# E-CS ACOUSTICAL MEASUREMENT PROCEDURES

## GENERAL PROCEDURES RELATED TO MEASUREMENTS FOR SITING WIND ENERGY SYSTEMS

### I. Introduction

The potential impact of sound and sound induced building vibration associated with the operation of wind powered electric generators is often a primary concern for citizens living near proposed wind energy systems (WES(s)). This is especially true of projects located near homes, residential neighborhoods, businesses, schools, and hospitals in quiet residential and rural communities. Determining the likely sound and vibration impacts is a highly technical undertaking and requires a serious effort in order to collect reliable and meaningful data for both the public and decision makers.

The protocols and procedures used by E-Coustic Solutions are based in part on criteria published in American National Standards Institute's (ANSI/ASA) S12.9 –Part 3: Quantities and Procedures for Description and Measurement of Environmental Sound, and S12.18 Procedures for Outdoor Measurement of Sound Pressure Level.

The use of standardized procedures that follow procedures set by the American National Standards Institute is intended to provide a consistent and scientifically sound protocol for evaluating existing background levels of audible and low frequency sound in a WES project area. It also standardizes the use of information normally provided by the project developer showing the predicted over-all sound levels in terms of $L_{Aeq}$ and $L_{Ceq}$ and 1/3 or 1/1 octave bands to predict community response and land-use compatibility. Where there is a complaint or some other situation involving measurement of wind turbine sound beyond the normal needs for pre-operation studies to establish long-term background sound levels or studies conducted to see if design goal sound levels were achieved once operation commences, these procedures will be followed with any needed and appropriate changes to accommodate the purpose of the test.

Where there are no controlling noise ordinance limits or where such limits exceed the limits of not-to-exceed $L_{A90\ +5}$ or 35 dBA (whichever is less) or $L_{C90\ +5}$ 55 dBC (whichever is less) the potential for adverse health effects related to sound immissions from the operation of wind turbines on the existing community's residents can be predicted. The information upon which the above criteria are based includes the recent understanding(s) of the effects of wind turbine sound immissions on people living near wind turbine projects. It is a combination of new and older, more established data, from WHO (2007) and independent medical researchers on annoyance, sleep disturbance and public health risks of night time sound.

For studies of the wind project after operation commences a comparison of the post-build sound levels to the predictions and the baseline study can be used to assess compliance and land-use compatibility. The level limits in the controlling noise ordinance (or the limits above indicated by research) will be applied to the post-build study's findings. If there have been any complaints about WES sound or low frequency noise emissions or wind turbine noise induced dwelling vibration by any resident of an occupied dwelling that property may be included in the post-build study for evaluation against the rules for sound level limits and compliance.

The characteristics of the proposed or operating WES project and the features of the surrounding environment will influence the design of the sound and vibration study. Often these details are subject to modification based on the conditions found at the test site, the weather, and other factors. Site layout, types of WES(s) selected and the existence of other



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significant local audible and low frequency sound sources and sensitive receptors will be taken into consideration when conducting the actual sound study.

### II. Instrumentation

All instruments and other tools used to measure audible, inaudible and low frequency sound shall meet the requirements for ANSI or IEC Type 1 Integrating Averaging Sound Level Meter Standards  The principle standard reference for this document is ANSI 12.9/Part 3 with important additional specific requirements for the measuring instrumentation and measurement protocol. All instruments have been laboratory calibrated and checked for malfunctions within the prior year.  Separate calibration records are created before and after each series of tests.  These are not always included in smaller reports.  They are available upon request should they be needed to verify calibration.

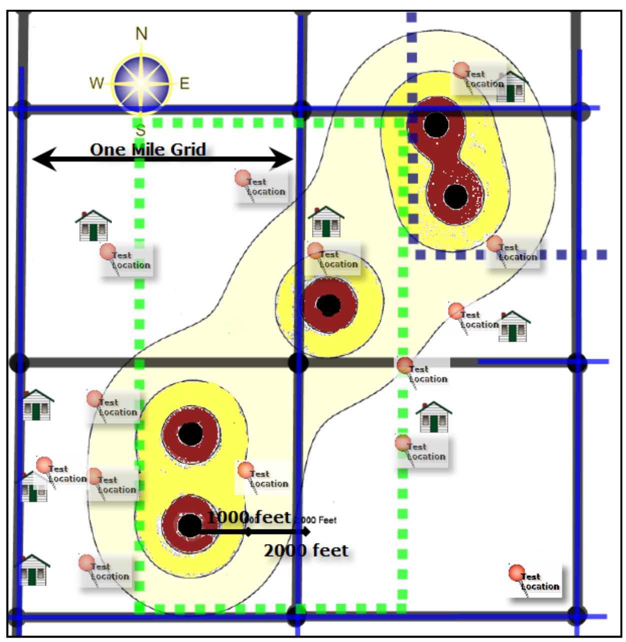
### III. Measurement of Pre-Construction Sound Environment (Baseline)

An assessment of the proposed WES project areas existing sound environment is the first step needed to predict the likely impact resulting from a proposed project. The following guidelines are used when developing a reasonable estimate of an area's existing background sound environment.

#### Sites with No Existing Wind Energy Systems (Base-line Sound Study)

Sound level measurements will be taken as follows:

The results of the model showing the predicted worst case $L_{Aeq}$ and $L_{Ceq}$ sound emissions of the proposed WES project will be overlaid on a map (or separate $L_{Aeq}$ and $L_{Ceq}$ maps) of the project area if such a map has been submitted by a wind project developer. Otherwise they will be supplied in Table format with information to identify the test location. An example of the use of the applicant's plan view map (right) shows an approximately two (2) mile square section with iso-level contour lines prepared by the applicant, sensitive receptors (homes) and locations selected for the baseline sound tests whichever are the controlling metric. The test points shall be located at the property line bounding the property of the turbine's host closest to the wind turbine. Additional sites may be added if appropriate.  A grid comprised of one (1) mile boundaries (each grid cell is one (1) square mile) should be used to assist in identifying between two (2) to ten (10) measurement points per cell. The grid shall extend to a minimum of two (2) miles beyond the perimeter of the project boundary. This may be extended to more than two (2) miles at the discretion of the client.  The measurement points shall be selected to represent the noise sensitive receptor sites based on the anticipated sound propagation from the combined WT in the project.  Usually, this



# E-CS ACOUSTICAL MEASUREMENT PROCEDURES

## GENERAL PROCEDURES RELATED TO MEASUREMENTS FOR SITING WIND ENERGY SYSTEMS

will be the closest WT. If there is more than one WT near-by then more than one test site may be required. When the location of a wind turbine is not known a mixture of property line and other sites located in outdoor areas used for recreational purposes may be used instead. In no case, shall the test sites be near sources of noise that could contaminate a long-term-background sound level test (roads, vegetation, flowing water, machinery that is not part of the long term background, etc.) unless the effect of such sources is removed from the final results for long-term background sound level.

The intent is to anticipate the locations along the bounding property line that will receive the highest sound immissions and where the "expectation of quiet" is the greatest. The sites that will most likely be negatively affected by the WES project's sound emissions should be given first priority in testing. These sites may include sites adjacent to occupied dwellings or other noise sensitive receptor sites. Sites will be selected to represent the locations where the background soundscape reflects the quietest locations of the sensitive receptor sites. Background sound levels (and 1/3 octave band sound pressure levels if required) may also be obtained according to the definitions and procedures provided in the controlling ordinance and recognized acoustical testing practice and standards.

All properties within the proposed WES project boundaries should be considered for this study.

Measurement points will be located with assistance from the client and any non-client property owner(s) and positioned such that no significant obstruction (building, trees, etc.) blocks sound and vibration from the nearest proposed WES site.

Duration of measurements shall be a minimum of ten (10) continuous minutes for all criteria at each location. The duration must include at least six (6) minutes that are not affected by transient sounds from near-by and non-nature sources. Multiple ten (10) minute samples over longer periods such as 30 minutes or one (1) hour may be used to improve the reliability of the $L_{A90}$ and $L_{C90}$ values. The ten (10) minute sample with the lowest valid $L_{90}$ values will be used to define the background sound.

The tests at each site selected for this study shall be taken during the expected 'quietest period of the day or night' as appropriate for the site. When determining background sound characteristics prior to any new source that operates during the nighttime hours the preferred testing time is from 10pm until 4 am. If circumstances indicated that a different time of the day should be sampled, the test may be conducted at the alternate time.

Sound level measurements will typically be made on a weekday of a non-holiday week. Weekend measurements may also be taken at selected sites where there are weekend activities that may be affected by WT sound.

Measurements must be taken with the microphone at 1.2 to 1.5 meters above the ground and at least 7.5 m. from any reflective surface following ANSI 12.9 Part 3 protocol. Additional requirements are provided in the Sections: Acoustical Test Procedure Reference Standards and the Excerpts From ANSI and ASA on Outdoor Measurements and Long Term Background Sound Level..



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Reporting

1. Each Measurement Point data which will typically include the following measurements but may also include others such as octave or 1/3 octave band sound pressure levels as deemed appropriate:

   a. $L_{Aeq}$, $L_{A10}$, and $L_{A90}$, and

   b. $L_{Ceq}$ , $L_{C10}$, and $L_{C90}$

2. A narrative description of any intermittent sounds registered during each measurement. This may be augmented with video and audio recordings.

3. A narrative description of the steady sounds that form the background soundscape. This may be augmented with video and audio recordings.

