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a new standard for
Acoustics in the Classroom

from the editor …
Education presently ranks high on the list of domestic issues, and for good reason. Overcrowding, disrepair, and obsolescence are widespread and severe enough to earn schools a D– in an assessment of the nation's infrastructure [1]. *Scholastic performance is suffering, too. According to the U.S. Chamber of Commerce, more than one-third of the people who sought jobs in 1998 lacked the reading and math skills necessary for employment.*

The current education reform movement seeks to close the gap between business needs and scholastic performance by making states responsible for developing strong academic standards and then holding schools accountable for meeting those standards. But more classrooms, lower student–teacher ratios, and modern equipment may not be enough. Studies indicate that poor acoustics interfere with learning and pose a particular barrier for students with special needs. So compelling is the evidence that it led to the recent approval of an industry standard, which establishes an ambitious acoustical target for learning environments.

With school construction projected at more than $31 billion for 2003 (with another $42 billion likely by 2008), it is wise to understand how the new standard will affect school design and classroom functionality.

ANSI/ASA S12.60–2002

As the result of a petition by the parent of a hearing-impaired child, the Architectural and Transportation Barriers Compliance Board (Access Board) enlisted the American National Standards Institute (ANSI) and the Acoustical Society of America (ASA) to develop a standard for classroom acoustical design. The culmination of that effort—ANSI/ASA S12.60, *Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools*—was completed and approved in 2002.*

ANSI/ASA S12.60–2002 details acoustical performance criteria for learning spaces, and defines requirements and guidelines for noise isolation. It divides learning spaces into several categories and sets maximum limits for each. The maximum permissible background-sound level for "typical" classrooms is 35 dBA, with a maximum reverberation time of 0.6 to 0.7 second (depending on room volume) [2].

This benchmark differs considerably from the acoustical environments existing in many classrooms (Figure 1, p. 2). Although there is no exhaustive database of measured sound levels in classrooms, there is considerable evidence that background noise varies widely from classroom to classroom and from school to school, regardless

* To obtain a copy, visit http://webstore.ansi.org/ansidocstore/ and search for "S12.60." The single-copy purchase price is $35 USD.

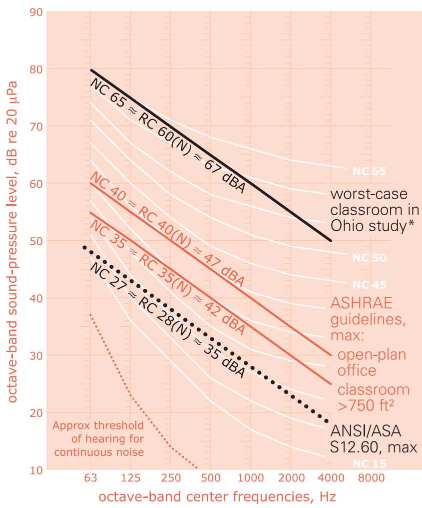
Gauging the education market

Improving the academic performance of U.S. students depends, in part, on our ability to create "learning-friendly" environments. Unfortunately, our nation's schools are seriously challenged by overcrowding and disrepair, substandard plumbing and HVAC systems, inadequate technology, and health- and safety-related concerns.

How big is the problem? The U.S. General Accounting Office estimates that it will cost $112 billion to bring existing K–12 public schools (many of which are more than 40 years old) to proper standards. With the student population expected to increase from 53 million to 54.4 million by 2008, another $73 billion is needed to add new facilities.

Industry watchers forecast that schools will continue to lead the nonresidential market for new construction (particularly in the Southwest), with investments for 2003 estimated at $31.6 billion. Another $16.4 billion is anticipated to modernize existing facilities (primarily in the Northeast and Midwest) [14], [15]. ■

Figure 1. Comparison of classroom acoustical environments



* Spectrum shape is based on an RC curve matching 67 dBA rather than on measured data.

SOURCES: Finitzo-Hieber and Tillman, 1978; *1999 ASHRAE Applications Handbook;* and ANSI/ASA S12.60–2002

of age or location. For example, a survey of 32 classrooms in eight Ohio public schools revealed background-sound levels ranging from 32 dBA to 67 dBA [3].

