Report on the Health Impacts of Wind Farms Shetland 2013

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INTRODUCTION

This report is written to respond to a request from the Shetland Charitable Trust, to provide a report on the “health effects (if any) of wind farms”.

In December 2012 a scoping of this piece of work was agreed.

Project Aim: To report on the known (ideally published) literature of Health Impact Assessment work done on wind farms (primarily but not exclusively English speaking publications) with commentary on the quality of the evidence presented in relation to the published literature on effective Health Impact Assessment work.

This report presents that work.

In the report I have used the range of sources available as described in the section on method, referencing the relevant material with hopefully enough explanation for the reader to understand not only the evidence and conclusions being presented, but also the strength and validity of the material to explain its contribution to our current understanding.

Reference is also made to Health Impact Assessment methodology in as much as this leads to a better understanding of the literature and information presented.

The potential impacts of wind farms in relation to the health of local populations can be summarised under the following headings: construction and operational safety, flicker, electromagnetic radiation, and noise including low frequency sound. The report is divided into sections under each of these headings.

Some Health and Environmental Impact Assessments also include features of social and economic impact that might be considered to have an indirect impact on health, but these are not covered in this report.

Chapter 1 sets out the method of this work, including an explanation of the range of literature found and used, with some explanation of the type and quality of evidence available and how it is interpreted. It briefly covers the methodology of Health Impact Assessments, and their role in both understanding health effects of environmental challenges, and of contributing to the management and potential mitigation of risks identified. It includes the definitions of health referred to in later sections.

Chapter 2 deals with construction and operational safety issues;

Chapter 3 explains the phenomenon and potential health impacts of flicker;

Chapter 4 briefly describes the known effects of electromagnetic radiation on the human body, in the frequency range associated with wind farms;

Chapter 5 covers noise. This section includes a brief explanation of sound, noise, its measurement, low frequency noise and infrasound, noise production from wind turbines, and the effects of noise on health in general and from wind turbines in particular.

Chapter 6 describes the literature on Wind Turbine Syndrome and Vibro Acoustic Disease.

Chapter 7 is a brief section referring to the literature on mitigation, though presenting this in detail was not seen as a core part of the brief for this project.

The report ends with conclusions and a summary.

Disclaimer:
This work has been undertaken by myself as a Public Health practitioner, and does not represent the views of Shetland NHS Board. I do not claim expertise in wind technology, nor in the clinical areas referred to. I am aiming this report at members of the Shetland community who would like to be better informed about the possible health effects of wind farms, and therefore it presents my understanding of the issues and available evidence. It is not a Health Impact Assessment of the Shetland Wind Farm proposal. Any omissions / errors are unintentional and mine alone.

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METHOD

The task in this review was to collect and present known literature on Health Impact Assessments (HIAs) of Wind Farms (WFs) and to give a general understanding of the conclusions reached.

An initial search of the formal literature was done using key words: health and health impact assessment(s), wind farms, wind turbine(s); via scientific publication databases including MEDLINE, PubMed, OVID, SAGE. Documents were also used from a search of a wider set of databases undertaken for the literature review to inform the Public Health Impact Assessment commissioned but unpublished by Viking Energy.

A limited number of formally published Health Impact Assessments on individual wind farm projects were found, along with a larger number of published literature reviews, and summaries / reviews of evidence of the health impacts and effects of wind farms, which have been used to inform this report.

The published assessments and reviews call on a common body of published literature, the detail depending on the time, scale, academic rigour and context of the work.

I have also referred directly to a range of this source literature and the original research referenced in the published HIAs and reviews, to get an understanding of the technology, of the phenomena referred to, and of the mechanisms of potential health impact as reported, and to make sense of the HIA literature and of the conclusions reached, to be able to present this in a meaningful way.

Where Health Impact Assessments and reviews of evidence have given wider literature sources than I have used directly, I have tried to indicate this, so that readers can pursue details of interest themselves.

Types and quality of evidence and its interpretation

Most of the more formal evidence reviews contain an element of analysis and critique of the evidence base[1] [2] [3] [4] and some, particularly those from academic units, are peer-reviewed.

The most recent found[1] is an update of an original evidence review[4] of available research on the characteristics of wind turbines that may have the potential to affect the health of nearby residents, published in Canada.

Some are presented as summaries with or without comment, for instance a web-based publication of extracted highlights of a range of literature, without explicit methodology or critique[5]. Some are explicit about the methodologies used in the review, including database sources, search terms, and distinguishing between types and quality of literature sources.[1 3 4 6] Some refer only to peer-reviewed scientific literature and others also to the most prominent information from popular literature.

They include evidence reviews commissioned by government or public bodies working at policy level,[3] expert and / or independent Panel Reports,[7 8] reviews commissioned by the Wind Energy sector and its supporters, and by opposers to wind farm development.[9] Some are carried out by independent professionals whether or not they are commissioned.[10 11 12]

At best publications declare interests in terms of both the researchers and the commissioning body, though not all do this. The literature also includes responses to reviews and impact assessments which include criticisms of their methodology and / or conclusions. Some of the published criticisms of particular pieces of work refer specifically to undeclared interests of the authors which lead critics to be sceptical of the validity of the work or more often of the conclusions drawn.[13]

There are a number of publications presented as Health Impact Assessments of wind farms in general[14] and a number of published HIAs of specific wind farm projects, sometimes published as an element of Environmental Impact Assessments.[7 15 16 17 18 19]

There are a small number of pieces of original research in this field that are designed with a clear research purpose, explicit methodologies of study design and analysis, peer-reviewed in terms of methodology, results and conclusions, and published in peer-reviewed scientific journals. Quantitative research[A] of this type specifically on aspects of wind farms and health include a number of field studies,[20 21] which are cross sectional, with randomised control samples, valid theoretical hypotheses and structures from recognised scientific backgrounds of research. The purpose is masked to avoid bias, they include valid measurement tools, and outcomes are quantified and expressed in terms of statistical significance.

There are a number of surveys of people living near wind farms.[10 22 23] These vary in their methodologies: some such as MORI attempt to avoid bias by avoiding asking people directly about sources. Others also masked the subject with other themes or presenting a neutral theme, and other questions as well as on wind farms.[21]

Qualitative research[B] includes case studies which range from those published in the scientific literature which examine numbers of cases of people presenting with problems, with varying degrees of, and sometimes without substantiation, drawing variable theoretical / observational conclusions; to anecdotal reports from unpublished literature, popular media sources and personal communications.

[A] Quantitative research; refers to investigations via mathematical or statistical measurement.
[B] Qualitative research: gathers information often from case studies for a more in depth understanding of behaviour, situations or context.

Publications are often categorised as those published formally in peer reviewed scientific journals, grey literature[C] and popular literature including material found through internet searches or in the media. Some reviews[2] give a history of the literature on environmental noise to show how it has developed with the development of wind power, and refer to the power of web-based media in influencing public opinion compared to the scientific and grey literature.

Finally of relevance to this report is the range of explanatory literature of different effects under consideration, mostly general but some specific to wind farms - noise, low frequency noise (LFN) and infrasound, vibration etc. Again within these fields is published material of a range of 'quality' - from primary research peer-reviewed in scientific literature, subject to scientific scrutiny and debate, to popular literature and media publications with a varying degree of reference to bodies of science or exploration, and varying content in terms of methodologies, analysis and critique.

In general, formal peer-reviewed scientific publications and elements of grey literature such as reviews by recognised authorities e.g. WHO, are regarded by the scientific community as carrying more weight than case studies and anecdotal reports. There are formally recognised schemes for assessing or validating the quality and strength of evidence[24] which some of the more academic reviews refer to. A number also recognise scientific uncertainties in this area, and the qualities of 'good' research of experimental, observational and epidemiological design.[25]

Some publications refer to and summarise guidelines and regulations relevant to limiting health effects. It is not the purpose of this report to detail or comment on these in any detail, but they are referred to briefly in the section on Mitigation.

The methodology of Health Impact Assessments

Health Impact Assessments (HIAs) are a set of methodologies used to predict, assess and help manage the potential impacts on health of policy and practice in many sectors, and to make the consequences of decisions explicit. They have been described as being about the appropriate use of evidence and theory to enhance the quality of decision making in the interests of population health.[26] This often includes recommendations or actions to maximise any benefits to health, and to minimise or mitigate any potentially negative impacts.

In this context, health effects have been defined as 'the overall effects, direct and indirect, of a policy, strategy, programme or project on the health of a population'. In public health terms, health is usually defined in line with the World Health Organisation definition of health[27] as a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity, and though this is idealistic, it governs how we view and assess health. We recognise that the things that influence health are

[C] Defined as Information produced by all levels of government, academics, business and industry in electronic and print formats not controlled by commercial publishing.

complex, and may be the result of a number of factors including personal biology and genetics; environment; culture; socio-economic circumstances; personal beliefs and attitude; and behaviour. More recent work on public health and health improvement focusses on our sense of wellbeing and our capacity to cope, adapt and self–manage in the face of social, physical and emotional challenges. This is primarily about prevention, and then as much about learning to live through illness or with disability as it is about cure or treatment. Health is seen as inextricably linked with quality of life, about 'what it takes to make life worth living'.[28]

A large range of published literature and technical expertise on Health Impact Assessment (HIA) exists, including guidance issued by many national governments and public health organizations.[29] [30] [31]

Health Impact Assessments can range from a rapid appraisal to an in-depth piece of research, and may employ both qualitative and quantitative approaches to data collection. They ideally contain not only literature reviews and analysis of potential impacts (both positive and negative) of a policy or project in the local context, but also an element of consultation or engagement with interested parties[D]. Ideally, HIAs are carried out as part of policy development and the decision-making process rather than as a post-hoc retrospective exercise. They are sometimes included as a component of Environmental Impact Assessments.

The use of Health Impact Assessment by decision-makers, and steps to incorporate it into relevant policy development process, is important if we are to begin to positively affect the broad social determinants of health and impact in a more fundamental and holistic way. HIA does not remove the need for difficult decisions, but it makes the health consequences more explicit.[28]

This report is not a Health Impact Assessment of the proposals for wind farm development in Shetland, but it does draw on the published literature of Health Impact Assessments of wind farms.

Summary

There are a large number of reviews of the evidence of the health impacts of wind farms, and literature reviews of varying range and depth, available from government bodies internationally, from independent scientific bodies or expert panels, and from supporters and opposers to wind farm developments including the industry itself.

There is a limited amount of original scientific research, epidemiological field studies, observational and measurement studies, and a large number of case studies both from the formal scientific literature and in informal public media.

[D] Viking Energy Public Health Impact Assessment, unpublished.

There are a number of Health Impact Assessments done on individual wind farm developments that apply the findings of research to the local context.

This report draws on the evidence and literature published to date as found, and the summary and conclusions attempt to bring it together in a form that is accessible and understandable to the lay reader.

