Designation: E1686 – 16

Standard Guide for Applying Environmental Noise Measurement Methods and Criteria[1]

This standard is issued under the fixed designation E1686; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers many measurement methods and criteria for evaluating environmental noise. It includes the following:

1.1.1 The use of weightings, penalties, and normalization factors;

1.1.2 Types of noise measurements and criteria, indicating their limitations and best uses;

1.1.3 Sources of criteria;

1.1.4 Recommended procedures for criteria selection;

1.1.5 A catalog of selected available criteria; and

1.1.6 Suggested applications of sound level measurements and criteria.

1.2 *Criteria Selection*—This guide will assist users in selecting criteria for the following:

1.2.1 Evaluating the effect of existing or potential outdoor sounds on a community; or

1.2.2 Establishing or revising local noise ordinances, codes, or bylaws, including performance standards in zoning regulations.

1.3 *Reasons for Criteria*—This guide discusses the many reasons for noise criteria, ways sound can be measured and specified, and advantages and disadvantages of the most widely used types of criteria. The guide refers the user to appropriate documents for more detailed information and guidance. The listing of specific criteria includes national government regulatory requirements. Users needing further general background on sound and sound measurement are directed to the books listed in the References section.

1.4 *Criteria in Regulations*—Certain criteria are specified to be used by government regulation, law, or ordinance for specific purposes. Ease of enforcement and cost impact on government are considerations for these criteria. They may not be the most appropriate criteria in some circumstances. This guide will discuss the limitations of these criteria.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C634 Terminology Relating to Building and Environmental Acoustics

E966 Guide for Field Measurements of Airborne Sound Attenuation of Building Facades and Facade Elements

E1014 Guide for Measurement of Outdoor A-Weighted Sound Levels

E1503 Test Method for Conducting Outdoor Sound Measurements Using a Digital Statistical Sound Analysis System

2.2 *ANSI Standards:*[3]

ANSI S1.1 Acoustical Terminology

ANSI S1.4 Part 1, Electroacoustics – Sound Level Meters – Part 1: Specifications

ANSI S1.11 Part 1, Electroacoustics – Octave-Band and Fractional-Octave-Band Filters – Part 1: Specifications

ANSI S1.13 Measurement of Sound Pressure Levels in Air

ANSI S3.4 Procedure for the Computation of Loudness of Noise

ANSI S3.14 Rating Noise with Respect to Speech Interference

ANSI S12.4 Method for Assessment of High-Energy Impulsive Sounds with Respect to Residential Communities

ANSI S12.7 Methods for Measurement of Impulse Noise

ANSI S12.9 Quantities and Procedures for Description and Measurement of Environmental Sound – Part 1: Basic Quantities and Definitions; Part 2: Measurement of Long-Term, Wide-Area Sound; Part 3: Short Term Measurements with an Observer Present; Part 4: Noise Assessment

[1] This guide is under the jurisdiction of ASTM Committee E33 on Building and Environmental Acoustics and is the direct responsibility of Subcommittee E33.09 on Community Noise.

Current edition approved Oct. 1, 2016. Published October 2016. Originally approved in 1995. Last previous edition approved in 2010 as E1686 – $10^{\varepsilon1}$. DOI: 10.1520/E1686-16.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

and Prediction of Long-Term Community Response; Part 5: Sound Level Descriptors for Determination of Compatible Land Use; Part 6: Methods for Estimation of Awakenings Associated with Outdoor Noise Events Heard in Homes

ANSI S12.100 Methods to Define and Measure the Residual Sound in Protected Natural and Quiet Residential Areas

2.3 *ISO Standards:*[3]

ISO 532 Acoustics—Method for Calculating Loudness Level

ISO 1996 Assessment of Noise with Respect to Community Response

ISO 2204 Guide to the Measurement of Airborne Acoustical Noise and Evaluation of Its Effects on Man

2.4 *IEC Standard:*[4]

IEC Standard 61672 Electroacoustics-Sound Level Meters

2.5 *DIN Standard:*[5]

DIN 45692 Measurement technique for the simulation of auditory sensation of sharpness (in German)

2.6 *United States Military Standard:*[6]

Mil Std 1474E Department of Defense Design Criteria Standard Noise Limits

3. Terminology

3.1 *General*—This guide provides guidance for various measurement methods and criteria defined in other documents. Most acoustical terms used in both this and other ASTM standards are defined in Terminology C634 along with their abbreviations and symbols for use in equations.

3.2 *Definitions of Terms Specific to This Standard:* The following terms are not used in other ASTM standards:

3.2.1 *community noise equivalent level (CNEL)*—see *day-evening-night average sound level*.

3.2.2 *day-evening-night average sound level (DENL),* L_{*den}—where * is a letter denoting the frequency weighting (understood to be A if deleted), (dB), n—a time average sound level computed for a calendar day period with the addition of 4.77 dB to all levels between 7:00 pm and 10:00 pm, and 10 dB to all levels after 10:00 pm and before 7:00 am. A-weighting is understood unless clearly stated otherwise.

3.2.3 *day-night average sound level (DNL),* $L*_{dn}$—where * is a letter denoting the frequency weighting (understood to be A if deleted), (dB), n—a time-average sound level computed for a calendar day period with the addition of 10 dB to all levels after 10:00 pm and before 7:00 am. A-weighting is understood unless clearly stated otherwise.

3.2.4 *loudness, (sone), n*—that attribute of auditory sensation in terms of which sounds may be ordered on a scale extending from soft to loud. **ANSI S1.1**

3.2.5 *normalization, n—as applied to the evaluation of noise in communities*, the practice of adjusting a measured sound level to compare to criteria that are based on conditions different from those present at the time or location of the measurement.

3.2.6 *residual sound, n*—the all-encompassing sound, being usually a composite of sound from many sources from many directions, near and far, remaining at a given position in a given situation when all uniquely identifiable discrete sound sources of particular interest or considered an interference, whether steady or intermittent, are eliminated, rendered insignificant, or otherwise not included.

3.2.6.1 *Discussion*—Residual sound is distinguished from background noise which also includes the self-noise of measurement systems, and ambient noise which includes all sound present. It is also distinguished from a steady sound that is dominant between discrete events. The specific sounds excluded from the residual sounds should be identified. If the excluded sound is intermittent, the residual sound may be approximated by the L90. If an excluded sound is steady and there are intermittent events, the L90 can be used to approximate the level of such steady sound and the residual sound must be measured with the steady source not operating or approximated by a measurement at a nearby location where the steady source is not dominant. Though "background noise" by definition includes instrument self-noise, the terms "background sound" and "background noise" are often used interchangeably with "residual sound" when it is known that instrument self-noise is not an issue.

