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Dear Members,

Welcome to the first edition of New Zealand Acoustics for 2020. It's a big year ahead for acoustics in New Zealand and internationally. This year is the International Year of Sound which is a global initiative to highlight the importance of sound and related sciences and technologies for all in society. Further information can be found at www.sound2020.org.

We also have 'Acoustics 2020' which is our joint New Zealand and Australian Acoustical Societies Conference to be held at Te Papa in Wellington during November. The conference website is available to review at www.acoustics2020.com. This first edition and following second edition of the Journal this year will be a special edition on the World Health Organisation (WHO) Noise Guidelines on Community Noise – 1995 to 2018. The two papers include a review and comment on the 1995 and 1999 WHO guidelines for community noise (CNG), night noise guidelines (NNG) for Europe and the more recently released 2018 Environmental Noise Guidelines for the European region. The aim of the two papers are to provide a concise overview and history of the WHO guidelines and related research papers as well as provide a New Zealand perspective.

Cheers,

Jon Styles

President of the Acoustical Society of New Zealand

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Lindsay Hannah & Wyatt Page

Principal Editors

Lindsay Hannah

Wyatt Page

SPECIAL EDITION FEATURE

World Health Organization Guidelines on Community Noise 1999 to 2018

Lindsay Hannah[1], Wyatt Page[2]

[1]Acoustic Engineer, Cardno, Petone, Wellington New Zealand

[2]School of Health Sciences, Massey University, Wellington, New Zealand

Purpose

The purpose of this paper is to provide an overview of the World Health Organization (WHO) guidelines for noise. It includes a review of the 1999 WHO Guidelines for Community Noise (GCN 1999), 2009 Night Noise Guidelines for Europe (NNGfE 2009) and the recently released Environmental Noise Guidelines for the European Region (ENGfER 2018). The paper provides the reader with an overview of key areas of these WHO guidelines and related background research papers. A high-level review of current New Zealand acoustic standards for environmental noise with comparison to the WHO Guidelines, is also included.

Acoustics – A brief introduction

Acoustics is the science of sound. Sound waves are said to be nearly as old as the universe itself and the study of sound is one of the oldest sciences, having its origin in ancient Greece. Physically, sound is produced by mechanical vibrations propagated as a wave motion in air or some other media. Sound is produced by any vibrating body and is typically transmitted as a longitudinal wave motion in air. Physical sound evokes physiological responses in the ear and auditory pathways that are perceived and interpreted by the listener.

Acoustics is an interdisciplinary field encompassing many disciplines such as physics, mathematics, engineering, psychology, speech, audiology, music, architecture, physiology, neuroscience, and many more. The branches of acoustics are as diverse as the discipline itself with branches including architectural, physical, musical, psychoacoustics, electroacoustics, noise control, vibration, underwater acoustics, speech, physiological acoustics and more.

Physiological acoustics deals with the peripheral auditory system such as cochlear mechanism, stimulus and encoding in the auditory nerve. Psychological acoustics (also referred to as psycho-acoustics) deals with subjective attributes of sound and how they relate to physically objective measurable quantities such as the sound level, frequency, and spectrum.

Sound can be produced by many different processes and sources. Most environmental or community sound that reaches our ears comes from several different sources at once. Humans (and other animals) use sound to communicate and so human hearing is most sensitive over the frequency range covered by human speech. The intensity ratio between the sounds that bring pain to our ears and the weakest sounds we can hear is more than 10^{12}. The human auditory system is complex in both its structure and remarkable in its function, not only does it respond to a wide range of stimuli, but it precisely identifies the pitch, timbre and direction of a sound. Some of the hearing function is done in the organ we know commonly as the ear, some of it is done in the central nervous system. Sound waves below the frequency of human hearing are called infrasound, while sound waves with frequency above the range of human hearing are called ultrasound.

We are constantly exposed to sound in our daily lives. Sound is termed 'noise', typically when it results in adverse health effects. Noise exposure is an important health issue as excessive noise can harm our health in several different ways. Auditory effects include such things as hearing damage or hearing loss. While non-auditory effects can be divided into two main categories, physiological effects and performance effects. The exposure to noise outside our workplace is often referred to as community noise (a type of environmental noise). It has been demonstrated that community noise can potentially have direct adverse effects (other than auditory effects) on communication, performance, behaviour and non-auditory physiological effects such as noise-induced disturbance of sleep and community annoyance. Noise has and will continue to receive increasing recognition as one of our critical environmental pollution problems as our populations continue to grow. Like air and water pollution, noise pollution is generally a function of an increase in population density in our urban areas and cities and can be a serious threat to our quality of life either as direct health effects or loss of amenity value. The growth in noise pollution is likely to be unsustainable as it involves direct as well as cumulative adverse health effects. Noise adversely affects current and future generations and has socio-cultural, esthetical, economic effects of our populations as well as key vulnerable groups such as the elderly, the young children, the blind, hearing impaired and special needs persons.

World Health Organisation – A brief history

The World Health Organization (WHO) is a specialised agency of the United Nations (UN) concerned with international public health. When diplomats met to form the United Nations in 1945 one of the key things these diplomats discussed was setting up a global health organization. The WHO was established on 7th April 1948 in Switzerland (WHO 1946). A date WHO now celebrate every year, known officially as 'World Health Day'. The WHO is headquartered in Geneva and is a member of the United Nations Development Group (UNDG). Its predecessor, the Health Organisation was an agency of the League of Nations. The UNDG is a consortium of many United Nations agencies, created by the Secretary-General of the United Nations in 1997 to improve the effectiveness of UN development activities at the country level. The World Health Assembly (WHA) is the ultimate decision-making body for WHO. The WHA generally meets in Geneva in May each year and is attended by delegations from all 194 Member States. The WHA main function is to determine the policies of the WHO. The Health Assembly appoints the Director-General, supervises the financial policies of the WHO and reviews and approves the proposed programme budget. It similarly considers reports of the Executive Board, which it instructs regarding matters upon which further action, study, investigation, or report may be required.
New Zealand is listed as a WHO Member State – Region 13.

WHO 101 – A Definition of Health

The WHO defines health as:

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

This WHO definition has proved robust and all-encompassing, and has not been amended since drafted in 1948, some 70 or so years ago.

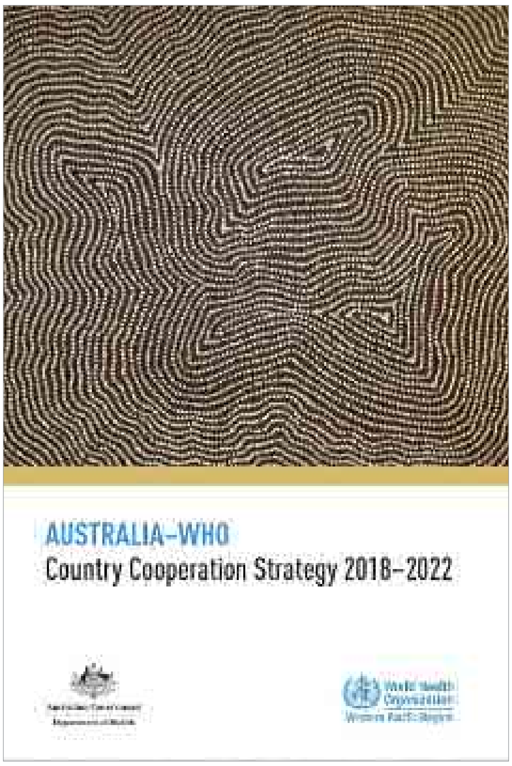
The WHO's primary goals and objectives are to improve equity in health, reduce health risks, promote healthy lifestyles and settings and respond to the underlying determinants of health, which includes community noise. The WHO method to achieve this primary goal is to develop and implement multisectoral public policies for health, integrated gender and age-sensitive approaches that facilitate community empowerment together with action for health promotion, self-care and health protection throughout the life course in cooperation with the relevant national and international partners.

WHO in the New Zealand and South Pacific region

The WHO Representative Office in the South Pacific (which includes New Zealand) is located in Suva, Fiji. The office operates under the umbrella of the Western Pacific regional office, where the WHO's role is to act as a catalyst and advocate for action at all levels, from local to global, on health issues of public concern. The Western Pacific Region, the largest and most diverse of the six WHO regions worldwide is home to just under 2 billion people or roughly a quarter of the world population. There are 37 countries and areas in the Region, stretching from China in the north, to New Zealand in the south. WHO staff work together with a range of partners on closely related public health activities; including research, evaluation, awareness raising and resource mobilization.

Under the leadership of the Regional Director, the Divisions of Programme Management and Administration and Finance, the WHO help countries develop WHO country cooperation strategies, support 15 country offices in the Region, and coordinate the Organization's work with other United Nations agencies and global health initiatives. The New Zealand Government does not have a WHO Country Cooperation Strategy relating to noise.

The Australian government Department of Health has a document entitled 'Australia-WHO Country Cooperation Strategy 2018 – 2022'.



Noise Indicators

A noise indicator, which is also called a noise index, noise descriptor or noise quantity, is a way to measure a property of noise, in a standardised way. This then enables the assessment of the noise in relation to the human response and/or impact on health and amenity.

To avoid ambiguity, noise indicators utilise a standard notation or format, such as *'value-unit-descriptor-time'*. For example, 55 dB $L_{Aeq,15\ min}$, which is read as 55 dB (deciBels) using the A-(frequency) weighted equivalent level, over a 15-minute period. The correct use of standardised notation helps ensure that the persons using it are clear on which noise indicator is being reported on. More complex indicators introduce weighting factors to take account of human response or sensitivity to noise at different times of the 24-hour day. A common example is the Day-Evening-Night equivalent level (L_{den}), which combines A-(frequency) weighted equivalent levels measured during the day (d), evening (d) and night (n) periods, to produce an overall measure for the 24-hour period.

From a scientific point of view, the best noise indicator to measure health or amenity effects is the one that performs best in predicting the effect of interest. There are several complex criteria that may influence the choice of indicator and in many cases various descriptors may be suitable for different end-points, such as health or annoyance. Every noise indicator has limitations, for example the use of L_{Aeq} has been shown to be a reasonable indicator for human response in situations where the noise environment consists of several events, however it may not be as well suited to an environment where the noise climate is dominated by a few occasional short bursts of high-level noise. The takeaway is the effects of noise on people is a very complicated subject and thus there is no perfect single noise indicator.

The current WHO guidelines (ENGER 2018) state that the selected indicators are intended to be suitable for policy-making in the WHO European Region and therefore focus on the most used noise indicators, L_{den} and/or L_{night}. These two indicators are those reported by European authorities and are widely used for exposure assessment in health effect studies. Currently in New Zealand standards, the L_{dn} (day-night level) indicator is used, but the L_{night} descriptor (a relatively new indicator) is not currently used in New Zealand Standards, regulations or guidelines.

The L_{Aeq}, L_{den} indicators and its components (L_{day}, $L_{evening}$ and L_{night}) are described and defined below. All these descriptors use A-(frequency) weighing, as is common practice to approximate the human hearing response to sound with frequency. However, there are significant limitations to using only A-weighed indicators in assessing the wider health effects of noise (see the section **'Issues with A-weighting and the wider health effects of noise'**).

$L_{Aeq,T}$

The A-weighted, equivalent sound pressure level (or 'energy average') over the integration period T. The formula is:

$$L_{Aeq,T} = 10\ lg\left(\frac{1}{T}\int_0^T\left(\frac{p}{p_0}\right)^2 dt\right)$$

Where

lg = $\log_{10}$ (logarithm base 10)
p is the measured A-weighted sound pressure (Pa)
p_0 is the reference pressure of 20 μPa

L_{den}

The Day-Evening-Night sound pressure level is a compound indicator combining the time weighted equivalent levels for each period, with sensitivity penalties for the evening and night time periods. The formula is:

$$L_{den} = 10\ lg\left(\frac{1}{24}\left(12\times10^{\frac{L_{day}}{10}} + 4\times10^{\frac{L_{evening}+5}{10}} + 8\times10^{\frac{L_{night}+10}{10}}\right)\right)$$

Where

L_{day} ($L_{Aeq,day}$) is the A-weighted sound pressure level over the day period. The default values for day is 07.00 hrs to 19.00 hrs (7.00 am to 7.00 pm)

$L_{evening}$ ($L_{Aeq,evening}$) is the A-weighted sound pressure level over all the evening. The default values for evening are 07.00 hrs to 23.00 hrs (7.00 pm to 11.00pm)

L_{night} ($L_{Aeq,night}$) is the A-weighted sound pressure level over the night period. The default values for night is 23.00 hrs to 07.00 hrs (11.00 pm to 7.00 am).

Note: *ISO 1996-1: 2016 Acoustics — Description, measurement and assessment of environmental noise* uses 1-year averages for L_{day}, $L_{evening}$ and L_{night} when calculating L_{den}. It also includes further information such distinct sampling methods for estimating these long-term measurements.

Note: In ENGER 2018, L_{den} (L_{day}, $L_{evening}$ and L_{night}) indicators for noise exposure are measured at the most exposed façade of the building, measured outdoors (generally at 4m above ground).

The WHO states that they acknowledge and know that many countries outside the European Union (EU) are not bound by the terms of 'The European Noise Directive' ('The END') (EC, 2002a) and/or use noise indicators other than L_{den} or L_{night} in their noise regulations, standards or guidelines. However, WHO do make the comment that they still can make use of these guidelines because energy-based average noise indicators are usually highly correlated with health effects and there are *"rule of thumb"* transformations from one indicator to another, as long as the conversion accounts for the long-term average of populations, rather than individual exposure situations. Empirically derived generic conversion terms between a wide range of different noise indicators are discussed further below.

In many situations, as already noted, average noise levels like the L_{den} or L_{night} indicators may not be the best to explain a specific noise effect. Single-event noise indicators – such as the maximum sound pressure level L_{Amax} (L_{AFmax}) and its frequency distribution are warranted in specific situations, such as in the context of night-time railway or aircraft noise events that can clearly elicit awakenings and other physiological reactions that are mostly determined by L_{Amax}. Nevertheless, the assessment of the relationship between different types of single-event noise indicators and long-term health outcomes at the population level remains tentative according to the WHO. The WHO guidelines therefore make no recommendations for single-event noise indicators in the current ENGER 2018 guidelines.

$L_{Amax,t}$

The maximum A-weighted sound pressure level over the measurement period t. It can be measured using the L_{AFmax} indicator (the maximum sound pressure level using A-(frequency) weighting and F-time weighting) or the maximum of $L_{Aeq,T}$ over a short integration time.

