B&W UNIVERSAL

INDUSTRIAL NOISE SERIES

PART II: COMMUNITY AND ENVIRONMENTAL NOISE

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TABLE OF CONTENTS

YOUR WORLD
CLEAN
QUIET
SAFE

ENVIRONMENTAL NOISE

The environment is a dynamic place that is always in flux as caused by seasons of the year, weather, flora and fauna, and human factors such as communities, rail and road traffic, industries and businesses, aircraft and airports, and a host of similar activities including sporting events that all produce environmental noise. Making sound level measurements under such conditions can be challenging, and in order to convey the dynamics of the environment, a time-history sound survey measurement is necessary. Depending on why the measurement is being performed, it may be over a period of time that may extend from a few minutes to hours, days, or for three or four seasons of the year. What is important is to make sure the measurement conveys the necessary information of the environmental sound level in order to make decisions.

A time-history measurement scheme is carefully planned and locations identified that best represent the community for assessing possible noise impacts from a planned facility or transportation corridor. The time-history scheme is set up to measure sound over incremental time intervals over the total survey period. This is fairly easy with today's sound equipment. Figure 1 presents an example of a sound level survey near a highway and presents a time-history of the environmental noise shown as sound level versus time. Note that *sound level* is the overall A-weighted sound level.

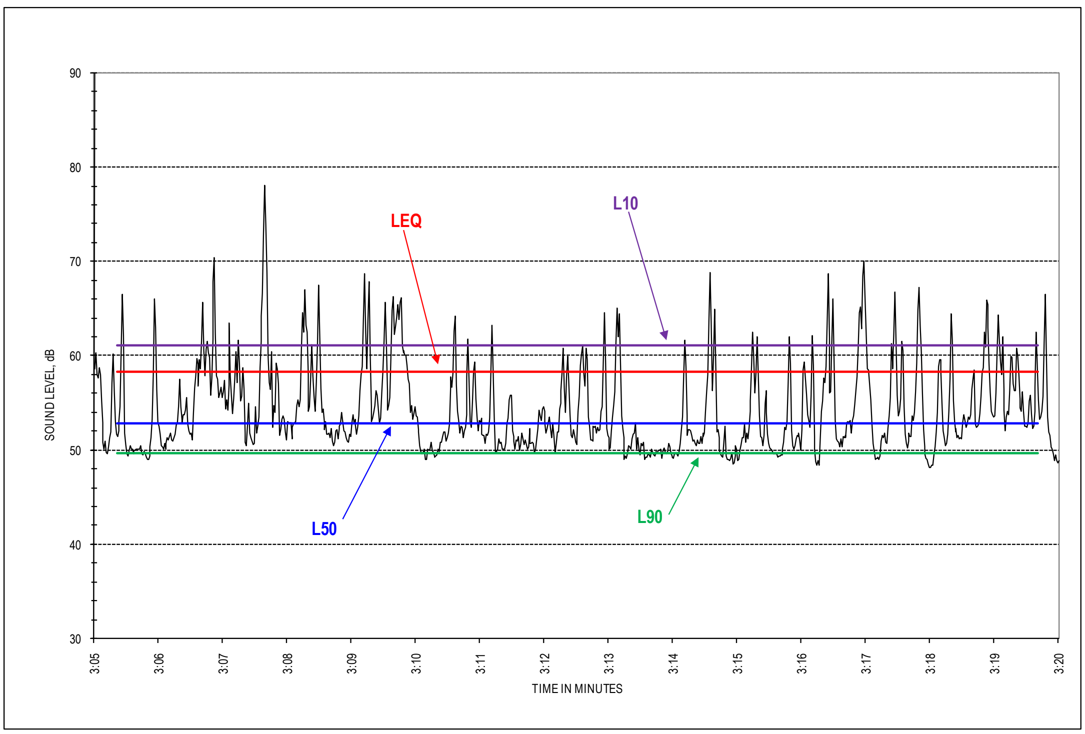

Figure 1 – Environmental Sound Level Vs. Time Near a Road

Figure 1 shows how dynamic environmental sound can be. The peaks of acoustical energy as shown in the figure are principally from traffic passing by the sound level monitor. Other sources of sound that are encountered are insects, frogs, birds, barking dogs, aircraft, rail traffic, cycling of home air conditioners, lawn mowers, business and industrial