

Wind Farm Generated Noise and Adverse Health Effects.

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Submitted to the Senate Hearing on 'Excessive Noise from Wind Farms' Bill, 14 November 2012

Keywords: annoyance, noise exposure, sleep disturbance, soundscape, quality of life, wind farms

1. Introduction

Annoyance and health-related quality of life concerns experienced by individuals living in the vicinity of two Australian wind farms are recorded. Noise exposures for individuals living in the vicinity of the same wind farms are examined for overall level and character. Twenty-one of the 25 respondents participating in the study reported severe to moderate adverse health effects. Reported adverse health effects include sleep disturbance, headaches, noise sensitivity, irritability, anxiousness, pressure on ear-drums, sinus problems, panic attacks, balance rotational problems, erratic/high blood pressure, tightened scalp / forehead, eye-strain and nausea. Nausea attacks are cited as being common, with some residents having to leave their home to sleep where there is no turbine noise. People affected by the wind farm appear to respond in two distinct groups: those affected almost as soon as the wind farm started operating and those affected some 6 to 8 months later. Persons interviewed live between 700 metres and a distance of around 3500 metres from the turbines, with an 'average' of 1400 metres.

The study was undertaken in January – June 2012 in Victoria, Australia. The study team consisted of persons qualified in acoustics, psychoacoustics, psychology, medicine (general practice), statistics and philosophy. Reviewers hold similar qualifications. The study design is exploratory and observational, establishing the research required for the development of a hypothesis or hypotheses. It is a scientific-method-driven determination of health-related, perceptual and environmental variables, i.e. health-related quality of life and noise exposure in a sample of adults exposed to wind farm generated noise. It is not within the scope of the study to determine if a causal relationship exists between variables.

2. The study design

The design consists of the following elements.

2.1 To investigate the relationship between factors describing health-related effects

Aims and Objectives

To investigate the relationship between variables such as annoyance and adverse health effects. The survey records the perceived intrusiveness of noise, annoyance towards the noise, sleep interference due to the noise exposure and general health. Claims of adverse health effects are described. Of necessity, the investigation was applied to residents who claim they are adversely affected. The study design was reviewed by an independent group of experts before the final design was implemented.

Design

The research is survey-based, and is largely exploratory in nature, that is, hypothesis generating. Strict confidentiality was and will be maintained.

Methods

The study used convenience sampling to obtain completed questionnaires. The study is a case-study within defined locales and is not intended to be referenced for epidemiological research.

Materials

A social attitudinal survey designed to compliment future research involving physical noise measurements was applied. The survey included self-report assessments on exposure to community noise and perceived intrusiveness of noise; annoyance and sleep interference due to noise exposure; psychological wellbeing, quality of life, and general health; noise sensitivity and personality traits; attitudes to noise sources; and demographic information. Questions were guided by pre-existing studies in the literature or by the use of pre-existing and validated inventories, including:

Table 2.1.1: Measures of health effect

Construct	Measure
Quality of Life and general health	The World Health Organization Quality of Life Scale (WHOQOL-BREF)
Annoyance	Questions from Thorne [3].
Noise sensitivity	Noise Sensitivity Questionnaire (NoiSeQ)
Health survey	SF-36v2
Sleep disturbance	Epworth Sleepiness Scale, Pittsburgh Sleep Quality Index
Turbines and health	Questions from Nissenbaum [4]

Analysis

Returned questionnaires were entered into a computer-based spreadsheet (Microsoft Excel) and from here exported to appropriate data analytical software packages (e.g., SPSS). An analysis protocol was developed as part of the peer review process. Analysis was applied in distinct steps:

- i) Data was assessed for suitability of inclusion (i.e., a missing value analysis/outlier analysis) and where appropriate items were reverse-coded.
- ii) The psychometric properties of the scales were assessed using reliability analyses (e.g., Cronbach's alpha), descriptive statistics for floor and ceiling effects (e.g., means/standard deviations), and validated for dimensionality using data ordination techniques (e.g., item-total correlations/Factor Analysis). Composite variables were computed and normalized if necessary.
- iii) Inferential tests were carried out (e.g., zero-order correlations, multiple linear regression, one-way analysis of variances, *t*-tests) to address research hypotheses.

2.2 Acoustic and Psychoacoustic measures as descriptors of noise perception and exposure

Aims and Objectives

To investigate the relationship between acoustical and psychoacoustic variables (e.g., sound levels in the environment, noise perception and noise sensitivity) and annoyance. These

measurements afford an examination of the correlation between sound, perceived noise, annoyance and health, and differences between groups in wind turbine areas vs. quiet areas in quality of life, noise sensitivity, and general health.

Design

The research is survey-based, and is largely exploratory in nature, that is, hypothesis generating. The study design was reviewed by an independent group of experts before the final design was implemented.

Methods

The study used spatial sampling to obtain sound levels from wind farm locales and non-affected locales. A minimum of 5 sites were measured for statistical sound levels over a period of 2 weeks. One site at an affected locale and one site at an unaffected locale were identified as permanent monitoring stations. Measurements were recorded in real-time data-streaming mode with audio recording. Selected sites had full monitoring for low frequency sound and infrasound. The population sampled were residents within 5 kilometres of two wind farms and a quiet 'greenfields' locale that is unaffected by wind farm noise.

Materials

An acoustical and psychoacoustical survey designed to compliment future research involving physical noise measurements will be developed. The survey included self-report assessments on exposure to community noise and perceived intrusiveness of noise; annoyance and sleep interference due to noise exposure; relational questionnaires to the health effects surveys, including the measurements in Table 2.2.1:

Table 2.2.1: Measures to describe sound and noise

Construct	Measure
Sound Exposure	Standard (Lp, Leq, Ldn) and statistical measures of sound; A- and Z-weighted
Audible characteristics	Amplitude modulation, loudness, fluctuation strength, roughness, tonality to relevant standards and guidelines
Perception characteristics	Measures from Thorne [3]

Analysis

Returned questionnaires and sound level datasets were entered into a computer-based spreadsheet (Microsoft Excel) and from here exported to appropriate data analytical software packages e.g. NoiseLab3 (from Delta Denmark), dBSONIC 4.5 (from 01dB-Metravib), AES [3], SpectraPlus5 (from Pioneer Hill Software). Analysis was in distinct steps:

- i) Data was assessed for suitability of inclusion (i.e., a missing value analysis / outlier analysis).
- ii) Where appropriate items datasets relating weather and sound levels are integrated.
- iii) Sound character and perception analysis was determined with methods of analysis for amplitude modulation, dissonance, impulsiveness, loudness, roughness, sharpness, salience, tonality and unbiased annoyance.

2.3 Participants in the study

The participants were 23 adults residing in rural locales nominally within 1000 to 3500 metres of clusters of 3 or more wind turbines. Two participants were chosen from a locale that does not currently have wind turbine activity. Participants were selected on the basis of health concerns evidenced through statutory declarations, submissions to hearings or through the research program interview process. The demographic profile of the sample is in Table 2.3.1.

Table 2.3.1. Demographic characteristics of participants ($n=25$).

Variable	Category	Number	Percent
Sex	Male	13	52
	Female	12	48
Age	25 - 34	1	4
	35 - 44	2	8
	45 - 54	10	40
	55 - 64	8	32
	65 - 74	0	0
	75 and over	4	16
Total		25	100

2.4 Instruments – WHOQOL BREF

In addition to items requesting demographic information, the survey contained three self-report assessments, providing measures of Health Related Quality of Life (HRQOL), noise annoyance, and noise sensitivity. Participants were asked to make their ratings with respect to the previous two weeks. Health-related quality of life was assessed using the World Health Organization Quality of Life (short-form) scale, the WHOQOL-BREF [2]. The WHOQOL-BREF consists of 26 items divided into four domains: physical health (7 items), psychological wellbeing (6 items), social relationships (3 items), and environmental factors (8 items). There are two additional items probing overall quality of life and general health. All 26 items in the WHOQoL-BREF consist of statements that are rated on a five point Likert scale. The respondents are asked to respond to these items, keeping the last two weeks in mind. Lower domain scores indicate more negative perceptions of Health-related Quality of Life, while higher scores indicate higher and more positive evaluations.

2.5 Instruments – SF36v2

The SF36v2 Questionnaire [5] was applied as an adjunct to the WHOQOL-BREF. The SF36v2 Questionnaire is a multi-purpose, short-form health survey. Two standardised summary scores are calculated from the SF-36; the physical component summary (PCS) and the mental health component summary (MCS). The weightings of the questionnaire are reviewed with the US norm applied to support or clarify clinical impressions for individuals, rather than as a population study [6].

2.6 Instruments – NoiSeQ

Noise sensitivity was estimated using the Noise Sensitivity Questionnaire (NoiSeQ) scale [7] which measures global noise sensitivity as well as sensitivity for different domains of everyday life: leisure, work, sleep, communication, and habitation. The subjective experience of annoyance represents the most frequent human reaction to noise. Different levels of annoyance show considerable inter-individual variations and are ascribed to the differences in the noise sensitivity. Noise sensitivity is considered as a stable personality trait, which affects an individuals' reactivity toward noise sources. According to the results of psycho-acoustic studies, noise sensitivity has no relation to auditory acuity but reflects a judgmental, evaluative predisposition towards the perception of sounds.

2.7 Instruments – Sleep Disturbance

Sleep disturbance was assessed through application of the Pittsburgh Sleep Quality Index (PSQI) [8], the Epworth Sleepiness Scale (ESS) [9] and the Nissenbaum [4] sleep quality – health effects questionnaire.

The Pittsburgh Sleep Quality Index is scored on the basis of 7 components: Subjective sleep quality; Sleep latency; Sleep duration; Habitual sleep efficiency; Sleep disturbances; Use of sleeping medication; and daytime dysfunction. Sleep problems commonly co-occur with anxiety, mood (especially depression and dysthymia), impulse-control, and substance abuse disorders. For example, persons with generalized anxiety disorder (GAD) are approximately three times (3x) more likely to report difficulty initiating sleep, problems maintaining sleep, and early morning awakening, and are indicated as being six times (6x) more likely to experience non-restorative sleep. All scores are combined according to the scoring criteria included with the form to produce a Global PSQI Score. Scores above 5 indicate clinically meaningfully disturbed or poor sleep.

