ANSI S12.9-2005/Part 4
(Revision of ANSI S12.9-1996/Part 4)

AMERICAN NATIONAL STANDARD

Quantities and Procedures for Description and Measurement of Environmental Sound – Part 4: Noise Assessment and Prediction of Long-term Community Response

ANSI S12.9-2005/Part 4

Accredited Standards Committee S12, Noise

Standards Secretariat
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AMERICAN NATIONAL STANDARD

QUANTITIES AND PROCEDURES FOR DESCRIPTION AND MEASUREMENT OF ENVIRONMENTAL SOUND — PART 4: NOISE ASSESSMENT AND PREDICTION OF LONG-TERM COMMUNITY RESPONSE

Secretariat:

Acoustical Society of America

Approved by:

American National Standards Institute, Inc.

Abstract

This Standard specifies methods to assess environmental sounds and to predict the annoyance response of communities to long-term noise from any and all types of environmental sounds produced by one or more distinct or distributed sound sources. The sound sources may be separate or in various combinations. Application of the method of the Standard is limited to areas where people reside and related long-term land uses. This Standard does not address the effects of intrusive sound on people in areas of short-term use such as parks and wilderness areas, nor does it address other effects of noise such as sleep disturbance or health effects. This Standard does not provide a method to predict the community response to short-term, infrequent, non-repetitive sources of sound.

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Foreword

[*This Foreword is for information only, and is not a part of the American National Standard ANSI S12.9 - 2005/Part 4 American National Standard Quantities and Procedures for Description and Measurement of Environmental Sound - Part 4: Noise Assessment and Prediction of Long-Term Community Response.*]

This standard comprises a part of a group of definitions, standards, and specifications for use in noise. It was developed and approved by Accredited Standards Committee S12 Noise, under its approved operating procedures. Those procedures have been accredited by the American National Standards Institute (ANSI). The Scope of Accredited Standards Committee S12 is as follows:

> *Standards, specifications, and terminology in the field of acoustical noise pertaining to methods of measurement, evaluation, and control; including biological safety, tolerance, and comfort, and physical acoustics as related to environmental and occupational noise.*

This standard is a revision of ANSI S12.9-1996/Part 4, which has been technically revised. The changes in this edition harmonize with the new material added to ISO 1996-1:2003. This includes a minor change to high-energy impulse noise assessment (less than 1 dB) so that it is totally in sync with ISO. Second, as appropriate, ISO assessment adjustments have been included. Also, some new cautionary notes from ISO are added to the estimation of "highly annoyed" as notes to the informative annex. A new Annex G addresses complaints in the limited situation of high-energy impulsive noise.

The current edition of ISO 1996-1:2003 actually began as the text of ANSI S12.9 - 1996/Part 4. However, the ISO standard was substantially revised during the WG and committee deliberations. For example, ISO recognizes the more general Day-Evening-Night Sound Level in contrast to S12's Day-Night Sound Level. Nighttime hours are not given in ISO because they vary from country to country. The terms "background" sound and "ambient" sound are NOT used in ISO because they have diametrically opposed meanings in different countries and regions. There are many other differences of this nature. ISO uses "rating" sound level; ANSI uses "adjusted" sound level, etc.

At the time this Standard was submitted to Accredited Standards Committee S12, Noise for approval, the membership was as follows:

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Suggestions for improvements of this standard will be welcomed. They should be sent to Accredited Standards Committee S12, Noise, in care of the Standards Secretariat of the Acoustical Society of America, 35 Pinelawn Road, Suite 114E, Melville, New York 11747-3177. Telephone: 631-390-0215; FAX: 631-390-0217; E-mail: asastds@aip.org

Introduction

0.1 Part 1 of ANSI S12.9 defines day-night average sound level and other descriptors of community noise. Part 2 of ANSI S12.9 describes measurement procedures. ANSI S12.9/Part 5 provides a recommended relation between long-term usages of land and day-night average sound level for purposes of long-term land-use planning. Since the early 1970s, many agencies within the United States of America have used day-night average sound level as the fundamental descriptor to predict the community response to environmental sounds.

0.2 The 1978 seminal paper by T.J. Schultz demonstrated the efficacy of day-night average sound level for predicting the annoyance response of a community as a result of noise from highway traffic, railroad, aircraft, and some industrial sites. Implementation of the concept of day-night average sound level for prediction of community response often combined the sound exposures from such sources.

0.3 Day-night average sound level has been used to predict the annoyance response of communities to types of noises that were not included in the Schultz database for the relation between the percentage of a population expressing high annoyance and the corresponding day-night average sound level. These additional types of noises include sounds with special characteristics, such as impulsiveness, dominant pure tones, rapid onset, and strong low-frequency content.

0.4 Technical reports and articles published in refereed engineering and scientific journals demonstrated that the community response to these sounds may be predicted, provided suitable adjustments are applied. A practical procedure to apply these adjustments is provided by this Standard.

0.5 For situations where activity interference is the major concern, use of adjusted day-night average sound level or adjusted total day-night sound exposure may not be appropriate. For example, day-night average sound level without adjustments may be a better predictor of speech interference than adjusted day-night average sound level. Descriptors such as maximum A-weighted sound level, time-above, or speech interference level may be even more appropriate for predicting speech interference.

American National Standard

QUANTITIES AND PROCEDURES FOR DESCRIPTION AND MEASUREMENT OF ENVIRONMENTAL SOUND — PART 4: NOISE ASSESSMENT AND PREDICTION OF LONG-TERM COMMUNITY RESPONSE

1 Scope

1.1 This Standard specifies methods to assess environmental sounds and to predict the potential annoyance response of a community to outdoor long-term noise from any and all types of environmental sounds from one or more discrete or distributed sound sources. The sound sources may be separate or in various combinations. Application of the prediction method is limited to areas where people reside and to related long-term land uses.

NOTE The long-term period is typically one year. However, the user of this Standard can employ these methods for shorter periods of time, but they should report this change and not attempt to predict percent highly annoyed using Clause 8.3 or Annex F, since the Annex F data all represent long-term situations.

1.2 This Standard describes adjustments for sounds that have special characteristics so that the long-term community response to such sounds can be predicted by a method that is based on day-night average sound level or total day-night sound exposure. Sounds, such as from highway traffic, are evaluated directly by sound exposure or sound level without adjustment. The prediction method is directly analogous to the use of day-night average sound level to predict the response of a community to general environmental sounds.

1.3 This Standard does not address the effects of short-term exposure of people to intrusive sounds in locations such as parks and wilderness areas. The Standard also does not address other effects of noise such as sleep disturbance or health effects. This Standard does not provide a method to predict the response of a community to short-term, infrequent, non-repetitive sources of sound.

1.4 This Standard introduces the application of new descriptors: adjusted sound exposure and adjusted sound exposure level. The new descriptors are closely related to sound exposure and sound exposure level, respectively. The new descriptors are introduced to facilitate the prediction of the response of communities to the wide range of outdoor sounds covered by the scope of the Standard.

1.5 The sounds are assessed either singly or in combination, allowing for consideration, when necessary, of the special characteristics of impulsiveness, tonality, onset rate, and low-frequency content. In the same manner as sound exposure and sound exposure level are used to generate total day-night sound exposure or total day-night average sound level, adjusted sound exposure or adjusted sound exposure level are used to generate adjusted total day-night sound exposure or adjusted day-night average sound level.

1.6 Annoyance is not the only possible measure of community response. One frequently cited measure is numbers of complaints, sometimes normalized to numbers of inhabitants. Complaints can be particularly relevant near factories and plants, by airports and military installations, etc. Complaints do not correlate well with long-term average metrics such as DNL (see Refs. 7 and 8 for example). Unfortunately, in general, metrics to predict the likelihood and prevalence of complaints do not yet exist with sufficient accuracy. One notable exception is the high-energy impulse sound generated by military activities and similar civilian noise sources, and informative Annex G provides procedures for assessing the risk of noise complaints from such sources.

1.7 The addition of adjustments eliminates the possibility to measure the total adjusted sound exposure or sound exposure level in a general situation that comprises a variety of sound sources (e.g., the combination of a highway leading to an airport and the airport itself). As a possible measurable alternative, this Standard introduces a new metric based on the equal-loudness level contours that were contained in ISO 226:1987. This new method uses the equal-loudness level contours as a set of dynamic filters that vary both with amplitude and frequency. This method is described in informative Annex H.

2 Normative references

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

[1] ANSI S1.1-1994 (R 2004) *American National Standard Acoustical Terminology.*

[2] ANSI S12.9-1988/Part 1 (R 2003) *American National Standard Quantities and Procedures for Description and Measurement of Environmental Sound - Part 1.*

[3] ANSI S12.9-1992/Part 2 (R 2003) *American National Standard Quantities and Procedures for Description and Measurement of Environmental Sound - Part 2: Measurement of Long-Term Wide-Area Sound.*

[4] ANSI S12.9-1993/Part 3 (R 2003*) American National Standard Quantities and Procedures for Description and Measurement of Environmental Sound - Part 3: Short-term Measurements with an Observer Present.*

[5] ANSI S12.9-1998/Part 5 (R 2003) *American National Standard Quantities and Procedures for Description and Measurement of Environmental Sound - Part 5: Sound Level Descriptors for Determination of Compatible Land Use.*

[6] ANSI S1.13-2005 *American National Standard Methods for the Measurement of Sound Pressure Levels in Air.*

3 Terms and definitions

For the purposes of this standard, the terms and definitions given in ANSI S1.1-1994 and the following apply:

3.1(a) adjusted sound exposure. Frequency-weighted sound exposure adjusted for the change in annoyance caused by certain impulsive sounds, the presence of prominent discrete-frequency tones, sounds that startle because of their rapid onset rate, sounds with strong low-frequency content, and the presence of masking background sound. Unit, pascal-squared second (Pa^2s); symbol, N.