3.2.7 *sound exposure level,—**SEL where * is a letter that denotes the frequency weighting (understood to be A if deleted), L_{*E} where * is a letter that denotes the frequency weighting (understood to be A if deleted), (dB), n—ten times the logarithm to the base ten of the ratio of a given time integral of squared instantaneous frequency-weighted sound pressure, over a stated time interval or event, to the product of the squared reference sound pressure of 20 micropascals and reference duration of one second.

3.2.8 *speech interference level, SIL,* L_{SI}*, (dB), n*—one-fourth of the sum of the band sound pressure levels for octave bands with nominal mid-band frequencies of 500, 1000, 2000, and 4000 Hz.

3.2.9 *time above (s or min per h or day), n*—the duration that the sound level or time-average sound level exceeds a corresponding specified level during a specified total measurement period. If sound level is used, then the time weighting shall be specified; if time-average sound level is used, then the measurement time interval for each sample shall be specified. The frequency weighting should be specified; otherwise, the A-weighting will be understood. The unit for time in the ratio shall be stated, for example, as seconds or minutes per hour or day. **ANSI S12.9, Part 1**

3.3 *Index of Terms*—The following commonly used terms are discussed in the sections referenced in this guide.

Term	Paragraph
A-weighting	6.2
C-weighting	6.2

[4] Available from International Electrotechnical Commission (IEC), 3 rue de Varembé, Case postale 131, CH-1211, Geneva 20, Switzerland, http://www.iec.ch.

[5] Available from Beuth Verlag GmbH (DIN-- DIN Deutsches Institut fur Normung e.V.), Burggrafenstrasse 6, 10787, Berlin, Germany, http://www.en.din.de.

[6] Available from DLA Document Services, Building 4/D, 700 Robbins Ave., Philadelphia, PA 19111-5094, http://quicksearch.dla.mil.

community noise equivalent level	8.5.3
day-evening-night average sound level	8.5.3
day-night average sound level	8.5.2
equivalent level	6.5 and 8.5.1
fast, time weighting or sound level	6.3
impulse, time weighting or sound level	6.3
loudness	8.11
maximum sound level	8.3
normalization	7.4
octave band, or one-third octave band	6.6 and 8.9
peak sound pressure level	6.4 and 8.4
percentile level	8.6
slow, time weighting or sound level	6.3
sound exposure level	8.5.4
speech interference level	8.10
time above	8.7
time-average sound level	6.5 and 8.5.1

4. Significance and Use

4.1 *Evaluation of Environmental Noise*—Environmental noise is evaluated by comparing a measurement or prediction of the noise to one or more criteria. There are many different criteria and ways of measuring and specifying noise, depending on the purpose of the evaluation.

4.2 *Selection of Criteria*—This guide assists in selecting the appropriate criteria and measurement method to evaluate noise. In making the selection, the user should consider the following: purpose of the evaluation (compatibility, activity interference, aesthetics, comfort, annoyance, health effects, hearing damage, etc.); type of data that are available or could be available (A-weighted, octave-band, average level, maximum level, day-night level, calibrated recordings including .wav files from which various measurements could be made, etc.); available budget for instrumentation and manpower to obtain that data; and regulatory or legal requirements for the use of a specific criterion. After selecting a measurement method, the user should consult appropriate references for more detailed guidance.

4.3 *Objective versus Subjective Evaluations*—The overall sound environment as perceived outdoors is often called a soundscape. Soundscapes have both objective (quantitative) and subjective (qualitative) attributes. This guide is limited to the objective measurement and evaluation of sound found outdoors though the criteria used may be influenced by qualitative factors. Current soundscape research involves evaluation methods and criteria that rely extensively on qualitative factors, both acoustical and non-acoustical, while including requirements for quantitative sound measurement. Two basic tenets of quantitative soundscape measurements are that the ambient sound at a location is comprised of a combination of specific acoustic events that can be measured individually and in combinations; and that the sounds should be measured using methods that represent the ways in which they are heard by people. (**1**)[7]

5. Bases of Criteria

5.1 Most criteria for environmental noise are based on the prevention of problems for people. However, there are criteria for evaluating effects on animals, physical damage to structures, or reduced utility of property. When selecting criteria to evaluate a situation, it is very important to recognize the many different problems that may be caused by the noise. Sound-scape methods address aesthetic components of sounds and provide for comfortable or satisfying sounds in addition to preventing noise problems.

5.1.1 *Health Impacts*—Damage to human hearing is the best documented effect of noise on health, with the best established criteria. Damage depends on sound levels and exposure time. Most noise-induced hearing loss is due to exposure over several years. People are often annoyed by noise at a much lower level than that required to damage hearing. This annoyance causes stress that can aggravate some physical conditions. Criteria for preventing these problems are usually based on annoyance. Research has shown some physical reactions of the human body to sound including cardiovascular effects such as elevation of blood pressure, mean respiratory volume, intestinal irritation and endocrine system responses among others. Pycho-social effects of noise including agitation, withdrawal, anxiety and depression among others have also been identified in the literature. (**2**, **3**, **4**)

5.1.2 *Speech or Communication Interference*—Speech communication is essential to the daily activities of most people. There are criteria for the residual or background sound levels needed to allow such communication.

5.1.3 *Sleep Interference*—High levels of sound and changes in sound level affect the quality of sleep or awaken sleepers. See ANSI S12.9 Part 6.

5.1.4 *Task Interference*—High sound levels can either hinder or improve the performance of a task. The effect depends on the nature of the task as well as the sound.

5.1.5 *Annoyance and Community Reaction*—Annoyance and community reaction are different effects. Annoyance is a personal reaction to noise. Community reaction is evidenced by complaints to authorities. Some people are annoyed but do not complain. Some people use noise as an excuse to complain when they are not annoyed directly by a sound. Often annoyance and reaction are related to speech or sleep interference, reduced environmental aesthetics, or the effect of these factors on the utility and value of property. Many of the criteria developed for noise in residential communities are based on survey studies of annoyance or on adverse community reaction directed to public officials.

5.1.6 *Noise Characteristics*—Certain quantitative criteria can be used to further restrict sounds that have been found to be particularity noticeable, intrusive or to increase perceived annoyance especially if persistent. Often such sounds contain strong discrete tones or are otherwise unbalanced in spectral content. Spectral criteria are used to specify or evaluate the aesthetic quality of the sound present. Some criteria can be used to evaluate whether a sound is rumbly or hissy, or has a perceptible or prominent tone. Other particularly noticeable sounds include information contained in speech or music as well as impulsive sounds from gunshots, bass music beats, hammering, etc. Such sounds are sometimes restricted to numerically lower overall A-weighted sound levels in ordinances and regulations. C-weighted limits or octave-band

[7] The boldface numbers in parentheses refer to the list of references at the end of this standard.

limits are sometimes used for sounds with strong low-frequency content that are also time variant such as music, but care must be used that such limits are not inappropriately applied to steady sounds when the problem is the time variation. When sound levels vary strongly from an average, such as with aircraft overflights or occasional heavy truck passbys, criteria that identify the variation such as "time above" or statistical counts of the number of events within certain ranges of maximum levels can be used. Measures attempting to evaluate for perceived annoyance may take into consideration such factors as loudness, the time of day, sharpness and the effect of time fluctuations of the sound including roughness and fluctuation strength.

