From:	Sarah Laurie
To:	Committee, Wind Turbines (SEN)
Subject:	Additional information re vibration and its impact on sleep disturbance.
Date:	Monday, 13 July 2015 6:03:10 PM
Attachments:	International Standard 1996-1;2003.pdf

Dear Senators and Committee Secretariat,

One of the issues which has come up repeatedly (including in the media and on social media with respect to stationary wind turbines in the last few weeks) is the issue that various residents report being able to perceive vibrations inside their homes - whether the source of the vibration energy is operating wind, coal or gas power generators, stationary wind power generators being hit by wind gusts, equipment used in coal mining - both open cut and underground (extractor fans).

This vibration and the physiological effects described by the residents who perceive it has been consistently reported to me by residents living near all these facilities.

The disturbing and unpleasant "physiological stress" impacts from these perceived ground borne vibrations occur especially if they are being perceived at night whilst people are horizontal. A few of the witnesses who have appeared before you in the current inquiry who have reported this effect independently to me came from Waubra, Macarthur, Waterloo, Glenthompson, Lithgow, and the others include residents from Tara/Chinchilla in Queensland. Some of these residents also report concurrent rattling of objects inside their homes, and door frames. The current International Standard into Environmental Noise ISO 1996 - 1 annexure C specifically mentions rattling of objects as a cause of what engineers call "annoyance", which residents report as symptoms of physiological stress. That Standard is attached for your reference, there are other aspects of Annex C which are also of relevance.

You have heard from some of the acousticians who have measured these vibration frequencies, particularly Les Huson, Steven Cooper and Bruce Rapley. Some years ago, because of his unrelated work on whole body vibration, Steven Cooper raised this possiblity that whole body vibration may also be involved in the pathology in those who report perceiving the vibrations. I have noticed that where people report perceiving the vibrations, that they seem to suffer more severe impacts more rapidly.

I think you are all now aware that the 2009 report issued by the Federal Department of Resources, Energy and Tourism, in section 3.2 "Health Amenity" also refers to vibration specifically in the context of known mining adverse health impacts. That report is here: http://www.industry.gov.au/resource/Documents/LPSDP/AirborneContaminantsNoiseVibrationHandbook_web.pdf

As with any acoustic exposure, it is the dose response relationship which is critical. Too much, and the impacts will be perceived and can harm health, via sleep disturbance and physiological stress. Insufficient dose, and the impacts will not be perceived, and should not be a problem based on our current knowledge. However vibroacoustic disease remains a possibility with very long term chronic exposure. As the leading VAD researchers have pointed out we simply don't know what levels of chronic exposure are safe but we do know that levels experienced by neighbours to existing wind turbine and other developments can certainly be harmful, both to humans as well as animals.

There is laboratory research into train noise and vibration which demonstrates that vibration of increasing amplitude can worsen the disturbance and physiological stress

effect on sleep and cardiovascular response.
http://waubrafoundation.org.au/resources/smith-m-g-et-al-effect-vibration-sleep-and-heart/

There is also research into the effects of ship vibration in textbooks of maritime medicine. The existence of the impacts from vibration are known - the issue with respect to industrial noise and vibration in quiet rural areas is the dose response relationship at these lower doses for longer chronic exposures - what is the dose which will trigger these involuntary physiological and tissue pathological (VAD) effects??.

The effects of vibration on people who are lying down who can perceive vibration through their bed (as some people living near wind turbines describe) have a profoundly negative effect on sleep quality in the case of shipping vibration.
http://waubrafoundation.org.au/resources/jegaden-d-effects-ship-vibration-humans/

There is a lot more information - these references are just given so you know that there is a body of work supportive of the possibility that these reported vibrations could well be having an adverse effect on the health and wellbeing of nearby residents, in addition to the actual sound energy, (audible or otherwise) regardless of the actual source of the noise and vibration.

That is why the Waubra Foundation has called for full spectrum measurement of the sound and vibration energy where problems are being reported by residents, regardless of the noise source, since May 2012 (Acoustic Pollution Assessment Guideline).

best wishes

Sarah

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INTERNATIONAL STANDARD

ISO 1996-1

Second edition
2003-08-01

Acoustics — Description, measurement and assessment of environmental noise —

Part 1: **Basic quantities and assessment procedures**

Acoustique — Description, mesurage et évaluation du bruit de l'environnement —

Partie 1: Grandeurs fondamentales et méthodes d'évaluation

Reference number
ISO 1996-1:2003(E)

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Published in Switzerland

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 1996-1 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

This second edition of ISO 1996-1, together with the second edition of ISO 1996-2, cancels and replaces the first edition (ISO 1996-1:1982), and ISO 1996-2:1987, ISO 1996-2:1987/Amd.1:1998 and ISO 1996-3:1987.

ISO 1996 consists of the following parts, under the general title *Acoustics — Description, measurement and assessment of environmental noise*:

— *Part 1: Basic quantities and assessment procedures*

— *Part 2: Determination of sound pressure levels*

Introduction

To be of practical use, any method of description, measurement and assessment of environmental noise must be related in some way to what is known about human response to noise. Many adverse consequences of environmental noise increase with increasing noise, but the precise dose-response relationships involved continue to be the subject of scientific debate. In addition, it is important that all methods used should be practicable within the social, economic and political climate in which they are used. For these reasons, there is a very large range of different methods currently in use around the world for different types of noise, and this creates considerable difficulties for international comparison and understanding.

The broad aim of the ISO 1996 series is to contribute to the international harmonization of methods of description, measurement and assessment of environmental noise from all sources.

The methods and procedures described in this part of ISO 1996 are intended to be applicable to noise from various sources, individually or in combination, which contribute to the total exposure at a site. At the present stage of technology, the evaluation of long-term noise annoyance seems to be best met by adopting the adjusted A-weighted equivalent continuous sound pressure level which is termed a “rating level”.

The aim of the ISO 1996 series is to provide authorities with material for the description and assessment of noise in community environments. Based on the principles described in this part of ISO 1996, national standards, regulations and corresponding acceptable limits for noise can be developed.

Acoustics — Description, measurement and assessment of environmental noise —

Part 1: Basic quantities and assessment procedures

1 Scope

This part of ISO 1996 defines the basic quantities to be used for the description of noise in community environments and describes basic assessment procedures. It also specifies methods to assess environmental noise and gives guidance on predicting the potential annoyance response of a community to long-term exposure from various types of environmental noises. The sound sources can be separate or in various combinations. Application of the method to predict annoyance response is limited to areas where people reside and to related long-term land uses.