The Epworth Sleepiness Scale is used to assess the level of daytime sleepiness. A score of 10 or more is considered sleepy. A score of 18 or more is very sleepy. The Nissenbaum sleep quality – health effects questionnaire provides supplemental questions relating to headaches and satisfaction ratings before and after the turbines went online.

In relation to sleep it has long been accepted that disrupted sleep reduces psychological wellbeing, compromises biological processes such as the immune system, and degrades day-to-day functionality. However, even noise insufficient to cause awakening may cause a brief arousals in state, with the sleeper moving from a deeper level of sleep to a lighter level and back to a deeper level. Because full wakefulness is not reached, the sleeper has no memory of the event but the sleep has been disrupted just as effectively as if wakefulness had occurred.

2.8 Instruments - Annoyance

Susceptibility to noise annoyance was assessed using a questionnaire developed by Thorne [8] and assessed annoyance due to other sources of neighborhood noise. Annoyance due to wind turbines and other sources is discussed in the 'Genlyd' noise annoyance model [10].

2.9 Instruments - Sound Perception

An outcome of the observations and interviews of the previous studies indicated a need to establish a baseline reference point with sounds of known characteristics that could be reviewed by any person at any time. The purpose was (and is) to identify the perceptions of the sound as experienced by the person listening to the sound. The study was expanded by presenting a series of environmental sounds or 'soundfiles' to be judged by the respondents. Each sound has a unique character or characteristics and these are correlated to significant acoustical and perception measures. The measures for loudness, sharpness, roughness, modulation and unbiased annoyance are calculated with dBSONIC v4.5, a sound quality analysis program [11].

2.10 Instruments - Sound Measurement

The surveys were monitored with Larson Davis 831 Class 1 sound level meters and PRM831 preamplifiers. Recording time was 50ms for events, 1 second for continuous time logging and 10 minutes for global data. Standard A-weighted and data was recorded. The frequency responses of the GRAS 40AZ microphone is $\pm 1\text{dB}$ 1Hz – 10kHz and $\pm 2\text{dB}$ 10 kHz – 20 kHz; the Larson Davis type 377B02 microphone is $\pm 1\text{dB}$ 5Hz – 10kHz and $\pm 2\text{dB}$ 3.15Hz – 20 kHz with a lower limiting frequency -3dB at 1.0 to 2Hz. The Larson Davis type 831 with PRM831 preamplifier typical Z-weighted frequency response with a lower limiting frequency -3dB at 2Hz to 3Hz. Each meter microphone was 1.3m above ground level and fitted with a standard 90mm windscreen.

Audio recordings were taken simultaneously with the Larson Davis 831 audio recording function with a sampling rate of 16,000 samples/second and analysed for sound character (as required) with specialized audio analysis software.

Sound levels were also recorded with Rion NL21 Class 2 sound level meters at 1.3 metres above ground and fitted with a standard 90 mm windscreen. The Rion has a calibrated low noise floor of 12 dB(A). Measurements were recorded as blocks of data every 10 minutes.

Each sound level meter was calibrated with a Class 1 calibrator immediately before and immediately after each measurement session.

The weather conditions during the study were fine and cool to mild. Generally the conditions were calm to a light breeze of 2.2 to 3.7 m/s (depending on time of day and location) from the south to south-west blowing towards the different monitoring locations. Cloud cover during the study varied from half-cover to 7/8th cover (nearly all cloud and little clear sky). Temperature was recorded as 12°C to 24°C (depending on time of day and location) and 50%-60% relative humidity. Measurements were taken with a Jaycar weather station at 10 metres above ground at the greenfields location and a handheld weather station at monitoring locations.

Infrasound measurements are recorded with the caveat that only levels taken under calm conditions or inside a dwelling are reliable. Levels below 10Hz taken under mild wind conditions below 2m/s are recorded but levels at wind speeds above 2m/s are disregarded. A purpose designed in-ground verified infrasound measurement system is required to complement indoor measurements.

The predicted sound level is necessary for the assessment of potential effects. The method under ISO9613-2:1996 *Acoustics-Attenuation of sound during propagation outdoors-Part 2 General method of calculation* is applied in this study.

2.11 Instruments – World Health Organization Health and Noise criteria

'Health' is defined by the World Health Organization [1] as

"A state of complete physical, mental and social well-being and not merely the absence of disease or infirmity"

Consequently 'Health' refers not only to physiology functioning, but also well-being, quality of life, and amenity. Quality of life, as defined by the World Health Organization [2] is a multifaceted concept:

"An individual's perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns. It is a broad ranging concept affected in a complex way by the person's physical health, psychological state, personal beliefs, social relationships and their relationship to salient features of their environment"

'Noise' is most often defined as 'unwanted sound'. The study presents the instruments necessary to establish the human perception of 'unwanted' and the acoustical measures for 'sound'. When these measures are combined, measures for the concepts of 'excessive noise' and 'serious harm to health' are defined.

The WHO Report 'Burden of disease from environmental noise – Quantification of healthy life years lost in Europe', 2011, is a review of the scientific evidence supporting exposure-response relationships and case studies in calculating burden of disease. The Report concludes that:

There is sufficient evidence from large scale epidemiological studies linking the population's exposure to environmental noise with adverse health effects. Therefore, environmental noise should be considered not only as a cause for nuisance but also a concern for public health and environmental health.

The Report considers sleep disturbance and its potential for adverse health effects. In 2009, WHO published the *Night Noise Guidelines for Europe*. This publication presented new evidence of the health damage of night-time noise exposure and recommended threshold values that, if breached at night, would threaten health. Health effects are identified in relation to nominated sound levels referenced as "instruments" for the study:

- A $L_{\text{night, outside}}$ level of 30 – 40 dB: a number of sleep effects are observed; 40 dB is equivalent to the lowest observed adverse effect level (LOAEL).
- A $L_{\text{night, outside}}$ level of 40 – 55 dB: adverse health effects are observed among the exposed population. Many people have to adapt their lives to cope with the noise at night. Vulnerable groups are more severely affected.
- The outdoor levels are applied with an insulation value of 21 dB from outside to inside the home; a level of 40 dB outside is 19 dB inside

The WHO recognizes the existence of vulnerable groups (such as children, the elderly, people with ill health) and acknowledges the existence of individual differences in noise sensitivity.

3. Results and Discussion – Quality of Life and Health Effects

Except where stated, all the results summarized in this section are from the respondents living within the locale of operational wind farms.

3.1 Health Related Quality of Life

The WHOQoL instruments have been shown to have excellent reliability and validity, and its use has been reported in thousands of studies. Furthermore, the WHOQoL-BREF has also been tested for its validity for different cultural groups and results demonstrate that the WHOQoL-BREF is a valid instrument to use across different cultural groups. Analyses [12] of Quality of Life data is given in Table 3.1.1

Table 3.1.1: Means, standard deviations (SD) and the Cronbach's alpha (α_c) of the summated scales for the WHOQOL-BREF

	<i>N</i>	No of items	<i>M</i>	<i>SD</i>	α_c
Physical	25	7	18.8	5.97	.880
Psychological	25	6	17.68	5.15	.887
Social	25	3	10.16	3.14	.695
Environment	25	8	25.15	6.74	.841

Table 3.1.1 displays, for the turbine noise exposure group, mean scores for the four health-related quality of life domains measured by the WHOQOL-BREF. Estimates of Cronbach's alpha are above, or sufficiently close to, $\alpha_c=0.7$, indicating that the data can be considered statistically reliable. The mean domain scores were then transformed [12] (see table below) to afford comparisons with Australian normative data, and Australian clinical data (the LIDO study). The Longitudinal Investigation of Depression Outcomes (LIDO) Study aimed to explore the relationship between major depressive disorders in primary care patients and their quality of life. The data presented in Table 3.1.2 suggests that the sample of individuals exposed to turbine noise have, on average, substantially lower health-related quality of life compared to the community and clinical samples.

Table 3.1.2: WHOQOL-BREF transformed scores calculated for the turbine samples compared to Australian normative data (Hawthorne, Herrman, & Murphy, 2005) and LIDO (inpatient/outpatient) clinical data.

	<i>Physical</i>	<i>Psychological</i>	<i>Social</i>	<i>Environmental</i>
Turbine Sample	42.43	48.67	59.67	53.63
Community Norms	73.5	70.6	71.5	75.1
Outpatient Norms (LIDO)	61.47	65.37	62.89	67.93
Inpatient Norms (LIDO)	51.55	64.04	63.36	66.99

Based on the results of the study it can be argued that, when exposed to wind farm noise and wind turbine generated air pressure variations, some will more likely than not be so affected that there is serious harm (also termed 'significant adverse effect') to health.

3.2 Results - SF36v2

The mean (rounded) values for the combined male and female profiles in the 1995 Australian Bureau of Statistics 1995 National Health Survey (SF36 Norms) are: PCS ages 18-44 = 53; MCS ages 18-44 = 49; PCS ages 45-54 = 50; PCS ages 55-64 = 47; PCS ages 65-74 = 43 and PCS ages 75 and over = 39. The MCS values are more consistent with ages 45 and above at 51. Assuming a mean of 50 and a standard deviation of 10 points the SF36v2 scores indicates that for most participants their physical (PCS) and mental health (MCS) is average or below average. The US demonstration scoring system as applied in this study, however, has a different point separation for assessments between below average (40-45), about average (45-49), average (50), about average (51-54), above average (55-). A score of less than 39 is recorded as being "very much below average". This is clearly a significant issue based on the MCS and PCS scores of many of the participants, figures 3.2.1 and 3.2.2. Only 4 participants were above average: the two 'greenfields' respondents and two local residents aged 75 and over.

