AN ASSESSMENT OF INFRASOUND AND OTHER POSSIBLE CAUSES OF THE ADVERSE EFFECTS OF WINDFARMS

Tharpaland International Retreat Centre
(TIRC)
Parkgate, Dumfries DG1 3LY

2004

CONTENTS

PREFACE

The following document is a preliminary draft. Although in an incomplete form, this draft is being presented at this time with the view of sharing information that is of great importance to the issue of public health in Scotland. It was felt that whatever shortcomings this preliminary draft may have, would be offset by the benefit of making it available to the wider public.

AN ASSESSMENT OF THE POSSIBLE CAUSES OF ADVERSE EFFECTS OF WINDFARMS

Introduction

In March 2003, following news of a proposal to build a massive wind farm close to Tharpaland International Retreat Centre[1] in the Forest of Ae, Tharpaland set about assessing the wider implications this would have on the Centres ability to provide suitable conditions for meditative retreat, if the windfarm was approved. To this end, Tharpaland decided to study the possible impact a windfarm might have on meditative retreaters, in particular. Studies were then carried out at three Scottish windfarms: Hagshaw Hill, Beinn An Tuirc, and Deucheran. The results of these studies are presented in 'The Effects of Windfarms on Meditative Retreaters: A Human Impact Assessment' (Tharpaland, 2003b).

Although the original studies were concerned with the impact of a windfarm on meditative retreaters alone, surprisingly the negative and adverse effects noted have serious implications for the health of the general population at large. Therefore, a follow-up analysis of the data, to explore the possible causes of these effects, was carried out.

The first section of this report presents a list of possible causes, followed by a brief analysis of 'visual impact' and 'auditory impact' in particular. However, a further analysis of the various health effects in the 3 windfarm studies (Tharpaland, 2003b), suggests a more <u>subtle</u> cause may be responsible. Therefore the rest of this report then concentrates on low frequency noise in general and infrasound in particular, as the main probable cause of these effects.

Possible Causes

Of the many possible <u>causes</u> of the adverse effects observed in the 3 windfarm studies:

- Some were originally suggested in Tharpaland's 'Initial Response to Scottish Power's Scoping Report March 2003' (Tharpaland, 2003b, Appendix 1)
- Some were indicated in the subjective reports by the subjects in the 3 windfarm studies (Tharpaland, 2003b)
- Some have been implicated in the relevant research literature (see Appendices 1-6)
- While others have been identified by, or are implicated in, the reports of residential communities experiencing quite similar adverse effects from living near existing wind farms (Tharpaland, 2003b, Appendix 7)

A list of possible causes compiled from these various sources is presented in Table 1 overleaf.

[1] For information about Tharpaland International Retreat Centre see: Tharpaland International Retreat Centre Brochure (Tharpaland, 2003a); and 'Reflections on Tharpaland', CD-Rom & Video (Tharpaland, 2003c).

Table 1. Possible Causes of the Adverse Effects Observed in the Three Windfarm Studies

1.	Low-frequency Noise and Infrasound	(1) Air-borne (2) Earth-borne
2.	Electromagnetic Fields	(1) Direct (2) Induced
3.	Geophysical	(1) Vibrations (2) Electromagnetically-induced conduction (3) Infrasound
4.	Synchronistic Structural (e.g. Tower)	(1) Resonance (2) Vibration
5.	Synchronistic anatomical vibration induced by	(1) Low frequency noise (2) Infrasound (3) Geophysical vibration
6.	Auditory impact	(1) Loudness (Pressure level, dB) (2) Cumulative (3) Rhythmic Patterning (4) Anti-Nodal (5) Aerodynamic (6) Mechanical – (normal operation, malfunction, squeaking, clanging, roaring etc.) (7) Electrical (Hum) – (transformer, cable, generator) (8) Subliminal (Low frequency noise, infrasound)
7.	Visual Impact	(1) Overwhelming size and visual presence (2) Spinning of blades (3) Asynchronistic rotational patterning of blades (4) Shadow-flicker (strobe effect) (5) Flicker of partially hidden blades (behind horizon) (6) Glinting
8.	Acoustic-Visual Interaction	
9.	Air Turbulence (in the wake of spinning blades)	
10.	Tower Deflection	
11.	Other related variables	(1) Individual differences (subjects) (2) Individual differences (wind turbines/farms) (3) Physiological responses (vestibular dysfunction, amygdala, reticular formation, limbic system, hypothalamus, visual cortical satiation, electro-chemical cortical patterning) (4) Psychological responses (5) Subliminal factors

In the windfarm studies (Tharpaland, 2003b), the subjects experienced adverse effects from many of the possible causes listed in Table 1, in particular, the auditory and visual impacts of the windfarms visited. The subjects often identified these causes directly as such in their subjective reports.

Visual Impacts

1. Almost all of the subjects participating in the 3 windfarm studies reported adverse physical and psychological effects just looking at the turbines. Some of the principal aspects of the visual impact of the turbines the subjects found most disturbing were:

    - the 'demand quality' of their enormous size
    - their dominating presence within the landscape
    - the hypnotic effects associated with their spinning blades
    - shadow flicker

2. Some of these visual impacts were effective in producing physical and psychological adverse effects, including distress, headache and nausea, from vantage points of up to 8.7 kilometres from the turbine field.

3. The subjects also reported very disturbing visual after-effects, including re-current visual imagery of spinning blades while awake, in meditation, and in dreams, hours and even days after the windfarm visits.

4. These findings of the windfarm studies indicate that 'visual impact' of windfarms is related:

    - not just to 'visual amenity' or external aesthetic issues alone,
    - but also to deep internal physiological and psychological processes within the person themselves,
    - and therefore have far-reaching medical implications for public health

5. These findings indicate that many aspects of the visual impact complex were functioning as causes of many of the adverse health effects reported in the 3 windfarm studies.

Auditory Impacts

1. Subjects experienced many of the different noises produced by the turbines to 'be highly intrusive and very disturbing'. These included many different types of mechanical, aerodynamic and other noises emitted by the turbines variously described as:

   - 'clanging' and 'clunking'
   - 'squeaking' and 'grating'
   - 'thumping'
   - 'constant high whining'
   - 'humming'
   - 'whooshing of the blades'

2. What made these noises most disturbing was that many of them were:

   - 'constant'
   - 'repetitive'
   - 'rhythmic' (inducing heart palpitations)

3. Far from being inaudible within the background noise, many of these sounds were:

   - not masked by ambient background sounds at all
   - audible at distances of up to several kilometres

4. Many residential groups living near existing windfarms in the UK, Sweden, and Germany also find the noises emitted from the turbines to be very intrusive and disturbing (See Appendix 6), describing them as:

   - 'frightening'
   - 'tormenting'
   - 'like Chinese water torture'
   - 'driving people mad'
   - 'making their lives unbearable'
   - 'making those affected physically sick'

5. Many of the main symptoms attributable to noise pollution described in the Noise Pollution Prevention Programme (Defra, 1998 - see Appendix 2) were reported both by the subjects in the Tharpaland windfarm studies (2003b), and by those living near existing windfarms (see tables on pages 26-30), including:

   - 'stress'
   - 'irritability'
   - 'anxiety'
   - 'bad moods'
   - 'aggressiveness'
   - 'hostile attitudes'
   - 'increased pulse rates'

- 'drowsiness'
- 'fatigue'
- ‘loss of concentration'
- 'headaches'

6. Therefore, one of the main probable causes of the adverse health effects reported in the 3 windfarm studies is noise pollution from the windfarms

Low Frequency Noise and Infrasound

Some of the most pronounced adverse effects reported in the windfarm studies (Tharpaland, 2003b), including the loss of concentration and many of the worst physiological and psychological symptoms were experienced in the absence of gross auditory and visual impact, and at too great a distance from the wind turbines/farms themselves to implicate more obvious auditory or visual factors as their possible causes.

A comparative analysis of these particular effects with those reported in the research literature, and with those experienced by residential communities living near to existing windfarms (Table 2 below), suggested that some more subtle, perhaps subliminal factors may be producing these effects. The following analysis suggests that one of the key subliminal factors may be low frequency noise and infrasound.

This possibility is explored in the following 8 sections which summarize anecdotal and referenced statements on infrasound, their effects, and its relationship to windfarms (turbines). These are followed by 6 appendices giving further details of references about the effects of infrasound.

Table 2

Comparison of symptoms from windfarms with symptoms of exposure to Infrasound and Low Frequency Noise

	Studies of the Effects of Infrasound and Low Frequency Noise Exposure	Windfarm studies and surveys of health effects		
Symptoms		**Barrow in Furness**	**Sweden**	**Tharpaland research**
Anger/Irritation/Aggression	Y	Y	Y	Y
Annoyance	Y	Y	Y	Y
Anxiety/Stress	Y	Y	Y	Y
Blood pressure increased	Y		Y	
Body vibration	Y		Y	Y
Breathing difficulties	Y	Y		Y
Depression	Y			Y
Difficulty concentrating	Y	Y		Y
Disturbed sleep/insomnia	Y	Y	Y	Y
Dizziness	Y	Y	Y	Y
Fatigue	Y	Y		Y
Headache/head pressure	Y	Y	Y	Y
Heart rate alterations, palpitations	Y	Y	Y	Y
Loss of confidence	Y			Y
Nausea	Y	Y		Y
Noise unbearable/tormenting	Y	Y	Y	Y
Noise that is felt, not heard	Y	Y		
Pressure in chest	Y	Y		Y
Pressure in ears	Y			Y
Pain in stomach	Y		Y	Y

1. What is Infrasound?

Leventhall (2003) (see Appendix 4) makes the following points about infrasound in the DEFRA report:

(1) 'Sound is detected by the ear in a mechanical process, which converts the sound waves to vibrations within the ear.' (2.1)

(2) 'The frequency of a sound is the number of oscillations which occur per second (Hz)…' (2.2)

(3) 'The frequency range of infrasound is normally taken to be below 20Hz**,** and that of audible noise from 20Hz to 20,000Hz.' (2.4)

(4) 'Low frequency noise spans the infrasonic and audible range and may be considered as the range from about 10Hz to 200Hz.' (2.4)

2. Do Wind Turbines Generate Infrasound?

It is now well known that wind turbines do generate infrasound.

(1) Shpilrain (2001) states that…

(2) 'A wind turbine generator may produce noise with both pulse-like (thumping) and broadband (swishing) characteristics.'

(3) 'The low frequency infrasound (below 16Hz frequency) tends to be the most annoying.'

(4) 'In the case of large systems, infrasound is generated by sudden blade deflection which occurs in the tower shadow.'

(5) Neil Kelley (1998) (see Appendix 1) of the US National Renewable Energy Laboratory writes:

(6) 'Because of the low rotational rates of the turbine blades, the peak acoustic energy radiated by the large wind turbines is in the infrasonic range, with a peak in the 8-12Hz range.'

(7) The **main** acoustic (sound) output produced by large wind turbines is therefore infrasound, and not the audible noises that these large turbines make. The infrasound output is generated by the regular beat of the wind turbine blades at low frequency in the upwind tower shadow of the wind turbines.

3. Propagation Characteristics and Attenuation of Infrasound

(1) Leventhall (2003) (see Appendix 4) notes the following points with respect to the propagation and control of infrasound:

- ‘The attenuation (drop in pressure level or volume) of sound in air increases with the square of the frequency of the sound and is very low at low levels.’
- ‘Other attenuating factors, such as absorption by the ground and shielding by barriers are also low at low frequencies.’
- ‘The net result is that the very low frequencies of infrasound are not attenuated during propagation as much as higher frequencies.’ (2.6.1)
- ‘Infrasound is difficult to control.’
- ‘Attenuation by an enclosure requires extremely heavy walls, whilst absorption requires a thickness of absorbing material up to about a quarter wavelength thick, which could be several metres.’
- ‘It is seen that air attenuations are small contributor to losses at low frequencies…’
- ‘As a result, noise which has traveled over long distances is normally biased toward the low frequencies.’ (2.7.1)

(2) Infrasound can therefore travel over far greater distances than audible sounds without diminishing in pressure level impact (volume) to the same extent as audible sound.

(3) Since infrasound is mostly below the threshold of human hearing, it can produce distant effects without itself being noticed.

(4) The infrasonic impact of an operational windfarm is likely to be:

- far greater than the audible noise of the windfarm would indicate
- produce its effects at a far greater distance from the windfarm than the drop in the audible noise level would suggest
- be impossible to mitigate in situ by either enclosure, shielding or absorption
- subliminal, and therefore not consciously attributable to its source, e.g. the adverse effects due to the infrasonic impact of the windfarm will most likely be mistakenly attributed to other causes

4. Effects of Infrasound (and Low Frequency Noise) on Health

(1) Infrasound in the Military and Film industry

- The Military use of Infrasound

  - Infrasound has been researched over many decades for possible use as a military weapon.

  - The intended function of such weapons would be to induce many of the principal symptoms of exposure to infrasound listed in the tables above to disable or destroy an enemy, or to disrupt or incapacitate a large populations centre, such as a city (Vassilatos, 1997: see appendix 6).

  - Infrasonic detection of distant nuclear testing, even thousands of miles away, is the purpose of '…a world-wide system of about 60 infrasound arrays, which are part of the monitoring for the Nuclear Test Ban Treaty.' (Leventhall, 2003) (see Appendix 4).

  - The Ministry of Defense (UK) has recently indicated that it would object to any windfarms being built within a 50 mile radius of their nuclear testing station at Eskdalemuir because the geophysical (earthborne) transmission of waves from the windfarms would disrupt the monitoring capability of the station (Annandale Herald, 2003) (see Appendix 7).

