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Infrasound levels near windfarms and in other environments

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Executive summary

This report presents the findings of a study into the level of infrasound within typical environments in South Australia, with a particular focus on comparing wind farm environments to urban and rural environments away from wind farms.

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. Both indoor and outdoor measurements were undertaken, with the outdoor measurements necessitating development of a specific technique for the outdoor measurement of infrasound. The indoor and outdoor measurement procedures are summarised in Appendix A of this report.

Urban environments

The following findings have been drawn from the measurements conducted in the locations in urban areas:

- Infrasound levels of between 60 and 70dB(G) commonly occur in the urban environment.
- Infrasound levels were typically 5 to 10dB(G) higher during the day than at night time.
- Noise generated by people and associated activities within a space was one of the most significant contributors to measured infrasound levels, with measured infrasound levels typically 10 to 15dB(G) higher when a space was occupied. Infrasound levels up to approximately 70dB(G) were measured in occupied spaces.
- Traffic may also influence the infrasound level in an urban environment, with measured levels during the daytime periods typically 10dB(G) higher than between midnight and 6 am, when traffic would be expected to be at its lowest.
- At two locations, the EPA offices and an office with a low frequency noise complaint, building air conditioning systems were identified as significant sources of infrasound. These locations exhibited some of the highest levels of infrasound measured during the study.

Rural environments

The measurements conducted within rural environments included simultaneous measurements of outdoor and indoor infrasound. It was found that the outdoor infrasound levels were similar to or marginally above the indoor infrasound level.

The following findings have been drawn from the measurements conducted in the locations in rural areas:

- Infrasound levels at houses adjacent to wind farms (Locations 8 and 9) are no higher than those at houses located a considerable distance from wind farms (Locations 10 and 11). For example, the outdoor infrasound levels at Location 8 are significantly

lower than those at Location 11, despite the house being located much closer to operational wind turbines (1.5 kilometres compared to 30 kilometres).

- Infrasound levels in the rural environment appear to be controlled by localised wind conditions. During low wind periods, levels as low as 40dB(G) were measured at locations both near to and away from wind turbines. At higher wind speeds, infrasound levels of 50 to 70dB(G) were common at both wind farm and non-wind farm sites.
- Organised shutdowns of the wind farms adjacent to Location 8 and Location 9 indicate that there did not appear to be any noticeable contribution from the wind farm to the G-weighted infrasound level measured at either house. This suggests that wind turbines are not a significant source of infrasound at houses located approximately 1.5 kilometres away from wind farm sites.

From an overall perspective, measured G-weighted infrasound levels at rural locations both near to and away from wind farms were no higher than infrasound levels measured at the urban locations. Furthermore, both outdoor and indoor infrasound levels were typically below the perception threshold by a significant margin. The most apparent difference between the urban and rural locations was that human activity and traffic appeared to be the primary source of infrasound in urban locations, while localised wind conditions are the primary source of infrasound in rural locations.

An additional analysis of the frequency content of the measured infrasound levels was conducted for each location. At both of the wind farm sites, peaks in the frequency spectrum corresponding to the turbine blade pass frequency and related harmonics (0.8Hz, 1.6Hz and 2.5Hz) were identified that may be attributable to the wind turbines. However, these peaks were only detectable during periods of low wind speed and therefore ambient infrasound at the residences. The peaks in the spectrum were found to be no higher than infrasound levels measured at these frequencies at both rural and urban locations away from wind farms, and also significantly (at least 50dB) lower than the threshold of perception for these very low frequencies.

Summary of results

The range of measured $L_{eq,10min}$ infrasound levels at each of the measurement locations is presented in Figure 1 on the following page, with the lines corresponding to the minimum, 25^{th} percentile, median, 75^{th} percentile and maximum infrasound levels from left to right.

It is clear from the results that the infrasound levels measured at the two residential locations near wind farms (Location 8 near the Bluff Wind Farm and Location 9 near Clements Gap Wind Farm) are within the range of infrasound levels measured at comparable locations away from wind farms. Of particular note, the results at one of the houses near a wind farm (Location 8) are the lowest infrasound levels measured at any of the 11 locations included in this study.

This study concludes that the level of infrasound at houses near the wind turbines assessed is no greater than that experienced in other urban and rural environments, and that the contribution of wind turbines to the measured infrasound levels is insignificant in comparison with the background level of infrasound in the environment.

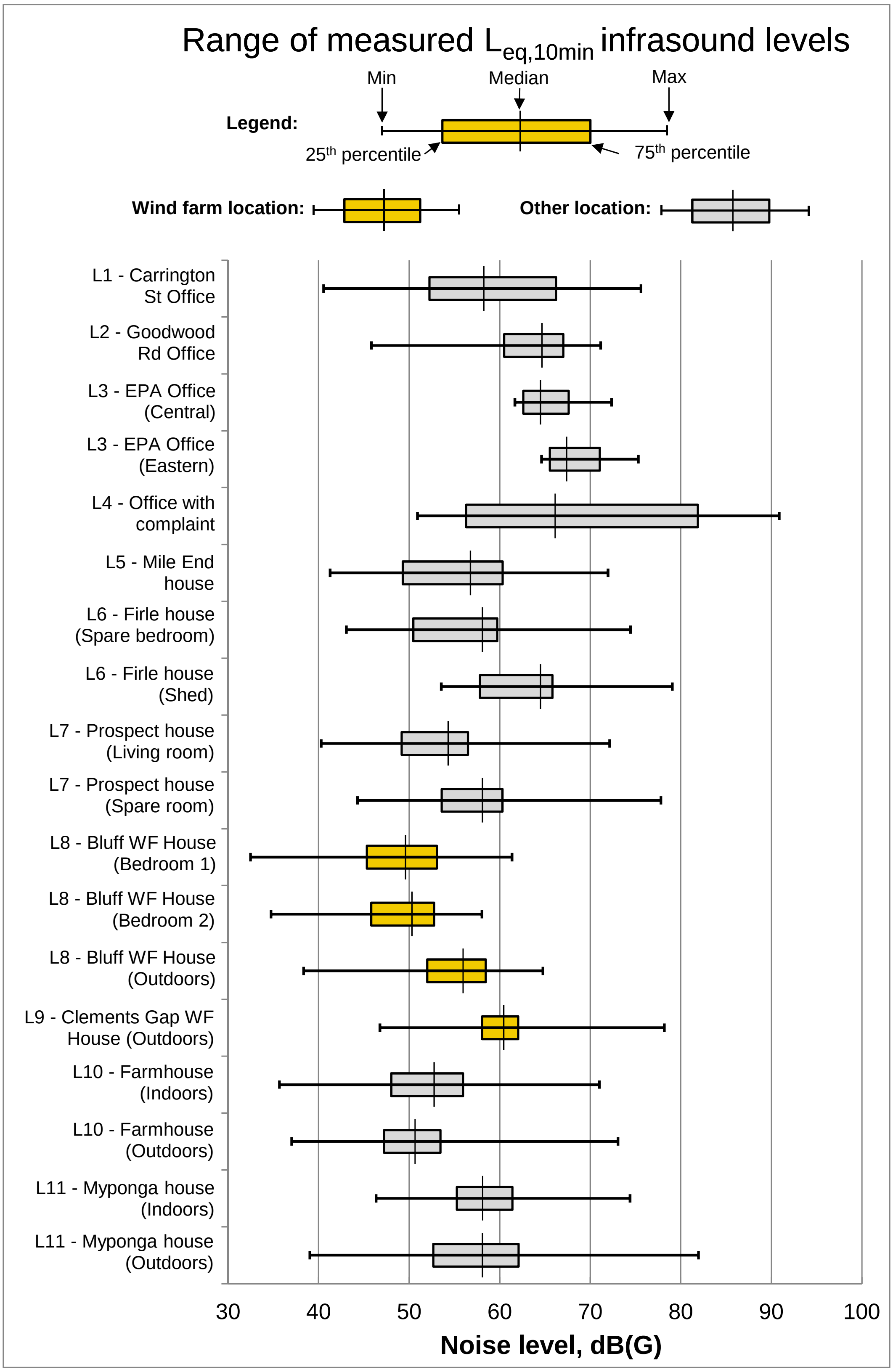

Figure 1 – Range of measured $L_{eq,10min}$ infrasound levels at each measurement location

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1 Introduction

This report presents the findings of a study into the levels of infrasound that people are exposed to within typical environments in South Australia. The aim of the study is to compare the levels of infrasound measured within the different environments in order to benchmark the levels at residential properties measured adjacent to wind farms.

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.

In addition to the above, simultaneous indoor and outdoor measurements of infrasound were also undertaken at the four locations in rural areas.

The measurement procedure employed during this study is outlined in Appendix A. This includes a discussion of the procedure used to measure outdoor infrasound levels, for which standard noise measurement equipment was not suitable.

A comparison between simultaneous outdoor and indoor measurements of infrasound is provided in Appendix B, to investigate whether any change in infrasound levels results from typical residential structures.

2 Background information

Infrasound is very low frequency noise, defined by ISO 7196[1] as:

> *Sound or noise whose frequency spectrum lies mainly in the band from 1Hz to 20Hz.*

Due to the typical levels of sound at these frequencies in the environment, infrasound is commonly thought of as occurring below the limit of the audible range of frequencies. However, sound at frequencies below 20Hz can be perceived by humans as long as the level is high enough (Leventhall, 2006), with hearing thresholds determined down to frequencies as low as 2Hz (Watanabe &Møller, 1990).

2.1 G-weighting

The G-weighting function is defined in ISO 7196 and is used to quantify sound that has a significant portion of its energy in the infrasonic range. The function weights noise levels between 0.25Hz and 315Hz to reflect human perception of infrasonic noise levels, and has been used throughout this study to characterise the level of infrasound.

Figure 2 shows the G-weighting function across the frequency range between 0.25Hz and 315Hz. The weighting shown is applied directly to the linear (unweighted) noise levels.

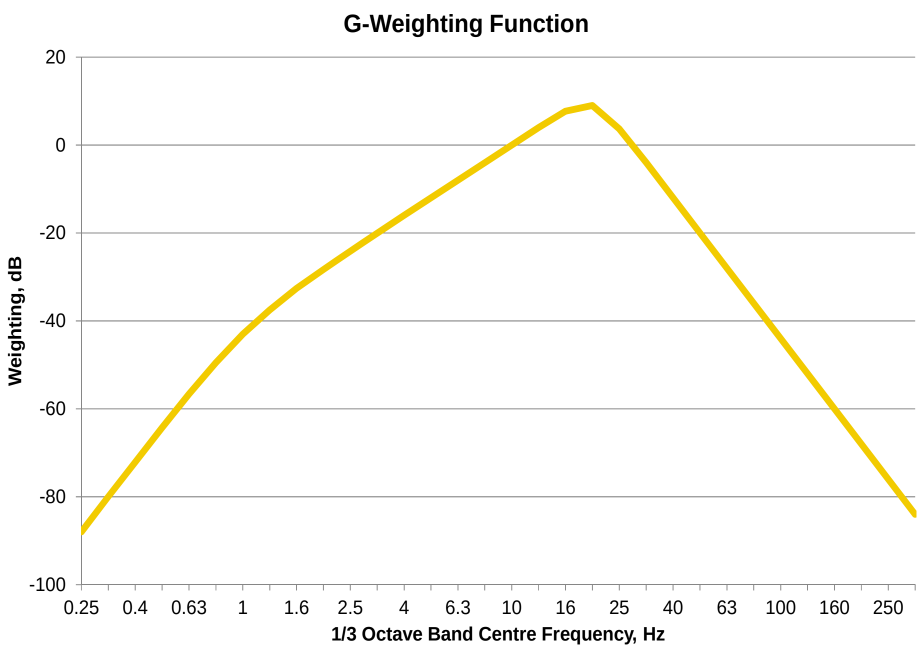

Figure 2 – G-weighting function

The perception of noise in the infrasonic range is greatest at 20Hz, with perception of infrasonic sound reducing as frequency decreases from that point. Sound above 20Hz is not the primary interest of either the G-weighting function or this study as this sound is better characterised by other acoustic descriptors. The G-weighting therefore negatively

[1] ISO 7196-2:1995, *Acoustics – Frequency-weighting characteristic for infrasound measurements*.

weights sound at frequencies above 25Hz, and discounts all sounds at frequencies above 315Hz.

Møller (1987) undertook a study into the relationship between G-weighted noise levels and annoyance from infrasound. There was found to be a close relationship between the annoyance rating and the G-weighted level of perceptible levels of infrasound, indicating it is an appropriate weighting to use to assess infrasound in the environment.

2.2 Thresholds of perception

Infrasound can be perceived by humans if the level is high enough. There has been debate about whether very low frequency noise levels are heard or rather felt through the body but current available evidence suggests that infrasound is heard through the ears at the onset of perception (Møller&Pedersen, 2004).

To investigate the perception of very low frequency noise through other parts of the body than the ears, Yamada et al. (1983) conducted an experiment with normally hearing and profoundly deaf subjects. The threshold of sensation of the deaf subjects (who felt sensations mainly in the chest) was 40 to 50dB above the hearing threshold of the normally hearing subjects up to a frequency of 63Hz. A study conducted by Landström, Lundström and Byström (1983) also demonstrated that normally hearing subjects reacted to levels of infrasound above the hearing threshold that deaf subjects did not react to. The conclusion from these two studies is that the perception of very low frequency noise and infrasound occurs first through the ears, at significantly lower levels than is required for perception through other parts of the body.

The threshold of perception for noise at low frequencies has been determined in a number of studies, using a range of different methodologies. The key studies are summarised in Figure 3 from Møller & Pedersen (2004). The standardised hearing threshold from 20Hz to 1kHz specified in ISO 226[2] is also presented.

It can be seen that, while there is variation in the thresholds reported by various studies, the hearing threshold increases as the frequency of sound decreases and significantly more sound energy is required to exceed the threshold below 10Hz than is required above 100Hz.

Of the studies summarised in Figure 3, Watanabe & Møller (1990) demonstrate the closest agreement with the ISO 226 threshold at and above 20Hz, and are also reflective of the lower determined hearing thresholds. The mean hearing threshold reported in their study is presented in Figure 4, with error bars corresponding to the standard deviation. The standard deviation in the low frequency hearing threshold of approximately 5dB, shown in Figure 4, is consistent with that of other studies (Møller& Pedersen, 2004).

[2] ISO 226:2003, *Acoustics – Normal equal-loudness-level contours*.

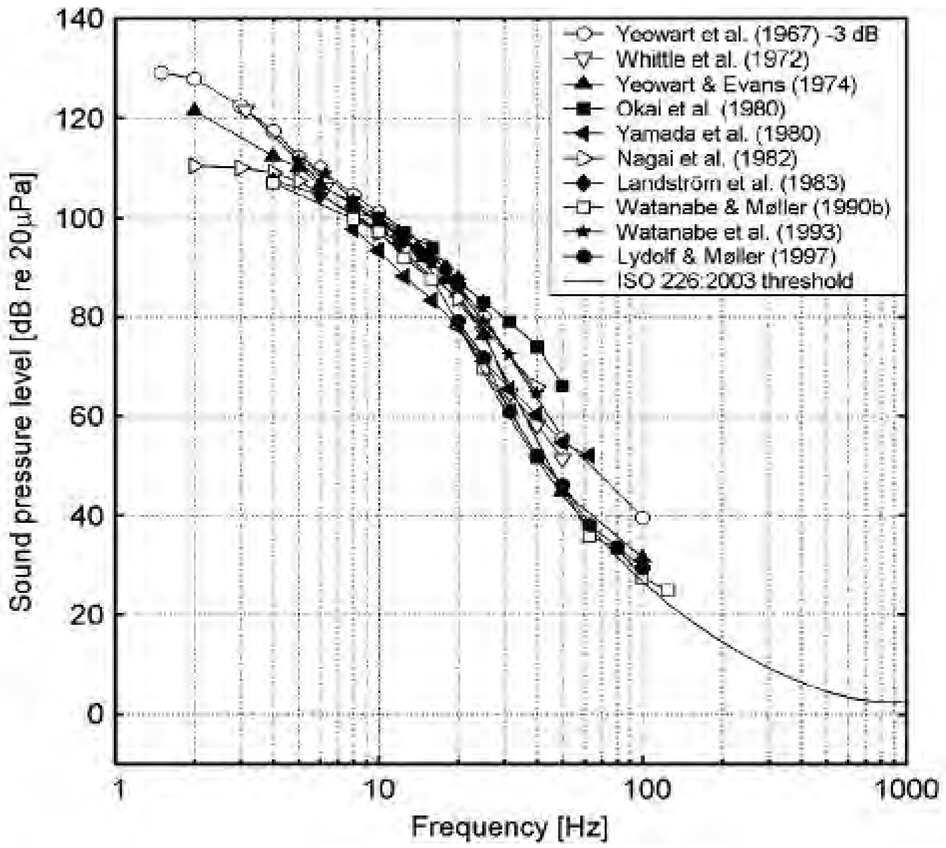

Figure 3 – Determined hearing thresholds below 1 kHz (Møller& Pedersen, 2004)

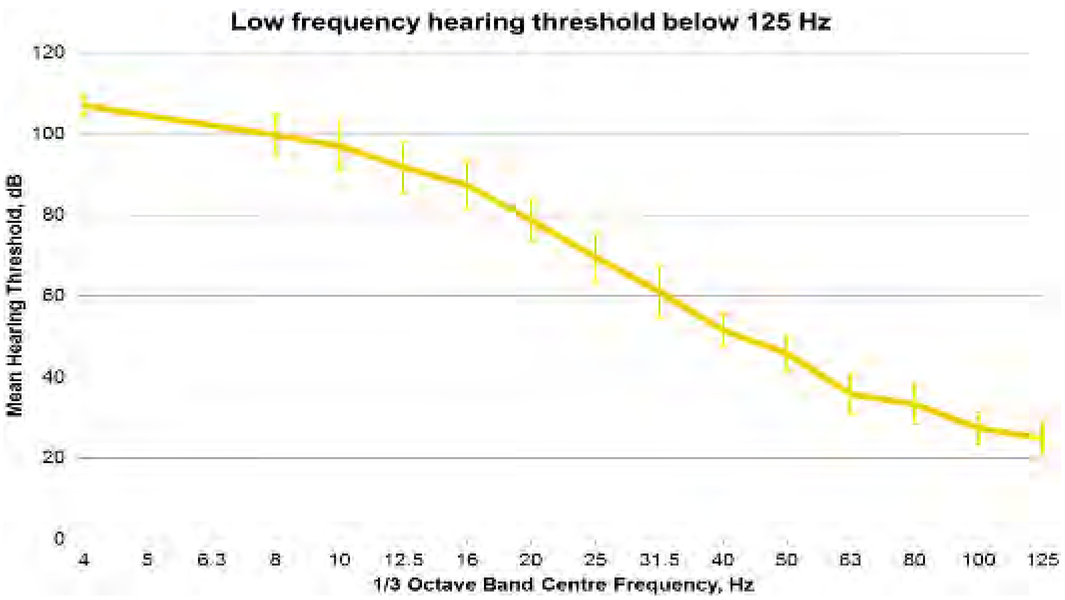

Figure 4 – Hearing threshold below 125Hz (Watanabe &Møller, 1990)

It is also important to note that these low frequency hearing thresholds have been determined on the basis of pure tones, i.e. a noise energy concentrated at the considered frequency. In reality, infrasound in the environment is much more likely to be relatively broadband across the infrasonic frequency range. Landström (1987) suggested that the hearing threshold to broadband infrasonic noise is approximately 1-5dB below the determined threshold curve for tones, consistent with the findings of Yeowart et al. (1969) but inconsistent with those of Nagai et al. (1982) who found the hearing threshold to broadband noise to be approximately 6dB higher than that of pure tones at 2 to 5Hz.

Regardless, the reported differences in the hearing thresholds between broadband infrasonic noise and pure tones appear to be relatively small. Møller & Pedersen (2004) state that “the pure-tone threshold can with a reasonable approximation be used as a guideline for the thresholds also for nonsinusoidal sounds”.

2.3 Infrasound and annoyance

A study conducted by Møller (1984) analysed the performance of sixteen subjects as they undertook various tasks while exposed to inaudible infrasound, audible infrasound, traffic noise and a relatively quiet level (as a control):

> *The most conspicuous effect of infrasound was a high rating of annoyance and a feeling of pressure on the ear at less than 20dB above the threshold of hearing. No influence on the cardiovascular system was seen and the performance only deteriorated in one of nine tasks. Infrasound below the hearing threshold had no effect.*

These findings are consistent with those of Landström and Byström (1984), who found that infrasound levels above the hearing threshold could be correlated to a reduction in wakefulness but that no clear effect was observed at pressure levels below the hearing threshold.Landström, Lundström and Byström (1983) linked this reduction in wakefulness to levels above the hearing threshold by studying the reaction of hearing and deaf subjects to a level of 115dB at 6Hz (equivalent to approximately 107dB(G)). It was observed that “reduced wakefulness was noticed among the hearing subjects but not among the deaf subjects”.

While it is apparent that infrasound only becomes annoying when levels exceed the hearing thresholds, it is important to note that the degree of annoyance can increase markedly for only relatively small increases in the infrasonic noise level once it is above the hearing threshold. In determining equal annoyance contours for infrasonic frequencies (shown in Figure 5), Andresen and Møller (1984) stated “the closeness of the curves in the infrasonic region implies that small changes in sound pressure may cause relatively large changes in annoyance”.

Møller (1987) found that, for infrasound, “annoyance ratings of 1/3 octave noise did not deviate from ratings of pure tones with the same sound pressure level”. This effect may be due to the relatively small bandwidths of 1/3 octave bands in the infrasound frequency range. The same study also identified that the annoyance rating given to noises with a high level of noise in the infrasonic range did not significantly change whether or not the infrasound was combined with noise at frequencies above 20Hz.

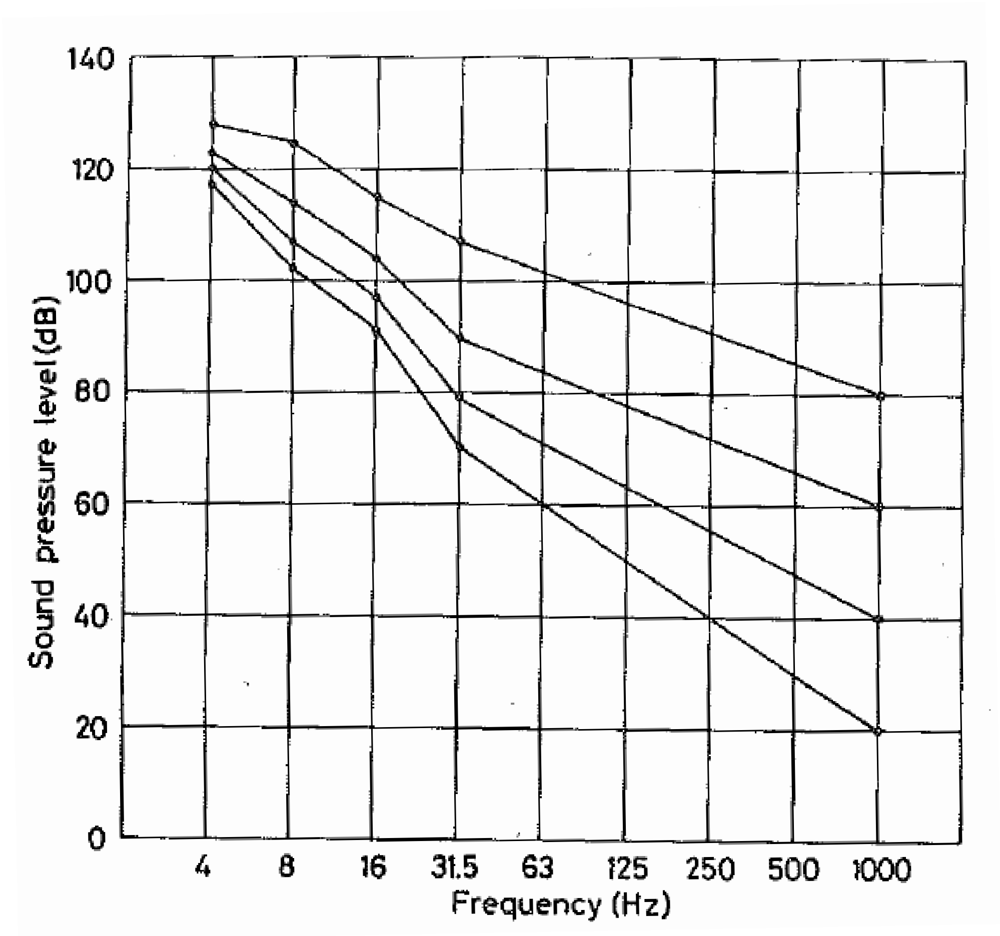

Figure 5 – Equal annoyance contours for pure infrasonic tones (Andresen &Møller, 1984)

In summary, the following conclusions can be drawn from research regarding effects of infrasound:

- The key effect of infrasound can be a high level of annoyance when the level exceeds the hearing threshold, i.e. it must be perceptible to have an effect.
- No physiological effects have been found to occur below the level of perceptibility.
- Once infrasound is perceptible, annoyance can increase faster than for noises at higher frequency as the level increases.
- Annoyance to infrasound does not change where noise above 20Hz is present in the signal.