activities, and so forth; all of which contribute to the cumulative environmental sound level and profile. As you may see from the figure, it is difficult to just pick out a point and state, "this is the sound level." To overcome this dilemma, a statistical approach is used and shown on the figure are the L_{10}, L_{50} and L_{90} percentile levels and the Leq (integrated equivalent, continuous sound level).

The statistical levels are calculated based on the distribution of varying sound levels versus time with L_{10}, L_{50} and L_{90} as the most commonly used values. The subscripted numbers indicate the percentage of time that the sound level is expected to be above that level. To provide insight as what these statistical sound levels represent, Figure 2 presents the distribution of sound levels measured over a 38-hour period.

Histogram of Power Plant Sound Levels 228 Measurements at Ten-Minute Intervals

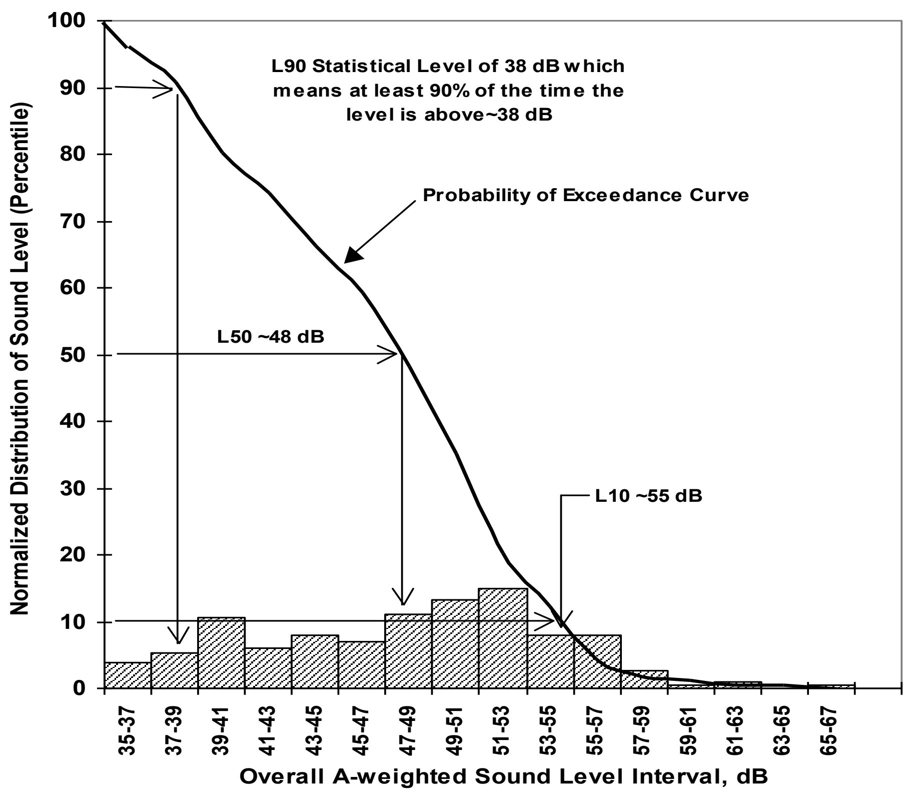

Figure 2 – Sound Level Histogram

The abscissa (horizontal axis) is divided into bands or "bins" of sound levels, in this case three-decibel bands, and for each incremental time period the measured sound level that fell into the appropriate "bin" was counted as an occurrence. The counts in each bin are normalized to the total counts in all the bins (thus each bin is a percentage) and the distribution of the count (sound levels) is shown by the curve (summing to 100%). The *probability of exceedance* curve is used to determine the statistical sound level that is exceeded the percentage of time indicated. Using Figure 2, the L_{50} level is determined by drawing a horizontal line from "50" to where it intersects the curve and then drops down to where it lands in the 47-49 dB range. Since it is near the center, 48 dB is the expected value. What this means is 50% of the time the sound level will exceed this level, or 50% of the time the sound level is at least 48 dB. L_{90} is the level that is exceeded 90% of the time, or conversely, it shows that for at least 90% of the time the sound level is no less than 38 dB.

