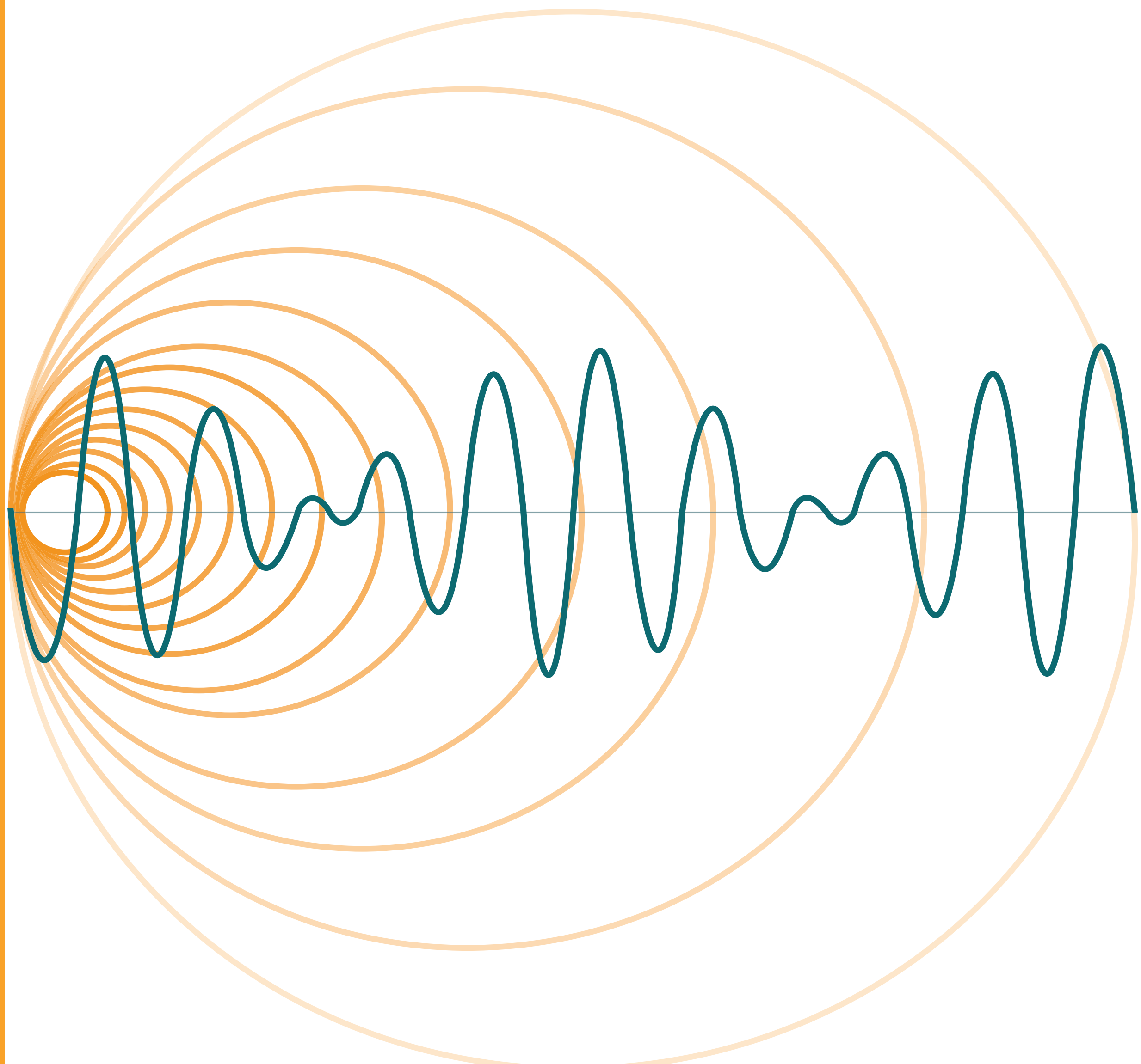
Acoustics in Schools



CISCA
Ceilings & Interior Systems
Construction Association

INTRODUCTION

Acoustics in Schools is a tool for architects, interior designers, and other design professionals who work to improve school environments for all users. It is an introduction to the acoustical issues commonly confronted on school projects. Literature on this topic, gathered by CISCA, overviews important acoustical considerations in schools. Practical design responses to these issues are presented in this white paper in "practitioner-friendly" language. Original sources and a glossary of terms are also included to provide further information. The following topics are discussed:

- **WHY ACOUSTICS MATTER**
- **WHO BENEFITS FROM IMPROVED ACOUSTICS?**
- **FUNDAMENTALS OF SOUND AND ACOUSTICS**
- **UNDERSTANDING THE PRIMARY ACOUSTIC PROBLEMS IN SCHOOLS**
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- **ACOUSTICS AND INDOOR AIR QUALITY (IAQ)**
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- **REFERENCE CITATIONS**

Considerations when applying this research:

The content of this white paper only relates to the literature accessed and does not reflect information available outside/beyond those sources, whether by a specific author or others. Research findings from a singular source should not be used as the basis for design solutions or other judgments and decisions by users of this white paper, but must be considered in the larger context of a full search of all available information and the user's synthesis of that collective information. Consider the date of publication of the individual sources to determine the timeliness of the information, especially if study data were used.

WHY ACOUSTICS MATTER

- Classroom acoustics are an important, often neglected, aspect of the learning environment. Up to 60% of classroom activities involve speech between teachers and students or between students, indicating the importance of environments that support clear communication (Accredited Standards Committee, S12, Noise, 2002). However, classrooms that have been constructed in the last 20 to 30 years to better engage students in hands-on activities or discussions have often resulted in active, noisy environments. Additionally, HVAC systems have created distracting background noise in classrooms (Nelson, 1999).

- Inappropriate levels of background noise, reverberation, and signal-to-noise ratios can also inhibit reading and spelling ability, behavior, attention, concentration, and academic performance. Furthermore, children who develop language skills in poor acoustic environments may develop long-term speech comprehension problems (Smaldino & Crandell, 1999). Good classroom acoustics are a basic classroom need, not an accessory, to give all students access to spoken instruction and discussion (Pepi, 1999).

- Acoustic problems persist in classrooms because of a lack of acoustics education for architects and engineers, the prohibitive expenses of acoustic refurbishment, and because adult listeners often do not consider the limitations of children's hearing abilities (Muehleisen, n.d.[b]).

[Classrooms in the United States typically have speech intelligibility ratings of 75% or less, meaning every fourth spoken word is not understood.]
(Seep, Glosemeyer, Hulce, Linn, & Aytar, 2000)

WHO BENEFITS FROM IMPROVED ACOUSTICS?