2.4 Assessment criteria

There are no widely accepted assessment criteria for infrasound. Normally, criteria that do exist have been proposed for infrasound and very low frequency noise based on the threshold of perception. For example, ISO 7196 states that sound pressure levels below 90dB(G) will “not normally be significant for human perception”. Andresen and Møller

(1984) proposed a criterion of 95dB(G) based on the onset of annoyance from perceptible infrasound.

In Australia, the Queensland Department of Environment and Resource Management's (DERM) Draft *ECOACCESS Guideline – Assessment of Low Frequency Noise* recommends an internal noise limit of 85dB(G) for dwellings, consistent with that recommended in Denmark (Jakobsen, 2001). This Queensland Guideline has remained in draft form and has not been formally released.

The proposed 85dB(G) and 95dB(G) limits are compared to the low frequency hearing threshold, from Watanabe &Møller (1990), and other low frequency noise assessment criteria between 0.5Hz and 20Hz in Figure 6.It can be seen that an infrasound criterion of 85dB(G) is reflective of the typical lowest assessment criteria applied to very low frequency noise, and lower than the mean hearing threshold up to a frequency of 20Hz.

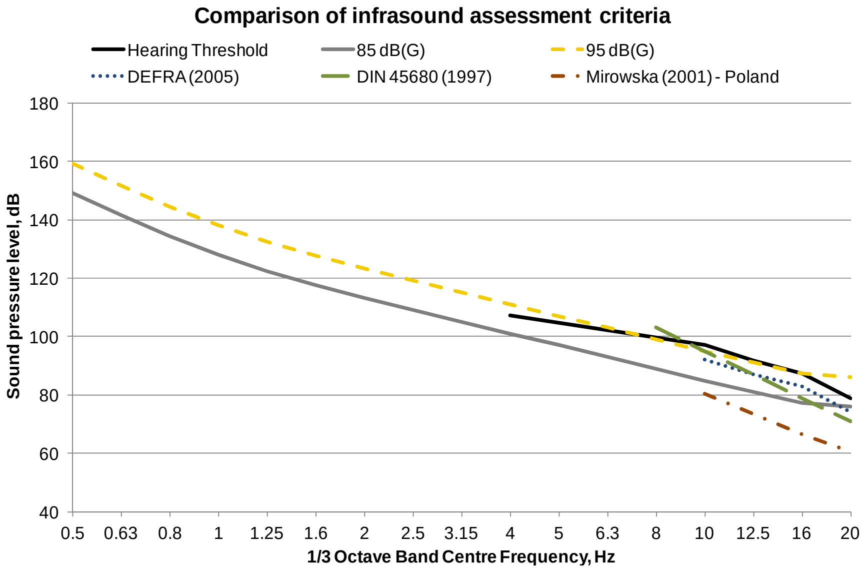

Figure 6 – Comparison of infrasound assessment criteria

Given that an 85dB(G) criterion is 5 to 10dB lower than the mean hearing threshold, it could be considered a conservative criterion that takes into account expected variations in individual hearing thresholds and any potential difference in the hearing thresholds between pure infrasonic tones and more broadband infrasonic noise.

The assessment criteria presented in Figure 6 allow measured infrasound levels as part of the present study to be placed in context. While the aim of this study is to compare infrasound levels between different environments rather than against assessment criteria, it is important to recognise that levels below 85dB(G) would be unlikely to cause adverse response in humans.

3 Measurement results – urban environments

Infrasound measurements were undertaken at seven locations within the Adelaide metropolitan area, to determine typical levels of infrasound 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 on Victoria Square
- Location 4 – Office with low frequency noise complaint
- Location 5 – residence in Mile End under flight path
- Location 6 – residence in Firle on a minor road and local bus route
- Location 7 – residence in Prospect near a major road.

3.1 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, a relatively low-trafficked street in the Adelaide area, which were left closed during the measurement period.

Figure 7 and Figure 8 present the measured infrasound levels over each 10-minute period at Location 1 for both measurement periods. Both the L_{eq} and L_{max} levels are presented. It can be seen that the higher measured levels occur during the daytime, with lower levels occurring at night time when the office was unoccupied. The maximum (L_{max}) levels are typically approximately 10dB(G) higher than the L_{eq} levels.

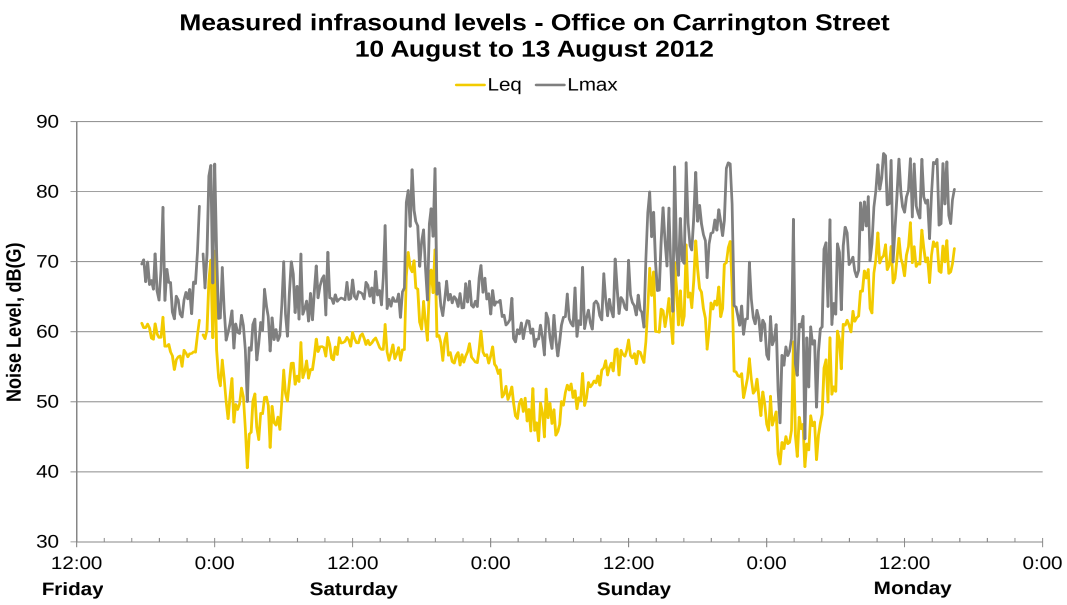

Figure 7 – Measured infrasound levels at Location 1 (Period 1)

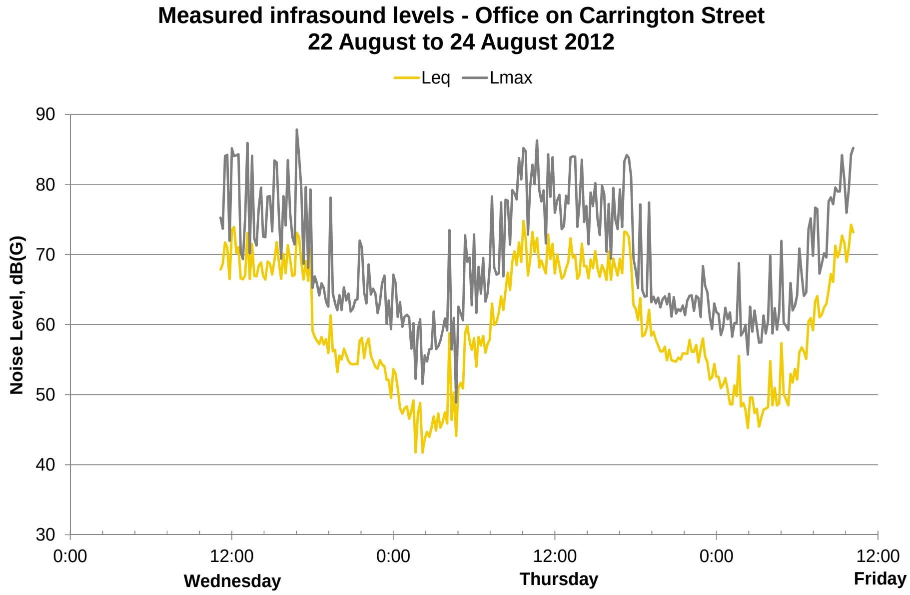

Figure 8 – Measured infrasound levels at Location 1 (Period 2)

Table 1 summarises the measured L_{eq}, L_{10} and L_{90} infrasound levels over both the day and night periods. The L_{10} and L_{90} levels may be considered representative of the typical measured upper and lower noise levels respectively. A night period of 10pm to 7am has been selected as this corresponds to the night time period specified in the *Environment Protection (Noise) Policy 2007*.

Table 1 – Measured infrasound levels in dB(G) at Location 1

Time period	L_{eq}	L_{10}	L_{90}
Day, 7 am to 10 pm	67	68	51
Night, 10 pm to 7 am	56	57	41

The primary factor affecting the measured infrasound levels at Location 1 appears to be occupation of the office, as evidenced by the marked rise in the measured levels at approximately 4pm on Saturday and 2pm on Sunday when staff were noted to enter the office. The $L_{eq,10min}$ on weekdays was typically 66 to 73dB(G), while during the night time it was significantly lower (typically between 45 and 55dB(G)).

To investigate whether this increase in infrasound levels when people were in the office was a result of people generating breezes across the microphone, which had been fitted with a standard 90mm windshield while indoors, infrasound levels were remeasured in the Carrington Street office using the Soundbook system. The two measurement channels were located immediately adjacent to each other, and the microphone of one channel was fitted with a standard 90mm windshield while the microphone of the second channel was fitted with the outdoor windshield to minimise any wind-induced noise. Over a period of 24 hours, no difference was noted in the measured infrasound levels between the two measurement microphones, and the same increase was noted in the G-weighted levels from both measurement channels when the office was occupied. This confirmed that the increase in infrasound levels when people were present in the office was not a result of wind-induced noise.

It also appears that traffic within the local area affected the level of infrasound as the daytime levels on the weekend when the office was unoccupied were 10 to 15dB(G) higher than that at night time.

3.2 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 measurements were undertaken with the Soundbook system, with the microphone located in the centre of the main room with windows facing onto Goodwood Road. The windows were kept closed during the measurement period.

Figure 9 presents the measured L_{eq} and L_{max} infrasound levels for each 10-minute period at Location 2. The maximum (L_{max}) levels are between 5 to 10dB(G) higher than the L_{eq} levels.

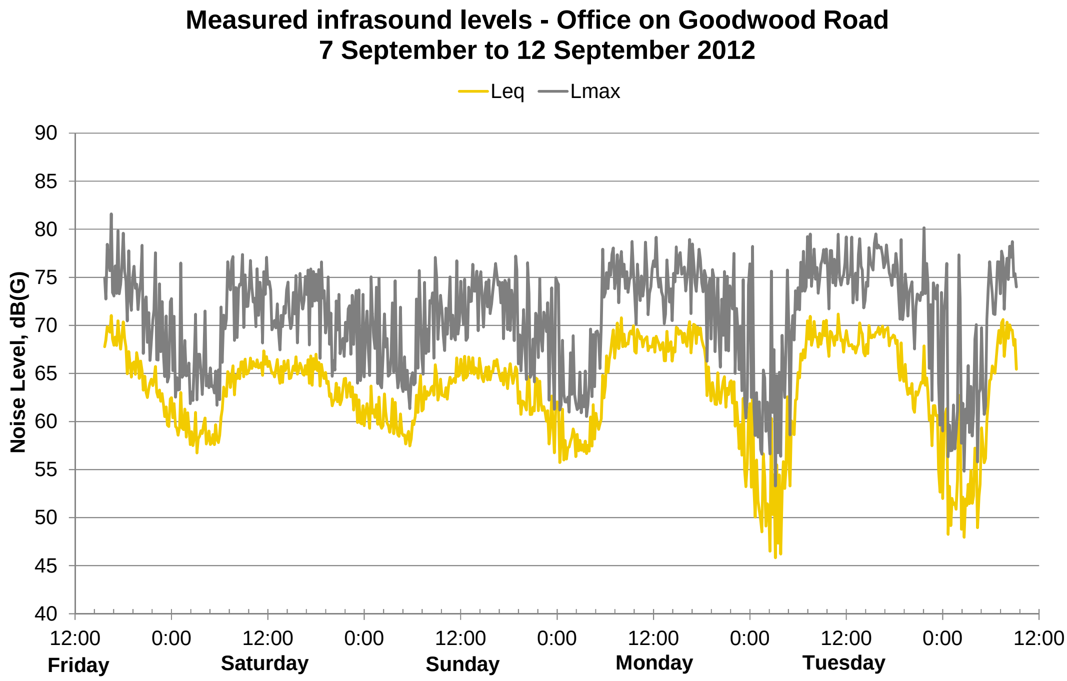

Figure 9 – Measured infrasound levels at Location 2

Table 2 summarises the measured L_{eq}, L_{10} and L_{90}infrasound levels at Location 2 over both the day and night periods.

Table 2 – Measured infrasound levels in dB(G) at Location 2

Time period	L_{eq}	L_{10}	L_{90}
Day, 7 am to 10 pm	67	70	61
Night, 10 pm to 7 am	61	63	48

As for Location 1, the measured infrasound levels are higher during the daytime and when the office is occupied. The daytime L_{eq} levels on weekdays were 4 to 5dB(G) higher than those on the weekend, and up to 20dB(G) higher than those at night. This suggests that both occupation of the office and traffic have affected the infrasound levels.

It can also be seen that the night time infrasound levels at Location 2 on the weekend were higher than those on weeknights. The measurements were undertaken during the opening week of the Royal Adelaide Show at the nearby Wayville Showgrounds and this may have increased night time traffic near the office.

3.3 Location 3 – EPA office

Measurements were undertaken at the EPA office, located on Level 9 of a building on Victoria Square in Adelaide, from 1 to 9 November 2012.The building has a central atrium and is equipped with an automatically timed air conditioning system that serves the entire building. The measurements were undertaken with the Soundbook system, with one microphone located in the office area nearer the atrium and the second microphone located towards the eastern glazed facade of the building, facing away from Victoria Square.

Figure 10 presents the measured L_{eq} infrasound levels for each 10-minute period at Location 3, with the central location referring to that near the atrium and the eastern location referring to that nearer the facade. The maximum (L_{max}) levels are not presented for clarity but were typically 2 to 4dB(G) higher than the L_{eq} levels.

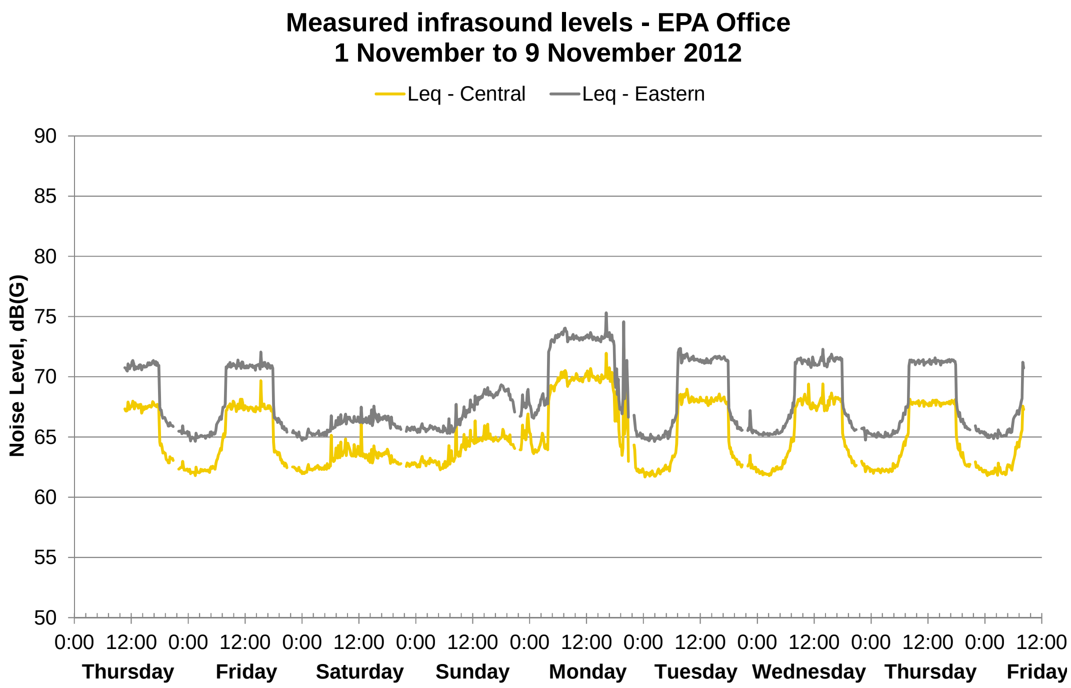

Figure 10 – Measured infrasound levels at Location 3

Table 3summarises the measured L_{eq}, L_{10} and L_{90} infrasound levels at Location 3 over both the day and night periods.

Table 3 – Measured infrasound levels in dB(G) at Location 3

Time period	Central			Eastern		
	L_{eq}	L_{10}	L_{90}	L_{eq}	L_{10}	L_{90}
Day, 7 am to 10 pm	67	67	66	70	70	66
Night, 10 pm to 7 am	63	63	62	66	66	65

The measurements indicate that L_{eq} infrasound levels in the EPA office range from 68 to 74dB(G) during weekdays, remaining steady throughout the day. This suggests that there is a constant source of the infrasound during these periods and, based on the start and end times, it is believed to be the result of mechanical plant located on the building roof. Infrasound levels at night and on weekends are lower but still remain at higher levels than in other locations, typically 62 to 66dB(G). As the increase is relatively steady, it suggests that this is the result of other rooftop plant operating 24 hours a day.

There also appears to be a relatively steady difference of 3dB(G) between infrasound levels in the two measurement locations, with the microphone located near to the building facade measuring higher levels than that located near the central atrium. This indicates that transmission of infrasound from rooftop plant is greater through the glazed facade.

Overall, the measured infrasound levels in the EPA office represent some of the highest levels measured at any of the urban and rural locations.

3.4 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 had been received. The source of the low frequency noise complaint was the air conditioning system for the building. The measurements were undertaken using a Brüel & Kjær Type 2250 sound level meter, and therefore the actual G-weighted noise levels will be marginally lower than presented in this report (as the instrument only measures to 6.3Hz).

Figure 11 presents the measured L_{eq} infrasound levels over each 15-minute period at Location 4, with the microphone located in the area from which the complaint was received. All windows to the office were closed and the air conditioning system was operating on the weekdays but not on the weekend.

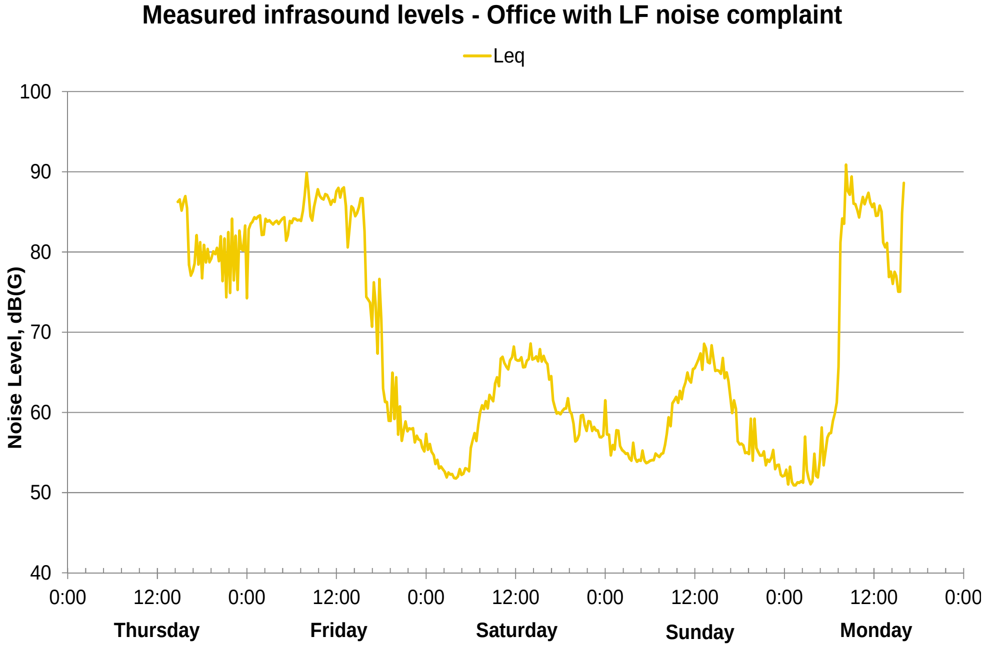

Figure 11 – Measured infrasound levels at Location 4

Table 4 summarises the measured L_{eq} infrasound levels at Location 4 over both the day and night periods.

Table 4 – Measured infrasound levels in dB(G) at Location 4

Time period	L_{eq}
Day, 7 am to 10 pm	82
Night, 10 pm to 7 am	76

The measurement results at Location 4 indicate that infrasound levels increased significantly when the air-conditioning system was operating. The measured $L_{eq,15min}$ infrasound levels at Location 4 regularly reached 85 to 90dB(G) when the system was operating, suggesting infrasound may have been just perceptible to occupants at times. However, it should be noted that noise levels measured within this building were controlled within the frequency range of 20 to 40Hz and therefore any adverse reaction of the office occupants may have been caused by low frequency noise rather than infrasound.

Over the weekend when the air conditioning system was not operating, measured infrasound levels were 20 to 30dB(G) lower. At these times, it appears as though traffic was the primary source of infrasound, with higher levels recorded during the daytime.

3.5 Location 5 – House at Mile End

Measurements were undertaken at a house located in Mile End, under an Adelaide Airport 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.

Figure 12 presents the measured L_{eq} and L_{max} infrasound levels for each 10 minute period at Location 5. As for the other urban locations, measured infrasound levels at Location 5 appear to be controlled by human activity, increasing sharply at the beginning of the day and decreasing suddenly at night.The maximum (L_{max}) levels are typically 10 to 15dB(G) higher than the L_{eq} levels during both the day and night time periods.

Table 5 summarises the measured L_{eq}, L_{10} and L_{90} infrasound levels at Location 5 over both the day and night periods.

Table 5 – Measured infrasound levels in dB(G) at Location 5

Time period	L_{eq}	L_{10}	L_{90}
Day, 7 am to 10 pm	61	61	52
Night, 10 pm to 7 am	53	53	43

Measured infrasound levels were noted to increase when aircraft from Adelaide Airport were taking off or landing, and this appears to be the cause of the larger difference between the measured L_{eq} and L_{max} levels at this location relative to the other urban locations. However, the overall measured L_{eq} infrasound levels at this location were typically lower than those measured at the office locations.