Community response to noise can vary differently among sound sources that are observed to have the same acoustic levels. This part of ISO 1996 describes adjustments for sounds that have different characteristics. The term “rating level” is used to describe physical sound predictions or measurements to which one or more adjustments have been added. On the basis of these rating levels, the long-term community response can be estimated.

The sounds are assessed either singly or in combination, allowing for consideration, when deemed necessary by responsible authorities, of the special characteristics of their impulsiveness, tonality and low-frequency content, and for the different characteristics of road traffic noise, other forms of transportation noise (such as aircraft noise) and industrial noise.

This part of ISO 1996 does not specify limits for environmental noise.

NOTE 1 In acoustics, several different physical measures describing sound can have their level expressed in decibels (e.g. sound pressure, maximum sound pressure, equivalent continuous sound pressure). The levels corresponding to these physical measures normally will differ for the same sound. This often leads to confusion. Therefore, it is necessary to specify the underlying physical quantity (e.g. sound pressure level, maximum sound pressure level, equivalent continuous sound pressure level).

NOTE 2 In this part of ISO 1996, quantities are expressed as levels in decibels. However, some countries validly express the underlying physical quantity, such as maximum sound pressure in pascals, or sound exposure in pascal-squared seconds.

NOTE 3 ISO 1996-2 deals with the determination of sound pressure levels.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61672-1, *Electroacoustics — Sound level meters — Part 1: Specifications* [1]

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1 Expression of levels

NOTE For levels defined in 3.1.1 to 3.1.6, frequency weighting or frequency bandwidth, as applicable, should be specified, and time-weighting, if applicable, should be specified.

3.1.1
time-weighted and frequency-weighted sound pressure level
ten times the logarithm to the base 10 of the square of the ratio of a given root-mean-square sound pressure to the reference sound pressure, being obtained with a standard frequency weighting and standard time weighting

NOTE 1 The reference sound pressure is 20 µPa.

NOTE 2 Sound pressure is expressed in pascals (Pa).

NOTE 3 The standard frequency weightings are A-weighting and C-weighting as specified in IEC 61672-1, and the standard time weightings are F-weighting and S-weighting as specified in IEC 61672-1.

NOTE 4 Time-weighted and frequency-weighted sound pressure level is expressed in decibels (dB).

3.1.2
maximum time-weighted and frequency-weighted sound pressure level
greatest time-weighted and frequency-weighted sound pressure level within a stated time interval

NOTE Maximum time-weighted and frequency-weighted sound pressure level is expressed in decibels (dB).

3.1.3
***N* percent exceedance level**
time-weighted and frequency-weighted sound pressure level that is exceeded for N % of the time interval considered

EXAMPLE $L_{\mathrm{AF95,1h}}$ is the A-frequency-weighted, F-time-weighted sound pressure level exceeded for 95 % of 1 h.

NOTE The N percent exceedance level is expressed in decibels (dB).

1) Amalgamated revision of IEC 60651 and IEC 60804.

3.1.4
peak sound pressure level
ten times the logarithm to the base 10 of the ratio of the square of the peak sound pressure to the square of the reference sound pressure, where the peak sound pressure is the maximum absolute value of the instantaneous sound pressure during a stated time interval with a standard frequency weighting or measurement bandwidth

NOTE 1 Peak sound pressure level is expressed in decibels (dB).

NOTE 2 Peak sound pressure should be determined with a detector as defined in IEC 61672. IEC 61672 only specifies the accuracy of a detector using C-weighting.

3.1.5
sound exposure level
ten times the logarithm to the base 10 of the ratio of the sound exposure, E, to the reference sound exposure, E_0, the sound exposure being the time integral of the time-varying square of the frequency-weighted instantaneous sound pressure over a stated time interval, T, or an event

NOTE 1 E_0 is equal to the square of the reference sound pressure of 20 μPa multiplied by the time interval of 1 s [400 $(\mu\text{Pa})^2\text{s}$].

$$L_E = 10 \lg \left(\frac{E}{E_0} \right) \text{dB}$$

where

$$E = \int_T p^2(t) \, \text{d}t \text{ dB}$$

NOTE 2 The sound exposure level is expressed in decibels (dB).

NOTE 3 The sound exposure is expressed in pascal-squared seconds (Pa^2s).

NOTE 4 The duration, T, of the integration is included implicitly in the time integral and need not be reported explicitly. For measurements of sound exposure over a specified time interval, the duration of integration should be reported and the notation should be L_{ET}.

NOTE 5 For sound exposure levels of an event, the nature of the event should be stated.

3.1.6
equivalent continuous sound pressure level
ten times the logarithm to the base 10 of the ratio of the square of the root-mean-square sound pressure over a stated time interval to the square of the reference sound pressure, the sound pressure being obtained with a standard frequency weighting

NOTE 1 The A-weighted equivalent continuous sound pressure level is

$$L_{\text{Aeq}\,T} = 10 \lg \left[\frac{1}{T} \int_T {p_\text{A}}^2(t) / {p_0}^2 \text{d}t \right] \text{dB}$$

where

$p_\text{A}(t)$ is the A-weighted instantaneous sound pressure at running time t;

p_0 is the reference sound pressure (= 20 μPa).

NOTE 2 The equivalent continuous sound pressure level is expressed in decibels (dB).

NOTE 3 The equivalent continuous sound pressure level is also termed the “time-averaged sound pressure level”.

3.2 Time intervals

3.2.1
reference time interval
time interval to which the rating of the sound is referred

NOTE 1 The reference time interval may be specified in national or international standards or by local authorities to cover typical human activities and variations in the operation of sound sources. Reference time intervals may be, for example, part of a day, the full day, or a full week. Some countries may define even longer reference time intervals.

NOTE 2 Different levels or sets of levels may be specified for different reference time intervals.

3.2.2
long-term time interval
specified time interval over which the sound of a series of reference time intervals is averaged or assessed

NOTE 1 The long-term time interval is determined for the purpose of describing environmental noise as it is generally designated by responsible authorities.

NOTE 2 For long-term assessments and land use planning, long-term time intervals that represent some significant fraction of a year should be used (e.g. 3 months, 6 months, 1 year).

3.3 Ratings

3.3.1
adjustment
any quantity, positive or negative, constant or variable, that is added to a predicted or measured acoustical level to account for some sound character, the time of day, or the source type

3.3.2
rating level
any predicted or measured acoustic level to which an adjustment has been added

NOTE 1 Measurements like day/night sound pressure level or day/evening/night sound pressure level are examples of rating levels because they are calculated from sound measured or predicted over different reference time periods, and adjustments are added to the reference time interval equivalent continuous sound pressure levels based on the time of day.

NOTE 2 A rating level may be created by adding adjustments to a measured or predicted level(s) to account for some character of the sound such as tonality or impulsiveness.

