ASHRAE Journal

Sound in the Classroom

Why Children Need Quiet

By Peggy B. Nelson

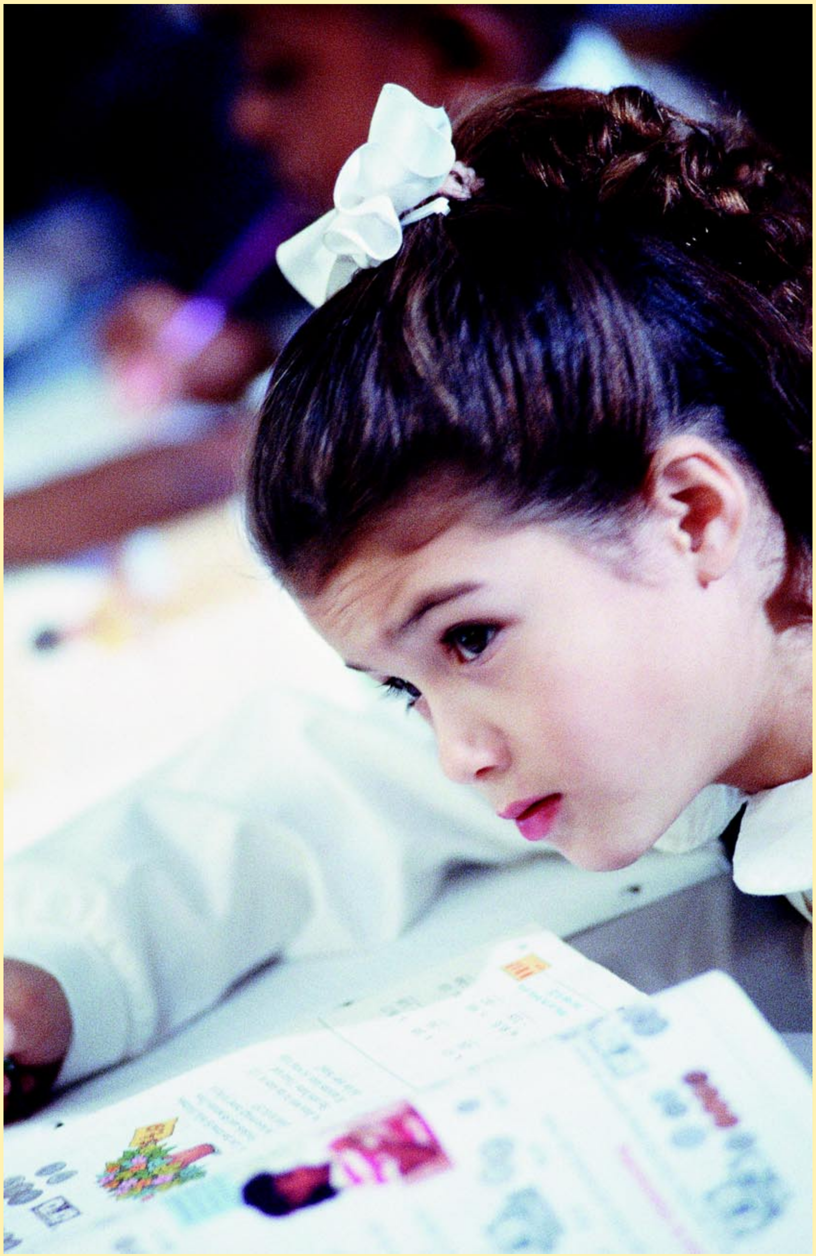
Children are not only smaller and noisier than adults, they are immature and inefficient listeners who are developing their speech perception abilities until their teen years. Evidence shows that children have more difficulty understanding speech in noisy and reverberant rooms than do adults. Thus, when we design rooms for teaching children, it is insufficient to rely on acoustics that are "good enough" for adults. Instead, it is desirable to design classrooms with the special needs of children in mind. Children need low noise and reverberation, so they can hear and understand everything that is said throughtout the room. While working with the American National Standards Institute (ANSI) and Acoustical Society of America (ASA) Working Group on Classroom Acoustics over the past four years, I learned three important lessons.

1. All children need good acoustics to understand familiar words and to learn new information.

Noise in classrooms is any unwanted sound, usually caused by noisy HVAC equipment, noise from sources outside the building, and noise from sources in adjacent rooms and hallways. (Noise is also generated by students, but that aspect of the noise environment is presumably under control of the teacher.) Classroom noise can be made worse by reverberation. Reverberation is the persistence of sound after the source itself stops, arising from sound reflecting off of hard walls, floors and ceilings. Reverberation time (RT60) is defined as the length of time in seconds that is required for the sound level to reduce by 60 decibels (dB) once the sound source has been turned off.

A great deal of research has shown that noise and reverberation adversely affect typical young children more than they affect typical adults. Werner and Boike[1] have shown that normally developing young children are immature listeners who don't easily separate signals from background noise. Stelmachowicz, et al.[2] showed that young children can repeat fully audible words and sentences in quiet conditions as well as adults. However, when the audibility of the words is reduced to 50% (still easy for adults) children cannot understand most of what is said. In conditions where adults can just barely understand most of the words spoken (25% audibility), young children 5 to 7 years of age can understand almost nothing, even when the words are familiar.

Children apparently develop their ability to understand in noisy and reverber-



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ant conditions. They improve throughout their early years and mature some time during adolescence. Soli and Sullivan[3] showed that adults can understand most familiar words when the noise level and the speech level (or the signal level) are approximately equal, i.e., when the signal-to-noise ratio or SNR is approximately zero. However, typical children younger than 13 years need background noise levels that are significantly quieter than the signal they are trying to hear.

Johnson[4] studied children ages 6 to 15 for their understanding of speech sounds in noise alone (at +13 dB SNR), in reverberation alone (with RT60 = 1.3 s), and in both noise and reverberation. Johnson found that the youngest children (6 to 7 years) misunderstood both consonants and vowels in noise and reverberation. Slightly older children (10 to 11 years) had adult-like vowel perception with reduced consonant perception. Fourteen-year-old children could identify vowels and consonants at adult-like levels in noise alone or in reverberation alone. However, in conditions of reverberation and noise, their perception of consonants did not reach adult levels until the late teen years. Simply increasing the overall level of the words did not significantly improve children's performance when the conditions were noisy or reverberant. The evidence clearly indicates that even normally developing children do not hear like adults.

2. Children who have hearing loss, those learning in a second language and those with auditory or attention problems need even more favorable acoustics.

Auditory learning problems are prevalent among school children. We know that large numbers of hard-of-hearing children are in schools. Some estimates suggest that at any given time, as many as 25% of young children have ear infections, and approximately 15% have slight hearing losses due to more permanent conditions like noise damage.[5,6,7] Most of these children are not aware that they have hearing loss. Children that have a hearing loss are significantly affected by background noise. They require lower background noise levels and higher signal levels for understanding than do children who are hearing well.[8]

In many school districts, large numbers of children speak other languages at home. According to a U.S. Census Bureau report in 1998, 2.5 million school-aged children had limited proficiency in English, making up between 5% and 11% of all school-aged children. Across the U.S., major metropolitan areas are reporting that 20% or more of their school children speak languages other than English at home.[9] In the early grades, 50% of children in the Los Angeles Unified School District speak other languages at home. All people listening in a non-native language are more susceptible to background noise.[10] Children learning English as a second language are especially affected by classroom noise and need quiet rooms to understand their teachers and English-speaking peers. Nelson, et al.[11] demonstrated that two groups of second-grade children (those whose first language was Spanish and those who spoke English only) performed equally well on English

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word understanding in quiet conditions. However, the Spanish-language children performed significantly poorer than English-speaking children for word understanding in noise at +10 dB SNR. In our increasingly diverse nation, multilingual families will become more common everywhere and children from those families will need favorable acoustic conditions.

In addition, estimates suggest that 5% or more of all school children have attention deficit/hyperactivity disorder (AD/HD), a neurobiological condition that affects the child's ability to maintain attention.[12] Poor acoustic conditions cause increased distractibility, reduced attention and increased impulsivity among children with AD/HD.[13]

Looking across these prevalent special populations, it is clear that there are children in all schools who need very favorable acoustics to minimize distractions and to understand the spoken message. Because of the recent educational trend of mainstreaming special education students by reducing special education classrooms, the improved acoustical environment that is needed by students with special needs is appropriate for all classrooms.[14]

3. Classrooms are frequently too noisy for learning.

The most significant noise source in many classrooms is the HVAC system. In some schools, the HVAC system pumps out 65 dBA (sound pressure level weighted to match the human ear) into the center of the room. This is the same approximate sound level as a typical teacher's voice at 1 m (3 ft) distance. Children in those rooms who sit farther than 1 m from the teacher can hear the HVAC noise better than they can hear the teacher. Obviously, not many children sit closer than 1 m to the teacher. Some teachers told working group members that they are forced to alternate between talking (teaching) and cooling the room because they simply cannot raise their voices above this intrusive noise. Knecht, et al.[15] measured reverberation and background noise levels in 32 unoccupied elementary classrooms in eight public school buildings in central Ohio. Background noise levels ranged from 32 to 67 dBA. The noisiest classrooms were those with loud HVAC units and other appliances running. Classrooms with HVAC systems turned on were 14 to 15 dB noisier than those with HVAC turned off.

Evidence also shows that noisy classrooms require teachers to speak at vocal levels that cause stress and fatigue to their voices.[16] Large numbers of teachers complain of tired voices, vocal strain, and health concerns because of their need to speak at such high vocal levels. In quieter classrooms, teachers can speak at more comfortable levels and their voices can be heard throughout the room.

Reverberation further complicates the noise problem. Excessive reverberation "smears" the temporal properties of speech signals when reverberation times (RT60s) exceed about 0.6 seconds. RT60 measurements for the 32 classrooms in the Knecht, et al.[15] study ranged from 0.2 to 1.27 seconds. Because of the combination of the observed noise levels (32 to 67 dBA) and RTs, teachers' voices are often reaching students at unacceptably low signal-to-noise ratios (SNRs) with excessive reverberation.

The Classroom Acoustics Standard

The new classroom acoustics standard (ANSI S12.60-2002[17]) recommends maximum noise and reverberation for all new school construction and significant renovation projects. The standard specifies that noise levels in core learning spaces should not exceed 35 dBA and 55 dBC throughout room. The frequency-filtering effects of the A-weighting and C-weighting curves are shown in *Table 1*. The A-weighting scale filters out lower frequencies much like the human ear, so the resulting sound level approximates the acoustical environment's subjective loudness. The C-weighting filter removes only the lowest frequency sound energy, and since the highest HVAC sound levels typically occur at low frequencies, a comparison of the A- and the C-weighted sound level provides an indication of the acoustical environment's low frequency content. Therefore, the standard's limits of 35 dBA and 55 dBC provide a simple way of specifying spectral balance without resorting to the use of more complex octave band sound analysis.

	Octave Band Center Frequency (Hz)								
	31	63	125	250	500	1,000	2,000	4,000	8,000
A-weighting	–40	–26	–16	–9	–3	0	1	1	–1
C-weighting	–2	0	0	0	0	0	0	0	–3

Table 1: Weighting values for dBA and dBC scales. To convert unweighted sound pressure levels into dB A-weighted (dBA) or C-weighted (dBC) levels, add or subtract the values shown here for the appropriate octave bands.[20]

The 35 dBA maximum noise level will ensure that the level of teachers' voices (usually 50-65 dBA, depending on the location of the child and speaker) will achieve the positive signal to noise levels needed by children. In order to minimize background noise levels, classrooms will need acoustically adequate doors, windows, floors, ceilings, and walls that are selected and installed properly so that they isolate one room from another. Proper selection and placement of acoustically absorptive materials will reduce the negative effects of reverberation on intelligibility. Classrooms also need quiet HVAC systems.

Some people question why we must make rooms quieter. Why not make the teachers' voices louder through amplification? The use of group sound reinforcement systems has become popular in classrooms, and personal amplification systems are necessary for many hard-of-hearing children. Group amplification systems may include wireless microphones, amplifiers and speakers placed around the classroom. Creative, customized use of wireless amplification systems can help. In these systems, the speaker (usually the teacher) uses an external microphone, and the speech from the microphone is amplified and sent directly via FM or infrared transmission to speakers around the room or to a personal receiver on a child. With these systems, the speech-to-noise level is improved because only the signal at the microphone, not the general background noise, is amplified. The amplified signal has a more favorable level relative to the unamplified noise arising from the HVAC system.[18,19] However, amplification systems are only a partial solution to the "signal-to-noise problem." Much of classroom learning is peer-based and active. The teacher is frequently a guide to group discussions, rather than a lecturer. In these group activities, the signal source changes frequently. The speech signal source changes frequently from teacher to student and between students. The results summarized previously from Johnson[4] also demonstrated that a higher signal level alone is not sufficient for children's full understanding of speech. Although amplification systems are an important tool for hard-of-hearing children who need higher signal levels, only by reducing the noise and reverberation throughout the room can we ensure full access to learning for all children.

Summary

Research shows that children need favorable acoustical conditions in the classroom because:

- Young children are ineffective listeners to speech in noise until they reach adolescence, when they achieve levels of speech understanding similar to those of adults.
- Large numbers of children (up to 20% of the school population) have hearing loss, as a result of congenital, genetic, and environmental causes. All people with hearing loss are more affected by both background noise and reverberation.
- Significant numbers of children are learning in a language not spoken in their home.
- Large numbers of children have difficulty focusing their attention to speech in background noise, even though they have normal hearing sensitivity and are learning in their native language.

Substantial evidence indicates that children require more favorable acoustical conditions than are currently found in most classrooms. Based on the extensive research, children in regular classrooms need the following:

- A target signal that is at least 15 decibels (dB) above the level of the background noise throughout the room,
- HVAC background noise that is less than 35 dBA and 55 dBC throughout the room, and
- Sound-absorbing architectural surface finishes (e.g., acoustical tiles) that minimize reverberation, resulting in reverberation times of less than 0.6 seconds in an unoccupied classroom.

Children are not unpredictable small adults. Rooms that are sufficiently quiet for adults may not be appropriate for children's learning. Children who are developing normally and those who have special needs have their own acoustical requirements. Acoustical controls should be in place so that children reach their full potential to hear in their classrooms, in the same way that lighting should allow children to see well and HVAC allows them to be comfortable. Our challenge is to design rooms for learning that meet children's unique needs for seating, lighting, comfort and sound.

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ANSI Standard: Complying With Background Noise Limits

By Mark E. Schaffer, P.E., Member ASHRAE

The new classroom acoustics standard, ANSI Standard S12.60,[1] specifies maximum background sound level limits of 35 dBA and 55 dBC, levels that are significantly lower than currently typical for classrooms. (See article on Page 22 for descriptions of dBA and dBC.) Lower background sound levels will significantly improve classroom speech intelligibility for students and teachers. Teachers will also benefit because they will not have to speak as loudly to be understood by the students, reducing vocal strain. Assuming that the classroom's architectural design has controlled any intruding noise to insignificant levels, the HVAC system becomes the dominant source of steady-state noise and, therefore, must be designed so that the classroom sound levels do not exceed the 35 dBA and 55 dBC limits.

The new standard's 0.6 second reverberation time (RT) limit leads to a collection of floor, wall and ceiling finishes that not only control reverberation, but also help control HVAC system noise. This is done by providing a Room Effect Factor (REF) of about 10 decibels (dB) in all eight of the octave bands from 63 to 8,000 hertz. The REF in each octave band is the difference between the sound power level, L_W, emitted into the room and the room's sound pressure level, L_P. In short, L_P @ L_W – 10.

Guidelines for Unducted Systems

An unducted system is one in which either the supply or return air side of the HVAC unit is not ducted and, as such, the acoustical measurement and rating procedures in ARI Standard 350[2] should be used to determine the unit's L_W ratings. Accordingly, based on an REF of 10 dB in each octave band, classrooms that use unducted unit ventilators and wall-mounted package units will comply with the 35 dBA and 55 dBC limits if the units' A-weighted and C-weighted L_W ratings are no more than L_{WA}=45 and L_{WC}=65, respectively. Field measurements made by the author and others in dozens of classrooms throughout the United States indicate that most wall-mounted package units have L_{WA} ratings that range from about L_{WA}=60 to L_{WA}=77. Unit ventilators are somewhat quieter with L_{WA} ratings that range from about L_{WA}=54 to L_{WA}=67.

Some manufacturers of wall-mounted package units and unit ventilators are attempting to develop quieter units that will be compatible with the new standard, while others offer accessory noise reduction packages that approach the recommended L_{WA}=45 and L_{WC}=65 limits.

Ducted Single-Zone Systems

Until quieter, unducted equipment becomes available, only ducted systems with appropriate noise control (e.g., duct liner, flexible ductwork and/or duct silencers) can yield conforming classroom sound levels. Because each school building design is unique, no single set of design guidelines will ensure compliance with the 35 dBA and 55 dBC limits for every project. The following guidelines provide a basic set of design steps that must be supplemented with additional, project-specific design measures if the new standard's L_P limits are to be achieved:

1. Keep system components (except grilles and diffusers) outside of the classroom and its ceiling plenum space; locate them in either a corridor ceiling plenum space or outdoors. This design approach is standard in some school districts because it permits servicing and maintaining the equipment without entering the classroom.
2. Keep outdoor equipment away from classroom windows.
3. Select the air-moving equipment for the lowest possible low-frequency octave band L_W values, as measured per ARI Standard 260.[3]
4. Select air-moving equipment with variable speed fans, if available, since fan noise is closely related to fan speed (e.g., a 20% speed reduction reduces fan noise by about 5 dB).
5. Size the supply and return air ductwork for a maximum air velocity of 1,000 fpm at the air-moving equipment connections, gradually reducing the velocity along the duct systems to no more than 400 fpm at the diffusers and grilles.
6. Assuming the use of four supply diffusers and one return grille, select diffusers and grilles for a catalog Noise Criteria (NC) rating of no more than NC-18, as derived from laboratory-measured L_W values per ARI Standard 890[4] and a 10 dB REF.
7. Hang suspended equipment with an internal compressor (e.g., water-source heat pumps) above a corridor or other non-sensitive area using spring hangers with a static deflection at least 1 in. (25 mm). Floor-mounted equipment with an internal compressor should be mounted on spring isolator mounts of the same minimum static deflection.

Central Station VAV or Multizone Systems

Basic design guidelines for central station VAV and multizone systems are identical to those for single-zone systems with three additions:

8. Do not locate an HVAC equipment room adjacent to a classroom or other noise-sensitive room. Use non-sensitive areas, such as storage or toilet rooms, as noise buffer zones.

9. Select the variable-air-volume boxes for the lowest possible Discharge and Casing-Radiated L_W values in the 125 hertz octave band when tested per ARI Standard 880.[5]

10. Install virtually all central plant equipment in a classroom building on spring isolators whose static deflection depends on the equipment selection, placement and operating conditions.

More complete information on the control of both noise and vibration can be found in Chapter 46 of the *1999 ASHRAE Handbook—HVAC Applications* and ASHRAE's *A Practical Guide to Noise and Vibration Control for HVAC Systems*[6] and *Application of Manufacturers' Sound Data*.[7]

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ARI's Views on ANSI S12.60-2002

By Michele Darbeau, Associate Member ASHRAE

The Air-Conditioning and Refrigeration Institute (ARI) appreciates the effort and expertise that the Accredited Standards Committee, S12 (Noise)/Working Group 42 (Classroom Acoustics) and its Secretariat, the Acoustical Society of America, has applied to the classroom acoustics initiative. This initiative resulted in ANSI S12.60-2002. We recognize the importance of good speech intelligibility and its role in learning, and advocate the development of a mandatory national standard using a process that involves all stakeholders and is inclusive of multiple compliance paths.