CONSTRUCTION AND OPERATIONAL SAFETY

Potential health impacts relating to the construction and operational safety of wind farms can be summarised in the following categories:

Construction

Wind farms in development are large, industrial scale construction sites with a well rehearsed range of health and safety issues. Some of the wind farm literature reviews[3] report limited specific literature on construction injuries in relation to wind farms, though injuries to workers during construction and transport have been recorded. There is a body of literature on construction and Health & Safety in general, beyond the scope of this report. Some wind farm reviews include specific mitigating actions, referred to in the later section on mitigation.

In summary, health impacts from the construction of wind farms occur from:

- workplace injuries;
- inappropriate access by the public to the construction site;
- Road Traffic Accidents from industrial traffic due to increased traffic volumes in the construction phase;
- the potential for traffic delays and temporary road blockage due to transporting heavy equipment / enabling road works, potentially a particular problem in remote and rural areas with single-track roads and limited access to remote sites.[16 17]

Concerns have also been expressed about noise from construction.[3]

Operational safety

Operational safety issues consist of structural failures including:

Blade failure:

A number of reviews report documented cases of wind turbine failure including fragments of blades or whole blades being dislodged, and turbine collapse. Cold stress can cause damage to components which increases the risk of turbine failure, but some reviews quote modern turbines being designed to withstand temperatures down to -40'C.[1]

The risks of blade failure have been quantified from historical data[1] as partial blade failure occurring in 1 in 4,000 turbines per year, and full blade failure between 1 in 2,400 and 1 in 20,000 turbines per year depending on rotor speed, though the data quoted is relatively old (pre-2001).

Throw distances of whole blades up to 150m, and of blade fragments up to 500m have been documented.[1]

Lightning strikes are quoted as being the commonest source of breakage, with vandalism or improper assembly as the likeliest causes of failure.[3]

This review reported in 2008 that up to that point, there had been no recorded evidence of injury to the public from a wind turbine, though deaths and injuries have been reported in construction workers.[1] More recent figures show updated information collated internationally from documented press reports and official information releases. 142 UK accidents were recorded from 2006 - 2010, though informal literature collection reports 10 x that many. This shows an upward trend in numbers from about 2002, in line with the increased number of turbines built nationally. In terms of fatalities internationally, the majority were wind industry or direct support workers. 6 injuries to members of the public have been recorded in the UK since the 1990s.[32]

Fire is the second commonest cause of injury noted in relation to turbines, and there are reported incidents of moorland fires caused by turbine fires.

These risks are addressed by setback and operational guidance, which are referred to in a number of reviews[1] [3] and in the chapter on Mitigations.

Icing: ice throw and ice shed:

Ice is a recognised phenomenon and a normal operating process when temperatures are low enough, and has been recorded in a number of countries. It consists of ice forming on the turbine blades, the likelihood of which depends on low temperatures and related climatic conditions such as cloud cover, precipitation and fog, as well as features of the turbines themselves.

Ice and ice fragments can be thrown from moving blades (known as ice throw) to a distance from the turbine: ice fragments up to 1kg in weight have been reported upto 100m from turbines in Canada and Finland,[1] which is a potential public hazard.
Or ice can break loose and fall to the ground when the blades are stationary - when the turbine is off or idling (known as ice shedding), which is most likely as a risk to construction workers and turbine operators.

Studies have been reported from Canada and Europe[1] with formal monitoring of ice formation and ice throw in specific wind farms, and the likelihood and risk rates have been modeled,[3] with recommendations on setback to avoid injury.[1]

<u>Summary</u>

The risks of construction work of wind farms on health are non-specific as for many large, industrial scale constructions with a well rehearsed range of health and safety issues in relation to workplace injuries; inappropriate access by the public to the construction site; road traffic accidents from industrial traffic due to increased traffic volumes in the construction phase; and the potential for traffic delays and road blockage causing delays to emergency services access. In the operational phase, safety issues with potential health consequences consist of structural failure of part or whole blades being thrown, turbine collapse, or ice fragment throw from icing of the blades in wintry conditions. These risks are minimised by setback limits and operational guidance.

FLICKER

Flicker occurs either from direct reflection of the sun off wind turbine blades or by the shadows created during sunny conditions. Moving shadows cause a flicker effect that varies according to the size and shape of the turbine and its blades, and features of the landscape and layout of wind turbines in relation to the sun and viewing distance and angle. Shadows have their longest reach when the sun is low in the sky.

About 5% of the population who suffer from epilepsy will have fits provoked by flicker. This is known as photosensitive epilepsy (PSE), and is estimated to affect about one in 4,000 of the general population.[1 33] In these individuals, fits can be precipitated by sunlight in reflection or when flickering or interrupted, and other precipitants including television, which is now governed by guidelines on flicker rates to prevent the occurrence. Examples of light interruption known to cause PSE include rotating helicopter blades.

The seizure-provoking effects of flicker are well understood, and the features of turbines that would combine to produce PSE are well described. [1 3 33] The likelihood of flicker induced PSE is affected by features of reflection and shadow effects: width and length of blades, visual angle, viewing distance and position of the sun, as well as the speed of rotation of the blades.

Wind turbines rotate at a variety of speeds depending on their design and the wind conditions, quoted in different articles as 0.3 - 1.75 Hz, [1 3 34] or up to 300 rpm for smaller turbines.[33]

1 Hz = 60 rpm (revolutions per minute) ie 1 rotation per second.
At 60rpm 3 bladed Wind Turbines produce flicker at a rate of 3Hz, at 30 rpm they produce flicker at 1.5 Hz.

The risks of inducing PSE have been quoted as happening at flicker frequencies of up to 30 Hz, most likely at 2.5 - 3 Hz and above,[1] below this the risk reduces though remains over considerable distances from the turbine.[33]

Turbines that rotate faster or have more blades, or where several turbines are in line with the sun's shadow and produce flicker from a combination of blades from different turbines, can have a higher frequency than from a single turbine, and are therefore more likely to produce PSE.

Some formal shadow flicker assessments have been done, finding flicker affecting some households for up to 21 hours per year.[3] Shadows are sometimes cast on the windows of dwellings causing effects inside the building.

In some studies flicker has been shown as a nuisance and source of annoyance in its own right, as well as contributing to the annoyance of noise below the thresholds for inducing epilepsy.[35]

It has also been noted as a distraction to passing motorists.

There are no other known health effects from flicker.

Summary

Shadows caused by wind turbine blade rotation can cause flickering that contributes to the annoyance perceived by some people. Shadow flicker can cause epileptic fits in some people with epilepsy, but this is unlikely at the normal rotational speed of wind turbines. Operational guidelines ideally include mitigations to reduce the risk of photosensitive epilepsy and annoyance from flicker.

ELECTROMAGNETIC RADIATION

Radiation can be classified as ionizing radiation (e.g. x-rays, gamma rays) and non-ionizing radiation (NIR), which is the term given to the part of the electromagnetic spectrum where there is insufficient quantum energy to cause ionisations in living matter. It includes static and power frequency fields, radiofrequencies, microwaves, infra-red, visible light and ultraviolet radiation. Electromagnetic fields (EMFs) arise from electric charges and the strength of a field at a point depends upon the distribution and behaviour of the charges involved.

The term EMF as used here covers fields in the frequency range below 300 gigahertz (GHz).

Electromagnetic fields include static fields such as the Earth's magnetic field and fields from electrostatic charges, electric and magnetic fields from the electricity supply (at power frequencies 50 Hz in the UK), and radio waves from TV, radio and mobile phones, radar and satellite communications.[36] For frequencies above 100Hz there are adverse effects caused by thermal effects - heat stress and tissue damage - equivalent to sun burn.

The main interaction of low frequency electric and magnetic fields (EMF) with the human body at the frequencies used for power generation is the induction of electric fields and associated currents in body tissues. The responsiveness of nerve & muscle tissue to electric stimuli is well established,[37] and is used diagnostically and therapeutically in medicine for nerve conduction studies and peripheral nerve stimulation. Magnetic Resonance Imaging (MRI) uses magnetic fields to diagnose a range of physical body changes. Exposure to low frequency electric fields can also cause surface electric charge effects, known as static electricity. This produces effects like hair standing on end, or micro shocks (muscle and nerve stimulation effects), generated from contact with objects that are charged in electric fields e.g. some nylon materials. These effects can be experienced outdoors beneath large power lines. There is an established effect of electric fields below the threshold for direct nerve or muscle excitation - the induction of magnetic phosphenes, a perception of faint flickering light in the periphery of the visual field, thought to result from the interaction of the induced electric field with electrically excitable cells in the retina.[37] This is considered as a model of the effects on the nervous system in general. The levels at which these known effects occur are well established, at levels many thousands of times higher than those found in buildings.

The bodies that regulate the use of non-ionising radiation such as the National Radiological Protection Board (NRPB) have been reviewing the available research and undertaking continuous surveillance for the last three decades, and more recently this has led to a harmonisation of protection guidelines across WHO & the European Union (EU). The available research covers epidemiological studies, experimental biology, volunteer studies and dosimetry (measurement).

There is a spectrum of opinion within the scientific community about the possible effects of exposure to radio-frequency fields. Some studies have suggested possible effects from mobile phone exposure, but the evidence on this remains inconclusive and the current guidance on exposure levels from living near to mobile phone base stations is that they are unlikely to pose a risk to health.[38 39]

The overall conclusion at present is that there is no clear evidence for neuro-behavioural effects such as cognition, sleep and mood (from volunteer experiments); nor for adverse effects from low frequency electric and / or magnetic fields on the neuroendocrine system. The biological and epidemiological evidence suggests that radio frequency fields do not cause cancer, and magnetic fields are not considered to have sufficient energy to damage cells, so there is no known mechanism or clear experimental evidence to explain how adverse effects might happen.

Studies have also looked at whether exposure to electromagnetic radiation is linked to the risk of a number of specific illnesses such as Parkinson's Disease, Multiple Sclerosis, Cardiovascular Disease, Alzheimer's Disease, and the results to date are described as inconclusive.[37]

The results of some epidemiological studies of human populations have suggested that there may be an increase in risk of childhood leukaemia at higher than usual magnetic field exposures in homes, some of which are near to large power lines. The evidence for this is described as weak, in that it might explain up to 1% of cases of childhood leukaemia in the UK, and there is ongoing research on this.[40]

There is also continuing research into the possible mechanisms of physiological changes caused by exposure to radio frequencies, much of this research is looking for positive effects.

With regard to non-thermal effects: a variety of mechanisms have been proposed, and are referred to in the informal literature on wind turbines. However, the scientific literature on non-ionizing radiation describes the plausibility of the various non-thermal mechanisms that have been proposed as very low, with little evidence to support the theories, though it accepts that it is in principle impossible to disprove their possible existence.[38 41]

There is some conjecture that EMR produces a false sensation of low frequency noise or infrasound in some people, but authorities on infrasound say there is no evidence to support this. High peak levels of pulsed EMR do lead to auditory effects such as clicks and buzzes but not at levels found in relation to wind farms.[11]

<u>Electromagnetic Radiation and Wind Farms</u>

Electromagnetic fields (EMF) in wind farms can originate from:

- grid connection lines, which are similar to other power lines, and generate low levels of EMF, comparable to those generated by household appliances;[42]

- wind turbine generators, situated inside the turbine's central housing 60-100m above ground level, so are reported to produce little or no EMF at ground level;[1]

- electrical transformers - generate EMF within the wind farm and are no different to electric transformers for any source;

- underground network cables - governed by protection guidelines like other cabled sources. The consistent view of published reviews and government guidelines is that any EMF generation by underground cables is not evident at the surface because of protective features such as phase conductors and screening.[1, 13, 37, 38, 40, 41, 43]

Some authors[44] discuss particular features of electrical activity that they believe occur with wind farms (high frequency spikes of electricity) that they link to the same phenomenon as sick building syndrome, and which they propose may account for some of the symptoms of people disturbed by proximity to wind turbines. This view is not supported in the majority of published literature.