Different noise sources – for example, road traffic noise and railway noise – can be characterized by different spectra, different noise level rise (and fall) times of noise events, different temporal distributions of events and different frequency distributions of maximum levels. Because of the extensive differences in the characteristics of individual noise sources, the ENGER 2018 only consider source-specific exposure–response functions (ERFs) and, therefore, formulate only source-specific recommendations.

Noise Annoyance and Socio-acoustic Surveys

One of the most common reported adverse health effects of noise is annoyance. Noise annoyance (NA) may be defined as a feeling of 'displeasure, nuisance, disturbance or irritation caused by a specific sound' (Ouis, 2001). This means that a person has to be awake and conscious to be annoyed. Numerous laboratory studies and field surveys have been conducted over the past 50 years to measure annoyance and to account for several variables, which are dependent on a person's individual circumstances and preferences. These laboratory studies of individual response to noise help isolate several factors contributing to annoyance, such as the intensity level and spectral characteristics of the noise, duration, the presence of impulses, tones, pitch, information content, and the degree of interference with activity.

In the ENGER 2018, *"annoyance"* refers to long-term noise annoyance. The main reason the scientific community adopted the use of long-term annoyance as a primary indicator of the community response to noise, is because it attempts to account for all negative aspects of effects from noise. Such as, increased annoyance due to being awakened the previous night by aircraft, and interference with everyday conversation.

Socio-acoustic surveys are the key tool used to measure noise annoyance in communities. The surveys attempt to measure the subjective response of participants to the noise in their community environments. The resulting responses can then be combined with objective measures of noise – (noise indicators), to produce a noise-dose response curve. Once the dose-noise curve has been established, it may be used as a predictor of average (health) response of the population exposed. The curves cannot predict the response of a single individual as they may have a greater or lesser than average sensitivity to the noise source.

The standard, *ISO/TS 15666:2003 Acoustics - Assessment of noise annoyance by means of social and socio-acoustic surveys*, includes details of questions to be asked, response scales, key aspects of conducting the survey, and reporting. Commonly a five-point scale is used with the points defined as: 1. not annoyed; 2. slightly annoyed; 3. moderately annoyed; 4. very annoyed; and 5. extremely annoyed. Schultz (1978) developed a relationship between the percentage of people choosing the top two descriptors (very annoyed and extremely annoyed), which are combined to produce the term 'highly annoyed'. Schultz used a mixture of several different social surveys that employed different response scales, and defined 'highly annoyed' respondents as those respondents whose self-described annoyance fell within the upper 28% of the response scale (roughly under 1/3 of the population). Schultz's definition of 'percent highly annoyed' (%HA) became the criterion of many environmental noise annoyance studies.

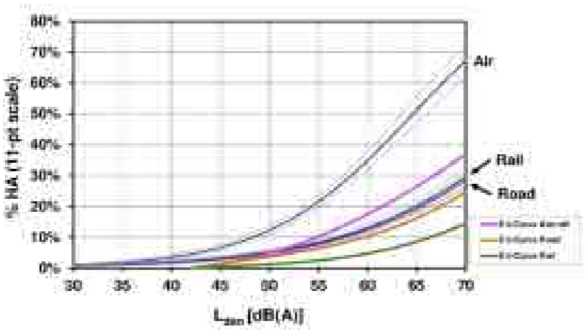


Figure 1 – *(above) illustrates a sample of EU curves for %HA as a function of L_{den} for aircraft, road and rail noise.*

An overview of the WHO Community Noise Guidelines

Since 1980, the WHO has attempted to address the complex problem of community noise. Health-based guidelines on community noise have served in part as the basis for deriving international noise standards within a framework of noise management worldwide and within New Zealand. Key tools used by WHO include abatement options; models for forecasting and for assessing source control action, setting noise emission standards for existing and planned sources, noise exposure assessment and testing the compliance of noise exposure with noise emission standards.

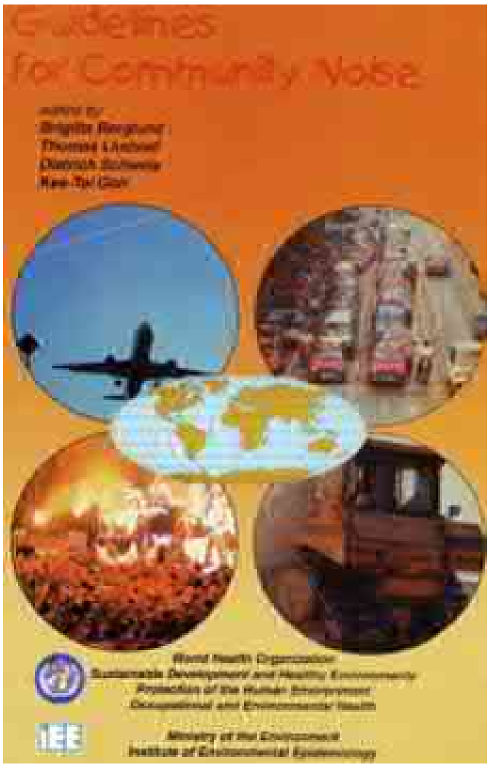
In 1992, the WHO Regional Office for Europe convened a task force meeting which set up guidelines for 'Community Noise'. A preliminary publication of the Karolinska Institute, Stockholm, on behalf of WHO, appeared in 1995 (WHO 1995). This publication served as the basis for the globally applicable 'Guidelines for Community Noise 1999' (GCN 1999).

The last decade has seen WHO Europe produced a steady stream of new guidelines, including the 'Night Noise Guidelines for Europe 2009' (NNGfE 2009) and most recently the Environmental Noise Guidelines for the European Region 2018 (ENGER 2018). Each of the guidelines are discussed in the following sections with a focus on the most recent one.

WHO Guidelines for Community Noise 1999

These 1999 guidelines (GCN 1999) were the outcome of the WHO- expert task force meeting held in London, United Kingdom, in April 1999. It is based on the document entitled "Community Noise" that was prepared for the World Health Organization and published in 1995 (WHO 1995) by the Stockholm University and Karolinska Institute.

These guidelines provided a practical response to the need for action on community noise at the local level, as well as the need for improved legislation, management and guidance at the national and regional levels. The document covers noise sources and their measurement, adverse health effects of noise, noise management and recommendations and the well referenced guideline values are also presented.



The GCN 1999 is organized according to specific environments. The time-base for L_{Aeq} for 'daytime' and 'night-time' is 16-hour day and 8-hour night. No separate time-base is given for evenings, however the guidelines state that typically such guideline value should be 5 to 10 dB lower than for a 12-hour daytime period. Other time bases are recommended for schools, preschools and playgrounds, depending on activity.

The different critical health effects are relevant to specific environments, and guideline values for community noise are proposed for each environment. These are summarised as follows:

a. Dwellings, including bedrooms and outdoor living areas

b. Schools and preschools, including rooms for sleeping and outdoor playgrounds

c. Hospitals, including ward and treatment rooms

d. Industrial, commercial shopping and traffic areas, including public addresses, indoors and outdoors

e. Ceremonies, festivals and entertainment events, indoors and outdoors

f. Music and other sounds through headphones

g. Impulse sounds from toys, fireworks and firearms

h. Outdoors in parkland and conservation areas

An adverse health effect of noise refers to any temporary or long-term deterioration in physical, psychological or social functioning that is associated with noise exposure. The GCN 1999 values represent the sound pressure levels that affect the most exposed receiver in the listed environment.

Supplementary to the guideline values provided, the WHO notes under section 4 of the guidelines, that based on available knowledge (at the time) of the adverse effects of noise on health, that the proposed guideline values for community noise are sufficient for the following effects:

a. Annoyance

b. Speech intelligibility and communication interference

c. Disturbance of information extraction

d. Sleep disturbance and

e. Hearing impairment

In the guideline values are those for the onset of health effects from noise exposure over the stated time bases. Table 4.1 from the GCN 1999 is reproduced below as ***Table 1***.

Supplementary Guideline Values – Vulnerable Groups

Supplementary to the GCN 1999 values given in ***Table 1***, precautionary recommendations and foot notes are provided in the guidelines under Section 4.2 and Section 4.3 of GCN 1999 for vulnerable groups, and for noise of a certain character (e.g. low-frequency components, low background noise), respectively.

In Section 3.10 of the guidelines, information is given in the guidelines regarding which critical effects and specific environments are considered relevant for vulnerable groups, and what precautionary noise protection would be needed in comparison to the general population.

Specific Environment	Critical Health Effect(s)	L_{Aeq} (dB)	Time Base Hours	L_{AFmax}	Internal or External
Outdoors Living area	Serious annoyance, daytime and evening	55	16 hrs		E
Outdoors Living area	Moderate annoyance, daytime and evening	50	16 hrs		E
Dwelling Indoors	Speech intelligibility and moderate annoyance, daytime and evening	35	16 hrs		I
Dwelling Indoors	Sleep disturbance, night-time	30	8 hrs	45	E
Outside Bedrooms	Sleep disturbance, window open (outdoor values)	45	8 hrs	60	E
Indoors. School classrooms and Pre-schools	Speech intelligibility, disturbance of information extraction, message communication	35	During Class		I
Indoors. Pre-school Bedrooms	Sleep disturbance	30	Sleeping time	45	I
Outdoors. School playground	Annoyance (external source)	55	During Play		E
Indoors. Hospital, wardrooms	Sleep disturbance, night-time	30	8	40	I
Indoors. Hospital, wardrooms	Sleep disturbance, daytime and evenings	30	16	NA	I
Indoors. Hospitals, treatment rooms	Interference with rest and recovery	#1			I
Indoors and Outdoors Industrial, commercial, shopping and traffic areas	Hearing impairment	70	24	110	I and E
Ceremonies, festivals and entertainment events	Hearing impairment (patrons: <5 times/year)	100	4	110	E
Public addresses, indoors and outdoors	Hearing impairment	85	1	110	I and E
Music through headphones/ Earphones	Hearing impairment (free-field value)	85 (#4)	1	110	
Impulse sounds from toys, fireworks and firearms	Hearing impairment (adults)			140	
Impulse sounds from toys, fireworks and firearms	Hearing impairment (children)			120	
Outdoors in parkland and conservation areas	Disruption of tranquillity	#3			

#1: as low as possible; #2: peak sound pressure (not L_{Amax}, fast), measured 100 mm from the ear; #3: existing quiet outdoor areas should be preserved and the ratio of intruding noise to natural background sound should be kept low; #4: under headphones, adapted to free-field values

Table 1 *– WHO Guideline values for community noise in specific environments*

Most of the population belongs to groups sensitive to interference with speech perception. Among some of the most sensitive are the elderly and persons with impaired hearing. Even slight hearing impairments in the high-frequency range may cause problems with speech perception in a noisy environment. From about 40 years of age onwards people demonstrate impaired ability to interpret difficult, spoken messages. It has also been shown that children, before language acquisition has been completed, have more adverse effects than young adults to high noise levels and long reverberation times.

Guideline Values – Dwelling Environments

A large proportion of our time is spent in our homes (dwellings). In dwellings the critical effects of noise are on sleep, annoyance and speech interference. To avoid sleep disturbance, indoor guideline values for bedrooms are set in the guidelines at 30 dB L_{Aeq} for continuous noise and 45 dB L_{Amax} for single one-off sound events.

To protect most people from being seriously annoyed during the daytime, the sound pressure level on balconies, terraces and outdoor living areas should accordingly to the guidelines not exceed 55 dB L_{Aeq} for a steady, continuous noise.

To protect most people from being moderately annoyed during the daytime, the outdoor sound pressure level should not exceed 50 dB L_{Aeq}. These values are based on annoyance studies, but many countries have adopted 40 dB L_{Aeq} as the maximum allowable level for new developments. Key to these values is they represent what the guidelines describe as *'the majority of people'* and not the entire population.

Sleep Disturbance and L_{Amax}

GCN 1999 notes that to avoid sleep disturbance, guidelines for community noise should be expressed in terms of equivalent sound pressure levels (L_{Aeq}) as well as L_{Amax}. This is because it is not enough to characterize the noise environment in terms of noise measures or indices based only on energy average summation (L_{Aeq}) alone because different critical health effects require different descriptions. Therefore, it is important to display the maximum values of the noise fluctuations, preferably combined with a measure of the number of noise events. A separate characterization of noise exposures during night-time would be required. For indoor environments, reverberation time is also an important factor. If the noise includes a large proportion of low frequency components, still lower guideline values should be applied. The more intense the background noise, the more disturbing is its effect on sleep.

Measurable effects on sleep start at background noise levels of about 30 dB L_{Aeq}. Physiological effects include changes in the pattern of sleep stages, especially a reduction in the proportion of REM sleep. Subjective effects have also been identified, such as difficulty in falling asleep, perceived sleep quality, and adverse after-effects such as headache and tiredness. Sensitive groups mainly include elderly persons, shift workers and persons with physical or mental disorders.

At night, as noted above the guidelines that for dwelling environs that sound pressure levels at the outside façades of the living spaces should not exceed 45 dB L_{Aeq} and 60 dB L_{Amax}, so that people may sleep with bedroom windows open. These values have been obtained by assuming that the noise reduction from outside to inside with the window partly open is 15 dB that is:

$$45\text{ dB}_{(\text{Exterior})} - 15\text{ dB}_{(\text{Façade reduction - windows open})} = 30\text{ dB } L_{Aeq(\text{indoors})}$$

The differences between indoor and outdoor levels due to windows being opened is complex but are usually estimated at around:

- 10 dB for open window;
- 15 dB for tilted or half-open window; and
- 25 dB for closed windows.

Where noise is continuous, the equivalent sound pressure level should not exceed 30 dB L_{Aeq} indoors, if negative effects on sleep are to be avoided. When the noise is composed of a large proportion of low-frequency sounds a still lower guideline value is recommended, because low frequency noise, e.g. from ventilation systems, can disturb rest and sleep even at low sound pressure levels. It should be noted that the adverse effect of noise partly depends on the nature of the source.

If the noise is not continuous, L_{Amax} or L_{AE} (sound exposure level (SEL)), is normally used to indicate the probability of noise induced awakenings. Effects have been observed at individual L_{Amax} exposures of 45 dB or less. Consequently, it is important to limit the number of noise events with a L_{Amax} exceeding 45 dB. Therefore, the guidelines are based on a combination of values of 30 dB $L_{Aeq,8h}$ and 45 dB L_{Amax}. To protect sensitive persons, a still lower guideline value would be preferred when the background level is low. Sleep disturbance from intermittent noise events increases with the maximum noise level.

