# INTERNATIONAL STANDARD

# ISO 1996-1

Third edition
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# 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 1996-1:2016(E)

# Contents

Page

# 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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

This third edition cancels and replaces the second edition (ISO 1996-1:2003), which has been technically revised. In particular, the following subclauses and annexes have been added or revised: 3.6, 6.3.1, 6.5, 8.1, 8.2.1 i), Annex A, Annex D, Annex E, Annex F, Annex G, and Annex H.

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 is intended to 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 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 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 stage of technology at the time of publication of this part of ISO 1996, 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, and 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, and 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 pascal 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 documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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*

## 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, it is essential that frequency weighting or frequency bandwidth, as applicable, be specified, and time weighting, if applicable, be specified.

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

Note 1 to entry: Sound pressure is expressed in pascal (Pa).

Note 2 to entry: The reference value is 20 µPa.

Note 3 to entry: Time-weighted and frequency-weighted sound pressure level is expressed in decibels (dB).

Note 4 to entry: 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.

**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 1 to entry: Maximum time-weighted and frequency-weighted sound pressure level is expressed in decibels (dB).

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

Note 1 to entry: $N$ percentage exceedance level is expressed in decibels (dB).

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

**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 value

Note 1 to entry: The reference value is 20 µPa.

Note 2 to entry: Peak sound pressure level is expressed in decibels (dB).

Note 3 to entry: Peak sound pressure should be determined with a detector as defined in IEC 61672-1. IEC 61672-1 only specifies the accuracy of a detector using C-weighting.

Note 4 to entry: The peak sound pressure is the maximum absolute value of the instantaneous sound pressure during a stated time interval.

**3.1.5**
**sound exposure level**
$L_E$
ten times the logarithm to the base 10 of the ratio of the sound exposure, $E$, being the integral of the square of the sound pressure, $p$, over a stated time interval or event of duration, $T$ (starting at $t_1$ and ending at $t_2$), to a reference value, $E_0$

$$L_E = 10 \lg \frac{E}{E_0} \text{ dB}$$

where

$$E = \int_{t_1}^{t_2} p^2(t)\,\mathrm{d}t \;;$$

$E_0 = 400\ \mu\text{Pa}^2\ \text{s}$

Note 1 to entry: Sound exposure is expressed in pascal-squared seconds. Sound exposure level is expressed in decibels (dB).

Note 2 to entry: Because of practical limitations of the measuring instruments, $p^2$ is always understood to denote the square of a frequency-weighted and frequency band-limited sound pressure. If a specific frequency weighting as specified in IEC 61672-1 is applied, this should be indicated by appropriate subscripts; e.g. $E_{\text{A},1\ \text{h}}$ denotes the A-weighted sound exposure over 1 h.

Note 3 to entry: The duration, $T$, of the integration is included implicitly in the time integral and need not to 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 $L_{E,T}$.

Note 4 to entry: For sound exposure levels of an event, the nature of the event should be stated.

Note 5 to entry: When applied to a single event, the sound exposure level is called “single-event sound exposure level”.

**3.1.6**
**equivalent continuous sound pressure level**
$L_{\text{eq},T}$
ten times the logarithm to the base 10 of the ratio of the time-average of the square of the sound pressure, $p$, during a stated time interval of duration, $T$ (starting at $t_1$ and ending $t_2$), to the square of the reference sound pressure, $p_0$

Note 1 to entry: The A-weighted equivalent continuous sound pressure level is

$$L_{\text{Aeq},T} = 10\lg \frac{\frac{1}{T}\int_{t_1}^{t_2} p_\text{A}^2(t)\mathrm{d}t}{p_0^2}\ \text{dB}$$

where

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

$p_0$ is equal to 20 μPa.

Note 2 to entry: The equivalent continuous sound pressure level is also termed “time-averaged sound pressure level”. It is expressed in decibels (dB).

## 3.2 Time intervals

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

Note 1 to entry: 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 can be, for example, part of a day, the full day, or a full week. Some countries define even longer reference time intervals.

Note 2 to entry: 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 to entry: The long-term time interval is determined for the purpose of describing environmental noise as it is generally designated by responsible authorities.

Note 2 to entry: 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, and 1 year).

## 3.3 Ratings

**3.3.1**
**adjustment**
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**
predicted or measured acoustic level to which an adjustment has been added

Note 1 to entry: Measurements such as 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.

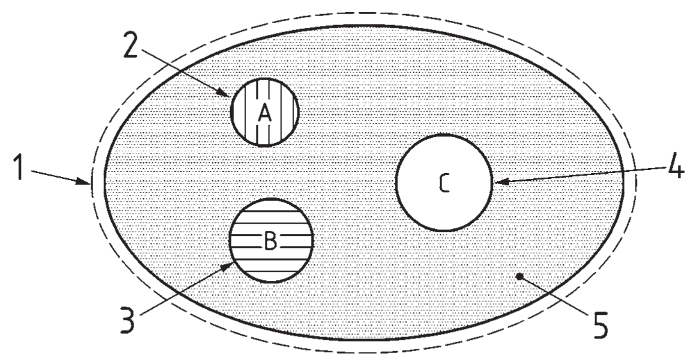
Note 2 to entry: A rating level may be created by adding adjustments to a measured or predicted level(s) to account for some character of the sound such as tonality or impulsiveness.

Note 3 to entry: 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

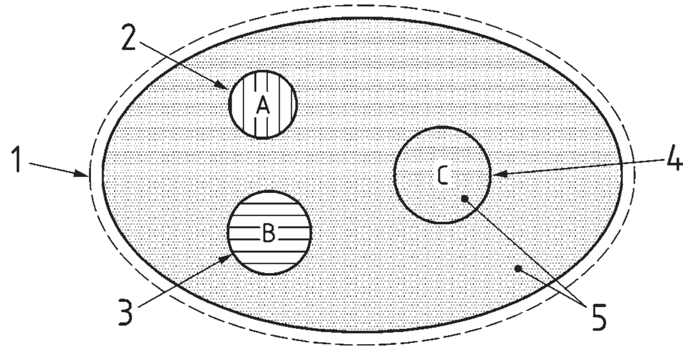
NOTE See Figure 1.

**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




**a) Three specific sounds A, B, and C 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 Figure 1 b), the residual sound includes the specific sound C as it is not under consideration.

**Figure 1 — Total, specific, and residual sound designations**

**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

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

EXAMPLE 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 1 to entry: 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 At the time of publication of this part of ISO 1996, 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**
explosive source where the equivalent mass of TNT exceeds 50 g, or sources with comparable characteristics and degree of intrusiveness

Note 1 to entry: 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.

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

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

EXAMPLE 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 source**
impulsive sound source that is neither highly impulsive nor high-energy impulsive sound source

Note 1 to entry: This category includes sounds that are sometimes described as impulsive, but are not normally judged to be as intrusive as highly impulsive sounds.

EXAMPLE 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 can also fall into this category.

## 3.6 Day, evening, night sound levels

**3.6.1**
**day sound level**
$L_{\text{day},h}$
equivalent continuous sound pressure level when the reference time interval is the day

Note 1 to entry: Subscript $h$ indicates the number of hours, e.g. $L_{\text{day},12}$.

Note 2 to entry: A day is normally the 12 h between 7 h and 19 h or the 15 h between 7 h and 22 h. However, individual countries define day differently, e.g. 6 h to 18 h or 6 h to 22 h.

**3.6.2**
**evening sound level**
$L_{\mathrm{evening},h}$
equivalent continuous sound pressure level when the reference time interval is the evening

Note 1 to entry: Subscript $h$ indicates the number of hours, e.g. $L_{\mathrm{evening},4}$.

Note 2 to entry: An evening is normally the 4 h between 19 h and 23 h. However, individual countries define evening differently, e.g. 18 h to 22 h.

**3.6.3**
**night sound level**
$L_{\mathrm{night},h}$
equivalent continuous sound pressure level when the reference time interval is the night

Note 1 to entry: Subscript $h$ indicates the number of hours, e.g. $L_{\mathrm{night},8}$.

Note 2 to entry: A night is normally the 8 h between 23 h and 7 h or the 9 h between 22 h and 7 h. However, individual countries define night differently, e.g. 22 h to 6 h.

**3.6.4**
**day-evening-night sound level**
$L_{\mathrm{den}}$
day-evening-night-weighted sound pressure level is defined by

$$L_{\mathrm{den}} = 10\ \lg\left[\frac{1}{24\,\mathrm{h}}\left(t_{\mathrm{day}}\cdot 10^{0,1L_{\mathrm{day},12}} + t_{\mathrm{evening}}\cdot 10^{0,1(L_{\mathrm{evening},4}+5\,\mathrm{dB})} + t_{\mathrm{night}}\cdot 10^{0,1(L_{\mathrm{night},8}+10\,\mathrm{dB})}\right)\right]\mathrm{dB}$$

where $t_{\mathrm{day}}$, $t_{\mathrm{evening}}$, and $t_{\mathrm{night}}$ are expressed in hours and $t_{\mathrm{day}} + t_{\mathrm{evening}} + t_{\mathrm{night}} = 24$ h.

Note 1 to entry: The default values for $t_{\mathrm{day}}$, $t_{\mathrm{evening}}$, and $t_{\mathrm{night}}$ are 12 h, 4 h, and 8 h, respectively, but individual countries, e.g. EU member states, reduce the evening period.

**3.6.5**
**day-night sound level**
$L_{\mathrm{dn}}$
day-night-weighted sound pressure level is defined by

$$L_{\mathrm{dn}} = 10\ \lg\left[\frac{1}{24\,\mathrm{h}}\left(t_{\mathrm{day}}\cdot 10^{0,1L_{\mathrm{day},15}} + t_{\mathrm{night}}\cdot 10^{0,1(L_{\mathrm{night},9}+10\,\mathrm{dB})}\right)\right]\mathrm{dB}$$

where $t_{\mathrm{day}}$ and $t_{\mathrm{night}}$ are expressed in hours and $t_{\mathrm{day}} + t_{\mathrm{night}} = 24$ h.

Note 1 to entry: The default values for $t_{\mathrm{day}}$ and $t_{\mathrm{night}}$ are 15 h and 9 h, respectively.

**3.6.6**
**community tolerance level**
$L_{\mathrm{ct}}$
day-night sound level at which 50 % of the people in a particular community are predicted to be highly annoyed by noise exposure

Note 1 to entry: $L_{\mathrm{ct}}$ is used as a parameter that accounts for differences between sources and/or communities when predicting the percentage highly annoyed by noise exposure.

Note 2 to entry: Annex H provides further information on $L_{\mathrm{ct}}$.

## 4 Symbols

Symbols are given in Table 1 where the A-frequency weighting and F-time weighting are indicated for illustrative purposes only (except for $L_{\mathrm{Cpeak}}$ where C-weighting normally is used but some other weighting, except A-weighting, could be used). Other frequency and time weightings as defined in IEC 61672-1 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-weighted and frequency-weighted sound pressure level | $L_{p\text{AF}}$ |
| Maximum time-weighted and frequency-weighted sound pressure level | $L_{\text{AFmax}}$ |
| Percentage exceedance level | $L_{\text{AF}NT}$ |
| Peak sound pressure level | $L_{\text{Cpeak}}$ |
| Sound exposure level | $L_{\text{EA}}$ |
| Equivalent-continuous sound pressure level | $L_{\text{Aeq},T}$ |
| Rating sound exposure level | $L_{\text{R}E}$ |
| Rating equivalent continuous level | $L_{\text{Req},T}$ |

# 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 the following:

a) the sound exposure level with specified frequency weighting;

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

c) the peak sound pressure level with specified frequency weighting.