- Infrasound in Films

  - The use of infrasound in the film industry dates from the 1991 production of the film, 'Silence of the Lambs' (Hartman, 2002: see Appendix 6).

  - Since then, infrasound has been used extensively in film soundtracks to produce psychological states such as fear and anxiety in their audiences.

  - A Dolby Surround Sound configuration in your local cinema may typically include 5 speakers for normal audible sound, and one speaker dedicated to infrasound (Hartman, 2002: see Appendix 6).

  - The particular uses of infrasound as a military weapon and in the film industry illustrate a common knowledge of the harmful physiological and psychological effects that exposure to infrasound can induce.

  - That the infrasonic emissions of a windfarm at a distance of up to 50 miles can disrupt the instrumentation of a Nuclear Test Monitoring site also illustrates that, unlike audible sound which diminishes rapidly with distance, infrasound can travel great distances from source and can produce effects at a great distance from source.

(2) Vibroacoustic Disease (VAD)

In relation to prolonged occupational noise exposure, Alves-Pereira (1999b) (see Appendix 4) states:

- ‘The notion that no other than auditory harmful organic noise effects can be attributed to noise exposure is widespread, and exceptions to this are few and far between.’

- ‘Vibroacoustic Disease (VAD) is a noise-induced, whole body pathology, of a systemic nature, caused by excessive and unmonitored exposure to LF (low frequency) noise…’

    - **‘Cardiac Infarcts’** (Castelo Branco, 1999; Castelo Branco et al, 1999)
    - **‘Stroke’** (ibid)
    - **‘Cancer’** (Silva et al, 1996; Castelo Branco et al, 1999)
    - **‘Epilepsy’** (Martinho Pimenta et al, 1999a)
    - **‘Rage Reactions’** (Castelo Branco et al, 1999)
    - **‘Suicide’** (Castelo Branco et al, 1999)

- ‘This raises the issue of LF noise-induced pathology to the domain of Public Health issues.’

- ‘VAD is essentially characterized by a proliferation of extra-cellular matrices.

    - ‘This means that blood vessels can become thicker, thus impeding the normal blood flow.’
    - ‘Within the cardiac structures, the parietal pericardium and the mitral and aortic valves also become thickened.’
    - ‘The most recent VAD studies have been suggesting that infrasound exposure may be crucial to the rate of evolution of VAD.’
    - ‘Occupational exposure to infrasound is suspected to cause an increase in the rate of thickening of the pericardium and cardiac valves…’ (Alves-Pereria et al, 1999)

- ‘Within the 20-500Hz range, 8 hours a day of an acoustic field at a 90dB amplitude can cause irreversible damage to several organ systems.’ (OHSA, 1995)

Scotland is a world-leader in the incidence of heart disease and cancer (ISD Scotland, 2003). These studies suggest that because of their low frequency noise and infrasonic emissions, the siting of windfarms near locations of human habitation and especially near major cities of population, such as Glasgow and Aberdeen, may dramatically increase the incidence of heart disease and cancer in the coming years.

(3) Other Research Literature

Many other adverse physical/physiological and psychological effects of infrasonic and low frequency noise exposure on both humans and animals are cited in the research literature, some of which is excerpted in Appendices 1-6 of this report.

- 117 experiences of adverse effects by humans, are cited from this literature in Table 5a and 5b (Appendix 3)

- Table 6a, 6b & 6c present the full list of adverse effects reported in the 3 windfarm studies (Appendix 3)

- Table 3 (overleaf) indicates that roughly one third of the adverse effects to exposure to infrasound and low frequency noise reported in the research literature were also reported by the subjects participating in the 3 windfarm studies, (Tharpaland, 2003b)

The most frequently reported health effects reported in both the research literature and the 3 windfarm studies (Tharpaland, 2003b) were as follows:

- **Physical**
  - 'Head pressure/pain'
  - 'Chest/heart pressure/pain'
  - 'Nausea'

- **Psychological**
  - 'Loss of concentration'
  - 'Mental excitement'
  - 'Fatigue'
  - 'Anxiety'
  - 'Disturbed'
  - 'Distressed'

- **Behavioral**
  - 'Impaired performance'
  - 'Sleep disturbance'

Table 3

A Comparative Analysis of the Frequency of the Same Symptoms as Cited in the Literature on the effects of Low Frequency Noise and Infrasound and as Reported in the Three Windfarm Studies (Tharpaland, 2003b)

Symptoms	Literature	3 Windfarm Studies
Physical		
'Head pressure/pain'	6	17
'Ear ache/pressure/vibration'	4	1
'**Chest/Heart Pressure/Pain**'	5	17
'Breathing Difficulties'	2	1
'Heart Palpitations'	2	2
'Throat pressure/pain'	1	2
'Nausea'	6	9
'Stomach pain'	1	1
'Body vibration'	1	1
'Dizzy'	4	5
Psychological		
'Concentration Loss'	7	13
'Mental Excitement/manic'	2	23
'Fatigue/Apathy'	8	5
'Impaired judgement'	3	1
'Memory lapse/loss'	1	4
'Disorientation'	3	1
'Loss of self-confidence'	1	1
'Discouragement'	1	1
'Sad/cried'	1	1
'Anxiety'	5	2
'Disturbed'	5	1
'Distressed'	8	3
'Fear/panic'	2	2
'Paranoia'	1	2
'Anger/aggression'	1	3
'Irritation'	6	5
'Depression'	4	1
Behavioural		
'Impaired performance'	8	7
'Sleep disturbance'	8	4
Reflective		
'Feel traumatised, noise unbearable and tormenting'	2	1

(4) Body and Body-Part Vibrations

- Strong acoustic waves, particularly infrasound, can cause parts of the body to oscillate. At very low frequencies the whole body oscillates as a unit. At frequencies above 4Hz, individual parts of the body will oscillate due to resonance. These somantic vibrations can cause many physical and physiological symptoms.

- Indeed, the most common physical/physiological symptoms reported in both the research literature and windfarm studies (Tharpaland, 2003b) fall within anatomical categories corresponding to the different frequency levels of infrasound exposure as indicated in Table 4 below.

Table 4

The Relationships of Body and Body-Part Vibration (resonance) to Different Frequency Levels (Hz) of Infrasound

	*	**
Head	20-30	
‘Headache’		13 - 20
‘Resonance in lower jaw’		6 – 8
Neck		
‘Feeling of constriction around throat’		12 – 16
‘Resonances in the larynx and bronchial tube affecting speaking’		13 - 20
Chest and Heart	5-10	
‘Thorax respiration effects’		4 – 8
‘Difficulty in breathing’		1 – 3
‘Pain in the chest’		5 – 7
Stomach	4-8	
‘Muscle contractions in the abdominal wall’		4.5 – 9
‘Stomach pain’		4.5 – 10
Pelvis		
‘Urge to urinate’		10 – 18
‘Urge to defecate’		10.5 – 18
Skeleton and muscles		
‘Muscle contractions in arms and legs’		4.5 – 9
‘Increased muscle tension in legs, back and neck’		8 – 12
‘General uneasiness’		4.5 – 9

* MacMillan (1998)
** http://www.brummt.de

(5) Conclusion

From all of the above, the most probable (but not the only) main cause of many of the adverse health effects reported in the 3 windfarm studies was exposure to a barrage of infrasonic and low frequency noise emissions radiating from the turbines within the 3 windfarms.

5. Are Infrasonic Emissions of Wind Turbines/Farms Measured or Assessed?

(1) The ETSU-R-97 guidelines for noise assessment of windfarms stipulate noise limits only at frequencies above 20Hz, and therefore infrasound (below 20Hz) is not measured.

- 'The (recommended) method for setting noise limits aims to assess the audibility of a tone as perceived by the average listener.'

- '…mainly establishing audibility criteria…emphasizing 'threshold of audibility' and A-weighted sound (dB) measurement' (by definition audible levels).

- '…The assessments are intended to address (external) amenity and sleep disturbance.' (ETSU-R-97)

(2) Alves-Pereira (1999b) states:

- 'Noise is thought to only affect the auditory system'
- 'Thus, noise protection is focused principally on the frequencies of acoustic phenomena that are audible to humans.'
- 'Consequently, infrasound is not considered'

- 'Infrasound is not audible to humans;
- it is therefore considered to have no impact on hearing loss,
- and consequently, environmental noise assessments within the infrasonic range are a rarity.'

(3) The measurement and assessment of the infrasonic outputs of windfarms are therefore…

- **not required within the statutory or advisory guidelines of the wind industry,**

- **not a part of the standard Environmental Impact Assessment methodologies, and therefore**

- **not included within the Environmental Statements accompanying windfarm development applications**

6. Summary

(1) Infrasound is the main component of the acoustic output of the large turbines of many of the windfarms being proposed today.

(2) Infrasound is well-known to produce a wide range of very harmful health effects, and is implicated in the development of many medical conditions including heart disease (myocardial infarction), cancer, epilepsy and suicide.

(3) Infrasound is not measured as part of the standard E.I.A. methodology in windfarm development applications.

(4) The Human Impact Assessment carried out by Tharpaland (2003b) is one of the first studies of its kind to systematically investigate the health effects of windfarms on human beings to date.

(5) This study demonstrated that windfarm impacts can produce a wide range of the same kinds of adverse health effects known to be caused by exposure to infrasound.

(6) The results of the Tharpaland (2003b) study are corroborated by surveys of the medical and psychological complaints of communities living near existing windfarms in the UK, Sweden and Germany.

7. Conclusions

(1) The propagation and attenuation characteristics of infrasound can explain why some of the health effects observed in the Tharpaland study, including loss of concentration, occurred at a considerable distance from the windfarms studied.

(2) That some of these effects occurred in the absence of audible sound (from the windfarm source) and visual stimulation, implicates a more subtle factor, such as infrasound as its probable cause.

(3) The extent of the agreement in the symptoms listed in the research literature on infrasound with those observed in the Tharpaland studies, also implicates infrasound as their probable cause.

(4) The corroboration of these effects with those reported by communities living near existing windfarms, indirectly implicate infrasound as their probable cause.

(5) Infrasound is therefore one, but not the only one, of the main probable causes of many of the adverse health effects observed in the Tharpaland studies.

8. Recommendations

(1) A full-range infrasonic radiation assessment methodology should be developed and included within the standard E.I.A. methodology for windfarm developments.

(2) This assessment should be carried out by an independent body, under, for example, the supervision of DEFRA, and not by the consultants of the wind farm developers.

(3) A systematic assessment of the complete infrasonic output of wind turbines should be undertaken.

(4) A complete systematic assessment of the infrasonic effects (physiological and psychological) of wind turbines and windfarms of different sizes should be undertaken.

(5) A thorough and sympathetic assessment of the complaints of those living near existing windfarms should be carried out.

(6) A systematic assessment of other possible causes of adverse health effects, other than infrasound, e.g. other auditory, visual and other impacts as identified in Table 1 should be carried out.

(7) The national grid should be extended into remote areas to enable the development of windfarms **far from** locations of human habitation.

(8) No more windfarms should be approved or constructed near to locations of human habitation (e.g. not within a 10 kilometre radius), (Tharpaland, 2003b) until all of the above recommendations have been carried out.

APPENDIX 1

Infrasound
&
Low Frequency Noise

Is Low Frequency Noise a Problem for Wind Turbines?
Neil Kelley, U.S. National Renewable Energy Laboratory

Low Frequency Noise
Casella Stanger (Report for DEFRA Noise Programme)

For full bibliographical details see References section

Is Low Frequency Noise a Problem for Wind Turbines?

(1998)

Neil Kelley
U.S. National Renewable Energy Laboratory

(Excerpts)

1) Because of the low rotational rates of the turbine blades, the peak acoustic energy radiated by large wind turbines is in the infrasonic range with a peak in the 8-12 Hz range.

2) …Typically, except very near the source, people out of doors cannot detect the presence of low-frequency noise from a wind turbine. They can, however if the noise has an impulsive characteristic, 'hear' it within homes in nearby communities again under the right set of circumstances. Often it is not clear with low-frequency noise if people are hearing or feeling it or some combination of both stimuli. Because of the impulsive nature of the acoustic low-frequency energy being emitted, there is an interaction between the incident acoustic pulses and the resonances of the homes which serve to amplify the stimulis creating vibrations as well as redistributing the energy higher into the audible frequency region.

Low Frequency Noise
(2001)

Casella Stanger
Technical Research Support
For
DEFRA Noise Programme

(Excerpts)

Low Frequency Noise Update

1 Introduction

1.1 This document has been produced by Casella Stanger under contract to DEFRA with the objective of providing

- An update of the current information available concerning low frequency noise; and
- Help for those involved in low frequency noise issues.

2 Background

2.1 Low frequency noise is not clearly defined but is generally taken to mean noise below a frequency of about 100 to 150 Hz. Noise at frequencies below about 20 Hz is sometimes referred to as infrasound and this type of noise presents even greater difficulties in its measurement and assessment. At these particularly low frequencies complainants often have difficulty in describing the source of their complaint, sometimes referring to ‘feeling the noise’ or to ‘pressure sensations’.

2.4 There are several factors relevant to low frequency noise propagation and its perception which need to be borne in mind:

- Mid and high frequency noise is attenuated by propagation through the atmosphere and also by attenuation due to its passage over acoustically soft ground such as grass land. Low frequency noise does not benefit to the same extent from either of these effects. This means that as a sound travels, its frequency content alters making the low frequencies more prominent at greater distances.