L_{10} typically results from short duration events such as aircraft flyover, traffic, insects, frogs, and barking dogs and is used to evaluate the intrusive level of noise. L_{50} typically measures moderate duration events and is generally useful for describing the audibility of planned facilities; that is, the L_{50} level in an ambient survey indicates the sound level at which a new source of noise will just be discernable. In the above figure, a new source of sound would not be noticeable until the sound level was about 48 dB or more. L_{90} is widely used to *indicate* the prevailing residual or background sound level in the absence of most transient noise events (the prevailing "quiet" period) and is frequently used for establishing the sound metric for assessing changes to the environment; that is, how people may react to new sources of noise introduced into the community. The U.S. EPA used L90 in most all its studies and assessment of environmental sound and its affects. So, when you hear experts or other speak of the L90 level or L50 level you can grasp what is being discussed and these are all sound levels; that is, the overall A-weighted sound level. Another point to consider is the time of year to conduct a survey, nighttime during winter is usually the quietest time as most insect noise and animal activities are subdued.

The Leq (integrated equivalent, continuous sound level) as shown in Figure 1, is the total sound energy (p) normalized over the measurement period (T), or simply, the averaged sound level expressed by,

$$Leq(T) = 10\,log\left\{\frac{1}{T}\int_0^T p^2(t)dt \,/\, p_0^2\right\} \quad \text{dB, re: 20 μPa} \qquad (1)$$

The term Leq (or LEQ) was adopted when sound level equipment incorporated signal processing capability to capture the data, integrate, and display the sound level or sound pressure level for the time period over which the measurement was made. Prior this capability, analog sound level meters were used, and short of performing measurements as shown in Figure 2, only an approximation of the sound level was reported as could be ascertained from the meter, a method called, "eyeball averaging;" imagine a meter with its indicator needle bouncing back and forth as would be the case in making measurements of variable sound levels.

COMMUNITY REACTION

Community noise impact generally occurs when the community becomes aware of any intrusive changes and may become sensitive to the increased environmental sound levels, particularly if there is any tonal or impulsive content to the intrusive noise. Quantitatively on an overall basis, a 3-decibel (dB) increase is almost imperceptible, a 5-6 dB increase is clearly perceptible and a 10 dB increase is a doubling of loudness (not power) and may lead to complaints. Keep in mind that these increases are in the presence of existing environmental noises. In controlled test booths the ear can distinguish changes in levels very well. The relative affects of changes to the existing environmental sound level is presented in the following table.

Table I - Perception of and Reaction to Environmental Sound Level Changes

Sound Level Changes	Human Perception of Sound Changes	Community Reaction
+ 3 dB (Louder)	Just a perceptible change	Very little reaction
+ 5 dB	Clearly perceptible change	Sporadic complaints
+ 10 dB	Twice as loud	Widespread complaints
+ 20 dB	Four times as loud	Vigorous complaints

The listed changes in sound level do not assess the affects from impulsive sounds or tones. Impulsive noises include blow-off vents, relief valves, or hammering from punch presses, and so forth. Tones or discrete frequency noises are generally continuous in nature that may come from pumps, motors, fans, continuous venting (whistling) and other such devices. Tones are difficult because tones are discernable even if they are several decibels below the environmental sound level; that is, the continuous background sound level, even though several decibels higher than the tone, does not effectively mask the tone. The higher the frequency, the more discernable is the tone. Inlet tones from compressors and similar equipment need to be effectively attenuated.