It is not recommended to use A-weighted peak sound levels (see Clause 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, can 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 can 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 such as 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 shall 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 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 $i$th single-event sound plus the level adjustment $K_j$ for the $j$th type of sound, expressed in decibels. Guidance on adjustments for specific source categories and specific situations is given in Annexes A, B, E, and F.

In mathematical notation,

$$L_{\mathrm{R}Eij} = L_{Eij} + K_j \quad (1)$$

NOTE This edition of this part of ISO 1996 introduces in 3.6.6 the concept of community tolerance level, $L_{ct}$; see References [7] and [18] to better understand and rate the prevalence of annoyance in communities. The community tolerance level is explained in Annex H. Annex E provides a unified set of adjustments to the day-evening-night sound level, $L_{den}$, and the day-night sound level, $L_{dn}$, that follow directly, and hence, exactly from the use of $L_{ct}$. Annex F provides a unified set of adjustments to $L_{den}$ and $L_{dn}$ that follow indirectly from the differences between the prevalence of annoyance functions fit separately to the three categories of transportation noise sources using the regression approach of Reference [15]. It is expected that countries will adopt either the adjustments in Annex E or those in Annex F.

### 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, $L_{\text{Req}\,j,Tn}$, for the $j$th source, is given by the actual equivalent continuous sound pressure level, $L_{\text{Aeq}\,j,Tn}$, plus the level adjustment $K_j$ for the $j$th source, expressed in decibels. Guidance on adjustments for specific source categories and specific situations are given in Annexes A, E, and F.

In mathematical notation,

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

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 Formula (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 defined in 3.2.

$$L_{\text{Req}\,j,Tn} = 10\,\lg\left(\frac{1}{T_n/t_0}\sum_i 10^{0,1 L_{\text{RE}ij}}\right)\text{dB} \tag{3}$$

where $t_0$ = 1 s.

### 6.4.2 Combined sources

General guidance to assess rating levels for combined sources is given in Annex G. 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 $L_{\text{Req}\,j,Tnj}$ is constant. The subdivision of $T$ may be different for the different sources. The rating equivalent continuous sound pressure level is then given by

$$L_{\text{Req},T} = 10\,\lg\left(\frac{1}{T}\sum_n\sum_j T_{nj}\cdot 10^{0,1 L_{\text{Req}\,j,Tnj}}\right)\text{dB} \tag{4}$$

where

$$T = \sum_n T_{nj}$$

for each source $j$.

NOTE As a practical matter, Formula (4) is typically evaluated one source at a time.

### 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, $L_{\mathrm{Rdn}}$, is given by

$$L_{\mathrm{Rdn}} = 10\ \lg\left[\frac{d}{24}\cdot 10^{0,1(L_{\mathrm{Rd}}+K_{\mathrm{d}})} + \frac{24-d}{24}\cdot 10^{0,1(L_{\mathrm{Rn}}+K_{\mathrm{n}})}\right]\mathrm{dB} \qquad (5)$$

where

$d$ is the number of daytime hours;

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

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

$K_{\mathrm{d}}$ is the adjustment for daytime;

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

A similar formula can be used to create a day-evening-night rating level, $L_{\mathrm{Rden}}$:

$$L_{\mathrm{Rden}} = 10\ \lg\left[\frac{d}{24}\cdot 10^{0,1(L_{\mathrm{Rd}}+K_{\mathrm{d}})} + \frac{e}{24}\cdot 10^{0,1(L_{\mathrm{Re}}+K_{\mathrm{e}})} + \frac{24-d-e}{24}\cdot 10^{0,1(L_{\mathrm{Rn}}+K_{\mathrm{n}})}\right]\mathrm{dB} \qquad (6)$$

where

$e$ is the number of evening hours;

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

$K_{\mathrm{e}}$ is the adjustment for evening-time;

and the other symbols are as defined for Formula (5).

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

If a jurisdiction includes weekend adjustments, then the rating level shall be calculated separately for weekdays, Saturdays, and Sundays. The yearly average should include the correct proportion of weekdays, Saturdays, and Sundays to portray the entire time period.

## 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, and 24 h), the activities to be protected (e.g. outdoor or indoor living, communication in schools, and recreation in parks), the type of sound source, and the situation (e.g. new residential developments in existing situations, new industrial or transportation installations near existing residential areas, and 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 source and its operating mode and environment;

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

e) the propagation conditions from source to receiver;

f) the method to take into account uncertainties to the prediction or measurement procedure;

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

h) the 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.

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 can 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 and 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 shall be met shall be clearly specified. If limits have to be verified by measurements near buildings 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 can 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 can 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.

Annex E or Annex F should be used to estimate the long-term annoyance response of communities to airport, road-traffic, or railroad noise. Each of these two annexes provides estimates of the percentage of a typical population that is likely to be highly annoyed by that environmental noise due to a specific annual average adjusted day-night sound level. The data of Annexes E and F exhibit great scatter that is evidenced by the values for the 95 % prediction intervals. The reaction in any specific community can vary greatly from the typical value. This variation from one community to another is quantified by the use of the community tolerance level which is introduced in Annex H and used in Annexes A, D, and E.

### 8.2 Test report

**8.2.1** Items to be included in the report, if relevant, are the following:

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(s);

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 including the 95 % prediction interval;

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) the 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 ($Pa^2$ 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 the following:

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 General

Scientific evidence shows that annoyance about transportation sound 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. Also, it is sometimes found that railroad noise is less annoying than road-traffic noise. However, the user is cautioned that the community tolerance level ($L_{ct}$) analysis method of Annex E and the new research results from Japan (see Reference [22]) suggest that the typical, conventional railroad noise adjustment is +2 dB to +3 dB. A negative adjustment of up to 9 dB exists only in special instances where the vibration and rattle levels, mainly transmitted through the ground, but also train-noise-induced vibrations are low because of such factors as a vibration-attenuating ground surface or vibration-isolated tracks.

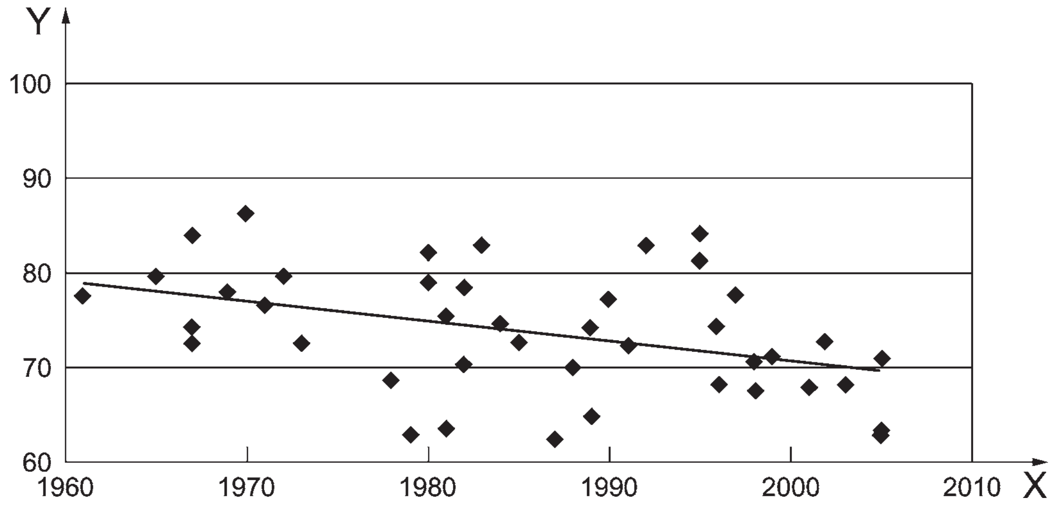
NOTE This part of ISO 1996 uses a rating level as given in Clause 6. For the rating level, positive changes are essentially penalties and negative changes are bonuses. This means that if the $L_{ct}$ for source A is 5 dB greater than the $L_{ct}$ for source B, then source B would engender a 5 dB penalty with respect to source A.

So, in the first paragraph of A.1, 2 dB to 3 dB should be added to the $L_{dn}$ of the trains producing the rattle to make the rating level of the train noise comparable with road traffic. Similarly, the change of −9 dB indicates that 9 dB should be subtracted from the $L_{dn}$ to make it into a rating level that is comparable with road traffic. All the tables in the annexes follow this sign convention.

Primarily, these low-vibration and rattle situations occur when the train is a conventional, electrically powered passenger train, and the transmission of vibration from the train-rail interaction is attenuated. Limited data suggest that there is a quite large positive adjustment for high-speed trains, i.e. trains with speeds in excess of 230 km/h.

The $L_{ct}$ can be used to examine changes in the prevalence of high annoyance with time. Figure A.1 from Reference [7] shows a small decrease in $L_{ct}$ for aircraft noise with time of about 0,2 dB per year from about 1960 to 2005 for a total change of almost 10 dB. Reference [10] reports a similar change using more or less the same data over approximately the same time period. Their analysis was carried out from 1967 to 2005 and uses a meta-regression to show an increase in the annoyance response at a given exposure level that is equivalent to an increase in level of around 10 dB.

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 road-traffic noise. Similarly, for sounds with a prominent tonal character, experimental data suggest that the annoyance is higher for those sounds than it is for road-traffic sounds at the same equivalent continuous sound pressure level. Adjustments for tonal or impulsive sound have been suggested in all editions of this part of ISO 1996 since its inception in 1971. This edition of this part of ISO 1996 continues this practice and adopts the same impulsive sound adjustments as contained in ISO 1996-2.




**Key**

X year when aircraft noise study began

Y community tolerance level $L_{ct}$ in dB

NOTE Figure A.1 contains a regression line fit to the data. This regression line has a slope of −0,2 dB/year. The trend appears to be clearly downwards.

**Figure A.1 — Change in the $L_{ct}$ for aircraft noise studies versus the year the study began**

For continuous industrial noise, sufficient information about dose-response relationships is lacking. 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 noise sources is assumed to depend on sound emergence. 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 jurisdictions. 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, the type of adjustment found in 6.3 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.

NOTE These adjustments are added only to levels of specific sound sources, and not to levels of residual sound. For example, if a stamping plant also has noise from an air handler and both are emitted into the community, the penalty for impulse noise is only attached to the stamping machine noise and not to the air handler noise.

Time-of-day adjustments can be applied to the sound exposure level or equivalent continuous sound pressure level, as appropriate or convenient. Because 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 airplane sound exposure level during evening or one can add 5 dB to the aircraft equivalent continuous sound pressure level during the evening; the result is the same. Table A.1 contains recommended adjustments.

The community tolerance level ($L_{ct}$) analysis directly results in source adjustments such as those in Table A.1, and these are given in Table E.3. For example, Table E.3 shows a +5 dB adjustment for aircraft noise in comparison with road-traffic noise. The $L_{ct}$ is also capable of examining changes in the prevalence of high annoyance to a noise source over time. Figure A.1 illustrates the temporal trend in $L_{ct}$. The 73,3 dB found to be the overall average for aircraft noise occurs in the year 1988. Extrapolating the linear regression line in Figure A.1 to 2012 suggests a current $L_{ct}$ of 68,0 dB, a decrease of more than 5 dB from the value in Table E.3. However, changing the $L_{ct}$ for aircraft noise to 68 dB is not recommended at this time because the future changes with time might reverse direction but this cannot be known until more time has elapsed.

