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Publisher’s version / Version de l'éditeur:
https://doi.org/10.4224/20328720
Canadian Building Digest, 1985-02-01

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Canadian Building Digest
Division of Building Research, National Research Council Canada

CBD-236

Introduction to Building Acoustics

Please note

Originally published February 1985.

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Abstract

Some of the fundamental terms and measures used in building acoustics to quantify sound and the acoustical properties of systems and materials are described.

Introduction

Sound waves are small rapid fluctuations in pressure that propagate in air as well as in solids and liquids. A distinction is made between airborne sound and structure-borne sound depending on the medium in which the sound waves are travelling. In buildings, sound waves may originate as airborne sound, then travel for some distance as structure-borne sound and be radiated again as airborne sound in another location.

Physical Properties of Sound

The frequency of a sound wave is the number of times that its basic pattern repeats itself per second. So, a musical note characterised by a pattern of pressure variations that repeats itself 1200 times per second has a frequency of 1200 Hertz (Hz).

To reduce the very wide range of sound pressures encountered in practice to more manageable numbers, the decibel (dB) scale is used. Sound pressure levels in dB are more easily related to human perceptions. A change in level of 10 dB corresponds approximately to a doubling of perceived loudness. Sound level meters can be designed with built-in electrical networks to respond to sound approximately as perceived by the ear. The A-weighting network is most commonly used for this purpose. Sound pressure levels of sources emitting a broad range of frequencies can be measured with a sound level meter incorporating this feature and the resulting sound pressure levels are expressed in dB(A). On the decibel scale, a soft whisper at 2 m distance would have a sound level of about 35 dB(A) while average background sound levels in an office would be about 40 dB(A). A jack hammer 15 m away can raise the sound level to 95 dB(A), while a discotheque can generate noise levels in excess of 110 dB(A).

Sound pressure levels in dB cannot be simply added together like other quantities. If N sources generating the same sound pressure level are combined, the overall sound pressure level will be increased by 10 log N dB. Two sounds with average levels of 60 dB, for example, will together create a sound pressure level of 60 + 10 log 2 = 63 dB. The greater the difference in noise level between two noise sources, the less effect there is on the combined level. Where the difference between two sources is more than 6 dB, the combined level will be less than 1 dB higher than the louder source alone. In practical situations, changes less than 3 dB are not considered significant.

Sound Perception

The range of audible frequencies for the human ear is about 20 Hz to 18 000 Hz. The ear, however, is not equally sensitive at all frequencies. Sounds of the same sound pressure level but with different frequencies are not judged to be equally loud. In general, the ear is less sensitive at low frequencies than it is at high frequencies. For example, a sound at 3 kHz and a level of 54 dB will sound about as loud as one at 50 Hz and a level of 79 dB. Measurements in building acoustics are not made over the entire frequency range of the human ear. The lowest frequency that is measured is usually about 100 Hz, although octave band measurements are sometimes made at 63 Hz when measuring heating, ventilating and air-conditioning (HVAC) noise. The high frequency limit for measurement is about 4000 Hz but may be as high as 15 000 Hz in special cases.

Noise Descriptors

Typical sources in buildings emit sound at many frequencies. A graph showing the energy at each frequency is called a spectrum. The information in a detailed or narrow-band spectrum can be very useful when dealing with machine resonances, but in building acoustics spectra are usually presented in standardised bands one-third of an octave or one octave wide (adjacent octave bands have centre frequencies that are different by a factor of two and fall in the standard sequence 31.5, 63, 125, 250...8000 Hz). Energy in specified regions of the acoustical spectrum is combined to give average sound levels in each octave or one-third octave band. This type of presentation gives information that relates more directly to the ear's perception.

It is convenient to quantify noise sources using a single number instead of a graph. Several methods have been developed for this purpose in addition to the A-weighting sound level meter previously mentioned. One method involves the use of noise criterion (NC) curves as references against which octave band spectra are compared.[1] NC ratings are often used to establish maximum noise levels associated with HVAC machinery.

It must be remembered that NC contours are not ideal background spectra to be sought after in rooms to guarantee occupant satisfaction but are primarily a method of rating the noise level. There is no generally accepted method of rating the subjective acceptability of the spectral and time-varying characteristics of ambient sounds. In fact, ambient noise having exactly an NC spectrum is likely to be described as both rumbly and hissy, and will probably cause some annoyance. Electronically-generated masking noise, sometimes used in open offices to increase speech privacy, tends to have less low and high frequency energy than an NC spectrum.

It is very important to keep background noise down to a level that ensures a congenial living or working environment for building occupants. Excessive noise levels can make speech communication or concentration difficult. Intrusive noise can be particularly annoying, even if it is not very loud, when it has some message associated with it, or if it is distinctive. Speech heard through a wall, a dripping faucet, buzzing from lights or the whine from a pump are examples of such noise.

The maximum tolerable background noise level varies with the use of the space. In concert halls, auditoria, music rooms, theatres, and churches it should not exceed 30 dB(A), while in apartments, classrooms, hospitals, cinemas, conference rooms, small offices, courtrooms, and libraries it can be as high as 45 dB(A). Recommended levels for different occupancies can be found in many standard acoustical text books. Sound levels should be checked under normal operating conditions after construction is over to be sure that design criteria have been met.

