ACOUSTICS IN THE BUILT ENVIRONMENT

Richard Guy
Department of Building, Civil and Environmental Engineering, Concordia University, Montreal, Quebec H3G 1M8, Canada

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Contents

1. Introduction
1.1 Equal Loudness Level Phon and (A) and (C) Weighting
1.2 The dB
1.3 The Sone
1.4 Bandwidths of sound, octave and third octave
1.5 Addition, subtraction and average of dB
2. External propagation
2.1 Atmospheric absorption and dispersion
2.2 Velocity of sound with temperature
2.3 Barriers
3. Community sources of sound
3.1 L_{Aeq}, (T), Ln and Ldn
3.2 Road traffic, Railway and Aircraft Noise
3.3 Occupational noise exposure
3.4 Ear protection
4. Noise intrusion
4.1 Noise intrusion at the façade
4.2 Sound reduction index
4.3 The simple wall
4.4 The sound transmission class (STC)
4.5 Double leaf walls or panels
4.6 Flanking transmission
4.7 Combination of insulation values
4.8 Floors and Ceilings
5. Indoor noise assessment (Background)
5.1 NC & PNC Curves
5.2 RC Curves
6. Indoor noise assessment (Quality)
6.1 Reverberation time or liveness
6.2 Early Decay Time
6.3 Running Liveness or Reverberance to Early Sound Ratio
6.4 Speech intelligibility
6.5 Clarity and Center Time
6.6 Lateral Energy Fraction
6.7 Assessment of Acoustic Quality in the Future
Glossary
Bibliography
Biographical Sketch

Summary

The following discourse takes the reader through the basics of sound, the assessment of physical outdoor noise, to its final impact on the indoor acoustic environment. In the process details and formulations are presented which allow the reader to assess relevant problems and their degree of difficulty. References, both hard copy and internet based will allow the reader to develop further in their topic of interest.

1. Introduction

Acoustics (n, pl), A science that deals with the generation, transmission, reception, effect and control of sound.

Within the built environment the ultimate receptor of interest is the human while the measurement devices are typically electronic instruments from which one may measure directly or infer time related acoustic energy, thus of main concern are objective measures of subjective response. We begin however with an overview of basics.

1.1 Equal Loudness Level Phon and (A) and (C) Weighting

Frequencies associated with human hearing are about 20 Hz, (below which acoustic energy tends to be felt rather than heard), up to about 20 kHz,(above which the average human hearing mechanism is very inefficient).

Energy levels of interest range from “The threshold of hearing 0dB” (energies just able to excite a good hearing mechanism) to “The threshold of pain, 120 dB” (energies which induce a reaction of pain rather than hearing).

The human hearing mechanism responds differently to different frequencies when played continuously. Lines of equal perceived sound energy for pure tone frequencies are referred to as lines of equal Phon [1]. The Phon level is defined by a continuous reference sound level at 1 kHz at which a good hearing subject perceives a sound at other frequencies to be of equal loudness and a set of “Equal-loudness contours i.e. equal Phon” are developed.

Instrument weighting networks are constructed to mimic wide band lower Phon levels, (A), wide band medium Phon levels, (B), and wide band higher Phon levels, (C). In practice it has been found that measures employing the (A) level-weighting (based on the 40 Phon contour), correlate sufficiently well with subjective response that it is now adopted for many objective measures over all Phon levels and for many time varying noises for which statistic metrics are employed.

The C weighting is sometimes incorporated into instruments as an approximation to Linear weighting at mid to higher frequencies. If a comparison between an A scale and C scale reading indicates a higher C scale value then it may be inferred that lower frequency energies are dominant.
1.2 The dB

The energy level at the Threshold of Pain is between twelve and fourteen million times that of the Threshold of Hearing so that for convenience acoustic measures are made by taking ten times the logarithmic ratio to base ten of the given energy level to the energy level at the Threshold of Hearing. Many measurement devices employ a single pressure-sensing microphone and an International reference pressure $P_0$ of $2 \times 10^{-5}$ pascals is prescribed.

For a number of wave types, the relationship between $I$ and $P_{rms}$ root mean square (rms) is

$$I = \rho_0 C_0 P_{rms}^2$$  \hspace{1cm} (1)

where $I$ is the Intensity W/m$^2$

$\rho_0$ is the density of air kg/m$^3$

$C_0$ is the velocity of sound in air m/s

In addition

$$L_p = 20 \log_{10} \left( \frac{P}{P_0} \right) dB$$ \hspace{1cm} (2)

where $P$ is the root mean square of the signal (Pascal)

$P_0$ is the reference pressure $2 \times 10^{-5}$ (Pascal)

and $L_p$ is The Sound Pressure Level

When an (A) scale weighting is introduced, the measure becomes dB (A)

1.3 The Sone

Complex sounds containing many frequencies at differing Phon levels cannot immediately be assessed for Loudness. For example an increase of 10 Phons at one discrete frequency compared to another is judged by many listeners to be a doubling of Loudness. A concept of relative loudness has been developed, one Sone is defined as the loudness experienced by a typical listener when listening to a tone of 1 kHz and a sound pressure level yielding 40 Phon. Levels relative to this standard are then judged as multiples of the 40 Phon reference. Then analogous subjective equal loudness contours are evolved for bands of noise and finally knowing the loudness to bandwidth, levels in one bandwidth may be added to the next to achieve an overall Sone level. The overall Sone Level may then be compared to a level achieved for another complex sound, typically suggesting which noise source warrants prioritized attention [2].