<u>Summary</u>

While many studies indicate that exposure to electric and magnetic fields do not cause health effects, and some phrase this as being unlikely to be harmful at the levels normally found in homes, there is some uncertainty regarding certain health effects: specifically the possibility of EMR contributing to the risk of childhood leukaemia in households living very close to overhead power lines.

The range of reviews in the mainstream scientific literature conclude that there is not evidence of any link between health effects and the EMR generated around wind turbines, and that the theories that various effects can be attributed to EMR are conjecture and unproven.

NOISE

What is noise?

Sound is made up of frequency (pitch) - measured in Hz (cycles / oscillations per second), and sound pressure (loudness): a measure of the vibrations of air transmitting the sound, measured in decibels (dB) which is a logarithmic scale. One decibel change in sound level is just perceptible, and 10 dB change is heard as a doubling or halving of the perceived level.

Noise is defined as 'unwanted sound'.

The frequency, complexity, and meaning, as well as the loudness of sound all have implications for how noise is perceived. So for instance, environmental sound such as crowing cockerels or church bells can be perceived as pleasant or as a nuisance. 'Unwantedness' is determined by the character and quality of the sound, as well as by the expectations and situation of people perceiving it.

There is a large body of literature about noise in general, environmental and community noise in particular, and its general impacts on people.[45] Noise is recognised as a general environmental stressor and nuisance.[46]

MEASURING SOUND

Most environmental sounds are made of a complex mixture of different frequencies, and various types of filters or frequency weightings are used to determine the relative strengths of frequency components when measuring environmental sound.

Environmental sound pressure levels are usually measured using an A-weighted scale[E]; this gives less weight to very low and very high frequency components, which is similar to the way the human ear perceives sound. Because of this, use of the A-weighting to measure sound will underestimate the likely influence of sound with more of a low frequency component.

Therefore, use of the C-weighted scale is recommended in some circumstances,[45 47] which takes into consideration low frequency noise components down to 50Hz. WHO also recommends the use of night-time weightings to reflect the expected increased sensitivity to annoyance caused by noise at night.

The G weighting is specifically designed for infrasound, which follows assumed hearing contours below 20Hz.[48]

[E] One of a family of curves defined in various national standards relating to the measurement of sound pressure levels.

Some[49] report the use of dB(L) to include the measurement of very low infrasonic frequencies.

Low Frequency Noise and Infrasound

Infrasound, sound and ultrasound refer to frequency ranges defined by the observed sensitivities of the human ear. The normal human ear usually perceives sounds at frequencies ranging from 20 - 20,000 Hz. Frequencies below 200 Hz are commonly referred to as low frequency sound, and those below 20Hz as infrasound, though these definitions vary and the boundaries between them are arbitrary. There is no physical distinction between infrasound and sounds in the audible range other than their frequency.[50]

There is variation between people in their ability to perceive sound, particularly at the ends of the frequency range. The levels used as hearing thresholds are determined from an average amongst hearing adults, so by definition many people hear below (or above) these thresholds,[11] for instance 10% of the population have hearing sensitivity 10-12db below the average quoted as the threshold.[12 51]

Sound across the whole low frequency noise range of <10-200Hz can be heard, though higher sound levels may be needed to hear the lower frequencies.[52] Sound at about 20Hz may be heard 'as a low rumble'.[43]

Age can decrease sensitivity to noise of higher frequencies, so leading to bias towards hearing the lower frequency range.

Acoustic scientists describe links between tonal activity and the effects experienced by some people, so the frequencies and levels at which individuals are affected may vary from person to person. The fact that only one member of a family may detect a noise can lead to additional distress for the hearer, who may not be believed in their perception and its consequences.

It is also recognised that low frequency noise and infrasound is less attenuated by solids e.g. building walls so may be more noticeable in a spectrum of noise inside a building that outside.

Sometimes infrasound is reported as 'perceived' but not recognised as sound,[12] and there is debate in the literature about detection mechanisms of sound in the infrasound range, though it is well established that infrasound at high-enough sound pressure levels can be audible to some people and the hearing threshold has been measured down to 1.5Hz.[51]

The level of sound (its loudness) comes from the vibrations of the air conducting the sound waves and the pressure changes they represent. For lower frequency sounds, a smaller increase in sound pressure level is perceived as a larger change in loudness of the sound. So when low frequency and infrasound are of sufficient level to be detected, a small change in pressure level will be perceived as a large change in loudness or be felt more strongly.

There is more recent research on the mechanisms within the ear that perceive very low frequency sound, which leads their authors to conclude that there are plausible explanations for the perception of infrasound by the human ear at lower frequency levels than has previously been acknowledged.[50 53 54] This provides a concept that infrasonic sound that cannot be heard can still have an influence on inner ear physiology. It is known that some clinical conditions cause individuals to be hypersensitive to infrasound, and this research appears to provide a theoretical possibility of causation of some symptoms attributed to infrasound.

Natural infrasound occurs in the range 0.01 - 2 Hz and is inaudible, occurring from many natural sources such as ocean waves, volcanic eruptions, meteors, wind and other effects. Man made sources include explosions, large combustion processes, machinery, slow speed fans. A child on a swing or a runner may experience infrasound due to changes in head height. A number of authors show charts comparing infrasound levels from different sources including normal activities,[51] and suggest that infrasound levels of between 1-10 Hz of 60-80 dB measured from wind farms equates to or is less than most natural infrasound sources.

However, there is general agreement that there are uncertainties associated with the measurement and characterisation of low frequency noise and infrasound particularly from environmental sources. Measuring infrasound is a complex technical science of applied physics, which includes reducing / suppressing wind noise at higher frequencies, and there are variable results of modelling and direct measurements of environmental noise in general, and wind turbine noise in particular, from a number of studies with variable interpretations by different authors.[55 56]

The mechanism of sound reception throughout the body includes vibrations. It is known that high levels of low-frequency noise excite body vibrations or resonance, for instance felt in the chest at 50-80Hz.[51]

Some people talk of ‘feeling’ noise, particularly at low frequencies in addition to, or even instead of, hearing it. The idea of ‘feeling’ noise at levels below the hearing threshold is controversial and complex and not one currently accepted by the majority of acousticians,[10] who argue that the evidence is that the ear is the most sensitive receptor for infrasound and low-frequency sound, that if you cannot hear a sound you cannot perceive it in other ways and it does not affect you.[11]

Research on a range of sources of environmental noise have recognised that there are genuine problems arising from low-level audible noise, particularly in the low-frequency region, where small increases in level of sound create a more rapid rise in loudness sensation. Low-frequency noise including infrasound attenuates less as it travels. The level decreases with distance, though possibly at different rates with different atmospheric conditions, but it is not absorbed in the same way as higher frequencies by the atmosphere or by obstacles. So, particularly for infrasound, because of its very long wavelength, screening has little effect.[55]

The literature includes technical discussions on the theoretical effects of buildings, where it is understood that the usual room acoustics models would not apply in the infra- sonic range,[55] and how increases in sound levels may occur indoors for low frequency sound.[12]

A number of studies and reviews[43 48 57] confirm that the primary effect of low frequency noise to humans is annoyance, and the recent research on the aural perception of infrasound[54] may contribute to a better understanding of this phenomenon in future.

Some people argue this into or from theories regarding the bodies resonance frequencies - see separate section on Vibroacoustic Disease.

Wind turbines and noise

NOISE PRODUCTION

The noise sources from wind turbines can be split into two groups: machinery noise and aerodynamic rotor noise.

Machinery noise comes from the movement of mechanical parts near the central housing, including the generator, from mechanisms common to other fields of application.[55] It may contain discrete tone components heard as a “beating” noise.[35]

Aerodynamic rotor noise is produced by the rotation of the turbine blades through air and the displacement of air by the turning blades.

Turbines produce both broadband and tonal (distinct pitch) sound. Different aerodynamic effects result in noise being generated at varying levels over a range of frequencies from infrasound to the normal audible range. There are technical descriptions available of the detail of air flow around, and sources of aerodynamic noise from, wind turbine blades.[8 12]

The sound levels from turbines varies according to design and wind speed. Older turbines have been reported as being noisier, and exceeding national recommended noise limits with resulting effects on local residents.[55] Modern industrial wind turbines have been variably reported as producing between 30 and 50 dB(A) measured 300-500m from the turbine[1 3 48 58] though this depends on meteorological and ground conditions.

SOUND LEVELS & QUALITY

Sound levels around wind turbines are usually predicted by modelling, rather than assessed by actual measurement, and some issues have been identified in relation to the limits of modeling.[4] Some studies measured noise and found wind speeds higher than expected from original modelled sound assessment, at hub height and at night, and a thumping noise which further increased annoyance.[59] A number of studies have used actual measured sound levels to investigate reported complaints,[12 21] and a number of reviews [10 60] have accepted the evidence that higher wind speeds at hub height at night can lead to significantly higher noise levels than predicted from modelling or measurement at ground level, because of a combination of atmospheric and sound propagation mechanisms, with resulting annoyance.

How much the noise from wind turbines carries across distance, and the features of the noise heard at different distances and in different environments (e.g. inside as well as outside of buildings) is the subject of some research and much review.

The higher frequency noise components of wind turbines (swishing) can be readily heard within 200-300m of a turbine. Levels of noise at different distances where people are living close to wind farms has been modelled and measured in relation to specific Wind Farms.[12 61] It has been described by some as being comparable to indoor background noise, and is at much lower levels than the levels of environmental noise linked to reported health effects on performance and blood pressure.