4. Information about wind speed and direction at the microphone (Measurement Point), humidity and temperature at time of measurement will be documented. Corresponding information from the nearest 10 meter weather reporting station shall also be obtained.

Measurements taken only when wind speeds are less than 2m/s (4.5 mph) at the microphone location will be considered valid for long term background sound studies in extremely quiet rural and wilderness areas. In suburban and urban areas where the long term background sound level will be above 30 dBA slightly higher wind speeds may be permitted as appropriate for each windscreens capability to prevent pseudo-noise. It shall never exceed 5.5 m/s (11 mph) A windscreen of the type recommended by the monitoring instrument's manufacturer will used for all data collection.

5. A map, and/or diagram clearly showing using the plot plan provided by client or developer, if available (if not available this information should be provided in table or aerial view or other form):

- The layout of the project area, including topography, the project boundary lines, and property lines.
- The locations of the Measurement Points (Optional).
- The distance between any Measurement Points and the nearest WT(s) (Optional).
- The location of significant local non-WES sound and vibration sources.
- The distance between all MPs and significant local sound sources (Optional). And,
- The location of all sensitive receptors including but not limited to: schools, day-care centers, hospitals, residences, residential neighborhoods, places of worship, and elderly care facilities (Optional).

### Background Sound Tests for Sites with Existing Wind Energy Systems

Two complete sets of sound level measurements should be taken as defined below:

1. One set of measurements with the wind generator(s) off unless the client elects to substitute the sound data collected for the background sound study. Wind speeds must be suitable for background sound tests as specified elsewhere in this document.

2. One set of measurements with the wind generator(s) running with wind speed at hub height sufficient to meet nominal rated power output or higher and, if possible, at less than 2 m/s below at the microphone location. If winds exceed 2 m/s but local conditions will permit valid



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tests with winds of 5 m/s or less, then testing may proceed with additional qualifications noted. Conditions should reflect the worst case sound emissions from the WES project. This will often involve tests taken during the evening or night when winds are calm (less than 2m/sec) at the ground surface yet, at hub height, sufficient to power the turbines.

Sound level measurements and meteorological conditions at the microphone shall be taken and documented as discussed above.

## IV. Wind Turbine Noise Complaint/Compliance and other Investigative Acoustical Measurements

The measurement procedures, requirements and protocols outlined above for baseline and operational testing of wind turbine sound immissions will be used as resources and guidelines for measurements conducted to address complaints or compliance. However, the nature of complaint/compliance measurements involves decisions that often cannot be anticipated until the conditions at the test site are personally observed. The test protocols are more investigative than the standardized measurements described above. The complaint/compliance tests often require that weather and other conditions that lead to the complaint condition be duplicated. Thus, the strict control over weather and other factors that is expected for the above measurements often cannot be achieved for this type of work. The compliance test location(s) will be selected based on the nature of the complaint/compliance question and may be determined at the time of field testing. The time of day for the testing and the wind farm operating conditions, wind speed and direction should replicate the conditions that generated the complaint, if those conditions are needed to reproduce the intruding noise. ANSI S12.9-Part 3 procedures apply as amended in the References. The effect of instrumentation limits for wind and other factors must be recognized and followed.

# I. DEFINITIONS

The following terms have the meanings indicated:

"**Aerodynamic Sound**" means a noise that is caused by the flow of air over and past the blades of a Wind Energy System (WES).

"**Ambient Sound"** Ambient sound encompasses all sound present in a given environment, being usually a composite of sounds from many sources near and far. It includes intermittent noise events, such as, from aircraft flying over, dogs barking, wind gusts, mobile farm or construction machinery, and the occasional vehicle traveling along a nearby road. The ambient also includes insect and other nearby sounds from birds and animals or people. The near-by and transient events are all part of the ambient sound environment but are not to be considered part of the background sound. If present, a different time or location should be selected for determining the $L_{90}$ background sound levels.

**"American National Standards Institute (ANSI)"** Standardized acoustical instrumentation and sound measurement protocol shall meet all the requirements of the following ANSI Standards:

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|---|---|
| ANSI S1.43 | Integrating Averaging Sound Level Meters: Type-1 (or IEC 61672-1) |
| ANSI S1.11 | Specification for Octave and One-third Octave-Band Filters (or IEC 61260) |
| ANSI S1.40 | Verification Procedures for Sound Calibrators |
| ANSI S12.9 Part 3 | Procedures for Measurement of Environmental Sound |
| ANSI S12.18 | Measurement of Outdoor Sound Pressure Level |
| IEC 61400-11 | Wind turbine generator systems –Part 11: Acoustic noise measurements |

"**Anemometer**" means a device for measuring the speed and direction of the wind..

"**A-Weighted Sound Level (dBA)**" A measure of over-all sound pressure level designed to reflect the response of the human ear, which does not respond equally to all frequencies. It is used to describe sound in a manner representative of the human ear's response. It reduces the effects of the low with respect to the frequencies centered around 1000 Hz. The resultant sound level is said to be "A-weighted" and the units are "dBA." Sound level meters have an A-weighting network for measuring A-weighted sound levels (dBA) meeting the characteristics and weighting specified in ANSI Specifications for Integrating Averaging Sound Level Meters, S1.43-1997 for Type 1 instruments and be capable of accurate readings (corrections for internal noise and microphone response permitted) at 20 dBA or lower. In this document dBA means $L_{Aeq}$ unless specified otherwise.

"**Background Sound ($L_{90}$)**" refers to the sound level present at least 90% of the time. Background sounds are those heard during lulls in the ambient sound environment. That is, when transient sounds from flora, fauna, and wind are not present. Background sound levels vary during different times of the day and night. Because WES operates 24/7 the background sound levels of interest are those during the quieter periods which are often the evening and night. Sounds from the WES of interest, near-by birds and animals or people must be excluded from the background sound test data. Nearby electrical noise from street lights, transformers and cycling AC units and pumps etc must also be excluded from the background sound test data.

The background noise environment consists of a multitude of distant sources of sound. Background sound level (dBA and dBC (as $L_{90}$)) is the sound level present 90% of the time during a period of observation that is representative of the quiet time for the soundscape under evaluation and with duration of ten (10) continuous minutes. Measurement periods such as at dusk when bird and insect activity is high or the early morning hours when the 'dawn chorus' is present are not acceptable measurement times. Longer term sound level averaging tests, such as 24 hours or multiple days are not at all appropriate since the purpose is to define the quiet time background sound level. It is defined by the $L_{A\,90}$ and $L_{C\,90}$ descriptors. It may be considered as the quietest one (1) minute during a ten (10) minute test. $L_{A\,90}$ results are valid only when $L_{A\,10}$ results are no more than 10 dB above $L_{A\,90}$ for the same period. $L_{C\,10}$ less $L_{C\,90}$ are not to exceed 10 dB to be valid.

Further, background $L_{90}$ sound levels documenting the pre-construction baseline conditions should be determined when the ten (10) minute maximum wind speed is less than 2 m/s (4.5 mph) near ground level/microphone location 1.5 m height.

"**Blade Passage Frequency**" (BPF) means the frequency at which the blades of a turbine pass a particular point during each revolution (e.g. lowest point or highest point in rotation) in terms of events per second. A three bladed turbine rotating at 28 rpm would have a BPF of 1.4 Hz. [E.g. ((3 blades times 28rpm)/60 seconds per minute = 1.4 Hz BPF)]

"**C-Weighted Sound Level (dBC)**" Similar in concept to the A-Weighted sound Level (dBA) but C-weighting does not de-emphasize the frequencies below 1k Hz as A-weighting does. It is used for measurements that must include the contribution of low frequencies in a single number representing the entire frequency spectrum. Sound level meters have a C-weighting network for measuring C-weighted sound levels (dBC)meeting the characteristics and weighting specified in ANSI S1.43-1997 Specifications for Integrating Averaging Sound Level Meters for Type 1 instruments. In this document dBC means $L_{Ceq}$ unless specified otherwise.

"**Decibel (dB)**" A dimensionless unit which denotes the ratio between two quantities that are proportional to power, energy or intensity. One of these quantities is a designated reference by which all other quantities of identical units are divided. The sound pressure level (Lp) in decibels is equal to 10 times the logarithm (to the base 10) of the ratio between the pressure squared divided by the reference pressure squared. The reference pressure used in acoustics is 20 MicroPascals.

"**Emission**" Sound energy that is emitted by a noise source (wind farm) is transmitted to a receiver (dwelling) where it is immitted (see "immission).

"**Frequency**" The number of oscillations or cycles per unit of time. Acoustical frequency is usually expressed in units of Hertz (Hz) where one Hz is equal to one cycle per second.

"**Height**" means the total distance measured from the grade of the property as existed prior to the construction of the wind energy system, facility, tower, turbine, or related facility at the base to its highest point.

"**Hertz (Hz)**" Frequency of sound expressed by cycles per second.

"**Immission**" Noise immitted at a receiver (dwelling) is transmitted from noise source (wind turbine) that emitted sound energy (see "emission").

**"Immission spectra imbalance**" The spectra are not in balance when the C-weighted sound level is more than 20 dB greater than the A-weighted sound level. For the purposes of this requirement, the A-weighted sound level is defined as the long-term background sound level ($L_{A90}$) +5 dBA. The C-weighted sound level is defined as the $L_{Ceq}$ measured during the operation of the wind turbine operated so as to result in its highest sound output. A Complaint test provided later in this document is based on the immission spectra imbalance criteria.