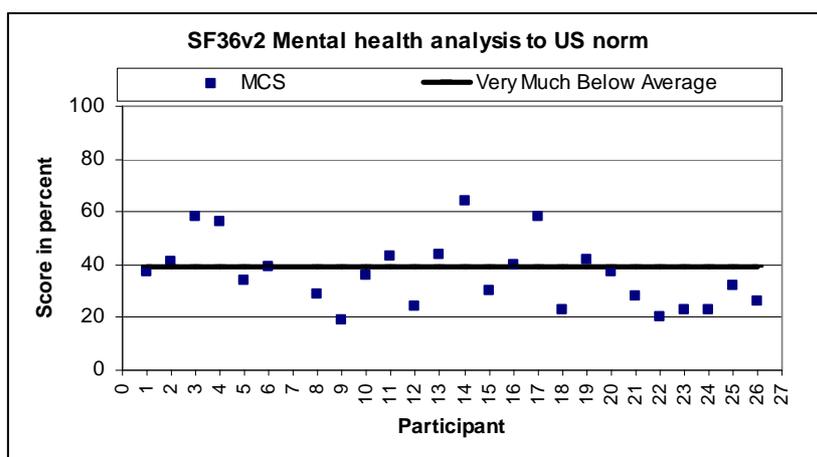


Figure 3.2.1: SF36v2 US norm analysis for mental (MCS) health

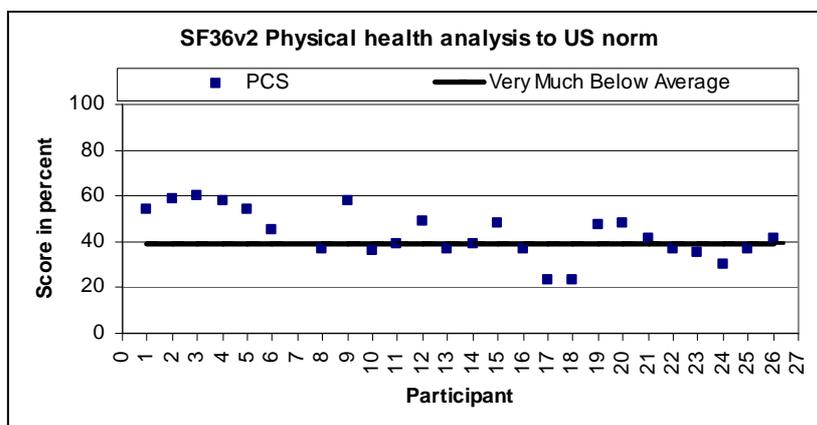


Figure 3.2.2: SF36v2 US norm analysis for physical (PCS) health

3.3 Results - Noise Sensitivity (NoiSeQ)

A detailed noise sensitivity analysis was performed in addition to the WHO Quality of Life analysis. The NoiSeQ analysis allows comparison with an earlier study of a rural locale affected by wind farms (Manawatu, New Zealand) and a totally urban locale (Brisbane city). The respondents are generally either self-employed or professional persons. The sensitivity of the respondents can vary depending on the subscale being measured. Higher values indicate higher noise sensitivity. Noise sensitivity influence annoyance and noise sensitivity also has an effect on the sound level-related changes of annoyance. Both rural locales of Manawatu and Victoria exhibit elevated levels of higher than average noise sensitivity for 'Sleep' and 'Global' compared to the urban respondents. All respondents are recorded.

The responses for Global Noise Sensitivity are: Above average - Manawatu 85%; Victoria 82%; Brisbane 71%. Average responses are Manawatu 15%; Victoria 18%; Brisbane 29%, making 100% in total.

The responses for Sleep Noise Sensitivity are: Above average - Manawatu 70%; Victoria 60%; Brisbane 21%. Average responses are Manawatu 15%; Victoria 40%; Brisbane 58%. The below average values are Manawatu 15%, Victoria 0%, Brisbane is 21%, making 100% in total.

3.4 Results - Noise Annoyance

In response to the question "Select the best description descriptions for sounds heard in your local environment – I find the sounds are..." the responses were: pleasant (43%); sometimes pleasant (22%); often pleasant (13%); *and* sometimes disturbing/irritating (86%); sometimes annoying (60%). The observations indicate that the rural environment soundscape is considered pleasant but there is a defined disturbing and annoying intrusion.

Of the respondents with an opinion, 60% found the sound of turbines intrusive with the sound sometimes noisy (73%), unpleasant (64%), with no respondent saying that the sound(s) could be ignored. The effect of the noise was well defined: 82% of the respondents stated that the noise was disturbing sleep, 56% disturbing rest or relaxation, and 64% stated that the noise was making that person anxious. In response 48% stated that 'I'm sensitized to a particular sound'. The respondents who reported being sensitized to a particular sound identified wind turbine noise as being the cause. Wind turbine noise was referred to as the sound most often affecting the respondents.

In response to the question 'Do the turbines annoy you inside the home' 91% of the respondents stated 'yes' and 9% stated 'no'. For turbine noise heard outside the home 95% of the respondents stated 'yes' and 5% stated 'no'.

When asked "Do you find noise in your environment (including your home environment) a problem" 56% replied 'Yes', 39% replied 'Sometimes' and one person (5%) said 'No'. This cross-check question related to all types of noise and not just from one or more specific sources.

All report that wind turbines affect sleep and the ability to work is dramatically affected. Nausea and vertigo are constants for some, occasional for others, as well as feelings of anxiety, anger and helplessness; and irritation with the turbine noise. Stress, anger and hopelessness are constants; not all day every day but recorded as frequent each week.

Families have moved away to sleep, must still work the land, will not sell. Two families report farm property is devalued; they have heritage homes and cannot rebuild. All of these factors compound the general feeling of annoyance with the placement and operation of the wind farm(s).

Building construction generally is inadequate to reduce or mitigate sound levels and, hence, annoyance. The observed homes are generally of light timber frame construction with metal roofing. Glazing is light-weight and thermal or acoustic glazing is not installed in any home.

3.5 Results - Pittsburgh Sleep Quality Index (PSQI)

Of the 25 participants, 92% have noted a change in sleeping patterns since the turbines went online. The 8% who have not experienced sleep changes are living in a greenfields locale. The changed sleep patterns are described as being entirely new by 80% of the respondents, with 8% of the non-affected persons being in the greenfields locale. For 24 % of the participants the sleep problems described (with the exception of getting up to use the bathroom) existed before but are now worsened since the turbines went online. With the exception of the greenfields participants, 80% of the respondents agreed that sleep improves when away from home (that is, home near the turbines). Critically, however, even those residents who sleep away from the influence of the wind turbines also record high PSQI scores indicating that working in a turbine-affected locale is not alleviated by living away. The Global PSQI scores are recorded in Figure 3.5.1.

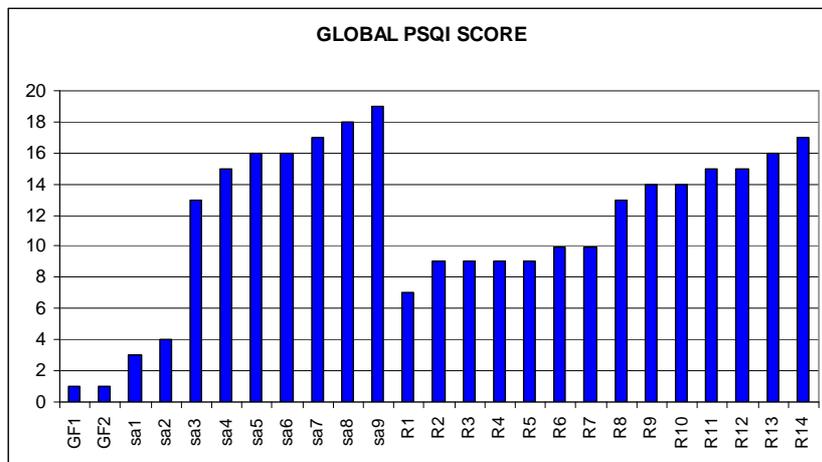


Figure 3.5.1 Global PSQI Score

(Key: GF=Greenfield, no turbines; sa= sleep away from wind farm; R=resident and sleep within wind farm influence)

One limitation with the study is the lack of a matched control group. In the event only 2 completely turbine-free (greenfield) residents are reported. The case-study is important, however, as the PSQI scores of residents who are residing and work in the locale are recorded against the scores of residents who have left their homes to reside away from the wind farm. These persons must still work their farms within the influence of the wind farm.

Having said that, the very high PSQI scores are worthy of comment: 80% >5 is exceptional, typical community values are 25-35% depending upon age and gender (higher in females and with

age). A later table locates the respondents by distance and predicted sound levels from turbine clusters.

3.6 Results - Headaches and associated health effects

In order to more fully assess the potential for adverse health effects experienced by the respondents a series of general health questions were presented. In response to general questions that asked 'What health effects such as headaches have you experienced since the turbines went online that did not exist previously' 24% responded with daily or constant headaches, 56% experienced headaches 2-4 times per week, 64% experienced a tight scalp or band-effect around the head, 52% experienced blurred vision, 40% stated dizziness was experienced, 4% experienced chest pains, 52% experienced nausea, 76% stated ear-ringing was experienced, 12% experienced pressure in the ears, and 60% experience vertigo/balance problems.

Of the persons who responded citing headaches as a problem 80% observe that headaches occur only when the turbines are operating.

Most of the respondents noted that these effects are not experienced all the time but often enough to be debilitating. The responses relating to nausea and the time before symptoms were experienced were probed further. In response to the question 'How long did it take after the turbines started before you felt unwell' 36% of the respondents said fairly quickly (a month or less) and 56% said 6-8 months. Of the people who responded 'fairly quickly' there were some who became unwell almost immediately. These respondents now find it very difficult to return to the locale to work when the turbines are operating as they suffer from headaches and/or nausea almost immediately. In 56% of the responses the symptoms improve/abate fairly quickly when the person leaves the locality.

3.7 Results – Infrasound, low frequency sound and health effects

This study and substantive reports [e.g. 13] have raised the question as to the reasons for the adverse health effects experienced by people affected by low frequency sound. Annoyance and sleep disturbance, with associated adverse health effects, are described in this paper. These effects, however, usually take some time before they become significant as stressors. The reported immediate health effects of nausea and headaches do not correspond to the readily perceived audible sound issues. One respondent observed that nausea experienced at 1000 metres is not experienced at 4200 metres downwind from the turbines.

The observation from this and earlier studies is that there is a physical effect affecting sensitive individuals. The premise for this is based on the fact that the individuals did not experience adverse health effects before the wind farm started operation but do so now when the turbines are operating. Some researchers suggest that this is an "infrasound" effect but this is not quite the observed effect.

The descriptor 'infrasound effect' is too broad in definition as individuals are always exposed to "infrasound" as this is a natural component of our wind environment. Wind has a very long wave length compared to (say) bird song and wind has a characteristic measurement in the 1 Hz to 20 Hz range of sound levels. The significant observation of the study is that there is a fundamental difference between an environment without a wind farm (no health effects) and a wind farm (health effects). The "effect" is recorded as being the physical action of the turbines. The turbine blades turn and extract energy from the wind and create audible and perceptible turbulence effects. The effect of the influence of the wind

turbine(s) is to change the character of the wind from a relatively smooth laminar flow to a disturbed air flow with readily measured air pressure variations.

