HANDBOOK OF ACOUSTICAL MEASUREMENTS AND NOISE CONTROL

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CHAPTER 50
COMMUNITY NOISE MEASUREMENTS

Dwight E. Bishop
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INTRODUCTION

Communities are exposed to noise from many sources. Most of the noise usually originates from transportation vehicles: automobiles, trucks, motorcycles, trains, aircraft, etc. The noisiest areas in a community are likely to be located near major airports or near major highways, freeways, or expressways. Some neighborhoods are exposed to noise from industrial sources (refineries, factories, etc.) or noise from commercial sources (air-conditioning equipment, etc.). In quieter areas, "people" noises (children's shouts and cries, door slams, etc.) and "nature" noises (dog barks, cricket chirps, etc.) may be important contributors to community noise.

In general, the term *community noise* refers to outdoor noise in the vicinity of inhabited areas. *Ambient noise* is the all-encompassing noise associated with a given community site, being usually a composite of sounds from many sources, near and far, with no particular sound dominant.

Community noise surveys usually include descriptions of the spatial and temporal variations in noise levels throughout the community. Such descriptions are relevant to the effects of noise on people located indoors or outdoors. Given the wide range of purposes for which measurements are made, community noise measurements vary widely in depth and detail. Because of the concern about the effects of noise on people, many noise surveys have concentrated on outdoor measurements in residential areas, with fewer measurements elsewhere. Indoor noise environments often are inferred from such outdoor measurements, but this procedure may result in sizable errors through neglect of the noise generated by indoor activities or the lack of accurate information about the noise reduction provided by the building structure.

Community noise varies greatly in magnitude and character among locations—from the quiet suburban areas bordering on farmland to downtown city streets exposed to the din of dense traffic. It generally varies with time of day, being relatively quiet at night when activities are at a minimum and noisier in morning and afternoons during peak traffic periods. Even within a small area, the noise environment varies significantly with position in the vicinity of local noise sources. For example, in a residential area, there can be a sizable difference in the magnitude and the temporal variation of sound levels measured at the curb of a street and in the backyard of a dwelling sheltered by adjacent buildings. In metropolitan areas, there may be considerable difference in the sound levels existing at the ground floor and outside an apartment many stories above the ground.

Much of the planning effort in community noise surveys is concerned with the development of methods for coping with such temporal and spatial variations in sound level. To provide concise descriptions that account for the temporal variations, several specialized noise measures are employed. Less frequently, a description of the variations in frequency spectra (resulting from different noise source characteristics and the differing sound propagation conditions involved) may be used. In addition, long-term temporal and spatial variations in the environment may be important. Temporal changes may range from considerations of day-to-day variability to seasonal and longer-term changes.

The purpose of a community noise survey heavily influences the type and number of measurements to be made. Typical purposes include the following:

1. To determine the suitability of land for differing uses and activities (i.e., involving the comparison of the existing or future noise environment with land-use criteria). For example, several federal agencies and states specify criteria in terms of day-night average sound level L_{dn} and equivalent-continuous (A-weighted) sound level L_{eq}.[1,2] Table 50.1 shows acceptable land use and minimum building noise insulation required for various values of the outdoor L_{dn} or L_{eq}.[1] As another example, if a proposed apartment, hotel, or motel is to be located where the value of L_{dn} (averaged over 1 year) exceeds 60 dB, the state of California requires a special noise analysis to show that building will provide noise insulation such that noise level in any habitable room will not exceed an L_{dn} of 45 dB.[3]
2. To compare sound levels with values specified in noise regulations or noise ordinances.
3. To obtain environmental descriptions for assessing current or future noise impacts as part of environmental impact statements (see Chap. 54).
4. To determine the need and/or extent of noise control of existing or future noise sources.
5. To identify outdoor noise sources and determine the extent of their influence.
6. To obtain a description of community noise for correlation with the community's response to noise (see Chap. 23).
7. To estimate the noise exposure of individuals (see Chap. 12).

METHODS FOR DESCRIBING COMMUNITY NOISE

Community noise surveys usually result in the accumulation of large amounts of data that are bulky to handle and difficult to assimilate or compare. To obtain meaningful and concise descriptions of community noise, single-number measures are often used that are simplified descriptors, often derived from statistical analysis or assumptions. However, such simple measures are necessarily incomplete representations of actual conditions and, on occasion, can be misleading. A number of special measures of the noise environment have been developed, each

TABLE 50.1 Land-Use Compatibility* with Yearly Day-Night Average Sound Levels

Land use	Yearly day-night average sound level (L_{dn}), dB					
	Below 65	65–70	70–75	75–80	80–85	Over 85
Residential:						
Residential, other than mobile homes and transient lodgings	Y	N(1)	N(1)	N	N	N
Mobile home parks	Y	N	N	N	N	N
Transient lodgings	Y	N(1)	N(1)	N(1)	N	N
Public use:						
Schools	Y	N(1)	N(1)	N	N	N
Hospital and nursing homes	Y	25	30	N	N	N
Churches, auditoriums, and concert halls	Y	25	30	N	N	N
Governmental services	Y	Y	25	30	N	N
Transportation	Y	Y	Y(2)	Y(3)	Y(4)	Y(4)
Parking	Y	Y	Y(2)	Y(3)	Y(4)	N
Commercial use:						
Offices, business and professional	Y	Y	25	30	N	N
Wholesale and retail—building materials, hardware, and farm equipment	Y	Y	Y(2)	Y(3)	Y(4)	N
Retail trade—general	Y	Y	25	30	N	N
Utilities	Y	Y	Y(2)	Y(3)	Y(4)	N
Communication	Y	Y	25	30	N	N
Manufacturing and production:						
Manufacturing, general	Y	Y	Y(2)	Y(3)	Y(4)	N
Photographic and optical	Y	Y	25	30	N	N
Agriculture (except livestock) and forestry	Y	Y(6)	Y(7)	Y(8)	Y(8)	Y(8)
Livestock farming and breeding	Y	Y(6)	Y(7)	N	N	N
Mining and fishing, resource production and extraction	Y	Y	Y	Y	Y	Y
Recreational:						
Outdoor sports arenas and spectator sports	Y	Y(5)	Y(5)	N	N	N
Outdoor music shells, amphitheaters	Y	N	N	N	N	N
Nature exhibits and zoos	Y	Y	N	N	N	N
Amusements, parks, resorts and camps	Y	Y	Y	N	N	N
Golf courses, riding stables, and water recreation	Y	Y	25	30	N	N

Numbers in parenthese refer to notes.

*The designations contained in this table do not constitute a federal determination that any use of land covered by a program is acceptable or unacceptable under federal, state, or local law. The responsibility for determining the acceptable and permissible land uses and the relationship between specific noise contours rests with the local authorities. FAA determinations under Part 150 are not intended to substitute federally determined land uses for those determined to be appropriate by local authorities in response to locally determined needs and values in achieving noise-compatible land uses.

Key: Y(yes) Land use and related structures compatible without restrictions. N(no) Land use and related structures are not compatible and should be prohibited. NLR Noise level reduction (outdoor to indoor) to be achieved through incorporation of noise attenuation into the design and construction of the structure. 25, 30, or 35 Land use and related structures generally compatible; measures to achieve an NLR of 25, 30, or 35 dB must be incorporated into the design and construction of the structure.

Notes: (1) Where the community determines that residential or school uses must be allowed, measures to achieve an outdoor to indoor noise level reduction (NLR) of at least 25 dB and 30 dB should be incorporated into building codes and be considered in individual approvals. Normal residential construction can be expected to provide an NLR of 20 dB; thus, the reduction requirements are often stated as 5, 10, or 15 dB over standard construction and normally assume mechanical ventilation and closed windows year-round. However, the use of NLR criteria will not eliminate outdoor noise problems. (2) Measures to achieve NLR 25 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise-sensitive areas, or where the normal noise level is low. (3) Measures to achieve NLR of 30 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise-sensitive areas, or where the normal noise level is low. (4) Measures to achieve NLR 35 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise-sensitive areas, or where the normal level is low. (5) Land use compatible provided special sound reinforcement systems are installed. (6) Residential buildings require an NLR of 25. (7) Residential buildings require an NLR of 30. (8) Residential buildings not permitted.

Source: Ref. 1.

emphasizing certain statistical characteristics of variations with time; each attempts to achieve a more meaningful measure of the noise as it affects the response of people exposed to it.

Variation in Spectral Content

There can be very wide variations in the spectral content of community noise, given the wide variety of noise sources within it. However, where community noise results largely from surface traffic, the noise spectra generally follow the trends shown in Figs. 50.1 and 50.2. Figure 50.1 illustrates the average octave-band sound pressure levels of ambient noise measured in a large number of res-