Given the uncertainty of the overall data, and the fact that data are only provided to 2005, the permitted airport noise adjustment in Table A.1 is +5 dB to +8 dB rather than +3 dB to +6 dB adjustment range, as found in the previous edition of this part of ISO 1996. That is, although the indicated change in airport $L_{ct}$ is 5 dB, only a 0 dB to 2 dB change is recommended at this time, with a corresponding change in the adjustment for aircraft noise in Table A.1 going up by 2 dB from a range of 3 dB to 6 dB to a range from 5 dB to 8 dB with the recommended adjustment increasing from 5 dB to 7 dB.

With the $L_{ct}$ method, conversion from a 5 dB penalty on aircraft noise to a 7 dB penalty is accomplished simply by reducing the community tolerance level, $L_{ct}$, by 2 dB. With the regression curve fitting methodology, the existing function that specifically relates aircraft noise to the percentage of a population highly annoyed and which exhibits about a 5 dB shift from the corresponding road-traffic function is made to be obsolete. As an approximation, one can add a 2 dB adjustment to aircraft sound levels and then assess the annoyance using the Reference [15] aircraft noise function, the function given in Annex F and which exhibits about a 5 dB penalty with respect to road-traffic noise. Countries that wish to increase the aircraft noise adjustment may elect to use the $L_{ct}$ methodology (see Annex E) because of its capability to directly deal with this type of change.

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

| Type | Specification | Level adjustment<br>dB |
|---|---|---|
| Source of sound | Road traffic<br>Aircraft<br>Railroad<br>Industry | 0<br>5 to 8[a]<br>−3 to −6[b]<br>0[c] |
| Source character | Regular impulsive<br>Highly impulsive<br>High-energy impulsive<br>Prominent tones | 5[d,e,f]<br>12<br>See Annex B<br>3 to 6[g] |
| Time period | Evening<br>Night<br>Weekend daytime | 5<br>10<br>5[h] |

[a] The aircraft noise adjustment range has been changed from +3 dB to +6 dB in the previous edition of this part of ISO 1996 to the +5 dB to +8 dB adjustment range herein.

[b] This adjustment applies to conventional railroad passenger trains with electric engines and vibration-isolated track or soil conditions that are not conducive to propagation of vibration.

[c] No level adjustment is stated for general industrial noise due to a lack of sufficient information on dose-response relationships at this stage.

[d] Adjustments for impulsive source character should only be applied for 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.

NOTE Audibility and tonal prominence are the subject of ISO 1996-2.

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

Separation of impulsive sound from the residual is a measurement issue and is dealt with in ISO 1996-2. However, because this is a rather new requirement, the following is suggested here for review and comment. The use of *D*' was developed to assess both the audibility and noticeability of sounds in the presences of residual sound.[19] *D*' is the bandwidth-adjusted signal-to-noise ratio and is taken to be 4 dB for audibility and 14 dB for noticeability. It is suggested that *D*' equal to 14 dB be the lower bound for when impulsive sound should be separated from the residual sound, as any lower level is not noticed.

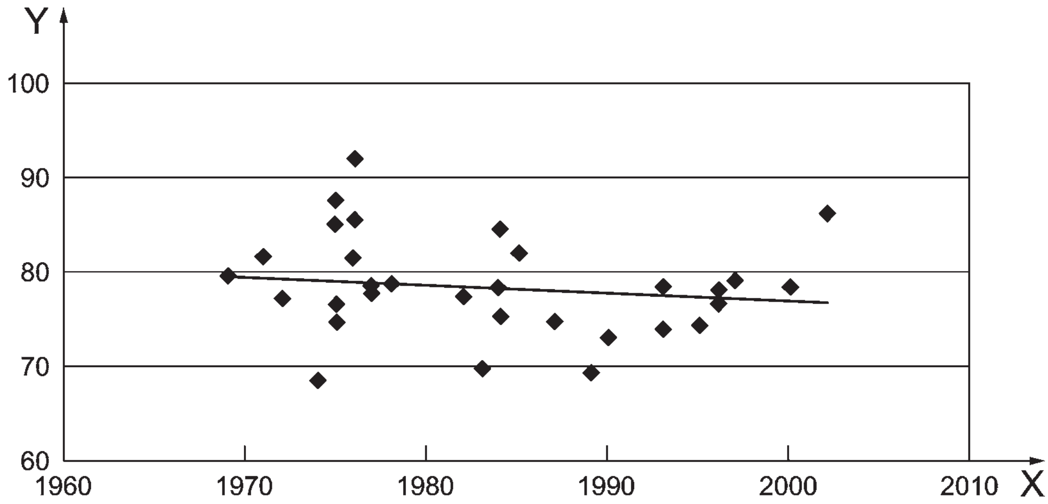
[f] Some countries apply objective prominence tests to assess whether sound sources are regular impulsive.

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

[h] Weekend daytime adjustments (nominally 7 h to 22 h) on sources subject to regulation may be applied to permit adequate rest and recuperation and to account for a greater number of people at home.

As an example of trends reversing in time, Figure A.2 illustrates the temporal trend in $L_{ct}$ for road-traffic noise. Examining the entire body of road-traffic data shows that the trend is not significantly different from zero, and the correlation with a regression line is very small. However, if one examines just the 15-year period from 1969 to 1983, one would conclude that the slope of the regression line is −0,3 dB/year; and if one examines the data for the 15-year period from 1989 to 2003, one would conclude that the slope of the regression line is +0,9 dB/year.




**Key**

X year when the road-traffic noise study began

Y community tolerance level $L_{ct}$ in dB

NOTE 1 Figure A.2 contains a regression line fit to the data. This regression line has a slope of −0,1 dB/year. However, unlike Figure A.1, the trend is NOT clearly downwards. There appears to be long periods of upward or downward growth, but the overall long-term trend appears to be zero.

NOTE 2 $L_{ct}$ is used here for the purpose of examining changes in the degree of annoyance as a function of time (in years). A similar analysis could be done over time using some other theoretical function, or one could use curve fitting but limit the data to the more recent data (e.g. newer than 2000).

**Figure A.2 — Change in the $L_{ct}$ for road-traffic noise studies versus the year the study began**

# Annex B
(informative)

# High-energy impulse sounds

## B.1 General

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 (see Reference [29]).

## B.2 Fundamental descriptor

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

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

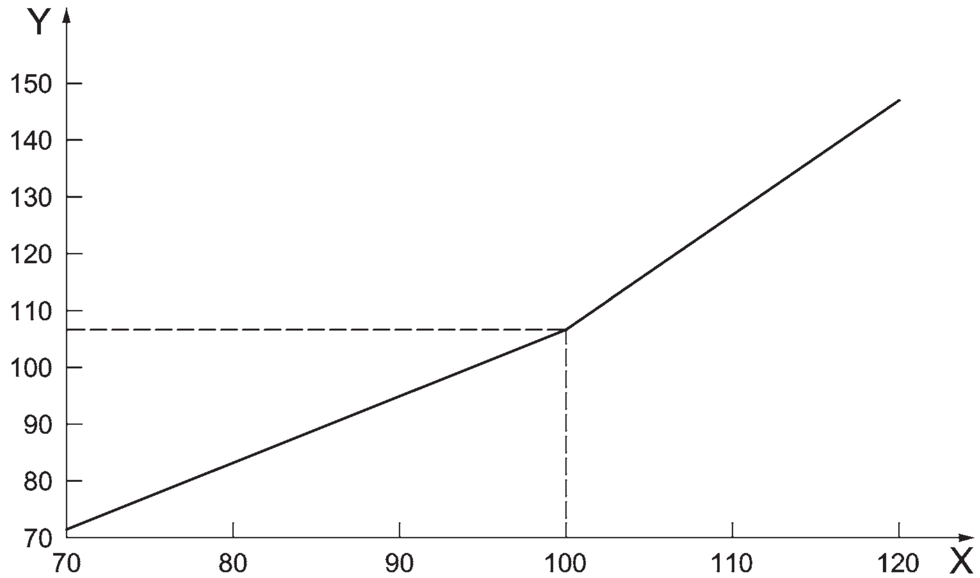
The adjusted sound exposure level $L_{RE}$ for each single-event high-energy impulsive sound should be calculated from the C-weighted sound exposure level $L_{EC}$ according to the following:

$$L_{RE} = 2\,L_{EC} - 93\text{ dB} \qquad \text{for } L_{EC} \geqslant 100\text{ dB} \tag{B.1}$$

$$L_{RE} = 1{,}18\,L_{EC} - 11\text{ dB} \qquad \text{for } L_{EC} < 100\text{ dB} \tag{B.2}$$

NOTE Formula (B.2) is only defined down to a level of 70 dB. Below this level, the energy is too low to be high energy and it is no longer relevant to human response.

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.




**Key**

X C-weighted sound exposure level $L_{EC}$ in dB

Y rating sound exposure level $L_{RE}$ in dB

NOTE The dashed lines show the intersection of the two curves at a rating level of 107 dB when $L_{EC}$ equals 100 dB.

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

## B.4 Alternative rating methods to calculate adjusted sound exposure level

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 Reference [32]), the basic formula is given by the following:

$$L_{RE} = 1{,}40\ L_{EC} - 0{,}92\ (L_{CFmax} - L_{AFmax}) - 21{,}9\ \text{dB} \quad \text{(B.3)}$$

This model uses the difference between the C-weighted 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 Reference [34]), the general formula is given by the following:

$$L_{RE} = L_{EA} + 12\ \text{dB} + 0{,}015\ (L_{EC} - L_{EA})(L_{EA} - 47\ \text{dB}) \quad \text{(B.4)}$$

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 General

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

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

— a 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;

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

— a 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 as 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 the following.

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 earlier.

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 can 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 might 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 in c) and d), 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)

# Relationships to estimate the percentage of a population highly annoyed and the 95 % prediction interval as a function of adjusted day-evening-night and day-night sound levels

## D.1 General

In 1978, Reference [19] published a relation between the percentage of a population expressing high annoyance to aircraft, road-traffic, and railroad noise and the corresponding A-weighted day-night sound level. A few years later, Reference [11] 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 railroad sounds was lower than that for road-traffic noise.

Since 1978, there have been several meta-analyses. Each of these meta-analyses finds similar systematic differences between aircraft, road-traffic, and railroad noise, differences that are of the type suggested by Reference [11]. All of the meta-analyses except References [7] and [18] fit curves to measured data. While most of the meta-analyses fit curves to cluster data, Reference [15] fits curves to individual subject data.

In contrast to curve fitting, References [7] and [18] theorize as to what the function should be, and in this process, as explained in these two references, a variable is created that indicates the position of this theoretical function along the $L_{dn}$ axis.

## D.2 Dose-response functions

The dose-response relationships are only specified for the range of the day-evening-night average sound level, $L_{den}$, or day-night sound level, $L_{dn}$, from 45 dB to 75 dB. The functions that relate the prevalence of high annoyance in a community to the $L_{den}$ or $L_{dn}$ obtained by References [7] and [18] for aircraft and road-traffic noise, respectively, which are presented in Annex E, are very similar but not identical to the functions obtained by Reference [15], which are presented in Annex F.

NOTE 1 “Specified” means stated, recorded, or presented. That is, these functions are based on all the available data but only a more limited range is tabulated and an even smaller range is “recommended” for actual use.