5.1.7 *Land Use Compatibility*—Noise compatibility criteria have been developed for land use planning. These are most useful in determining whether a certain type of development can be made compatible with existing noise. Care is necessary when applying these criteria to evaluate a new noise in an existing community that was developed without anticipation of the noise.

5.1.8 *Effects on Wildlife*—Research has established some effects of noise on wildlife. However, additional research is needed to establish appropriate criteria.

5.1.9 *Preservation of Natural Quiet*—Some locations such as large park, wilderness, and rural areas are noted for the limited presence of man-made sounds. The preservation of such existing conditions is often an objective.

6. Basics of Sound Measurement

6.1 *Introduction*—Sound usually is measured with a sound level meter. The basic instrument usually includes a choice of both frequency and time weightings. Frequency weighting adjusts the relative strength of sounds occurring at different frequencies before the level is indicated by the meter. Time weighting determines the reaction of the meter to rapidly changing sound levels. Some meters can respond to the instantaneous peak level and store or hold the highest value. Integrating-averaging meters also include the ability to measure the time-average sound level over a period. Specifications for meters are provided in ANSI S1.4 and IEC Standard 61672. Meters may include filters to measure sound in specific frequency bands. Specifications for these are found in ANSI S1.11. A classification of the types of sounds, as well as basic procedures for taking sound pressure level measurements at a single point in space, are found in ANSI S1.13.

6.2 *Frequency Weightings*—Several frequency-weighting networks (filters) have been internationally standardized. These networks provide a better match between measured sound pressure and human perception. The two used most frequently are designated A-weighting and C-weighting.

6.2.1 A-weighting is the most commonly used. It is used when a single-number overall sound level is needed. Results are expected to indicate human perception or the effects of sound on humans. A-weighting accounts for the reduced sensitivity of humans to low-frequency sounds, especially at lower sound levels.

6.2.2 C-weighting is sometimes used to evaluate sounds containing strong low-frequency components. It was originally devised to approximate human perception of high-level sounds.

6.2.3 B, D, and E weightings also exist but are seldom used. The Z-weighting defines the frequency limits of the previously non-standardized "flat" weighting.

6.3 *Exponential Time Weightings*—Sound levels often vary rapidly. It is not practical or useful for a meter to indicate every fluctuation of sound pressure. When it is desired to record the continuous variation in sound, the meter performs an exponential average process that emphasizes the most recently occurring sound. Three standard meter time-weighting characteristics are commonly used in sound measurements (slow, fast, and impulse). The exponential time weighting used in a measurement should always be stated. These are sometimes referred to as a "response" such as "slow response."

6.3.1 "Slow" is the most commonly used time weighting. It provides a slowly changing level indication that is easy to read and is often specified in regulations.

6.3.2 "Fast" more closely responds to human perception of sound variation. It provides a more rapid response to changing sound levels. Fast response is often used for short duration measurements such as motor vehicle drive-by tests.

6.3.3 "Impulse" allows a faster rise in indicated level than the fast weighting but causes a slower decrease in indicated level than the slow weighting so that one can read the maximum levels. The impulse time weighting is no longer required in sound level meters. As stated in Annex C of IEC 61672 various investigations have concluded that it "is not suitable for rating impulsive sounds with respect to their loudness – nor for determining the 'impulsiveness' of a sound." Since impulse response has been used in some regulations, the historical specifications for this time weighting are included in Annex C of IEC 61672.

6.3.4 All of the above time weightings will yield the same result if the sound is steady and not impulsive. They will yield different maximum and minimum levels for varying sound levels.

6.4 *Peak Sound Pressure Level*—A peak indicator measures the true peak level of a very short duration signal. It is not normally used to measure steady sounds or slowly varying sounds. A peak detector responds to the absolute positive or negative instantaneous value of the waveform rather than its effective or "root mean square" (rms) value. In normal use, a peak measuring instrument will hold its indication for ease of reading until reset or will store it in a memory for later reference. The measured peak level is dependent on the frequency bandwidth of the microphone and both the frequency bandwidth and the rise time (microseconds/volt) of the associated electronic instrumentation. A reduced frequency bandwidth will reduce the effective rise time. Sound level meter standards specify tolerances for accuracy of the C-weighted peak level but not the rise time. When Z-weighting is used, it is important to validate the performance of your instrumentation using for example a method given in Mil Std 1474E section 4.7.4.3. C-weighting can reduce the influence of wind on the microphone and low frequency instrument self-noise on the measured result. The difference between results measured with Z or C weighting is often minor. Rise time can be an important factor in some cases such as measurements close to a firearm. (In order to minimize confusion, the term "peak" should never be used to describe the maximum level measured with fast or slow time weighting.)

6.5 *Time-Average Sound Level*—Sometimes it is desirable to measure the average sound present over a specified period. This time-average sound level is often called the equivalent sound level or equivalent continuous sound level. It is the steady sound level whose sound energy is equivalent to that of varying sound in the measured period. The frequency weighting should be specified. Otherwise, for overall sound levels, it is understood to be A-weighting. The time-average sound level should be measured directly using an integrating-averaging sound level meter without the use of an exponential time weighing. However, regulations or instrument limitations sometimes require the time-average sound level to be computed from many individual measurements using fast or slow time weightings.

6.6 *Frequency Analysis*—Electronic filters can be used to separate sound into frequency bands so measurements with any of the methods described above can be made in specific frequency bands. When frequency analysis is performed for environmental noise, measurements are usually made in standardized octave or one-third octave bands (ANSI S1.11). Octave-band or one-third octave band data or criteria are understood to be Z weighted unless it is clearly stated otherwise. Frequency analysis can be a useful diagnostic tool to characterize, identify, and quantify individual sources of sound.

6.7 *Time History Analysis*—Plots of the time history of sound variation can demonstrate the variability of sound level and serve as a tool in identifying, separating, and quantifying individual components of the overall sound that are varying with time. Time history and frequency analysis are sometimes combined on the same three-dimensional plot. These analyses are usually based on calibrated recordings of the sound.

7. Adjustments to Sound Levels to Account for Conditions Influencing Human Response

7.1 *Introduction*—Many acoustical and non-acoustical factors influence human response to environmental noise. Special measurements and criteria apply adjustments to the sound level for these factors.

7.2 *Time-of-Day Penalties*—Many people expect and need lower sound levels at night, primarily for sleep and relaxation. In most outdoor locations, ambient noise levels are lower at night. It is preferable to have lower limits for sound during normal sleeping hours, most commonly from 10:00 p.m. until 7:00 a.m. The difference between daytime and nighttime limits in local ordinances for residential areas is usually 5 or 10 dB. For those criteria based on average levels over a period containing both day and night, a 10 dB penalty is commonly added to sound levels during the night period before computing the average level. In some cases an evening penalty of approximately 5 dB is also used.