NOTE 1 Adjustments and frequency weightings for various types of sounds are given in Clause 7.

NOTE 2 The unit of pascal-squared second for adjusted sound exposure has been abbreviated as “pasque.”

3.1(b) reference sound exposure. The product of the square of the reference sound pressure of 20 μPa and the reference time of 1 s. Unit, pascal-squared second (Pa^2s); symbol, E_0.

3.1(c) adjusted sound exposure level. Ten times the base-10 logarithm of the ratio of the adjusted sound exposure to the reference sound exposure E_0. Unit, decibel (dB); symbol, L_{NE}.

3.2 adjusted total day-night sound exposure. Frequency-weighted sound exposure for a 24-hour day calculated by adding adjusted sound exposure obtained during the daytime (0700-2200 hours) to ten times adjusted sound exposure obtained during the nighttime (0000-0700 and 2200-2400 hours). Unit, pascal-squared second (Pa^2s); symbol, N_{dn}.

3.3(a) adjusted day-night average sound pressure. Square root of ratio of adjusted total day-night sound exposure to 86,400 s. Unit, pascals (Pa).

3.3(b) adjusted day-night average sound level. Ten times the base-10 logarithm of the ratio of the square of the adjusted day-night average sound pressure to the square of the reference sound pressure of 20 μPa. Unit, decibel (dB); symbol, $L_{N\mathrm{dn}}$.

3.4 impulsive sound. Sound characterized by brief excursions of sound pressure (acoustic impulses) that significantly exceed the ambient environmental sound pressure. The duration of a single impulsive sound is usually less than one second.

NOTE At the time of publication, no mathematical descriptor existed to unequivocally define the presence of impulsive sound or to separate impulsive sounds into categories.

3.4.1 highly impulsive sound. Sound from one of the following enumerated categories of sound sources: small-arms gunfire, metal hammering, wood hammering, drop hammering, pile driving, drop forging, pneumatic hammering, pavement breaking, metal impacts during rail-yard shunting operation, and riveting.

3.4.2 high-energy impulsive sound. Sound from one of the following enumerated categories of sound sources: quarry and mining explosions, sonic booms, demolition and industrial processes that use high explosives, military ordnance (e.g., armor, artillery and mortar fire, and bombs), explosive ignition of rockets and missiles, explosive industrial circuit breakers, and any other explosive source where the equivalent mass of dynamite exceeds 25 g. Normally, for single impulsive sounds of concern for this Standard, the A-weighted sound exposure level will exceed 65 dB and the C-weighted sound exposure level will exceed 85 dB.

3.4.3 regular impulsive sound. Impulsive sound that is not highly impulsive sound or high-energy impulsive sound.

3.5 onset rate. Nominally, the average rate of change of sound level during the onset of a noise event. Mathematically, onset rate is the rate of change of the A-weighted event sound level between the time the event sound level first exceeds the ambient sound level by 10 dB, and the time the event sound level first exceeds a level that is 10 dB less than the event's maximum fast-time-weighted sound level. Onset rate is defined for those event sound levels for which the maximum A-frequency-weighted, fast-time-weighted sound level exceeds the ambient sound level by at least 30 dB. Unit, decibels per second (dB/s).

NOTE 1 The nominal 125-ms time constant of fast time weighting normally is not small enough to accurately determine onset rate. Onset rate should be determined from the time variation of the level of the squared sound pressure. A digital system that provides a series of short-time-average sound levels may be used. In this case, the averaging time for each sound level in the series should be no greater than 1/10 and no less than 1/25 of the time span over which the onset rate is determined. A digital or analog system with exponential time weighting also may be used. In this case, the exponential time constant should be no greater than 1/4 and no less than 1/10 of the time span over which the onset rate is determined.

NOTE 2 A determination of onset rate should not be unduly influenced by anomalous fluctuations in the sound level.

3.6 time above. The time per stated unit time interval that the sound pressure level exceeds a criterion level (e.g., 30 s per hour). The frequency weighting or filtering (e.g., A-weighting), time weighting or integration time interval, and the unit time interval all must be stated. Typical Units: seconds (s) or minutes.

4 Descriptors for environmental sounds

4.1 Single-event sounds

4.1.1 Descriptors

Sounds from single events such as the passby of a truck, the flyby of an airplane, or an explosion at a quarry are all examples of single-event sounds. Each sound can be characterized by many descriptors. These descriptors include physical quantities and the corresponding levels in decibels. The level of a descriptor and its corresponding physical quantity form a descriptor pair. Three descriptor pairs often are used to describe the sound of single events. For each of these, frequency-weighting A is understood except for high-amplitude impulsive sounds or sounds with strong low-frequency content. The preferred three descriptor pairs are:

peak (frequency-weighted) sound pressure and peak (frequency-weighted) sound pressure level;

maximum exponential-time-weighted sound pressure and maximum sound level; and

sound exposure and sound exposure level.

NOTE 1 For the above descriptor pairs, the frequency weighting should be specified if frequency-weighting A is not employed, e.g., as peak C-weighted sound pressure level, C-weighted sound exposure level.

NOTE 2 For maximum sound pressure (and maximum sound level), the exponential-time-weighting should be specified, e.g., as fast (F) or slow (S).

4.1.2 Event duration

Event duration shall be specified relative to some characteristic of the sound such as the time of occurrence of the maximum sound level or the time some threshold was exceeded. For example, duration may be the total time that the sound level is within 10 dB of the maximum sound level.

4.2 Continuous sounds

Environmental sounds from sources such as transformers, fans, or cooling towers are examples of continuous sounds. Amplitudes of continuous sounds may be constant or slowly varying. Each sound can be characterized by many descriptors. Two descriptor pairs are commonly used to describe a continuous sound. For each of these, frequency-weighting A is commonly used. The two preferred descriptor pairs are:

maximum (exponential-time-weighted) sound and maximum sound level; and

time-average sound pressure and time-average (equivalent-continuous) sound level.

NOTE 1 For both of the above descriptors, the frequency weighting should be specified if frequency-weighting A is not employed.

NOTE 2 For maximum (exponential-time-weighted) sound (and maximum sound level), the exponential-time weighting should be specified, e.g., as fast (F) or slow (S).

NOTE 3 See Clauses 5.1.4, 5.1.5, and 5.1.6 in ANSI S12.9-1988/Part 1 (R2003) for definitions of these quantities.

4.3 Repetitive single-event sounds

Repetitive single-event environmental sounds typically are recurrences of single-event sounds. For example, during a day, the sound from traffic on a highway is the sum of the sound from multiple individual vehicle passbys. In this Standard, all repetitive single-event sounds utilize the descriptor for the particular single-event sounds and the corresponding number of events.

5 Sound measurement locations

All sounds, except high-energy impulsive sounds, shall be measured or predicted as if they had been measured by a microphone outdoors, over acoustically absorptive ground (grass), at a height of approximately 1.2 m and with no nearby reflecting surfaces except the ground. Alternative microphone locations may be used, but their acoustical characteristics shall be specified. An example of an alternative location is outside an open, upper-story window in a high-rise apartment building where the purpose is to predict or assess the environmental sound at that location. High-energy impulsive sounds shall be measured or predicted as if they had been measured by a microphone within 50 mm of a hard reflecting surface (e.g., a building wall, roof, or ground plane, as appropriate).

NOTE 1 A reflecting surface is required because sonic booms, which are one form of high-energy impulsive sounds, have traditionally been measured or predicted for a location on a reflecting ground plane or structure.

NOTE 2 To ensure comparable data, sonic booms should be measured on a reflecting ground plane or other equivalent structure.

6 Adjustments for background sound

6.1 General

Annex A discusses a general method to include adjustments for background sound. The general method is applicable to three cases: (1) the sound of concern is very noticeable and detectable in the background setting of interest, (2) the sound of concern is virtually unnoticeable and undetectable in the background setting of interest, and (3) the sound of concern is in a range such that it may be noticeable and detectable only for a portion of the time.

6.2 Specific requirements

When the conditions of 6.1(2) apply and the sound is virtually unnoticeable and undetectable in the background setting of interest, then its sound exposure shall not be included in a calculation of the total sound exposure from multiple sound sources. If some particular sound is excluded, then the physical background setting shall be specified. For example, this setting may be “urban residential not near an arterial street, outdoors," or "suburban residential indoors with windows partially open," or "urban residential near an arterial street, indoors with windows closed."

NOTE Direct measurements may be used to determine the background sound level prevailing for the environment. Procedures in Part 3 of ANSI S12.9 should be used to measure the background sound level.

Alternatively, the nominal background sound levels given in Part 3 of ANSI S12.9 may be used for various urban environments.

7 Method to assess environmental sounds either singly or in combination

This Standard permits assessment of environmental sounds from individual sources or any combination of sources. If the sound has special characteristics or unusual community response, then adjusted sound exposure or adjusted sound exposure level shall be used to describe the source(s) of sound. In addition, the total adjusted sound environment shall include a weekend daytime adjustment, and is used to predict long-term community response.

7.1 General environmental sounds

General environmental sounds are assessed using frequency-weighting A. (Environmental sounds with special characteristics are described in 7.2.) Sound exposure, sound exposure level, total time-period sound exposure, time-average sound level, total day-night sound exposure, and day-night average sound level are the preferred descriptors. The exposure method of presentation is described in 7.1.1, the left-hand column below. The level method of presentation is described in 7.1.2, the right-hand column below.

