Sound Advice for Acoustic Design

An Online Continuing Education Course for Engineers

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Acoustics in General

Merriam-Webster defines acoustics as a science, a body of knowledge, dealing with the production of, transmission of, reception of, control of, and effects of sound.

Given that sound is a direct input into one of our five senses, it shapes our perceptions of reality and in a very real sense, our identity. Given nuances of how it affects us, there are many subjects and fields of study contained within those five broad classifications. These range from physics of sound, changes in it because of environment, physiological reactions to it, psychological reactions to it, its application in the arts, its use in medicine, and numerous subsets of each of these.

For our purposes, we will examine only architectural acoustics. We will focus on how sound from within and without, and the characteristics and quality of the same, positively and negatively affect inhabitants of environments we create. We will consider what can be done to enhance or mitigate those effects, to control or alter characteristics of such sound. We will examine how sound radiates outward from points of origin, how it moves through objects and space, and how it is perceived by people. We will consider control of sound through spatial design, material choices, and construction techniques. Finally, we will examine problems with which we still struggle, how to deal with them in specific building types, and why it is becoming so important to do so.

But first, we begin with some basic terms and concepts.

<u>General Vocabulary Regarding Sound</u>

Sound: *The transmission of kinetic energy, through vibration of an elastic medium (matter comprised of things like air, or building materials) from a source to a receiver. This energy travels outward from a source in waves of energy that can be directed, absorbed, or otherwise controlled. It is transmitted through materials or assemblies when it strikes them from one side, causing them to vibrate and set up similar vibrations in the air again, on the opposite side.*

Noise: *Unwanted sound. The most objectionable sounds are those loud enough to be uncomfortable, and ones that are intermittent, rather than continuous.*

Noise Nuisance: *An excess of noise that has a negative effect on the hearer. Noise will always be present to some degree and defined in the same two ways. It will either be acceptable or unacceptable.*

Air Borne Sound: *Energy traveling in waves, directly through the air to a receiver, like a microphone or the human ear.*

Impact Noise: *Sound transferred through the structure of a building, also labeled as structure borne sound. It occurs when vibrations are induced in one surface struck by another object. Kinetic energy of the impact travels through the material as vibrations, producing sound waves in the air around what was impacted. This kinetic energy then continues traveling as air borne sound.*

Echo: *A repeated sound, produced by sound waves reflecting from solid obstructions like walls or mountains.*

Reverberation: *Repetitive occurrences of the same sound, after its source has ceased vibrating. This persistence occurs when air borne sound is reflected from surfaces to return multiple times to a listener. It bounces around until it loses enough energy to become inaudible. Some is absorbed, causing building assemblies defining the space to also vibrate. Long lasting reverberation is detrimental to speech comprehension.*

Reverberation Time: *How many seconds it takes for a sound to diminish in intensity by 60 decibels, once the source has ceased emitting sound waves. A reverberation time of over one second creates problems with speech intelligibility. Too little reverberation time results in performed music being perceived as flat and lifeless.*

Resonance: *When a sound is prolonged by reverberation, usually beneficial to the perception and enjoyment of music being produced.*

Building Acoustics: *The art of controlling sound entering, or generated inside, a building. How well it is accomplished in construction and use of a built environment, will impact communication, health and productivity of the users of the space.*

Sound Insulation: *The effectiveness of materials in causing a loss of energy, or perceived sound, as it passes through an intervening barrier like a wall or ceiling assembly.*

Sound Absorption: *The loss of energy occurring when sound waves contact or pass through absorbent materials like leaves or insulation. Absorptive materials trap and dissipate some kinetic energy of sound waves, usually by converting it to heat. They trap varying percentages of energy within themselves, till it dissipates to below an audible range.*

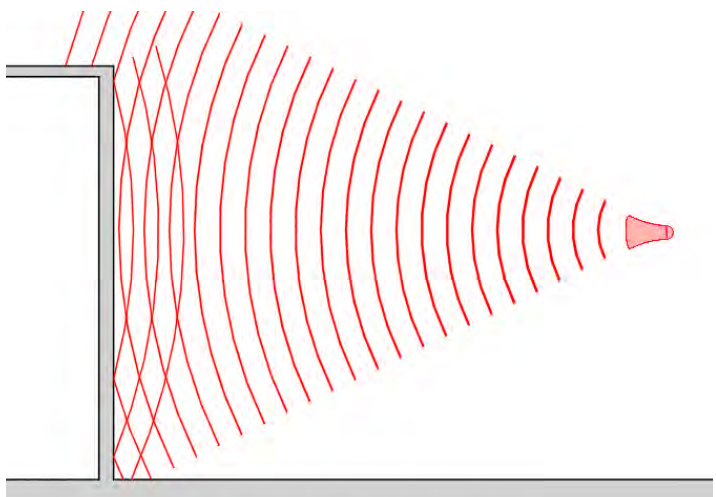
Sound Reflection: *The deflection of some energy from a sound source, back toward its origin, rather than allowing all to pass through. The amount of reflection is a function of the stiffness of the material it strikes, or its resistance to vibration.*

Decibels: *The most common measurement of intensity of sound levels. This scale rates sound on human perception of relative loudness. The lowest threshold of human perception is around 5* *decibels, while a rock concert can top 120 decibels. Sound at 150 decibels can destroy the human ear.*

General Nature of Sound

Sound can be measured by two characteristics. Frequency or pitch, is the time interval between each wave of pressure. Loudness is the intensity of the wave pressure. The human ear can only comfortably handle certain ranges of both loudness and frequency.