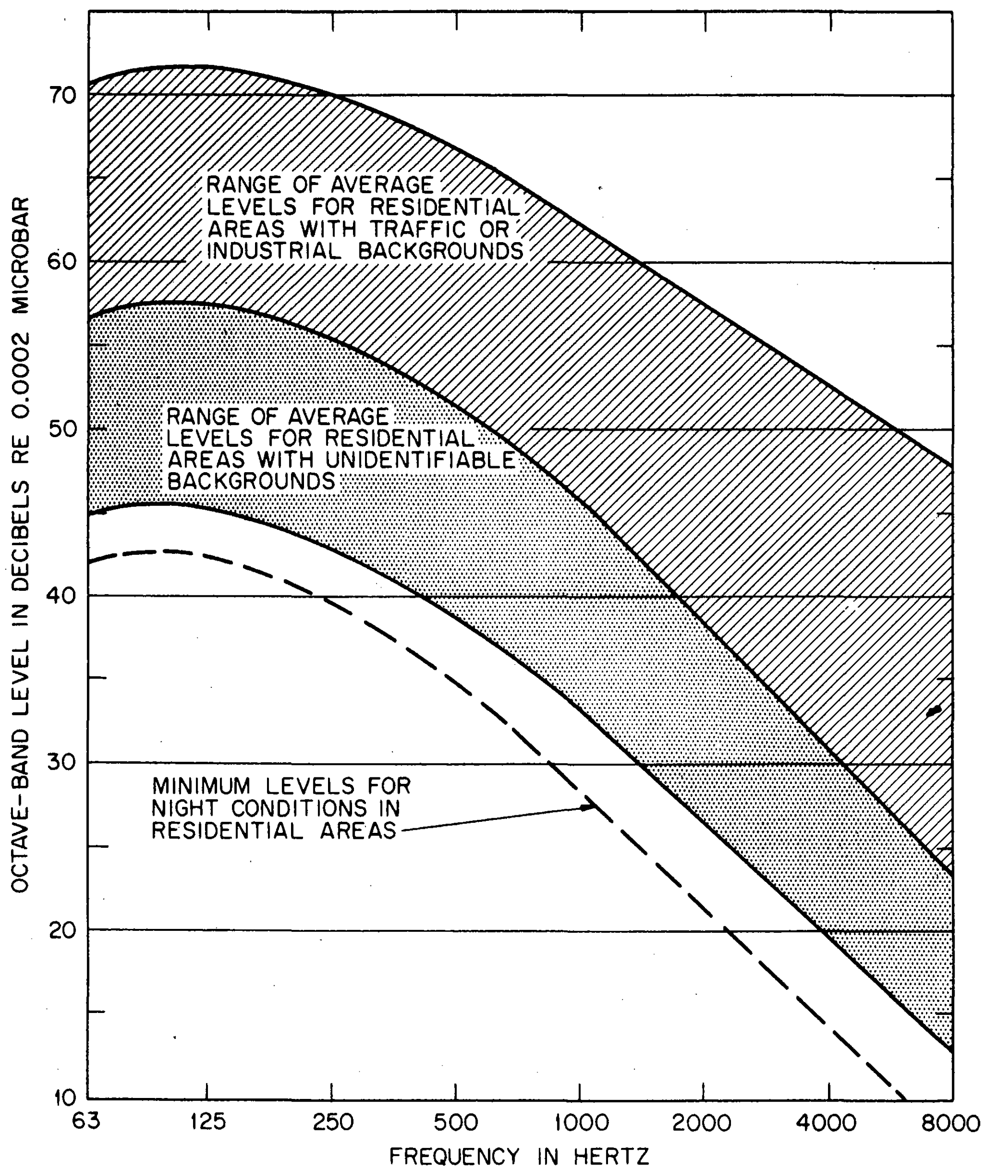

FIG. 50.1 Average octave-band spectra of ambient noise measured in residential areas. *(After Bonvallet.[4])*

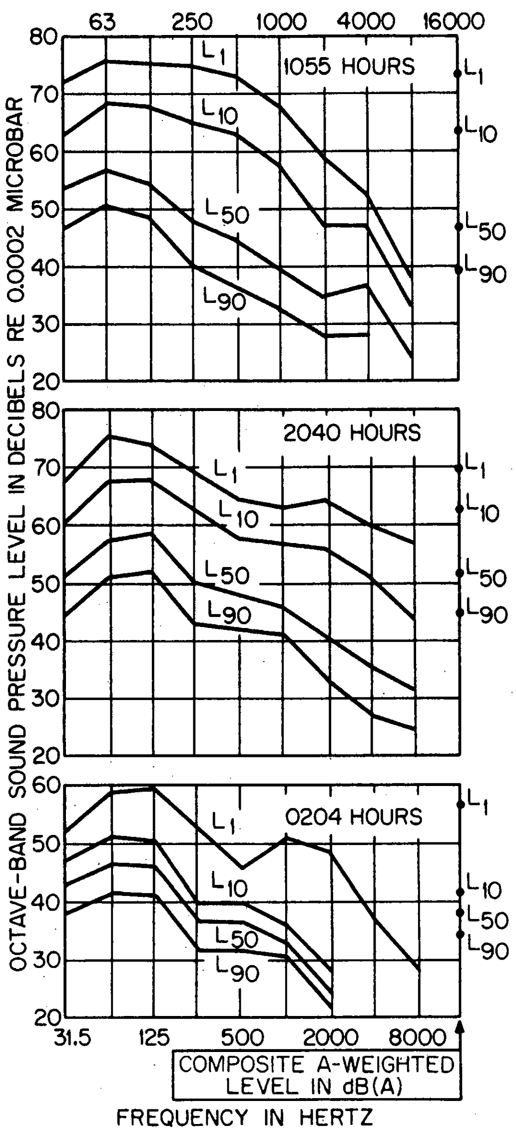

FIG. 50.2 Octave-band spectra of ambient noise in a residential area in Portland, Oregon.

idential areas in Chicago some years ago.[4] These measurements were made in the absence of noise from nearby sources, such as children at play or dogs barking.

Figure 50.2 shows the result of statistical analysis of three 10-minute samples of ambient noise in a residential area in Portland, Oregon,[5] in which the noise from all events was included. A-weighted sound levels are shown, as well as the octave-band sound pressure levels. The subscripts refer to the percentage of time the levels are exceeded. For example, the 10-percentile-exceeded sound level is L_{10}. The 50-percentile-exceeded sound level L_{50} is sometimes described as the *median sound level*. The range between the L_1 and the L_{90} curves provides a good indication of the variability in the spectral content during the period of measurement.

Most community measurements show octave-band spectra with slopes which are similar to those of Fig. 50.1 and 50.2, with sound levels nearly equal or irregular in the octave bands centered at frequencies of 31.5, 63, and 125 Hz. At higher frequencies, the octave-band sound pressure levels decrease with frequency at rates of 3 to 6 dB per octave.

Many local or intermittent noise sources can produce spectra that are distinctly different from the trends shown in Figs. 50.1 and 50.2. For example, Figs. 50.3 and 50.4 illustrate some people and animal noises which produce relatively high sound levels at frequencies above 1000 Hz.[6]

For most purposes other than detailed noise control studies, and for situations involving sources which produce high noise levels at extremely low frequencies, the A-weighted sound level serves as an adequate descriptor. Furthermore, it is the descriptor most used in community noise regulations. Hence, the rest of this chapter relies primarily on descriptions of community noise based on A-weighted sound level measurements.

For detailed noise control studies, the A-weighted sound level measurements should be supplemented or replaced by octave-band or one-third-octave-band spectral analysis. It is rarely necessary to employ finer spectral analysis. In general, temporal and spatial variations in the outdoor noise environment are so large that placing large emphasis on minor spectral variations should be avoided.

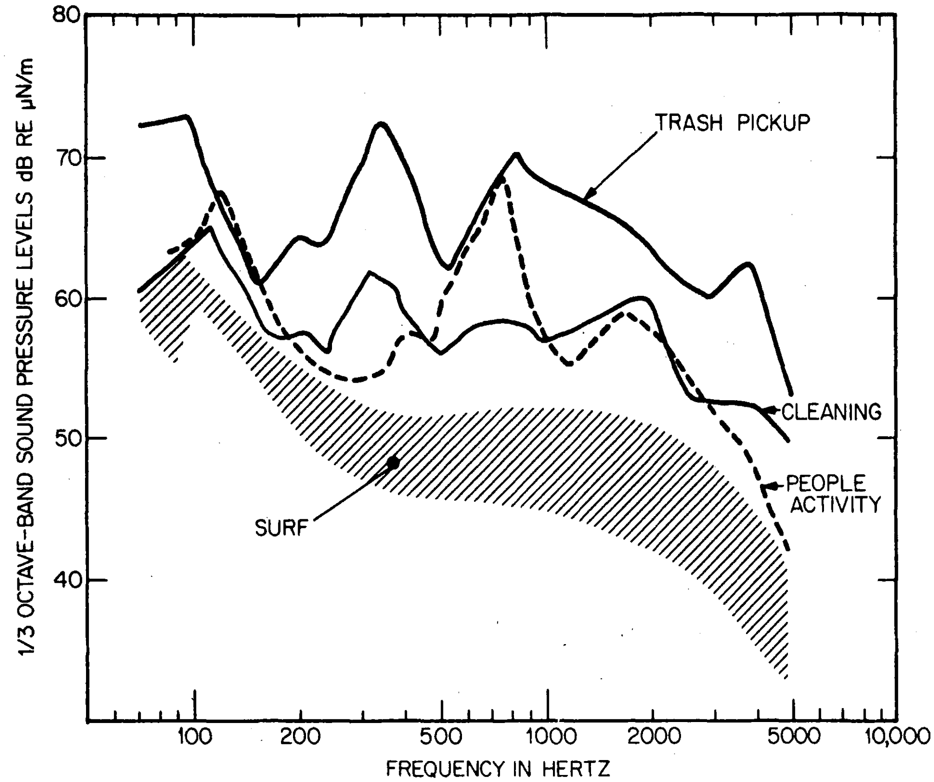

FIG. 50.3 One-third-octave-band spectra of noise measured at a beach.

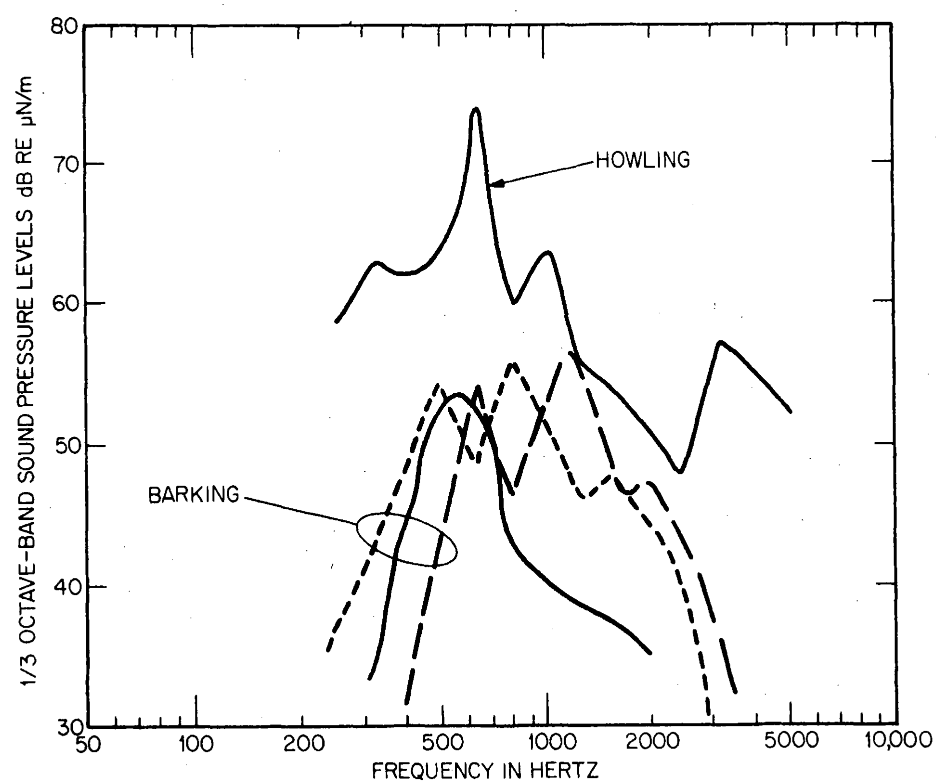

FIG. 50.4 One-third-octave-band spectra of noise of a dog barking and howling.