7.1.1 Exposure method	7.1.2 Level method
7.1.1.1 Sound exposure Sound exposure is a descriptor for characterizing the sound from individual acoustical events. For individual single-event sounds such as vehicle passbys, sound exposure may be directly measured or predicted for the sound-producing events under consideration. For a continuous source, the total time-period sound exposure may be measured or predicted for the time period of interest. A-weighted sound exposure E_A, in pascal-squared seconds, may be calculated as the product of the time-mean-squared, A-weighted sound pressure $\overline{p_A^2}$ in pascals squared and the duration, in seconds, of the time period of interest T, i.e., as $E_A = \overline{p_A^2}T$. (1a)	**7.1.2.1 Sound exposure level** Sound exposure level is a descriptor for characterizing the sound from individual acoustical events. For individual single-event sounds such as vehicle passbys, sound exposure level may be directly measured or predicted for the sound-producing events under consideration. For a continuous source, the sound exposure level may be measured or predicted for the time period of interest. A-weighted sound exposure level L_{AE}, in decibels, may be calculated as ten times the base-10 logarithm of the ratio of the A-weighted sound exposure E_A to the reference sound exposure E_0 defined in 3.1(b), i.e., as $L_{AE} = 10 \lg (E_A/E_0)$. (1b)

7.1.1.2 Total sound exposure

Total sound exposure may be used to characterize the sound of one or more events from individual or combined sources of sound during a time period of interest such as the hour from 1600 to 1700, daytime from 0700 to 2200, or nighttime from 2200 to 2400 and 0000 to 0700. Total A-weighted sound exposure in a time period $E_{A(period)}$, in pascal-squared seconds, is the sum of the N sound exposures E_{Ai} from the i-th individual single-event sounds during the stated time period.

In mathematical notation,

$$E_{A(period)} = \sum_{i=1}^{N} E_{A\,i} \,. \qquad (2a)$$

NOTE The stated time period may be of any duration such as one daytime period for one day or for any number of days up to 365 days of a year. Furthermore, the sound exposure E_{Ai} for the i-th event may be for any one sound source or a combination of sources.

7.1.2.2 Time-average sound level

Time-average sound level may be used to characterize the sound of one or more events from individual or combined sources of sound during a time period of interest such as the hour from 1600 to 1700, daytime from 0700 to 2200, or nighttime from 0000 to 0700 and 2200 to 2400. Time-average, A-weighted sound level $L_{A(period)}$, in decibels, is calculated from the total sound exposure in the period.

In mathematical notation,

$$L_{A(period)} = 10 \lg \left[(T_0 / T) \sum_{i=1}^{I} 10^{0.1 L_{AEi}} \right], \qquad (2b)$$

where T_0 is the reference time of 1 s and T is the total time period in seconds for the duration of the time average.

NOTE For a constant time-average sound level of 60 dB, sound exposure level $L_{AE(period)}$ and sound exposure $E_{A(period)}$ are related as shown in Table 1 for selected integration time periods T.

7.1.1.3 Total day-night sound exposure

Total day-night sound exposure is a descriptor for characterizing long-term acoustical environments from sounds of one or more events from individual or combined sound sources. Total day-night sound exposure E_{Adn}, in pascal-squared seconds, is the sum of daytime sound exposures plus 10 times the sum of nighttime sound exposures where daytime is the 15 hours from 0700 to 2200 and nighttime is the nine hours from 0000 to 0700 and from 2200 to 2400 in any 24-hour day.

In mathematical notation,

$$E_{Adn} = \sum_{i=1}^{N_d} E_{A\,i} + 10 \sum_{i=1}^{N_n} E_{A\,i} \,, \qquad (3a)$$

$$= E_{Ad} + 10 E_{An} \,,$$

where N_d is the number of daytime sound exposures and N_n is the number of nighttime sound exposures.

7.1.2.3 Day-night average sound level

Day-night average sound level is a descriptor for characterizing long-term acoustical environments from sounds of one or more events from individual or combined sound sources. Day-night average sound level, in decibels, is calculated from ten times the base-10 logarithm of the sum of the daytime sound exposures plus the nighttime sound exposures, where sound exposure levels or sound levels occurring during nighttime hours are weighted by 10 dB.

In mathematical notation,

$$L_{dn} = 10 \lg \left[(15/24)(T_0 / T_d) \sum_{i=1}^{N_d} 10^{0.1 L_{AEi}} \right] + 10 \lg \left[(9/24)(T_0 / T_n) \sum_{i=1}^{N_n} 10^{0.1 (L_{AEi} + 10)} \right] \qquad (3b)$$

$$= 10 \lg \left[(15/24) 10^{0.1 L_d} + (9/24) 10^{0.1 (L_n + 10)} \right]$$

where T_d = the 15 daytime hours or 54,000 s and T_n = the 9 nighttime hours or 32,400 s.

Table 1 — Relation between sound exposure level and sound exposure for a constant sound level of 60 dB.

T	$L_{AE(\text{period})}$ (dB)	$E_{A(\text{period})}$ (Pa^{2}s)	T	$L_{AE(\text{period})}$ (dB)	$E_{A(\text{period})}$ (Pa^{2}s)
1 s	60.0	0.0004	1 h	95.6	1.44
1 min	77.8	0.024	24 h	109.4	34.6

NOTE A day-night sound exposure of 10 Pa^{2}s corresponds to a nominal day-night average sound level of 55 dB. A day night average sound level of 65 dB corresponds to a nominal total day-night sound exposure of 100 Pa^{2}s.

7.2 Adjustments to general environmental sound

Research has shown that frequency-weighting A, alone, is not sufficient to assess sounds characterized by tonality, impulsiveness, very fast onset rates, or strong low-frequency content. Also, research has shown that frequency-weighting A, alone, under-predicts the community response to aircraft noise and to weekend daytime noise. To predict the long-term response of a community to sounds with some of those special characteristics, sources, or times of occurrence, an adjustment factor is used to multiply the sound exposure or an adjustment in decibels is added to the A-weighted sound exposure level. Annex H contains a bibliography of reports and articles describing the technical basis of the assessment and prediction methods of this Part 4.

Sound exposure and sound exposure level as discussed in 7.1.1.1 and 7.1.2.1 are descriptors for characterizing the environmental sound from individual acoustical events. Frequency weighting A is used for all sound sources except (1) high-energy impulsive sounds for which frequency-weighting C is used, and (2) sounds with strong low-frequency content. Adjusted sound exposure is the quantity used in this Standard to assess sounds without and with special characteristics with respect to the potential community response. For general environmental sounds without special characteristics (i.e., sounds assessed by the method of 7.1), adjusted sound exposure is numerically equal to A-weighted sound exposure.

For sounds with special characteristics, sources, or times of occurrence, the calculation of adjusted sound exposure or adjusted sound exposure level is performed as described below. The adjusted exposure method of presentation is described in 7.2.1, the left-hand column below. The adjusted level method of presentation is described in 7.2.2, the right-hand column below.

7.2.1 Adjusted exposure method	**7.2.2 Adjusted level method**
7.2.1.1 Adjusted sound exposure For any sound except high-energy impulsive sound or sounds having strong low-frequency content, adjusted sound exposure N_j is given by the sound exposure E_i for the i-th single-event sound multiplied by the adjustment factor K_j for the j-th type of sound, as given in Table 2. In mathematical notation, $N_j = K_j E_i$. (4a)	**7.2.2.1 Adjusted sound exposure level** For any sound except high-energy impulsive sound or sounds having strong low-frequency content, adjusted sound exposure level L_{Nj} is given by the sound exposure level L_{Ei} for the i-th single-event sound plus the level adjustment $\overline{K}_i$ for the j-th type of sound, as given in Table 2. In mathematical notation, $L_{Nj} = L_{Ei} + \overline{K_j}$. (4b)

Equations to convert between adjusted sound exposure, in pascal-squared seconds, and adjusted sound exposure level, in decibels, are:

$$L_{Nj} = 10\,\lg(N_j / p_0^2 T_0) = 10\,\lg(N_j / T_0) + 94 \tag{5a}$$

$$N_j = (T_0)10^{0.1(L_{Nj} - 94)}, \tag{5b}$$

where $-10\,\lg(p_0^2) = 94$ dB and T_0 is the reference time of 1 s.

7.2.1.2 Adjusted total sound exposure

During a time period of interest such as daytime, the adjusted total sound exposure $N_{(\text{period})}$, in pascal-squared seconds, is the sum of the adjusted sound exposures N_{ij} from each individual event i of I events, for each source of sound j of J sources during the stated time period.

In mathematical notation,

$$N_{(\text{period})} = \sum_{i=1}^{I} \sum_{j=1}^{J} N_{ij}\,. \tag{6a}$$

The stated time period may be of any duration such as one daytime period for one day or for any number of days up to 365 days of a year. Furthermore, the adjusted sound exposure N_{ij} for the i-th event may be for any one source j or a combination of sources.

In equation (6a), sounds without special characteristics are included with an adjustment factor of 1 as shown in Table 2.

7.2.2.2 Adjusted time-average sound level

During a time period of interest such as daytime, the adjusted time-average sound level $L_{N(\text{period})}$, in decibels, is calculated from the adjusted sound exposure levels L_{Nij} from each individual event i of I events, for each source of sound j of J sources during the stated time period.

