is produced by transportation (aircraft, cars and locomotives), industrial (pumps, compressors, turbines) and natural (wind) sources. Two sources of noise, which are dominated by low frequency noise and that will be familiar to almost everyone are truck exhausts and bass music.

The definition of low frequency noise varies to some degree between different standards and guidelines used for its assessment. In South Australia, the *Environment Protection (Noise) Policy 2007* states that noise has a low frequency characteristic if “it has a characteristic that dominates the overall noise level with content between 20 hertz and 250 hertz”.

This frequency range differs from that provided in other documents. For example, a frequency range from 10Hz to 160Hz is used to assess low frequency noise in both the UK (DEFRA, 2005) and Denmark (Poulsen & Mortensen, 2002). German Standard DIN 45680<sup>1</sup> considers a frequency range from 8Hz to 100Hz, although predominantly focuses on the region from 10Hz to 80Hz.

For the purposes of this study, noise levels between 8Hz and 250Hz have been considered to provide a wide definition of low frequency noise. This includes an extended frequency range beyond the traditional “audible” range (which starts at 20Hz) to allow calculation of relevant acoustical descriptors. However, it is important to note that some commonly used low frequency noise assessment criteria only consider noise across a limited frequency range between 8Hz and 250Hz. Where these criteria have been applied to measured levels, the frequency range used for the assessment has been limited appropriately.

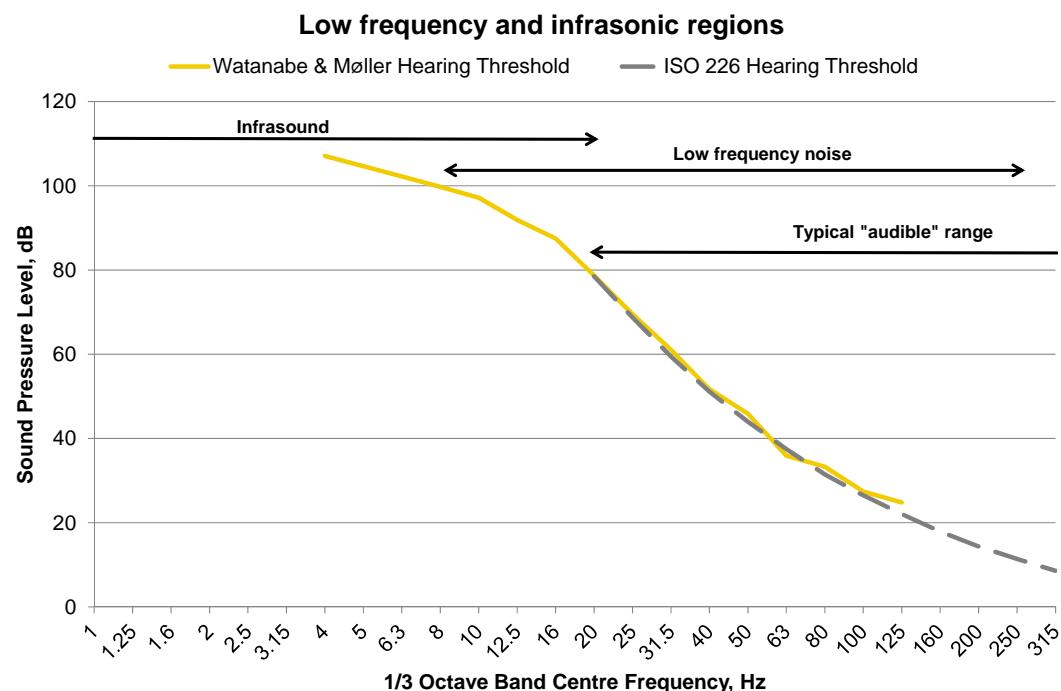
### 2.2 Low frequency noise and infrasound

There is often confusion regarding the separation between low frequency noise and infrasound, and it could be argued that there is no clear separation and that infrasound is simply very low frequency noise. However, acousticians have traditionally separated them such that infrasound refers to noise at frequencies below 20Hz and low frequency noise refers to noise in the range from 10Hz up to approximately 200Hz. This results in some overlap between infrasound and low frequency noise, as shown in Figure 2.

Considering infrasound and low frequency noise separately does provide some benefits. Humans lose tonal perception of noise at frequencies below approximately 16 to 18Hz, and this represents a key element of the perception of noise (Leventhal, 2003).

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<sup>1</sup>DIN 45680:1997, *Measurement and evaluation of low-frequency environmental noise*.



**Figure 2 – Low frequency and infrasonic regions**

Our previous study focused on infrasound levels in the environment, both on G-weighted sound pressure levels and on linear (unweighted) sound pressure levels across the frequency range from 0.25Hz to 20Hz. This study considers sound pressure levels across the low frequency range, so will overlap in the frequency range from 8Hz to 20Hz but will also consider sound pressure levels up to 250Hz.

Figure 2 shows the low frequency and infrasonic regions. Mean low frequency hearing thresholds at one third octave band centre frequencies from 4Hz to 125Hz (Watanabe & Møller, 1990) and from 20Hz to 250Hz (ISO 226<sup>2</sup>) are also shown.

The typical “audible” range is shown on Figure 2 from 20Hz and continues up to 20kHz. It is important to note that noise at frequencies below 20Hz is audible as long as the sound pressure level is high enough. The human hearing threshold increases steadily as the frequency decreases over the low frequency range, reaching a sufficient level at 20Hz that it is relatively uncommon that the ambient level of environmental noise at these frequencies exceeds the hearing threshold.

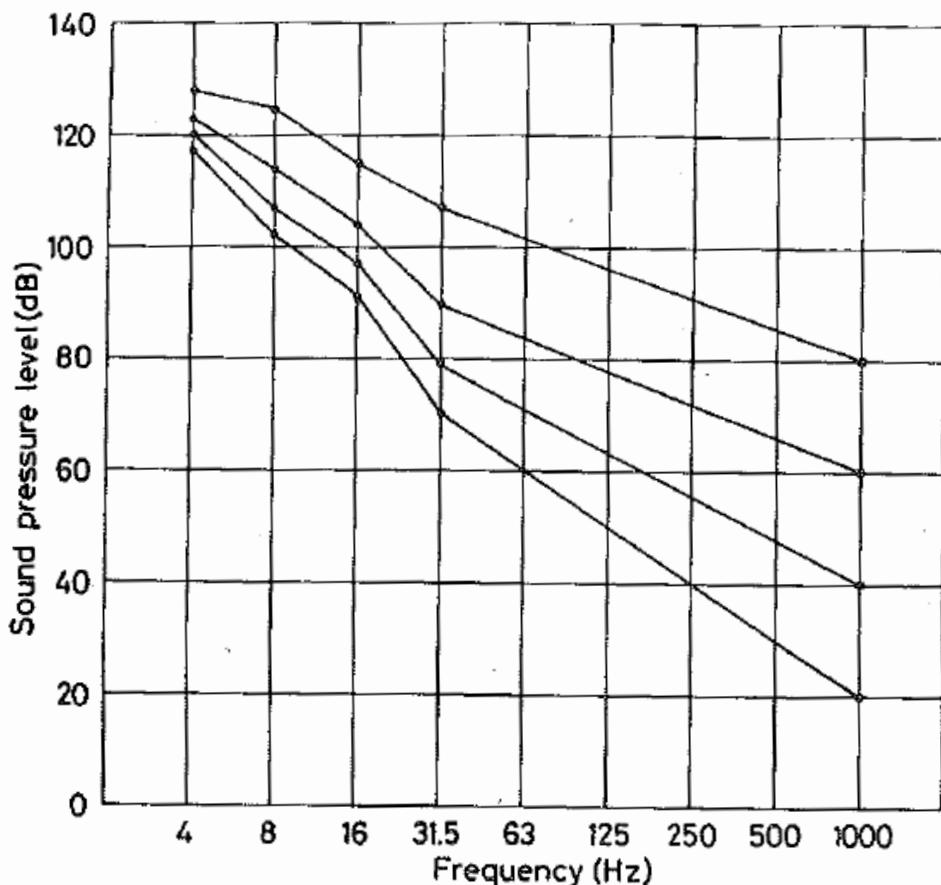
There is also variation around the mean hearing threshold within the population. In a review of previous studies Møller and Pedersen (2004) state that “in general the standard deviations between subjects are in the order of 5dB nearly independent of frequency, maybe with a slight increase at 20-50Hz.” Any increase at 20 to 50Hz is very slight and would at most be in the order of 1 to 2dB.

<sup>2</sup> ISO 226:2003, *Acoustics – Normal equal-loudness-level contours*.

## 2.3 Effects of low frequency noise

While this study is focused on a presentation of measured low frequency noise levels and comparison against relevant assessment criteria, a brief overview is provided on effects of low frequency noise that underpin the assessment methodologies considered in the study.

The primary effect of low frequency noise, and that most frequently reported, is annoyance (Broner, 1978). At very low frequencies, including those in the infrasonic range, annoyance tends to arise just above the threshold of hearing and increases more quickly than for mid-to-high frequency noise (Andresen & Møller, 1984). As the frequency of the noise increases, greater increases in noise level can be tolerated for the same degree of annoyance as shown by Figure 3 from Andresen & Møller (1984).



**Figure 3 – Equal annoyance contours for pure infrasonic and low frequency tones  
(Andresen & Møller, 1984)**

Direct effects of low frequency noise on other parts of the human body only start to occur at a level well above that at which low frequency noise is first heard through the ears. Experiments conducted with normally hearing and profoundly deaf subjects found that the threshold of sensation of the deaf subjects was approximately 40 to 50dB above the hearing threshold of the normally hearing subjects at a frequency of 63Hz, and the margin

was even greater at higher frequencies (Yamada et al, 2003). Where the profoundly deaf subjects were able to sense the noise, it was felt mainly within the chest.

Body vibrations due to low frequency noise at approximately 50Hz will be familiar to most people who have stood nearby to a truck pass-by or to a subwoofer at a concert, as this corresponds to frequencies where there is a resonance within the chest. However, inherent body vibrations will mask excitations resulting from external noise levels lower than 70 to 80dB at approximately 50 to 60Hz (Leventhal, 2003). Levels of low frequency noise within homes and offices presented in this study are well below this level in this frequency range.

A number of procedures for low frequency noise assessment have been developed and the key assessment methodologies considered in this study are summarised in Section 3. The assessment criteria reported in these studies are designed to address levels at which there would be no reported annoyance for the majority of the population.

## 2.4 Limitations of this study

As the focus of the original study was to present sound pressure levels over the infrasonic frequency range at a number of locations, the measurement campaign was designed in such a way as to accurately measure infrasonic levels. However, this has lead to some limitations of this additional analysis, which aims to compare low frequency noise levels in the environment. These limitations are discussed in Table 1, with comments provided as to their effect on the study findings.

**Table 1 – Study limitations**

Limitation	Comments
Measurement location selection	<p>As the previous study focused on infrasound levels people are exposed to where they live, work and sleep, office locations provided a relevant point of comparison. Similarly, annoyance from infrasound typically occurs around the threshold of perception, and this is as relevant in an office environment as it would be in a residence in a rural location.</p> <p>Low frequency noise assessment criteria differ in that they typically allow an audible level of low frequency noise but limit it to a level at which the majority of the population will not be annoyed. The level at which it is limited will vary between locations where people sleep and locations where people work.</p> <p>However, some low frequency noise assessment procedures include annoyance criteria for office locations (refer Section 3). Furthermore, the measured levels at the office locations help to put low frequency noise levels at other locations into context. Therefore, while comparisons between the residential locations are of most relevance to this study, the office locations are also presented as informative.</p>

Limitation	Comments
Indoor measurement locations	<p>Infrasound levels do not vary significantly within a room, as discussed in our previous study. Therefore, indoor measurement locations were selected in typical locations within a room where occupants would spend time.</p> <p>Low frequency noise levels in the range from approximately 50 to 160Hz can vary considerably within a room depending on the measurement location. This can occur when the wavelength of the sound at these frequencies is similar to the room dimensions, and results in a modal response (areas of high and low noise levels). Where an indoor low frequency noise problem may exist, measurements would normally be taken at multiple locations within a room to obtain an average response at low frequencies.</p> <p>This was not necessary for the infrasound study and therefore is a limitation on the results presented in this study. However, as measurement results are available across a number of locations, and include periods where wind turbines were on and off, the data is still considered to provide useful information as to low frequency noise levels near wind farms and in other environments.</p>
Measurement equipment	<p>The Soundbook measurement system with the Brüel&amp;Kjær Type 4193 microphone and low frequency adaptor was found to have a noise floor that was significant at frequencies of approximately 2kHz and above, and may have affected measured noise levels at the quieter rural locations at frequencies of 1kHz and above. It is understood that this noise floor is primarily a result of noise generated within the microphone, preamplifier and low frequency noise adapter used with the Soundbook.</p> <p>This noise floor did not affect the measured noise levels presented in the previous infrasound study, and does not influence the measured noise levels across the frequency range from 8 to 250Hz considered in this study. However, it does affect the measured overall A-weighted and (to some degree) the C-weighted noise levels at quiet measurement locations, and means that the simpler dB(C) – dB(A) criterion for assessment of low frequency noise cannot be accurately reported at those locations where the Soundbook measurement system was used.</p> <p>Note that the noise floors of the SVAN 945A and Brüel&amp;Kjær2250 measurement setups did not appear to affect measurement results at any location.</p>

Limitation	Comments
Averaging period	<p>A 10 second minimum averaging period was used to calculate short-term G-weighted noise levels (<math>L_{max}</math>) during the original study. An averaging time of this length was critical such that the measured noise levels at very low frequencies were sufficiently accurate and in accordance with relevant standards.</p> <p>However, an averaging period of 10 seconds is longer than the minimum required over the frequency range from 8Hz to 250Hz and a shorter averaging period could have been used if the original study was only focused across this range.</p> <p>Despite this, the low frequency noise assessment criteria considered in this study are applied to 10-minute averaged <math>L_{eq}</math> levels (or <math>L_{eq}</math> levels over similar time periods) rather than short-term <math>L_{max}</math> levels. Therefore, this limitation is not considered to have affected the findings of this study against the assessment criteria. Similarly, comparisons of the measured noise levels at each site can still be made.</p>
Electrical noise	<p>Electrical interference in noise measurement systems can commonly occur at frequencies of 50Hz and associated harmonics (100Hz and 160Hz as one third octave band centre frequencies). This appears to have affected the measured noise levels at some locations.</p> <p>This did not affect the assessment of results during the infrasound study as it primarily considered sound pressure levels at 20Hz and lower. Any effect of electrical noise at 50Hz, 100Hz and 160Hz on the measured G-weighted levels would be negligible as the G-weighting results in a considerable negative weighting at these frequencies.</p> <p>However, the potential presence of electrical noise has been considered within this low frequency noise study at some locations.</p>

### 3 Assessment criteria

A number of international regulatory authorities define assessment criteria for low frequency noise. These criteria are designed to prevent annoyance from low frequency noise for the majority of the population.

The key assessment criteria for low frequency noise considered within this study are presented below. Note that the presented criteria are typically intended to be applied indoors, with the exception of the outdoor C-weighted criterion in Section 3.5.

#### 3.1 Difference between C-weighted and A-weighted levels

The *Guidelines for the Use of the Environment Protection (Noise) Policy 2007*, issued by the Environment Protection Authority, state the following regarding low frequency noise characteristics:

*An objective test to identify low frequency noise has not been established by an Australian Standard. However, such a test could comprise measuring and comparing 'A' and 'C' frequency weighted equivalent noise level results. A difference of 15dB or more is established in the New South Wales Industrial Noise Policy (1999) as a measure to establish the presence of a low frequency characteristic.*

While the Guidelines suggest a difference of 15dB between the  $L_{Ceq}$  and  $L_{Aeq}$  levels may indicate the potential for a low frequency noise characteristic, other research indicates that the difference may need to be greater if it is to be used as an indicator of potential annoyance. Leventhall (2003) suggests the difference should be greater than 20dB, while Broner (2011) suggests that the level may need to exceed 25dB when the A-weighted noise level is low.

It has also been suggested that the difference between the  $L_{Ceq}$  and  $L_{Aeq}$  levels should not be used as an assessment criterion for low frequency noise. Leventhall (2003) states that the difference is rather an indicator that there may be a potential low frequency noise problem that should be further investigated using the assessment criteria outlined in the following sections.

#### 3.2 DEFRA criteria

A 2005 report prepared by the University of Salford for the UK Department of Environment, Food and Rural Affairs (DEFRA, 2005) examined low frequency noise criteria applied in other European countries and undertook field studies and laboratory tests to develop proposed criteria for the assessment of low frequency noise disturbance.

The criteria apply indoors, and measurements should be taken with the microphone in an unoccupied room where "a complainant says the noise is present." The  $L_{eq}$ ,  $L_{10}$  and  $L_{90}$  noise levels are recorded in each one third octave band from 10Hz to 160Hz. The measured  $L_{eq}$  levels are compared to the reference curve tabulated in Table 2.

**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

It is important to note that the reference curve levels in Table 2 are the applicable values for the night time period, and may be increased by 5dB where the noise is occurring during the daytime.

The levels may also be relaxed by 5dB if the noise is steady, assessed on the basis of whether either of the following conditions is met for the one third octave band which exceeds the reference curve values by the greatest margin:

- $L_{10} - L_{90} < 5\text{dB}$
- the rate of change of sound pressure level (Fast time weighting) is less than 10dB per second.

### 3.3 Danish criteria

The Danish Environmental Protection Agency set low frequency noise criteria based on the A-weighted noise level calculated on the one third octave band levels from 10Hz to 160Hz inclusive ( $L_{pA,LF}$ ). The criteria are presented in Table 3.

**Table 3 – Danish low frequency noise criteria**

Occupancy type	Time period	Criterion
		$L_{pA,LF}$ , dB(A)
Dwellings	Day, 7am to 6 pm	25
	Evening/Night, 6pm to 7am	20
Offices / classrooms	–	30
Other work rooms	–	35

Low frequency noise levels are assessed based on 10-minute measurements, with a 5dB penalty added to the measured level for impulsive noise if necessary (DEFRA, 2005). The measured level is determined as the energy average of measurements conducted at three points within each room – one near a corner and two locations representing typical locations where people would be (with consideration given to any locations where an occupant may indicate they find the noise to be particularly annoying).

The Danish low frequency noise criteria were found to provide the highest correlation between objective and subjective assessments of low frequency noise when compared to other criteria applied in Europe (Poulsen & Mortensen, 2002). The DEFRA criteria presented in Section 3.2 were developed with consideration of the Danish criteria.

These low frequency noise criteria have recently been included in the Danish Statutory Order on noise from wind turbines, revised 15 December 2011, which applies an indoor low frequency noise limit for night time periods of 20dB(A)  $L_{pA,LF}$ . The limit is applied during calculations of wind turbine noise, and only for wind speeds of 6 m/s and 8 m/s at 10 metres above ground level under standard conditions.