Temporal Variations in Sound Levels

The temporal pattern of sound levels at a given position may be observed on a continuous graphic level record such as the two 8-minute samples shown in Fig. 50.5. These samples illustrate some of the important features found in most community noise surveys:

- A-weighted sound levels vary significantly with time (in this case, over a range of 33 dB).
- Community noise appears to be characterized by a fairly steady *lower sound level* on which is superimposed the increased sound levels associated with discrete single events. The all-encompassing ambient noise depicted in Fig. 50.5 includes contributions from distant unidentifiable sources *and* local sources which produce discrete noise events. The distinct noise events often are classified as *intrusive noise*. The fairly steady lower sound level on which is superimposed the discrete single events is sometimes called the *residual sound level*, as noted in Fig. 50.5.
- There is a marked difference in the sound-level-vs.- time patterns for different discrete noise events. The sound levels resulting from aircraft rise above the ambient noise level for a duration of approximately 80 seconds, whereas the sound levels from the cars passing result in patterns of much shorter duration.

Descriptors that Eliminate Temporal Details

Exceedance Levels. Continuous recordings of noise provide much information for understanding the nature of the outdoor environment at a given location.

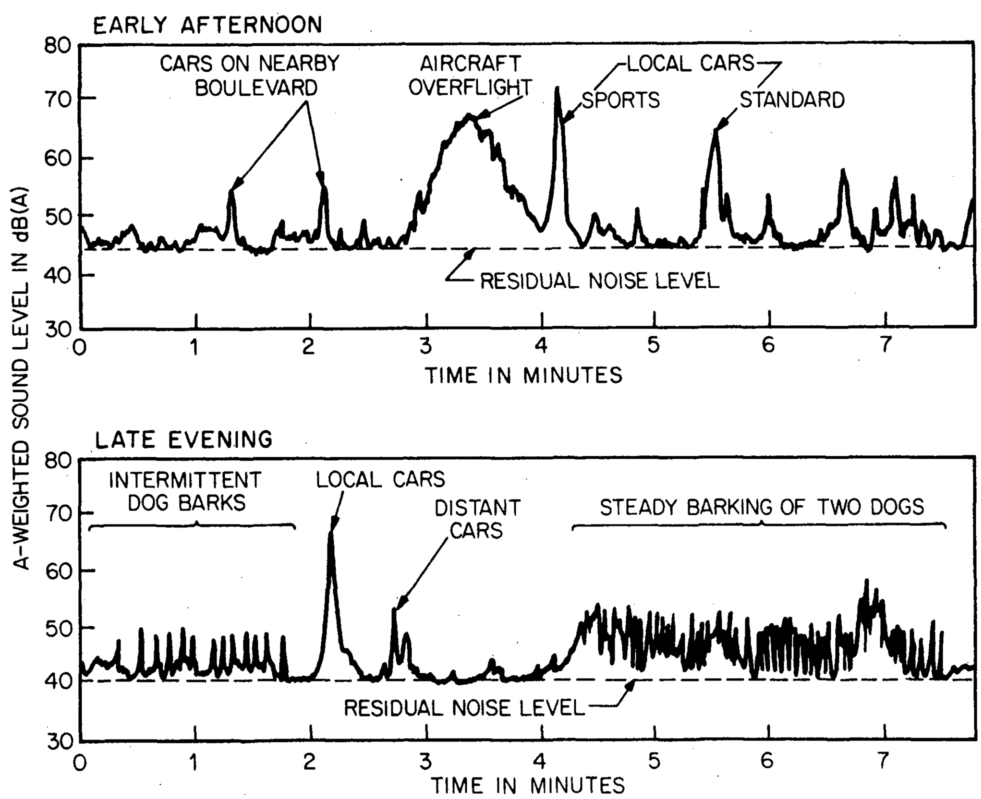

FIG. 50.5 Two samples showing A-weighed sound levels of outdoor noise vs. time in a suburban neighborhood with the microphone located 6.1 m (20 ft) from the street curb.

However, for a convenient comparison with the noise at other locations, it is necessary to simplify descriptions by eliminating much of the temporal details. One method of doing this is to measure the percentage of the total sample time that the noise falls between two sound levels, L_i and $L_i + L_d$ (where d is "window" size which influences the value of L_d). From this information a sound level histogram can be constructed, in addition to the cumulative distribution of sound levels. From the cumulative distribution, the sound levels exceeded for various percentages of time can be determined. From these data, the equivalent-continuous (A-weighted) sound level L_{eq} as well as other special descriptors of sound level can be calculated. Figures 50.6, 50.7, and 50.8 illustrate various ways of presenting the results of such statistical data. Figure 50.6 shows the 1-, 10-, 50-, and 90-percentile-exceeded sound levels calculated from hourly samples, over a 24-hour day, measured inside and outside a downtown office building in Los Angeles.[7] Also shown is the hourly equivalent-continuous (A-weighted) sound level L_{eq} (also called *hourly average level*) calculated from each hourly sample. Descriptions of the noise in terms of the values of L_1, L_{10}, L_{50}, L_{90}, and L_{eq} are more than sufficient for most purposes.

The value of the equivalent-continuous sound level L_{eq} is the most useful single number for describing the noise environment over a given short period of time. The 90-percentile-exceeded sound level L_{90} often is taken as a measure of the residual noise level, little influenced by nearby discrete events. The L_1, and, to a lesser extent, the L_{10} sound levels are heavily influenced by the noisier discrete events that may occur.

Figures 50.7 and 50.8 show the distributions in sound level for day and night periods computed from the hourly data of Fig. 50.6. In Fig. 50.7 the noise data are presented as a histogram. The distributions are skewed with a larger tail at higher levels. Figure 50.8 shows the same data plotted as cumulative distributions on normal probability paper. If the measured distributions are normal or gaussian, the distributions form straight lines. In contrast, the curves of Fig. 50.8 show a distinct curvature, a consequence of the shapes of the histograms shown in Fig. 50.7.

Daily (24-Hour) Sound Level Descriptors. For more concise descriptions of the 24-hour noise environment, the equivalent-continuous sound levels for day and night periods (or day, evening, and night periods) can be computed. For a

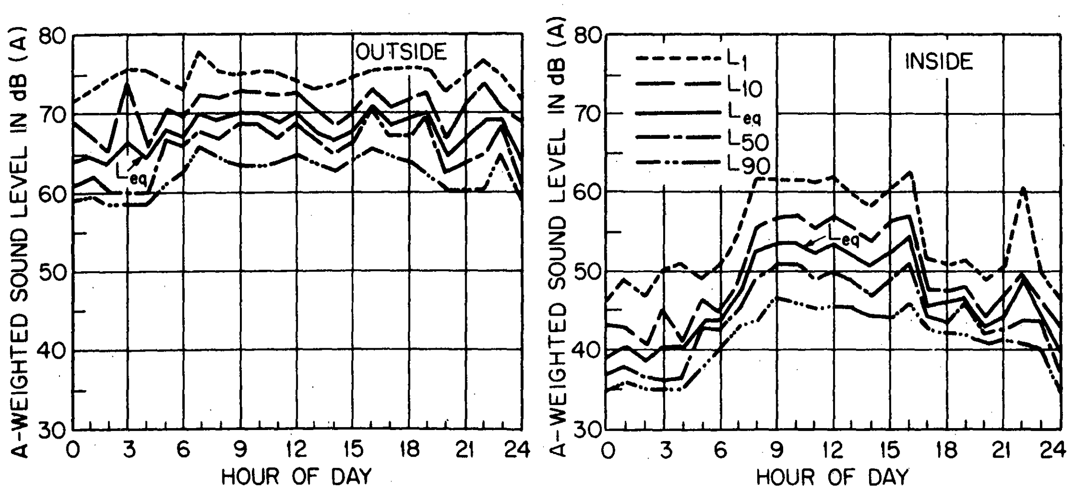

FIG. 50.6 Sound levels vs. time for noise measured outside and inside an urban downtown office building, Los Angeles.