It is therefore postulated that *“Adverse health effects are experienced by sensitive individuals due to modulating air pressure variations broadly measured in the 1Hz to 40Hz third octave bands.”*

Not all individuals in the study appear to have these adverse health effects recorded, however, and this is a confounder relating to the physical properties of wind farms. The general effect can be termed as ‘land-sickness’, similar to sea-sickness or car-sickness as the described symptoms are very similar. The mechanisms involved in adverse reactions to wind turbines are not well understood but anxiety is a common response by individuals. It is clear that responses due to “acoustical” mechanisms are only a part of the response paradigm. Information applicable to normal physiological responses is critical. Balaban [14], for example, has investigated the neurological bases between balance control and avoidance conditioning, anxiety and conditioned fear responses.

In this study, of the 13 individuals who experience nausea, 6 are susceptible sea-sickness or car-sickness. Two individuals who are significantly adversely affected by nausea are not susceptible to sea-sickness or car-sickness, however. Instead of noise as such the effect may be better described as being due to vibration. Thus the adverse health effects on persons living near the turbines may be due to a unique combination of presently undefined acoustical, psychological and physiological responses. This is a significant area of new research.

4. Results and Discussion - Turbines and sound levels

Turbine noise criteria are often referenced to a single A-weighted sound level value. Analysis of ‘single-value’ A-weighted wind farm sound levels in the presence of all the sounds in the environment (the real world) is extremely difficult to do as at any one time there are at least 3 separate ‘sources of sound’ influencing sound levels – local sounds (e.g. insects), the turbines, and distant sources. It is not possible to separate out the contribution of each source once it is recorded as a single-value measure (e.g. LA90 or LAeq) at a specific location, such as a residence. It is possible, however, to identify individual sound characteristics of, for example, insect vs. turbine sound. ***Conversely, it is easy for people to hear wind farm noise within “ordinary” ambient sound.*** The following study results and observations quantify and qualify the above statements.

4.1 Audible sound and noise exposure

Wind turbine sound has a unique nature that is variable over time and is highly dependent on wind speed and directions, as well as locale. Objective measurement of such sound is not easy yet can be achieved using suitable measurement methods. Some standards refer to “audible characteristics” such as amplitude modulation, tonality, impulsiveness and so on. Observations at the different locations near the wind farms under different weather conditions and measurement distances indicate the sound of turbines are individually observable (swish, rumbles, clunks, whines) at distances of 200 – 500 metres. At around 900 metres only clearly distinctive turbines are identifiable (swish, rumbles) and by 2000-3000 metres the sound of turbines is cumulative and is heard as a general source of noise. At

each wind farm turbines could be clearly heard at dwellings approximately 2000 metres from the nearest turbines. The sound of turbines can be heard 2000 metres both upwind and 2000 metres downwind, as well at an angle to the turbines. The sound, with turbines operating, can be described as a steady rumble with a mixture of rumble – thumps. Turbine sound character varies regularly both in “loudness” and “tonality”. The general character over a long time period of an hour or so is of a steady rumble. This, however, depends considerably on wind speed and direction. The sound of turbines is also evident and sometimes more pronounced inside a dwelling, windows open.

It is observed that wind turbine sound at residences around 2000 metres or so is perceptible outside or inside a dwelling. The sound of turbines is often clearer inside a dwelling as higher frequencies are reduced through the building fabric. The question then becomes “Can the sound be analysed and assessed in a meaningful way?” This is an important question as sound character of the wind farm is clearly different within locales.

The general character of a long time period of an hour or so is of a steady rumble. This, however, depends considerably on wind speed and direction. Masking of turbine sound by tree rustle, wind noise or insects was not observed as being significant at the time of the study. The general wind speed at ground level was 2-3m/s with the breeze blowing from the turbines to the observer. Sound measurements at wind speeds above 3m/s recorded unacceptable levels of wind induced noise within the recording. Insect noise and bird-calls affect the measurements at all the different sound levels (LAeq, Ldn, Lden, LA95) and at specific times of the day and night – most commonly towards dawn.

4.2 Sound assessment of wind farms

Prediction of the potential sound levels at residences from turbines within a wind farm is a necessary first step in establishing potential effects. The calculation methodology of ISO 9613-2 [15] is employed. The method is a simple approach to sound prediction and can be considered as the first ‘rough-cut’ or scoping risk assessment. Reasonably accurate noise predictions are complex. Meteorological conditions, wind turbine spacing and associated wake and turbulence effects, vortex effects, turbine synchronicity, tower height, blade length, and power settings all contribute to sound levels heard or perceived at residences. In addition to this the method of prediction has what is known as “uncertainty”. ISO 9613-2 has an uncertainty of $\pm 3\text{dB(A)}$ at 1000 metres. However, in an operational wind farm sound levels are not just from the turbines immediately upwind (that is, sending sound ‘down’ to residences) but also from turbines downwind. Observations indicate turbines at a distance of about 2000 metres upwind and downwind are audible and affect the received levels at a central residence. The scatter in figure 4.2.1 and the ‘840 metre’ data in table 4.2.1 (for example) illustrates the effect of multiple turbines. Table 4.2.1 presents the distances of the respondents’ homes from turbines and the predicted sound levels at each residence. The measured sound levels at sampled residences are included.

Table 4.2.1: Measured and predicted sound levels at participant's homes from wind farms.

3+ turbines Distance (m)	Predicted Sound Levels		Outdoor measured sound levels (24hr)					Turbine sound causes	
	LAeq	LA95	LAeq	Ldn	Lden	LA95	LA95 night	Distress	Annoyance
800	42	40						yes	yes
800	42	40						yes	yes
840*	44	42						yes	yes
840*	44	42	48	56	56	31	38 - 45	yes	yes
1000	41	39						yes	yes
1000	41	39						yes	yes
1100	40	38						yes	yes
1100	40	38	50	54	54	41	28 - 51	yes	yes
1190	40	38						yes	yes
1575	36	34	61	65	65	41	36 - 43	yes	no
1575	36	34						yes	yes
1435	38	36						yes	yes
1435	38	36						yes	yes
1525	37	35						yes	yes
1400	34	32						no	no
1740	38	36	43	46	47	33	25 - 35	no	yes
1915	38	36	49	54	54	38	39	yes	yes
1915	38	36						yes	yes
2245	30	28						yes	yes
2245	30	28						yes	yes
3400	<28	<26						yes	yes
3400	<28	<26						yes	yes
3500	<28	<26						yes	no

Note * this location is affected by more than 6 turbines within 1500-2000 metres in a 270 degree arc around the residence

Figure 4.2.1 identifies the relationship between distance from a wind turbine (or group of turbines) and an affected residence. The distance is the shortest distance to a residence from the midpoint of the 3 nearest turbines. Spearman's Rho = -0.9 , $p < 0.001$ indicates that there is a strong correlation that as distance increases, predicted sound level decreases.

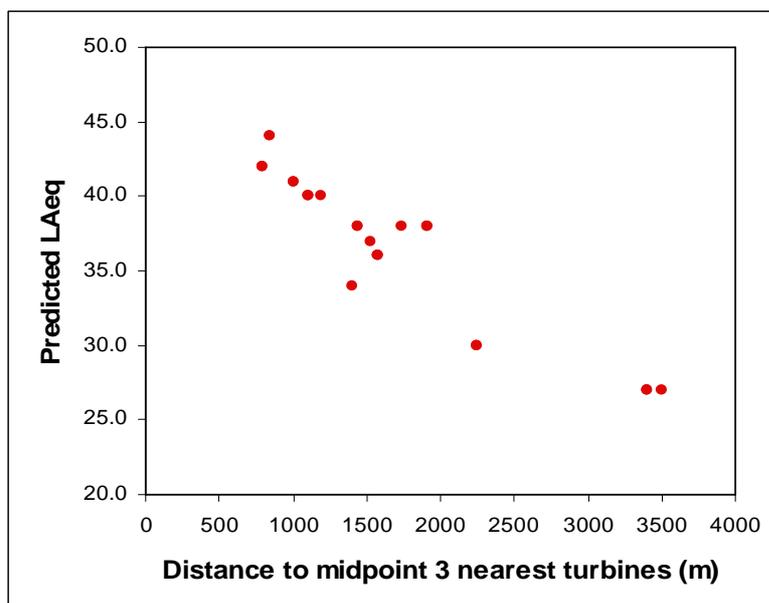


Figure 4.2.1: Correlation of distance to predicted sound levels (LAeq).

4.3 Audible Sound Character

When asked to ‘describe any one sound that is clearly noticeable when you are here at home’, respondents who live and sleep within the locale of the wind farms described the sound of the turbines as being “a distinctive hum or drone (63%)”, “repetitive (77%)”, “fluctuating, undulating or beating (77%)”. Of the residents offering an opinion, 32% found the sound percussive and 36% found the sound tonal in nature.

A sound audible to one person may be inaudible to another and, therefore, a method is needed to define, measure and assess “audible sound” [16]. A sound is said to be audible if it can be heard within the ambient sound (soundscape) of the locality. That is, the sound is not masked by the soundscape. This is a signal-to-noise phenomenon and can be defined in terms of sound detectability. Audibility can be considered as a psychophysical quantitative relationship between physical and psychological events:

- the physical relationship is considered as being the role of signal detection
- the psychological or behavioural and perceptive reactions of an individual are considered as psychoacoustical or sound quality relationships

In order to confirm that ‘audible characteristics’ exist and can be measured, measures of sound character are applied in Table 4.3.1 to describe the character of the sound of the turbines. The observations were made throughout the survey and the sample time in the Table reflects the observed time when people in a rural environment tend to be easily awakened. The outdoor measurements were taken 9 metres from the most affected façade; the indoor measurements were taken at head level, on the bed, by the pillow. The measures for loudness, sharpness, roughness, and modulation are calculated with dBSONIC v4.5, a sound quality analysis program.

Table 4.3.1: Example: Measures of sound character vs. outdoor sound level.