DAY-NIGHT SOUND LEVEL

The Day-Night sound level (DNL) was developed to assess intrusive nighttime noise or predict community response to a new source of noise. To penalize nighttime noise intrusion, the nighttime sound level is adjusted by adding ten decibels to the measured level; for example, an actual sound level of 58 dB has a nighttime adjusted level of 68 dB. The nighttime penalty is applied from 10:00 PM to 7:00 AM the following morning. There is no penalty for daytime sound levels measured from 7:00 AM to 10:00 PM.

The DNL is calculated by the following expression and DNL is always the overall A-weighted sound level. It is inappropriate to annotate the sound level as “dBA.”

$$DNL = L_{dn} = 10 \text{ Log } \{[(15)(10^{Ld/10}) + (9)(10^{(Ln+10)/10})] / 24\} \text{ dB} \quad (2)$$

The DNL may be used for the assessment of a new source of noise in a community. The *adjusted* DNL (beyond the scope of this paper) uses various weighting factors for assessing the impact from the new source of noise. The adjustments are applied to the present DNL. Figure 3 presents a generalized assessment of community response to the “adjusted” day-night sound level (DNL). The listing of community reactions shows considerable overlap as would be expected for categorizing community (human) responses.

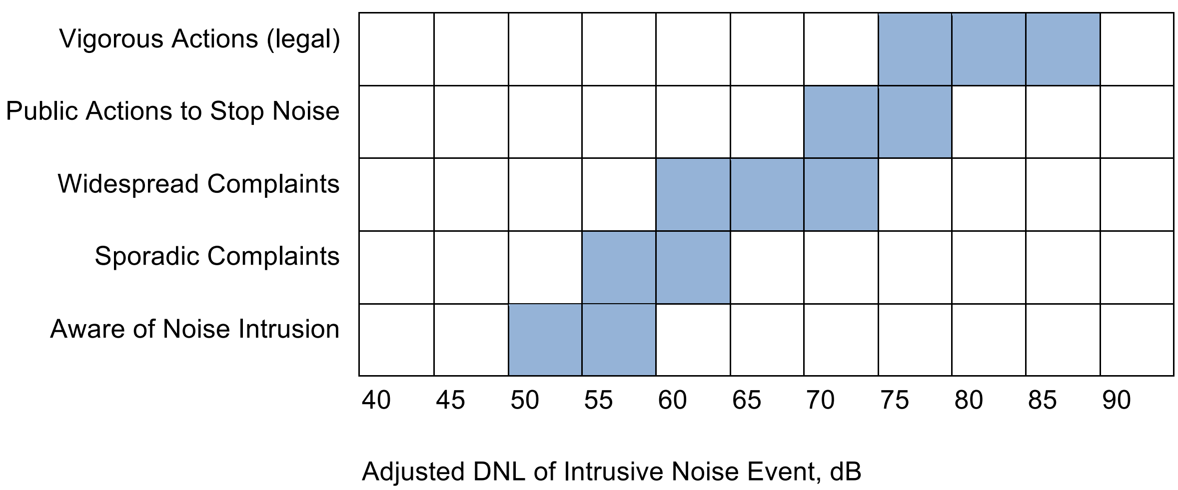

Figure-3 General Community Response to Intrusive Noise

FERC (Federal Energy Regulatory Commission), which regulates interstate transportation of fuels and energy, specifies that pumping and compressor stations cannot exceed a DNL 55 dB at the nearest noise sensitive area. Thus, based on 24-hour operation, the facility cannot cause the sound level at the receptor to exceed L_A 48.6 dB.

It is inappropriate to use DNL in measuring and analyzing quiescent ambient noise areas that are absent of any manmade noise because it arbitrarily raises the nighttime level by ten decibels when there is no intrusive noise source. Also, the time periods were established well before the population shift to bedroom communities where now, early morning commuter traffic may begin as early as 5 a.m., which skews the nighttime sound level to be higher.