"**Infra-Sound**" sound with energy in the frequency range of 0-20 Hz is considered to be infra-sound. It is normally considered to not be audible for most people unless in relatively high amplitude. However, there is a wide range between the most sensitive and least sensitive people to perception of sound and perception is not limited to stimulus of the auditory senses. The most significant exterior noise induced dwelling vibration occurs in the frequency range between 5 Hz and 50 Hz. Moreover, levels below the threshold of audibility can still cause measurable resonances inside dwelling interiors. Conditions that support or magnify resonance may also exist in human body cavities and organs under certain conditions. Although no specific test for infrasound is provided in this document, the test for immission spectra imbalance will limit low frequency sound and thus, indirectly limit infrasound. See low-frequency noise (LFN) for more information.

"**Low Frequency Noise (LFN)**" refers to sounds with energy in the lower frequency range of 20 to 200 Hz. LFN is deemed to be excessive when the difference between a C-weighted sound level and an A-weighted sound level is greater than 20 decibels at any measurement point outside a residence or other occupied structure.

"**Measurement Point (MP)**" means location where sound measurements are taken such that no significant obstruction blocks sound from the site. The Measurement Point should be located so as to not be near large objects such as buildings and in the line-of-sight to the nearest turbines. Proximity to large buildings or other structures should be twice the largest dimension of the structure, if possible. Measurement Points should be at quiet locations remote from street lights, transformers, street traffic, flowing water and other local noise sources.

"**Measurement Wind Speed**" For measurements conducted to establish the background noise levels ($L_{A90\ 10\ min}$, $L_{C90\ 10\ min}$, and etc.) the maximum wind speed, sampled within 5m of the microphone and at its height, shall be less than 2 m/s (4.5 mph) for valid background measurements. For valid wind farm noises measurements conducted to establish the post-construction sound level the maximum wind speed, sampled within 5m of the microphone and at its height, shall be less than 4m/s (9 mph). The wind speed at the WES blade height shall be at or above the nominal rated wind speed and operating in its highest sound output mode. For purposes of enforcement, the wind speed and direction at the WES blade height shall be selected to reproduce the conditions leading to the enforcement action while also restricting maximum wind speeds at the microphone to less than 4 m/s (9 mph).

"**Mechanical Noise**" means sound produced as a byproduct of the operation of the mechanical components of a WES(s) such as the gearbox, generator and transformers.

"**Noise**" means any unwanted sound. Not all noise needs to be excessively loud to represent an annoyance or interference.

"**Project Boundary**" means the external property boundaries of parcels owned by or leased by the WES developers. It is represented on a plot plan view by a continuous line encompassing all WES(s) and related equipment associated with the WES project.

"**Property Line**" means the recognized and mapped property parcel boundary line.

"**Sensitive Receptor**" means places or structures intended for human habitation, whether inhabited or not, public parks, state and federal wildlife areas, the manicured areas of recreational establishments designed for public use, including but not limited to golf courses, camp grounds and other nonagricultural state or federal licensed businesses. These areas are more likely to be sensitive to the exposure of the noise, shadow or flicker, etc. generated by a WES or WESF. These areas include, but are not limited to: schools, daycare centers, elder care facilities, hospitals, places of seated assemblage, non-agricultural businesses and residences.

"**Sound**" A fluctuation of air pressure which is propagated as a wave through air

"**Sound Power**" The total sound energy radiated by a source per unit time. The unit of measurement is the watt. Abbreviated as $L_w$. This information is determined for the WES manufacturer under laboratory conditions specified by IEC 61400-11 and provided to the local developer for use in computer model construction. There is known measurement error in this test procedure that must be disclosed and accounted for in the computer models. Even with the measurement error correction it cannot be assumed that the reported $L_w$ values represent the highest sound output for all operating conditions. They reflect the operating conditions required to meet the IEC 61400-11 requirements. The lowest frequency is 50 Hz for acoustic power ($L_w$) requirement (at present) in IEC 61400-11.

"**Sound Pressure**" The instantaneous difference between the actual pressure produced by a sound wave and the average or barometric pressure at a given point in space.

"**Sound Pressure Level (SPL)**" 20 times the logarithm, to the base 10, of the ratio of the pressure of the sound measured to the reference pressure, which is 20 micronewtons per square meter. In equation form, sound pressure level in units of decibels is expressed as SPL (dB) = 20 log p/pr.

"**Spectrum**" The description of a sound wave's resolution into its components of frequency and amplitude. The WES manufacturer is required to supply a one-third octave band frequency spectrum of the wind turbine sound emission at 90% of rated power. The published sound spectrum is often presented as A-weighted values but C-weighted values are preferred. This information is used to construct a model of the wind farm's sound immission levels at locations of interest in and around the WES. The frequency range of interest for wind turbine noise is approximately 6 Hz to 10k Hz.

"**Statistical Noise Levels**" Sounds that vary in level over time, such as road traffic noise and most community noise, are commonly described in terms of the statistical exceedance levels $L_{NA}$, where $L_{NA}$ is the A-weighted sound level exceeded for N% of a given measurement period. For example, $L_{10}$ is the noise level exceeded for 10% of the time. Of particular relevance, are: $L_{A10}$ and $L_{C10}$ the noise level exceed for 10% of the ten (10) minute interval. This is commonly referred to as the average maximum noise level. $L_{A90}$ and $L_{C90}$ are the A-weighted and C-weighted sound levels exceeded for 90% of the ten (10) minute sample period. The $L_{90}$ noise level is defined by ANSI as the long-term background sound level (i.e. the sounds one hears in the absence of the noise source under consideration and without short term or near-by sounds from other sources), or simply the "background level." $L_{eq}$ is the A or C-weighted equivalent noise level (the "average" noise level). It is defined as the steady sound level that contains the same amount of acoustical energy as the corresponding time-varying sound.

"**Tonal sound or tonality**" Tonal audibility. A sound for which the sound pressure is a simple sinusoidal function of the time, and characterized by its singleness of pitch. Tonal sound can be simple or complex.

"**Wind Energy Systems (WES)**" means equipment that converts and then transfers energy from the wind into usable forms of electrical energy.

"**Wind Turbine" or "Turbine" (WT)** means an industrial scale mechanical device which captures the kinetic energy of the wind and converts it into electricity. The primary components of a wind turbine are the blade assembly, electrical generator and tower.

## ANSI S12.9 Part 3 with Required Amendments

**ANSI/ASA S12.9-1993/Part 3 (R2008) - American National Standard Quantities and Procedures for Description and Measurement of Environmental Sound, Part 3: Short-Term Measurements with an Observer Present**.

This standard is the second in a series of parts concerning description and measurement of outdoor environmental sound. The standard describes recommended procedures for measurement of short-term, time-average environmental sound outdoors at one or more locations in a community for environmental assessment or planning for compatible land uses and for other purposes such as demonstrating compliance with a regulation. These measurements are distinguished by the requirement to have an observer present. Sound may be produced by one or more separate, distributed sources of sound such as a highway, factory, or airport. Methods are given to correct the measured levels for the influence of background sound.

**Wind Turbine Siting Acoustical Measurements**
**ANSI S12.9 Part 3 Selected Options and Requirement Amendments**

For the purposes of conducting sound tesing related to wind turbine siting and in particular for determining long term background sound levels and wind turbine operational sound levels specific options that are provided in ANSI S12.9-Part 3 (2008) shall apply with the additional following requirements to Sections in ANSI S12.9/Part 3:

5.2 background sound: Use definition (1) 'long-term'
5.3 long-term background sound: The $L_{90}$ excludes short term background sounds
5.4 basic measurement period: Ten (10) minutes $L_{90(10\ min)}$
5.6 Sound Measuring Instrument: Type 1 integrating meeting ANSI S1.43 or IEC 61672-1. The sound level meter shall contain one-third octave band analyzer with frequency range from 6.3 Hz to 20k Hz and capability to simultaneously measure dBA $L_N$ and dBC $L_N$. The instrument must also be capable of accurately measuring low level background sounds down to 20 dBA.
6.5 Windscreen: Required
6.6(a) An anemometer accurate to ± 10% at 2m/s. Ignore reference to full scale accuracy. The anemometer shall be located 2m above the ground and orientated to record maximum wind velocity. The maximum wind velocity, wind direction, temperature and humidity shall be recorded for each 10 minute sound measurement period observed within 5m of the measuring microphone..
7.1 Long-term background sound
7.2 Data collection Methods: Second method Observed samples to avoid contamination by short term sounds (purpose: to avoid loss of statistical data)
8 Source(s) Data Collection: All requirements in ANSI S12.18 Method #2 precision to the extent possible while still permitting testing of the conditions that lead to complaints. The meteorological requirements in ANSI S12.18 may not be applicable. For sound measurements in response to a complaint, the compliance sound measurements should be made under conditions that replicate the conditions that caused the complaint.
8.1(b) Measuring microphone with windscreen shall be located 1.2m to 1.8m above the ground and greater than 8m from large sound reflecting surface.

8.3(a) All meteorological observations required at both (not either) microphone and nearest 10m weather reporting station.

8.3(b) For a 10 minute background sound measurement to be valid the wind velocity shall be less then 2m/s (4.5 mph) measured less than 5m from the microphone. Compliance sound measurements shall not be taken when winds shall be less than 4m/s.