### 3.4 German criteria

German Standard DIN 45680 proposes separate criteria for tonal low frequency noise and broadband low frequency noise, on the assumption that the majority of low frequency noise problems from industry are related to tones (Leventhal, 2003). Low frequency noise levels are measured and, if the level in a particular one third octave band from 8Hz to 100Hz exceeds the level in the two neighbouring bands by 5dB or more, then the noise is considered tonal.

Where noise is tonal, the night time criteria set by DIN 45680 are as shown in Table 4. The criteria are similar to the DEFRA criteria although are between 4 to 8dB more stringent at frequencies from 63Hz to 100Hz.

**Table 4 – DIN 45680 night time criteria for low frequency tonal noise**

Night time criteria in dB(Lin) at 1/3 octave band centre frequency (Hz)											
8	10	12.5	16	20	25	31.5	40	50	63	80	100
103	95	87	79	71	63	56	48	41	34	33	34

Where low frequency noise is broadband (non-tonal), then a night time limit of 25dB(A) is applied, calculated over the frequency range of 10Hz to 80Hz. Only those one third octave bands where the measured level is above the hearing threshold are considered in the calculation of the A-weighted level. In this regard, the DIN 45680 criteria for broadband low frequency noise are significantly less stringent than the comparable Danish criteria.

The German criteria have not been considered in this study as the DEFRA criteria are more conservative (for non-tonal noise) and were developed with due consideration of other criteria applied internationally at the time. However, they help to illustrate that tonal low frequency noise is often of more concern than broadband low frequency noise.

### 3.5 Outdoor C-weighted criteria

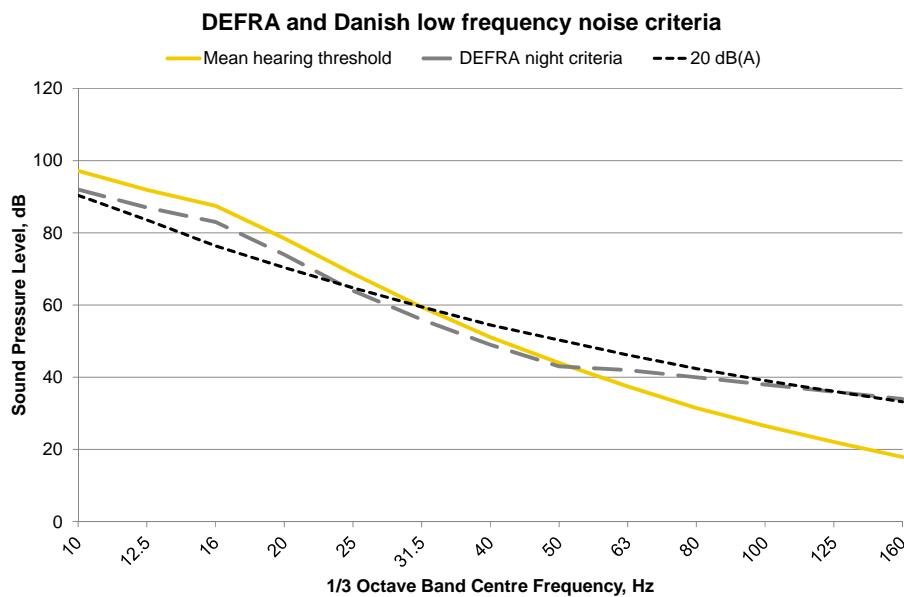
Broner (2011) proposed a simple outdoor assessment criterion for low frequency noise of 60dB(C) (desirable) to 65dB(C) (maximum), in residential areas where the source of the noise operates for extended periods during the night time.

The measurements should be conducted over a period of at least three to five minutes, and a penalty of 5dB(C) should be added to the measured level where the noise is fluctuating, i.e.  $L_{C10}$  is more than 5dB above the  $L_{C90}$ .

### 3.6 Summary of applicable criteria

This study has primarily considered measured  $L_{pA,LF}$  noise levels and linear noise levels across the low frequency range for comparison to the Danish and DEFRA criteria respectively. Where measurements are available to a suitable degree of accuracy, the measured difference between the  $L_{Ceq}$  and  $L_{Aeq}$  levels, and the outdoor  $L_{Ceq}$  levels have also been considered.

The DEFRA and Danish (20dB(A),  $L_{pA,LF}$ ) night time low frequency noise criteria are compared to the mean hearing threshold in Figure 4.



**Figure 4 – DEFRA and Danish low frequency noise criteria**

It can be seen that the DEFRA criteria sit approximately one standard deviation below the mean hearing threshold up to a frequency of approximately 40Hz. At frequencies of 50Hz and above, they recognise that people typically accept a low level of audible low frequency noise. The Danish 20dB(A) criterion appears less stringent than the DEFRA criteria in the region from 25Hz to 100Hz but will commonly be more stringent as the level presented in Figure 4 assumes that all of the sound energy is concentrated at that single one third octave band. When the energy is spread across multiple bands the allowable energy in anyone band is lower.

## 4 Measurement results – urban environments

Measurements were undertaken at seven locations within the Adelaide metropolitan area, to determine typical levels of low frequency noise within the urban environment.

The seven urban locations were:

- Location 1 – Office on Carrington Street, Adelaide
- Location 2 – Office on Goodwood Road, Goodwood
- Location 3 – EPA office
- Location 4 – Office with low frequency noise complaint
- Location 5 – House in Mile End under flight path
- Location 6 – House in Firle on a minor road and local bus route
- Location 7 – House in Prospect near a major road.

The overall metrics considered in this Section are:

- $L_{pA,LF}$ : A-weighted noise level between 10Hz and 160Hz (i.e. Danish criterion)
- $L_{Ceq} - L_{Aeq}$ : overall C-weighted level less the overall A-weighted level
- $L_{Ceq}$ : overall C-weighted level.

We note that only the  $L_{pA,LF}$  levels could be calculated at those locations where the Soundbook measurement system was used due to the influence of the noise floor on the measurement system at frequencies of 1 to 2kHz and above. This noise floor affected the accurate determination of overall A-weighted and C-weighted levels at these locations.

Analysis of the measured linear (unweighted) noise levels against the DEFRA criteria has also been undertaken for each measurement location in Section 6 of this report.

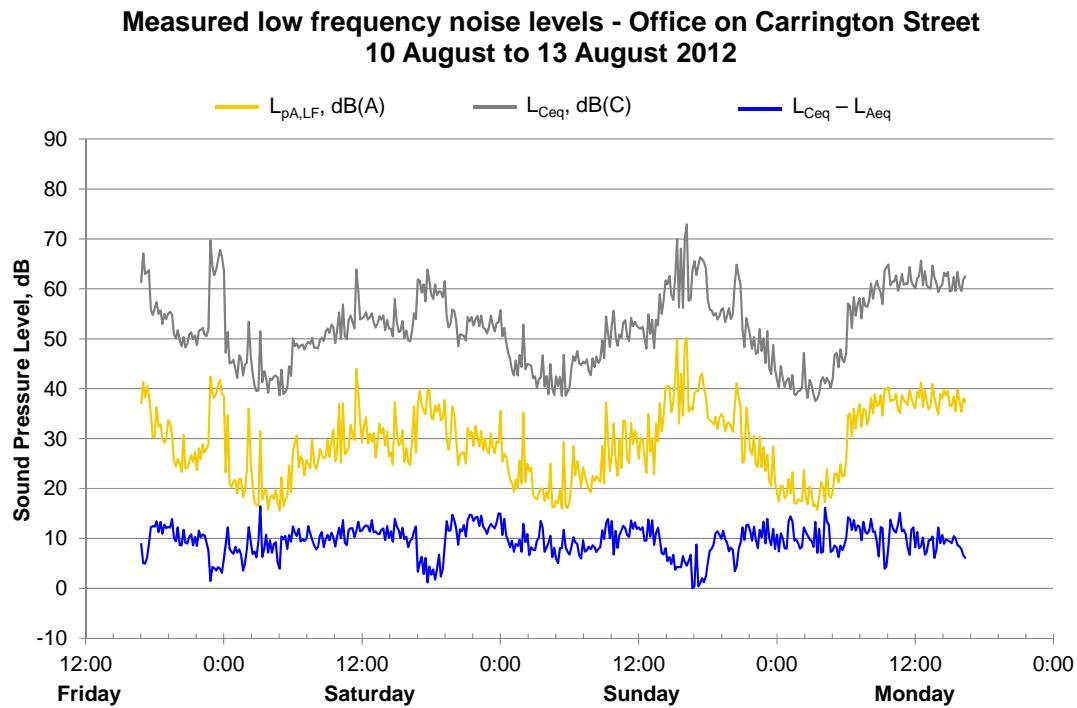
### 4.1 Location 1 – Office on Carrington Street

Measurements were undertaken at an office located in Carrington Street in Adelaide from 10 to 13 August and from 22 to 24 August 2012. The measurements were undertaken with the SVAN 945A sound level meter, located in the centre of the office. The office had windows that faced onto Carrington Street, which were left closed during the measurement period.

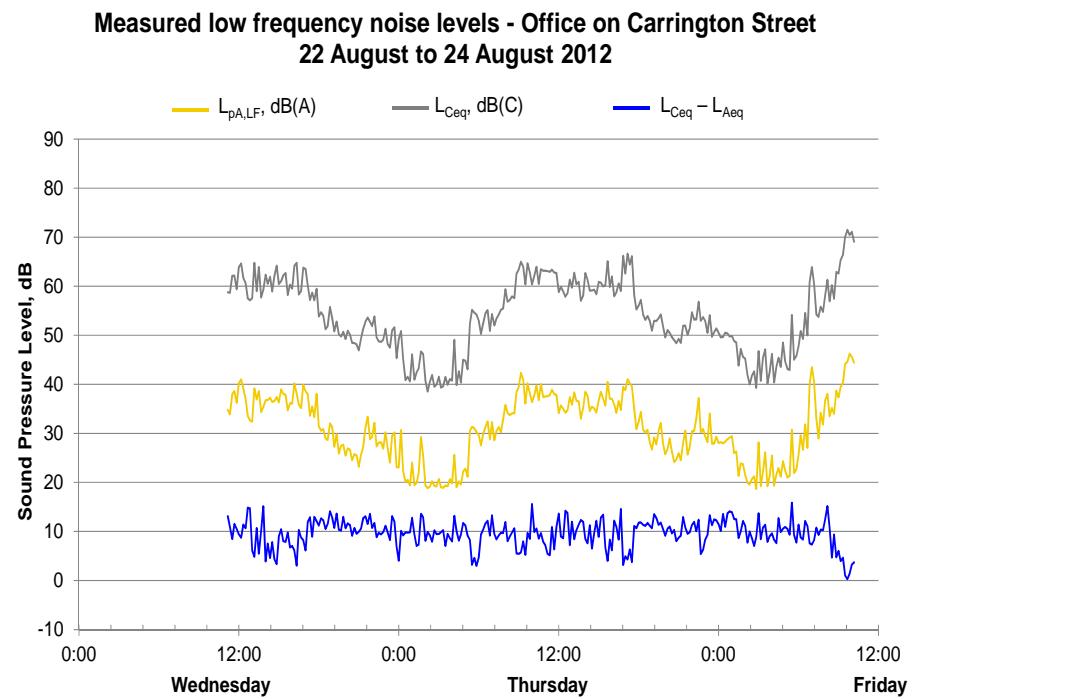
Figure 5 and Figure 6 present the measured  $L_{pA,LF}$ ,  $L_{Ceq} - L_{Aeq}$  and  $L_{Ceq}$  levels over each 10-minute period at Location 1 for the first and second measurement period respectively. Note that the blue line on the graph ( $L_{Aeq} - L_{Ceq}$ ) will not correspond to the difference between the two other lines as the  $L_{pA,LF}$  level is only calculated between 10Hz and 160Hz, while the  $L_{Aeq}$  level is calculated between 10Hz and 20kHz.

From Figure 5 and Figure 6, it is clear that higher low frequency noise levels occur during the daytime, particularly during periods when the room was occupied. For example, there is an increase in the  $L_{pA,LF}$  and  $L_{Ceq}$  level from approximately 3pm to 7pm on the Saturday

during the first monitoring period, which corresponds to a time when the office was occupied. Note that it was unoccupied prior to that period.



**Figure 5 – Measured low frequency noise levels at Location 1 (Period 1)**



**Figure 6 – Measured low frequency levels at Location 1 (Period 2)**

The  $L_{pA,LF}$  level within the office typically varied between 20 and 40dB(A), with higher levels occurring during the daytime. The  $L_{Ceq}$  level varied between 40 and 70dB(C) and exhibited a similar temporal relationship to the  $L_{pA,LF}$  level. The difference between the  $L_{Ceq}$  and  $L_{Aeq}$  levels typically varied between 5 and 15dB, and often decreased during periods when the office was occupied. This suggests that, while human activity within the office generated relatively high levels of low frequency noise, it was typically accompanied by a similar or larger increase in the overall A-weighted levels.

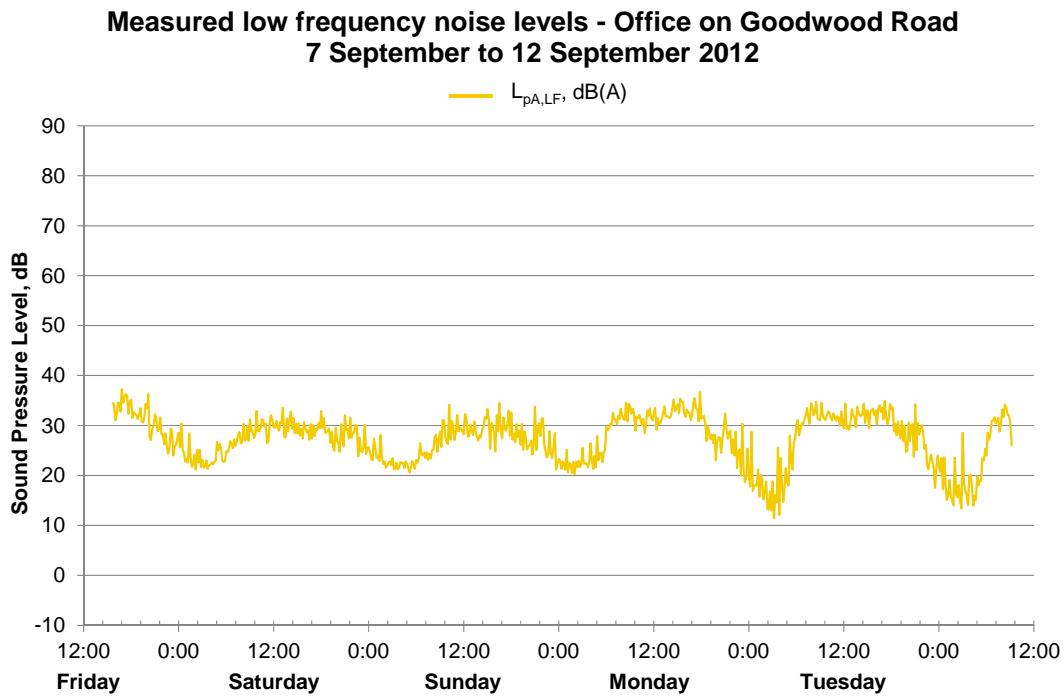
It is difficult to compare the measured  $L_{pA,LF}$  levels during the daytime to the Danish criterion for offices of 30dB(A) as this should be assessed during unoccupied periods. However, it appears reasonable to compare the measured levels during the night time period with the Danish criterion of 20dB(A) for residential locations as the office is located immediately adjacent to residential buildings with similar façade constructions. The air conditioning system was not operating in the office during the measurement period due to the time of year, meaning that the low frequency noise level would have been controlled by external factors that neighbouring residences would also have been exposed to.

During the night time periods (10pm to 7am), the Danish low frequency noise criterion of 20dB(A)  $L_{pA,LF}$  was exceeded for 67% of the 10-minute measurement periods across the entire measurement set at Location 1. However, the difference between the  $L_{Ceq}$  and  $L_{Aeq}$  levels did not exceed 15dB.

## 4.2 Location 2 – Office on Goodwood Road

Measurements were undertaken at an office located on Goodwood Road in Goodwood from 7 to 12 September 2012. The Soundbook measurement system was used during the data acquisition period. The microphone was located in the centre of the main room with closed windows facing onto Goodwood Road.

Figure 7 presents the measured  $L_{pA,LF}$  level for each 10-minute period at Location 2. As the measurements were conducted using the Soundbook system, overall C-weighted and A-weighted levels were not able to be determined to a satisfactory degree of accuracy.



**Figure 7 – Measured low frequency noise levels at Location 2**

As discussed in Section 6, there was also some concern about potential electrical noise generated in the measurement system at Location 2 for frequencies of 50Hz and 100Hz. Therefore the  $L_{pA,LF}$  levels were calculated such that, where potential electrical noise was present, the lowest measured level from the one third octave bands on either side was assigned to the one third octave band potentially affected by the electrical noise. This would most likely result in the  $L_{pA,LF}$  levels presented in Figure 7 being marginally lower than those actually present within the space.

The measured  $L_{pA,LF}$  levels at Location 2 typically varied between 25 and 35dB(A) during the daytime period, and typically between 15 and 30dB(A) during the night time period. It can be seen that the night time  $L_{pA,LF}$  levels during the weekend (Friday to Sunday nights) were higher than those measured on both Monday and Tuesday nights. This is believed to be a result of higher levels of traffic on Goodwood Road on the weekend due to it being the opening weekend of the Royal Adelaide Show at the nearby Wayville Showgrounds. The relatively sharp rise in measured  $L_{pA,LF}$  levels between 4 and 6am on both Tuesday and Wednesday morning would also support traffic as being a key source of low frequency noise at this location.

The measured daytime  $L_{pA,LF}$  levels on both Saturday and Sunday can be compared to the Danish 30dB(A) criterion as the office was generally unoccupied during these periods. The measured level typically varied between 27 and 34dB(A) during the weekend daytime periods, with the 30dB(A) criterion being exceeded for 41% of the 10-minute periods from 7am to 10pm.

