USG *Presents*

Understanding Acoustics in Architectural Design

by: *James D. Janning, AIA, CSI*
Architectural Systems Manager, USG Corporation

In today's architectural environment, good acoustical design isn't a luxury – it's a necessity. Acoustics impacts everything from employee productivity in office settings to performance quality in auditoriums to the market value of apartments, condominiums and single-family homes.

While the science behind sound is well understood, using that science to create desired acoustical performance within a specific building or room is complex. There's no single acoustical "solution" that can be universally applied to building design. Each built environment offers its own unique set of acoustical parameters. The acoustical design for a business conference room, for instance, differs greatly from the design needed for a kindergarten classroom.

Understanding these differences and knowing how to utilize building materials, system design and technologies are key factors behind successful acoustical design. This article will provide basic background on the science and measurement of sound, as well as insights into some of the principles of wall partition and ceiling system acoustical design.

The Science of Sound

Technically speaking, sound is defined as a vibration in an elastic medium. An elastic medium is any material (air, water, physical object, etc.) that has the ability to return to its normal state after being deflected by an outside force such as a sound vibration. The more elastic a substance, the better it is able to conduct sound waves. Lead, for instance, is very inelastic and therefore a poor sound conductor. Steel, on the other hand, is highly elastic and an excellent sound conductor.

Sound vibrations travel through elastic mediums in the form of small pressure changes alternating above and below the static (at rest) nature of the conducting material. Picture a vibrating tuning fork. As it moves in one direction, it compresses the air particles next to it. They, in turn, pass on the reaction to adjacent particles of air. As the tuning fork vibrates in the other direction, it leaves a void or rarefaction. This rarefaction follows along behind the compression. It, in turn, is followed by another compression, and then another rarefaction and so on.

Each of these compression/rarefaction cycles is called a wave. The number of waves that occur per second is termed frequency. Frequency is measured in terms of hertz (Hz). One Hz is equal to one cycle per second. The human ear can discern sounds ranging from approximately 20 to 20,000 Hz. Human speech ranges between 125 and 4,000 Hz.

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CONTINUING EDUCATION Series

Use the learning objectives below to focus your study as you read **Understanding Acoustics in Architectural Design**. To earn one AIA/CES Learning Unit including one hour of health safety welfare credit, answer the questions on page 297, then follow the reporting instructions on page 368 or use the Continuing Education self report form located at *architecturalrecord.com*.

Learning Objectives:

- Know how sound waves form and how they travel through elastic mediums
- Understand how sound can be isolated and absorbed in building design
- Realize the benefits that sound masking provides for closed and open-office spaces

The amplitude of sound waves – how far they travel above and below the static pressure of the elastic medium they are traveling through – is measured in decibels (dB). The higher the decibel level, the higher the volume, or loudness of a sound. A jet airplane has an amplitude of 140dB, while a human whisper is approximately 20dB. A typical office environment usually falls in the 40 to 60dB range.

Sound Movement

Architectural acoustics is the process of managing how both airborne and impact sound is transmitted – and controlled – within a building design. While virtually every material within a room – from furniture to floor coverings to computer screens – affects sound levels to one degree or another, wall partitions, ceiling systems and floor/ceiling assemblies are the primary elements that designers use to control sound.

Sound moves through building spaces in a variety of ways. Most commonly, it is transmitted through air. But wall partitions, ceilings and floor/ceiling assemblies can also transmit both airborne sound, such as human voices and ringing telephones, and impact sound, such as footsteps on a floor. Sound waves actually travel through many physical objects faster and with less loss of energy than they travel through air. Sound waves travel at a rate of 1,128 feet per second through air (at 70 degrees F); 11,700 feet per second through wood; and 18,000 feet per second through steel.

Sound reflection occurs when sound waves bounce off smooth, hard wall, ceiling and floor surfaces. Concave surfaces tend to concentrate or focus reflected sound in one area. Convex surfaces do just the opposite; they tend to disperse sound in multiple directions.