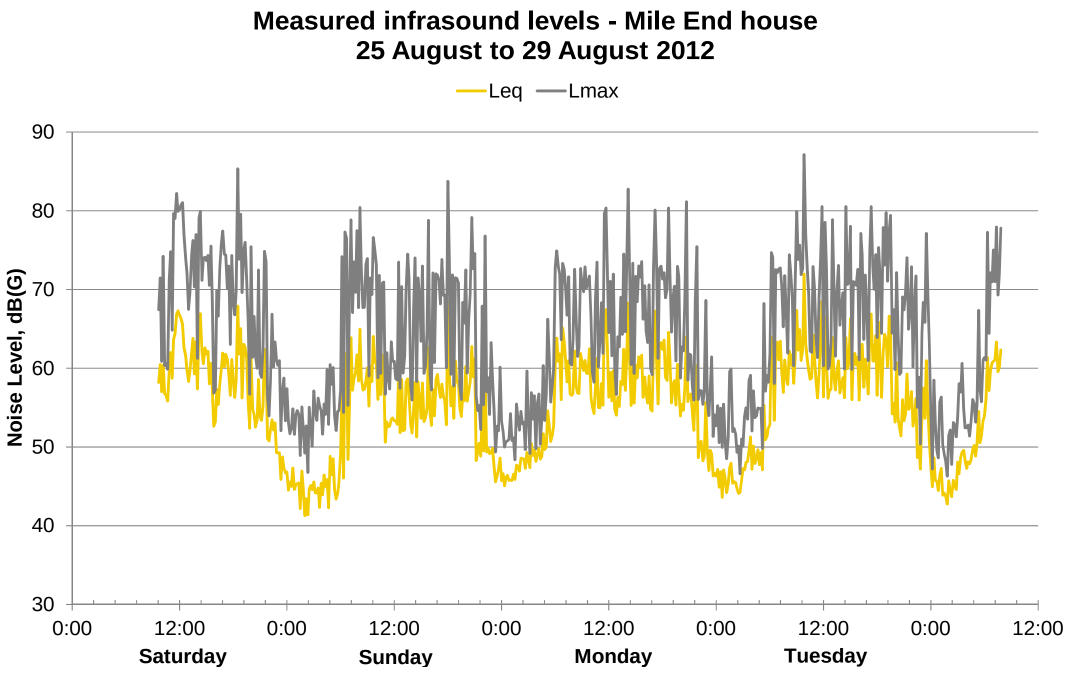

Figure 12 – Measured infrasound levels at Location 5

3.6 Location 6 – House at Firle

Measurements were undertaken at a house located in Firle, from 30 August to 4 September 2012. The house is on a local bus route but is located over 200 metres from the nearest major road.

The measurements were undertaken with the Soundbook system, with one microphone located in a spare bedroom of the residence and the second microphone located in a closed shed towards the rear of the property. The house was unoccupied for some of the measurement period, including from approximately 11 am on Saturday until approximately 4 pm on Monday.

Figure 13 presents the measured L_{eq} infrasound levels for each 10-minute period in the spare bedroom of the residence and in the shed. L_{max} infrasound levels have not been presented for clarity but were between 5 to 15dB(G) above the L_{eq} infrasound levels in both measurement locations.

Table 6 summarises the measured L_{eq}, L_{10} and L_{90} infrasound levels at Location 6 over both the day and night periods.

Table 6 – Measured infrasound levels indB(G) at Location 6

Time period	Bedroom			Shed		
	L_{eq}	L_{10}	L_{90}	L_{eq}	L_{10}	L_{90}
Day, 7 am to 10 pm	61	62	52	66	68	60
Night, 10 pm to 7 am	54	54	44	60	63	54

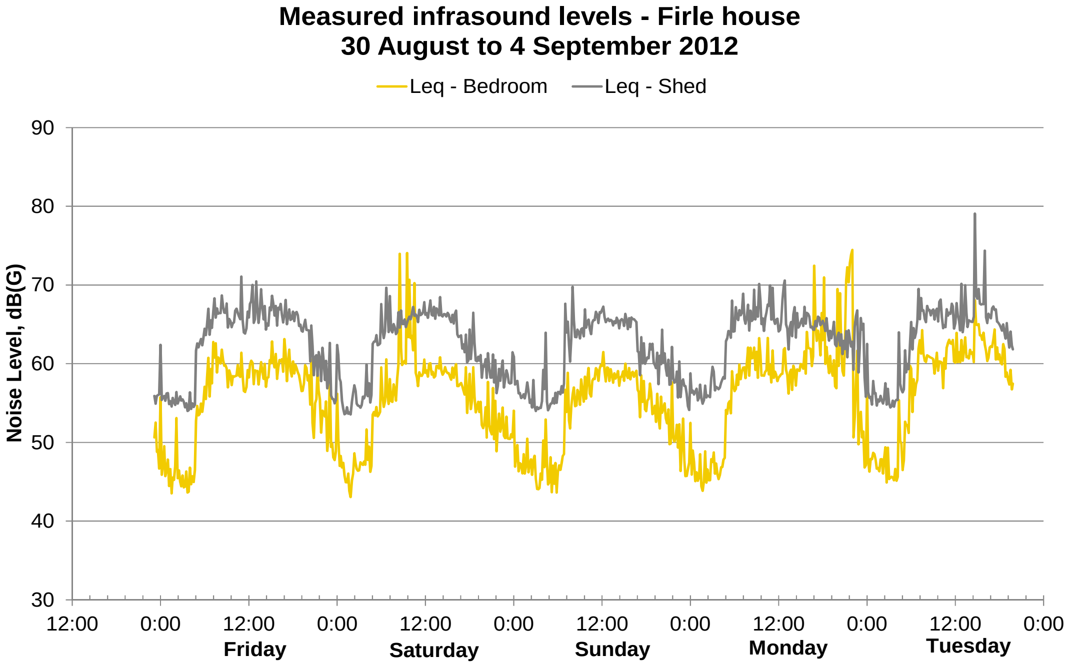

Figure 13 – Measured infrasound levels at Location 6

The measurement results at Location 6 indicate that infrasound levels are higher during the daytime than at night, suggesting that traffic and human activity is the primary source of infrasound. Activity within the house was also a source of higher levels of infrasound as, while the spare bedroom was generally unoccupied with the door closed, the occupants of the house entered the room from approximately 9 to 11 am on Saturday and 9 to 11 pm on Monday resulting in a marked increase in both the measured L_{eq} and L_{max} levels.

It can also be seen that infrasound levels in the shed were typically 5 to 10dB(G) higher than the infrasound levels in the spare bedroom. A review of the frequency content for both locations found that this was due to noise levels in the shed being considerably higher than those in the bedroom across the frequency range from 16 to 31.5Hz. This frequency range typically controls the G-weighted noise level and therefore resulted in higher measured G-weighted noise levels in the shed relative to the bedroom.

The shed is constructed from sheet metal whereas the house is of a double brick construction. The house appears to provide a considerably higher attenuation of infrasound levels.

3.7 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 14 presents the measured L_{eq} G-weighted infrasound levels for each 10-minute period in the downstairs living area and the upstairs spare room.

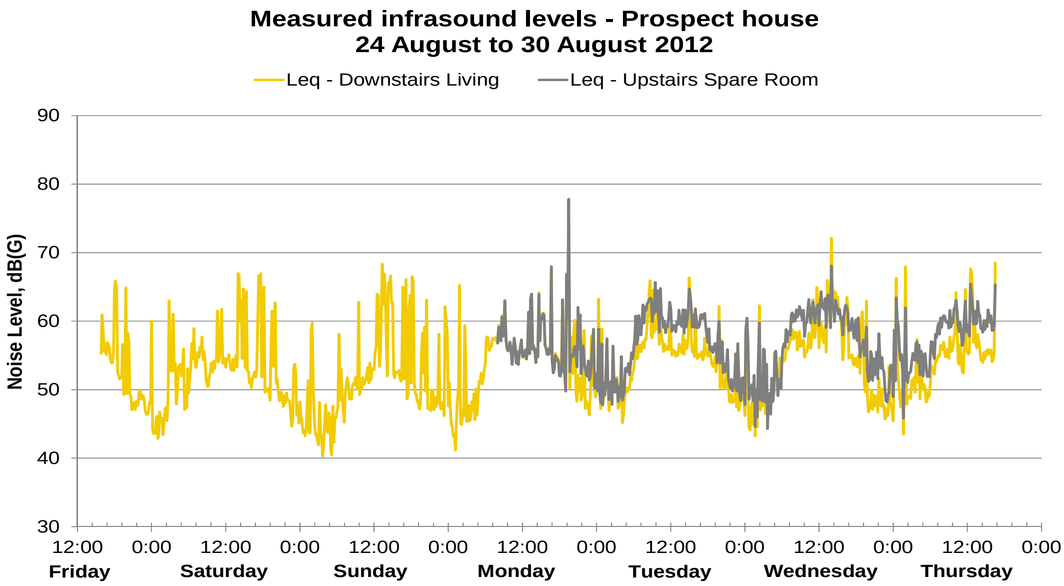

Figure 14 – Measured infrasound levels at Location 7

Table 7 summarises the measured L_{eq}, L_{10} and L_{90}infrasound levels at Location 7 over both the day and night periods.

Table 7 – Measured infrasound levels in dB(G) at Location 7

Time period	Downstairs living area			Upstairs spare room		
	L_{eq}	L_{10}	L_{90}	L_{eq}	L_{10}	L_{90}
Day, 7 am to 10 pm	59	59	49	61	62	52
Night, 10 pm to 7 am	53	54	43	54	57	45

The measured infrasound levels at this location are similar to those at the other residential locations, with measured $L_{eq,10min}$ levels between 45 and 65dB(G). This suggests that the relative proximity to a major road (when compared to Location 5 and Location 6) has not significantly influenced the measured levels. Infrasound levels increase during the day and decrease at night, with peaks in the measured levels corresponding to periods when the rooms were occupied.

The measured noise levels in the upstairs spare room were higher than those in the downstairs living area despite the room being unoccupied for considerably longer periods. This is believed to have been the result of a window in the spare room being slightly ajar for the majority of the measurement period.

3.8 Summary of measured urban infrasound levels

Table 8 summarises the measured infrasound levels, across both the day and night periods, at each of the urban locations.

Table 8 – Summary of measured urban infrasound levels in dB(G)

Location	Day, 7 am to 10 pm			Night, 10 pm to 7 am		
	L_{eq}	L_{10}	L_{90}	L_{eq}	L_{10}	L_{90}
1	67	68	51	56	57	41
2	67	70	61	61	63	48
3 – Central	67	67	66	63	63	62
3 – Eastern	70	70	66	66	66	65
4	82	–	–	76	–	–
5	61	61	52	53	53	43
6 – Bedroom	61	62	52	54	54	44
6 – Shed	66	68	60	60	63	54
7 – Downstairs living	59	59	49	53	54	43
7 – Upstairs spare	61	62	52	54	57	45

From the measurement results, it is clear that day time infrasound levels of between 60 and 70dB(G) commonly occur in the urban environment. Infrasound levels are generally between 5 to 10dB(G) lower during the night time period.

Given the differences in level noted between unoccupied and occupied periods at each location, and between the day and night time periods:

- Noise generated by people within a space is the most significant contributor to measured infrasound levels, as the measured levels during occupied periods were 10 to 15dB(G) higher than unoccupied periods.
- Traffic may also influence the infrasound level in an environment, with measured levels during the daytime periods typically 10dB(G) higher than between midnight and 6am, when traffic would be expected to be at its lowest.

At Location 3 (the EPA office), infrasound generated from rooftop mechanical plant appeared to control levels during weekdays. Levels of between 68 and 73dB(G) were measured in the office while the rooftop plant was operating. Similarly, at Location 4, where there was a low frequency noise complaint, infrasound levels regularly exceeded 85dB(G) during operation of the air conditioning system causing the complaint. These results suggest that mechanical air-conditioning plant can be a significant source of infrasound as these two locations exhibited some of the highest levels of infrasound measured during the study.

4 Measurement results – rural environments

Infrasound 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.

Both outdoor and indoor infrasound measurements were undertaken at each of these locations. It was found that the indoor level of infrasound was typically similar to or slightly lower than the outdoor level of infrasound at each of the locations, once the effect of extraneous noise sources had been discounted. Refer to Appendix B for a discussion of the difference between the measured outdoor and indoor infrasound levels.

4.1 Location 8 – House near Bluff Wind Farm

Measurements were undertaken at a house located near to the Bluff Wind Farm, northwest 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 located to the west of the house, and is comprised of the same S88 2.1MW turbines. The nearest turbine at North Brown Hill is positioned 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, minimising influences from extraneous noise sources. The SVAN 945A was located in one bedroom (Bedroom 1) with one measurement channel of the Soundbook system positioned in the second bedroom (Bedroom 2). The second measurement channel of the Soundbook system was located 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, typical of many rural residences in South Australia. The two bedrooms used for the indoor measurements both had sash windows facing towards the Bluff Wind Farm. The windows in each bedroom were able to be properly closed such that wind-induced noise across the indoor microphone was not of significant concern to the measurement results.

Figure 15 presents the measured indoor $L_{eq,10min}$ and L_{max} infrasound levels across the measurement period at Location 8. 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.

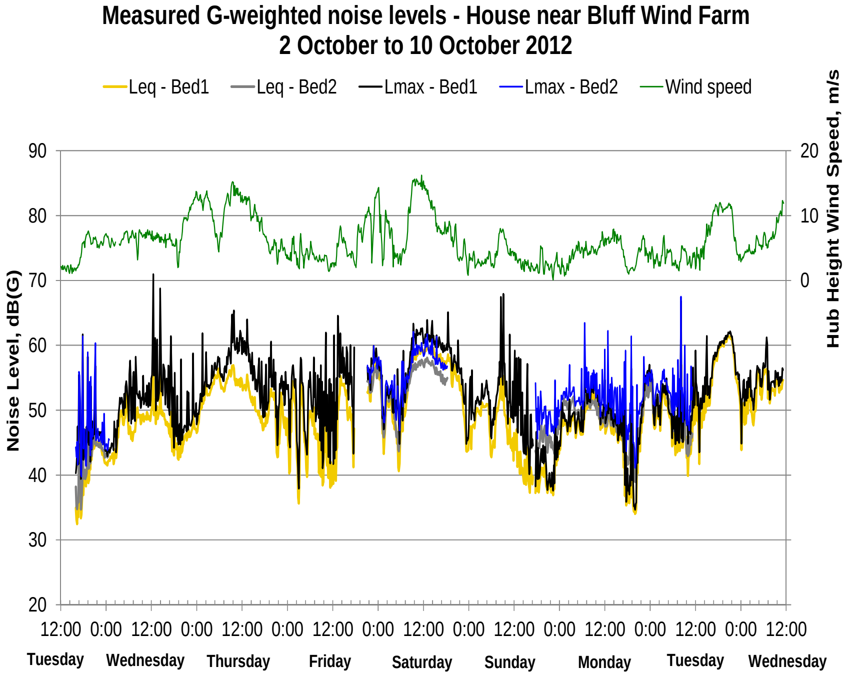

Figure 15 – Measured indoor infrasound levels at Location 8

Note that gaps in the datasets are due to the battery supply to the Soundbook system running low (as there was no mains power at the measurement site) or due to data being downloaded from either of the analysers. Semi-regular trips were made to replace batteries but only a limited dataset could be gathered each time on the Soundbook system, which requires significantly more power than the SVAN 945A.

The results demonstrate that infrasound levels at the house located near the wind farm typically range from 40 to 60dB(G).The measured levels were approximately equivalent in both rooms, suggesting that there is not a significant variation in infrasound levels across different rooms facing towards the wind farm.

Unlike the urban locations, the infrasound levels at Location 8 do not show a clear correlation with time of day, with night time levels sometimes higher and at other times lower than the levels measured during the daytime. It can also be seen from Figure 15 that the L_{max} infrasound levels are typically 3 to 10dB(G) above the L_{eq} levels, and that short-term infrasound levels at Location 8 are no greater than at the urban locations.

The measured outdoor infrasound levels have not been presented on Figure 15 for clarity, but the L_{eq} levels were found typically to be about 5dB(G) above the measured indoor L_{eq} infrasound levels. The measured outdoor infrasound L_{max} levels were typically 2 to 10dB(G) above the measured L_{eq} levels. Further discussion of the difference between outdoor and indoor infrasound levels is provided in Appendix B.

Table 9 summarises the measured L_{eq}, L_{10} and L_{90}infrasound levels at Location 8 over both the day and night periods.

Table 9 – Measured infrasound levels in dB(G) at Location 8

Time period	Bedroom 1			Bedroom 2			Outdoor		
	L_{eq}	L_{10}	L_{90}	L_{eq}	L_{10}	L_{90}	L_{eq}	L_{10}	L_{90}
Day, 7 am to 10 pm	53	53	43	51	50	43	58	55	52
Night, 10 pm to 7 am	50	53	43	51	52	45	56	57	55

Figure 16 presents the measured indoor infrasound levels at Location 8 versus hub height wind speed at the wind farm site. The results are presented separately for downwind conditions (e.g. wind blowing from the wind farm to the measurement location within ±45° from the line connecting the measurement location and the nearest turbine) and for all other wind directions. There appears to be some correlation in the datasets with wind speed at the wind farm site, with infrasound levels generally increasing as the wind speed increases. However, the correlation is relatively weak, such that wind speed at the wind farm site does not appear to be the main factor affecting infrasound levels at the house.

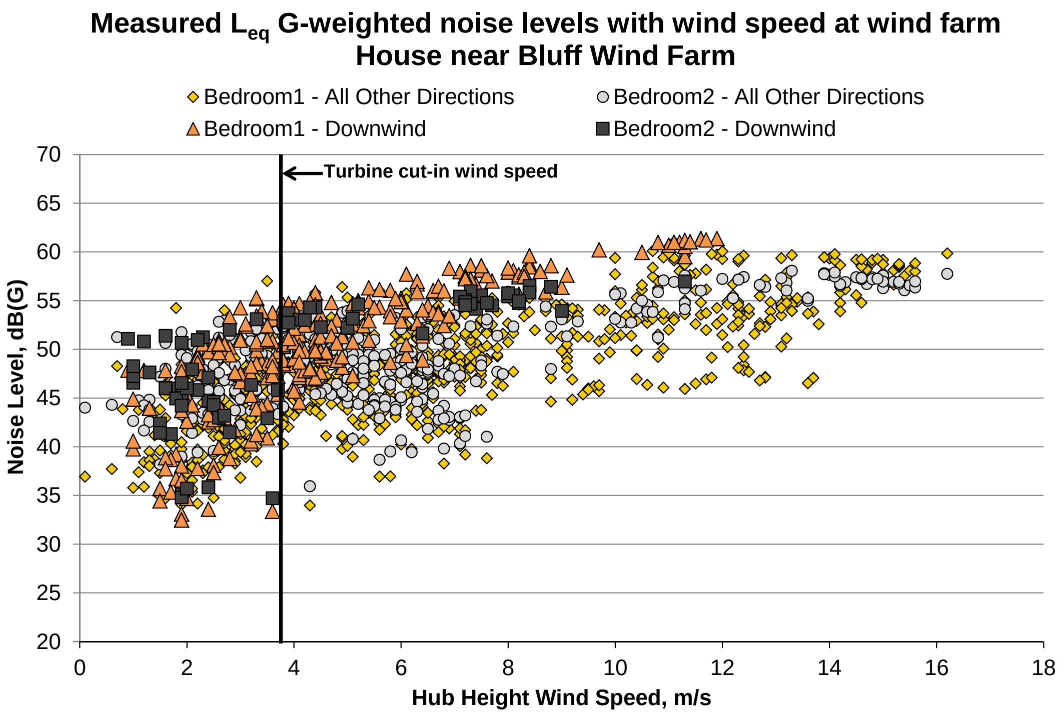

Figure 16– Measured indoor infrasound levels with wind speed, Location 8

Similarly, infrasound levels appear to increase during downwind conditions but this increase is noted even when the wind speed is below the turbine cut-in wind speed (4 m/s) and the turbines are not operating. Therefore, this downwind increase is less likely to be a result of the operation of the wind farm.

Figure 17presents the measured outdoor infrasound levels at Location 8 with hub height wind speed at the wind farm site. A similar result can be seen as in Figure 16, where there is some correlation in the datasets with wind speed, but that the correlation is still somewhat limited.

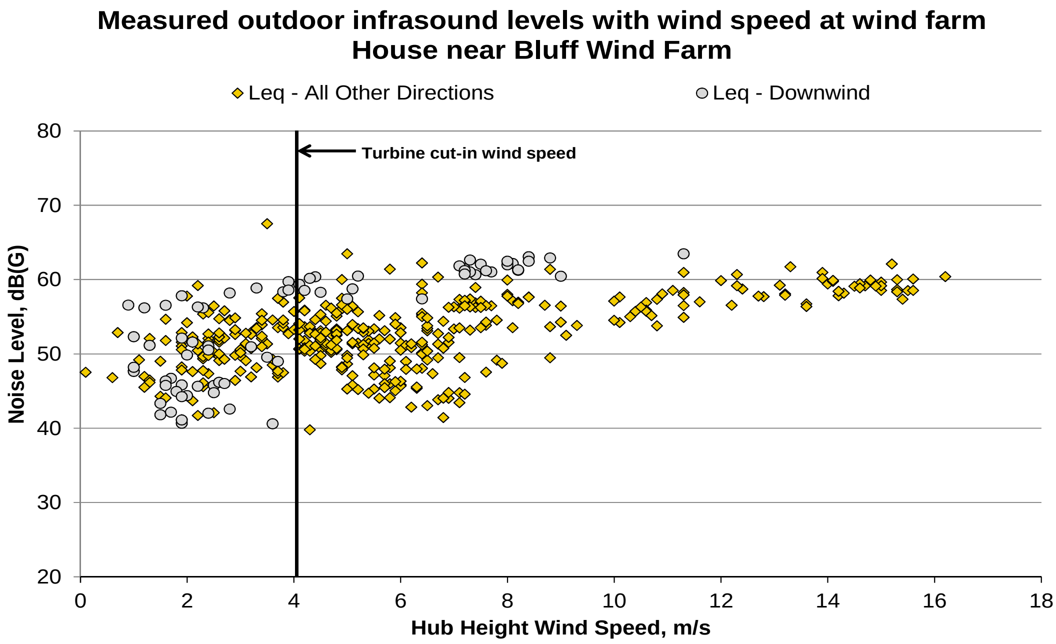

Figure 17 – Measured outdoor infrasound levels with wind speed, Location 8

Based on the lack of strong correlation between noise level and wind speed at the wind farm it appears that localised wind conditions, rather than wind conditions at the wind farm, may control infrasound levels at the house. This could also explain the increase in infrasound levels in Bedroom 1 and Bedroom 2 under downwind conditions, as these rooms would be more exposed to wind during downwind periods (when they would be in the most exposed facade) than during other periods when they would be shielded by the other parts of the house.

To confirm the contribution of the Bluff Wind Farm to infrasound 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 the 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).

The measured infrasound levels at Location 8 both during and after the shutdown period are shown in Figure 18, along with the wind speed measured at the nearest meteorological mast at the Bluff Wind Farm. A period approximately four hours after the shutdown is highlighted for comparison as the same wind conditions (speed and direction) occurred as occurred during the shutdown.

It can be seen that the typical levels of infrasound in the two bedrooms during the shutdown were 51 to 55dB(G) L_{eq} and 54 to 58dB(G) L_{max}. The outdoor infrasound levels were 5 to 7dB(G) above the indoor levels. In the period immediately following the shutdown, the wind direction changed by approximately 90° (to upwind) and the measurement results are unable to be directly compared. However, it appears as though the infrasound levels remained relatively steady following the shutdown, with a marginal 2 to 3dB(G) increase in the infrasound levels corresponding to an increase in the wind speed relative to the shutdown period.

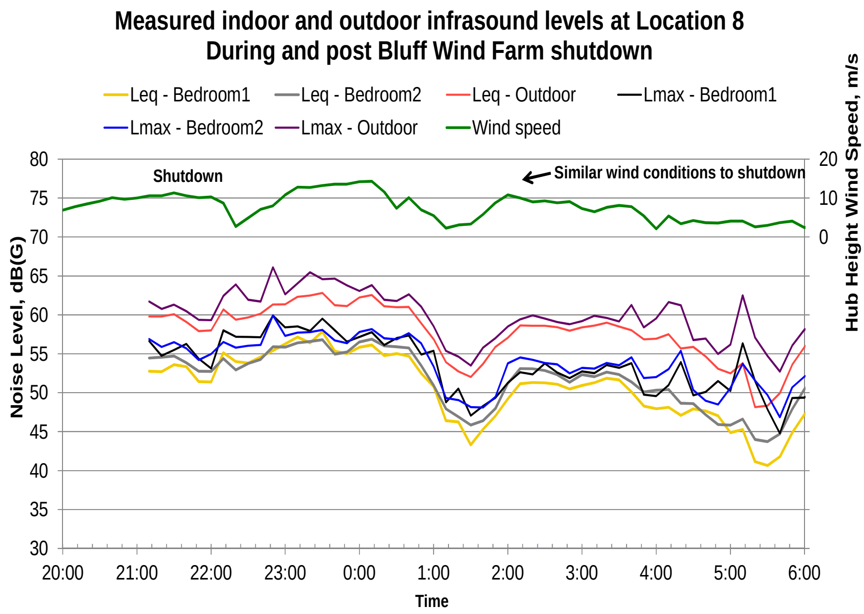

Figure 18 – Measured infrasound levels during and after Bluff Wind Farm shutdown

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 infrasound levels both during the shutdown and with the wind farm operational are summarised in Table 10, including the wind speed and wind direction relative to the house (0° corresponds to upwind).