In mathematical notation,

$$L_{N(\text{period})} = 10\,\lg\left[(T_0 / T)\sum_{i=1}^{I} \sum_{j=1}^{J} 10^{0.1 L_{Nij}}\right]. \tag{6b}$$

The stated time period T, in seconds, may be of any duration such as one daytime period for one day or for any number of days up to 365 days of a year. Furthermore, the adjusted sound exposure level L_{Nij} for the i-th event may be for any one source j or a combination of sources.

In equation (6b), sounds without special characteristics are included with a level adjustment of 0 as shown in Table 2.

For an averaging time period T in seconds, equations to convert adjusted total sound exposure in pascal-squared seconds and adjusted time-average sound level in decibels are:

$$L_{N(\text{period})} = 10\,\lg(N_{(\text{period})} / p_0^2 T_0) - 10\,\lg(T / T_0) = 10\,\lg(N_{(\text{period})} / T) + 94 \tag{7a}$$

$$N_{(\text{period})} = (T)10^{0.1(L_{N(\text{period})} - 94)} \tag{7b}$$

7.2.1.3 Adjusted total day-night sound exposure	**7.2.2.3 Adjusted day-night average sound level**
Adjusted total day-night sound exposure is similar to total day-night sound exposure, but includes the adjustment factors described in Table 2. Adjusted nighttime sound exposures are weighted by a factor of 10. The mathematical formulation of adjusted total day-night sound exposure N_{dn} is similar to that for total day-night sound exposure described in 7.1.1.3.	Adjusted day-night average sound level is similar to day-night average sound level, but includes the level adjustments described in Table 2. Ten decibels are added to adjusted nighttime sound exposure levels. The mathematical formulation of adjusted day-night average sound level $L_{N\mathrm{dn}}$ is similar to that for day-night average sound level described in 7.1.2.3.

For a time period T_{dn} of 24 h or 86,400 s, equations to convert adjusted day-night average sound level $L_{N\mathrm{dn}}$ in decibels and adjusted total day-night sound exposure N_{dn} in pascal-squared seconds are:

$$\begin{aligned} L_{N\mathrm{dn}} &= 10\ \lg(N_{\mathrm{dn}}\ /\ p_0^2 T_0) - 10\ \lg(T_{\mathrm{dn}}\ /\ T_0) \\ &= 10\ \lg\ (N_{\mathrm{dn}}\ /\ T_0) + 44.6 \end{aligned} \tag{8a}$$

$$N_{\mathrm{dn}} = (T_0)10^{0.1(L_{N\mathrm{dn}} - 44.6)}, \tag{8b}$$

where $-10\ \lg(p_0^2) - 10\ \lg(T_{\mathrm{dn}}/T_0) = 94 - 49.4 = 44.6$ dB, and $T_0 = 1$ s.

Table 2 — Adjustment factors and level adjustments for assessment of all types of environmental sounds.

Sound source		K_j		$\overline{K}_j = 10\lg(K_j)$	
Factor	Type	Symbol	Value	(dB)	Condition
without special characteristics	general broadband sound (e.g., road traffic)	K	1	0	…
Special characteristics	regular impulsive	K_I	3	5	…
	highly impulsive	K_I	16	12	…
	high-energy impulsive				see Annex B
	rapid onset rate R	K_R	1	0	R < 15 dB/s
		K_R	$10^{1.1\ \lg(R/15)}$	11 lg(R/15)	15 ≤ R < 150 dB/s
		K_R	12.6	11	R ≥ 150 dB/s
	tonal	K_t	3	5	see Annex C
	strong low-frequency content				see Annex D
Sources	aircraft	K_A	1	0	DNL<55
		K_A	10*lg(DNL-55)	DNL-55	55<DNL<60
		K_A	3	5	DNL≥60
Time of Day	nighttime	K_N	10	10	
Day of the Week	weekends, daytime	K_W	3	5	

NOTE 1 If more than one special characteristic adjustment applies to a given single sound source such as a fan, only the largest adjustment shall be applied. Time-of-day and day-of-the-week adjustments are always included in addition to other adjustments, if any.

NOTE 2 Each adjusted sound exposure N_{ij} is calculated from its corresponding sound exposure level L_{AEij} and adjustment factor K_j according to

$$N_{ij} = (K_j)[(T_0)(10^{0.1(L_{AEij}-94)})]. \tag{9}$$

NOTE 3 Each adjusted sound exposure level L_{Nij} is calculated from its corresponding sound exposure level and level adjustment $\overline{K}_j$ according to

$$L_{Nij} = L_{AEij} + \overline{K}_j . \tag{10}$$

NOTE 4 If sounds are not audible at the location of interest, then the concepts of Clause 6 apply and the adjusted sound exposure for those sounds shall not be included in the total.

NOTE 5 The assessment method for essentially continuous sounds with strong low-frequency content shall not be applied unless the time-average C-weighted sound level exceeds the A-weighted sound level by at least 10 dB.

NOTE 6 Normally, the onset rate is measured. Annex E provides an approximate method to calculate the onset rate for low-flying airplanes.

NOTE 7 If highly impulsive sounds occur at a rate greater than about 20 per second, then the sounds usually are not perceived as distinct impulses and no adjustment shall be applied. If the rate is regular and greater than 30 per second, then a tone will be perceived and a tonal adjustment may be required. If the rate is irregular and greater than 20 per second, then the highly impulsive sounds will appear to merge into a broadband noise-like sound and no adjustment shall be applied.

8 Reporting assessments of environmental sounds and prediction of long-term community annoyance response

8.1 Use of A-weighted sound exposure and day-night average sound level

If the acoustical environment includes only sounds having no special characteristics, then adjusted sound exposure is numerically equal to the sound exposure. All reporting then shall be in terms of A-weighted day-night average sound level or A-weighted sound exposure. If the acoustical environment includes any combination of sounds having special characteristics, then the numerical description of the total acoustical environment shall be reported in terms of adjusted sound exposure or adjusted sound exposure level. This procedure is required because adjusted sound exposure and adjusted sound exposure level are not measured quantities.

8.2 Assessment of environmental sounds

A measurement or calculation of the (adjusted) total sound exposure or time-average sound level shall be used to assess environmental sounds.

To predict or measure the (adjusted) total sound exposure or time-average sound level during a time period of interest, (adjusted) sound exposures shall be summed over the duration of the stated time period, typically, for some hour of the day, all day, all night, or a combination of the day-night sound or (adjusted) day-night sound exposure.

For example, for an airport, factory, or highway, one might measure or calculate the annual average total day-night sound exposure or annual average adjusted total day-night sound exposure on an average day by summing the total sound exposure or adjusted total sound exposure throughout the year using equations (1a) or (6a), respectively, and then dividing by 365.

NOTE The user of this Standard can employ these methods for shorter periods of time, but they should report this change and not attempt to predict percent highly annoyed using Clause 8.3 or Annex F, since the Annex F data all represent long-term situations

8.3 Prediction of long-term annoyance response of communities

Annual average (adjusted) total day-night sound exposure or annual average (adjusted) day-night average sound level is needed to predict the long-term annoyance response of a community.

Table F.1 in Annex F may be used to predict the percentage of a population that is likely to be highly annoyed by the environmental sound with that annual average (adjusted) total day-night sound exposure or that annual average (adjusted) day-night average sound level.

8.4 Reporting

Reporting shall include the following:

a) the stated time period (e.g., daytime, 1600 to 1700 hours);

b) the day or days included in the time average;

c) the adjusted time-period total sound exposure or adjusted time-period time-average sound level;

d) a description of the sound source or sources included in the total time period;

e) a description of the measurement or prediction site;

f) a description of any procedures used in accordance with Clause 7 and Annex A to correct for contamination by background sound and a description of the background sound; and

g) the results of the prediction of long-term annoyance response of the community.

NOTE The stated time period may be for any duration such as one daytime period for one day or for any number of days up to 365 days of a year. Furthermore, the sound exposure or adjusted sound exposure, E_{Aj} or N_j, for the j-th source, may be for any one source or a combination of sources.

Annex A

(informative)

Adjustments for background sound

A.1 Introduction

A.1.1 General

Analysis of the annoyance generated by any given source of community noise is usually based on the assumption that the given source is the primary source of noise, and that the annoyance is not influenced by the presence (or absence) of sounds from other sources. For example, airports or roadways are often assessed as if they were the only source of sound.

Because there almost always is noise from more than one source, two questions arise:

1) When does the amplitude of the sound from other sources become sufficient in magnitude to modify the annoyance generated by the source under evaluation?

2) Under what circumstances does the presence of sound from one source alter the annoyance caused by another source?

A.1.2 Background sound

Background noise is defined in ANSI S1.1 as "the total of all sources of interference in a system used for the production, detection, measurement, or recording of a signal, independent of the presence of the signal." For the purposes of this annex, background sound is the total of all sounds produced by sources other than the one for which the annoyance response is being evaluated. The amplitude of the background sound can be continuous or time-varying. Background sound may be produced by a variety of sources.

A.1.3 Background sound situations

There are at least two situations when background sound may influence or alter the presumed relation between annoyance and a physical measure of the sound for a given type of noise:

1) Masking is present when the threshold of detection of one sound is raised by the presence of another (masking) sound. Masking may be of varying degree, with complete masking resulting in the inaudibility (and resulting absence of annoyance) of the sound signal under evaluation. Given the time varying nature of many community sounds and their differences in spectral composition, the degree of masking is difficult to determine in most situations unless the differences between the time-average sound levels of the different sources are at least 20 dB.

NOTE A masking analysis requires comparison of sound pressure levels in different frequency bands. Sounds having similar A-weighted sound levels may have quite different spectral content. Hence, it is impossible to determine the degree of masking from A-weighted sound levels.