L_{AE}

The A-weighted, equivalent sound exposure level (SEL), as if all the energy of the sound occurred in one second. The formula is:

$$L_{AE} = 10\, lg \left(\int_0^T \left(\frac{p}{p_0} \right)^2 dt \right)$$

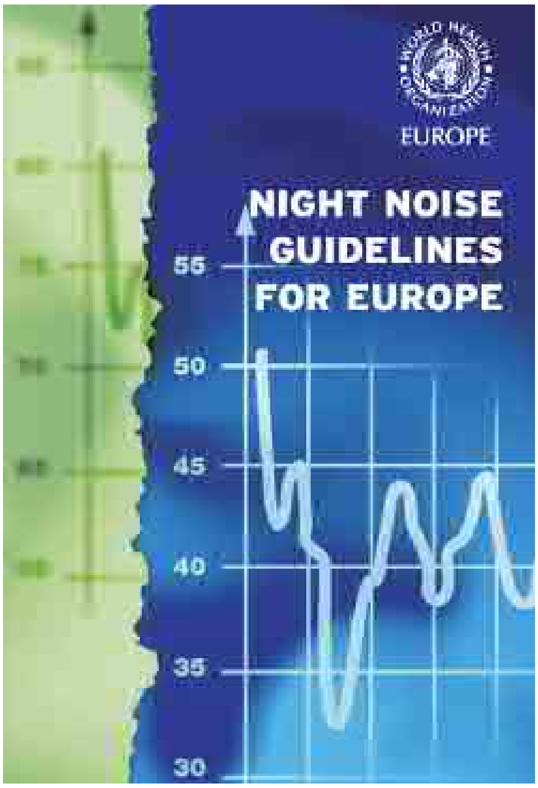
Where

lg = log10 (logarithm base 10)

p is the measured A-weighted sound pressure (Pa)

p_0 is the reference pressure of 20 μPa

Night Noise Guidelines for Europe 2009



In 2009 WHO published guidelines to protect human health, specifically from and night noise exposure. The Night Noise Guidelines for Europe 2009 (NNGfE 2009) was one of the first substantial updates for WHO noise guidelines in approximately 10 years since the release of the 1999 guidelines. During the 10-year period a large body of research and studies on community noise exposure and health outcomes had become available, along with updated research on relationships with annoyance; cardiovascular effects; obesity and metabolic effects such as diabetes; cognitive impairment; sleep disturbance; hearing impairment and tinnitus, mental health, and wellbeing, to name just a few.

Another key development was that whilst earlier studies focused mainly on road traffic and aircraft noise, since the release of the 1999 guidelines newer studies also included noise from other sources such as railways and wind turbines as well as updated studies from road traffic and aircraft noise also being produced. Thus, with more than 10 years of new research, the NNGfE 2009 provided both updated evidence and recommendations that countries could use to introduce targeted (interim) limits for night noise. These guidelines support and integrate the END, which requires countries to map noise hot spots and reduce exposure but does not set limit values.

Based on the systematic review of evidence produced by epidemiological and experimental studies, the relationship between night noise exposure and health effects are summarized in ***Table 2***. Key to the levels expressed in the table are for continuous noise levels over a year expressed as $L_{night,outside}$.

Average night noise level over a year L_{night},outside	Health effects observed in the population
Up to 30 dB	Although individual sensitivities and circumstances may differ, it appears that up to this level no substantial biological effects are observed. $L_{night,outside}$ of 30 dB is equivalent to the no observed effect level **(NOEL)** for night noise.
30 dB to 40 dB	Number of effects on sleep are observed for this range: body movements, awakening, self-reported sleep disturbance, arousals. The intensity of the effect depends on the nature of the source and the number of events. Vulnerable groups (for example children, the chronically ill and the elderly) are more susceptible. However, even in the worst cases the effects seem modest. $L_{night,outside}$ of 40 dB is equivalent to the lowest observed adverse effect level **(LOAEL)** for night noise.
40 to 45 dB	Adverse health effects are observed among the exposed population. Many people have to adapt their lives to cope with the noise at night. Vulnerable groups are more severely affected.
Above 55 dB	The situation is considered increasingly dangerous for public health. Adverse health effects occur frequently, a sizeable proportion of the population is highly annoyed and sleep-disturbed. There is evidence that the risk of cardiovascular disease increases.

Table 2 *– Effects of different levels of night noise on the population's health*

Based on the exposure-effects relationship, the night noise guideline values recommended for the protection of public health from night noise are below. The night noise guidelines for Europe reviews the health effects of exposure to night-time noise, examines dose–effect relations, and presents interim guideline values for exposure.

Recommended night noise guidelines for Europe	
Night noise guideline (NNG)	$L_{night, outside}$ = 40 dB
Interim target (IT)	$L_{night, outside}$ = 55 dB

As discussed above, $L_{night,outside}$ is the night-time noise indicator (L_{night}) of the END, the A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the night periods of a year; in which: the night is eight hours (usually 23.00 – 07.00 local time), a year is a relevant year as regards the emission of sound and an average year as regards the meteorological circumstances.

A lot of attention is paid in the NNGfE 2009 to the use of single event descriptors such as L_{Amax} (maximum outdoor sound pressure level) and L_{AE} (sound exposure level). As the Position Paper on EU noise indicators (EC, 2000) points out, this is an important tool to describe instantaneous reactions to noise. But, when it comes to long-term protection, the number of events is equally important. The possibility of predicting after-effects like sleepiness, reaction time, sleeping pill use and health complaints, requires a combination of a number of events and their level instead of just the average L_{Amax} or average SEL. For events with a similar time pattern, there is a relatively simple relation between L_{Amax} and L_{AE}, and therefore between L_{Amax} and L_{night}.

The NNGfE 2009 state, based on research to date, let it suffice to say that a choice for a L_{night} level ties the L_{Amax} related effects to a maximum and therefore allows for a protective/conservative approach. ***Figure 2*** is based on a sound level measurement in a bedroom for one night. The top of the peaks is the L_{Amax} levels, the total energy is the L_{night} (thick red horizontal line). The sound energy in one event is the SEL (not represented). The L_{night} value is the average over all nights in one year. This reasoning applies also to the issue of long-term average. A value for an arbitrary single night will, except in extreme cases, bear no relationship to an individual's long-term health status, whereas a sustained sufficiently high level over a long period may.

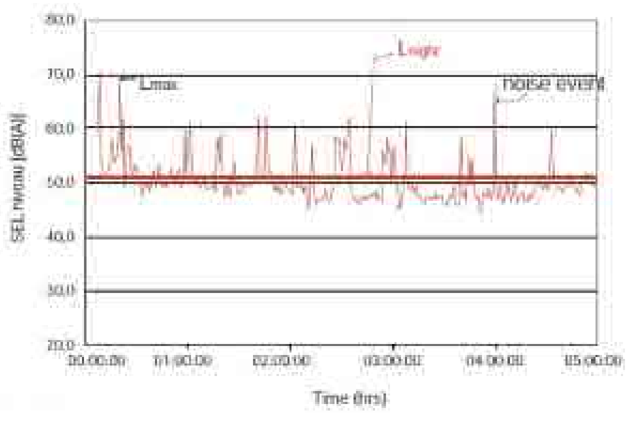


Figure 2 – *Sound level measurements in a bedroom for one night*

There is no generally accepted way to count the number of (relevant) noise events. Proposals range from the number of measured L_{Amax} events, the number of units (vehicles, aeroplanes, trains) passing by, to the number exceeding a certain L_{Amax} level (commonly indicated by NAxx; NA70 is the number of events higher than 70 dB).

L_{night} is defined as the 1-year L_{Aeq} (exposure to noise) over 8 hours outside at the most exposed facade. For the purpose of strategic noise mapping and reporting the height is fixed at 4 metres. As L_{night} is a relatively new indicator and because the studies rarely cover such a long period, the research data are rarely expressed in L_{night}. The most frequently used noise descriptor in sleep research is the L_{Amax} or L_{AE} near the sleeper. This means that a considerable amount of further research and conversion work needs to be done if relations are to be expressed in L_{night}. There are four issues to consider:

1. conversion between L_{AE} and L_{Amax}
2. conversion from instantaneous to long-term
3. conversion from inside to outside; and
4. conversion from (outside) bedroom level to most exposed façade.

L_{AE} to L_{Amax}

L_{AE} is only used for aircraft noise in the WHO noise guidelines and reporting and, according to Ollerhead et al. (1992) from <u>ground-based</u> measurements, the following relation was found:

$$L_{AE} = 23.9 + 0.81*L_{Amax}$$

A more general approach can be used to estimate L_{AE} for transportation noise. If the shape of the time pattern of the sound level can be approximated by a block form, then:

$$L_{AE} \approx L_{Amax} + 10 \log_{10} t$$

Where

t (in seconds) is the duration of the noise event.

This rule can be used, inter alia, for a long freight train that passes at a short distance when t is in the range from 3 to 30 seconds, then L_{AE} is 5–15 dB higher than L_{Amax}. For most passages of aircraft, road vehicles or trains, the shape of the time pattern of the sound level can be better approximated with a triangle.

If the sound level increases with rate a (in dB per second), and thereafter is at its maximum for a short duration before it decreases with rate -a, then $L_{AE} \approx L_{Amax} - 10 \log_{10}(a) + 9.4$. Depending on the distance to the source, for most dwellings near transportation sources the rate of increase is in the order of a few dB per second up to 5 dB per second. When (a) is in the range from 9 dB to 1 dB per second, then L_{AE} is 0–9 dB higher than L_{Amax}.

Events to Long-term

When the L_{AE} values are known (if necessary, after converting from L_{Amax}) they can be converted to L_{night}. In general terms, the relation between L_{night} and L_{AE} is:

$$L_{night}=10 \log_{10} \left(\sum_{1}^{N} 10^{L_{AE,i}} \right) - 10 \log_{10} (T)$$

If all (N) events have approximately the same L_{AE} level, this may be reduced to

$$L_{night}=L_{AE}+10 \log_{10} (N) - 70.2$$

Where

N = the number of events occurring in period T;

T = time during which the events occur in seconds. For a (night) year $10 \log_{10}(T)$ is 70.2.

The notation adheres to the END, where the L_{night} is defined as a year average at the most exposed facade. Any reference to an inside level is noted as such, that is, as L_{night}, inside. In order to avoid any doubt, the notation $L_{night,outside}$ may be used, for instance in tables where both occur.

Inside to outside

As the L_{night} is a year value, the insulation value is also to be expressed as such. This means that if the insulation value is 30 dB with windows closed and 15 dB with windows open, the resulting value is 18 dB if the window is open 50% of the time. If these windows are closed only 10% of the time, the result is little more than 15 dB. The issue is complicated by the fact that closing behaviour is, to a certain extent, dependent on noise level. When results about effects are expressed with indoor (that is, inside bedrooms) exposure levels, they need to be converted to L_{night}, in accordance with the END definition. The most important assumption is the correction for inside levels to outside levels. An average level difference of 21 dB has been chosen, as this takes into account that even in well-insulated houses windows may be open a large part of the year. In general

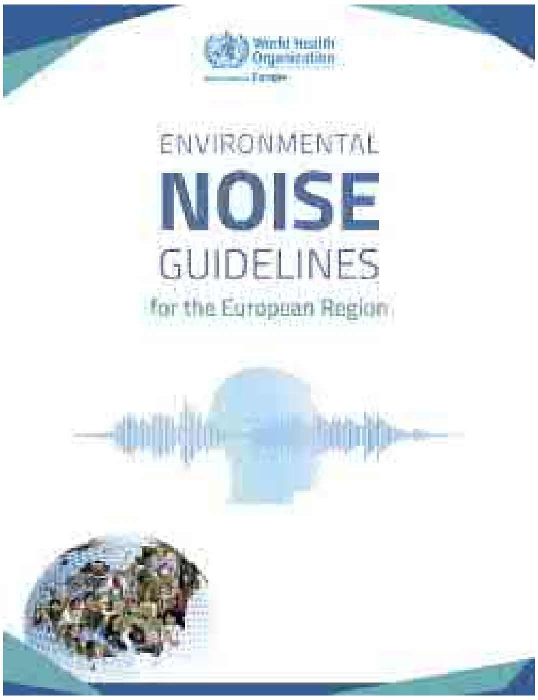
$$L_{night} = L_{night,inside} + Y \text{ (dB)}$$

Where

Y is the year average insulation value of the (bedroom) facade.

It should be stressed that this conversion is thought to be highly dependent on local building habits, climate and window opening behaviour. Night-time environmental noise affects residents mainly inside their homes. In order to protect residents inside their homes from noise from outside sources, attention should be focused on windows since they are generally the weakest points in the sound propagation path. Roofs must also be considered with regard to aircraft noise. There are many types of window in the EU, varying from single thin panes within frames without additional insulation, to four-pane windows within insulated frames. The simplest types of facade have a sound reduction (from outside to inside) of usually less than 24 dB, and the most elaborate facades (built to cope with cold climates, for example), have sound reductions of more than 45 dB.   In central Europe, most windows are double-glazed, mounted in a rigid and well-insulated frame. Their range of sound reduction is between 30 dB and 35 dB when closed. When night-time environmental noise reaches high levels, residents tend to close their bedroom windows (cf. Langdon and Buller, 1977; Scharnberg et al., 1982; Schreckenberg et al., 1999; Diaz et al., 2001).

WHO Environmental Noise Guidelines for the European Region 2018



The WHO Regional Office for Europe developed the Environmental Noise Guidelines for the European Region 2018 (ENGfER 2018). They were developed in accordance with the *WHO Handbook for Guideline Development* (WHO 2014c). The most recent guideline is over 150 pages of detailed content. Officially launched to countries and stakeholders in Basel, Switzerland on 10 October 2018, the guidelines identify levels at which noise has significant health impacts and recommends actions to reduce exposure. Following the publication of WHO's community noise guidelines in 1999 and night noise guidelines for Europe in 2009, these latest guidelines represent what the editor of the document rightfully describes as *'the next evolutionary step, taking advantage of the growing diversity and quality standards in this research domain'.*

The key purpose of ENGfER 2018 is the same as all past WHO noise guidelines, that being to provide recommendations for protecting human health from exposure to environmental noise originating from various sources which include transportation (road traffic, railway and aircraft) noise, wind turbine noise and leisure noise. The guidelines represent an update on all previous WHO guidelines for noise.

The guidelines provide robust public health advice underpinned by detailed evidence, which is essential to drive policy action that will protect communities from the adverse effects of noise. The guidelines are published by the WHO Regional Office for Europe. In terms of their health implications, the recommended exposure levels can be considered applicable in other regions and suitable for a global audience.