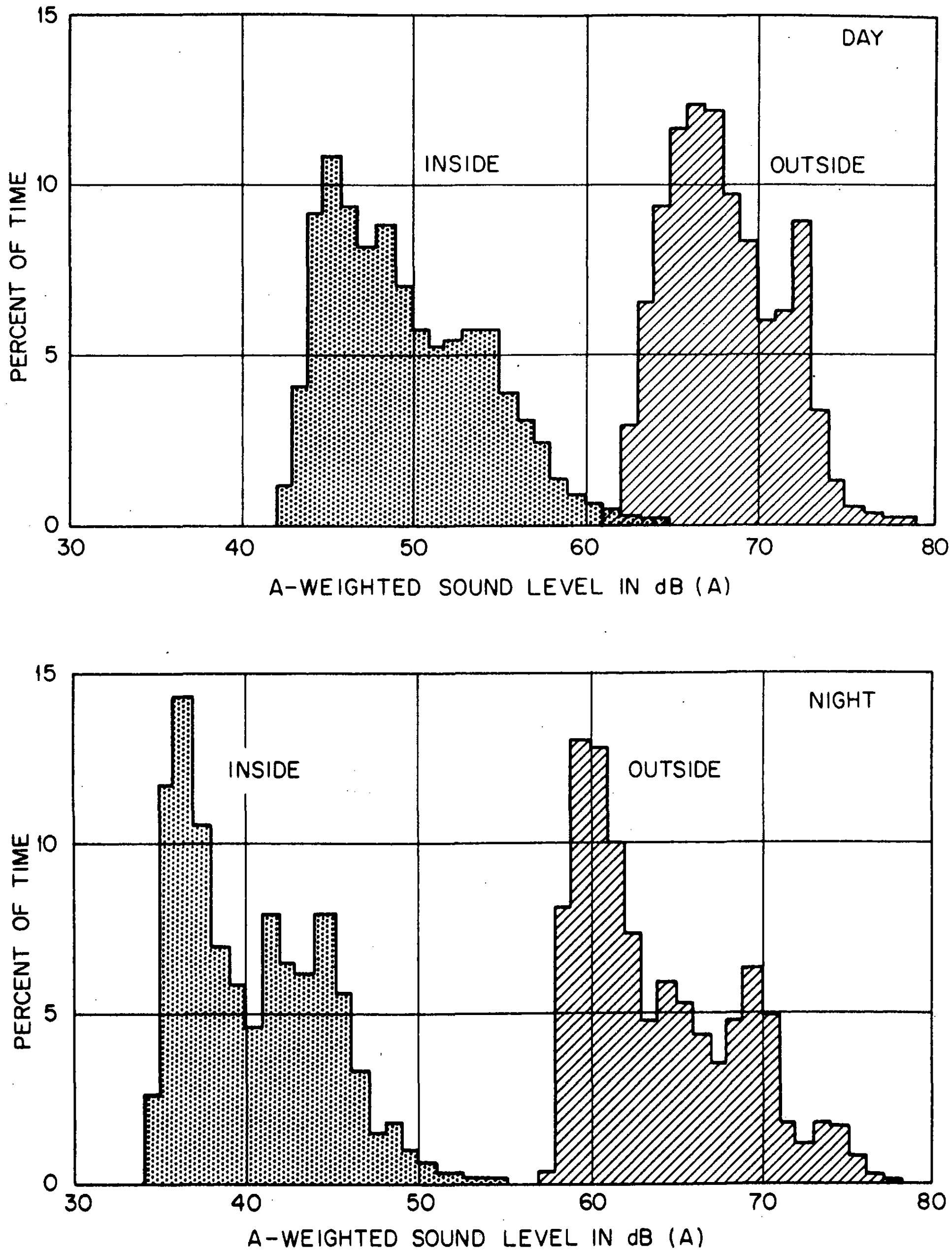

FIG. 50.7 A histogram showing the distribution of A-weighted sound levels measured outside and inside an urban downtown building, Los Angeles.

single number description, the *day-night average sound level* L_{dn} (defined in Chap. 11) is recommended. [A measure similar to the day-night average level, the *community noise equivalent level* (CNEL)—defined in Chap. 11, is used in the state of California.] The day-night average sound level can readily be calculated either from the hourly equivalent-continuous sound levels or from the equivalent-continuous sound levels for day (7:00 a.m. to 10:00 p.m.) and night (10:00 p.m. to 7:00 a.m.) periods.

Noise Pollution Level (NPL). A noise measure sometimes used to describe community noise is the noise pollution level,[8] which employs the equivalent-continuous (A-weighted) sound level L_{eq} and the magnitude of the time fluctua-

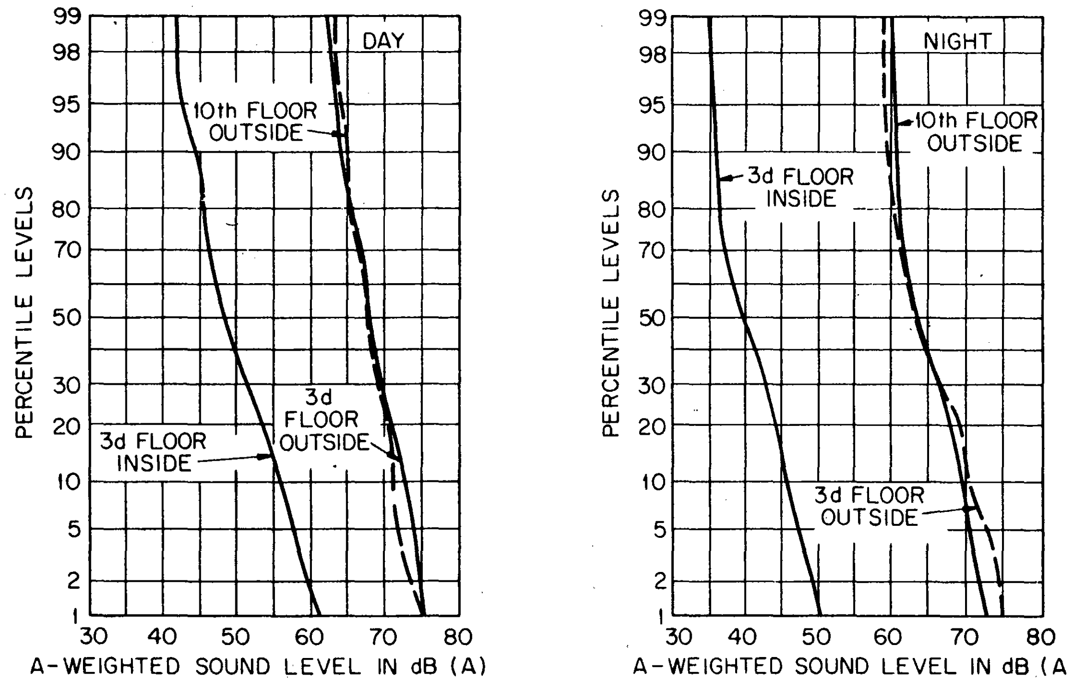

FIG. 50.8 Cumulative distributions of A-weighted sound levels, for daytime and nighttime periods, for noise measured outside and inside an urban downtown office building, Los Angeles.

tions in levels. It attempts to account for the increased annoyance due to temporal fluctuations in the noise. Noise pollution level is defined as

$$L_{NP} = L_{eq} + 2.56\sigma \quad \text{dB} \tag{50.1}$$

where L_{NP} is the letter symbol for noise pollution level and σ is the standard deviation of the instantaneous sound levels sampled during the period of measurement.

Traffic Noise Index (TNI). The traffic noise index sometimes is used to describe community noise. The traffic noise index takes into account the amount of variability in observed sound levels in an attempt to improve the correlation between traffic noise measurements and subjective response to noise. The traffic noise index is defined as

$$\text{TNI} = 4(L_{10} - L_{90}) + L_{90} - 30 \quad \text{dB} \tag{50.2}$$

where L_{10} and L_{90} are described in the section "Temporal Variations in sound levels," above. The first term represents the range between the 10-percentile-exceeded sound levels and the 90-percentile-exceeded sound level ($L_{10} - L_{90}$), and the second term represents the ambient noise level. The traffic noise index and the noise pollution level both have apparent limitations or show inconsistencies when applied to widely different kinds of community noise.[9]

Variations with Time of Day. Community noise levels show variations with time of day which correlate with the time pattern of human activities and usage of the dominant noise sources. For areas exposed primarily to motor vehicle traffic, the noise environment shows patterns distinctly related to the flow of motor vehicle traffic, with modifications produced by other sources. For example, Fig. 50.6 shows a moderate variation of sound levels with hour of day in a busy downtown area. A more typical hourly pattern for sites not located near airports or freeways,[10] Fig. 50.9, shows the difference between the hourly values of the

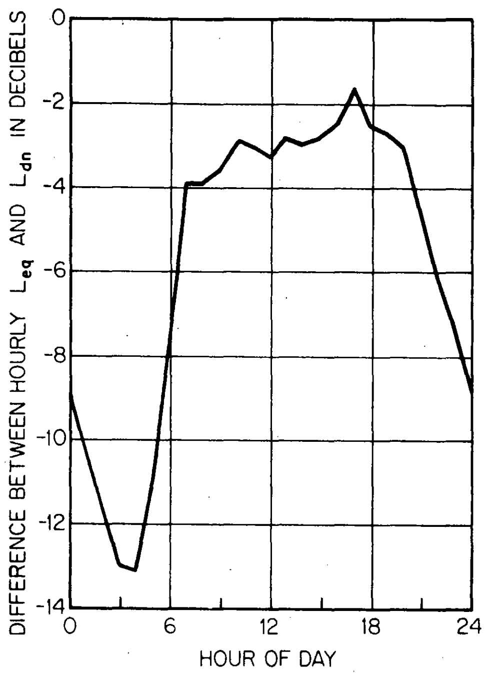

FIG. 50.9 Difference between hourly L_{eq} and L_{dn} vs. time of day.

equivalent-continuous sound level L_{eq} values and the day-night average sound level L_{dn} plotted for each hour of the day. These data represent a composite (median values) of patterns measured at 100 sites encompassing a wide range of population densities. Although the standard deviation of the sound levels within each hour ranged from 2.5 to 4.0 dB, showing considerable variation among the sites, there was a well-defined pattern, with a difference of about 11 dB between the quietest hour (3:00 to 4:00 a.m.) and the noisiest hour (4:00 to 5:00 p.m.).

There are generally differences in patterns between suburban (low population density) and urban (high population density) areas. The suburban areas show maximum sound levels in evening hours, while the high-population-density locations show less variation between the day and night hours, and maximum sound levels occur during the morning rush hours rather than the evening hours. For the 100 samples of Fig. 50.9, the median difference between the equivalent-continuous sound level L_{eq} values for day and night periods is approximately 6 dB; the difference increases to 8 to 10 dB for low values of the day-night average sound level in suburban areas and decreases to 4 to 5 dB for higher values of the day-night average sound level observed in the higher-density urban areas.

Figure 50.10 illustrates typical changes in levels for different traffic flows categorized as follows:

- Light traffic—typically eight vehicles or fewer per minute during peak daytime flow
- Heavy traffic—more than eight vehicles per minute during traffic flow
- Limited-access highways or freeways

Figure 50.10 is based on measurements at a distance of 10.7 m (35 ft) from the nearest roadway at 41 different locations in urban and suburban areas in 5 cities.[11] It illustrates noise level increases with traffic volume and the narrowing difference between daytime and nighttime levels with typical freeway traffic compared with light traffic.

Statistical Distribution Patterns. The statistical distribution of sound levels at a site often shows well-defined patterns which can be related to the major noise sources. For sites exposed to moderate and high volumes of motor vehicle traffic noise, and where there are no other "strong" sources, the distributions of sound levels approximate the shape of a gaussian distribution.