8.3(c) In addition to the required acoustic calibration checks, the sound measuring instrument internal noise floor, including microphone, must also be checked at the end of each series of ten minute measurements and no less frequently than once per day. Insert the microphone into the acoustic calibrator with the calibrator signal off. Record the observed dBA and dBC reading on the sound level meter to determine an approximation of the instrument self noise. Perform this test before leaving the background measurement location. This calibrator covered microphone must demonstrate the results of this test are at least 5 dB below the immediately previous ten minute acoustic test results, for the acoustic background data to be valid. This test is necessary to detect undesired increase in the microphone and sound level meter internal self noise. As a precaution sound measuring instrumentation should be removed from any air conditioned space at least an hour before use. Nighttime measurements are often performed very near the meteorological dew point. Minor moisture condensation inside a microphone or sound level meter can increase the instrument self noise and void the measured background data.

8.4 The remaining sections starting at 8.4 in ANSI S12.9 Part 3 Standard do not apply.

**ANSI S12.18-1994 (R2004) American National Standard Procedures for Outdoor Measurement of Sound Pressure Level**

This American National Standard describes procedures for the measurement of sound pressure levels in the outdoor environment, considering the effects of the ground, the effects of refraction due to wind and temperature gradients, and the effects due to turbulence. This standard is focused on measurement of sound pressure levels produced by specific sources outdoors. The measured sound pressure levels can be used to calculate sound pressure levels at other distances from the source or to extrapolate to other environmental conditions or to assess compliance with regulation. This standard describes two methods to measure sound pressure levels outdoors. METHOD No. 1: general method; outlines conditions for routine measurements. METHOD No. 2: precision method; describes strict conditions for more accurate measurements. This standard assumes the measurement of A-weighted sound pressure level or time-averaged sound pressure level or octave, 1/3-octave or narrow-band sound pressure level, but does not preclude determination of other sound descriptors.

**ANSI S1.43-1997(R2007) American National Standard Specifications for Integrating Averaging Sound Level Meters**

This Standard describes instruments for the measurement of frequency-weighted and time-average sound pressure levels. Optionally, sound exposure levels may be measured. This standard is consistent with the relevant requirements of ANSI S1.4-1983(R 1997) American National Standard Specification for Sound Level Meters, but specifies additional characteristics that are necessary to measure the time-average sound pressure level of steady, intermittent, fluctuating, and impulsive sounds.

**ANSI S1.11-2004 American National Standard 'Specification for Octave-Band and Fractional-Octave-Band Analog and Digital Filters'**

This standard provides performance requirements for analog, sampled-data, and digital implementations of band-pass filters that comprise a filter set or spectrum analyzer for acoustical measurements. It supersedes ANSI S1.11-1986 (R1998) American National Standard Specification for Octave-Band and Fractional-Octave-Band Analog and Digital Filters, and is a counterpart to International Standard IEC 61260:1995 Electroacoustics - Octave-Band and Fractional-Octave-Band Filters. Significant changes from ANSI S1.11-1986 have been adopted in order to conform to most of the specifications of IEC 61260:1995. This standard differs from IEC 61260:1995 in three ways: (1) the test methods of IEC 61260 clauses 5 is moved to an informative annex, (2) the term 'band number,' not present in IEC 61260, is used as in ANSI S1.11-1986, (3) references to American National Standards are incorporated, and (4) minor editorial and style differences are incorporated.

**ANSI S1.40-2006 American National Standard Specifications and Verification Procedures for Sound Calibrators**

**IEC 61400-11**

Second edition 2002-12, Amendment 1 2006-05

**IEC 61400-11**

Second edition 2002-12, Amendment 1 2006-0

**Wind turbine generator systems –Part 11: Acoustic noise measurement techniques**

The purpose of this part of IEC 61400 is to provide a uniform methodology that will ensure consistency and accuracy in the measurement and analysis of acoustical emissions by wind turbine generator systems. The standard has been prepared with the anticipation that it would be applied by:

- the wind turbine manufacturer striving to meet well defined acoustic emission performance requirements and/or a possible declaration system;
- the wind turbine purchaser in specifying such performance requirements;
- the wind turbine operator who may be required to verify that stated, or required, acoustic performance specifications are met for new or refurbished units;
- the wind turbine planner or regulator who must be able to accurately and fairly define acoustical emission characteristics of a wind turbine in response to environmental regulations or permit requirements for new or modified installations.

This standard provides guidance in the measurement, analysis and reporting of complex acoustic emissions from wind turbine generator systems. The standard will benefit those parties involved in the manufacture, installation, planning and permitting, operation, utilization, and regulation of wind turbines. The measurement and analysis techniques recommended in this document should be applied by all parties to insure that continuing development and operation of wind turbines is carried out in an atmosphere of consistent and accurate communication relative to environmental concerns. This standard presents measurement and reporting procedures expected to provide accurate results that can be replicated by others.

Excerpts From American National Standards Institute (ANSI) And Acoustical Society Of America (ASA) Standards Defining Generally Accepted Acoustical Test Procedures For Outdoor Measurement Of Long Term Background Sound Level (LTB)

## ANSI/ASA S12.9 Quantities And Procedures For Description And Measurement Of Environmental Sound. Part 3: Short-Term Measurements With An Observer Present

### Section 5.4 Long-Term Background Sound:

Background sound measured during the measurement period specified in this standard, after excluding the contribution of short-term background sounds in accordance with one of the methods specified in this standard. Long-term background sound is assumed to be approximately stationary in a statistical sense, over the measurement duration, and it is described solely by its sound exposure per unit time (in each frequency weighted or frequency-filtered band of entrance).

### 7.1 Background Sound.

Background sound affects measurements by directly adding extraneous sound energy to the sound produced by the specific source or source under measurements. Background sound can be divided into two categories: (1) short-term background sounds and (2) long-term background sound. Short-term background sounds are caused by such sources as the nearby barking dog, a nearby decelerating motor vehicle, or an aircraft flyover. Short-term background sounds are relatively loud and their time of occurrence and sound exposure cannot be statistically described during the basic measurement period. Long-term background sound includes the composite of all sounds from sources far and near which are (1) not short-term background sounds and (2) not sound from the specific noise source understudy. Long-term background sound is considered in these procedures be statistically stationary over the basic measurement. (E.G., one hour).

**Notes**

(1) The sound from any specific background source such as a truck passed by or aircraft flyover may be part of the short or long-term background sound depending on the situation. In a quiet neighborhood, infrequent loud trucks generally cause short-term background sounds. However, near a busy highway or freeway, the same sounds would be part of long-term background, because they can occur frequently (several per minute) and their time of occurrence can be described statistically as a stationary process. Similarly, infrequent aircraft flyover cause short-term background sounds, but the regular occurrence of flyovers resulting from aircraft taking off from a busy runway every few minutes would be part of the long-term background sound.

(2) In the procedures of this Standard, the background sound energy is considered to be uncorrelated with the sound energy of the source, so the influence of long-term background sound is removed by simple subtraction.

### 8.1 Site Selection

(a) Measurements shall be taken at one or more microphone positions designated receiving locations and shall be consistent with the general requirements of ANSI S12.18 – 1994 (rev 2004). However, when more controlled sound pressure level measurements from a specific source are required, the procedures of ANSI S. 12.18 – 1994 (rev 2004) shall be used.

(b) Microphones should be located 7.5 m or farther from any surface where reflections may influence the measured sound pressure levels. If measurements are taken within 7.5 m of such surfaces, the effect, if any, of the reflecting surface on the measured data shall be determined from experimental data.

**Notes:**

(1) Reflecting objects with small dimensions (trees, posts, bushes, etc.) should not be within 1.5 m of the microphone position. If sound pressure levels are measured within 1.5 m of such objects, the effect, if any, in the measured data should be determined from measurements made at another

location where the objects are a greater distance, or by an equivalent procedure.

(2) Reflecting surfaces refer to those other than the ground, which, by 8.2 (a), are normally between 1 and 2m. from the microphone.

(3) Nearby reflecting objects should also be avoided since they may increase the level of the background sound (E.G., sound produced by the rustling of leaves).

(c) While sound measurements are being taken, the operator shall be far enough from the microphone so as to minimize any influence on the measurements. Normally, this is accomplished by placing the microphone on a tripod or support connecting it to the sound level meter by an extension cable that is the least 1.5 m long. If a microphone extension cable is not available, the operator shall position the microphone and sound level meter in accordance with the manufacturer's instructions for the measurement of sound levels with a minimum reflections from the observer.

(b) To minimize the effects of wind on the microphone, sound measurements should not be taken when the wind velocity is greater than 5.5 m/s (11 mph or 10 knots) at the microphone position, when measured a height of 2 m above the ground.

Note: At source-to-receiver distances greater than 30 m and at elevation angles smaller than 20° from the source-to-measurement location, measurements not made under essentially calm wind conditions with a temperature inversion or with the measurement location downwind of the source will have significantly altered spectra and generally lower sound pressure levels. To avoid these altered spectra or generally lower sound pressure levels, the procedures of ANSI S12.18 -- 1994 (rev 2004) should be considered.

(c) Measure the frequency-weighted or filtered equivalent-continuous sound pressure levels or sound exposures for each block duration. Omit the sound pressure levels or sound exposures of any block corrupted by short-term background sounds.

(d) After deleting measurements that are "corrupted" by the influence of short-term background sounds. There will be some number of "good" data blocks remaining. This number of "good" data blocks shall be designated as Ng where g stands for "good." These remaining blocks are numbered consecutively with subscript i denoting the time sequence of the good data blocks.

### 8.6.2 Data Collection Using Large, Continuous Blocks of Time

(a) The measuring instrument shall be adjusted to continuously measure equivalent-continuous sound pressure level(s), or sound exposures(s).

(b) A means shall be available to inhibit data collection. Whenever a short-term background sound occurs. On some instruments, similar means may be available to delete the most recent previous measurement.
These means should be used to eliminate the contribution of short-term background sounds.