Excessive background noise may result, in part, from purchasing decisions that are influenced largely by first cost and from building codes that outline minimum construction requirements without sufficient attention to function. Although U.S. model building codes address lighting, ventilation, and indoor air quality for classrooms, they are silent on the subject of acoustics. Only a few states (Washington and New York, to name two) have amended their codes to include sound-level requirements for schools [4].

This omission leaves most school administrations without a mandate to specify acoustics when designing and constructing new educational facilities. Not surprisingly, overlooking this aspect of the built environment can result in the selection of materials and equipment that inadvertently raises the sound level in the classroom.

For now, compliance with the ANSI/ASA standard is voluntary unless the standard is referenced by a code, ordinance, or regulation. Recognizing that states and other governing bodies look to model code agencies for examples of legally binding "best practices," the Access Board submitted the new standard to the International Code Council (ICC) for inclusion in the 2003 International Building Code. However, the standard was not adopted due to concerns about the feasibility of applying certain technical specifications, the associated costs of implementation, and the method by which the standard was developed.

The ICC's rejection does not preclude future adoption of a modified version of the standard, nor does it prevent individual states or other code-writing bodies from embodying all or part of the existing standard. School systems, too, can choose to specify compliance with the standard in construction documents for new facilities. In the meantime, the debate generated by the new standard is raising public awareness of the importance of acoustics in functional classrooms.

Implications for School Design

Numerous factors determine the sound levels in a particular room (Figure 2), including: where the building is situated; the size and shape of the room; its placement relative to other interior spaces; surface treatment (which determines sound absorption) and construction of the ceiling, walls, and floor; the number, type, and location of sound sources, and the strength of the sounds they produce.

Designing to meet an acoustical target requires careful attention to all of these factors. A partial summary of design considerations follows. For more information, consult the *Classroom Acoustics* booklet published by the Acoustical Society of America (ASA, http://asa.aip.org) [5].

Note: Renovations and retrofits represent a considerable portion of the school construction market. Unfortunately, acoustical solutions are

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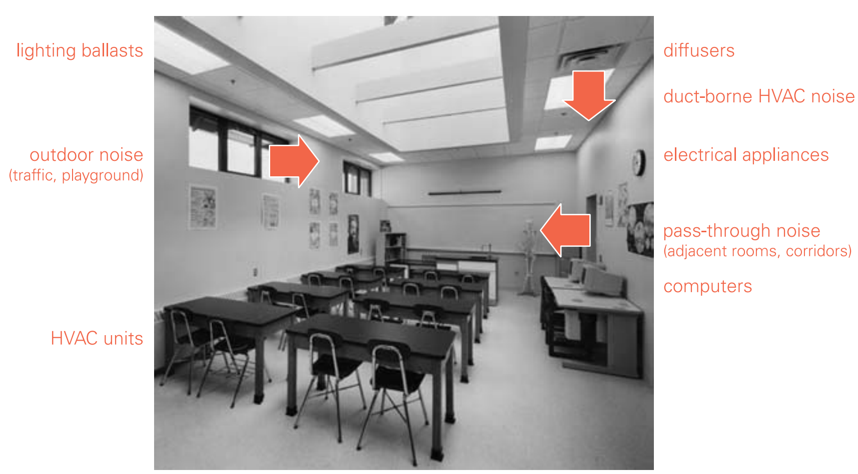
Figure 2. Sources of background noise in an unoccupied classroom



more difficult, and more costly, to achieve in existing facilities.

Background noise from external sound sources. Thoughtful siting of the school building, coupled with good landscape design, can help minimize the intrusion of traffic-related noise from nearby roads, flight paths, and railways. Give similar attention to building services and utilities by placing roof-mounted and grade-level equipment where it will not raise the background-sound level in classrooms.

To achieve the desired outdoor-to-indoor noise reduction, select construction materials with appropriate Sound Transmission Class (STC) ratings for the slab, roof, and exterior walls (including doors and windows).