Sound pressure levels of this low magnitude are not considered a problem when it comes to other sources of community noise, such as road traffic and aircraft. But we know that sound quality as well as quantity is important when assessing the impact of a noise,[45] and the character of the sound from wind turbines appears to increase the risk of negative perception. These sound characteristics include: amplitude modulation, audible low frequency noise, infrasound, tonal noise, impulse noise and night time noise.[62]

Amplitude modulation is a feature of wind turbine rotation and is determined by the pace of the rotor blades, which gives a rhythmical and characteristic swishing sound. The low frequency element of the sound is amplified by the blade movement.[12]

Such sounds are known to be more easily perceived than an even sound, and some studies report them as more negatively appraised i.e. that they can be heard as more disturbing and stressful.[58 62]

Noise reduces in intensity (loudness) as it spreads out from the source (known as attenuation). Propagation of noise over long distances reduces the high frequency content because atmospheric absorption reduces high frequency sounds more than low frequency sounds. Attenuation is therefore lower at low frequencies, and ground absorption and shielding by barriers work less well for low frequencies. Attenuation is also affected by climate. Large off shore wind farms have shown variations up to 50% in the expected rate of attenuation at 3km due to effects of wind and temperature.[12]

LOW FREQUENCY NOISE (LFN) & INFRASOUND FROM WIND TURBINES

In descriptions of the mechanics and aerodynamics of turbine blade rotation, it is recognised that sound is generated across the range of frequencies including infrasound. Part of the noise has a discrete frequency character, and a number of harmonics. Where the wind turbine emits strong sound in the infrasound range (90dB near 1Hz) the noise is sometimes described as having a thumping character.[55]

A number of studies measuring noise from wind farms have shown that turbine noise is dominated by low frequency and infrasound components.[3 19 20 55 63]

A number of reviews dismiss the high level, low frequency noise perceived from turbines by some, on the basis that the sound is not perceptible, and some acknowledge that low frequency turbulence sound may be audible but no greater than that experienced in other urban and rural environments.[12 63]

Indoor measurement of noise from wind turbines within rooms with windows closed has been found above the threshold of audibility, but less than traffic noise along local roads, and at lower levels than national criteria for Night Time LFN.[11 12]

This and other studies consider that the common cause of complaints from wind farms was not associated with low frequency noise but with the audible modulation of the aerodynamic noise, especially at night.

However, it has been found that the relative amount of low frequency noise produced by turbines is statistically significantly higher for large turbines than for small turbines, and the effect becomes more pronounced at distance because of the effect of air absorption on the higher frequencies. So high frequency sound dominates close to the turbines, but at increased distances it is sound in the low frequency range (125-250Hz) that dominates, and for several of the largest turbines the highest level of noise is at or below 250Hz. This has been heard up to 1km from Wind Turbines,[12] and recorded low frequency noise has been heard in time with the blade passage so giving a muffled version of the audible swish.

The theory, backed by some observations,[55] is that the modulation can be strong, even at large distances, in a stable atmosphere which can occur at night time when the wind is not too strong. This means that the swishing does not attenuate with distance in the same way as modelling would suggest, because of the characteristics of low frequency noise. Wind direction and night time airflow are thought to exacerbate the effect, as are large wind farms where pulses can synchronise. Because low frequency variation is less well tolerated some link this to the symptoms and complaints about night time noise and annoyance presented by people living in the vicinity of wind farms.

Studies measuring levels of infrasound in relation to wind farm environments vary in their findings and have come to a range of different conclusions.

There is a view that the contribution of wind turbines to the measured infrasound levels is insignificant in comparison with the background level of infrasound in the environment. Infrasound levels from turbulent wind is an environmental source anyway, so the sound perception from a wind turbine that is turning will be mixed with wind sourced perception.

Earlier reviews modelled indoor infrasound levels as far below recommended limits for environmental infrasound, and recognised that some turbines might produce levels in excess of this out to several hundred metres, but well below 1km distance. They concluded that infrasound is not responsible for the complaints around wind turbines.[55] Some more recent studies have measured infrasound levels using empirical observations and come to different conclusions.[63]

One recent study reported that the dBA and dBC filters in the measuring instruments were not responding fast enough to measure the infrasound amplitudes produced by wind turbine blades.[49]

The more recent research on the perception of infrasound suggests that some inner ear components may respond to infrasound at the levels and frequencies generated by wind turbines.[54] These researchers acknowledge that this does not necessarily mean that the sounds will be perceived or disturb function in any way, but that it leads to the possibility that it could be influencing function or causing unfamiliar sensations, in ways that are yet to be established.

Most studies and reviews conclude with the need for more research to better understand the phenomenon.

Effects of noise

The effects of noise in general on health, are well described and can be summarised as: hearing impairment, sleep disturbance, direct and indirect stress-related health effects, and annoyance.[45] [64]

Hearing impairment and tinnitus: exposure to continuous noise of 85-90 dBA and above (usually industrial) and short-term exposure to louder levels, can lead to progressive loss of hearing and tinnitus, due to the direct effects of sound energy on the mechanisms of hearing in the inner ear.

High levels of infrasound have well-recognised acute adverse effects - aural pain and eardrum rupture can occur.[43]

Other effects have different mechanisms. Noise has been recognised for many years as an environmental stressor, and can lead to psychological, behavioural and somatic responses which have been well described for a range of environmental causes.

Noise can have a direct effect on performance: there is good evidence that noise exposure impairs performance of complex tasks, workers exposed to occupational noise show both adverse effects on performance and after-effects from chronic exposure. Noise can impair reading at levels of speech noise, and it can interfere with speech intelligibility at specific known levels.[45] Other direct effects of noise exposure have been shown in areas such as memory, and it may increase aggression, and reduce helping behaviours.[46] Most of this research comes from occupational settings or laboratory studies.

There is evidence that noise exposure causes a number of predictable short-term physiological responses. Studies come from a range of settings: occupational where noise exposures tend to be at higher levels, and from community settings.

The evidence on the effects of environmental noise from the published literature has been summarised in a number of places.[6 46 47 64] Research includes laboratory, field and community studies, most of which have been until recently in relation to occupational exposure, road & rail traffic, and aircraft noise in proximity to airports.

<u>Links to Cardiovascular Disease</u>: Noise disturbance from road traffic during sleep has been shown to increase blood pressure, heart rate and pulse amplitude. There are studies showing links to high blood pressure from prolonged exposure to higher sound levels in occupational settings. There are epidemiological studies in community settings showing links to cardiovascular disease (with raised blood pressure and higher hospital admissions from Ischaemic Heart Disease) through exposure to road traffic noise at levels of >70 dB(A), and aircraft noise >55 dB(A). There is also evidence of raised levels of stress hormones in children in relation to road traffic and aircraft noise.

There is debate as to how much of these physiological responses in some settings are mediated through other factors such as annoyance - see later section.

NOISE AND SLEEP DISTURBANCE

There is a well established literature on noise and sleep disturbance, which includes both objective and subjective evidence, including laboratory and field studies, and the exposure effects of different noise levels on sleep.[46 47 65]

Uninterrupted sleep is regarded as a prerequisite for health and functioning.[45 47] Noise disturbs sleep through stopping people getting to sleep, or waking them, or interfering with the natural rate of change of sleep stages. The difference in the background noise level and noise events may be more significant in the effect on sleep than the level of noise of an individual event. Over time there may be some adaptation to disturbed sleep in individuals, but complete habituation does not occur.

Objective (measured) sleep disturbance from environmental noise has been found at a range of levels in different studies, and some studies use self-reported sleep disturbance. WHO reports measurable effects of noise on sleep beginning at 30dB(A), but recognises that lower levels may be disturbing depending on the nature of the noise source. There is increased sensitivity to noise at night leading to annoyance and sleep disturbance, reflected in night-time weightings added into noise measurement.[47] It is recognised that the links between noise and sleep disturbance are not a straightforward relationship.

The secondary effects of sleep disturbance include fatigue, reduced reaction time, decreased performance and depressed mood.

WHO Community and Night Time Noise Guidelines say that for a good night's sleep, noise should not exceed 30dB(A) indoors and 40dB outdoors for continuous background levels, and 45 dB(A) for individual noise events. They also advise that outside noise levels should be low enough to allow people to sleep with their bedroom windows open.

Low frequency noise from a range of environmental sources, including mechanical sources from household equipment such as fans and ventilation systems, has been identified as causing nuisance with adverse outcomes such as disturbed rest and sleep.[45] This can occur at low sound levels equivalent to those generated by wind farms, though some of this evidence is controversial.

Wind Turbine noise and sleep disturbance

A number of studies have found a relationship between noise annoyance from wind turbines and sleep quality.[58 61]

Some studies that have measured wind turbine noise and effects have found that on quiet nights, the noise of turbines rotating at high speed can be heard at distances up to several kilometers.[61]

The effects include sleep interruption (more likely at high sound levels >45 dBA), and annoyance related to difficulties falling asleep and to higher stress scores; morning tiredness and tenseness associated significantly with annoyance; and poorer sleep quality associated with lower Quality of Life scores.[21]

MENTAL HEALTH & WELLBEING INCLUDING STRESS & ANNOYANCE

The WHO definition of health,[27] in recognising the psycho-social context as well as the physical, applies equally to our understanding of mental health: to include not only mental illness, but also our capacity to deal with mental health problems and challenges to our mental health, and our overall mental wellbeing.

The literature on noise and its impact on health recognises the links between mental health and wellbeing, the experience of stress related symptoms, annoyance and quality of life.

No associations have been found between noise and psychiatric disorder, from studies on aircraft and road traffic noise, though there are suggestion of links with the use of drugs such as sleeping pills and anxiolytics (used to treat anxiety).[45]

It is well recognised that noise exposure can be associated with stress and other psychological effects such as anxiety levels, and that environmental noise can be a cause of annoyance. Annoyance in contemporary medicine is used "as a precise technical term describing a mental state characterized by distress and aversion, which if maintained, can lead to a deterioration in health and wellbeing".[66] WHO recognises annoyance as a "critical health effect".[45] The word 'disease' perhaps better reflects the seriousness of annoyance when used in this way. A range of symptoms of stress have been found in community surveys on environmental noise: headache, disturbed sleep and restless nights, being tense and edgy. Some consider these secondary effects as stress related disease emerging from chronic annoyance and sleep disturbance.

The causes of these symptoms are recognised as complex. We understand that levels of hearing vary physiologically, and there is also a varying response in individuals to noise heard. These responses are related to a range of factors including features of the noise itself, the noise source, perception and appraisal of the noise by people hearing it in terms of danger, nuisance and benefit, the environment, the context, and interaction between these factors. The perception of noise is a complex phenomenon and not a passive process. Perceived control and predictability are also important in determining the effects of noise exposure, and this has been shown in occupational and laboratory as well as community settings.[4 46 65]

Some individuals are also identified as noise sensitive - being more likely to hear or pay attention to sound, to evaluate sound negatively and to have stronger emotional reactions to noise. Most of the work on this relates to general environmental noise.[21] Whether this is a psychological factor or has a physiological basis is not clear.[65]

Efforts have been made to define dose–response relationships[F] between sound levels and the frequency of annoyance (as a measure of impairment) in order to form a basis for noise regulations. A number of studies have found clear dose-response relationships between a range of symptoms that can be described as stress related, and sources of community noise, including aircraft and road traffic noise. WHO recognises the nature of annoyance from noise as causing disability and gives it a weighting as a health risk due to environmental conditions.[45]

More recently noise from wind farms has been shown to be associated with annoyance in a dose-response relationship.[6 20 21 63]

[F] Dose-response relationship: describes an effect where a change in exposure has a direct relationship with a change in effect.

Though the primary characteristic for unwantedness is loudness or perceived intensity, it is apparent that different noise characteristics have different impacts on people living in the vicinity of the sources, despite sound levels.

An interaction of stressors such as vibration and noise have been shown to have synergistic effects from laboratory studies, and some of the studies on wind farms show interaction between noise and other factors including the perception of vibration in the levels of annoyance reported.