Students

- Children, especially those younger than 13 years of age, have an undeveloped sense of hearing, making the impacts of background noise on hearing, comprehending, and learning more pronounced for children than adults. (Accredited Standards Commitee..., 2002; Committee to Review and Assess the Health and Productivity Benefits of Green Schools, 2006; Nelson, 2003).

- Temporary illnesses causing mild hearing loss (e.g., middle ear infections) are on the rise (Nelson, 1999).

- Students with learning, attention, or reading deficits are more adversely affected by poor acoustic conditions than the average student (Committee to Review..., 2006; Nelson, 2003).

- Students speaking English as a second language (ESL) require significantly better acoustic conditions to hear the teacher than others (Collaborative for High Performance Schools, 2005a; LightSPEED Technologies, Inc., n.d.; Nelson, 2003).

- Hearing-impaired students require a significantly better acoustic environment to adequately hear than the average student (Nelson, 2003).

Teachers

- Loud or reverberant classrooms may cause teachers to raise their voices, leading to increased teacher stress and fatigue (Tiesler & Oberdörster, 2008).

- Teachers speaking in noisy classrooms may be at risk for voice impairment (Committee to Review..., 2006).

FUNDAMENTALS OF SOUND AND ACOUSTICS

Technically, sound is air pressure fluctuations resulting in audible vibrations. These vibrations travel in wave patterns away from the sound's source, and the waves are characterized by their frequency, wavelength, and amplitude. When a sound-wave contacts a surface, for example a wall in a closed room, the energy and direction of the sound is altered. These alterations are perceived as sound reflections and reverberations, which can affect auditory perceptions (Muehleisen, n.d.[a]).

The human auditory system is less sensitive to extremely low (below 500 Hz; e.g., mechanical or automotive rumbling) and high (above 8000 Hz; e.g., light fixture buzzing, mechanical ringing) frequencies (Muehleisen, n.d.[a]). Low frequency noise tends to have the detrimental effect of masking speech, particularly consonants. Individuals with hearing loss are particularly susceptible to the masking effects of loud low frequency noise (Committee to Review..., 2006).

Frequency

def. [The number of sound waves created in a given amount of time, indicating the pitch of the sound, expressed as Hertz (Hz)]

Wavelength

def. [The distance between corresponding points on consecutive sound waves]

Amplitude

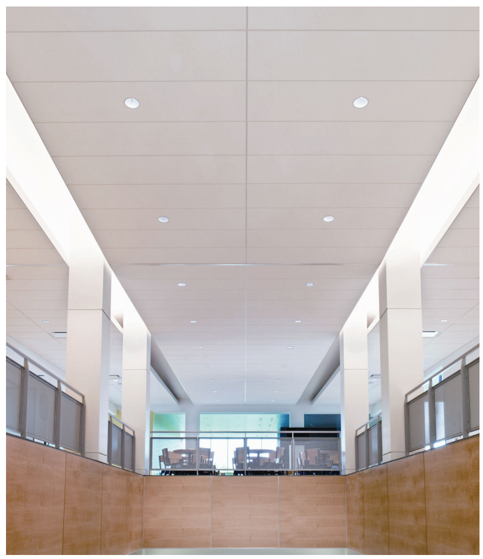
def. [The magnitude of a sound wave, indicating the intensity of the sound]

UNDERSTANDING THE PRIMARY ACOUSTIC PROBLEMS IN SCHOOLS

Acoustical barriers to learning may exist even if teachers and/or students are unaware that they exist. Adults' perceptions of speech intelligibility are often better than children's perceptions, indicating adults should not rely on their own subjective assessments of listening conditions inside of a classroom (Committee to Review..., 2006). Speech intelligibility decreases when background noise increases or with long reverberation times. When both background noise and long reverberation times are present, they have a combined effect on both people with and without normal speech, hearing, and language abilities (Accredited Standards Committee..., 2002). Designers should focus on controlling background noise levels, reverberation times, and signal-to-noise ratios to improve the acoustic environment of schools. These three issues are discussed below.

Background Noise

- Excessive noise in schools has a negative impact on student learning and performance (Haines, Stansfeld, Job, Berglund, & Head, 2001).
- While a 1 decibel (dB(A)) change in sound level is barely noticeable, background noises are perceived as doubling in loudness every 10 dB(A) (Muehleisen, n.d.[a]).
- Background noise in unoccupied classrooms should not exceed 30-35 dB(A) (Crandell & Smaldino, 1999a; Accredited Standards Committee..., 2002). Major sources of background noise include:
    - HVAC noise (vents, ductwork, A/C unit)
    - Outdoor noise (automobiles, airplanes)
    - Reflected speech sounds (echo)
    - Noise from adjacent spaces (Committee to Review..., 2006; Harght & Coffeen, 2008)



Background Noise

def. [Any auditory disturbance within a room that interferes with what a listener wants to hear] (Crandell & Smaldino, 1999a)

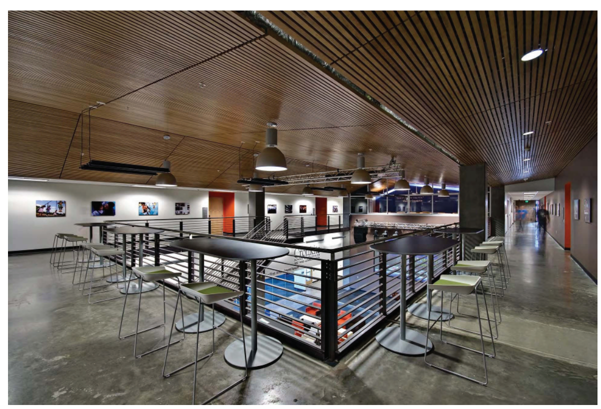
Reverberation

- Reverberations occur when sound waves strike surfaces (e.g., floors, walls, ceilings) in a room and are reflected back into the space. Reverberation will continue until all the sound waves have been absorbed or have dissipated (Bess, 1999).

- Reverberations are affected by the quantity and effectiveness of sound-absorbing surfaces in a room.
  - Sound reflective surfaces are typically hard and smooth. They provide little friction to absorb sound energy, prolonging sound reverberation.
  - Sound-absorbing surfaces are typically fibrous or porous, significantly reducing sound energy through friction between the air and material fibers. Sound-absorbing surfaces can help reduce sound reflection and reverberation, but they do not reduce the intensity of the sound's source itself (Muehleisen, n.d.[a]).