NOTE 2 The difference between $L_{den}$ and $L_{dn}$ is taken to be 0,6 dB, although in special cases, this difference can be significantly larger.

## D.3 95 % prediction interval

Annex E includes the approximate 95 % prediction intervals representing the range within which 95 % of the cluster data can be found. In general, for the same numerical value of day-night sound level and day-evening-night sound level, the 95 % prediction interval is slightly larger for the day-night sound level values, but typically by no more than a few tenths of a percent. Therefore, to be slightly conservative, only the 95 % prediction intervals based on day-night sound level are contained and used in this part of ISO 1996. They are used with the predictions based on day-evening-night sound level, as well as day-night sound level of Annex E using the community tolerance level ($L_{ct}$) method. These same approximate prediction intervals are used with the predictions of Annex F that are based on the method of Reference [15].

NOTE The 95 % prediction intervals were calculated as a part of the development of this part of ISO 1996 and utilized the cluster data of Reference [7]. Although these cluster data and prediction intervals do not correspond with the statistical method used by Reference [15], which was based on the individual subject data (see Reference [9] for more information on statistical uncertainty), both are based on largely the same set of airport noise attitudinal surveys performed worldwide over a 35-year span.

## D.4 Qualifications to the dose-response functions [Formulae (E.1) to (E.9) and (F.1) to (F.8)]

**D.4.1** These formulae are applicable only to long-term environmental sounds such as the yearly average.

**D.4.2** These formulae should not be used with shorter time periods such as weekends, a single season or “busy days”. Rather, the annual average or some other long-term period should be used.

**D.4.3** These formulae are not applicable to a short-term environmental sound such as from an increase in road traffic due to a short-duration construction project.

**D.4.4** These formulae are 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-mentioned two factors are additive. A new, unfamiliar sound source cited in a quiet rural area can engender much greater annoyance levels than are normally estimated by these formulae. This increase in annoyance may be equivalent to adding up to 15 dB to the measured or predicted levels.

# Annex E
(informative)

# Estimated prevalence of a population highly annoyed as a function of adjusted day-evening-night or day-night sound levels using the community tolerance level formulation

## E.1 Aircraft noise

### E.1.1 Aircraft noise using day-night sound level, $L_{dn}$

Formula (E.1) and corresponding Table E.1 quantify the prevalence of high annoyance as a function of $L_{dn}$ for aircraft noise based on Reference [7]. The prevalence of high annoyance, $P_{HA}$, expressed as a percentage is given by:

$$P_{HA} = 100\ e^{-\left(\frac{1}{10^{0,1(L_{dn} - L_{ct} + 5,3\,dB)}}\right)^{0,3}} \tag{E.1}$$

When $L_{ct}$ is set to 71,3 dB in order to implement a 7 dB adjustment for aircraft noise with respect to road-traffic noise, this becomes:

$$P_{HA} = 100\ e^{-\left(\frac{1}{10^{0,1(L_{dn} - 66\,dB)}}\right)^{0,3}} \tag{E.2}$$

According to Table A.1, the recommended adjustment for aircraft noise ranges from +5 dB to +8 dB. Formula (E.2), with the constant of 66 dB, implements a 7 dB adjustment, so, to implement a 5 dB, 6 dB, or 8 dB adjustment, add 2 dB, add 1 dB, or subtract 1 dB, respectively, from the constant of 66 dB in Formula (E.2). For example, an adjustment of 8 dB would have a constant of 65 dB. Alternatively, use Table E.1 with the entries in the day-night sound level or day-evening-night sound level column shifted from the 7 dB adjustment (column 2) by adding 2 dB, adding 1 dB, or subtracting 1 dB, respectively. For example, the current value for the prevalence of high annoyance for a day-night level of 60 dB, using the 7 dB adjustment column, is 22 %. To change the aircraft noise adjustment from 7 dB to 8 dB, shift sound levels in the 7 dB adjustment column down by one row, so the entry is 59 dB when the prevalence of high annoyance is 22 %.

### E.1.2 Aircraft noise using day-evening-night sound level, $L_{den}$

The typical difference between day-night sound level, $L_{dn}$, and day-evening-night sound level, $L_{den}$, is 0,6 dB. That is, to express $P_{HA}$ as a function of $L_{den}$, ($L_{den}$ − 0,6 dB) is substituted for $L_{dn}$ in Formula (E.1) yielding:

$$P_{HA} = 100\ e^{-\left(\frac{1}{10^{0,1(L_{den} - L_{ct} + 4,7\,dB)}}\right)^{0,3}} \tag{E.3}$$

Data for Formula (E.3) evaluated in 1 dB steps also are contained in Table E.1.

**Table E.1 — Prevalence of high annoyance and the corresponding 95 % prediction interval as functions of $L_{dn}$ or $L_{den}$ for aircraft noise implementing approximately either a 5 dB penalty or 7 dB penalty compared with road-traffic**

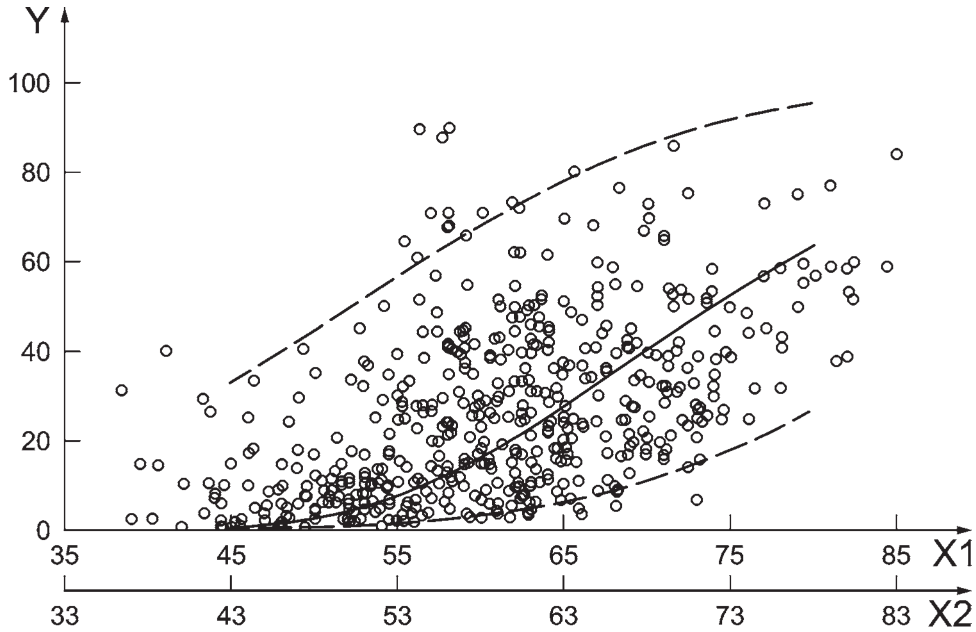
| $L_{dn}$ or $L_{den}$ implementing a 5 dB penalty compared with road-traffic noise<br>dB | $L_{dn}$ or $L_{den}$ implementing a 7 dB penalty compared with road-traffic noise<br>dB | Upper 95 % prediction interval<br>% | Lower 95 % prediction interval<br>% | Prevalence of high annoyance using $L_{dn}$ based on Reference [7]<br>% | Prevalence of high annoyance using $L_{den}$ based on Reference [7]<br>% |
|---|---|---|---|---|---|
| 45 | 43 | 33,5 | 0,3 | 0,7 | 0,6 |
| 46 | 44 | 35,7 | 0,4 | 1,0 | 0,9 |
| 47 | 45 | 38,0 | 0,4 | 1,4 | 1,2 |
| 48 | 46 | 40,3 | 0,5 | 1,9 | 1,6 |
| 49 | 47 | 42,7 | 0,6 | 2,4 | 2,1 |
| 50 | 48 | 45,1 | 0,7 | 3,1 | 2,7 |
| 51 | 49 | 47,5 | 0,9 | 3,9 | 3,4 |
| 52 | 50 | 49,9 | 1,0 | 4,9 | 4,3 |
| 53 | 51 | 52,3 | 1,2 | 6,0 | 5,3 |
| 54 | 52 | 54,7 | 1,4 | 7,2 | 6,5 |
| 55 | 53 | 57,1 | 1,7 | 8,6 | 7,7 |
| 56 | 54 | 59,5 | 1,9 | 10,1 | 9,2 |
| 57 | 55 | 61,8 | 2,2 | 11,8 | 10,8 |
| 58 | 56 | 64,1 | 2,6 | 13,6 | 12,5 |
| 59 | 57 | 66,3 | 3,0 | 15,5 | 14,4 |
| 60 | 58 | 68,5 | 3,4 | 17,6 | 16,4 |
| 61 | 59 | 70,6 | 3,9 | 19,8 | 18,5 |
| 62 | 60 | 72,7 | 4,4 | 22,0 | 20,7 |
| 63 | 61 | 74,7 | 5,0 | 24,4 | 22,9 |
| 64 | 62 | 76,6 | 5,7 | 26,8 | 25,3 |
| 65 | 63 | 78,4 | 6,4 | 29,2 | 27,7 |
| 66 | 64 | 80,1 | 7,2 | 31,7 | 30,2 |
| 67 | 65 | 81,8 | 8,1 | 34,3 | 32,7 |
| 68 | 66 | 83,4 | 9,0 | 36,8 | 35,3 |
| 69 | 67 | 84,8 | 10,0 | 39,3 | 37,8 |
| 70 | 68 | 86,2 | 11,1 | 41,9 | 40,3 |
| 71 | 69 | 87,5 | 12,3 | 44,4 | 42,9 |
| 72 | 70 | 88,7 | 13,6 | 46,8 | 45,4 |
| 73 | 71 | 89,9 | 15,0 | 49,3 | 47,8 |
| 74 | 72 | 90,9 | 16,4 | 51,7 | 50,2 |
| 75 | 73 | 91,9 | 18,0 | 54,0 | 52,6 |
| 76 | 74 | 92,7 | 19,6 | 56,3 | 54,9 |
| 77 | 75 | 93,6 | 21,3 | 58,5 | 57,1 |
| 78 | 76 | 94,3 | 23,1 | 60,6 | 59,3 |

NOTE The four rightmost columns (columns 3 to 6) are used either with the first column to implement a 5 dB penalty or with the second column to implement a 7 dB penalty relative to road-traffic noise.

Table E.1 values are for a +5 dB or a +7 dB adjustment to aircraft noise relative to road-traffic noise. That is, $L_{ct}$ is set to 78,3 dB for road-traffic noise and $L_{ct}$ is set to 73,3 dB for aircraft noise yielding a difference of 5 dB from road-traffic noise (column 1), or $L_{ct}$ is set to 71,3 dB for aircraft noise yielding a difference of 7 dB from road-traffic noise (column 2).

To fully implement, for example, this +7 dB adjustment, the user should subtract 2 dB (the difference between the desired adjustment and +5 dB) from each value in the first column of Table E.1.

Figure E.1 illustrates the data in Table E.1 when using the first column to enter $L_{dn}$ or $L_{den}$ levels into the table, the column that corresponds to approximately a 5 dB penalty to aircraft noise with respect to road-traffic noise. When using the alternate axis in Figure E.1, the figure illustrates the data in Table E.1 when using the second column to enter $L_{dn}$ or $L_{den}$ levels into the table, the column that corresponds to approximately a 7 dB penalty to aircraft noise with respect to road-traffic noise.