NOTE 3 A rating level may be created by adding adjustments to a measured or predicted level(s) to account for differences between source types. For example, using road traffic as the base sound source, adjustments may be applied to the levels for aircraft or railway sources.

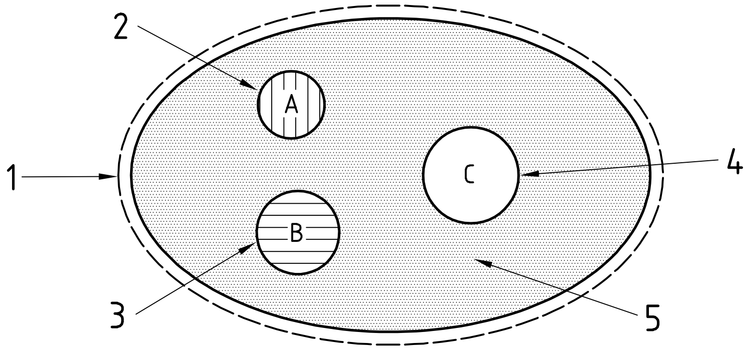
3.4 Sound designations

See Figure 1.

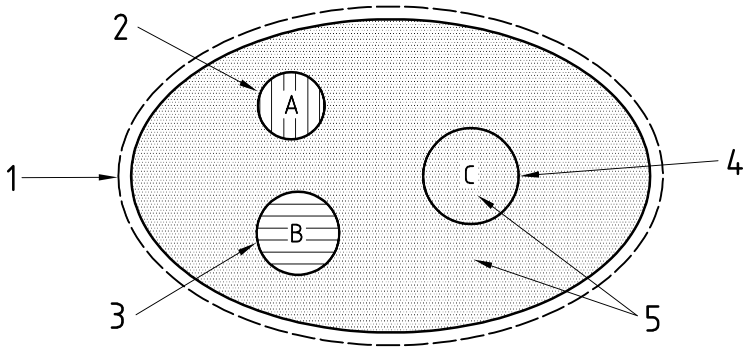
3.4.1
total sound
totally encompassing sound in a given situation at a given time, usually composed of sound from many sources near and far

3.4.2
specific sound
component of the total sound that can be specifically identified and which is associated with a specific source

3.4.3
residual sound
total sound remaining at a given position in a given situation when the specific sounds under consideration are suppressed



a) Three specific sounds under consideration, the residual sound and the total sound



b) Two specific sounds A and B under consideration, the residual sound and the total sound

Key

1 total sound
2 specific sound A
3 specific sound B
4 specific sound C
5 residual sound

NOTE 1 The lowest residual sound level is obtained when all specific sounds are suppressed.

NOTE 2 The dotted area indicates the residual sound when sounds A, B and C are suppressed.

NOTE 3 In b) the residual sound includes the specific sound C since it is not under consideration.

Figure 1 — Total, specific and residual sound designations

3.4.4
initial sound
total sound present in an initial situation before any change to the existing situation occurs

3.4.5
fluctuating sound
continuous sound whose sound pressure level varies significantly, but not in an impulsive manner, during the observation period

3.4.6
intermittent sound
sounds that are present at the observer only during certain time periods that occur at regular or irregular time intervals and are such that the duration of each such occurrence is more than about 5 s

EXAMPLES Motor vehicle noise under conditions of small traffic volume, train noise, aircraft noise and air-compressor noise.

3.4.7
sound emergence
increase in the total sound in a given situation that results from the introduction of some specific sound

3.4.8
impulsive sound
sound characterized by brief bursts of sound pressure

NOTE The duration of a single impulsive sound is usually less than 1 s.

3.4.9
tonal sound
sound characterized by a single frequency component or narrow-band components that emerge audibly from the total sound

3.5 Impulsive sound sources

NOTE Currently, no mathematical descriptor exists which can define unequivocally the presence of impulsive sound or can separate impulsive sounds into the categories given in 3.5.1 to 3.5.3. These three categories, however, have been found to correlate best with community response. Thus the sources of sound listed in 3.5.1 to 3.5.3 are used to define impulsive sound sources.

3.5.1
high-energy impulsive sound source
any explosive source where the equivalent mass of TNT exceeds 50 g, or sources with comparable characteristics and degree of intrusiveness

EXAMPLES Quarry and mining explosions, sonic booms, demolition or industrial processes that use high explosives, explosive industrial circuit breakers, military ordnance (e.g. armour, artillery, mortar fire, bombs, explosive ignition of rockets and missiles).

NOTE Sources of sonic booms include such items as aircraft, rockets, artillery projectiles, armour projectiles and other similar sources. This category does not include the short duration sonic booms generated by small arms fire and other similar sources.

3.5.2
highly impulsive sound source
any source with highly impulsive characteristics and a high degree of intrusiveness

EXAMPLES Small arms fire, hammering on metal or wood, nail guns, drop-hammer, pile driver, drop forging, punch presses, pneumatic hammering, pavement breaking, or metal impacts in rail-yard shunting operations.

3.5.3
regular impulsive sound sources
impulsive sound sources that are neither highly impulsive nor high-energy impulsive sound sources

NOTE This category includes sounds that are sometimes described as impulsive, but are not normally judged to be as intrusive as highly impulsive sounds.

EXAMPLES Slamming of car door, outdoor ball games such as football (soccer) or basketball, and church bells. Very fast pass-bys of low-flying military aircraft may also fall into this category.

4 Symbols

Symbols are given in Table 1 where the A frequency weighting and F time weighting are indicated for illustrative purposes only. Other frequency and time weightings shall be substituted as appropriate and/or as required by responsible authorities.

Table 1 — Symbols for sound pressure and sound exposure levels

Quantity	Symbol
Time-averaged and frequency-weighted sound pressure level	$L_{p\mathrm{AF}}$
Maximum time-averaged and frequency-weighted sound pressure level	L_{AFmax}
Percent exceedance level	$L_{\mathrm{AF}NT}$
Peak sound pressure level	L_{Cpeak}
Sound exposure level	$L_{\mathrm{A}E}$
Equivalent-continuous sound pressure level	$L_{\mathrm{Aeq}T}$
Rating sound exposure level	$L_{\mathrm{R}E}$
Rating equivalent continuous level	$L_{\mathrm{Req}T}$

5 Descriptors for environmental noise(s)

5.1 Single events

5.1.1 Descriptors

Sounds from single events (such as the pass-by of a truck, the fly-by of an aircraft, or an explosion at a quarry) are all examples of single-event sounds. A single-event sound can be characterized by many descriptors. These descriptors include physical quantities and the corresponding levels in decibels. Three descriptors are often used to describe the sound of single events. Frequency weighting A is used except for high-energy impulsive sounds or sounds with strong low-frequency content. The preferred three descriptors are

a) sound exposure level with specified frequency weighting,

b) maximum sound pressure level with specified time weighting and frequency weighting, and

c) peak sound pressure level with specified frequency weighting.