In a similar manner to Location 1, it is also reasonable to compare the measured night time levels to the Danish 20dB(A) criterion for residential locations as the facade construction would be similar to that of nearby residences, and we understand the air conditioning system would not be operating at night time. During the night time periods

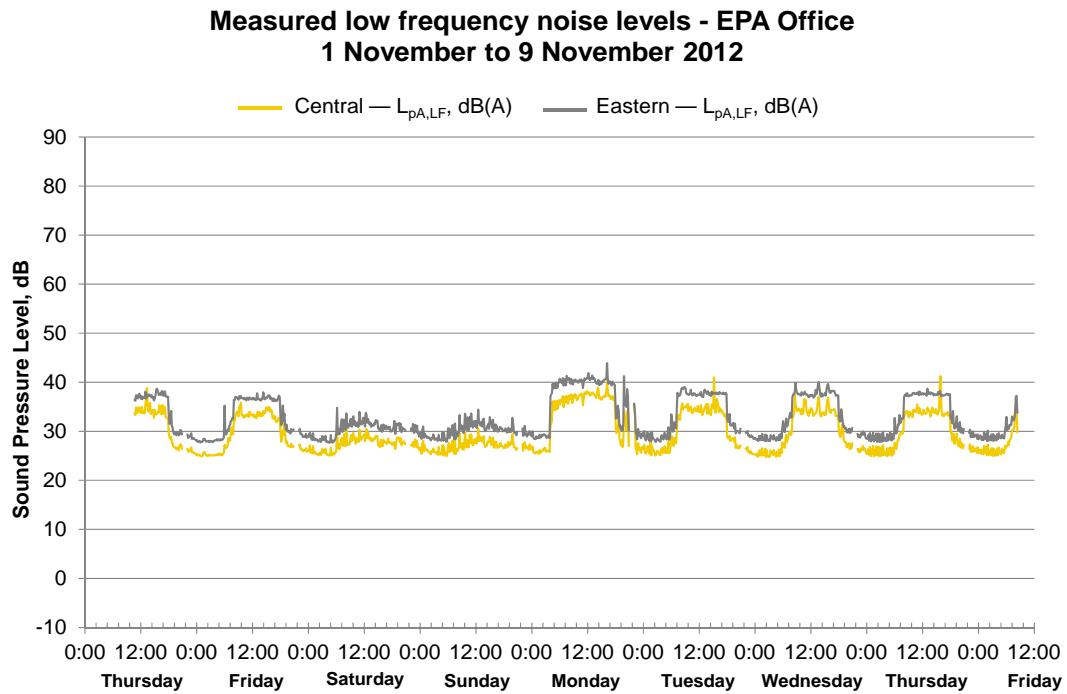
(10pm to 7am) at Location 2, the measured 10-minute  $L_{pA,LF}$  levels exceeded the Danish 20dB(A) criterion 86% of the time.

### 4.3 Location 3 – EPA office

Measurements were undertaken at the EPA office located on Victoria Square in Adelaide from 1 to 9 November 2012. The EPA office is located on the top floor (9<sup>th</sup> floor) of the building, which has a central atrium. The Soundbook measurement system was used with one microphone located in the office area nearer the atrium and the second microphone located towards the eastern glazed facade, facing away from Victoria Square.

Figure 8 presents the measured  $L_{pA,LF}$  level for each 10-minute period at the two measurement locations at Location 3. As the measurements were conducted using the Soundbook system, overall C-weighted and A-weighted levels were not able to be determined to a satisfactory degree of accuracy.

As discussed in Section 6, there was also some concern about potential electrical noise generated in the measurement system at Location 3 at 50Hz. There is a tone at 50Hz present in the EPA office and it is likely that this was the source of the 50Hz noise rather than electrical noise in the measurement system. However, to provide a conservative estimate, the  $L_{pA,LF}$  levels were calculated excluding noise at 50Hz where this may have been affected by electrical noise. This would most likely result in the  $L_{pA,LF}$  levels presented in Figure 8 being marginally lower than that actually present within the space.



**Figure 8 – Measured low frequency noise levels at Location 3**

It is clear from the measurement results at Location 3 that the low-frequency noise levels were affected by noise from the air conditioning system that was in operation on weekdays. Low frequency  $L_{pA,LF}$  noise levels at the Central location were typically 35 to 38dB(A) on weekdays but reduced to between 27 and 30dB(A) on both the weekend and

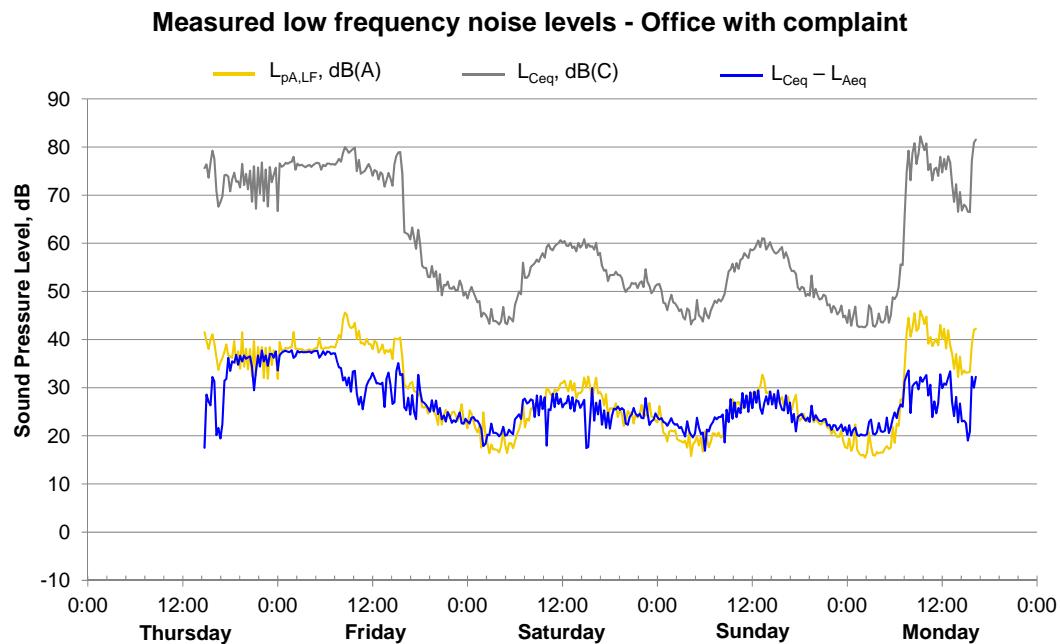
during the night time period. Measured levels at the Eastern Location were consistently 3dB higher than those at the Central location, suggesting that this measurement point was more exposed to noise from the air conditioning system or other outdoor sources.

The low frequency  $L_{pA,LF}$  levels at Location 3 were over 20dB(A) for the entire measurement period. However, we note that these measured noise levels can not be compared to night time low frequency noise criteria for residences as the mechanical plant associated with the office building is unlikely to be representative of that at residential locations.

#### 4.4 Location 4 – Office with LF noise complaint

Measurements were undertaken at an office located in the metropolitan Adelaide area where a low frequency noise complaint has been received. The source of the low frequency noise complaint was the air conditioning system for the building. The measurements were performed using a Brüel & Kjær Type 2250 sound level meter, capable of measuring to a minimum frequency of 6.3Hz.

Figure 9 presents the measured  $L_{pA,LF}$ ,  $L_{Ceq} - L_{Aeq}$  and  $L_{Ceq}$  levels over each 10-minute period at Location 4. Note that the blue line on the graph ( $L_{Aeq} - L_{Ceq}$ ) will not correspond to the difference between the two other lines as the  $L_{pA,LF}$  level is only calculated between 10Hz and 160Hz, while the  $L_{Aeq}$  level is calculated between 10Hz and 20kHz.



**Figure 9 – Measured low frequency noise levels at Location 4**

The air conditioning system that was the source of the low frequency complaint was operating from the start of the measurement period until the office closed on the Friday afternoon. It restarted on the Monday morning. During the operational periods, measured low frequency noise levels were controlled by the air conditioning system with:

- Typical  $L_{Ceq}$  levels of between 70 and 80dB(C)
- Typical  $L_{pA,LF}$  levels of between 35 and 45dB(A)

- a typical difference of 30 to 35dB between the measured  $L_{Ceq}$  and  $L_{Aeq}$  levels.

The above levels during operation of the air conditioning system clearly exceed the daytime Danish criterion of 30dB(A) for offices and the measured  $L_{Ceq}$  levels would also be considered to be high.

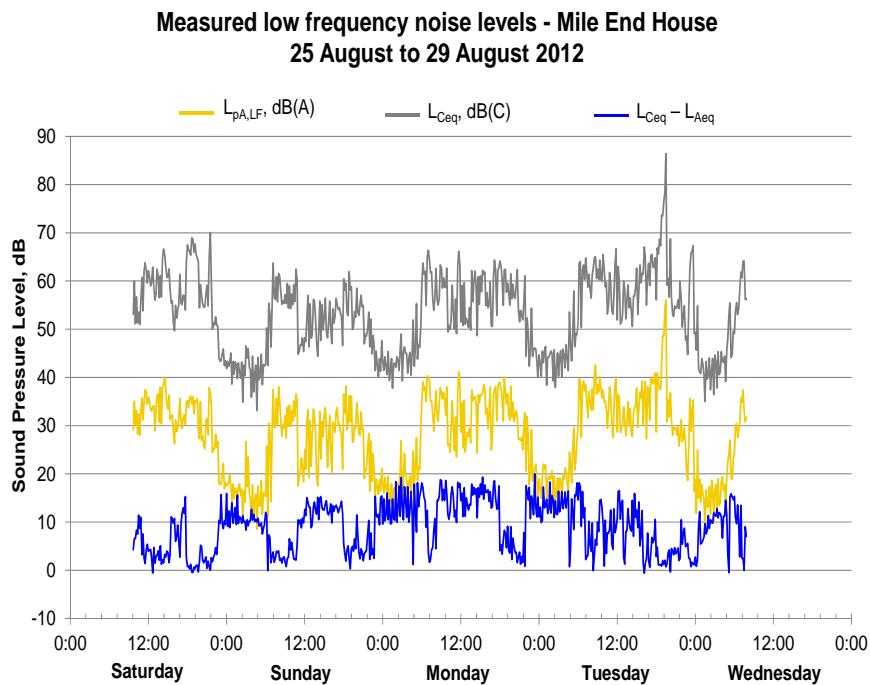
From Friday afternoon until Monday morning, the measured levels were not controlled by the air conditioning system and are considered representative of noise levels from other sources such as local traffic. It would be reasonable to compare these levels to the residential criterion given the location of the office in a mixed residential and commercial area.

During the night time periods (10pm to 7am) from Friday night through to Monday morning, the measured 10-minute average  $L_{pA,LF}$  levels at Location 4 exceeded the Danish 20dB(A) criterion for 42% of the measurement period. The difference between the measured  $L_{Ceq}$  and  $L_{Aeq}$  levels exceeded 20dB for 77% of the measurement period but only exceeded 25dB on three occasions.

## 4.5 Location 5 – House at Mile End

Measurements were undertaken at a house located in Mile End, under the flight path, from 25 to 29 August 2012. The house is located approximately 3 km from the Adelaide Airport main runway and 300 metres from South Road. The measurements were undertaken with the SVAN 945A sound level meter, located in the living room, and the house was occupied during the majority of the measurement period with the exception of weekdays during work hours (typically 8am to 6pm).

Figure 10 presents the measured  $L_{pA,LF}$ ,  $L_{Ceq} - L_{Aeq}$  and  $L_{Ceq}$  levels over each 10-minute period at Location 5. Note that the blue line on the graph ( $L_{Aeq} - L_{Ceq}$ ) does not correspond to the difference between the two other lines as the  $L_{pA,LF}$  level is only calculated between 10Hz and 160Hz, while the  $L_{Aeq}$  level is calculated between 10Hz and 20kHz.



**Figure 10 – Measured low frequency noise levels at Location 5**

From Figure 10, it can be seen that measured low frequency noise levels during work hours on both Monday and Tuesday (when the house was unoccupied) were as high as those measured during the daytime period on the weekend. This indicates that external factors were a key source of low frequency noise, most likely noise from traffic and from aircraft taking off and landing at Adelaide Airport.

Typically, for Location 5:

- $L_{Ceq}$  levels varied between 50 and 65dB(C) during the daytime, decreasing to between 35 and 50dB(C) during the night time periods
- $L_{pA,LF}$ -levels varied between 25 and 40dB(A) during the daytime and between 15 and 30dB(A) during the night time

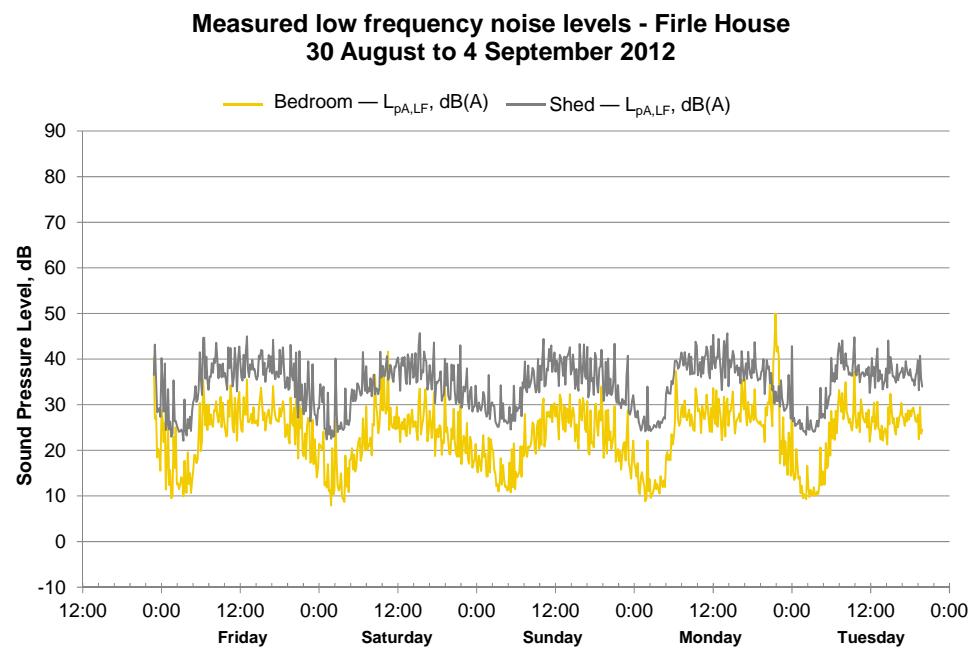
- the difference between the measured  $L_{Aeq}$  and  $L_{Ceq}$  levels was approximately 5 to 15dB and did not appear to follow any clear pattern with time of day.

During the night time periods (10pm to 7am), the measured 10-minute average  $L_{pA,LF}$  levels at Location 5 exceeded the Danish 20dB(A) criterion for 35% of the measurement period. The night time difference between the measured  $L_{Ceq}$  and  $L_{Aeq}$  levels did not exceed 20dB during the monitoring.

#### 4.6 Location 6 – House at Firle

Measurements were undertaken at a house located in Firle, from 30 August to 4 September 2012. Measurements were undertaken using the Soundbook system, with one channel located in a spare bedroom and the second channel located outdoors in a shed.

Figure 11 presents the measured  $L_{pA,LF}$  level for each 10-minute period at the two measurement locations at Location 6. As the measurements were conducted using the Soundbook system, overall C-weighted and A-weighted levels were not able to be determined to a satisfactory degree of accuracy.



**Figure 11 – Measured low frequency noise levels at Location 6**

The measured  $L_{pA,LF}$  levels within the bedroom typically varied between 25 and 30dB(A) during the daytime, and between 10 and 25dB(A) during the night time period. This included periods when the house was unoccupied from approximately midday on Saturday until 4pm on Monday.

The levels in the shed were consistently 10 to 15dB above those in the bedroom with the exception of periods when the spare bedroom was briefly occupied. While the level of low frequency noise in the shed is not relevant for comparison with other occupied spaces, this provides an indication of the level of low frequency noise reduction afforded by the façade construction of the house.

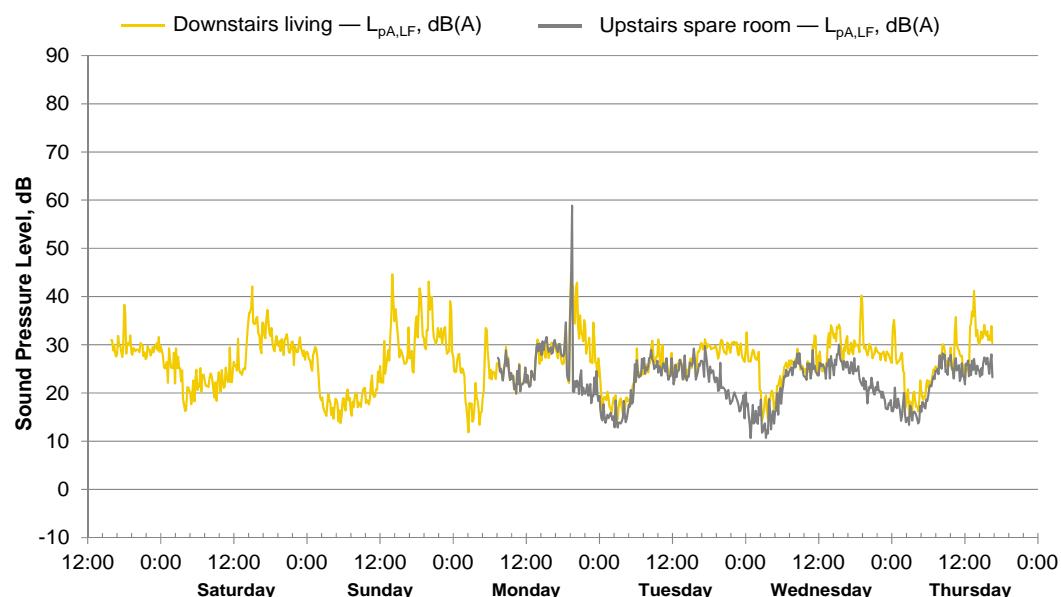
Overall, during the night time periods (10pm to 7am), the measured 10-minute average  $L_{pA,LF}$  levels at Location 6 exceeded the Danish 20dB(A) criterion for 27% of the measurement period.

#### 4.7 Location 7 – House at Prospect

Measurements were undertaken at a house located in Prospect, approximately 45 metres from Regency Road, between 24 August and 30 August 2012. The measurements were undertaken with the Soundbook system, with one microphone located in the downstairs living area and the second microphone located in the upstairs spare room (from 27 August). The house was occupied during the measurements.

Figure 12 presents the measured  $L_{pA,LF}$  level for each 10-minute period at the two measurement locations at Location 7. As the measurements were conducted using the Soundbook system, overall C-weighted and A-weighted levels were not able to be determined to a satisfactory degree of accuracy.

**Measured low frequency noise levels - Prospect House  
24 August to 30 August 2012**



**Figure 12 – Measured low frequency noise levels at Location 7**

The measured  $L_{pA,LF}$  low frequency noise levels at Location 7 typically range from 15 to 40dB(A) in the living room but only from 15 to 30dB(A) in the spare room. It is expected that this is due to the living room being occupied far more often than the spare room, and this is most evident in the period from approximately 6pm to 2am when we understand the living room (and adjoining areas) would be occupied but the spare room unoccupied.

Overall, during the night time periods (10pm to 7am), the measured 10-minute average  $L_{pA,LF}$  levels at Location 6 exceeded the Danish 20dB(A) criterion for:

- 62% of the measurement period in the living room
- 16% of the measurement period in the spare bedroom.

The difference between the two is considered to be the result of the living room being occupied during a reasonable portion of the night time period at this particular location. The measured levels in the spare room are therefore more likely to represent low frequency noise levels due to external factors such as traffic.

#### 4.8 Summary of results for urban locations

Based on the measurement results collected at the seven urban locations, it appears that the following factors can affect indoor low frequency noise levels at offices and residences:

- traffic from major and local roads, and aircraft
- mechanical plant (e.g. air-conditioning systems)
- daily activities of people within a standard office or a home.