TONES AND INFRA-SOUND

The preceding sections primarily addressed A-weighted sound levels in evaluating the acceptability of noise in a community. Achieving a criterion level or satisfying a DNL goal may not adequately address the total acoustical environment. DNL and virtually every regulatory agency use noise limits that are based on overall A-weighted sound level averaged over some time period. This is because these types of measurements are fairly straightforward and can be done by any moderately skilled person with a meter; however, A-weighting does not adequately measure low frequency (infra-) sound, annoying tones or impulsive noise events.

TONES

Discrete frequency tones and impulsive noise are probably some of the most annoying elements of intrusive noise. People have a general tendency to adjust to their environment even if moderately noisy except for tones and periodic impulsive noises which can be quite intrusive. Although the overall A-weighted sound level may be low, and may meet a community noise requirement, this type of noise can still be considered a nuisance. In these cases, the allowable sound level needs to be further adjusted (downward) to compensate for these intrusive sounds or special frequency band requirements imposed, say octave band or one-third octave band sound level limits. If is it known that a planned facility will produce tones then it is important that these be addressed at the earliest stages of planning so adequate noise control measures can be developed. After the fact, fixing the problem can be very expensive and take several months if not longer.

INFRA-SOUND

Infrasound is very low frequency sound that is generally less than 20 Hz and some agencies extend this range slightly higher. The affects of infrasound can cause structures to vibrate from the low frequency airborne noise coupling with the building or structure. At very low frequencies the sound wave is very large and as it collides with structures causes motion to be imparted (vibration) and the sound energy is easily transmitted through walls and windows. This can have a dramatic impact upon residential communities, hospitals, schools, and nearby industrial-commercial enterprises that operate high precision equipment. Figure 4 presents a typical range of sound levels that can cause structures to vibrate that lead to the rattling of objects (windows, doors, shelves, etc.); it also shows the low frequency threshold of hearing based on quiet ambient conditions.

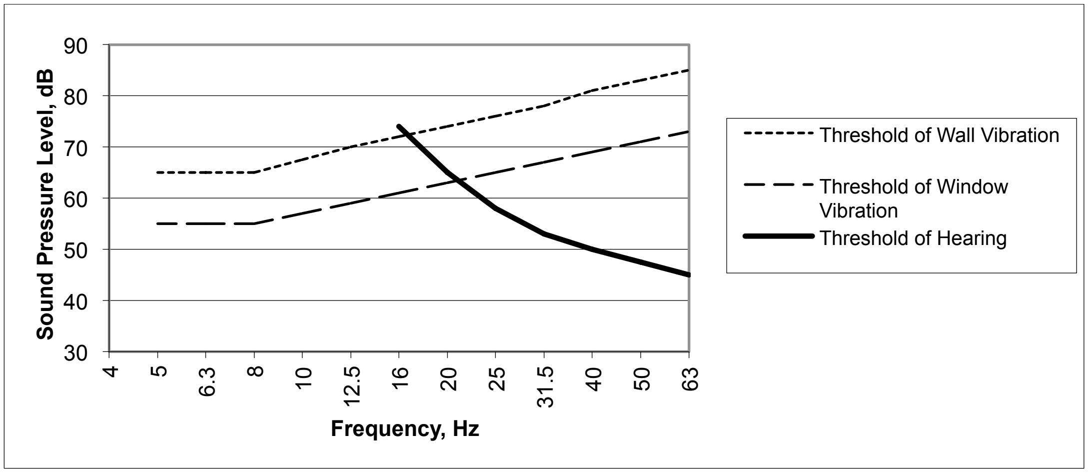

Figure 4 - General Range of Sound Pressure Levels that May Induce Vibration and Rattling in Structures – Windows, Doors, Shelves, etc.

People are generally incapable of hearing sound at frequencies below 16 Hz but a sound pressure level of 70 dB at 16 Hz can cause vibration (motion of the structure) causing secondary rattling, which can be heard. Complaints typically start when sound pressure levels in the 16 Hz and/or 31.5 Hz bands are near 70-75 dB, which correlate to overall C-weighted level of about the same amplitude, ~75 dB which is the typical basis for some community standards limiting the C-weighted sound level. But the major challenge with infrasound is its very low frequency character, which makes it difficult to identify and is usually expensive to attenuate. To give an example of a low frequency event causing higher frequency sound, take a mallet and repeatedly strike a surface. You cannot hear the sound rate of the mallet but what you hear is the higher frequency response of the surface being struck.