The standard as written has opposition from educators based on concerns about the ability to implement the standard in a practical manner and the cost of such implementation. This opposition was recently illustrated at the International Building Code (IBC) hearing in Fort Worth, Texas, where a proposal to include substantial extracts from ANSI S12.60-2002 into the 2003 IBC was rejected.

To address these concerns and to implement a mandatory rather than voluntary national standard, accessibility guidelines for classroom acoustics need to be promulgated by the U.S. Architectural and Transportation Barriers Compliance Board (the Access Board) under its authority to develop and adopt Americans with Disabilities Act Accessibility Guidelines (ADAAG). This will provide the opportunity for the participation of all directly and materially affected parties, ranging from acoustical engineers and consultants to parents, school facility planners, educators, architects, contractors, and manufacturers. This would provide a forum for the technical, practical, and cost concerns to be addressed, particularly those relating to providing alternate, more flexible and implementable design approaches. As with other ADAAG, a classroom acoustics guideline would provide the guidance and flexibility for individual school districts to determine the most cost effective construction design for new and renovated school facilities, while providing the established acoustical performance needs of the specific learning situations.

As stated in the main article, for an optimum learning environment in schools, adequate clearance is needed between a teacher's voice level and the background noise level in the room; that is, an adequate signal-to-noise ratio (SNR). This SNR depends on many factors and can be obtained by means such as raising voice levels using electronic amplification, moving the students with the greatest need for a higher SNR closer to the teacher, and/or lowering the occupied space background sound levels. These alternatives will make attaining the goal of conducive learning environments feasible for the renovation of existing schools as well as for the construction of new schools.

In its current form, ANSI S12.60-2002 creates an overly stringent requirement by setting a single SNR for classrooms and core learning spaces without:

- considering the contribution of other background noise sources (example, computer or other electronic instructional equipment and student self noise);

• allowing for different learning group SNR needs;

• exploring alternate approaches to minimizing voice drop;

• facilitating design flexibility;

• considering the intended use of the learning space;

• allowing for spatial averaging of background levels; and

• recognizing that some proposed solutions may conflict with other classroom design standards to improve indoor air quality.

The use of alternate methods of achieving the desired SNR should be allowed, where appropriate, which would permit a variety of optimal, cost effective approaches to be employed.

Through the Access Board's administrative process, educators, acoustical engineers, school facility designers and specialists, and manufacturers must come together to further the classroom acoustics initiative and develop a practical and useful guideline that will enhance our children's learning environments. ARI is committed to working with the Access Board, the S12 Committee and other stakeholders to fulfill this goal.

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ASHRAE JOURNAL

Understanding the Problem

Noise in the Classroom

By Jerry G. Lilly, P.E.
Member ASHRAE

Most of today's air-conditioned school classrooms are too noisy. Newer school classrooms all too often are built with HVAC units that are selected on the basis of lowest first cost with insufficient regard to overall system quality, durability, optimum air distribution, and acceptable background noise levels. When noise levels are too high, the result is reduced speech intelligibility and a reduction in the overall learning capacity of the students. The problem is not one of technical capability; it is one of awareness, understanding and priorities.

Currently, a national task force of approximately 50 educators, architects, acoustical consultants and audiologists is preparing a draft standard that will specify minimum acoustical requirements for all classrooms in the United States. This proposed standard addresses all acoustical issues affecting speech intelligibility in the classroom including background noise, reverberation, and sound isolation from other interior and exterior spaces. Although the new standard is not yet finalized, it is likely to have a significant impact on the design of all new and remodeled classrooms in the near future. This article presents guidelines for designing classroom HVAC systems that will be able to achieve the lower background noise levels required by this standard.

Noise Criteria

The background noise criteria that are being considered by the committee developing the new standards for school classrooms are very close to NC-30. The *1999 ASHRAE Handbook* suggests that higher background noise levels are acceptable, but that is likely to conflict with the new national standard for classrooms. The NC-30 criteria should be applied to all school classrooms, regardless of student age and course content. The only exception would be for special purpose classrooms that are used to instruct hearing-impaired students, students who do not speak the native language, and foreign language classrooms. Because of the difficulties of distinguishing subtle differences in language, these special purpose classrooms should be designed to meet lower background noise criteria (approximately NC-25).

Other schoolrooms may have higher background noise levels. For example, offices, libraries, assembly spaces, and cafeterias usually can tolerate background noise levels as high as NC-35. Background noise levels in corridors and lobbies can be around NC-40. Additional detailed information concerning background noise criteria for HVAC systems can be found in Chapter 46 of the *1999 ASHRAE Handbook*.

Because of the recently emphasized need for low noise levels in school classrooms, HVAC system designers need to reassess how they approach system design for these projects. If we are to succeed in achieving the recommended acoustical criteria we must consider noise from the beginning of the design process. The goal should no longer be lowest first cost. We should design for overall system quality, while considering the life-cycle cost, including the less tangible (but extremely important) cost of the educational impact of the students in the classroom.

System Design Guidelines

Basically, two general HVAC system types exist that can achieve the recommended noise criteria. One type is a central system where a single air-handling unit serves many classrooms from a central supply duct system, and the other type uses a dedicated air-handling unit for each classroom. The central system often is the most economical choice, because a single air-handling unit can be used for the entire system and because the fan, motor, and compressor (e.g., the noisy equipment) can be located far from the classrooms, making noise control more manageable.

Although a dedicated unit is much smaller and generates less noise at the fan, the fact that it must be located in or next to the classroom makes noise control more difficult. The following paragraphs present some general design guidelines for achieving acceptable background noise levels in classrooms.

HVAC systems that should be avoided in school classroom applications include:

1) Self-contained AC units located in the classroom.

2) Rooftop AC units located above classrooms.

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3) Water source heat pumps above the classroom ceiling.

4) Any unit mounted in a window or wall.

These system and unit types should be avoided because they are inherently noisy, and cannot achieve the recommended NC-30 noise criteria with current technology.

The classroom air distribution system should be a low velocity system to minimize flow-generated noise and to minimize static pressure requirements on the supply fan. The system fans should be selected for maximum efficiency, which generally yields minimum noise generation.

Improper fan selection is one of the most common design errors that result in noisy HVAC systems. To correctly select a fan, the designer must have an accurate estimate of the total system static pressure at the design airflow rate. If the duty point is too far left of peak efficiency for a given fan (e.g., fan is too large), then the fan may go into surge, becoming unstable and extremely noisy with excessive vibration. This is especially true with forward curved centrifugal fans. If the duty point is too far right of peak efficiency (fan too small), the fan usually generates much higher levels of noise. This effect occurs with all types of centrifugal fans. As a result, simply overestimating the total system static pressure (as a conservative method to ensure adequate airflow) generally is not a good idea. Computer software programs should be used to accurately assess the system requirements prior to fan selection.

The same classroom air distribution system should be used for both the central and dedicated systems. The recommended classroom supply air distribution system is an array of ceiling diffusers as shown in *Figure 1*. For classrooms less than 1,000 ft^2 (93 m^2) (floor area) a total of four 4-way ceiling diffusers is recommended. If fewer than four diffusers are used, it is likely that there will be excessive diffuser noise in the room. In essence, the throw requirements will be too severe to meet the air distribution needs without exceeding the noise criteria.

Because of the additive effects of multiple diffusers and because of the need to accommodate noise from other HVAC system components (VAV boxes, duct breakout, etc.), the designer should not select diffusers to exactly match the design criteria. Supply diffuser NC ratings are based on the assumption that only one diffuser is in the room, the listener is not close to the diffuser, and no other sources of noise exist. If only one diffuser is in a room, size that diffuser for at least 3 NC points less than the NC criteria. This will help to compensate for other noise sources and listener locations relatively close to the diffuser. If there are two diffusers in a room, size each diffuser for 6 NC points less than the NC criteria. If there are four diffusers, size the diffusers at 9 NC points less than the criteria.

Each time the number of diffusers is doubled, the NC rating of each diffuser should be reduced by 3 NC points. Therefore, to meet NC-30 in a classroom with four diffusers, size each diffuser for NC-21. To ensure the desired acoustical performance from the diffuser, the designer must also make sure that the volume damper is not located at the diffuser inlet. This damper should be located at the flex duct connection to the low pressure duct above the ceiling—at least 6 ft (1.8 m) from the diffuser. In addition, provide at least 3 diameters of straight flex duct at the diffuser inlet. If an elbow or bend is in the flex duct near the diffuser inlet, the air velocity distribution at the inlet of the diffuser will not be uniform and the diffuser will be noisier than its catalog rating.

This effect can increase noise as much as 10 to 15 dB, depending upon the angle and location of the bend. This important detail must be checked during construction. If there is not adequate space to ensure a minimum of three duct diameters of straight flex prior to the diffuser inlet, the diffuser should be oversized to help compensate for the noise level increase cause by uneven flow distribution at the diffuser inlet.

The low-pressure ductwork above the classroom ceiling should be internally lined sheet metal ductwork sized for a velocity of 800 to 1,000 fpm (4 to 5 m/s). Lower velocities are not necessary, nor are they recommended because they will result in larger ducts with a greater surface area resulting in greater breakout

Definition of Acoustical Terms

Acoustic Frequency: number of acoustic pressure oscillations per second, expressed in Hertz (Hz). The human ear is most sensitive at frequencies near 2,000 Hz, but most people with good hearing can hear sounds as low as 20 Hz and as high as 16,000 Hz.

Breakout: noise radiation from the exterior surfaces of HVAC ductwork.

Noise: unwanted sound. Noise is usually distributed (though not uniformly) over a wide range of acoustic frequencies.

NC: background noise rating system based on the octave band sound pressure levels in the occupied space with all HVAC equipment operating. Higher values represent higher background noise levels.

Octave Band: range of acoustic frequencies, extending from 0.707 times the center frequency to 1.414 times the center frequency. The 10 standard octave band center frequencies covering the range of human hearing are: 16, 31.5, 63, 125, 250, 500, 1,000, 2,000, 4,000, and 8,000 Hz.

Octave Band Noise Level: the total acoustic pressure in an octave band, expressed in decibels (dB). Higher decibel levels generally represent an increase in loudness if compared within the same octave band.

Sound Pressure Level: a measure of the intensity or loudness of a sound, expressed in dB. In general, the sound pressure level decreases with distance from the source because the acoustic energy is distributed over a broader area.

Sound Power Level: a measure of the total acoustic power radiated by a source in all directions, expressed in dB (ref. 1 picowatt). Unlike the sound pressure level, the sound power level cannot be measured directly, and is generally unaffected by the acoustic environment.

noise problems, not to mention the higher construction costs and problems with space limitations. The duct liner should be 2 in. (50 mm) thick and extend at least for the first 10 ft (3 m) of ductwork above the ceiling. If acoustical duct lining is not desired in the low-pressure duct system, it can be replaced by a sound attenuator at the beginning of the low-presssure duct. The sound attenuator should provide a minimum insertion loss of 10 dB in the 125 Hz octave band.

Central System: Design Guidelines

With a central system the main (medium pressure) supply duct should be located above the corridor, not above the classrooms. The branch duct fittings to each classroom should be low-pressure drop conical tee fittings to minimize self-generated noise at the fitting. If VAV boxes are used to regulate airflow to each classroom, they must be selected for low noise. Fan powered VAV boxes are too noisy to be located above classrooms, but they can be located above the corridor if there is room.

Standard VAV boxes can be located above the classroom ceiling if the VAV box is selected properly. To meet the recommended NC-30 design criteria, the *radiated* sound power level of the VAV box in the 125 Hz octave band must be 65 dB (ref. 1 picowatt) or less. Octave band sound power level ratings for VAV boxes are generally available from the manufacturer. The reader should be cautioned about using the VAV box NC ratings for selection purposes because these ratings are based on assumptions that are not always valid for the intended installation. It is best to use the octave band sound power levels for selection purposes.

The *discharge* sound power level of the VAV box in the 125 Hz octave band should be 70 dB or less if the discharge duct is acoustically lined or if a sound attenuator is provided on the discharge duct. If the discharge sound power level exceeds 70 dB in the 125 Hz octave band, an improved sound attenuator should be provided to the low pressure ductwork to compensate. Unfortunately, sound attenuators cannot be used to compensate for excessive radiated sound power if the VAV box is located above the classroom. VAV boxes are available to meet these criteria, provided they are properly sized and the inlet static pressure to the VAV box is not too high. If the inlet static pressure is above 1 in. of water (249 Pa), the sound power levels will likely be too high to meet the recommended criteria. Therefore, it may be necessary to add a manual volume damper in the branch duct upstream of the VAV box to reduce the inlet static pressure to 1 in. (249 Pa) or less.

The inlet duct to the VAV box should be round spiral pipe, not flex duct. Flex duct is nearly transparent to noise, so the VAV box inlet damper noise could radiate into the classroom if flex duct is used at the VAV box inlet. Of course, if the VAV box can be located entirely above the corridor, this would not be as great a concern since the corridor noise criteria is about 10 dB higher than the classroom.

In general, round ductwork is preferred over rectangular because it eliminates the problem of low frequency breakout that is so typical of rectangular ductwork. Main duct velocities should be less than 1,800 fpm (9 m/s) for rectangular main ducts. Main ducts constructed from spiral round pipe can support flow velocities as high as 2,500 fpm (13 m/s) if low-pressure drop fittings

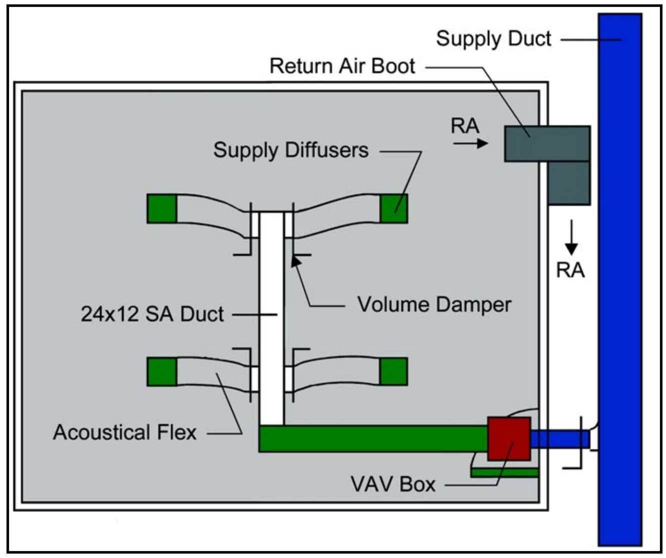

Figure 1: Typical layout of central HVAC system serving classroom.

Acoustical Duct Lining

During the past 10 to 15 years, there has been much discussion regarding the environmental impact of placing fiberglass duct liner in HVAC ductwork. Most of this discussion has centered on the concerns that the fibers may be carcinogenic and/or that duct liners may promote microbial growth. ASHRAE Technical Committee 2.6, Sound and Vibration Control has reviewed the available scientific information in this regard and has adopted the position that acoustical duct lining is both a reasonable and cost-effective noise control alternative in many HVAC systems (including educational facilities), provided that it is properly installed. For additional details, see Page 46.17 of the *1999 ASHRAE Handbook—HVAC Applications*.

are used throughout. Acoustical duct lining generally is not required in the main supply duct, provided that the fan noise control is taken care of at the central unit.

It is extremely important to locate the central air-handling unit away from the classrooms and other noise sensitive spaces. The most popular location is on the roof of the building. This is fine if the equipment is positioned above non-sensitive areas like storage rooms, restrooms, locker rooms, and entry vestibules. The roof structure should be stiff and massive to provide a solid foundation for the unit and minimize the possibility of excessive building vibration.

The supply fan in the central air-handling unit should be selected for maximum efficiency and minimum noise generation. There are lots of different fan types (forward curved, airfoil, plenum fan, etc.) that should be carefully evaluated prior to making a final decision regarding fan selection. This step is critical. All too often a fan is selected for an application without careful evaluation of the impact of the fan selection on the system. The result is often too much noise in the conditioned space, or excessive noise control is needed to achieve the required sound level. Also, when making this evaluation, be sure

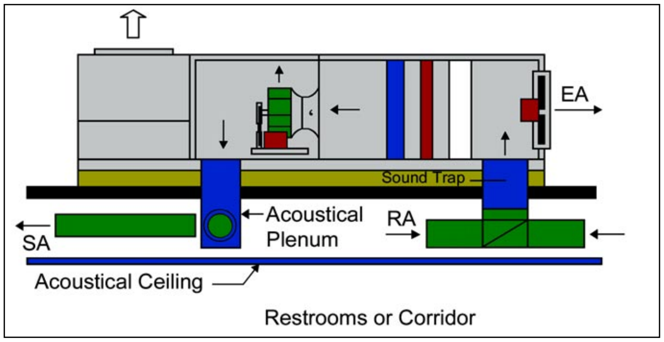

Figure 2: Rooftop air-handling unit with noise and vibration control.

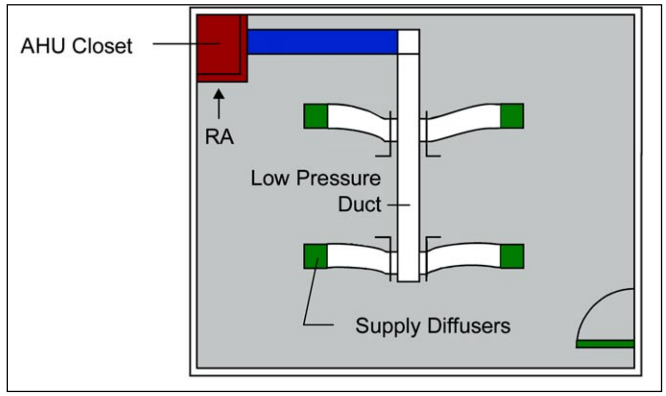

Figure 3: Typical layout of dedicated HVAC system serving classroom.

to consider impacts of noise transmission via the return air path as well as casing radiated noise. The supply air path is the most obvious, but oftentimes the other transmission paths will control the optimum fan selection.

No matter which fan type is used, provide internal spring vibration isolators on the fan/motor assembly (with a flex connection at the fan intake/discharge) in air-handling units (e.g., units without compressors and condenser fans). Self-contained package units should be externally vibration isolated with spring isolators (e.g., a spring isolation curb if roof-mounted) because vibration from the compressors, refrigerant piping, and condenser fans cannot be effectively isolated within the unit.

In most cases even the quietest central supply fan will be too noisy to meet the classroom noise criteria without an additional sound attenuator and/or acoustical duct lining somewhere in the main supply duct system. It is best if the sound attenuator can be installed inside the air-handling unit. This is often possible with custom equipment, but generally is not feasible with less expensive production units.

It is usually best to locate the sound attenuators as close as possible to the noise source, but the attenuator can also be too close to the fan, so be careful to observe the manufacturer's

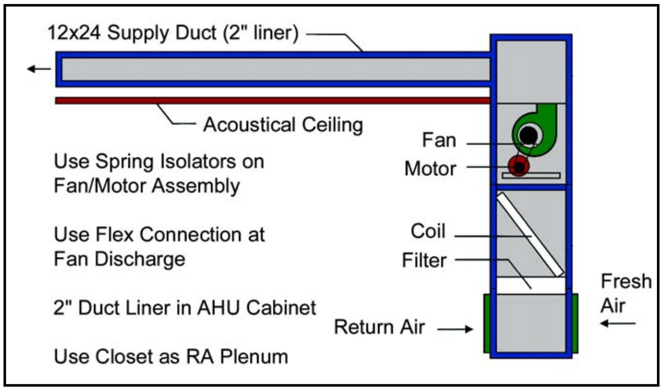

Figure 4A: Typical dedicated classroom HVAV unit with noise control.