In some settings high frequency noise has been perceived as more annoying than low frequency noise,[46] though much of the research on annoyance from wind farms has characterised it in relation to low frequency noise. WHO recognises that a large proportion of low frequency components in noise may increase considerably the adverse effects on health.[45]

Studies also suggest that annoyance effects do not habituate without active intervention to mitigate the levels of noise.

The impact of different noise sources is understood to vary for people living in the vicinity of the sources, partly but not only relating to sound levels, and this applies also in the context of wind farms.[67]

Much of the research on this is based on the assumption that attitude influences noise annoyance, but recognises that you cannot exclude the possibility that causality is the opposite way i.e. that annoyance causes a negative attitude to the source, and possibly a feedback loop between these variables. This would need to be tested with a before and after longitudinal study, though some case studies report individuals well disposed to wind turbines who become annoyed once they are built when they suffer from disturbance.[68]

It is recognised that environmental noise can have a higher impact in areas of low background noise, e.g. rural areas, where recorded levels of background noise are lower than those used in guidelines, quoting studies on aircraft noise in wilderness areas.[10] Some countries e.g. parts of Holland, require background noise level surveys as part of noise control regulations.

LOW FREQUENCY NOISE / INFRASOUND AND EFFECTS ON HEALTH

The effects that unwanted noise can produce in terms of symptoms of stress and annoyance have also been found in relation to components of low frequency noise and infrasound within environmental noise.

Reactions have been recognised to extremely intense levels of infrasound from occupational and experimental exposure (at sound pressure levels 130 - 150 dB) which “can resemble those of mild stress reaction and may include bizarre auditory sensations, describable as pulsation and flutter”.[45]

Chronic exposure to low frequency noise at high intensities is known to increase stress and affect well-being,[57] and some research[69] reports pathological changes following occupational exposures, but these findings are yet to be replicated in other studies.

A phenomenon known as ‘‘The Hum’’ has also been recognised: a noise of unknown origin, not normally detectable by sensitive measuring equipment, but causing considerable problems to a small number of people, for whom it leads to a stressful, poor quality of life. In the past this phenomenon has sometimes been attributed to sources such as domestic appliances and machinery, and has sometimes been successfully mitigated by dealing with the source.[11]

Most reviews conclude that there is no reliable evidence to say that infrasound at these levels produces other physiological or psychological effects.[45] However, more recent research which has looked at ways in which low frequency sounds at levels that may or may not be heard could influence the function of the ear, offers explanations for the perception of infrasound, and argues that the traditional viewpoint fails to recognise the physiological response of the ear to low frequency sounds.[50]

Wind Turbine noise and effects on health

A number of studies published in peer reviewed scientific journals, have measured noise levels from wind turbines and their impact on samples of people living in the vicinity. They have found a range of symptoms attributed to the noise of wind turbines in people living close to them, increased awareness of noise with higher sound levels, and increasing levels of annoyance.

The symptoms described are those associated with general environmental noise exposure, often also described as stress symptoms. They include headache, irritability, difficulty concentrating, fatigue, dizziness, anxiety, and sleep disturbance, and are often described in relation to annoyance.

A three countries study in the Netherlands, Germany & Denmark found many of those surveyed experienced noise at around 35dB: 7% were rather annoyed and 4% were very annoyed.[70]

A study of residents near a wind farm in Yorkshire found 83% were not at all or not very concerned about the noise, 17% were concerned.[22]

A study in Sweden found a dose-response relationship between exposure to noise in residents and annoyance - none were very annoyed at levels below 32.5dBA, 36% were very annoyed at levels >40dBA. This study differentiated people who regarded themselves as noise sensitive who experienced little difference below 35dB, but above this noise sensitive people rapidly became more annoyed.[20]

Another study showed a correlation between perception of noise, annoyance and modelled noise levels from 12 different areas 600 - 1014m from WTs. 39% noticed sound at the lowest recorded levels and the % increased almost linearly with increasing sound levels up to 90% at the highest levels recorded >40dB(A).[58]

In another study, respondents increasingly noticed the sound from the turbines as decibel levels increased: 25% at 30dB or less; 80% at 35dB or more.[71]

A study undertaken for the Scottish Executive found 1% people living within 20km of wind farms said they were noisy, most with neither a positive or negative effect,[23] but did not ask details of those living close.

A Dutch study showed increased awareness of noise with higher sound levels, and increased annoyance. 2% were rather or v annoyed at <30dBA and up to 25% at 40-45 dBA.[61]

There are a number of standard measures of quality of life relating specifically to physical, psychological and social components of health, and one recent study used such a tool to quantify health related effects from wind turbines.[21]

This cross-sectional study compared individuals living close (<2km) to wind turbines to a comparison group living further away (>8km), using noise levels measured by an independent noise survey, and found a statistically significant reduction in sleep quality, lower overall quality of life, and lower physical and environmental quality of life features in those living closer to wind turbines. They found no significant difference in psychological quality of life score. Their findings included the fact that self reported noise sensitivity was not associated with distance from wind turbines, so there were no more people living closer to wind turbines who regarded themselves as noise sensitive than amongst those living further away. However, 23/39 (59%) of the turbine group identified turbine noise as extremely annoying, and other annoying noise sources were identified in the comparison group but at much lower levels - 7/158 (4%).

There are also a number of case studies in the formal scientific literature, and a large number in popular and informal literature and the media, that report the effects of wind turbine noise on individuals and households, often in terms of the symptoms that may be described as stress symptoms, and a negative relationship between wind turbine noise and well-being, with more qualitative research showing correlations between wind turbine noise, annoyance and sleep disturbance.

Some authors have concluded that, though they recognise annoyance reported from wind farm noise, this does not constitute a health impact concern. The rationale for this argument is in terms of the relative sound levels from wind turbines compared to other sources of community noise, both domestic and external.[3]

Some studies challenge the traditional methods of modelling sound levels, on the grounds that models underestimate sound levels at dwellings particularly if there are large differences in altitude between the source and receiver, and that models don't take into account the quality of the sounds and the detail of how sound travels, how it is dispersed and absorbed particularly in relation to low frequency sound and infrasound.[58]

In summary, a number of these studies found a direct relationships between sound pressure levels (modelled and measured) and reported perception of sound, and annoyance. Hearing noise is directly related to levels of sound from wind turbines. The higher the sound pressure, the more likely people are to hear the sound, and though a small % of people who hear sound are annoyed by it, that % increased with increasing sound levels.

The conclusion that a number of studies make is that annoyance is a genuine phenomenon related to the sound generated, and that research shows that living close to wind farms has a negative impact on quality of life for some people, in whom their health is compromised by a source of environmental noise that is annoying and / or can disturb sleep.[4 9 20 21 61 70 71]

VARIABLES

Some studies have been done to understand in more detail the nature of and factors in producing annoyance and its potential health impact in the context of wind farms. Some earlier studies on the characteristics of Wind Turbine noise and links to annoyance have shown variable results, including some that could not explain differences in perception.[72] Some work recognizes that noise from wind turbines is perceived as annoying at much lower levels than noise causing annoyance from other environmental sources.[71 73]

A number of the more recent field studies that showed a correlation between sound pressure level and noise annoyance among people living in the vicinity of wind turbines, also showed that annoyance was influenced by a number of other factors including visual factors, the wind turbine impact on the landscape, and respondents attitude to the landscape e.g. as a place for economic growth compared to a place for peace and quiet. People were more likely to be annoyed if they were: living in a rural area, living in an area with low background noise, employed, seeing at least one turbine, thinking of themselves as noise-sensitive; when they noticed changes for the worse to their living environment, when they had a more negative attitude to wind turbines in general or to their visual impact on the landscape.[61 67 71]

These authors explain how environmental stressors disrupt how people think about the place they live, and the value that they get from their home environment. So for instance working people use home for rest and leisure, home has a 'restorative' value. If this is disrupted, and particularly if their rest is disturbed, that may result in an increased risk of annoyance, and stress related symptoms.

One study also showed some coping strategies relevant specifically to wind farms to be associated with positive annoyance but less signs of stress and stain – i.e. linked to annoyance but leading to less impact on individuals in terms of symptoms. Seeking information and discussing wind turbines as a coping strategy could decrease adverse health effects.[58]

Visual Impact

The interaction between noise and visual stimulation is recognised from other environmental sources of noise annoyance, and a number of studies have specifically found links between the visual impact of turbines and annoyance. Those who could see a wind turbine from their dwelling were exposed to higher levels of noise, and responded more negatively to the noise - they were more likely to perceive the wind turbine as annoying. When wind turbines are not visible they cause less annoyance, even at similar noise levels.[4 58 61 67]

Both laboratory and field research suggest that this interaction is complicated.

A number of studies have compared different visual features, and aspects of the landscape, and found associations with the perception of wind turbines, noise and annoyance.[20 61 67]

People's attitude towards a noise including their visual evaluation of it, is known to influence their response to the noise. Whether or not someone can see a wind turbine influences their attitude towards the noise, they are more likely to be annoyed by it, particularly in flat terrain. This is explained as human visual processing being geared to detect contrasts, so a wind turbine in flat terrain is more likely to draw visual attention where it provides a greater contrast to the surrounding area. The theory is that they are also more incongruent, and therefore their visual impact has more of an influencing effect on the response to noise.

Negative visual perception of wind turbines is described variably as intruders in the landscape, or spoiling views, or the constant movement of the rotor blades always attracting the eyes, and this makes people more likely to be annoyed by the noise. This is influenced by the height and closeness of the wind turbines. Respondents might like wind turbines in theory but find them ugly, and were then more likely to be annoyed than if they found them beautiful.

Studies comparing residents exposed to wind turbines in different areas have had mixed results. Some have shown that respondents in flat areas were exposed to higher levels of wind turbine noise and responded more negatively to the noise, than those living in hilly terrain.[58] Since annoyance is directly related to the level of noise perceived, it might equally be that people who are annoyed by them because of higher noise levels are more likely to perceive them negatively. However, people who expected peace and quiet in their living environment were more likely to consider the noise from wind turbines as an intrusion of privacy. Those who lived in rural areas responded more negatively that those in built-up areas.[20] Plus people living in a rural area have different expectations and perceptions of community noise than those living elsewhere, and other studies have shown that people's perception is linked to what people felt about an area, its pleasantness or other values that make it a desirable place to live.

Other factors appear to have an influence such as difference in altitude between dwelling and wind turbine hub when the wind turbine is visible which can create more of a sense of intrusion, and the role of barriers which might affect noise levels and variation as well as visual impact. In addition, noise barriers perceived as a positive part of the landscape are more effective at mediating the response to the noise.

One study[58] attempted to quantify the features studied, and found that the different features only accounted for around 50% of variability in responses - they ask for more research on other factors of impact not yet understood.

Vibration

Studies have recognised noise induced vibrations of building elements including walls and windows in circumstances such as from blast on artillery ranges but have not been able to draw conclusions about wind farms from the data available.[55]

A number of case studies report individuals identifying vibration as a source or component of annoyance, see also section on Vibroacoustic Disease.

Economic Benefit

Different studies have shown variation in the links between annoyance and economic gain.