Where there are noise sources which produce high sound levels for short periods of time, the resultant distribution patterns show large departures from gaussian distributions. For example, Figs. 50.11 and 50.12 show the histograms

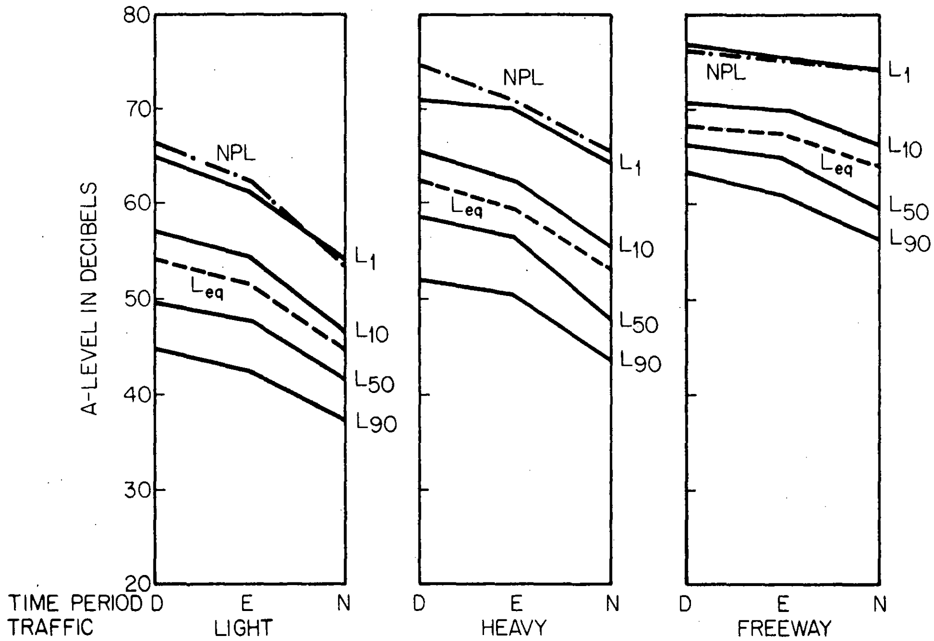

FIG. 50.10 Median A-weighted sound levels for different traffice exposures.

and cumulative distribution patterns measured inside and outside a dwelling located under the approach path to a major airport.[11]

Noise data measured in residential areas exposed primarily to motor vehicle traffic often show patterns with distinct curvature in the cumulative distribution curves. Many patterns show a distinct break in the curves, indicating that the

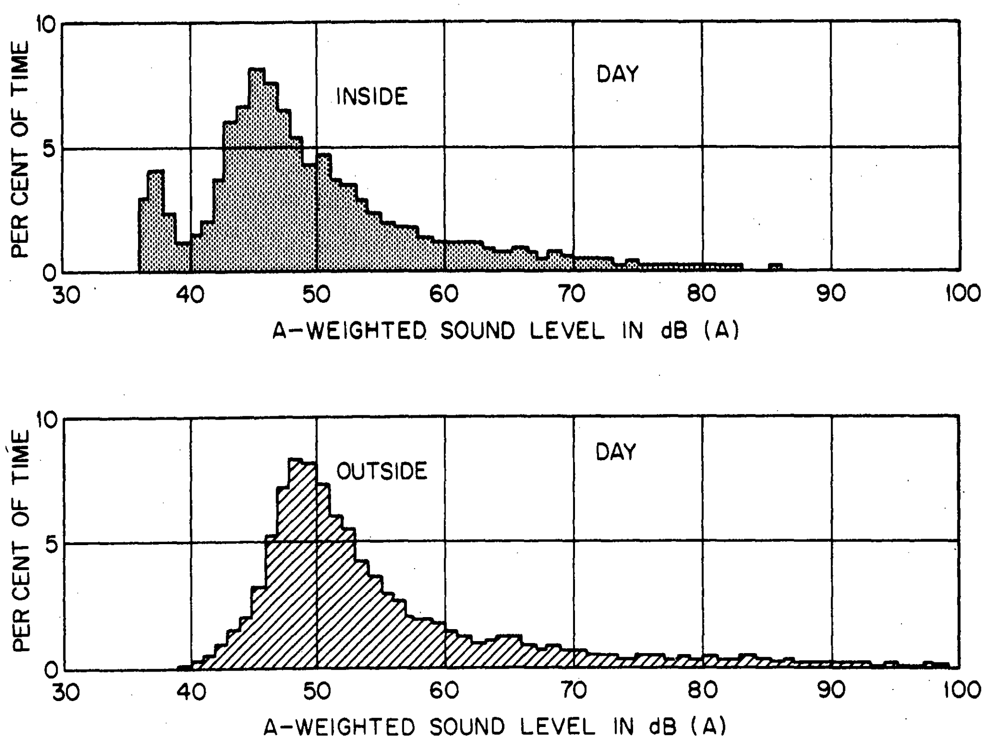

FIG. 50.11 A-weighted sound level distributions outside and inside a residence under the landing path at Los Angeles International Airport.

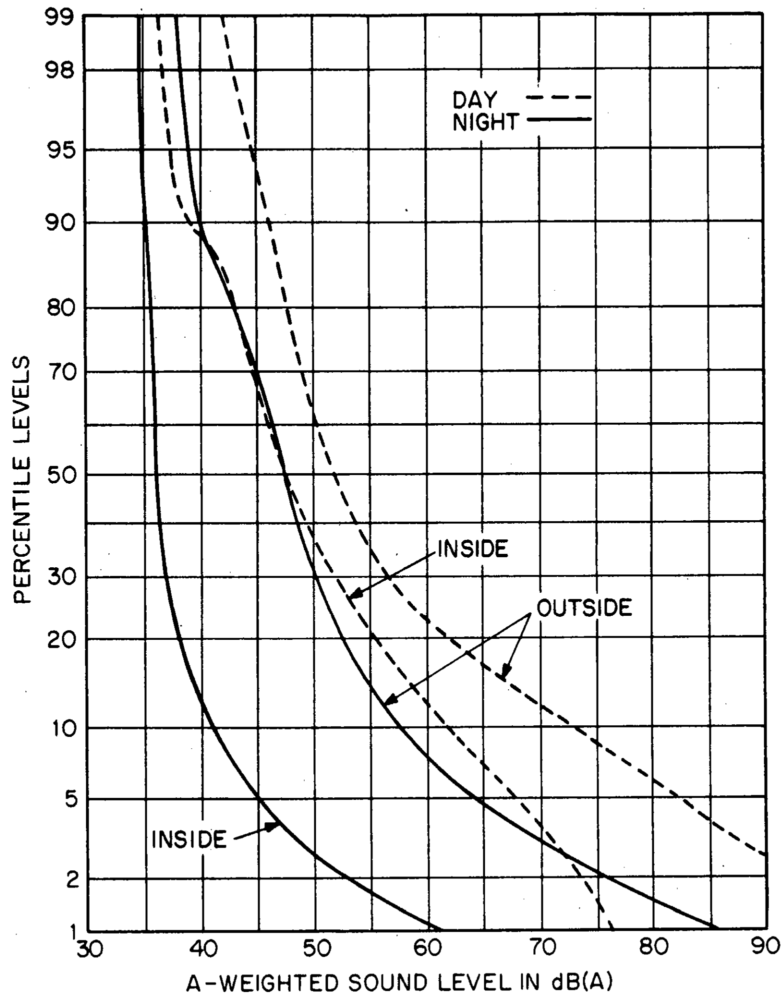

FIG. 50.12 Cumulative distribution of A-weighted sound levels of daytime and nighttime periods outside and inside a residence under the landing path at Los Angeles International Airport.

noise environment is composed of two distinct classes of noise, each of which has a near-gaussian distribution.

Long-Term (Many Year) Changes in Community Noise. Comparisons of noise surveys undertaken since 1937 show that where the land use has not changed, there is no strong trend of increases in the average suburban, urban residential, or downtown metropolitan area 50-percentile-exceeded sound levels L_{50} over the years.[6] However, where there have been great increases in the numbers of sources which produce high sound levels, there have been large increases in the areas exposed to relatively high sound levels. Thus, since 1955, there have been manifold increases in the areas of land near airports and urban freeways that are exposed to day-night average sound levels of 65 dB or greater.[6]

Day-to-Day Variability in Community Noise. The community day-night average sound level L_{dn} values for different types of communities show standard deviations in the range of 2 to 5 dB; this variation limits the extent of agreement in repeated measurements. The variability in usage or activity of the major noise-producing sources increases this range. For example, near major roadways, there are usually significant differences in patterns of noise exposure between weekdays and weekends when large differences exist between traffic flows for days during the week and days during the weekend.

At many airports, different runways are used, depending on wind conditions. Hence there can be large changes in noise exposure in a given community area, depending on weather conditions. For those airports which handle large volumes of airline traffic, the total number of operations usually does not vary significantly on a day-to-day basis. Hence the noise exposure (barring shift in runway usage) does not show large day-to-day variations. In contrast, for many military airports, there can be a sharp decrease in operations during weekends and holidays; hence the community noise levels are markedly lower during such weekend and holiday periods. The converse may happen when the military is a reserve or guard unit, or in the vicinity of many general aviation (nonairline) airports, since peak activity may well occur during weekends rather than weekdays.

Seasonal Variability in Community Noise. The variability in the week-to-week noise environment in different types of communities arises mainly from seasonal shifts in weather conditions and/or seasonal shifts in noise source operations or conditions. At many locations, wind direction, speed, and the frequency of temperature inversions vary with the season. These can effect changes in the day-night average sound level L_{dn} of 10 dB or more. Seasonal changes can also affect the source. Factory windows may be open in the summer but closed in the winter, or, as noted above, runway usage at an airport mirrors changes in prevailing winds. These sources of variation combine with the day-to-day variation to increase the standard deviation of the day-night average sound level L_{dn} values over the 2 to 5 dB range given above.

Variations at Sites Not Near Highways or Freeways. Some information on the repeatability of measurements in community areas not exposed to freeway or aircraft noise is provided by two sets of 24-hour measurements made at 24 residential sites, approximately 1 year apart.[12] The sites spanned a wide range of population densities, approximately 3100 to 142,000 people per square kilometer (1200 to 55,000 people per square mile). The average difference in values of L_{dn} and in day and night L_{10}, L_{50}, and L_{eq} ranged from -0.2 to 1.1 dB (with L_{dn} showing a 0.1-dB average change). However, the standard deviations of the differences ranged from 2.6 to 5.2 dB (3.2 dB for L_{dn}), indicating that relatively large changes were observed at some individual sites.