- Reverberation times (RT) should not exceed 0.4 seconds in classrooms primarily used by hearing disabled students or 0.6 seconds in general classrooms (Accredited Standards Committee..., 2002; Committee to Review..., 2006; Crandell & Smaldino, 1999a; Pepi, 1999).

- Reducing the RT to acceptable limits will help with speech intelligibility, and the added absorption will reduce the overall sound level within the room without adversely affecting the signal-to-noise ratio (Committee to Review..., 2006).



Reverberation Time (RT)

def. [The time it takes for sound to decay once the source of sound has stopped]

[Reverberation Time = .05 (Volume of room in cubic feet / Total sound absorption units in the room)] (Pepi, 1999)

Signal-to-Noise Ratio

- Signal-to-noise ratios (SNRs) generally become less favorable for hearing as the distance between the speaker and the student increases, suggesting that different locations within an individual classroom may have different SNRs (Bess, 1999).

- SNRs are typically lowest at the back of classrooms or near a noise source (e.g., air conditioning unit) (Seep, Glosemeyer, Hulce, Linn, & Aytar, 2000). Students seated in the rear of a classroom may not understand a teacher's speech to the same extent as one seated at the front of the classroom (CertainTeed Ceilings, 2008).

- Children with hearing disabilities generally require significantly higher SNRs than children with normal hearing. Environments with SNRs of +20 dB to +30 dB provide optimal speech comprehension for children with hearing disabilities (Bess, 1999).

- SNRs should meet or exceed +15 dB in all locations of a classroom (Accredited Standards Committee..., 2002; Crandell & Smaldino, 1999a; Nelson, 2003).

Signal-to-Noise Ratio (SNR)

def. [The ratio of desired sound to undesired background noise; Larger numbers denote better acoustic performance]

ACOUSTICAL DESIGN STRATEGIES: *GENERAL CLASSROOMS*

Both the background noise level and the reverberation time should be controlled in classrooms (Accredited Standards Committee..., 2002). Background noise can come from outside the school building (road traffic, air traffic), outside the classroom (hallways, adjacent classrooms), or inside the classroom (HVAC systems, instructional equipment, shuffling furniture). Consider the following measures to limit the impact of background noise on the classroom environment.

External Background Noise

Site Planning

- Locate critical listening environments (e.g., core classrooms) away from external noise sources (e.g., automobile traffic, railroads, construction sites, airports, mechanical units) to prevent background noise from interfering in the classroom (Accredited Standards Committee..., 2002; Crandell & Smaldino, 1999a; Seep et al., 2000; Shield & Dockrell, 2005).
- Communicate with facility managers and school administrators to minimize noise intrusions (e.g., schedule lawn-mowing when the classroom is unoccupied) in classrooms that depend on natural ventilation (Wilson, Valentine, Halstead, McGunnigle, Dodd, Hellier, Wood, & Simpson, 2002).
- Avoid planning traditionally-constructed educational facilities in areas where the yearly average, day-night sound level is above 60-65 dB(A). Avoid planning educational facilities designed with a noise insulating exterior shell in areas where the yearly average, day-night sound level is above 65-75 dB(A) (Accredited Standards Committee..., 2002).
- Predict the impact of exterior noise levels by assessing outdoor industrial and transportation noise sources using methods available to acoustical consultants and environmental planners (Accredited Standards Committee..., 2002).

Landscape Design

- Use trees, shrubs, earthen banks, and concrete barriers around school buildings to reduce the amount of external noise entering classrooms (Bess, 1999).

Structural Considerations

- Place acoustically absorbent materials (e.g., mineral wool board) on top of concrete foundation flooring (UK Department of Education and Skills, 2003b).
- Install double-skin steel roofing with acoustically absorbent materials (e.g., mineral wool board) to increase the structural roof's sound insulation level (UK Department of Education and Skills, 2003b).
- Consider the impact of rain noise on occupants when designing lightweight roofs or incorporating roof lights into a design (UK Department of Education and Skills, 2003a).
- Install pads underneath the school's supporting structure to reduce structurally-borne background noise (Crandell & Smaldino, 1999a).

Exterior Wall Construction

- Install dense, insulated external walls with few openings (e.g., doors, windows) near sources of high external noise (Crandell & Smaldino, 1999a).
- Add several layers of gypsum or plywood board (5/8" minimum) to exterior frame walls or thickness to exterior concrete or block walls to increase wall sound transmission class (STC) values (Crandell & Smaldino, 1999a).
- Fill cracks or gaps in exterior walls with elastic bonding to improve noise isolation (Muehleisen, n.d.[a]).
- Insulate walls with absorptive materials (e.g., fiberglass insulation) between wall studs to increase their sound insulation (Crandell & Smaldino, 1999a).
- Air cracks, gaps, or insufficient amounts of insulation can compromise the sound isolation of a wall. Carefully construct exterior walls without gaps and monitor their degradation to improve their sound isolation (Muehleisen, n.d.[a]).

Sound Transmission Class (STC)

def. [A numerical rating of the sound control performance of a wall and/or floor-ceiling assemblies; Higher numbers indicate better sound control]

Doors and Windows

- Seal gaps in window frames and doorways (Seep et al., 2000).

- Understand that windows near loud sources of external noise should be properly installed, heavily weighted, double-paned, and remain closed when possible to reduce background noise in classrooms (Crandell & Smaldino, 1999a).

- Hang acoustically-treated curtains or draperies in front of windows to reduce the proliferation of external noises in classrooms (Bess, 1999).

- Be aware that single-pane windows are generally poor noise insulators (Bess, 1999).

Interior Background Noise

Noise from Adjacent Spaces

- Separate particularly sound-sensitive spaces (e.g., classrooms, counseling offices) from both external and internal sources of noise (e.g., playgrounds, gymnasiums, band rooms) by using non-acoustically sensitive areas (corridors, storage spaces) as buffer spaces (Accredited Standards Committee..., 2002; Seep et al., 2000; UK Department of Education and Skills, 2003b).

- Inspect and, if needed, adjust seals to entry doors every six months to ensure good maintenance and conform to the STC ratings needed in classrooms. Avoid painting door seals (Accredited Standards Committee..., 2002; Seep et al., 2000).

- For new construction school projects, avoid locating classrooms or core learning spaces below gymnasia, dance studios, or other spaces with a high level of activity. When this situation is unavoidable in renovated buildings, conform to the recommended IIC ratings for floor-ceiling assemblies in ANSI S12.60-2002 (Accredited Standards Committee..., 2002).