In some there have been no differences in noise perception based on whether the project economically benefitted the respondent, but respondents receiving some sort of economic benefit from the project reported nearly no annoyance at any sound level.[61]

This study noted a decrease in annoyance at very close quarters where almost all of the respondents had economic benefit from the wind turbines.[61]

Other work has detailed the arrangements that wind farm developers or owners have entered into with local people, either as rent for using land, or as compensation for recognised effects including annoyance.[68] These often include confidentiality clauses or clauses in which residents waive their rights to complain about noise or adverse effects. It would then be unsurprising that these people did not complain about noise or annoyance if subsequently surveyed.

Community Conflict

Some commentators suggest that the conflict between communities or opposers and developers foments the unrest and resistance that leads to complaints or negative impacts.[2] Some research has studied this directly and concluded that the degradation of quality of life they found was related to noise exposure rather than to community conflict.[21]

A number of the field studies that found statistically significant links between perception and annoyance due to wind turbines, masked the nature of the study so that respondents were not directed to wind turbines as a source of effects.[58]

One general conclusion is that, whilst the element of resistance and community conflict may well have a bearing on the reported experience of some, there is sufficient well-researched evidence to accept a non-trivial proportion of persons being highly annoyed.[74]

Discussion

There are a number of areas of controversy within the literature, about the effects on health of noise at the levels generated by wind farms.

There is dispute about whether significant levels of noise are heard at all at distances further from turbines, and how loud they are relative to background noise levels. Nevertheless, a number of studies show a dose-response relationship between wind turbine noise and measured effects.

There are different views about the nature of what is heard particularly with regard to elements of noise, and the role of low frequency noise and infrasound, though there is an increasing body of evidence about the mechanics of turbine generated noise and particularly the amplitude modulation effects that are perceived.

There are also areas of disagreement about the nature of the health effects found in some studies, particularly whether the effects described are an indirect effect secondary to annoyance, or a direct effect from wind turbines themselves.

This is discussed in some places as the individual’s response to psychosocial stressors, but there is also discussion about cause and effect, and whether stress symptoms lead to, or are a result of annoyance.

The public health approach to health including mental health, recognises the pychosocial and environmental components that affect our wellbeing. It also recognises that our health is dependent on coping mechanisms, and building resilience to live with and respond to challenges, so how we perceive and deal with threats and risks to our wellbeing is key to our health.

There is discussion in the wind farm literature about perceived control, and how much communities and individuals who benefit directly from wind farm development, or who are in a position to turn them on and off (e.g. domestic wind turbines owned by householders), have different perceptions of annoyance, or are less likely to report adverse effects.

This is directly linked by some to economic gain, which may be about the balance of risk / cost and benefit in people's responses, but also about confidentiality clauses in rental or compensation agreements preventing complaint.

At least one review has introduced the concept of the nocebo effect (the opposite of the placebo effect[G] the attitude of the hearer giving a negative impact to their perception.[2] This links to the research on annoyance, and factors that have been shown to influence annoyance, including finding that some people are more likely to be annoyed if they have a negative perception of wind farms. However, the fact that studies on annoyance have detailed a number of factors in addition to preconceived attitudes, that have an independent effect on levels of annoyance, would suggest that it is only one factor to be taken into account. This is supported by a number of formally published case studies where people initially predisposed to wind turbines have been subsequently negatively affected by noise.[68]

Some authors discuss the interpretation of symptoms related by some people to wind farm noise. People seek meaning for symptoms that are unexplained, or for effects not regarded by others as valid because of either a lack of understanding or objective measurement, which may lead others to discount personal experience if it cannot be explained. This may lead people to pursue less credible theories, rather than seeking better research to further scientific understanding.

Some authors[75] argue that the thousands of adverse event reports alongside the systematically gathered data provide compelling evidence of causation as well as of the seriousness of the problems reported. They also argue that the failure of explanatory models does not or should not allow us to deny the existence of the problem, but it does mean that we do not know how to sufficiently mitigate the effects.

Some of the features of wind turbine noise are particularly relevant to the Shetland context:

Low ambient noise levels for instance in rural areas, mean that background noise is often below the levels assumed in noise guidelines, so it might be expected that noise awareness from wind turbines is greater than in areas with higher levels of background noise, and that mitigations should take account of this in recommending setback limits, especially at night.

People were more likely to be annoyed by noise from turbines if they were living in a rural area, or an area with low background noise, seeing at least one turbine, when they

[G] Placebo effect: a positive reaction to a non-active or ineffectual intervention.

noticed changes for the worse to their living environment, when they had a more negative attitude to wind turbines in general or to their visual impact on the landscape.

VIBROACOUSTIC DISEASE & WIND TURBINE SYNDROME

VIBRO-ACOUSTIC EFFECTS

Vibration refers to the way energy travels through solid material (whereas sound is energy travelling through gas or liquid). At higher frequencies vibrations attenuate rapidly, it is low frequencies which are of potential concern to human health. When vibration is detected through a body part in contact with a surface, it is the mechanical vibration of the surface that is transmitted and felt. Parts of the body also perceive acoustic sources of vibration - sound waves (described in the section on noise), but they act differently to a transmitted mechanical vibration.[8] Vibration of parts of the body by sound at one of its resonant frequencies occurs only at very high sound levels and is not considered a factor in the perception of wind turbine noise by most of the mainstream scientific literature.

Some people identify the perception of vibration as a component of the noise heard from wind turbines, sometime as a secondary source of noise from building vibration - windows, floors etc.

Vibroacoustic Disease

Vibroacoustic Disease (VAD) is described as a condition caused by occupational exposure to high levels of low frequency noise, found in groups of workers with a set of symptoms attributed to their exposure. It is proposed that low frequency noise may induce pathological changes in various tissues in exposed personnel and in animal models that accounts for these symptoms, which consist of depression, increased irritability and aggressiveness, a tendency for isolation, and decreased cognitive skills, a tendency to epilepsy and cancer, and cardiac problems with specific pathological features.[69]

Some people (publishing in the informal literature) link the symptoms described in relation to annoyance from wind farms as having origins in the same mechanisms as are described for VAD, and argue that prolonged exposure to lower levels may cause similar problems, though the scientific establishment regard the risk of this as remote in light of the much lower levels of low frequency noise and vibration associated with wind farms.[8]

Wind Turbine Syndrome

Dr Nina Pierpont published a book: Wind Turbine Syndrome: A Report on a Natural Experiment[76] described as “a scientific report presenting original, primary research on symptomatic people living near large industrial wind turbines.” She describes a phenomenon ‘Wind Turbine Syndrome’ of a set of symptoms that a number of people present, that they associate with proximity to wind turbines. She describes a range of symptoms: sleep disturbance and deprivation, headache, tinnitus, feelings of pressure in the ears, dizziness, vertigo, nausea, visual blurring, tachycardia, irritability, problems with concentration and memory and panic episodes. She describes a number of people being more susceptible due to a range of pre-existing conditions such as migraine, motion sensitivity and inner ear damage, but that the symptoms are not ‘statistically associated’ with pre-existing anxiety or other mental disorders.

Dr Pierpont proposes a mechanism of disturbance to balance and position sense caused by noise and / or vibration, especially low-frequency components, which she calls Visceral Vibratory Vestibular Disturbance (VVVD). She claims support for these theories in relation to ‘balance-related neural relationships’ as an “anatomic and physiologic framework for WTS”. She uses ‘mail-in survey studies’ of people affected by wind turbines in terms of annoyance to support her theory, and refers to the published literature on the effects of environmental noise.

She concludes that further research is needed to clarify the causes and mechanisms of the effects she attributes to living near wind turbines.

Most of the reviews and health impact assessments published in the formal scientific literature have disputed the mechanisms proposed by Dr Pierpoint. Though the role of the vestibular system in the ear is well recognised in causing motion sickness and similar problems, they argue that the suggestion that VVVD causes vibrations in a number of organs in the body that link to neural signals and cause conflict with other sensory inputs, is not considered plausible.

A recent review[8] sums the mainstream scientific position as there being no credible scientific evidence to support these theories, and provides a critique based on peer-reviewed evidence to counter her theories.

A number of authors recognise the symptoms in relation to annoyance and stress responses.[77] [78]

To date the proponents of Wind Turbine Syndrome as described by Dr Pierpoint have not published research to support their position in the formal peer reviewed scientific literature.

A number of case studies have documented individual accounts of situations or experiences, which some authors have linked to Dr Pierpoint’s theories.

The most commonly sited of these is a study which involved questionnaires sent to people around the UK already known to be suffering from problems which they felt were due to their proximity to wind farms.[79]

The author recognises noise as an intrusion causing annoyance, and that annoyance may lead to as stress response which may lead to symptoms and illness, but then goes on to refer to a range of potential theoretical bases for the problems presented, including Wind Turbine Syndrome as described by Pierpoint, and the Vibroacoustic

Disease theories described above, suggesting that the lower levels of exposure over time may cause similar structural changes of tissues.

Though the effects of long term sleep disturbance are well recognised in the formal literature, the basis of the other theories referred to here are not currently accepted by much of the mainstream medical community.

There is a problem in that Wind Turbine Syndrome symptoms are all common symptoms in the general population, and beyond the research on annoyance, there is little to show that they are more prevalent in the population living close to wind turbines. Many are common stress responses and so difficult to distinguish or determine the difference between a stress response to the recognised annoyance from noise,[11] and a separate wind turbine related condition that at present does not appear to have a substantial theoretical basis.

In summary, science is developed by the generation of hypotheses and the use of experiments and formal studies to test and prove / disprove them. At present there does not appear to be any recognised scientific evidence presented to support these hypotheses.

At best we might say that there are numbers of people who report negative affects and some consider the mechanisms to be in dispute.

MITIGATIONS

There is a range of published literature on legislative and best practice guidelines and mitigations to minimise the potential negative impacts of wind farms.

It is not the purpose of this report to detail or comment on these in any detail, but those that have been identified in the found literature are referred to briefly here.

A number of reviews and Expert Panels on the health impacts of wind farms refer to national setback limits and operational guidelines governing or advising on wind turbines and how to mitigate adverse impacts.[1 2 3 4] A number of countries including Scotland are now setting setback limits of 2km to reduce risks, though these are mostly guidelines for best practice rather than legal requirements.

Some strategic health impact assessments include advice on the development of wind farms in terms of gaining community acceptance and reducing adverse impacts through community engagement, including the importance of “communities consulted with in a meaningful way”.[23] There is a literature on community conflict in relation to wind farm development, which is not included here.