2) The presence of sound from one source may alter an evaluation of the annoyance of the sound from another source. For example, at an outdoor music concert, one might be mildly annoyed by the noise from an aircraft flyover occurring during an intermission, but be highly annoyed by a similar

noise intrusion during the musical performance, even though the background sound levels during the intermission and performance are the same.

Alternatively, one might ask whether the presence of intrusive sounds from one source alters the annoyance resulting from another intermittent sound, even though no masking of sounds may occur. (An example of this situation might be the evaluation of aircraft noise at a location exposed to noise from trains.)

NOTE The influence of interactions between sound sources, outlined in the alternative situation above, is usually difficult to determine or is unknown, and is ignored in the analysis given in this annex.

A.2 Mathematical development

A.2.1 Single-event sounds

For single-event sounds, N_{ij} is the adjusted sound exposure produced by a discrete event i and sound type j. K_{Bij} is the background sound adjustment factor for event i and sound type j. In the absence of noise from other sources, K_B equals 1. In the presence of noise from other sources K_B may vary from 1 to 0. With complete masking from other sources, $K_B = 0$.

Background sound adjustments are equivalent to changes in the noise adjustment factor K_B as a consequence of masking by other sound sources.

A.2.2 Continuous, or near-continuous, sounds and single-event sounds

For continuous, or near-continuous, sounds, time-average, A-weighted sound level is symbolized by L_{Acont} during the stated averaging time T.

Consider a situation where there are two sources of single-event sound [for example, (1) trains for which the adjusted sound exposures are N_{1i} and (2) aircraft for which the adjusted sound exposures are N_{2i}] and one source of continuous sound. The total adjusted sound exposure N_T for the three sources over time duration T is determined from

$$N_T = \sum_{i=1}^{I1} (N_{1i})(K_{B1i}) + \sum_{i=1}^{I2} (N_{2i})(K_{B2i}) + \left[10^{0.1(L_{Acont} - 94)}\right](T)(K_{Bcont}). \tag{A.1}$$

NOTE 1 This 3-source example may be expanded to include any number of different sources of single-event or continuous sounds.

NOTE 2 I1 is the number of trains and I2 is the number of aircraft during time duration T.

For the situation where the single-event sounds for each source occurring during a time period of duration T are nearly equal (i.e., the sound exposure levels and maximum A-weighted sound levels are nearly equal), equation (A.1) is replaced by

$$
\begin{aligned}
N_T = {} & (I1)(N_{1i})(K_{B1i}) + \\
& (I2)(N_{2i})(K_{B2i}) + \\
& \left[10^{0.1(L_{\mathrm{Acont}} - 94)}\right](T)(K_{\mathrm{Bcont}}) .
\end{aligned}
\tag{A.2}
$$

A.3 Background sound adjustment situations

There are three groups of situations where background sound adjustments may need to be considered.

A.3.1 Situations having little need for background sound adjustments

A.3.1.1 Maximum single-event sound level much greater than the sound level of the continuous sound source

When the maximum A-weighted sound levels of individual noise events from two sources are at least 15 dB greater than the time-average A-weighted sound level of the continuous sound source, and the number of individual noise events is not large (so that the probabilities of individual noise events from the two sources occurring at the same time are small), then there is little need for background sound adjustment to the sound exposures from the individual noise events. Hence, in this situation, background sound adjustment factors K_{B1i} and K_{B2i} in equations (A.1) and (A.2) remain equal to 1.0.

A.3.1.2 Few individual noise events

The impact of sound from individual sources on the background sound adjustment factor for continuous sound K_{Bcont} is negligible if there are only a few individual noise events from the sources. In this situation there is little likelihood of K_{Bcont} changing from a value of 1.

A.3.1.3 Many individual noise events

When there are many noise events from individual sound sources, separately or in combination, the total adjusted sound exposure from these sources is likely to be much larger than the sound exposure for the continuous noise. In this situation the contribution from the continuous sound source will have little effect on the total adjusted sound exposure.

A.3.2 Situations where background sound adjustments may be needed

A.3.2.1 Maximum single-event sound level nearly equal to the sound level of the continuous sound source

When the maximum A-weighted sound levels of individual single-event sounds from either of the two example sources, or both, are within 10 dB of the time-average A-weighted sound level, background sound adjustments K_{B1} and/or K_{B2} are needed because of partial masking. In this situation, a value of K_{B1} and/or K_{B2} equal to ½ may be appropriate.

A.3.2.2 Many individual noise events from either of both sound sources

When the maximum A-weighted sound levels of individual noise events from the two example sound sources are of the same order of magnitude and when the number of noise events from one or both sources is large, background sound adjustments K_{B1} or K_{B2}, or both, are needed because of partial masking of one individual noise event by another. In this situation, a value of K_{B1} and/or K_{B2} equal to ½ may be appropriate.

A.3.3 Situations where significant background sound adjustments are needed

When the maximum A-weighted sound levels of individual noise events are at least 10 dB less than the time-average A-weighted sound level for the continuous sound, partial or complete masking of the sound from the individual events is likely to occur. In this situation, a value of zero for the background sound adjustments of K_{B1} and K_{B2} is recommended.

A.3.4 Guidance on the development of background sound adjustment factors

Appropriate background sound adjustment factors may be developed from considerations of the level of the A-weighted signal-to-noise ratio β equal to (S+N)/N, i.e., the combined level of the A-weighted signal plus the A-weighted noise, minus the level of the A-weighted noise.

In situations where the spectra of the sounds from the sound sources are vastly different, the levels of signal-to-noise ratios determined from octave- or one-third-octave-band sound pressure levels should be examined instead of A-weighted sound levels to establish background sound adjustment factors K_{Bjk} for each *j*-th source and spectral band *k*. These spectral signal-to-noise levels are then examined to determine how the sound exposures in question should be combined in the calculation of total sound exposure.

Recommended values for K_{Bjk} are:

$$K_{Bjk} = 1, \text{ for } \beta \geq 20 \text{ dB} \tag{A.3}$$

$$K_{Bjk} = \beta / 20, \text{ for } 0 < \beta \leq 20 \text{ dB} \tag{A.4}$$

$$K_{Bjk} = 0, \text{ for } \beta = 0 . \tag{A.5}$$

Annex B

(normative)

High-energy impulsive sounds

B.1 Introduction

The procedure in this annex is based on a 1996 study by the National Research Council, Committee on Hearing, Bioacoustics, and Biomechanics (CHABA); see Ref. 14. It conforms with ISO 1996:1-2003 (Ref. 6) which is also based, in part, on the CHABA study.

NOTE The CHABA study presented two methods to assess high-energy impulsive sounds. One method is amenable to the concept of adjusted sound exposure and is presented in this annex. The other method is not amenable to the concept of adjusted sound exposure.

B.2 Fundamental descriptor

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

B.3 Measurement

C-weighted sound exposure (or C-weighted sound exposure level) shall be measured or predicted as if it had been measured by a microphone in a “free-field” and at least 15 m from any large reflecting object other than the ground which should be grass or a field.

B.4 Calculation of adjusted sound exposure level for high-energy impulsive sounds from C-weighted sound exposure level

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

$$L_{NE} = 2\ L_{CE} - 93 \text{ dB for } L_{CE} \geq 100 \text{ dB} \quad \text{(B.1)}$$

$$L_{NE} = 1.18\ L_{CE} - 11 \text{ dB for } L_{CE} < 100 \text{ dB}$$

The two relations intersect at a C-weighted sound exposure level of 100 dB.

B.5 Calculation of adjusted sound exposure level from C-weighted sound exposure level

Adjusted sound exposure N for high-energy impulsive sounds is related to adjusted sound exposure level L_{NE} according to

$$N = 10^{0.1(L_{NE}-94)}. \quad \text{(B.2)}$$

Substituting equation (B.1) in equation (B.2) yields

$$N = 10^{0.1(2L_{CE} - 93 - 94)} \quad (B.3a)$$
$$= 10^{0.1(2L_{CE} - 187)}$$

for $L_{CE} \geq 100$.

$$N = 10^{0.1(1.18L_{CE} - 11 - 94)} \quad (B.3b)$$
$$= 10^{0.1(1.18L_{CE} - 105)}$$

for $L_{CE} \leq 100$.

B.6 Calculation of adjusted sound exposure level from C-weighted sound exposure

C-weighted sound exposure level L_{CE} is related to C-weighted sound exposure E_C by

$$L_{CE} = 94 + 10 \lg (E_C / 1) . \quad (B.4)$$

Substituting equation (B.4) in equation (B.3) yields the relation between adjusted sound exposure N and C-weighted sound exposure E_C for high-energy impulsive sounds as

$$N = 10^{0.1\{2[94 + 10 \lg(E_C/1)] - 187\}} \quad (B.5a)$$
$$= 10^{[\lg (E_C/1)^2 + 0.1]}$$
$$= (E_C)^2 (10^{+0.1})$$
$$= 1.2589 (E_C)^2$$

for $E_C \geq 3.9811$.

$$N = 10^{0.1\{1.18[94 + 10 \lg(E_C/1)] - 105\}} \quad (B.5b)$$
$$= 10^{[\lg (E_C/1)^{1.18} + 0.592]}$$
$$= (E_C)^{1.18} (10^{+0.592})$$
$$= 3.908 (E_C)^{1.18}$$

for $E_C < 3.9811$.

B.7 Use of adjusted sound exposure

Adjusted sound exposures determined by the procedures in B.4, B.5, or B.6 are used in equation (6a) to provide the contributions from high-energy impulsive sounds to the total adjusted sound exposure.