Table 10 – Infrasound levels in dB(G) at Location 8 during and after shutdown

Date	Time	Bedroom 1		Bedroom 2		Outdoor		Wind conditions	
		L_{eq}	L_{max}	L_{eq}	L_{max}	L_{eq}	L_{max}	Speed, m/s	Relative direction (0° upwind)
Shutdown periods									
5/10	21:10	53	57	55	57	60	62	10.6	103°
5/10	21:20	53	55	55	56	60	61	10.6	100°
5/10	21:30	54	56	55	56	60	61	11.3	96°
5/10	21:40	53	56	54	57	59	61	10.6	92°
5/10	21:50	51	54	53	54	58	59	10.1	92°
5/10	22:00	51	53	53	55	58	59	10.3	82°
Operational periods									
5/10	23:00	56	58	56	57	61	63	10.8	46°
6/10	00:20	55	56	56	57	61	62	11.6	43°
6/10	02:00	49	51	51	54	57	59	10.8	87°
6/10	02:10	51	53	53	55	58	59	10	96°

It can be seen that a marginal 2 to 3dB(G) increase in infrasound levels occurred during the measurements at 11 am and 12:20 am, but that this could well have resulted from a change in wind conditions (a small increase in wind speed and 40° to 50° shift in wind direction).

The periods at 2am and 2:10am provide a more direct comparison as wind conditions were very similar to the shutdown periods. During these periods, the infrasound levels measured at the house with the wind farm operating were up to 4dB(G) lower than that measured during the shutdown.

The analysis of the measured infrasound levels both during and after the Bluff Wind Farm shutdown indicates that the wind farm did not contribute to the level of infrasound at the house.

4.2 Location 9 – House near Clements Gap Wind Farm

Measurements were undertaken at a house located near to the Clements Gap Wind Farm, southwest 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 located 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 located 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 windowsand 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, which with the gaps in the facade of the room 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 (and generating infrasound) on the roof near the measurement room during a site visit at a time of high winds near the conclusion of the measurements. These observations during the measurements lead to significant concern about the accuracy of the indoor measurements, and the outdoor measurements at this location are considered to be a more reliable data set for this study. However, it should be noted that the outdoor measurements were also conducted relatively close to the loose sheet of roofing iron, and this may have affected the measurements during high winds.

Figure 19presents the measured indoor and outdoor $L_{eq,10min}$ and L_{max} infrasound levels across the measurement period at Location 9. 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.

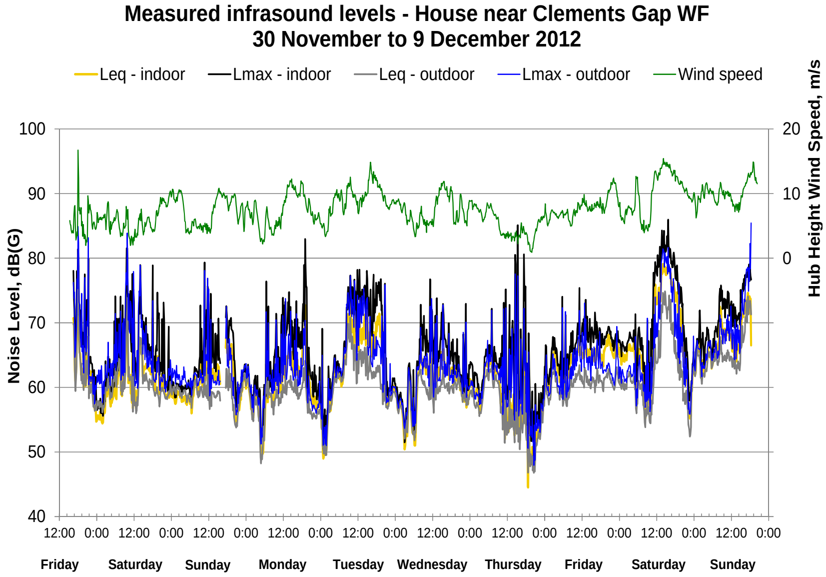

Figure 19 – Measured indoor and outdoor infrasound levels at Location 9

The results indicate that outdoor infrasound levels at Location 9 range from 50 to 75dB(G) L_{eq}, with L_{max} levels typically between 5 to 15dB(G) above the L_{eq} levels. It can also be seen that the indoor infrasound levels are often similar to the outdoor levels but that there are extended periods where the indoor levels are markedly higher than the outdoor. Based on the occasional site inspections, a number of these periods were identified as times when renovation work was occurring or when the external door was open, suggesting that the infrasound levels measured outdoors provide a better representation of the actual infrasound levels at Location 9.

Table 11 summarises the measured L_{eq}, L_{10} and L_{90} noise levels over both the day and night periods.

Table 11 – Measured infrasound levels in dB(G) at Location 9

Time period	Indoor			Outdoor		
	L_{eq}	L_{10}	L_{90}	L_{eq}	L_{10}	L_{90}
Day, 7 am to 10 pm	66	71	58	62	66	56
Night, 10 pm to 7 am	57	65	55	56	62	55

The measured levels at Location 9 show a slight change with time of day, with measured magnitudes during daytime typically higher than those at night. This also suggests that renovation works at the house influenced the infrasound levels. However, there does also appear to be some relationship with wind speed at the wind farm during particular periods.

Figure 20presents the measured infrasound levels with at Location 9 with hub height wind speed at the wind farm site. The results are presented separately for downwind conditions (e.g. wind blowing from the wind farm to the measurement location) and for all other wind directions. It can be seen that there is an upward trend in the measured levels with wind speed, but that there is a considerable spread in the dataset. The data points collected during downwind conditions do not seem to be noticeably higher than those collected during other wind conditions, suggesting there is no reason to believe that infrasound levels are higher when the measurement location is positioned downwind of the wind farm. A lack of strong correlation between hub height wind speed at the wind farm and infrasound levels at the house, and no sudden reduction in infrasound levels below turbine cut-in is noted, which suggests the wind farm may not be a significant contributor to the infrasound levels at the measurement locations.

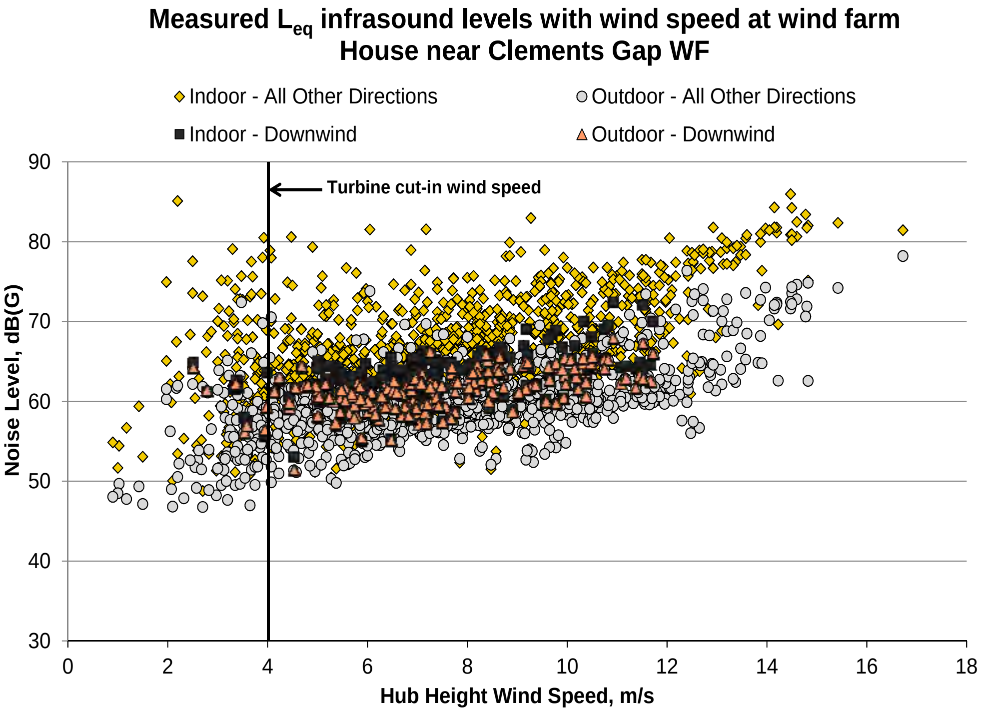

Figure 20 – Measured infrasound levels versus wind speed, Location 9

It is also apparent that there is considerable scatter in the indoor dataset, confirming that the indoor location was more affected by extraneous noise sources.

It should be noted that the relatively high levels of infrasound measured under high winds at this location are believed to be a result of the loose sheet of iron on the roof immediately above the room in which the indoor microphone was located. The sheet at Location 9 was found to be noticeably rattling under high wind conditions and would have influenced the measurement results at the indoor location in particular.

To check the contribution of Clements Gap Wind Farm to the infrasound levels at the Location 9, the wind farm was shutdown from approximately 8:20pm to 10:50pm on 8 December 2012. During this period, the hub height wind speed at the wind farm was between 9 to 11 m/s, and the wind direction was approximately 70º to 80º relative to the house (crosswind, slightly upwind conditions).The measured indoor and outdoor infrasound levels at the house near the wind farm before, during and after the shutdown are shown in Figure 21. Note that the indoor levels are presented for information only as it is believed that these measurements were unduly affected by extraneous noise or wind-induced noise both during and outside of the shutdown period.

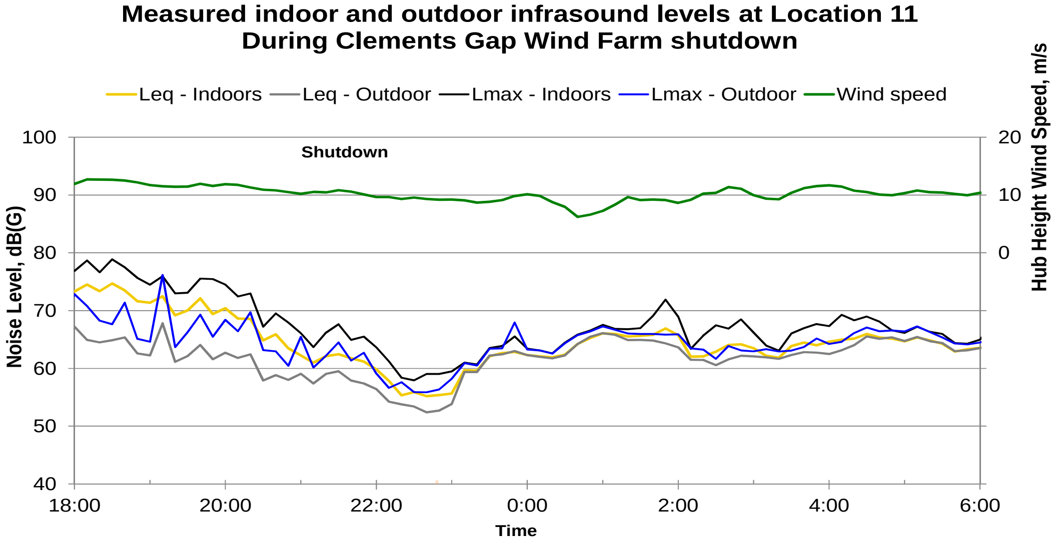

Figure 21 – Measured infrasound levels during shutdown of Clements Gap Wind Farm

While the measured infrasound levels during the shutdown are lower than those measured immediately before and after, no direct conclusions can be drawn as to the contribution of the wind farm to the measured infrasound level as the wind speed was reducing relative to the period before the shutdown and a change in wind direction was observed immediately after the shutdown. This change in wind direction (approximately 50° to 60° in magnitude, towards downwind) is the most likely reason for the marked increase in infrasound levels that occurred after the shutdown.

Similarly, while there was a marked increase in the measured infrasound levels of approximately 5dB(G) at around the time that the turbines became operational, this was not matched by a reduction of the same magnitude when the turbines were originally shutdown. This suggests that other factors may have caused or contributed to these changes.

Figure 22 presents the outdoor infrasound levels versus wind speed for both the shutdown periods and the operational periods under that particular wind direction. Note that the shutdown periods at low wind speed occurred when the wind speed at the turbines was below the cut-in wind speed. A 25º wide wind direction sector has been considered for this analysis, to match the wind directions observed during the shutdown.

The results presented in Figure 22 indicate that, while the shutdown period resulted in some of the lower levels of infrasound during the measurements at Location 9, similar levels of infrasound were measured at the same wind speeds while the turbines were operating. Similarly, the infrasound levels measured at wind speeds below the cut-in wind speed of the turbines were higher than those measured during a number of periods at higher wind speeds when the turbines were operating. Therefore, the typical level of ambient infrasound in the environment around Location 9 is similar to that measured when the turbines are operating.

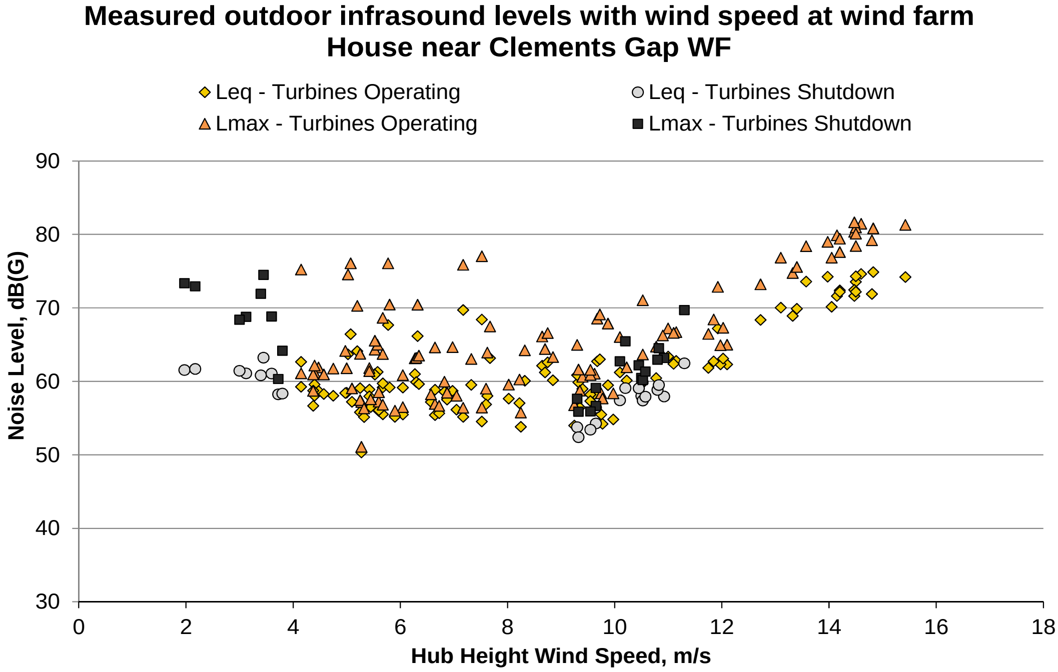

Figure 22 – Measured infrasound levels during same wind direction as shutdown period, Location 9

Overall, the measurement results at Location 9 demonstrate that, while there may be a relatively minor contribution to measured infrasound levels due to operation of the Clements Gap Wind Farm, the wind farm is not resulting in infrasound levels at the house that are any higher than the existing level of infrasound in the environment.

4.3 Location 10 – Farmhouse near Jamestown

To provide a comparison of rural infrasound levels at a location further away from wind turbines, measurements were undertaken at a farmhouse situated near Jamestown. The farmhouse is about 10 kilometres away 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 23 presents the measured indoor and outdoor $L_{eq,10min}$ and L_{max} infrasound levels across the measurement period at Location 10. The 10-minute average hub height (80 metres above ground level) wind speed measured at the nearest meteorological mast at the North Brown Hill Wind Farm is also presented on the figure for comparison. The mast is located approximately 11 kilometres from the house.

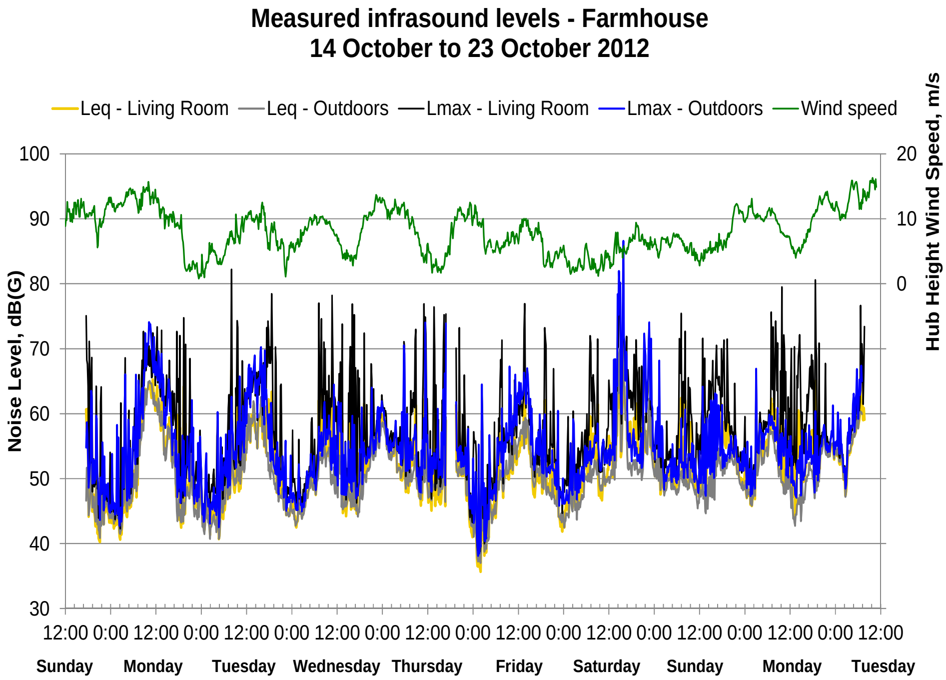

Figure 23 – Measured infrasound levels at Location 10

The measurement results indicate that infrasound levels within the living room at Location 10 typically range between 45 and 65dB(G) L_{eq}, with the L_{max} levels generally 5 to 15dB(G) higher than the L_{eq} levels. The highest levels appear to occur during the daytime periods when people are moving about and generating noise. Noise levels at night are considerably lower, although infrasound magnitudes of up to 60dB(G) L_{eq} were measured during some night periods.

The outdoor L_{eq} levels are typically similar to the indoor levels, but the L_{max} levels measured outdoors are often much lower than the indoors L_{max} levels, particularly during the daytime periods. This suggests that human activity in the house was the source of the higher indoor L_{max} levels.

Table 12 summarises the measured L_{eq}, L_{10} and L_{90} noise levels over both the day and night periods.

Table 12 – Measured infrasound levels in dB(G) at Location 10

Time period	Living room			Outdoor		
	L_{eq}	L_{10}	L_{90}	L_{eq}	L_{10}	L_{90}
Day, 7 am to 10 pm	54	61	47	52	58	46
Night, 10 pm to 7 am	47	56	43	47	55	43

Figure 24 presents the measured indoor and outdoor infrasound levels at Location 10 referenced against the hub height wind speed from the nearest meteorological mast at North Brown Hill Wind Farm. It shows that, while there is a slight upwards trend in infrasound levels with wind speed, the correlation is poor. Note that the highest levels of infrasound appear to be the result of human activities within the house, similar to what was found to occur at the urban locations. On average, indoor infrasound levels are greater than outdoor levels, which suggests that the occupants' activities and operation of home appliances appear to be controlling the infrasound level within the house.

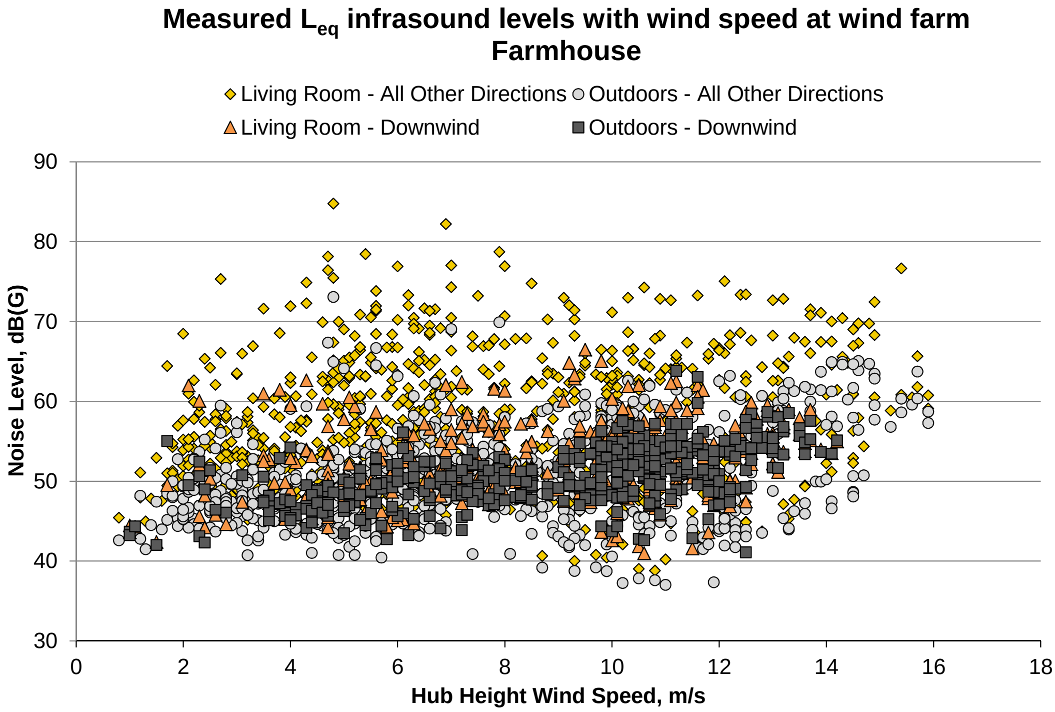

Figure 24 – Infrasound levels with wind speed at wind farm at Location 10

Infrasound levels measured during periods when the farmhouse was downwind of the turbines at North Brown Hill are also presented separately on the graph. The level of infrasound during these downwind periods was typically lower than for other wind conditions. We note that the facade of the living room and outdoor measurement location are both more sheltered under this wind direction, suggesting lower infrasound levels are measured at times of lower localised wind speeds.

The lack of correlation between wind speed at the wind farm, the strong correlation between activity in the house and infrasound, and no change in infrasound at speeds below 4 m/s (turbine cut-in wind speed speed) all indicate that infrasound levels at the house are not related to wind farm operation, but rather are representative of the ambient infrasound environment at the farmhouse.

4.4 Location 11 – House near Myponga

An additional comparison of infrasound levels at rural properties was obtained by undertaking measurements 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 during the 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 system 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 the house. The house has large glazed areas, including one fully glazed facade.

Figure 25 presents the measured $L_{eq,10min}$ and L_{max} infrasound levels across the measurement period at Location 11. The 10-minute average wind speed (at a height of 10 metres above ground) measured at a mast located at the house is also presented on the figure for comparison. It can be seen that the measured infrasound levels at Location 11 regularly range from 50 to 70dB(G) L_{eq}, even excluding the period during which it was occupied (both weekends). Measured L_{max} levels are typically 5 to 10dB(G) higher than the L_{eq} levels.