- For people inside buildings with windows closed, this effect is exacerbated by the sound insulation properties of the building envelope. Again mid and high frequencies are attenuated to a much greater extent than low frequencies. Thus the frequency content again alters emphasizing still further the low frequency content.

- Resonance can be set up inside a room with nodes (quiet points) and anti-nodes (loud points). The number and position of these nodes and anti-nodes will depend on the specific room dimensions and the frequency of the noise.

The consequence is that the room resonances can cause elevated levels of low frequency noise at points within a room.

3 Possible Sources

3.1 Possible sources of low frequency noise are many and varied but are often industry related. The following is a list of common sources:

Pumps	Fans
Boilers	Ventilation plant
Heavy industry	Blasting
Electrical installations	Road, rail, sea and air traffic
Amplified music	Cooling towers
Windfarms	

4 Possible Effects

4.1 As with any noise, reported effects include annoyance, stress, irritation, unease, fatigue, headache, possible nausea and disturbed sleep.

4.2 As people's hearing sensitivity varies from one individual to another it is often the case that low frequency noise can be heard by one person and not by another. Consequently it may annoy one person but not the other. This feature can sometimes mean that the person who is annoyed can also feel isolated.

4.3 Low frequency noise is sometimes confused with vibration. This is mainly due to the fact that certain parts of the human body can resonate at various low frequencies. For example the chest wall can resonate at frequencies of about 50 to 100 Hz and the head at 20 to 30 Hz.

4.4 In addition low frequency noise can cause lightweight elements of a building structure to vibrate causing a secondary source of noise. This vibration is generally superficial and should not be confused with vibration of the whole building.

APPENDIX 2

Health Effects
of
Noise Pollution in General

Health Effect Based Noise Assessment Methods: A Review and Feasibility Study
Department for Environment, Food & Rural Affairs (DEFRA)
Noise and Nuisance Policy

Noise Pollution Prevention Program
Bayer International

For full bibliographical details see References section

Health Effect Based Noise Assessment Methods:
A Review and Feasibility Study
(September 1998)

Department for Environment, Food & Rural Affairs (DEFRA)
Noise and Nuisance Policy

(Excerpts)

3.2: Potential Effects of Noise on Health

Performance – concentration and task interference

Noise can contribute to increased arousal; can require changes of mental strategy; can impair social performance; can distract attention from relevant social cues; can mask wanted signals in tasks involving auditory cues; and can contribute to what has been described as unwanted aversive changes in affective state. Interference of this type can contribute to the creation of less desirable living environments and might therefore lead to increased annoyance and stress or to a decreased state of well-being or general health.

Noise induced stress related effects

…many studies have implicitly assumed that noise could be considered as an unspecified stressor leading to over-stimulation of the central nervous and endocrine systems. Potential indicators of health impact due to stress-related effects and appearing in the literature include changes in blood pressure, abnormalities in the electrocardiogram, rates of diagnosing clinical hypertension, occurrence rates of ischaemic heart disease and other cardiovascular disorders, biochemical effects, changes in the immune system, and effects on the unborn child such as birthweight effects and incidence rates for various congential defects.

Noise Pollution Prevention Program
(2001)

Author Unknown
Bayer International, Spain

(Excerpts)

4.2 Cardiovascular illness

‘Beside **stress, irritability and anxiety**, noise pollution can **cause and worsen cardiovascular diseases** and **seriously damage the heart**. According to recent studies, noise **increases the pulse rate and heartbeat, and raises blood cholesterol levels. Prolonged exposure** to noise has been linked to **increases in blood pressure.’**

4.3 Insomnia

‘At night time, noise levels above 35 dBA can wake you up and lead to insomnia. If this problem becomes chronic, it leads to serious physical and mental consequences, such as **daytime drowsiness, fatigue and a lack of concentration**.’

4.4 Stress

‘The high stress levels brought about by noise can lead to **insomnia, irritability and anxiety**, as well as many unwanted secondary effects to our health, such as **constipation, bad moods and headaches.’**

5.3 Poor Concentration

‘Due to a **reduction in concentration**, noise pollution can cause serious work or traffic accidents and seriously **affect intellectual performance** and productivity at work. Noise also lowers our capacity for reaction and **increases aggressive and hostile attitudes**.’

APPENDIX 3

Tables of Health Effects of Infrasound and Windfarm Studies

Table 5a: Physical/Physiological Symptoms of Infrasound and Low Frequency Noise Exposure Reported in the Research Literature

Table 5b: Psychological and Behavioural Symptoms of Infrasound and Low Frequency Noise Exposure Reported in the Research Literature

Table 6a: From 3 Windfarm Studies: Frequency Analysis of Psychological Factors Affecting Concentration

Table 6b: From 3 Windfarm Studies: Frequency Analysis of Physiological and Psychological Factors Affecting Concentration

Table 6c: From 3 Windfarm Studies: Frequency Analysis of Negative After Effects

Table 5a

Physical/Physiological Symptoms of Infrasound and Low Frequency Noise Exposure Reported in the Research Literature*

Head
- 'Pain'
- 'Pressure'

Eye (ball)
- 'Pressure'
- 'Loss of Visibility'
- 'Nistagmus'

Ear
- 'Hearing damage'
- 'Pressure / Vibration / Flutter'
- 'Pulsation'
- 'Tinnitus'

Neck
- 'Pain'
- 'Difficulty swallowing'
- 'Pressure'
- 'Pain swallowing'
- 'Choking'
- 'Tingling'

Chest
- 'Inability to breathe'
- 'Flutter'
- 'Throbbing'
- 'Pressure'
- 'Coughing'
- 'Trembling'
- 'Breathing Difficulty'
- 'Decreased Respiratory rate'
- 'Pain'
- 'Bronchitis'
- 'Respiratory Infection'
- 'Myocardial Ischemia'
- 'Heart muscle contractory strength reduced'

Heart/Circulation
- 'Blood pressure changes'
- 'Palpitations'
- 'Heart Ailments'
- 'Decreased pulse rate'
- 'Increased pulse rate'
- 'Disturbed blood circulation'

Back
- 'Pain'

Stomach/Abdomen
- 'Nausea'
- 'Loss of appetite'
- 'Pain/problems'
- 'Diarrhoea'
- 'Vibration of internal organs'
- 'Body tingling'
- 'Gastrointestinal dysfunction'

Arms/Hands
- 'Shivering wrist'
- 'Pressure – Side of hand'
- 'Tingling arms'

Other
- 'Stitch'
- 'Voice modulation'
- 'Reduced GSR'
- 'Epilepsy'
- 'Convulsions'
- 'Torque'
- 'Skin flushing'
- 'Sense of coldness'
- 'Tension in body'
- 'Goosebumps'
- 'Vertigo'
- 'Disequilibrium'
- 'Dizziness'
- 'Changes in vibro-tactile feeling threshold'
- 'Affect pituitary function'
- 'Reduction in blood circulation in gastric mucosa'
- 'Altered cortical function'
- 'Disruption of normal cortisal pattern'
- 'Slowdown of psychological and physiological systems'
- 'Changes in erythrocytosis'

* See Appendix 4 and References

Table 5b

Psychological and Behavioural Symptoms of Infrasound and Low Frequency Noise Exposure Reported in the Research Literature*

Psychological Symptoms

'Loss of concentration'
'Fatigue'
'Drowsy'
'Lethargy'
'Loss of memory'
'Disturbance'
'Loss of alertness'

'Apathy'
'Weakness'

'Impaired judgment'
'Confusion'
'Indecision'
'Less confident'
'Loss of intelligence'

'Depression'
'Less happy'
'Crying'
'Sense of sorrow'

'Disorientation'
'Altered time perception'
'Poor social orientation'
'Disturbed spatial orientation'

'Anxiety'
'Psychological tension'

'Fear'
'Discomfort'
'Nervousness'
'Frustration'
'Stress'
'Emotional tension'
'Panic'

'Anger/aggressiveness'
'Defensive reaction'
'Irritation'
'Annoyance'

Other Psychological Symptoms

'Psychosomatic complaints'
'Disturbance of well-being'
'Character changes'
'Experienced torment'

Behavioral Symptoms

'Impaired performance'
'Traffic accident increase'
'School absence increase'
'Behavioral change'

'Sleep disturbance'
'Reading disturbance'

'Slurred speech'
'Visual-motor response prolonged'

'Loss of manual dexterity'
'Increased fatality'

* See Appendix 4 and References

Table 6a
From 3 Windfarm Studies (Tharpaland, 2003b)

Frequency Analysis of Psychological Factors Affecting Concentration

Psychological Factors Affecting Concentration	No. of times reported*
Loss/less/poor concentration'	13
'Great effort'	2
'Total loss'	2
Mental Excitement 1) '*More Distractions*' 2) '*Scattered Thoughts*' 3) '*Agitated'*	 5 5 2
'Mental Dullness' 1) '*Feeling Heavy'* 2) '*Tired/Fatigued/Drained'* 3) '*Feel Drunk'* 4) '*Feel Stoned'* 5) *'Slow/Lethargic'*	7 4 5 1 1 1
Mental Sinking 1) *'Lack Clarity/Foggy'* 2) *'Sinking'* 3) *'Spaced out'* 4) *'Cloudy & Obstructed'*	 5 3 3 1
'Temporary long-term memory lapse/loss'	4
'*Disoriented'*	3
Total of Reports of Psychological Factors Affecting Concentration	**67**

* 'No. of times reported' refers to the *total* number of times a symptom was reported *not* the total number of people who reported it. For example, 3 people may have reported one particular symptom several times, throughout the visits, giving a total of 12.

This refers also to Tables 6b & 6c

Table 6b
From 3 Windfarm Studies (Tharpaland, 2003b)

Frequency Analysis of Physiological and Psychological Factors Affecting Concentration

Physical Symptoms	**No. of times reported**
Head	
1) *'Pressure'* 2) *'Pain'* 3) *'Intense Pain'*	8 8 1
Chest	
1) *'Pressure'* 2) *'Pain'* 3) *'Intense Pain'* 4) *'Palpitations/Missed Beats'*	9 7 1 2
Stomach	
1) *'Sick/Nauseous'* 2) *'Pain'* 3) *'Incessant Burping'* 4) *'Very sick/retching'*	9 1 1 2
Other	
1) *'Breast Pain'* 2) *'Tightness – throat'* 3) *'Ear Ache'* 4) *'Tired/Drained'* 5) *'Faint Headed/Dizzy'*	2 2 1 2 5
Total No. of Reports of Physical Symptoms	**61**

Negative States of Mind	**No. of times reported**
'Confusion'	3
'Weak mindfulness'	2
'Strong sense of 'I' /Self-absorbed/ Egocentricity'	1
1) *'Loss of self confidence'* 2) *'Discouragement'* 3) *'Sad'* 4) *'Emotional'* 5) *'Cried'*	1 1 1 2 1
'Anxiety'	2
1) *'Mentally troubled/disturbed'* 2) *'Discomfort & Disturbance/Distress'* 3) *'Mild panic/panic'* 4) *'Paranoia'*	1 3 2 2
'Attachment'	1
'Anger'	3
1) *'Irritable'*	5
Other	
1) *'Hypnotic/Mesmerized* 2) *'Seduced'* 3) *'Optical illusions (hallucinations)*	4 1 1
Total No. of Reports of Negative States of Mind	**37**

Table 6c
From 3 Windfarm Studies (Tharpaland, 2003b)

Frequency Analysis of Negative After Effects

Negative After Effects	No. of times reported
Mental state	
1) *'Manic Energy/Madness'*	9
2) *'Loss/Degeneration of spiritual attitude and intention'*	8
3) *'Thoughts & feelings out of control'*	1
4) *'Pre-occupation with sex'*	4
5) *'Degeneration of mindfulness & concentration'*	4
6) *'Tired/Run down/Fatigue & Lethargy/Drained'*	5
7) *'Drugged/Hung over/Cut-off & Flat'*	1
8) *'Lack of concentration/Distracted'*	3
9) *'Impaired judgement'*	1
10) *'Paralysed/Freaked out'*	3
Negative states of mind	
1) *'Attachment (strong)'*	1
1. 'Jealousy'	1
2. 'Selfishness'	1
2) *Anxiety/Fear*	
1. 'Less self-confident'	3
2. 'Very emotional'	1
3. ' Cried'	3
4. 'Fearful'	1
5. 'Depression and despair'	1
6. 'Subtle background paranoia'	2
3) ' Anger'	
1. 'Very irritable'	4
2. 'Aggressive'	1
Behaviour	
1) *'Out of control'*	5
2) *'Reckless Driving'*	2
3) *'Vulgar Conversation'*	1
Other	
1) After Deucheran	
1. 'Scared to go to bed'	1
2. 'Disturbing dreams'	1
3. 'Recurrent imagery of turbines'	1
4. 'Dreamt back in windfarm'	1
5. 'Temporary loss of long-term memory'	1
6. 'Poor speech/memory co-ordination'	1
2) Next Few Days	
1. 'Lots of background noise in mind'	1
2. 'Heard turbine in meditation room'	1
3. 'Feel have been traumatized'	1
4. 'Feeling gone from meditation'	1
5. 'Meditation and practice have taken a nose dive'	1
6. 'My M.E. symptoms have returned'	1
Total No. of Reports of Negative After-effects	**80**

APPENDIX 4

Health Effects
of Infrasound
&
Low Frequency Noise

A Review of Published Research on Low Frequency Noise and its Effects
Report for DEFRA by Dr Geoff Leventhall, assisted by Dr Peter Pelmear and Dr Stephen Benton.