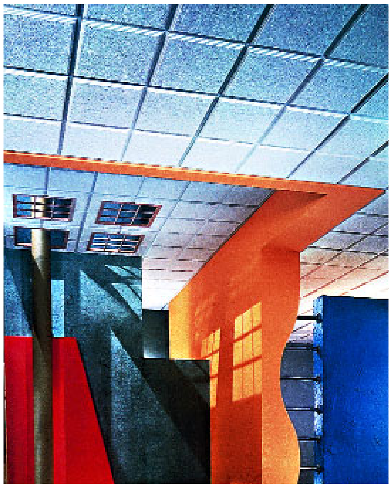
Sound reverberation is the persistence of sound reflection after the source of the sound has ceased. Reverberation can have both a positive and negative effect in architectural design. For example, specifying highly reflective ceiling panels directly above the stage area in an auditorium will help direct sound toward specific seating areas, thus enhancing the room's acoustical performance. However, that same reflective performance will become a negative factor if highly reflective wall and ceiling materials are installed in the rear of the auditorium. That's because the sound reflections from the rear of the room take too long to reach the audience, resulting in a distracting echo effect.

Water-felted mineral fiber panels have face perforations to improve acoustical performance. They are the most economical acoustical ceiling choice.

Sound can also diffract, or bend and flow around an object or through a small space or opening. This gives sound waves the ability to "squeeze" through very small openings with little loss of energy. The small openings under and around doors, floor tracks, electrical boxes and conduit and HVAC ducting are typical sources of sound diffraction. These are commonly referred to as "flanking" or "leaking" paths. They can be controlled by the proper application of acoustical sealant.

Isolating Sound

A primary goal of a wall partition, ceiling system and floor/ceiling assembly design is to minimize the flow of airborne and impact sound through the use of special materials, methods of construction and designs.



Polymer-matrix ceiling panels feature smooth, natural textures, excellent sag resistance and excellent NRC and CAC performance.

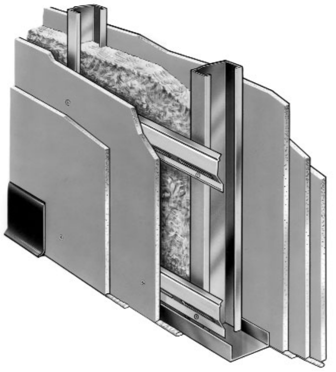
The effectiveness of an assembly's ability to isolate airborne sound is quantified by Sound Transmission Class (STC) ratings. STC is expressed as a single number and usually ranges from approximately 35 to 70. It quantifies the transmission loss (TL) of an assembly. A wall partition or floor/ceiling assembly that reduces the overall incoming sound levels from 80dBA to 20dBA would have an STC rating of approximately 60.

A related measurement is Ceiling Attenuation Class (CAC). This rating quantifies how much sound is lost when it is transmitted through the ceiling of one room into an adjacent room through a common plenum. Like STC, a higher CAC rating indicates that the ceiling system allows less sound transmission. For closed-office environments, a CAC of 40 to 44 is usually desirable.

Impact sound transmission in a floor/ceiling assembly is quantified by Impact Isolation Class (IIC). This is a single number rating that quantifies an assembly's ability to isolate impact sounds generated from footsteps and other impact sources. It is tested in laboratory conditions by a tapping machine that impacts the floor of a "source" room. The sound of the tapping is measured in a "receiving" room, located directly beneath the source room.

Wall Partitions and STC

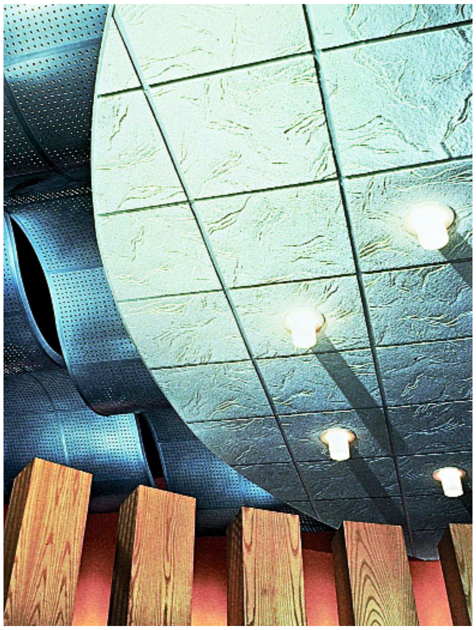
Reducing sound transmission through wall partitions can be accomplished in a variety of ways, including isolation (the separation of adjoining wall partition surfaces), mass, absorption, decoupling (inelasticity) and the elimination of flanking paths (sound leakage).