Sound Character Psychoacoustic Measures	Inside bedroom		Outside bedroom	
	Windows closed 4:00am	Windows open 4:40am	Windows closed 4:00am	Windows open 4:40am
Loudness N sone	2.5	3.0	2.9	8.5
Sharpness S acum	1.7	1.1	1.7	1.5
Fluctuation F vacil	0.10	0.03	0.07	0.08
Roughness R asper	0.17	0.02	0.12	0.36
	5Hz, 85% at	5Hz, 40% at	5Hz, 40% at	5Hz, 40% at
Modulation vs band	400Hz band	25/31.5/40Hz	25/31.5/40Hz	25/31.5/40Hz
LAeq dB 60sec	19	24	33	32

The measured levels as shown in Table 4.3.1 are due to observed turbine sound alone. The values change depending on wind speed and direction and are measured in the absence of other confounding sound, such as bird or insect song and tree-leaf rustle. It is the audible and inaudible sound character of the turbines that is the critical and overlooked factor in turbine noise assessment. People do not hear “dBA”. People hear sound and hear instantaneous variations in pitch (“swish”), thump, and loudness.

Observations at a residence approximately 430 – 750 metres from the nearest 5 turbines confirmed it is possible to hear distinct differences in sound character (whine, whoosh, thump) from individual turbines on a minute by minute basis. The resident affected made the observation that he records the turbines as being 'none', 'quiet', 'noisy' and 'roaring'. It is very noticeable when the turbines stop as only 'ordinary' ambient sounds remain. The observed and recorded difference between 'quiet' and 'noisy' is the character of the thump/whoosh noise as well as the overall LAeq sound level. A 'noisy' level is recorded outdoors at 42 LAeq dB. A 'quiet' level is recorded outdoors at 40 LAeq dB. The difference was in the character or loudness of the turbine noise.

The characteristics of 'whoosh', 'thump' etc are often grouped into a generic term called "amplitude modulation". Modulation can be a variation in the dBA sound level; for example, a variation in the tonal nature of the individual turbine, or a combination of both. At levels about 40 dB Fastl and Zwicker [17] state that a degree of amplitude modulation of 6% becomes noticeable. In a simple analysis 'modulation vs. band' is recorded, Table 4.3.1, where modulation may be more pronounced in specific third octave sound level bands (typically the 25Hz, 31.5Hz, 40Hz and 400Hz bands).

The lowest values in Table 4.3.1 are of – as far as could be recorded over 60 seconds – sounds predominantly due to audible wind turbine noise free of vegetation and or insect / animal / other noise. Higher values will be influenced by extraneous noise. This indicates that there is not yet a good objective measure for the character of audible turbine sound; from observation this appears to be a function of wind speed and direction and whether 2 or more turbines influence the sound.

Sound character changes over distance and the effect is critical in noise assessment for human perception. Measurements and observations show that as sound moves away from the turbines it changes its character with a rapid loss of higher frequencies leaving the lower frequencies audible. Changes in wind speed and direction also modify this change in character and low frequencies can be enhanced (increased) downwind. Upwind the lower frequencies are still audible even when there is a ground level breeze of 2m/s - 3m/s blowing against the turbines. It is also observed that as the temperature drops to around 10°C and a shifting breeze of 2m/s - 3m/s it becomes harder to physically distinguish sound because of the wind chill on the ears. Sound level meters may detect the variation in sound character but cannot identify the source. This must be done by observation.

Sound level decay rates by distance are shown following for a nominal wind turbine that has a sound power level of 104 dB(A) at a wind speed of 8 m/s. The overall A-weighted sound level for a single turbine decreases from 37 dB(A) at 500 metres to 12 dB(A) at 4500 metres, Figure 4.3.1. Figure 4.3.2 illustrates the difference between the A-weighted reduction in sound level and the true reduction in sound level referenced to the Z-weighting. The frequency bands that characterize observed modulated sound are presented. At low sound levels the Z-weighted values relate to audibility and a person's threshold of hearing. The A-weighted sound levels do not do this. The figures clearly show that the 'modulated' 25Hz, 31.5Hz and 40Hz bands are significantly understated in the A-weighted values compared to the Z-weighted values.

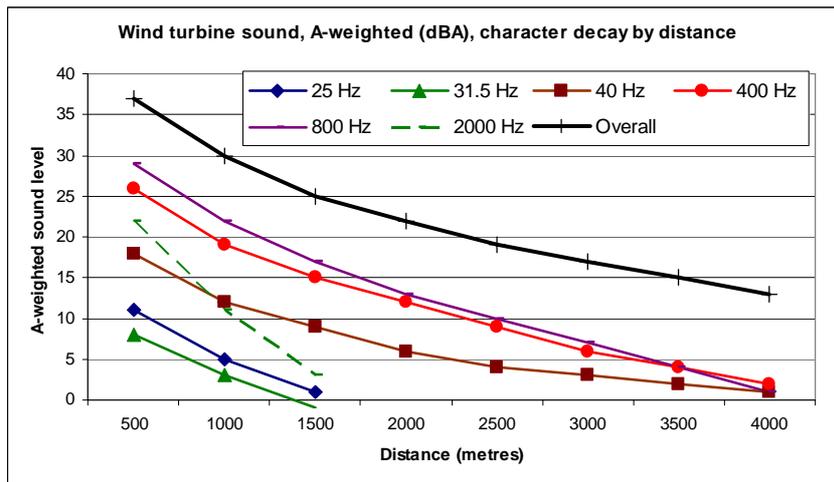


Figure 4.3.1: Sound level decrease by distance for a 104 dB(A) SWL turbine, A-weighted

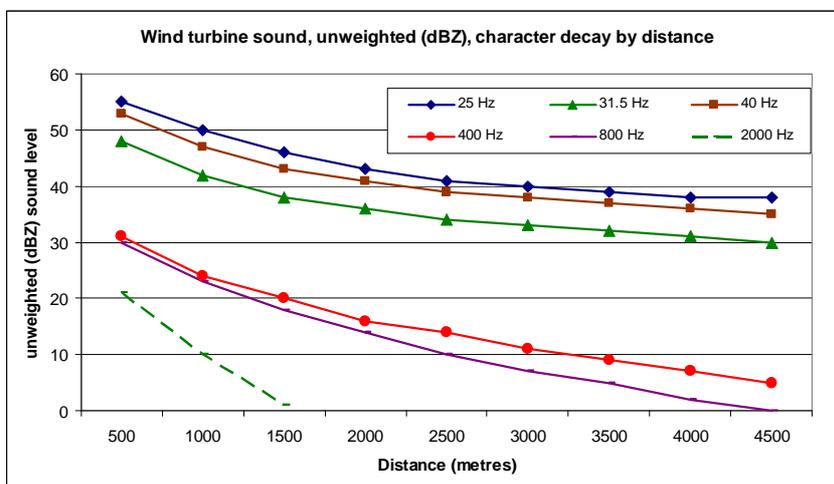


Figure 4.3.2: Sound level decrease by distance for a 104 dB(A) SWL turbine, Z-weighted

The sound levels from four active turbines are illustrated in Figures 4.3.3 – 4.3.5 following. Measurements were made in line with two sets of two turbines. There is a 4.5 dB(A) LA95 noise reduction with a doubling of distance from the measurement location to the turbines (153 metres v 327 metres). This indicates noise reduction per doubling of distance between that for a point source (-6dB) and of a line source (-3dB). This suggests that the 'standard' noise reduction of 6 dB per doubling of distance must be treated with caution when prediction of noise from a group of turbines is being considered in the near field.

- 1) Turbine Group 1: measured LAeq 45.2, LA95 43.6, nearest turbine at 153 metres
A clean 'whrr' sound, no thumps, turbines running but no audible turbulence noise, wind blowing from turbines to measurement, breeze 2.5m/s – 4.8m/s at ground level
- 2) Turbine Group 2: measured LAeq 40.6, LA95 39.1, nearest turbine at 327 metres
A clean 'whrr' sound, no thumps, tonal noise, turbines running but no audible turbulence noise, wind blowing from turbines to measurement, 1.6m/s at ground level.