Variations at Sites Near Airports. The standard deviations of some measurements of the community noise equivalent level (CNEL), taken at positions near airports, are shown in Fig. 50.13. Data are shown for 16 locations at four airports (three civil and one military) handling mostly jet aircraft.[13] The measurements covered periods ranging from 13 to 193 days per position. In Fig. 50.13 the standard deviations in the daily sound levels are plotted against distance from the aircraft flight path. The solid line is a regression line fitted to all of the data; the dashed line is fitted to *only* the takeoff data. These data indicate a moderate increase in standard deviation with distance. For the dashed line, the slope approximates a 0.5-dB increase in the standard deviation per doubling of distance from the aircraft; the standard deviation is about 2 dB at 304.8 m (1000 ft), increasing to about 3 dB at 1219 m (4000 ft) from the aircraft.

Figure 50.14 shows daily L_{dn} levels at two airport sites where seasonal changes in weather is a factor. Here the standard deviation in L_{dn} is on the order of 3 dB.

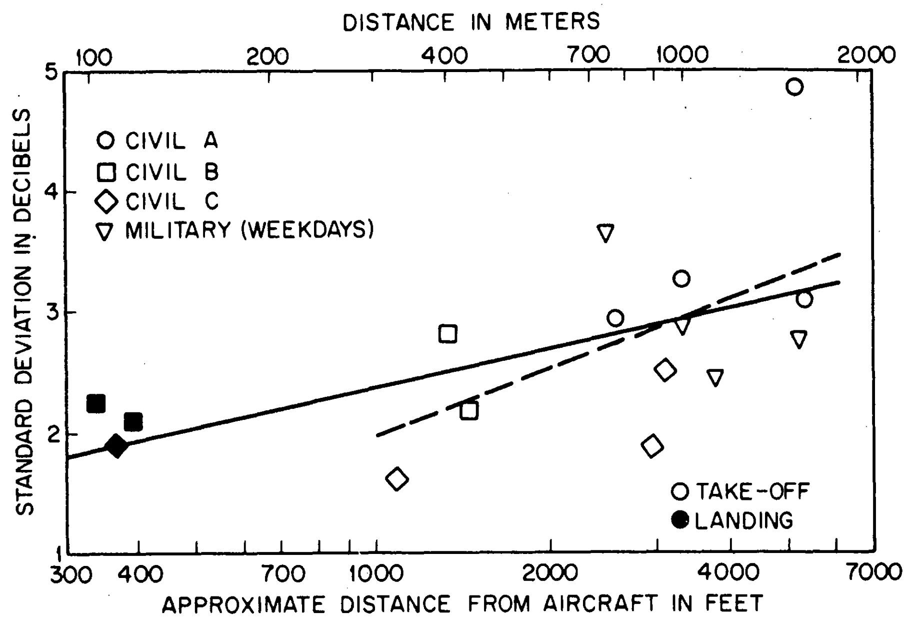

FIG. 50.13 Variability in daily community noise equivalent level (CNEL) measured at various distance from aircraft at four airports.

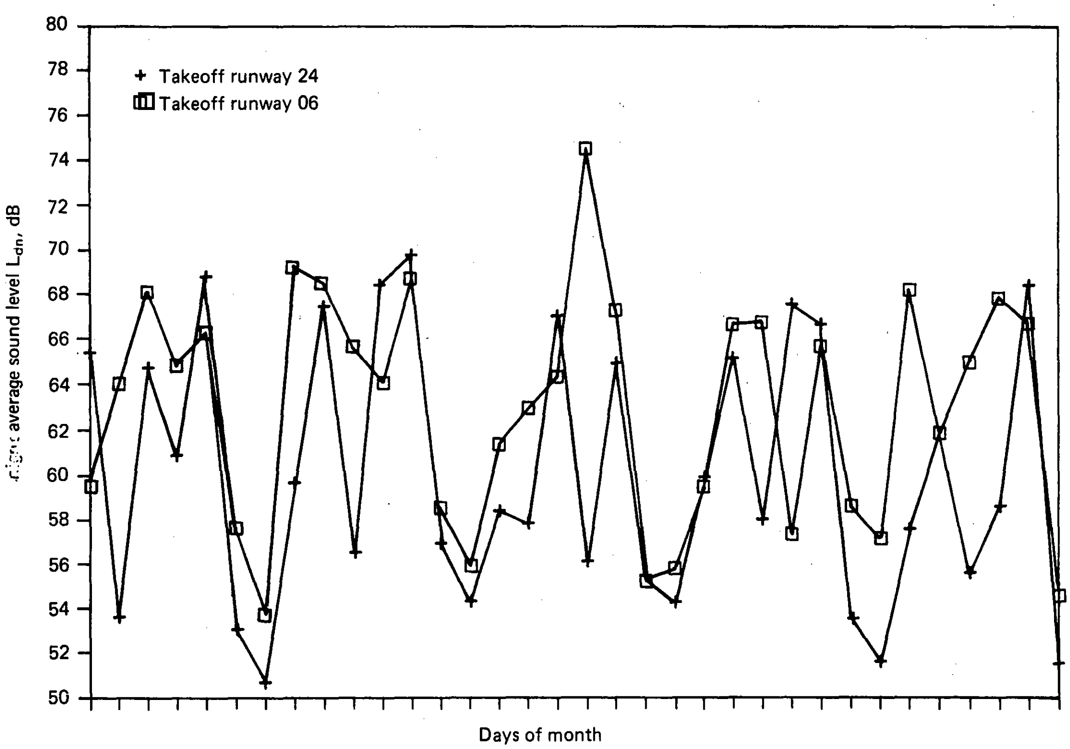

FIG. 50.14 Sample of daily day-night average sound levels measured at two positions near an airport where frequent wind changes occur.

With the sizable variability indicated by the above data, and where seasonal variations are small, measurements must be made over a number of days to obtain accurate results. Figure 9.7 provides a rough guide for determining the minimum number of measurements needed to determine an average within different intervals with 90 percent confidence. For example, for a standard deviation of about 2 dB in daily levels, 5 days of measurements must be made to determine levels to within ±2 dB. With a 3-dB standard deviation, a ±2-dB confidence interval requires 8 days of measurements.

Where seasonal changes are not small, measurements of L_{dn} must be sampled throughout a year. One strategy shown to yield a +2- to −3-dB, 95 percent confidence interval is to sample for four 1-week periods, with 1 week chosen randomly from each season.

Spatial Variations

To describe spatial variations in sound levels, statistical descriptions similar to those described above for temporal variations may be applied to a given measure of sound level (L_{50}, L_{eq}, or L_{dn} values, for example) taken at different locations. Where it is important to show differences in sound level between locations, a contour presentation is used. Contours of equal sound levels are drawn on a map, similar to those of equal elevation on a topographical map. Computer programs are available for drawing such contours for highway traffic noise, aircraft noise, and some types of industrial noise. (See Chaps. 47 and 48.)

Variations in Noise Levels with Location. To illustrate the wide range of noise environments that may be encountered, Figs 50.15 and 50.16 show the results of outdoor noise measurements made at 18 sites which varied from wilderness to downtown metropolitan areas.[6] Figure 50.15 shows the range of outdoor daytime A-weighted sound levels (i.e., the daytime average sound levels). Figure 50.16 presents the corresponding night average sound levels. The locations are listed from top to bottom in descending order of their daytime values of L_{90}. The day-

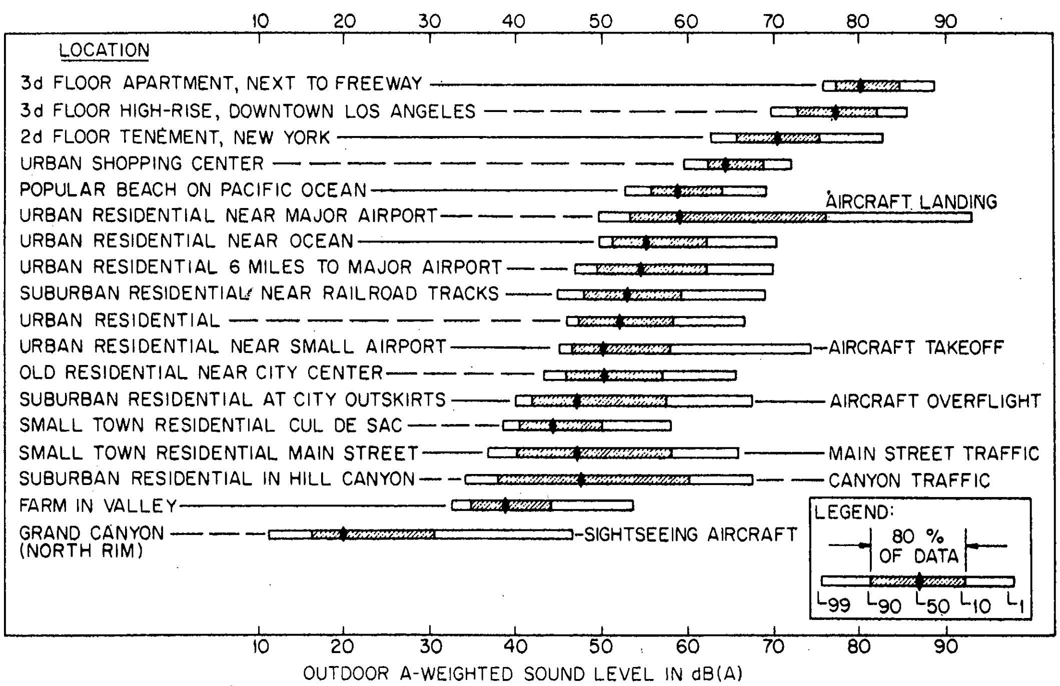

FIG. 50.15 A-weighted sound levels measured during the daytime at 18 outdoor locations, as indicated. Data are the arithmetic averages of the 12 hourly values in the daytime period from 7:00 a.m. to 7:00 p.m. (i.e., these are the daytime average sound levels).