Annex C

(informative)

Sounds with tonal content

The test for the presence of a prominent discrete-frequency spectral component (tone) typically compares the time-average sound pressure level in some one-third-octave band with the time-average sound pressure levels in the adjacent two one-third-octave bands. For a prominent discrete tone to be identified as present, the time-average sound pressure level in the one-third-octave band of interest is required to exceed the time-average sound pressure level for the two adjacent one-third-octave band by some constant level difference.

The constant level difference may vary with frequency. Possible choices for the level differences are: 15 dB in low-frequency one-third-octave bands (25-125 Hz), 8 dB in middle-frequency bands (160-400 Hz), and 5 dB in high-frequency bands (500-10,000 Hz).

NOTE 1 The above guidance is from Annex C of Part 3 of ANSI S12.9. Part 3 of ANSI S12.9 also contains guidance on the measurement of one-third-octave-band sound pressure levels.

NOTE 2 ANSI S1.13 Annex A presents more accurate methods for determining the presence of prominent discrete tones using narrow-band analysis.

Annex D

(informative)

Sounds with strong low-frequency content

D.1 Introduction

Sounds with strong low-frequency content engender greater annoyance than is predicted from the A-weighted sound level. The additional annoyance may result from a variety of factors including (1) less building sound transmission loss at low frequencies than at high frequencies and (2) increased growth in subjective loudness with changes in sound pressure level at low frequencies. In addition, environmental sound pressure levels in excess of 75 to 80 dB in the 16, 31.5, or 63-Hz octave bands may result in noticeable building rattle sounds. Rattle sounds can cause a large increase in annoyance. The methods in this annex may be used to assess environmental sounds with strong low-frequency content.

D.2 Analysis factors

Analysis of sounds with strong low-frequency content is based on the following three factors:

1) Generally, annoyance is minimal when octave-band sound pressure levels are less than 65 dB at 16, 31.5, and 63-Hz midband frequencies. However, low-frequency sound sources characterized by rapidly fluctuating amplitude, such as rhythm instruments for popular music, may cause annoyance when these octave-band sound pressure levels are less than 65 dB.

2) Annoyance grows quite rapidly with sound pressure level at very low frequencies. A "squared" function represents this phenomenon in this annex.

3) Annoyance to sounds with strong low-frequency content is virtually only an indoor problem.

Although windows and house walls have significant high-frequency sound transmission loss, sounds in the 16, 31.5 and 63-Hz octave bands pass through these structures to the interior with relative ease. The low-frequency sound pressure level within these structures is nearly equal to the outdoor sound pressure level because the minimal sound transmission loss of the windows and walls often is offset by modal resonance amplification in enclosed rooms.

D.3 Applicability

The procedures in this annex only should be applied to essentially continuous sounds with strong low-frequency content.

NOTE In accordance with NOTE 5 to Table 2, the adjustment factors for essentially continuous sounds with strong low-frequency content shall not be applied unless the time-average C-weighted sound level exceeds the A-weighted sound level by at least 10 dB.

D.4 Descriptor

The descriptor for sounds with strong low-frequency content is the summation of the time-mean-square sound pressures in the 16, 31.5, and 63-Hz octave bands. The result is the low-frequency, time-mean-square sound pressure p_{LF}^2. The corresponding low-frequency sound pressure level is symbolized by L_{LF}.

D.5 Adjusted sound exposures for sounds with strong low-frequency content

D.5.1 Adjusted sound exposure level from low-frequency sound pressure level

For sounds with strong low-frequency content, adjusted sound exposure level L_{NE} is calculated from low-frequency sound pressure level L_{LF} by

$$\begin{aligned} L_{NE} &= 2(L_{LF} - 65) + 55 + 10\,\lg(T/1) \\ &= 2L_{LF} - 75 + 10\,\lg(T/1) \end{aligned} \qquad \text{(D.1)}$$

where T is the time duration of interest, in seconds, over which the low-frequency sound is present. The factor of 2 in equation (D.1) accounts for the rapid increase in annoyance with sound pressure level at low frequencies. Equation (D.1) also accounts for the additional annoyance from rattles that begins when the low-frequency sound pressure level exceeds 75 dB.

D.5.2 Adjusted sound exposure from low-frequency sound pressure level

For sounds with strong low-frequency content, adjusted sound exposure N is calculated from low-frequency sound pressure level L_{LF} by means of

$$\begin{aligned} N &= T[10^{0.1(2L_{LF}-75-94)}] \\ &= T[10^{0.1(2L_{LF}-169)}]. \end{aligned} \qquad \text{(D.2)}$$

D.5.3 Adjusted sound exposure from low-frequency sound pressure

For sounds with strong low-frequency content, adjusted sound exposure N also may be calculated from the time-mean-square low-frequency sound pressure p_{LF}^2 by use of equation (D.2) as

$$\begin{aligned} N &= T[10^{0.1(2L_{LF}-169)}] \\ &= T[10^{0.1\{2[10\lg(p_{LF}^2/1)+94]-169\}}] \\ &= T[10^{0.1[10\lg(p_{LF}^4/1)+19]}] \\ &= (T)(p_{LF}^4)(10^{1.9}). \end{aligned} \qquad \text{(D.3)}$$

D.6 Use of adjusted sound exposure

Adjusted sound exposures calculated by means of equations (D.2) or (D.3) are used in equation (6a) to provide the contributions to the total adjusted sound exposure from sounds with strong low-frequency content.

D.7 Noise-induced rattles

There is evidence that noise-induced rattles are very annoying and not accounted for by direct measurement of the audible sound. The evidence suggests that rattle annoyance may be independent of the number or duration of events. To prevent the likelihood of noise-induced rattles, the low-frequency sound pressure level should be less than 70 dB.

Annex E

(informative)

Onset rate for airplane flybys

Onset rate for the sound from a low-flying airplane may be estimated if the height of the airplane above ground, lateral offset of the calculation location from the nominal ground track, groundspeed, and the A-weighted sound exposure level of the airplane flyby are known.

The following equation provides an empirical estimate for use in Table 2 of the onset rate *R* in decibels per second for an airplane flying past some location.

$$
\begin{aligned}
R = 3.7 + \exp(&-1.1668 - 0.000563z \\
&-0.000177y + 0.0045v \\
&+0.02884L_{AE})
\end{aligned}
\tag{E.1}
$$

where

z = aircraft height above the elevation of the calculation location (metres);

y = lateral offset from the nominal aircraft track to the calculation location (metres);

v = aircraft groundspeed (nautical miles per hour or knots); and

L_{AE} = calculated or measured A-weighted sound exposure level at the calculation location (decibels).

As an example, assume that z = 90 m, y = 150 m, v = 500 knots, and L_{AE} = 115 dB. Equation (E.1) yields R = 79.1 dB/s. The applicable formula in Table 2 indicates that the corresponding level adjustment for this rapid onset rate is given by 11 lg(79.1/15) = 7.9 dB.

In U.S. customary units of feet for aircraft height and lateral offset, equation (E.1) becomes

$$
\begin{aligned}
R = 3.7 + \exp(&-1.1668 - 0.00185z \\
&-0.000581y + 0.0045v \\
&+0.02884L_{AE})
\end{aligned}
\tag{E.2}
$$

Annex F

(informative)

Estimated percentage of a population highly annoyed as a function of adjusted day-night sound level

F.1 Introduction

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

Revised curves published in 1994 by Finegold *et al*. were derived from a wider set of data than the set used by Schultz. The revised data show aircraft, road traffic and railway noise separately since, as noted earlier by Kryter, there was a systematic difference among them, at least at high sound pressure levels. Recently Miedema and Vos have concluded yet another meta-analysis and found somewhat similar systematic differences.

F.2 The Dose-response function

The dose-response relationship for road traffic noise obtained by Finegold *et al.* estimates the percentages of highly annoyed respondents that were slightly lower than the percentages from the Schultz curve. The dose-response relationship for road traffic noise obtained by Miedema and Vos, however, estimates percentages of highly annoyed respondents that are slightly higher than the percentages from the Schultz curve.

The average of the curves obtained by Finegold *et al.* and by Miedema and Vos virtually coincides with the Schultz curve. Therefore, for simplicity and historical significance, the Schultz curve is taken as the curve to define the percentage of a population that is highly annoyed (%HA) to road traffic noise as a function of the day-night sound level, L_{dn} determined for the free field condition (i.e., the reflection at the building is not taken into account). The solid line in Figure F.1 shows the Schultz curve. About 90% of the grouped results from the various field surveys would fall within the two broken lines.