7.3 *Penalties based on Sound Characteristics*—Sounds that give the sensation of pitch are called discrete tones, and may occur by themselves or within other sounds. These can be particularly perceptible, intrusive, unpleasant, and annoying especially if persistent. The same is true of sounds consisting of repeated pulses less than a second apart, which are called repetitive impulsive noise. In such cases, it is common for local noise ordinances to specify that the objective criterion be 5 dB more stringent than would be the case if the sound character were broad-band and steady.

7.4 *Normalization or Adjustments to Sound Levels*—Some criteria presume conditions that are not appropriate in all cases. When these conditions are not met, the measured level is adjusted or normalized for the different conditions before comparing it to the criterion. This is done by adding or subtracting a number of decibels from the measured or calculated expected level for each factor different from the normal assumption. Table 1 shows typical adjustments suggested by the U.S. Environmental Protection Agency (EPA) (**5**) in its "normalization" procedure. Similarly, ANSI S12.9 Part 4

TABLE 1 Corrections Added to the Measured Noise Level to Obtain Normalized Level

Type of Correction	Description	Amount Added to Measured Level in dB
Seasonal correction	Summer (or year-round operation)	0
	Winter only (or windows always closed)	–5
Correction for outdoor noise level measured in absence of intruding noise	Quiet suburban or rural community (remote from large cities and from industrial activity and trucking)	+10
	Normal suburban community (not located near industrial activity)	+5
	Urban residential community (not immediately adjacent to heavily traveled roads and industrial areas)	0
	Noisy urban residential community (near relatively busy roads or industrial areas)	–5
	Very noisy urban residential community	–10
Correction for previous exposure and community attitudes	No prior experience with intruding noise	+5
	Community has had some previous exposure to intruding noise, but little effort is being made to control the noise. This correction may also be applied in a situation where the community has not been exposed to the noise previously, but the people are aware that bona fide efforts are being made to control the noise.	0
	Community has had considerable previous exposure to the intruding noise, and the noise maker's relations with the community are good.	–5
	Community is aware that operation causing noise is very necessary and it will not continue indefinitely. This correction can be applied for an operation of limited duration and under emergency circumstances.	–10
Discrete tone or impulse	No discrete tone or impulsive character	0
	Discrete tone or impulsive character present	+5

provides ways to account for various residual or background sound conditions and sound characteristics. The DNL is "adjusted" by 5 dB for tonal or normal impulsive sound or sound occurring during daytime on weekends, 12 dB for highly impulsive sound such as small arms gunfire, hammering, riveting, and railyard shunting operations, up to 5 dB for normal aircraft sound, and up to 11 dB for rapid onset sound such as from fast, low-flying aircraft. The result is called the "adjusted DNL."

7.5 *Psycho-acoustical factors*—From a psycho-acoustical perspective, human response to sound can be positive (for example, pleasantness) or negative (for example, annoyance). Various psycho-acoustical quantities have been developed for characterizing separate sensations of sound. These quantities include but are not limited to loudness, pitch, subjective duration, sharpness, roughness and fluctuation strength. Only loudness (ANSI S3.4 and ISO 532) and sharpness (DIN 45692) have been defined in standards. Methods have been proposed that combine some of these quantities to evaluate for negative human response such as annoyance. However, as with the quantities themselves, these methods have not yet been incorporated into standards. **(6)**

8. Sound Measurements, Their Best Uses and Weaknesses

8.1 *Introduction*—There are many ways of measuring and specifying limits on sound. The most appropriate measurement method and criteria should be selected for a specific case. For a given measurement method, the appropriate criterion could be an absolute level or a change in level. For instance, speech interference occurs above some absolute level. However, a change in level may better reflect the impact of a new sound on the aesthetic quality of a community. This section describes several measurement methods on which criteria are based and discusses their strengths and weaknesses. Other factors in the selection of the best measurement method and criteria are discussed in Section 9. Further guidance on the use of the most common measures of overall sound in the outdoor environment, as discussed in 8.2–8.7, can be found in the ANSI S12.9 series of standards.

8.2 *Level of Steady Sound*—When sound is steady, and its frequency content is stable the sound level can be measured with simple instrumentation without the need for averaging or statistical sampling. Criteria may simply state that the sound not exceed some overall level, usually A-weighted. If the frequency content is critical to the function and acceptance of the sound, more complex criteria and measurements are necessary. The criterion should address the possibility that the sound may not be steady in environments where it should be.

8.3 *Maximum Sound Level of Time Varying Sound* (Symbol L_{max}. Additional subscripts may be used to denote frequency and time weighting.)—Some criteria state maximum sound levels not to be exceeded by time varying sounds when measured with a specified time weighting, fast or slow. In modern usage this refers to the maximum instantaneous level observed using a specified time weighting. Many older documents referring to limits on sound levels are actually referring to approximate average sound levels measured by procedures in ANSI S1.13 and earlier standards used before the advent of integrating-averaging instruments.This type of criterion is useful when sound above the specified level creates a problem for even a short time, especially if it is recurring. Maximum sound level limits are often used in combination with other criteria. Maximum sound level limits alone are insufficient for specifying community noise criteria. If set appropriately for short duration noise, maximum sound level limits are too high to limit continuous noises properly. Limits set appropriately for recurring short-duration sounds may be too stringent for a sound that occurs only once and is not repeated.

8.4 *Peak Sound Pressure Level* (Symbol L_{Pk}. An additional subscript may be used to denote frequency weighting.)—When sounds are identified as discrete events lasting much less than 1 s, such as individual gunshots, discrete musical notes or hammer blows, it is appropriate to use the peak level. Further guidance can be found in ANSI S12.7.

8.5 *Time-Average Sound Level and Variants*—The availability of instruments to measure the time-average sound level has made this a popular way to measure and specify criteria for nonsteady sounds. It is a preferred method of measuring, comparing, and specifying levels for sounds varying irregularly but by only a few decibels. It also can be used where the variation in level is large. High-level short-duration events strongly influence the time-average level. There is some psychoacoustics uncertainty whether two sounds of the same energy equivalent level are always perceived by people to be equally loud or annoying. While a steady sound of a given level may be perfectly acceptable, a sound with widely varying levels having the same time-average level may be unacceptable, or vice-versa. The perceived loudness of a series of events over a period may be different from the perceived loudness of a steady sound of the same energy equivalent average sound level over the same period. The time-average sound level has been used to characterize the long-term acoustical environment. However, people expect and need quieter sound levels during some parts of the day. Therefore, it is common practice to use night-time or evening penalties to compute modified time-average sound levels. The most familiar of these descriptors is the day-night average sound level. An advantage of the time-average sound level concept is that the expected levels can be calculated from databases for common sound sources without measuring every situation. The frequency weighting should be specified for all variants of time-average sound level. Otherwise, A-weighting is understood. Further guidance can be found in ANSI S12.1 Part I.