Pass-through noise from adjacent spaces. Arrange classroom and non-classroom spaces to minimize the effect of occupancy-, equipment-, and environment-related noise that originates beyond the walls of the classroom. Specify construction that provides ceilings, floors, and partitions (including doors and other openings) with suitable STC ratings.

Wherever possible, **avoid open-plan classroom layouts**: although they support simultaneous student activities, they provide little opportunity to acoustically isolate one activity area from another. Sound from adjacent activities will seriously degrade speech intelligibility and will likely result in a background-sound level that exceeds the maximum limit set by ANSI/ASA S12.60–2002.

Note: The standard's limit on the background-sound level does not take into account the intermittent noise generated by students. Rustling paper, shuffling feet, and sliding desks or chairs make speech less intelligible.

Background noise from sound sources within the room. **HVAC equipment** is not the sole source of background sound in the classroom, but it is often the predominant source. Schools commonly choose HVAC systems that place equipment within each room rather than opt for more expensive centralized systems. Although this decision saves first cost, it provides few opportunities to attenuate the sounds generated by compressors and minimally ducted fans nor sounds introduced through outdoor-air intakes.

> *"background noise in most classrooms exceeded the recommended level by 10 dB to 15 dB even with the HVAC equipment turned off"*

With little practical means of attenuation, reducing the noise from units within (or near) the classroom becomes a matter of selecting quieter equipment. If units quiet enough to meet the acoustical target are not available, then the obvious solution is to move the HVAC equipment out of the classroom (or to fabricate an enclosure around it) and add ductwork to the supply and return openings. However, *simply moving the HVAC equipment out of the room will not guarantee a quiet classroom environment*. Enclosures and added ductwork will change the unit's performance—by reducing airflow (and capacity) and/or increasing the static pressure burden on the fan (which also increases fan sound). An acoustical analysis of fan, ductwork, and diffuser selections is critical to assess and, if necessary, refine the design of each sound path.

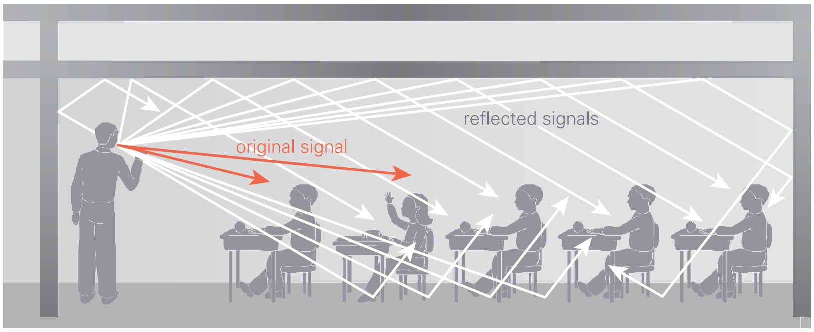
Building utilities and services also emit constant or intermittent sounds to the classroom. Actual measurements in existing classrooms disclosed cases where sound from light fixtures alone exceeded the limits set by ANSI/ASA S12.60–2002. Although the highest sound-level measurements in the Ohio study (see p. 2) coincided with HVAC operation, the background noise in most classrooms exceeded the recommended level by 10 dB to 15 dB *even with the HVAC equipment turned off* [6].

Evaluate the overall magnitude of sound that will result from the *simultaneous* operation of utilities and services to assure that it does not exceed the limit set by the standard. A further caveat: The standard also stipulates that the sound level from these sources must not fluctuate by more than 3 dB in any 5-second period, nor create an annoying sound like a buzz, rattle, whine, hiss, or whistle.

Note: ANSI/ASA S12.60 exempts sound generated by overhead projectors and other instructional equipment despite the sometimes significant contribution of these in-room sources to background sound.

Classroom size, proportion, and sound absorption. Sound waves that "bounce off" hard surfaces, such as walls and ceilings, create reflected waves that prolong the original sound (Figure 3, p. 4). This prolongation, which is described as *reverberation,* is measured in terms of the time it takes for a sound to diminish by a

Figure 3. Reverberation



fixed amount. (A drop of 60 dB in one second is written as RT_{60} = 1.0 second).