As mentioned before, sound is basically kinetic energy, compressing air into pressure waves, moving outward from a source. There are three distinct stages in that journey. It is first generated, then moves through air or other matter like structures, and is received or perceived by a receiver like the human ear.



General behavior of sound

To some degree, sound forms part of every environment, including those we create. Just as any other form of energy affects us, so does sound. It can be painful or soothing, and distract from, or enhance communication.

Occupants of any environment quickly notice three acoustic characteristics of that space. One is how much reverberation of sound occurs in it. Another is the level of background noise. The third is how much noise enters the space from outside sources. These all affect decisions on how, or even if, we continue to occupy and use that space, and for what purpose. Sound studios don't often locate in spaces below landing paths of jetliners.

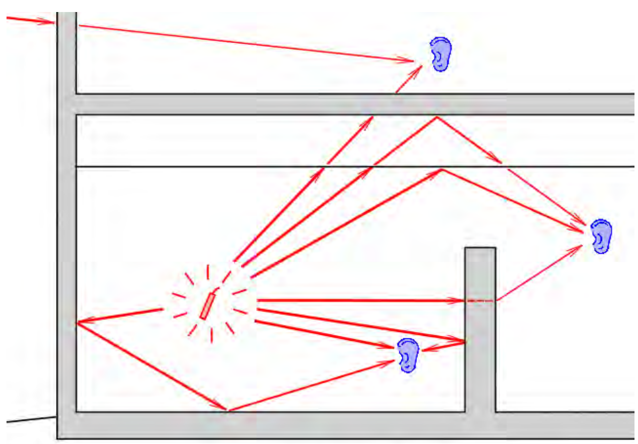
Inside man-made environments like building spaces, we can, and should, control sound in many ways. The quality of sound received, and its intelligibility, are important to the function of our designed environments and even the health of users. We can actively alter the nature of sound at its point of origin, the ways it is transmitted, and how it is perceived by the receiver. We can passively control it with the volume of a space, the geometry of the same, and materials used to define the space.

Sound should not be able to control us, but rather the opposite. After all, we produce most of the noise that troubles us.

Production

Sound is generally produced in either one basic frequency, like a voice, or in a combination of frequencies, like music. Some travels to the listener in a straight path, but that direct sound is not all the listener will hear.

Unless a room is highly absorbent, listeners will receive several variations of produced sound. Because sound radiates, a portion strikes surfaces that will reflect waves back toward the listener. Some will hit surfaces that will somewhat absorb its energy, resulting in reflected waves at measurably lower decibels. If the room volume allows it, some energy will bounce between parallel surfaces before arriving at the listener as reverberation and echoes. If the space is large enough, there can be an audible gap between times when varying versions of the original sound arrive at the ear of the listener. These various versions of the sound, arriving at different times, will tend to 'muddy' what is being heard.



Differing paths for sound

Designing usable acoustic environments requires two pieces of knowledge. The first is the intended use of the space. The second is the combination of space volume, space geometry, absorbent materials, and reflective materials that optimize usability for that purpose. We will discuss the acoustic results of different combinations of materials, in the upcoming section on general design solutions. We will discuss acoustic concerns of different building uses, in the upcoming section on building types. In both, we explore how we can control sound in our spaces.

Control

Noise is the number one complaint of building users. This is especially true of hospital patients, hotel guests, and diners in restaurants. A patient that cannot obtain restorative rest is a patient whose health is in grave danger. Hotel guests who cannot sleep, will not return. A good 'atmosphere' in a restaurant is usually one that provides perceived privacy for personal conversation. Excessive noise in schools and workplaces has been well documented to lower comprehension and productivity.

Unacceptable and unwanted sound will always require attention from designers, preferably before the environment has been constructed and found deficient.

Whether sleeping, eating, working, or learning, building occupants need to be able to use spaces as intended. This will involve examining sources of potential noise entering spaces, like sound from building systems or known external sources by the site. It will require envelope material selection and planning of adjacent uses in the building layout. It will involve prediction of generated sound moving through space, how paths of each sound might intersect, and how many times each sound should be heard at an audible level. Some study will be needed into the frequencies of expected and unacceptable noise, since different materials in envelope assemblies react differently to varying frequencies.