### 8.7 Minimum Data Collection Requirements for Basic Measurement Data Collection

**The measure**ment period for basic measurement data collection of 8.6.1 shall proceed initially for the required measurement period, either the basic Measurement. (E.G., one hour) or a 10 minute period for the measurement of long-term background sound. Because of corrections for short-term background sounds, the actual reported data collection time, Tg, in seconds may be less than the basic measurement period, but shall not be less than half of the required measurement period.

### 10.2 Background Sound

**(a)** Background sound data to be reported shall be the long-term background equivalent continuous sound pressure levels or time-mean-square sound pressure used to correct the measured source(s) data.

(b) The several most important sources of sound, contributing to the long-term background sound shall be listed and briefly described.

(c) The number of measurement seconds not corrupted by short-term background transient sounds, shall also be reported.

**Notes:**

(1) If the 10 minute long-term background sound is divided into smaller time blocks than the total duration of measurements is given by the number of non-discarded measurement plots multiply by the duration of each block in seconds.

(2) If data collection is inhibited when short-term background transit sounds occur, then the duration of good measurements is the total un-inhibited measurement duration during the 10 minute long-term background.

(d) While sources of long-term background sound data is being measured, short-term background transient sounds may interfere. The specific nature of these interfering sounds and the time of occurrence shall be recorded.

Excerpts From American National Standards Institute (ANSI) And Acoustical Society Of America (ASA) Standards Defining Generally Accepted Acoustical Test Procedures For Outdoor Measurement Of Long Term Background Sound Level (LTB)

## ANSI S12.18--1994 (reaffirmed: 2004) Procedures for Outdoor Measurement of Sound Pressure Level

### 4 Environmental Requirements.

### 4.1 General

The sound pressure levels measured in the vicinity of an outdoor source is influenced by the medium through which the sound propagates. Normally occurring variations in meteorological conditions can easily result in sound pressure level variations on the order of 20 dB or more. The presence of the ground, in particular or other services normally influence the measured sound pressure levels. Small changes in source orientation can also affect measured sound pressure levels when the source exhibits directional radiation characteristics. In order to obtain accurate, reproducible data, it is imperative to understand and consider the influence of environmental variables on the measurement of sound pressure level.

### 4.3.3 Environmental Measurements

Wind velocity shall be measured at the height of 2 +/- 0.2 m above the ground.

The component all of wind velocity from the source to receiver for a given set up acoustical measurements shall be determined by:

(1) Monitoring wind velocity (speed and direction) throughout any period of acoustical measurement;

(2) Noting the average speed and direction over the period of any acoustical measurement; and

(3) Computing from these averages the vector component of wind velocity in the direction from the source to receiver; for line sources, this component shall be computed along the normal line between source and receiver;...

### 4.4.1.1 Wind, Temperature and Cloud Cover

No sound level measurement shall be made when the average wind velocity exceeds 5 m/s when measured at the height of 2 ± 0.2 m above the ground. No attempt shall be made to adjust measured noise levels based on the wind data.

### 4.5.1.1 Requirements (used for long-term background sound tests)

Measurements shall only be made if:

(1) Direction of the wind vector is within angle of +/- 45° of the direction connecting the center of the sound source in the center of the specified receiver area, with the wind blowing from the source to receiver; and,

(2) Wind velocity is between approximately 1 and 3 m/s measured a height of 2+ -0.2 m above the ground.

Alternatively, measurement and any near horizontal direction can be made if;

(3) Propagation occurs under a well developed ground based temperature inversion with winds less than 1 m/s measured a height of 2±0.2 m. The existence of a temperature inversion shall be carefully documented.

No measurements shall be made during measurable precipitation or freezing rain. Measurable precipitation almost always influences outdoor sound levels. For example, tires rolling over a surface produce higher sound levels when the payment is wet. Ground that is saturated water after heavy rainfall can produce erratic values of $A_{env}$ in Eq. (2). Also, fallen snow on the ground will affect the measured sound level at about any distance from the source by strongly influencing the values of $A_{env}$ in Eq. (2).

Measurement during precipitation or when the ground is wet or snow-covered is highly discouraged. If it is necessary to obtain data when the ground is wet or snow-covered, the conditions shall be carefully described.

## 6 .7 Wind Speed and Direction.

An anemometer or other device for measuring wind speed and direction shall be used. This device shall have an accuracy of ± 10% of full scale or better. And averaging time of 10 to 20 seconds is desirable. The device shall be supported at the height of 2 ± 0.2 m. For octave or one third octave band measurements, some means of storing time history wind speed and direction is recommended (e.g., strip chart recorder or digitized signal). If vertical profiles of wind speed are being measured, a support is needed that can be varied from the ground to 10% above the height of the path of sound propagation.

## 1.3.2 General Meteorological Conditions.

If the meteorological conditions such as wind speed and direction do not fall within the specifications for either Method #1 or Method #2 as specified in Section 5, measurements do not conform with the requirements of this standard. No attempt shall be made to correct measured sound pressure levels based on wind or temperature data except for the adjustment for Aair for temperature as specified in 8.1.3.1.

Data from meteorological sensors shall be recorded in sufficient detail to document calculation of the component of average wind velocity of the source to receiver, the average temperature, and humidity. The cloud cover class, shall also be specified, with a brief statement as to existing weather conditions.

This is the end of the excerpts

WORLD HEALTH ORGANIZATION
**REGIONAL OFFICE FOR EUROPE**

WELTGESUNDHEITSORGANISATION
**REGIONALBÜRO FÜR EUROPA**

ORGANISATION MONDIALE DE LA SANTÉ
**BUREAU RÉGIONAL DE L'EUROPE**

ВСЕМИРНАЯ ОРГАНИЗАЦИЯ ЗДРАВООХРАНЕНИЯ
**ЕВРОПЕЙСКОЕ РЕГИОНАЛЬНОЕ БЮРО**

**EUROPEAN CENTRE FOR ENVIRONMENT AND HEALTH**
**BONN OFFICE**

# NIGHT NOISE GUIDELINES (NNGL) FOR EUROPE

**Grant Agreement 2003309**
**Between the European Commission, DG Sanco**
**and the World Health Organization, Regional Office for Europe**

# Final implementation report

Notice The following are excerpts from the study that relate to preventing adverse health effects from nighttime noise and sleep disturbance. In some cases sections have been rearranged for this summary. [1]

## "Introduction

"Policies and legislations aiming at night noise control are often based on sleep disturbance in European countries. However, the impacts of noise-induced sleep disturbance on health, either short-term or long-term, have not been investigated comprehensively to support policy-makers. From June 2003 until December 2006, WHO Regional Office for Europe European Centre for Environment and Health (Bonn office) implemented the Night Noise Guideline (NNGL) project co-sponsored by the European Commission.

"The goal of the NNGL project was to provide expertise and scientific advice to the European Commission and its Member States in developing future legislations in the area of night noise exposure control and surveillance. The key objectives of the project was to reach a consensus of experts and stakeholders on the following subjects: (a) guideline values for night noise to protect the public from

[1] **© World Health Organization 2007**
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adverse health effects, (b) an agreement on the night penalty factor to be allocated to night time noise in the calculation of $L_{den}$.[2]

### "10 Relation to the 2000 *WHO Guidelines for Community Noise*

"The *WHO Guidelines for Community Noise*, published in 2000, also address night noise. As they are based on studies carried out up to 1995 (and a few meta-analyses some years after), important new studies have become available since then, together with new insights into normal and disturbed sleep.

"The currently recommended guideline values of Lnight,outside = 30 dB, 40dB, 55 dB are not directly comparable with the 2000 guideline value of LAmax,inside = 45 dB(A) because the sound level units are different. However, it is clear that new information since 2000 has made more precise assessment of the risk from night noise. The thresholds for a number of effects are now known, and this is much lower than an LAmax,inside of 45 dB.

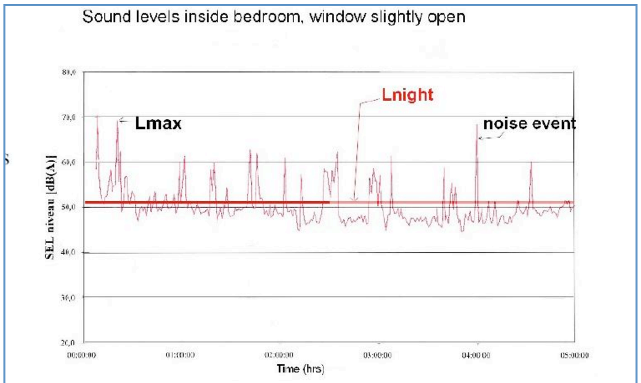



*Figure 6. Relation between $L_{night}$, $L_{Amax}$ and SEL*
*This is a sound recording in a bedroom for one night. The top of the peaks are the $L_{Amax}$-levels, the total energy is the $L_{night}$ (thick horizontal line). The sound energy in one event is the SEL (not represented). In reality the $L_{night}$ is the average over all nights in one year.*

"One important recommendation still stands: there are good reasons for people to sleep with their windows open, and to prevent sleep disturbances one should consider the equivalent sound pressure level and the number of sound events. The present guidelines allow relevant authorities and stakeholders to do this. Viewed in this way, the present guidelines may be considered as an extension to, as well as an update of, the 2000 WHO *Guidelines for Community Noise*. That also means that the recommendations contained in the sections on noise management and control of 2000 document can be applied to the guideline values of this document.