As a complement to the limits on background-sound level, the standard also limits reverberation time to 0.6 or 0.7 second, depending on room volume. Three factors determine reverberation: the volume of the room (size and ceiling height), its proportions (shape), and the extent to which the materials used on the walls, floor, and ceiling absorb sound energy. Careful placement of absorptive and non-absorptive materials can direct the teacher's voice to students without unwanted reflections.

The size and shape of a classroom also determines the loudness of the teacher's voice (signal) based on the distance between the teacher (signal source) and each student. At a distance of 3 ft, the loudness of a voice usually measures approximately 60 dB. However, each doubling of distance reduces the signal strength by roughly 6 dB. For a student sitting 6 ft away, the signal is 54 dB. At 12 ft, the signal is only 48 dB.

A microphone and multiple speakers can boost the teacher's voice and distribute it uniformly throughout the room, which facilitates lecture-style teaching. But voice amplification is, at best, a partial solution. The amplified sound may interfere with adjacent classrooms if the interior walls do not provide an adequate acoustical barrier. Class discussions will require additional microphones (or passing a single microphone from person to person), making two-way communication cumbersome.

Once is not enough. Attention to classroom acoustics does not end with the acceptance of an acoustically appropriate design. Subsequent modifications require review to assess their effect on the classroom's acoustical environment. Conscientious follow-through from the design phase through construction is equally critical to help prevent last-minute alterations from undermining the design.

Worth the Effort?

Compliance with a sound standard as stringent as ANSI/ASA S12.60–2002 is both time-consuming and costly. But is it also worthwhile, given school budgets that are already overtaxed? If one of the design goals is to make the building appropriately functional, then perhaps this is a better question: *What, if any, role does acoustics play in learning?*

Much of the education that takes place in K–12 classrooms hinges on oral communication. Each student plays an active role in that process by analyzing and evaluating what s/he hears based on individual experience and understanding of language.

When we miss or mishear the patterns of vowels and consonants that constitute speech, we automatically "fill in the blanks." The greater our vocabulary and experience, the more likely we are to guess correctly and the easier it is to separate what we want to hear (the teacher's voice) from the noise accompanying it (rustling papers, the hum of a fan). Deciphering unfamiliar sounds, such as new words or concepts, requires extra effort; the task becomes more difficult if the signal is unclear or distorted.

As inexperienced listeners, children 16 years of age and younger lack the knowledge and maturity to correctly infer meaning from missed and misheard words. While an adult can readily perceive spoken information that is only 50 percent intelligible, a child under the same circumstances will not understand most of what is said [7].

Less than acoustically optimal conditions in the classroom affect the academic performance of all students, but they pose a particular challenge for students learning in a non-native language, coping with learning disabilities, or hindered by impaired hearing. Studies show that such students suffer socially and behaviorally as well as scholastically [8].

How big is the problem? Experts believe that as many as one-third of all students miss up to 33 percent of

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the oral communication that occurs in the classroom [9].[†]

Evaluating Speech Intelligibility

Three attributes make it possible to prescribe and achieve a favorable listening environment: signal-to-noise ratio, reverberation, and speaker-to-listener distance.

Signal-to-noise ratio (SNR) indicates the intelligibility of spoken information by comparing the loudness of the teacher's voice (signal) to the background-sound level (noise) at a particular location (student's ear). The signal-to-noise ratio is simply the A-weighted signal level minus the A-weighted noise level. As the SNR increases, the signal becomes more distinguishable. Based on the considerable evidence available, experts have concluded that an SNR of +15 dB throughout the classroom provides the acoustical environment necessary for all students to fully perceive oral messages [10].

[†] The problem with poor classroom acoustics is not unique to the United States. The World Health Organization has established noise-level requirements, as have Germany, Portugal, Sweden, Italy, the United Kingdom, Australia, New Zealand, and South Africa.

Reverberation also affects the intelligibility of speech: It raises the overall noise level in the room, which lowers the SNR, and it overlaps the original signal with reflections that "blur" the sound of subsequent words (Figure 3, p. 4).