- When possible, use solid floor construction in classrooms to reduce drumming effects associate with light, timberframe construction. Specify two layers of particle board or concrete slab, as opposed to one layer of particle board (Wilson et al., 2002).

- Stagger classroom doors in hallways to create longer, less direct paths for noise to travel between rooms (Accredited Standards Committee..., 2002; Seep et al., 2000).

- Avoid placing adjoining doors on shared classroom walls, as this will limit sound isolation (UK Department of Education and Skills, 2003a).

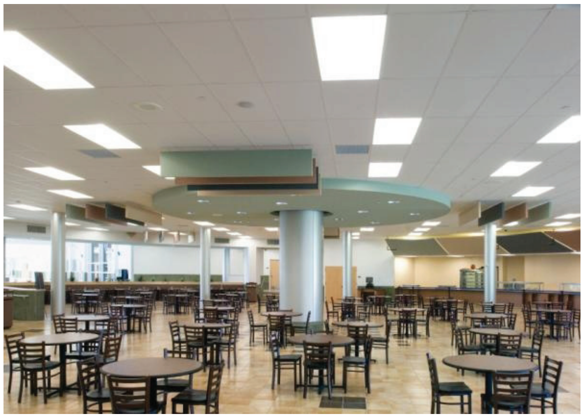
- Avoid open-plan classrooms and classrooms with thin or partial partition walls between instruction areas to reduce sound transmission between rooms (Accredited Standards Committee..., 2002; Crandell & Smaldino, 1999a).

Partition Wall Construction

- Use additional layers of gypsum or plywood to partition walls and ensure their gap-free construction to increase the STC and reduce interior noise in classrooms (Crandell & Smaldino, 1999a).
- Understand the importance of workmanship and product quality in achieving satisfactory acoustic environments in learning spaces (Accredited Standards Committee..., 2002).
- Extend partition walls from the structural floor to the structural ceiling of a classroom to ensure sounds cannot travel above or below walls into adjacent spaces (Seep et al., 2000).
- Mount sound-absorbing materials in front of an air cavity and use batt-insulation in the cavities of walls to improve sound-absorbing performance (Muehleisen, n.d.[a]).

Materials and Surfaces

- Consider using acoustically-treated furniture to reduce interior noise in classrooms. However, be aware that some acoustically-treated furniture may be unhygienic (Crandell & Smaldino, 1999a).
- Install carpeting in classrooms to reduce ambient noises of movement (e.g., movement of chairs and desks, shuffling feet) (Crandell & Smaldino, 1999a; UK Department of Education and Skills, 2003a).
- Use dense, acoustically treated doors with rubber or gasket seals to reduce sound transmission (Crandell & Smaldino, 1999a).
- Consider using carpeting and acoustical ceiling tiles in hallways to reduce noise (Crandell & Smaldino, 1999a).
- Consider using a suspended acoustical ceiling (full) or acoustical cloud (partial ceiling) to provide sound absorption to reduce interior noise within the room.
- Understand that carpeting alone will not provide sufficient sound absorption in classrooms (Accredited Standards Committee..., 2002; Seep et al., 2000).
- Be aware that sound absorption levels of classroom materials (e.g., tack boards, notice-boards) can change when covered or painted (UK Department of Education and Skills, 2003b).
- Specify chairs with neoprene chair leg tips to minimize noise from moving chairs in classrooms without carpeting (Accredited Standards Committee..., 2002).



Instructional Equipment

- Locate instructional equipment (e.g., computers, printers, audio-visual equipment) in areas of classrooms that will minimize their background noise (Accredited Standards Committee..., 2002; Wilson et al., 2002).

- Be aware that computers may be a primary source of non-student generated noise in classrooms (Committee to Review..., 2006).

- Ensure that the background noise created by instructional equipment does not exceed standards for background noise when combined with noise created by HVAC systems and other building utilities (Accredited Standards Committee..., 2002).

- Install rubber padding under mechanical instruments (e.g., keyboards, printers, office equipment) to reduce vibratory noise in classrooms (Accredited Standards Committee..., 2002; Crandell & Smaldino, 1999a).

- Create noise isolating enclosures for instructional equipment that is needed for long-term use in areas of the classroom that are noise-sensitive (Accredited Standards Committee..., 2002).

- Specify computers with low operating noise ratings to minimize the amount of background noise they create (Wilson et al., 2002).

Mechanical Noise

- Locate mechanical sources of background noise (e.g., fans, air, plumbing, conditioners, heating ducts, faulty lighting devices) away from critical listening environments (Accredited Standards Committee..., 2002).

- Position HVAC system equipment over hallways or outside the building to minimize the background noise they create (Collaborative for High Performance Schools, 2005b; Seep et al., 2000).

- Use low–noise ballast fluorescent lamps in classrooms (Accredited Standards Committee..., 2002) and maintain and replace lamps regularly to reduce the background noise they can create (Crandell & Smaldino, 1999a).

- Use natural ventilation systems with acoustically insulated intake louvers, vents, and ducts (UK Department of Education and Skills, 2003b).

- Line heating and cooling ducts that serve more than one room with acoustical materials or install silencers to decrease the transmission of noise between classrooms (Crandell & Smaldino, 1999a).

- Use rubber supports and flexible sleeves or joints in ductwork systems to reduce the transmission of structurally-borne noise (Accredited Standards Committee..., 2002; Crandell & Smaldino, 1999a).

- Select air handling units and ducts with low sound-level ratings, below Noise Criteria (NC)-20 (Seep et al., 2000).

- Lubricate and maintain mechanical equipment regularly to reduce internal classroom noise (Crandell & Smaldino, 1999a).

- Consider specifying quiet fans, fan silencers, and duct systems delivering air at low velocities to minimize flow noise in classrooms (Committee to Review..., 2006).

Reducing Reverberation

Excessive reverberation can cause echoes that interfere with speech intelligibility. Smaller classrooms generally have shorter reverberation times than large classrooms. However, sound waves may be reflected more frequently and can create a masking effect (Bess, 1999). It is important to develop design strategies that minimize reverberations to improve speech intelligibility.

Materials and Surfaces

- Increase the amount of soft, rough, or porous surfaces (e.g., acoustical paneling, bulletin boards, carpeting, bookcases) and decrease the amount of smooth, hard surfaces (e.g., exposed concrete walls, glass) to reduce room reverberation times and overall noise levels (Crandell & Smaldino, 1999a).

- In classrooms with fixed lecture positions, consider ringing the upper wall and ceiling with sound-absorbing materials to enhance speech intelligibility between students and teachers and among students. Avoid placing sound-absorbing material directly above or in front of the teacher's lecture position (Accredited Standards Committee..., 2002).