### "5 Noise, sleep and health

"There is plenty of evidence that sleep is a biological necessity, and disturbed sleep is associated with a number of health problems. Studies of sleep disturbance in children and in shift workers clearly show the adverse effects.

> ***"Sufficient evidence:*** *A causal relation has been established between exposure to night noise and a health effect. In studies where coincidence, bias and distortion could reasonably be excluded, the relation could be observed. The biological plausibility of the noise leading to the health effect is also well established.*
> ***"Limited evidence:*** *A relation between the noise and the health effect has not been observed directly, but there is available evidence of good quality supporting the causal association. Indirect evidence is often abundant, linking noise exposure to an intermediate effect of physiological changes which lead to the adverse health effects."*

"Noise disturbs sleep by a number of direct and indirect pathways. Even at very low levels physiological reactions (increase in heart rate, body movements and arousals) can be reliably measured. Also, it was shown that awakening reactions are relatively rare, occurring at a much higher level than the physiological reactions.

[2] "The methodology of developing night noise guidelines was based on the WHO publication EUR/00/5020369 "Evaluation and use of epidemiological evidence for environmental risk assessment" that can be accessible at http://www.euro.who.int/document/e68940.pdf.

"The working group agreed that there is sufficient evidence that night noise is related to self-reported sleep disturbance, use of pharmaceuticals, self-reported health problems and insomnia like symptoms. These effects can lead to a considerable burden of disease in the population. For other effects (hypertension, myocardial infarctions, depression and others), limited evidence was found: although the studies were few or not conclusive, a biologically plausible pathway could be constructed from the evidence.

"An example of a health effect with limited evidence is myocardial infarctions. Although evidence for increased risk of myocardial infarctions related to Lday is sufficient according to an updated meta-analysis, the evidence in relation to Lnight,outside was considered limited. This is because Lnight,outside is a relatively new exposure indicator, and few field studies have focused on night noise when considering cardiovascular outcomes. Nevertheless, there is evidence from animal and human studies supporting a hypothesis that night noise exposure might be more strongly associated with cardiovascular effects than daytime exposure, highlighting the need for future epidemiological studies on this topic.

"The review of available evidence leads to the following conclusions.

- Sleep is a biological necessity, and disturbed sleep is associated with a number of adverse impacts on health.
- There is sufficient evidence for biological effects of noise during sleep: increase in heart rate, arousals, sleep stage changes, hormone level changes and awakening.
- There is sufficient evidence that night noise exposure causes self-reported sleep disturbance, increase in medicine use, increase in body movements and (environmental) insomnia.
- While noise-induced sleep disturbance is viewed as a health problem in itself (environmental insomnia) it also leads to further consequences for health and well-being.
- There is limited evidence that disturbed sleep causes fatigue, accidents and reduced performance.
- There is limited evidence that noise at night causes clinical conditions such as cardiovascular illness, depression and other mental illness. It should be stressed that a plausible biological model is available with sufficient evidence for the elements of the causal chain.

## "6 Vulnerable groups

"Children have a higher awakening threshold than adults and therefore are often seen to be less sensitive to night noise. For other effects, however, children seem to be equally or more reactive than adults. As children also spend more time in bed they are exposed more and to higher noise levels. For these reasons children are considered a risk group.

"Since with age the sleep structure becomes more fragmented, elderly people are more vulnerable to disturbance. This also happens in pregnant women and people with ill health, so they too are a group at risk.

"Finally, shift workers are at risk because their sleep structure is under stress due to the adaptations of their circadian rhythm.

## "7 Thresholds for observed effects

The (no) observed adverse effect level (NOAEL) is a concept from toxicology, and is defined as the greatest concentration which causes no detectable adverse alteration of morphology, functional capacity, growth, development or lifespan of the target organism. For the topic of night noise (where the adversity of effects is not always clear) this concept is less useful. Instead, the observed effect thresholds are provided: the level above which an effect starts to occur or shows itself to be dependent on the exposure level. It can also be a serious pathological effect, such as myocardial infarctions, or a changed physiological effect, such as increased body movement.

Threshold levels of noise exposure are important milestones in the process of evaluating the health consequences of environmental exposure. The threshold levels also delimit the study area, which may lead to a better insight into overall consequences. In Table 1, all effects are summarized for which sufficient or *limited evidence* exists. For the effects with *sufficient evidence* the threshold levels are usually well known, and for some the dose-effect relations over a range of exposures could also be established.

| | Effect | Indicator | Threshold, dB |
|---|---|---|---|
| Biological effects | Change in cardiovascular activity | * | * |
| | EEG awakening | LAmax,inside | 35 |
| | Motility, onset of motility | LAmax,inside | 32 |
| | Changes in duration of various stages of sleep, in sleep structure and fragmentation of sleep | LAmax,inside | 35 |
| Sleep quality | Waking up in the night and/or too early in the morning | LAmax,inside | 42 |
| | Prolongation of the sleep inception period, difficulty getting to sleep | * | * |
| | Sleep fragmentation, reduced sleeping time | * | * |
| | Increased average motility when sleeping | Lnight,outside | 42 |
| Well-being | Self-reported sleep disturbance | Lnight,outside | 42 |
| | Use of somnifacient drugs and sedatives | Lnight,outside | 40 |
| Medical conditions | Environmental insomnia[1] | Lnight,outside | 42 |
| * Although the effect has been shown to occur or a plausible biological pathway could be constructed, indicators or threshold levels could not be determined. | | | |

Table 1. Summary of effects and threshold levels for effects where **sufficient** evidence is available.[3]

## 9 Recommendations for health protection

Sleep is an essential part of human functioning and is recognized as a fundamental right under the European Convention on Human Rights.2 Based on the evidence of the health effects of night noise, an overall summary of the relation between night noise levels and health effects, and stepwise guideline values are presented as shown in Table 3 and 4, respectively.

Table 3. Summary of the relation between night noise and health effects in the population
Especially in the range Lnight,outside from 30 to 55 dB, a closer look may be needed into the precise impact as this may depend much on the exact circumstances. Above 55 dB the cardiovascular effects become the dominant effect, which is thought to be less dependent on the nature of the noise.

[3] Please note that "environmental insomnia" is the result of diagnosis by a medical professional whilst "self-reported sleep disturbance" is essentially the same, but reported in the context of a social survey. Number of questions and exact wording may differ.

From Table 1, it is clear that a number of instantaneous effects are related to threshold levels expressed in $L_{Amax}$. The health relevance of these effects cannot be easily established. It can be safely assumed, however, that an increase in the number of such effects over the base line may constitute an subclinical adverse health effect.

For the primary prevention of subclinical adverse health effects in the population related to night noise, it is recommended that the population should not be exposed to night noise levels greater than 30 dB of Lnight,outside during the night when most people are in bed. Therefore, Lnight,outside 30 dB is the ultimate target of Night Noise Guideline (NNGL) to protect the public, including the most vulnerable groups such as children, the chronically ill and the elderly, from the adverse health effects of night noise.

Table 3. Summary of the relation between night noise and health effects in the population

| | |
|---|---|
| $L_{night,outside}$ **up to 30 dB** | Although individual sensitivities and circumstances differ, it appears that up to this level no substantial biological effects are observed. |
| $L_{night,outside}$ of **30 to 40 dB** | A number of effects are observed to increase: body movements, awakening, self-reported sleep disturbance, arousals. With the intensity of the effect depending on the nature of the source and on the number of events, even in the worst cases the effects seem modest. It cannot be ruled out that vulnerable groups (for example children, the chronically ill and the elderly) are affected to some degree. |
| $L_{night,outside}$ of **40 to 55 dB** | There is a sharp increase in adverse health effects, and many of the exposed population are now affected and have to adapt their lives to cope with the noise. Vulnerable groups are now severely affected. |
| $L_{night,outside}$ of **above 55 dB** | The situation is considered increasingly dangerous for public health. Adverse health effects occur frequently, a high percentage of the population is highly annoyed and there is some limited evidence that the cardiovascular system is coming under stress. |

End of WHO 2007 Guideline Excerpts

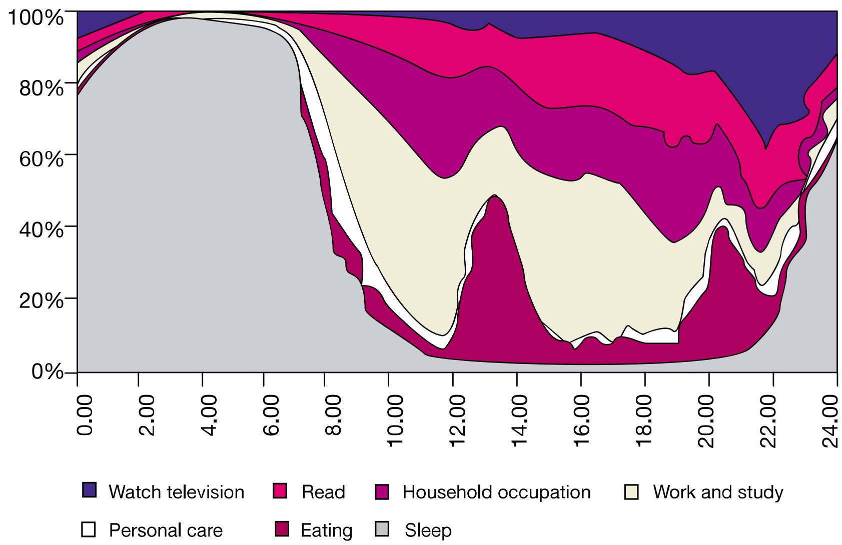



**Fig. 2 Percentage of time that the Portuguese population spend asleep or in different activities**

*Source: http://www.ine.pt/prodserv/destaque/arquivo.asp, based on a study by the Instituto Nacional de Estatistica Portugal, 1999.*

# NOISE, SLEEP AND HEALTH

There is plenty of evidence that sleep is a biological necessity, and disturbed sleep is associated with a number of health problems. Studies of sleep disturbance in children and in shift workers clearly show the adverse effects.

