Learning to Use Architectural Acoustics In Engineering

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Last month's "Engineer's Notebook" column about acoustics reviewed how acoustical design has become fundamental for the A/E/C industry and offered a simple vocabulary of basic acoustic terms. This column introduces how room functionality improves with improved architectural acoustics, especially in rooms used for collaboration, instruction, and assembly where clear speech is needed.

Acoustics has clearly become a fundamental in architectural design in which speech intelligibility and acoustic comfort including HVAC ambient background noise have become more important. We have seen the need dramatically increase during the 2020–2021 pandemic when remote conferencing imposes a new standard of care.

For instance, learning can be improved with better acoustics and noise control, and room acoustical design is now routine in the educational market for remote conferencing where large classrooms are used. Both professors and students are demanding better interaction from remote classrooms. They want less of the ubiquitous "Can you hear me now?" syndrome imposed on their workflow.

These classrooms should be designed for quiet (low noise criteria, NC) and short room reverberation time without echo (RT60). This is particularly evident for the students at the remote location who must engage and collaborate interactively without distraction from noise, echo and poor speech clarity.

Universities have begun budgeting for more seamless presentations for their educational venues. Good design for acoustics allows people and audiovisual (AV) systems to work better and support the hearing impaired, the student with an attention deficit and the student with a youthful lack of concentration, for example. When we hear better, we see and learn better due to less distraction and better concentration.

The Room

Advanced learning spaces must support live in-person engagement, then transfer that quality clearly to a remote site. People at interactive remote sites must be able to chime in without being cut off, chopped, truncated, or have excessive room reverberation. Architectural acoustics can either support or

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TABLE 1 Sound pressure levels for various sound sources.

SOURCE OF SOUND	SOUND PRESSURE, dBA
Handgun (Arm's Length), Pain Threshold	130
Very Loud Nightclub, Two-Stroke Chainsaw	110
Typical Rock Concert	100
High School or Band Class (High School Band Class 4 Hour Exposure Limit for OSHA Hearing Protection)	90
Very Loud Restaurant, Alarm Clock	80
Loud TV in Hotel Room w/ Complaints, Car in Next Lane at 50 mph	70
Conversational Speech at 6 ft	60
Business Call Center, Open Office	50
Executive Office, Home, Birds Chirping	40
Good Conference or Sleeping Room (Whisper Near Ear)	30
Quiet Rural Area, Mosquito	20
Good Recording Studio; Slow, Shallow Breathing	10
Threshold of Hearing (Young Person)	0
Anechoic Chamber	–10

IMEG site tests/calibrated readings.

TABLE 2 Acoustic design begins with the source, path and receiver.

1. First Determine How Loud it Needs to Be for a Receptor?
2. Quiet The Source, First!
3. Find Path Leaks
4. Break Vibration Paths
   - Use springs or pads, placed first at the AHU.
   - Float and/or decouple the floor.
   - Use air voids, gaps. Separated studs.
   - Use decouplers. Beware of recoupling with only resilient channel.

compromise this very quickly. The clear market trend is to improve rooms and limit arbitrary design compromise in acoustic design. But many projects still live with a degree of acoustic compromise with permanent embedded shortcomings. A more circumspect approach that is not defined by a product alone requires a balanced viewpoint with acoustic metrics that are applied well.

Room acoustics are inextricably tied to designed AV systems. AV systems need good acoustics because AV technology has limitations built in, including bandwidth and compression artifacts that regularly degrade speech intelligibility if the room is not providing a good acoustic environment. A room with a good acoustic signature includes low background noise and barrier control even before absorption is added. Fuzzy wall panels alone are no longer "the acoustics" for a space.

Architects are now challenged more often to predict room acoustics before a building is built. Most people reading this are engineers, and we (the authors) aspire to move the reader to the level where you can look at architectural plans and say, "This will not be a good acoustic environment for your client." Engineers can be thought leaders and should assist their architects in as many areas as possible, especially where acoustics and noise control are a key metric for speech intelligibility.

The first task in room acoustics design is to assess programming and select the acoustic metrics appropriate for the needs of listeners connected to it. For example, noise control for an on-air broadcast should address exterior building barriers more stringently than a simple office or retail building might. The International WELL Building Institute's WELL guidelines ask for an STC barrier for building shells so urban noise is abated. Yet the abatement chosen does not depend on the building skin or the guideline, but on how loud the noise source is first. For example, if you are near an airport, train or other very loud source, the envelope is much more important.

Acoustics 101

Defining a room's "source-path-receiver" criteria is Acoustics 101. One should apply noise control at the source first, then along the path and for the need of the receivers. But there is a sequence. It always begins with how loud the source is. Then how quiet do you need it to be at the receivers? Only after these questions are evaluated are the wall barrier assemblies and silencers in the path considered. This process of design is counter to the usual noise abatement request for "What product do I use?" or "Give me a wall barrier rating." Product selection alone does not assess source-path-receiver design methods. Again, the first question instead is simply how loud or quiet must it be. The best design results are usually from source-path-receiver design methods and are often the lower-budget solution with more accurate and refined results.