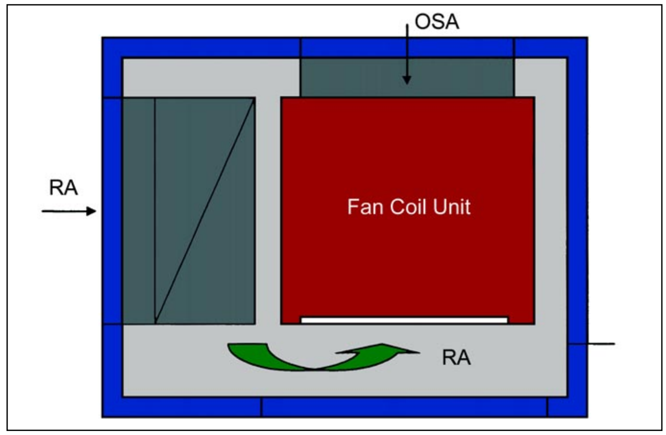

Figure 4B: Top section view of mechanical closet showing fan coil unit and RA duct.

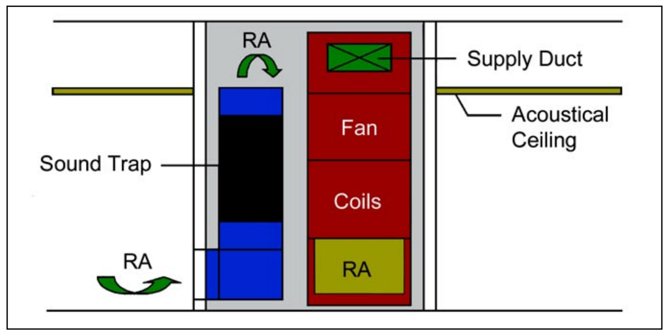

Figure 4C: Front elevation view of classroom HVAC unit in closet.

recommendations in this regard. *Figure 2* shows a section through a rooftop unit in a system designed for low background noise. Note that the supply air is discharged into an acoustical plenum (shown in blue) that penetrates the concrete roof deck (shown in black).

The yellow band above the roof and below the unit represents a spring isolation curb that controls structure-borne sound transmission from the compressors and condenser fans into the roof structure. Round supply air ducts are shown to eliminate low frequency breakout from the supply duct system. A sound attenuator also is shown in the return air opening through the roof (above the ceiling of the corridor or rest room). This particular drawing shows a plenum fan, but a standard centrifugal fan also could be used as well.

The sound attenuator and/or acoustical duct lining should be designed to reduce the remaining sound power level of the supply fan at the point the duct enters the classroom to no more than 80 dB at 63 Hz, 73 dB at 125 Hz, and 70 dB at 250 Hz. This is the maximum allowable sound power level entering the classroom supply duct that can achieve NC-30 with the recommended low pressure supply duct layout shown in *Figure 1*. Sound attenuators may also be required at the return air opening of the central unit (as shown in *Figure 1*), although this is oftentimes far enough removed that it may not impact the classroom noise level.

Dedicated System: Design Guidelines

A layout of the typical dedicated system is shown in *Figure 3*. The ceiling supply air-distribution system in the classroom is identical to the one recommended for the central system. A VAV box is not required because there is only one zone in this system. The closet enclosing the air-handling unit can be located in a corner of the classroom (as shown here) or it could be placed next to another mechanical or storage closet serving the adjacent classroom in a nested fashion. The dedicated unit should be a fan coil unit, not a self-contained package unit or a heat pump since these devices contain noisy compressors and condenser fans. Cooling should be provided from a remote central chiller with a chilled water distribution system.

As with the central system, the maximum allowable sound power level entering the supply duct above the ceiling should not exceed 80 dB at 63 Hz, 73 dB at 125 Hz, and 70 dB at 250 Hz. To meet these levels, the fan inside the dedicated AHU will probably have to be an airfoil or forward curve centrifugal fan selected for maximum efficiency and minimum noise. It is very important to keep the total system static pressure below 2 in. (500 Pa) if this goal is to be achieved.

In addition, a fan discharge plenum should be mounted to the top of the unit (internally lined with 2 in. [50 mm] acoustical duct liner) to provide additional fan noise control prior to the supply duct connection. If exposed duct liner is not desired in the discharge plenum, the insulation can be wrapped in 1 mil polyethylene (or equivalent material) and faced with perforated sheet metal.

Another alternative to the acoustical discharge plenum would be to use an elbow silencer. Custom designed elbow silencers are now available from several manufacturers. If the fan is properly selected, it should be possible to meet the recommended sound power levels without the use of an attenuator in the supply air system, but only if an acoustical discharge plenum is used in conjunction with duct lining. If the supply fan sound power levels exceed the recommended values, a duct silencer can be installed in the supply air duct positioned just above the mechanical closet wall.

The dedicated AHU casing should be minimum 18 gauge steel with 2 in. (50 mm) thick internal acoustical lining throughout. In addition, the fan/motor assembly must be internally isolated on spring isolators with a minimum design static deflection of one inch. The fan discharge should be vertical into an acoustically lined discharge plenum that extends above the classroom ceiling line. The AHU return air opening should be located near the floor inside the closet. The return air from the classroom must pass through a lined duct with a sound attenuator located next to the AHU in the closet as shown in the layout above to minimize noise radiation from the AHU casing and the AHU inlet opening.

This design requires a 60 in. (1.5 m) long sound attenuator sized for a face velocity of 500 fpm (2.5 m/s). The closet wall construction should be one layer of 5/8 in. (16 mm) gypsum board on each side of 3.5 in. (89 mm) (25 gauge) metal studs spaced 24 in. (60 cm) on center with fiberglass insulation filling the stud cavity. The closet door should be a minimum 1.75 in. (44 mm) thick solid core wood with perimeter acoustical seals and an automatic door bottom. The fan coil unit should be spaced away from the closet wall by at least 3 in. (76 mm).

Figure 4A illustrates the recommended noise control features of a typical dedicated classroom HVAC unit. Note the upward discharge of the supply fan into an acoustically lined plenum above the ceiling line. The closet walls are not shown for clarity. *Figures 4B* and *4C* show a top and front elevation view, respectively.

Summary

It is not difficult to design and build a school classroom HVAC system to achieve low background sound levels comparable to NC-30. This can be accomplished with conventional HVAC system components using either a central system or a dedicated air-handling unit located in a closet in or adjacent to the classroom. Simply follow the few simple design guidelines presented earlier. Engineers who would like additional assistance in specific system designs can find help from members of the National Council of Acoustical Consultants at www.ncac.com.

Acknowledgments

Appreciation should be given to those individuals who were first to recognize and promote the need for lower background noise levels in classrooms, and those who continue to champion the work toward the creation of a national standard. Specific recognition should be given to Robin M. "Buzz" Towne (a longtime ASHRAE member who died in August 1998) who started the ball rolling several years ago with Michael Nixon. In addition, Lou Sutherland and David Lubman are leading the current task force for the national classroom acoustical performance standard. ■

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Draft ANSI S12.60-200X
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16 May 2002

AMERICAN NATIONAL STANDARD

ACOUSTICAL PERFORMANCE CRITERIA, DESIGN REQUIREMENTS AND GUIDELINES FOR SCHOOLS

ANSI S12.60-200x

Accredited Standards Committee S12, Noise

Standards Secretariat
Acoustical Society of America
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Draft ANSI S12.60-200X
Draft 12E, 2002 May 16

AMERICAN NATIONAL STANDARD

ACOUSTICAL PERFORMANCE CRITERIA, DESIGN REQUIREMENTS AND GUIDELINES FOR SCHOOLS

Secretariat

Acoustical Society of America

Draft - Not approved by:

American National Standards Institute, Inc.

Abstract

This standard provides acoustical performance criteria, design requirements and design guidelines for new school classrooms and other learning spaces. The standard may be applied when practicable to the major renovation of existing classrooms. These criteria, requirements, and guidelines are keyed to the acoustical qualities needed to achieve a high degree of speech intelligibility in learning spaces. Design guidelines in informative annexes are intended to aid in conforming to the performance and design requirements, but do not guarantee conformance. Test procedures are provided in an annex when conformance to this standard is to be verified.

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Contents Page

Foreword

[This foreword is for information only and is not an integral part of American National Standard, *Acoustical Performance Criteria, Design Requirements and Guidelines for Schools*.]

This standard contains 7 annexes.

This standard was developed under the jurisdiction of Accredited Standards Committee S12, Noise, which has the following scope:

Standards, specifications, and terminology in the field of acoustical noise pertaining to methods of measurement, evaluation, and control, including biological safety, tolerance, and comfort, and physical acoustics as related to environmental and occupational noise.

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Suggestions for the improvement of this standard are welcome. They should be made in writing to Accredited Standards Committee S12, Noise, in care of the Standards Secretariat, Acoustical Society of America, 35 Pinelawn Road, Suite 114E, Melville, New York 11747.

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American National Standard

ACOUSTICAL PERFORMANCE CRITERIA, DESIGN REQUIREMENTS AND GUIDELINES FOR SCHOOLS

0 Introduction

Good acoustical qualities are essential in classrooms and other learning spaces in which speech communication is an important part of the learning process. Excessive background noise or reverberation in such spaces interferes with speech communication and thus presents an acoustical barrier to learning. With good classroom acoustics, learning is easier, deeper, more sustained, and less fatiguing. Teaching should be more effective and less stressful with good acoustical characteristics in a classroom. There can be more verbal interaction and less repetition between teacher and students when spoken words are clearly understood. Although all those in a classroom, including teachers and adult learners, will benefit, special beneficiaries are young children and persons with hearing, language, speech, attention deficit, or learning disabilities. As discussed further in annex A, conformance to this standard will improve the quality of education by eliminating acoustical barriers for all students and teachers, including those with communication disabilities. Good design and attention to detail throughout the construction or renovation process can ensure conformance to the requirements of this standard.

1 Scope, purpose, and applications

1.1 Scope

1.1.1 This standard provides acoustical performance criteria and design requirements for classrooms and other learning spaces. Annexes are included to provide information on good design and construction practices, installation methods, and optional procedures to demonstrate conformance to the acoustical performance and design requirements of this standard. This standard seeks to provide design flexibility without compromising the goal of obtaining adequate speech intelligibility for all students and teachers in classrooms and learning spaces within the scope of this standard.

1.1.2 Acoustical performance criteria are specified in this standard by limits on maximum one-hour A-weighted and C-weighted background noise levels and limits on maximum reverberation times. An objective of these performance criteria is to achieve a level of speech that is sufficiently high relative to the background noise level for listeners throughout the classroom or learning space. However, a requirement for the relative difference between speech levels and levels of background noise, usually referred to as the signal-to-noise ratio, is not within the scope of this standard.

1.1.3 The control of background noise levels in this standard is achieved, in part, by specifying the minimum noise isolation for school building elements. Noise isolation requirements are applicable to the following two types of intrusive noise.

- Noise that intrudes into the classroom or learning space from sources outside of the school building envelope. These noise sources include vehicular traffic, aircraft, industrial plants, and activity in schoolyards or from grounds maintenance. (Schools usually can control only the schoolyard and grounds-maintenance noise sources. However, when a new school site is under consideration, sound from commercial, industrial and transportation noise sources can be taken into account.)

- Noise that originates within the school building and intrudes into the classroom through classroom walls and partitions, floor-ceiling assemblies and ventilation systems. Interior noise sources can be isolated through the proper design and construction of the school building and by noise control measures applied to the building services and utilities.

1.1.4 This standard does not apply to noise generated within a classroom by its occupants. Occupant-generated noise sources include voices and the sounds of classroom activities such as the moving of chairs. Furthermore, this standard does not apply to the noise from portable or permanent built-in equipment used during the course of instruction, such as audiovisual equipment and computers. However, the background noise generated by occupants and instructional equipment can seriously degrade communication or speech intelligibility in learning spaces. Recommendations are given in B5 in annex B for noise control of instructional equipment. Recommendations for background noise assessment procedures are given in E3.2.1 in annex E for such equipment. The teacher can reduce classroom activity noise directly through appropriate controls This activity noise can also be reduced indirectly in classrooms with acoustical qualities that conform to this standard since a quiet classroom with low reverberation tends inherently to encourage children to lower the level of their voices and the sounds of their activity.

1.1.5 The following annexes are provided to support this standard.

- Annex A: Rationale for the acoustical performance criteria in this standard. (Informative)

- Annex B: Design guidelines for noise control for building services, utilities, and instructional equipment. (Informative)

- Annex C: Design guidelines for controlling reverberation in classrooms and other learning spaces. (Informative)

- Annex D: Design guidelines for noise isolation between adjacent learning spaces within a school building and noise isolation by the building facade. (Informative)

- Annex E: "Good architectural practices" and procedures to verify conformance to the standard. (Normative but Informative if conformance is not to be verified.)

- Annex F: Potential conflict between the acoustical requirements of this standard and indoor air quality (IAQ) and multiple chemical sensitivity (MCS) (Informative)

- Annex G: Cautionary remarks on using supplemental descriptors for evaluating noise in classrooms and other learning spaces. (Informative)

1.2 Purpose

This standard is intended to help school planners and designers provide the acoustical qualities necessary for good speech communication between students and teachers in classrooms and other learning spaces without the use of electronic amplification systems.

1.3 Applications

1.3.1 This standard applies to classrooms and other core learning spaces of small-to-moderate size with volumes not exceeding 566 m^3 (20 000 ft^3) and to ancillary learning spaces of any volume. Core learning spaces larger than the above volume limit shall be considered ancillary spaces for purposes of this standard. The standard does not apply to special-purpose classrooms, teleconferencing rooms, special education rooms, such as those for severely acoustically-challenged students or other spaces, such as large auditoria that have unique or more stringent acoustical requirements. Conformance to the requirements of this standard should be considered to be a minimum goal for the acoustical qualities of such spaces, excluding auditoria. The standard does not provide recommendations for electronic amplification or for electronic aids for persons with hearing impairment.

1.3.2 The acoustical performance criteria and design requirements of this standard apply during the design and construction of all new classrooms or learning spaces of small-to-moderate size as specified in 1.3.1. As far as is practicable, these acoustical performance criteria and design requirements also apply during the design and reconstruction of all renovated classrooms and learning spaces. However, the noise reduction and reverberation control principles in this standard also apply to larger classrooms or learning spaces. Thus, while this standard does not necessarily apply to all college and university classrooms or lecture halls, business or professional educational institutions or other adult education centers, acoustical performance criteria and design requirements similar to those in this standard may still pertain to such applications. Appropriate application of this standard to such alternative learning spaces is encouraged.

1.3.3 This standard is intended for use by school building specialists, educators, and parents. The information in annexes B, C, and D is intended for direct application by school design professionals including architects.

2 Normative references

The following standards contain provisions that, through reference in this text, constitute provisions of this American National Standard. At the time of approval of this standard by the American National Standards Institute, Inc. (ANSI), the editions indicated were valid. Because standards are revised from time to time, users should consult the latest revision approved by the American National Standards Institute (ANSI), International Electroacoustical Commission (IEC), and the American Society for Testing and Materials (now called ASTM International). For the purposes of this standard, the use of the latest revision of a referenced standard is not mandatory. Information on recent editions is available from the ASA Standards Secretariat and ASTM International.

ANSI S1.1-1994 (R1999), *American National Standard Acoustical Terminology* [Web Site - http://asa.aip.org].

ANSI S1.4-1983 (R2001), *American National Standard for Sound Level Meters.*

ASTM E336-97, *Standard Test Method for Measurement of Airborne Sound Insulation in Buildings.* [Web site - http://www.astm.org].

ASTM E413-87 (1999), *Standard Classification for Rating Sound Insulation.*

ASTM E989-89 (1999), *Standard Classification for Determination of Impact Insulation Class (IIC)*

ASTM E1007-97, *Standard Test Method for Field Measurement of Tapping Machine Impact Sound Transmission Through Floor-Ceiling Assemblies and Associated Support Structures.*

IEC 61672-1, *Electroacoustics — Sound level meters — Part 1: Specifications* [Web site - http://www.iec.ch]

3 Definitions

The following definitions apply for the purposes of this standard.

3.1 General terms

3.1.1 classrooms and other learning spaces. Locations within buildings where students assemble for educational purposes.

3.1.1.1 core learning spaces. Spaces for educational activities where the primary functions are teaching and learning and where good speech communication is critical to a student's academic achievement. These spaces include, but are not limited to, classrooms, (enclosed or open plan), instructional pods or activity areas, group instruction rooms, conference rooms, libraries, offices, speech clinics, offices used for educational purposes and music rooms for instruction, practice and performance.

3.1.1.2 ancillary learning spaces. Spaces where good communication is important to a student's educational progress but for which the primary educational functions are informal learning, social interaction or similar activity other than formal instruction. These areas include, but are not limited to, corridors, cafeterias, gymnasia, and indoor swimming pools.

3.1.2 acoustical privacy. Pertains to the acoustical attenuation between spaces that is needed to prevent conversation in one space from being understood in an adjacent space.

3.1.3 conforming learning space. Any classroom or other learning space for which the acoustical performance criteria and design requirements conform to this standard.

3.2 Terms relating to acoustical performance and design

The following terms are defined in a simplified form. Complete technical definitions are provided in ANSI S1.1.

3.2.1 noise level or sound level. Generic terms employed interchangeably throughout this standard to represent the frequency-weighted sound pressure level of an airborne sound. This descriptor is used to express the magnitude of a sound in a manner related to how the ear perceives this magnitude. Noise level or sound level is expressed in decibels, unit symbol dB.

3.2.1.1 A-weighted sound level. Sound pressure level measured with a conventional frequency weighting that roughly approximates how the human ear hears different frequency components of sounds at typical listening levels for speech. The A-weighting (see ANSI S1.4 or IEC 61672-1) attenuates the low-frequency (or low-pitch) content of a sound. A-weighted sound level is expressed in decibels, unit symbol dB.

3.2.1.2 C-weighted sound level. Sound pressure level measured with a conventional frequency weighting (see ANSI S1.4 or IEC 61672-1) that does not significantly attenuate the low-frequency (or low-pitch) content of a sound. C-weighted sound level is expressed in decibels, unit symbol dB.

3.2.1.3 one-hour-average A-weighted or C-weighted sound level. Level of the time-mean-square A-weighted or C-weighted sound pressure averaged over a one-hour period. One-hour-average sound level is expressed in decibels, unit symbol dB.

3.2.1.4 yearly average day-night average sound level. Level of the time-mean-square A-weighted sound pressure averaged over a one-year period with 10 dB added to sound levels occurring in each nighttime period from 22:00 hours to 07:00 hours. Yearly average day-night average sound level is expressed in decibels, unit symbol dB.

3.2.2 background noise level. Sound in a furnished, unoccupied learning space, including sounds from outdoors, building services and utilities operating at their maximum levels. For the purposes of this standard, this excludes sound generated by people within the building or sound generated by temporary or permanent instructional equipment.

3.2.2.1 steady background noise. Noise from building services and utilities and from outdoor noise sources that is fairly constant over time.

3.2.2.2 unsteady background noise. Time varying noise from transportation sources, such as aircraft, vehicle traffic or from other time varying outdoor or indoor noise sources. Unsteady background noise varies substantially over time.

3.2.3 reverberation. An acoustical phenomenon that occurs in an enclosed space, such as a classroom, when sound persists in that space as a result of repeated reflection or scattering from surfaces enclosing the space or objects in the space, such as chairs or cabinets.