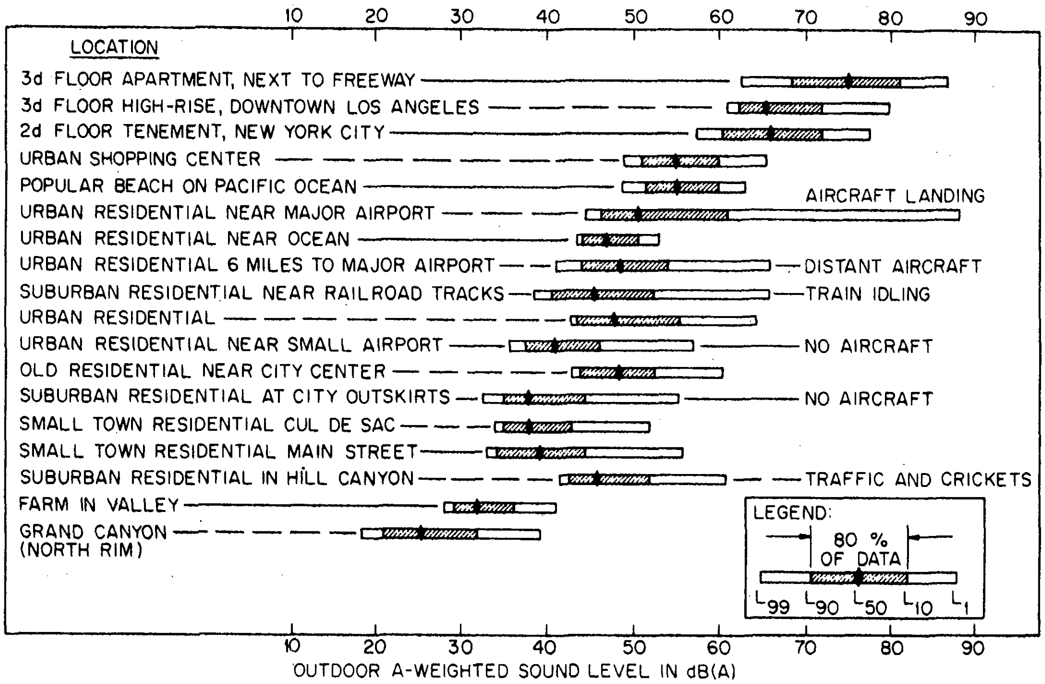

FIG. 50.16 A-weighted sound levels measured during the night at 18 outdoor locations, as indicated. Data are arithmetic averages of the 9 hourly values in the night period from 10:00 p.m. to 7:00 a.m.

time 50-percentile-exceeded sound level L_{50} values range from 20 to 80 dB among the 18 sites.

Variation in Noise Levels with Height. In high-population-density metropolitan areas, the noise environment must be considered as a function of height as well as horizontally. Of particular interest is the variation of sound level outside multistory apartment buildings. One study[14] indicates that the ambient noise level (excluding strong local sources) above a continuous distribution of random noise sources in the horizontal plane decreases slowly with height; the rate of decrease with height lessens as the density of noise sources increases. For isolated multistory buildings, the noise contributions from strong local sources decrease more or less as in free-field conditions. However, where there are many multistory buildings, even the noise from local sources decreases more slowly (or even increases) owing to the reflections from adjacent buildings. Given this difference in the decrease of noise from distant sources compared with the local sources, the 90-percentile-exceeded sound level values decrease slowly with height, while the lower-percentile-exceeded sound levels (L_1 or L_{10}), which are generally dictated by the stronger local sources, drop off more rapidly. This results in smaller fluctuations in noise levels with height. Such behavior is illustrated by the data shown in Fig. 50.17, which are based on measurements outside four different floors of a 39-story apartment building in New York City.[15] For A-weighted sound level data taken on various floors, the range in 50-percentile-exceeded sound level L_{50} is approximately 5 dB; the range in the 1-percentile-exceeded sound level L_1 is approximately 20 dB. A less pronounced change in levels with height is shown in a comparison of third- and tenth-floor measurements shown in Fig. 50.8. Note that L_{50} levels are essentially the same, while L_{10} levels have decreased only 2 dB with height.

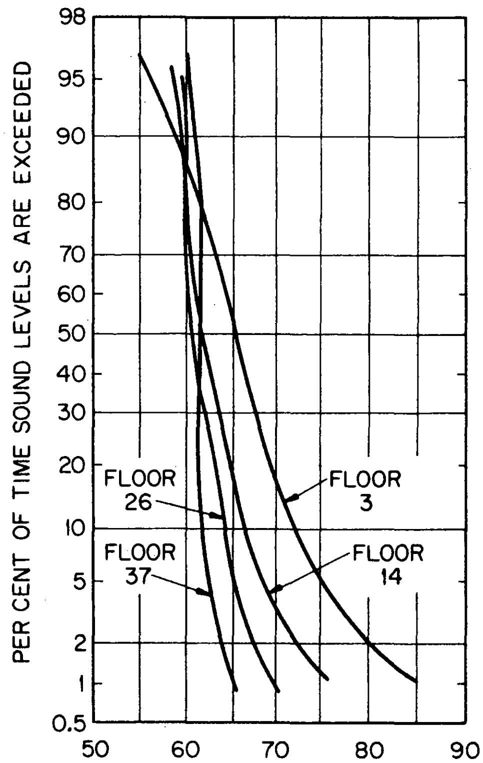

FIG. 50.17 Cumulative distributions of A-weighted sound levels measured outside a 39-story apartment building in New York City.

Indoor vs. Outdoor Noise Measurements. Most community noise surveys rely primarily on outdoor noise measurements; usually, they are convenient to make, and they may be related to outdoor noise sources. However, from the standpoint of defining the noise environment to which people are actually exposed during their daily routine, outdoor measurements are inadequate and misleading because such data neglect the noise contributions of the many indoor noise sources and the noises arising from "people" activities.

A comparison of outdoor and indoor noise environments clearly illustrates these discrepancies. Figure 50.18 shows the difference between the outdoor and indoor hourly average (A-weighted) sound levels shown in Fig. 50.7 for an urban downtown office. Note the sharp change in the differences between outside and inside sound levels for the hours of office activity, approximately 8:00 a.m. to 4:00 p.m. Outdoor and indoor hourly average (A-weighted) sound levels measured at two residential sites are shown in Fig. 50.19; measurements at both sites compare sound levels in living rooms with outdoor measurements. Note the differences in patterns of noise exposure.

PREDICTION OF COMMUNITY NOISE

Methods for predicting community noise depend on information or assumptions concerning the principal outdoor noise sources. If a community is exposed to noise from a single "strong" source, the community noise can be predicted solely from consideration of that source. Thus for communities close to airports or major highways, the appropriate aircraft and highway noise prediction models provide predictions of the community noise. If the noise is due to several local sources, the contributions of each can be calculated and then combined.[16]* However, in many communities, the noise environment results from many sources, both distant and close. Predictions based only on local sources (e.g., traffic on a local residential street) generally lead to an underestimation of the noise environment. Predictions of community noise usually are based on more or less distant,

*It is tedious to calculate the combined noise level distribution from the noise level distributions of individual noise sources. However, if the values of the equivalent-continuous level L_{eq} for each source are known, the resulting combined equivalent-continuous sound level can be calculated by use of Fig. 1.14.

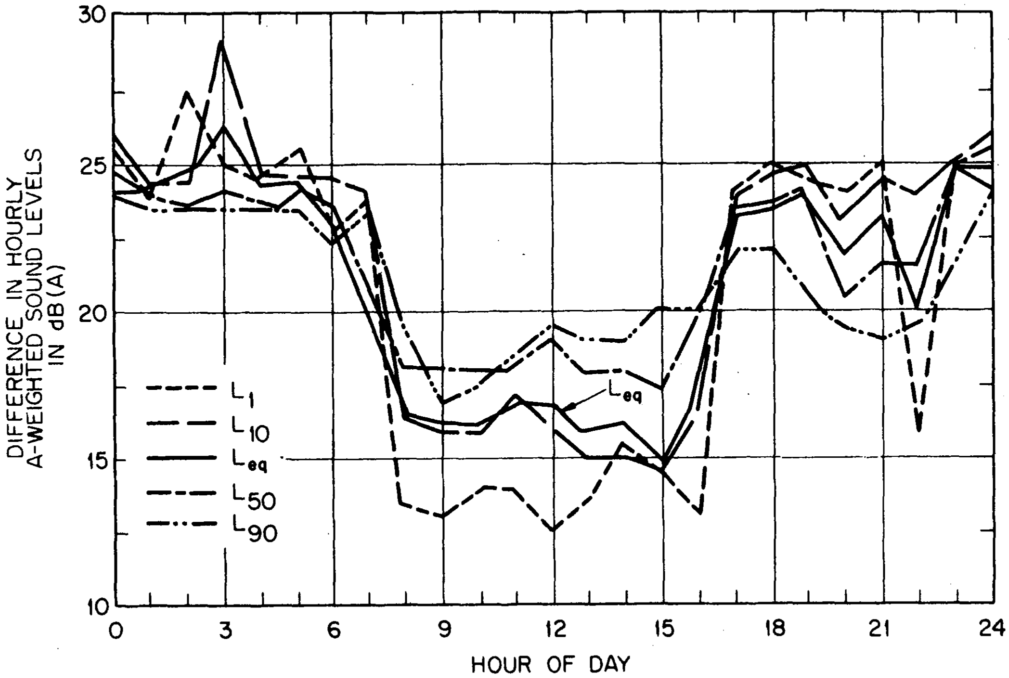

FIG. 50.18 Differences between outside and inside hourly average A-weighted sound levels for urban downtown office building, Los Angeles.

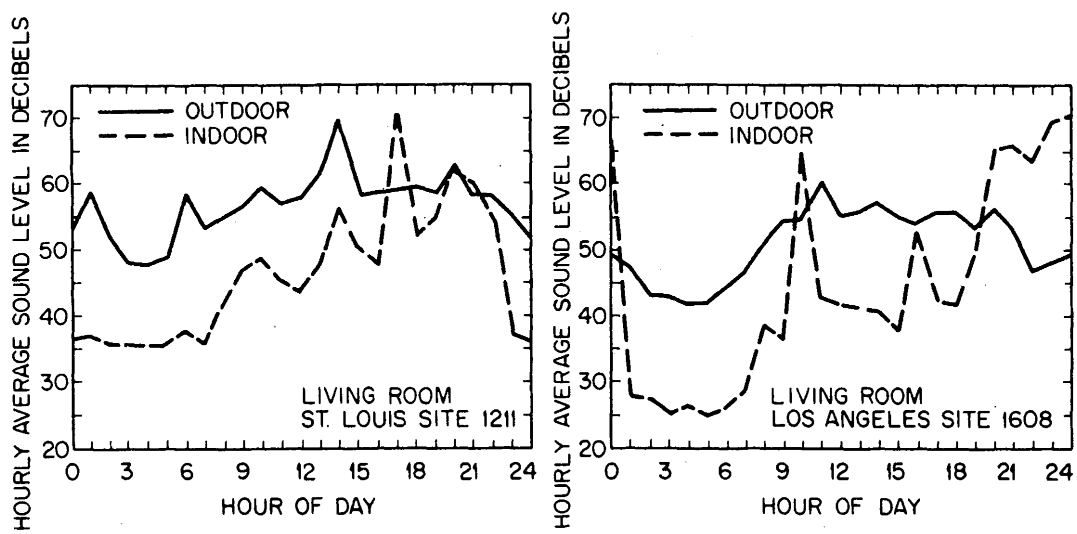

FIG. 50.19 Comparison of indoor (living room) and outdoor hourly average A-weighted sound levels at two residential sites.

undefined noise sources. To this, the contributions of local noise sources must be added when they are significant.