Noise Reduction Coefficient (NRC)

def. [A measure of the average sound absorption of a surface used to compare the sound-absorbing characteristics of building materials]

- Install acoustical tiling with an absorption coefficient of at least 0.65 to cover hard, sound reflective ceilings (Crandell & Smaldino, 1999a).

- Be aware that performance of sound-absorbing materials (e.g., suspended acoustical ceilings) is generally improved when mounted with an air space behind them (Accredited Standards Committee..., 2002; Muehleisen, n.d.[a]).

- Install sound-absorbing wall panels or sound-absorbing concrete masonry units to lower reverberation times in especially problematic rooms (e.g., high ceilings, many windows) (Muehleisen, n.d.[b]).

- Install acoustic ceiling tile with an NRC in excess of 0.9 to lower classroom reverberation times. Alternatively, install spray-on acoustic absorbers, close-fitting, sound-absorbing panels, or acoustic metal decking to reduce classroom reverberation times (Muehleisen, n.d.[b]).

- In classrooms without a fixed lecture position and ceilings less than 10 feet high, consider placing most or all of sound-absorbing materials on the ceiling. With ceilings more than 10 feet in height, consider placing some sound-absorbing materials on the wall. If all sound-absorbing material is on the ceiling, place bookshelves along the wall to reflect sound waves in the direction of the ceiling (Accredited Standards Committee..., 2002).

- Install acoustical ceilings adhering to minimum airspace requirements. Consult professionals when reverberations from frequencies less than 500 Hz are a concern (Accredited Standards Committee..., 2002).

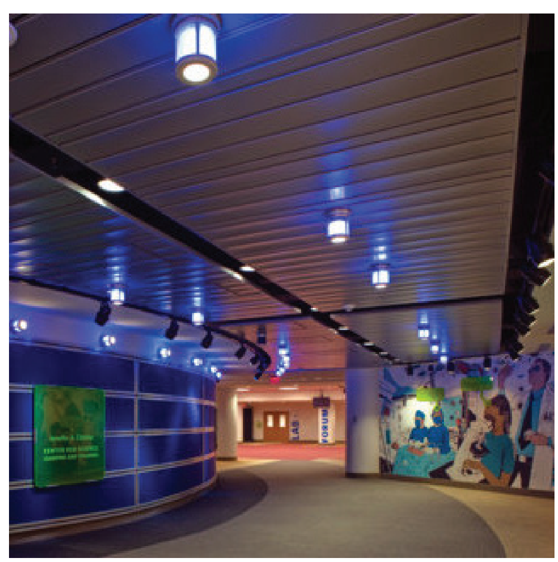
- Position large reflective surfaces (e.g., blackboards, glazing) at non-parallel angles to the walls to reduce echoes (Crandell & Smaldino, 1999a).

- Install a suspended ceiling of sound-absorbing tile with an NRC of 0.75 or better below the structural ceiling of classrooms with high ceilings* to lower reverberation times (Seep et al., 2000).

- Design classrooms with non-parallel walls or mount acoustical panels alternately on parallel sidewalls to reduce flutter echoes in classrooms (Crandell & Smaldino, 1999a; Seep et al., 2000).

- In large learning spaces with ceilings 12 feet high or lower, consider installing a suspended ceiling with a NRC of 0.7 or higher that covers the whole ceiling surface area, excluding ventilation grills and light fixtures (Accredited Standards Committee..., 2002).

- Place sound-absorbing materials on the rear wall of classrooms to prevent sounds from echoing back to the front of the classroom, eliminating discrete echoes and improving classroom speech intelligibility (Seep et al., 2000).



* Refer to CISCA publication *Acoustical Ceilings Use & Practice* for further definitions.

Improving Signal-to-Noise Ratios

While background noise and reverberation times are important, signal-to-noise ratios (SNR) may be the most important consideration within a classroom's acoustical environment. High SNRs are necessary to ensure students and teachers can hear one another. SNR values below +15 dB(A) make hearing, teaching, and learning more difficult (Lawton, 2008). In general, classroom layouts maintaining short distances (6-8 feet) between the speaker and the student improve classroom SNRs (Bess, 1999).

Amplification Interventions

- Consider the use of hearing-assistive technologies such as personal frequency modulation (FM), sound-field FM amplification systems, induction loop, infrared voice transmitters, or hard-wired voice transmitters to offer children with sensorineural hearing loss (SNHL) adequate SNRs (Crandell & Smaldino, 1999b; Seep et al., 2000).

- Understand that classroom amplification systems should be considered in addition to, not as an alternative for, optimal classroom acoustical design (Wilson et al., 2002).

- Understand that sound-field classroom amplification may improve word recognition of children learning English as a second language (LightSPEED Technologies, Inc., n.d.).

- Be aware of the following limitations associated with amplification systems:
  - Many forms of the personal hearing aids amplify background noise as well as a speaker's voice, doing little to improve SNRs in classrooms (Crandell & Smaldino, 1999b).
  - While amplification devices (e.g., external microphone, soundfield FM) can be useful for increasing the volume of a speaker, these devices do not support acoustics during peer-based or group discussion interactions (Crandell & Smaldino, 1999b; Nelson, 2003).

Sensorineural Hearing Loss

def. [Hearing loss resulting from problems of the nerves of the inner ear or brain]

ACOUSTICAL DESIGN STRATEGIES: *CLASSROOMS FOR THE HEARING-IMPAIRED*

Hearing-impaired students or students using amplification devices (e.g., cochlear implants, personal FM sound field systems) require lower reverberation times and less background noise than an average student to hear adequately. Typical classrooms do not meet the acoustical needs of hearing-impaired students. The following design recommendations pertain specifically to classrooms occupied by hearing-impaired students (Pepi, 1999).

- Install high performance (0.95 NRC) acoustic tiles in classrooms with hearing-impaired students to reduce classroom reverberation times.
- Specify easily movable sound-absorptive materials in classrooms with hearing-impaired students so they can relocate to other rooms as the children advance to new classrooms. For cost-effectiveness, assure materials are easy for school maintenance or custodial staff to install.
- Reverberation times in classrooms with hearing-impaired students or students using hearing assistive technologies (e.g., cochlear implants) should not exceed 0.4 seconds.
- Assign support personnel (e.g., speech/language pathologist, teacher's aide) to assist hearing-impaired students in classrooms.