Only after the noise source is identified and receptors are characterized is the path solution dealt with. One must find the weakest barrier or the "leaks" in the path first. These often include a too-low sound transmission class (STC) barrier value for window glazing, or duct entrances above an accessible ceiling. Door bottom thresholds are classic shortcomings. Further, a hotel using a local room HVAC with packaged terminal air conditioner (PTAC) may be an open hole to a highway with truck brakes outside and people sleeping inside. These holes and openings are the first sources of noise to treat.

After the weakest barrier or open leaks are assessed, further design can acoustically protect where people reside, sleep and work. In this process, the A-weighted decibel (dBA) (*Table 1*) and noise criteria (NC) are used to determine how quiet it must be. To determine the appropriate NC value, HVAC decibel values are identified from noise sources in octave center bands. (Figure 1 in last month's column shows an NC graph.) If sound power is cited, it must be converted to sound pressure level because sound power is a 10-logarithm math function, and sound pressure is a 20-logarithm function. Then an A-weighting filter is applied, and evaluations begin with dBA, because that is how humans hear. It is important to know a "dB" is not a "dBA."

Only later in a design are duct noise abatement strategies considered. These are based on sources (such as a fan, flow rate, connection to a radiating building member) and for HVAC housing, case or duct radiating noise (*Table 2*). This may include regenerated noise from tight bends and downstream VAV devices that add more noise later in the path. While an isolated fan inside an AHU offers reduced noise, air turbulence still generates case radiated noise that occurs after the internal fan isolation. So internally isolated fans do not always address noise. This leads to adding isolation for case radiated noise when the AHU is hard coupled to a deck. After the above items are addressed, silencers can be considered. But this also means a good design may not need add-on silencers.

Next, the room reflection time (RT60) is considered. The reverberation time of any room depends on its cubic volume and is driven by room surfaces and ceiling height. All room surfaces are acoustical surfaces, with each assigned an attribute for absorption characteristics. These absorption factors are assembled and calculated to arrive at the reverberation time (RT60) for a room as a design benchmark. If the AHU and duct supply noise are marginal to meet the desired NC, and the room is found too reflective from hard surfaces, the room will amplify HVAC noise, and the NC value for quietness will increase from its scheduled loudness value. If ceilings are high, this will also increase reflection time and noise.

Techniques

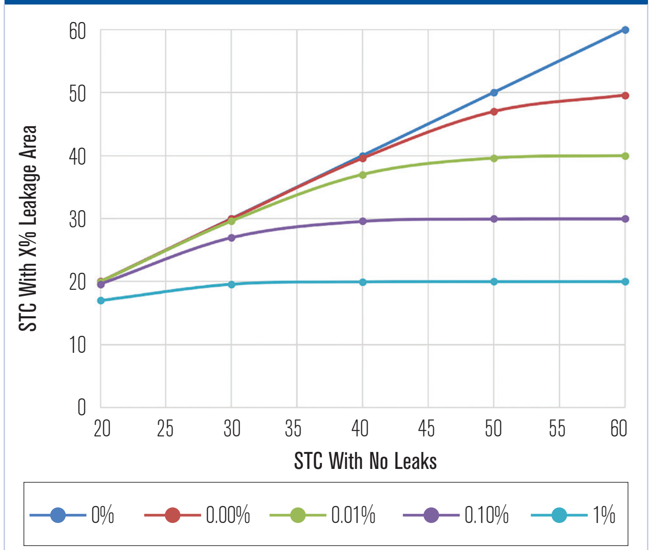
When a room is considered too noisy or too reflective (or both), a ceiling height might be lowered as a first response. This early design factor might replace adding a silencer. Lowering the ceiling lowers room reverberation time by reducing the room cubic volume, therefore not amplifying duct noise that could produce a sustained, elevated and louder ambient noise. When excess reverberation is still found, treatments are carefully located to lower the room reverberation and echo characteristics. If the ceiling grid is already absorptive, the next choice is increasing the ceiling absorptive value (NRC) and adding acoustic treatment with appropriate surface areas and locations.

The first room surface to evaluate acoustically might be the farthest surface from a talker or an AV loudspeaker. This surface often needs treatment by virtue of its distance and travel time from a source to a listener in a room; this distant surface can produce a late and destructive echo due to the longer time of reflection it fosters. Late echo reduction in a room is Job #1 for acousticians, but only after the level of quiet is selected.

The next step after determining noise criteria (NC-x) for quiet might be determining the shape of the room. This is more important for small rooms with a repetitive sound "flutter." Changing the room shape can be a small adjustment of any two parallel walls, like a telemedicine room where talkers must be clear as they share information or stream their conference to a remote site.