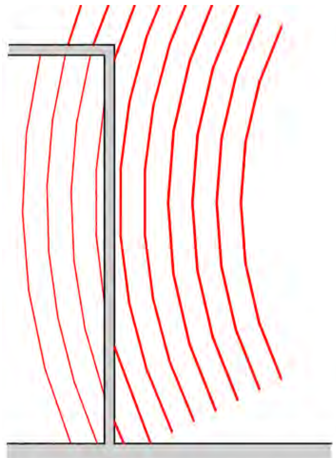
Stated together, all the acoustic parameters in designing spaces effective for intended use, makes success in acoustic design seem daunting. An understanding of basic principles and design approaches will simplify how we best serve our clientele. Simply put, the goal is to control sounds generated within the spaces, and the transmission of unwanted sound (noise) from the exterior, from building systems, and from adjacent spaces, into our created spaces.

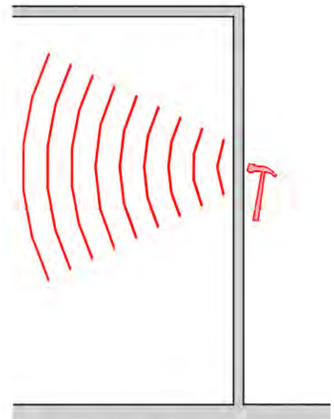
Sound Transmission

Structural building components can indirectly transmit sound energy. The energy of air borne sound waves strikes building components at one level of intensity, causing them to vibrate. This in turn causes air, on the opposite side of the building element, to vibrate at that same frequency, reproducing the sound at a lower level of intensity, as air borne sound waves. Basically, sound energizes the building elements, causing them to vibrate like diaphragms and reproduce the sound. This is one form of structurally transmitted sound.

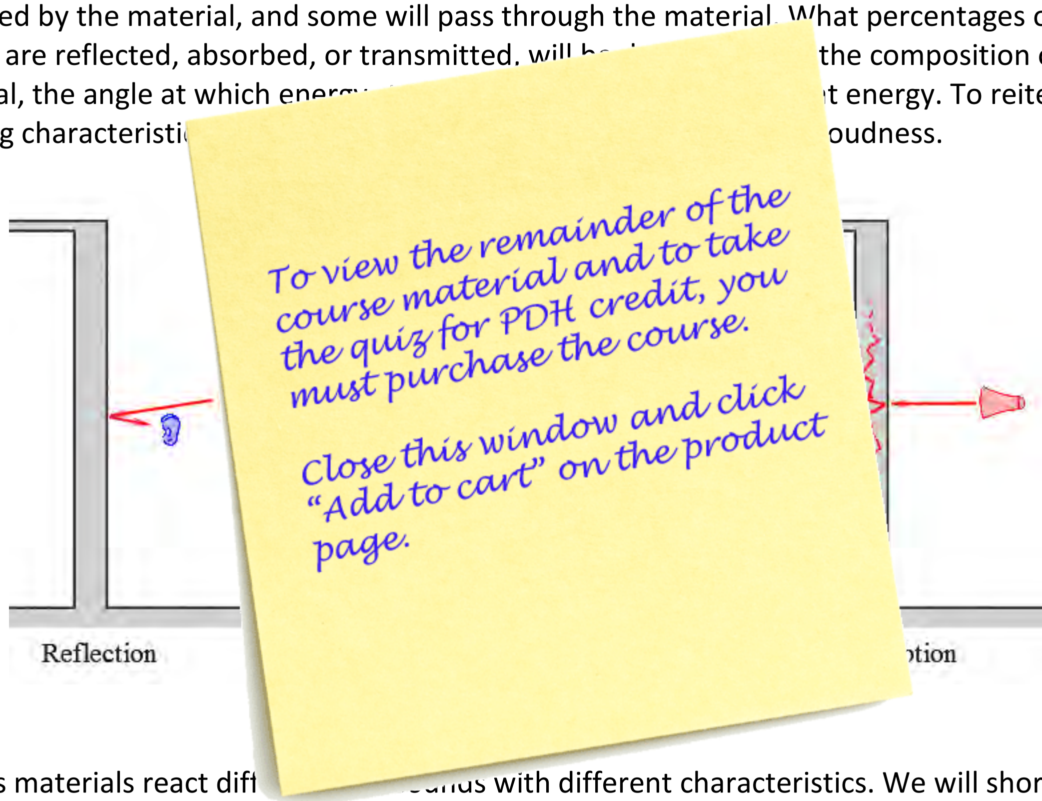
The other form of structure borne sound is impact noise. This results from direct impacts against parts of components of a building. Examples are; footsteps from a level above or beside the listener, people jumping on, or bumping against, building components, equipment vibrations, or basketballs hitting a wall separating an auditorium from a youth gymnasium.

Impacts cause building components to vibrate, setting up sound waves on each side of the surface or structure.


Diaphragm transmission


Impact noise transmission

Building components react in other ways to sound transmitted through air, or air borne sound. Energy from either sound, light, or heat, coming through air and striking any material, will be affected by that material in one of three ways. Some will reflect off the material, some will be absorbed by the material, and some will pass through the material. What percentages of energy are reflected, absorbed, or transmitted, will b… the composition of the material, the angle at which energ… …t energy. To reiterate, defining characteristi… …oudness.



Reflection … …ption

Various materials react dif… …ounds with different characteristics. We will shortly examine two ways used to measure how different materials react to the energy of sound. One