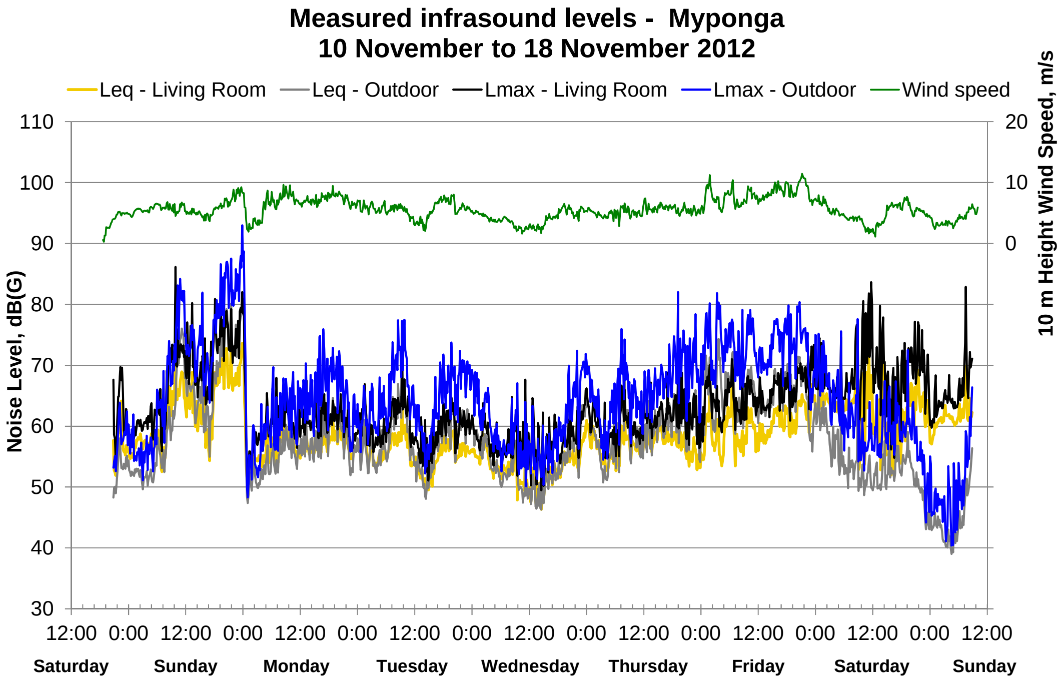

Figure 25 – Measured infrasound levels at Location 11

Outdoor infrasound levels were typically similar to the indoor levels with the exception of the final weekend when measured infrasound levels in the living room increased due to human activity. The measured L_{max} levels outdoors were generally 10 to 15dB(G) higher than the measured L_{eq} levels.

Table 13 summarises the measured indoor L_{eq}, L_{10} and L_{90} noise levels over both the day and night periods.

Table 13 – Measured indoor noise levels in dB(G) at Location 11

Time period	Living room			Outdoor		
	L_{eq}	L_{10}	L_{90}	L_{eq}	L_{10}	L_{90}
Day, 7 am to 10 pm	59	65	52	61	68	51
Night, 10 pm to 7 am	57	64	54	59	65	46

As for the other unoccupied rural locations (Location 8 and Location 9), there does not appear to be a significant change in infrasound levels with time of day, other than during the period when the house was occupied. When the house was unoccupied, measured infrasound levels during the night are often higher than during the day.

There does appear to be a relationship between the infrasound levels and measured 10 metre wind speed at the house, including a sharp drop in measured infrasound level that occurred just after midnight on the Monday and matched a sharp drop in the wind speed. The wind speed and direction data for this period was reviewed and it was found that this sudden drop in wind speed also corresponded to a change in the wind direction. Prior to this period, higher infrasound levels were detected while a strong wind was blowing directly at the glazed facade. Afterwards, lower infrasound levels were measured at similar wind speeds but while the wind was blowing in almost the opposite direction (so the windows were shielded from the wind). Like measurements at Location 10, this suggests that wind direction can have a significant influence on both indoor and outdoor infrasound levels.

Figure 26 presents the measured indoor and outdoor infrasound levels with wind speed for Location 11. The final two days of data collected in the living room have been excluded from the figure for clarity as they were significantly influenced by the activity of people in the house. 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.

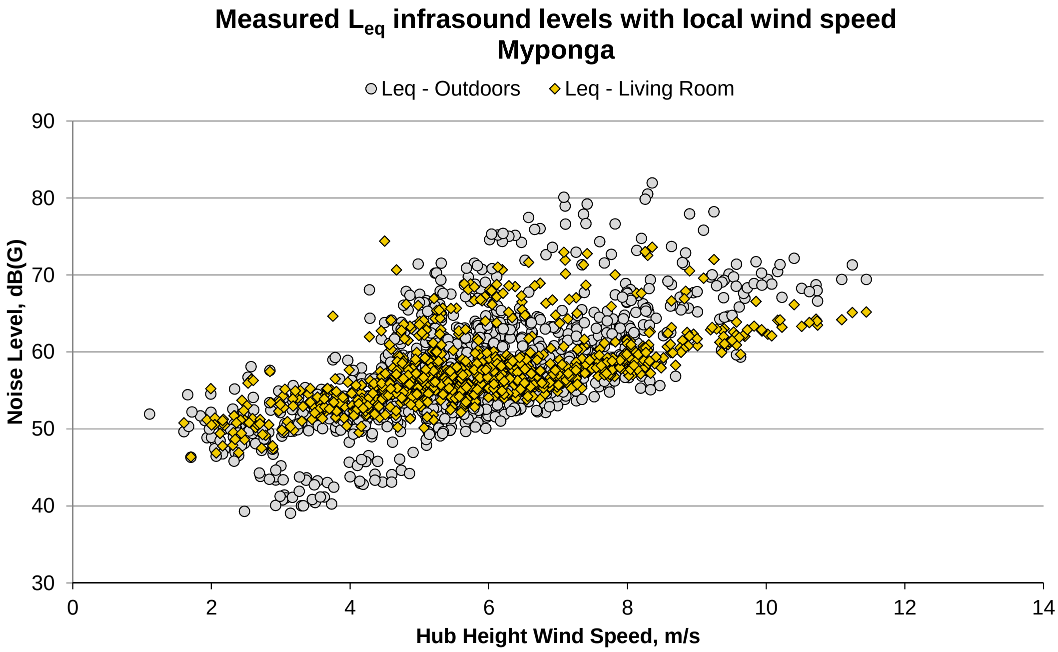

Figure 26 – Measured infrasound levels with localised wind speed at Location 11

It can be seen that there is a good correlation between the measured infrasound level and local wind speed. This confirms that local wind speed (and localised turbulence) is a primary cause of infrasound levels at a location, and have a similar effect on both outdoor and indoor levels of infrasound.

4.5 Summary of measured rural infrasound levels

Table 14 summarises the measured indoor infrasound levels, across both the day and night periods, at each of the rural locations.

Table 14 – Summary of measured rural infrasound levels indB(G)

Location	Day, 7 am to 10 pm			Night, 10 pm to 7 am		
	L_{eq}	L_{10}	L_{90}	L_{eq}	L_{10}	L_{90}
8 – Bedroom 1	53	53	43	50	53	43
8 – Bedroom 2	51	50	43	51	52	45
8 – Outdoor	58	55	52	56	57	55
9 – Outdoor	62	66	56	56	62	55
10 – Indoors	54	61	47	47	56	43
10 – Outdoors	52	58	46	47	55	43
11 – Indoors	59	65	52	57	64	54
11 – Outdoors	61	68	51	59	65	46

The measurement results demonstrate that infrasound levels at houses adjacent to wind farms (Locations 8 and 9) are no higher than those at houses located a considerable distance from wind farms (Locations 10 and 11). For example, the outdoor infrasound levels at Location 8 are significantly lower than those at Location 11, despite Location 8 being located much closer to operational wind turbines (1.5 kilometres compared to 30 kilometres).

Based on the measurement results collected, infrasound levels in the rural environment appear to be controlled by localised wind conditions. During low wind conditions, levels as low as 40dB(G) were measured at locations both near to and away from wind turbines. At higher wind speeds, infrasound levels of 50 to 70dB(G) were common at both wind farm and non-wind farm sites.

At all of the rural locations, the equivalent infrasound levels were generally significantly below the threshold of perception. This was with the exception of brief periods where they appeared to be affected by extraneous sources, such as activities associated with people, in which case the margin below the typical infrasound perceptibility limit was lower.

The results also indicate that wind turbines are unlikely to be significantly contributing to the infrasound levels at houses considered as part of this study, and this was confirmed through the comparison of measured infrasound levels under the same wind conditions both while the nearest wind turbines were operational and while they were shutdown. It was found that there was no discernible difference in the measured G-weighted infrasound levels during operational and non-operational periods at two houses located approximately 1.5 kilometres from two separate wind farms.

5 Frequency analysis

The G-weighting has been used throughout this study to characterise infrasound levels as previous research has shown it to correlate well with human perception of infrasound (Møller, 1987). However, a review of the frequency content of the measured infrasound levels between the different locations has also been undertaken as part of an additional analysis of the measurement results.

A summary of the measured average unweighted sound pressure levels in third octave bands between 0.25 and 20Hz(the infrasonic frequency range) are presented in this Section. A more detailed discussion of the results presented is provided in Appendix C.

5.1 Comparison between urban and rural residences

Figure 27 provides a comparison of measured infrasound levels with frequency for medium wind speeds at the indoor locations at the three rural residences and for the night time period at the four urban residences. This represents the period with the lowest infrasound magnitudes for the urban residences and the period with the lowest infrasound magnitudes for the rural residences when wind turbines could potentially be operating.

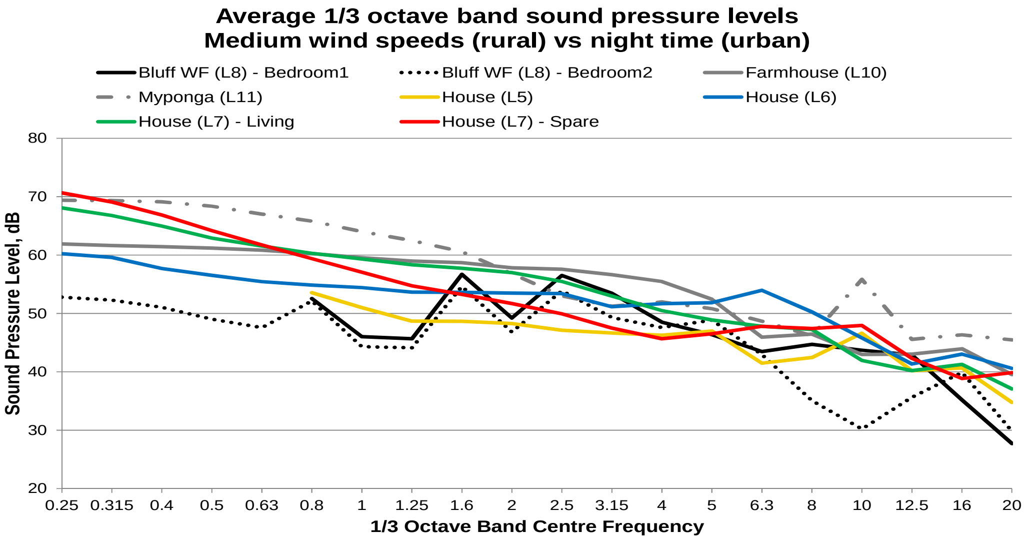

Figure 27 – Comparison of measured sound pressure levels with frequency for medium wind speeds (rural locations) and night time (urban locations)

The measured data for higher wind speeds at the rural locations and the day period at the urban locations is presented in Figure 28.

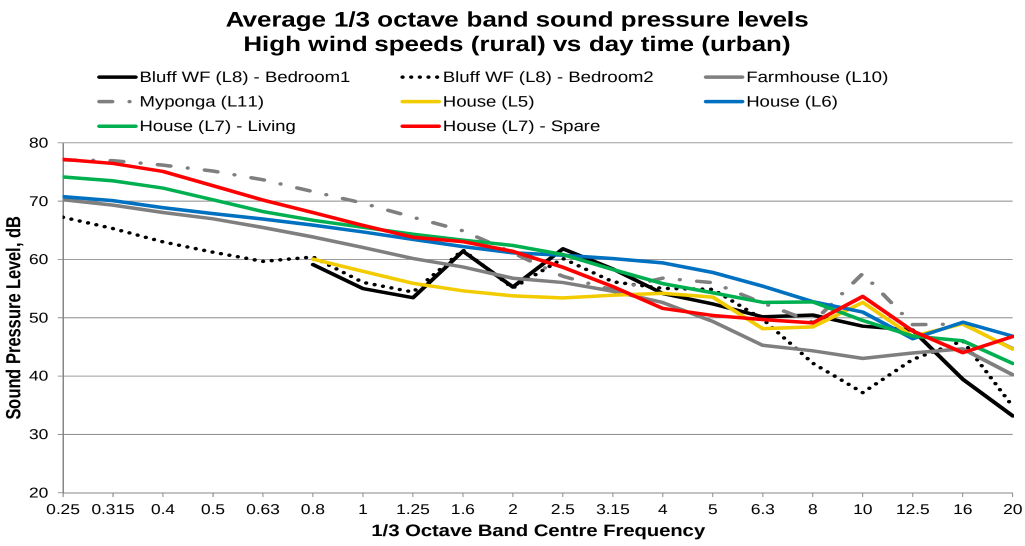

Figure 28 – Comparison of measured sound pressure levels with frequency for high wind speeds (rural locations) and daytime (urban locations)

From Figure 27and Figure 28, it can be seen that there is a reasonable degree of similarity in sound pressure levels in the infrasonic frequency range between these residential locations. The measurements conducted at the two bedrooms in the house near the Bluff Wind Farm typically resulted in the lower levels across the frequency range from 0.25 to 20Hz.

The results suggests that indoor infrasound levels at rural residences near to wind farms are no higher than those at rural residences away from wind farms, nor than infrasound levels at residences within urban areas.

5.2 Wind farm shutdown periods

To determine any contribution from the wind farms at specific frequencies within the infrasonic range, the measured sound pressure levels with frequency were compared at the house near the Bluff Wind Farm (Location 8) and the house near Clements Gap Wind Farm (Location 9) with the wind farm on and the wind farm off.

Figure 29 presents the measured average 10-minute sound pressure levels across the infrasonic frequency range for Bedroom 2 at the house near the Bluff Wind Farm (Location 8) for periods with the wind farm shutdown and equivalent periods when it was operational. The hub height wind speed and direction for each of the periods presented in the figures is as summarised in Table 10 in Section 4.1.

The measured sound pressure levels for Bedroom 1 and the outdoors location at Location 8 demonstrate similar results and are presented in Appendix C (Figure C6 and Figure C8).

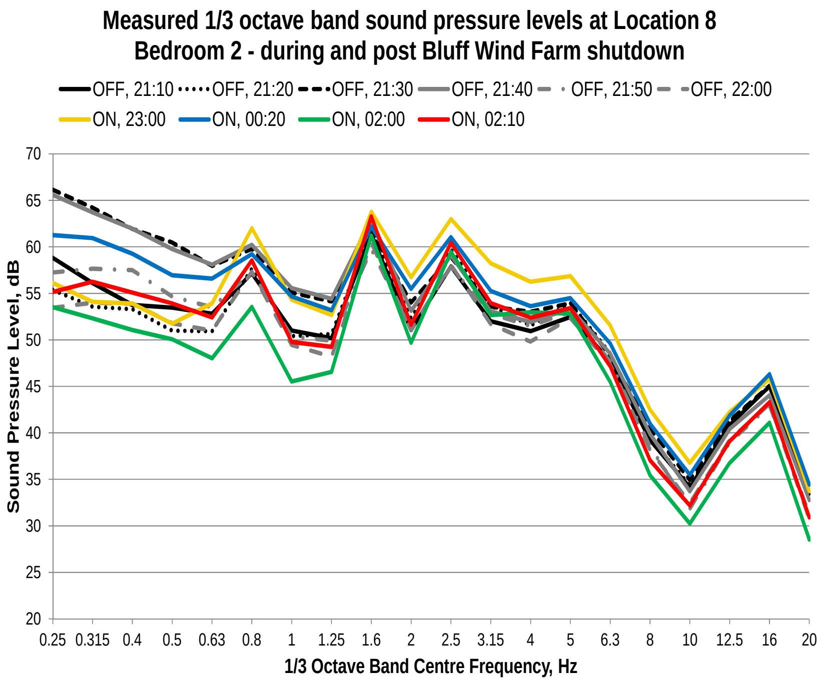

Figure 29 – Measured sound pressure levels with wind farm on and off, Bedroom 2 at house near Bluff Wind Farm

Figure 29 indicates that there does not appear to be any significant increase in sound pressure level at frequencies below 20Hz when the wind farm is operating, relative to when it was shutdown. While sound pressure levels did marginally increase at some frequencies during the operational periods at 23:00 and 0:20, these periods were also characterised by a change in wind direction relative to the shutdown period.

The periods at 2:00 and 2:10 provide a better comparison to the shutdown periods as the wind speed and direction measured at the meteorological mast was the same as during the shutdown. During these two periods, there was no noticeable increase in sound pressure levels across the frequency range from 0.25 to 20Hz.

It can also be seen that, although there is a peak in the frequency spectrum at the blade pass frequency and next two harmonics (0.8Hz, 1.6Hz and 2.5Hz third octave bands) at all three locations, this peak is also present to a similar degree during the shutdown periods. These results are discussed further in Section 5.3.

Figure 30 presents the measured average 10-minute sound pressure levels across the infrasonic frequency range for the outdoors location at the house near the Clements Gap Wind Farm (Location 9), for periods with the wind farm shutdown and operational. During the shutdown, the hub height wind speed at the wind farm varied between 9 and 11 m/s. Therefore, two operational periods (denoted (1) and (2)) were selected for comparison at each of these wind speeds which most closely matched the wind speed and direction of the corresponding shutdown period.

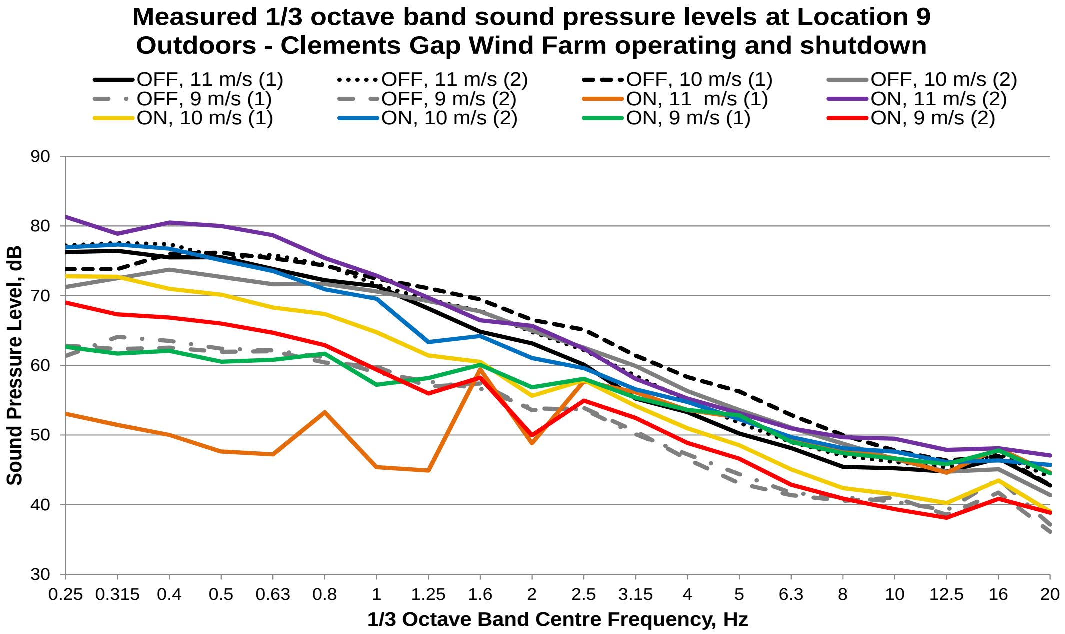

Figure 30– Measured sound pressure levels with wind farm on and off, Outdoors at house near Clements Gap Wind Farm

As for the result at Location 8, the overall sound pressure levels at frequencies of 20Hz and below do not increase when the Clements Gap Wind Farm is operating relative to when it is shutdown. While there is considerable variation in sound pressure levels in the infrasonic frequency range for the measurement periods shown in Figure 30, this occurs during both the shutdown and operational periods leading to the conclusion that it is a result of localised wind conditions rather than wind farm operation.

During some of the quietest operational periods, a peak is evident in the frequency spectrum at the blade pass frequency of the wind turbines and the next two harmonics (0.8Hz, 1.6Hz and 2.5Hz). Peaks at 1.6Hz and 2.5Hz were also visible during the shutdown measurements, but to a much lesser degree. The difference in level between the peaks during the shutdown and operational periods may indicate that the peak is a result of wind turbine operation. However, a review of the full Clements Gap data set indicated that the measured sound pressure levels of the peaks at these frequencies appear to be in the order of 53 to 63dB(Lin), a similar or lower level than typically measured sound pressure level at these frequencies at non-wind farm locations, and at least 50dB below the threshold of perception. These results are discussed further in Section 5.3.

The sound pressure levels measured at the indoor location at Clements Gap Wind Farm are presented in Appendix C (Figure C9). These results indicated that there were markedly higher sound pressure levels measured indoors at frequencies between 2Hz and 20Hz, which occurred at the same level whether the wind farm was operating or shutdown. This is believed to be the result of the loose sheet of iron on the roof rattling and significantly affecting the measured sound pressure levels within the infrasonic frequency range. Therefore, only limited relevant data could be obtained from the indoor measurements at Location 9.

Overall, the comparison of frequency spectra at Location 8 and Location 9 during wind farm shutdown periods and comparable operational periods indicate that there is very little change in the measured sound pressure levels at frequencies below 20Hz. This indicates that there is minimal contribution from either the Bluff Wind Farm or the Clements Gap Wind Farm to sound pressure levels in the infrasonic region at the houses located approximately 1.5 kilometres away.

5.3 Blade pass frequency

As identified in Figure 30, wind farm operation appears to result in relatively low level peaks in sound pressure levels at the third-octave frequency bands that correspond to the blade pass frequency (and associated harmonics) of the wind turbines – 0.8Hz, 1.6Hz and 2.5Hz. Of the identified maximums, the peak at 1.6Hz was found to occur at higher sound pressure levels than the peak at 0.8Hz and at 2.5Hz.

At Location 9 near Clements Gap Wind Farm, these peaks could occasionally be seen in the spectrum when the overall measured infrasound level at the outdoor location was low, but were not evident when the sound pressure levels increased due to infrasound generated by localised wind conditions. From a review of all data collected at Location 9, the peaks also occurred at a much lower level during comparable shutdown periods suggesting the cause was wind farm operation. However, the absolute levels of the peaks at these frequencies were such that they were often masked by the ambient levels of infrasound in the environment.

At Location 8 near the Bluff Wind Farm (Figure 29), the peaks were detected at a similar level during both operational and shutdown periods. While this suggests that the cause of the peaks may not be the wind farm, there is a possibility that the peaks in the spectrum during the shutdown resulted from operation of North Brown Hill Wind Farm which was noted to be very faintly audible at Location 8 during the shutdown. North Brown Hill Wind Farm is comprised of the same type of wind turbines as the Bluff Wind Farm.

As the nearest turbine at the North Brown Hill Wind Farm is located more than 8 kilometres from the measurement location (whereas the nearest turbine at the Bluff Wind Farm is 1.5 kilometres away), the level of these low frequency peaks could reasonably have been expected to decrease during the shutdown if the turbines were the source. However, no change in measured level was observed during the shutdown.

Table 15 presents the range of measured $L_{eq,10min}$ sound pressure levels in each of the 0.8Hz, 1.6Hz and 2.5Hz third octave bands for periods when the peak at blade pass frequency or either harmonic was observed at Location 8 and Location 9. For comparison, the typical range (5^{th} to 95^{th} percentile) of measured $L_{eq,10min}$ sound pressure levels observed in these third octave bands at the other non-wind farm measurement locations are also presented.

It can be seen that the maximum $L_{eq,10min}$ sound pressure levels in these third-octave bands, that may be due to the operation of the wind farm, are typically between 60 to 65dB. However, similar or greater sound pressure levels were also observed at the majority of the other measurement locations away from wind farms. Therefore, sound pressure levels at these blade pass frequencies are no greater at residences adjacent to wind farms than at other locations.