8.5.1 *Time-Average Sound Level* (Symbol L_*, where * is the measurement period. An additional subscript may indicate the frequency weighting. The name equivalent sound level, Symbol L_{eq}, and abbreviation LEQ are also commonly used.)—This is the actual energy-equivalent average sound level measured over a specified length of time. The time can be anywhere from less than 1 s to several years. The time-average sound level measured over a period from a few minutes to 1 h is often used in local noise ordinances. In such cases, it is common to specify a lower required level at night in residential areas. The time-average sound level is one method used by the

U.S. Federal Highway Administration (FHWA) for evaluating highway noise. Time-average sound level has a clear advantage over a maximum level specification since most environmental sounds vary with time. A disadvantage is that a single number time-average sound level may disguise a wide variation in sound levels.

8.5.2 *Day-Night Average Sound Level* (Abbreviation DNL, with LDN commonly used, and Symbol L_{dn}. An additional subscript may indicate the frequency weighting.)—This variant adds 10 dB to all sound between 10:00 p.m. and 7:00 a.m. before computing the average level over a 24 h period. Day-night average sound level is used extensively for community land use planning purposes and in U.S. federal government criteria for funding housing and evaluating airport noise. It is the preferred method for these uses. An advantage of this type of criterion is the ease of calculating expected noise levels without actually measuring the specific situation. Day-night average sound level is measured or computed for a minimum period of 24 h or multiples thereof. It is most common to compute day-night average sound level as an annual average. Such long-term averages may not indicate problems that exist during only part of a year or even part of a day. Variations in response to day-night average sound level among communities can sometimes be explained by normalizing the data (see 7.4).

8.5.3 *Day-Evening-Night Average Sound Level* (Symbol L_{den}. An additional subscript may indicate the frequency weighting.)—This measure, very similar to day-night average sound level, is used primarily in California, where it is called Community Noise Equivalent Level (CNEL). In addition to the 10 dB night-time penalty, day-evening-night average sound level adds a penalty of approximately 5 dB to all sound between 7:00 p.m. and 10:00 p.m. before computing the average.

8.5.4 *Sound Exposure Level* (Abbreviation SEL and Symbol L_E. An additional subscript may indicate the frequency weighting.)—It is often useful to compare the total sound energy among discrete events or the total energy accumulated over periods of different durations. This can be accomplished by converting the time-average sound level of the event or period to an energy-equivalent level for a sound lasting exactly 1 s. This is the sound exposure level. For sounds lasting more than 1 s, the sound exposure level will always be greater than both the average and maximum levels of the sound. The way in which the event duration is defined may be either a specific time, the time during which the sound is within 10 dB of the maximum level, the time the sound is above a specified level, or the time the sound is above the average residual or background sound level. The most common use of sound exposure level is in databases for aircraft noise, from which day-night average sound level may be computed. The disadvantages of sound exposure level in criteria are that people do not easily understand it, and there is little research relating sound exposure level to effects. Data are now available in ANSI S12.9 Part 6 relating SEL of aircraft events to sleep disturbance.

8.6 *Percentile Level* (Abbreviation L* and Symbol L_*, where * = a number from 1 to 99 indicating the percentage of time the level is exceeded. Additional subscripts may indicate the frequency and time weighting.)—This is an indication of the sound level that is exceeded for a stated percentage of a specified measurement period. It is also commonly called percentile exceedance level. For instance, the level exceeded 90 % of the time for a stated period is the 90 percentile level or L90. This is often taken as an indication of residual or background sound present from unidentifiable sources. The 10 percentile level, L10, and the median level, L50, are sometimes used to state community noise limits. The median level alone as a criterion has a particular weakness. Very loud levels could occur almost 50 % of the time and not be reflected in an evaluation. L10 is more likely to reflect the presence of loud sounds unless they occur during less than 10 % of the measurement or analysis period. Using the L10 to specify limits rather than time-average sound level will often impose a lower effective limit on sound with varying sound levels compared to a steady sound. Guide E1014 and Test Method E1503 provide methods of gathering data for determination of percentile levels.

8.7 *Time-Above*—This is the time above a stated sound level during a stated measurement period. In some situations sound below a given threshold may not present a severe problem. However, the degree of the problem is related to the time above the threshold more so than the actual maximum level. For instance, aircraft noise may interfere with activity in an office only during the time it exceeds some level. The amount of time above this level could be the key information of concern. Care should be used with this criterion, since it sets no limits on the sound below the threshold or on the degree to which the threshold is exceeded.

8.8 *Increase in Sound Level*—The US EPA found (**5**) that the increase in sound level is the parameter most strongly correlated to adverse community reaction. A measure that evaluates this change can be very useful but is often difficult to implement in practical local regulations. One common and appropriate use is to evaluate change due to new large industrial facilities. Usually the before and after sound is measured in the same way such as the time-average sound level. However, some regulations compare the time-average sound level of the proposed activity to the existing L90 and allow differences of as much as 10 dB. If the pre-existing time-average sound level is close to the L90, the allowed increase can be too great, or if the existing difference between the L90 and time-average level is large, the limit may be lower than the existing level. The various regulations of the US Department of Transportation include provisions to consider increases in sound level (**7, 8**). In some cases the goal is to add new sources to a location with no net increase in sound by reducing the sound of some existing sources. Establishing the existing baseline sound levels in a community is essential to being able to assess such net-zero or noise-neutral impacts for new facilities and is a topic of current research.

8.9 *Octave-Band (or One-Third-Octave-Band) Criteria*—Often a single overall sound level is not sufficient to evaluate or specify the noise environment fully. This is especially the case for steady sounds of long duration. In such cases it is usually desirable to ensure that the quality of the sound matches the normal expectation in the environment. Evaluating both aesthetic appeal and speech interference requires knowledge of the frequency content of the sound. The most common criteria of this type are the octave-band curves used to evaluate and rate the steady residual or background sound in rooms. Similar curves have been used for evaluating outdoor community noise. In the outdoor environment it is usually assumed that the noise controlled or evaluated by such criteria is steady. Better availability of instruments for rapidly measuring octave-band levels of non-steady sounds may lead to wider use of these criteria for such sounds. Criteria based on one-third-octave-bands are rare. See 11.3.4 for a discussion of obsolete octave bands.

8.10 *Speech Interference Level* (Abbreviation SIL)—The speech interference level is based on octave-band sound pressure levels. However, it is a single number. It is the arithmetic average of the steady sound pressure levels in the three or four octaves that most affect the understanding of speech. It is often used for a first approximation to find the distance from a source at which speech of a given voice level can be understood in the environment. It can be used to evaluate speech clarity in outdoor performance spaces and in indoor spaces exposed to outdoor sound. For these uses, it is clearly superior to A-weighting. The current method of calculating and using SIL is presented in ANSI S3.14.