Vibroacoustic Disease: The Need for a New Attitude Towards Noise
Mariana Alves-Pereira, Centre for Human Performance, Averca, Portugal; and Nuno Castelo Branco, Drexel University, Philadelphia.

Infrasound: Brief Review of Toxicological Literature
Haneke K.E. et al, National Toxicology Program, Integrated Laboratory Systems, Inc.

The Biological Effect of Airborne Infrasound
Dr Reinhard Bartsch, Jena University, Vienna.

Infrasound
John D. Cody, Borderland Sciences Research Foundation Inc.

For full bibliographical details see References section

A Review of Published Research on Low Frequency Noise and its Effects

(*May 2003)*

Report for DEFRA by Dr Geoff Leventhall
Assisted by Dr Peter Pelmear and Dr Stephen Benton

(Excerpts)

1. Preamble

Low frequency noise causes extreme distress to a number of people who are sensitive to its effects. Such sensitivity may be a result of heightened sensory response within the whole or part of the auditory range or may be acquired. The noise levels are often low, occurring in the region of the hearing threshold, where there are considerable individual differences. There is still much to be done to gain a fuller understanding of low level, low frequency noise, its effects, assessment and management. Survey papers of low frequency noise and its occurrence include (Backteman et al., 1983a; Backteman et al., 1983b; Backteman et al., 1984a; Backteman et al., 1984b; Berglund et al., 1996; Broner, 1978a; Hood and Leventhall, 1971).

However, infrasound has long been a respected area of study in meteorology, where the frequencies range from as low as one cycle in 1000 seconds up to a few cycles per second. Large arrays of infrasound microphones detect low frequencies originating in atmospheric effects, meteorites, supersonic aircraft, explosions etc. There is also a worldwide system of about 60 infrasound arrays, which are part of the monitoring for the Nuclear Test Ban Treaty.

The World Health Organisation is one of the bodies which recognises the special place of low frequency noise as an environmental problem. Its publication on Community Noise (Berglund et al., 2000) makes a number of references to low frequency noise, some of which are as follows:

- ‘It should be noted that low frequency noise, for example, from ventilation systems can disturb rest and sleep even at low sound levels’
- ‘For noise with a large proportion of low frequency sounds a still lower guideline (than 30 dBA) is recommended’
- ‘When prominent low frequency components are present, noise measures based on A-weighting are inappropriate.’
- ‘Since A-weighting underestimates the sound pressure level of noise with low frequency components, a better assessment of health effects would be to use C-weighting.’
- ‘It should be noted that a large proportion of low frequency components in a noise may increase considerably the adverse effects on health’
- ‘The evidence on low frequency noise is sufficiently strong to warrant immediate concern’

This present study considers some properties of low frequency sounds, their perception, effects on people and the criteria which have been developed for assessment of their effects. Proposals are made for further research, to help to solve the continuing problems of low frequency environmental noise.

2. Introduction to the physics of low frequency noise

2.5.1 **Sources**. Low frequency noise and infrasound are produced by machinery, both rotational and reciprocating, all forms of transport and turbulence. For example, typical sources might be pumps, compressors, diesel engines, aircraft, shipping, combustion, air turbulence, wind and fans. Structure borne noise, originating in vibration, is also of low frequency, as is neighbour noise heard through a wall, since the wall blocks higher frequencies more than it blocks lower frequencies (Hood and Leventhall, 1971; Leventhall, 1988).

2.6.1 **Propagation.** The attenuation of sound in air increases with the square of the frequency of the sound and is very low at low frequencies. Other attenuating factors, such as absorption by the ground and shielding by barriers, are also low at low frequencies. The net result is that the very low frequencies of infrasound are not attenuated during propagation as much as higher frequencies, although the reduction in intensity due to spreading out from the source still applies. This is a reduction of 6Db for each doubling of distance. Wind and temperature also affect the propagation of sound.

2.6.2 **Control.** Infrasound is difficult to stop or absorb. Attenuation by an enclosure requires extremely heavy walls, whilst absorption requires a thickness of absorbing material up to about a quarter wavelength thick, which could be several metres.

2.6.3 **Resonance.** Resonance occurs in enclosed, or partially open, spaces. When the wavelength of a sound is twice the longest dimensions of a room, the condition for lowest frequency resonance occurs. From *c* =□□ f , if a room is 5m long, the lowest resonance is at 34Hz, which is above the infrasonic range. However, a room with an open door or window can act as a Helmholtz resonator. This is the effect which is similar to that obtained when blowing across the top of an empty bottle. The resonance frequency is lower for greater volumes, with the result that Helmholtz resonances in the range of about 5Hz **to 10 Hz are possible in rooms with a suitable door, window or ventilation opening.**

2.7.1 **Propagation**…noise which has traveled over long distances is normally biased towards the low frequencies**.**

8. Annoyance

8.1 The meaning of annoyance

The noise load causes activity interference (e.g. to communication, recreation, sleep), together with vegetative reactions (e.g. blood pressure changes, defensive reactions). Activity interference develops into annoyance and disturbance. Prolonged vegetative reactions may lead to effects on health (Guski 1999).

8.2.10 Level variations

Holmberg et al (1997) investigated noise in workplaces. This work represents an advance, in that it shows the importance of fluctuations in noise level. A limitation of much work on assessment of low frequency noise has been that long term averaged measurements were used and, consequently, information on fluctuations was lost.

This work confirms the importance of fluctuations as a contributor to annoyance and the limitation of those assessment methods, which do not include fluctuations in the assessment.

8.2.11 Field Investigations

Further work (Vasudevan and Leventhall, 1982), confirmed that levels close to threshold caused annoyance, which increased if the noise also fluctuated. This work included spectra with tonal peaks and emphasised that the nature (quality) of the noise was important. Fluctuating noises may be far more annoying than predicted by their average sound levels.

9. Effects of low frequency noise on behaviour, sleep periods, task performance and social attitudes

9.1 **Naturally occurring infrasound.** The effects of infrasound generated by storms up to 1500 miles away were investigated in Chicago during May 1967, a period when the weather in Chicago was calm (Green and Dunn, 1968). Statistics on road traffic accidents and school absences indicated higher correlations on days of intense infrasonic disturbances, as compared with days of mild infrasound.

9.3 **Low frequency noise and task performance**. The hypothesis that low frequency noise may cause deterioration in the performance of tasks has been tested a number of times (Kyriakides and Leventhall, 1977; Landstrom et al., 1991; Persson – Waye et al., 2001; Persson-Waye et al., 1997).

Perrson Waye et al (2001) refined and extended this work in order to answer the following questions:

- Can low frequency noise, at a level normally present in control rooms and offices, influence performance and subjective well being?
- What kind of performance tasks are affected by low frequency noise?
- How is the performance affected by duration of exposure?

- What is the relation between self rated sensitivity and noise effects?

The results showed that low frequency noise, at levels occurring in office and control rooms, had a negative influence on more demanding verbal tasks, but its effect on more routine tasks was less clear. There was an indication that the low frequency noise was more difficult to ignore or habituate to, which may reduce available information processing resources. The study supports the hypothesis that low frequency noise may impair work performance.

10. Low frequency noise and stress

Stresses may be grouped into 3 broad types: cataclysmic stress, personal stress and background stress. Cataclysmic stress includes widespread and devastating physical events. Personal stress includes bereavements and similar personal tragedies. Cataclysmic and personal stresses are evident occurrences, which are met with sympathy and support, whilst their impacts normally reduce with time. Background stresses are persistent events, which may become routine elements of our life. Constant low frequency noise has been classified as a background stressor (Benton, 1997b; Benton and Leventhall, 1994). Whilst it is acceptable, under the effects of cataclysmic and personal stress, to withdraw from coping with normal daily demands, this is not permitted for low level background stresses. Inadequate reserves of coping ability then lead to the development of stress symptoms. In this way, chronic psychophysiological damage may result from long-term exposure to low-level low frequency noise.

Changes in behaviour also follow from long-term exposure to low frequency noise. Those exposed may adopt protective strategies, such as sleeping in their garage if the noise is less disturbing there. Or they may sleep elsewhere, returning to their own homes only during the day. Others tense into the noise and, over time, may undergo character changes, particularly in relation to social orientation, consistent with their failure to recruit support and consent that they do have a genuine noise problem. The claim that their 'lives have been ruined' by the noise is not an exaggeration, although their reaction to the noise might have been modifiable at an earlier stage.

10.1 **Low frequency noise and cortisol secretion.** It is difficult to measure stress directly, but cortisol secretion has been used as a stress indicator (Ising and Ising, 2002; Persson-Waye et al., 2002; Persson-Waye et al., 2003). Under normal circumstances, cortisol levels follow a distinct circadian pattern in which the diurnal variation of cortisol is to drop to very low levels during the early morning sleep period, rising towards the awakening time. The rise continues until about 30 minutes after awakening, followed by a fall until midday and further fluctuations. Stress disrupts the normal cortisol pattern.

Ising and Ising (2002) discuss how noise, perceived as a threat, stimulates release of cortisol. This also occurs during sleep, thus increasing the level of night cortisol, which may interrupt recreative and other qualities of sleep. Measurements were made of the effect on children who, because of traffic changes, had become exposed to a high level of night lorry noise. There were two groups of subjects, exposed to high and low noise levels. The indoor noise spectrum for high levels typically peaked at around 60 Hz, at 65dB, with a difference of maximum L_C and L_A of 26dB. The difference of average levels was

25dB, thus indicating a low frequency noise problem. Children exposed to the higher noise levels in the sample had significantly more problems with concentration, memory and sleep and also had higher cortisol secretions.

Conclusions of the work were that the A-weighting is inadequate and that safer limits are needed for low frequency noise at night.

Perrson-Waye et al (2003), studied the effect on sleep quality and wakening of traffic noise (35dB L_{Aeq}, 50dBL_{Amax}) and low frequency noise (40dBL_{Aeq}). The low frequency noise peaked at 50 Hz with aa level of 70dB. In addition to cortisol determinations from saliva samples, the subjects completed questionnaires on their quality of sleep, relaxation and social inclinations. The main findings of the study were that levels of the cortisol awakening response were depressed after exposure to low frequency noise and that this was associated with tiredness and a negative mood.

In a laboratory study of noise sensitive subjects performing work tasks, it was found that enhanced salivary cortisol levels were produced by exposure to low frequency noise (Persson-Waye et al., 2002). A finding was that subjects who were sensitive to low frequency noise generally maintained higher cortisol levels and also had impaired performance. A hypothesis from the study is that changes in cortisol levels, such as produced by low frequency noise, may have a negative influence on health, heightened by chronic noise exposure.

The three studies reviewed above show how low frequency noise disturbs the normal cortisol pattern during night, awakening and daytime exposure. The disturbances are associated with stress related effects.

12. Surveys of occurrence and effects

12.1.4 **Denmark.** An extensive survey of individual complainants has been carried out in Denmark (Møller and Lydolf, 2002). 198 fully completed questionnaires were returned. The survey was detailed, containing 45 questions. The main results are:

Descriptions of the sound: Humming, rumbling, constant and unpleasant, pressure in ears, affects whole body, sounds like large idling engine, coming from far away.

Where are when heard: Mainly indoors at home (81.8%), some experience the noise outside, particularly close to home, only a slight preponderance for night time awareness.

Sensory perception: 92.9% heard the noise through their ears. Others were aware of it but did not register the noise as a sound. There was some vibration perception either through the body or by feeling vibration in buildings.

Time before trouble starts: Respondents were asked how long it was between awareness of the sound and adverse reactions to it. For over 60% it started immediately. About 25% required a few minutes awareness, 6% required ½ to 1 hour. A small percentage took longer.

Do other people hear or sense the sound? Nearly 40% were the only ones who perceived the sound. Nearly 30% said that just a few other persons did so, whilst 14% claimed that everybody did.

Type of effects: There were multiple effects. Disturbance while falling asleep (77.2%), Awakened from sleep (53.8%). Frequent awareness (68%). Frequent irritation (75.1%). Disturbed when reading (61.9%). The sound is a torment (76.1%).

Other Troubles. Insomnia (67.5%). Dizziness (29.4%). Headaches (40.1%). Palpitation (41.1%). Lack of concentration (67%). Other effects (39.1%).

12.2 **Effects on health.** In an epidemiological survey of low frequency noise from plant and appliances in or near domestic buildings, the focus is on health effects (Mirowska and Mroz, 2000).

Percentages of exposed adults and the sources were as in Table 4.

Table 4. Noise Exposures in Survey

Noise source	**L_A dB**	**Percentage people exposed**	**Kind of exposure**
Fans	26 – 31	33	Day, intermittent
Central heating pumps	23 – 33	18	Night, day intermittent
Transformers	20 - 23	30	Continuous
Refrigeration units	21 – 32	19	Night, day intermittent

In 81% of the test flats, levels were below the 25dBA night and the 35dBA day criteria.

A control group of dwellings had comparable conditions to the test group, with similar A-weighted levels, except that there was no low frequency noise. There were 27 individuals in the test group and 22 in the control group.

The test group suffered more from their noise than the control group did, particularly in terms of annoyance and sleep disturbance. They were also less happy, less confident and more inclined to depression.

The comparison of the symptoms between the tested group and the control group show clear differences, as in Table 5.

Table 5. Health Comparison of Exposed and Control Group

Symptom	Test group %	Control group %
Chronic fatigue	59	38
Heart ailments anxiety, stitch, beating palpitation	81	54
Chronic insomnia	41	9
Repeated headaches	89	59
Repeated ear pulsation, pains in neck, backache	70	40
Frequent ear vibration, eye ball and other pressure	55	5
Shortness of breath, shallow breathing, chest trembling	58	10
Frequent irritation, nervousness, anxiety	93	59
Frustration, depression, indecision	85	19
Depression	30	5

These results are extremely interesting as an epidemiological survey of an affected and a control group. Table 5 shows very adverse effects from low frequency noise levels which are close to the threshold and which do not exceed A-weighted limits.