**Key**

X1 day-evening-night sound level $L_{den}$ in dB for a 5 dB penalty

X2 day-evening-night sound level $L_{den}$ in dB for a 7 dB penalty

Y prevalence of high annoyance $P_{HA}$ in %

NOTE 1 Figure E.1 is intended to apply to both $L_{dn}$ and $L_{den}$ as the scale is very coarse, and the difference between $L_{dn}$ and $L_{den}$ in Table E.1 in terms of prevalence of high annoyance is at most 1,5 %. Figure E.1 is based on $L_{den}$ from Table E.1. It could have been based equally well on the $L_{dn}$ levels, which are approximately 0,6 dB lower. This difference of 0,6 dB is very difficult to detect visually, so only one figure has been included, rather than two virtually identical figures.

NOTE 2 The second axis, X2, shows a 2 dB change to a community tolerance level ($L_{ct}$) function that differs by 7 dB from the $L_{ct}$ function for road-traffic noise.

NOTE 3 Figure E.1 contains two sets of values for the average $L_{den}$. The upper set, X1, implements a 5 dB penalty to aircraft noise with respect to road-traffic noise and the lower set, X2, implements a 7 dB penalty. To change Figure E.1 to be considering a 7 dB penalty relative to road-traffic noise, one needs only to relabel the sound levels changing 45 dB to 43 dB, 55 dB to 53 dB, etc., as shown with the alternate axis X2.

**Figure E.1 — Prevalence of high annoyance to aircraft noise (solid line) and the corresponding 95 % prediction interval (upper and lower limits as dashed lines) versus $L_{den}$ based on Reference [7]**

The data points portrayed in Figure E.1 are the cluster data from Reference [7], and the dashed lines are the approximate 95 % prediction interval fit to these cluster data. These data indicate the interval wherein 95 % of newly created environmental noise scenarios should reside. For example, if the $L_{den}$ at a new airport is predicted to be 58 dB and one is using the 5 dB penalty of the first column (or the

7 dB penalty of the second column), then from Table E.1, the prevalence of high annoyance, $P_{HA}$, is predicted to be 12,5 % (or 16,4 %) and 95 % of such communities (19 out of 20) would actually exhibit a prevalence of high annoyance that ranges from 2,6 % to 64,1 % (or 3,4 % to 68,5 %), and 1 community out of 20 would be outside this range.

## E.2 Road-traffic noise

### E.2.1 Road-traffic noise using day-night sound level, $L_{dn}$

Formula (E.4) and corresponding Table E.2 quantify the prevalence of high annoyance as a function of $L_{dn}$ for road-traffic noise based on Reference [18]. The prevalence of high annoyance, $P_{HA}$, expressed as a percentage is given by:

$$P_{HA} = 100\ e^{-\left(\frac{1}{10^{0,1(L_{dn}-73\,dB)}}\right)^{0,3}} \tag{E.4}$$

Figure E.2 illustrates these results where $L_{ct}$ is set to 78,3 dB in order to predict the prevalence of high annoyance to road-traffic noise with no adjustment.

### E.2.2 Road-traffic noise using day-evening-night sound level, $L_{den}$

The typical difference between day-night sound level, $L_{dn}$, and day-evening-night sound level, $L_{den}$, is 0,6 dB. That is, to express $P_{HA}$ as a function of $L_{den}$, ($L_{den}$ – 0,6 dB) is substituted for $L_{dn}$ in Formula (E.4) yielding:

$$P_{HA} = 100\ e^{-\left(\frac{1}{10^{0,1(L_{den}-73,6\,dB)}}\right)^{0,3}} \tag{E.5}$$

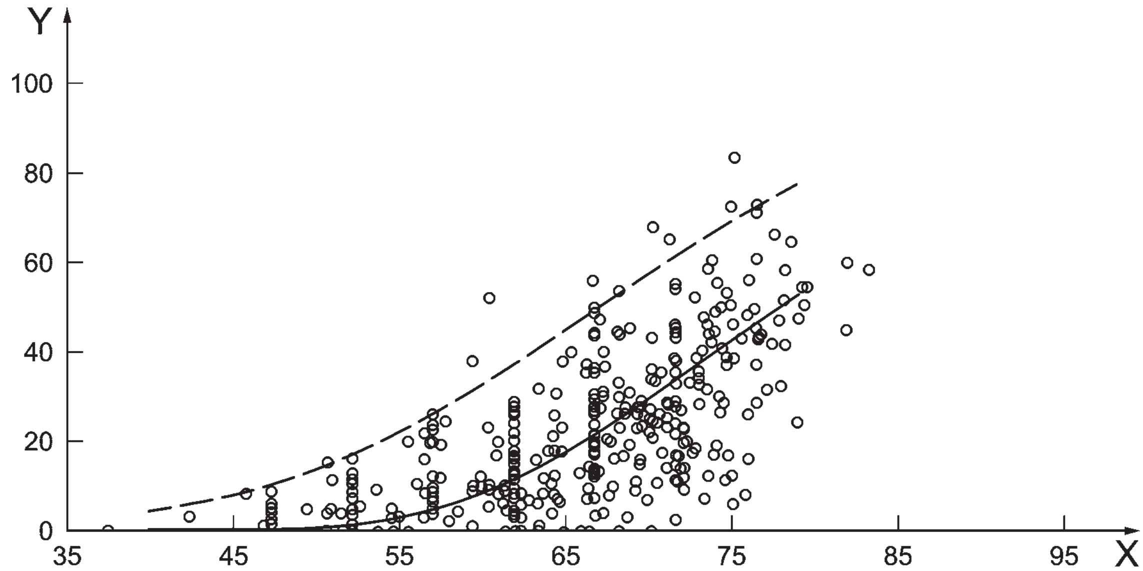
Data for Formula (E.5) evaluated in 1 dB steps are also contained in Table E.2.

**Table E.2 — Prevalence of high annoyance and the corresponding 95 % prediction interval as functions of $L_{dn}$ or $L_{den}$ for road-traffic noise**

| $L_{dn}$ or $L_{den}$<br>dB | Upper 95 % prediction interval<br>% | Lower 95 % prediction interval<br>% | Prevalence of high annoyance using $L_{dn}$ based on Reference [18]<br>% | Prevalence of high annoyance using $L_{den}$ based on Reference [18]<br>% |
|---|---|---|---|---|
| 45 | 8,2 | 0,0 | 0,1 | 0,1 |
| 46 | 9,1 | 0,0 | 0,2 | 0,1 |
| 47 | 10,2 | 0,0 | 0,2 | 0,2 |
| 48 | 11,3 | 0,0 | 0,4 | 0,3 |
| 49 | 12,5 | 0,0 | 0,5 | 0,4 |
| 50 | 13,8 | 0,0 | 0,7 | 0,6 |
| 51 | 15,2 | 0,0 | 1,0 | 0,9 |
| 52 | 16,7 | 0,0 | 1,4 | 1,2 |
| 53 | 18,3 | 0,0 | 1,9 | 1,6 |
| 54 | 19,9 | 0,0 | 2,4 | 2,1 |
| 55 | 21,7 | 0,0 | 3,1 | 2,7 |
| 56 | 23,5 | 0,0 | 3,9 | 3,4 |
| 57 | 25,5 | 0,0 | 4,9 | 4,3 |
| 58 | 27,5 | 0,0 | 6,0 | 5,3 |
| 59 | 29,5 | 0,0 | 7,2 | 6,5 |
| 60 | 31,7 | 0,0 | 8,6 | 7,7 |
| 61 | 33,9 | 0,0 | 10,1 | 9,2 |
| 62 | 36,2 | 0,0 | 11,8 | 10,8 |
| 63 | 38,5 | 0,0 | 13,6 | 12,5 |
| 64 | 40,8 | 0,0 | 15,5 | 14,4 |
| 65 | 43,2 | 0,0 | 17,6 | 16,3 |
| 66 | 45,7 | 0,0 | 19,8 | 18,4 |
| 67 | 48,1 | 0,0 | 22,0 | 20,7 |
| 68 | 50,6 | 0,0 | 24,4 | 22,9 |
| 69 | 53,0 | 0,0 | 26,8 | 25,3 |
| 70 | 55,4 | 0,0 | 29,2 | 27,7 |
| 71 | 57,8 | 0,0 | 31,7 | 30,2 |
| 72 | 60,2 | 0,1 | 34,3 | 32,7 |
| 73 | 62,6 | 0,1 | 36,8 | 35,3 |
| 74 | 64,9 | 0,1 | 39,3 | 37,8 |
| 75 | 67,1 | 0,1 | 41,9 | 40,3 |
| NOTE These values are for $L_{ct}$ = 78,3 dB, the overall $L_{ct}$ for road-traffic noise. | | | | |

Figure E.2 illustrates the data in Table E.2. These data indicate the approximate 95 % prediction interval, which is the interval wherein 95 % of newly created environmental noise situations should reside. For example, if the $L_{den}$ at a new roadway is predicted to be 53 dB, then from Table E.2, the prevalence of high annoyance, $P_{HA}$, is predicted to be 1,6 % and 95 % of such communities (19 out of 20) would actually exhibit a prevalence of high annoyance that ranges from 0,0 % to 18,3 %, and 1 community out of 20 would be outside this range.




**Key**

X day-evening-night sound level $L_{den}$ in dB

Y prevalence of high annoyance $P_{HA}$ in %

NOTE 1 Like Figure E.1, Figure E.2 is intended to apply to both $L_{dn}$ and $L_{den}$, see Note 1 to Figure E.1.

NOTE 2 The lower values for the 95 % prediction interval are essentially zero throughout the entire range of interest, and hence zero shows in the figure.

**Figure E.2 — Prevalence of high annoyance to road-traffic noise (solid line) and the corresponding 95 % prediction interval (upper limit as dashed line) versus $L_{den}$ based on Reference [18]**

## E.3 Railroad noise

### E.3.1 General

Conventional railroad noise data divide on the basis of whether vibration levels induced by the train, either through the air or through the ground, are classified as being low or high. Low-vibration conventional railroads are generally associated with passenger trains with electric engines and vibration-isolated track or soil conditions that are not conducive to propagation of vibration. High-vibration conventional railroads are generally all conventional railroads other than those described beforehand.

Table E.3 lists the $L_{ct}$ values found by Reference [18] for these two categories of railroads and for road-traffic noise. For completeness, Table E.3 also includes aircraft as found by Reference [7].

Table E.4 provides the standard deviations of the railroad data from Reference [18].

**Table E.3 — Average $L_{ct}$ values for different transportation noise sources**

| **Source** | $L_c$<br>dB | **Difference from road traffic**<br>dB |
|---|---|---|
| Road-traffic noise | 78,3 | 0 |
| Airport noise | 73,3 | 5 |
| Low-vibration conventional rail | 87,8 | −9,5 |
| High-vibration conventional rail | 75,8 | 2,5 |
| NOTE For high-speed trains (velocity > 230 km/h), even with low-vibration levels, the difference of the $L_{ct}$ for high-speed railroads from the $L_{ct}$ for road-traffic noise can be severe. | | |

**Table E.4 — Standard deviations of the railroad data**

| **Source and condition** | **Mean** $L_{ct}$<br>dB | **Difference from road traffic**<br>dB | **Standard deviation**<br>dB | **95 % prediction interval**<br>dB |
|---|---|---|---|---|
| Railroad (low-vibration levels) | 87,8 | −9,5 | 3,5 | 87,8 ± 7,0 |
| Railroad (high-vibration levels) | 75,8 | 2,5 | 4,2 | 75,8 ± 8,4 |

### E.3.2 Railroad noise using $L_{den}$

Formulae (E.6) and (E.7) describe the prevalence of high annoyance for conventional, high-vibration, and low-vibration railroad noise, respectively, using $L_{den}$.