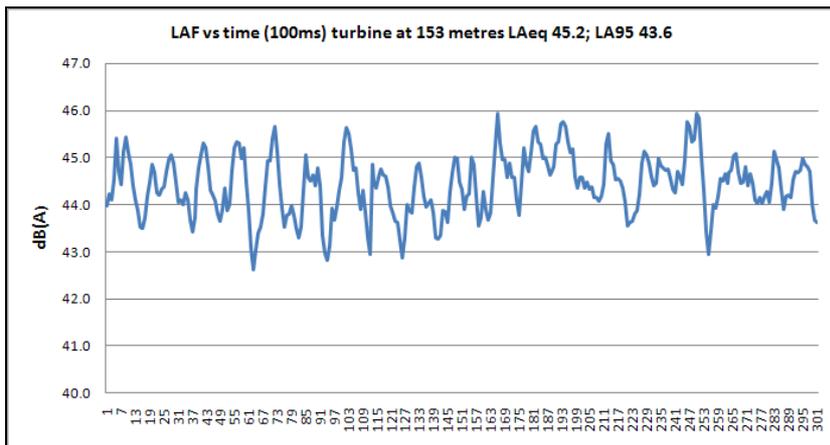


Figure 4.3.3 Turbine sound levels at 153 metres

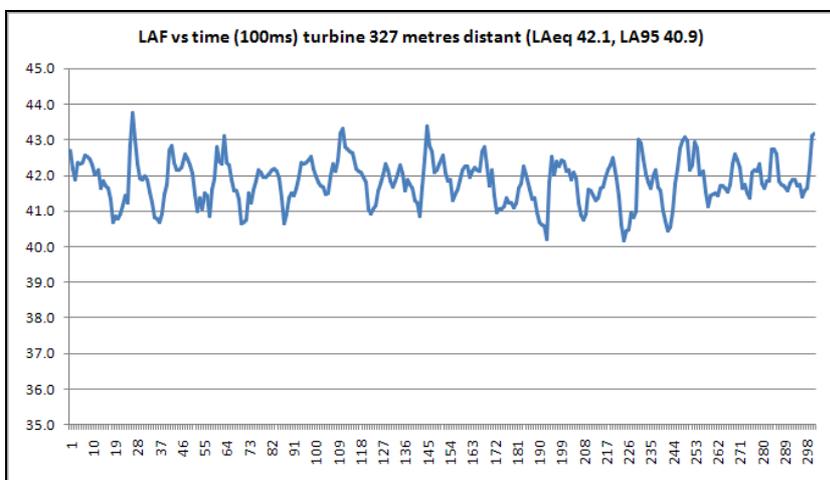


Figure 4.3.4 Turbine sound levels at 327 metres

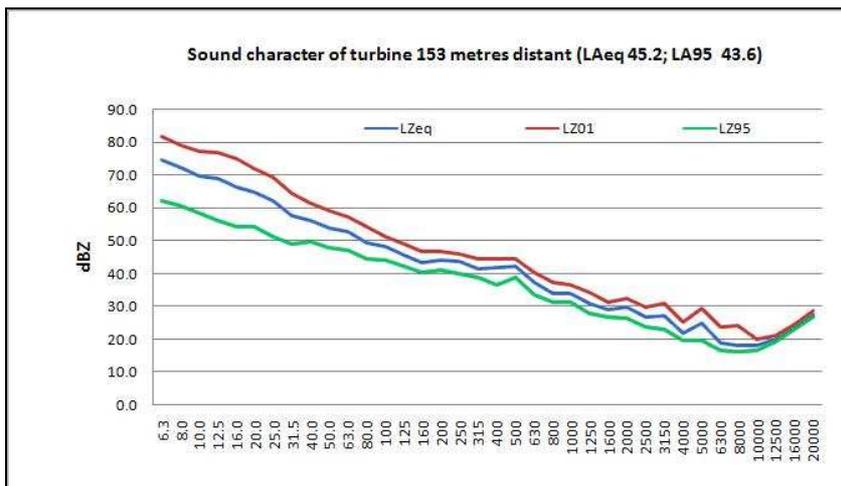


Figure 4.3.5 Turbine sound levels in third octave bands

The observations show a regular beat in the order of 2 dB. This beat is in the overall sound levels and would not normally be audible. The modulation shows, however, that audible sound components can be generated from normally operating turbines. The later figure shows that infrasound levels can be readily measured in the field under conditions of low wind speed when a standard wind

shied is acceptable. The 4 turbines to the south appear to have their loudest 'whoosh' on the downstroke, approximately 30 degrees from the horizontal. There are deep 'whoomph' lasting for approximately 3 to 6 blade / tower pass-bys. The whoosh can also be heard on the upstroke, as well as whines and clunks.

However, while the study is concerned with health effects and sound character it is acknowledged that all noise criteria dealing with wind farm noise are based on single values, usually related to the A-weighted background level or equivalent-continuous level. This means that all detail is lost, figure 4.3.6. It is not possible to say what the actual sound levels consisted of without observational detail. In this particular case, the observational detail noted turbine activity and high ambient levels due to wind noise in vegetation. The conclusion is that single-level noise criteria have almost no value or applicability in determining sound levels and effects from wind turbine noise emissions.

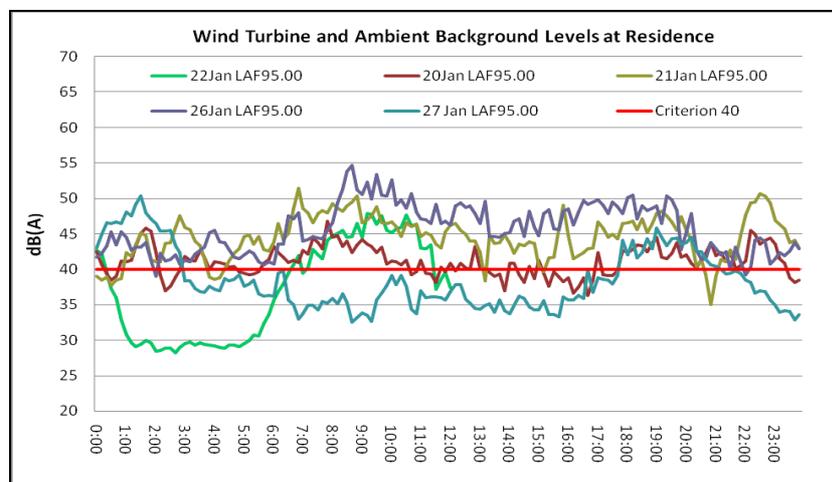


Figure 4.3.6 Turbine and ambient sound levels on different days

Field notes from one of the study days illustrate the type of information that is needed to clearly identify the sound of turbines compared to the sound of the local environment:

4:32am Small bedroom to side of the house. Opened window beside bed and turbines clearly audible as a 'roar' 10min LAeq 24.1dB; LA95 20.9dB; 8Hz-12Hz around 59dB and modulating 53dB-63dB; The rear yard is a lot quieter than the front yard as the eastern turbines are a lot more noticeable

- Turbines to the east clearly audible inside living room with window open
- Opened windows in main bedroom (above bed, large window to the east).

Shifting character of the turbine noise noticeable inside and outside the home. The sound of the turbines began to fade at first light – weather still calm. At dawn the wind picked up and tree rustle plus infrequent bird song and infrequent dog bark.

4.4 Sound Outside - Inside the Home

The sound of turbines is also evident and sometimes more pronounced inside a dwelling, windows open or closed. Observations confirm that wind turbine sound at residences around 2000 metres or so is perceptible outside or inside a dwelling. The sound of turbines is often clearer inside a dwelling as higher frequencies from wind and insect activity are reduced through the building fabric.

Figure 4.4.1 presents measured sound levels inside and outside a home located approximately 900 metres from turbines, windows closed and open, at 4am.

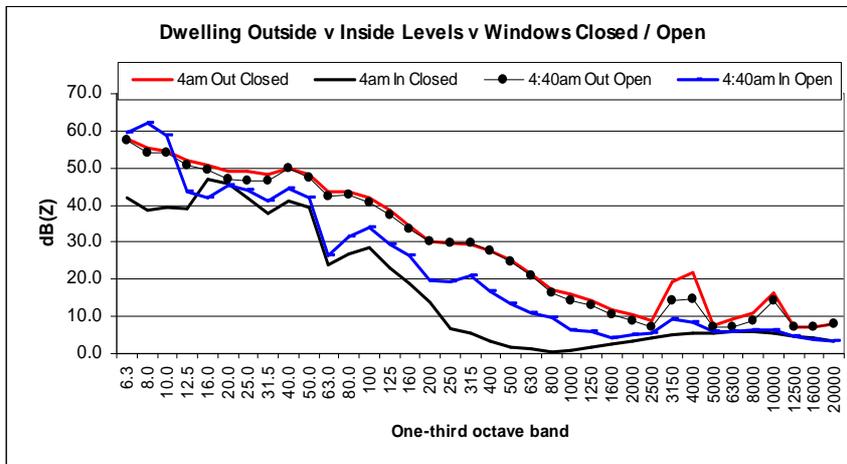


Figure 4.4.1: Measured LZeq sound levels inside and outside a home, windows closed and open.

Table 4.2.3 (see previous section ‘Audible Sound Character’) analyses the character of the sound at the same times. Figure 4.4.1 shows that insect and bird noise (3150-4000Hz and 10,000Hz) heard outside the bedroom is not significant inside with the windows closed. The sound is audible with the windows open. Critically, however, the infrasound and low frequency sound levels (12.5Hz to 60Hz) are not reduced as much as the higher frequencies. Most importantly the infrasound levels at 6.3Hz – 10Hz actually increase. These are the frequencies (to 40Hz) of interest in this research with respect to nausea and general wellbeing.

The following figures (4.4.2 to 4.4.4) provide more detail as to the different measures summarised in Table 2. The figures further confirm that audible characteristics such as modulation can be measured with a variety of standard psychoacoustical – sound character measures.

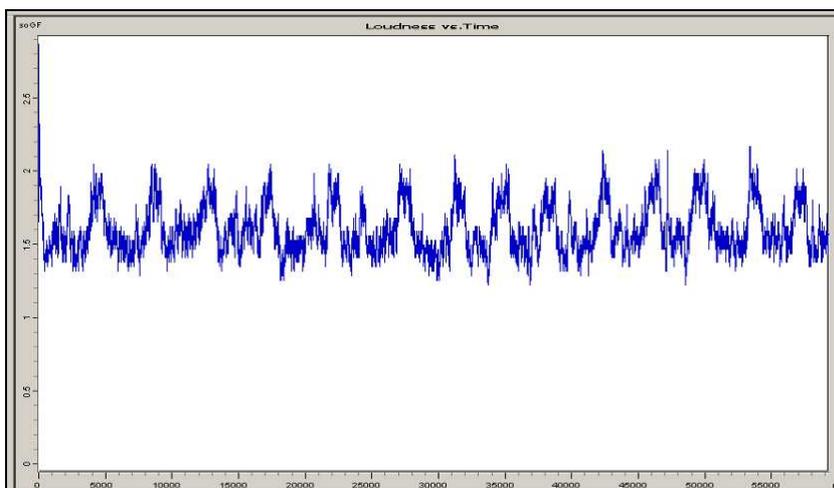


Figure 4.4.2: Time variation of turbine noise, outdoors, turbines 930-1280 metres distant, showing regular amplitude modulation (loudness) at 4am outside the bedroom

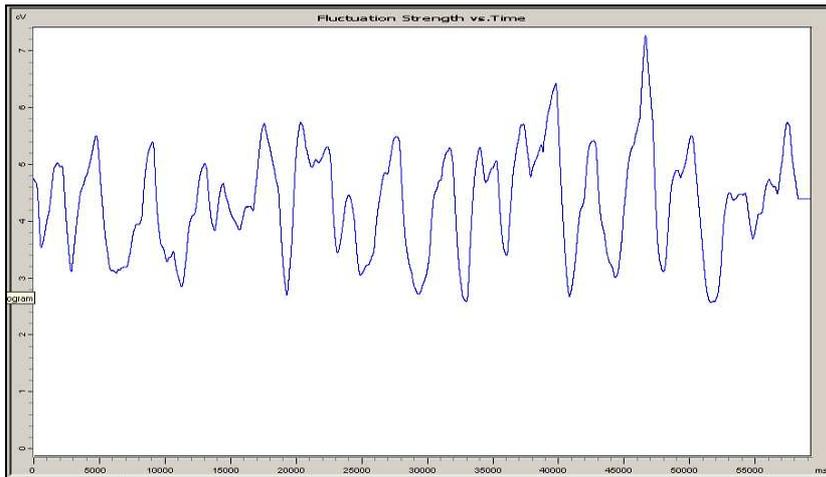


Figure 4.4.3: Time variation of turbine noise, outdoors, turbines 930-1280 metres distant, showing regular modulation (fluctuation strength) at 4am outside the bedroom