Compared to previous WHO guidelines on noise, the ENGfER 2018 version contains five notable developments:

1. Inclusion of new noise sources, namely wind turbine noise and leisure noise, in addition to noise from transportation (aircraft, rail and road traffic);

2. Use of a standardised approach to assess the evidence;

3. A systematic review of evidence, defining the relationship between noise exposure and risk of adverse health outcomes;

4. Use of long-term average noise exposure indicators to better predict adverse health outcomes

5. Stronger evidence of the cardiovascular and metabolic effects of environmental noise;

The objective and purpose of the ENGfER 2018 guidelines is to provide recommendations for protecting human health from exposure to environmental noise originating from various sources: transportation (road traffic, railway and aircraft) noise, wind turbine noise and leisure noise. The guidelines focus on information on the exposure–response relationships between exposure to environmental noise from different noise sources and the proportion of people affected by certain health outcomes, as well as interventions that are considered efficient in reducing exposure to environmental noise and related health outcomes. The guideline values are evidence-based public health-oriented recommendations.

Leisure noise in the context of the guidelines refers to all noise sources that people are exposed to due to leisure activities, such as attending nightclubs, pubs, fitness classes, live sporting events, concerts or live music venues and listening to loud music through personal listening devices. The guidelines focus on the WHO European Region and provide policy guidance to Member States that is compatible with the noise indicators used in the END. The following two key questions identify the issues addressed by the guidelines.

1. In the general population exposed to environmental noise, what is the exposure–response relationship between exposure to environmental noise (reported as various indicators) and the proportion of people with a validated measure of health outcome, when adjusted for confounders?

2. In the general population exposed to environmental noise, are interventions effective in reducing exposure to and/or health outcomes from environmental noise?

The 'Recommendations Assessment, Development and Evaluation' (GRADE) approach was followed. Based on the defined scope and key questions, the guidelines reviewed the pertinent literature in order to incorporate significant research undertaken in the area of environmental noise and health since the GCN 1999 and the NNGfE 2009, were issued.

The ENGfER 2018 guidelines are intended to be suitable for policy-making in the WHO European Region. They focus on the most widely used noise indicators, L_{den} and/or L_{night}, and are provided for exposure at the most exposed façade, outdoors.

Recommendations and strength of recommendations

Specific recommendations have been formulated in the guidelines for road traffic noise, railway noise, aircraft noise, wind turbine noise and leisure noise. Recommendations are rated as either *strong* or *conditional*. The ENGfER 2018 define these two terms as follows:

- A strong recommendation can be adopted as policy in most situations. The guideline is based on the confidence that the desirable effects of adherence to the recommendation outweigh the undesirable consequences. The quality of evidence for a net benefit – combined with information about the values, preferences and resources – inform this recommendation, which should be implemented in most circumstances.

- A conditional recommendation requires a policy-making process with substantial debate and involvement of various stakeholders. There is less certainty of its efficacy owing to lower quality of evidence of a net benefit, opposing values and preferences of individuals and populations affected or the high resource implications of the recommendation, meaning there may be circumstances or settings in which it will not apply.

Alongside specific recommendations, several guiding principles were developed within the guidelines to provide generic advice and support for the incorporation of recommendations into a policy framework. They apply to the implementation of all of the specific recommendations. The guiding principles are to reduce, promote, coordinate and involve. The guidelines describe these guiding principles as follows:

1. Reduce exposure to noise, while conserving quiet areas.

   The recommendations focus on reduction of population exposure to environmental noise from a variety of sources, in different settings. The general population can be exposed regularly to more than one source of noise simultaneously *(including, in some cases, occupational noise), as well as to other non-acoustic factors that can modify the response to noise (such as vibration from railways, air pollution from traffic or visual aspects of wind turbines). Thus, overall reduction of exposure from all sources should be promoted. Furthermore, noise exposure reduction in one area should not come at the expense of an increase in noise elsewhere; existing large quiet outdoor areas should be preserved*

2. Promote interventions to reduce exposure to noise and improve health.

   The second principle is to promote interventions to reduce exposure to noise and improve health. The evidence from epidemiological studies on adverse health effects at certain noise levels, used as a basis to derive the guideline values proposed in the recommendations, supports the promotion of noise interventions. The potential health impacts from environmental noise are significant, especially when considering the widespread exposure to environmental noise across the population and the high baseline rates for various health outcomes associated with environmental noise.

Type	Category	Sub-Category
A	Source	• change in emission levels of sources • time restrictions on source operations
B	Path	• change in the path between source and receiver • path control through insulation of receiver / receiver's dwelling
C	New / Closed Infrastructure	• opening of a new infrastructure noise source • closure of an exisitng one • planning controls between (new) receivers and sources
D	Physical	• change in other physical dimensions of dwelling / neighbourhood
E	Behaviours	• change in individual behaviour to reduce exposure • avoidance or duration of exposure • community education, communication

Table 3 *– Environmental noise intervention categories*

Interventions on environmental noise were defined according to five broad categories based on the available intervention literature and the experience of decades of environmental noise management as defined below in ***Table 3*** (also see Brown & van Kamp, 2017).

1. Coordinate approaches to control noise sources and other environmental health risks.

   The third principle is to coordinate approaches to control noise sources and other environmental health risks. Considering the common transport-related sources of environmental noise and air pollution, and in particular the evidence of independent effects on the cardiovascular system, a coordinated approach to policy development in the sectors related to urban planning, transport, climate and energy should be adopted for policies with an impact on environmental noise, air quality and/or climate. Such an approach should yield multiple benefits through increased commitment and financial resources; increased attention to securing health considerations in all policies; and use of policy to control noise and other environmental risks such as air pollutants, including short-lived climate pollutants. There is wide consensus on the value of pursuing coordinated policies that can deliver health and other benefits, such as those associated with the local environment and economic development. Furthermore, coordinated policy-making is potentially cost-saving.

2. Inform and involve communities potentially affected by a change in noise exposure.

   The fourth principle is to inform and involve communities that may be affected by a change in noise exposure. In planning new urban and/or rural developments (transport schemes, new infrastructures in less densely populated areas, noise abatement and mitigation strategies), bringing together planners, environmental professionals and public health experts with policy-makers and citizens is key to public acceptability and involvement and to the successful guidance of the decision-making process. Potential health effects from environmental noise should be included as part of health impact assessments of future policies, plans and projects, and the communities potentially affected by a positive or negative change in noise exposure should be well informed and engaged from the outset to maximize potential benefits to health. Introducing measures incrementally may help with acceptance.

Recommended Guidelines

The ENGfER 2018 notes that road traffic noise is the most significant source of annoyance, generally followed by community or neighbourhood specific noise. Aircraft noise can also be a substantial source of annoyance. Railway noise and industrial or commercial noise are enumerated less frequently. Only limited data are available on the population's perception of newer sources of noise, such as wind turbines. In New Zealand no data is available on the population's perception of the five noise sources (road, rail, aircraft, wind turbines and leisure) discussed in the guidelines.

In general transportation noise (road, rail and aircraft) can be divided into three main sources being engine noise, rolling noise (tyre or wheel noise) and aerodynamic noise. Wind turbine noise relates to mechanical and aerodynamic noise while leisure noise relates to all noise sources related specifically to leisure activities.

Specific to traffic sources, traffic noise levels are a function of several variables (including but not limited to) the number of traffic movements, type of traffic (car, truck), road surface, distance, speed and the noise source itself (tyre noise, engine noise, exhaust noise and aerodynamic noise). One of the most important factors regarding noise levels is the number and mix of vehicles, followed by speed. There is also a host of other factors that can influence noise levels such as vehicle operating factors which contribute to the fluctuations in road traffic noise. All vehicles produce noise from their gear boxes and exhaust systems. In addition to this, heavy vehicles may also produce rattles, squeaks and vibrations which, in turn, depend on the degree of loading and the age of the vehicle for example. Heavy goods vehicles with diesel engines, for example, are generally noisy than say a passenger vehicle (car). However, two small passenger vehicles can also produce varying levels for example one vehicle may be petrol combustion engine and the other electrically driven vehicle, which would be the quieter of the two vehicle types. The actual pattern of traffic noise on a road is quite complex. In cities and built up populations it is common to have regular distinctive peaks in traffic density in the morning, late afternoon and evening as people travel to work and return home, respectively. Generally, traffic noise is only perceptible within a few hundred metres of the roading corridor.

Source	Recommended Average Noise Exposure Level	Recommended Night Level L_{night}	GDG Recommendation
Traffic	< 53 dB L_{den}	< 45 dB L_{night}	GDC strongly recommends to that policy-makers implement suitable measures to *reduce* noise exposure from road traffic in the population exposed to levels above the guideline values for average and night noise exposure.
Aircraft	< 45 dB L_{den}	< 40 dB L_{night}	GDG strongly recommends that policy-makers implement suitable measures to reduce noise exposure from aircraft in the population exposed to levels above the guideline values for average and night noise exposure.
Railway	< 54 dB L_{den}	< 44 dB L_{night}	GDC strongly recommends to that policy-makers implement suitable measures to reduce noise exposure from railway traffic in the population exposed to levels above the guideline values for average and night noise exposure.
Wind Turbine	< 45 dB L_{den}	No Recommendation	GDC conditionally recommends to that policy-makers implement suitable measures to reduce noise exposure from wind turbines in the population exposed to levels above the guideline values for average noise exposure. No Lnight levels are recommended.
Leisure Noise	70 dB $L_{Aeq,24h}$	Not Applicable	GDG conditionally recommends reducing the yearly average from all leisure noise sources combined to 70 dB $L_{Aeq,24h}$. For single-event and impulse noise exposures, the GDG conditionally recommends following existing guidelines and legal regulations. the GDG strongly recommends that policy-makers take action to prevent exposure above the guideline values for average noise and single-event and impulse noise exposures.

Table 4 – *ENGfER 2018 GDG recommendations by source*

Railway noise is divided into three main categories being engine noise, rolling noise and aerodynamic noise. Rail noise sources generally cover freight and passenger movements. Railway noise is principally a problem of freight trains and trains containing older wagons or engines. Rolling noise is generally higher from poorly maintained rail vehicles and is a function of the infrastructure such as track type, sleeper type, wheel and rail roughness for example. Aerodynamic noise is particularly relevant for high speed lines which is generally not an issue in New Zealand. Engine noise is most relevant at lower speeds up to about 30 km/h, rolling noise above 30 km/h and aerodynamic noise dominates above 200 km/h (which again does not apply to rail movements in New Zealand). The key noise source is rolling noise, which affects all kinds of train. Generally, railway noise from rail movements is perceptible only within a few hundred meters of the railway corridor.

Aircraft noise is divided into two main categories being while airside (on the ground) and while the aircraft is in flight. Aircraft noise while in flight is caused by two key variables being air going over the aircraft's airframe (fuselage and wings) and by the aircraft's engines. Airframe noise occurs friction and turbulence are caused from noise passing over the airframe which produces aerodynamic noise. The level of noise that is generated varies according to a host of variables including the type of aircraft and the method or way the aircraft is flown. Modern aircraft noise is much quieter than say 20 years ago and as technology advances it would be expected that current aircraft noise levels produced today become even quieter in the future. Generally, aircraft noise from aircraft is audible when under a flight path or near an airport when the aircraft is on approach (landing) or departure (taking off) from the airport.

Wind turbine generators (wind turbines) emit a relatively low level of noise but this noise often has special audible characteristics which are deemed more annoying than typical environmental broadband sound. The combination of noise sources from a wind turbine can generally be described as a mechanical noise combined with an aerodynamic noise. The aerodynamic noise is chiefly generated by the movement of the blades through the air. This produces a swishing sound which is a function of the rate with the rotation of the blades i.e. the higher the wind speeds the faster the blades rotate and thus the higher the noise levels produced. There are four types of sound generated by wind turbine aerodynamic operation: tonal, broadband, low frequency/infrasound, and impulsive. In New Zealand wind farms are generally located in rural settings with only small portions of the population within audible range from the wind turbines, nevertheless anecdotal evidence suggests there is still a certain level of annoyance for these communities from this specific noise source. Like all noise sources the further the receiver is from source the lower the noise level becomes. Noise from wind turbine generators and wind farms may be perceptible long distances from the source, such levels may be low but contain often has special audible characteristic such as low frequency components.

Regarding leisure noise, this source covers a wide extent of noise source. The WHO guidelines specifically state that all leisure noise sources are those specifically related to leisure activities, such as attending nightclubs, pubs, fitness classes, live sporting events, concerts or live music venues and listening to loud music through personal listening devices.

The five noise sources discussed above covered in the WHO guidelines are complex noise sources with noise outputs which are characterised by a host of variables including (but not limited to) different spectra, different noise level rise times, different temporal distributions and different frequency distributions of maximum levels. The WHO guidelines are source-specific and do not incorporate combined exposure effects of multiple noise sources or other pollutants. The guidelines also note that different noise sources for example, road traffic noise and railway noise, can be characterized by different spectra and extensive variables. Because of the extensive differences in the characteristics of individual noise sources, the WHO guidelines only consider source-specific exposure–response functions (ERFs) and, therefore, formulate only source-specific recommendations.

The recommendations for all sources summarised in ENGfER 2018 are shown in ***Table 3*** and the detailed 'Guidelines Development Group' (GDG) recommendations, source by source, are summarised from the guidelines in ***Table 4***.

Road Traffic Noise

The GDG set a guideline exposure level of 53.3 dB L_{den} for average exposure to road traffic noise, based on the relevant increase of the absolute %HA. It was confident that there was an increased risk for annoyance below this noise exposure level, but probably no increased risk for other priority health outcomes. In accordance with the defined rounding procedure, the value was rounded to 53 dB L_{den}. As the evidence on the adverse effects of road traffic noise was rated moderate quality, the GDG made the recommendation strong. Based on the evidence of the adverse effects of road traffic noise on sleep disturbance, the GDG defined a guideline exposure level of 45.4 dB L_{night}. The exact exposure value was rounded to 45 dB Lnight. As the evidence was rated moderate quality, the GDG made the recommendation strong (see ***Table 5*** below).