NOTE It is not recommended to use A-weighted peak sound levels (see 3.1.4).

5.1.2 Event duration

Event duration shall be specified relative to some characteristic of the sound, such as the number of times that some fixed level was exceeded.

EXAMPLE The duration of a sound event can be defined as the total time that the sound pressure level is within 10 dB of its maximum sound pressure level.

NOTE While the sound exposure level combines sound level and duration, the concept of event duration can be useful to differentiate events. For example, an aircraft pass-by can have a duration of 10 s to 20 s, while the duration of a gunshot is less than 1 s.

5.2 Repetitive single events

Repetitive single-event environmental sounds are typically re-occurrences of single-event sounds. For example, aircraft noise, railway noise, or road traffic noise with a low traffic volume, may be considered as the sum of the sound from multiple individual events. Also, the sound from gunfire is the sum of the sound from multiple individual gunshot sounds. In this part of ISO 1996, the description of all repetitive single-event sound sources utilizes the sound exposure levels of the single-event sounds and the corresponding number of events to determine the rating equivalent continuous sound pressure levels.

5.3 Continuous sound

Transformers, fans and cooling towers are examples of continuous sound sources. The sound pressure level of the sound from a continuous sound source can be constant, fluctuating or slowly varying over a time interval. Continuous sound is preferably described by the A-weighted equivalent continuous sound pressure level over a specified time interval. For fluctuating and intermittent sounds, the A-weighted maximum sound pressure level with a specified time weighting may also be used.

NOTE Depending on the situation, road traffic noise can be classified as a continuous source or as the sum of many repetitive single-event sounds.

6 Noise annoyance

6.1 Descriptors for community noise

This part of ISO 1996 provides guidance on the assessment of environmental noise from individual sources or any combination of sources. Responsible authorities may decide what sources, if any, are to be combined, and what adjustments, if any, are to be applied. If the sound has special characteristics, then the rating equivalent continuous sound pressure level shall be the primary measure used to describe the sound. Other measures like the maximum sound pressure level, the (adjusted) sound exposure level, or the peak sound pressure level also may be specified.

Research has shown that the frequency weighting A, alone, is not sufficient to assess sounds characterized by tonality, impulsiveness or strong low-frequency content. To estimate the long-term annoyance response of a community to sounds with some of these special characteristics, an adjustment, in decibels, is added to the A-weighted sound exposure level or A-weighted equivalent continuous sound pressure level. Also, research has shown that different transportation sounds or industrial sounds evoke different community annoyance responses for the same A-weighted equivalent continuous sound pressure level. The Bibliography contains a list of reports and publications describing the technical basis of the assessment and prediction methods of this part of ISO 1996.

6.2 Frequency weightings

Frequency weighting A is generally used to assess all sound sources except high-energy impulsive sounds or sounds with strong low-frequency content. Frequency weighting A must not be used to measure peak sound pressure levels.

6.3 Adjusted levels

6.3.1 Adjusted sound exposure levels

When the sound exposure levels of single events can be measured separately or calculated, then the following method shall be used. If, in a measurement situation, sounds from single events cannot be distinguished from other sources, then the method of 6.3.2 shall be used.

For any single-event sound except for high-energy impulsive sound or sounds having strong low-frequency content, the adjusted sound exposure level $L_{\mathrm{R}Eij}$ is given by the sound exposure level L_{Eij} for the ith single-event sound plus the level adjustment K_j for the jth type of sound, expressed in decibels. Guidance on adjustments for specific source categories and specific situations is given in Annexes A to C.

In mathematical notation:

$$L_{\mathrm{R}E_{ij}} = L_{E_{ij}} + K_j \tag{1}$$

6.3.2 Adjusted equivalent continuous sound pressure level

Over a time interval T_n, the adjusted equivalent continuous sound pressure level or rating level $L_{\mathrm{Req}\,j,Tn}$ for the jth source, is given by the actual equivalent continuous sound pressure level, $L_{\mathrm{Aeq}\,j,Tn}$, plus the level adjustment K_j for the jth source, expressed in decibels. Guidance on adjustments for specific source categories and specific situations are given in Annexes A to C.

In mathematical notation

$$L_{\mathrm{Req}\,j,Tn} = L_{\mathrm{Aeq}\,j,Tn} + K_j \tag{2}$$

For adjustments that relate to the character of the sound, these adjustments shall only be applied during the time that the specific character is present. For example, if sound is tonal in character, then the adjustments shall only be applied when the tonal sound is perceivable.

6.4 Rating levels

6.4.1 One sound source

If for a time interval, T_n, only one sound source is of relevance; the rating level is the equivalent continuous sound pressure level calculated using Equation (3) from the adjusted sound exposure levels given by 6.3.1, or it is the adjusted equivalent continuous sound pressure level given by 6.3.2. Rating levels can be developed for any of the time intervals specified in 3.2.

$$L_{\mathrm{Req}\,j,Tn} = 10\ \mathrm{lg}\left(\frac{1}{T_n}\sum_i 10^{L_{\mathrm{R}Eij}/10}\right)\ \mathrm{dB} \tag{3}$$

6.4.2 Combined sources

General guidance to assess rating levels for combined sources is given in Annex E. Combined-source rating levels can be developed for any of the time intervals specified in 3.2. In general, the time interval T is subdivided into time intervals T_{nj} for each source j. The value of T_{nj} is chosen in such a way that the adjustment in $L_{\mathrm{Req}\,j,\,Tn}$ is constant. The subdivision of T may be different for the different sources. The rating equivalent continuous sound pressure level is then given by:

$$L_{\mathrm{Req}T} = 10\ \mathrm{lg}\left(\frac{1}{T}\sum_n\sum_j T_{nj} \times 10^{L_{\mathrm{Req}j,Tnj}/10}\right)\ \mathrm{dB} \tag{4}$$

where

$$T = \sum_{n} T_{nj} \tag{5}$$

for each source j.