Detail of setbacks and other technical mitigations are included in a number of industry codes of practice and government publications on specific effects.[37 38 40 48 80]

During the construction phase, to avoid workplace injuries and public health and safety risks, general health and safety measures associated with any major construction programme are advised, including for instance limiting access to construction sites.[3]

Flicker: Planning guidance in the UK requires developers to investigate the impact of shadow flicker. Though it is not subject to government standards in many countries, best practices are referred to in setback limits and operational guidelines.[3 81] Advice includes: that turbines should be programmed to stop when blade rotation exceeds 3Hz to avoid the photosensitivity range; recommendations of limits to the numbers of hours per year for shadow flicker exposure for an individual dwelling; that the layout of wind farms should ensure that shadows cast by one turbine upon another are not readily visible to the public; that shadows should not fall across windows of nearby buildings; and that the reflection from blades should be minimised through the use of non-reflective and / or dark colouring.[1 33]

EMR: Guidelines are in place giving advice on restrictions on exposure and other measures to avoid adverse effects from electromagnetic radiation, developed by a number of government bodies both nationally and internationally. The Health & Safety Executive (HSE), National Radiation Protection Board (NRPB) and Ofcom (for emissions around mobile phone base stations) are the main regulating agencies in the UK. These bodies also disseminate information and advice to the public on the potential health hazards of non-ionising radiation.

Exposure guidelines are designed to avoid levels known to cause stimulation and physical effects, and are now more conservative than historically due to revised modelling. Exposure guidelines for the public have become more restricted (20%) than for occupational exposure, a precautionary approach which allows for greater sensitivity e.g. in children, medicated individuals and older people.[40]

For very localised sources, guidelines recommend assessment through dosimetry i.e. direct measurement case by case.

Noise: Noise regulations that apply to wind farms vary between different countries, some regulating noise levels are specific to wind turbines, others were developed for different noise sources. Some are absolute e.g. Germany, whilst others relate to background noise levels e.g. France.

There are recommended international and national limits for a range of noise levels and situations: WHO Community[45] and Night Time Noise Guidelines[47] which specify that outside sound levels should be low enough at night to allow people to sleep with their bedroom windows open, and some nations have limits for environmental low frequency and infrasound levels indoors and outdoors.[1 55]

A number of publications conclude that wind turbines affect health at distances currently permitted under national guidelines,[82] and include recommendations for review of guidance on specific effects associated with the impacts of noise from wind farms. Technical UK guidance on noise limits recognises that the current guidance does not take account of the distinguishing characteristics of wind turbines (higher levels of modulation), that have given rise to complaints.[12] Some researchers ask for more specific mitigations for instance on setback distances of >2km in hilly terrain.[21]

More recent publications argue the need for further research to inform the development of different approaches to mitigation and moderating effects, for instance to safeguard community health and well-being given the annoyance linked to health effects, recognising that impacts are only partly known and understood. [66 67 83]

The principles of mitigation are well described in documents such as WHO Community Noise which refers to UN Agenda 21 supporting a number of environmental management principles including the precautionary principle and the ‘pollutor pays’ principle.

“When there is a reasonable possibility that the public health will be endangered, even though scientific proof may be lacking, action should be taken to protect the public health, without awaiting the full scientific proof. The full costs associated with noise pollution (including monitoring, management, lowering levels and supervision) should be met by those responsible for the source of the noise. Action should be taken wherever possible to reduce noise at the source.”[45]

WHO also recommends levels should be set “to protect the majority of people from being seriously annoyed.”

Risk is something that we all live with on a daily basis. Public policy is usually developed in relation to acceptable levels of risk. What constitutes ‘acceptable’ in the literature on mitigating the effect of wind farms on health is still the subject of some debate.

“Any new technology brings questions and concerns regarding health and safety implications that must be assessed, and the impact of such, publicly acknowledged."[3]

SUMMARY

This report is written to respond to a request from the Shetland Charitable Trust, to provide a report on the “health effects (if any) of wind farms”.

METHOD

There are a large number of reviews of the evidence of the health impacts of wind farms[1 2 4 14] and literature reviews of varying range and depth,[3 6 9] available from government bodies internationally, from independent scientific bodies or expert panels,[7 10 11] and from supporters and opposers to wind farm developments including the industry itself.

There is a limited amount of original scientific research, epidemiological field studies, [20 21 61 71] observational and measurement studies,[10 21 22 23] and a large number of case studies both from the formal scientific literature and in informal public media.

There are a number of Health Impact Assessments done on individual wind farm developments[15 16 17 18] that apply the findings of research to the local context.

This report draws on the evidence and literature published to date as found, and the summary and conclusions attempt to bring it together in a form that is accessible and understandable to the lay reader. Any omissions / errors are unintentional and mine alone.

The potential impacts of wind farms in relation to the health of local populations can be summarised under the following headings: construction and operational safety; flicker, electromagnetic radiation, and noise including low frequency sound. The report is divided into sections under each of these headings. Some Health and Environmental Impact Assessments also include features of social and economic impact that might be considered to have an indirect impact on health, but these are not covered in this report.

CONSTRUCTION AND OPERATIONAL SAFETY

The risks of construction work of wind farms on health are non-specific as for many large, industrial scale constructions with a well rehearsed range of health and safety issues in relation to workplace injuries; inappropriate access by the public to the construction site; Road Traffic Accidents from industrial traffic due to increased traffic volumes in the construction phase; and the potential for traffic delays and road blockage causing delays to emergency services access.[3 16 17]

In the operational phase, safety issues with potential health consequences consist of structural failure of part or whole blades being thrown, turbine collapse, or ice fragment throw from icing of the blades in wintry conditions.[1 32] These risks are minimised by setback limits and operational guidance.

FLICKER

Shadows caused by wind turbine blade rotation can cause flickering that contributes to the annoyance perceived by some people.[35] Shadow flicker can cause epileptic fits in some people with epilepsy, though this is unlikely at the normal rotational speed of wind turbines.[1 3 33]

ELECTROMAGNETIC RADIATION

While many studies indicate that exposure to electric and magnetic fields at the levels normally found in homes does not cause health effects,[37] there is some uncertainty regarding the risk of childhood leukaemia in households living very close to overhead power lines.[25]

Magnetic fields are not considered to have sufficient energy to damage cells, so there is no known mechanism or clear experimental evidence to explain how these effects might happen. The general view is that there is no evidence of any link between health effects and the electromagnetic radiation generated around wind turbines[1 36 44] though some authors dispute this.[44]

NOISE

Noise at much higher levels than generated by wind farms (usually industrial) can cause hearing impairment, and effects on performance. There is some evidence from community studies that environmental noise at levels experienced from road traffic and aircraft is related to hypertension and may be a minor risk factor for Coronary Heart Disease. There are well established links between noise and sleep disturbance, and there is increased sensitivity to noise at night leading to annoyance and sleep disturbance.[45 47]

It is generally accepted that the primary effect of low frequency noise on people is annoyance.[43 47 57] Annoyance is recognised as a critical health effect, and is associated in some people with stress, sleep disturbance, and interference with daily living.[45]

There is an increasing body of evidence that noise levels associated with wind farms cause annoyance, in a dose-related response. The higher the sound level, the more likely people are to hear noise, and though a small % of people who hear sound are annoyed by it, that % increases with increasing sound levels.[20 22 58 61 70 71]

A range of symptoms are attributed to the noise of wind turbines in people living close to them, which are those associated with general environmental noise exposure, and are often also described as stress symptoms. They include headache, irritability, difficulty concentrating, fatigue, dizziness, anxiety, and sleep disturbance, and are often described in relation to annoyance.

There are some particular features of the noise associated with wind turbines that contributes to the annoyance perceived by some people, including visual and environmental factors, and it is recognised that low level noise from wind turbines is more often found to cause annoyance than similar levels from other sources.[61 67 71]

Some consider that the common cause of complaints from wind farms is not associated with low frequency noise but with the audible modulation of the aerodynamic noise, especially at night.[11 12] There is also evidence that some people perceive the low frequency noise components of wind turbine noise, and that these are more significant at night and with large wind turbines.[20 54 56]

There are mitigating factors that reduce the impact of noise from wind farms on local people, including some features of the landscape, and environmental and attitudinal perceptions to wind turbines.

There is no reliable evidence to say that infrasound at the levels produced by wind farms causes either physiological or psychological effects, but more recent theories of the potential perception of infrasound might lend support to reports of effects not previously measured or understood.[50 53 54]

Regardless of whether the perceived impacts of noise from wind farms are physiological or psychological in nature, they are considered to cause adverse health effects through sleep disturbance, reducing the quality of life and as a source of annoyance which sometimes leads to stress related symptoms.[1 3 4 21 62]

"Any new technology brings questions and concerns regarding health and safety implications that must be assessed, and the impact of such, publicly acknowledged"[3] and research into the relationship between Wind Turbine noise and health effects continues.[1]

Vibroacoustic Disease and Wind Turbine Syndrome

Vibroacoustic Disease (VAD) is a condition associated with very high exposures to low frequency noise in some occupational settings.[69]

Wind Turbine Syndrome[76] is not a recognized medical diagnosis, but is used by some to describe a set of symptoms that some people associate with living near to wind farms. The general view from the scientific community is that the collective symptoms labelled as WTS in some people exposed to wind turbines are likely to be associated with annoyance.[8]

MITIGATIONS

This report does not cover the literature on mitigations in any detail, but there is a range of published literature on legislative and best practice guidelines and mitigations to minimise the potential negative impacts of wind farms. These are usually framed as setback limits and operational guidelines which include advice to minimise the potential impacts of blade throw, flicker and noise. A number of reviews of the health impacts of wind farms propose more sensitive limits to deal with specific features that cause annoyance.

CONCLUSIONS

Wind turbines are known to cause a number of effects that have an impact on health: risks from ice throw and structural failures that are minimised by appropriate setback distances; noise and shadow flicker that are sources of annoyance, sleep disturbance and symptoms of stress in some people.

Current mitigations do not entirely deal with the annoyance caused by wind farms, the results of which are a cause of distress and related ill health for a number of people living in the vicinity.