Designing High-STC Wall Partitions: This gypsum board wall assembly uses mass (2 gypsum board layers are on one side, and 3 layers are on the other side), decoupling (resilient channels are screw-attached to the steel studs) and absorption (a layer of mineral fiber insulation is friction-fitted in the partition cavity) to enhance STC performance.

Increasing the mass of a partition forces sound waves to work harder and expend more energy to pass through the medium. Specifically, doubling the mass of a partition can reduce sound transmission by up to 5dB. However, using mass alone to increase sound control has definite limitations. To achieve a 60dB reduction, a total mass of 320 pounds per square foot is required. This is equivalent to approximately 3 feet of solid concrete, which is obviously impractical for virtually any building design.

Isolating air space within a partition is an effective means for raising STC performance, but like mass, it has its limitations. Doubling the partition air space can reduce sound transmission by up to 5dB, but to achieve a reduction of 60dB requires an isolated air space 4 feet wide. Again, this is hardly practical for building design. The effectiveness of air isolation is limited by the fact that the



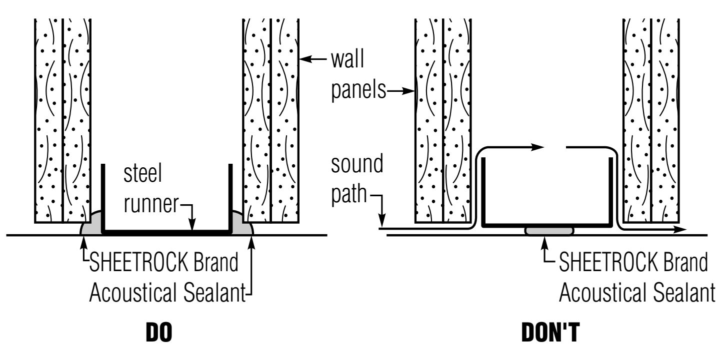
Cast mineral fiber ceiling panels feature natural textures, integrated color and excellent durability. Their high NRC and CAC values make them a versatile option for a wide range of applications.

wood or steel studs attaching both sides of the partition assembly transmit sound no matter how wide the isolated space. Like electricity, sound waves seek the path of least resistance, which in this case is the structural framing.

Adding a layer of fibrous sound-absorbing insulation material, such as mineral wool, into the partition cavity dissipates sound by creating friction, which transforms sound energy into heat. Again, however, the effectiveness of sound attenuation blankets is limited by the presence of studs, which provide a direct route for sound waves to travel through the assembly.

Decoupling the partition through the use of resilient channels, which decouples the surface diaphragm from the structural member, increases the effectiveness of both air isolation and absorption. Resilient channels are attached to framing, with the attachment leg facing down. The screws attaching the gypsum panels should not penetrate through the channel and into the stud, as this negatively impacts resilient channel acoustical performance.

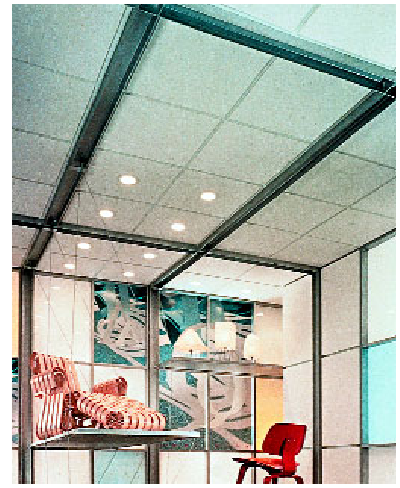
Finally, sealing flanking paths (small air gaps that enable sound to travel with little energy dissipation) is a critically important factor in controlling sound transmission. A properly sealed wall assembly featuring two layers of 5/8-inch gypsum board on both sides and a 1 1/2-inch thick sound attenuation blanket achieves an STC of 53. The same wall without the acoustical sealant has an STC of approximately 29 – a dramatic difference. The key is to apply an adequate bead of acoustical sealant on the outside edge of the floor, ceiling and intersection tracks on both sides of the partition. Applying bead to only one side of the assembly does not fully seal all possible flanking paths. It is necessary to acoustically seal both the space between the floor track and the floor, and between the panel and the track.