Excluding periods clearly affected by the daily activities of people, A-weighted low frequency noise levels at all locations were found to regularly exceed the night time residential criterion of 20dB(A) used in Denmark, between 16% and 86% of the time. This suggests that people living in urban areas are regularly exposed to low frequency noise levels in excess of this criterion.

It may also be an indication that the  $L_{pA,LF}$  criterion is too stringent for urban areas where there are variety of low frequency sources. The Danish criterion is typically intended to apply where a specific industrial source of low frequency noise exists (DEFRA, 2005), and would not necessarily apply to the general ambient noise level in an environment.

It is important to recognise that, in urban areas, these low frequency noise levels are often accompanied by higher levels of broadband noise as well. A simple assessment procedure to determine whether low frequency noise may present an annoyance problem is to compare the difference between the  $L_{Ceq}$  and  $L_{Aeq}$  levels which analyses the low frequency noise content relative to the overall noise content. This information was available at three of the urban measurement locations and at only one of the locations was the measured difference in excess of 20dB. This was Location 4 where a low frequency noise complaint was registered, and the measured  $L_{pA,LF}$  levels were also above the relevant criterion.

## 5 Measurement results – rural environments

Measurements were undertaken at four rural locations, for comparison with measurements gathered in the urban environments:

- Location 8 – House located adjacent to Bluff Wind Farm
- Location 9 – House located near Clements Gap Wind Farm
- Location 10 – Farmhouse located near Jamestown, 10 km from nearest wind turbine
- Location 11 – House located near Myponga, 30 km from nearest wind turbine.

### 5.1 Location 8 – House near Bluff Wind Farm

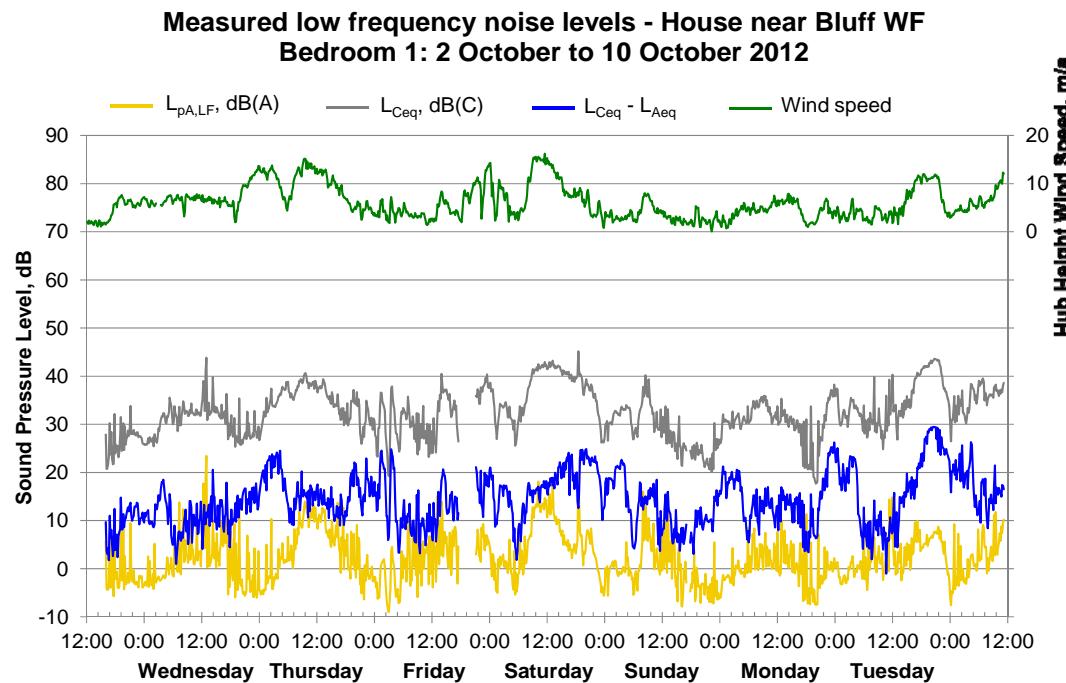
Measurements were undertaken at a house located near to the Bluff Wind Farm, North West of Hallett. The wind farm is comprised of 24 Suzlon S88 2.1 MW turbines and one Suzlon S97 2.1 MW turbine, with the house located approximately 1.5 kilometres from the nearest turbine. North Brown Hill Wind Farm is also situated to the West of the house, and is comprised of the same S88 2.1MW turbines. The nearest turbine at North Brown Hill is located 8 kilometres from the measurement location, and 22 of the turbines at the Bluff Wind Farm were closer than the nearest turbine at North Brown Hill.

The measurements were undertaken between 2 October and 10 October 2012. During this period, the house was unoccupied and the mains power and water supply were switched off. The SVAN 945A was located in one bedroom (Bedroom 1) with one measurement channel of the Soundbook system located in the second bedroom (Bedroom 2). The second measurement channel of the Soundbook system was positioned outside, approximately 10 metres from the window of Bedroom 2. The house is of a masonry construction and is estimated to be approximately 100 years old. The two bedrooms used for the indoor measurements both had sash windows facing towards the Bluff Wind Farm. The windows in each bedroom could be properly closed such that wind-induced noise across the indoor microphone was not of significant concern to the measurement results.

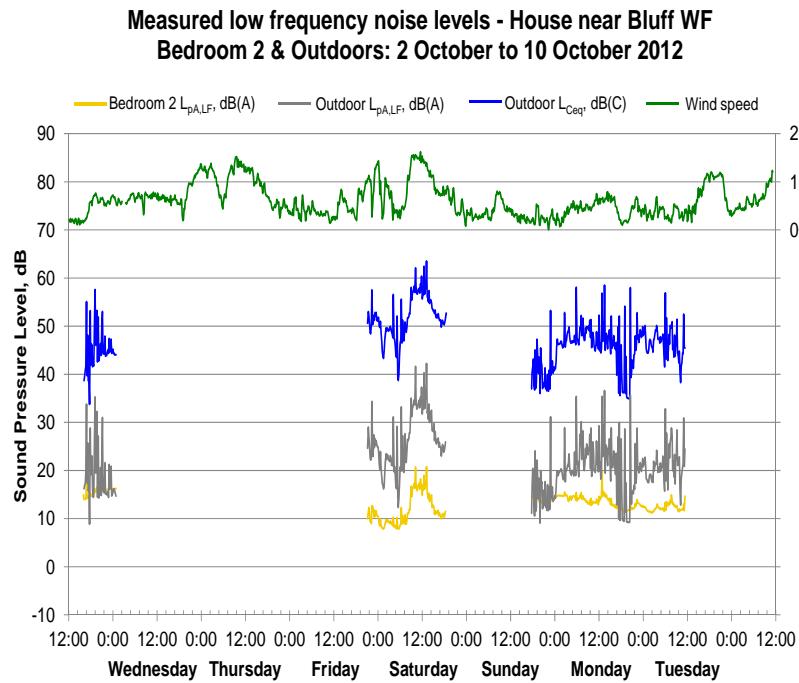
Figure 13 and Figure 14 present the measured low frequency noise levels at Location 8 for Bedroom 1 and for the other two measurement locations respectively. The 10-minute average hub height (80 metres above ground level) wind speed measured at the nearest meteorological mast at the Bluff Wind Farm is also presented on the figure for comparison. The mast is located approximately 1.4 kilometres from the house.

Note that, as the measurements in Bedroom 2 and outdoors were conducted using the Soundbook system, overall A-weighted levels were not able to be determined to a satisfactory degree of accuracy. There was also concern regarding the accuracy of the overall C-weighted levels given the noise floor of the Soundbook system at higher frequencies and the  $L_{Ceq}$  levels at the outdoors location were therefore determined based on the one third octave bands from 10Hz to 800Hz inclusive. In environments where low frequency noise is dominant (situations of interest to this investigation), this approach of ignoring frequencies above 800Hz will have minimal impact on C-weighted levels. In situations where higher frequency noise is dominant (situations of no interest to this investigation), this approach will underestimate overall C-weighted levels. We believe

this approach provides a reasonable estimate of the low frequency controlled C-weighted noise level.



**Figure 13 – Measured low frequency noise levels at Location 8, Bedroom 1**



**Figure 14 – Measured low frequency noise levels at Location 8, Bedroom 2 and outdoors**

Both C-weighted and A-weighted levels could be accurately measured using the SVAN 945A sound level meter located in Bedroom 1.

The measured  $L_{pA,LF}$  low frequency noise levels at Location 8 typically ranged from:

- -5 to 15dB(A) in Bedroom 1
- 9 to 17dB(A) in Bedroom 2
- 10 to 35dB(A) outdoors.

The outdoor  $L_{Ceq}$  levels typically varied between 37 and 58dB(C).

The difference in the A-weighted low frequency noise levels between Bedroom 1 and Bedroom 2 is believed to be a result of noise generated by power supply of the Soundbook system (with the system located in Bedroom 2 during the measurements). The effective noise floor on the measurement system due to the power supply appears to be in the order of approximately 10dB(A) $L_{pA,LF}$ , most evident during a period on the Monday when the outdoor  $L_{pA,LF}$  levels dropped below the indoor  $L_{pA,LF}$  levels in Bedroom 2. This has had the effect of increasing the measured low frequency noise levels in Bedroom 2 but does not appear to have affected the measured low frequency noise levels in Bedroom 1 or outdoors.

Typically, the measured 10-minute average  $L_{pA,LF}$  noise levels in both Bedroom 1 and Bedroom 2 were compliant with the Danish night time criterion of 20dB(A) for the entire night time measurement period. The daytime 10-minute average  $L_{pA,LF}$  noise level exceeded 20dB(A) on only one occasion during the measurements but at this occurred only once during the daytime and when the wind speed was relatively low (6 m/s at hub height) it is considered unlikely to be a result of wind farm operation.

The difference between the  $L_{Ceq}$  and  $L_{Aeq}$  levels observed in Bedroom 1 typically varied between 5 and 25dB during the measurement period. The measured night time  $L_{Ceq} - L_{Aeq}$  level exceeded 25dB for only 1% of the measurement period but exceeded 20dB for 24% of the measurement period. It is important to note that, as the A-weighted and C-weighted noise levels in this room were very low, the application of a 20dB difference criterion may not be appropriate for this site (Broner, 2011).

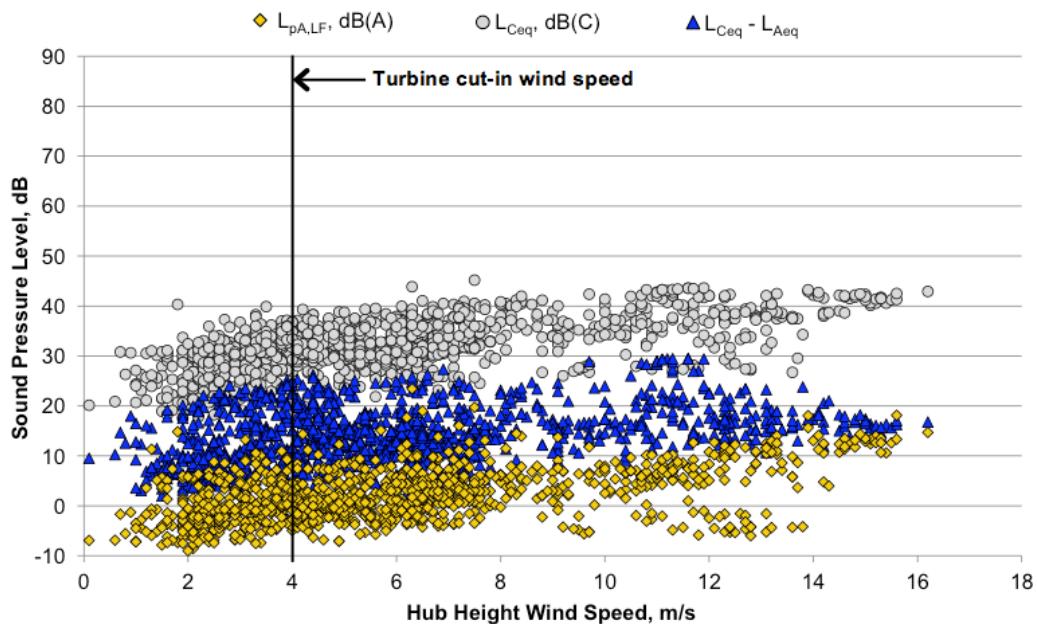
The variation in low frequency noise levels measured at Location 8 has some relation to the time period, with low frequency noise levels appearing to be higher during the daytime than at night time. However, the variation is not as consistent as it was at the urban locations and there also appears to be a relationship between the measured low frequency noise levels and wind speed.

Figure 15 presents the measured low frequency noise levels for Bedroom 1 at Location 8 versus hub height wind speed at the wind farm site. There appears to be some correlation in the datasets with wind speed at the wind farm site, with low frequency noise levels generally increasing as the wind speed increases. It is important to note that this could be a result of low frequency noise generated by the wind itself rather than the wind farm. Interestingly, no change in low frequency noise is evident when levels at wind speeds just below cut-in (4 m/s) are compared to measurements at speeds just above the cut-in speed. This indicates low frequency noise levels are not controlled by the operation of the wind farm at the lower speeds when the turbines operate.

Figure 16 presents the measured outdoor  $L_{pA,LF}$  and  $L_{Ceq}$  noise levels at Location 8 for periods when the measurement location was downwind ( $\pm 45^\circ$ ) of the nearest turbines at

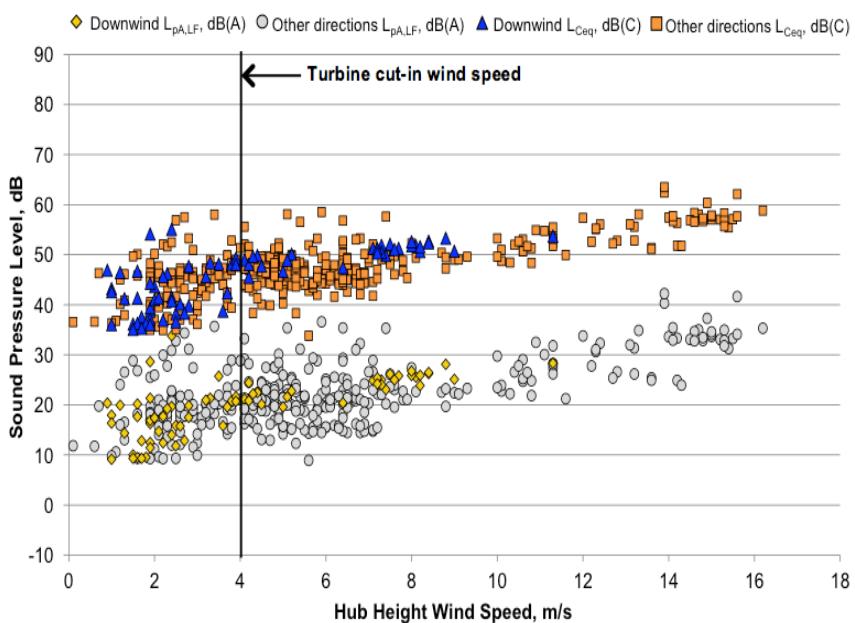
the Bluff Wind Farm and for periods when the wind was blowing in other directions. It can be seen that there is no discernible difference between the two datasets. This suggests that the Bluff Wind Farm may not be the controlling source of low frequency noise levels at Location 8.

#### Measured low frequency noise levels with wind speed House near Bluff Wind Farm, Bedroom 1



**Figure 15 – Measured low frequency noise levels with wind speed at Location 8, Bedroom 1**

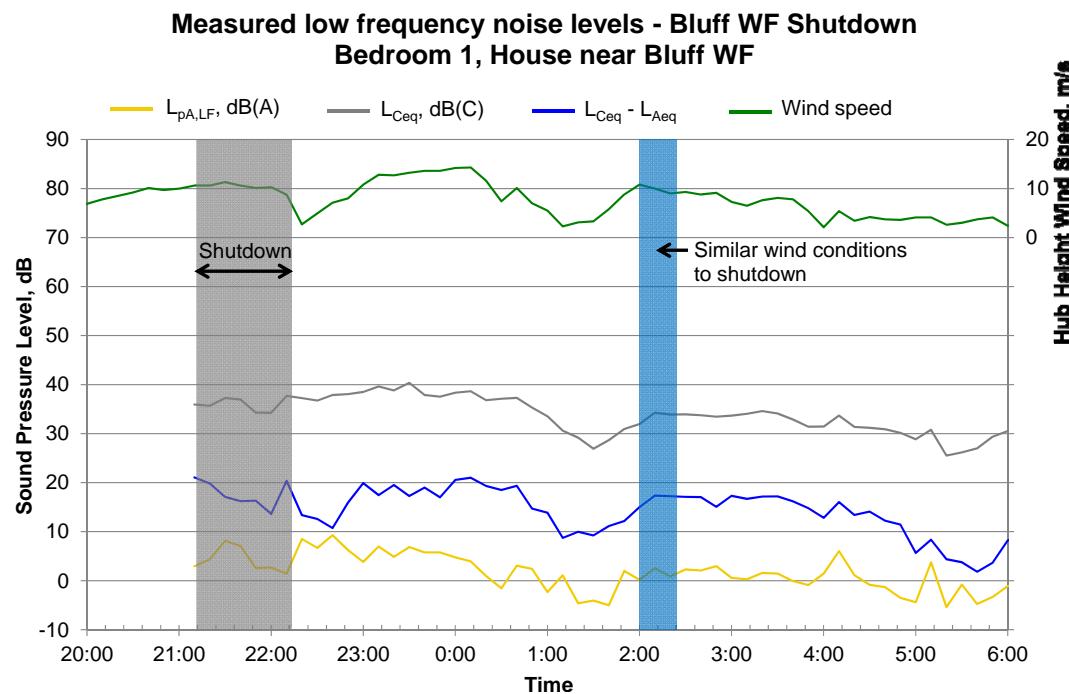
#### Measured low frequency noise levels with wind speed House near Bluff Wind Farm, outdoors



**Figure 16 – Measured low frequency noise levels with wind speed at Location 8, Outdoors**

To assist in confirming the contribution of the Bluff Wind Farm to low frequency noise levels at the house, a shutdown of the whole wind farm was arranged to occur from approximately 9pm to 10pm on 5 October 2012. During this arranged shutdown, the 10-minute wind speed measured at the meteorological mast was 10 to 12 m/s and the wind direction was approximately 90° relative to the line from the nearest turbine to the house (i.e. crosswind conditions).

Figure 17 presents the measured low frequency noise levels in Bedroom 1 during and after the shutdown of the Bluff Wind Farm. The wind speed measured at the nearest meteorological mast at the wind farm is also shown. A 20-minute period that occurred approximately four hours after the shutdown is highlighted for comparison, as the same wind conditions (speed and direction) were measured as occurred during the shutdown.