Recommendation	Strength
For average noise exposure, the GDG strongly recommends reducing noise levels produced by road traffic below 53 decibels (dB) L_{den}, as road traffic noise above this level is associated with adverse health effects.	Strong
For night noise exposure, the GDG strongly recommends reducing noise levels produced by road traffic during night-time below 45 dB L_{night}, as night-time road traffic noise above this level is associated with adverse effects on sleep.	Strong
To reduce health effects, the GDG strongly recommends that policy-makers implement suitable measures to reduce noise exposure from road traffic in the population exposed to levels above the guideline values for average and night noise exposure. For specific interventions, the GDG recommends reducing noise both at the source and on the route between the source and the affected population by changes in infrastructure.	Strong

Table 5 – *Road Traffic Noise Recommendations*

The GDG also considered the evidence for the effectiveness of interventions. The results showed that:

- Addressing the source by improving the choice of appropriate tyres, road surface, truck restrictions or by lowering traffic flow can reduce noise exposure;
- Path interventions such as insulation and barrier construction reduce noise exposure, annoyance and sleep disturbance;
- Changes in infrastructure such as construction of road tunnels lower noise exposure, annoyance and sleep disturbance;
- Other physical interventions such as the availability of a quiet side of the residence reduce noise exposure, annoyance and sleep disturbance.

Given that it is possible to reduce noise exposure and that best practices already exist for the management of noise from road traffic, the GDG made a strong recommendation. The key question posed was:

> *in the general population exposed to road traffic noise, what is the exposure–response relationship between exposure to road traffic noise (reported as various noise indicators) and the* proportion of people with a validated measure of health outcome, when adjusted for main confounders?

A summary of the PICOS (population, intervention, comparator, outcome and study) / PECCOS (population, exposure, comparator, confounder, outcome and study [framework]);

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scheme applied and the main findings set out in the guidelines for traffic noise is summarised in ***Table 6*** as follows. PICOS/PECCOS is an evidence-based technique that frames health care-related questions to facilitate the search for suitable studies that can provide answers to the questions at hand. The PICOS/PECCOS study approaches are defined in the WHO handbook for guideline development (WHO, 2014c).

PECO	Description
Population	General population
Exposure	Exposure to high levels of noise produced by road traffic (average/night-time)
Comparison	Exposure to lower levels of noise produced by road traffic (average/night-time)
Outcomes	For average noise exposure: 1. cardiovascular disease 2. annoyance 3. cognitive impairment 4. hearing impairment and tinnitus 5. adverse birth outcomes 6. quality of life, well-being and mental health 7. metabolic outcomes
Outcomes	For night noise exposure: 1. effects on sleep

Table 6 *– PICOS/PECCOS scheme of critical health outcomes for exposure to road traffic noise*

Annoyance

A vast amount of research demonstrates an association between road traffic noise and annoyance. In total, 17 road traffic noise studies were identified that were used to model ERFs of the relationship between L_{den} and %HA (Babisch et al., 2009; Brink, 2013; Brink et al., 2016; Brown et al., 2014; 2015; Champelovier et al., 2003; Heimann et al., 2007; Lercher et al., 2007; Medizinische Universitaet Innsbruck, 2008; Nguyen et al., 2012a; Pierette et al., 2012; Sato et al., 2002; Shimoyama et al., 2014). These incorporated data from 34 112 study participants. The estimated data points of each of the studies are plotted in ***Figure 3***, alongside an aggregated ERF including the data from all the individual studies (see the black line for "WHO full dataset"). The lowest category of noise exposure considered in any of the studies, and hence included in the systematic review, is 40 dB, corresponding to approximately 9 %HA. The benchmark level of 10 %HA is reached at 53.3 dB L_{den}. ***Figure 3*** show a scatterplot of the data and quadratic regression of the relationship between road traffic noise (L_{den}) and annoyance (%HA).

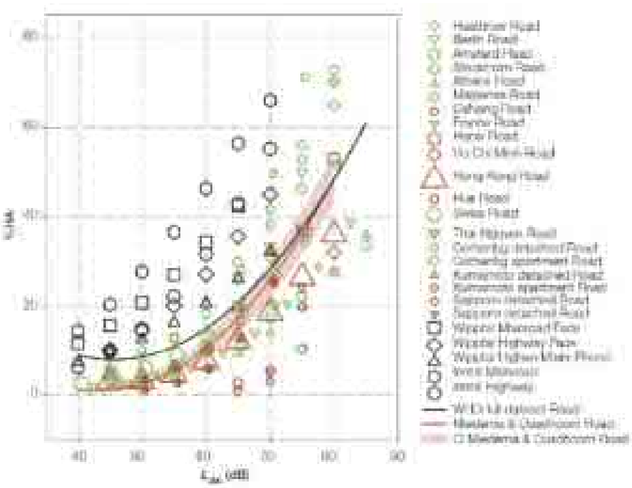


Figure 3 *– Road traffic noise (L_{den}) versus annoyance*

The association between exposure to road traffic noise (L_{den}) and annoyance (%HA)	
L_{den} (dB)	% HA
40	9
45	8
50	8.6
55	11
60	15.1
65	20/9
70	28.4
75	37.7
80	48.5

Table 7 – *Road Traffic Noise,* shows the %HA in relation to exposure to road traffic noise. The calculations are based on the regression equation derived from the systematic review (Guski et al., 2017).

Railway Traffic Noise

The GDG set a guideline exposure level of 53.7 dB L_{den} for average exposure, based on the relevant increase of the absolute %HA. In accordance with the defined rounding procedure, the value was rounded to 54 dB L_{den}. As the evidence on the adverse effects of railway noise was rated moderate quality, the GDG made the recommendation strong. Based on the evidence of the adverse effects of railway noise on sleep disturbance, the GDG defined a guideline exposure level of 43.7 dB L_{night}. The exact exposure value was rounded to 44 dB L_{night}. As the evidence was rated moderate quality, the GDG made the recommendation strong. The GDG also considered the evidence for the effectiveness of interventions. The results showed that:

- intervening at the source by applying rail grinding procedures can reduce noise annoyance;
- behavioural interventions such as informing the community about noise interventions can reduce noise annoyance.

Table 8 – *Road Traffic Noise – Summary of the assessment of the strength of the road traffic noise recommendation*

Factors influencing the strength of recommendation	Decision
Quality of Evidence	**Average exposure (L_{den})** *Health effects* • Evidence for a relevant RR (Relative Risk) increase for incidence of IHD (ischemic heart disease) at 59 dB L_{den} was rated high quality. • Evidence for the incidence of hypertension was rated low quality. • Evidence for a relevant absolute risk of annoyance at 53 dB L_{den} was rated moderate quality. • Evidence for a relevant RR increase for reading and oral comprehension was rated very low quality. *Interventions* • Evidence on effectiveness of interventions to reduce noise exposure and/or health outcomes from road traffic noise is of varying quality. **Night-time exposure (L_{night})** *Health effects* • Evidence for a relevant absolute risk of sleep disturbance related to night noise exposure from road traffic at 45 dB L_{night} was rated moderate quality. *Interventions* • Evidence on effectiveness of interventions to reduce noise exposure and/or sleep disturbance from road traffic noise is of varying quality.
Balance of benefits versus harms and burdens	Health benefits can be gained from markedly reducing exposure of the population to road traffic noise; benefits outweigh the harms of interventions to reduce continuous road traffic noise.
Values and preferences	Quiet areas are valued by the population, especially by those affected by continuous noise exposure. Some variability is possible between those who benefit from interventions to reduce road traffic noise and those who finance the interventions.
Equity	Risk of exposure to road traffic noise is not equally distributed.
Resource use and implications	No comprehensive cost–effectiveness analysis data are available; nevertheless, a wide range of solutions exist, and several are being implemented, showing that effective interventions are both feasible and economically reasonable.
Decisions on recommendation strength	• Strong for guideline level for average noise exposure (L_{den}) • Strong for guideline value for average night noise exposure (L_{night}) • Strong for specific interventions to reduce noise exposure

Recommendation	Strength
For average noise exposure, the GDG strongly recommends reducing noise levels produced by railway traffic below 54 dB L_{den}, as railway noise above this level is associated with adverse health effects.	Strong
For night noise exposure, the GDG strongly recommends reducing noise levels produced by railway traffic during night-time below 44 dB L_{night}, as night-time railway noise above this level is associated with adverse effects on sleep.	Strong
To reduce health effects, the GDG strongly recommends that policy-makers implement suitable measures to reduce noise exposure from railways in the population exposed to levels above the guideline values for average and night noise exposure. There is, however, insufficient evidence to recommend one type of intervention over another.	Strong

Table 9 *– Railway traffic noise recommendations and strength*

Considering the strong evidence about the adverse health effects, the GDG followed a precautionary approach and made a strong recommendation for interventions on railway noise, as it was confident that interventions are realizable and that best practices already exist for the management of noise from railways. Since the empirical evidence on the effectiveness of different types of intervention was rated either low or very low quality, the GDG felt that no recommendation could be made on the preferred type of intervention and agreed not to recommend any specific type of intervention over another.

PECO	Description
Population	General population
Exposure	Exposure to high levels of noise produced by railway traffic (average/ night-time)
Comparison	Exposure to high levels of noise produced by railway traffic (average/ night-time)
Outcomes	For average noise exposure: 1. cardiovascular disease 2. annoyance 3. cognitive impairment 4. hearing impairment and tinnitus 5. adverse birth outcomes 6. quality of life, well-being and mental health 7. metabolic outcomes
Outcomes	For night noise exposure: 1. effects on sleep

Table 10 *– PICOS/PECCOS scheme of critical health outcomes for exposure to railway noise*

Annoyance

In total, 10 studies with ERFs on the association between railway noise and annoyance were included in analyses (Champelovier et al., 2003; Gidloef-Gunnarsson et al., 2012; Lercher et al., 2007; 2008; Sato et al., 2004; Schreckenberg, 2013; Yano et al., 2005; Yokoshima et al., 2008). The studies incorporated individual data from 10,970 participants. The estimated data points of each of these studies are plotted in ***Figure 4***, alongside an aggregated ERF including the data from all the individual studies (see the black line for "WHO dataset, Rail"). The lowest category of noise exposure considered in any of the studies, and hence included in the systematic review is 40 dB, corresponding to approximately 1.5 %HA. The 10% benchmark for %HA is reached at 53.7 dB L_{den} (see ***Figure 4***).

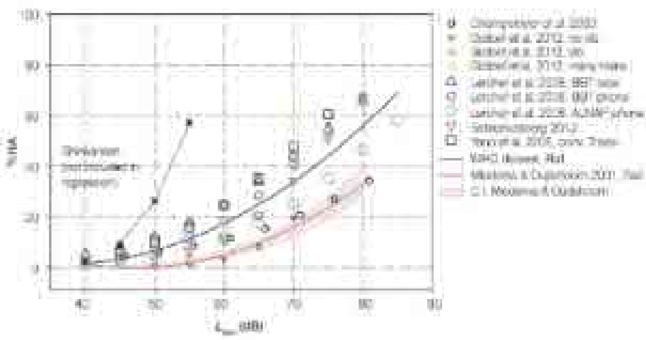


Figure 4 *– L_{den} versus %HA for 10 studies*

Regarding the strength of association between exposure and annoyance outcome for noise sources, the guidelines states that all intervention studies demonstrated that the response was of at least the magnitude estimated by a steady-state ERF. The limited available evidence on long-term effects shows that this excess response undergoes some attenuation but is largely maintained over several years. Despite the high risk of bias in all studies, the evidence in the systematic review was initially assessed as high quality, due to an upgrade because of the dose-response effect. However, the guidelines note this decision was made to downgrade this assessment to maximize consistency with the grading approach of the remaining systematic reviews. It was therefore rated moderate quality.

Table 11 – *Rail Traffic Noise* shows the %HA for rail noise exposure. The calculations are based on the regression equation derived from the systematic review (Guski et al., 2017). The overall evidence was rated moderate quality.

The association between exposure to rail traffic noise (L_{den}) and annoyance (%HA)	
L_{den} (dB)	% HA
40	1.5
45	3.4
50	6.6
55	11.3
60	17.4
65	25
70	33.9
75	44.3
80	56.1

Factors influencing the strength of recommendation	Decision
Quality of Evidence	**Average exposure (L_{den})** *Health effects* • Evidence for a relevant absolute risk of annoyance at 54 dB L_{den} was rated moderate quality. • Evidence for a relevant RR increase of the incidence of hypertension was rated low quality. One study met the inclusion criteria but did not find a significant increase. *Interventions* • Evidence that different types of intervention reduce noise annoyance from railways was rated very low quality. **Night-time exposure (L_{night})** *Health effects* • Evidence for a relevant absolute risk of sleep disturbance related to night noise exposure from railways at 44 dB L_{night} was rated moderate quality. *Interventions* • No evidence was available on the effectiveness of interventions.
Balance of benefits versus harms and burdens	Railway noise is a major source of localized pollution. The health benefits of adapting the recommendation outweigh the harms. Nevertheless, it is important to consider the relevance of railways as an environmentally friendly mode of transportation.
Values and preferences	Quiet areas are valued by the population; especially by those affected by continuous noise exposure. Some variability is expected among those directly affected by railway noise and those not affected.
Equity	Risk of exposure to road traffic noise is not equally distributed.
Resource use and implications	No comprehensive cost–effectiveness-analysis data are available, although a wide range of interventions exists, indicating that measures are both feasible and economically reasonable.
Decisions on recommendation strength	• Strong for guideline level for average noise exposure (L_{den}) • Strong for guideline value for average night noise exposure (L_{night}) • Strong for specific interventions to reduce noise exposure

Table 12 – *Rail Traffic Noise – Summary of the strength of the railway noise recommendation*

Aircraft Noise

The GDG set a guideline exposure level of 45.4 dB L_{den} for average exposure to aircraft noise, based on the absolute %HA. It was confident that there was an increased risk for annoyance below this exposure level, but probably no relevant risk increase for other priority health outcomes. In accordance with the defined rounding procedure, the value was rounded to 45 dB L_{den}.

Recommendation	Strength
For average noise exposure, the GDG strongly recommends reducing noise levels produced by aircraft below 45 dB L_{den}, as aircraft noise above this level is associated with adverse health effects.	Strong
For night noise exposure, the GDG strongly recommends reducing noise levels produced by aircraft during night-time below 40 dB L_{night}, as night-time aircraft noise above this level is associated with adverse effects on sleep.	Strong
To reduce health effects, the GDG strongly recommends that policy-makers implement suitable measures to reduce noise exposure from aircraft in the population exposed to levels above the guideline values for average and night noise exposure. For specific interventions the GDG recommends implementing suitable changes in infrastructure.	Strong

Table 13 – *Aircraft traffic noise recommendations and strength*

As the evidence on the adverse effects of aircraft noise was rated moderate quality, the GDG made the recommendation strong. The key question posed was: in the general population exposed to aircraft noise, what is the exposure–response relationship between exposure to aircraft noise (reported as various noise indicators) and the proportion of people with a validated measure of health outcome, when adjusted for main confounders?