Sealing flanking paths in wall partitions is a critically important factor in controlling transmission. An adequate bead of acoustical sealant should be applied to both outside edges of the floor, ceiling and intersection tracks (left).

Ceiling Panels and NRC

Another way to control airborne sound within a room is through the use of materials that absorb sound by converting sound waves into heat. The ability of a material to absorb sound is quantified by Noise Reduction Coefficient (NRC) ratings. NRC represents the average amount of sound energy a material absorbs over frequencies between 250 and 2,000 Hz. NRC values range from 0.00 to 1.00. To have any acoustical value at all, a material must have a minimum NRC of 0.50. That means that the material absorbs 50 percent of the sound and reflects the other 50 percent. An acoustical material that doesn't reflect any sound (it absorbs 100 percent) has an NRC of 1.00.



Dry-felted glass fiber ceiling panels typically offer the highest NRC values (.95 to 1.00) in the industry, making them ideal choices for open offices and other areas requiring speech privacy.

NRC is a key factor in determining the performance of acoustical ceiling panels. Various types of ceiling panels provide varying levels of NRC, as well as CAC performance.

Cast mineral fiber panels offer the best combination of NRC and CAC. The panels are made from an individual cast process that combines excellent sound absorption properties with outstanding durability. The NRC performance of cast panels ranges from 0.65 to 0.95 and the CAC performance ranges from 35 to 44. Cast panels are ideal for conference/speech privacy areas, as well as hospitality, entertainment and retail environments.

Polymer-matrix mineral fiber ceiling panels combine a smooth, natural texture with high NRC (ranging from 0.65 to 0.95) and high CAC (35 to 39). The panels offer superior sag resistance and outstanding dimensional durability. They are non-perforated and ideal for room-to-room privacy areas, as well as reception and lobby areas, hotels, offices and other applications where sound absorbency is needed.

Dry-felted glass fiber panels offer extremely high NRC ratings (0.95 to 1.00), but CAC ratings of 20 to 29 are lower than other types of acoustical panels. The lightweight, sag-resistant panels are ideal for open floor plans, retail stores, auditoriums and gymnasiums, conference rooms and executive offices, but are not recommended for office-to-office privacy.

Water-felted mineral fiber ceiling panels are made using a dense, continuous manufacturing process that orients the mineral fibers for optimal sound absorption. The panels feature perforations and fissures in the surface to enhance sound performance, and range in NRC from 0.50 to 0.60. Their CAC ranges from 35 to 39. The panels come in a wide range of textures and colors and offer a cost-effective choice for a variety of general-purpose applications.

Generally speaking, panels with a high NRC are good choices for open-office areas, healthcare facilities, schools and other applications where speech privacy is a priority. Panels with a high CAC are best for private offices and other areas where sound needs to be confined within a particular space.

In open-office settings, the ceiling's acoustical performance can be significantly enhanced through the use of sound-masking technologies. Sound-masking systems produce electronic sounds similar to that of softly blowing air. The sound is projected through special speakers installed above the ceiling panels. Sound masking is set 3 to 5 decibels above conversational speech, thus enabling speech privacy and alleviating distractions from other office noise. (For more information on sound masking in open office environments, see the “Sound Masking: An Effective Solution for Open Office Environments” article below.)

Successful Acoustical Design

When creating acoustical specifications, remember that every space presents a unique acoustical challenge. An employment office, for example, may require all-confidential private offices, while a bank may warrant varying levels of speech privacy. In office settings, conference rooms and executive offices usually require high levels of acoustical control, but other areas may require only moderate measures. Consider the past environment of the occupants. What are they accustomed to? Next, establish the privacy needs of the occupants and finally, establish the privacy potential of each working space. Which areas, given the layout preference, offer the best potential for confidential uses? And which will work better in a more open environment?

Successful acoustical design is a detail-oriented process, both in terms of specification and construction. Careful material and systems specifications are imperative, as are good construction practices. Acoustical performance often depends not so much on what was done correctly, but what was done incorrectly. The key to success is careful attention to detail during all phases of planning, design and construction. ■

Sound Masking: An Effective Solution for Open-Office Environments

The demand for open office environments isn’t going away. A report by The International Facility Management Association (IFMA) shows that more than 80 percent of respondents use open-plan systems in their space planning.