Other work has investigated a group of 279 persons exposed to noise from heat pump and ventilation installations in their homes (Persson-Waye and Rylander, 2001). The experimental groups were 108 persons exposed to low frequency noise and 171 non-exposed controls. There was no significant difference in medical or psycho-social symptoms between the groups. This work did show that the prevalence of annoyance and disturbed concentration and rest was significantly greater among the persons exposed to low frequency noise. The A-weighted levels did not predict annoyance.

Effects of low frequency noise have also been investigated in the laboratory using the same subjects performing intellectual tasks, with and without low frequency noise in the noise climate, but at the same A-weighted level. It has been shown that, after the exposure sessions with low frequency noise, the subjects were less happy and recorded a poorer social orientation (Persson-Waye et al., 1997).

13. General Review of Effects of Low Frequency Noise on Health[2]

The results of a recent survey of complaints about infrasound and low frequency noise on 198 persons in Denmark (Møller and Lydolf, 2002) revealed that nearly all reported a sensory perception of sound. They perceived the sound with their ears, but many mentioned also the perception of vibration, either in their body or in external objects. The sound disturbs and irritates during most activities, and many considered its presence as a torment to them. Many reported secondary effects, such as insomnia, headache and palpitation. These findings support earlier reports in the published literature.

[2] This section was contributed by Dr P L Pelmear

13.2 **Effects on humans**. Infrasound exposure is ubiquitous in modern life. It is generated by natural sources such as earthquakes and wind. It is common in urban environments, and as an emission from many artificial sources: automobiles, rail traffic, aircraft, industrial machinery, artillery and mining explosions, air movement machinery including wind turbines, compressors, and ventilation or air-conditioning units, household appliances such as washing machines and some therapeutic devices. The effects of infrasound or low frequency noise are of particular concern because of its pervasiveness due to numerous sources, efficient propagations, and reduced efficiency of many structures (dwellings, walls, and hearing protection) in attenuating low-frequency noise compared with other noise.

In humans the effects studied have been on the cardiovascular and nervous systems, eye structure, hearing and vestibular function, and the endocrine system. Special central nervous system (CNS) effects studied included annoyance, sleep and wakefulness, perception, evoked potentials, electroencephalographic changes, and cognition. Reduction in wakefulness during periods of infrasonic exposure above the hearing threshold has been identified through changes in EEG, blood pressure, respiration, hormonal production, performance and heart activity. Infrasound has been observed to affect the pattern of sleep minutely. Exposure to 6 and 16Hz levels at 10 dB above the auditory threshold have been associated with a reduction in wakefulness (Landström and Byström, 1984). It has also been possible to confirm that the reduction on wakefulness is based on hearing perception since deaf subjects have an absence of weariness (Landström, 1987).

In moderate infrasonic exposures, the physiological effects observed in experimental studies often seem to reflect a general slowdown of the physiological and psychological state. The reduction in wakefulness and the correlated physiological responses are not isolated phenomena and the physiological changes are considered to be secondary reactions to a primary effect on the CNS. The effects of moderate infrasound exposure are thought to arise from a correlation between hearing perception and a following stimulation of the CNS. The participation of the reticular activating system (RAS) and the hypothalamus is thought to be of great importance. Taking this into account, changes in the physiological reactions are not just a question of whether soundwaves are above the hearing threshold. Furthermore reactions within the CNS, including RAS, hypothalamus, limbic system, and cortical regions are probably highly influenced by the quality of the sound. Some frequencies and characters of the noise are probably more effective than others for producing weariness.

A high degree of caution is necessary before ascribing the origin of physiological changes in working situations to infrasonic exposure because of their association. When analysing the factors promoting fatigue e.g. driving, many aspects have to be considered. The environment is usually a combination of many factors such as seat comfort, visibility, instrumentation, vibration and noise. However, it is an important fact that in many situations, e.g. transport operations, there is a high degree of prolonged monotonous low frequency noise stimulation. This could be crucial in inducing worker fatigue and thereby constitute a safety hazard. Thus although exposure to infrasound at the levels normally experienced by man does not tend to produce dramatic health effects, exposure above the hearing perception level will produce symptoms including weariness, annoyance, and unease. This may precipitate safety concerns in some environmental and many work situations (Landström and Pelmear, 1993).

The primary effect of infrasound in humans appears to be annoyance. (Andresen and Møller, 1984; Broner, 1978a; Møller, 1984). To achieve a given amount of annoyance, low frequencies were found to require greater sound pressure than with higher frequencies; small changes in sound pressure could then possible cause significantly large changes in annoyance in the infrasonic region (Andresen and Møller, 1984). Beginning at 127 to 133DB, pressure sensation is experienced in the middle ear (Broner 1978a). Regarding potential hearing damage Johnson (Johnson, 1982) concluded that short periods of continuous exposure to infrasound below 150dB are safe and that continuous exposures up to 24 hours are safe if the levels are below 118dB.

13.3 **Biological effects on humans.** In the numerous published studies there is little or no agreement about the biological activity following exposure to infrasound. Reported effects include those on the inner ear, vertigo, imbalance etc.; intolerable sensations, incapacitation, disorientation, nausea, vomiting, bowl spasm; and resonances in inner organs, such as the abdomen and heart. Workers exposed to simulated industrial infrasound of 5 and 10 Hz and levels of 100 and 135dB for 15 minutes reported feelings of fatigue, apathy and depression, pressure in the ears, loss of concentration, drowsiness, and vibration of internal organs. In addition, effects were found in the CNS, cardiovascular and respiratory systems (Karpova et al., 1970). In contrast, a study of drivers of long distance transport trucks exposed to infrasound at 115 dB found no statistically significant incidence of such symptoms (e.g. fatigue, subdued sensation, abdominal symptoms, and hypertension (Kawano et al., 1991).

Danielson and Landstom (Danielsson and Landstrom, 1985) exposed twenty healthy male volunteers to infrasound in a pressure chamber and the effects on blood pressure, pulse rate and serum cortisol levels of acute infrasonic stimulation were studied. Varying frequencies (6, 12,16Hz) and sound pressure levels (95, 110, 125dB) were tested. Significantly increased diastolic and decreased systolic blood pressure reached a maximal mean of about 8 mm Hg after 30 minutes exposure. Lidstrom (Lidstrom, 1978) found that long-term exposure of active aircraft pilots to infrasound of 14 or 16Hz at 125dB produced the same changes. Additional findings in the pilots were decreased alertness, faster decrease in the electrical resistance of the skin compared to unexposed individuals, and alteration of hearing threshold and time perception.

13.4 **Infrasound studies in laboratory animals.** The results of some animal studies reporting adverse effects from infrasound exposure may be relevant for indicating possible human health effects. The following studies would seem to be of interest.

<u>a) Vascular Myocardium</u>

Alekseev (Alekseev et al., 1985) exposed rats and guinea pigs (5 test animals, 2 controls per group) to infrasound (4 to 16 Hz) at 90 to 145dB for 3h/day for 45 days; and tissues were collected on days 5, 10, 15, 25, and 45 for pathomorphological examination. A single exposure to 4 to 10 Hz at 120 to

125dB led to short-term arterial constriction and capillary dialation in the myocardium. Prolonged exposure led to nuclear deformation, mitochondrial damage and other pathologies. Effects were most marked after 10 to 15Hz exposures at 135 to 145 dB. Regenerative changes were observed within 40 days after exposure.

Gordeladze (Gordeladze et al., 1986) exposed rats and guinea pigs (10 animals per group) tp 8Hz at 120dB for 3h/day for 1, 5, 15, 25 or 40 days. Concentrations of oxidation-reduction enzymes were measured in the myocardium. Pathological changes in myocardial cell, disturbances of the microcirculation, and mitochondrial destruction in endothelial cells of the capillaries increased in severity with increasing length of exposure. Ischemic foci formed in the myocardium. However, changes were reversible after exposure ceased.

Rats and guinea pigs exposed to infrasound (8 to 16Hz) at 120 to 140dB for 3h/day for 1 to 40 days showed morphological and physiological changes in the myocardium. (Nekhoroshev and Glinchikov, 1991).

-<u>Conjunctiva</u>

Male rats (10/group) exposed to infrasound (8Hz) at 100 and 140dB for 3 h/day for 5, 10, 15, or 25 days showed constriction of all parts of the conjunctival vasculature within 5 days (Svidovyi and Kuklina, 1985). Swelling of the cytoplasm and the nuclei of the endotheliocytes accompanied the decrease in the lumen of the capillaries. The capillaries, pre-capillaries, and arterioles became crimped. Morphological changes were reported in the vessels after exposure for 10, 15, and 25 days. After 25 days, increased permeability of the blood vessels led to swelling of tissues and surrounding capillaries and to peri-vascular leukocyte infiltration. Significant aggregates of formed elements of the blood were observed in the large vessels.

<u>b) Liver</u>

Infrasound exposure damaged the nuclei apparatus, intracellular membrane, and mitochondria of rat hepatocytes in vivo (Aledseev et al, 1987). Infrasound (2, 4, 8, or 16 Hz) at 90 to 14dB for 3h/day for 40 days induced histopathological and morphological changes in hepatocytes from rats on days 5 to 40. Infrasound (8Hz) at 120 to 140dB induced pathological changes in hepatocytes from the glandular parenchyma and sinusoids.

Morphological and histochemical changes were studied in the hepatocytes of rats and guinea pigs exposed to infrasound (2, 4, 8, or 16HZ) at 90, 100, 110, 120, 130 or 140dB for 3 h/day for 5 to 40 days (Nekhoroshev and Glinchikov, 1992a). Hepatocytes showed increased functional activity, but exposures for 25 and 40 days induced irreversible changes. Changes were more pronounced at 8 and 16 Hz than at 2 and 4Hz. Exposures impaired cell organoids and nuclear chromatin. Single exposures did not induce any changes in the hepatocytes and small blood vessels.

<u>c) Metabolism</u>

(Shvaiko et al., 1984) found that rats exposed to 8Hz at 90, 115, or 135dB exhibited statistically significant changes in copper, molybdenum, iron, and/or manganese concentrations in liver, spleen, brain, skeletal muscle, and/or femur compared to concentrations in the tissues of controls. Practically all tissues showed significant changes in all the elements for exposures at 135dB. Changes included elevations and depressions in concentrations. The trends were consistent with increasing sound pressure except for some tissue copper values.

d) Auditory

(Nekhoroshev, 1985) exposed rates to noise of frequencies 4, 31.5, or 53Hz at 110dB for 0.5h, 3h, or 3h/day for 40 days. Infrasound exposure caused graver changes than exposure to sound at 31.5 or 53Hz. Changes observed after exposure to this acoustic factor included reduced activity of alkaline phosphotase in the stria vascularis vessels and their impaired permeability. Impaired labyrinthine hemodynamics led to neurosensory hearing impairment.

(Bohne and Harding, 2000) sought to determine if noise damage in the organ of Corti was different in the low- and high-frequency regions of the cochlea. Chinchillas were exposed for 2 to 432 days to a 0.5 (low-frequency) or 4kHz (high-frequency) octave band noise at 47 to 95dB sound pressure level. Auditory thresholds were determined before, during and after noise exposure. The cochlea's were examined microscopically, missing cells counted, and the sequence of degeneration was determined as s function of recovery time (0-30 days). With high-frequency noise, primary damage began as small focal losses of outer hair cells in the 4-8kHz region. With continued exposure, damage progressed to involve loss of an entire segment of the organ of Corti, along with adjacent myelinated nerve fibres. With low-frequency noise, primary damage appeared as outer high cell loss scattered over a broad area in the apex. With continued exposure, additional apical hair cells degenerated, while supporting cells, inner hair cells, and nerve fibres remained intact. Continued exposure to low-frequency noise also resulted in focal lesions in the basal cochlea that were indistinguishable from those resulting from high-frequency noise.

In guinea pigs, low-frequency pressure changes have been shown to cause head and eye movements (nystagmus) of the animals for square wave pulses with pressure above 150dB (Parker et al., 1968).

e) Brain

(Nishimura et al., 1987) suggested from experiments on animals that infrasound influences the rat's pituitary adreno-cortical system as a stressor, and that the effects begin at sound pressure levels between 100 and 120DB at 16Hz. The concentration of hormones shows a slight increase with exposure to infrasound. In the task performance a reduction was seen in the rate of working. It seems probable that concentration was impaired by infrasound exposure.

(Nekhoroshev and Glinchikov, 1992b) exposed rats and guinea pigs (3 per sex per dose level) to 8Hz at 120 and 140dB for 3 hours or 3 h/day for 5, 10, 15, 25, or 40 days and they showed changes in the heart, neurons, and the auditory cortex increasing in severity with increasing length of exposure. The presence of hemorrhagic changes are attributed mostly to the mechanical action rather than to the acoustic action of infrasound. They suggested that the changes in the brain may be more important than in the ears.

f) Lung

Histopathological and histomorphological changes were determined in the lungs of male albino mice exposed to infrasound (2, 4, 8, or 16 Hz) at 90 to 120dB for 3 h/day for up to 40 days (Svidovyi and Glinchikov, 1987). After prolonged exposure to 8 Hz at 120 dB sectioned lungs revealed filling of acini with erythrocytes and thickening of inter-alveolar septa; after prolonged exposure to 8 and 16Hz at 140dB sectioned lungs revealed ruptured blood vessel walls, partially destroyed acini, and induced hypertrophy of type-II cells.