6.5 Composite whole-day rating levels

Another widely used method to describe a community noise environment is to assess a whole-day composite rating level from the rating levels during different periods of one whole day. For example, a day/night rating level, L_{Rdn}, is given by:

$$L_{\text{Rdn}} = 10 \lg \left[\frac{d}{24} \times 10^{(L_{\text{Rd}}+K_{\text{d}})/10} + \frac{24-d}{24} \times 10^{(L_{\text{Rn}}+K_{\text{n}})/10} \right] \text{dB} \tag{6}$$

where

d is the number of daytime hours;

L_{Rd} is the rating level for daytime, including adjustments for sound sources and sound character;

L_{Rn} is the rating level for night-time, including adjustments for sound sources and sound character;

K_{d} is the adjustment for weekend daytime, if applicable;

K_{n} is the adjustment for night-time.

Similar equations can be used to create a day/evening/night rating level, L_{Rden}.

$$L_{\text{Rden}} = 10 \lg \left[\frac{d}{24} \times 10^{(L_{\text{Rd}}+K_{\text{d}})/10} + \frac{e}{24} \times 10^{(L_{\text{Re}}+K_{\text{e}})/10} + \frac{24-d-e}{24} \times 10^{(L_{\text{Rn}}+K_{\text{n}})/10} \right] \text{dB} \tag{7}$$

where

e is the number of evening hours;

L_{Re} is the rating level for evening-time, including adjustments for sound sources and sound character;

and the other symbols are as defined for Equation (6).

Responsible authorities should set the choice of the duration of the day and those hours that comprise the day.

7 Noise limit requirements

7.1 General

Noise limits are set by responsible authorities on the basis of knowledge about the effects of noise on human health and well-being (especially dose-response relationships on annoyance), taking into account social and economic factors.

Such limits depend on many factors such as the time of day (e.g. day, evening, night, 24 h), the activities to be protected (e.g. outdoor or indoor living, communication in schools, recreation in parks), the type of sound source, the situation (e.g. new residential developments in existing situations, new industrial or transportation installations near existing residential areas, remedial measures in existing situations).

Noise limit regulations comprise both limit values and procedures describing the circumstances under which compliance with the regulations can be verified. These procedures can be based either on calculations from sound prediction models or on measurements.

A procedure shall include the following elements:

a) one or more sound descriptors;

b) the relevant time intervals;

c) the location(s) where the noise limits are to be verified;

d) the type and character of the area where the noise limits are to be used;

e) the source and its operating mode and environment;

f) the propagation conditions from source to receiver;

g) criteria for assessing compliance with limits.

7.2 Specifications

7.2.1 Noise descriptors

The preferred noise descriptor for the specification of noise limits is the rating level during one or more given reference time intervals. When using rating levels, the adjustments that have to be taken into account shall be specified.

NOTE In some countries differences in the assessment of sound sources are not taken into account by means of adjustments but by means of source specific limits. Limits that apply to sound events may be specified in terms of sound exposure levels or maximum levels. In both cases the (statistical) value to which the limit is related should be stated (e.g. the maximum level in a given time interval, the mean of maximum levels for the loudest category of a stated source).

If additional limits are specified in terms of other descriptors such as sound emergence, the procedures for determining such values shall be specified.

7.2.2 Relevant time intervals

The reference time intervals to which the assessment is referred shall be specified. They shall be related to typical human activities and variations in the operation of the sound source.

It shall be clearly stated as to which variations of sound emission and sound transmission shall be accounted for within the reference time intervals when checking compliance with limits.

Additionally, long-term time intervals shall be specified (see 3.2.2).

7.2.3 Sound sources and their operating conditions

The sources to which the noise limits apply shall be specified. Where appropriate, the operating conditions of the source shall also be specified.

7.2.4 Locations

The locations at which the noise limits must be met shall be clearly specified. If limits have to be verified by measurements near building or other large reflecting objects, then the guidance given in ISO 1996-2 should be taken into account.

7.2.5 Propagation conditions

For outdoor transmission of sound, changes in meteorological conditions may influence the received sound pressure level. In such cases, the noise limits shall be based on an average value for either all relevant propagation conditions or for a single specified condition.

7.2.6 Uncertainties

The method to take into account uncertainties to the prediction or measurement procedure when assessing compliance with limits shall be stated. In the case of measurements, it may be necessary to specify a minimum number of statistically independent measurements.

NOTE Further guidance on uncertainties is given in ISO 1996-2.

8 Reporting assessments of environmental noise(s) and estimation of long-term community annoyance response

8.1 Estimation of long-term annoyance response of communities

Noise assessments representing a long-term time interval, typically a year, are used to estimate the annoyance response of communities to the overall, steady sound situation.

NOTE Annex D may be used to estimate the long-term annoyance response of communities to road traffic noise. It estimates the percentage of a typical population that is likely to be highly annoyed by environmental noise due to a specific annual average adjusted day/night sound level. There is great scatter to the data used to create the results in Annex D. The reaction in any specific community can vary greatly from the typical value. See Figure D.1.

8.2 Test report

8.2.1 Items to be included in the report, if relevant, are as follows:

a) the reference time interval;

b) the long-term time interval;

c) for measurements, the instrumentation, its calibration and layout, and the measurement time intervals;

d) the rating level and the components, including acoustic levels contributing to the rating level;

e) a description of the sound source or sources included in the reference time intervals;

f) a description of the operating conditions of the sound source or sources;

g) a description of the assessment site including the topography, the building geometry, the ground cover and condition;

h) a description of any procedures used to correct for contamination by residual sound and a description of the residual sound;

i) the results of the estimation of long-term annoyance response of the community;

j) a description of the weather conditions during the measurements and, especially, the wind direction and speed, the cloud cover and whether precipitation was present;

k) uncertainties of the results and the method(s) used to take these uncertainties into account (see 7.2.6);

l) for calculations, the origin of the input data and activities performed to verify the reliability of the input data.

NOTE For items c), h), j) and k), more details are given in ISO 1996-2.

Although the text of this part of ISO 1996 uses sound pressure levels and rating levels expressed in decibels, it is equally valid to express the results in terms of underlying physical quantities such as sound exposure in pascal-squared seconds ($Pa^2 \cdot s$). Additive adjustments to levels shall be converted to the corresponding factors for the physical quantities.

8.2.2 Additional requirements for reporting compliance with limits are as follows:

a) the relevant section of the noise limit regulation;

b) if prediction is used, a description of the prediction model and the assumptions on which it is based;

c) if prediction is used, uncertainties to the predicted value of the sound descriptor.

Annex A
(informative)

Adjustments for sound source rating levels

A.1 Introduction

Scientific evidence shows that annoyance to transportation sound sources differs with the mode of transportation. It is usually found that for the same equivalent continuous sound pressure level, aircraft noise is more annoying than road traffic noise, especially at moderate to high levels. It is also usually found that railway noise is less annoying than road traffic noise, again, especially at moderate to high levels. However, this conclusion for railway noise may only apply especially to short (typically 12 car to 20 car) electrically powered trains. No data exist to extend this conclusion to long (typically 50 car to 100 car) diesel-powered trains, or to trains travelling in excess of 250 km/h.