A summary of the PICOS/PECCOS scheme applied and the main findings is set out in ***Table 14***.

PECO	Description
Population	General population
Exposure	Exposure to high levels of noise produced by aircraft traffic (average/ night time)
Comparison	Exposure to high levels of noise produced by aircraft traffic (average/ night time)
Outcomes	For average noise exposure: 1. cardiovascular disease 2. annoyance 3. cognitive impairment 4. hearing impairment and tinnitus 5. adverse birth outcomes 6. quality of life, well-being and mental health 7. metabolic outcomes
Outcomes	For night noise exposure: 1. effects on sleep

Table 14 – *PICOS/PECCOS scheme of critical health outcomes for exposure to aircraft noise*

Annoyance

A vast amount of evidence proves the association between aircraft noise and annoyance. In total, 12 aircraft noise studies were identified that were used to model ERFs of the relationship between L_{den} and %HA (Babisch et al., 2009; Bartels et al., 2013; Breugelmans et al., 2004; Brink et al., 2008; Gelderblom et al., 2014; Nguyen et al., 2011; 2012a; 2012b; Sato & Yano, 2011; Schreckenberg & Meis, 2007). These include data from 17,094 study participants. The estimated data points of each of the studies are plotted in ***Figure 5*** alongside an aggregated ERF including the data from all the individual studies (see the black line for 'Regr WHO full dataset'). The lowest category of noise exposure considered in any of the studies, and hence included in the systematic review, is 40 dB, corresponding to approximately 1.2 %HA. The benchmark level of 10 %HA is reached at approximately 45 dB L_{den} (see ***Figure 5***).

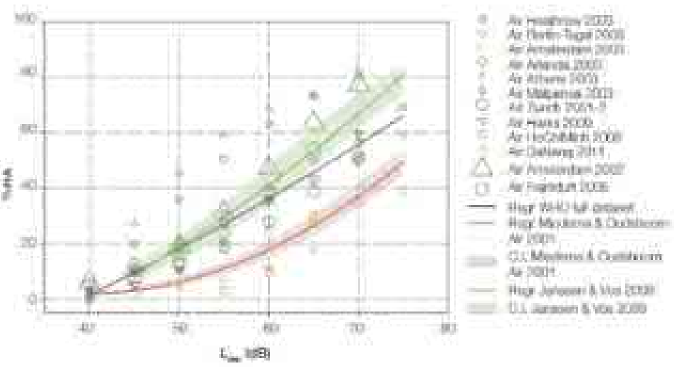


Figure 5 – *L_{den} versus %HA for aircraft noise*

The association between exposure to aircraft noise (L_{den}) and annoyance (%HA)	
L_{den} (dB)	% HA
40	1.2
45	9.4
50	17.9
55	26.7
60	36.0
65	45.5
70	55.5

Table 15 – *Aircraft noise*

This table shows the %HA in relation to exposure to aircraft traffic noise. It is based on the regression equation derived from the systematic review (Guski et al., 2017). As many of the studies are cross-sectional, the evidence was rated moderate quality.

Factors influencing the strength of recommendation	Decision
Quality of Evidence	**Average exposure (L_{den})** *Health effects* • Evidence for a relevant RR increase of the incidence of IHD at 52 dB L_{den} was rated very low quality. • Evidence for a relevant RR increase of the incidence of hypertension was rated low quality. • Evidence for a relevant absolute risk of annoyance at 45 dB L_{den} was rated moderate quality. • Evidence for a relevant RR increase of impaired reading and oral comprehension at 55 dB L_{den} was rated moderate quality. *Interventions* • Evidence on effectiveness of interventions to reduce noise exposure and/or health outcomes from aircraft noise was of varying quality. **Night-time exposure (L_{night})** *Health effects* • Evidence for a relevant absolute risk of sleep disturbance related to night noise exposure from aircraft at 40 dB L_{night} was rated moderate quality. *Interventions* • Evidence on effectiveness of changes in infrastructure (flight path changes) to reduce sleep disturbance from aircraft noise was rated low quality.
Balance of benefits versus harms and burdens	Aircraft noise is a major source of localized noise pollution. The health benefits of adapting the recommendations are expected to outweigh the harms.
Values and preferences	Quiet areas are valued by the population, especially by those affected by continuous aircraft noise exposure. Some variability is expected among those directly affected by aircraft noise and those not affected.
Resource use and implications	No comprehensive cost–effectiveness analysis data are available; nevertheless, a wide variety of interventions exist (some at very low cost), indicating that measures are both feasible and economically reasonable.
Decisions on recommendation strength	• Strong for guideline level for average noise exposure (L_{den}) • Strong for guideline value for average night noise exposure (L_{night}) • Strong for specific interventions to reduce noise exposure

Table 16 – *Aircraft Noise – Summary of the assessment of the strength of the aircraft noise recommendation*

Wind Turbine Noise

Wind turbine noise is new to the WHO guidelines. The recommendations are conditional only mean there is less certainty of its efficacy owing to lower quality of evidence of a net benefit. The GDG set a guideline exposure level of 45 dB L_{den} for average exposure, based on the relevant increase of the absolute %HA. The GDG stressed that there might be an increased risk for annoyance below this noise exposure level, but it could not state whether there was an increased risk for the other health outcomes below this level owing to a lack of evidence. As the evidence on the adverse effects of wind turbine noise was rated low quality, the GDG made the recommendation conditional. Based on the low quantity and heterogeneous nature of the evidence, the GDG was not able to formulate a recommendation addressing sleep disturbance due to wind turbine noise at night-time (see ***Table 17***).

Recommendation	Strength
For average noise exposure, the GDG conditionally recommends reducing noise levels produced by wind turbines below 45 dB L_{den}, as wind turbine noise above this level is associated with adverse health effects. No recommendation is made for average night noise exposure L_{night} of wind turbines. The quality of evidence of night-time exposure to wind turbine noise is too low to allow a recommendation.	Conditional
To reduce health effects, the GDG conditionally recommends that policy-makers implement suitable measures to reduce noise exposure from wind turbines in the population exposed to levels above the guideline values for average noise exposure. No evidence is available, however, to facilitate the recommendation of one particular type of intervention over another.	Conditional

Table 17 – *Wind turbine noise recommendations and strength*

PECO	Description
Population	General population
Exposure	Exposure to high levels of noise produced by wind turbine (average/night-time)
Comparison	Exposure to high levels of noise produced by wind turbines traffic (average/night-time)
Outcomes	For average noise exposure: 1. cardiovascular disease 2. annoyance 3. cognitive impairment 4. hearing impairment and tinnitus 5. adverse birth outcomes 6. quality of life, well-being and mental health 7. metabolic outcomes
Outcomes	For night noise exposure: 1. effects on sleep

Table 18 – *PICOS/PECCOS scheme of critical health outcomes for exposure to wind turbine noise*

The key question posed was: in the general population exposed to wind turbine noise, what is the exposure–response relationship between exposure to wind turbine noise (reported as various noise indicators) and the proportion of people with a validated measure of health outcome, when adjusted for main confounders? A summary of the PICOS/PECCOS scheme applied and the main findings is set out in ***Table 18***.

Two publications containing descriptions of four individual studies were retrieved (Janssen et al., 2011; Kuwano et al., 2014). All four studies used measurements in the vicinity of the respondents' addresses; the noise exposure metrics used in the three original studies (Pedersen, 2011; Pedersen & Persson Waye, 2004; 2007) included in Janssen et al. (2011) were recalculated into L_{den}. ***Figure 6*** shows the %HA from the two publications. The 10% criterion for %HA is reached at around 45 dB L_{den} (where the two curves coincide). There was a wide variability in %HA between studies, with a range of 3–13 %HA at 42.5 dB and 0–32 %HA at 47.5 dB. The %HA in the sample is comparatively high, given the relatively low noise levels.

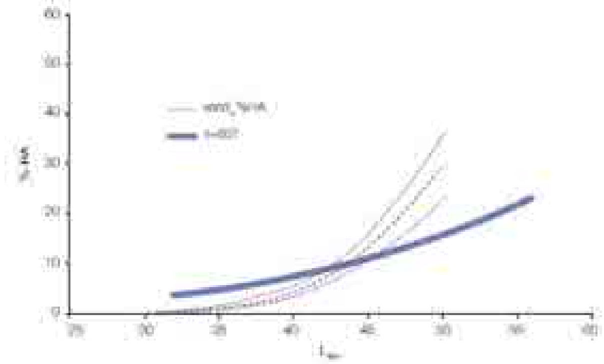
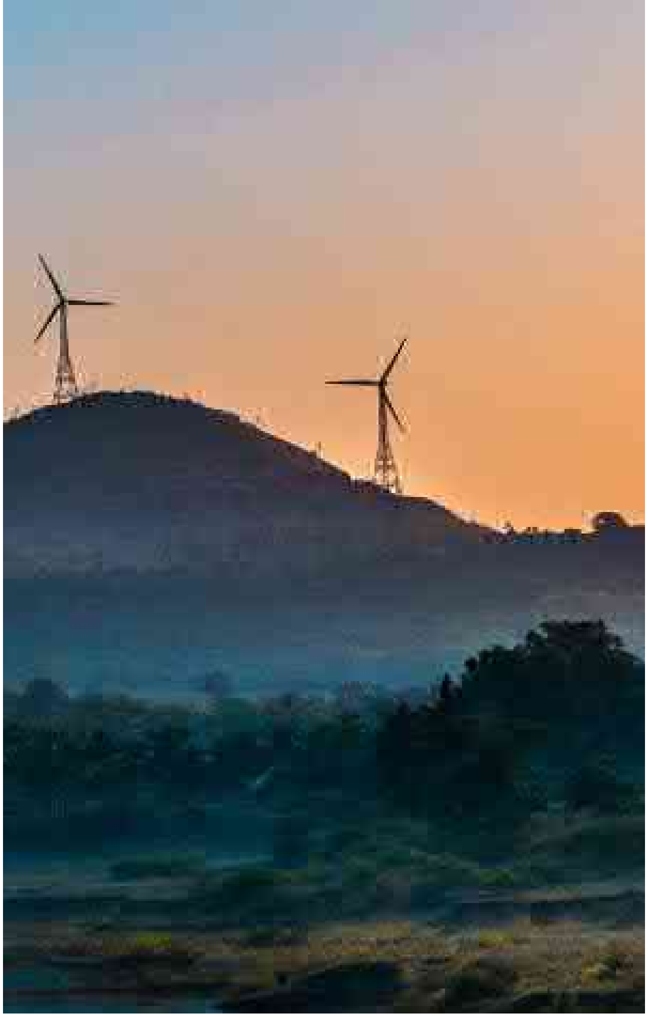


Figure 6 – *L_{den} versus %HA for wind farm noise*

The GDG state that there are serious issues with noise exposure assessment related to wind turbines. However, they confirm in regards to balance of benefits versus harms and burdens, that further work and research is required to assess fully the benefits and harms of exposure to environmental noise from wind turbines and to clarify whether the potential benefits associated with reducing exposure to environmental noise for individuals living in the vicinity of wind turbines outweigh the impact on the development of renewable energy policies in the WHO European Region. The GDG would expect a general health benefit from a marked reduction in any kind of long-term environmental noise exposure. Health effects of individuals living in the vicinity of wind turbines can theoretically be related not only to long-term noise exposure from the wind turbines but also to disruption caused during the construction phase.



Leisure Noise

Leisure noise is new to the WHO guidelines. In ENGfER 2018 the leisure noise context refers to all noise sources that people are exposed to due to leisure activities, such as attending nightclubs, fitness classes, pubs, live sporting events, concerts or live music venues and listening to loud music through personal listening devices.

The leisure noise recommendations in ENGfER 2018 are partly conditional, meaning there is less certainty of its efficacy owing to lower quality of evidence of a net benefit The GDG states that as specific evidence for the relationship between leisure noise and hearing loss is of insufficient quality, the GDG decided to follow a different approach for this noise source, based on knowledge regarding prevention of hearing loss in the workplace and on GCN 1999. There is enough evidence that the nature of the noise matters little in causing hearing loss, so using the existing guidelines is a justified step to prevent permanent hearing loss from leisure noise. In accordance with the evidence on the effects of PLDs on permanent hearing loss from leisure noise, the GDG

recommended a guideline exposure level of 70 $dB_{LAeq,24h}$ yearly average from all leisure noise sources combined. It was confident that there was no relevant risk increase for permanent hearing impairment below this exposure level of average leisure noise.

Because of a lack of evidence, the GDG was not able to formulate a recommendation addressing sleep disturbance due to leisure noise at night-time.

Factors influencing the strength of recommendation	Decision
Quality of Evidence	**Average exposure (L_{den})** *Health effects* • Evidence for a relevant absolute risk of annoyance at 45 dB L_{den} was rated low quality. *Interventions* • No evidence was available on the effectiveness of interventions to reduce noise exposure and/or health outcomes from wind turbines. **Night-time exposure (L_{night})** *Health effects* • No statistically significant evidence was available for sleep disturbance related to exposure from wind turbine noise at night. *Interventions* • No evidence was available on the effectiveness of interventions to reduce noise exposure and/or sleep disturbance from wind turbines.
Balance of benefits versus harms and burdens	Further work is required to assess fully the benefits and harms of exposure to environmental noise from wind turbines and to clarify whether the potential benefits associated with reducing exposure to environmental noise for individuals living in the vicinity of wind turbines outweigh the impact on the development of renewable energy policies in the WHO European Region.
Values and preferences	There is wide variability in the values and preferences of the population, with particularly strong negative attitudes in populations living in the vicinity of wind turbines.
Resource use and implications	Information on existing interventions (and associated costs) to reduce harms from wind turbine noise is not available.
Additional considerations or uncertainties	There are serious issues with noise exposure assessment related to wind turbines.
Decisions on recommendation strength	• Conditional for guideline value for average noise exposure (L_{den}) • Conditional for the effectiveness of interventions (L_{night})

Table 19 – *Wind turbine noise – Summary of the assessment of the strength of the wind turbine noise recommendation*

Recommendation	Strength
For average noise exposure, the GDG conditionally recommends reducing the yearly average from all leisure noise sources combined to 70 dB $L_{Aeq,24h}$ as leisure noise above this level is associated with adverse health effects. The equal energy principle can be used to derive exposure limits for other time averages, which might be more practical in regulatory processes.	Conditional
For single-event and impulse noise exposures, the GDG conditionally recommends following existing guidelines and legal regulations to limit the risk of increases in hearing impairment from leisure noise in both children and adults.	Strong
Following a precautionary approach, to reduce possible health effects, the GDG strongly recommends that policy-makers take action to prevent exposure above the guideline values for average noise and single-event and impulse noise exposures. This is particularly relevant as a large number of people may be exposed to and at risk of hearing impairment through the use of personal listening devices. There is insufficient evidence, however, to recommend one type of intervention over another.	Conditional

Table 20 – *Leisure Noise recommendations and strength*

The GCN 1999 recommend a limit of 70 $L_{Aeq,24h}$ for preventing hearing loss from industrial, commercial shopping and traffic areas, indoors and outdoors. Health and safety regulations are usually based on an exposure profile of a typical worker (eight hours per day, five days per week). Using the existing knowledge from the ISO standard and established health and safety regulations, it is possible to use the equal energy principle to derive the resulting noise exposure level for an exposure profile more appropriately suited for leisure noise. Converting 40 hours at 80 dB to a continuous exposure to noise (24 hours per day, seven days per week), this leads to a yearly average exposure of 71 dB for lifelong exposure – based on 71 dB = 80 dB (derived from ISO standard) − 6.2 dB (conversion of yearly average of 40 working hours divided by continuous exposure to noise: (10 $\log_{10}$(2080hrs/8760 hrs)) – 3 dB (extrapolation of 40 working years to lifelong exposure). This value is the same as the WHO recommendation of 70 dB in the GCN 1999.