Another consideration is the physiological impact from sound and vibration affects. The following table presents general categories of the physical affects of sound or vibration upon the human body. Each person's anatomy is different thus the general range of intrusive frequencies and each person has their own threshold of discomfort.

Table II - Reaction to Sound or Vibration Affects

Nature of Discomfort	Frequency, Hz
Respiration Difficulty	3 – 8
Chest Pains	5 – 9
Abdominal Pains	4 - 12
Muscular Pains	4 - 20

Equipment or facilities that can produce low frequency noise need to be assessed for possible community impacts.

REGULATORY SOUND LEVELS

Essentially, there are no national noise regulations with regard to industrial or community noise limits within the United States. Other than state, county, or local ordinances that may impose some type of environmental noise limits, there are no federal regulations limiting noise from industrial plants or any fixed base facilities except for FERC (Federal Energy Regulatory Commission), which regulates interstate transportation of fuels and energy; this typically applies to pumping and compressor stations. Highway noise (Federal programs) and airport noise are regulated by the U.S. DOT (FHWA, FAA), and HUD specifies noise limits in federally funded urban renewal projects. The U.S. EPA was active in environmental noise work during the 1970’s and produced many important studies and recommendations; unfortunately, during the early 1980’s the EPA office for environmental noise and noise abatement was terminated.

The U.S. EPA developed a generic model noise ordinance,[1] including tonal limits, but requires each community to develop the specific noise limits to be incorporated into the model ordinance.

International organizations have introduced environmental-community guidelines to protect developing countries and communities. A recent publication[2] by the World Health Organization (WHO) presented recommended upper noise level limits for various community environments. The following table is a selection of common environments that are encountered and the effects of exposure to those sound levels.

Table III - WHO Guideline Values for Community Noise

Specific Environment	Critical Health Effects	TAL, dB	Time Base (hrs)
Outdoor Residential Areas	Serious annoyance, daytime and evening	55	16
	Moderate annoyance, daytime and evening	50	16
	Sleep disturbance, windows open	45	8
	Speech Intelligibility	55	
School playground	General annoyance	55	

*TAL – Time based A-weighted sound level

[1] “Model Community Noise Control Ordinance,” U.S. EPA Report, EPA 550/9-76-003, Sept. 1975

[2] “Guidelines for Community Noise,” World Health Organization, 20, Avenue Appia, CH 1211 Geneva 27 Switzerland (1999)

The World Bank Group has published [3] limits to environmental noise from power plants, which are listed in the following table and is used as a criterion for those projects financed through that institution. In the event ambient sound levels are greater than 45 dB (nighttime), then the plant noise level can be no higher than the ambient level so the total increase to the environment is only 3 dB.

Table IV - World Bank Group Maximum Allowable Hourly, Leq Sound Levels

Receptor Classification	Daytime: 07:00-22:00	Nighttime 22:00-07:00
Residential, Institutional, Educational	55	45
Industrial, Commercial	70	70

Note that the maximum allowable sound level has been set at 70 dB. This is because extensive research has shown this to be the upper limit where people can be continuously exposed to this sound level without sustaining hearing damage. Thus, in many industrial and manufacturing zoned areas, the property line limit is typically 70 dB.

ENVIRONMENTAL SOUND DESCRIPTORS

The following glossary is provided as a handy reference for terms that may be encountered and presents the mathematical expressions used in assessing noise impacts to communities.

Ambient sound level: ANSI S1.13- 2005 describes ambient sound as the all-encompassing sound at an existing point in the absence of intermittent sounds as from distant passing traffic. This is the most challenging type of environmental measurement.

Background Noise: The L_{90} statistical sound level is defined as background noise or sound level by some regulatory agencies. The US EPA and other agencies have used L_{90} measurements quite extensively for assessing and evaluating acoustical changes and impacts to communities.