For regular and highly impulsive sounds, there is ample evidence that for comparable equivalent continuous sound pressure levels, the annoyance caused by the impulsive sounds is higher than that caused by the road traffic noise. Similarly, for sounds with a prominent tonal character, experimental data suggest that the annoyance is higher than that for road-traffic sounds at the same equivalent continuous sound pressure level. Adjustments for tonal or impulsive sound have been suggested in all versions of ISO 1996 since its inception in 1971. This edition of ISO 1996 continues this practice and adopts the same impulsive sound adjustments as contained in ISO 1996-2:1998/Amd. 1.

For continuous industrial noise, there is insufficient information about dose-response relationships. Experience in some countries indicates that industrial noise can be more annoying than road traffic noise, even if it does not contain clearly audible tones or impulses. In some countries, annoyance caused by industrial (and neighbourhood noise) is assumed to depend on sound emergence. Nevertheless, for the time being, it is assumed that the annoyance caused by these sounds is not different from that caused by road traffic noise. However, much industrial noise is either tonal (fans and pumps) or impulsive in nature and these sounds are assessed with adjustments owing to their unique character.

Adjustments for time of day are accepted current practice in many countries and currently proposed in several significant new regulations. These adjustments are used to enhance the comparability between the community response to sounds in specific time periods of the day or the week. This part of ISO 1996 recommends application of adjustments for the evening, night-time and weekend. Time-of-day adjustments are an option responsible authorities may decide to adopt.

A.2 Adjustments

Because of the differences in noise annoyance to differing sources of sound, sound character, times of day, etc., adjustments should be added to measured or predicted levels. These adjustments should be added to the measured or predicted sound exposure level or equivalent continuous sound pressure level, as appropriate according to 6.3. For single-sound events, this type of adjustment is applied to the sound exposure level of each applicable event. For continuous sources of sound, this type of adjustment is applied to the measured or predicted equivalent continuous sound pressure level. Time-of-day adjustments can be applied to the sound exposure level or equivalent continuous sound pressure level, as appropriate or convenient. Since the time-of-day adjustments are constant across all sound sources during the time period, the result is identical. For example, one can add 5 dB to each aircraft sound exposure level during evening or one can add 5 dB to the aircraft equivalent continuous sound pressure level during evening; the result is the same. Table A.1 contains recommended adjustments. In most cases these are given as ranges for sound source categories.

Table A.1 — Typical level adjustments based on sound source category and time of day

Type	Specification	Level adjustment dB
Sources of sound	Road traffic	0
	Aircraft	3 to 6
	Railway[a]	–3 to –6
	Industry	0
Source character	Regular impulsive[b]	5
	Highly impulsive	12
	High-energy impulsive	See Annex B
	Prominent tones[c]	3 to 6
Time period	Evening	5
	Night	10
	Weekend daytime[d]	5

[a] The railway adjustments do not apply to long diesel trains or to trains travelling in excess of 250 km/h.

[b] Some countries apply objective prominence tests to assess whether sound sources are regular impulsive.

[c] If the presence of prominent tonal content is in dispute, then ISO 1996-2 provides measurement procedures that should be used to verify its presence.

[d] The weekend daytime adjustment is added to L_d as defined by the corresponding authority (see 6.5).

Weekend adjustments on sources subject to regulation may be applied to permit adequate rest and recuperation and to account for the greater numbers of people at home.

If more than one adjustment applies for the source type or character of a given single sound source, only the largest adjustment shall be applied. However, time period adjustments are always added to the otherwise adjusted levels.

Adjustments for impulsive source character should only be applied to impulsive sound sources that are audible at the receiver location. Adjustments for tonal character should only be applied when the total sound is audibly tonal at the receiver location.

When the sound produced by an impulsive source is so low that it cannot be separated from sound produced by other sources, infrequent impulses should not be considered. The adjustment should be 5 dB when the impulsive events occur at or exceed a rate specified by the responsible authorities. Typically this rate ranges from one event every few seconds to one event every few minutes.

Annex B
(informative)

High-energy impulse sounds

B.1 Introduction

The procedure in this annex is based on published research from Germany, the Netherlands and the United States and on a 1996 review of this research by the National Research Council, Committee on Hearing, Bioacoustics, and Biomechanics (CHABA).

B.2 Fundamental descriptor

For single-event, high-energy impulsive sounds, the fundamental descriptor is the C-weighted sound exposure level L_{CE}.

B.3 Calculation of adjusted sound exposure level for high-energy impulsive sounds from C-weighted sound exposure level

For each single event, the adjusted sound exposure level L_{RE} for high-energy impulsive sounds should be calculated from the C-weighted sound exposure level L_{CE} according to

$L_{RE} = 2\,L_{CE} - 93$ dB for $L_{CE} \geqslant 100$ dB

$L_{RE} = 1{,}18\,L_{CE} - 11$ dB for $L_{CE} < 100$ dB

The two relationships intersect at a C-weighted sound exposure level of 100 dB. The rating sound exposure level for a C-weighted sound exposure level of 100 dB is 107 dB. The general relationship is plotted in Figure B.1.

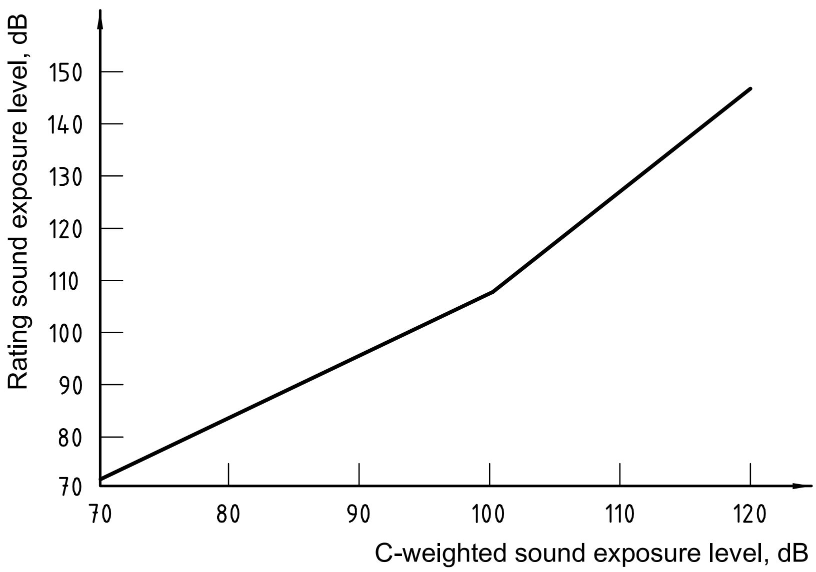


Figure B.1 — Rating sound exposure level as a function of C-weighted sound exposure level for high-energy impulse sounds

B.4 Alternative noise models

Based on field or laboratory data with real sounds, two related models have been developed that assess the full range of gunfire sounds ranging from small firearms to medium-to-large weapons (e.g. 35 mm) and to large weapons (e.g. 155 mm). They each use the difference between the C-weighted level and the A-weighted level in combination with the A-weighted or C-weighted level itself. As such, they, like methods based on the loudness function, are more sensitive to spectral content than is A-weighting alone.