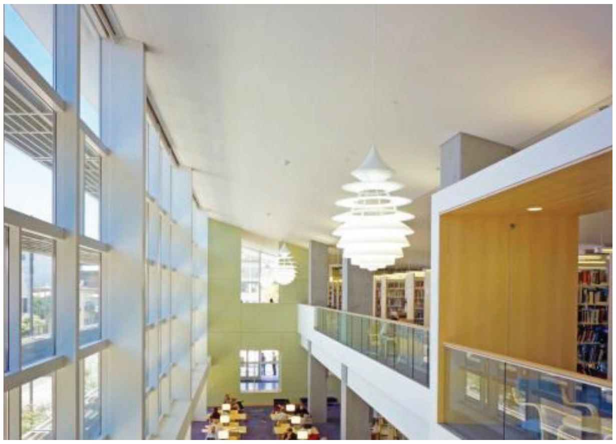
ACOUSTICAL DESIGN STRATEGIES: *OPEN-PLAN CLASSROOMS*

Open-plan classrooms may not support satisfactory acoustic conditions and therefore may have a negative effect on the learning process, possibly negating the impact of any desirable effects from teaching methodologies used in open-plan classrooms (Accredited Standards Committee..., 2002). The partial height and length walls typical in open-plan classrooms may not sufficiently insulate noise from adjacent rooms, which increases overall background noise levels in schools and classrooms and reduces speech transmission index (STI) values (UK Department of Education and Skill, 2003b). However, if open-plan classrooms are used, consider the following recommendations:

- Understand that it may be difficult to achieve speech intelligibility that meets building standards in open-plan classrooms unless rigorous acoustic designs are implemented (UK Department of Education and Skill, 2003b).

- In open-plan classrooms, separate group tables as much as possible to increase privacy and minimize noise impact (Wilson et al., 2002).

- Discuss the acoustical ramifications of an open-plan layout with the client to minimize the negative impact of acoustics in the space (UK Department of Education and Building Skills, 2003a):
  - Locate typical positions of both teacher and students in the space.
  - Be aware of the number of teachers and/or students that will simultaneously be giving presentations and the number of people who may be walking through the space at any given time.
  - Identify the equipment that will be running in the space.

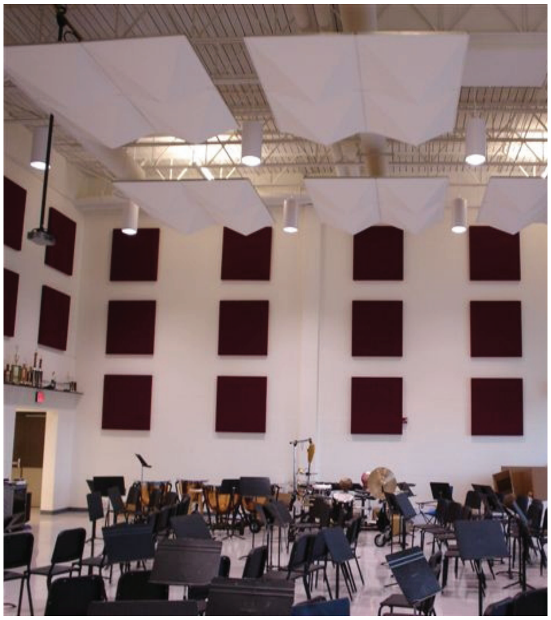


ACOUSTICAL DESIGN STRATEGIES: *OTHER EDUCATIONAL SPACES*

Different rooms in schools (e.g., study, lecture halls, music halls, nurseries, auditoriums) require different acoustic performance standards based on the room's purpose (UK Department of Education and Skills, 2003a). Large rooms (larger than 20,000 square feet; e.g., auditoriums) require different acoustic design requirements than general classrooms, as they often differ in size, shape, and function. The teacher-student configuration within spaces is often fixed; however, the shape of the room can vary greatly. Additionally, HVAC systems often have greater capacities and speech reinforcement systems and other audiovisual aids are typically present in these rooms (Accredited Standards Committee..., 2002). The following are design considerations for some of these principal spaces commonly found in schools.

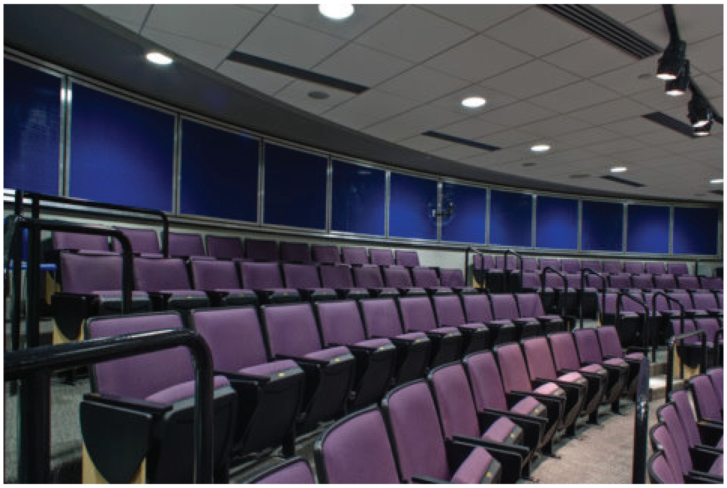
Music Rooms

- Provide 25 square feet of floor area per person for band rooms and 15 square feet per person for chorus rooms to adequately size rooms for ideal acoustic performance (Stewart, 2002).
- Ensure ceiling heights are at least 16 feet high, although 20 foot high ceilings offer better performance (Stewart, 2002).
- Separate music rooms from neighboring quiet spaces (e.g., classrooms, administration offices, libraries) with unoccupied buffer areas (Stewart, 2002).
- Include more sound-absorbing surfaces in rooms primarily used for teaching and more sound-diffusing surfaces in rooms primarily used for performance (Stewart, 2002).
- Install quiet ventilation systems (Stewart, 2002).
- Increase wall sound-isolation levels to prevent music performances from disturbing other classrooms (Stewart, 2002).