Vibroacoustic Disease: The Need for a New Attitude Towards Noise
(1999)

Mariana Alves-Pereira & Nuno Castelo Branco
Centre for Human Performance, Averca, Portugal
School of Biomedical Engineering, Drexel University, Philadelphia

(Excerpts)

The Status Quo

Noise pollution is largely regarded as an agent that causes hearing loss and/or minor annoyance and discomfort. The notion that no other harmful organic effects can be attributed to noise exposure is widespread, and exceptions to this are few and far between (Alvers-Pereira, 1999).

Noise exposure protection focuses primarily on these frequencies, because its goal is to prevent hearing loss. Acoustic phenomena within the low frequency (LF) range (*500 Hz) are also audible, but require a higher intensity to be perceived. Infrasound (*20Hz) is non-audible to humans; it is therefore considered to have no impact upon hearing loss, and consequently, environmental noise assessments within the infrasonic range are a rarity (Alves-Pereira, 1999).

Vibroacoustic Disease

Vibroacoustic disease (VAD) is a noise-induced, whole body pathology, of a systemic nature, caused by excessive and unmonitored exposure to LF noise.

VAD evolves over long-term noise exposure, in years, and can lead to severe medical conditions, such as cardiac infarcts (Castelo Branco, 1999 and Castelo Branco et al, 1999), stroke (Castelo et al, 1999), epilepsy (Martinho Pimenta et al, 1999a), rage reactions (Castelo Branco et al, 1999), and suicide (Castelo Branco et al, 1999). When VAD was first identified in professional groups known to be exposed to noise, it was initially thought to be limited to the realm of occupational diseases. However, it has since been diagnosed in individuals exposed to noise in non-occupational settings, or in seemingly non – ‘noisy’ environments (Castelo Branco et al, 1999). This raises the issue of LF noise-induced pathology to the domain of Public Health issues.

LF noise is a stressor, and, as such, initial exposure causes disorders generally considered as ‘stress-related’, such as gastrointestinal dysfunction or infections of the oropharynx. However, LF noise-specific features of VAD can be identified in the mild stage, such as thickened cardiac structures (Marciniak et al, 1999), increased frequency of sister chromatid exchanges (Silva et al, 1996), immunological changes (Castro et al, 1999), altered values of hemostasis and coagulation parameters (Crespo et al, 1988), and specific neurophysiological (Martinho Pimenta et al, 1999a, b and c; Pimenta et al, 1999) and cognitive (Gomes et al, 1999) changes. In the severe stages of VAD, as mentioned above, more serious disorders can develop.

VAD is essentially characterized by a proliferation of extra-cellular matrix. This means that blood vessels can become thicker, thus impeding the normal blood flow. Within the cardiac structures, the parietal pericardium and the mitral and aortic valves also become thickened. The most recent VAD studies have been suggesting that infrasound is suspected to cause an increase in the rate of thickening of the pericardium and cardiac valves in commercial airline pilots over that of flight attendants (Alves-Pereira et al, 1999).

Among the most serious on-the-job consequences of untreated VAD are rage-reactions, epilepsy, and suicide. VAD patients do not have the usual suicidal profile: after the event, if unsuccessful, they remember nothing, and are confused about the entire episode (Castelo Branco et al, 1999). Similarly, patients who suffer rage-reactions also appear confused and seem to remember nothing (Castelo Branco et al, 1999).

The Problem

Noise is thought to only affect the auditory system. Thus, noise protection is focused principally on the frequencies of acoustic phenomena that are audible to humans. Consequently, infrasound is not considered.

Legislation for workers in ‘noisy’ environments is based on hourly exposures and acoustic amplitude levels. Fore example, according to the United States Occupational Safety and Health Administration, a worker can be exposed to a 90dB-level acoustic environment for 8 hours per day (OHSA, 1995). No mention is made to the frequency bands that, together, compose the 90 dB level. Are they predominantly in the 20-500Hz range, or in the 1000-5000 Hz range? This is highly relevant information since different organ systems are susceptible to different acoustic frequencies. Within the 20-500 Hz range, 8 hours a day of an acoustic field at a 90 dB amplitude can cause irreversible damage to several organ systems. However, frequency distribution analyses of the environment are generally only performed to determine the best hearing protection device. There seems to be no legislation for infrasound.

Current problems regarding noise-pollution can be summarized as follows:

a. The steadfast but erroneous concept that noise only causes damage to ear;
b. Lack of legislation regarding LF noise exposure;
c. A workforce with increasing absenteeism, lowered productivity, and increased risk in the workplace;
d. Widespread effects of LF noise exposure among the general population are unknown;
e. Public awareness of the danger of LF noise exposure is close to non-existent.

The Solution

Recognition of a previously unacknowledged environmental stressor is always a traumatic event. Classifying LF noise as an agent of disease, and VAD an occupational pathology, will certainly cause some upheaval, especially since physical protection against LF noise is not a feasible option. The dimensions of acoustic barriers are directly related to the wave length of the acoustic phenomenon. Within the low frequency range, wave lengths can be in the order of meters. Hence, acoustic barriers would be too large to be practical.

Proposed short-term solutions:

a. All environmental and/or occupational noise assessments should include a frequency distribution analysis, and evaluation of infrasound levels should be included in the acoustic evaluation;

Proposed long-term solutions:

c. Establishment of LF noise as an agent of disease, and VAD as an occupational disease.

It is no longer acceptable that individuals have their lives destroyed because of excessive LF noise exposure. Worse than undesirable, it is unethical to keep workers within 'noisy' environments, and ignore the potentially devastating, whole-body, acoustic trauma.

Infrasound: Brief Review of Toxicological Literature

(November 2001)

Haneke, K.E; Carson, G.L; Gregorio, C.A; Maull, E.A
Integrated Laboratory Systems, Inc.
National Toxicology Program

(Excerpts)

Radneva, R 1997. Studying the effect of acoustic conditions in the living environment of multifamily buildings on inhabitants. Khig. Zdraveopazvane 40 (3-4):40-44 (Bulgarian) EMBASE record 1998252323. (Ref. No. 85)

Studies of 1063 residents in multifamily buildings in Sofia, Bulgaria, experiencing noise level above 60 dBA and infrasound levels from 55 to 78 dB found a statistically increased percentage of persons with psychosomatic complaints (e.g. weakness and fatigue) and sleep disturbance (e.g., restlessness during sleep) versus those exposed to lower level noise and infrasound.

Danielsson, A., and U. Landstrom. 1985. Blood pressure changes in man during infrasonic exposure. An experimental study. Acta Med. Scand. 217(5):531-535. MEDLINE record 85275572. (Ref. No. 31)

Infrasound (at all tested frequencies) was observed to increase diastolic blood pressure – the most significant effect was seen with 16 Hz, and the maximum mean increase of 8 mm HG occurred after 30 minutes – and decrease systolic blood pressure and pulse rate, suggesting that a peripheral vasoconstriction with increased blood pressure was induced with acute infrasound stimulation.

Ising, H. 1980. Psychological, ergonomical, and physiological effects of long-term exposure to infrasound and audiosound. Noise Vib. Bull. [volume and number not provided]: 168-174. NIOSHTIC record 1997:64651. (Ref. No. 87)

When subjects were exposed to 3 to 6 Hz, 6 to 12 Hz, or 12 to 24 Hz at 110 dB or a combination of 6 to 12 Hz tones with motorcycle race noise (500-2000 Hz at 75 dB), stress effects of low frequency sounds were smaller than those of higher frequency noise. Psychological tensions and loss of concentration were increased as the sound frequencies increased. In contrast, reaction time, respiration, and heart rate were not affected by the exposure.

Karpova, N.I., S.V. Alekseev, V.N. Erokhin, E.N. Kadyskina, and O.V. Reutov. 1970. Early response of the organism to low-frequency acoustic oscillations. Noise Vib. Bull. 11(65): 100-103. NIOSHTIC record 1997:59793. (Ref.No. 29).

When male volunteers were exposed to simulated industrial infrasound of 5 and 10 Hz and levels of 100 and 135 dB for 15 minutes, feeling of fatigue, apathy, and depression, pressure in the ears, loss of concentration, drowsiness, and vibration of internal organs were reported. In addition, effects were found in the central nervous system, the cardiovascular system, and the respiratory system. Synchronization phenomena were enhanced in the left hemisphere. Visual motor responses to stimuli were prolonged, and the strength of effector response was reduced. Heart rate was increased during the initial minutes of exposure. Depression of the encephalic hemodynamics with decreased venous flow from the skull cavity was observed. Heart muscle contraction strength was reduced. Respiration rate was significantly reduced after the first minute of exposure.

Strandberg, U.D., P. Bjerle, A. Danielsson, S.Hornqwist-Bylund, and U. Landstrom. 1986. Studies of Circulation Changes During Exposure to Infrasound. Arbetarskyddsstyrelsen, Publikationsservice, Soln, Sweden, 29 pp. (Swedish) TOXLINE record 1988:73119. (Ref. No. 92)

Eleven healthy subjects exposed to infrasound at 16 Hz at 125 dB in a specially prepared pressure chamber for one hour had an increased diastolic blood pressure and a decreased systolic blood pressure. In addition, pulse rate was increased. There were no effects on peripheral and deep circulation.

Acknowledgements

Support to the National Toxicology Program for the preparation of Infrasound – Brief Review of Toxicological Literature was provided by Integrated Laboratory Systems, Inc., through NIEHS Contract Number N01-ES-65402. Contributors included: Karen E. Haneke, M.S. (Principal Investigator); Bonnie L. Carson, M.S. (Co-Principal Investigator); Claudine A. Gregorio, M.A., and Elizabeth A. Maull, Ph.D

The Biological Effect of Airborne Infrasound

(2001)

Dr Reinhard Bartsch
Jena University, Vienna

(Excerpts)

The principal of infrasound is like any other sound. An evaluation of 100 sources of literature shows that [it has] the same effects on health and well-being as with audible sound, and thus noise cannot be excluded. Apart from causing temporary or permanent auditory threshold drifts, up to deafness with sufficient levels (if infrasound is clearly above 130 dB), the following psychomental disturbances are listed under [the] so-called extra-aural effects: fear, loss of appetite, dizziness, fatigue, reduction of concentration, headache, reduction in efficiency, lethargy, stomach problems, ear pressure, irritability, sleep disturbances and disturbance of well-being.

Furthermore the following health impairments are quite controversially discussed: eye problems, influences on blood pressure, depression, disturbances to blood circulation, epilepsy, influences on the endoctrinal system, changes in Erythrozyten, changes in the vibrotactile feeling threshold, equilibrium disturbances, affects on skin temperature and skin resistance[?], effects on heart beat frequency and the function of the pituitary gland, Myocardial Ischemia, reduction of blood circulation in the gastric mucosa, Neuromotor [?] and Nystagmus, as well as occurrences of Tinnitus.

(This document was translated from German, and as such some of the exact terms were difficult to translate)

Infrasound
(2000)

John D. Cody
Borderland Sciences Research Foundation Inc

(Excerpts)

The human organism continues to reel under intermittent infrasonic assault for numerous reasons. After less than a five minute exposure to low intensity infrasound of 10 cycles per second, dizziness will last for hours. Infrasound of 12 cycles per second produces severe and long lasting nausea after a brief low intensity exposure.

The Mistral, the northward winds of the African continent, sweeps over the southern Mediterranean coastlands during late fall.

The Mistral, weak in infrasonic intensity, does not wreak havoc with material structures. But the Mistral works its permeating harm nonetheless. For the inhabitants of certain coastal areas, the low intensity infrasound of the Mistral brings with it a peculiear seasonal anxiety and depression. In certain locations across the Mediterranean coastland there are individuals who suffer from 'seasonal nervous exhaustion' and other 'neurophysical maladies'. It is known that whenever the Mistral blows, there will be increased emotional tension, depression, and irritability. The Mistral, in numerous cases, has produced fatalities.

Fohn winds are dry and warm southerly winds which traverse the Alpine regions of Europe. Fohn weather is characterised by clear skies, high visibility, and dry atmosphere.

The biological effects of both Mistral and Fohn weather have been well documented. These include extreme irritability, accident-prone loss of objective judgement, slight disorientation, mild nausea and diarrhoea.

It is an established fact that sustained low intensity infrasound alters human behaviour and health. Higher accident rates are correlated with pre-Fohn weather onset. This high accident rate rises until the establishment of Fohn weather, having been attributed to the infrasonic content of the winds.

APPENDIX 5

Health Effects at Other Windfarms

Adverse Effects Experienced by People living Near Existing Windfarms
Tharpaland International Retreat Centre

For full bibliographical details see References section

Adverse Effects Experienced by People Living Near Existing Windfarms
(2003)

Tharpaland International Retreat Centre

(Excerpts)

The subjects participating in the 3 windfarm studies represent, not a general population, but the specific population of meditative retreaters who frequently attend retreats at Tharpaland. Because of their extreme sensitivity to the external environment, the adverse effects reported by these subjects might therefore be considered atypical with respect to the general population. However, many people living near windfarms have reported adverse effects and experiences that are very similar and, as indicated below, in many cases identical to those reported by the subjects of the 3 windfarm studies. The following is a selection of such reports.