3.2.3.1 reverberation time. A measure of the amount of reverberation in a space and equal to the time required for the level of a steady sound to decay by 60 dB after it has been turned off. The decay rate depends on the amount of sound absorption in a room, the room geometry, and the frequency of the sound. Reverberation time is expressed in seconds, unit symbol s.

3.2.4 sound absorption and reflection. Acoustical phenomena that occur whenever sound strikes a surface. Absorbed sound is the portion of the sound energy striking the surface that is not returned as sound energy. Reflected sound is the remaining portion that bounces off the surface. The magnitude of the reflected sound in a room is determined by the amount of sound absorption at the surfaces, the room geometry, and the frequency of the sound. As distance from a sound source in a classroom increases, the sound is increasingly dominated by reflected sound.

3.2.4.1 sound absorption coefficient. A measure of the ability of a material to absorb sound and equal to the ratio of the intensity of the absorbed sound to the intensity of the incident sound. The sound absorption coefficient of a material normally varies with frequency. It ranges from about 0.2 to about 1.0 for sound-absorbing materials, to less than 0.05 for a smooth, painted concrete floor. Sound absorption coefficients measured in a laboratory (that is, in a reverberation room) can be larger than 1.0 because of test method and sample size effects.

3.2.5 acoustic isolation. A measure of the decrease in sound level (attenuation) when sound passes from one room to another, such as from one side of a wall to the other side. The passage of sound may be via an airborne path or via a structureborne path.

3.2.5.1 attenuation of airborne sound. Attenuation of sound passing through walls or ceilings, between spaces within a building, or through roofs or external walls. The attenuation of airborne sound depends on the sound reduction through these elements, on their size, on sound leakage around their periphery, on the sound absorption in the receiving space, and on the frequency of the sound.

3.2.5.2 sound transmission class. Single number rating for the acoustic attenuation of airborne sound passing through a partition or any other building element such as a wall, roof, or door as measured in an acoustical testing laboratory following accepted industry practice, abbreviation STC. A higher STC rating provides more sound attenuation through a partition.

3.2.5.3 noise isolation class. Single number rating of the noise isolation between two enclosed spaces that are acoustically connected by one or more paths, abbreviation NIC. The rating is derived from the difference in sound levels between two spaces. A higher NIC rating provides more noise isolation between the two spaces.

3.2.5.4 impact insulation class. Single number rating for the attenuation, measured in an acoustical testing laboratory, of structureborne sound through floor or floor-ceiling assemblies from floor impacts into the space below, abbreviation IIC. A higher IIC rating provides more impact sound attenuation into the space below.

3.2.5.5 field impact insulation class. Single number rating of the structureborne noise isolation provided by a floor or floor-ceiling assembly, abbreviation FIIC. The rating is derived from the sound levels measured in the receiving room when a standard tapping machine is operating on the floor assembly in the source room above. The higher the FIIC rating, the more the impact noise isolation between the two spaces.

4 Acoustical performance criteria and noise isolation design requirements and guidelines

4.1 Introduction

Acoustical performance criteria and design requirements are contained in the following subclauses. The performance criteria shall apply to classrooms and other core learning spaces and to ancillary learning spaces. For purposes of this standard it shall be assumed that the learning spaces are furnished consistent with their use and the building is unoccupied with doors and windows closed. Acoustical design requirements for minimum noise isolation apply only to fully enclosed classrooms and learning spaces.

4.2 Performance criteria for background noise and reverberation time

The one-hour-average A-weighted steady background noise level and the reverberation times shall not exceed the limits specified in table 1. The limits for the background noise shall apply for the following conditions:

1) for the noisiest continuous one-hour period during times when learning activities take place;
2) exterior and interior noise sources are operating simultaneously;
3) interior sources are operating as defined in 4.3.2; and
4) portable and permanent (built-in) instructional equipment, such as computers and audio-visual equipment, are turned off.

While designing to conform to both acoustical performance criteria in table 1 is required, conformance to the background noise level criterion is the more important of the two. When optional conformance testing is carried out, the tolerances specified in 4.7 reflect this relative importance.

Table 1 —Maximum A-weighted steady background noise levels and maximum reverberation times in unoccupied, furnished learning spaces

Learning space a)	**Maximum one-hour-average A-weighted steady background noise level** b, c) DB	**Maximum reverberation time for sound pressure levels in octave bands with midband frequencies of 500, 1000 and 2000 Hz** s
Core learning space with enclosed volume < 283 m^3 (< 10 000 ft^3)	35	0.6
Core learning space with enclosed volume > 283 m^3 and ≤ 566 m^3 (> 10 000 ft^3 and ≤ 20 000 ft^3)	35	0.7
Core learning spaces with enclosed volumes > 566 m^3 (20 000 ft^3) and all ancillary learning spaces	40 d)	e)

a) See 3.1.1.1 and 3.1.1.2 for definitions of core and ancillary learning spaces.

b) See 4.3.1 for limits on unsteady (time varying) background noise levels.

c) See 4.3.2 for other limits on background noise from building services and utilities including C-weighted steady background noise levels.

d) When corridors are used solely for conveyance of occupants within the school building and structured learning activities do not occur, the A-weighted steady background noise level limit for such corridors may be increased to 45 dB. The use of corridors for formal learning purposes should be avoided.

e) See C3.3 in annex C for recommendations on control of reverberation in these spaces.

4.3 Background noise levels

4.3.1 Unsteady background noise from transportation noise sources

School facilities should be sited and designed to limit the noise levels inside learning spaces from transportation noise sources, such as aircraft, road vehicles and trains. (See D2.3 in annex D for further guidance on outdoor-indoor noise isolation and school siting.)

The limits on A-weighted background noise levels in table 1 shall be increased by 5 dB when the noisiest hour is dominated by transportation noise and the following conditions apply to the A-weighted SLOW time-weighted background noise level. For core learning spaces with enclosed volumes not greater than 566 m^3 (20 000 ft^3), this level does not exceed 40 dB for more than 10% of this noisiest hour. For core learning spaces with enclosed volumes greater than 566 m^3 (20 000 ft^3) and for ancillary learning spaces, this level does not exceed 45 dB for more than 10% of this noisiest hour. (See E3.7.2 in annex E for a measurement method for this evaluation.)

4.3.2 Background noise from building services and utilities

Steady background noise from HVAC systems and other building services and utilities operating simultaneously shall conform to the requirements of table 1 for all operating modes (for example, cooling, heating, ventilating, and dehumidifying) and at the maximum operating conditions (for example, maximum fan speed with all lights on). Unsteady background noise levels from plumbing systems (for example, toilets and bathing rooms) operating at their noisiest condition, shall also conform to the limits in table 1 taking into consideration their normally limited operating time within any one hour. (See annex B for guidelines on control of noise from HVAC systems, building services, and utilities.)

4.3.2.1 Limits on steady C-weighted background noise levels from building services and utilities

The maximum one-hour-average C-weighted steady background noise levels from the combination of HVAC systems, lighting, and other building services and utilities operating simultaneously shall not exceed the limits on A-weighted steady background noise levels in table 1 by more than 20 dB.

4.3.2.2 Limits on disturbing sounds from building services and utilities

Disturbing sounds, such as rumble, hum, buzz, whine, hiss, or whistle, from HVAC systems and other building services and utilities shall be controlled so as to not interfere with speech communication or be distracting or annoying to the occupants of the learning spaces.

4.3.2.3 Limits on time-varying noise levels from building services and utilities

The A-frequency-weighted and SLOW time-weighted noise level at any usable location in a room, from HVAC systems and other building services operating as specified in 4.3.2 shall not vary by more than 3 dB during any 5-s period. This shall be measured with a sound level meter conforming to at least the Type 2 requirements of ANSI S1.4 or the class 2 requirements of IEC 61672-1. Such time-varying noise shall be considered to be caused by the building systems and services, unless the noise is clearly recognized as being produced by transportation noise sources, such as road traffic or aircraft, addressed in 4.3.1.

4.3.3 Background noise from instructional equipment

For this standard, noise from instructional equipment is not included in the steady background noise. However, control of such noise, especially that from permanent built-in instructional equipment, should be carefully addressed in the planning stages for new and renovated schools. (See B5 in annex B for guidance on applicable noise control measures for such instructional equipment.)

4.4 Reverberation times

The maximum allowable reverberation times in unoccupied, furnished core learning spaces are specified in table 1 for core learning spaces with enclosed volumes of not more than 566 m^3 (20 000 ft^3). Design guidelines for controlling reverberation time in learning spaces of all sizes and for selection and proper certification for any acoustical materials applied to control this reverberation are presented in annex C.

4.5 Noise isolation design

The first and most cost effective step in achieving good noise isolation between learning spaces and other spaces in a school is accomplished in the facility planning stage. This includes optimizing the location of noisy spaces and activities to protect sensitive learning spaces. Where this is not possible, adequate noise isolation is needed.

4.5.1 Need for noise isolation

The acoustical performance criteria for background noise levels in 4.2 and 4.3 apply to unoccupied facilities. However, in occupied facilities, activity noises generated in one space can be transmitted through walls, floors, ceilings, and doors to adjacent learning spaces, thus contributing to the overall background noise level in those spaces. Adequate sound isolation is required to limit noise transmission between core learning spaces and adjacent spaces in occupied facilities. The minimum STC ratings of table 2 and table 3 are intended to provide this noise isolation for normal activities in adjoining spaces.

Certain educational styles (such as open plan and group learning) intentionally avoid the use of full enclosures between learning groups. Sometimes, partial height sound barriers or no barriers at all separate adjacent learning groups. Adequate noise isolation between adjacent learning groups cannot be assured unless each learning group is fully enclosed by ceiling-height sound barriers. Because of the inherent low noise isolation, partially enclosed or unenclosed learning spaces are not recommended when good speech communication is desired.

In occupied multistory educational facilities, the transmission of impact noise through the floor of the room above to the learning space below also contributes to the overall background noise level. To limit impact noise disturbances in learning spaces, this standard also provides minimum impact insulation class (IIC) design requirements for the floor-ceiling assemblies above learning spaces for multistory educational facilities.

As discussed further in D1 in annex D, the noise isolation requirements of this standard are similar in concept to those in existing national and international building codes.

4.5.2 Noise isolation design requirements

In this standard, noise isolation is specified by the minimum values for the STC and IIC ratings for single and composite building elements that may provide acceptable noise isolation for learning spaces. Selection of these minimum ratings, achieved during architectural design, is the basis for limiting the transmission of background noise from external and interior sources into an enclosed learning space. After construction, a field measurement may be made to verify the noise isolation achieved [see 4.6 (3)].

When high noise isolation is required, as for music rooms, flanking of sound along common floors, walls, and roofs can become a limiting factor unless controlled with proper breaks in sound transmission paths or other similar treatments. There are many publications that provide details on design and construction of separating partitions that may achieve the required STC ratings. Annex D provides guidelines and references for such noise isolation design and construction.

4.5.3 Sound transmission class (STC) ratings

4.5.3.1 Core learning spaces

The minimum STC ratings in table 2 shall be employed for the acoustical design of wall, floor-ceiling and roof assemblies that separate enclosed or open plan core learning spaces from adjacent spaces. When the assembly includes two or more elements, such as doors or windows, the STC of this composite assembly also shall conform to the requirements of table 2.

Composite assemblies are walls, floor-ceiling and roof-ceiling constructions composed of more than one element (for example, a wall with a door, window, or penetrations by HVAC ducts or other services). (See NOTE a) to table 2 for special requirements for doors in corridor, office or conference room walls.)

Walls and floor-ceiling assemblies may not maintain their design STC rating if penetrations or openings for piping, electrical devices, recessed cabinets, soffits, or heating, ventilating or exhaust ducts are unsealed. For this reason, all penetrations in sound-rated partitions shall be sealed and treated to maintain the required ratings. The STC rating requirements of table 2 shall also be employed for the design of temporary partitions that subdivide a learning space.

Table 2 — Minimum STC ratings required for single or composite wall, floor-ceiling and roof-ceiling assemblies that separate a core learning space from an adjacent space

Adjacent space			
Other enclosed or open plan core learning space, speech clinic, health care room and outdoors [c)]	**Common use and public use toilet room and bathing room**	**Corridor,** [a)] **staircase, office or conference room** [a, b)]	**Music room, mechanical equipment room,** [d)] **cafeteria, gymnasium, and indoor swimming pool**
50	53	45	60

a) For corridor, office, or conference room walls containing doors, the basic wall, exclusive of the door, shall have an STC rating as shown in the appropriate column in this table. The entrance door shall conform to the requirements of 4.5.5.

b) When the need for acoustical privacy is critical, the minimum STC rating of the partitions around an office or conference room shall be increased to 50.

c) An STC rating of 50 is the minimum for the exterior walls and roofs of a core learning space. However, this rating does not ensure conformance to the background noise limits in table 1 for noise from major outdoor noise sources. See D2.3 in annex D for further guidance on the selection of appropriate STC ratings.

d) When the adjacent space is a mechanical equipment room containing fans circulating 140 m^3/min. (5000 ft^3 /min.) or more, the minimum STC rating shall be 60. When the fan circulation is less than this rate, the STC rating may be as low as 45 providing the maximum A-weighted steady background noise level in the adjacent core learning space does not exceed 35 dB. The minimum STC rating shall include the effect of entry door(s) into the mechanical equipment room.

4.5.3.2 Ancillary learning spaces

Recommendations are given in table 3 for STC ratings for partitions (that is, walls and floor-ceiling assemblies) that enclose an ancillary learning space or that separate two ancillary spaces. When the partition includes two or more elements, such as doors, windows, or penetrations of the partition for HVAC ducts or other services, the STC of this composite construction also should conform to the recommendations of table 3.

Table 3 — Minimum STC ratings recommended for single or composite wall, floor-ceiling and roof-ceiling assemblies separating an ancillary space from an adjacent space

Receiving ancillary Learning space	Adjacent space				
	Corridor, a) staircase, common use and public use toilet and bathing room b)	Music room	Office or conference room a)	Outdoors e)	Mechanical equipment room, f) cafeteria, gymnasium or indoor swimming pool
Corridor	45	60 c)	45 d)	45 c)	55 c)
Music room	60	60	60	45	60
Office or conference room	45	60	45 d)	45	60

a) For corridor, office or conference room walls containing entrance doors, the STC rating of the basic wall, exclusive of the door, should be 45. The entrance door should conform to the requirements of 4.5.5.

b) The STC rating for an ancillary space/toilet partition does not apply when the toilet is private and connected to a private office. An STC rating higher than 45 may be required for separating a quiet office or conference room from a common use or public use toilet or bathing room.

c) When the corridor will not be used as an ancillary learning space, the minimum STC rating may be reduced to not less than 45 or to not less than 40 for an exterior wall. Use of corridors as ancillary learning spaces should be avoided when they are located next to the noisy spaces indicated in the table by the high STC ratings.

d) When the need for acoustical privacy is critical, the STC rating should be increased to 50.

e) See D2.3 in annex D for further guidance on the selection of appropriate STC ratings.

f) NOTE d) of table 2 applies except that the STC rating may be as low as 40 providing the maximum A-weighted steady background noise level in the adjacent ancillary learning space does not exceed 40 dB.

4.5.4 Composite partitions

The required minimum STC ratings in table 2 apply to single or composite partitions. Basic wall assemblies (except those identified in NOTE a) for table 2) which contain doors or windows with STC ratings less than those given in table 2, will require higher STC ratings to conform to the required minimum STC ratings of the composite construction. This design technique is also recommended for partitions enclosing the ancillary learning spaces covered by table 3. A method for estimating the STC rating of composite partitions is provided in D2.4 in annex D.

4.5.5 Entry doors into classrooms and other core learning spaces

To conform to the STC requirements of table 2 for composite walls, entrance doors into classrooms or other core learning spaces would be expected to have laboratory STC ratings of 30 or more in their operable condition. The STC rating for interior entry doors into, or between, music rooms shall be not less than 40. The location of classroom entry doors across a corridor should be staggered to minimize noise transmission between these classrooms.

Provisions should be made to ensure that the perimeter seals of sound rated doors are well maintained. Seals for entrance doors should be inspected and adjusted, as necessary, every six months. The gaskets of door seals should never be painted.

4.5.6 Impact Insulation Class (IIC) rating

The floor-ceiling assemblies of normally occupied rooms located above core learning spaces shall have IIC ratings of at least 45 and preferably 50. If a room below is an ancillary learning space, the floor-ceiling assembly shall have an IIC rating of at least 45. These IIC ratings shall apply without carpeting on the floor in the room above. In new construction, gymnasia, dance studios or other high floor impact activity, shall not be located above classrooms or other core learning spaces. For refurbishment of existing structures, if it is not possible to avoid such an incompatible condition, the IIC rating of the separating floor-ceiling assembly shall be at least 70 when located above a core learning space with an enclosed volume not greater than 566 m^3 (20 000 ft^3); 65 when located above a core learning space with an enclosed volume greater than 566 m^3 (20 000 ft^3); and 65 when located above an ancillary learning space. Clause D2.5.1 in annex D provides further guidance on impact noise isolation.

4.6 Conformance to acoustical performance criteria and noise isolation design requirements

It is recommended that conformance to the acoustical performance criteria and noise isolation design requirements be verified by test. However, this standard does not require testing to demonstrate conformance. When optional tests are performed to verify conformance with the requirements and recommendations of this standard, the following procedures shall be followed.

1) Tests to demonstrate conformance to the limits on background noise levels in table 1, 4.3.1, and 4.3.2.1 shall be performed in accordance with the procedures in E3 in annex If necessary, appropriate tests shall be performed to demonstrate conformance with the limits on disturbing or time varying noise from building services and utilities given in 4.3.2.2 and 4.3.2.3, (See E3.7.3 in annex E.)
2) Conformance to the limits on reverberation times in table 1 shall be verified by calculation or by measurement procedures in conformance, or equivalent, to those in E4 of annex E.
3) Conformance to the minimum sound transmission class (STC) design requirements of table 2 and the design recommendations of table 3 shall be verified by field determination of the noise isolation class (NIC) as described in E5.1 in annex E. However, it shall be considered unnecessary to verify conformance to these noise isolation design requirements and recommendations if conformance to the noise limits of table 1 is demonstrated. for the noisiest hour when learning takes place.
4) Conformance to the impact insulation class (IIC) requirements of 4.5.6 shall be verified by the field testing procedures in E5.2 in annex E.

4.7 Conformance tolerances

When conformance testing or evaluation is performed, conformance to the requirements and recommendations of this standard is demonstrated if each of the following is achieved. No additional tolerances shall be allowed for the test methods or instruments used for such demonstrations except as specified in this subclause.

1) The measured A-weighted steady or unsteady background noise levels do not exceed the limits specified in table 1 and 4.3.1, respectively, by more than 2 dB. The C-weighted steady background noise levels do not exceed the limits in 4.3.2.1 by more than 2 dB.
2) Mean reverberation times, if calculated, do not exceed the limits in table 1 or, if measured, do not exceed the limits in table 1 by more than 0.1 s.
3) All separating walls and floor-ceiling assemblies have NIC ratings that are not less than a rating 5 points below the required STC rating in table 2 or the recommended rating in table 3. For example, for a partition between a classroom and a speech clinic, conformance to the minimum STC rating of 50 in table 2 is achieved if the NIC rating is not less than 45.

4) All floor-ceiling assemblies separating occupied spaces from learning spaces below have a field impact insulation class (FIIC) rating that is not less than a rating 5 points below the design requirement specified in 4.5.6.