Community Noise Equivalent Level (CNEL) is used to assess noise over a 24-hour period (or specified period of time) and is used in order to penalize evening and nighttime intrusive noises because the environment is generally quieter and the objective is to minimize intrusive noise disturbances. The evening noise level (L_{ev}) measured from 7:00 PM to 10:00 PM (3 hrs.) incurs a 5 dB (evening) noise penalty and nighttime noise level (L_n) from 10:00 PM to 7:00 AM (9 hrs.) incurs a 10 dB penalty. The daytime hours (L_d) are not penalized.

[3] *Pollution Prevention and Abatement Handbook* – Part III, Thermal Power – Guidelines for New Plants, World Bank Group, September 1, 1997

The following equation is used for calculation of CNEL,

$$L_{den} = 10 \text{ Log } \{1/24[(12)(10^{Ld/10}) + (3)(10^{(Lev+5)/10}) + (9)(10^{(Ln+10)/10})]\} \text{ dB} \quad (1)$$

The CNEL is easily determined by adding 6.7 dB to the overall 24-hour steady state sound level; for example, if the expected continuous steady state sound level is L_{AT} 55.0 dB then the CNEL is 61.7 dB (den is day-evening-night, sometimes denoted as DEN, all A-weighted sound levels).

Day-Night Level (DNL) rating is used to assess noise over a 24-hour period and is used in a number of government and industry standards. DNL is used to penalize nighttime intrusive noise because at night the environment is generally quieter and the objective is to minimize intrusive noise disturbances. DNL is calculated in two parts, first the daytime levels (L_d) are averaged to arrive at a single value for the hours between 7:00 AM to 10:00 PM (15 hours), and second, the nighttime levels (L_n) are averaged to arrive at a single value for the hours between 10:00 PM to 7:00 AM (9 hours) but the nighttime value is adjusted by adding a ten decibel noise penalty. The two levels are then combined to arrive at a single DNL value. The DNL is calculated as follows,

$$L_{dn} = 10 \text{ Log } \{[(15)(10^{Ld/10}) + (9)(10^{(Ln+10)/10})]/24\} \text{ dB} \quad (2)$$

The DNL is easily determined by adding 6.4 dB to the overall 24-hour steady state sound level; for example, if the expected continuous (intrusive) steady state sound level is L_{AT} 55.0 dB then the DNL is 61.4 dB (an A-weighted level).

LEQ (integrated equivalent, continuous sound level), as was shown in Figure 1, is the total sound energy (p) normalized over the measurement period (T), or simply, the averaged sound level or sound pressure level (SPL) over a specified time period expressed by,

$$Leq(T) = 10\,log\left\{\frac{1}{T}\int_0^T p^2(t)dt / p_0^2\right\} \text{ dB, re: 20 μPa} \quad (3)$$

Noise and Number Index (NNI) is based on assessing reaction to periodic noise events where an assessment is made of the annoyance based on the maximum perceived noise level (L_{PNmax}) and number of noticeable events (n) of noise intrusions. This works well for assessing transient noise events including aircraft flyover noise and traffic noise. The resulting NNI is then compared to curves reflecting community annoyance potentials.

$$NNI = L_{PNmax} + 15 \text{ Log } (n) - 80 \text{ dB} \quad (4)$$

Perceived Noise Level (PNL) is based on assessing reaction to noise events that can be considered as potentially annoying. This metric was principally developed to assess aircraft flyover noise but is sometimes used in other applications. This methodology takes into consideration the frequency content of the noise and is a complex process that assigns a unique noy value (a quantity of noisiness) based on sound level and frequency. This is done for each one-third octave band sound level from 50 Hz to 10k Hz (24 values) and all the values of the noys are then summed and adjusted (∑ noys). The PNL is then compared to curves reflecting community annoyance potentials. The PNL is calculated by,

$$L_{PN} = 33.22 \text{ Log } \sum(\text{noys}) + 40 \text{ dB} \quad (5)$$

Statistical sound levels as describe herein: L10, L50 and L90.

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