The guidelines provide comment on combination of hourly exposure and number of hours per week to arrive at a yearly average L_{Aeq}, for specific events taking place for one-, two- or four-hour averages, once a week (such as visiting a discotheque or watching a loud movie), an hourly noise level of 85 dB would lead to an average yearly exposure of 63 dB, 66 dB and 69 dB, respectively. However, the same hourly exposure of 85 dB for an activity taking place for 14 hours per week (two hours per day, seven days a week) would lead to a yearly exposure of 74 dB, which exceeds the recommendations. The equal energy principle cannot be used to derive single-event limits because at high levels the ear starts to respond with nonlinear behaviour. The GCN 1999 provides several values, using different descriptors: 110 dB L_{AFmax} for industrial noises (no distance stated), 140 dB $L_{peak,lin}$ for adults and 120 dB for children (measured at 100 mm). The END, on the minimum health and safety requirements regarding the exposure of workers, recommends a lower action level of 135 dB L_{Cpeak} (at 100 mm). In a recent overview Hohmann (2015) provided an ERF for hearing damage caused by shooting noise, from which it appears that a safe level of 120 dB $_{LAE}$ can be derived. Although it is clear that high noise levels cause acute hearing damage, there is no agreement on a safe level. Further research is highly recommended.-

PECO	Description
Population	General population
Exposure	Exposure to high levels of noise produced by leisure activities (average/night-time)
Comparison	Exposure to high levels of noise produced by leisure activities (average/night-time)
Outcomes	For average noise exposure: 1. cardiovascular disease 2. annoyance 3. cognitive impairment 4. hearing impairment and tinnitus 5. adverse birth outcomes 6. quality of life, well-being and mental health 7. metabolic outcomes
Outcomes	For night noise exposure: 1. effects on sleep

Table 21 – *PICOS/PECCOS scheme of critical health outcomes for exposure to leisure*

The key question posed was: in the general population exposed to leisure noise, what is the exposure–response relationship between exposure to leisure noise (reported as various noise indicators) and the proportion of people with a validated measure of health outcome, when adjusted for main confounders? A summary of the PICOS/PECCOS scheme applied and the main findings is set out in ***Table 21***.

Single event levels

The ENGfER 2018 guideline values for the night-time are only based on the prevalence of self-reported sleep disturbance and do not take physiological effects into account noting that the link between immediate physiological reactions and long-term adverse health effects is complex and difficult to prove. The L_{AFmax} is the maximum time-weighted and A-weighted sound pressure level within a stated time interval. L_{AFmax} is often used in the case of noisy but short duration noise like noise emitted by transportation such as road, aircraft or rail for example. This is a measure of the maximum sound pressure reached during a defined measurement period and is sometimes considered in studies to determine certain health effects (such as awakening reactions). The WHO 2018 Guidelines acknowledge that in many situations, average noise levels like the L_{den} or L_{night} indicators may not be the best to explain a particular noise effect. Single-event noise indicators such as L_{AFmax} are warranted as can clearly elicit awakenings and other physiological reactions that are mostly determined by $L_{AFmax.}$ Nevertheless, the WHO assessment of the relationship between different types of single-event noise indicators and long-term health outcomes at the population level remains tentative. The guidelines therefore state that they make no recommendations for single-event noise indicators. Nevertheless, the evidence reviews on noise and sleep by Basner & McGuire (2018) can be reviewed by readers to gain an overview of single-event exposure–effect relationships.

Interim Targets

An interim target was proposed in NNGfE 2009, however it emphasized that an interim target is *"not a health-based limit value by itself and that vulnerable groups for example cannot be protected at these levels."* The GDG discussed whether to propose interim targets as part of the current guidelines and concludes there was consensus among members of the GDG not to provide interim targets.

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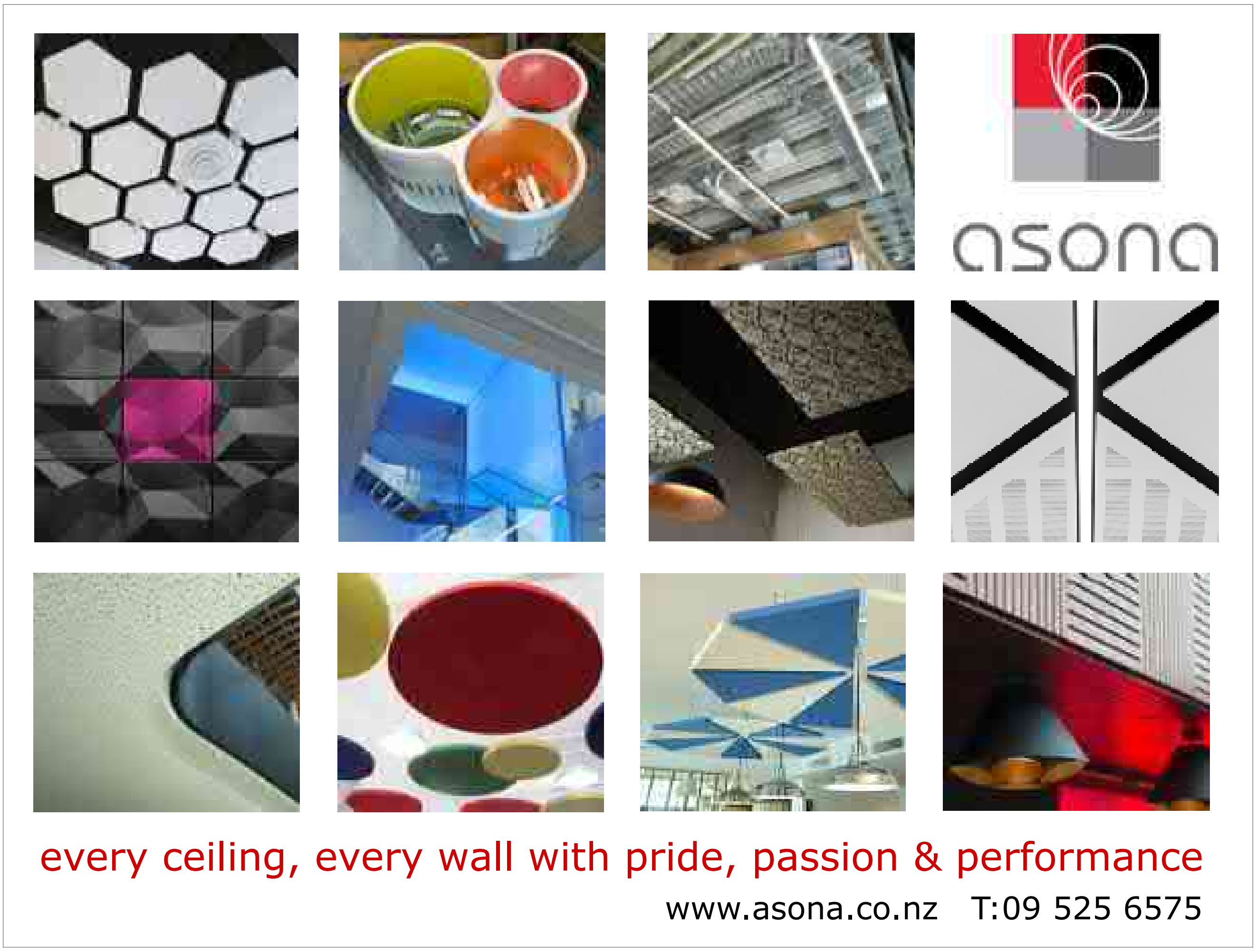

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Target audience and application of Guidelines

In terms of their health implications, the recommended exposure levels in ENGfER 2018 can be considered applicable in other regions and suitable for a global audience, as a large body of the evidence underpinning the recommendations was derived not only from European noise effect studies but also from research in other parts of the world – mainly in America, Asia and Australia.

Factors influencing the strength of recommendation	Decision
Quality of Evidence	**Average exposure ($L_{Aeq,24h}$)** *Health effects* • Evidence of an effect from PLDs on hearing impairment and tinnitus, in the absence of evidence for other health outcomes and absence of evidence on hearing impairment and tinnitus from other types of leisure noise besides PLDs, was rated very low quality. *Interventions* • No evidence was available on the effectiveness of interventions to reduce noise exposure and/or health outcomes from leisure noise.
Balance of benefits versus harms and burdens	The general benefit from reduction of leisure noise outweighs any potential harms.
Values and preferences	There is variability in the values and preferences of the general population.
Resource use and implications	The resources needed to reduce exposure to leisure noise are not expected to be intensive, but implementation and the long-term success of measures may be challenging, mainly due to cultural factors.
Decisions on recommendation strength	• Conditional for guideline level for average noise exposure ($L_{Aeq,24h}$) • Conditional for guideline single-event and impulse noise • Strong for interventions to reduce noise exposure

Table 22 – *Leisure Noise – Summary of the assessment of the strength of the leisure noise recommendation*

Difference from Historic WHO Guidelines

In 2009 the WHO Regional Office for Europe published the NNGfE 2009 to provide scientifically based advice to Member States for the development of future legislation and policy action in the area of assessment and control of night noise exposure. The NNGfE 2009 complement the previous GCN 1999, incorporating the advancement of research on noise and sleep disturbance up to 2006. The working group of experts reviewed available scientific evidence on the health effects of night noise and derived health-based guideline values. Again, WHO had not yet introduced its evidence-based recommendations policy and the NNGfE 2009 were mainly expert-based. They considered the scientific evidence on the threshold of night noise exposure indicated by L_{night} as defined in the END, and the experts concluded that a L_{night} value of 40 dB should be the target of the NNGfE 2009 (for all sources) to protect the public, including the most vulnerable groups such as children, chronically ill and elderly people. Further, a L_{night} value of 55 dB was recommended as an interim target for countries that could not follow the and elderly people. Further, a L_{night} value of 55 dB was recommended as an interim target for countries that could not follow the guidelines in the short term for various reasons or where policy-makers chose to adopt a stepwise approach.

The current ENGfER 2018 guidelines differ from the older ones, recommending levels of exposure unlike those previously outlined (especially by the NNGfE 2009). There are therefore a host of major differences between the previous and current guidelines which the reader should understand some of (but not all) the key differences are summarised as follows:

1. The development process for the current guidelines adhered to a new, rigorous, evidence-based methodology, as outlined in the WHO handbook for guideline development (WHO, 2014c). WHO adopted these internationally recognized standards to ensure high methodological quality and a transparent, evidence-based decision-making process in the guideline development.
2. The current guidelines consider cardiovascular disease a critical health outcome measure. They also consider a broader set of health outcomes, including adverse birth outcomes, diabetes, obesity and mental well-being. Wherever applicable, incidence, prevalence and mortality were considered separately. The current guidelines cover two new noise sources: wind turbines and leisure noise.
3. Critical and important health outcomes are considered separately for each of the noise sources.
4. The guideline development process included the health effects of intervention measures to mitigate noise exposure from different noise sources for the first time.

5. The style of recommendations differs: the current guidelines include an exact exposure value for every health outcome regarded as critical, for each noise source. Guideline recommendation values were set for each of the noise sources separately, based on the exact exposure values and a prioritization scheme, developed with the help of DWs.

6. The current guidelines apply a 1 dB increment scheme, whereas prior guidelines (GCN 1999 and NNGfE 2009) formulated or presented recommendations in 5 dB steps.

7. In comparison to GCN 1999, which defined environment-specific exposure levels, the current guidelines are source specific. They recommend values for outdoor exposure to road traffic, railway, aircraft and wind turbine noise, and indoor as well as outdoor exposure levels for leisure noise.

8. Except for leisure noise, all exposure levels recommended in the current guidelines are average sound pressure levels for outdoor exposure.

9. The current guidelines make use of the noise indices defined in the END: L_{den} and L_{night}.

10. The definition of "community noise" used in GCN 1999 was also adapted. The GDG agreed to use the term "environmental noise" instead and offered an operational definition of: "noise emitted from all sources except sources of occupational noise exposure in workplaces".

11. The current environmental noise guidelines ENGfER 2018, supersede GCN 1999. Nevertheless, the GDG recommends that all GCN 1999 indoor guideline values and any values not covered by the current guidelines (such as industrial noise and shopping areas) should remain valid.

Relationship between NNGfE 2009 and ENGfER 2018

As guiding principles, the NNGfE 2009 defined effect thresholds or *"lowest observed adverse health effect levels"* for both immediate physiological reactions during sleep (i.e. awakening reactions or body movements during sleep) and long-term adverse health effects (i.e. self-reported sleep disturbance). These guideline exposure levels defined a level below which no effects were expected to occur (corresponding to 30 dB L_{night}) and proceeded to define the level where adverse effects start to occur (corresponding to 40 dB L_{night}), with the aim of protecting the whole population, including – to some extent – vulnerable groups. The development of the NNGfE 2009 values relied on evidence-based expert judgement. In contrast, the current guidelines formulate recommendations more strictly based on the available evidence and following the guiding principle to identify exposure values based on a relevant risk increase of adverse health effects. Thus, the recommended guideline values might not lead to full protection of the population, including all vulnerable groups. The GDG stresses that the aim of the current guidelines is to define an exposure level at which effects certainly begin.