Annex A
(Informative)

Rationale for acoustical performance criteria

A1 Introduction

The school classroom is an environment in which spoken language communication facilitates and enables students to learn essential academic, social, and cultural skills. Thus, the classroom serves as a communication channel for learning and should be free of acoustical barriers. This informative annex defines the perceptual, educational, and developmental rationale for the acoustical performance criteria specified in table 1 of this standard. These rationales allow determination of the signal-to-noise ratio and reverberation time that can ensure most children, adult learners, and teachers full and equal access to spoken communication within the classroom The acoustical performance criteria in the standard are derived from empirical studies of classroom noise and reverberation and their effects on speech communication.

A1.1 Educational rationale

Intensive and continuous learning of social, intellectual, and communication skills occurs throughout childhood. A wide range of educational research studies [A1]* has shown that learning is predicated on the ability to communicate with spoken language, and that language input and language proficiency form the bases for most cognitive skills. Additionally, other research [A2] has shown that perception of spoken language provides the foundation for the ability to read and write. Communication with spoken language is essential to most classroom learning activities. Typically, as much as 60% of these activities involve students listening to and participating in spoken communications with the teacher and other students. The central role of spoken language in classroom learning underscores the need for a clear communication channel accessible to all students and teachers.

A1.2 Perceptual rationale

Communication with spoken language can occur successfully only when speech intelligibility is high. Research in speech perception [A3] has found that when the background noise is very low speech intelligibility depends in part on the absolute sound level of the speech, and in part on the absence of excessive reverberation.

A1.3 Speech intelligibility in background noise

Most speech communication in classrooms occurs in the presence of background noise. When background noise is present, intelligibility depends on the sound pressure level of the speech and also on the level of the speech relative to the level of the noise, that is, the signal-to-noise ratio (SNR) [A4]. The sound levels of both the speech and noise are expressed as A-weighted sound levels in decibels. The relative speech to noise level, or SNR, expressed in decibels, is the sound level of the speech alone in the presence of background noise minus the sound level of the background noise.

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* Designations within brackets "[AX]" refer to references in A6 at the end of this annex.

Intelligibility increases as the SNR increases, either by raising the speech level or by decreasing the noise level. Speech perception research [A5] has shown that individuals with hearing impairments, speech and language disorders, or limited English proficiency require more favorable signal-to-noise ratios than individuals without these impairments or disorders to achieve high levels of speech intelligibility.

A1.4 Speech intelligibility in reverberant environments

Classrooms are enclosed spaces in which sound produces reverberation. Reverberation times in excess of 0.4 s to 0.6 s reduce speech intelligibility both in quiet and in noise. When both background noise and excessive reverberation are present, their effects on speech intelligibility are additive for individuals with normal speech, language, and hearing abilities. Speech perception research [A4, A6] has shown that individuals with impaired speech, language, and hearing abilities require signal-to-noise ratios that are at least 3 dB more favorable to offset their susceptibility to the negative effects of reverberation, as compared with individuals without impairments.

A1.5 Selective acoustical barriers to learning produced by background noise and reverberation

If spoken communication in the classroom becomes inaudible or unintelligible for some students and teachers because of excessive background noise or reverberation, a clear communication channel is no longer accessible to these children, creating a selective acoustical barrier to learning. Neither the child’s ability to understand in quiet nor the adult teacher’s ability to understand in the noisy classroom is a good predictor of when such barriers might exist. This difficulty in prediction is also exacerbated by a young child’s unawareness of these barriers to learning.

A1.6 Scholastic achievement and the classroom acoustical environment

The link between the acoustical barriers in the classroom and the scholastic achievement of students has been evaluated in studies supporting the objectives of this standard. The reading scores of 2nd to 6th grade children in a school exposed to noise from a nearby elevated urban train track [A7, A8] were compared in quieter and noisier classrooms. The students, comparable in all respects, were receiving the same type of instruction. However, the children in the lower grades and noisier classrooms were three to four months behind in reading scores relative to those in the quieter classrooms and as much as 11 months behind for the higher grades. After a subsequent reduction of the track noise by 3 to 8 dB, the reading scores in the noisy classrooms were still approximately one year behind those in the quiet classrooms.

A major, controlled study of noise effects on scholastic achievement [A9] was carried out in 81 classrooms in 15 socio-economically matched Los Angeles schools located different distances from freeways. These differences caused the traffic-noise-generated indoor background noise to differ by up to 19 dB between the noisiest and quietest classrooms. Reading and math grade-equivalent scores evaluated for English-proficient students in 3rd and 6th grade classes, showed a decrease of approximately 2.2 years between the noisiest and quietest schools for the 6th grade classes and 0.7 years for the 3rd grade classes. This prominent noise effect on grade differences in scholastic achievement is believed the result of either differences in teaching style between grades or, more insidious, a possible cumulative, compounded effect of poor acoustics on learning as a student progresses through school.

A study of 13 schools in the United Kingdom [A10] compared their acoustical environment and corresponding speech communication conditions and teacher satisfaction before and after sound-absorbing treatment of the ceilings. After treatment, the average A-weighted background noise level in the unoccupied classrooms dropped from 45 dB to 40 dB reflecting the decrease in reverberant background noise level. The average reverberation time in the unoccupied rooms dropped from 0.7 to 0.4 seconds. The acoustically treated classrooms were favored by the teachers and pupils, who reported a greater ease of communication and increased student performance.

A2 Developmental rationale

Young children are more susceptible than adults to the effects of background noise and reverberation on communication with spoken language. Because of this susceptibility, young children also require more favorable classroom signal-to-noise ratios and reverberation times to achieve the same level of speech intelligibility as adults do. Developmental status, linguistic and cognitive proficiency, temporary hearing impairments, and early receptive and expressive language disorders are all factors that affect the greater susceptibility of young children to background noise and reverberation. For example, in a longitudinal study [A11] of pre-school children in acoustically-treated or non-treated rooms in a child-care center, the children in the treated rooms scored higher in number-letter-word recognition after one year of reduced noise exposure than their cohorts in the non-treated rooms.

A2.1 Developmental status

Speech communication in unfavorable listening conditions is a complex, high-level task requiring a level of neurological maturity that is usually achieved only by 13 to 15 years of age. Consequently, young children may require more favorable signal-to-noise ratios and shorter reverberation times than older children require. Speech perception research [A12] has shown that 6-year-old children with normal hearing and normal language proficiency require signal-to-noise ratios 2 dB more favorable than 15-year-old children to achieve the same level of speech intelligibility. The 15-year olds, however, required the same signal-to-noise ratios as adults. In quiet listening conditions, the adults and both age groups of children had good speech intelligibility.

A3 Hearing impairment

Young children are also more susceptible to temporary conductive hearing impairment caused by ear infection (otitis media) than adults. Demographic research [A13] has identified otitis media as the most common medical disorder in young children, with an estimated incidence as high as 25% to 30% among kindergarten and first grade children. Other research [A14] has found an incidence greater than 10% of mild high-frequency sensorineural hearing impairment among children 6 to 19 years of age. Signal-to-noise ratio improvements of 3 dB to 5 dB together with increases in absolute speech sound levels of 10 dB to 30 dB are necessary for children with these impairments to achieve the same level of speech intelligibility in classrooms with high background noise.

A4 Language proficiency and language disorders

Children with expressive and receptive language disorders may also require more favorable signal-to-noise ratios to achieve good intelligibility, as compared with children without these disorders. Research studies have shown, for example, that children with language disorders have 10% to 40% poorer speech intelligibility in background noise than children without these disorders, despite comparable results in quiet environments. Children for whom English is not the first or primary language may have limited English proficiency. These children are often learning English in school at the same time that they are learning the regular academic curriculum.

Limitations in vocabulary and in the ability to “fill in the blanks” when partial communication occurs in difficult listening situations have been shown to reduce intelligibility for children with limited English proficiency [A15], again despite normal intelligibility in quiet environments. These children may require 2 to 5 dB more favorable signal-to-noise ratios in difficult listening situations to achieve the same level of intelligibility as children with normal English proficiency.

A related speech disorder problem caused by poor classroom acoustics stems from the increased frequency of voice impairments and their consequences for communication. In noisy or reverberant classrooms, teachers are more likely to have to raise their voices. The results are higher incidences of voice impairment among teachers and children have greater difficulty hearing verbal instruction presented by voice-impaired teachers in such noise or reverberation.

A5 Determining appropriate acoustical performance criteria and noise isolation design requirements

The acoustical performance criteria for this standard are expressed in table 1 in terms of background noise levels and reverberation times. Noise isolation design requirements for this standard are given in table 2, in terms of sound transmission class (STC) ratings for enclosed learning spaces, despite the fact that the rationale for these criteria and requirements is based on absolute and relative levels of speech. The terminology of the standard is necessary because speech levels are difficult to prescribe or standardize. However, the research literature on classroom speech sound levels can be used to specify the expected range of speech sound levels seen throughout a classroom. These sound levels, together with knowledge of the signal-to-noise ratios and reverberation times necessary for high intelligibility, were used to determine the requirements for acceptable background noise levels and reverberation times for unoccupied, furnished classrooms in table 1. The background noise level criteria were, in turn, used to determine acceptable STC ratings for walls, ceilings, and floors, in table 2, that will prevent noise from adjacent occupied enclosed spaces from exceeding the background noise level criteria in the classroom.

A5.1 Classroom speech levels

Research studies [A16] of sound levels for conversational speech and teachers' classroom speech [A17] show for the latter, the average A-weighted sound level is 67 dB at 1 m in a quiet classroom. In typical classrooms with little reverberation, speech sound levels in the rear of the classroom may be as low as 50 dB. The criteria for background noise levels in this standard assume minimum speech sound levels will be 50 dB anywhere in the classroom.

A5.2 Background noise levels

The 35 dB acoustical performance criteria for steady classroom background noise levels in table 1 were based on the assumption that a signal-to-noise ratio of at least +15 dB was necessary to ensure that noise will not be a barrier to learning within a classroom. Assuming a minimum speech level of 50 dB, a signal-to-noise ratio of at least +15 dB will always be achieved if the background noise level does not exceed 35 dB. The choice of +15 dB for the signal-to-noise ratio was based on several considerations. The American Speech-Language-Hearing Association [A18] recommends at least a +15 dB signal-to-noise ratio in classrooms to ensure that children with hearing impairments and language disabilities are able to achieve high speech intelligibility. In addition, the research literature summarized in this annex also supports a signal-to-noise ratio of +15 dB.

Normal adults typically require 0 dB signal-to-noise ratios for high speech intelligibility when listening to simple and familiar speech material for short periods of time. An additional 2 dB is needed to compensate for neurological immaturity; an additional 5 dB is required to compensate for sensorineural and conductive hearing losses; an additional 5 dB is required for limited English proficiency and language disorders; and an additional 3 dB is required to compensate for the effects of excessive reverberation. These additional requirements for classrooms total 15 dB over that of normal adults, or a signal-to-noise ratio of +15 dB. This conclusion does not include any further increase in the signal-to-noise ratio that may be associated with the fact that children in the lower grades may be listening to unfamiliar speech material.

A5.3 Reverberation times

According to available research data, the effects of reverberation on speech intelligibility are controlled primarily by reverberation times at the three frequencies specified in table 1: 500, 1000, and 2000 Hz. Based on this research, it was assumed that reverberation times of 0.6 s, or less, in small and mid-sized classrooms and 0.7 s, or less, in larger classrooms will not degrade speech intelligibility excessively as long as signal-to-noise ratios of +15 dB or better are maintained. (The reverberation times in table 1 are given for unoccupied, furnished spaces. For occupied spaces, the reverberation times are expected to be 0.1 s to 0.2 s less than those in table 1.) These signal-to-noise ratios will be achieved if the background noise performance criteria also are satisfied. Thus, the acoustical performance criteria for both steady background noise levels and reverberation times should be satisfied simultaneously to ensure the elimination of acoustical barriers to classroom learning.

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Annex B
(Informative)

Design guidelines for noise control for building services, utilities, and instructional equipment

B1 Introduction

HVAC systems and other building services and utilities are complex systems of mechanical, electrical, and plumbing components supplied by many different manufacturers. This observation is particularly true for most HVAC systems designed for specific projects. Noise from these building systems can be generated and transmitted to a room in a wide variety of ways. Responsibility for providing an adequate noise control design that will allow conformance to the background noise level limits in table 1 resides with the architect and the architect’s design subcontractors. During construction, responsibility for implementing the noise control design for each element of the building services may rest with each individual subcontractor, but the general contractor is likely to have overall responsibility to ensure that the design and implementation conforms to the background noise level limits in table 1.

B2 HVAC noise control

Specific limits on the maximum allowable A-weighted and C-weighted background noise level from HVAC equipment are given in 4.3. To achieve these limits, an HVAC system should be designed with noise control in mind. The following are some of the minimum features that should be employed for HVAC systems intended for any learning facility.

1) Unducted systems should not be employed since the sound they produce is inherently unable to conform to the background noise level criteria in table 1.

2) All grilles and diffusers (air devices) should be selected to have a catalog Noise Criteria (NC) rating of NC 18 or less for a single diffuser, providing the NC catalog ratings are based on a correction of 10 dB for sound absorption in the room. [B1]

   NOTE — Noise Criteria (NC) is a single number rating of room noise based on comparison of the octave-band sound pressure level spectrum of a noise with standardized octave-band sound pressure level contours that include low-frequency sound (see annex G).

3) Airflow velocities in trunk ducts should not exceed 4.1 m/s (800 ft/min). Branch ductwork sizes should match the air device's duct connection size. Duct silencers will be required inside the air-handling unit or in the main supply and return air ducts in most systems.

4) All ductwork should be fabricated and installed so as to achieve a low static pressure loss in accordance with procedures in the Sheet Metal & Air-Conditioning Contractors National Association (SMACNA) for HVAC System Duct Design, [B2]. To achieve the rated performance of air diffusers, the plenum depth should be the equivalent of at least three to four diameters of the duct going to the diffuser.

5) All rotating equipment and equipment with static pressure control dampers should be 3.3 m (10 ft), or farther if possible, from the classroom. HVAC fan equipment serving more than one classroom should be farther from the classrooms than equipment serving only one classroom.

6) Centrifugal fans with airfoil-shaped blades should be used in most cases in order to achieve the background sound levels required for the learning spaces. Centrifugal fans with forward curved blades should be avoided (especially with central air distribution systems) because this fan design typically generates excessive low-frequency noise when the total static pressure is greater than 2 inches of water.

7) Ductwork serving adjacent learning spaces should include sound attenuators or sound-absorbing duct lining (if required), or both, to reduce crosstalk through the duct system. The attenuation should be sufficient to preserve the noise isolation between the adjacent learning spaces.

8) To minimize HVAC noise transmission into core learning spaces, variable air volume (VAV) boxes and fan-powered boxes should not be located over these spaces. Instead, the elements should be located over less sensitive spaces, which may include corridors.

The above guidelines are examples of the many noise control provisions that may be needed when designing an HVAC system. Before finalizing any HVAC noise control design, considering the very large number of HVAC systems types that may be employed for schools, the facility designer or the responsible subcontractor should consult one or more references such as those listed in clause B7. The ASHRAE Handbooks, [B3-B5] are especially helpful to assist in achieving a HVAC system design that will conform to the required minimum level of steady background noise. HVAC manufacturers should be able to provide useful design or noise-rating information for their systems or components [B6]. References [B7], [B8] and [B9] provide further guidance on noise control for HVAC systems and other building services.

B3 Noise control considerations for electrical equipment and systems

Significant background noise in a learning space can be produced by electrical equipment and its installation. Two such sources of noise are electrical fixtures and light fixture ballasts. Light fixtures with low-noise ballasts should be used in learning spaces to assist in conforming to the requirements of table 1 for background noise levels. Improper installation of electrical or cable boxes can degrade sound isolation between rooms. For single stud walls, electrical outlet boxes on opposing walls should never be in the same stud space. For dual-stud walls, the boxes should be separated by at least 0.6 m (24 inches). If back-to-back electrical boxes are necessary in double stud walls, either of the following methods should be used. The boxes should be enclosed in full gypsum board enclosures that do not contact the framing of the other row of studs and have all joints sealed with caulking or both boxes should be of the vapor-barrier type that are properly caulked and sealed.

B4 Plumbing systems noise control

Water flow noise from plumbing systems can be a significant contributor to the background noise level in a learning space. To minimize noise from plumbing fixtures and piping located adjacent to core and ancillary learning spaces, consideration should be given to the following installation details.

1) Run piping above corridor ceilings, not above learning spaces.

2) Locate restrooms away from classrooms.

3) Use cast iron waste water pipes, when possible. Plastic piping may require special care during installation to ensure quiet operation and should be wrapped with one or more layers of sound-attenuating material or, for plastic waste pipe, wrapped with sound-absorbing material and boxed in with gypsum wallboard.

4) Isolate all water piping from the building walls and structure using foam rubber wrapping or resilient clamps and hangers.

5) When it is necessary for a plumbing wall chase to be adjacent to a learning space, the wall should employ double stud construction [with a minimum 2.5 cm (1 inch) gap between the two rows of studs] with two layers of gypsum board on the classroom side and sound-absorbing insulation batts in both stud cavities.

6) Reduce the pressure of the supply water as much as possible and employ trapped-air water-hammer arrestors for water supply pipes serving flush or solenoid valve fixtures to reduce water hammer noise.

7) Use water siphon jet fixtures instead of blowout fixtures.

8) Inspect all plumbing installations for conformance to the noise control features before sealing the walls.

B5 Noise control for instructional equipment used in a classroom

As stated in 1.1.4, the background noise from portable or permanent, built-in equipment used during the course of instruction, such as audio-visual equipment or computers, is not within the scope of this standard. Cooling fans or other internal rotating components usually generate this noise. Because this noise can increase the background noise level in learning spaces, this equipment should be carefully selected and located to minimize its noise impact on the learning process. Except for computers, standards for the acoustical emission characteristics (for example, sound power level) of such equipment are not currently available.

Such instructional equipment, when operating, should be located as far as possible from students or placed in noise-isolating enclosures. This procedure is especially important and practical for built-in audio-visual systems or overhead projectors. For such built-in equipment, a design goal should be to ensure that its operation will not cause the total one-hour average background noise level to exceed the limits specified in table 1 while HVAC systems and other building services and utilities are also operating.

The designer of the noise-control features should actively seek to determine whether potentially noisy instructional equipment is planned for permanent or long-term installation in a noise-sensitive instructional space. If so, appropriate noise isolating enclosures should be included in the classroom design planning.

The background noise level in a learning space containing a large number of computers, each with its own cooling fan, may be well above the background noise limits in table 1. In such learning spaces, special consideration should be given to noise control by selection of low-noise computers and the addition of more sound-absorbing treatment than needed to conform to the reverberation criteria in table 1 in order to minimize the reverberant level of this background noise. Sound-absorbing partial barriers may be needed between computer stations.

B6 Conforming to the limits for background noise level

Conforming to the noise level criteria specified in table 1 and the design techniques discussed in this annex may require coordinated action by the architects for design of the school building, the general building contractor, the school-facility design staff, the equipment suppliers, and a person with professional experience in building noise control technology.

Selection of a person experienced in building noise control technology is the ultimate responsibility of the owner or designer of the educational facility. However, such a person should be able to provide evidence of professionally recognized expertise in noise-control technology for building services, utilities, and equipment, or be employed by a firm with the same professionally recognized expertise.

The fact that a project has a person trained in building noise control technology on the design team does not ensure conformance to the provisions of this standard. Workmanship and the quality of products used on the project are also major factors in achieving the required acoustical environment in all learning spaces. The best design can be negated by poor workmanship and use of products that do not conform to published performance specifications.