Lecture Halls and Auditoriums

- Distribute reflective and absorbent surfaces evenly across both ceilings and walls of large auditoriums to improve acoustic performance (Accredited Standards Committee..., 2002; Ronsse, 2006; Seep et al., 2000; UK Department of Education and Skills, 2003b).
- For spaces with ceilings higher than 12 feet, consult an acoustic professional to provide sufficient reverberation control (Accredited Standards Committee..., 2002).
- Use hard, sound-reflecting materials (e.g., gypsum board) over the front and center of the ceilings of large halls to project speakers' voices towards the rear of the room (Accredited Standards Committee..., 2002; Seep et al., 2000). Provide sound absorption along the edges of the ceiling to control sound reverberation if necessary (Ronsse, 2006).
- Use sound-absorbing materials and/or tilt the back wall of small auditoriums to minimize echoes and avoid unwanted reflections, respectively (Accredited Standards Committee..., 2002).
- Specify upholstered chairs in small auditoriums to ensure less reverberation variability, no matter how many seats are occupied (Accredited Standards Committee..., 2002; Ronsse, 2006).
- Reduce background noise levels to below NC-35 and reverberation times to below 1.5 seconds to improve lecture hall speech intelligibility (Ronsse, 2006).
- Consider using the "variable acoustics" technique (i.e., using movable panels, drapery, and other items that can be rearranged to create different acoustical environments) when designing school auditoriums that have the potential to be used for a variety of purposes (Seep et al., 2000).
- Pitch seating steeply to support audience lines of sight and hearing (Ronsse, 2006).
- Use sound-reflecting material above the lecturer to create sound reflections into the audience in small auditoriums (Accredited Standards Committee..., 2002).



Libraries

- Locate libraries away from sources of internal and external noise (Stewart Acoustical Consultants, 2004).
- Arrange seating into small groups spread apart to encourage quiet discussion (Stewart Acoustical Consultants, 2004).
- Mask distracting noises with steady, non-distracting sounds such as an unobtrusive ventilation system (Stewart Acoustical Consultants, 2004).
- Install carpet to reduce sound levels (Stewart Acoustical Consultants, 2004).

Gymnasiums

- Hang sound-absorbing baffles or banners from the ceiling to reduce reverberation times (Seep et al., 2000; Stewart, 2004).
- Include sound-absorbing panels above perforated metal and fiberglass roof decking on ceilings to reduce reverberation times (Seep et al., 2000; Stewart, 2004).
- Install acoustical panels or bleachers on at least one of two parallel walls to reduce flutter echoes (Stewart, 2004).
- Leave ceilings above bleachers non-absorptive to support livelier cheering (Stewart, 2004).

Program Spaces

- Install sound-absorbing materials in ancillary school spaces (e.g., hallways, gymnasiums, cafeterias) in areas equal to 50-75% of the ceiling surface area. In high-traffic areas, attempt to cover 75% of the ceiling surface area (Accredited Standards Committee..., 2002).
- Be aware that noise levels in classrooms for children with hearing disabilities used for developing skills (e.g, art rooms, gymnasiums) should not exceed 45 dB(A) (Bess, 1999).

COLLABORATING WITH OTHERS TO IMPROVE CLASSROOM ACOUSTICS

Teachers

The acoustical characteristics of unoccupied classrooms may vary significantly from occupied classrooms. Even the sound quality in classrooms designed for excellent acoustics can decline when the classroom is occupied (Kennedy, 2005). Working with teachers to anticipate the activities that will take place in the classroom is an important aspect of creating a satisfactory acoustic environment.

- Consider teaching methods and learning styles when planning the classroom's acoustical environment, as they can have a significant impact on the type of noise created (Wilson et al., 2002).

- Encouraging the following classroom procedures and teaching styles may improve the learning environment:
  - Train teachers to speak with clear pronunciation, a reduced tempo, and a slightly higher pitch to more effectively communicate with students (Crandell & Smaldino, 1999b).
  - Educate students, particularly those with poor hearing, about proper listening habits and strategies to improve their hearing ability (Crandell & Smaldino, 1999b).
  - Enhance visual communication in environments with poor acoustics to accommodate students unable to adequately hear the teacher (Crandell & Smaldino, 1999b).

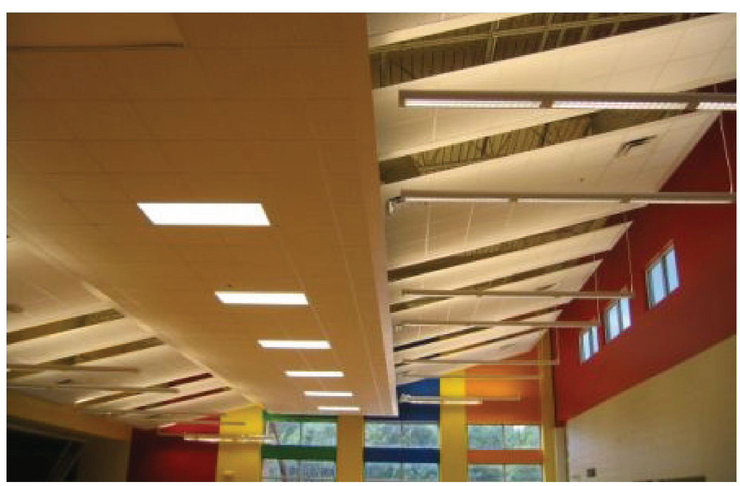
- Observe classroom sessions before undertaking classroom modifications, paying attention to the location of the teacher, student-teacher distance, the teaching methodology (e.g., lecture, group discussion), sources of background noise, and student disabilities (Crandell & Smaldino, 1999a).

- Understand that the type of noise created in primary classrooms (K-6) may be significantly different than that of secondary classrooms (7-12) (Wilson, 2002).

Other Design Professionals

Creating acoustic environments in schools that support student learning and teacher health requires everyone involved to work together and communicate with each other. Miscommunication can result in missteps that prevent the desirable acoustic effects from being achieved. Consider the following when working with other design professionals.

- Coordinate with architects, building contractors, school facility managers, equipment suppliers, and acoustic professionals to adequately control noise in learning environments (Accredited Standards Committee..., 2002).
- After classroom construction is complete, monitor the space for degradation of acoustical materials and respond to complaints about the acoustical environment (Accredited Standards Committee..., 2002).
- Consult an acoustical professional early on in any project demanding more than a basic acoustic design to avoid expensive acoustical mistakes (UK Department of Education and Skills, 2003a), especially for spaces that have unique acoustical requirements (e.g., music rooms, theaters) (Seep et al., 2000).
- Train the appropriate tradespeople in unconventional or non-traditional construction methods used to ensure acoustically satisfactory classroom and learning environments (Accredited Standards Committee..., 2002).



MEETING THE STANDARDS

Building performance industries use standard acoustic performance criteria to assess a school's environmental performance. The following sections highlight some important aspects of these standards. Refer to the standards themselves for more detailed information.