**Figure 17 – Measured low frequency noise levels during shutdown at Location 8, Bedroom 1**

It is apparent from Figure 17 that there is only a marginal change in the low frequency noise levels for comparable periods both during and after the shutdown of the Bluff Wind Farm. It appears as though there may be an insignificant increase in the difference between the  $L_{Ceq}$  and  $L_{Aeq}$  levels, but this is not consistent for the entire shutdown period. Overall, the collected data suggests that low frequency noise levels at Bedroom 1 of Location 8 were not controlled by noise from the Bluff Wind Farm.

From 2 am to 2:20 am on 6 October (4 hours after the shutdown) the wind speed and wind direction at the meteorological mast was similar to that during the shutdown allowing a comparison between the two periods. The measured low frequency noise levels both during the shutdown and with the wind farm operational are summarised in Table 5, including the wind speed and direction relative to the house (0° corresponds to upwind).

The results presented in Table 5 indicate that, as for the results presented in Figure 17, there was no noticeable change in low frequency noise levels at any of the measurement

points at Location 8 for shutdown and operational periods of comparable wind speed and direction. Noise levels from the Bluff Wind Farm did not appear to be controlling the low frequency noise environment at Location 8.

**Table 5 – Low frequency noise levels at Location 8 during and after shutdown**

Date & Time	Bed 1			Bed 2	Outdoor		Wind conditions	
	L <sub>pA,LF</sub> , dB(A)	L <sub>Ceq</sub> , dB(C)	L <sub>Ceq</sub> - L <sub>Aeq</sub>	L <sub>pA,LF</sub> , dB(A)	L <sub>pA,LF</sub> , dB(A)	L <sub>Ceq</sub> , dB(C)	Speed m/s	Relative direction, 0° upwind
<i>Shutdown periods</i>								
5/10 21:10	3	36	21	10	25	51	10.6	103°
5/10 21:20	4	36	20	11	29	53	10.6	100°
5/10 21:30	8	37	17	12	27	52	11.3	96°
5/10 21:40	7	37	16	11	25	51	10.6	92°
5/10 21:50	3	34	16	10	23	49	10.1	92°
5/10 22:00	3	34	14	10	22	48	10.3	82°
<i>Operational periods</i>								
5/10 23:00	4	39	20	10	25	51	10.8	46°
6/10 00:20	1	37	19	9	21	50	11.6	43°
6/10 02:00	0	32	15	9	22	48	10.8	87°
6/10 02:10	3	34	17	10	24	50	10	96°

## 5.2 Location 9 – House near Clements Gap Wind Farm

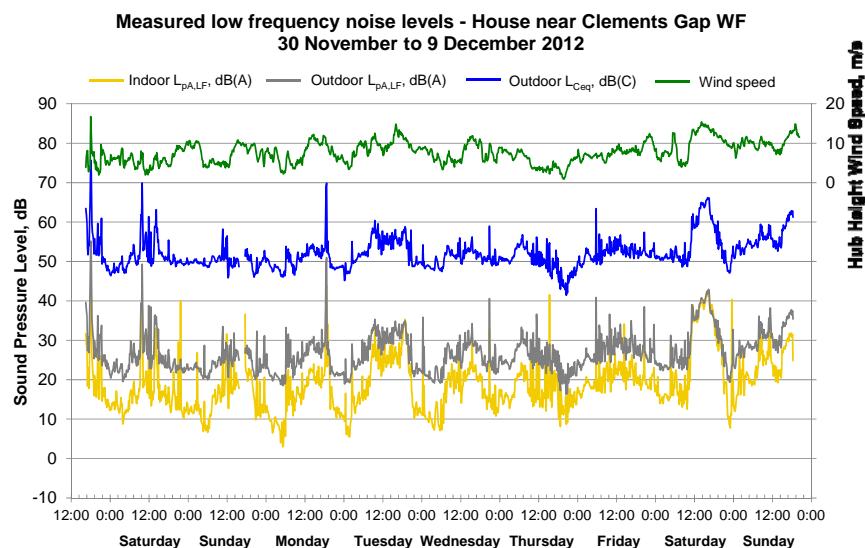
Measurements were undertaken at a house located near to the Clements Gap Wind Farm, South West of Crystal Brook. The wind farm is comprised of 27 Suzlon S88 2.1 MW turbines. The house made available for the measurements adjacent to Clements Gap Wind Farm is situated approximately 1.4 kilometres from the nearest turbine.

The measurements were undertaken between 30 November and 9 December 2012. During this period, the house was unoccupied although the resident was undertaking renovation work during daytime hours. One measurement channel of the Soundbook system was positioned inside a room that had a window facing towards the Clements Gap Wind Farm. The second measurement channel of the Soundbook system was located outside, approximately 5 metres from the window of the bedroom.

The house is of a masonry construction and is estimated to be approximately 100 years old (similar to Location 8). The room used for the indoor measurements had two windows and one external door (as part of an adjoining room) facing towards Clements Gap Wind Farm, and a third window facing in another direction. The house was in the process of renovation and there were gaps in the facade and around windows and external doors.

During occasional visits to site, it was found that the external door had been left open for some of the measurement period following renovation works. This, combined with the gaps in the facade, may have resulted in air movement in the room with the indoor microphone. A sheet of iron held by a single nail in one corner was also noted to be banging on the roof near the measurement room during a site visit at a time of high winds near the conclusion of the measurements. This was likely to be generating low frequency noise within the room. These observations lead to significant concern about the accuracy of the indoor measurements.

Figure 18 presents the measured indoor and outdoor  $L_{PA,LF}$  levels and the outdoor  $L_{Ceq}$  levels at Location 9 during the monitoring period. The 10-minute average hub height (80 metres above ground level) wind speed from the nearest turbines at the Clements Gap Wind Farm is also presented on the figure for comparison. As the Soundbook measurement system was used, accurate overall A-weighted levels could not be obtained in a quiet environment and the C-weighted levels were limited across the one third octave bands from 10Hz to 800Hz inclusive. The  $L_{PA,LF}$  levels and  $L_{Ceq}$  levels during any periods, where electrical noise may have affected the results at 50Hz (and associated harmonics), were calculated by applying the lower level from the adjoining one third octave bands to the affected one third octave band.



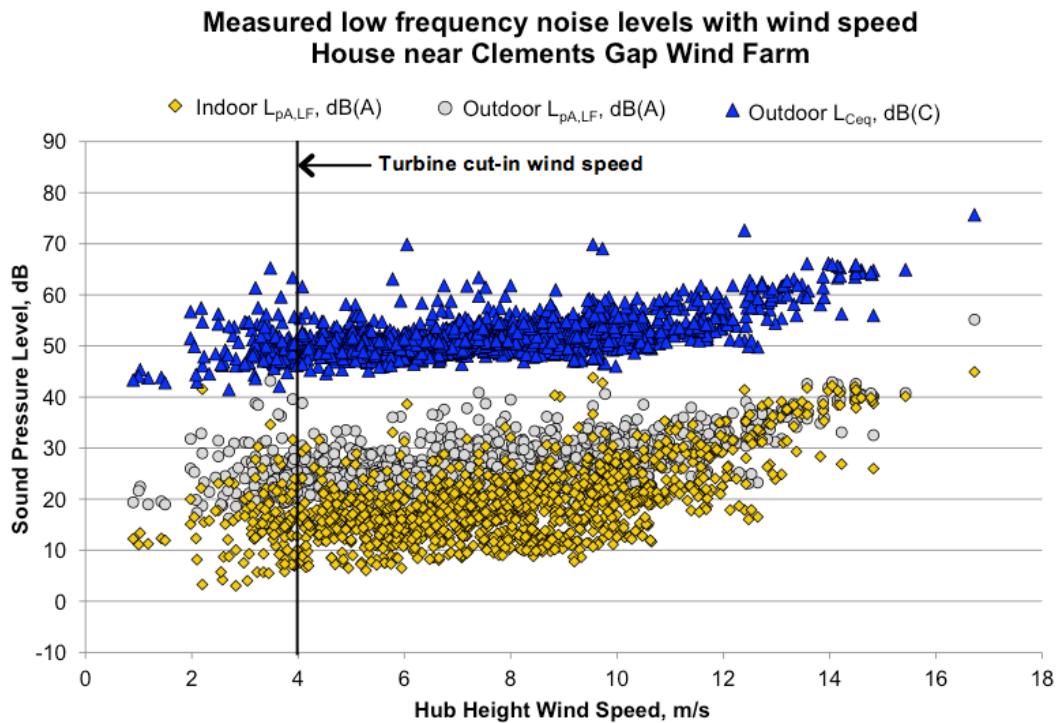
**Figure 18 – Measured low frequency noise levels at Location 9**

It can be seen from Figure 18 that the indoor  $L_{PA,LF}$  levels typically vary from 5 to 22dB(A) during the night time period, with 10% of the measured levels exceeding 20dB(A). Higher levels were measured during the daytime period but this is believed to be result of extraneous noise generated by renovation works at the house. The outdoor night time  $L_{Ceq}$  levels typically range from 45 to 55dB(C).

There was a period of higher winds from about 11am to 8pm on the Saturday (8<sup>th</sup> December) where the outdoor and indoor  $L_{PA,LF}$  levels were almost identical. During a daytime inspection to the site on the Saturday it was found that the higher wind speeds were causing the loose sheet of iron on the roof to noticeably rattle and this is considered the most likely cause of the elevated indoor low frequency levels. The wind direction during this period was crosswind with respect to the house, and during the inspection low frequency noise from the wind farm was not noticeable at the house, suggesting that the influence of the wind farm on low frequency noise levels during this period would not have been significant.

Figure 19 presents the measured low frequency noise levels at Location 9 with hub height wind speed measured at Clements Gap Wind Farm. It can be seen that there is an upward trend in low frequency noise levels with wind speed but the contribution of the wind farm to the measured levels is unknown. The higher upward trend in measured

indoor  $L_{pA,LF}$  levels at wind speeds above 10m/s is believed to be due to the loose sheet of iron on the roof rattling under higher winds as discussed above.



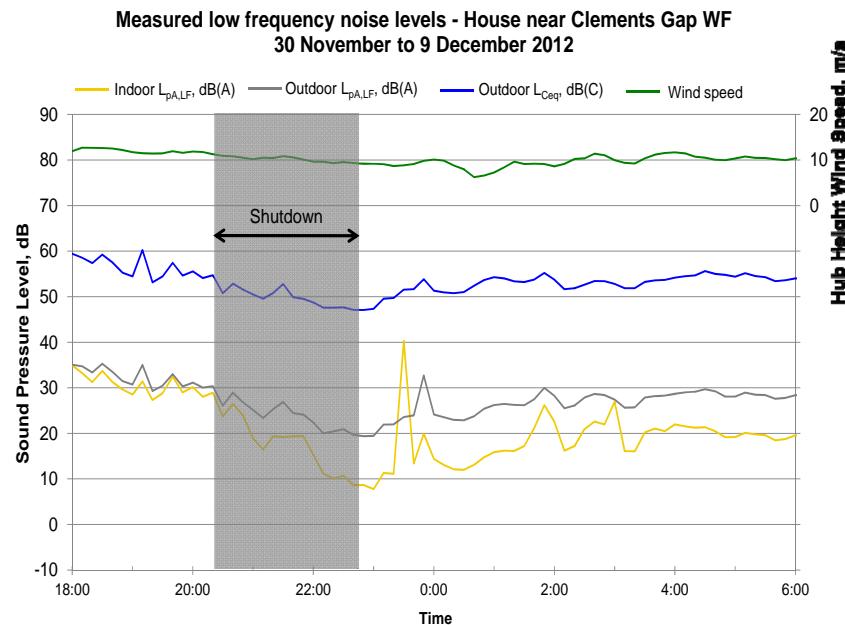
**Figure 19 – Measured low frequency noise levels with wind speed at Location 9**

To check the contribution of Clements Gap Wind Farm to the measured low frequency noise levels at Location 9, the wind farm was shutdown from approximately 8:20pm to 10:50pm on 8<sup>th</sup> December 2012. During this period, the hub height wind speed at the wind farm was between 9 and 11m/s, and the wind direction was approximately 70° to 80° relative to the house (crosswind, slightly upwind conditions). The measured indoor and outdoor low frequency noise levels outside and inside the house before, during and after the shutdown are shown in Figure 20.

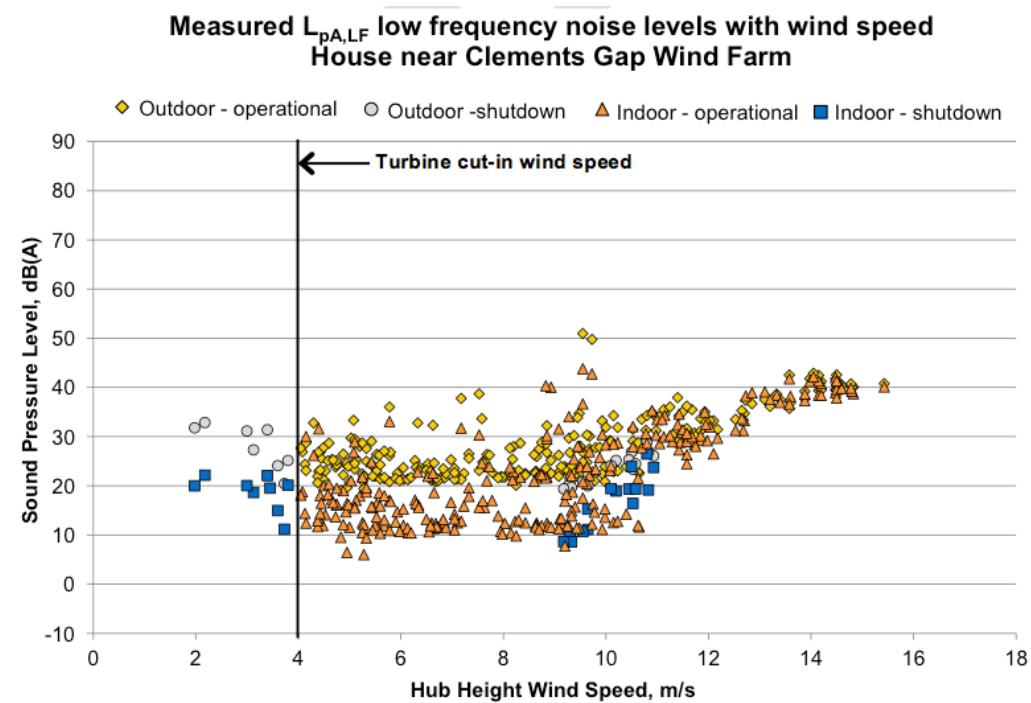
It can be seen that the low frequency noise levels trend downwards during the shutdown but, as they start at a higher level during the first 20 to 30 minutes, the initial higher levels appear to be a result of something other than noise from the Clements Gap Wind Farm. At the conclusion of the shutdown there may be a small, but not significant, increase in the indoor  $L_{pA,LF}$  levels that may result from noise from the wind farm. However, the measured indoor levels immediately after the wind farm commenced operation again are only in the order of 10dB(A) $L_{pA,LF}$ . Wind conditions did not change significantly after the shutdown period. It is important to note that a change in wind direction was observed immediately after the shutdown, approximately 50° to 60° in magnitude towards the downwind direction. Therefore it is difficult to make direct comparisons regarding the low frequency noise data presented in Figure 20.

Figure 21 presents the indoor and outdoor low frequency noise levels versus wind speed for both the shutdown periods and the operational periods under the particular wind directions observed during the shutdown. The shutdown periods at low wind speed occurred when the wind speed at the turbines was below the cut-in wind speed (rather

than a planned shutdown). A 25° wide wind direction sector has been considered for this analysis, to best match the wind directions observed during the shutdown.



**Figure 20 – Measured low frequency noise levels at Location 9 during shutdown of Clements Gap Wind Farm**



**Figure 21 – Measured low frequency noise levels at Location 9 during same wind direction as shutdown at Clements Gap Wind Farm**

The results presented in Figure 21 indicate that the low frequency noise levels measured during shutdown periods were similar to those measured at other times during the monitoring when Clements Gap Wind Farm was operational. At higher wind speeds, the

shutdown periods resulted in some of the lower levels both indoors and outdoors but similar levels were still measured for the same wind conditions at other times. Overall, the measurement results at Location 9 demonstrate that, while noise from Clements Gap Wind Farm may contribute to low frequency noise levels at the house, the contribution would not be significantly higher than the level of low frequency noise already present in the environment.

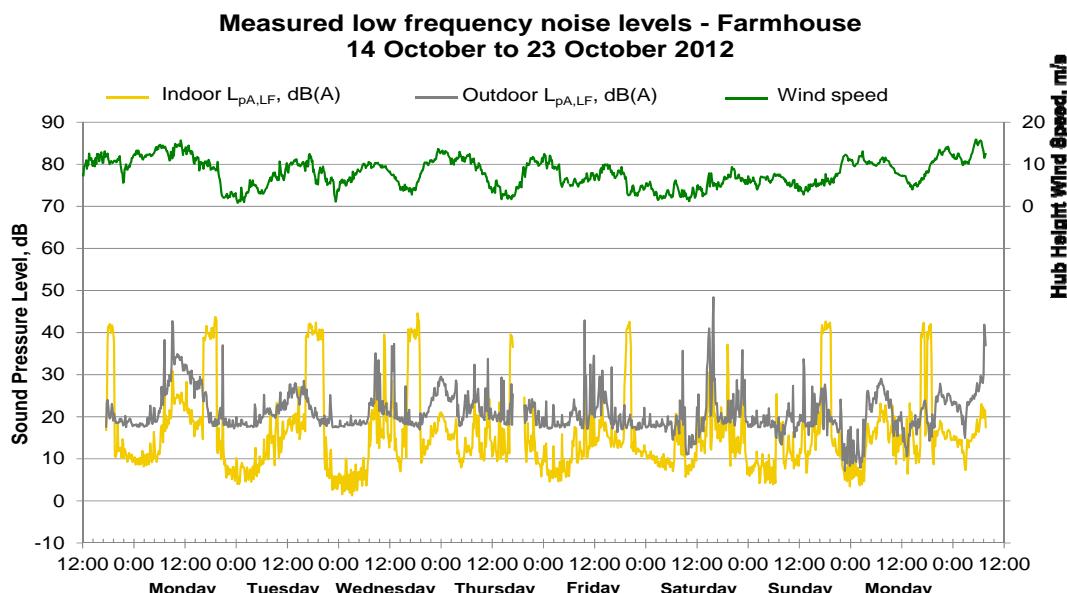
## 5.3 Location 10 – Farmhouse

Measurements were also undertaken at a farmhouse located near Jamestown, providing a comparison between low frequency noise levels at a rural house further away from the nearest wind turbines. The farmhouse is located 10 kilometres from the nearest wind turbine at the North Brown Hill Wind Farm.

The measurements were undertaken between 14 October and 23 October 2012, and the house was occupied during this period. One measurement channel of the Soundbook system was located in a living room and the second measurement channel was located outside, approximately 8 metres from the living room window.

The house is of a weatherboard construction and approximately 60 years old. The living room in which the measurements were taken has a single large window, which was kept closed during the measurement period. The living room is on the side of the house facing away from the North Brown Hill Wind Farm.