8.11 *Criteria Based on Loudness*—Differences in perceived loudness are not always indicated correctly by the A-weighted sound level. More accurate methods have been devised to quantify human perceptions of loudness. These require calculations using sound pressure levels measured with a frequency analyzer, usually in octave or one-third-octave bands. Thus, the calculated loudness has not been widely used in environmental noise criteria. However, recent electronic technology advances make it possible to program the calculation procedures within measurement instruments, making these criteria more practical for use in the field. Current standard methods apply only to steady sounds (ANSI S3.4 and ISO 532). Research indicates potential for a better method of quantifying the perceived loudness of a sequence of events during a period and methods have been developed to account for many perceptual factors not included in the standards (**6**).

9. Considerations in Criteria Selection

9.1 The selection of criteria and measurement methods for a particular project is influenced by the goals of the evaluation, regulatory requirements, budget constraints, and the availability of existing data.

9.1.1 *Regulatory Requirements*—These include workplace noise exposure limits, local community noise regulations, construction regulations to limit indoor levels due to outdoor noises in noisy areas, and requirements to qualify for financing of construction. These regulatory requirements are often minimum requirements.

9.2 *Goals of Evaluation*—Regulatory criteria may be insufficient to guide the design of high-quality environments or to determine the effects of new sounds on such environments. More complex measurements and criteria may be needed. The consideration of aesthetics, health impacts, perception and meanings of sounds by people are among other issues that may impact selection of criteria and measurement methods.

9.3 *Budget and Availability of Data*—The cost of measurements for various criteria can vary significantly. In some cases some data may be readily available. It is usually best to evaluate the sound based on the simplest criterion first, as this can give some indication of the need to proceed with further analysis.

10. Applications of Sound Level Measurements and Criteria

10.1 *Introduction*—Criteria for sound levels and sound exposure play an important role in evaluating and regulating noise in the environment. Managing noise in the environment to reduce the number of people impacted by high noise levels, reducing the number of people exposed to health effects of noise and conscious design of the aesthetic components of the community soundscape are among considerations that can form the basis for applying various criteria and measurement methods. Some local, state, and provincial governments have extensive regulations to assist in the planning and control of noise in the environment. In other places there are no formal planning efforts or regulations referencing noise levels. Situations then have to be evaluated and problems resolved without the assistance of relevant regulations. Land use planning based on noise exposure is essential near major transportation-noise sources. Local regulations on noise crossing boundaries can be useful in any community. However, these become more essential as the density of population in a community increases. This section discusses the following frequent specific uses of sound level measurements and criteria.

10.1.1 *Sound Contours*—In many applications sound levels expected due to a source or several sources are shown as contours of equal sound level. These contours are often interpreted as having a greater precision than actually exists. The calculation methods are often simplified without considering some localized effects such as building shielding that affect the sound level at locations of interest. (**9**)

10.2 *Environmental Impact Assessment*—Formal environmental impact statements are often required for specific projects expected to increase noise in a community. Examples include new, expanded, or upgraded airports, highways, railroads, utility plants, and quarry operations. The environmental impact statement will usually show existing and projected future noise. This is often accomplished graphically with a set of sound level contour maps. The metric and methodology to be used is often specified by a government agency and can differ widely depending on the responsible agency. Transportation sources are covered by federal requirements, while other sources are governed by state, provincial, or local requirements. For airports, the expected day-night average sound level is the primary metric, but is often supplemented by a measure of single event noise or "time above". Highway assessments are usually based on the L10 or time-average sound level for the worst hour of the day. Railroad assessments are usually based on the change in day-night average sound level.

10.3 *Land Use Planning*—Many communities have found it helpful to establish land use planning programs based partially on varying noise levels in the community. These programs usually use long-term average-level contours based on day-night average sound level. The contours most commonly reflect noise from major transportation noise sources such as airports, highways, or railroads. The contours usually establish lines of equal day-night average sound level in 5 dB increments on a map. Land within the contours is zoned for uses compatible with the expected noise exposure. Highway and aircraft noises with the same day-night average sound level often are considered equivalent. This may not be valid for some land uses. For instance, a highway producing a day-night average sound level of 75 dB may be almost unnoticeable in an office building. However, aircraft noise with the same day-night average sound level could produce many disrupting events with maximum A-weighted sound levels of more than 70 dB in the same building. The numerical value of the maximum sound level generated by a brief train passby event is typically much greater than the numerical value of the longer-term day-night average sound level. The better planning efforts also relate housing types to noise exposures. Higher-density, multi-family apartments with few outdoor amenities are more compatible with high noise levels than single-family homes on large lots with outdoor pools. Planning guidelines are best used to guide new development where options are available to make the development compatible with the noise.

10.4 *Site Suitability*—Property owners or buyers often have to determine whether a site is suitable for a particular use. The use may demand peace and quiet, or it may produce a lot of noise that would be difficult to control in a very quiet area. If the community has extensive noise planning activities, there may be data available from the planning office to help in the evaluation. Such data are often in the form of day-night average sound level contours. These types of average-level data may not be sufficient if the proposed site use requires existing steady noise levels to mask its sound, or if high maximum noise levels would affect the use. The evaluator may have to develop a measurement and evaluation program consistent with the needs of the particular planned use. Various measurement techniques and criteria might be used depending on the specific situation. Sites for proposed residential use may have to meet guidelines such as those of the U. S. Department of Housing and Urban Development (**2**). Industrial or commercial uses may need to meet state, provincial, or local regulations.

10.5 *Local Ordinances*—Many state, provincial, and local governments have adopted quantitative ordinances and bylaws limiting sound crossing real property boundaries. These may be in the form of either general or zoning ordinances. The limit imposed is usually determined by the use of the property onto which the sound is traveling. Thus, an industrial plant next to a residential property is subjected to a lower limit than one surrounded by other industrial properties. Sometimes both the source and receiver property uses are considered in setting the limit. Setting the limit based solely on the source property results in unreasonably high noise transmitted from industrial to residential usages. Of necessity local ordinances must usually be made simple, and cannot consider all the factors that influence the perception of sound.

10.5.1 Practical criteria for local ordinances are based on a measurement that can be performed in less than 1 h.

10.5.1.1 The earliest ordinances specified a sound level not to be exceeded based on approximate average sound levels. Later ordinances frequently used L10 or L50 as the criterion and measured it manually with a sampling technique of 100 measurements 10 s apart. Time-average sound level is now widely used as new instruments make it easy to measure. The time-average sound level or statistical measure should be over a period of at least 10 min since the criterion is based on sound that is continuous.