Noise disturbs sleep by a number of direct and indirect pathways. Even at very low levels physiological reactions (increase in heart rate, body movements and arousals) can be reliably measured. Also, it was shown that awakening reactions are relatively rare, occurring at a much higher level than the physiological reactions.

## DEFINITION OF "SUFFICIENT" AND "LIMITED" EVIDENCE

Sufficient evidence: A causal relation has been established between exposure to night noise and a health effect. In studies where coincidence, bias and distortion could reasonably be excluded, the relation could be observed. The biological plausibility of the noise leading to the health effect is also well established.

Limited evidence: A relation between the noise and the health effect has not been observed directly, but there is available evidence of good quality supporting the causal association. Indirect evidence is often abundant, linking noise exposure to an intermediate effect of physiological changes which lead to the adverse health effects.

The working group agreed that there is sufficient evidence that night noise is related to self-reported sleep disturbance, use of pharmaceuticals, self-reported health problems and insomnia-like symptoms. These effects can lead to a considerable burden of disease in the population. For other effects (hypertension, myocardial infarctions, depression and others), limited evidence was found: although the studies were few or not conclusive, a biologically plausible pathway could be constructed from the evidence.

An example of a health effect with limited evidence is myocardial infarction. Although evidence for increased risk of myocardial infarction related to $L_{day}$ is sufficient according to an updated meta-analysis, the evidence in relation to $L_{night, outside}$ was considered limited. This is because $L_{night, outside}$ is a relatively new exposure indicator, and few field studies have focused on night noise when considering cardiovascular outcomes. Nevertheless, there is evidence from animal and human studies supporting a hypothesis that night noise exposure might be more strongly associated with cardiovascular effects than daytime exposure, highlighting the need for future epidemiological studies on this topic.

**The review of available evidence leads to the following conclusions.**

- Sleep is a biological necessity and disturbed sleep is associated with a number of adverse impacts on health.
- There is sufficient evidence for biological effects of noise during sleep: increase in heart rate, arousals, sleep stage changes and awakening.
- There is sufficient evidence that night noise exposure causes self-reported sleep disturbance, increase in medicine use, increase in body movements and (environmental) insomnia.
- While noise-induced sleep disturbance is viewed as a health problem in itself (environmental insomnia), it also leads to further consequences for health and well-being.
- There is limited evidence that disturbed sleep causes fatigue, accidents and reduced performance.
- There is limited evidence that noise at night causes hormone level changes and clinical conditions such as cardiovascular illness, depression and other mental illness. It should be stressed that a plausible biological model is available with sufficient evidence for the elements of the causal chain.

## VULNERABLE GROUPS

Children have a higher awakening threshold than adults and therefore are often seen to be less sensitive to night noise. For other effects, however, children seem to be equally or more reactive than adults. As children also spend more time in bed they are exposed more to night noise levels. For these reasons children are considered a risk group.

Since with age the sleep structure becomes more fragmented, elderly people are more vulnerable to disturbance. This also happens in pregnant women and people with ill health, so they too are a group at risk.

Finally, shift workers are at risk because their sleep structure is under stress due to the adaptations of their circadian rhythm.

## THRESHOLDS FOR OBSERVED EFFECTS

The no observed adverse effect level (NOAEL) is a concept from toxicology, and is defined as the greatest concentration which causes no detectable adverse alteration of morphology, functional capacity, growth, development or lifespan of the target organism. For the topic of night noise (where the adversity of effects is not always clear) this concept is less useful. Instead, the observed effect thresholds are provided: the level above which an effect starts to occur or shows itself to be dependent on the exposure level. It can also be a serious pathological effect, such as myocardial infarctions, or a changed physiological effect, such as increased body movement.

Threshold levels of noise exposure are important milestones in the process of evaluating the health consequences of environmental exposure. The threshold levels also delimit the study area, which may lead to a better insight into overall consequences. In Tables 1 and 2, all effects are summarized for which *sufficient and limited evidence* exists. For these effects, the threshold levels are usually well known, and for some the dose-effect relations over a range of exposures could also be established.

| Effect | | Indicator | Threshold, dB |
|---|---|---|---|
| Biological effects | Change in cardiovascular activity | * | * |
| | EEG awakening | $L_{Amax,inside}$ | 35 |
| | Motility, onset of motility | $L_{Amax,inside}$ | 32 |
| | Changes in duration of various stages of sleep, in sleep structure and fragmentation of sleep | $L_{Amax,inside}$ | 35 |
| Sleep quality | Waking up in the night and/or too early in the morning | $L_{Amax,inside}$ | 42 |
| | Prolongation of the sleep inception period, difficulty getting to sleep | * | * |
| | Sleep fragmentation, reduced sleeping time | * | * |
| | Increased average motility when sleeping | $L_{night,outside}$ | 42 |
| Well-being | Self-reported sleep disturbance | $L_{night,outside}$ | 42 |
| | Use of somnifacient drugs and sedatives | $L_{night,outside}$ | 40 |
| Medical conditions | Environmental insomnia** | $L_{night,outside}$ | 42 |

**Table 1 Summary of effects and threshold levels for effects where *sufficient* evidence is available**

* *Although the effect has been shown to occur or a plausible biological pathway could be constructed, indicators or threshold levels could not be determined.*

***Note that "environmental insomnia" is the result of diagnosis by a medical professional whilst "self-reported sleep disturbance" is essentially the same, but reported in the context of a social survey. Number of questions and exact wording may differ.*

**Table 2**
**Summary of effects and threshold levels for effects where *limited* evidence is available****

| Effect | | Indicator | Estimated threshold, dB |
|---|---|---|---|
| Biological effects | Changes in (stress) hormone levels | * | * |
| Well-being | Drowsiness/tiredness during the day and evening | * | * |
| | Increased daytime irritability | * | * |
| | Impaired social contacts | * | * |
| | Complaints | $L_{night, outside}$ | 35 |
| | Impaired cognitive performance | * | * |
| Medical conditions | Insomnia | * | * |
| | Hypertension | $L_{night, outside}$ | 50 |
| | Obesity | * | * |
| | Depression (in women) | * | * |
| | Myocardial infarction | $L_{night, outside}$ | 50 |
| | Reduction in life expectancy (premature mortality) | * | * |
| | Psychic disorders | $L_{night, outside}$ | 60 |
| | (Occupational) accidents | * | * |

* *Although the effect has been shown to occur or a plausible biological pathway could be constructed, indicators or threshold levels could not be determined.*

** *Note that as the evidence for the effects in this table is limited, the threshold levels also have a limited weight. In general they are based on expert judgement of the evidence.*

## RELATIONS WITH $L_{NIGHT, OUTSIDE}$

Over the next few years, the END will require that night 'noise' exposures are reported in $L_{night, outside}$. It is, therefore, interesting to look into the relation between $L_{night, outside}$ and adverse health effects. The relation between the effects and $L_{night, outside}$ is, however, not straightforward. Short-term effects are mainly related to maximum levels per event inside the bedroom: $L_{Amax, inside}$. In order to express the (expected) effects in relation to the single European Union indicator, some calculation needs to be done. The calculation for the total number of effects from reaction data on events (arousals, body movements and awakenings) needs a number of assumptions. The first that needs to be made is independence: although there is evidence that the order of events of different loudness strongly influences the reactions, the calculation is nearly impossible to carry out if this is taken into consideration. Secondly, the reactions per event are known in relation to levels at the ear of the sleeper, so an assumption for an average insulation value must be made. In the report a value of 21 dB has been selected. This value is, however, subject to national and cultural differences. One thing that stands out is the desire of a large part of the population to sleep with windows (slightly) open. The relatively low value of 21 dB takes this into account already. If noise levels increase, people do indeed close their windows, but obviously reluctantly, as complaints about bad air then increase and sleep disturbance remains high. This was already pointed out in the WHO *Guidelines for community noise* (1999).

From source to source the number of separate events varies considerably. Road traffic noise is characterized by relatively low levels per event and high numbers, while air and rail traffic are characterized by high levels per event and low numbers. For two typical situations estimates have been made and presented in graphical form. The first is an average urban road (600 motor vehicles per night, which corresponds roughly to a 24-hour use of 8000 motor vehicles, or 3 million per year, the lower boundary the END sets) and the second case is for an average situation of air traffic exposure (8 flights per night, nearly 3000 per year).

Fig. 3 shows how effects increase with an increase of $L_{night, outside}$ values for the typical road traffic situation (urban road). A large number of events lead to high levels of awakening once the threshold of $L_{Amax, inside}$ is exceeded. To illustrate this in practical terms: values over 60 dB $L_{night, outside}$ occur at less then 5 metres from the centre of the road.

In Fig. 4 the same graph is presented for the typical airport situation. Due to a lower number of events there are fewer awakenings than in the road traffic case (Fig. 3), but the same or more health effects. In these examples the worst case figures can be factors higher: the maximum number of awakenings for an $L_{night, outside}$ of 60–65 dB is around 300 per year.