Table 15 – Range of measured sound pressure levels at blade pass frequency and second and thirdharmonics

Location	Measured sound pressure level in dB at blade pass frequency and harmonics		
	0.8Hz	**1.6Hz**	**2.5Hz**
Range of measured $L_{eq,10min}$ sound pressure levels when peak observed at blade pass frequency and/or harmonics			
Location 8 – Bedroom 1	39 – 64	41 – 66	40 – 63
Location 8 – Bedroom 2	47 – 62	38 – 64	37 – 62
Location 8 – Outdoors	46 – 60	38 – 64	36 – 62
Location 9 – Indoors	47 – 62	45 – 63	44 – 61
Location 9 – Outdoors	47 – 58	41 – 62	43 – 60
Range of measured $L_{eq,10min}$ sound pressure levels at non-wind farm locations			
Location 1	42 – 71	37 – 69	36 – 68
Location 2	47 – 63	44 – 60	37 – 59
Location 3 – Central	47 – 67	42 – 66	40 – 62
Location 3 – Eastern	47 – 67	42 – 67	42 – 63
Location 5	48 – 65	42 – 60	40 – 59
Location 6 – Bedroom	47 – 72	41 – 69	40 – 67
Location 6 – Shed	46 – 70	40 – 64	38 – 60
Location 7 – Living Room	48 – 72	44 – 69	44 – 66
Location 7 – Spare Room	52 – 71	47 – 65	44 – 62
Location 10 – Indoors	40 – 69	37 – 65	36 – 63
Location 10 – Outdoors	39 – 75	36 – 69	33 – 64
Location 11 – Indoors	50 – 76	44 – 70	38 – 64
Location 11 – Outdoors	56 – 86	49 – 81	43 – 77

Figure 31 presents the range of measured $L_{eq,10min}$ sound pressure levels within the 1.6Hz third-octave frequency band, which produced the peaks with the greatest sound pressure levels, for the identified peaks at Location 8 and Location 9, and for the measurements conducted at the other locations away from wind farms for which data was available at 1.6Hz. It shows that the sound pressure levels of the peaks, that may be produced by the wind farms, are within the range of sound pressure levels measured at 1.6Hz at other comparable locations.

It is also important to note that, while the threshold of perceptibility of sound pressure levels at frequencies of 0.8Hz and 1.6Hz has not been well defined, available evidence of the threshold at a frequency of 2.5Hz suggests that it would be at least 110dB (refer Figure 3 in Section 2.2). It would be reasonable to assume that the threshold of perception at frequencies lower than 2.5Hz would be higher than this. Therefore, the level of infrasound produced by the wind farms near Location 8 and Location 9 were more than 40dB below the threshold of perceptibility at blade pass frequency and associated harmonics.

Similarly, the G-weightings applied at the third-octave band frequencies of 0.8Hz, 1.6Hz and 2.5Hz are -49.5dB, -32.6dB and -24.1dB respectively. This reflects the low sensitivity of humans to levels at these frequencies.

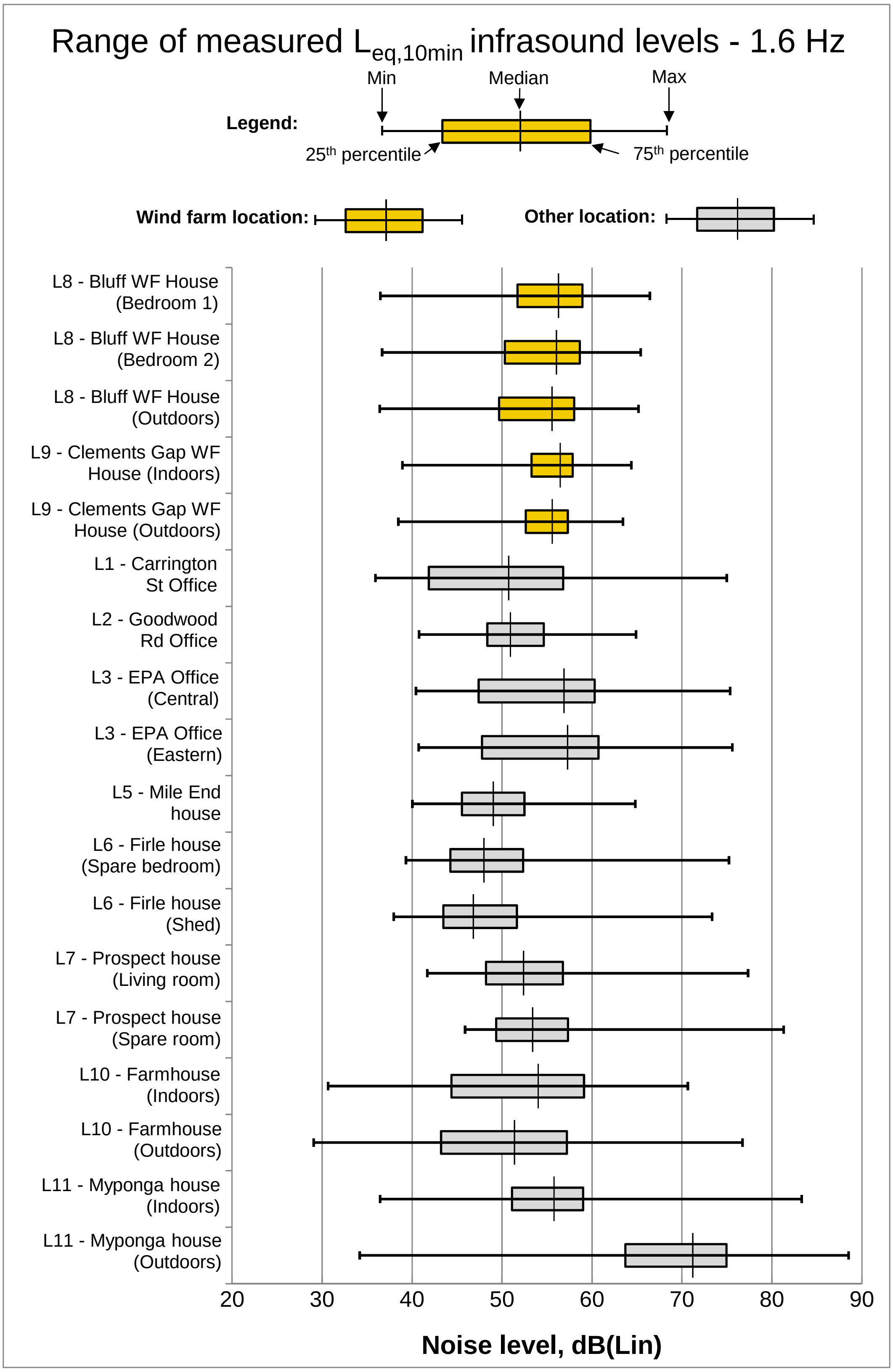

Figure 31 – Range of measured $L_{eq,10min}$ infrasound levels at each measurement location for 1.6Hz 1/3 octave band

5.4 Summary of frequency analysis

Additional analysis of the infrasonic frequency content at the 11 measurement locations considered in this study indicates that there does not appear to be any significant difference in frequency content between sites adjacent to wind farms and sites located away from wind farms. Sound pressure levels measured across the infrasonic frequency range at houses located adjacent to wind farms were at or below the levels measured at comparable locations away from wind farms.

At times, there were peaks in the frequency spectrum at the third-octave band frequencies of 0.8Hz, 1.6Hz and 2.5Hz at the two locations adjacent to the wind farms. This may have been attributable to the operation of wind turbines, as the frequencies correspond to the blade pass frequency and the next two harmonics. However, this effect is not consistent and was also observed during wind farm shut down periods. When the absolute sound pressure levels of these peaks were compared to the sound pressure levels at these frequencies at non-wind farm sites, levels at the wind farms were no greater than those measured at other sites.

6 Conclusion

This report presents the findings of a comparative study into the level of infrasound within typical environments in South Australia, with a particular focus on comparing wind farm environments to urban and rural environments away from wind farms.

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.

From an overall perspective, measured G-weighted infrasound levels at rural locations both near to and away from wind farms were no higher than infrasound levels measured at the urban locations. The most significant difference between the urban and rural locations was that human activity and traffic appeared to be the primary source of infrasound in urban locations, while localised wind conditions appeared to be the primary source of infrasound in rural locations. Of particular note, the results at one of the houses near a wind farm (Location 8) are the lowest infrasound levels measured at any of the 11 locations included in this study.

This study concludes that the level of infrasound at houses near the wind turbines assessed is no greater than that experienced in other urban and rural environments, and is also significantly below the human perception threshold.

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Glossary

Decibel (dB or dB(Lin))	Unit of sound pressure level, referenced to 20 µPa. Where dB is used in this report, it refers to the level in decibels with no frequency weighting applied.
dB(G)	Unit of sound pressure levels which have had the G-weighting applied to them.
Frequency	Rate of sound pressure variations – noise or sound is composed of energy across a wide range of frequencies including 20Hz or lower (infrasound).
G-weighting	Frequency weighting as defined in ISO 7196:1995, used to approximate how the human ear responds to infrasonic noise levels.
Hertz (Hz)	Unit of frequency – one Hz is equivalent to one cycle per second.
Infrasound	Sound or noise where the energy lies mainly in the frequency range below 20Hz.
L_{10}	Noise level exceeded for 10% of the measurement period. Typically used to represent the typical upper noise level in an environment.
L_{90}	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.
L_{eq}	Equivalent noise level – energy averaged noise level over the measurement period. Most common descriptor used to quantify noise sources.
$L_{eq,10min}$	Equivalent noise level over a 10 minute measurement period.
$L_{eq,15min}$	Equivalent noise level over a 15 minute measurement period.
L_{max}	Maximum noise level in the measurement period.

Appendix A – Measurement procedure

Measurement of noise levels in the infrasonic range is complicated by factors that do not affect measurements in the normal audible range of sounds, in particular the use of equipment with an accurate measured response to a low enough frequency. The majority of sound level meters and microphones are generally designed to only measure noise levels accurately at audio frequencies (20Hz – 20kHz), and are insufficient for the accurate determination of G-weighted noise levels.

An additional complication for the measurement of infrasound is the effect of wind-induced noise when measurements are undertaken outdoors. Atmospheric and self-generated noise as a result of airflow through and across the windshield makes outdoor measurements inherently noisy at low and infrasound frequencies (Strassberg, 1988, Morgan &Raspet, 1992, Hessler et al, 2008, Shams et al, 2008). Even relatively slight levels of wind can significantly increase measured infrasound and low frequency noise levels, causing significant problems in the identification of the actual infrasound levels generated by any noise source of interest.

All measurements in this report have been taken at a height of 1.2 to 1.5 metres above floor/ground level with the exception of the below ground measurements. All microphones have been firmly fixed onto tripods or microphone poles. It should be noted that very low frequency noise levels (i.e. less than 10Hz) are not able to be accurately measured during hand-held measurements due to errors introduced through the movement of the instrument during the measurement.

Equipment

Measurements were carried out using the equipment listed in Table A1. All equipment holds current calibration certificates from a certified laboratory.

Table A1 – Measurement equipment

Analyser	Microphone	Calibration due	Frequency range[1]
SVANTEK SVAN 945A (S/N 8603)	GRAS 40AN (S/N 54371)	July 2014	0.8Hz – 20kHz
Sinus SoundbookQuadro+ (S/N 06364)	Brüel&Kjær Type 4193[2] (S/N 2751414)	March 2014	0.2Hz – 20kHz
	Brüel&Kjær Type 4193[2] (S/N 2751414)	March 2014	0.2Hz – 20kHz

1. Frequency range determined based on the minimum of the analyser or microphone.
2. Fitted with a Brüel&Kjær Type UC-0211 low frequency noise adaptor.

The SVAN 945A sound level meter meets the requirements of ISO 7196, and is capable of measuring both G-weighted noise levels and third-octave band noise levels from 0.8Hz to 20kHz.

Two Brüel&Kjær Type 4193 microphones have been used for simultaneous two-channel measurements with the Soundbook data acquisition system. The calibration chart for the data acquisition system shows negligible deviation of the instrument frequency response to frequencies as low as 0.1Hz. The microphone calibration charts also show negligible deviation of the instrument frequency response but are only reported to a frequency of 1Hz. To expand the frequency range over which the microphones had uniform frequency response, they have each been used in combination with a Brüel&Kjær Type UC-0211 low frequency adaptor and a GRAS 26AK pre-amplifier. The sensitivity of this measurement system at 0.2Hz was calculated in accordance with information obtained from the manufacturer (Brüel&Kjær, 1995) and found to deviate by less than 0.5dB. Therefore, measured levels using this measurement system could be considered across the entire frequency range required by ISO 7196 (0.25 to 315Hz).

Some additional measurements were carried out at one additional non wind-farm location (Location 3) using a Brüel&Kjær Type 2250 Class 1 sound level meter, with a Type 4189 microphone. This sound level meter and microphone is capable of accurately measuring third-octave band levels down to 6.3Hz. Therefore, the G-weighted sound pressure levels calculated will be lower than the actual G-weighted noise levels in the environment. However, the difference in G-weighted noise level is likely to be relatively small as the G-weighting reduces noise levels at frequencies of 6.3Hz and lower by more than 20dB relative to the peak sensitivity at 20Hz.

Reported descriptors

The equipment was configured to measure the linear (unweighted) L_{eq} noise levels in third-octave bands from 0.2 (or 0.8) to 315Hz every 10 seconds during the measurement period. A basic integration period of 10 seconds was selected in accordance with Appendix A of ISO 7196, which states:

> *The integrating time constant chosen should be sufficiently long for the observed value to be representative of the noise being measured. Usually, this will be the case for an integration time/time constant of 10 s.*

The measured $L_{eq,10s}$ noise levels were then G-weighted and used to determine L_{eq}, L_{10}, L_{90} and L_{max} noise levels over each 10 minute period during the measurements. A 10 minute period was selected as it is recommended as the basic interval for use during wind farm noise monitoring in many regulatory documents, and matches the typical wind mast logging interval.

Indoor measurement procedure

In order to determine the levels of infrasound that people are most commonly exposed to within the environment, the majority of measurements as part of this study have been undertaken indoors. By undertaking the measurements indoors, it was also possible to minimise the influence of wind-generated turbulence on the measured infrasound levels. The microphone was fitted with a 90mm windshield and located near the centre of the room. For the majority of the measurement period in each location, windows and doors were kept closed.

It is known that low frequency noise levels can vary within a room due to the modal response of rooms to noise at wavelengths on a similar scale to the physical dimensions of the room. However, a study conducted by DELTA (2008) showed the measurement position within a room has minimal effect on noise levels at frequencies of 50Hz and below, which will control the G-weighted levels.

To test this finding, simultaneous measurements were taken using the two measurement channels of the Soundbook system, within a room in the rural house near the Bluff Wind Farm (Location 8 in Section 4). The approximate dimensions of the room were 3 m (L) x 3.5 m (W) x 3.5 m (H). Measurements of the noise level across each third octave band in the infrasonic region were taken simultaneously for a period of approximately one minute at both the centre of the room and at each of the corners of the room. An additional measurement was undertaken at the centre of the room and the window facing the Bluff Wind Farm.

The results of the measurements between 0.25 and 20Hz are shown in Figure A1, with the deviation in noise level from the centre of the room shown for each location. The maximum variation from the level at the centre of the room in any third octave band was 5.6dB. This occurred in the lowest frequency for which there is a large negative G-weighting, and therefore is not important for the reported G-weighted measurements. From the 0.5Hz band to 20Hz, the maximum difference at any position was 2.2dB.

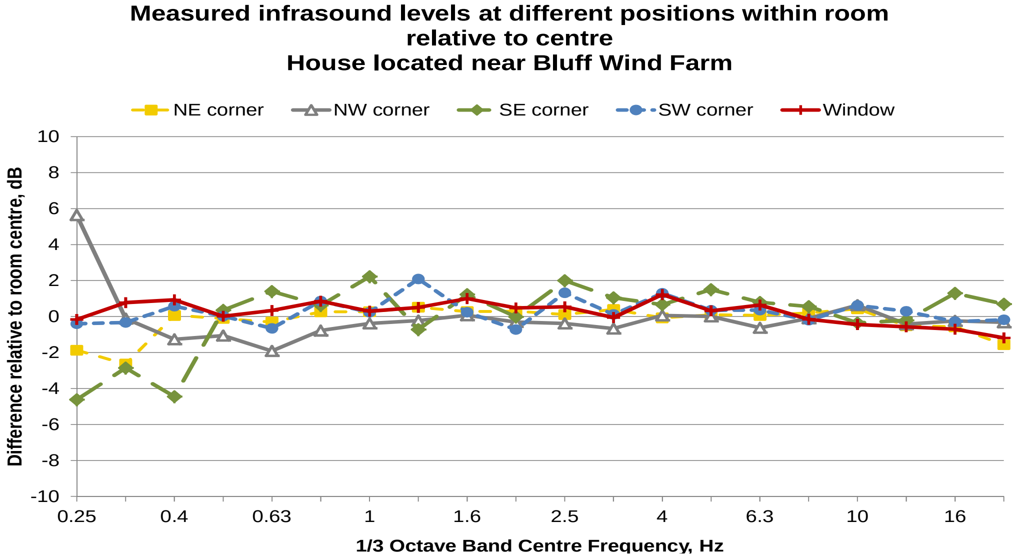

Figure A1 – Comparison of measured infrasound at different positions within room

Overall, the difference in G-weighted noise levels between the centre of the room and any of the other locations was negligible, with a maximum difference of 1.1dB(G). Therefore, having the microphone positioned near the centre of each room in which measurements have been undertaken is considered sufficient to characterise indoor infrasound levels for the purpose of this study.

Outdoor measurement procedure

In addition to indoor measurements, outdoor infrasound measurements were also taken at the four rural locations, with the aim of identifying whether rural houses provided any reduction in or amplification of infrasound levels.

Wind-induced noise on a microphone can be a problem during all types of outdoor noise measurements, particularly during infrasound and low frequency noise measurements, as it results in erroneously high measurements of the noise level. While standard (90mm diameter) windshields are sufficient to control wind-induced microphone self-noise for general environmental noise measurements, they are unsuitable for the protection of microphones during outdoor measurement of infrasound.

In order to remove this wind-induced effect from outdoor measurements of infrasonic frequencies, Betke et al (1996) developed a method whereby the microphone was located in a small cavity in the ground. The cavity was covered with a windshield, in addition to the standard microphone windshield. However, we note this method is not accurate for measurements at higher non-infrasonic frequencies and would not be suitable to undertake outdoor measurements over a period of days due to the potential for rain to collect in the cavity and the potential safety hazard.

Therefore, an alternative measurement setup was developed and used during this study, with the microphone protected by a standard 90mm wind screen and three layers of acoustically transparent fabric at diameters of 250mm, 400mm and 750mm. The fabric at 250mm was slightly thicker than that at the other diameters. The setup is shown diagrammatically in A2.

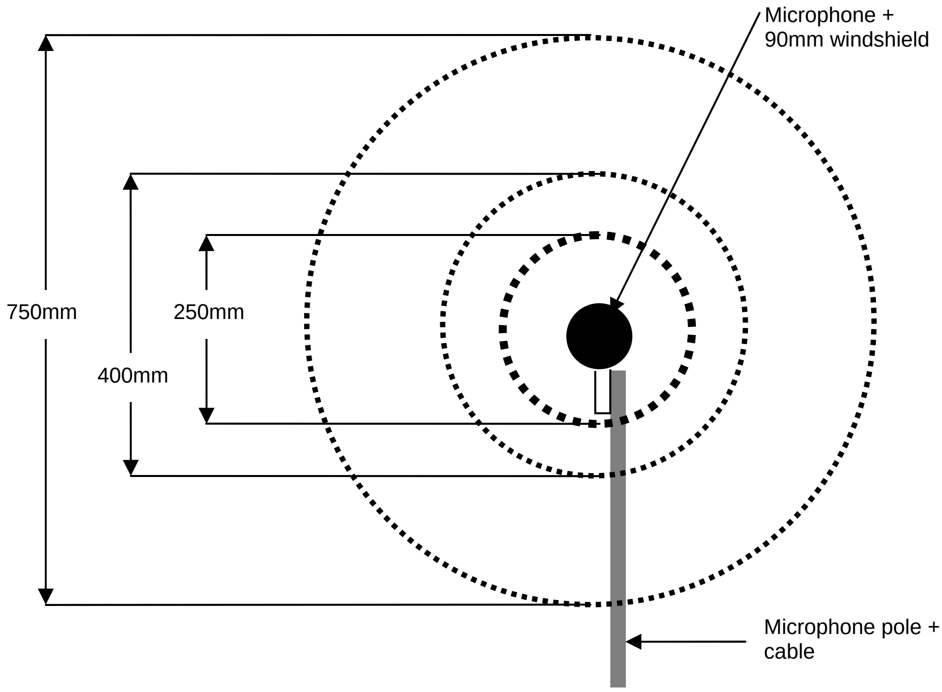

Figure A2 – Outdoor measurement setup

The suitability of the developed 750mm windshield for the measurement of infrasound was confirmed through testing to check that:

- The 750mm windshield mitigated wind-induced noise due to air movement past the microphone diaphragm.
- The 750mm windshield did not attenuate sound at infrasonic frequencies.

The results of the testing are discussed in the following sections. The testing results also highlight the potential errors (approximately 20dB(G)) that can arise from the use of standard 90mm windshields for outdoor infrasound measurements, even at relatively low wind speeds.

Testing for reduction of wind-induced noise

The testing of the mitigation of wind-induced noise by the 750mm windshield was undertaken away from any wind farms in the middle of an open paddock, which had been recently cut with a windrower to a height of approximately 100mm in preparation for baling hay. Measurements were undertaken to compare the effectiveness of a standard 90mm windshield, the 750mm windshield, and a microphone placed in a cavity in the ground (the Betke method). The cavity measured 500 x 500 x 500mm and was covered using a 100mm thick layer of open cell foam, with the microphone in the cavity protected using a standard 90mm windshield.

Both noise levels and wind speed at the height of the microphone (1.5m) were logged in 1 minute intervals during the test. The anemometer logging wind speed was located approximately 1.5 metres from the test microphones and crosswind so that results were not affected by the wake of either the anemometer or wind shield.

Figure A3 shows the relationship between the measured G-weighted noise level and wind speed for the different windshield setups. The measurements indicate that the 750mm diameter windshield performance was very similar to that of the below ground method, with performance significantly better than a standard 90mm windshield.

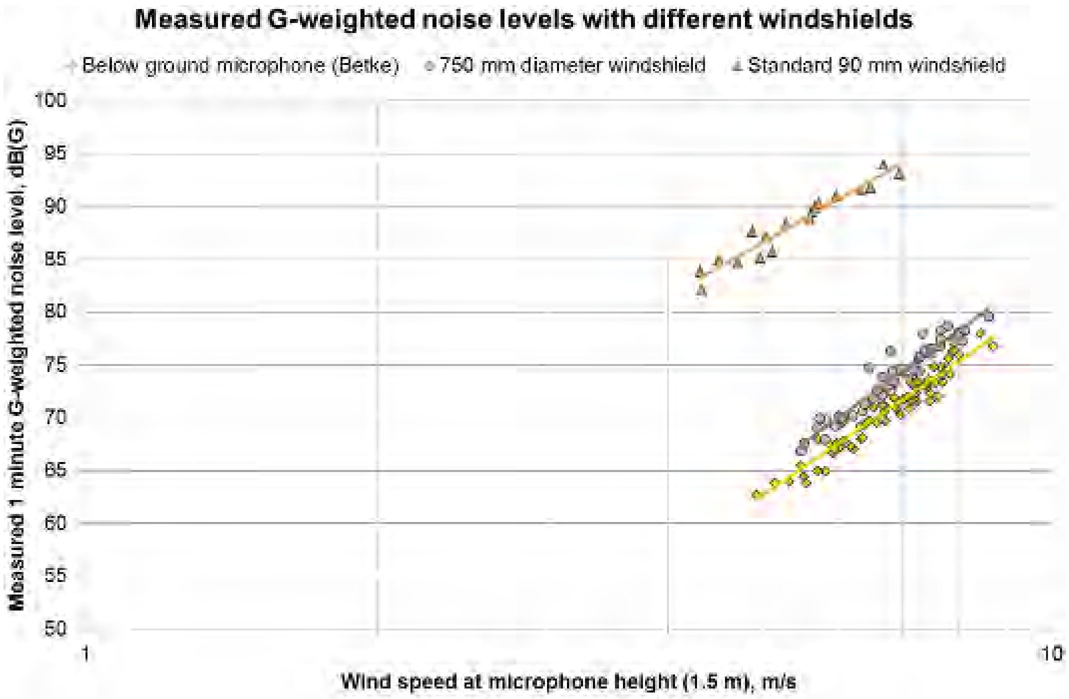

Figure A3– G-weighted noise level from wind induced noise on the microphone.

The measurements using a standard 90mm windshield indicated that a wind induced G-weighted noise level of 85 to 95dB(G) will result from wind speeds of just 4.5 to 7 m/s at the microphone. The apparent wind induced noise on the microphone therefore falsely indicated an exceedance of the 85dB(G) criterion at wind speeds that would be anticipated to occur at residential locations near to wind farms. The use of standard 90mm windshields during outdoor measurements of infrasound from a wind farm is therefore not acceptable practice, even at relatively low wind speeds.