When $L_{ct}$ = 75,8 dB for high vibration, then from Formula (E.3) follows:

$$P_{HA} = 100\ e^{-\left(\frac{1}{10^{0,1(L_{den} - 71,1 dB)}}\right)^{0,3}} \tag{E.6}$$

and when $L_{ct}$ = 87,8 dB for low vibration, then from Formula (E.3) follows:

$$P_{HA} = 100\ e^{-\left(\frac{1}{10^{0,1(L_{den} - 83,1 dB)}}\right)^{0,3}} \tag{E.7}$$

### E.3.3 Railroad noise using $L_{dn}$

Formulae (E.8) and (E.9) describe the prevalence of high annoyance for conventional, high-vibration, and low-vibration railroad noise, respectively, using $L_{dn}$.

When $L_{ct}$ = 75,8 dB for high vibration, then from Formula (E.1) follows:

$$P_{HA} = 100\ e^{-\left(\frac{1}{10^{0,1(L_{dn} - 70,5 dB)}}\right)^{0,3}} \tag{E.8}$$

and when $L_{ct}$ = 87,8 dB for low vibration, then from Formula (E.1) follows:

$$P_{HA} = 100\ e^{-\left(\frac{1}{10^{0,1(L_{dn} - 82,5 dB)}}\right)^{0,3}} \tag{E.9}$$

# Annex F
(informative)

# Estimated prevalence of a population highly annoyed as a function of adjusted day-evening-night or day-night sound level using a regression formulation

## F.1 Aircraft noise

### F.1.1 Aircraft noise using day-evening-night sound level, $L_{den}$

Formula (F.1) and corresponding Table F.1 quantify the prevalence of high annoyance as a function of $L_{den}$ for aircraft noise based on Reference [15]. The prevalence of high annoyance, $P_{HA}$, expressed as a percentage is given by:

$$P_{HA} = -9{,}199 \times 10^{-5} (L_{den} - 42\ dB)^3 + 3{,}932 \times 10^{-2} (L_{den} - 42\ dB)^2 + 0{,}294 (L_{den} - 42\ dB) \qquad (F.1)$$

The use of Formula (F.1) results in approximately a 5 dB penalty with respect to road-traffic noise.

According to Annex A, the recommended single-number adjustment for aircraft noise with respect to road-traffic noise is 7 dB. To convert Formula (F.1) so that it corresponds approximately to the application of a 7 dB adjustment, one needs only to subtract 2 from each of the “42” in Formula (F.1) yielding:

$$P_{HA} = -9{,}199 \times 10^{-5} (L_{den} - 40\ dB)^3 + 3{,}932 \times 10^{-2} (L_{den} - 40\ dB)^2 + 0{,}294 (L_{den} - 40\ dB) \qquad (F.2)$$

### F.1.2 Aircraft noise using day-night sound level, $L_{dn}$

Formula (F.3) and corresponding Table F.1 quantify the prevalence of high annoyance as a function of $L_{dn}$ for aircraft noise based on Reference [15]. The prevalence of high annoyance, $P_{HA}$, expressed as a percentage is given by:

$$P_{HA} = -1{,}395 \times 10^{-4} (L_{dn} - 42\ dB)^3 + 4{,}081 \times 10^{-2} (L_{dn} - 42\ dB)^2 + 0{,}342 (L_{dn} - 42\ dB) \qquad (F.3)$$

The use of Formula (F.3) results in approximately a 5 dB penalty with respect to road-traffic noise.

According to Annex A, the recommended single-number adjustment for aircraft noise with respect to road-traffic noise is 7 dB. To convert Formula (F.3) so that it corresponds approximately to the applications of a 7 dB adjustment, one needs only to subtract 2 from each of the “42” in Formula (F.3) yielding:

$$P_{HA} = -1{,}395 \times 10^{-4} (L_{dn} - 40\ dB)^3 + 4{,}081 \times 10^{-2} (L_{dn} - 40\ dB)^2 + 0{,}342 (L_{dn} - 40\ dB) \qquad (F.4)$$

NOTE Formulae (F.1) to (F.4), and Formulae (F.5) to (F.8) for other sources, are polynomial approximations of the underlying model and are only valid for the $L_{den}$ or $L_{dn}$ interval between 45 dB and 75 dB. More detailed information on the statistical method, a multilevel grouped regression on the individual subject data which takes into account both individual and study variance, can be found in Reference [9].

**Table F.1 — Prevalence of high annoyance and the corresponding 95 % prediction interval for aircraft noise as functions of $L_{den}$ or $L_{dn}$ implementing approximately either a 5 dB penalty or 7 dB penalty compared with road-traffic noise by using the aircraft noise function (see Annex D)**

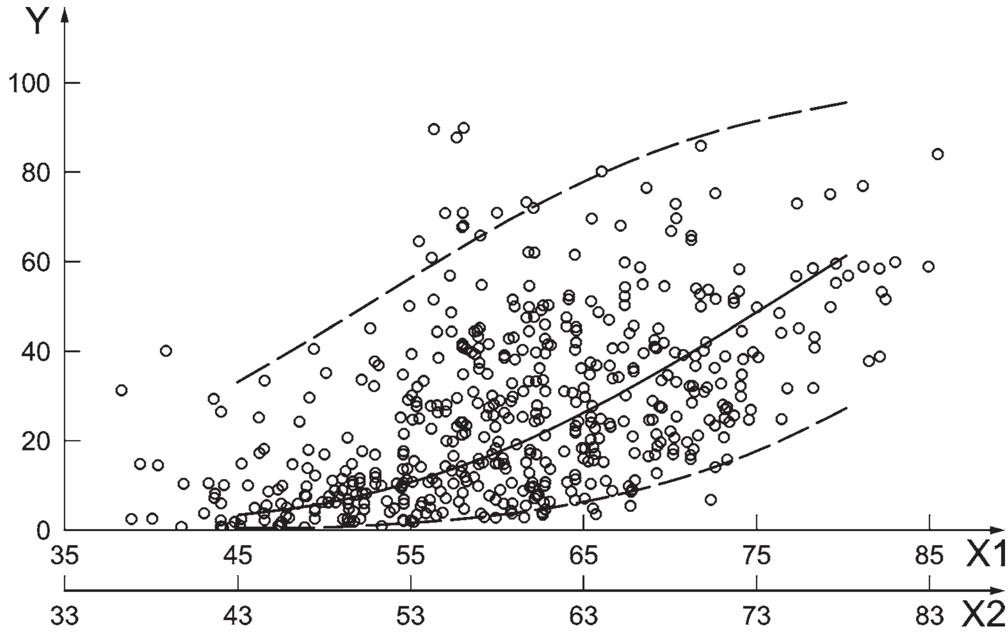
| $L_{dn}$ or $L_{den}$ implementing the airport noise function which is approximately a 5 dB penalty compared with road-traffic noise<br>dB | $L_{dn}$ or $L_{den}$ implementing approximately a 7 dB penalty compared with road-traffic noise<br>dB | Upper 95 % prediction interval<br>% | Lower 95 % prediction interval<br>% | Prevalence of high annoyance versus $L_{dn}$ based on Reference [15]<br>% | Prevalence of high annoyance versus $L_{den}$ based on Reference [15]<br>% |
|---|---|---|---|---|---|
| 45 | 43 | 33,5 | 0,3 | 1,4 | 1,2 |
| 46 | 44 | 35,7 | 0,4 | 2,0 | 1,8 |
| 47 | 45 | 38,0 | 0,4 | 2,7 | 2,4 |
| 48 | 46 | 40,3 | 0,5 | 3,5 | 3,2 |
| 49 | 47 | 42,7 | 0,6 | 4,3 | 4,0 |
| 50 | 48 | 45,1 | 0,7 | 5,3 | 4,8 |
| 51 | 49 | 47,5 | 0,9 | 6,3 | 5,8 |
| 52 | 50 | 49,9 | 1,0 | 7,4 | 6,8 |
| 53 | 51 | 52,3 | 1,2 | 8,5 | 7,9 |
| 54 | 52 | 54,7 | 1,4 | 9,7 | 9,0 |
| 55 | 53 | 57,1 | 1,7 | 11,0 | 10,3 |
| 56 | 54 | 59,5 | 1,9 | 12,4 | 11,6 |
| 57 | 55 | 61,8 | 2,2 | 13,8 | 12,9 |
| 58 | 56 | 64,1 | 2,6 | 15,3 | 14,4 |
| 59 | 57 | 66,3 | 3,0 | 16,9 | 15,9 |
| 60 | 58 | 68,5 | 3,4 | 18,6 | 17,5 |
| 61 | 59 | 70,6 | 3,9 | 20,3 | 19,1 |
| 62 | 60 | 72,7 | 4,4 | 22,0 | 20,9 |
| 63 | 61 | 74,7 | 5,0 | 23,9 | 22,7 |
| 64 | 62 | 76,6 | 5,7 | 25,8 | 24,5 |
| 65 | 63 | 78,4 | 6,4 | 27,8 | 26,4 |
| 66 | 64 | 80,1 | 7,2 | 29,8 | 28,4 |
| 67 | 65 | 81,8 | 8,1 | 31,9 | 30,5 |
| 68 | 66 | 83,4 | 9,0 | 34,0 | 32,6 |
| 69 | 67 | 84,8 | 10,0 | 36,2 | 34,8 |
| 70 | 68 | 86,2 | 11,1 | 38,5 | 37,0 |
| 71 | 69 | 87,5 | 12,3 | 40,8 | 39,3 |
| 72 | 70 | 88,7 | 13,6 | 43,2 | 41,7 |
| 73 | 71 | 89,9 | 15,0 | 45,7 | 44,2 |
| 74 | 72 | 90,9 | 16,4 | 48,2 | 46,7 |
| 75 | 73 | 91,9 | 18,0 | 50,7 | 49,2 |

NOTE The four rightmost columns (columns 3 to 6) are used either with the first column to implement a 5 dB penalty or with the second column to implement a 7 dB penalty relative to road-traffic noise.

Figure F.1 illustrates the data in Table F.1 when using the first column to enter $L_{dn}$ or $L_{den}$ levels into the table, the column that corresponds to approximately a 5 dB penalty to aircraft noise with respect to road-traffic noise. When using the alternate axis in Figure F.1, the figure illustrates the data in Table F.1

when using the second column to enter $L_{dn}$ or $L_{den}$ levels into the table, the column that corresponds to approximately a 7 dB penalty to aircraft noise with respect to road-traffic noise.




**Key**

X1 day-evening-night sound level $L_{den}$ in dB for a 5 dB penalty

X2 day-evening-night sound level $L_{den}$ in dB for a 7 dB penalty

Y prevalence of high annoyance $P_{HA}$ in %

NOTE Figure F.1 contains two sets of values for the average $L_{den}$. The upper set, X1, implements a 5 dB penalty to aircraft noise with respect to road-traffic noise and the lower set, X2, implements a 7 dB penalty. To change Figure F.1 to be considering a 7 dB penalty relative to road-traffic noise, one needs only to relabel the sound levels changing 45 dB to 43 dB, 55 dB to 53 dB, etc., as shown with the alternate axis X2.