In addition, many businesses are now allotting less space to employees within open plans, upping the number of people within a room in order to cut overhead. And the trend toward a “team” environment has brought upper management and other executives out of their once private offices and into the mix.

Add speaker phones, voicemail and other noisy technology, and the office environment can easily become distracting. With statistics showing that productivity levels in a non-distracting space will rise anywhere from 3 to 20 percent, open-office acoustics are an increasingly critical design issue for architects.

This isn’t to say that the role of the architect is to create an office that is dead quiet. In very quiet environments, employees, clients and/or customers often won’t speak in a normal tone of voice and instead will lower their voices to near-whispers in order not to distract other employees and to avoid being overheard. And the smallest of sounds, from a tapping pen to a clicking keyboard, can easily shatter the fragile concentration of coworkers.

As office walls come down and more employees are packed together into the workplace, privacy is affected as well. And industry research indicates that workplaces will continue to become noisier, affecting employee productivity, morale and retention.

Architects are increasingly turning to sound masking to override sounds that can’t be absorbed or blocked by design elements such as carpeting, acoustical wall panels, ceiling panels or partitions. At the other end of the spectrum, sound masking in quiet environments allows employees to speak at normal conversational levels while maintaining speech privacy.

Lencore’s Spectra Sound Masking creates a harmonious atmosphere in which to work that increases people’s ability to concentrate, restores speech privacy and allows for greater employee productivity and efficiency.

Today’s sound masking has gone well-beyond simple white noise machines. Diffracted sound can be masked with electronically produced sound that’s evenly distributed through a space by speakers placed above the ceiling.

Sound masking provides a constant, fixed level of unobtrusive background sound that is set to cover speech level and soften other office noises, which then do not appear as distractions to the human ear. To be effective, the masking level should be 3 to 5 decibels louder than incoming speech from adjacent work stations. In an open plan office, the STC (Sound Transmission Class) and NRC (Noise Reduction Coefficient) must be balanced to achieve good speech privacy, while the background sound levels are comfortable and uniformly maintained.

Because sound masking is complementary to the speech spectrum and effectively covers speech levels, it reduces the intelligibility of conversations, which makes conversations less distracting to those working nearby.

Architects should consider specifying sound-masking units that have a step attenuator, a rotating volume control for precise sound level adjustment volume control and a rotating volume control for paging/music. Units should be able to produce up to 86dBA to meet the requirements for all ceiling treatments, and should have adjustable sound spectrum shaping controls in order to meet the varying spectral requirements of drywall ceilings, various types of ceiling panels, air return grills and openings around lighting fixtures. The sound-generating units must also generate random sequence sounds and not produce a noticeable repetitive pattern or sequence.

While effective sound-masking systems have traditionally utilized loudspeakers strategically placed above the office ceiling to produce uniform sound masking throughout the workspace, one of the newest and most popular options for architects are sound-masking systems that work in tandem with acoustical ceiling panels. These ceiling sound-masking systems are superior to other types of centralized or flat-surface speakers alone, giving the architect more options and control over ceiling design and sound-masking systems. These systems can be ordered from the acoustic ceiling panel manufacturer and/or the sound-masking company.

Click for Additional Required Reading

As part of this CES activity, you are required to read the “Room Acoustics” section of USG Corporation’s Sound Control Manual. To access the material online go to http://www.usg.com/Design_Solutions/2_3_11_acoustics.asp. To request a faxed copy of the material, contact Marty Duffy at (312) 606-5781 or mduffy@usg.com. (For a further detailed discussion of sound and acoustics you can access other sections of this document at that site, but only the Room Acoustics section material is included in the final quiz.)

Learning Objectives

- Know how sound waves form and how they travel through elastic mediums
- Understand how sound can be isolated and absorbed in building design
- Realize the benefits that sound masking provides for closed and open-office spaces

Instructions

Refer to the learning objectives above. Complete the questions below. Go to the self report form on page 243. Follow the reporting instructions, answer the test questions and submit the form. Or use the Continuing Education self report form on *Record's* website—*architecturalrecord.com*—to receive one AIA/CES Learning Unit including one hour of health safety welfare credit.