The equation of the Schultz curve shown in Figure F.1 is given by

$$\%HA = 100 / [1 + \exp(10.4 - 0.132\, L_{dn})] \quad (F.1)$$

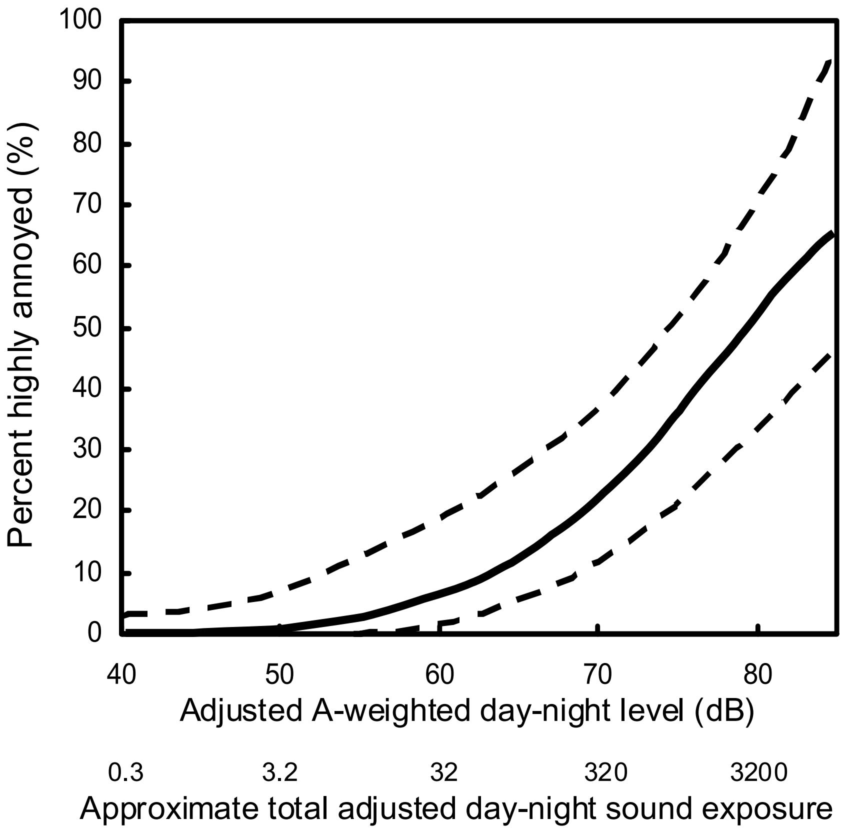

Figure F.1 — Percentage of respondents highly annoyed by road traffic sounds, as a function of the A-weighted day-night level

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

NOTE This dose-response relationship also can be used to assess the community annoyance response for other sources if the relevant source adjustments suggested in this document have been applied.

F.3 Qualifications to the dose-response function

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

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

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

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

F.3.4.1 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.

F.3.4.2 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.

F.3.4.3 The above two factors are additive. A new, unfamiliar sound source sited in a quiet rural area can engender much greater annoyance levels than are normally estimated by relations like equation (F.1). This increase in annoyance may be equivalent to adding up to 15 dB to the measured or predicted levels.

For acoustical environments that include sounds with special characteristics, the annual-average adjusted day-night sound level $L_{N\mathrm{dn}}$ should be used in equation (F.1) instead of the non-adjusted annual-average day-night sound level L_{dn}.

Table F.1 provides annual-average adjusted day-night sound levels at 1-dB increments and the corresponding total adjusted day-night sound exposures and percentages of highly annoyed.

Table F.1 — Annual-average adjusted A-weighted day-night sound levels and corresponding total adjusted day-night sound exposures and percentages of a population highly annoyed

Annual-average adjusted day-night sound level (dB)	Total adjusted day-night sound exposure (Pa^2s)	Approximate total adjusted day-night sound exposure (Pa^2s)	Percentage highly annoyed (%)	Annual-average adjusted day-night sound level (dB)	Total adjusted day-night sound exposure (Pa^2s)	Approximate total adjusted day-night sound exposure (Pa^2s)	Percentage highly annoyed (%)
40	0.3	0.3	0.6	61	43.3	40	8.7
41	0.4	0.4	0.7	62	54.5	50	9.8
42	0.5	0.5	0.8	63	68.6	63	11.1
43	0.7	0.6	0.9	64	86.4	80	12.4
44	0.9	0.8	1.0	65	109	100	13.9
45	1.1	1	1.1	66	137	125	15.6
46	1.4	1.3	1.3	67	172	160	17.4
47	1.7	1.6	1.5	68	217	200	19.4
48	2.2	2	1.7	69	273	250	21.6
49	2.7	2.5	1.9	70	344	315	23.9
50	3.4	3.2	2.2	71	433	400	26.3
51	4.3	4	2.5	72	545	500	29.0
52	5.5	5	2.8	73	686	630	31.8
53	6.9	6.3	3.2	74	864	800	34.7
54	8.6	8	3.7	75	1088	1000	37.8
55	10.9	10	4.1	76	1369	1250	40.9
56	13.7	12.5	4.7	77	1724	1600	44.1
57	17.2	16	5.3	78	2170	2000	47.4
58	21.7	20	6.0	79	2732	2500	50.7
59	27.3	25	6.8	80	3440	3150	54.0
60	34.4	32	7.7	81	4330	4000	57.2

NOTE 1 The relationships in Table F.1 also apply for annual-average day-night sound levels of environmental sounds without special characteristics or unusual community response.

NOTE 2 Table F.1 is applicable only to long-term environmental sounds such as the yearly average.

NOTE 3 Table F.1 is not applicable to “busy days” such as an average for say 30 days selected from a year because those 30 days had many noise-producing events and the other 335 days had many fewer such events.

NOTE 4 Table F.1 is not applicable to a short-term transient environmental sound such as from a short-duration construction project.

NOTE 5 Table F.1 is not applicable if there is sound-induced building vibration or rattles. Some studies have shown sound-induced building vibration or rattles to increase the equivalent annoyance by at least 10 dB. (See also D.7.)

Annex G

(informative)

Assessing the complaint potential of high-amplitude impulse noise

G.1 Introduction

Several decades of experience in handling noise complaints at military installations shows that substantive complaints typically result from the louder and/or more unusual events. Thus, a long-term average noise level metric arguably is not adequate alone to predict community complaint response, or indeed to protect against valid damage claims. A viable procedure is to supplement the long-term average (e.g. DNL) noise impact assessment procedure with risk criteria for community response in terms of complaints as a function of a single-event metric. Appropriate candidate metrics are suggested in Clause 4.1.1.

This annex provides a method to assess the complaint risk from military high-amplitude impulse sound such as the sounds produced by artillery or tank gun fire, bombs, military explosives, and similar civilian sources.[1] Historically, the peak level has been used with success to predict military blast noise complaints, though it does not account for the effect of event duration. Another candidate is the sound exposure level. For historical simplicity, the wide-band peak level is used in this annex. These risk criteria are only intended to be applied to blast noise events from large weapons such as artillery and tank guns and from fairly large explosions (approximately 0.1 to 100 kg). These sources exhibit considerable low frequency sound energy, with a sound exposure level spectrum that typically peaks in the range from 10 to 100 Hz. These noise complaint risk criteria should not be used for other sources of noise such as small arms noise and aircraft noise.

G.2 Complaint criteria

A set of risk criteria was developed by the Navy (Ref. 23) to guide decisions that balance risk of noise complaints against the cost or other consequences of canceling training or testing activity. These guidelines were based on records of complaints received, sound level measurements, sound level calculations, and balloon-suspended radiosonde meteorological soundings. The guidelines were also evaluated during a subsequent study (Ref. 26) and found to be a reliable method to predict complaints resulting from the firing of large guns. The risk criteria, presented in Table G.1, are expressed in terms of degree of complaint risk as a function of the value of the unweighted peak noise metric.

G.3 Complaint risk prediction

Large caliber weapons are very strong acoustic sources. The sound from firing these weapons can be easily audible at long distances, often as far as several tens of kilometers. Change in weather conditions can profoundly influence received noise levels. Sound propagation is influenced by vertical and horizontal profiles of values of atmospheric meteorological parameters such as temperature,

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[1] For purposes of this annex, the weight of charge should be, approximately, between 0.1 and 50 kg.

humidity, wind speed and wind direction. Variation as large as 50 dB in received values of single-event noise metrics such as peak and SEL are routinely encountered (see for example Ref. 24).

The criteria presented in Table G.1 are based on the correlation of degree of risk of noise complaints for known event levels. Useful prediction of complaint risk also must take into account the expected statistical variation in received single-event peak noise level due to weather. If one predicts the mean peak level for all expected event levels, the actual noise level will be higher than the predicted mean level for 50% of all expected events, and may be higher by as much as 25 dB. This affords rather limited protection against receiving noise complaints, since a 25-dB change in event level can change complaint risk from low to high. On the other hand, basing risk of noise complaints on the maximum expected level would be far too conservative. An adequate procedure is to base assessment of complaint risk on a predicted exceedance level. As an example, consider PK15, the peak (unweighted) level that can be expected to be exceeded by 15% of expected blast noise events. A prediction of PK15 = 130 dB means that the risk of receiving a noise complaint would be expected to be high for 15% of all expected events. This strategy requires that the variance in received noise level due to weather effects are known, which is the case for blast noise from large guns.

Table G.1 – Complaint Risk Criteria

Risk of Noise Complaints	**Large Caliber Weapons Noise Level (Unweighted Peak)**
Low	< 115
Medium	115 – 130
High	130 – 140
Risk of physiological damage to unprotected human ears and structural damage claims	> 140

Annex H

(informative)

Loudness-level weighting

H.1 Introduction

The A-weighting filter can be replaced by the equal-loudness-level contours (Figure H.1) from ISO 226 (May 1987) as a dynamic filter that changes both with amplitude and with frequency. To approximate sound heard indoors, the sound is first filtered by a generalized house filter that is adjusted to approximate a window's slightly open condition—on the order of 5 cm (Figure H.2)[2]. This new method eliminates the need for the aircraft source adjustments in Table 2. Thus, with this new method, one can measure all transportation noise sources in a given situation. In effect, this new method provides a family of curves that vary systematically with sound frequency and level (Figure H.1).

Schomer (2000) shows that the use of loudness-level weighting provides for much better correlation with subjective annoyance responses than does the A-weighting. This new method uses fast-time-weighted one-third-octave-band spectra sampled every 100 ms over the duration of an event such as an aircraft flyby. Fast-time weighting is used to approximate the integration time of human hearing. Each spectral band level is replaced by its corresponding phon level using an analytical representation of Figure H.1. These phon levels are summed over time and frequency on an energy basis to form the loudness-level-weighted sound exposure level (LLSEL). The analytical representation is given in Table H.1.