GLOSSARY AND ABBREVIATIONS

EMF	electromagnetic fields
EMR	electromagnetic radiation
EU	European Union
HIA	Health Impact Assessment
HPA	Health Protection Authority
HSE	Health & Safety Executive
Hz	Hertz: cycles per second: a measure of frequency of noise or radio waves
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IS	Infrasound: sound below the threshold of human hearing, usually <20Hz
LFN	low frequency noise
NIR	non-ionizing radiation
NRPB	National Radiological Protection Board
PSE	photosensitive epilepsy
WF	wind farms
WT	wind turbines
WHO	World Health Organisation

REFERENCES

[1] NCCEH Evidence Review: Wind Turbines and Health. Fortin P, Rideout K, Copes R, Bos C. 2013

[2] NHMRC Australian Govt 2010 Wind Turbines and Health: A Rapid Review of the Evidence

[3] Chatham-Kent 2008 The Health Impact of Wind Turbines: A Review of the Current White, Grey and Published Literature. Chatham-Kent Public Health Unit

[4] CMOH 2010 The potential health impact of wind turbines, Chief Medical Officer of Health Report Ontario

[5] Chapman S 2012 (latest as at March 2013) Wind Health Reviews: Summary of main conclusions reached in reviews of the research literature

[6] Knopper and Ollson 2011 Health effects and wind turbines: A review of the literature. Environ Health.2011;10-78

[7] Massachusetts 2012 Wind turbine health impact study: Report of Independent Expert Panel

[8] Colby WD, Dobie R, Leventhall G, Lipscomb DM, McCunney RJ, Seilo MT et al. Wind turbine sound and health effects. An expert panel review: American Wind Energy Association & Canadian Wind Energy Association; 2009

[9] Frey B, Hadden P. Wind Turbines and Proximity to Homes: The Impact of Wind Turbine Noise on Health: a review of the literature & discussion of the issues. http://docs.wind-watch.org/Frey_Hadden_WT_noise_health_01Jan2012.pdf

[10] UK Noise Association: Location, location, location 2006

[11] Leventhall G. A Review of Published Research on Low Frequency Noise and its Effects. Report for DEFRA 2003

[12] Hayes Mackenzie for DTI. The Measurement of Low Frequency Noise at 3 UK Wind Farms 2006

[13] Borders. Health effects and wind turbines: A rapid review of the literature. 2012

[14] HIA Programme Oregon Health Authority Strategic Health Impact Assessment on Wind Energy Development in Oregon 2012

[15] Knob Hill Wind Farm Environmental Assessment Application 2004

[16] Western Isles 2005 Submission of NHS Western Isles to Comhairle Nan Eilean Siar: Health Impact Assessment

[17] Western Isles 2007 Health Impact Assessment – Proposed development by Scottish & Southern Energy Plc of 57 Wind Turbines at Pairc, South Lochs, Isle of Lewis

[18] Savage, R. (2006). Epidemiology Report: The Effects of Wind Turbines on Human Health. Huron County Health Unit

[19] Howe, B. (2007). Wind Turbines and Sound: Review and Best Practice Guidelines. Howe Gastmeier Chapnik Limited. Mississauga, ON

[20] Pederson E, Persson Waye K. Perception and annoyance due to wind turbine noise - a dose-response relationship. J Acoust Soc Am. 2004;116(6):3460-70

[21] Shepherd D, McBride D, Welch D, Dirks KN, Hill EM. Evaluating the impact of wind turbine noise on health-related quality of life. Noise Health. 2011 Sep-Oct;13(54):333-9. doi: 10.4103/1463-1741.85502.

[22] British Wind Energy Association 1994

[23] MORI. Public Attitude to Windfarms, Scottish Office, 2003

[24] Cochrane Reviews. The Cochrane Collaboration. http://www.cochrane.org/cochrane-reviews

[25] NRPB Advice on Limiting Exposure to Electromagnetic Fields (0-300 GHz). National Radiological Protection Board Vol 15 No 2 2004

[26] Tannahill A, Douglas M. Ethics-based decision-making and health impact assessment. Health Promot. Int. (2012) doi:10.1093/heapro/das040

[27] WHO Constitution of the World Health Organisation. Geneva: World Health Organisation; 2006. Available at : www.who/int/governance/eb/who_constitution_en.pdf

[28] PHAR 2007 NHS Shetland Public Health Annual Report 2007 http://www.shb.scot.nhs.uk/board/publichealth/index.asp

[29] Lock K. Health impact assessment. Br Med J 2000;320:1395-1398

[30] WHO European Centre for Health Policy: Health Impact Assessment: Main concepts and suggested approach. Gothenburg consensus paper 1999

[31] Health Impact Assessment – a guide for local authorities http://www.healthscotland.com/documents/1283.aspx

[32] Caithness Windfarm Information Forum 2013 www.caithnesswindfarms.co.uk

[33] Harding G, Harding P and Wilkins A, Wind turbines, flicker, and photosensitive epilepsy. Epilepsia, 49(6):1095-1098, 2008

[34] Gadawski A, Lynch G. The real truth about wind energy; a literature review on wind turbines in Ontario. Ottawa ON: Sierra Club Canada; 2011. http://www.caw.ca/assets/pdf/Turbine_Safety_Report.pdf.

[35] Ison E, Pearce-Smith N. Rapid Review of the Health Impacts of Wind Energy 2009

[36] HPA Health effects of electric and magnetic fields website
http://www.hpa.org.uk/Topics/Radiation/UnderstandingRadiation/

[37] ICNIRP International Commission on Non-Ionizing Radiation Protection Fact Sheet on the Guidelines for Limiting Exposure to Time-Varying Electric and Magnetic Fields (1 Hz - 100 kHz) Published in Health Phys 99(6):818-836;2010

[38] ICNIRP Statement on Guidelines for limiting exposure to EMFs upto 300GHz 2009

[39] IEGMP Independent Expert Group on Mobile Phones http://www.iegmp.org.uk/

[40] NRPB Review of the Scientific Evidence for Limiting Exposure to Electromagnetic fields (0-300 GHz). National Radiological Protection Board 2004 NRPB Vol 15 No 3 updated 2009

[41] NRPB Health Effects from Radiofrequency Electromagnetic Fields: Report of an Independent Advisory Group on Non-ionising Radiation NRPB Vol 14, No 2. 2003

[42] Palgrave. The health effects of magnetic fields generated by wind turbines, Windrush Energy 2004

[43] HPA Health Effects of Exposure to Ultrasound & Infrasound Report of Independent Advisory Group on Non-Ionising Radiation 2010

[44] Havas M, Colling D. Wind Turbines Make Waves : Why Some Residents Near Wind Turbines Become Ill. *Bulletin of Science Technology & Society* 2011 31: 414

[45] WHO Guidelines for Community Noise 1999
http://www.who.int/docstore/peh/noise/Comnoise.htm

[46] Stansfield, S.A, & Matheson MP. Noise pollution: non-auditory effects on health. British Medical Bulletin 2003; 68: 243–257

[47] WHO Night Noise Guidelines for Europe 2009 http://www.who.int

[48] British Wind Energy Association (BWEA) Low Frequency Noise and Wind Turbines Technical Annex 2005

[49] Ambrose S, Rand R, Krogh C. Falmouth, Massachusetts wind turbine infrasound and low frequency noise measurements. InterNoise conference NY 2012 inter.noise 2012 in12_325

[50] Salt A, Hullar T. Responses of the ear to low frequency sound, infrasound and wind turbines. Hear Res. 2010 Sept.1;268(1-2):12-21

[51] Leventhall G. What is infrasound? Progress in Biophysics and Molecular Biology 2007; 93: 130-137

[52] Manley, Styles and Moorhouse. Perceptions of the Public of Low Frequency Noise, Journal of Low Frequency Noise, Vibration and Active Control 2002

[53] Swinbanks M.A. Numerical simulation of infrasound perception, with reference to prior reported laboratory effects. InterNoise conference NY 2012

[54] Salt A, Lichtenhan J. Perception-based protection from low-frequency sounds may not be enough. InterNoise conference NY 2012

[55] Jakobsen J. Infrasound Emission from Wind Turbines. Journal of Low Frequency Noise, Vibration and Active Control 2005;24:3:145-155

[56] Moller H, Pederson CS Low-frequency noise from large wind turbines. J Acoust Soc Am, 2011 Jun;129(6):3727-44

[57] Sienkiewicz 2007: Rapporteur report: roundup, discussion and recommendations. Prog Biophys Mol Biol. 2007;93(1-3):414-20. Workshop: HPA, Radiation Protection Division UK Govt Centre for Radiation, Chemical & Environmental Hazards held 2006

[58] Pederson E, Persson Waye K. Wind turbine noise, annoyance and self-reported health and well-being in different living environments Occup. Environ. Med. 2007;64;480-486

[59] van den Berg G, Effects of the wind profile at night on wind turbine sound. Journal of Sound and Vibration 277 (2004) 955-970

[60] Pederson E. Noise annoyance from wind turbines - a review. Swedish Environmental Protection Agency 2003

[61]Van den Berg F, Pederson E, Bakker R, Bouma J. 2008. Wind farm aural and visual impact in the Netherlands. WINDFARM perception study. Acoustics www.acoustics08-paris.org

[62] Krogh C, Jeffery R, Aramini J, Horner B. Wind turbine noise perception, pathways and effects: a case study. inter.noise 2012_304

[63] Evans T, Cooper J, Lenchine V. Infrasound levels near windfarms and in other environments. South Australia Environment Protection Agency 2013. http://www.epa.sa.gov.au/xstd_files/Noise/Report/infrasound.pdf

[64] WHO Technical meetings on exposure-response relationships of noise on health 2003 & 2007

[65] Miedema HM, Vos H. Demographic and attitudinal factors that modify annoyance from transportation noise. J Acoust Soc Am 1999;105:3336-44

[66] Shepherd D, Billington R. Mitigating the Acoustic Impacts of Modern technologies: Acoustic, Health and Psychosocial Factors Informing Wind Farm Placement. Bulletin of Science, Technology & Society 2011 31(5) 389-398.

[67] Pedersen E, Larsman P. The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines J Env Psych. 2008;28:379-89 doi:10.1016/j.jenvp.2008.02.009

[68] Krogh C, Jeffery R, Aramini J, Horner B. Wind turbines can harm humans: a case study InterNoise conference NY 2012

[69] Castelo Branco N, Alves-Pereira M. Vibroacoustic disease. Noise Health 2004;6:3-20

[70] Wolsink M, Sprengers M, Keuper A, Pederson T, Westra C. 1993. Annoyance from wind turbine noise on sixteen sites in three countries. Proceedings of the European Community Wind Energy Conference. 273-276

[71] Pederson E, van den Berg F, Bakker R, Bouma J. Response to noise from modern wind farms in The Netherlands. J Acoust Soc Am. 2009;126(2):634-43 doi: 10.1121/1.3160293

[72] Persson Waye K, Ohrstrom E, Psycho-acoustic characters of relevance for annoyance of wind turbine noise. Journal of Sound and Vibration 2002;250(1):65-73

[73] Janssen SA, Vos H, Eisses AR, Pedersen E. A comparison between exposure-response relationships for wind turbine annoyance and annoyance due to other noise sources. J Acoust Soc Am 2011 Dec;130(6):3746-53. doi: 10.1121/1.3653984

[74] Howe Gastmeier consultancy Literature Review 2010 for Ontario Ministry of Environment

[75] Phillips C.V. Properly Interpreting the Epidemiologic Evidence About the Health Effects of Industrial Wind Turbines on Nearby Residents. Bulletin of Science, Technology & Society 2011 31(4) 303-315

[76] Pierpoint N. Wind Turbine Syndrome: A Report on a Natural Experiment 2009

[77]Farboud A, Crunkhorn R, Trinidade A. 'Wind turbine syndrome': fact or fiction? J Laryngol Otol. 2013 Mar;127(3):222-6. doi: 10.1017/S0022215112002964.

[78] Roberts JD, Roberts MA. Wind turbines: is there a human health risk? J Environ Health. 2013 Apr;75(8):8-13, 16-7.

[79] Harry A. Wind Turbines, Noise and Health 2007

[80] British Wind Energy Association (BWEA) Guidelines for Health and Safety in the Wind Energy Industry 2005

[81] DECC Update of UK Shadow Flicker Evidence Base for Department of Energy and Climate Change 2008

[82] Hanning C. Evans A. Wind turbine noise. BMJ 2012;344:e1527

[83] Horner B, Jeffery R, Krogh C. Literature Reviews on Wind turbines and Health: Are They Enough? Bulletin of Science,Technology & Society 2011 31(5) 399–413 http://bst.sagepub.com/content/31/5/399