Figure 22 presents the measured indoor and outdoor  $L_{pA,LF}$  noise levels at Location 10. The  $L_{pA,LF}$  levels levels during any periods where electrical noise may have affected the results at 50Hz (and associated harmonics) were calculated by applying the lower level from the adjoining third one octave bands to the affected band. Measured noise levels at this location were only stored in one third octave bands up to 315Hz and therefore overall A-weighted and C-weighted noise levels could not be calculated.



**Figure 22 – Measured low frequency noise levels at Location 10**

The results presented in Figure 22 show that the measured  $L_{pA,LF}$  levels typically ranged from:

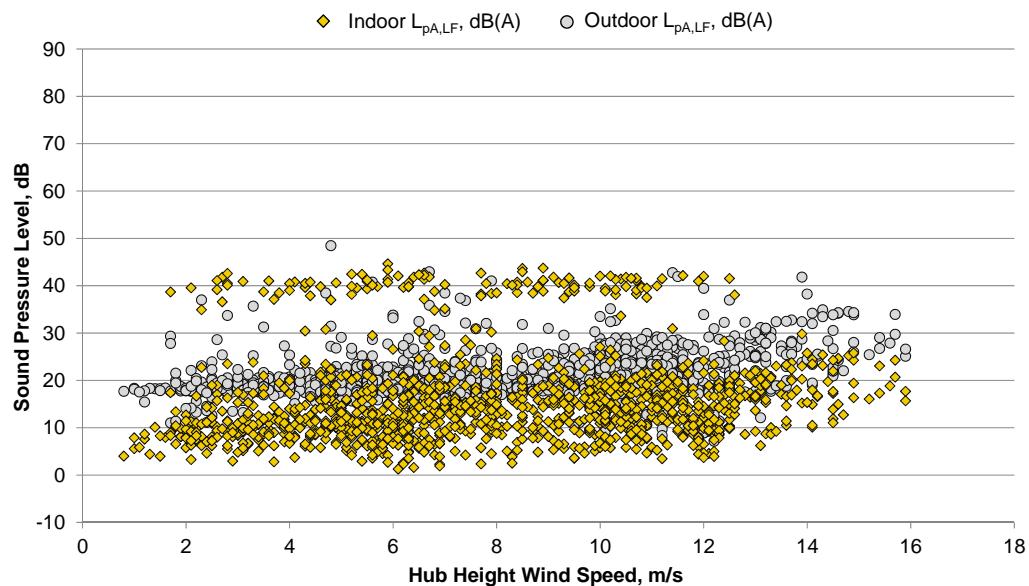
- 5 to 20dB(A) indoors
- 10 to 30dB(A) outdoors.

The Danish night time criterion of 20dB(A)  $L_{pA,LF}$  was exceeded for 2.5% of the total measurement period at the indoor location.

There were regular periods in the evenings when the indoor  $L_{pA,LF}$  levels increased markedly but there was no corresponding increase in the outdoor levels. This was due to the living room being occupied during these evening periods.

Figure 23 presents the measured low frequency noise levels at Location 10 with hub height wind speed measured at North Brown Hill Wind Farm, with the meteorological mast located over 10 kilometres away. It can be seen that, while there is a slight upwards trend in  $L_{pA,LF}$  noise levels with wind speed, there is no strong correlation. This suggests that noise from North Brown Hill Wind Farm was not contributing to the measured low frequency noise levels at this location.

**Measured low frequency noise levels with wind speed at wind farm Farmhouse**



**Figure 23 – Measured low frequency noise levels with wind speed at Location 10**

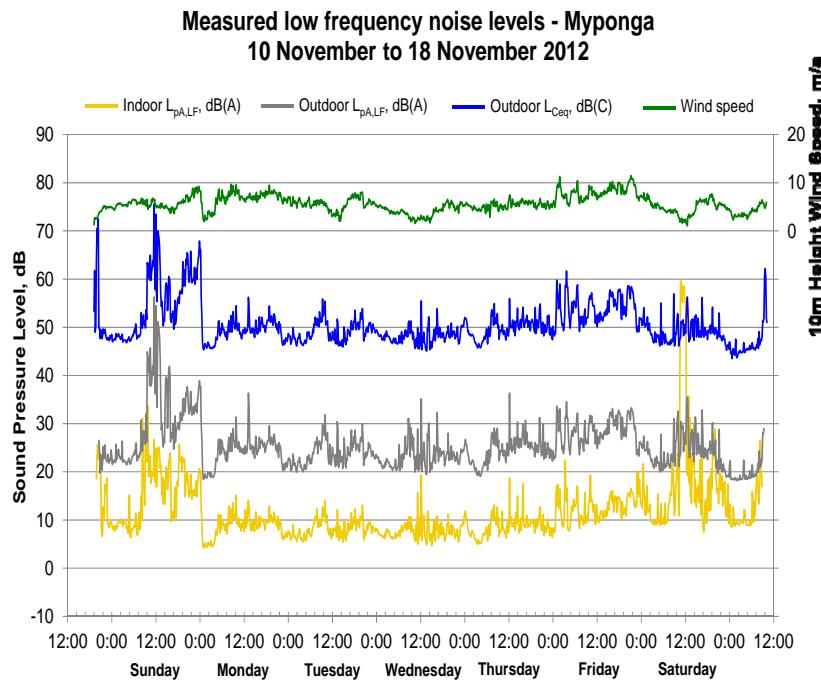
#### 5.4 Location 11 – House near Myponga

Additional measurements at a rural location were undertaken at a house located near Myponga. The house is situated approximately 30 kilometres from the nearest wind turbine (at Starfish Hill Wind Farm).

The measurements were undertaken between 10 November and 18 November 2012. The house was unoccupied on weekdays, but was occupied on the weekends. One measurement channel of the Soundbook system was located in a living room and the

second measurement channel was positioned outside, approximately 10 metres from the living room window. The house is of a modern construction, with masonry and glazed external walls. The interior of the house is open plan and the living room in which the indoor microphone was located is open to the rest of house. The house has large glazed areas, including one fully glazed facade.

Figure 24 presents the measured indoor and outdoor  $L_{pA,LF}$  levels and the outdoor  $L_{Ceq}$  levels at Location 11 during the monitoring period. The 10-minute average wind speed measured at a 10 metre high mast at the house is also presented on the figure for comparison. As the Soundbook measurement system was used, accurate overall A-weighted levels could not be obtained and the C-weighted levels were limited across the one third octave bands from 10Hz to 800Hz inclusive. The  $L_{pA,LF}$  levels and  $L_{Ceq}$  levels during any periods where electrical noise may have affected the results at 50Hz (and associated harmonics) were calculated by applying the lower level from the adjoining one third octave bands to the affected one third octave band.



**Figure 24 – Measured low frequency noise levels at Location 11**

The measured  $L_{pA,LF}$  low frequency noise levels at night time at Location 11 typically range from:

- 7 to 25dB(A) indoors
- 19 to 38dB(A) outdoors.

The outdoor C-weighted noise levels at night time typically ranged from 46 to 66dB(C).

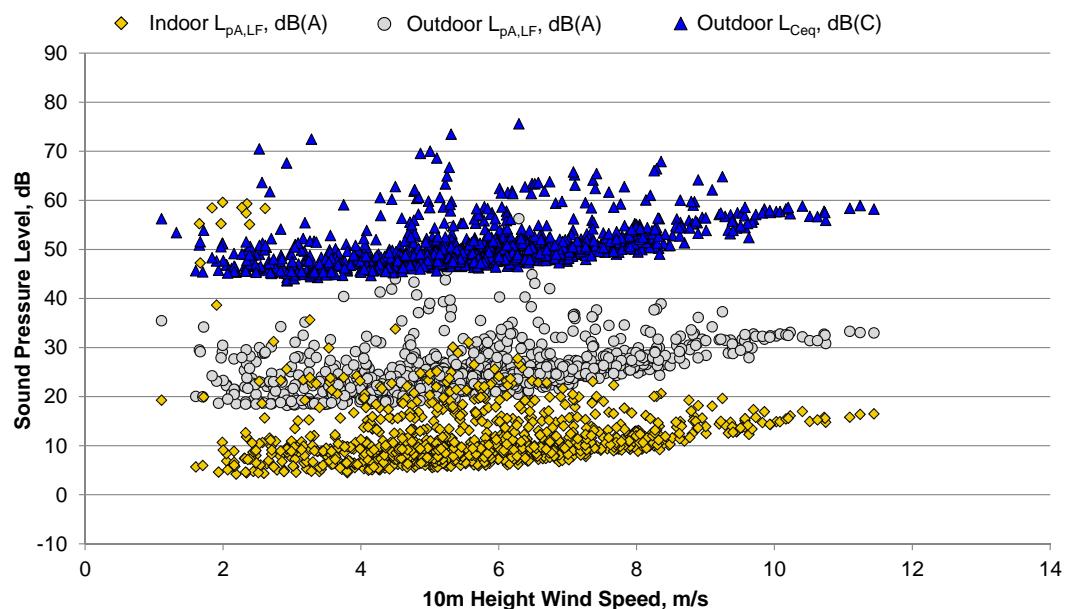
Generally, low frequency noise levels during the night time complied with the Danish 20dB(A)  $L_{pA,LF}$  indoor night time criterion (exceeding for 2.5% of the measurement period) and the 60dB(C) outdoor criterion proposed by Broner (2011). However, on the Sunday evening (6pm to midnight) there was a period of higher wind speeds in a particular wind direction where the indoor and outdoor criterion was marginally exceeded. As this

occurred in a period when the house was unoccupied, this was most likely due to external noise sources such as wind.

As with Location 8 and Location 9, the measured low frequency noise levels did appear to change with wind speed and with wind direction. In particular, the period on the Sunday night (when the house was unoccupied) shows a significant drop in both outdoor and indoor low frequency noise levels corresponding to a sharp change in wind direction.

Figure 25 presents the measured low frequency noise levels at Location 11 with the local wind speed. Note that the wind speed is measured at 10 metres above ground and can therefore not be directly compared to the hub height wind speed measurements used for the other rural sites.

### Measured low frequency noise levels with local wind speed Myponga



**Figure 25 – Measured low frequency noise levels with wind speed at Location 11**

It can be seen that there is a very good correlation between the measured low frequency noise levels and wind speed measured at 10 metres height only 60 metres from the house. This confirms that local wind speed (and localised turbulence) is a source of low frequency noise levels at a location, and appears to have a similar effect on both outdoor and indoor low frequency noise levels.

## 5.5 Summary of results for rural locations

The measurements at the four rural locations indicate that there is a lower level of low frequency noise in the environment relative to the seven urban locations. The measured night time  $L_{pA,LF}$  levels at the four locations only exceeded the 20dB(A) Danish criterion for 10% of the time or less. At one location, this 20dB(A) criterion was not exceeded. The levels of low frequency noise appeared to be correlated to wind speed at the site, but were also affected by the presence of people within a space at some locations.

The levels of low frequency noise at the two wind farm locations were low in comparison to the urban areas. The  $L_{pA,LF}$  levels at Location 8 remained below the Danish criteria at all times (as the single level above 20dB(A) occurred during the daytime), and the outdoor levels remained below 60dB(C) throughout the night time periods. The Danish 20dB(A) night time criterion was exceeded for 10% of the measurement period at Location 9 but this is believed to be due to the construction of the house rather than the contribution of noise from Clements Gap Wind Farm.

The organised shutdowns of the wind farms indicated that the Bluff Wind Farm most likely does not control the low frequency noise environment at Location 8. There did appear to be a relatively small contribution to the measured low frequency noise levels at Location 9 from the Clements Gap Wind Farm, but the measured  $L_{pA,LF}$  levels were generally controlled by other factors, presumed to be localised wind conditions and their interaction with the house.

At one of the locations, Location 8, the difference between the  $L_{Ceq}$  and  $L_{Aeq}$  levels could be determined for one of the rooms. Within this room the difference exceeded 20dB for approximately 24% of the measurement period, although both the A-weighted and C-weighted levels were low such that a 20dB difference criterion may not be appropriate (Broner, 2011). Regardless, the difference between the  $L_{Ceq}$  and  $L_{Aeq}$  levels did not change at this site during the shutdown of the Bluff Wind Farm. This suggests that the difference between  $L_{Ceq}$  and  $L_{Aeq}$  levels may be higher in rural areas than in urban areas regardless of whether a wind farm is located nearby or not, and maybe due to the lack of high frequency sources associated with human activity that are present in urban areas and would potentially increase the measured  $L_{Aeq}$  levels relative to the  $L_{Ceq}$  levels.

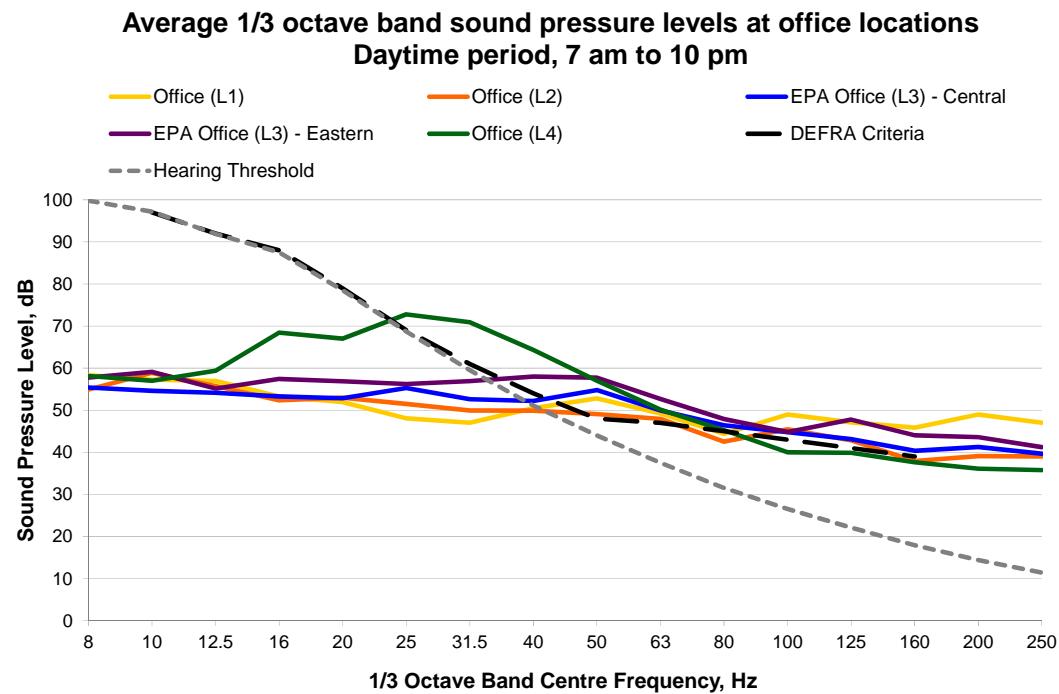
## 6 Assessment against DEFRA criteria

Section 4 and Section 5 present the measured low frequency levels based on a single number value, whether that be the measured  $L_{pA,LF}$ ,  $L_{Ceq}$  or  $L_{Ceq} - L_{Aeq}$  levels.

This Section presents the energy averaged measured indoor levels in each one third octave band across the low frequency region (taken to be 8Hz to 250Hz), and compares them to the DEFRA criteria that apply across the one third octave bands from 10Hz to 160Hz. Note that the DEFRA criteria can strictly apply to individual 10-minute periods rather than energy averaged periods and this is addressed in Table 6 in Section 6.3. However, a comparison of the energy averaged levels across the day and night time periods at each location is considered informative.

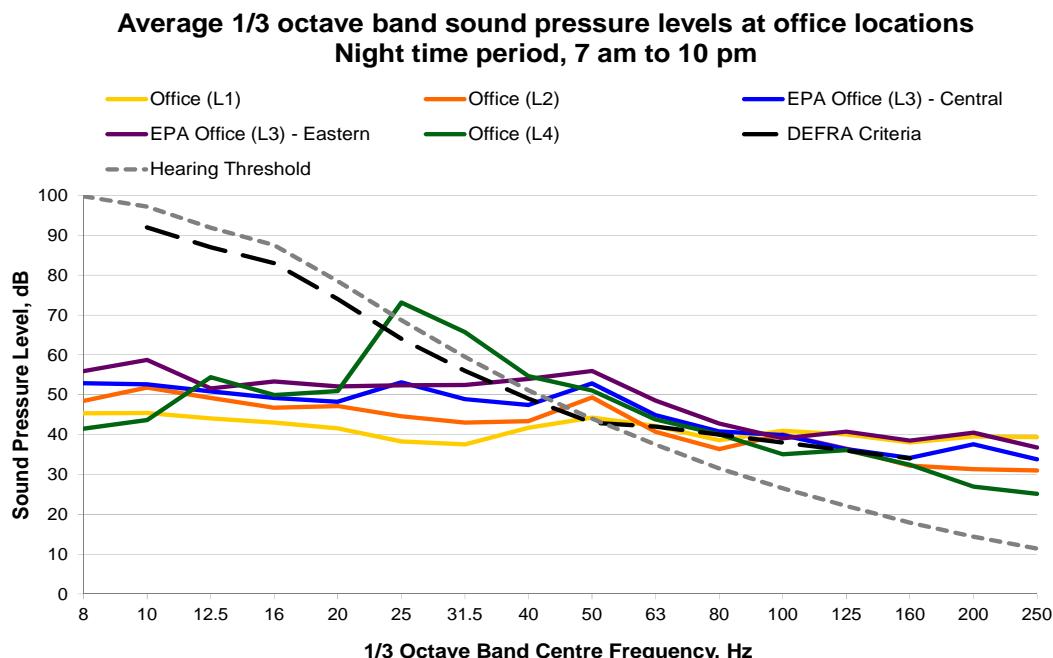
### 6.1 Urban locations

Low frequency noise levels were measured in both offices and residences in urban areas. Figure 26 and Figure 27 present the energy averaged indoor sound pressure levels in the one third octave bands for the urban office locations during the day period (7am to 10pm) and night periods (10pm to 7am) respectively. The mean hearing threshold and minimum DEFRA criteria for non-steady noise for the relevant period are also presented.



**Figure 26 – Average daytime indoor sound pressure levels in 1/3 octave bands at urban office locations**

Although the measured daytime levels in the offices are above the DEFRA criteria at most locations for frequencies above approximately 50Hz, no significant conclusions can be drawn from this data as the offices were occupied and are not representative of residential locations during the daytime.