ANSI S12.60-2002

The ANSI S12.60-2002 ("American National Standard Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools") provides a minimum standard for acoustic performance of general education classrooms and secondary spaces. Standards do not apply to special-purpose classrooms (e.g., special education classrooms for students with hearing disabilities). The acoustical performance standards in ANSI S12.60-2002 are based on the results of studies on classroom noise and reverberations and the resulting impact on speech communication (Accredited Standards Committee..., 2002). Although ANSI S12.60-2002 is not mandated by all state codes, ordinances, and regulations, it may be beneficial to adhere to the standard to create satisfactory acoustic environments (Thibault, 2005). The following points highlight some of the essential factors:

- Use wall, floor, and ceiling assemblies with a minimum STC rating of 45 in adjacent corridors, 50 STC for general adjacent enclosed classrooms, and 60 STC in louder adjacent rooms (e.g., music room, gymnasium) (Accredited Standards Committee..., 2002).

- Reverberation times in unoccupied, furnished classrooms with a volume under 10,000 cubic feet may not exceed 0.6 seconds. Classrooms between 10,000 and 20,000 cubic feet may have a maximum reverberation time of 0.7 seconds (Accredited Standards Committee..., 2002).

- Background noise in unoccupied classrooms should not exceed 35 dB(A) (Accredited Standards Committee..., 2002).

- Understand that the noise isolation requirements for ANSI S12.60-2002, while similar to other standards, may be more stringent (Accredited Standards Committee..., 2002).

- Understand that HVAC units are currently being designed that may help meet ANSI 12.60-2002 standard for a 35dB(A) maximum background noise (Lawton, 2008).

Getting the Point: LEED® for Schools

- For new or substantially renovated schools to be LEED® certified, unoccupied classroom background noise levels cannot exceed 45 dB(A). Additionally, classrooms smaller than 20,000 cubic feet require the total area of sound-absorbing finishes with a minimum NRC rating of 0.70 equal to the room's ceiling area, while classrooms larger than 20,000 cubic feet require a reverberation time of less than 1.5 seconds (U.S. Green Building Council, 2009).

- An additional point can be attained by limiting the unoccupied background noise to below 40 dB(A) and constructing all core learning environment walls with the minimum STC rating per room purpose as specified by ANSI S12.60-2002 (U.S. Green Building Council, 2009).

    - Be aware that meeting minimum STC requirements does not ensure that the background noise level requirement will be met, as rooms with high external noise (e.g., near highways, airports) may require greater STC performance to meet background noise level requirements (Muehleisen, n.d.[b]).
    - While schools located in undeveloped areas may have low outdoor background noise levels, reduced STC requirements are only permitted with proof that the noise level will not significantly change over the building's lifetime (Muehleisen, n.d.[b]).

ACOUSTICS AND INDOOR AIR QUALITY (IAQ)

Using sound-absorbing materials in some classrooms has led to concerns about indoor air quality (IAQ) and multiple chemical sensitivity. However, good acoustical design and IAQ can be achieved when proper materials are specified and maintained over time (Accredited Standards Committee..., 2002). Review the following factors to provide satisfactory acoustics and IAQ simultaneously.

- Consider how material composition, potential off-gassing, and operation and maintenance strategies may affect IAQ when specifying materials for acoustic purposes (Accredited Standards Committee..., 2002).
- Be aware that needs of other building systems (e.g., lighting, thermal, ventilation) may interfere with optimal acoustic designs; however, special architectural elements (e.g., acoustic doors, acoustic windows) are available that decrease the negative effects on acoustics (Muehleisen, n.d.[b]).
- Consider acoustical ceiling tiles and wall panels in elementary classrooms over soft furnishings and cloth wall-hangings to improve the acoustic environment while minimizing fire and health hazards (Wilson et al., 2002).

GLOSSARY OF TERMS

This Glossary of Terms offers basic definitions for terms that can be found in this document. Refer to CISCA publication *Acoustical Ceilings Use & Practice* for further definitions.

A-Weighting (dB(A)): A measure of sound pressure level designed to reflect the response of the human ear, which is less sensitive to low and high frequencies.

Amplitude: The magnitude of a sound wave, indicating the intensity of the sound.

Ceiling Attenuation Class (CAC): A rating, measured in decibels (dB), indicating a ceiling panel's ability to reduce sound transmission between two adjacent rooms. Higher ratings indicate better performance (i.e., greater reduction in sound transmission).

Clarity Index (C50): The ratio of the energy arriving at a given seat within the first 50 milliseconds with the energy at the same seat afterwards.

Decibel (dB): A unit measurement of the loudness of a sound. Louder sounds have larger decibel values.

Diffusion: The scattering of sound in all directions caused after sound strikes a surface.

Discrete Echo: Continuously reflected sounds in a classroom which can interfere with the intelligibility of speech.

Early Decay Time: The reverberation time measured over the first 10 dB of the decay which offers a more subjective evaluation of reverberation times, as the human ear interprets the initial rate of decay more significantly than the following decay.

Flutter Echo: A ringing echo created when two parallel hard surfaces rapidly reflect sound back and forth across a room.

Frequency: The number of sound waves created in a given amount of time, indicating the pitch of the sound, expressed as Hertz (Hz).

Noise Criteria (NC): A one-number measure of background noise, created by measuring the sound pressure level at the loudest points in an environment.

Noise Reduction Coefficient (NRC): A measure of the average sound absorption of a surface used to compare the sound-absorbing characteristics of building materials.

RC Mark II: A method for rating background noise levels of a room; useful for diagnosing noise problems.

Reverberation Time (RT): The time it takes for sound to decay by 60 dB once the source of sound has stopped.

Signal-to-Noise Ratio (SNR): The ratio of desired sound (e.g., teacher's voice) to undesired background noise (e.g., mechanical noise). Larger numbers denote better acoustic performance.

Sound Absorption: Sound deadened upon striking a surface.

Sound Pressure Level (SPL): The physical loudness of a sound on a decibel scale determined by the air pressure change caused by a sound wave.

Sound Reflection: The change of direction caused after sound waves strike a surface.

Sound Transmission: Sound which passes through a surface to the space beyond it.

Sound Transmission Class (STC): A numerical rating of the sound control performance of a wall or ceiling; the higher the number, the better the sound control.

Speech Intelligibility: A measure indicating to what extent speech is understood in a given environment.

Speech Transmission Index (STI): An index measuring the speech intelligibility in a given area ranging from 0 (no intelligibility) to 1 (perfect intelligibility).

Transmission Loss (TL): The reduction in sound power caused by placing a wall or barrier between the sound source and receiver.

Wavelength: The distance between corresponding points on consecutive sound waves.

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VISION

CISCA is to be the recognized authority and resource for the acoustical ceiling and wall systems industry.

MISSION

Over the next three years,
CISCA will:

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- Provide dynamic and accessible forums to advance relationships within the industry

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