Questions

Q: 1. The more elastic a substance, the better it is able to conduct sound waves.
A: a. True
b. False

Q: 2. A higher CAC rating indicates that a ceiling system allows more sound transmission.
A: a. True
b. False

Q: 3. Ways to isolate sound include all but which of the following:
A: a. Increasing the mass of a partition
b. Isolating air space within a partition
c. Installing masking systems
d. Sealing flanking paths

Q: 4. A wall partition or floor/ceiling assembly that reduces the overall incoming sound levels from 80dBA to 20dBA would have an STC rating of approximately:
A: a. 100
b. 60
c. Minus 60
d. One quarter (1/4)

Q: 5. To seal flanking paths, the key is to apply the acoustical sealant:
A: a. On the side of the assembly where the source originates
b. On both sides of the assembly
c. On the side of the assembly where the sound is being received

Q: 6. An acoustical material that doesn't reflect any sound has an NRC of:
A: a. 0.00
b. 0.50
c. 1.00

Q: 7. Which ceiling panels offer the best combination of NRC and CAC?
A: a. Cast mineral fiber panels
b. Water-felted mineral fiber panels
c. Dry-felted glass fiber panels
d. Polymer-matrix mineral fiber panels

Q: 8. Generally speaking, panels with a high ______ are good choices for open-office areas.
A: a. CAC
b. IIC
c. NRC

Q: 9. The purpose of sound masking is to:
A: a. Provide a distraction to speech and office sounds
b. Cover speech level and soften other office noises
c. Create an office that is dead quiet and therefore more productive
d. Promote the open-office team environment

Q: 10. To be effective, sound masking should be:
A: a. 3 to 5 decibels lower than incoming speech
b. the same decibel level as incoming speech
c. 3 to 5 decibels louder than incoming speech

Q: 11. Match the term with the correct definition:
A: a. Noise Reduction Coefficient (NRC)
b. Sound Transmission Class (STC)
c. Ceiling Attenuation Class (CAC):
1. Quantifies the effectiveness of an assembly's ability to isolate airborne sound.
2. Quantifies how much sound is lost when transmitted through a ceiling of one room into an adjacent room through a common plenum
3. Quantifies the ability of a material to absorb sound

About USG

USG Corporation is a *Fortune 500* company with subsidiaries that are market leaders in their key products groups: gypsum wallboard, joint compound and related gypsum products; cement board; gypsum fiber panels; ceiling panels and grid; and building products distribution. The company received the 2001 AIA/CES Award for Excellence for its commitment to providing quality continuing education programs.

USG subsidiaries United States Gypsum Company and USG Interiors, Inc. are industry leaders in the design, development and testing of acoustical wall, floor and ceiling systems.

USG Interiors, a leading manufacturer of acoustical ceiling panels and suspension systems, offers a wide range of cast, polymer-matrix mineral fiber, glass fiber and water-felted mineral fiber ceiling panels to accommodate virtually any acoustical design. The company's recently introduced HALCYON™ CLIMAPLUS™ Ceiling Panels provide a highest-possible NRC rating of 1.0. The panels other superior sound performance for open offices, lobbies, libraries and other areas where acoustical privacy is a priority.

USG Interiors has formed a strategic partnership with Lencore Acoustics Corp., to offer Lencore's state-of-the-art sound-masking systems with all USG acoustical ceilings.

Lencore Acoustics, the country's leader in sound masking, offers a full range of products and services that address the acoustics within office environments. By manufacturing the highest quality background sound masking systems available, and offering a full line of acoustical wall panel and baffle products, Lencore is in a unique position to meet the acoustical challenges of *Fortune 500* companies around the globe. The company is the only manufacturer of sound masking that can provide E-Sound™ and IndePage™ technologies. E-Sound ensures the highest quality masking sound, while IndePage allows for an individual volume control for paging. With a widespread network of representatives and manufacturing capabilities, Lencore can custom design the right sound masking system for virtually any office environment. The company backs its products with an unconditional 10-year full warranty. For more information, call Lencore at (516) 223-4747 or visit the company's Web site at www.lencore.com.

For further information about USG's acoustical wall, ceiling and floor systems, write USG Corporation, P.O. Box 806278, Chicago, IL 60680-4124, call USG 's Customer Service Department at 800-USG-4YOU or visit the company's Web site at www.usg.com.