Manufacturers of school building services equipment, utilities (for example, HVAC and lighting) and instructional equipment usually can supply noise emission levels for their products. This information should be evaluated carefully during the equipment selection process.

B7 Bibliography for further guidance on noise control for HVAC, electrical, and plumbing systems

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Annex C
(Informative)

Design guidelines for controlling reverberation in classrooms and other learning spaces

C1 Introduction

The amounts and locations of sound absorption treatments needed to limit reverberation are important considerations for good acoustical characteristics in learning spaces. Excessive reverberation can reduce the understanding of spoken words. Conversely, too much sound-absorbing treatment, especially in dedicated lecture rooms, can reduce beneficial early sound reflections causing speech levels from a talker to fall off rapidly with distance and thereby reduce speech intelligibility for distant listeners. This annex provides design guidelines for the control of reverberation in learning spaces by the addition of sound-absorbing materials. The guidelines are intended to assist in achieving conformance to the reverberation time criteria in table 1.

C2 Procedure to estimate the amount of sound-absorbing material needed to achieve the design goal for reverberation time

The first step in developing an estimate of the minimum required area of acoustical treatment for installation in a learning space is to apply the Sabine formula [C1]. According to this formula, the minimum total sound absorption A needed to achieve a reverberation time of T_{60} seconds or less in a room of enclosed volume V is given by:

$$A \geq kV/T_{60} \qquad \text{(C.1)}$$

The constant k = 0.161 s/m when volume V is in cubic meters and the sound absorption A is in square meters. Constant k = 0.049 s/ft when volume V is in cubic feet and sound absorption A is in square feet.

Next, the total sound absorption is broken down into the sum of the products of the surface area S_i of each such sound-absorbing surface and the sound absorption coefficient α_i for this surface. That is, the total sound absorption A is given by the summation over all treated surfaces as expressed by the following relation:

$$A = \alpha_1 S_1 + \alpha_2 S_2 + \alpha_3 S_3 + \bullet\bullet\bullet\bullet + \alpha_i S_i + A_R \qquad \text{(C.2)}$$

where A_R is the residual sound absorption. A default value of A_R equal to 15% of the floor area accounts for the acoustically untreated room surfaces (for example, the untreated walls, ceiling, and bare, uncarpeted floor) and for the furnishings (for example, tables, chairs, and shelves (see C3.5). For a carpeted room, a value for $A_{R,}$ of 20% of the floor area is recommended as a conservative default design value.

Alternatively, the designer can set A_R equal to 13% of the floor area plus the product of the carpet surface area and its sound absorption coefficient. The latter may vary from a minimum of less than 0.1 at 500 Hz to as high as 0.65 at 2000 Hz, depending on the type and thickness of the carpet and its underlayment. Many references, such as those listed in the bibliography to this annex, provide tables of sound absorption coefficients for different acoustical materials, including carpet, at different frequencies.

These same references may be used to provide alternative sound absorption coefficients for other surfaces in place of the preceding default assumptions. Tabulations of the sound absorption per table or chair are available from these references. Their values may be used if these furnishings are comparable to those intended for the learning space.

For best accuracy in calculations of reverberation time, it is recommended that laboratory-certified sound absorption coefficients be used. These are normally available from acoustical material manufacturers, (see C2.1).

Next, the values of α_I and S_i for the proposed materials and surface areas are substituted into equation (C.2). If necessary, the choices of material and material areas are adjusted until equation (C.1) is satisfied. The minimum total sound absorption is calculated from application of equation (C.1) for frequencies of 500 Hz, 1000 Hz, and 2000 Hz.

The process described above can be simplified substantially when only one type of sound-absorbing material is to be installed and A_R is assumed to be 15% of the floor area.

The volume V of the learning space can be expressed as the product of floor area S_f and average ceiling height H. Using equations (C.1) and (C.2) and a residual absorption of 15% of the uncarpeted floor area, it is straightforward to construct a table of the minimum required surface area S_1 as a percentage of the floor area for maximum reverberation times of 0.6 s and 0.7 s from table 1. The variables in the table are the sound absorption coefficient α_1 of the acoustical treatment and average ceiling height H.

With the assumptions described above, the entries in table C.1 for the minimum surface area of acoustical treatment S_1 as a percentage of floor area S_f were calculated from the following expression.

$$100\ (S_1/S_f) \geq 100\ \{[(kH/T_{60}) - 0.15]\ /\ \alpha_1\} \qquad \text{(C.3)}$$

where k is the constant employed in equation (C.1).

As shown in table C.1, for either of the two reverberation times, the required minimum surface area of acoustical treatment increases as the ceiling height increases and as the sound absorption coefficient decreases. The table shows the need to apply acoustical treatment to the walls as well as the ceiling for rooms with high ceilings and low sound absorption coefficients. Two examples illustrate application of the data in the table.

Example 1. A rectangular core learning space has dimensions of 40 ft long by 25 ft wide by 9 ft high. It is planned to install sound-absorbing material only on the ceiling. The enclosed volume is $(40 \times 25 \times 9) = 9000\ \text{ft}^3$. From table 1, for this enclosed volume, the maximum reverberation time is 0.6 s at each of the three specified frequencies. Manufacturer's data indicate that the proposed acoustical ceiling material has sound absorption coefficients of 0.65, 0.80, and 0.90 at 500 Hz, 1000 Hz, and 2000 Hz, respectively

From table C.1, for the smallest absorption coefficient of 0.65 and the 9-ft ceiling height, the required minimum area of treatment is 90% of the floor area of $40 \times 25 = 1000\ \text{ft}^2$, or $900\ \text{ft}^2$. This leaves 10% of the ceiling area free for lighting and other services. If the allowance for lighting area is inadequate, some acoustical treatment may have to be installed on the walls.

NOTES

1. While the required sound absorption should be confirmed at each of the three frequencies, it will generally be found that conformance to the reverberation-time requirement of table 1 at 500 Hz will also ensure conformance at the two higher frequencies.

2. If the manufacturer's sound absorption data are between the sound absorption coefficients listed in the first column of table C.1, the required treatment area can be computed by interpolation in the table. For example, if the lowest sound absorption coefficient for example 1 were 0.67 instead 0.65, the relative treatment area for the ceiling would be 90% × (0.65/0.67) or 87% of the floor area or 870 ft^2 instead of 900 ft^2.

Table C.1 — Minimum surface area of acoustical treatment for different sound absorption coefficients, ceiling heights, and reverberation times.

(a) Reverberation time, T_{60}, of 0.6 s

Sound absorption coefficient, α_1	Ceiling height, H, ft								
	8	9	10	11	12	13	14	15	16
	Ceiling height, H, m								
	2.44	2.74	3.05	3.35	3.66	3.96	4.27	4.57	4.88
	Minimum area of sound-absorbing material as a percentage of the floor area								
0.45	112	130	148	167	185	203	221	239	257
0.50	101	117	134	150	166	183	199	215	232
0.55	92	107	121	136	151	166	181	196	211
0.60	84	98	111	125	139	152	166	179	193
0.65	78	90	103	115	128	141	153	166	178
0.70	72	84	95	107	119	130	142	154	166
0.75	67	78	89	100	111	122	133	144	154
0.80	63	73	83	94	104	114	124	135	145
0.85	59	69	79	88	98	107	117	127	136
0.90	56	65	74	83	92	101	111	120	129
0.95	53	62	70	79	88	98	105	113	116
1.00	50	59	67	75	83	91	100	108	116
NOTE — Sound absorption coefficients stated by a manufacturer to be greater than 1.0 based on laboratory tests may be taken as equal to 1.00 for purposes of this annex.									

(b) Reverberation time, T_{60}, of 0.7 s

Sound absorption coefficient, α_1	Ceiling height, H, ft								
	8	9	10	11	12	13	14	15	16
	Ceiling height, H, m								
	2.44	2.74	3.05	3.35	3.66	3.96	4.27	4.57	4.88
	Minimum area of sound-absorbing material as a percentage of the floor area								
0.45	91	107	122	138	154	169	185	200	216
0.50	82	96	110	124	138	152	166	180	194
0.55	75	87	100	113	126	138	151	164	177
0.60	68	80	92	104	115	127	139	150	162
0.65	63	74	85	96	106	117	128	139	149
0.70	59	69	79	89	99	109	119	129	139
0.75	55	64	73	83	92	102	111	120	130
0.80	51	60	69	78	86	95	104	113	121
0.85	48	57	65	73	81	90	98	106	114
0.90	46	53	61	69	77	85	92	100	108
0.95	43	51	58	65	73	80	88	95	102
1.00	41	48	55	62	69	76	83	90	97
NOTE — Sound absorption coefficients stated by a manufacturer to be greater than 1.0 based on laboratory tests may be taken as equal to 1.00 for purposes of this annex.									

NOTE — A similar table can be constructed from equation (C.3) for a carpeted floor by changing the default value for A_R/S_f from 0.15 for uncarpeted floors to 0.2 for carpeted floors.

Example 2. For the same core learning space as in example 1, it is now considered necessary to improve the intelligibility of speech in this lecture-type classroom. In accordance with the guidance in C3.1.2, additional sound-absorbing material is to be installed as a ring around the walls near the ceiling. The sound-absorbing ceiling treatment is to be of the same material as for example 1, but the proposed acoustical wall treatment has manufacturer-stated absorption coefficients of 0.45, 0.60, and 0.70 at 500 Hz, 1000 Hz, and 2000 Hz, respectively.

In this case, as a working assumption, assume that the ceiling is to provide 60% of the total sound absorption while the remaining 40% of the total sound absorption is provided by the wall treatment.

Therefore, the ceiling treatment area should be 60% of the 900 ft^2 determined for example 1 or $0.6 \times 900 = 540$ ft^2. According to table C.1, for the 9-ft ceiling and the smallest sound absorption coefficient of 0.45 for the wall treatment, the minimum required surface area of wall-treatment material would be 130% of the floor area of 1000 ft^2 if it were the only material used. However under the assumptions, only 40% of that area is required or $0.4 \times 1.3 \times 1000 = 520$ ft^2. For the room perimeter of 130 ft, the height of the wall treatment would need to be 4 ft on each of the four walls or 44% of the total wall area.

In summary, 540 ft^2 of ceiling treatment material and 520 ft^2 of wall treatment material would be required for the core learning space to conform to the 0.6-s reverberation time limit in table 1 while providing good intelligibility of spoken words. Other distributions of ceiling and wall treatment areas could be evaluated if it were considered that too much of the available wall area was devoted to sound-absorbing material.

C2.1 Sound absorption coefficients and related design considerations

The sound absorption coefficients for all acoustical materials supplied for the project should be determined in accordance with ASTM C423 [C2]. The learning facility owner's representative should request from the acoustical materials contractor(s): a) appropriate certification that all material(s) have been tested in full accordance with ASTM C423 and b) a table of the laboratory-certified sound absorption coefficients at 500, 1000 and 2000 Hz for the materials employed (see E4.2.1 in annex E). The mounting condition employed for these tests should be identified and, preferably, should be the same as the as-installed mounting configuration. The designer should recognize that when the cavity depth behind the acoustical material in a laboratory configuration mounting is greater than for the as-installed depth, the installed low-frequency sound absorption coefficients are usually lower than those for the laboratory tests.

Tradeoffs between the sound-absorption coefficients and the surface areas of treatment are allowed if the tradeoffs result in the same or lower reverberation times than those specified in table 1 for each of the three frequencies.

When selecting acoustical materials to meet the reverberation time performance criteria in table 1, it is prudent to allow for sufficient surface area coverage using sound absorption coefficients that fall in the lower range that alternative suppliers may provide. This procedure helps insure that the properly certified material from the lowest bidder is adequate.

C3 Further design guidance

C3.1 Location of the absorbing material

C3.1.1 General Classrooms

In cases where there is no fixed lecture position for the teacher, and when ceiling heights are less than about 3 m (10 ft), the best option is to place most if not all of the sound-absorbing material on the ceiling. For ceiling heights greater than 3 m (10 ft), which is discouraged for classrooms, an increasing amount of the sound-absorbing material will have to be on the walls as the wall height increases above 3 m. If nearly all of the installed sound-absorbing material is on the ceiling, then it is prudent to introduce furnishings such as bookshelves of adequate height to assure that sound waves traveling across the room are scattered in the direction of the sound-absorbing acoustical ceiling.

C3.1.2 Lecture-type classrooms

Speech intelligibility studies [C3] have shown that, for lecture-type classrooms, it is best to ring the upper wall and ceiling with sound-absorbing material. This configuration enhances reflections to and from the back of the room, as well as back and forth across the room, thus promoting good speech communication between teacher and student and vice versa, as well as among students. This arrangement also enhances better communication for group discussions and pod formats where the teacher moves around the room.

For classrooms that have a relatively fixed teacher position, the sound-absorbing material should not be placed just above and in front of the teacher's position because that position would reduce the level of the teacher's voice at the positions of the students.

C3.2 Mounting of acoustical treatment in classrooms

Ceiling acoustical treatment is normally suspended from the ceiling with an air space specified by the architect. The height of the airspace may, or may not, be the same as the 40 cm (16 inch) airspace commonly used by manufacturers to achieve the sound absorption coefficients that are measured by a testing laboratory. As long as the minimum airspace required for installing a lay-in ceiling exists, the actual sound absorption at frequencies of 500 Hz and higher should be not less than the published values. Experienced professionals should be consulted when reverberation at frequencies less than 500 Hz is a major concern. Wall-mounted materials should be installed, as recommended by the manufacturer, with clips or glue to the wall surface or be fastened to added spacers to achieve the stated sound absorption coefficients.

C3.3 Reverberation control for ancillary and large core learning spaces

For ancillary spaces, such as corridors, gymnasia, cafeterias and large core learning spaces [volume > 566 m^3 (> 20 000 ft^3)] sound-absorbing material should be installed to reduce noise caused by the activities of occupants, as well as to control reverberation. The amount of acoustical treatment will vary widely, but corridors should generally have a total surface area of sound-absorbing material that is not less than 50% of the ceiling area and up to 75% if possible; 75% treatment area is recommended for corridors with high traffic or noisy lockers.

A measure of the sound absorption coefficient of acoustical materials is provided by a single number rating called the noise reduction coefficient (NRC), [C4, C5]. For cafeterias and for large core learning spaces with ceiling heights up to 3.7 m (12 ft), a suspended ceiling with a NRC of 0.70 or higher should be used for the full ceiling area exclusive of the area required for lights and ventilation grilles. Higher NRC ratings should be considered especially for ceiling heights less

than 3.7 m. When the ceiling height is greater than 3.7 m (12 ft), especially if greater than 4.6 m (15 ft), a more detailed analysis by experienced personnel may be required to provide adequate control of reverberation. In any event, as suggested by table C.1, wall treatment should be included for such high-ceiling rooms. Depending on the amount of wall treatment, the ceiling NRC or treated area might then be reduced when some of the wall area is covered by sound-absorbing material. When permitted within sanitation restrictions, similar acoustical treatment should be employed in food-serving and food-preparation areas.

NOTE — The Noise Reduction Coefficient is equal to the arithmetic mean of the sound absorption coefficients at 250, 500, 1000, and 2000 Hz, rounded to the nearest multiple of 0.05. The NRC of acoustical material should not be used for design or calculation of reverberation time for core learning spaces for purposes of this standard.

For rooms with high ceilings, such as gymnasia, the installation of acoustical treatment on the walls is important to minimize reverberant build-up of noise level. Absence of any acoustical treatment on the walls of high-ceiling rooms can make the material on the ceiling less effective than expected.

Guidance is available in the references listed in the bibliography in C5 for many other architectural acoustics design objectives applicable to reverberation control in ancillary spaces and large core learning spaces. These objectives include but are not limited to:

- providing suitable reverberation times for large core learning spaces and dual-purpose ancillary spaces such as a cafeteria also used as an auditorium (e.g. - Ref. C5, C6, or C7), and

- including additional sound-absorbing material on the walls in corridors connecting noisy rooms to quieter areas of the school and in corridors with busy foot traffic or noisy lockers.

C3.4 Carpeting in classrooms

Carpeting in a classroom (for example, in an area where young children sit on the floor together for a story) can help substantially to reduce background noise in the classroom from chair and foot impacts or scuffling. Carpeting can also attenuate the transmission of this impact noise to the room below. The alternative use of neoprene chair leg tips should be considered as a way to help minimize chair-shuffling noise without the use of carpeting. See annex F for discussion of indoor air quality (IAQ) and multiple chemical sensitivity (MCS) issues for carpeting.

Carpeting alone usually does not provide enough sound absorption for classrooms since it is generally poor at low frequencies, even when newly installed. (See text following Equation C.2 for further details.)

C3.5 Absorption of furnishings and occupants

Calculations of reverberation times for learning spaces assume typical furnishings such as chairs, tables, and storage cabinets. A sound absorption equal to 5% of the floor area, already included in the residual absorption term A_R in equation C.2, is a conservative approximation for the sound absorption of these furnishings. These furnishings are normally floor-mounted and thus their quantity and hence their sound absorption will tend to be proportional to the floor area. The 5% figure is consistent with limited experimental data comparing the reverberation for furnished and unfurnished classrooms.

The sound absorption of learning space occupants was considered in setting the limits on reverberation time in table 1 and should not be included in any calculations for the reverberation time of an unoccupied space. The sound absorption provided by an occupant is approximately equal to 0.55 m^2 (6.0 ft^2) for an adult student and about 20% less for a high school student and 40% less for an elementary grade student [C4].

C4 Guidelines for good acoustics in large classrooms and lecture rooms

This standard does not specify performance criteria or design requirements for enclosed learning spaces larger than 566 m^3 (20 000 ft^3). However, limited additional recommendations and design guidelines for larger rooms and other spaces in educational facilities, aside from those in C3.3, are given in this subclause.

Large lecture rooms generally differ physically and functionally in many ways from classrooms found in elementary and secondary schools. The teacher-student configuration tends to be fixed; the size of the room can vary greatly, sometimes accommodating hundreds of students. The shape of the room may vary from a traditional rectangular shape; HVAC systems usually have much greater capacities; and speech reinforcement systems as well as other fixed audiovisual facilities are common in such spaces.

For unamplified speech, beneficial sound-reflecting surfaces, especially over the teacher-lecturer, are necessary to assure adequate speech sound levels in the back of the room with relatively uniform distribution of the sound of spoken words. If the teacher-student configuration is fixed, beneficial reflections can be obtained with sound-reflecting surfaces placed above the lecturer, sometimes extending over the audience, on the ceiling, or sidewalls. Because of the larger room volumes, reverberation times usually are greater than in small classrooms, with values of 0.7 s to 1.1 s in occupied rooms not uncommon. To assure less variability in the reverberation time with changes in occupancy, it is always desirable to have sound-absorbing upholstered chairs in small auditoria. To minimize echoes, the back wall is often made sound absorbing, or is tilted to avoid sending reflections back toward the source, or both.

Because of the complexity of the design of large lecture rooms, experienced professionals should be consulted to ensure that the design and its implementation achieve the acoustical objectives of this standard.

Further guidance for detailed design considerations of lecture rooms can be found in a number of sources including [C1, C4-C11] listed in the bibliography.

C5 Bibliography

[C1] R.E. Apfel, *Deaf Architects and Blind Acousticians, A Guide to the Principles of Sound Design,* Apple Enterprises Press, New Haven, CT, (1998).