10.5.1.2 For a very steady sound, the L10, L50, and time-average sound level will be about the same. However, for variable sounds, the time-average sound level will be greater than the L50, and the L10 will usually be greater than the time-average sound level. If a very strong sound lasts less than 10 % of the measurement period, the time-average sound level can be greater than the L10. L10 and L50 limits impose no limit on such short duration sounds, and thus it is advisable to use a separate limit on the maximum level when ordinances are based on L10 or L50.

10.5.1.3 Maximum level criteria should not be used alone in ordinances. A reasonable maximum-level limit for a continuous sound would be too low for a very brief noise occurring infrequently. Such a reasonable limit for the infrequent brief noise would be too high for the continuous noise.

10.5.1.4 No simple measurement of overall sound level over a period of time can differentiate all the variables that influence the perception of sound so that two sounds that differ significantly in perception may result in the same measured level.

10.5.2 Octave-band sound-level limits may be used in addition to or as an alternative to an A-weighted sound level limit.

10.5.2.1 Octave-band limits may be used to specifically limit sounds from sources that may generate noticeable tonal component or have other undesirable spectral characteristics. However, such limits in octave bands often will not adequately constrain tonal sounds.

10.5.2.2 It is rare for the actual sound to exactly match limits specified in octave bands. Thus, such limits in practice actually limit the overall A-weighted sound level to a level significantly lower than the weighted combination of the band limits. This effect should be considered in setting the limits in the octave bands.

10.5.2.3 If both octave-band and A-weighted limits are imposed, it is advisable to set the octave band limits so that the combination of the weighted band levels is greater than the A-weighted level limit, and to require that both the band limits and A-weighted level limit be met. If the octave-band limits are set so that the weighted combination of their levels is equal to the A-weighted level limit, then the limit on the A-weighted levels is only a short way to verify non-compliance without measuring the octave-band levels.

10.5.3 Some ordinances set the limits in part based on the residual (often called background) sound level existing in the community while most limits are set without regard to the varying existing sound throughout the area covered by the ordinance.

10.5.3.1 Ordinances that evaluate noise acceptability based on existing residual sound levels commonly limit the increase in sound level above that residual sound level. These ordinances sometimes base the measurement of that existing sound level on the L90, a common statistical descriptor of minimal residual sound levels, but base the limits on the new sound on the time-average sound level. See 8.8 regarding problems introduced by this practice. Accurate measurement of the residual sound level at a location can be difficult as it can vary with season of the year as well as time of day.

10.5.3.2 Ordinances that do not consider existing sound levels in the basic limits may specify limits that are much greater than existing sound levels in some areas and less than existing sound level in others. Such improperly specified limits may allow unreasonable increases in noise levels in some locations and limit increases in other locations to unreasonable small amounts.

10.5.3.3 Even if the limits are not related to the residual sound level, the ordinance must have a provision to ensure that the source being cited is causing the measured level to exceed the ordinance limits.

10.5.4 Some ordinances contain no quantitative requirements and instead use language such as "unreasonable noise" which is impossible to properly or uniformly interpret and enforce. Such ordinances have often been ruled unenforceable by courts.

10.6 *Problem Resolution*—Acoustical consultants and local officials are often called upon to resolve disputes between landowners when one introduces a noise impacting a neighbor. A quantitative local ordinance limiting the sound crossing property boundaries can be useful if such exists. Many locations have no such ordinances. Even when ordinances exist, there may be problems not resolved by the ordinance. This occurs when the noise crossing the boundary does not exceed the limit of the ordinance but still creates a problem. Resolution of the situation requires a careful selection of appropriate criteria and evaluation according to those criteria.

10.7 *Building Inspection*—In some noisy areas, regulations require that the building structure be sufficient to limit the indoor sound level that is due to outdoor sources. These regulations will specify a criterion for the indoor sound level. They will usually use levels from land use planning documents to define the outdoor level. To determine compliance, it may be necessary to measure the outdoor and indoor sound levels simultaneously. The outdoor-indoor level reduction is then established according to Guide E966. This level reduction should then be applied to the expected long-term outdoor noise to determine whether the structure is in compliance. It is not reasonable to measure only the indoor noise levels since the outdoor levels during the measurement may not be those normally present in the community.

11. Sources of Criteria and Representative Available Criteria

11.1 *Standards*—There is only limited information on environmental noise criteria available in national standards. The American National Standards Institute (ANSI) and the International Standards Organization (ISO) each have standards on environmental noise criteria for certain circumstances. Other ANSI and ISO standards on measurement methods provide criteria information for reference. The following is a partial list of standards (from Section 2) that could be useful in particular situations: ANSI S3.4, ANSI S3.14, ANSI S12.4, ANSI S12.7, ANSI S12.9, ANSI S12.100, ISO 532, ISO 1996, and ISO 2204. ANSI S12.9 Part 4 provides detailed guidance on noise assessment and prediction of long-term community response for many circumstances. ANSI S12.9 Part 5 describes use of day-night average sound level and provides reference information on land uses compatible with various day-night average sound level values. ANSI S12.100 covers very quiet areas.

11.2 *National Government Guidelines and Regulations*—The U.S. government currently has no active central agency or policy for environmental noise. Federal agencies regulate environmental noise using different methods and criteria. In most cases, the criteria are based on day-night average sound level. Initially, a day-night average sound level of 55 dB was established as the level required to protect the public health and welfare with an adequate margin of safety. The current guidelines for land use compatibility used by most U.S. agencies consider cost and technical feasibility in addition to impact of noise on people. Most of these guidelines indicate a day-night average sound level of 65 dB or lower to be compatible with residential use. This recognizes that many people will accept noise to this level provided there are other primary reasons to live at that location. This criterion can be misleading if used to evaluate the impact of a new or increased noise on a community where acoustical quality is a primary asset. More recent criteria for noise impact developed and used by the U.S. agencies regulating railroad and transit noise are more closely related to the day-night sound level of 55 dB, with allowance for higher levels when such are pre-existing at a site. The criteria characterize new noise with day-night average sound level as low 55-60 dB to be a severe impact on previously quiet communities. When the EPA first introduced the day-night average sound level, it recommended that the day-night average sound level in a community should be normalized for local conditions to better correlate with the community reaction (**5**). No U.S. federal agency currently normalizes day-night average sound level data for local conditions or looks at other important criteria such as maximum sound levels or day-night average sound levels for periods of less than one year. The Committee on Hearing, Bioacoustics, and Biomechanics of the U.S. National Research Council initially developed guidelines for environmental impact statements on noise. However, individual federal agencies often provide methodology and criteria. The Canadian government has published comprehensive national guidelines for environmental noise control including recommended criteria. Refs (**5**, **7**, **8**, **10-16**) and are selected national government publications.