Reverberation and Absorption

When a sound source in a room stops, the sound energy drops (decays) at a measurable rate that is dependant on the amount of sound absorbing material in the room. The reverberation time (RT), widely used as a design parameter in architectural acoustics, is the time that sound would take to decay through 60 dB so that RT = 60/decay rate. Excessively reverberant rooms are usually noisy and speech communication may be interfered with. The reverberant sound level and the RT in the room can be reduced through the installation of appropriate sound absorbing materials.[2]

The ability of a material to absorb sound is expressed in terms of a sound absorption coefficient. It can also be expressed as a percentage. The coefficient varies with sound frequency and the angle of incidence of the sound waves, These coefficients are normally determined for one-third octave bands under standard conditions.[3]

The noise reduction coefficient (NRC)[3] is the average of the sound absorption coefficients at 250, 500, 1000 and 2000 Hz. It is useful for roughly comparing materials.

Sound Transmission Loss

It is very important to distinguish between sound absorption and sound transmission loss. Sound absorbing materials control sound within spaces and function by allowing sound to pass through them relatively easily. They are generally porous and absorb sound as a result of many interactions. Conversely, a material or system that provides a good sound transmission loss is usually non-porous and a good reflector of sound, although double-layer partitions often contain sound absorbing materials to reduce the reflection of sound inside the partition.

When sound waves strike a partition, the pressure variations cause the partition to vibrate. A portion of the vibration energy on the sound source side will be transferred through the partition where it is re-radiated as airborne sound on the other side.

The ratio of the sound power incident on one side of a partition (or floor system) to that radiated from the other side is used to calculate the sound transmission loss in dB. The transmission loss (TL) usually increases with the frequency of the incident sound. Although it also varies with the direction of the sound waves, it is usually assumed to be the average for all possible angles of incidence.

Laboratory measurements[4] of the TL of an assembly are made in one-third octave bands from 125 to 4000 Hz. It is convenient, however, to have a single number to compare building assemblies. The designation most commonly used in North America is the sound transmission class (STC).[5] It is determined by comparing the measured TL curve of an assembly to reference STC contours.[4] Only a limited portion of the TL curve is permitted to fall below the STC contour. The larger the STC value, the better the partition.

The transmission of sound between rooms involves not only the direct path through the separating assembly, but the flanking paths around the assembly as well.[6] Holes, fissures and similar defects provide a path for sound travel that can increase the sound transmission between rooms. On-site tests, however, can be made between rooms to measure the effective sound transmission loss, including the effect of flanking paths and construction defects.[7] The single number rating derived is the field sound transmission class (FSTC).

A shorter test procedure has also been developed to give a single number rating from simple measurements.[8] It gives a normalized A-weighted level difference between two rooms which is typically within one or two points of the FSTC values and can be very useful for quality control in building construction.

Impact Noise

Impact noise is created when a solid object comes in abrupt contact with the structure (e.g., footsteps). This generates vibrations directly in the structure and these structure-borne sound waves travel through the building to be radiated elsewhere as airborne sound. A test has been developed to measure impact sound transmission through floor-ceiling assemblies using a standardized tapping device as the impact noise source.[9]Sound pressure levels are measured in the room below the test assembly in one-third octave bands from 100 to 3150 Hz. The impact insulation class (IIC) is determined by comparing the measured sound pressure levels to reference curves.[10] The higher the IIC value, the better the floor system. A field test to measure impact transmission is also available.

The single number ratings given above are the criteria most frequently used to specify the acoustical performance of building elements or materials. The particular criteria chosen will depend to some extent on the end use. This subject will be dealt with in a future publication.

Fundamental Noise Control Procedures

Three important techniques are used in almost all noise control situations. Figure 1 shows a source placed on a resilient support inside an enclosure with high sound transmission losses and lined with sound absorbing material. If the resilient supports are omitted, the vibrational energy from the machine would pass into the building structure with very little attenuation to radiate as sound elsewhere. If the solid enclosure were not there, the sound would pass through the sound absorbing material with very little attenuation. If the sound absorbing material were omitted, the reverberant sound inside the enclosure would build up and the energy loss through the enclosure would be much less than expected. All three elements should be present.

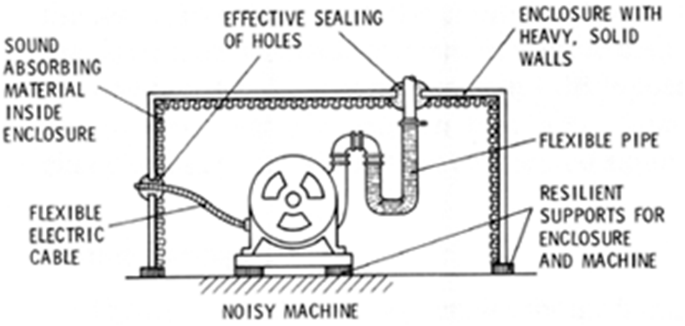

Figure 1. Principles of isolation of a noisy machine

The correct application of these three measures is the cornerstone of good acoustical design. The enclosure can be a box small enough to house a printer, a large room containing several noisy machines or a living room in an apartment, but the principles remain the same: good sound control incorporates resilient supports or connections, sound absorbing materials and leak-free sound barriers. Criteria should be set during the design stage and inspection or measurements made during or after construction to ensure that the criteria are being met.

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* Available from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA., 19103, U.S.A.