In one model (see [14]), the basic formula is given by

$$L_{\mathrm{R}E} = 1{,}40\ L_{\mathrm{C}E} - 0{,}92(L_{\mathrm{CFmax}} - L_{\mathrm{AFmax}}) - 21{,}9\ \mathrm{dB}$$

This model uses the difference between the C- and A-weighted maximum sound pressure levels, both F-time-weighted, in combination with the C-weighted sound exposure level, three quantities for which there usually is sufficient signal-to-noise ratio for adequate measurements.

In the other model (see [22]), the general formula is given by

$$L_{\mathrm{R}E} = L_{\mathrm{A}E} + 12\ \mathrm{dB} + 0{,}015(L_{\mathrm{C}E} - L_{\mathrm{A}E})(L_{\mathrm{A}E} - 47\ \mathrm{dB})$$

Here the difference between the C-weighted and A-weighted sound exposure levels is used in combination with the A-weighted sound exposure level. However, the A-weighted sound exposure level can be hard to measure for distant gunfire, so an appropriate propagation model is required.

Annex C
(informative)

Sounds with strong low-frequency content

C.1 Introduction

Investigations have shown that the perception and the effects of sounds differ considerably at low frequencies as compared to mid or high frequencies. The main reasons for these differences are as follows:

— a weakening of pitch sensation as the frequency of the sound decreases below 60 Hz;

— perception of sounds as pulsations and fluctuations;

— a much more rapid increase in loudness and annoyance with increasing sound pressure levels at low frequencies than at mid or high frequencies;

— complaints about feelings of ear pressure;

— annoyance caused by secondary effects like rattling of buildings elements, windows, and doors or the tinkling of bric-a-brac;

— less building sound transmission loss at low frequencies than at mid or high frequencies.

For the assessment of sounds with strong low-frequency content, the rating procedures should be modified. The measurement location may be changed and the frequency weighting is affected since sounds with strong low-frequency content engender greater annoyance than is predicted by the A-weighted sound pressure level.

C.2 Analysis factors

The main factors are as follows.

a) The frequency range of interest appears to be about 5 Hz to about 100 Hz. In the range below about 20 Hz, some countries use the G-weighting to assess sound. Above about 15 Hz, several countries use octave-band or one-third-octave band analysis in the range from about 16 Hz to 100 Hz.

   NOTE The G-weighting is specified in ISO 7196.

b) Countries with specific procedures to assess low-frequency sound do not use the A-weighting in the same way as it is used to assess mid- and high-frequency sound. Rather, they assess the low-frequency sound only in the restricted frequency range discussed above.

c) Several countries have set low-frequency noise criteria based on indoor rather than outdoor measurements of the sound. Others use both indoor and outdoor measurements in their national standards.

d) One of the issues in low-frequency noise assessment is that room resonances at low frequencies can create situations that may be hard to predict from outdoor measurements. This can be especially important in evaluating specific residences. However, for the purposes of estimating the prevalence of high annoyance in a large community population, outdoor measurements may be sufficient.

e) Sound-induced rattles in building elements are important determinants of the annoyance caused by low-frequency sound. The methods of Annex B specifically account for this rattle factor as related to high-energy impulsive sound. As noted above, for continuous sounds, some countries have set indoor room criteria that incorporate both audible sound and rattles. Others have set separate indoor limits to assess the potential for sound-induced rattles.

Annex D
(informative)

Estimated percentage of a population highly annoyed as a function of adjusted day/night sound levels

D.1 Introduction

In 1978, a relationship was published[1] between the percentage of a population expressing high annoyance to aircraft, road traffic and railway noise and the corresponding A-weighted day/night sound level. A few years later[6], it was argued that the community response to transportation noise could not be represented by one single curve: for equal day/night levels; the percentage of respondents being highly annoyed by aircraft noise was higher, and the percentage of respondents being highly annoyed by railway sounds was lower than that for road traffic noise.

Revised curves published in 1994[2] were derived from a wider set of data than the set used in 1978. The revised data show aircraft, road traffic and railway noise separately since, as noted earlier[6], there was a systematic difference among them, at least at high sound pressure levels. Recently[3] another meta-analysis found somewhat similar systematic differences.

D.2 Dose-response function

A dose-response relationship for road-traffic noise[2] estimated percentages of highly annoyed respondents that were slightly lower than the percentages from the Schultz curve[1]. Another dose-response relationship for road traffic noise[3], however, estimated percentages of highly annoyed respondents that were slightly higher than the percentages from the Schultz curve.

The average of the curves obtained[2], [3] virtually coincides with the Schultz curve[1]. Therefore, for simplicity and historical significance, the Schultz curve is taken as the curve to define the percentage of a population that is highly annoyed (HA) to road traffic noise as a function of the day/night sound level[2)], L_{dn}, determined for freefield conditions (i.e. the reflection at the building is not taken into account). The solid line in Figure D.1 shows the Schultz curve. About 90 % of the grouped results from the various field surveys would fall within the two broken lines.

The equation for the Schultz curve shown in Figure D.1 is given by

$$\text{HA} = 100 / [1 + \exp(10{,}4 - 0{,}132\, L_{dn})]\ \% \qquad \text{(D.1)}$$

2) Day/night sound level (L_{dn}) is a specific composite whole-day rating level as described in 6.5. For L_{dn}, the number of daylight hours equals 15, the adjustment for weekend daytime equals 10 dB, and daytime is defined as the hours from 07:00 until 22:00.