11.3 *State, Provincial, and Local Government Guidelines and Regulations*—A wide variety of guidelines and regulations have been adopted by various state, provincial, and local governments. These differ in the way the sound is measured, the point at which it is measured and the limits imposed. These are typically addressing sound crossing property boundaries. Though these sometimes impose limits on the sound reaching a property, these regulations are essentially limiting the sound emitted from a source property. The residual sound present may interfere with the ability to accurately measure this emitted sound.

11.3.1 Most local ordinances are based on measurements of the A-weighted sound level over a period of less than 1 h, but some use octave-band limits or a combination of both. Many do not specify any averaging or sampling but just indicate that the measured sound level should not exceed the stated limit. Others will indicate an averaging period, or a sampling method with an L10 or L50 determined from the sample.

11.3.2 The measurement point may be specified at the boundary of the source property, some distance beyond that boundary, or on the impacted property.

11.3.3 For sound reaching residential areas, the A-weighted sound level limits are typically in the range of 50 to 65 dB in the daytime and 45 to 55 dB during nighttime. The definition of day and night varies, but night is most commonly 10 pm until 7 am. Some may have separate "evening" limits with the most common evening period being from 7 pm until 10 pm. In recent years the trend is toward limits at the higher ends of these ranges especially in more densely populated areas where sound levels are inherently higher. However, the World Health Organization, the European Community and current research indicates that concerns for health effects of noise, sleep disturbance and psycho-social noise effects should be addressed (**2, 3, 4**). Limits at the lower end of the range may be so restrictive that many residential air-conditioning systems are in violation. Higher limits are usually allowed for sound entering commercial and industrial areas. Sometimes the limits are based partially on whether the source is residential, commercial, or industrial. The limits may be based on the actual use of the source or receiving property or on its zoning. Some state regulations for new large industrial or utility facilities set limits based on existing sound in the community. Where such local laws do not exist, review of several local ordinances from other jurisdictions could be helpful in establishing criteria.

11.3.4 Special care should be used when evaluating local ordinances as these are often based on obsolete measurement methods or criteria. Some ordinances have octave-band frequency ranges specified based on obsolete standards for which instruments are no longer available to make the specified measurements. It is often but not always possible to demonstrate compliance or non-compliance with such ordinances using one-third-octave-band measurements. For instance, if the combined level present in the two modern one-third-octave bands that are fully within the old octave band exceeds the limit in the old octave, there is clearly a violation. On the other hand, if the combined level present in the four modern one-third-octave bands that fully encompass the old octave does not exceed the limit for that old octave band, then clearly there is no violation of the limit for that band. Ordinances based on such obsolete octave bands may be updated by converting the criteria to equivalent criteria in current octave bands using a procedure provided in Ref (**17**). Some ordinances appear to refer to limits on maximum sound levels. However, the wording was originally written when "sound level" referred to an approximate average level measured with a standard (not integrating-averaging) sound level meter using procedures in ANSI S1.13 and prior standards.

11.4 *Technical Society Publications, Books, and Research Papers*—Several books with good summaries of various criteria for noise are widely used by professionals in acoustical evaluation. Criteria for some situations have been examined and developed by researchers but not yet included in standards or regulations. In some cases the only way to find appropriate criteria could be in published technical papers. Ref (**2, 18-23**) can guide the selection of criteria.

12. Keywords

12.1 community noise; environmental noise; noise; noise assessment; noise criteria; noise evaluation; noise level measurement; noise metrics

REFERENCES

(1) Harris, C. M., *Handbook of Acoustical Measurements and Noise Control*, McGraw Hill, New York, NY, 1991. Reprinted by the Acoustical Society of America, Melville, NY, 1998. (Previous editions published under the title *Handbook of Noise Control* in 1957 and 1979.)

(2) Kang, Jian. Urban Sound Environment. Taylor and Francis, London, 2007.

(3) Fay, Thomas H., ed. Noise and Health. New York Academy of Medicine, New York, 1991.

(4) Yost, William A., Fundamentals of Hearing: An Introduction Fifth Edition, Academic Press, San Diego, 2006.

(5) *Information on Levels of Environmental Noise Requisite to Protect the Public Health and Welfare With an Adequate Margin of Safety*, Report 550/9-74-004, U.S. Environmental Protection Agency, March 1974. (Contains justification for use of day-night average sound level and information on normalization.)

(6) Zwicker, E. and Fastl, H., Psycho-acoustics: Facts and Models, Springer, Berlin, 1999.

(7) High-Speed Ground Transportation Noise and Vibration Impact Assessment, US Department of Transportation, Federal Railroad Administration, 2005.

(8) Procedures for Abatement of Highway Traffic Noise and Construction Noise, CFR, Title 23, Part 772.

(9) Staiano, M. A., "Representing Highway Noise Exposures, Downfall of Contourtionists," Sound and Vibration Magazine, Vol 40, No. 8, August 2006.

(10) Department of Housing and Urban Development Environmental Criteria and Standards, CFR, Title 24, Part 51, issued 1979, amended 1984.

(11) *Guidelines for Considering Noise in Land Use Planning and Control*, Federal Interagency Committee on Urban Noise, June 1980.

(12) *Federal Agency Review of Selected Airport Noise Analysis Issues*, Federal Interagency Committee on Noise, August 1992.

(13) *FAA Regulations on Airport Noise Compatibility Planning Programs*, CFR, Title 14, Chapter I, Subchapter I, Part 150.

(14) *Guidelines for Preparing Environmental Impact Statements on Noise*, Committee on Hearing, Bioacoustics, and Biomechanics, U.S. National Research Council, 1977.

(15) *Model Community Noise Control Ordinance*, Report EPA 550/9-76-003, U.S. Environmental Protection Agency, September 1975.

(16) *National Guidelines for Environmental Noise Control, Procedures and Concepts for the Drafting of Environmental Noise Regulations/By-laws in Canada*, Department of National Health and Welfare, Catalog No. H49-37/1989E, March 1989.

(17) Schultz, T. J., "Conversion between old and new octave band levels," *Journal of the Acoustical Society of America*, Vol. 36, No. 12, December 1964, p. 2415.

(18) Cowan, J. P., Handbook of Environmental Acoustics, Van Nostrand Reinhold, New York, 1994.

(19) Eldred, K. McK., and von Gierke, H. E., "Effects of Noise on People," *Noise/News International*, Vol 1, No. 2, June 1993.

(20) Garcia, A., ed, Environmental Urban Noise, WIT Press, Southampton, 2006.

(21) Kryter, K. D., *Effects of Noise on Man*, 2nd Ed., Academic Press, Orlando, FL, 1985.

(22) Shultz, T. J., Community Noise Rating, 2nd ed., Applied Science, New York, NY 1982.

(23) Ver, I. L., and Beranek, L. L., Noise and Vibration Control Engineering, Principles and Applications, Second Edition, John Wiley and Sons, Inc., New York, NY, 2005. (First Edition 1992 and earlier similar books edited by L. L. Beranek.)