A 1978 study measured the effect of signal-to-noise ratio and reverberation time on speech recognition (Table 1) [11]. In a "relatively good classroom listening environment (SNR = +6 dB; RT = 0.4 second)," children with normal hearing correctly recognized 71 percent of the spoken message. Perception scores dropped to less than 30 percent in a "poor, but commonly reported classroom environment (SNR = 0 dB; RT = 1.2 seconds)" [12].

Speaker-to-listener distance (SLD) plays a role as well. As the distance between speaker and listener increases, the loudness of the signal, and therefore the signal-to-noise ratio, decreases (Figure 4). A separate study of 5-to-7-year-old children measured speech perception at SLDs of 6 ft, 12 ft, and 24 ft in a classroom setting with 0.45 second RT and a +6 dB SNR near the teacher. Mean perception scores fell from 89 percent at 6 ft to 55 percent at 12 ft, and to 36 percent at 24 ft [13].

Figure 4. Signal-to-noise ratio (SNR)

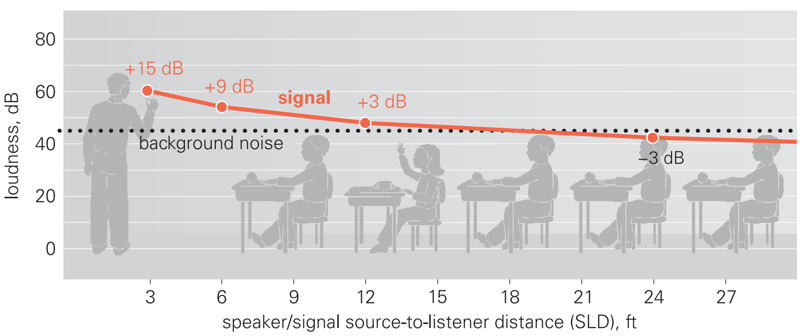

Table 1. Mean scores for speech recognition, % correct[a]

Test environment		Hearing sensitivity	
RT	SNR	Normal	Slightly impaired
0.0 second	quiet	94.5	83.0
	+12 dB	89.2	70.0
	+6 dB	79.7	59.5
	0 dB	60.2	39.0
0.4 second	quiet	92.5	74.0
	+12 dB	82.8	60.2
	+6 dB	**71.3**	**52.2**
	0 dB	47.7	27.8
1.2 seconds	quiet	76.5	45.0
	+12 dB	68.8	41.2
	+6 dB	54.2	27.0
	0 dB	**29.7**	**11.2**

[a] Table adapted from Finitzo-Hieber and Tillman, 1978. RT = reverberation time. SNR = signal-to-noise ratio.

This and other research point to an obvious conclusion: Classrooms can better support learning if they are designed with the acoustical characteristics of the finished space in mind.

Closing Thoughts

Although it is impossible to predict when, or even if, stringent classroom sound requirements will be mandated for schools, we do know this:

- The body of research substantiating the link between learning and the acoustical character of classrooms is extensive and compelling. Given the vested interest that each of us has in education—whether as a parent, a taxpayer, or an employer—classroom acoustics is sure to receive widespread attention.
- It *is* possible to create quieter classrooms using current technology

(design practices, construction materials, and equipment).

■ The education sector of the market for building construction and renovation is large and will remain so for years to come. The size of that market—coupled with heightened awareness of the effect of acoustics on learning access and academic performance—will undoubtedly prompt HVAC manufacturers to develop quieter classroom equipment. In the meantime, the acoustical benchmark set by ANSI/ASA S12.60–2002 is likely to favor ducted systems.

On this basis, it is reasonable to conclude that quieter classrooms will soon become a requirement.

The number of variables in an acoustically appropriate design precludes a one-size-fits-all formula. But a "good" listening and learning environment *is* achievable if classroom acoustics are considered at the outset of the design process, *and* with *early* collaboration of school planners, architects, contractors, and suppliers.

Accurate sound data, acoustical analyses, detailed specifications, appropriate materials, and careful construction can help to assure that the classroom environment adequately limits background noise and reverberation. ■

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Endnotes

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