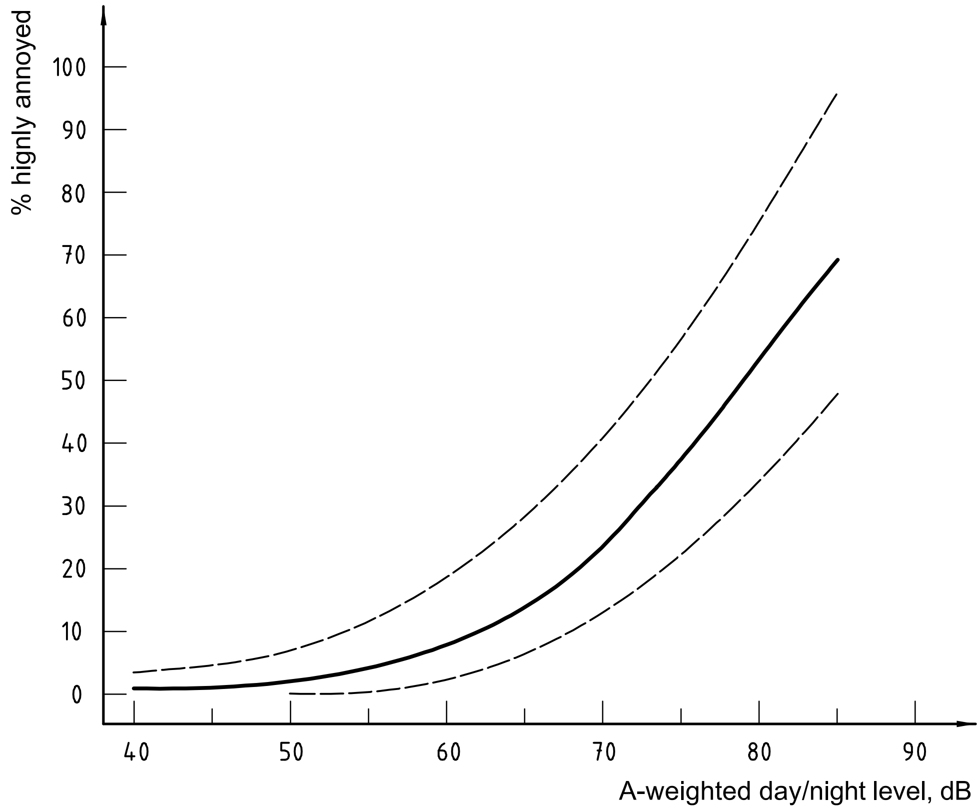


Figure D.1 — Percentage of respondents highly annoyed by road traffic sounds, as a function of the A-weighted day/night level

About 90 % of the raw data points on which the average curve is based fall within the two dashed lines.

This dose-response relationship may also be used to assess the community annoyance response for other sources if the relevant source adjustments suggested in this part of ISO 1996 have been applied.

NOTE The difference between L_{dn} and L_{den} (see 6.5) for busy roads is typically of the order of 0 dB to –2 dB.

D.3 Qualifications to the dose-response function

D.3.1 Equation (D.1) is applicable only to long-term environmental sounds such as the yearly average.

D.3.2 Equation (D.1) should not be used with shorter time periods like weekends, a single season, or "busy days". Rather, the annual average or some other long-term period should be used.

D.3.3 Equation (D.1) is not applicable to a short-term environmental sound such as that from an increase in road traffic due to a short-duration construction project.

D.3.4 Equation (D.1) is only applicable to existing situations.

In newly created situations, especially when the community is not familiar with the sound source in question, higher community annoyance can be expected. This difference may be equivalent to up to 5 dB.

Research has shown that there is a greater expectation for and value placed on "peace and quiet" in quiet rural settings. In quiet rural areas, this greater expectation for "peace and quiet" may be equivalent to up to 10 dB.

The above two factors are additive. A new, unfamiliar sound source sited in a quiet rural area can engender much greater annoyance levels than are normally estimated by relationships like Equation (D.1). This increase in annoyance may be equivalent to adding up to 15 dB to the measured or predicted levels.

Annex E
(informative)

Annoyance caused by exposure to sound in multi-source environments

E.1 General

This annex presents three of the most common theoretical frameworks for assessing the annoyance caused by exposure to sound in multi-source environments. One method assumes that total annoyance is related to a combined source composite rating level as described in 6.4.2 and 6.5. The second method assumes that total annoyance is related to an energy sum of all the sound-source adjusted equivalent continuous sound pressure levels. In practice, when the adjustments (Annex A) are constants, the two methods yield the same results. These two methods will differ when the adjustments are not constant (Annex B). The third method is to use metric(s) that combine all sources without the need for source type or most of the source sound character adjustments described in this part of ISO 1996. These methods are still under development and are discussed briefly below.

E.2 Single-event method

The single-event method assumes that the total annoyance is directly related to the combined source rating level as given by Equation (5). In particular, one can calculate a combined-source composite whole-day rating level. With appropriate choices for hours of the day and the night-time adjustment, this quantity can be a composite-source day/night rating level (L_{Rdn}). Since, in this part of ISO 1996, traffic noise is the source to which other sources are compared, as a first approximation, Equation (D.1) can be used to estimate the percentage of a population that is highly annoyed to the indicated combined-source, day/night rating level. To estimate the percentage of the population being highly annoyed, substitute L_{Rdn} for L_{dn} in Equation (D.1).

E.3 Equivalent-level method

The equivalent-level method assumes that the total annoyance is directly related to the sum of incremental annoyance generated by the equivalent levels for each source on an average day. This model assumes that the subject separately accumulates (sums) the annoyance from each source and then “sums” these sums.

To apply this method, it is recommended to measure the sound exposure level for each sound event (each pass-by) and add these contributions on an energy basis. The corresponding dose-response curve (for road traffic) is used to convert the noise metric (e.g. time-period adjusted equivalent level) into the appropriate annoyance metric, for instance “annoyance score”.

This method may be expanded to cover a multi-source situation, as follows.

Measure the sound exposure level for each single event for each of the different sources, and add the contributions on an energy basis to find the total equivalent level for each source. Select a common reference source, and use the dose-response curves to convert the equivalent level for each source into an equally annoying (to the reference source) adjusted equivalent level. Add these adjusted equivalent levels on an energy basis and use the dose-response curve for the reference source to find the corresponding annoyance for the multi-source situation. A-weighted equivalent level, L_{Aeq}, or a derivative such as L_{dn} or L_{den} is recommended as the noise dose metric for the dose-response curves.

E.4 Loudness-based methods

Loudness calculations and loudness level weighting have both been suggested for assessing the annoyance engendered by noise. The loudness method uses loudness calculations to assess noise annoyance. The calculations use the logarithm to the base 2 arithmetic inherant in loudness judgments.

The loudness-level weighting method replaces the A-weighting with the equal-loudness level contours, thereby providing a filter that changes with both amplitude and frequency. This method retains the logarithm to the base 10 arithmetic currently used with A-weighted assessments, and it preserves the concepts of equivalent level and sound exposure level.

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