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Annex D

(Informative)

Design guidelines for noise isolation

D1 Introduction

This annex provides informative design guidelines for noise isolation between learning spaces and between a learning space and other interior or exterior spaces. Application of these design guidelines will assist, but not guarantee, achieving conformance to the background noise level limits in table 1. The STC and IIC ratings in 4.5 are intended to provide a practical means of achieving this conformance. All acoustical aspects of the design and construction should therefore be consistent with this intent. In support of this intent, since many finished component assemblies involve the work of more than one building trade, architectural specifications should refer to noise control and isolation measures in all applicable sections. After completion of construction, on-site testing may also be needed when it is necessary to verify conformance to the STC or IIC ratings of 4.5, (see E5.1 in annex E).

The noise isolation provided by wall or ceiling elements depends on both the materials used and the installation practices and may be strongly affected by sound leakage at joints and penetrations and unintended flanking paths around these elements. When a high degree of noise isolation is required, as for music rooms, flanking of sound transmission through common floors, walls, and ceilings can limit the isolation actually achieved unless proper steps are taken in the design and construction.

The noise isolation requirements of this standard are similar in concept to requirements incorporated in several existing national and international building codes. Examples include: a) Appendix Chapter 12 Division II-Sound Transmission Control of the 1997 Uniform Building Code (UBC), b) Section 1206 of the 2000 International Building Code, and c) Standard SSTD 8-87 of Southern Building Code Conference International (SBCCI). All of these prescribe minimum STC ratings for separating walls and floor-ceiling assemblies. Except for the SBCCI code, they also prescribe minimum IIC ratings for floor-ceiling assemblies. The requirements for this standard differ from those in the above codes because the application for the space is different and, in many cases, have more stringent acoustical design requirements.

D2 Noise isolation

D2.1 Noise isolation between interior spaces

Table 2 specifies the required minimum STC ratings for interior and exterior walls surrounding enclosed learning spaces. The table presents design requirements for STC ratings of typical wall constructions where the wall is continuous to the floor below or floor-ceiling system above, with all penetrations adequately sealed, (see the guidance in ASTM E497 [D1]). General design guidance on noise isolation is provided in many texts and reports on building noise control including references D2 to D15.

D2.2 Noise isolation of open-plan classrooms

The low noise isolation that is inherent with open-plan classrooms is generally well below the design requirements in table 2. Therefore, this standard emphasizes that open-plan classroom design should be strongly discouraged since the resulting background noise levels in a core learning space as a result of activities by students in other core learning spaces within an open classroom setting are highly likely to exceed the background noise limits in table I. The poor acoustical performance of open-plan systems has a negative impact on the learning process and tends to defeat any teaching methodology advantages that may accrue from their use.

D2.3 Outdoor-to-indoor noise isolation

D2.3.1 Outdoor-to-noise environments

There is no single answer for the proper amount of noise isolation to include in the design to shield a learning space from industrial or transportation outdoor noise sources. Each situation is unique with regards to distance to, and the extent and characteristics of, industrial sources, local traffic, or other transportation noise sources. The best solution to outdoor-to-indoor noise isolation design is to measure the current, or predict the future, noise levels of external sources at the proposed locations for facades. The next step is to determine the necessary outdoor-to-indoor noise level reduction to achieve the required interior background noise level in table 1. (See D2.3.3 for one approximate method.) It is good design practice to allow a margin of safety to account for uncertainties, including the possibility that current outdoor sound levels may increase in the future. For predictions of external noise levels, widely accepted models for assessing industrial or transportation noise sources will normally be available to environmental planners or acoustical consultants. For some sites, maps or contours of the current or projected outdoor noise environment may be available from local planning departments.

Selection of materials and acoustical design for the exterior envelope of a school building should consider these measured or predicted noise levels. Knowledge of these levels can assist in achieving adequate acoustical design features to attenuate the outdoor noise levels and ensure that the interior background levels do not exceed the limits in table 1.

D2.3.2 Selecting sites for learning facilities.

As recommended by ANSI S12.9/Part 5 [D10], learning facilities should not be located at sites where the yearly average A-weighted day-night average sound level exceeds the following limits with corresponding construction methods:

- 60 dB to 65 dB for conventional construction methods for the learning facility, providing the external walls are designed to a minimum STC rating of 50 consistent with the minimum ratings in table 2 and table 3;

- 65 dB to 75 dB if the external shell of the learning facility is designed to provide adequate noise isolation in order to conform to the limits in table 1 for background noise levels (see D2.3.3).

Under no conditions should a new learning facility be located at a site where the yearly average A-weighted day-night average sound level exceeds, or is predicted to exceed, 75 dB.

D2.3.3 Approximate STC ratings to achieve a desired outdoor-to-indoor noise level reduction

Given the limits on background noise levels from table 1 and the external noise environments established by one of the procedures outlined in D2.3.1 and D2.3.2, the recommended STC rating for the wall, roof, door, and window elements of the school building envelope may be estimated from the data in table D.1.

Table D.1 gives the approximate difference in decibels between the minimum STC rating of the exterior elements of a learning space and the required outdoor-to-indoor noise level reduction for two ranges of the relative area of the fenestration in the envelope. While only an approximation, the data in the table may be used for initial estimates of the STC rating required for the components of the exterior envelope of the structure.

NOTE — Outdoor-to-indoor noise level reduction is the difference in A-weighted sound level between a specified outdoor sound field and the resulting A-weighted sound level in the room abutting the facade or facade element of interest. It can be measured in accordance with ASTM E966 [D9] where it is called "outdoor-indoor level reduction".

Table D.1 — Approximate difference between the minimum STC rating required for building envelope components and the required outdoor-to-indoor noise level reduction

Fenestration %	**(STC rating of walls and roofs) minus (outdoor-to-indoor noise level reduction)** dB	**(STC rating of doors and windows) minus (outdoor-to-indoor noise level reduction)** dB
1 to 25	15	6
26 to 70	20	11

NOTES

1 Fenestration is the percentage of the total wall and roof surface area that consists of windows, doors, and other openings. For rooms without a roof, it is the percentage of the total wall area made up of windows, doors, and other openings.

2 The values for the nominal STC rating minus the outdoor-indoor noise level reduction in columns 2 and 3 are based on the expectation that the dominant outdoor noise source is vehicular traffic. If other sources dominate, adjustments may be needed. For example, if aircraft noise is the dominant source, the minimum required STC rating may increase by about 2 dB.

As an example, assume that the dominant source of exterior noise is road traffic and that the maximum one-hour-average A-weighted noise level is 65 dB at the nearest exterior classroom wall facing the traffic. To conform to the background noise limit inside the classrom of 35 dB from table 1, the nominal outdoor-to-indoor noise level reduction would have to be 65 – 35 or 30 dB. According to table D.1, for an exterior wall with fenestration greater than 25%, the nominal STC rating of the exterior walls would have to be at least 30 + 20 or 50. The STC rating of the windows would have to be at least 30 + 11 or 41.

To obtain estimates of the required STC ratings that are better than those obtained from application of table D.1 would require an assessment of the frequency spectrum of the long-term-average exterior noise level. Also needed is the frequency-dependent sound transmission through the walls, roof, windows, and doors that are planned for the envelope of the school building (see ref. D8, D9).

D2.4 STC ratings for composite elements of a wall or roof assembly

STC ratings for a composite of several elements in a structural assembly may be estimated by application of the data in table D.2. Table D.2 may be employed to determine the STC rating of two different building elements such as walls, doors and windows with STC ratings, STC (1) and STC (2), where STC (1) is greater than STC (2).

Enter table D.2 in the column across the top with the difference in the STC ratings rounded to the nearest 3 dB. Then go down to the row indicated in the left-most column to the range that includes the area S2 as a percentage of the total area (S1 + S2) of both elements. At the intersection of the row and column, find the correction to subtract from STC (1) to yield the estimate for the STC rating of the composite assembly. For more than two elements in a composite assembly, repeat the process by combining the STC of the composite assembly consisting of the first two elements with the STC of the third element, and so on.

As stated in NOTE a) to tables 2 and 3, the STC rating for the walls of a corridor, office, or conference room containing entrance doors excludes these entrance doors. The design and anticipated STC rating for such entrance doors is given in 4.5.5.

Table D.2 — Correction data for estimating the STC rating of a two-element composite building assembly.

[STC (1) and STC (2) are the STC ratings of elements 1 and 2, with corresponding surface areas S1 and S2, and STC (1) is greater than STC (2)]

S2 / (S1+ S2) x 100%	STC (1) rating minus STC (2) rating, dB									
	3	6	9	12	15	18	21	24	27	30
	Correction to subtract from STC (1) to obtain the STC rating of the composite assembly, dB									
0 to 0.2	0	0	0	0	0	0	0	1	2	3
>0.2 to 0.5	0	0	0	0	0	1	1	3	4	6
>0.5 to 1	0	0	0	0	1	2	3	4	7	9
>1 to 2	0	0	0	1	2	3	4	7	9	12
>2 to 5	0	0	1	2	3	5	7	10	12	15
>5 to 10	0	1	2	3	5	7	10	13	16	19
>10 to 20	1	2	3	5	7	10	13	16	19	20
>20 to 30	1	2	4	7	9	12	15	18	21	24
>30 to 40	1	3	5	8	11	14	17	20	23	26
>40 to 60	2	4	7	9	12	15	18	21	24	27
>60 to 80	2	5	8	10	13	16	19	22	25	28
>80 to 100	3	6	9	12	15	18	21	24	27	30

D2.5 Isolation from impact noise or vibrating machinery

D2.5.1 Design guideline for impact noise isolation for floor-ceiling assemblies

For learning spaces in multi-story school buildings, classrooms in lower stories may need to be protected from the noise of impacts on the floor of rooms immediately above. Impact noise may arise from footfalls or the scuffling of furniture in the room above. Impact noise can be reduced sufficiently by ensuring that the floor-ceiling system has an adequately high Impact Insulation Class (IIC) rating. Installing carpet on the floor will almost always ensure an IIC rating greater than 50 but may not reduce the low-frequency impact sounds sufficiently. It is good practice to design the floor-ceiling assemblies to achieve a minimum IIC 50 rating without carpeting above classrooms or other core learning spaces. For this purpose a permanent resilient underlayment may be required to isolate the finished floor from the structural floor system.

To achieve high IIC ratings, it may be necessary to isolate the ceiling from the floor above. This can be accomplished by suspending the ceiling with resilient channels or isolation hangers, Good architectural practices, including careful isolation design and attention to detail in construction, are important to ensure the realization of high IIC ratings. References D8 and D11 to D15 in the bibliography provide extensive IIC test data. Product manufacturers can be consulted for additional data.

D2.5.2 Design guideline for noise isolation from vibrating machinery

Vibration isolation methods, such as rubber pads or spring systems under the mounting points, should always be employed under rotating machinery to isolate it from floor-ceiling systems and prevent structurally-transmitted sound from entering learning spaces. This isolation is particularly important for roof-mounted rotating machinery where the deflection of the roof has to be considered in vibration isolation design. Design methods for such vibration isolation are documented in widely available noise control handbooks, (See ref. D2, D8 and D15 in the bibliography).

D3 Bibliography for further guidance on noise and vibration isolation in school buildings

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Annex E
(Normative)

"Good architectural practices" and procedures to verify conformance to this standard

E1 Introduction

This annex provides recommendations in clause E2 for "good architectural practices" that will help to achieve the objectives of this standard. Clauses E3, E4, and E5 describe procedures that shall be followed to verify conformance to the requirements and recommendations of this standard, in the event that such verification is required. If verification of conformance is not required, the procedures described in clauses E3, E4, and E5 are provided for information only and the entire annex then shall be considered to be informative rather than normative.

This standard covers a range of requirements, some of which are relatively simple to accommodate by following the design guidelines given in other annexes. However, concerns about the actual acoustical environment of learning spaces may arise depending on a combination of factors such as building siting, variability in the installation of the HVAC system, and variability in the details of the construction techniques. For these and other reasons, verification tests may be necessary to evaluate conformance to the requirements of this standard.

Nonconformance to the provisions of this standard may be suspected when subjective evaluation of a learning space under typical use indicates excessive background noise, reverberation, insufficient noise isolation, or poor speech intelligibility.

Verification tests and analyses, if required, should be performed by qualified personnel (see B6 in annex B).

E2 "Good architectural practices" and acoustical performance considerations during and after construction

E2.1 Prior to completing construction

"Good architectural practices" during the design and construction of a new or renovated learning space include the following actions:

phase 1 designing to conform to this standard (see annexes B, C, and D);

phase 2 monitoring activities during construction to ensure that acoustically important design features are not compromised; and

phase 3 checking for conformance to the principal requirements of this standard before completion of construction or renovation is accepted.

For a new or a renovated learning space, the architectural design in phase 1 should utilize the guidance provided in annexes B, C, and D. Because many structural component assemblies involve work by more than one building trade, the architect's specifications should cross-reference the noise control and noise isolation measures in all applicable sections of the specifications.

During construction phase 2, in addition to, and in advance of, conventional on-site inspections, special training should be provided to those in relevant building trades who will perform the work or to their supervisors. The training should describe guidelines for implementing what often may be unconventional or unfamiliar construction methods. For example, representatives of certain building trades may not realize that inadvertent or careless disposal of debris or temporary bracing in the space between wall surfaces can cause a drastic reduction in noise isolation between adjacent learning spaces.

It is important to emphasize to those doing the work during the construction phase that all cracks or joints between wall segments or wall-floor or wall-ceiling joints should be sealed with a permanently flexible caulking compound. However, no attempt should be made to seal cracks or joints that are wider than 6 mm (0.25 in.). Solid filler, also caulked, with a surface weight density comparable to that of the material on each side of the crack should be used to seal cracks that are wider than 6 mm. ASTM C919 [E1] provides procedures for the use of sealants to maintain the design for noise isolation. The architectural design drawings should include a reference to ASTM C919 for sealing procedures.

To check conformance to the key requirements of this standard after construction is completed but before the learning space is occupied (phase 3), the following evaluations are recommended: 1) measure the background noise levels within learning spaces, 2) measure the noise isolation between them, and 3) calculate (or measure) reverberation times (see E3, E4 and E5 for procedures).

E2.2 After commissioning

After commissioning (accepting completion of construction), "good architectural practices" include:

1) being alert for, and monitoring of, degradation of acoustical materials, and

2) responding to complaints about the acoustical environment in a learning space.

Over time, some of the noise control features designed into a learning facility may degrade. One example of such degradation is changes in the balance, or fan operation, of the HVAC system leading to excessive low-frequency noise. Another example is the degradation of designed noise isolation provided by operable partitions as a result of wear and tear of floor and edge seals. A third example is painting of the sound-absorbing material on ceilings and walls.

Tests to verify conformance to this standard may be performed in response to complaints about the acoustical environment in the learning spaces. The results of these tests, and those performed prior to accepting completion of construction, will assist in analyzing the basis for any future complaints about the acoustical environment in the learning spaces.

E3 Verifying background noise levels

E3.1 Selecting learning space for measurements

Ordinarily, comprehensive testing is not required for all learning spaces in a given facility to which this standard applies and appropriate sampling procedures should be adequate. Selection of the size of the sample should consider the need to evaluate spaces expected to have the highest levels of background noise because of their proximity to internal noise sources (e.g., mechanical equipment rooms) or their proximity to external noise sources (e.g., road traffic).

The test procedures in the balance of this clause apply to each learning space in which background noise levels are to be measured.

E3.2 Room conditions

Background noise levels shall be measured while adjacent spaces (for example, rooms and corridors beside, above, and below the space in which the measurements are to be made) are unoccupied. Students or school staff members, in the remainder of the facility, shall be requested to not carry out any activity that could increase the background noise level in the room under investigation.

Background noise levels shall be measured during an hour when the background noise levels are expected to be a maximum. Background noise levels shall be measured with the HVAC system and other building services at their appropriate maximum operational conditions as specified in 4.3.2. Lights shall be on; doors and windows shall be closed.

E3.2.1 Instructional equipment

Portable and permanent instructional equipment (for example, computers and audio-visual systems) shall be turned off to obtain background noise levels required by this standard.

However, it is strongly recommended that background noise levels also be measured according to the procedures in this annex when such instructional equipment and building services are operating simultaneously. When this total background noise level exceeds the limit in table 1 by more than 3 dB, steps should be taken to reduce the level of the noise produced by the instructional equipment.

E3.3 Room description

The overall dimensions of the learning space shall be measured and the enclosing volume calculated. The locations and dimensions of major features shall be noted on a diagram with plan and elevation views showing: 1) the location of HVAC components and other noise sources within the space; 2) the position and dimensions of windows and doors; and 3) the heights and locations of partial height walls.

E3.4 Test instruments

Two types of instruments are required — a sound level meter and a compatible acoustical calibrator (or sound calibrator).

E3.4.1 Sound level meter

The sound level meter shall provide frequency weightings A and C, and SLOW time-weighting. The sound level meter shall be an integrating-averaging type capable of measuring time-average sound levels or a conventional sound level meter capable of measuring SLOW time-weighted sound levels. An integrating-averaging meter is preferred.

An integrating-averaging sound level meter shall conform to the class 1-performance specifications of IEC 61672-1 [E2] or to the performance specifications of ANSI S1.43 [E3] for type 1 integrating-averaging sound level meters. A conventional sound level meter shall conform to the class 1 specifications of IEC 61672-1 or to the specifications of ANSI S1.4 [E4] for type 1 sound level meters. For either type of sound level meter, conformance to IEC 61672-1 is preferred.

To demonstrate conformance to the background noise limits of table 1, the maximum A-weighted level of self-generated noise of the sound level meter shall not exceed 30 dB for the model of microphone installed on the sound level meter.

> NOTE — Sound level meters designed in conformance with the above IEC or ANSI standards may have A-weighted self-noise levels greater than 30 dB. Conformance to these standards does not assure compliance with this required maximum self-noise level.

To carry out the preliminary survey of the background noise levels in the manner described in E3.7, a conventional sound level meter conforming to IEC 61672-1 class- 2 or ANSI S1.4 type- 2 specifications may be an acceptable alternative. To be acceptable, the lowest noise level measurable by the instrument shall be at least 5 dB below the actual measured background level. This ability may be demonstrated by observation in a very quiet location. Alternatively, the manufacturer may provide the lowest measurable level for this instrument.

E3.4.2 Acoustical calibrator

The acoustical calibrator shall conform to the requirements of IEC 60942 [E5] for a class 1 instrument or to the requirements of ANSI S1.40 [E6] for a type 1 instrument. Conformance to the standard corresponding to the sound level meter standard is preferred. The actual sound pressure level and nominal frequency of the calibration signal shall be known for the microphone installed on the sound level meter.

E3.5 Calibration

The sound level meter and the acoustical calibrator shall each have a certificate from a qualified acoustical testing laboratory indicating that a calibration of both instruments has been performed within the time interval recommended by the manufacturer but not more than 24 months prior to the date of the tests. The certificate shall apply for reference environmental conditions defined by the manufacturer. The calibration of the sound level meter and acoustical calibrator shall be checked periodically to ensure that measurements with the sound level meter are accurate.
Before initiating sound level measurements, the calibration of the sound level meter shall be verified in accordance with the procedure described in the Instruction Manual for the calibrator. Adjustments shall be made to the calibration in accordance with this manual to account for any significant difference between the prevailing atmospheric pressure and air temperature and the reference conditions (i.e. - 760 mm Hg, and 23 °C).

E3.6 Selecting measurement locations

The customary listening areas used for speech communication shall be determined for each learning space. The customary listening areas include the students' seating areas and the areas used by the teacher. These listening areas may be relatively fixed within a classroom or vary substantially, depending on the seating arrangement and teaching style. A maximum of six measurement locations shall be selected within the customary listening area and at distances not less than 1 m (40 in.) from a wall or other large solid surface, except for measurement locations close to the floor.