H.2 The method

A sound event such as the sound of an airplane flyby or a truck passby is analyzed into one-third-octave bands. Human hearing is such that short-duration sounds are not perceived to be as loud as long-duration sounds. To be perceived with full loudness, sound must be present for a duration that is longer than the integration time of the ear. Thus, in this procedure, the one-third octave band spectra are *fast* time weighted and sampled every 100 ms. The *fast* time weighting is used to approximate the integration time of the ear which data indicate lies between 25 ms and 250 ms. Since the time constant for *fast*-time-weighting is 125 ms, 100 ms is an adequate rate with which to sample the spectra. This forms a time-series of one-third-octave-band spectra.

Equal-loudness-level contours are given in functional form in Table H.1 However, this method requires that the sound first be filtered by the house filter of Figure H.2 and as given in Table H.1. Then the analytical functions given in Table H.1 can be applied. The loudness-level functions and house filter in Table H.1 correspond to one-third-octave-band center frequencies from 20 Hz to 12,500 Hz. Each filtered one-third-octave-band sound pressure level (SPL) is assigned the phon level that corresponds to that frequency and level. For example, from Table H.1, a filtered one-third-octave-band SPL of 82 dB in the 125-Hz band would be assigned a value of 80 phon since it corresponds to a phon level of 80. Similarly, a filtered one-third-octave-band level of 82 dB in the 31.5-Hz band would be assigned a value of 51 phon.

[2] The house filter simulates the Sound Transmission Loss (TL) of a typical house, in this case with windows open about 2 cm, when sound is transmitted from outdoors to indoors.

The overall time-integrated phon level (LLSEL) is calculated from the time and frequency energy summation of the time-series of filtered one-third-octave band spectra. This time-series of 100 ms, filtered one-third-octave-band spectra is used to calculate the overall time- and frequency-summed phon level, L_L, that is given by:

$$L_L = 10\log\left\langle \sum_j \sum_i 10^{\left(L_{Lij}/10\right)} \right\rangle \tag{H.1}$$

where L_{Lij} is the phon level corresponding to the ith filtered one-third-octave band during the jth time sample.

The quantity calculated by equation (H.1), L_L, has been designated as the loudness-level-weighted sound exposure level (LLSEL). It is similar to the A-weighted sound exposure level (ASEL) except that instead of using a filter (A-weighting) that varies only with frequency, LLSEL uses a dynamic filter that varies with both SPL and frequency. Similarly, one can calculate loudness-level-weighted equivalent level (LL-LEQ) or loudness-level weighted day-night level (LL-DNL).

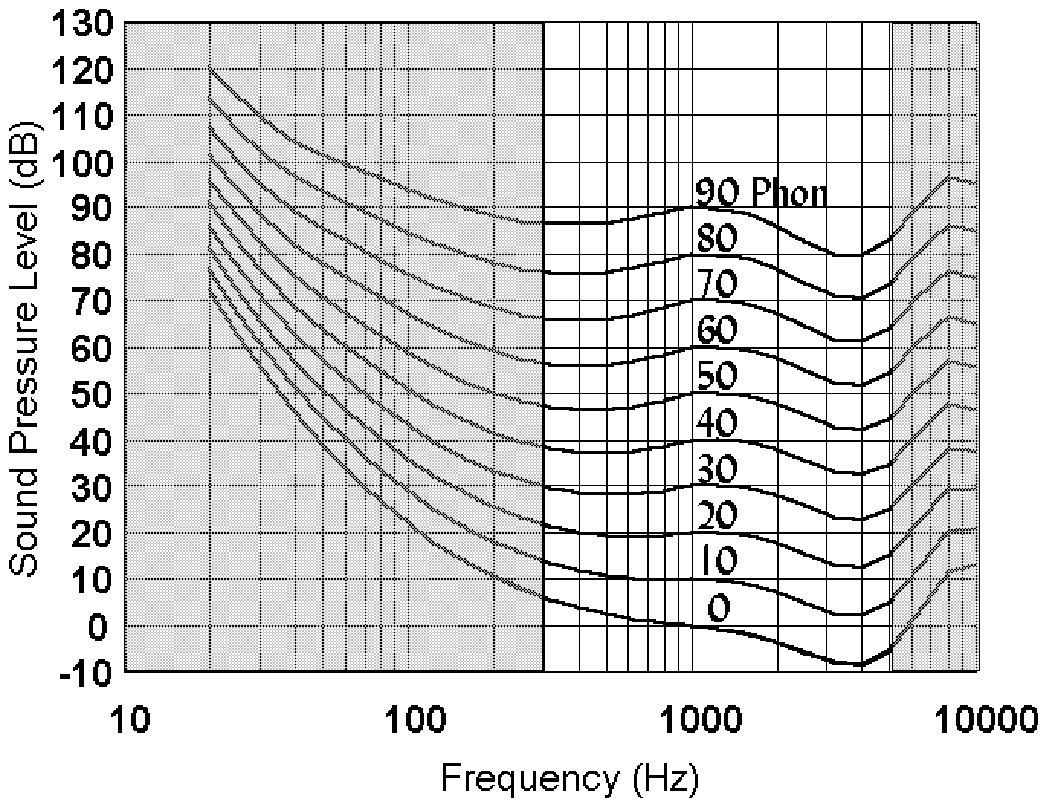

Figure H.1 — Equal loudness level contours in phons from ISO 226-1987. The non-shaded area shows the frequency range where, approximately, a 10-dB change in sound pressure level corresponds to a 10-dB change in phon level. At low frequencies this relationship does not occur. For example, at 31 Hz, a 10-dB change in sound pressure level corresponds to about a 20-dB change in phon level.

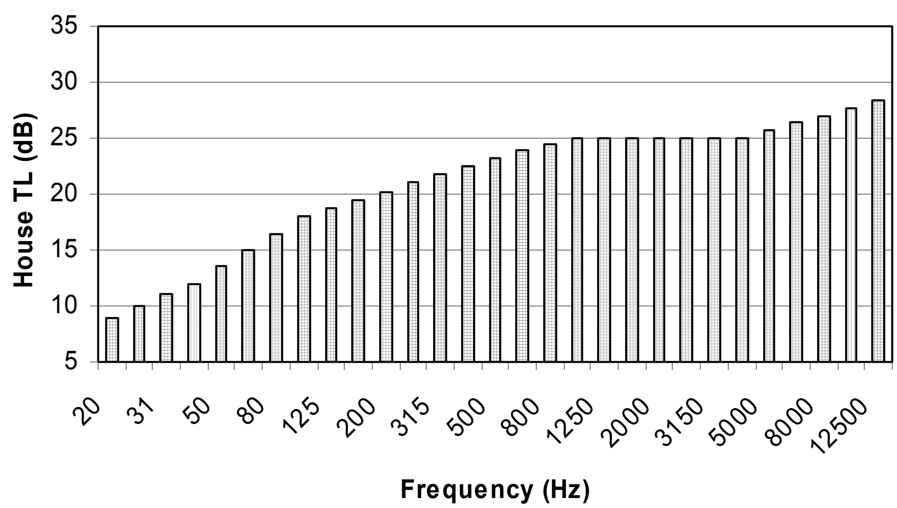

Figure H.2 — Generalized house TL for windows open on the order of 5 cm.

Frequency	20	25	31	40	50	63	80	100
af	2.347	2.190	2.050	1.879	1.724	1.597	1.512	1.466
Lu	0.00561	0.00527	0.00481	0.00404	0.00338	0.00286	0.00259	0.00257
Tf	74.3	65	56.3	48.4	41.7	35.5	29.8	25.1
House TL	9	10	11	12	13.5	15	16.5	18

Frequency	125	160	200	250	315	400	500	630
af	1.426	1.394	1.372	1.344	1.304	1.256	1.203	1.136
Lu	0.00256	0.00256	0.00254	0.00248	0.00229	0.00201	0.00162	0.00111
Tf	20.7	16.8	13.8	11.2	8.9	7.2	6	5
House TL	18.75	19.5	20.25	21	21.75	22.5	23.25	24

Frequency	800	1000	1250	1600	2000	2500	3150	4000
af	1.062	1.000	0.967	0.943	0.932	0.933	0.937	0.952
Lu	0.00052	0	-0.00039	-0.00067	-0.00092	-0.00105	-0.00104	-0.00088
Tf	4.4	4.2	3.7	2.6	1	-1.2	-3.6	-3.9
House TL	24.5	25	25	25	25	25	25	25

Frequency	5000	6300	8000	10000	12500
af	0.974	1.027	1.135	1.266	1.501
Lu	-0.00055	0	0.00089	0.00211	0.00489
Tf	-1.1	6.6	15.3	16.4	11.6
House TL	25.65	26.35	27	27.65	28.35

Table H.1 — Coefficients for calculation loudness level from band sound pressure level. The table also includes the house filter characteristics shown in Figure H.2.

For any band, loudness level is calculated from the respective band j sound pressure level, L_j by:

$$LL_j = 4.2 + [af_l\,(L_i - Tf_i)]/[1 + Lu_l\,(L_i - Tf_i)] \quad \text{(H.2)}$$

where LL_j is the loudness level in the jth band.

The house TL is included by modifying (H.2) to:

$$LL_j = 4.2 + [af_i\,(L_i - TL_i - Tf_i)]/[1 + Lu_l\,(L_i - TL_i - Tf_i)] \quad \text{(H.3)}$$

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