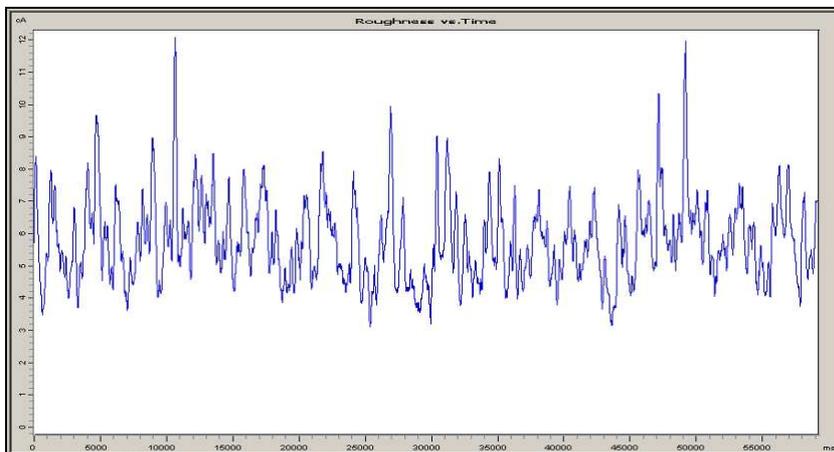


Figure 4.4.4: Time variation of turbine noise, outdoors, turbines 930-1280 metres distant, showing regular modulation (roughness) at 4am outside the bedroom

The variability of sound by character is illustrated in Figure 4.4.5. The figure shows distinct 'peaks' at different frequencies and these peaks can be attributed to different types of noise sources. Broadly, for example, below 1000 Hz belongs to wind turbine sound; 3000-4000 Hz belongs to insects; 6000 Hz belongs to bird-calls, and so on. It is the sound of the insects that dictates the overall A-weighted sound level and this illustrates the extremely difficult task of attributing A-weighted 'background' sound levels to any one source. For much of the time the sound levels will be a mixture of short-term sound (such as bird-calls), medium-term sound (such as insect noise) and long-term sound from turbine activity. The turbines – when running – provide a constant source of 'background' noise into the environment. This source can be affected by wind in vegetation which can be identified by reference to spectrum analysis. Standard sound analysis using 'background' measures fail to differentiate between different types of sound that make up the total acoustic environment.

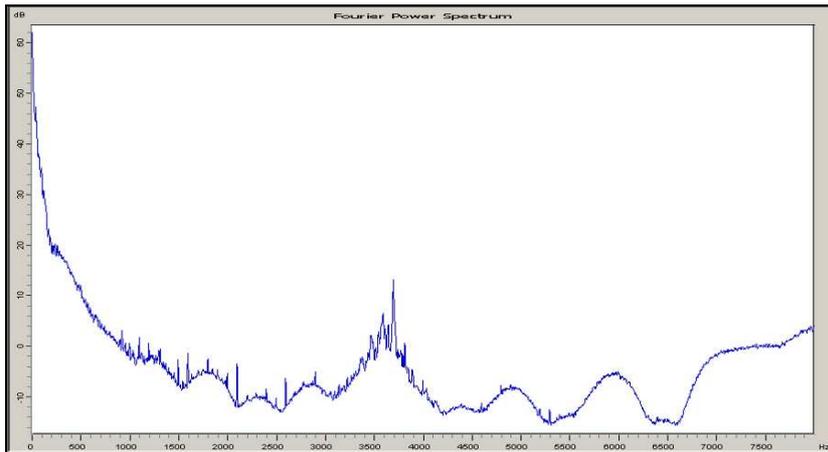


Figure 4.4.5: FFT spectrum of turbine noise, outdoors, turbines 930-1280 metres distant, at 4am outside the bedroom showing the effect of insect/animal/bird noise at 3500Hz and at other frequencies.

Figure 4.4.5 shows that conservatively, the dB(A) value could be reduced by 10 dB or more if this source of noise is removed from the calculation. Audible turbine sound is generally important in the 25 Hz-40 Hz and 160 Hz – 800 Hz third-octave bands and clearly audible as rumble and clunks. Audible or sub-audible sound emissions from turbines will not occur all the time, of course, as turbines are often stopped and operate at different times and under different prevailing wind directions and wind speeds. If the character of the sound is foreign to the existing environment then it has less chance of being accepted. To an individual, the time of the day the sound is heard is important with unusual sounds in the early morning being less acceptable than if they are heard during the day.

Additionally, if the sound has information content that the person does not want to hear that sound is perceived negatively. The evidence, however, is that once a person has become sensitised to the activity of the turbines this sensitivity is not habituated. Personal perception of a sound as “noise” therefore combines a variety of attributes that cannot be measured by simple instrumentation. The perception of audible character by individuals is ‘active all the time’. Practical assessment therefore requires monitoring, measurement and assessment must be in real-time on a continuous ‘24/7’ basis using automated sound quality analysis software.

4.5 Low frequency Noise and Infrasound

Low frequency noise and infrasound are normal characteristics within the environment. Wind itself has measurable low frequency and infrasound character. Measured levels of infrasound inside and outside a dwelling as described in the previous section give an indication of potential effect. Putting aside the question of audibility the levels in the following Figures 4.5.1 and 4.5.2 are assessed on the basis of their energy variation at an analysis rate of 10 ‘samples’ per second. The pulses are seen as being regular in nature with a confined peak to trough shift of 6 dB to 7dB over a range of approximately 13 dB. Modulating sound with these characteristics outside and inside a home indicates that the sound is not natural but is being generated by an external source. In this case the operation of the wind farm. The people living in the home are affected by wind farm activity outside and inside the home. The potential affect of low frequency infrasound is assessed more as a sound induced vibration, or by rapid variation in perceived air pressure, Table 4.5.1, rather than as audible sound.

Table 4.5.1: psychological and physiological sequelae resulting from low frequency vibration [20].

Frequency of vibration	Symptoms	Frequency of vibration	Symptoms
4–9 Hz	Feelings of discomfort	10–18 Hz	Urge to urinate
5–7 Hz	Chest pains	13–20 Hz	Head Aches

The following figures, 4.5.1 and 4.5.2, illustrate the character of the 12.5 Hz band over 60 seconds inside and outside a dwelling. The sound is from wind turbines (as recorded by observations of the audible sound). The 12.5 Hz band is illustrated as a ‘marker’ for potential adverse health effects due to air pressure variations but the band is not the only marker. The interior figure shows regular peaks and troughs compared to the outside levels recorded at the same time. Turbine sound character within the bedroom is related to building construction and room dimensions. This is most noticeable at 38Hz – 40Hz where the sound is audible.

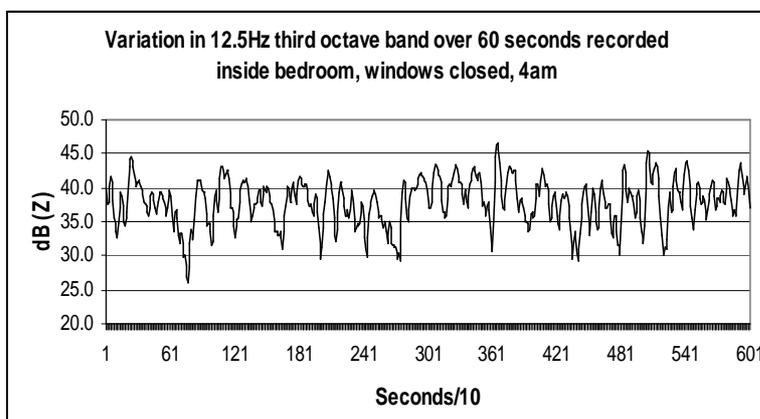


Figure 4.5.1: Variation in infrasound levels, inside bedroom at 4am

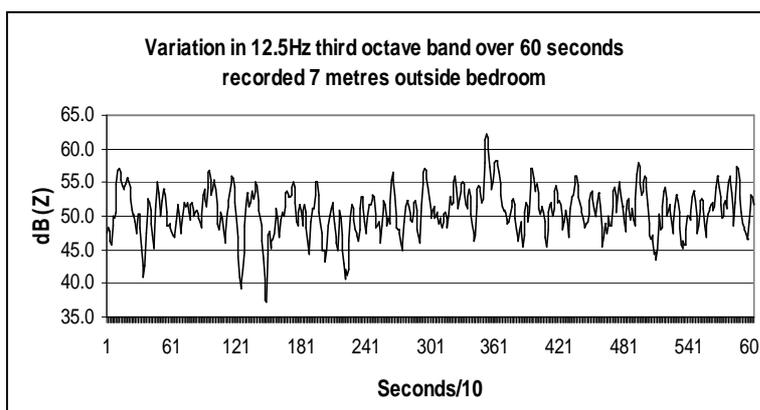


Figure 4.5.2 Variation in infrasound levels, outside bedroom at 4am

In comparison to the relatively consistent (both in sound level and modulation) wind farm affected levels (above) figure 4.5.3 illustrates the natural sound levels in the 12.5 Hz third octave band level recorded in a rural environment without turbines. At a mild breeze of 2m/s the levels vary considerably from 32 dB to 78 dB, with distinctive shifts in 100ms LZeq levels over the 60 seconds.

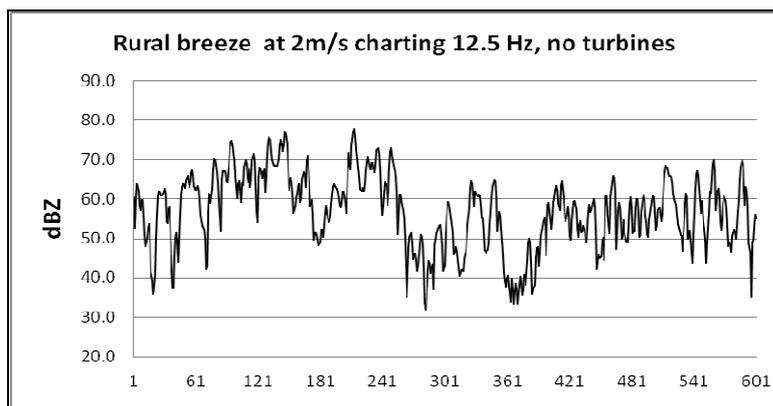


Figure 4.5.3: Outdoor rural natural sound levels in the 12.5Hz LZeq third octave band

Not all wind farms recorded as part of this research appear to have adverse health effects recorded for the infrasound frequencies and this is a confounder relating to the physical properties (wind turbine power rating and design, wind farm layout, topography, wind speeds and wind direction) of specific wind farms.