The location in the customary listening area that has the highest sound level shall be designated the 'key location'. This location shall be determined by observing the A-frequency-weighted and SLOW time-weighted sound level as the sound level meter is carried around the learning space with the room conditions as noted in E3.2. Sound levels shall be noted at measurement heights representative of seated and standing students. Alternatively, this key location may be selected by listening at suitable positions near the apparent source of highest noise levels. If this subjective choice of the key location cannot be confirmed by the subsequent measurements of background noise, the background noise measurements shall be repeated using a correct key location. Before determining the other measurement locations it is prudent to evaluate preliminary survey results at the key location, as called for in E3.7.

A second location shall be on the opposite side of the listening area from the key location. Four other locations, two on each side of the listening area, shall be selected ahead and behind the key and second locations.
Three of the measurement heights above the floor, including that for the key location, shall be at the nominal ear elevation for students seated in a chair or on the floor. The other three heights shall be representative of the ear position of a standing student. The recommended approximate heights are shown in the following table.

Grade level	Approximate measurement height above the floor		
	Seated positions		Standing
	In a chair	On the floor	
K to 6	0.8 m (33 in.)	0.5 m (20 in.)	1.1 m (44 in.)
7 to 9	1.0 m (40 in.)	Not applicable	1.4 m (54 in.)
10 to 12 and adults	1.1 m (44 in.)	Not applicable	1.5 m (60 in.)

For learning spaces used by students of widely varying ages, at least four of the six measurement locations shall be those for the younger students.
Each measurement location shall be shown on a floor plan diagram and shall include the actual measurement heights employed.

E3.7 Measuring background noise

Following the initial survey described below, which can employ a hand-held sound level meter, the remainder of the background noise measurements should be conducted with the meter mounted on a tripod to minimize operator-induced noise and reflections from the operator's body. (A tripod may be necessary for even the initial survey if the observed sound levels are very low). A large flat surface, such as a table or chair seat, shall not be used to support the instrument. To ensure that any air currents do not affect the reading of the sound level meter, and to protect the microphone from accidental damage, an appropriate microphone windscreen shall always be employed. The number of persons in the listening area shall be minimized, preferably with the test conductor the only person in the area.

The measurement of background noise shall begin with a preliminary survey to: 1) find the key location where the background noise level is the highest (see E3.6); 2) assess the likelihood that the background noise level conforms to the limits in table 1; and 3) determine if the background noise is steady or unsteady. The sound level meter used for this preliminary survey may be an integrating-averaging type or a conventional type. In either case, it may be one that conforms only to the class-2 requirements of IEC 61672-1 or the type 2 requirements of ANSI S1.4 if the meter also conforms to the requirements in E3.4.1 for the lowest measurable level.

At the key location, the time-average A-weighted sound level shall be measured over each of five nominally consecutive 30-second intervals. The highest 30-second average, the lowest 30-second average and the total average of all five 30-second averages shall be noted. The same type of data shall be obtained for C-weighted sound levels. Each 30-second average may be obtained with an integrating-averaging meter set to a 30-second averaging period or, with a conventional sound meter, by visually observing the mean indication of the A-weighted and SLOW time-weighted sound level over the 30-second interval.

If the average background noise level from the above five A-weighted measurements is at least 3 dB more than the limits in table 1, then it may be concluded that the background noise levels in the room are not in conformance with the standard. No further background noise measurements are needed. If the average background noise level from the above five measurements is at least 3 dB less than the limits in table 1 and the background noise is judged steady as defined below, it may be concluded that the background noise levels in the room are in conformance with the standard. No further A-weighted background noise measurements are needed.

If the average of the five 30-second samples falls within a 3 dB range above or below the limits of table 1, then confirmation of conformance or nonconformance to these limits shall be determined by additional tests carried out in accordance with one of the following procedures.

If the difference between the highest and the lowest noise levels of the five 30-second samples at the key location is not more than 3 dB, the background noise shall be judged steady and the measurement procedure in E3.7.1 shall be employed. If this difference is more than 3 dB, the background noise shall be judged unsteady and the measurement procedure of E3.7.2 shall be employed.

E3.7.1 Steady background noise

The one-hour-average steady background level for the typical usage hour may be obtained from measurements of one 30-second average sound level at each measurement location after ensuring that the room conditions are as specified in E3.2. Each 30-second average sound level may be measured in one of two ways and the results noted for each measurement location:

1) by use of an integrating-averaging sound level meter for a 30-second measurement interval or

2) by visual observation for 30 seconds of the mean sound level observed on a conventional sound level meter with SLOW time-weighting.

If any non-typical short-duration sound, such as a door slam, occurs during any measurement period, the measurement shall be stopped, the memory cleared if an integrating-averaging instrument is being used, and the 30-second measurement repeated.

The C-weighted sound level also shall be measured at the key measurement location applying the same process employed for the A-weighted sound levels. If the C-weighted sound level at this location exceeds the limit for A-weighted levels in table 1 by more 18 dB, it is recommended that a more thorough evaluation be made of the C-weighted levels at other locations in the room to ensure conformance to 4.3.2.1.

E3.7.2 Unsteady background noise from transportation noise sources

For unsteady background noise, the measurement procedure of E3.7.1 (1) shall be followed, using an integrating-averaging sound level meter which, preferably, can also determine the A-weighted SLOW time-weighted noise level exceeded for 10% of any measurement interval. The integration and averaging measurement interval shall be 60 minutes instead of 30 seconds.

During this measurement, the time of day and the apparent sources of significant transportation noise shall be identified and noted. Non-typical short-duration loud sounds that occur during the integration interval shall be noted, but the integration shall not be interrupted. Prior to reporting the one-hour-average sound level, the measured data may be processed to exclude such non-typical short-duration sounds

The A-weighted, SLOW time-weighted noise level exceeded for 10% of the observation hour shall be noted directly if the sound level meter has this capability. Alternatively, manual data processing may be employed. For example, a record of 120 observations of 30-second samples of the A-weighted SLOW time-weighted noise level can be used to determine the level exceeded for 10% of the hour.

E3.7.3 Disturbing sounds from building services and utilities

If the presence of disturbing sounds (see 4.3.2.2) is suspected from building services and other utilities, a more thorough analysis of the acoustic environment may be required using appropriate signal analysis equipment familiar to an experienced observer.

E3.8 Verifying conformance to background noise limits

E3.8.1 Steady background noise

For the customary listening area in the learning space, conformance to the requirements of this standard is verified for steady background noise when the following conditions are satisfied.

- The 30-second-average A-weighted sound level at each measurement location does not exceed the corresponding limit specified in table 1, within the tolerance of 4.7 (1); and

- The 30-second-average C-weighted sound level at the key measurement location does not exceed the corresponding 30-second-average A-weighted sound level by more than the limit specified in 4.3.2.1.

E3.8.2 Unsteady background noise from transportation noise sources

Conformance is verified if the one-hour-average A-weighted sound level and the A-weighted, SLOW time-weighted level exceeded 10% of the time do not exceed the limits specified in 4.3.1. The tolerance of 4.7 (1) applies separately and not cumulatively to each of these limits for the continuous test hour.

E4 Verifying reverberation times

E4.1 Methods

The preferred method to verify that the actual reverberation times do not exceed the maximum reverberation time specified in table 1 is to calculate the reverberation time at 500 Hz, 1000 Hz, and 2000 Hz. Alternatively, reverberation times may be measured directly. Reverberation times shall be measured when the calculated reverberation times exceed the limits from table 1, when the observed reverberation of the learning space appears to be excessive, or when significant differences are suspected between the assumed and the actual mounting conditions for the acoustic treatment.

If calculated and measured reverberation times differ by more than 0.1 s, the measured reverberation time shall take precedence. Results of calculations or measurements of reverberation times shall be rounded to the nearest 0.1 s and shall be within the tolerance limits of 4.7 (4) of the performance requirements in table 1.

E4.2 Reverberation time by calculation

The dimensions of the room shall be measured and the enclosing volume calculated. The dimensions of the sound-absorbing surfaces on the ceiling and walls shall be measured and the surface areas calculated for each different type of sound-absorbing surface.

The total sound-absorbing area in the room shall be determined by means of equation (C.2) in annex C with appropriate estimates for the sound absorption coefficients for the various sound-absorbing surfaces. A residual sound-absorbing area shall be computed according to C2.1 in annex C to account for absorption by furnishings and untreated surfaces. A default value for this residual absorption shall be 15% of the floor area for uncarpeted rooms or 20% for carpeted rooms. Sound absorption provided by occupants of the room shall be ignored. The reverberation time shall be calculated for each frequency by the Sabine equation (e.g. - see equation (C.1) in annex C).

E4.2.1 Sound absorption coefficients used for calculations

To calculate the reverberation time, best estimates of the sound absorption coefficients for the as-installed acoustic materials shall be used. These coefficients (see NOTE) shall be obtained from:

a) the acoustical materials contractor, accompanied by the certification that they were obtained in accordance with ASTM C423 (see C2.1 in annex C) or,

b) published results obtained in accordance with ASTM C423 for nominally identical materials and mounting configurations, (see bibliography)

If possible, allowance should be made for acoustically significant differences between the tested and as-installed mounting configuration.

> NOTE — Manufacturers do not commonly provide the octave band sound absorption coefficients needed for this standard. The values reported are usually those measured for one-third octave bands centered at these octave frequencies. If desired, sound absorption coefficients over the full octave band may be estimated by arithmetically averaging available one-third octave band values at 400, 500, and 630 Hz for the 500 Hz octave band, at 800, 1000 and 1250 Hz for the 1000 Hz octave band, and at 1650, 2000, and 2500 Hz for the 2000 Hz octave band.

When such reasonable data or estimates of the sound absorption coefficients are not available then verification of reverberation time shall only be done using the measurement method in E4.3.

E4.3 Reverberation time by measurement

Measurements of reverberation times shall be performed by, or under the supervision of, a person experienced in performing such measurements. The measurements shall follow procedures in conformance with, or equivalent to, those specified for field tests in ASTM E336 [E7] or in Appendix X2 of ASTM C423 [E8]. The recommended sound signal is random noise with a bandwidth extending at least from 315 Hz to 3150 Hz.

Reverberation times shall be measured at least at the key location noted in E3.6 for each learning space where reverberation times are to be measured.

Before measuring reverberation times, all HVAC fans and other noise-generating equipment, such as instructional equipment, should be turned off if their noise prevents acquisition of valid measurements of reverberation times. All soft materials that are not a permanent part of the learning space (such as loose clothing and art supplies) shall be removed from the room. The learning space shall be otherwise furnished in the normal manner with chairs, tables, shelves, or cabinets. All windows, doors, and cabinets shall be closed. No more than two persons shall be present during the actual measurements.

No adjustments shall be made to any reverberation time measurements to account for the added absorption of any furnishings of any sort that were not present in the room at the time of the measurements.

E5 Verifying airborne and structureborne noise isolation

E5.1 Airborne noise isolation

When required, tests for conformance to airborne noise isolation requirements in table 2 shall be performed in accordance with the procedures of ASTM E336 [E7] and ASTM E413 [E9] for determining the Noise Isolation Class (NIC) as an approximation to the sound transmission class (STC) rating of a structural element. If there are no significant flanking sound-transmission paths and all sound leaks have been well sealed, the NIC rating is usually equal to, or slightly greater than, the STC rating determined by field tests for assemblies that separate two enclosed learning spaces.

The same ASTM test procedures also should be used to demonstrate conformance with the STC ratings recommended in table 3 for receiving ancillary learning spaces. All sound transmitted from the source room to the receiving room shall be considered to be transmitted through the separating partition. Engineering judgment shall be applied in the interpretation of measured NIC ratings; guidance for this judgment is provided in ASTM E336. The measured NIC ratings shall be within the tolerance limits of 4.7 (2) of the STC design requirements in table 2 and design recommendations in table 3.

E5.2 Structureborne (impact) noise isolation

When required, tests for conformance to structureborne or impact noise isolation requirements in 4.5.6 shall be performed in accordance with the testing procedures for determination of the Field Impact Insulation Class (FIIC) as defined in ASTM E1007 [E10] for floor-ceiling assemblies separating occupied spaces from learning spaces below. All sound transmitted from the source room to the receiving room below shall be considered to be transmitted through the floor-ceiling assemblies.

E5.3 Sound leakage paths

Tests for airborne and structureborne noise isolation shall not be attempted until all sound leakage paths and gaps have been eliminated by caulking and sealing in accordance with the recommended practice in ASTM C919 [E1].

E6 Test report

A test report shall document the results of all tests or calculations carried out in conformance with the procedures of E3 to E5 of this annex. The report shall reference this standard and the applicable clauses of this annex. The report shall describe the instruments used and their dates of calibration when applicable. The report shall include tables of all measured data and the results of all analyses. Drawings shall be included to show the items noted in E3.3 and E3.6. To support validation of the reverberation time by calculations, the report shall also include the types, locations, and areas of permanently installed sound-absorbing material and their mounting methods.

The report shall state whether the learning space does or does not conform to the requirements of this standard and shall identify the applicable clause(s). If the space does not conform to the requirements of this standard, the report may include, if requested, recommendations for modifications to achieve compliance. These recommendations should be prepared or approved by a person experienced in the applicable acoustic technology.

The report shall name the persons performing the validation tests or calculations and the name of the person who prepared the report.

E7 Bibliography

[E1] ASTM C919-98, *Standard Practice for Use of Sealants in Acoustical Applications* [Web site - http://www.astm.org].

[E2] IEC 61672-1, *Electroacoustics — Sound level meters — Part 1: Specifications.* [Web site - http://www.iec.ch]

[E3] ANSI S1.43-1997, *American National Standard Specification for Integrating-Averaging Sound Level Meters* [Web site - http://asa.aip.org].

[E4] ANSI S1.4-1983 (R 2001), *American National Standard Specification for Sound Level Meters*.

[E5] IEC 60942: 1997, *Electroacoustics — Sound calibrators.* (Including IEC 60942-am1:2000.)

[E6] ANSI S1.40-1984 (R 2001), *American National Standard Specification for Acoustical Calibrators*

[E7] ASTM E336-97, *Standard Test Method for Measurement of Airborne Sound Insulation in Buildings*.

[E8] ASTM C423-00, *Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method.*

[E9] ASTM E413-87 (1999), *Standard Classifications for Rating Sound Insulation*.

[E10] ASTM E1007-97, *Standard Test Method for Field Measurement of Tapping Machine Impact Sound Transmission Through Floor-Ceiling and Associated Support Structures.*

Annex F

(Informative)

Potential conflicts between the acoustical requirements of this standard and indoor air quality (IAQ) and multiple chemical sensitivity (MCS)

F1 Introduction

Concerns about indoor air quality (IAQ) and multiple chemical sensitivity (MCS) issues have caused some schools to remove all porous materials from the classrooms and, in some cases, from the ventilation supply ducts, thus potentially compromising the benefits for classrooms that used these acoustical materials. However, according to available literature and other sources such as those listed below, there is little or no conflict between the applications of this standard for classroom acoustics and IAQ and MCS issues when the proper materials are used and properly maintained. Nevertheless, the concerns need to be addressed. This annex provides a bibliography of references from government organizations, industry associations, and other organizations that offer relevant information.

Educational facility planners and architectural designers should objectively investigate any questions and concerns about IAQ and MCS issues that they may have relative to the acoustical design concepts presented in this standard.

Many materials employed to provide the desired acoustical environments by means of effective noise control are porous or fibrous in nature. Therefore, certain considerations such as material composition, potential out-gassing, and appropriate operating and maintenance strategies need to be addressed in the decision-making process relative to the types of materials proposed for acoustical purposes.

If acoustical materials are considered to be inappropriate under certain conditions, alternative materials, strategies, or applications should be employed to ensure conformance to the acoustical requirements of this standard.

In some cases a management commitment will need to be made to ensure that materials selected and used in a facility will be maintained in an appropriate manner, as recommended by the manufacturer or other governing bodies, under operational conditions after construction of the facility. For example, in hot and humid climates a facility should be adequately ventilated or other recommended measures should be taken at all times to ensure prevention strategies involving the potential for mold growth.

To reduce the potential for mold growth in HVAC systems, good design, installation and maintenance practices should be employed in order to keep filters and sound-attenuating materials clean and dry. This practice should include cleaning and periodically replacing or discarding tennis ball halves that are frequently used on chair legs to minimize shuffling noise. Limited tests have shown that these tennis ball halves develop an active fungal growth. The alternative method for quieting shuffling noise with neoprene chair leg tips should be encouraged.

F2 Bibliography

[F1] Carpet & Rug Institute, [Web site - http://www.carpet-rug.com].

[F2] United States Environmental Protection Agency (EPA).

a) *IAQ Tools for Schools*, [Web site - http://www.epa.gov/iaq/schools/tfs/building.html].
b) *IAQ in Schools*, [Web site - http://www.epa.gov/iaq/schools/index.html].
c) *A Guide to Indoor Air Quality*, [Web site - http://www.epa.gov/iaq/pubs/insidest.html].

[F3] American Indoor Air Quality Council, [Web site -http://iaqcouncil.org].

[F4] North American Insulation Manufacturers Association (NAIMA), [Web site -http://www.naima.org].

[F5] American Society of Heating, Refrigeration, Air-Conditioning Engineers (ASHRAE), [Web site - http://ashrae.org].

[F6] California Interagency Working Group on IAQ, Department of Health Services, [Web site - http://www.cal-iaq.org].

[F7] Environmental Building News. [Web site - http://www.ebuild.com].

Annex G

(Informative)

Cautionary remarks on using supplemental descriptors for evaluating noise in classrooms and other learning spaces

G1 Introduction

There are at least three noise descriptors, other than A-weighted sound levels, that are used to assess background noise or speech intelligibility in enclosed spaces, especially when low-frequency content is a major concern. However, applying the descriptors discussed below requires determining the frequency spectrum of the noise – a refinement that is beyond the scope of this standard and is not recommended.

A-weighted and C-weighted sound levels are considered adequate descriptors for purposes of this standard to evaluate the acoustical environment in learning spaces. The difference, measured in 56 classrooms, between the A-weighted time-average sound level of steady background noise and the corresponding value of any of the three descriptors noted below varied from 2 dB to 24 dB depending on the location of the learning space in the U.S. and whether the HVAC system was operating. *Thus, none of these supplemental descriptors should be employed for judging conformance to this standard.*

G2 Noise Criteria Rating (NC)

The noise criteria (NC) rating, in common use by architects and consultants for acoustical room design, is based on contours of octave-band sound pressure levels of the background noise. It is thus a measure of the frequency spectrum of this noise and reflects the change in the sensitivity of human hearing as the background noise level changes [G1], especially at frequencies important for speech communication and for annoyance of low-frequency sound.

G3 Balanced Noise Criteria Rating (NCB)

The balanced noise criteria (NCB) rating [G2] are also based on similar contours of octave-band sound pressure levels. The contours for the NCB descriptor extend to lower frequencies than do the contours for the NC descriptor.

G4 Room Criteria Rating (RC)

The room criteria (RC) rating [G3] is recommended by ASHRAE for evaluating background noise from HVAC systems and other mechanical equipment by use of contours of octave-band sound pressure levels. These contours are similar to those for the NC and NCB descriptors but have lower allowable sound levels at very low and very high frequencies.

G5 Bibliography

[G1] L.L. Beranek and I. L. Ver, *Noise and Vibration Control Engineering*, Wiley, NY (1992).

[G2] ANSI S12.2-1995, *American National Standard Criteria for Evaluating Room Noise*. [Web site - http://asa.aip.org].

[G3] *ASHRAE Handbook*, *HVAC Applications*, (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA 30329 (1999). [Web site - http://ashrae.org].