1.4 Bandwidths of sound, octave and third octave

Complex sounds typically contain many frequencies of interest and it is desirable to package their energies into a fewer number of convenient frequency bandwidths; the most common for subjective assessment purposes is the Octave bandwidth. An Octave bandwidth is defined by the relationship
\[ f_c \times 2^{-\frac{1}{2}} < f_c < f_c \times 2^{\frac{1}{2}} \]  

(3)

where by international agreement the center frequencies \( f_c \) are:
31.5Hz, 63Hz, 125Hz, 250 Hz, 500 Hz, 1kHz, 2kHz, 4kHz, 8kHz and 16 kHz.

A narrower bandwidth is typical for engineering purposes and the Third Octave is usually chosen.

The Third Octave Bandwidths are defined by the relationship
\[ f_c \times 2^{-\frac{1}{6}} < f_c < f_c \times 2^{\frac{1}{6}} \]  

(4)

Where by international agreement the center frequencies \( f_c \) are:
25 Hz, 31.5 Hz, 40 Hz, 50 Hz, 63 Hz, 80 Hz, 125 Hz, 160 Hz, 200 Hz, 250 Hz, 315 Hz, 400 Hz, 500 Hz, 630 Hz, 800 Hz, 1 kHz, 1.25 kHz, 1.6 kHz, 2 kHz, 2.5 kHz, 3.15 kHz, 4 kHz, 5 kHz, 6.3 kHz, 8 kHz, 10 kHz, 12.5 kHz, 16 kHz and 20 kHz.

Instruments capable of narrower bands of measurement, to fractional frequencies exist.

1.5 Addition, subtraction and average of dB

dB addition or subtraction of two sound pressure levels is achieved via:

**Sound Pressure Level (addition)**
\[ L_p = 10 \log_{10} \left( \frac{P_1^2 + P_2^2}{P_0^2} \right) \]  

(5)

**Sound Pressure Level (subtraction)**
\[ L_p = 10 \log_{10} \left( \frac{P_1^2 - P_2^2}{P_0^2} \right) \]  

(6)

Where \( P_1 > P_2 \).

Expressed in terms of Sound Pressure Levels throughout,

**Sound Pressure Level (addition)**
\[ L_p = 10 \log_{10} \left( 10^{\frac{L_{p_1}}{10}} + 10^{\frac{L_{p_2}}{10}} \right) \]  

(7)

**Sound Pressure Level (subtraction)**
\[ L_p = 10 \log_{10} \left( 10^{\frac{L_{p_1}}{10}} - 10^{\frac{L_{p_2}}{10}} \right) \]  

(8)

Where \( L_{p_1} > L_{p_2} \)
The relationships above show that a sound pressure level added to another of equal magnitude yields a 3dB increase and a difference of 10 dB or greater between two levels causes a negligible change to the higher level.

The average of dB is the average energy related content i.e.

\[ L_{P_{av}} = 10 \log_{10} \left( \frac{1}{N} \sum_{i=1}^{N} 10 \frac{L_{P_i}}{10} \right) \]  

(9)

See reference [3], “Working in dB”.

2. External Propagation

Several factors affect the propagation of sound in the atmosphere. If the dimension of the source is small with respect to the distance of the receiver then the source appears as a point and sound intensity decreases as the square of the radius i.e. 6dB decrease for doubling of distance.

If the source appears as a line e.g. a line of vehicles, then intensity dispersion as a function of radius occurs, i.e. 3dB decrease for doubling of distance. As the distance from the source increases, the line source tends to a point. Also as distance to the source increases, atmospheric absorption becomes important.

2.1 Atmospheric absorption and dispersion

Atmospheric absorption and dispersion is a complicated function of relative humidity or precipitation, air density (temperature) and frequency, higher frequencies being most affected, see reference [4].

The terrain over which the sound travels also influences the intensity loss with distance with respect to a surface source and receiver. For example propagation over a lined surface e.g. concrete, exhibits less attenuation with distance than propagation over grass or snow, through trees or bushes. Each of these features is also a complex function of frequency and ground type.

Weather conditions will also influence propagation. Wind will effect the propagation by causing more energy to flow downwind than upwind.

Over varying ground surfaces the wind increases as a power law with respect to height and surface type, thus a shadow zone upwind with a reinforcement downwind often occurs; thus for outdoor measurement it is better to measure down wind, as a worst case occurrence.

Temperature gradients in the atmosphere can also influence the propagation of sound causing a shadow effect some distance away from the source when a normal temperature decrease with height is encountered.

However, in the event of a temperature inversion, i.e. temperature increase over a limited height within the vicinity of the earth’s surface, sound reinforcement, typically at distances greater than one kilometer can be encountered.
Bibliography


2. ISO. 532-1975 Methods for calculating loudness level. See also “ Loudness Calculator ( Zwicker Method ) ”http://www.measure.demon.co.uk/Acoustics_Software/loudness.html


Under “ Products and services”, Choose- “ International Standards”; then Search – Acoustics.


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Canada Mortgage and Housing Corporation (CMHC)  http://www.cmhc-schl.gc.ca/en/burema/himu/himu_005.cfm


Under “ Products and services “ Choose “ International Standards “; then, Search – Acoustics,


See Abstract at:- http://users.aol.com/NCEJABS/ab420102.html

NOTE: Web sites listed above are current at the time of writing. They can be exploited for numerous additional entries regarding noise, its effects, measurement and problem resolution.

Biographical Sketch

Dr. Richard Guy received a Master of Science degree in Acoustics from the Institute of Sound and Vibration Research, Southampton University, England (1971). He received his Ph.D. from the Acoustic Research Unit of Liverpool University, England, (1975). Since that time he has been working in the area of sound transmission in Buildings and the Surrounds. He has published extensively in learned journals and via conference presentations. His research continues at the Department of Building, Civil and Environmental Engineering of Concordia University, Montreal, Canada where he holds the position of full professor.