4.6 Sound Perception

An outcome of the observations and interviews of the previous studies indicated a need to establish a baseline reference point with sounds of known characteristics that could be reviewed by any person at any time. The purpose was (and is) to identify the perceptions of the sound as experienced by the person listening to the sound. The study was expanded by presenting a series of environmental sounds or 'soundfiles' to be judged by the respondents. Each soundfile was recorded at a sampling rate of 44100 Hz, 16 bit, mono and saved in Microsoft PCM .wav format. The character of the soundfile was not made known to the respondents until after the person had made an initial assessment. The character was then discussed.

The reference soundfiles consisted of: (1) Amplitude modulated fluctuating noise; (2) Outdoor residential neighbourhood and wind farm noise; (3) Outdoor rural environment with sound of wind farm 2200 metres distant, through trees; (4) sound plus tones at 150 Hz, 990 Hz and 4000Hz; (5) sound plus tones at 330 Hz, 400 Hz and 471 Hz; (6) Sound of wind turbines 930 metres distant, inside bedroom, windows closed [19]. Each sound has a unique character or characteristics and these can be identified by acoustical, musical and sound quality measures.

The aim of this part of the study was to observe if respondents can identify wind turbine sound in ambient sound. In response to the question "Choose, from the following list, the words that best describe the quality or character or 'soundscape' of your environment that you hear when you are here at home. The usual character is..." selected 28% smooth, 16% bright, 4% warm, 44% gentle, 12% rich, 24% powerful, and 44% rough. In this question there was some confusion between different homes, with some referring to homes away from the wind farm locale. The words used by respondents to describe the 'rough' quality of their environment used the words industrial, monotonous, irritating, invasive and beating and these referred to the activity of the wind turbines.

The question 'Choose, from the following list, the words that best describe any one sound that is clearly noticeable when you are here at home. The sound is...' was answered by the respondents to

describe the environment, including wind turbine sound as gentle 24%, powerful 32%, rough 16%, sharp or metallic 12%, percussive 32%, dull 16%, tonal 36%, harsh 16%, a distinctive hum or drone 48%, fluctuating or beating 60%, impulsive 36%, and repetitive 60%. Post response interviews with respondents indicated that this question was answered with people providing an impression of the environment when the turbines were not operating (e.g. gentle) and when they are operating (e.g. beating).

The personal (individual) perceptions of the character of soundfile (6), figure 4.5.4, with distinctive wind turbine sound is described by 90% of the respondents as being 'annoying', with 68% saying the sound had a 'thumping' characteristic and 88% saying the sound is repetitive. The dominant characteristics are described by the respondents as being: Fluctuating, undulating, beating (84% of respondents); rumble (72%); a distinctive hum (52%); tonal (32%); percussive (48%); and powerful (40%). Similar characteristics were observed for wind turbine soundfiles 2 and 3.

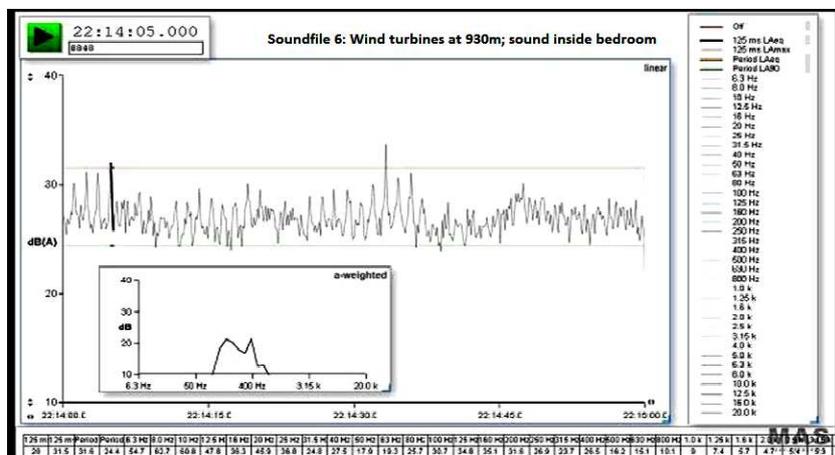


Figure 4.5.4: Soundfile 6” turbine thump

The ‘thumps’ are shown in the figure as groups of 3 spikes and it is this characteristic that people find intrusive, disturbing and annoying. The three peak-to-trough levels at 3-5 seconds, for example, exceeds 4 dB(A) and is assessed as being unreasonable, tending to excessive. It is therefore reasonable to apply the subjective terms of thump, beating, hum, etc to the definition of ‘audible characteristics’ and apply them as objective measures of wind farm noise assessment.

5. Study Limitations

First, the sample size was a major limiting factor in the analysis and interpretation of the data. However, while the findings reported here may be considered somewhat speculative and need to be confirmed with a larger sample, they are congruent with findings reported overseas on health-related quality of life and exposures to noises. Future studies capturing more participants would afford the use of structural equations modeling, a more powerful multivariate technique capable of elucidating and testing causal relationships.

Second, while objective measures of sound levels (A-weighted and Z-weighted values) are applied in this study, such measurements have had very limited success in predicting health outcomes

and they are severely lacking in predicting individual responses to noise. Additional objective measures of sound character are presented (loudness, sharpness, roughness, and fluctuation) and this study concludes they have limited application although more descriptive than measures of sound levels alone.

Third, while use of predicted noise contours calculated are applied, the study shows that it is essential to undertake actual real-time outdoor and indoor noise measurements to further elucidate the relationship between noise and health. Additionally, estimating the time that residents are exposed to the measured noise is an important covariate.

Finally, the use of subjective versus objective health measures to detect changes in health due to environmental factors maybe viewed as “soft”. Objective outcome metrics such as blood pressure or chronically elevated cortisol levels are arguably well defined and easily measured, while noise-induced sleep disruption, stress, and similar subjective symptoms are less easily measured and distinguished from the background levels present in the population. However, objective manifestation of health effects associated with noise-related annoyance may emerge after some years since the onset of exposure, whereas subjective appraisals of wellbeing and health suffer no such time lag. Thus for cross-sectional studies as reported here subjective measures are more suitable.

6. Discussion Summary

The study is the final in a 7-year research program into low amplitude intrusive noise. The persons who took part in the study (apart from the greenfields’ respondents) are all adversely affected by wind farm activity and, as recorded in individuals’ case study, there is evidence of serious harm to health. The subjective experience of annoyance is a common reaction to noise. Different individuals can exhibit different annoyance reactions to the same noise, and these individual differences can be ascribed partly to differences in noise sensitivity. The findings suggest that the individuals living near the wind farms of this study have a degraded Health-Related Quality of Life through annoyance and sleep disruption and that their health is significantly and seriously adversely affected (harmed) by noise.

Based on the results of the study it is argued that, when exposed to wind farm noise and wind turbine generated air pressure variations, some individuals will more likely than not be so affected that there is a known risk of serious harm (also termed ‘significant adverse effect’) to health. By ‘serious harm’ it is meant harm that is more than mere annoyance and that can be quantified in terms of reported illness, sleep disturbance or other physical effect. Definitions of ‘serious harm’ are postulated:

- 1) A measure of serious harm is if the exposed individual is adversely affected to the extent that he or she is obliged to remove himself or herself from the exposure in order to mitigate the harm; and / or
- 2) A measure of serious harm is if three or more serious adverse health effects are recorded for an individual. Three serious adverse health effects are established from this study as being:
 - a) sleep disturbance with a global PSQI greater than 5,
 - b) a state of constant anxiety, anger and helplessness,
 - c) an SF36v2 mental health value of less than 40.

The outcomes of the study are concerned with the potential for adverse health effects due to *wind farm modified* audible and low frequency sound and infrasound. The study confirms that the logging of sound levels without a detailed knowledge of what the sound levels relate to renders the data uncertain in nature and content. Observation is needed to confirm the character of the sound being recorded. Sound recordings are needed to confirm the character of the sound being recorded.

The measures of wind turbine noise exposure that the study has identified as being acoustical markers for excessive noise and known risk of serious harm to health (significant adverse health effects) are:

1. Criterion: An LAeq or 'F' sound level of 32 dB(A) or above over any 10 minute interval, outside;
2. Criterion: An LAeq or 'F' sound level of 22 dB(A) or above over any 10 minute interval inside a dwelling with windows open or closed.
3. Criterion: Measured sound levels shall not exhibit unreasonable or excessive modulation ('fluctuation').
4. Criterion: An audible sound level is modulating when measured by the A-weighted LAeq or 'F' time-weighting at 8 to 10 discrete samples/second and (a) the amplitude of peak to trough variation or (b) if the third octave or narrow band characteristics exhibit a peak to trough variation that exceeds the following criteria on a regularly varying basis: 2dB exceedance is negligible, 4dB exceedance is unreasonable and 6dB exceedance is excessive.
5. Criterion: A low frequency sound and infrasound is modulating when measured by the Z-weighted LZeq or 'F' time-weighting at 8 to 10 discrete samples/second and (a) the amplitude of peak to trough variation or (b) if the third octave or narrow band characteristics exhibit a peak to trough variation that exceeds the following criteria on a regularly varying basis: 2dB exceedance is negligible, 4dB exceedance is unreasonable and 6dB exceedance is excessive.
6. Definitions: 'LAeq' means the A-weighted equivalent-continuous sound pressure level [18]; 'F' time-weighting has the meaning under IEC 61672-1 and [18]; "regularly varying" is where the sound exceeds the criterion for 10% or more of the measurement time interval [18] of 10 minutes; and Z-weighting has the meaning under AS IEC 61672.1 with a lower limit of 0.5Hz.
7. Approval authorities and regulators should set wind farm noise compliance levels at least 5 dB(A) below the sound levels in criterion (1) and criterion (2) above. The compliance levels then become the criteria for unreasonable noise.

Measures (1-6) above are appropriate for a 'noise' assessment by visual display and level comparison. Investigation of health effects and the complex nature of wind turbine noise require the more detailed perceptual measures of sound character such as audibility, loudness, fluctuation strength, and dissonance.

7. Acknowledgement

Funding for this study was provided through a Research and Development grant from Noise Measurement Services Pty Ltd Brisbane Australia.

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