Adjusting a simple wall dimension can be important to tame destructive influences. A room that is 10 ft × 10 ft × 10 ft (3 m × 3 m × 3 m) is a bad-sounding room, as are circular rooms. One of the authors worked with a client with a circular reception room. When he walked up to the receptionist, he was at the center focus of the room, and the echo impacted his sense of balance.

FIGURE 1 Effect of gaps in walls on actual sound transmission class (STC).



Another example was a bank counter with a curved wall and domed ceiling. Private discussions became focused to a remote patron that should not hear private bank balances from remote tellers who were amplified by the room.

Next, flanking paths around barrier walls and over ceilings often create privacy issues. These constructions must maintain acoustics for private or confidentiality. If a transfer "Z" duct is used, its length should be evaluated, and the use of an open-cell or rated lining considered to absorb noise. Lining is almost always an open-cell media, never closed-cell absorption. Walls should also be checked for tight extension to the deck for privacy needs. Supply and return duct must be designed to minimize openings between rooms used for privacy. Always keep Z-duct openings far away from return grilles.

Noise leaks (*Figure 1*) are especially challenging with corrugated metal decks that are not flat on the bottom. A seal must be made, and packing flutes with absorbent insulation is often not a final solution without adding a solid barrier. This is because absorption, e.g., fiberglass, does not work for high STC-rated barriers. This small point is one of the most consistent misconceptions of noise control. Low density, soft absorption is not a solid barrier.

After the process above is completed, architectural interiors and room finishes can be considered. Interior design first determines the amount of noise abatement needed, then calculates the required surface areas with appropriate locations. Finishes may include hard panels with perforation, or a hard diffusion treatment located over talkers for a conference room ceiling. Note, if the acoustician first starts his acoustic design with only interior treatments, a scope gap may already exist.

It is important for hard reflecting surfaces that support speech, instead of absorbent materials to be located above and behind most talkers. To reduce the reverberation time, presentation rooms might incorporate absorbent wall panels placed along one rear wall and then extend only through one corner to the next wall. This treatment is likely in addition to the selection of a higher absorption value (NRC) for acoustical ceiling tiles. Absorptive wall panels can be used to truncate a destructive reflection path between walls—and despite having an absorbent ceiling still in the room.

When AV technology is added, loudspeaker integration to a room is important and assessed for location, aim and seat coverage. For AV, we turn down the speaker loudness when possible, then increase loudspeaker density and coverage. This aids speech clarity. Any large or powerful loudspeaker is usually modeled in software to keep its projected sound off the rear and distant walls. This reduces echo and improves clarity. Good loudspeaker integration is a priority for acoustical design and for designers who understand acoustics with professional audio is an improved trend for the A/E industry.

Room "Voice"

All rooms have a transfer function. This term means how the room translates sound as a composite acoustic signature that we hear and process in our human hearing mechanism. This refers to our term "sense of place" discussed in last month's column. That sense of place can be understood and heard intuitively by humans due to small aural cues embedded in what we hear and perceive. For example, a blind person can perceive when they approach a wall as their sense of place is naturally enabled. Room acoustics are full of these small aural cues.

We can see this when a child enters a long tunnel and naturally likes to make noise and listen excitedly to the tunnel's noise signature. He is not told about this, but he hears and reacts intuitively. These aural cues are very important for remote conferencing and clarity for conference rooms, classrooms, and intelligibility in occupied spaces.

The room's aural translation to support good clarity depends first on the important direct, line of sight shortest signal, then its ratio to everything else in the signal chain, such as reverberance (RT60), to name but one. The direct sound of a talker or a loudspeaker must be unimpeded to be clear. This clear sound information must preserve speech consonants. Think of words you can abbreviate—you can leave out the vowels. Then timing and strength of all other room reflections are important. These short room reflections can be positive and constructive if their reflection time is short (less than approximately 30 milliseconds). This time also converts to distance—approximately 30+ ft (9 m) as a general dimension marker. So, a total path of 60 ft (18 m) (30 ft [9 m] from podium to rear wall and 30 ft [9 m] back to a front row can be a late-arriving destructive influence.

These longer reflections are destructive due to long physical distances that distract listeners—the brain interprets them as echoes instead of part of the original speech signal. The existence of these late signals can determine when to acoustically treat a near surface for positive support for speech clarity, or when to treat for late and destructive echo. Your local acoustician will be glad to help.

Conclusion

Acoustical design is a basic process with fundamental metrics assembled in a thoughtful sequence. Absorption has been equated with "acoustics" in the last century, but absorption is often misunderstood and overused. While absorption remains useful, recent design has advanced to new practices that are integrated and more important for architectural styles found today. This includes using diffusion and controlled reflection for speech support as well as designing HVAC with predictable quietness. While soft absorptive panels and new acoustic felts are exciting visual geometrics, they should only be used in appropriate or limited amounts because the room composite signature is a balance of hard diffusion and the amount of quietness needed first. When a room is properly designed it may not need to be treated with soft absorptive panels, and the goal of appropriate acoustics may mean less is more. ■

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