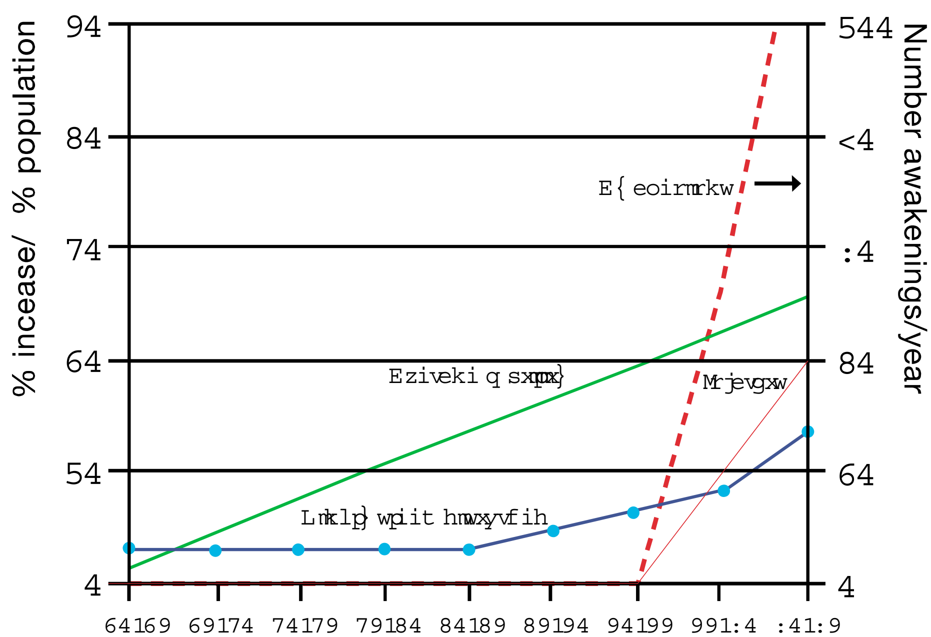


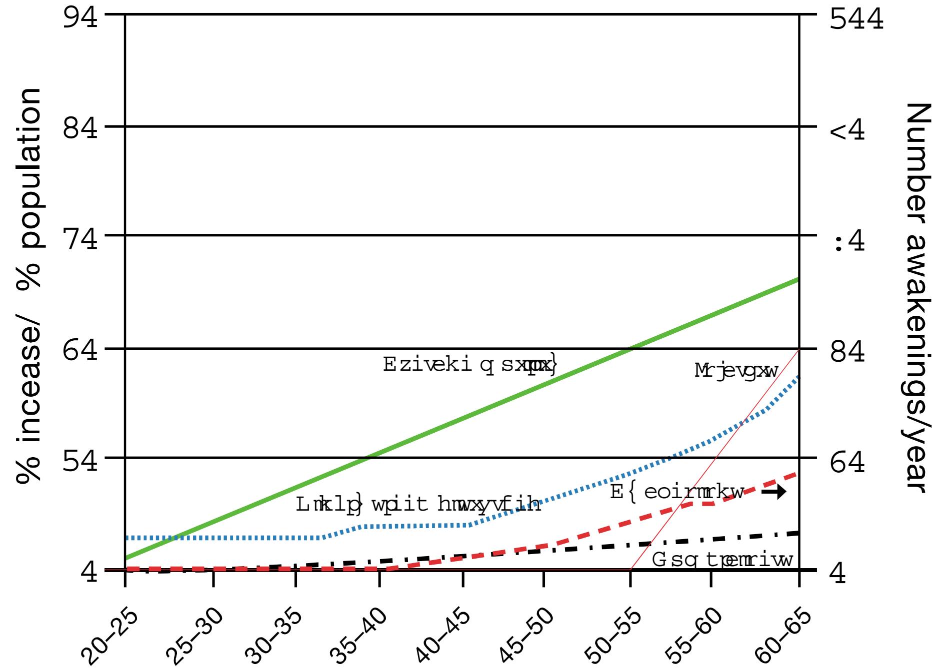

**Fig. 3 Effects of road traffic noise at night***

*Average motility and infarcts are expressed in percent increase (compared to baseline number); the number of highly sleep disturbed people is expressed as a percent of the population; awakenings are expressed in number of additional awakenings per year.*

A recent study suggests that high background levels of noise (from motorways) with a low number of separate events can cause high levels of average motility.

Therefore, by using the $L_{night, outside}$ as a single indicator, a relation between effects and indicator can be established. For some effects, however, the relation can be

**Fig. 4 Effects of aircraft noise at night***




**Average motility and infarcts are expressed in percent increase (compared to baseline number); the number of highly sleep disturbed people is expressed as a percent of the population; complainers are expressed as a % of the neighbourhood population; awakenings are expressed in number of additional awakenings per year.*

source dependent. Although $L_{night}$ gives a good relation for most effects, there is a difference between sources for some. Train noise gives fewer awakenings, for instance. Once source is accounted for, the relations are reasonably accurate.

## RECOMMENDATIONS FOR HEALTH PROTECTION

Based on the systematic review of evidence produced by epidemiological and experimental studies, the relationship between night noise exposure and health effects can be summarized as below. (Table 3)

Below the level of 30 dB $L_{night, outside}$, no effects on sleep are observed except for a slight increase in the frequency of body movements during sleep due to night noise. There is no sufficient evidence that the biological effects observed at the level below 40 dB $L_{night, outside}$ are harmful to health. However, adverse health effects are observed at the level above 40 dB $L_{night, outside}$ , such as self-reported sleep disturbance, environmental insomnia, and increased use of somnifacient drugs and sedatives.

Therefore, 40 dB $L_{night, outside}$ is equivalent to the lowest observed adverse effect level (LOAEL) for night noise. Above 55 dB the cardiovascular effects become the major public health concern, which are likely to be less dependent on the nature of the noise. Closer examination of the precise impact will be necessary in the range between 30 dB and 55 dB as much will depend on the detailed circumstances of each case.

| 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 to 40 dB | A number of effects on sleep are observed from 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 55 dB | Adverse health effects are observed among the exposed population. Many people have to adapt their lives to cope with the noise at night. Vulnerable groups are more severely affected. |
| 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 3**
**Effects of different levels of night noise on the population's health**

A number of instantaneous effects are connected to threshold levels expressed in $L_{Amax}$. The health relevance of these effects cannot be easily established. It can be safely assumed, however, that an increase in the number of such events over the baseline may constitute a subclinical adverse health effect by itself leading to significant clinical health outcomes.

Based on the exposure-effects relationship summarized in Table 3, the night noise guideline values are recommended for the protection of public health from night noise as below.

**Table 4**
**Recommended night noise guidelines for Europe**

| | |
|---|---|
| Night noise guideline (NNG) | $L_{night, outside}$ = 40 dB |
| Interim target (IT) | $L_{night, outside}$ = 55 dB |

[1] $L_{night, outside}$ is the night-time noise indicator ($L_{night}$) of Directive 2002/49/EC of 25 June 2002: 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, the incident sound is considered, the assessment point is the same as for $L_{den}$. See *Official Journal of the European Communities*, 18.7.2002, for more details.

For the primary prevention of subclinical adverse health effects related to night noise in the population, it is recommended that the population should not be exposed to night noise levels greater than 40 dB of $L_{night,outside}$ during the part of the night when most people are in bed. The LOAEL of night noise, 40 dB $L_{night,outside}$, can be considered a health-based limit value of the night noise guidelines (NNG) necessary to protect the public, including most of the vulnerable groups such as children, the chronically ill and the elderly, from the adverse health effects of night noise.

An interim target (IT) of 55 dB $L_{night,outside}$ is recommended in the situations where the achievement of NNG is not feasible in the short run for various reasons. It should be emphasized that IT is not a health-based limit value by itself. Vulnerable groups cannot be protected at this level. Therefore, IT should be considered only as a feasibility-based intermediate target which can be temporarily considered by policy-makers for exceptional local situations.

## RELATION WITH THE GUIDELINES FOR COMMUNITY NOISE (1999)

Impact of night-time exposure to noise and sleep disturbance is indeed covered in the 1999 guidelines, as below (WHO, 1999):

> "If negative effects on sleep are to be avoided the equivalent sound pressure level should not exceed 30 dBA indoors for continuous noise. If the noise is not continuous, sleep disturbance correlates best with $L_{Amax}$ and effects have been observed at 45 dB or less. This is particularly true if the background level is low. Noise events exceeding 45 dBA should therefore be limited if possible. For sensitive people an even lower limit would be preferred. It should be noted that it should be possible to sleep with a bedroom window slightly open (a reduction from outside to inside of 15 dB). To prevent sleep disturbances, one should thus consider the equivalent sound pressure level and the number and level of sound events. Mitigation targeted to the first part of the night is believed to be effective for the ability to fall asleep."

The 1999 guidelines are based on studies carried out up to 1995 (and a few meta-analyses some years later). Important new studies (Passchier-Vermeer et al., 2002; Basner et al., 2004) have become available since then, together with new insights into normal and disturbed sleep. New information has made more precise assessment of exposure-effect relationship. The thresholds are now known to be lower than $L_{Amax}$ of 45 dB for a number of effects. The last three sentences still stand: there are good reasons for people to sleep with their windows open, and to prevent sleep disturbances one should consider the equivalent sound pressure level and the number of sound events. The present guidelines allow responsible authorities and stakeholders to do this. Viewed in this way, the *night noise guidelines for Europe* are complementary to the 1999 guidelines. This means that the recommendations on government policy framework on noise management elaborated in the 1999 guidelines should be considered valid and relevant for the Member States to achieve the guideline values of this document.