**Figure F.1 — Prevalence of high annoyance to aircraft noise (solid line) versus $L_{den}$ or $L_{dn}$ based on Reference [15] and the corresponding 95 % prediction interval (upper and lower limits as dashed lines)**

The data points portrayed in Figure F.1 are the cluster data from Reference [7], and the dashed lines are the approximate 95 % prediction interval fit to these cluster data. These data indicate the interval wherein 95 % of newly created environmental noise scenarios should reside. For example, if the $L_{den}$ at a new airport is predicted to be 58 dB and one is using the 5 dB penalty of the first column (or the 7 dB penalty of the second column), then from Table F.1, the prevalence of high annoyance, $P_{HA}$, is predicted to be 14,5 % (or 17,5 %) and 95 % of such communities (19 out of 20) would actually exhibit a prevalence of high annoyance, $P_{HA}$, that ranges from 2,6 % to 64,1 % (or 3,4 % to 68,5 %), and 1 community out of 20 would be outside this range.

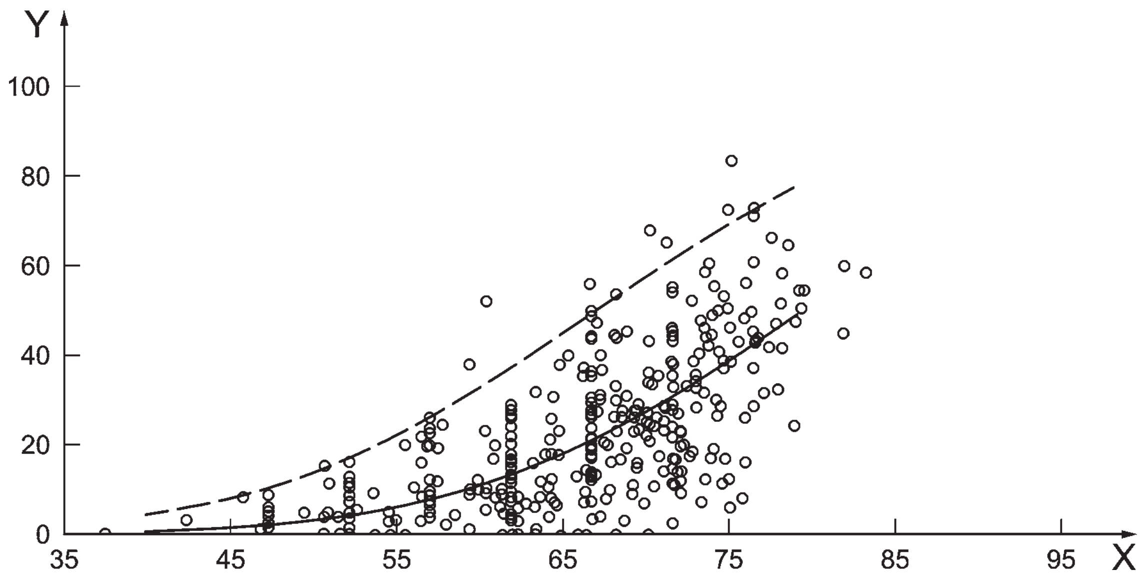
## F.2 Road-traffic noise

### F.2.1 Road-traffic noise using day-evening-night sound level, $L_{den}$

Formula (F.5) and corresponding Table F.2 quantify the prevalence of high annoyance as a function of $L_{den}$ for road-traffic noise based on Reference [15]. The prevalence of high annoyance, $P_{HA}$, expressed as a percentage is given by:

$$P_{HA} = 9{,}868 \times 10^{-4} (L_{den} - 42 \text{ dB})^3 - 1{,}436 \times 10^{-2} (L_{den} - 42 \text{ dB})^2 + 0{,}512 (L_{den} - 42 \text{ dB}) \qquad \text{(F.5)}$$

The data points portrayed in Figure F.2 are the cluster data from Reference [18], and the dashed lines are the approximate 95 % prediction interval fit to these cluster data.




**Key**

X day-evening-night sound level $L_{den}$ in dB

Y prevalence of high annoyance $P_{HA}$ in %

NOTE 1 The lower values for the 95 % prediction interval are essentially zero throughout the entire range of interest, and hence zero shows in the figure.

**Figure F.2 — Prevalence of high annoyance to road-traffic noise (solid line) versus $L_{den}$ based on Reference [15] and the corresponding 95 % prediction interval (upper limit as dashed line)**

### F.2.2 Road-traffic noise using day-night sound pressure level, $L_{dn}$

Formula (F.6) and corresponding Table F.2 quantify the prevalence of high annoyance as a function of $L_{dn}$ for road-traffic noise based on Reference [15]. The prevalence of high annoyance, $P_{HA}$, expressed as a percentage is given by:

$$P_{HA} = 9{,}994 \times 10^{-4} (L_{dn} - 42 \text{ dB})^3 - 1{,}523 \times 10^{-2} (L_{dn} - 42 \text{ dB})^2 + 0{,}538 (L_{dn} - 42 \text{ dB}) \qquad \text{(F.6)}$$

**Table F.2 — Prevalence of high annoyance and the corresponding 95 % prediction interval as functions of $L_{den}$ or $L_{dn}$ for road-traffic noise**

| $L_{den}$ or $L_{dn}$ dB | Upper 95 % prediction interval % | Lower 95 % prediction interval % | Prevalence of high annoyance versus $L_{dn}$ based on Reference [15] % | Prevalence of high annoyance versus $L_{den}$ based on Reference [15] % |
|---|---|---|---|---|
| 45 | 8,0 | 0,0 | 1,5 | 1,4 |
| 46 | 9,0 | 0,0 | 2,0 | 1,9 |
| 47 | 10,0 | 0,0 | 2,4 | 2,3 |
| 48 | 11,1 | 0,0 | 2,9 | 2,8 |
| 49 | 12,3 | 0,0 | 3,4 | 3,2 |
| 50 | 13,6 | 0,0 | 3,8 | 3,7 |
| 51 | 15,0 | 0,0 | 4,3 | 4,2 |
| 52 | 16,5 | 0,0 | 4,9 | 4,7 |
| 53 | 18,1 | 0,0 | 5,4 | 5,2 |
| 54 | 19,7 | 0,0 | 6,0 | 5,8 |
| 55 | 21,5 | 0,0 | 6,6 | 6,4 |
| 56 | 23,3 | 0,0 | 7,3 | 7,1 |
| 57 | 25,2 | 0,0 | 8,0 | 7,8 |
| 58 | 27,3 | 0,0 | 8,8 | 8,6 |
| 59 | 29,3 | 0,0 | 9,7 | 9,4 |
| 60 | 31,5 | 0,0 | 10,6 | 10,3 |
| 61 | 33,7 | 0,0 | 11,6 | 11,3 |
| 62 | 36,0 | 0,0 | 12,7 | 12,4 |
| 63 | 38,3 | 0,0 | 13,8 | 13,6 |
| 64 | 40,7 | 0,0 | 15,1 | 14,8 |
| 65 | 43,1 | 0,0 | 16,5 | 16,2 |
| 66 | 45,5 | 0,0 | 18,0 | 17,7 |
| 67 | 48,0 | 0,0 | 19,5 | 19,2 |
| 68 | 50,4 | 0,0 | 21,3 | 20,9 |
| 69 | 52,9 | 0,0 | 23,1 | 22,8 |
| 70 | 55,3 | 0,0 | 25,1 | 24,7 |
| 71 | 57,8 | 0,0 | 27,2 | 26,8 |
| 72 | 60,2 | 0,1 | 29,4 | 29,1 |
| 73 | 62,5 | 0,1 | 31,8 | 31,5 |
| 74 | 64,8 | 0,1 | 34,4 | 34,0 |
| 75 | 67,1 | 0,1 | 37,1 | 36,7 |

## F.3 Railroad noise

Formulae (F.7) and (F.8), based on Reference [15], relate the overall data set for the prevalence of high annoyance to train noise as functions of $L_{den}$ or $L_{dn}$. These formulae treat all of the train survey data as equal and do not attempt to separate survey data for which there were high-level vibrations and/or rattle from surveys for which there were not high levels of vibrations and/or rattle.

For $L_{den}$, high annoyance to train noise, $P_{HA}$, expressed as a percentage is:

$$P_{HA} = 7{,}239 \times 10^{-4}\,(L_{den} - 42\text{ dB})^3 - 7{,}851 \times 10^{-3}\,(L_{den} - 42\text{ dB})^2 + 0{,}170\,(L_{den} - 42\text{ dB}) \qquad \text{(F.7)}$$

For $L_{dn}$, high annoyance to train noise, $P_{HA}$, expressed as a percentage is:

$$P_{HA} = 7{,}158 \times 10^{-4}\,(L_{dn} - 42\text{ dB})^3 - 7{,}774 \times 10^{-3}\,(L_{dn} - 42\text{ dB})^2 + 0{,}163\,(L_{dn} - 42\text{ dB}) \qquad \text{(F.8)}$$

# Annex G
(informative)

# Annoyance caused by exposure to sound in multi-source environments

## G.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. These methods are the following:

a) Single-event method — This method assumes that total annoyance is related to a combined source composite rating level as described in 6.4.2 and 6.5.

b) Equivalent-level method — This 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 (see Annex A) are constants, the two methods yield the same results. These two methods will differ when the adjustments are not constant (see Annex B).

c) Loudness-based method — This 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 in G.2 to G.4.

## G.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 Formula (4). 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 ($L_{Rdn}$) as given by Formula (5). Since, in this part of ISO 1996, traffic noise is the source to which other sources are compared, as a first approximation, Formulae (E.4) and (E.5), or (F.6) and (F.5), can be used to estimate the percentage of a population that is highly annoyed, one has the choice of using the method in either Annex E or in Annex F; depending on the method chosen, the formulae or tables in Annex E or Annex F will be used. If using Annex E, substitute $L_{Rdn}$ for $L_{dn}$ in Formula (E.4) and $L_{Rden}$ for $L_{den}$ in Formula (E.5), or look up the percentages in Table E.2. If using Annex F, substitute $L_{Rdn}$ for $L_{dn}$ in Formula (F.6) and $L_{Rden}$ for $L_{den}$ in Formula (F.5), or look up the percentages in Table F.2.

## G.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, e.g. "annoyance score".

This method can 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.

NOTE For $L_{ct}$, this adjustment is the difference between $L_{ct}$ for the source in question and $L_{ct}$ for road traffic, assuming road traffic is the reference source.

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.

## G.4 Loudness-based method

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 inherent in loudness judgments.

The loudness-level weighting method replaces the A-weighting with the equal-loudness level contours (see ISO 226), 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.

# Annex H
(informative)

# Theory-based approach to predict the growth of annoyance

Figure E.1 portrays aircraft noise attitudinal survey data that could be found and put into the form of percentage of a population highly annoyed as a function of $L_{den}$. The data occupy a large amorphous cloud. Curves fit to the data typically explain less than 40 % of the variance, and the prediction interval is very large. For example, at a $L_{den}$ of 60 dB, the predicted percentage of a population highly annoyed is 16 %, but the prediction interval ranges from 3 % to 69 %. That is, one is 95 % confident that the actual percentage will be between 3 % and 69 % of a population highly annoyed, which is a huge range. This situation is somewhat analogous to having a plane flight scheduled to take off at 15 h, and knowing only that 19 times out of 20, it will take off sometime between 12 h and 22 h. This huge range of the attitudinal survey data results from a lack of theory to explain the variability. This Annex presents a theory-based explanation of the variability.