Symptoms and other adverse experiences reported by the residents near Marton, Askam and Ireleth, near Barrow-in-Furness, England:

- *'a noise that you feel rather than hear.'*
- *'a feeling of pressure on the head and chest area.'*
- *'a feeling of breathing and heart beat wanting to keep in synch with the 'noise', and feelings of distress if this changes.'*
- *'Anxiety, annoyance, stress, irritation, anger.'*
- '*pains in head'*
- '*ear popping'*
- 'heart *rate change'*
- '*heart moves in rhythm with the sounds of the turbines.'*
- 'bre*athlessness'*
- *'intensification of asthmatic condition'*
- *'crushing feeling'*
- '*distress'*
- '*difficulty to concentrate'*
- *'sleep disturbance'*

- *'loss of sleep'*
- *'Headaches, fatigue' – 'one farmer working close by cannot be there for more than 2 hours because of just these symptoms' – he states 'it does my head in''.*
- *'Made physically sick – nauseous in close proximity to the turbines.'*
- *'one resident is convinced, although not medically confirmed, that the brain haemorrhage she suffered is attributable to the turbines being close to her premises.'*
- *'complaints referring to the shadow flicker …of nausea and dizziness.'*
- *'Those of use who are unfortunate enough to live closest to the turbines are experiencing a barrage of background noise pollution that is actually making some of those most affected physically sick.'*

Symptoms and other adverse experiences reported by residents in Laholm, Sweden

- *'The unbearable noise disturbance'*
- *'the shadows that drives them mad'*
- *'The visual effect is making you stressed'*
- *'People are becoming really ill'*
- *'I had to leave my house in January, 1999. I realized that I could not stay unless I was willing to become ill'*
- *'By the end of 1998 I had high blood pressure'*
- *'…and every time I was on my way home from work or getting up in the morning I was afraid, and I mean really afraid, that the wind might be negative'*
- *'Tension'*
- *'Stomach-ache'*
- *'Blood pressure'*
- *'Aggression'.*
- *'When the sound continued for more than a week due to the wind, I was literally broken.'*

Darmstadt Manifesto (Initiative Group, 1998)**: Excerpt from a paper on wind energy signed by a group of 100 German academics which includes symptoms and other adverse experiences reported by residents in Germany:**

- *'People are describing their lives as unbearable when they are directly exposed to the acoustic and optical effects of windfarms.'*

- *'There are reports of people being signed off sick and unfit for work.'*

- *'There is a growing number of complaints about symptoms such as pulse irregularities and states of anxiety which are known to be from the effects of infrasound.'*

The above impacts that many people living near existing windfarms exhibit are much the same symptomology as the subjects who participated in the windfarm studies (see table below); the only difference being that the subjects, due to their spiritual training, are probably more sensitive to and aware of windfarm impacts and therefore quicker to experience them and quicker to identify them as such.

Symptoms	**Windfarm environments**		
	Sweden	**Barrow in Furness**	**TIRC studies**
Anger/Irritation/Aggression	Y	Y	Y
Annoyance	Y	Y	Y
Anxiety/Stress	Y	Y	Y
Blood pressure increased	Y		
Body vibration			Y
Breathing difficulties		Y	Y
Depression			Y
Difficulty concentrating		Y	Y
Disturbed sleep/insomnia	Y	Y	Y
Dizziness		Y	Y
Fatigue		Y	Y
Headache/head pressure	Y	Y	Y
Heart rate alterations		Y	Y
Loss of confidence			Y
Nausea		Y	Y
Unbearable/tormenting noise	Y	Y	Y
Noise that is felt, not heard		Y	Y
Pressure in chest		Y	Y
Pressure in ears			Y
Pain in stomach	Y		Y

NB. Where a 'Y' is omitted does not mean the residents of that area do not experience those symptoms but that they have not necessarily reported them in their literature or communication.

APPENDIX 6

Infrasound
in
Films, Concert,
&
Military Applications

Mysterious Signals – Where do they come from? The Secret World of Noises
Anne Hartman

Infrasonic – Summary of Results
C O'Keefe, Purcell Room Soundless Music (Infrasonic) Project.

The Sonic Weapon of Vladimir Gavreau
Gerry Vassilatos, Borderland Sciences Research Foundation Inc.

Windfarms Bombshell
Chris Story, Annandale Herald.

For full bibliographical details see References section

Mysterious signals – Where do they come from?
The Secret World of Noises
(2 October 2002)

Broadcast by the German TV Station ‘Zweites Deutsches Fernsehen’ ‘Adventure Knowledge’ TV series

Below is an on-line article by Anne Hartman on ZDF website

‘Mysterious signals’ ‘What do human beings hear?’ was broadcast by the ZDF in the framework of the TV series ‘Adventure Knowledge’ on October 2nd 2002.

It is easy to imagine that it takes a lot of tinkering in sound recording studios to produce the sounds for a movie, since it is only the appropriate background sounds that give a movie the right mood, be it an action or a horror movie. For a few years now, sound technicians have been working on new movie sounds.

‘The White Noise’

Sound designers use low sounds from within the infrasound range in order to deliberately produce specific emotions in the viewers. This is also the case with Lothar Segeler and Uwe Dresch, two sound engineers from the ‘Soundvision’ company in Cologne. Last year they produced the final dolby-movie sound mixture for the movie ‘The White Noise’, an impressive story of a schizophrenic adolescent. At that time they did not anticipate that their work would be award-winning and showered with accolades from critics. What they did know, however, was that success in cinema depends not so much on the images, but above all on the sound.

Raw Nerves in the Studio

Lothar Segeler and Uwe Dresch have known each other for years, so far they have been a harmonious team. However, during the extensive film production something unusual happens: The two bicker. Never before have they argued so fiercely – to such an extent that they are about to stop the production. It is only days later that they recognize the cause - they have become victims of their own sound expertise. What strained their nerves were the extremely low sounds coming from the speakers in the studio, which they used to intensify a conflict situation in the movie.

Dolby Surround

Since the mid 90s, a small sound technological revolution has gradually been taking place in cinemas. Dolby Surround and other high tech sound systems provide a completely new sound experience in the movie theatre. Thus, for instance the Hollywood shocker ‘Silence of the Lambs’ (USA 1991) was one of the first movies to use sounds which could not even be heard by the viewers. However, they show their effect in the form of disturbing vibrations directly in the stomach region. These sounds penetrate the subconscious and cause fear and anxiety.

The Effect of Low Sounds

Uwe Dresch has already been working on psychoacoustic effects for years. His sounds should maintain their power even in situations where the viewer closes his eyes out of fear. The sound designer does not work with individual sounds but with a mixture of many different sounds, that are manipulated with elaborate technology. A soundmix is being created which continually increases and decreases, similar to the noise described by ‘grumbling tone’ victims. However, not only movie goers can be manipulated by such eerie sounds. Recently low frequency sounds have begun to be applied in psychiatry, with doctors in New York using them in the treatment of schizophrenic patients. Thus by means of sound, they want to penetrate the unconscious of the patients. Perhaps these low sounds can heal; they can definitely trigger fear and make us scared and what is clear by now is that in the long run they make us sick.

TV-report: Thomas Weidenbach
Online-report: Anne Hartmann

Infrasonic – Summary of Results

(31 May 2003)

C O'Keefe
Purcell Room Soundless Music (Infrasonic) Project

(Excerpts)

This paper outlines the results of a highly unusual experiment that was staged during two contemporary music concerts. Although the concerts consisted of audible sound, two pieces in each event were laced with infrasound – extreme bass sound, below 20Hz in frequency. Infrasound is of considerable interest to psychologists, acousticians and musical scholars as it is used in sacred organ music and has been implicated in the strange feelings experienced at ostensibly haunted sites (Tandy and Lawrence, 1998).

Our experiment took place at the Purcell Room, London. It was based around a concert for live piano and electronics. Some of the music in the concert was laced with infrasound, produced by an infrasound generator, designed and built for the experiment. The infrasound had a fundamental frequency of 17Hz.

Unusual experiences

Many unusual experiences were reported during the concerts, ranging from the emotional (e.g. 'sense of sorrow', 'brief moment of anxiety', 'excited') to the physiological (e.g. 'increased heart-rate', 'headache', 'tingling in neck and shoulders', 'nausea', 'sense of coldness'). The majority of reported experiences were physiological.

Comparing the pieces

With the exception of Piece B, there is a significant correlation (at the 0.05 level) between number of experiences reported and the presence of infrasound.

Quotes – Piece A (5pm performance)

Male	Slight nausea, difficulty swallowing, fat head
Male	Felt like being in a jet before it takes off
Female	Pre-orgasmic tension in body and arms but not in legs
Female	Heightened sense of smell
Male	Slight throbbing at side of chest
Female	Sudden memory of an emotional loss
Female	Slight rush of adrenaline, strange feeling in back

Quotes – Piece B (3pm performance)

Female	Sensation of warm or shiny thing on chest and under throat
Female	Feeling of compression around head and neck
Male	Pressure on side of hand and pulsing pressure on myself
Female	Hot and cold
Male	Felt unusual depth to the sound, lightheaded and compression in chest
Male	Strange blend on tranquillity and unease

Quotes – Piece C (5pm performance)

Male	Like I was looking out of a train into a tunnel, like every memory was running through my head
Male	Slight tingling on my arms
Female	Intense feeling of paying to be in an experiment
Male	Excitement, chest flutter, disorientation, pressure in ear, drumming

Quotes – Piece D (3pm performance)

Male	Goosebumps, could feel oscillations
Male	Shivering on my wrist, odd feeling in stomach
Male	Increased heart rate, ears fluttering, anxious
Female	Chill down left side, sense of panic and confusion
Female	A gentle dance, back in the past

The Sonic Weapon of Vladimir Gavreau
(1997)

Gerry Vassilatos
Borderland Sciences Research Foundation Inc.

(Excerpts)

Infrasound produces varied physiological sensations which begin as vague 'irritations'. At certain pitch, infrasound produces physical pressure. At specific low intensity – fear and disorientation.

The central research theme of Dr. Vladimir Gavreau[3] was the development of remote controlled automatons and robotic devices. To this end he assembled a group of scientists in 1957. The group, including Marcel Miane, Henri Saul and Raymond Comdat, successfully developed a great variety of robotic devices for industrial and military purposes. In the course of developing mobile robots for use in battlefields and industrial fields, Dr. Gavreau and his staff made a strange and astounding observation which, not only interrupted their work, but became their major research theme.

The first devices Dr. Gavreau implemented were designed to imitate the 'accident' which first made his research group aware of infrasonics. They designed real organ pipes of exceedingly great width and length. The first of these was six feet in diameter and seventy five feet long.

The main resonant frequency of these pipes occurred in the 'range of death', found to lie between three and seven cycles per second. These sounds could not be humanly heard, a distinct advantage for a defense system. The effects were felt however. The symptoms come on rapidly and unexpectedly, though the pipes were operating for a few seconds. Their pressure waves impacted against the entire body in a terrible and inescapable grip. The grip was a pressure which came in on one from all sides simultaneously, an envelope of death.

Next came the pain, dull infrasonic pressure against the eyes and ears. Then came a frightening manifestation on the material supports of the device itself. With sustained operation of the pipe, a sudden rumble rocked the area, nearly destroying the test building. Every pillar and joint of the massive structure bolted and moved. One of the technicians managed to ignore the pain enough to shut down the power supply.

These experiments with infrasonics were as dangerous as those early investigations of nuclear energy. Dr. Gavreau and his associates were dangerously ill for nearly a day after these preliminary tests. These malodies were sustained for hours after the device was turned off. Infrasonic assaults on the body are the more lethal because they come with dreadful silence. The eyesight of Dr. Gavreau and his fellow workers were affected for days. More dangerously were their internal organs affected: the heart, lungs, stomach, intestinal cavity were filled with continual painful spasms for an equal time period.

---

[3] In the late-1950s [Dr Vladimir Gavreau, a French military scientist specialising in robotics], and his team had a problem: they constantly suffered from nausea. A long air duct, coupled to a slow motor, was found to be acting as a giant pipe, creating an infrasonic wave. If that was blocked, so was the nausea. This discovery triggered a series of experiments to investigate the power of such waves when driven at very high levels.' (Pascal Wyse, The Guardian, Friday May 16, 2003)

Musculature convulses, torques, and tears were the symptoms of infrasonic exposure. All the resonant body cavities absorbed the self-destructive acoustic energy, and would have been torn apart had the power not been extinguished at that precise moment. The effectiveness of infrasound as a defense weapon of frightening power having been demonstrated ‘to satisfaction’, more questions were asked. After this dreadful accident, approaching the equipment once again was almost a fearful exercise. How powerful could the output of an infrasonic device be raised before even the operating engineers were affected?

Walt Disney and his artists were once made seriously ill when a sound effect, intended for a short cartoon scene, was slowed down several times on a tape machine and amplified through a theatre sound system. The original sound source was a soldering iron, whose buzzing 60 cycle tone was lowered five times to 12 cycles. This tone produced a lingering nausea in the crew which lasted for days.

Physiology seems to remain paralysed by infrasound. Infrasound stimulates middle ear disruptions, ruining organismic equilibrium. The effect is like severe and prolonged seasickness. Infrasound immobilizes its victims. Restoration to normal vitality requires several hours, or even days. Exposure to mild infrasound intensities produces illness, but increased intensities result in death. Alarming responses to infrasound have been accurately recorded by military medical experts.