Wind speeds were also measured at the microphone during the infrasound measurements conducted at the four rural locations (Section 4), with the results in Figure A3 used to check whether wind induced self-noise was controlling the measurement result. During higher wind speed measurements, some influence of wind induced noise on was noted typically at frequencies up to 2.5Hz at all of the outdoor locations. As noted previously, magnitudes at such low frequencies are not important for reporting G-weighted infrasound measurements due to the character of the G-weighting. The 750mm diameter windshield provided adequate protection of the microphone from wind induced G-weighted noise, with the exception of some high wind speed measurements at the Myponga measurement location.

Testing for attenuation of the windshield

Measurements were undertaken to confirm whether the addition of three layers of lightweight fabric around the microphone was resulting in any attenuation of infrasound, when compared to measurements using a standard 90mm windshield.

The assessment of windshield attenuation was undertaken during relatively still conditions, such that wind-induced noise could be excluded from the results. The tests were undertaken using two channels on the Soundbook system. Two microphones were set up side by side, one protected using a 90mm windshield, and the other protected using the 750mm diameter windshield. A noise source placed equidistant from the two microphones was measured simultaneously on the two measurement channels, with the measurement results compared to determine the attenuation through the windshields.

Figure A4 presents attenuation of the 750mm windshield relative to the standard 90mm windshield. Note that, while every attempt was made to take the measurements under completely still wind conditions, the occasional slight air movement during the test was noticeably influencing the very low frequency results from the microphone protected with only the 90mm windshield. For this reason, results below 2.5Hz are not presented on Figure A4.

From Figure A4, the attenuation of the 750mm diameter windshield was negligible at frequencies of less than 40Hz (frequencies of significant contribution to infrasound levels). The attenuation of the 750mm diameter windshield was also found to be no more than 2dB at frequencies up to 12.5 kHz.

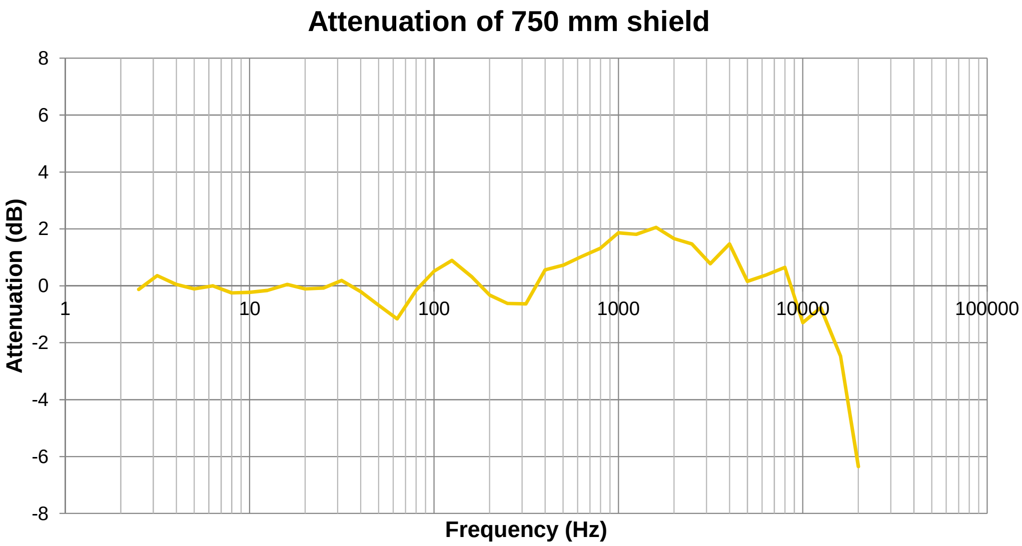

Figure A4 – Attenuation of 750mm diameter windshield compared to standard 90mm windshield.

Appendix B – Outdoor-to-indoor comparison

In order to determine the typical reduction in infrasound levels provided by residential structures, simultaneous outdoor and indoor measurements of infrasound were undertaken at the four rural locations (Location 8 to Location 11). One measurement channel of the Soundbook system was located within a room with a closed window, while the second measurement channel was located outside and approximately 5 metres from the window.

This Appendix presents a comparison of the measured $L_{eq,10min}$ indoor and outdoor infrasound levels with wind speed to determine if there is any significant attenuation of infrasound provided by a building facade.

Location 8 – House near Bluff Wind Farm

The arithmetic difference in noise levels between the outdoor and indoor measurement location at the house near the Bluff Wind farm is provided in Figure B1. As the house was unoccupied for the duration of the measurements, the indoor measurements at this site are less influenced by extraneous noise than the other rural locations. This house was of masonry construction, with a window facing out towards the outdoor measurement location and wind farm.

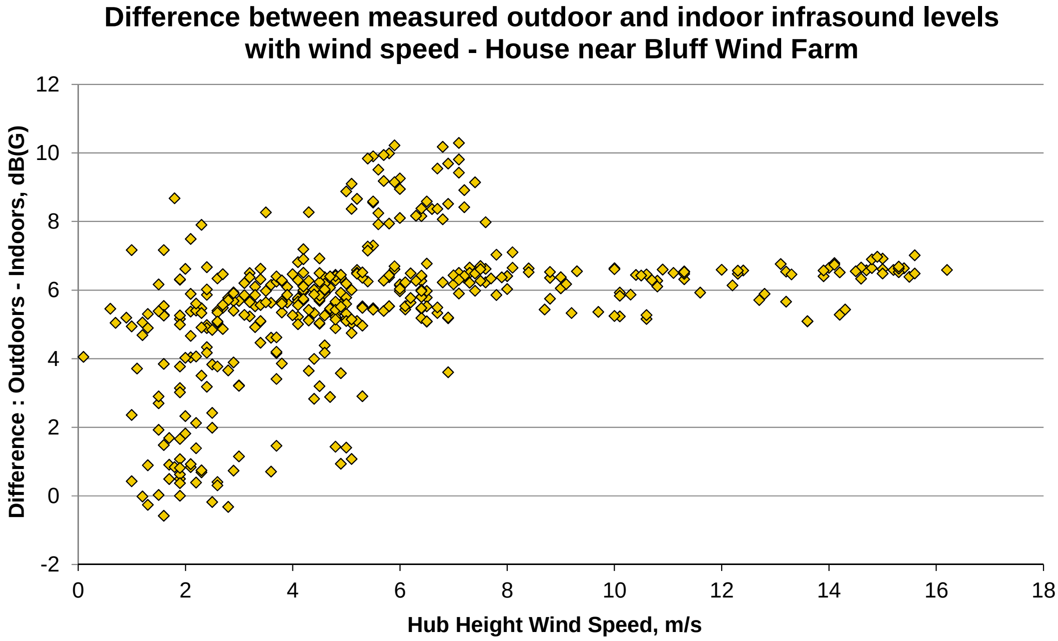

Figure B1 – Reduction in infrasound levels from outdoors to indoors with wind speed at Location 8

Figure B1 indicates that the reduction in noise levels between the outdoor and indoor measurement location was typically 5 to 7dB(G). Variations in attenuation outside this 5 to 7dB(G) range were found to be the result of either:

- localised extraneous noise affecting one of the microphones;

- significant change in spectrum of the noise, such that the G-weighted noise level was controlled by noise at frequencies of 20Hz and above, and more attenuation was provided by the building facade.

Review of the data points that showed a difference of levels from outdoors to indoors of close to 0dB indicates that these data points all occur when the measured infrasound level was 40dB(G) or lower. It is suspected that the lack of a decrease in indoor noise levels at these very low wind speeds is responsible for this effect. The cooling fans on the inverter used to power the Soundbook appeared the most likely source of the indoor noise.

Location 9 – House near Clements Gap Wind Farm

The house located adjacent to the Clements Gap wind farm was also of masonry construction, but was currently being renovated. The house was therefore occupied for some of the measurement period, and doors and windows in the facade left wide open for several periods during the measurements. Air gaps were noted between the top of the external walls and ceiling of the measurement room. As discussed in Section 4.2, these factors appear to have significantly affected a considerable portion of the indoor measurements and only limited conclusions on the attenuation of infrasound through the facade can be made from the dataset at this location.

Figure B2 indicates that a range of arithmetic differences in facade attenuation were measured at this house. Extraneous noise from the renovation works appears to be the cause of the periods when a large increase in indoor levels relative to outdoor levels was measured. When only the night time period is considered (times when renovations were not occurring), the outdoor and indoor levels were normally within 2dB(G) of each other.

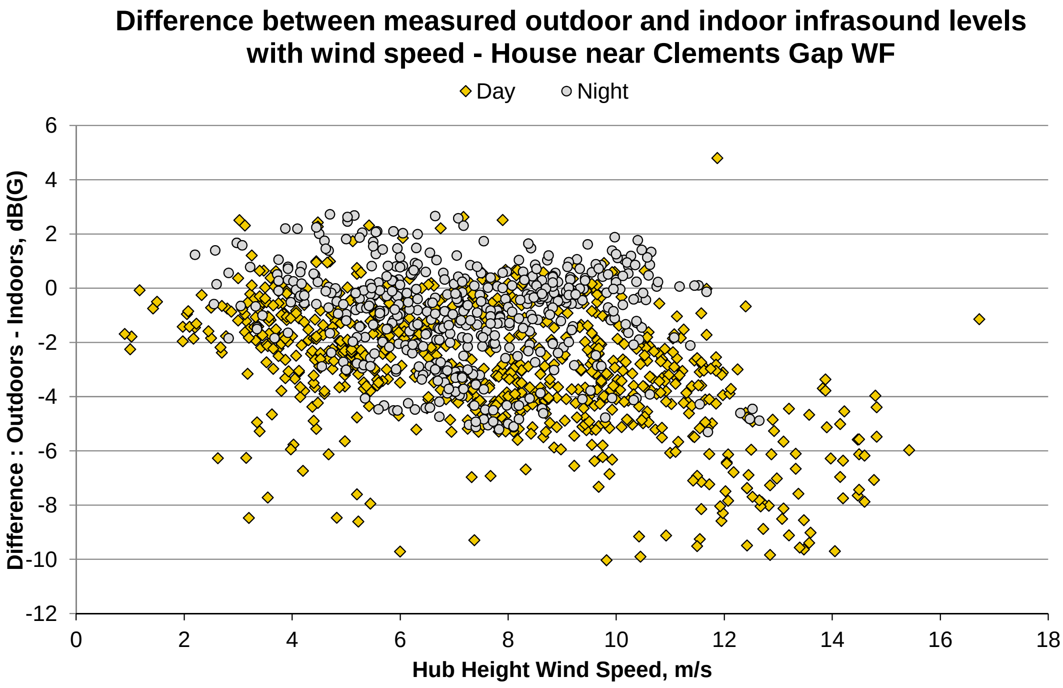

Figure B2 – Reduction in infrasound levels from outdoors to indoors with wind speed at Location 9

Review of the difference in outdoor and indoor measured noise levels indicated some relationship with wind direction (cross winds typically resulting in higher internal noise levels than measurements when the site was downwind of the wind farm), suggesting there may be extraneous noise on the indoor microphone as wind moved through the various openings in the facade, and rattled a loose sheet of iron on the roof.

Location 10 – Farmhouse near Jamestown

The farmhouse located near Jamestown is of weatherboard construction and was occupied for the full duration of the test. The arithmetic difference in noise levels between the outdoor and indoor measurement location at this location is presented in Figure B3. As the house was occupied during the measurements, the results are presented separately for day and night.

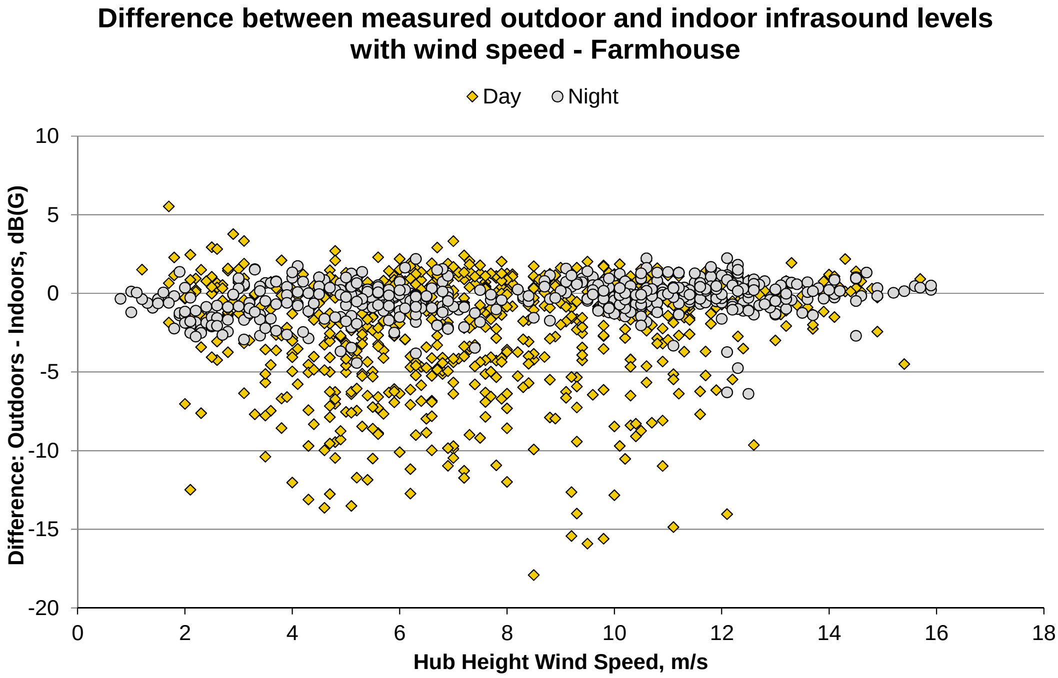

Figure B3 – Reduction in infrasound levels from outdoors to indoors with wind speed at Location 10

The results in Figure B3 indicate that the difference between outdoor and indoor measured infrasound levels was typically within 2dB(G) during the night time, when the occupants were generally asleep.

During the daytime periods, the difference between outdoor and indoor levels varies more significantly and this was found to be due to extraneous noise affecting the results, primarily a result of the activities of the occupants of the farmhouse.

Location 11 – House near Myponga

The house located near Myponga was of modern construction, with masonry and glazed external walls. The house was occupied during the weekend periods, but unoccupied between Monday and Friday.

Figure B4 presents the arithmetic difference between the measured outdoor and indoor infrasound levels at the house. The periods during which the house was occupied are presented separately to those periods during which it was unoccupied.

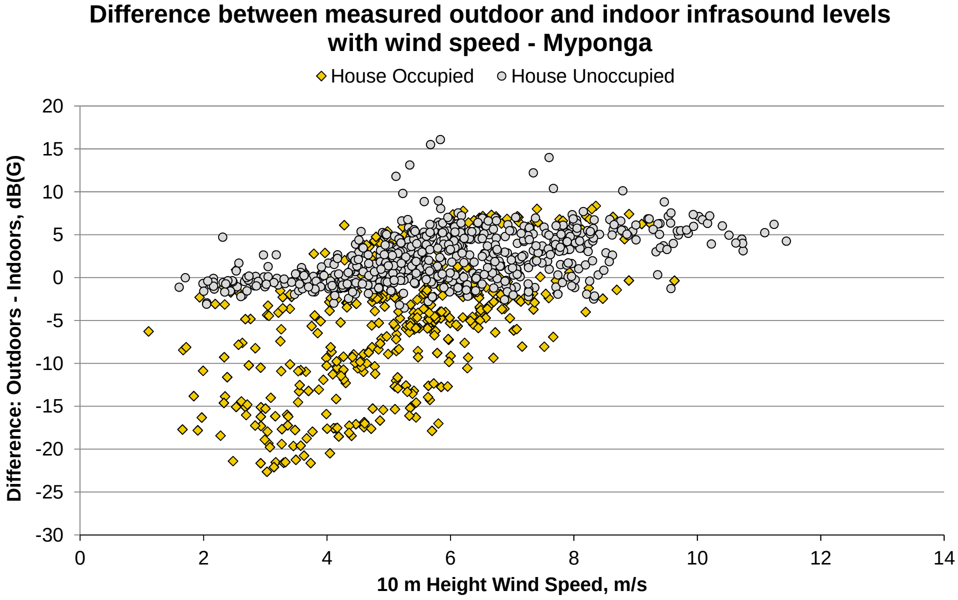

Figure B4 – Reduction in infrasound levels from outdoors to indoors with wind speed at Location 11

Figure B4 indicates a significant difference in the apparent transmission loss across the facade for the periods during which the house was occupied and unoccupied. The apparent increase in infrasound levels by up to 22dB(G) during times when the house occupied is the result of extraneous indoor noise due to the activities of the occupants, rather than an actual change due to the structural amplification or decrease in the facade performance.

Data measured while the house was unoccupied indicates that the typical reduction in infrasound achieved across the facade is typically -1 to 5dB(G).

Summary of outdoor-to-indoor comparison

Based on simultaneous outdoor and indoor infrasound measurements conducted at the four rural measurement locations, there is no significant change in infrasound levels between outdoors and indoors. The difference (outdoors less indoors) was found to normally be in the range of -2 to 7dB(G) once extraneous sources of infrasound had been excluded from the dataset. This result is relatively consistent with wind speed.

Most notably, the outdoor-to-indoor infrasound reduction at the house near the Bluff Wind Farm (Location 8) is typically around 6dB(G). This is the only location were the vast majority of the reported data is unaffected by human activities and operation of home appliances or domestic machines (since mains power and water supplies were switched off). This location is therefore considered to provide the most reliable dataset for the comparison of outdoor and indoor infrasound levels.

This indicates that outdoor measurements of infrasound, using appropriate equipment to reduce wind-induced noise across the microphone, can be used to represent indoor G-weighted levels of infrasound. Outdoor measurements of infrasound have the advantage that they are far less susceptible to the influence of the often significant extraneous infrasound that is generated by occupants of the house or the operation of home appliances.

Appendix C – Frequency analysis

The measured average unweighted sound pressure levels in third octave bands between 0.25Hz and 20Hz (the infrasonic frequency range) are presented in the following sections. This Appendix is intended to provide additional information to that presented in Section 5.

Urban locations

As identified in Section 3, the measured infrasound levels at the seven urban locations appear to vary considerably with time of day. Therefore, average spectral levels for both the day (7 am to 10pm) and night (10pm to 7 am) periods have been determined for each location.

Figure C1 and Figure C2 present the average sound pressure levels with frequency for the day and night time periods respectively.

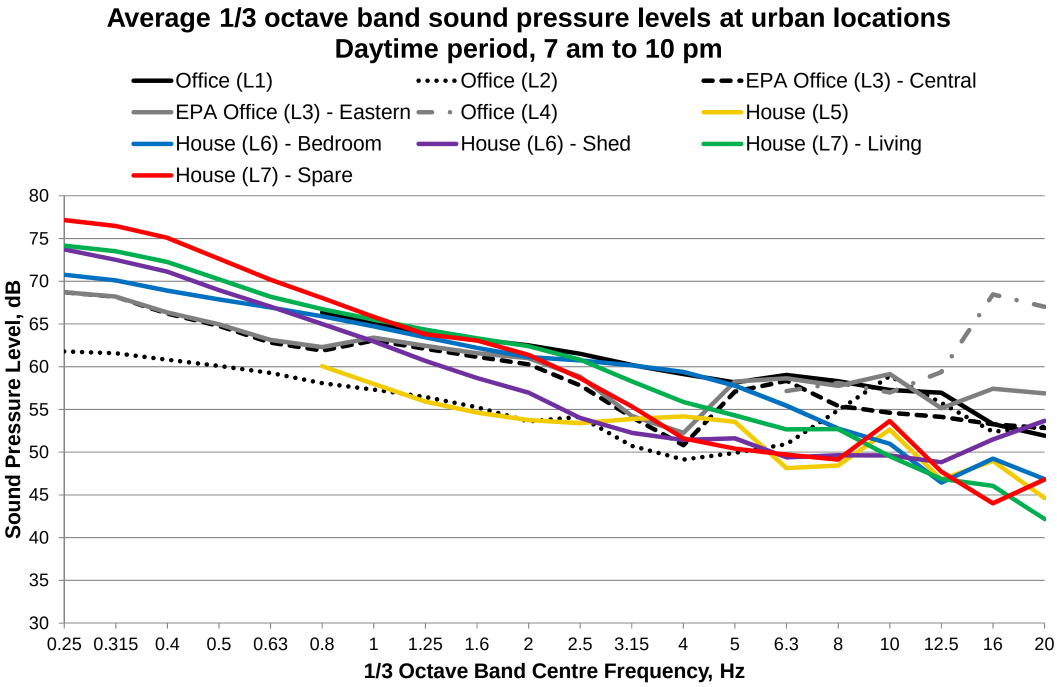

Figure C1 – Average day sound pressure levels for infrasonic frequencies at urban locations

Comparison of the figures indicates that there is a considerable increase in the average levels during the daytime at frequencies below approximately 5Hz, suggesting noise at these frequencies is associated with human activities.

The measured daytime levels at the four office locations are markedly higher at frequencies above approximately 6.3Hz. This daytime increase is a result of both mechanical plant noise (particularly Location 3 and Location 4) as well as human activity within the space.

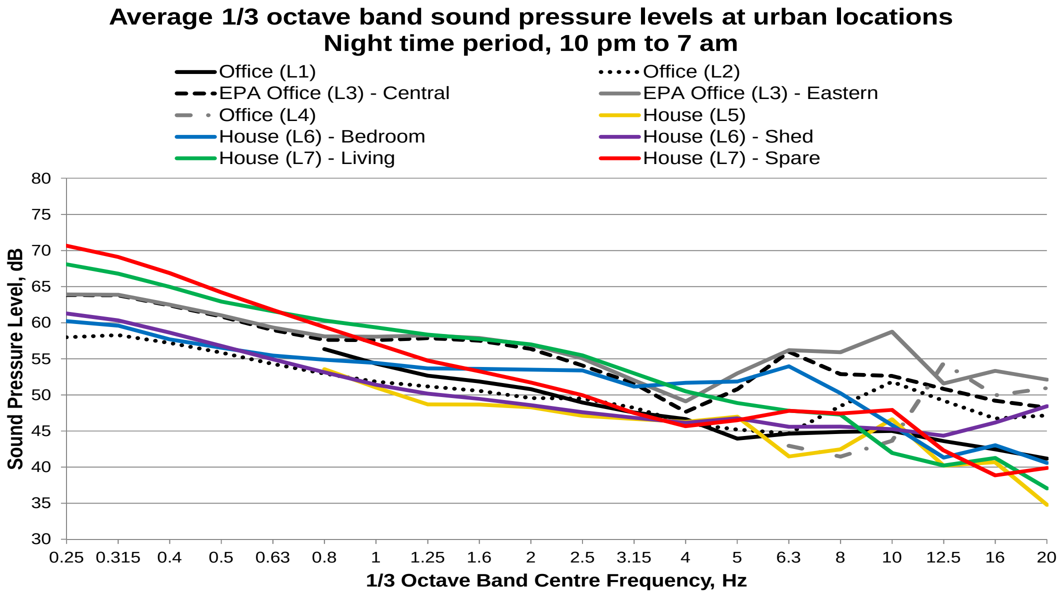

Figure C2 – Average night sound pressure levels for infrasonic frequencies at urban locations

Rural locations

Unlike the urban locations, the measured infrasound levels at the four rural locations appear to change more with wind speed than with time of day. Therefore, average spectral levels have been grouped according to the following low, medium and high wind speed ranges:

- Low, wind speeds of 0 to 3 m/s at typical turbine hub height (80 metres) – at these low wind speeds, wind turbines are not operating.
- Medium, wind speeds of 5 to 7 m/s at 80 metres – at these medium wind speeds, wind turbines would be operating and emitting noise but would not have reached the level of maximum noise emission.
- High, wind speeds of 9 to 14 m/s at 80 metres – at these high wind speeds, wind turbines would be operating near to or at the level of maximum noise emission.

Note that measurements at Location 11 were against a 10 metre height mast located at the house, rather than an 80 metre hub height mast. To allow approximate comparison of measurements at Location 11 to the remaining locations, the low, medium and high wind speed ranges used for location 11 are 0 – 2 m/s, 3 – 5 m/s, and 6 – 10 m/s respectively.

Figure C3, Figure C4 and Figure C5 present the average sound pressure levels with frequency at the four rural locations for low, medium and high wind speeds respectively.

We note that the indoor results at the Clements Gap wind farm are influenced by an extraneous source (which was also present during the shutdown periods). The indoor results are presented for information only, and are not indicating higher infrasound due to the operation of the wind farm in the frequency range of particularly 10 to 20 Hz.