References [7] and [18] theorize that the rate of change of annoyance with the day-night average sound level, $L_{dn}$, of the noise from various modes of transportation closely resembles a duration-adjusted loudness calculation using $L_{dn}$. It is well known that loudness is proportional to sound pressure squared raised to the power of 0,3. But the sensation of loudness grows for only a fraction of a second, and then becomes constant independent of the duration of the sound. In contrast, annoyance appears to grow in direct proportion to the duration of the sound. So, References [7] and [18] convert $L_{dn}$ to units of pressure squared, raise this to the power of 0,3, and continue the growth in direct proportion to the duration of the sound. In essence, annoyance is assumed to be fully proportional to loudness times duration. Hence, this calculation is described as resembling a duration-adjusted loudness calculation using $L_{dn}$. In References [7] and [18], the universe of attitudinal survey data confirms this theory. The theory accounts for two-thirds of the variability to the data and identifies some factors that cause this variability. As a result, 50 % more of the variance is explained than is explained by just fitting curves that are functions of $L_{dn}$ alone.

NOTE 1 Precise formulations for predicting loudness, such as ISO 532, ANSI/ASA S3.4, or DIN 45631, include various factors that affect the calculation of loudness. To a first approximation, however, loudness grows as the power of 0,3 of sound level.

In addition to the assumption that the prevalence of high annoyance is based on time-integrated loudness of noise exposure, a transition function is assumed. This functional relationship, of the form $e^{-x}$, is the simplest (single parameter) transition function. As the noise goes from very very quiet to very very loud, it transitions between an asymptotic value of 0 (0 % of a community highly annoyed when the noise is very very quiet) to an asymptotic value of 100 (100 % of a community highly annoyed when the noise is very very loud).

Predictions of annoyance are based on a family of these transition functions, differing only by spacing along the exposure ($L_{dn}$) axis. It is current practice to calculate $L_{ct}$ to a 0,1 dB precision, over a range of $L_{ct}$ values that go as low or high as the user desires. However, in this part of ISO 1996, the range over which $L_{dn}$ may vary is limited to 45 dB to 75 dB. The user should observe that with the community tolerance level ($L_{ct}$) method, one is not fitting a curve to data, one is fitting data to a curve. Specifically, a set of social survey findings (that is, pairs of $L_{dn}$ and $P_{HA}$ values) is compared with the family of transition function curves. The $L_{ct}$ curve, which the data most closely approximate (as determined by either a maximum likelihood fit or a minimum root-mean-square fit), is used to designate the $L_{ct}$ for those data.

Formula (H.1) shows the prevalence of high annoyance, $P_{HA}$, expressed as a transition function:

$$P_{HA} = 100\ \mathrm{e}^{-x} = 100\ \mathrm{e}^{-\left(\frac{1}{m}\right)^{0,3}} \tag{H.1}$$

where $m$ is a noise dose with units of pressure squared.

NOTE 2 In prior formulations of this predictive function, the exponent is specified as the quotient of a community-specific scalar variable, A, and noise dose, $m$. In the present formulation, the shape of the predictive function is controlled solely by $m$, while the quantity $L_{ct}$ serves to translate the predictive function along the abscissa to a community-specific position.

Specifically, in Formula (H.1), $x$ is given as $1/m$ and the exponent of 0,3 converts pressure squared to a value proportional to loudness. The total noise dose, which is given by $10^{0,1(L_{dn} - L_{ct} + 5,3\,\mathrm{dB})}$, is substituted for $m$ in Formula (H.1), yielding Formula (H.2). Hence, in a community, the prevalence of high annoyance, $P_{HA}$, from a transportation noise source is given as the following:

$$P_{HA} = 100\ \mathrm{e}^{-\left(\frac{1}{10^{0,1(L_{dn} - L_{ct} + 5,3\,\mathrm{dB})}}\right)^{0,3}} \tag{H.2}$$

In Formula (H.2), the quantity $L_{ct}$ is expressed in units of $L_{dn}$.

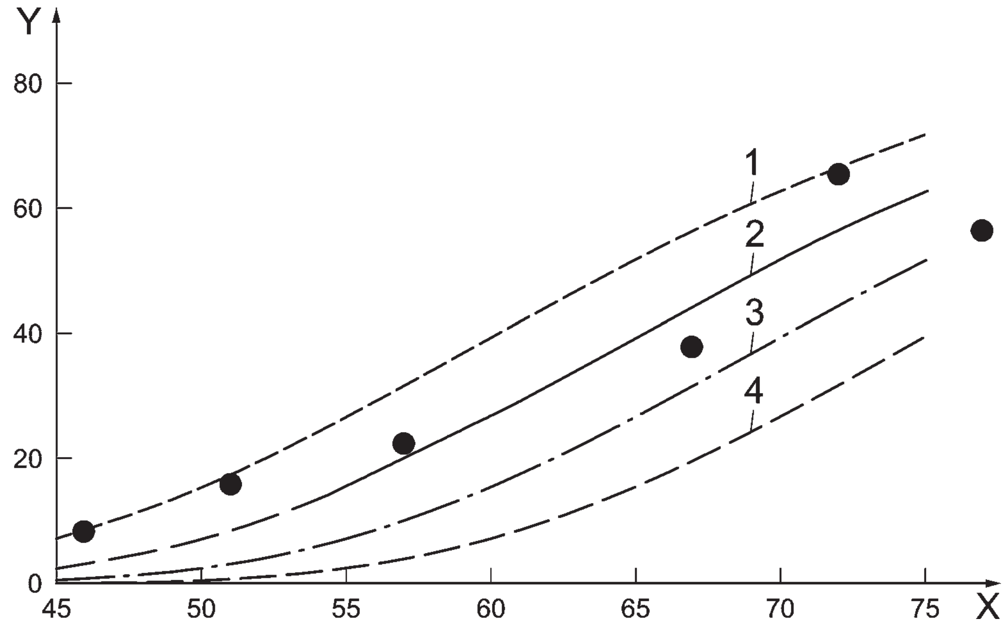
NOTE 3 Formula (H.2) is identical to Formula (E.1).

NOTE 4 A numerical value of $L_{ct}$ found by minimizing the mean square difference between empirically observed percentages and those predicted using Formula (H.2) causes $L_{ct}$ to correspond to the 50 % point, the midpoint of the function. The constant 5,3 dB in Formula (H.2) exactly is 5,306 dB to cause $L_{ct}$ to be the 50 % point. With a different value for this constant, the 10 % point could have been used or the 33,3 % point. The choice of 50 % and the corresponding constant (of about) 5,3 dB was purely arbitrary and was chosen just because 50 % was the midpoint of the distribution. Although arbitrary, once chosen, the 50 % value cannot be changed; it is part of the definition of $L_{ct}$.

In summary, the theory that annoyance is proportional to loudness times duration is supported by the available data and this accounts for deterministic variation. But $L_{dn}$ does not allow different annoyance results for the same dose. With this method, an additional free variable termed $L_{ct}$ is used to account for the statistical variation in the proportionality for different communities, sources, etc.

At the time of publication of this part of ISO 1996, no theory-based method has yet been published for predicting the $L_{ct}$ values in any given community. In practice, the value of $L_{ct}$ for a given community is established by finding the value of $L_{ct}$ that minimizes the root-mean-square (r.m.s.) difference between Formula (H.2) and pairs of empirical ($L_{dn}$ and $P_{HA}$) observations at interviewing sites within a social survey. This is done by translating Formula (H.2) along the $L_{dn}$ axis and computing the r.m.s. values of differences between predicted, according to Formula (H.2), and observed annoyance prevalence rates. Figure H.1 illustrates the process with respect to pairs of ($L_{dn}$ and $P_{HA}$) values observed in an Austrian road traffic social survey.

NOTE 5 While $L_{ct}$ cannot currently be predicted, many general factors that can affect the $L_{ct}$ value are known such as attitudes towards the noise source, community setting (urban, suburban, or rural), characteristics of the sound (impulsive, tonal), and temporal exposure pattern.




**Key**

X day-night sound level $L_{dn}$ in dB

Y prevalence of high annoyance $P_{HA}$ in %

1 64,3 dB

2 69,3 dB

3 74,3 dB

4 79,3 dB

NOTE The best (least-squared) fit of the Austrian road survey data was found to be 69,3 dB. The figure also shows the $L_{ct}$ curve minus 5 dB, plus 5 dB, and 10 dB which is 64,3 dB, 74,3 dB, and 79,3 dB, respectively. This figure shows that all the data are to the right of the 64,3 dB curve, all the data are to the left or just on the 74,3 dB curve, and the data are nowhere near the 79,3 dB curve. In a practical case, one plots, in essence, the $L_{ct}$ for every tenth of a decibel and finds the best fit, the smallest least-squared error. In this case, the smallest least-squared error leads to $L_{ct}$ = 69,3 dB.

**Figure H.1 — Example of fitting a set of data to an $L_{ct}$ curve**

The three major strengths of this theory-based approach are the following:

1) The $L_{ct}$ as a single-number parameter allows for numerical differentiation among differing exposure situations such as between differing modes of transportation, differing factors such as good or poor community relations, differing times of day, differing communities (urban or rural), etc., and as shown in Annex A, differing years.

2) The $L_{ct}$ parameter accounts for 50 % more of the variance than does $L_{dn}$ or $L_{den}$ alone.

3) Finding the $L_{ct}$ for a common group of attitudinal surveys such as all road-traffic surveys allows one to make comparisons between and within modes of transportation. Reference [18] shows the adjustments for different groups of transportation noise sources relative to road-traffic noise as given in Table H.1, which lists the mean $L_{ct}$ and the standard deviation to the data for the four sound sources and conditions.

NOTE 6 Table H.1 repeats material found in Annex E, but is placed here as a summary so that the reader can identify the differences among all the sources found using $L_{ct}$.

**Table H.1 — Mean $L_{ct}$ and standard deviations**

| Source and condition | Mean $L_{ct}$<br>dB | Difference from road traffic<br>dB | Number of surveys | Standard deviation<br>dB | 95 % Prediction interval<br>dB |
|---|---|---|---|---|---|
| Aircraft | 73,3 | 5 | 43 | 7,1 | 73,3 ± 14,2 |
| Road traffic | 78,3 | 0 | 37 | 5,1 | 78,3 ± 10,2 |
| Railroad (low-vibration levels) | 87,8 | −9,5 | 9 | 3,5 | 87,8 ± 7,0 |
| Railroad (high-vibration levels) | 75,8 | 2,5 | 6 | 4,2 | 75,80 ± 8,4 |

One potential use for $L_{ct}$ is to quantify various noise benefits and dis-benefits. Because $L_{ct}$ is a free variable with units of $L_{dn}$, one can envision studies that quantify the answer to such questions as the benefit of sound insulation to dwelling units; the benefits of a “quiet side”; the difference between “highly annoyed”, “moderately annoyed”, and “a little annoyed”; or the dis-benefit of poor community relations.

With further research, it is reasonable to expect that one will be able to predict the $L_{ct}$ of differing communities based on community-wide attributes, standards, and conditions, etc. (see Reference [18]).

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