Tolerances from 40 to 100 cycles per second have been recorded by military examiners. The results are sobering ones. As infrasonic pitches decrease, the deadly symptoms increase. Altered cardiac rhythms, with pulse rates rising to 40 percent of their rest values, are the precursors to other pre-lethal states. Mild nausea, giddiness, skin flushing, and body tingling occur at 100 cycles per second. Vertigo, anxiety, extreme fatigue, throat pressure, and respiratory dysfunction follow. Coughing, severe sternal pressure, choking, excessive salivation, extreme swallowing pains, inability to breathe, headache, and abdominal pain occur between 60 and 70 cycles per second. Post exposure fatigue is marked. Certain subjects continued to cough for half an hour, while many continued the skin-flush manifestation for up to four hours.

Significant visual acuity decrements are noted when humans are exposed to infrasounds between 43 and 73 cycles per second. Intelligibility scores for persons exposed, fall to a low of 77 percent their normal scores. Spatial orientation becomes completely distorted. Muscular coordination and equilibrium falter considerably. Depressed manual dexterity and slurred speech have been noted before individuals blackout. Just before this point, a significant loss in intelligibility is noted.

The findings of Dr. Gavreau in the infrasonic range between 1 and 10 cycles per second are truly shocking. Lethal infrasonic pitch lies in the 7 cycle range. Small amplitude increases affect human behaviour in this pitch range. Intellectual activity is first inhibited, blocked, and then destroyed. As the amplitude is increased, several disconcerting responses had been noted. These responses begin as complete neurological interference. The action of the medulla is physiologically blocked, its autonomic functions cease.

Windfarms Bombshell

(December 2003)

Chris Story
Annandale Herald

Defence Chiefs this week dealt a sensational blow that could block any plans for massive windfarms throughout Dumfriesshire.

They fear seismological testing equipment at their remote Eskdalemuir observation post could be affected by the waves released by huge wind turbines.

Such is its sensitivity that the Ministry of Defence say any developments within a 50-mile radius of the station ‘would not be permissible’.

If the power-generating farms did get the go-ahead, it is understood they would impact on the United Kingdom’s involvement in an international treaty to monitor nuclear arms testing, in which Eskdalemuir will play a key role.

References

References

Alves-Pereira M. (1999a): Noise-Induced Extra-Aural Pathology: A Review and Commentary. *Aviation Space Environmental Medicine* 70 (3, Suppl), A7-21.

Alves Pereira M, Castelo Branco N (1999b): Vibroacoustic disease: The Need for a New Attitude Towards Noise. *International Conference on Public Participation and Information Technologies (ICPPIT 99).*

Andresen, J., and Møller, H. (1984): Equal annoyance contours for low frequency noise. *Jnl Low Freq Noise Vibn* 3, 1-9.

Annandale Herald. Story, C. 'Windfarms Bombshell' 26 December 2003

Backteman, O., Köhler, J., and Sjöberg, L. (1983a): Infrasound – Tutorial and Review. Part 1. *Jnl Low Freq Noise Vibn* **2**, 1-31.

Backteman, O., Köhler, J., and Sjöberg, L. (1983b): Infrasound – Tutorial and Review. Part2. *Jnl Low Freq Noise Vibn* **2**, 176-210.

Backteman, O., Köhler, J., and Sjöberg, L (1984a): Infrasound – Tutorial and Review. Part 3. *Jnl Low Freq Noise Vibn* **3**, 28-67.

Bartsch, R (2001) Die Biologische Wirkung von Luftgeleitetem Infraschall (The biological effect of airborne infrasound)

Bayer (2001) Noise Pollution Prevention Program

Benton, S. (1997): Low frequency noise and the impact upon an individuals quality of life: Case study reports. *Jnl Low Freq Noise Vibn* 16, 203-208.

Benton, S., and Leventhall, H. G. (1994): The role of 'background stressors' in the formation of annoyance and stress responses. *Jnl Low Freq Noise Vibn* 13, 95-102.

Berglund, B., Lindvall, T., Schwela, D., and Goh, K.-T. (2000): Guidelines for Community Noise. *World Health Organisation*.

Brenner, Malcolm (2003) Infrasound: I'm all shook up! *The Sun-Herald* 24 August 2003 http://www.sun-herald.com/NewsArchive2/082403/tp3ch18.htm

Canas J, Martinho Pimenta AJF, Castelo Branco NAA. (1993): ERP P300 and MRI Studies of the CNS in Military Pilots: A Comparative Study of Early Degenerative Brain Process. *Aviation Space Environmental Medicine* 64, 451.

Carmo G, Albuquerque e Sousa J, Dinis da Gama A, Castelo Branco NAA. (1992) Carotid Angiodynographic Studies in Helicopter Pilots. *Aviation Space Environmental Medicine* 63, 385.

Casella-Stanger (2001): Low Frequency Noise. Technical Research Support for DEFRA Noise Programme. Department for Environment, Food and Rural Affairs.

Castelo Branco NAA. (1999) The Clinical Stages of Vibroacoustic Disease. *Aviation Space Environmental Medicine* 70 (3, Suppl), A32-9.

Castelo Branco NAA, Rodriguez E, Alves-Pereira M, Jones DR. (1999) Vibroacoustic Disease: Some Forensic Aspects. *Aviation Space Environmental Medicine* 70 (3, Suppl), A145-51).

Castro AP, Aguas AP, Grande NR, Monteiro E, Castelo Branco NAA. (1999) Increase in CD8--+ and CD4--+ T lymphocytes in patients with vibroacoustic disease. *Aviation Space Environmental Medicine* 70 (3, Suppl), A141-4.

Cody, J. D (2000) Infrasound. *Borderland Sciences Research Foundation, Inc*

Crespo F, Ferreira CAN, Castelo Branco MSNAA, Castelo Branco NAA. (1988) Doença sistémica das vibrações III – Estudo da coagulação e hemostase em doentes com a DSV. *Systemic vibration disease III – hemostasis and coagulation studies in patients with this disease.* *Revista Portuguesa de Medicina Militar* 36, 86-9.

Department for Environment, Food & Rural Affairs (DEFRA), Noise and Nuisance Policy (1998) Health Effect Based Noise Assessment Methods: A Review and Feasibility Study.

Danielsson, A., and Landstrom, U. (1985): Blood pressure changes in man during infrasonic exposure. An experimental study. *Acta Med Scand* 217, 531 - 535.

Gomes LMP, Martinho Pimenta AJF, Castelo Branco NAA. (1999) Effects of occupational exposure to low frequency on cognition. *Aviation Space Environmental Medicine* 70 (3, Suppl), A115-8.

Green, J. E., and Dunn, F. (1968): Correlation of naturally occurring infrasonics and selected human behavior. *J Acoust Soc Am* 44, 1456-1457.

Guski, R. (1999). Personal and social variables as co-determinants of noise annoyance. Noise & Health, 3, 45-56.

Haneke, K. E, Carson, B. L; Gregorio, C. A; Maull, E. A (2001) Infrasound. Brief Review of Toxicological Literature. Integrated Laboratory Systerms, Inc, National Toxicology Program

Hartman, A (2002) Mysterious signals – Where do they come from. The Secret World of Noises. Broadcast by the German TV Station 'Zweites Deutches Fernsehen' Adventure Knowledge TV Series. http://www.zdf.de

Holmberg, K., Landstrom, U., and Kjellberg, A. (1997): Low frequency noise level variations and annoyance in working environments. *Jnl Low Freq Noise Vibn* 16,

Hood, R. A., and Leventhall, H. G. (1971): Field measurement of infrasonic noise. *Acustica* 25, 10-13.

ISD Scotland (2003), Information and Statistics Division.

Ising, H., and Ising, M. (2002): Chronic cortisol increases in the first half of the night caused by road traffic noise. *Noise and Health* 4, 13-21.

Ising, H (1980): Psychological, ergonomical, and physiological effects of long-term exposure to infrasound and audiosound. Noise Vib. Bull. [volume and number not provided]

Karpova, N. I., Alekseev, S. V., Erohkin, V., Kayskina, E. N., and Reutov, R. P. (1970): Early response of the organism to low frequency acoustic oscillations. *Noise and Vibration Bulletin* 11, 100-103.

Kelley, N (1998) Is low frequency noise a problem for wind turbines? *American Wind Energy Association*

Kyriakides, K., and Leventhall, H. G. (1977): Some effects of infrasound on task performance. *J Sound Vibration* 50, 369-388.

Landström, U. (1987): Laboratory and field studies on infrasound and its effects on humans. *Jnl Low Freq Noise Vibn 6*, 22-33

Landström, U., Kjellberg, A., Söderberg, L., and Norström, B. (1991): The effects of broadband, tonal and masked ventilation noise on performance, wakefulness and annoyance. *Jnl Low Freq Noise Vibn* 10.

Landström, U., and Byström, M. (1984): Infrasonic threshold levels of physiological effects effects. *Jnl Low Freq Noise Vibn* 3, 167-173.

Leventhall, H. G. (1988): Low frequency noise in buildings. Internal and external sources. *Jnl Low Freq Noise Vibn* 7, 74-85.

Leventhall, G, Pelmear, P and Benton, S (2003): A Review of Published Research on Low Frequency Noise and its Effects. A report for DEFRA. Department for Environment, Food and Rural Affairs

MacMillan R (1998). The Safetyline Institute.

Marciniak W, Rodriguez E, Olszowska K, Atkov O, et al. (1999) Echocardiographic evaluation in 485 aeronautical workers exposed to different noise environments. *Aviation Space Environmental Medicine* 70 (3, Suppl), A46-53.

Martinho Pimenta AJF, Castelo Branco NAA. (1999a) Neurological aspects of vibroacoustic disease. *Aviation Space Environmental Medicine* 70 (3, Suppl), A91-5.

Martinho Pimenta AJF, Castelo Branco MSNA, Castelo Branco NAA. (1999b) Balance disturbances in individuals with vibroacoustic disease. *Aviation Space Environmental Medicine* 70 (3, Suppl), A96-9.

Martinho Pimenta AJF, Castelo Branco MSNA, Castelo Branco NAA. (1999c) The palmo-mental reflex in vibroacoustic disease. *Aviation Space Environmental Medicine* 70 (3, Suppl), A100-6).

Mirowska, M., and Mroz, E. (2000): Effect of low frequency noise at low levels on human health in light of questionnaire investigation. *Proc Inter-Noise 2000, 5, 2809 - 2812*.

Møller, H., and Lydolf, M. (2002): A questionnaire survey of complaints of infrasound and low frequency noise. *Jnl Low Freq Noise Vibn* 21, 53 - 65.

O'Keeffe, C. (2003): Infrasonic-Summary of Results, Purcell Room Soundless Music

(Infrasonic) Project

Occupational Safety and Health Administration (1995). Hearing Conservation 3074. US Dept. Labor: Washington DC.

Persson-Waye, K., Bengtsson, J., Kjellberg, A., and Benton, S. (2001): Low frequency 'noise pollution' interferes with performance. *Noise and Health* 4, 33-49.

Persson-Waye, K., Rylander, R., Benton, S., and Leventhall, H. G. (1997): Effects on performance and work quality due to low frequency ventilation noise. *J Sound Vibration* 205, 467-474.

Persson-Waye, K., Bengtsson, J., Rylander, R., Hucklebridge, F., Evans, P., and Clow, A. (2002): Low frequency noise enhances cortisol among noise sensitive subjects during work performance. *Life Sciences* 70, 745-758.

Persson-Waye, K., Clow, A., Edwards, S., Hucklebridge, F., and Rylander, R. (2003): Effects of nighttime low frequency noise on the cortisol response to awakening and subjective sleep quality. *Life Sciences* 72, 863-875.

Pimenta MG, Martinho Pimenta AJF, Castelo Branco MSN, Castelo Branco NAA. (1999) ERP P300 and brain magnetic resonance imaging in patients with vibroacoustic disease. *Aviation Space Environmental Medicine* 70 (3,Suppl), A107-14.

Porter, N. D; Berry, B. F. and Flindell, I H (1998): Noise and Nuisance Policy. Health Effect Based Noise Assessment Methods: A Review and Feasibility Study. *Department for Environment, Food and Rural Affairs*

Radevna, R. (1997): Studying the effect of acoustic conditions in the living environment of multifamily buildings on inhabitants. (Bulgarian)

Ratcliffe, K (1996) Windfarm Development. ISVR Consulting, University of Southampton.

Shpilrain, E.E (2001):Distributed Power Problems, Opportunities and Challenges. Environmental Aspects of Res Utilization for Distributed Power. *World Energy Council.*

Silva MJ, Carothers A, Castelo Branco NAA, Dias A, Boavida MG. (1996) Sister chromatid exchanges worders exposed to noise and vibration. *Mutation Research* 369, 113-21.

Strandberg, U. D, Bjerle, P; Danielsson, A; Hornqwist-Bylund, S; Landstrom, U (1986) Studies of Circulation Changes During Exposure to Infrasound. Arbetarskyddsstryrelsen, Publikatinsservice, Solna, Sweden (Swedish)

Tharpaland International Retreat Centre (2003a): Tharpaland International Retreat Centre. TIRC.

Tharpaland International Retreat Centre (2003b): The Effects of Windfarms on Meditative Retreaters: A Human Impact Assessment (Interim Report). TIRC.

Tharpaland International Retreat Centre (2003c): Reflections on Tharpland. Cd-Rom and Video, TIRC.

Traditional Housing Bureau (2002) 'Noise – the unseen menace' Press release 19 June.

Vassilatos, G. (1997): The Sonic Weapon of Vladimir Gavreau. Borderland Sciences Research Foundation, Inc.

Vasudevan, R. N., and Leventhall, H. G. (1982): A study of annoyance due to low frequency noise in the home. *Jnl Low Freq Noise Vibn* 2, 157-164.

Welsh Affairs Committee (1994), Wind energy, volume 1. Report and proceedings. House of Commons