The NNGfE 2009 also comprehensively investigate the immediate short-term effects of environmental noise during sleep, including physiological reactions such as awakening reactions and body movements. They also provided threshold information about single-event noise indicators (such as the L_{Amax}). In contrast, the current guideline values for the night-

time are only based on the prevalence of self-reported sleep disturbance and do not take physiological effects into account. The causal link between immediate physiological reactions and long-term adverse health effects is complex and difficult to prove. Thus, the current guidelines are restricted to long-term health effects during night-time and therefore only include recommendations about average noise indicators: Lnight. Nevertheless, as noted above the evidence reviews on noise and sleep (Basner & McGuire, 2018) includes an overview of single-event exposure–effect relationships which the reader should make themselves aware of.

Noise Annoyance

Noise annoyance may be defined as a feeling of displeasure, nuisance, disturbance or irritation caused by a specific sound. In the ENGfER 2018 guidelines, *"annoyance"* refers to long-term noise annoyance. The importance of considering both annoyance and other effects such health outcomes is supported by evidence indicating that they may be part of the causal pathway of noise-induced diseases.

In noise annoyance studies non-acoustic factors may explain up to 33% of the variance (Guski, 1999). The higher the quality of evidence, the lower confounding effects of non-acoustic factors may be expected. Nevertheless, as with measurement errors, confounding cannot be avoided. Based on the retrieval and evaluation of the pertinent literature, the GDG decided to address the association of environmental noise from different sources and health outcomes separately and individually for each source of noise, and for critical and important health outcomes.

In addition, the GDG states as part of the review works systematic reviews of the health effects of environmental noise, a narrative review of biological mechanisms of non-auditory effects was conducted (Eriksson et al., 2018). This covers literature related to pathways for non-auditory effects and provides supporting evidence on the association between environmental noise and health outcomes in humans, especially related to cardiovascular and metabolic diseases. The guidelines note that data on perception of specific sources of environmental noise as a problem are not available for the entire WHO European Region. Nevertheless, some countries – including France, Germany, the Netherlands, Slovakia and the United Kingdom – conduct national surveys on noise annoyance. The conclusion for annoyance according to these large-scale surveys is:

1. Road traffic noise is the most important source of annoyance, generally followed closely by neighbour noise.
2. Aircraft noise can also be a substantial source of annoyance.
3. Railway noise and industrial noise are enumerated less frequently.
4. Only limited data are available on the population's perception of newer sources of noise, such as wind turbines.

The guidelines note that while perception surveys do not provide information on actual quantitative relationships between noise exposure and health outcomes, it is important to note that the results of such surveys represent people's preferences and values regarding environmental noise. It is important to note that people are not always aware of the health impacts of noise. Greater awareness of the issue may further increase positive values and preferences. Most studies that form the body of evidence for the recommendations in these guidelines – among them large-scale epidemiological studies and socio-acoustic surveys on annoyance.

Depending on the health effect under investigation, possible non-acoustic factors may include a host of factors these include (but are not limited to) gender, age, education, subjective noise sensitivity, extroversion/introversion, general stress score, co-morbidity, length of residence, duration of stay at dwelling in the day, window orientation of a bedroom or living room towards the street, personal evaluation of the source, attitudes towards the noise source, coping capacity with respect to noise, perception of malfeasance by the authorities responsible, body mass index and smoking habits.

Multiple noise exposures

The ENGfER 2018 do not include recommendations about any kind of multiple exposures. That's is, the guidelines refer to traffic noise or railway noise only but not both. It is key to understand that in everyday life people can be exposed to noise from several sources at the same time. In Germany, for example, the guidelines note that 44% of the population are annoyed by at least two and up to five sources of noise (Umweltbundesamt, 2015). Research indicates that, alongside exposure to more than one source of noise, combined exposure to different factors – for example, noise and vibration or noise and air pollution – has gained increasing relevance in recent years (Sörensen et al., 2017) thus the WHO guidelines acknowledges the need to develop comprehensive models to quantify the effects of multiple exposures on human health.

Issues with A-weighting and the wider health effects of noise

All agreed EU Environmental noise descriptors use A-frequency weighting ($L_{Aeq,t}$; L_{night} and L_{den} are based on $L_{Aeq,t}$ values). As do the occupational noise descriptors for continuous noise exposure ($L_{Aeq,8h}$). The reason for the use of A-(frequency) weighing is that it crudely approximates the human hearing sensitivity with frequency. So, in effect, all agreed noise descriptors for the EU focus on the auditory pathway as the pathway for assessment of adverse health effects. However, GCN 1999 noted that, *"...low-frequency noise can disturb rest and sleep even at low sound pressure levels".*

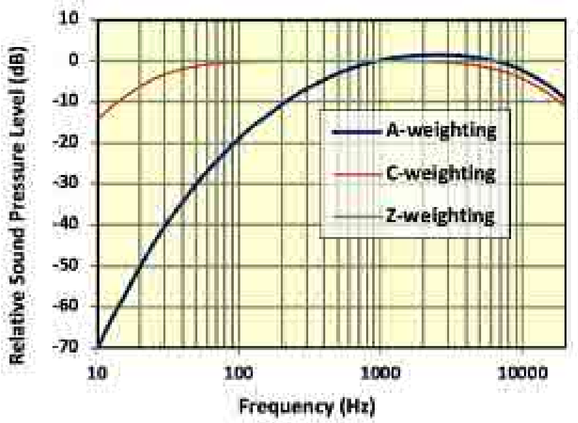

Figure 7 – *Frequency weightings (A,C,Z) and relative sound pressure level in dB*

Measurements using A-weighting descriptors does not enable assessment of the low frequency effects of noise. Various definitions for low frequency noise (LFN) exist, but typically it implies sound with frequencies below 200 Hz. When this is extended into the infrasound region (< 20 Hz), it is usually called, ILFN (Infra and Low Frequency Noise). To illustrate the effect of using A-weighting on LFN measurement, if a sound has significant power at 20 Hz, then the use of A-weighting (see ***Figure 7***) means that its contribution to the common noise descriptor L_{Aeq}, is attenuated by 50 dB compared to 1 kHz, a reduction of 10^5 or 100,000 in power. Even at 200 Hz, the attenuation is 10 dB (relative to 1 kHz) corresponding to a 10-fold reduction in its contribution to the descriptor. So, if there are adverse health effects to be observed for LFN, it is unlikely that the use of data collected using A-weighted descriptor would enable this.

A portion of the population are highly sensitive to LFN. Studies show greater effects on cognitive performance and physiological stress when exposed to LFN compared to broadband noise (Waye et al. 2002; Rossi, Prato, Lesina & Schiavi, 2018; Abbasi et al., 2018). Compared to high frequencies, low frequencies:

- Propagate long distances (with low attenuation)
- Pass with low attenuation through walls / windows etc.
- Easily becomes structure-born – turning into mechanical vibration
- Long distances from a source, the spectrum is dominated by low frequencies;

The WHO 2009 'Burden of disease from environmental noise. Quantification of healthy life years lost in Europe' (BDEN 2009) makes no mention of the health effects of LFN, probably because it is exclusively based on data collected using A-frequency weighted descriptors, as a result of the END. However, ENGfER 2018 states, *"Studies should use measures of exposure including noise exposure at a wide range of levels and frequencies (including low-frequency noise), with information on noise levels outdoors and indoors."* This acknowledges the increasing importance, particularly in urban and industrial settings, where the spectra of sources are typically dominated by LFN.

So, to address the limitations of using A-weighted noise descriptors, studies need to include measures that allow assessment of the (low-frequency) spectral, temporal, and if present, vibration characteristics of noise, to enable assessment of the wider health effects. At a minimum, C-weighted equivalent sound pressure levels ($L_{Ceq,t}$) should be collected alongside $L_{Aeq,t}$, preferable supported with spectral information. From a practical measurement perspective, this is challenging, because at low frequencies the microphones on sound level meters are highly susceptible to wind-induced-noise (WIN), that is, false sound pressure level readings due to wind gusts (and turbulence). A-weighted descriptors are far less susceptible to this type of contamination because they significantly attenuate the contribution of LFN.

To robustly measured LFN, protocols and procedures must be adopted that significantly reduce WIN. This means developing and using wind shielding that is effective in wind velocity range (0-20 kph) commonly deemed acceptable for general environmental noise measurements. It also means modeling the potential for WIN contamination and taking this into account in the analysis. A good starting point would be work done on wind turbine noise measurements, where double and even triple wind shielding is routine, in order to collect robust data.

It is highly likely that when robust environmental noise data is collected that includes the contribution of LFN, that analysis will show the full extent of the adverse health effects of noise. This will build on and extend the current WHO community noise guidelines, enabling action to be taken on community noise at a local level, while providing improved legislation, management and guidance for an international audience.

Publications and reference documents

The review is based on information available from World Health Organization web site, www.euro.who.int/en/health-topics/environment-and-health/noise

Qualifications and Copyright

This paper review is intended as a guide only; it is not intended to be surrogate for any expert advice from a professional acoustic consultant. The authors wish to make it clear that the contents of the paper have been sourced from a number of key sources including the World Health Organization (WHO) guidelines for noise and the New Zealand Acoustic Standards.

The reader and users should further understand that the information within this review does not attempt to cover all areas and applications of the standards and therefore there are a host of omissions. While all care has been taken in the preparation of this work and the information which is included is believed to be correct at the time of preparation, users of this paper should apply discretion and rely on their own judgments regarding the use of the above information.

Abbreviations

%HA – Percentage of the population 'highly annoyed'

AADT – Annual Average Daily Traffic

ACC – Accident Compensation Corporation

AGL – Above Ground Level

CAA – Civil Aviation Authority of New Zealand

EC – European Commission

EEA – European Environment Agency

END – 'The European Noise Directive' 2002/49/EC

ENGfER 2018 – WHO Environmental Noise Guidelines for the European Region 2018

ERF – Exposure–response function

EU – European Union

GRADE – Grading of Recommendations Assessment Development and Evaluation

GCN 1999 – WHO Guidelines for Community Noise 1999

GDG – Guidelines Development Group

ICBEN – International Commission on Biological Effects of Noise

IHD – ischaemic heart disease

MoH – Ministry of Health

NIHL – Noise Induce Hearing Loss

NNGfE 2009 – Night Noise Guidelines for Europe 2009

NZTA – New Zealand Transport Agency

PECCOS – Population, exposure, comparator, confounder, outcome and study [framework]

PICOS – Population, intervention, comparator, outcome and study [framework]

PLD – personal listening device

PPFs – Protected premises and facilities

RMA 1991 – Resource Management Act 1991

UNDG – United Nations Development Group

WHA – World Health Assembly

WHO –Å World Health Organization

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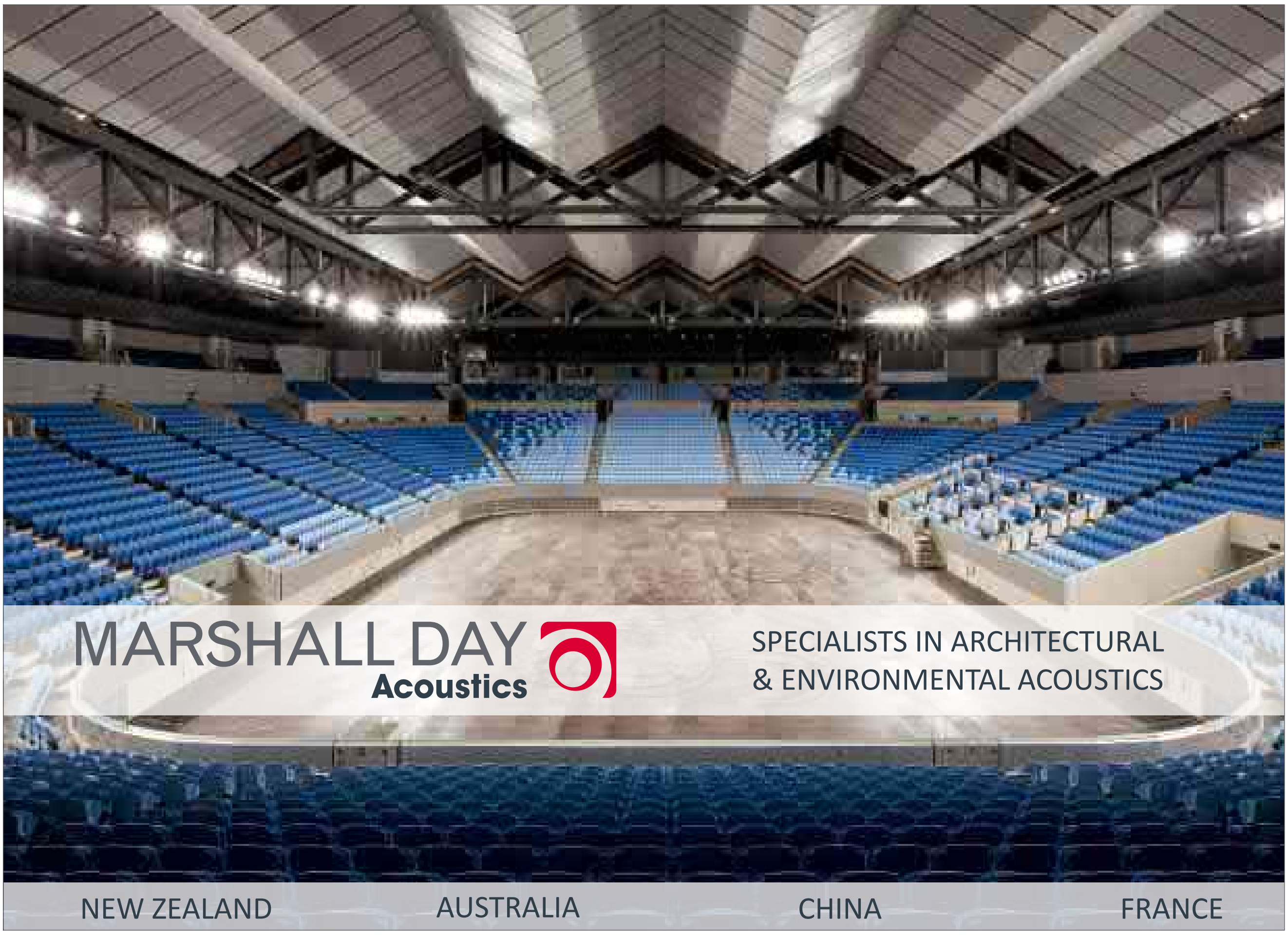
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