Prediction of General Community Noise from Population Density

One method for predicting community noise assumes that motor vehicle traffic is the most important single contributor to the noise environment for communities not located near major highways or airports.[10] It considers that over a wide range of population densities and total urban populations, the number of automobiles per person is almost constant, that the ratio of trucks in service to automobiles is almost constant, and that motor vehicle usage is directly proportional to population density. It also considers that if limited-access-highway traffic is omitted, the average speed of motor vehicles in urban areas is essentially constant. According to this predictive method, the day-night average sound level L_{dn} from the population density in the vicinity of the residential site is given by

$$L_{dn} = 10 \log_{10} p + A \quad \text{dB} \tag{50.3}$$

where p is the population density. If p is expressed in people per square mile, A = 22 dB; if p is expressed in people per square kilometer, A = 26 dB. This equation applies to community areas which are not located near strong localized noise sources. To this value must be added the contributions from strong noise sources such as major highways, railroads, industrial plants, or aircraft. For example, suppose that the population density in a suburban area is 772 inhabitants per square kilometer (2000 inhabitants per square mile). Then, according to Eq. (50.3), the day-night average sound level is 55 dB.

Estimates of the Distribution of Outdoor Noise with Population

Table 50.2 shows an estimate of the number of people in the U.S.A. exposed to various outdoor day-night average sound levels.[17] These data include populations heavily affected by freeway and airport noise.

TABLE 50.2 Number of People in the U.S.A. Living in Residences Exposed to Various Outdoor Day-Night Average Sound Levels

	Number of people, millions					
Day-night level, dB*	Traffic only	Traffic and aircraft	Traffic and construction†	Traffic and rail	Traffic and industrial	Total
> 80	0.1	0.1				0.2
> 75	0.9	0.5		0.1		1.5
> 70	4.5	2.2	0.2	1.0	0.2	8.1
> 65	15.2	7.6	0.8	3.0	1.2	27.8
> 60	36.6	16.1	2.8	4.4	3.7	63.6
> 58	49.2	24.3	6.0	6.0	6.9	92.4

*The distribution starts at 58 dB, since the analysis involves combining distributions of population at 55 dB and above.

†Includes only residential exposure to construction noise.

Source: After Ref. 17.

CONSIDERATIONS FOR UNDERTAKING A COMMUNITY NOISE SURVEY

The purposes of the survey, its scope, and the desired accuracy of measurements will have a major influence on the survey complexity, duration, and costs. Thus, these major survey requirements should be clearly stated. With these defined, the problems of community noise measurement reduces to two issues:

1. Ensure that sufficient, statistically independent data are collected such that the desired accuracy and significance are achieved.
2. If the purpose is to measure the community noise produced by a particular source, ensure that the measurements include substantially all of the sound produced by that source without contribution from other extraneous sound sources.

Sometimes the purpose of the community noise measurements is to measure the ambient noise level. Such measurements may be used to verify that a site meets the noise requirements for a proposed land use, or it may be used to monitor long-term community noise trends, etc. Measurement of ambient noise is usually the simplest type of community noise measurement, since, in this case, all noises at a site are included in the measurement. In making such measurements, it is important to ensure that the duration of a continuous measurement is long enough, or that the number of sampled measurements is sufficient for the desired accuracy.

Statistical accuracy of measurements can be increased only by additional independent information, either from added independent acoustical data or from nonacoustical data such as information concerning the operations of the various noise sources.

Data samples which are too close together in time are not independent. Consider acoustical data that are 1-day measurements of the day-night average level; the dominant noise source is a nearby freeway, and the measurement site is downwind of the freeway on a given measurement day. Then at many locations in the world it is likely that the site will be downwind on the next day. Typical weather patterns can be such that only samples several days or more apart are truly independent. Weather patterns may also affect the operations of the source, as well as the acoustical sound propagation. Wind direction affects runway usage at an airport, and this, in turn, affects the noise received in the community. Also, the source itself may have a temporal pattern. The freeway may be busier on weekdays, the road to the beach may be busier on the weekend, the factory may close on the weekend, and the airport may have many extra charter flights on Saturday.

The more difficult situation is the community measurement of the noise from a specific source such as an airport, a highway, or a factory. In this case one must not only solve the temporal measurement accuracy questions but also ensure that the acoustical measurements include virtually all of the noise produced by the source under study without including significant amounts of noise from any other noise sources. For example, one may wish to sample the airport noise near an airport to compare measured data with computer-predicted levels. In this case, the measurements must be such that noise from all other sources (e.g., factories, roadways, and freeways) is of sufficiently low level that it does not appreciably increase the measured results.

Typically, community noise measurement of a specific source can be accomplished only with careful selection and monitoring of measurement sites. This may sometimes dictate the need for observers at the site or complex acoustical and nonacoustical signal processing. At an airport, one can require that valid data be such that two monitors in a line sequentially measure (acoustically) appropriate levels, in the correct sequence and with the correct temporal spacing for the operation as listed by the aviation authorities at the airport. So in this example, one is applying three tests to the data: (1) the source must be operational—a plane is flying, (2) the temporal sequence at adjacent monitors is such that it fits the operation of the source, and (3) the acoustical levels are within expected bounds for the aircraft operation being performed.

Long-Term Temporal Sampling Requirements

The problem of long-term temporal sampling can be broken down into two predominant variables. First, weather conditions affect the propagation of sound from source to receiver. Wind direction and its altitude profile and the presence (or absence) and altitude profile of low-level temperature inversions are the primary factors affecting sound propagation over distances of as little as 100 m (328 ft). Relative humidity is a significant factor controlling the quantity of sound absorbed by the atmosphere. These factors may vary with season. Winds may be southerly in summer and northerly in winter, temperature inversions may be common in winter and rare in summer, and relative humidity may vary with the season, being highest in the spring.

The variation of received community sound with weather conditions increases with increasing distance from the sound source and the spectral content of the sound source. In general, variation increases with distance and sound frequency. Typical community sound sources will vary 10 dB at 300 m (984 ft) and will vary by 40 dB or more at 3 km (1.9 mi). Since weather is the primary factor affecting sound propagation, in the absence of other information, it is impossible to measure average sound levels any faster than it is possible to measure the average weather conditions on which the sound propagation is based. If wind is the primary variable at a given site, then it is impossible to accurately measure the average received sound unless one measures long enough to incorporate a good average of wind conditions or otherwise takes into account the variation of received sound with weather.

A means to avoid protracted community noise measurements is to measure the received sound under a set variety of weather conditions, especially for spatially fixed sound sources. One could measure the received noise from a factory under downwind, upwind, and crosswind conditions. Then, using long-term weather statistics, one could compute a predicted average for the received sound.

Instrumentation and Measurement Considerations

Special Instrumentation. Portable equipment is available for measuring noise continuously over 24-hour periods. Typically, such equipment can operate one or more days without need for servicing. A-weighted sound levels are sampled at frequent intervals (1/8- to 2-second intervals) and stored for further processing or printout. Typical capabilities of such equipment include the calculation of the equivalent-continuous sound level L_{eq} and levels for various percentiles for hourly or other specified time periods. Some equipment will also calculate the day-night average sound level for each 24 hours of measurement. Some equipment will also have additional capabilities for measuring the level, time of occurrence, and duration of individual noise events whose levels exceed a selected noise threshold.

Time-Sampling of Noises. Occasionally, it is convenient to estimate the 24-hour noise exposure from sampled (rather than continuous) measurements. Then the noise is sampled at more or less regular periods throughout the day by either of the following techniques.

Method 1. Obtain a continuous sample of noise for a duration of X minutes each hour during a 24-hour period (where X is a number less than 60), e.g., 5-, 10-, or 20-minute samples. Record such samples on tape, or measure the A-weighted sound levels directly.

Method 2. Record many short samples on tape (typically 2 to 10 seconds in duration, spaced at equal intervals throughout a period of 1 hour). For example, with this sampling technique (sometimes called *microsampling*), the noise might be measured a total of 10 minutes during an hour, with the acquisition of sixty 10-second samples.

The differences between the noise level statistics obtained from such samples and those obtained by continuous observation depend on the variability in the noise environment and the number of discrete noise events that may occur. Close to a busy freeway, a short sample a few minutes in duration will show statistics very similar to those for a continuous hour sample. In contrast, where one or two noise events, such as an aircraft flyover, determine the L_1 and L_{eq} values for that hour, short samples may show large differences.

For most situations, where there are likely to be a relatively large number of events occurring per hour (20 per hour or more), sampling of 10 minutes per hour provides reasonable accuracy; if practicable, the 10 minutes should be composed of several shorter samples distributed throughout the hour. Where the equivalent-continuous sound levels are largely influenced by a few noisy events occurring per hour (aircraft flyovers, for example), it is much better to obtain a measurement of only those few noisy events than to attempt random samplings over the time period. Often information can be obtained on the average number of noise events that occur, thus enabling one to estimate values of the equivalent-continuous (A-weighted) sound level from measurements of only a few discrete events.

"Master-Slave" Measurements. Continuous 24-hour measurement capabilities can be augmented significantly in many situations by sampling noise at intervals at other auxiliary positions in the vicinity of a 24-hour monitor location. A comparison of the short sample levels with those measured at the continuous monitor position at the same time will establish the differences in the noise environment at the auxiliary stations with respect to the "master" station and will enable one to estimate 24-hour noise exposure at the auxiliary stations from limited sampling base. Similarly, long-term levels can be predicted quite accurately by a comparison of short-term (over several days) monitoring data obtained at one site with continuous (long term) noise monitoring data at another site.[18]

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