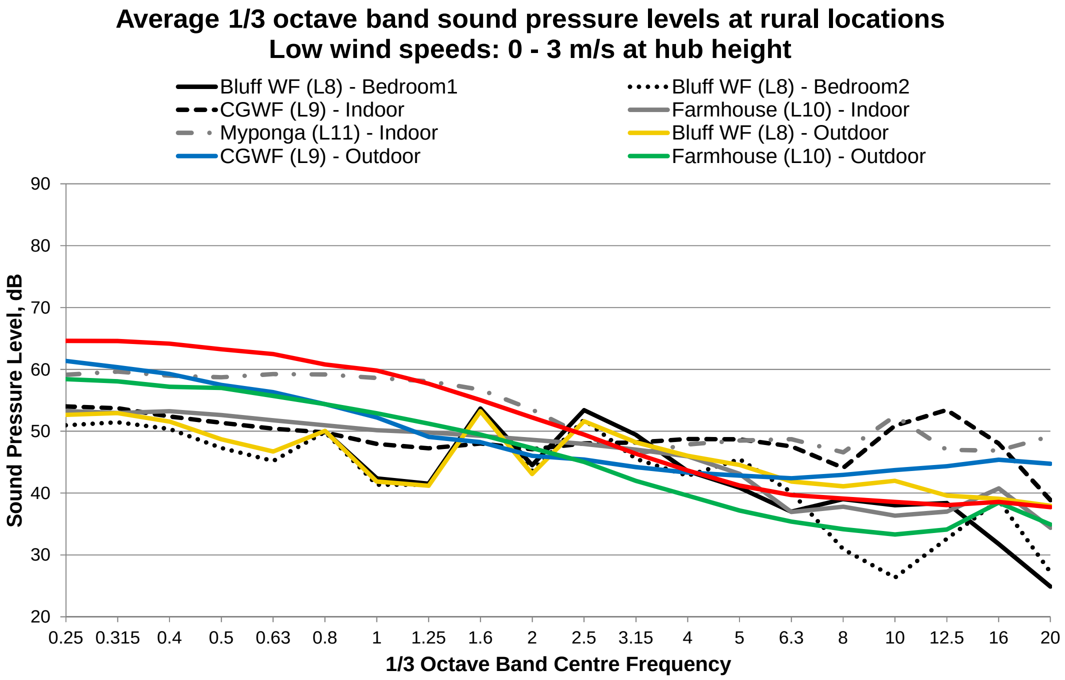

Figure C3 – Average low wind speed sound pressure levels for infrasonic frequencies at rural locations

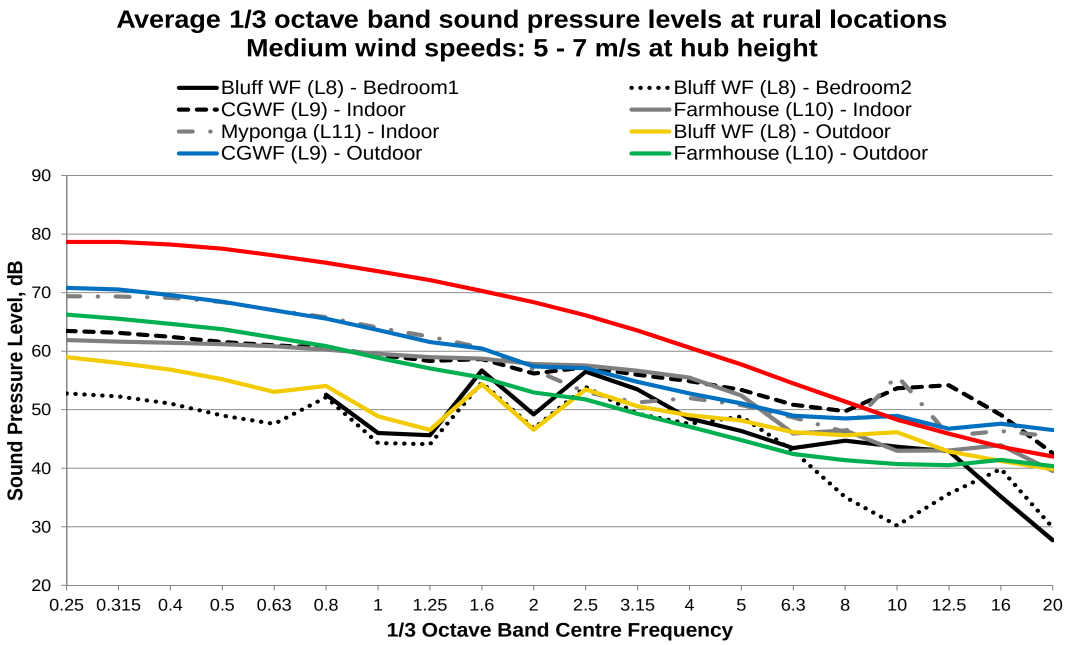

Figure C4 – Average medium wind speed sound pressure levels for infrasonic frequencies at rural locations

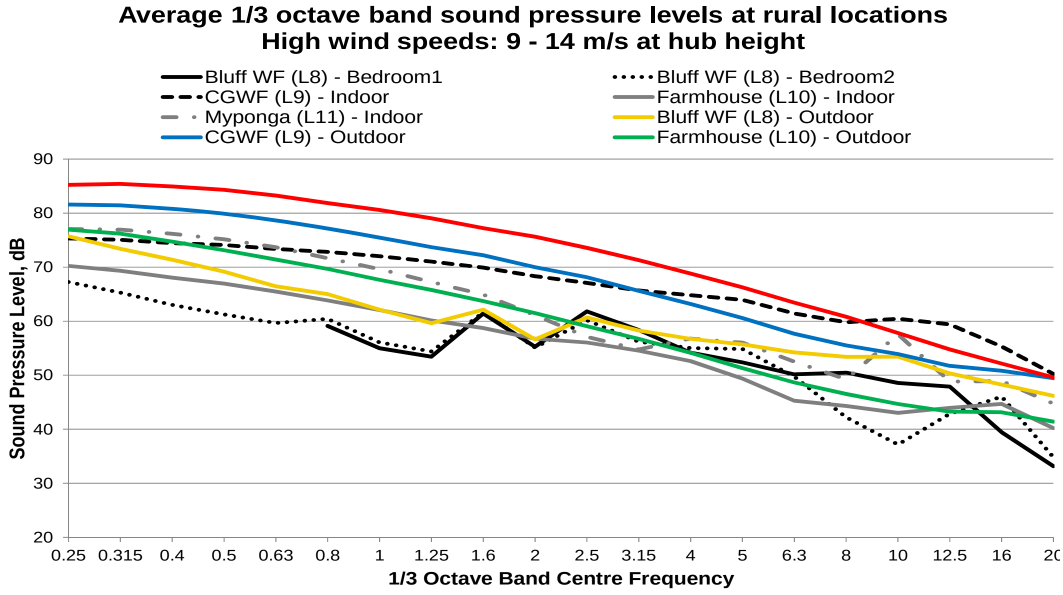

Figure C5 – Average high wind speed sound pressure levels for infrasonic frequencies at rural locations

Note that the levels measured at the four outdoor locations appear to have been affected by wind-induced noise generated by localised wind turbulence at low frequencies. This wind-induced noise is evident at frequencies typically below approximately 5Hz, and characterised by the smooth steady increase in sound pressure levels with decreasing frequency. This effect is most pronounced at Location 11, which is away from the wind farms. As noise at these frequencies is of little importance for human perception, these frequencies are subject to relatively large negative weightings by the G-weighting function. The wind induced results at very low frequencies would therefore not have noticeably affected the G-weighted infrasound levels presented in Section 4.

The measurement location at the house near the Bluff Wind Farm (Location 8) was the most sheltered of all of the rural measurement locations. It is evident that the sound pressure levels measured at the house near to the Bluff Wind Farm are lower than at the majority of other locations across the frequency range from 0.25 to 20Hz. The measured outdoor levels at the house near the Clements Gap Wind Farm are representative of some of the higher measured levels, but are still generally lower than those measured outdoors at Location 11 at Myponga (away from any wind farm). The measurement location at the Myponga site was the most wind exposed measurement location, closely followed by the measurement location at the house near Clements Gap Wind Farm (Location 9).

The measured levels at the house near the Bluff Wind Farm do show a slight peak in the spectrum at frequencies of 0.8Hz, 1.6Hz and 2.5Hz. These frequency bands correspond to the blade pass frequency of the wind turbines (which normally operate between approximately 15 to 17rpm) as well as the second and third harmonics, and so the peaks may be a result of wind turbine operation. The measured sound pressure levels at the blade pass frequency and the two harmonics are also discussed further in Section 5.3 of the main body of the report.

Overall, comparing the infrasonic frequency spectra for low, medium and high wind speeds suggests that there is no significant change in frequency content between locations near to and at significant distances away from wind turbines. In terms of long term average exposure, the levels measured over the infrasonic frequency range were not found to be any higher at the locations near to wind farms than at comparable locations away from wind farms.

Wind farm shutdown periods

To determine any contribution from the wind farms at specific frequencies within the infrasonic range, the measured sound pressure levels with frequency were compared at the house near the Bluff Wind Farm (Location 8) and the house near Clements Gap Wind Farm (Location 9) with the wind farm on and the wind farm off.

Figure C6, Figure C7 and Figure C8 present the measured average 10-minute sound pressure levels across the infrasonic frequency range for Bedroom 1, Bedroom 2 and the outdoors location respectively at the house near the Bluff Wind Farm for periods with the wind farm shutdown and periods with similar environmental conditions when it was operational. The hub height wind speed and direction for each of the periods presented in the figures is as summarised in Table 10 in Section 4.1.

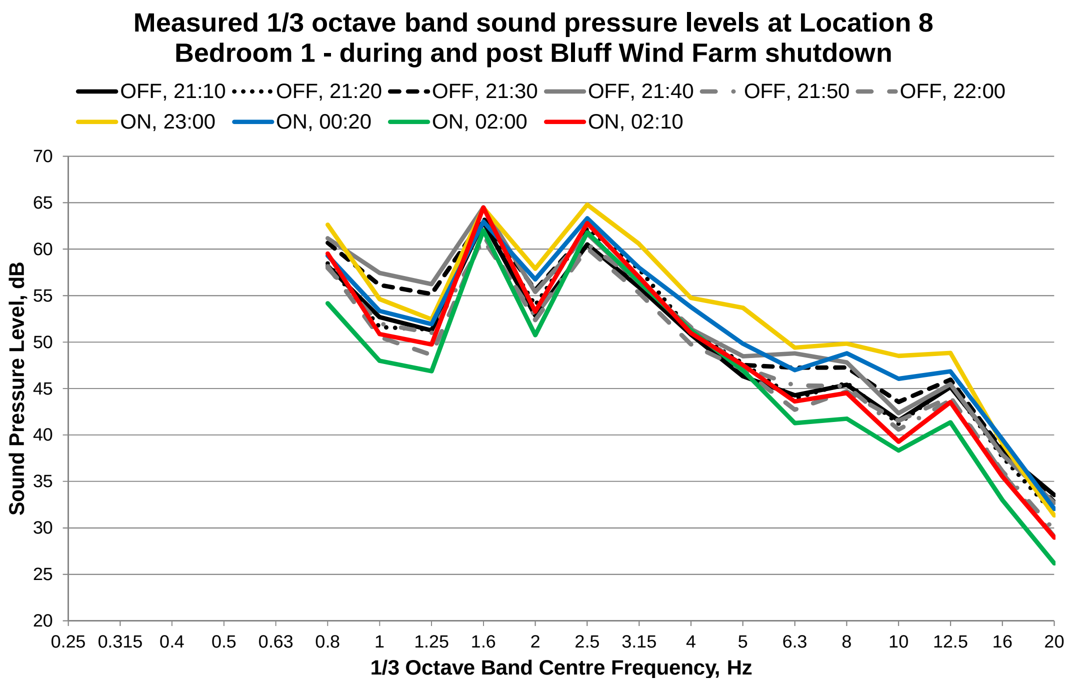

Figure C6 – Measured sound pressure levels with wind farm on and off, Bedroom 1 at house near Bluff Wind Farm

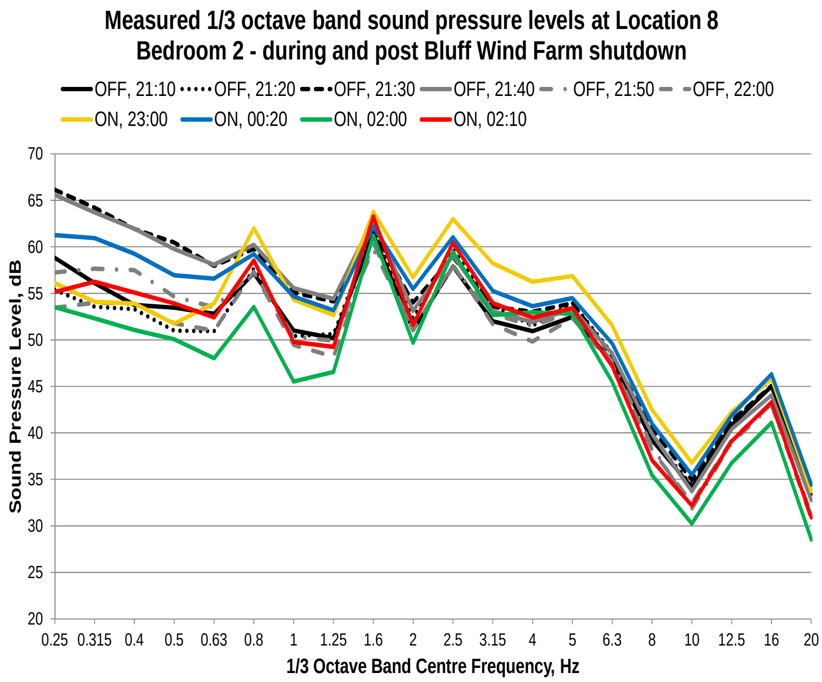

Figure C7 – Measured sound pressure levels with wind farm on and off, Bedroom 2 at house near Bluff Wind Farm

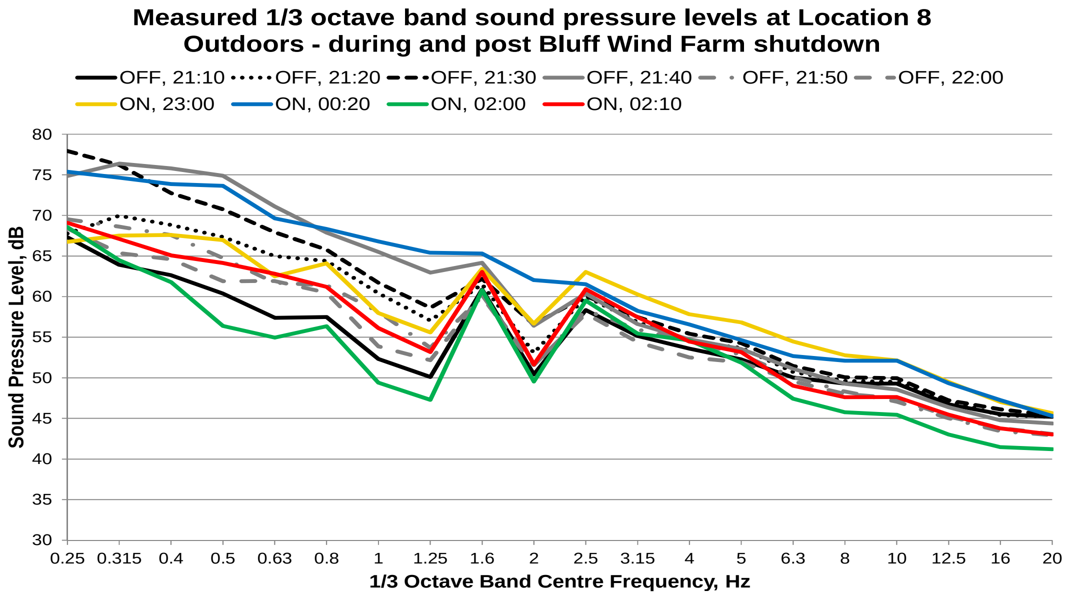

Figure C8 – Measured sound pressure levels with wind farm on and off, Outdoors at house near Bluff Wind Farm

The figures indicate that there does not appear to be any significant increase in sound pressure level at frequencies below 20Hz when the wind farm is operating, relative to when it was shutdown. While sound pressure levels did marginally increase at some frequencies during the operational periods at 23:00 and 0:20, these time intervals were also characterised by a change in wind direction relative to the shutdown period.

The periods at 2:00 and 2:10 provide a better comparison to the shutdown periods as the wind speed and direction measured at the meteorological mast was the same as during the shutdown. During these two periods, there was no noticeable increase in sound pressure levels across the frequency range from 0.25 to 20Hz.

It can also be seen that, although there is a peak in the frequency spectrum at the blade pass frequency and the next two harmonics (0.8Hz, 1.6Hz and 2.5Hz third octave bands) at all three locations, this peak is also present to a similar degree during the shutdown periods. These results are discussed further in Section 5.3 of the report.

Figure C9 and Figure C10 presents the measured average 10-minute sound pressure levels across the infrasonic frequency range for the indoor and outdoor locations at the house near the Clements Gap Wind Farm (Location 9), for periods with the wind farm shutdown and operational. During the shutdown, the hub height wind speed at the wind farm varied between 9 and 11 m/s and the house was unoccupied. Two operational periods were selected for comparison at each of these wind speeds which most closely matched the wind speed and direction of the corresponding shutdown period.

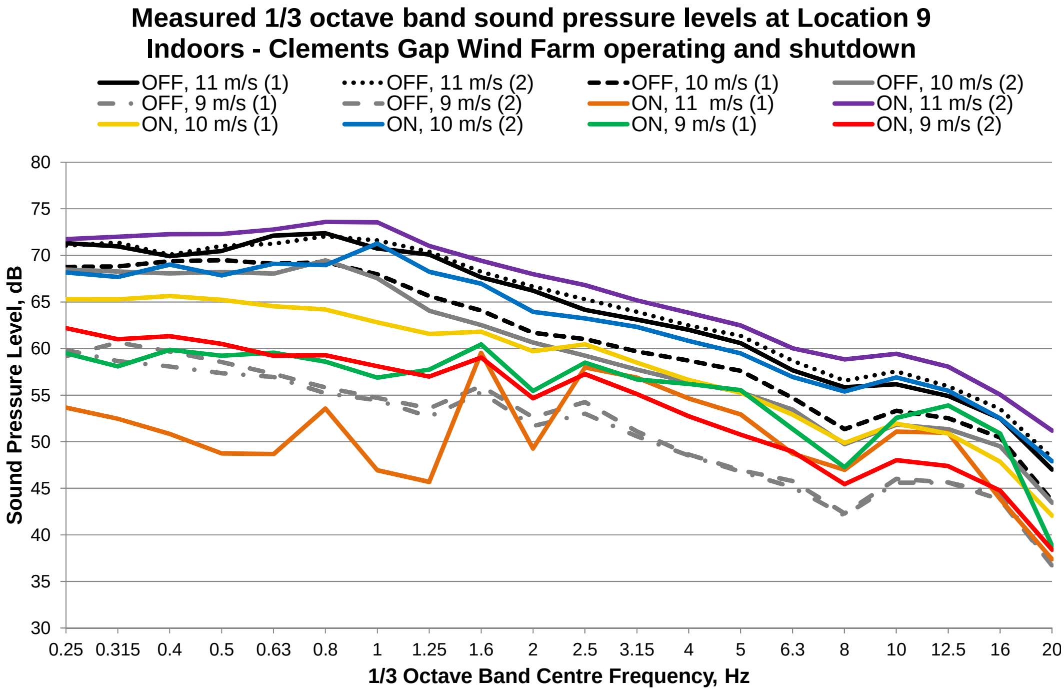

Figure C9 – Measured sound pressure levels with wind farm on and off, Indoors at house near Clements Gap Wind Farm

When compared to other locations, there are time periods when the sound pressure levels measured indoors at Location 9 (Figure C9) are markedly higher at frequencies between 2 and 20Hz. This effect occurred both when the wind farm was operating and when it was shutdown. This is believed to be the result of the loose sheet of iron on the roof rattling and significantly affecting the measured sound pressure levels within the infrasonic frequency range.

Therefore, while the measurement results at the indoor locations with the wind farm operating and shutdown demonstrated there was no clear change across the infrasonic frequency range, only limited relevant data could be obtained from the indoor measurements at Location 9. This also supports the findings regarding the accuracy of measurements at this location discussed in Section 4.2 of the report.

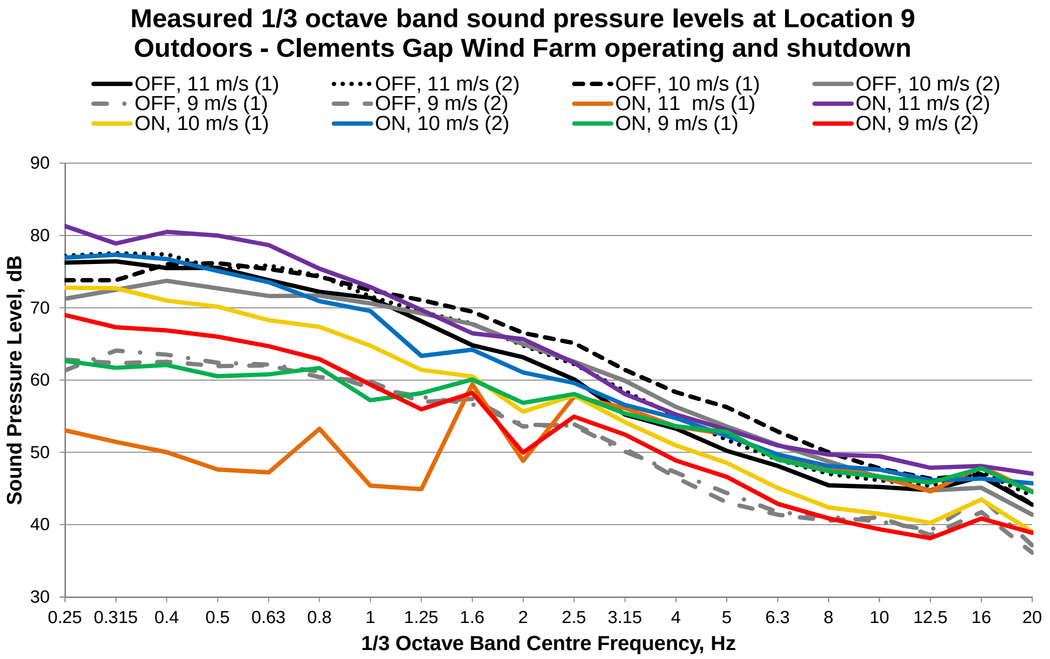

Figure C10 – Measured sound pressure levels with wind farm on and off, Outdoors at house near Clements Gap Wind Farm

As for the result at Location 8, the overall sound pressure levels at frequencies of 20Hz and below do not increase when the Clements Gap Wind Farm is operating relative to when it is shutdown. While there is considerable variation in sound pressure levels in the infrasonic frequency range for the measurement periods shown in Figure C10, this occurs during both the shutdown and operational periods leading to the conclusion that it is a result of localised wind conditions rather than wind farm operation.

During some of the quietest operational periods, a peak is evident in the frequency spectrum at the blade pass frequency of the wind turbines and the next two harmonics (0.8Hz, 1.6Hz and 2.5Hz). Peaks at 1.6Hz and 2.5Hz were also visible during the shutdown measurements, but to a much lesser degree. The difference in level between the peaks during the shutdown and operational periods may indicate that the peak is a result of wind turbine operation. However, a review of the full Clements Gap data set shows that the measured sound pressure levels of the peaks at these frequencies appear to be in the order of 53 to 60dB(Lin), a similar or lower level than typically measured sound pressure level at these frequencies at non-wind farm locations, and approximately 50dB below the threshold of perception. Therefore, these peaks are often masked by the background noise levels at these frequencies. These results also are discussed in Section 5.3 of the report.

Overall, the comparison of frequency spectra at Location 8 and Location 9 during wind farm shutdown periods and comparable operational periods indicates that there is very little change in the measured sound pressure levels at frequencies below 20Hz. This demonstrates that there is insignificant contribution from either the Bluff Wind Farm or the

Clements Gap Wind Farm to sound pressure levels in the infrasonic region at the houses located approximately 1.5 kilometres away.