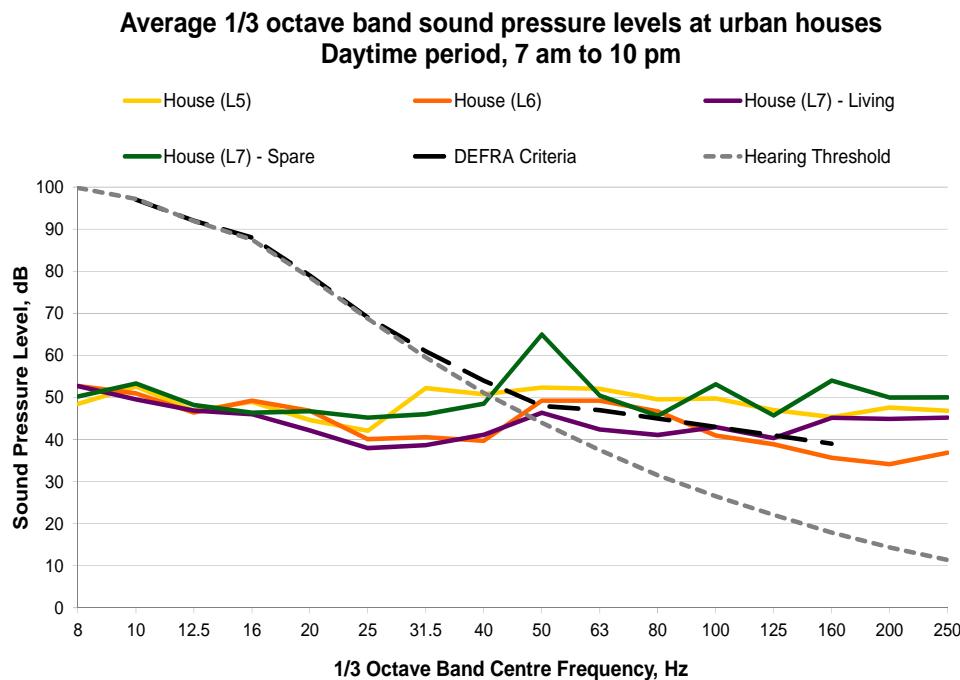
**Figure 27 – Average night time indoor sound pressure levels in 1/3 octave bands at urban office locations**

At night, both Locations 1 and 2 may be considered representative of residential locations in the same area. The measured average low frequency noise levels at L1 exceeded the DEFRA night criteria at 100Hz and above, while the average levels at L2 remained compliant with the criteria. Note that the exceedance at 50Hz is due to electrical noise.

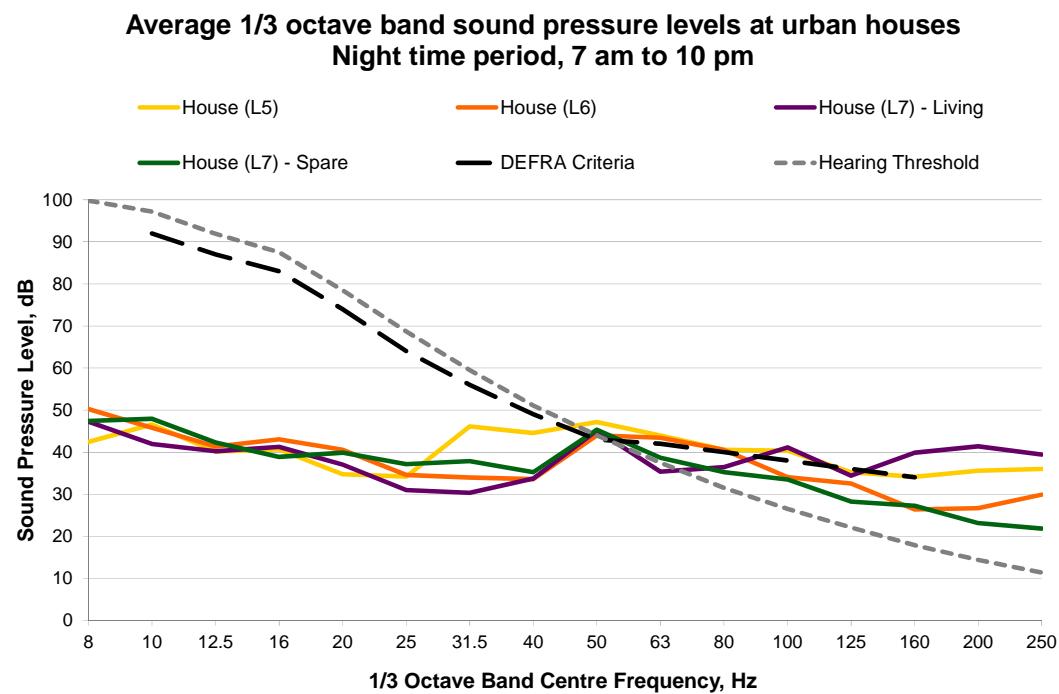
The elevated night time noise levels at L4 at 25Hz and 31.5Hz are due to night time operation of the air conditioning system causing the low frequency noise complaint and would not be representative of low frequency noise levels at residential locations.

Figure 28 and Figure 29 present the energy averaged indoor sound pressure levels in one third octave bands for the urban residential locations during the day period (7am to 10pm) and night periods (10pm to 7am) respectively. The mean hearing threshold and minimum DEFRA criteria for non-steady noise during the relevant period are also presented.

During the daytime period it can be seen that the average low frequency noise levels at the urban residential locations are typically above the daytime DEFRA criteria at frequencies above 50Hz. Note that the exceedances at 50Hz and 100Hz at Location 7 are believed to be a result of electrical noise, although the average measured levels at other frequencies are also above the daytime criteria at this location. While there is likely to be some influence from noise generated by people within these rooms during the daytime, it is also considered that traffic noise (Location 7) and aircraft noise (Location 5) are likely to have contributed to the higher measured daytime low frequency noise levels.



**Figure 28 – Average daytime indoor sound pressure levels in 1/3 octave bands at urban residential locations**



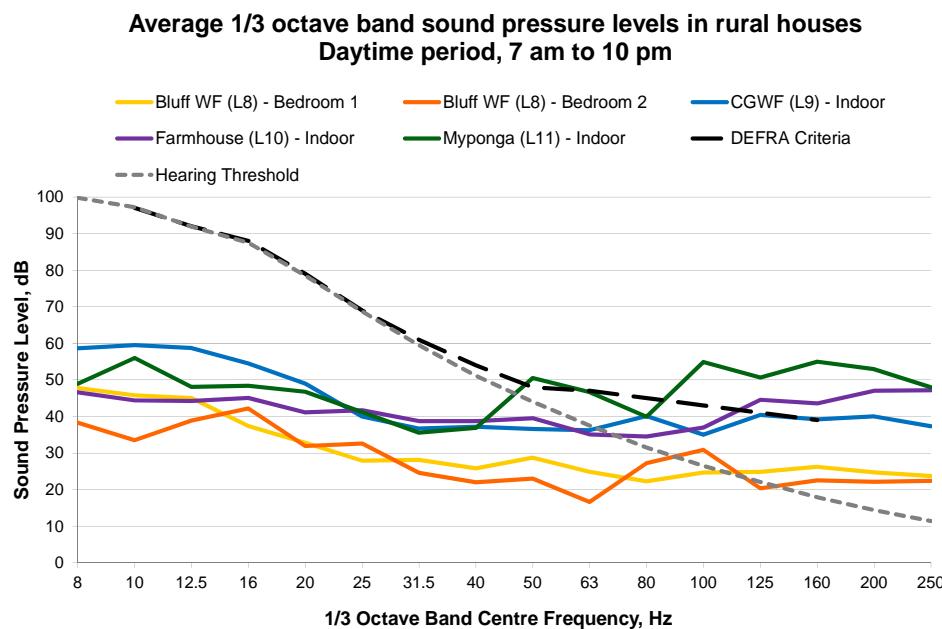
**Figure 29 – Average night time indoor sound pressure levels in 1/3 octave bands at urban residential locations**

From Figure 29, it is apparent that the average night time low frequency noise levels are considerably lower than the daytime levels. There appear to be minor exceedances of the DEFRA criteria at each location at frequencies above 50Hz. Note that electrical noise may have controlled the measured levels at Location 7 at 50Hz.

The measurement results at the urban locations indicate that residents in these areas are likely to be regularly exposed to low frequency noise levels at or above the DEFRA criteria for low frequency noise.

## 6.2 Rural locations

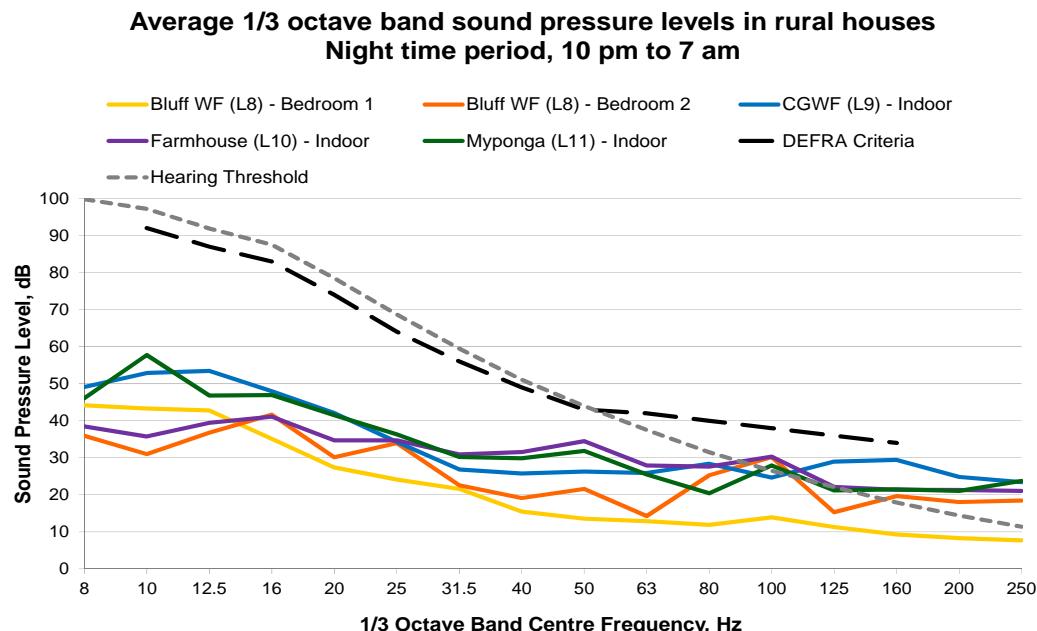
Figure 30 and Figure 31 show the energy averaged indoor sound pressure levels in one third octave bands for the rural residential locations during the day (7am to 10pm) and night periods (10pm to 7am) respectively. The mean hearing threshold and minimum DEFRA criteria for non-steady noise during the relevant period are also presented.



**Figure 30 – Average daytime indoor sound pressure levels in 1/3 octave bands at rural residential locations**

The average daytime sound pressure levels at the residential locations are typically below the DEFRA criteria with the exception of noise levels at 100Hz and above at Location 10 and Location 11. The average daytime sound pressure levels at the two locations near wind farms (Location 8 and Location 9) did not exceed the minimum DEFRA criteria. The average measured noise levels in the two indoor locations at the house near Bluff Wind Farm were less than the mean hearing threshold at frequencies below 100Hz.

The measured average night time sound pressure levels at the four rural locations remained at least 5dB below the DEFRA criteria at all locations. The measured low frequency noise levels at Location 8 were typically the lowest at any of the locations, with the average measured levels in Bedroom 1 remaining below the mean hearing threshold across the entire low frequency region. The average night time noise levels at Location 9, Location 10 and Location 11 were relatively similar across the low frequency region, although with higher levels measured at Location 9 for frequencies of 125Hz and 160Hz.



**Figure 31 – Average night time indoor sound pressure levels in 1/3 octave bands at rural residential locations**

Typically, the measurement results at the rural locations indicate that low frequency noise levels at these residences were significantly lower than those measured at the urban residential locations.

Generally, there did not appear to be higher levels of low frequency noise measured at the two houses located approximately 1.5 kilometres from a wind farm, with low frequency noise levels at Location 8 being amongst the lowest measured at any of the locations. However, there were higher levels of low frequency noise measured at Location 9 at frequencies of 125Hz and 160Hz.

The contribution of the wind farm to the measured low frequency noise levels at both Location 8 and Location 9 is discussed further in Section 7.2 and Section 7.3 respectively.

### 6.3 Summary for DEFRA criteria assessment

Measured low frequency levels at the rural locations were markedly lower than at the urban locations, and did not exceed the DEFRA low frequency noise criteria as regularly. In fact, on an energy-averaged basis, the DEFRA night time criteria were not exceeded at any of the rural locations.

The measured levels at the two houses near wind farms (Location 8 and Location 9) were not significantly higher than at the other rural locations over the low frequency range. The noise levels at Location 8 were the lowest of any location, and the measured levels at Location 9 were typically the same as or lower than at Location 10 and Location 11, with the exception of the 125Hz and 160Hz one-third octave bands.

Table 6 presents the percentage of 10-minute night time periods for each indoor location at which an exceedance of the DEFRA criteria for non-steady noise (e.g. minimum

DEFRA criteria) was detected in each one-third octave band. Only the night time periods have been selected as these are less affected by occupant activities at those sites where this may have been a significant source of extraneous noise during the daytime period. Any locations and frequencies where electrical noise may have affected the results are printed in italicised type.

**Table 6 – Percentage of 10-minute data points for which minimum DEFRA criteria exceeded during night time (10pm to 7am)**

<b>Location</b>	% of 10-minute periods for which minimum DEFRA night time criteria exceeded in third-octave band (in Hz)												
	10	12.5	16	20	25	31.5	40	50	63	80	100	125	160
1 Office	0	0	0	0	0	0	3	27	26	21	32	37	24
2 Office	0	0	0	0	0	0	3	66	14	8	44	29	15
3 EPA (Central)	0	0	0	0	0	0	5	100	87	18	39	10	7
3 EPA (Eastern)	0	0	0	0	0	3	100	100	100	87	9	46	100
4 Office with complaint	0	0	0	0	25	25	26	46	41	30	24	26	24
5 Mile End	0	0	0	0	0	4	6	38	13	13	19	13	13
6 Firle (Bedroom)	0	0	0	0	0	0	0	17	21	12	6	5	1
7 Prospect (Living)	0	0	0	0	0	0	0	45	2	3	77	12	68
7 Prospect (Spare)	0	0	0	0	0	0	0	100	13	4	3	1	1
8 Bluff WF Bed 1	0	0	0	0	0	0	0	0	0	0	0	0	0
8 Bluff WF Bed 2	0	0	0	0	0	0	0	0	0	0	0	0	0
9 CGWF	0	0	0	0	0	0	0	0	0	0	0	2	1
10 Farmhouse	0	0	0	0	0	0	0	1	0	0	0	0	1
11 Myponga	0	0	0	0	0	0	0	1	0	0	0	2	0

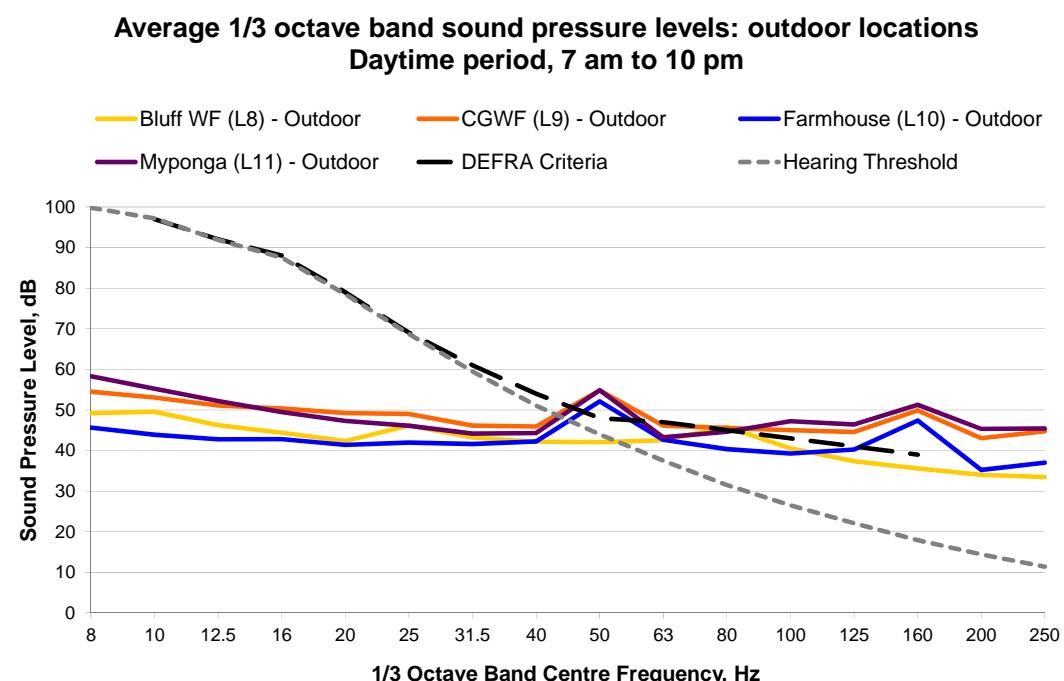
It is apparent that the DEFRA criteria are regularly exceeded at the urban locations, but only infrequently at the rural locations. No more exceedances were noted at the two wind farm locations than at the two other rural locations.

## 7 Additional information

### 7.1 Outdoor low frequency noise levels

In addition to the measured indoor low frequency noise levels, outdoor low frequency levels were measured at the four rural locations.

Figure 32 and Figure 33 present the energy averaged outdoor sound pressure levels at the four rural locations for the day and night time periods respectively. The DEFRA criteria for the relevant time period are presented for reference but, as these criteria apply indoors, no comparison can be made between the measured levels and the criteria.



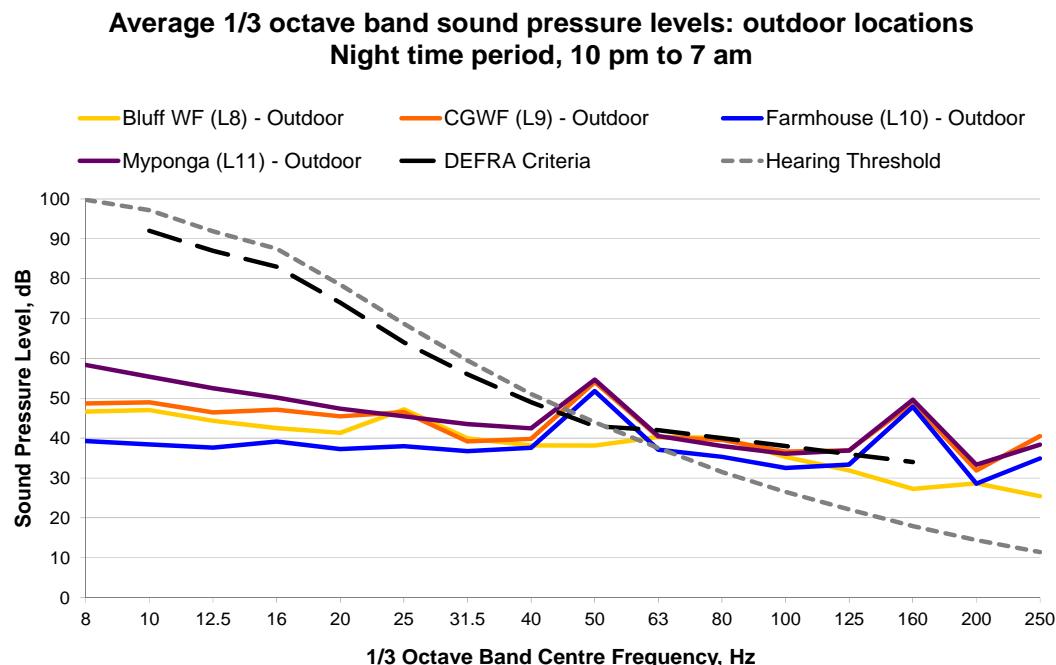
**Figure 32 – Average daytime outdoor sound pressure levels in 1/3 octave bands at rural locations**

Note that, as the measurements at the outdoor locations were all performed using the Soundbook measurement system with a 30 metre long microphone cable, the measured levels at Location 9, Location 10 and Location 11 may have been affected by electrical noise in the 50Hz and 160Hz one-third octave bands. Location 8 was not affected by electrical noise as mains power was disconnected at this residence.

Comparing the measured outdoor low frequency noise levels between the sites, and accounting for the electrical noise, it is apparent that Location 8 and Location 10 exhibit the lowest outdoor levels despite Location 8 being located significantly nearer to a wind farm than both Location 10 and Location 11.

Measured low frequency noise levels are relatively similar between Location 9 and Location 11. This is believed to be as these two locations were the most wind-exposed

sites and indicates that local wind conditions are likely to be a significant contributor to outdoor low frequency noise levels.



**Figure 33 – Average night time outdoor sound pressure levels in 1/3 octave bands at rural locations**

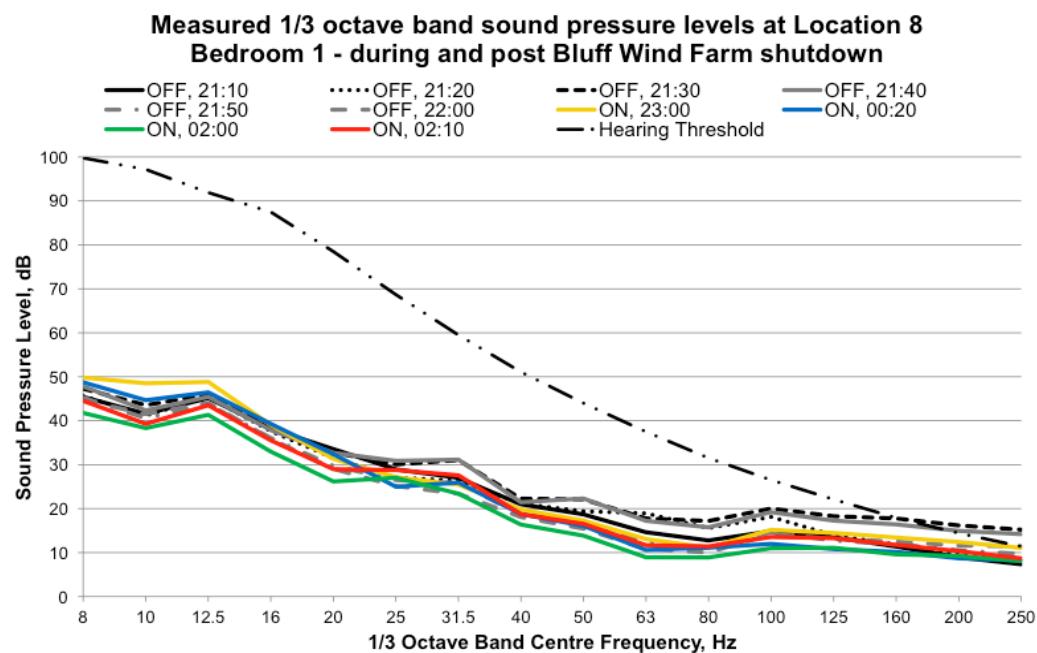
## 7.2 Bluff Wind Farm shutdown

Figure 34, Figure 35 and Figure 36 present the measured low frequency noise levels at the three measurement points at Location 8 both during and after the shutdown of the Bluff Wind Farm on 5 October 2012. The combined mean hearing threshold between 8Hz and 250Hz from Watanabe &Møller (1990) and from ISO 226 is also shown.

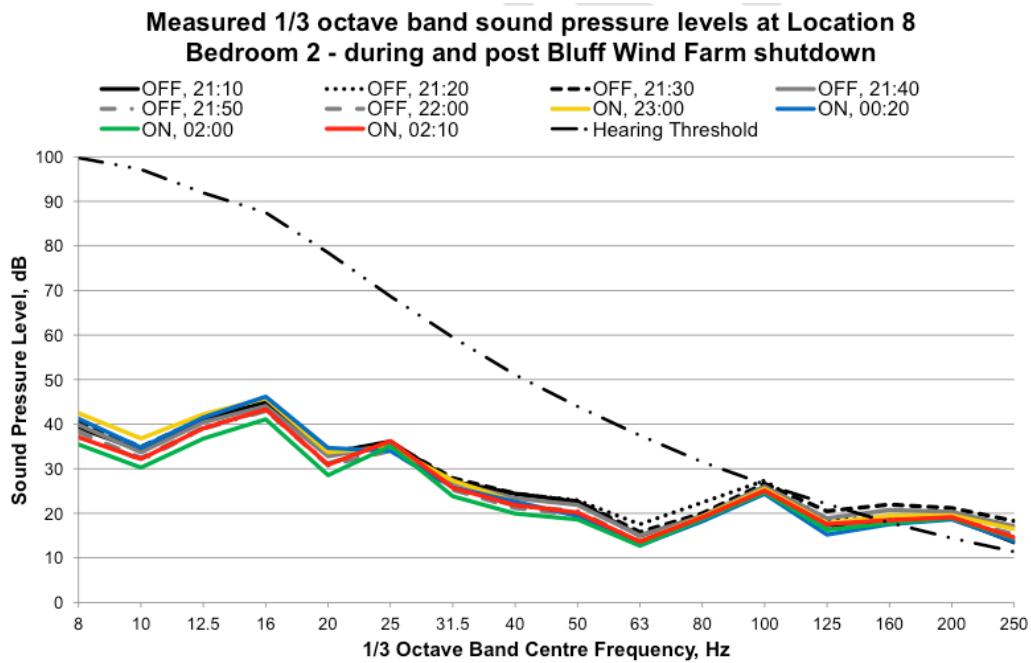
The measured operational periods have been selected as per Table 5, with the operational periods at 2am and 2:10am representing the closest wind speed and wind direction match to the shutdown periods. Wind speed and direction data for each period is provided in Table 5.

From each of the Figures, it can be seen that there is negligible change between the shutdown and operational periods at any of the measurement locations. Based on the measurement data gathered at Location 8, it appears that the Bluff Wind Farm is not controlling the low frequency noise levels at the house located 1.5 kilometres away.

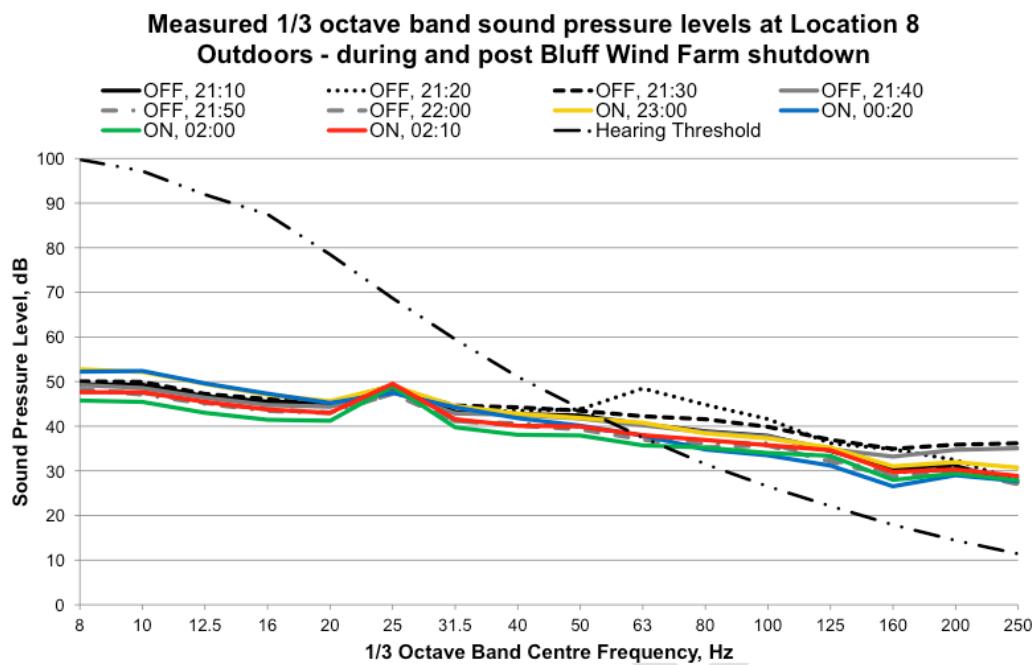
It can also be seen that low frequency noise levels at the two indoor locations are below the mean hearing threshold up to approximately 160Hz, indicating that low frequency noise levels at the site were low despite wind speeds of 10 to 11m/s. The measured outdoor levels were above the mean hearing threshold at frequencies of 63Hz and above. This is believed to have resulted from the house at Location 8 being in a very wind sheltered location, which minimised extraneous noise.



**Figure 34 – Measured low frequency sound pressure levels in 1/3 octave bands at Location 8 during and post shutdown, Bedroom 1**



**Figure 35 – Measured low frequency sound pressure levels in 1/3 octave bands at Location 8 during and post shutdown, Bedroom 2**



**Figure 36 – Measured low frequency sound pressure levels in 1/3 octave bands at Location 8 during and post shutdown, Outdoors**

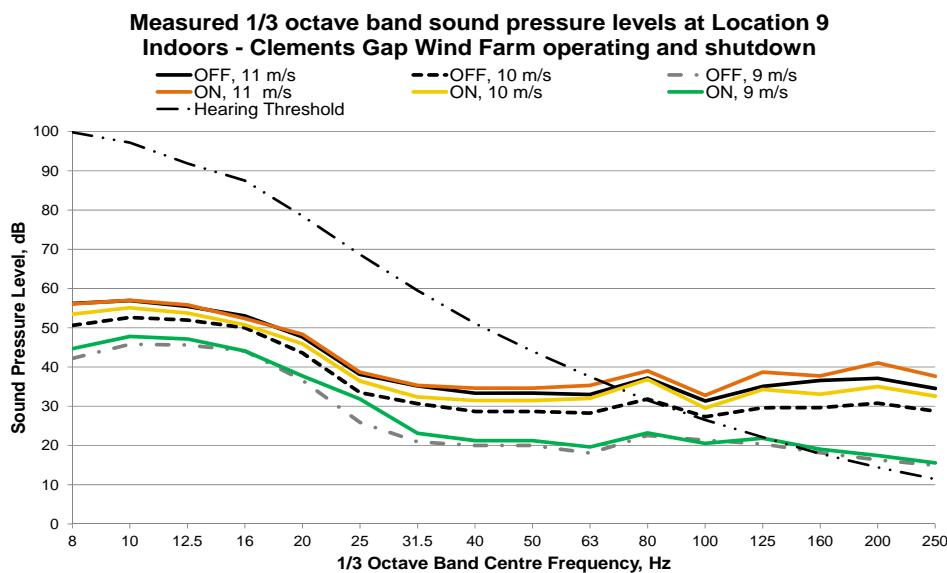
### 7.3 Clements Gap Wind Farm shutdown

Figure 37 and Figure 38 present the measured low frequency noise levels at the outdoor and indoor measurement locations at Location 9 both during operational and shutdown periods for Clements Gap Wind Farm. Note that the outdoor measurements appeared to have been affected by electrical noise at 160Hz third octave frequency band. The combined mean hearing threshold between 8Hz and 250Hz is also shown on both Figures.

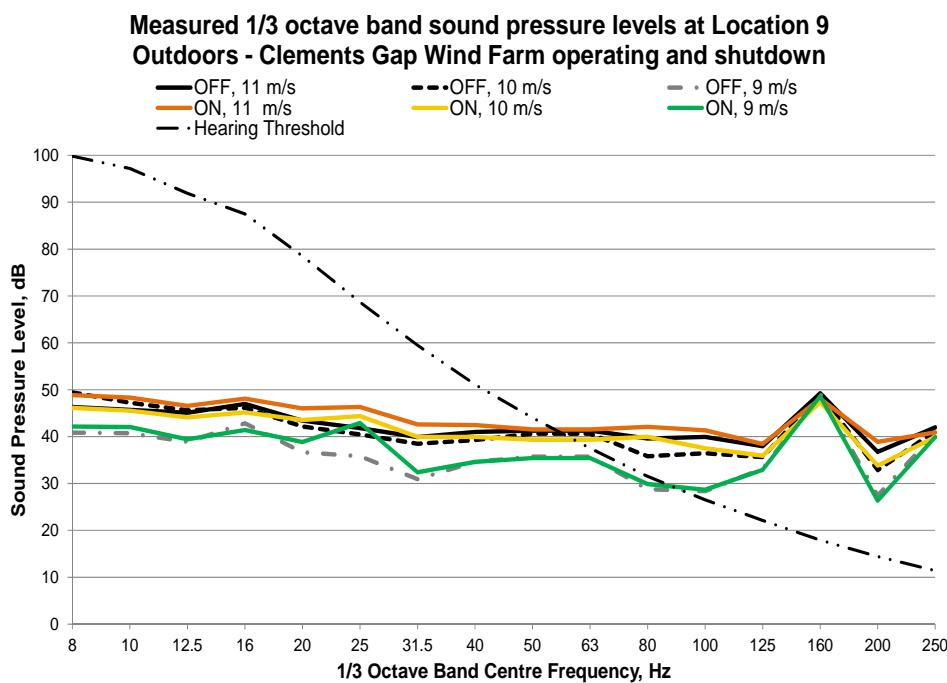
The shutdown and operational levels were both energy averaged over two 10-minute periods. The two 10-minute operational periods were selected for each integer wind speed from 9 m/s to 11 m/s, based on the wind speed and wind direction most closely matching that measured during the shutdown.

From Figure 37 and Figure 38, it can be seen that operation of the Clements Gap Wind Farm produces a relatively low level of noise at the house at frequencies of 25Hz, and at frequencies of 100Hz and above. At 100Hz and above, it appears as though the wind farm is contributing a relatively low level of audible low frequency noise at the indoor measurement location. The noise level generated at 25Hz is approximately 25dB and 30dB below the mean hearing threshold at the indoor and outdoor locations respectively.

Based on the measurements conducted at Location 9 near Clements Gap Wind Farm, the wind farm is contributing a relatively small amount of low frequency noise. At the lowest frequency (25Hz) this is well below the mean hearing threshold. At higher frequencies (above 100Hz), noise levels from the wind farm may be audible above the background noise at Location 9. Note that during site inspections at Location 9 it was found that wind turbine noise was audible at times, but that this was generally controlled by mid frequency noise rather than low frequency noise.



**Figure 37 – Measured low frequency sound pressure levels in 1/3 octave bands at Location 9 with wind farm shutdown and operating, Indoors**



**Figure 38 – Measured low frequency sound pressure levels in 1/3 octave bands at Location 9 with wind farm shutdown and operating, Outdoors**

## 8 Conclusion

This report presents the findings of a study into low frequency noise levels within typical environments in South Australia, with a particular focus on comparing wind farm environments to urban and rural environments away from wind farms. This particular study is based on data collected during the infrasound study published by the Environment Protection Authority (Evans, Cooper & Lenchine, 2013).

Measurements were undertaken over a period of approximately one week at seven locations in urban areas and four locations in rural areas including two residences approximately 1.5 kilometres away from the wind turbines. Measured low frequency noise levels were compared to relevant assessment criteria, and shutdowns of the wind farms were organised to compare on/off low frequency noise levels at those two residences.

Measured low frequency noise levels were considerably higher in urban areas than in rural areas, and appeared to be generated by traffic, air conditioning systems and human activity depending on the particular location. The relevant criteria were exceeded for a significant percentage of the night time periods at the majority of the urban locations. However, it is also important to note that this low frequency noise is accompanied with a higher level of overall noise within the urban environment.

Low frequency noise levels were markedly lower in the rural areas, and appeared to be related to wind conditions in the local environment. The relevant night time low frequency noise criteria were only exceeded on isolated occasions during the monitoring at one location near a wind farm, as well as at two locations away from wind farms. At the other location near the Bluff Wind Farm, the low frequency noise criteria were not exceeded throughout the monitoring period.

Typically, low frequency noise levels at the two wind farm locations were not noticeably higher than those at the two rural houses away from wind farms, with the low frequency noise levels at Location 8 near the Bluff Wind Farm being the lowest out of any location in the study. Organised shutdowns of the two wind farms also found that the contribution of the Bluff Wind Farm to low frequency noise levels at the house was negligible, while there may have been a relatively small contribution of low frequency noise levels from the Clements Gap Wind Farm at frequencies of 100Hz and above.

It is important to note that this study has considered locations with wind turbines rated at 2.1MW, and that low frequency noise levels may change with different wind turbine types and ratings due to varying levels of mechanical noise in the range of approximately 100Hz. However, the collected data has shown that low frequency noise levels at two locations approximately 1.5 kilometres from the considered wind farms is compliant with relevant assessment criteria and is not higher than that measured at other locations.

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## Glossary

<b>A-weighting</b>	Frequency weighting used to approximate how the human ear responds to lower levels of noise.
<b>C-weighting</b>	Frequency weighting used to approximate how the human ear responds to higher levels of noise.
<b>Decibel (dB or dB(Lin))</b>	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.
<b>dB(A)</b>	Unit of sound pressure levels, which have had the A-weighting applied to them.
<b>dB(C)</b>	Unit of sound pressure levels, which have had the C-weighting applied to them.
<b>Frequency</b>	Rate of sound pressure variations – noise or sound is composed of energy across a wide range of frequencies including the low frequency range.
<b>Hertz (Hz)</b>	Unit of frequency – one Hz is equivalent to one cycle per second.
<b>Infrasound</b>	Sound or noise where the energy lies mainly in the frequency range below 20Hz.
<b>L<sub>10</sub></b>	Noise level exceeded for 10% of the measurement period. Typically used to represent the typical upper noise level in an environment.
<b>L<sub>90</sub></b>	Noise level exceeded for 90% of the measurement period. Typically used to represent the background noise level in an environment or typical lower noise level.
<b>L<sub>eq</sub></b>	Equivalent noise level – energy averaged noise level over the measurement period. Most common descriptor used to quantify noise sources.
<b>L<sub>eq,10min</sub></b>	Equivalent noise level over a 10 minute measurement period.
<b>L<sub>eq,15min</sub></b>	Equivalent noise level over a 15 minute measurement period.
<b>L<sub>max</sub></b>	Maximum noise level in the measurement period.
<b>Low frequency noise</b>	Noise within the lower end of the frequency range. A frequency range of 8Hz to 250Hz has been considered in this report.
<b>One-third octave band</b>	Standardised frequency bands used for the analysis of measured noise levels