Classroom Acoustics for Architects

A companion booklet for ANSI/ASA S12.60 Parts 1 and 2

A publication of the Acoustical Society of America

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How to Use this Booklet

This booklet is intended as a reference and as an educational resource for architects, design teams, and the schools they serve. The booklet can be read front to back (recommended) and explains the whys and wherefores of the standard all the way to the “how to”. The following table breaks down the subject matter so that one can read about a particular topic for clarification, or read about a subject on a given level. Note that the mechanical and plumbing issues are presented in appendices so they can be easily shared with your engineering consultants.

Topic	Introductory	Intermediate and suggested approaches	Design Application
Site Selection	Section 3, 4	Section 4	See OITC
Background Noise	Section 2, 3, 5	---	---
Room Acoustics and Reverberation Time	Section 2, 6, 7,10	Section 8	Section 12
STC-Isolation (Sound Transmission Class)	Section 6, 7	Section 11, 13	Section 16, 17 Appendix D
Isolation-IIC (Impact Isolation Class)	Section 6, 7	Section 11,13	Section 16
OITC Isolation (Outdoor Indoor Isolation Class)	Section 4	Section 11	Section 17
Teaching Technology	Section 1	Section 9	Section 18
Mechanical /Plumbing	---	Section 14, 16	Appendix B and C
Vibration Control	Section 6	Section 14	Appendix B and C
Sound Reinforcement	Section 9	Section 15	N/A

You will find the appendices of this booklet a useful resource- Take a moment to look through them.

WE RECOMMEND YOU HAVE A COPY OF THE ANSI/ASA S12.60 STANDARD AVAILABLE FOR REFERENCE WHEN YOU ARE READING THIS BOOKLET.
It is available as a free download at https://global.ihs.com/home_page_asa.cfm?&rid=ASA.

Section 1: In the beginning, there was Silence!

"I would trade all of my technology for an afternoon with Socrates."

Steve Jobs, CEO Apple Computer, *Newsweek*, October 29, 2001

Remember that Socrates preferred to teach in the open air?

"I teach under a tree!"

But how realistic is this in the modern world? Weather, daylight, and of increasing importance, technology, all require that teaching take place in specialized environments where students not only can see and hear the teacher, but where comfort and provisions for changing technology can also be accommodated.

Notice the surroundings in the illustration above where the teacher talks in close proximity to the students. Pleasant. Peaceful. Quiet surroundings. But today's students live in a world of constant distraction where products, PCs, peers and all variety of 'pods and pads' compete vigorously for their attention.

Not to mention background noise…

Frequently asked questions:

Does meeting the ANSI/ASA S12.60 standard increase the cost of my building? Employing good practice in layout of the building/building systems and use of typical construction materials can meet the standard when the surrounding environmental noise is normal. Bringing an acoustical consultant familiar with the requirements on board early to help with layout can save considerable headache and money further into the project. A poor footprint and placement of mechanical systems can result in a need for heavier/more robust constructions and other noise control measures.

Does all of the ANSI/ASA S12.60 standard need to be met in LEED? Currently LEED partially adopts the standard and LEED is revised every two years. LEED is moving toward full adoption of ANSI/ASA S12.60 as the design and construction industries adapt to the requirements; LEED is working on best methods to simplify the integration of the standard.

What is the standard based on? Please refer to **Appendix G** for a list of references.

Why not use sound systems to overcome background noise and ensure the teacher is heard? Please refer to **Section 15** on sound reinforcement in the classroom.

Section 2: Why a classroom acoustics standard? Comprehension!

Studies have shown that students learn faster, and comprehend and retain more knowledge in the proper acoustic environments; this is even more critical for the youngest students who are still learning how to pronounce words. A good acoustic environment is particularly important for students with hearing impairment or learning disabilities.

How effectively can students learn if they cannot both hear and understand their teachers? What can designers do to ensure the intelligibility of speech in the classroom? It's critical to recognize that good room acoustics and low background noise go hand in hand in achieving this successfully, and that they must both be addressed in tandem.

Note:

The new ANSI/ASA Standard S12.60: Part 1 applies to classrooms in permanent schools, Part 2 applies to modular or relocatable classrooms.

The Standard does not apply to natatoria, auditoria, music performance spaces, teleconferencing classrooms or special education classrooms for the severely acoustically challenged students which all require special acoustical design and treatment that is not within the scope of this standard.

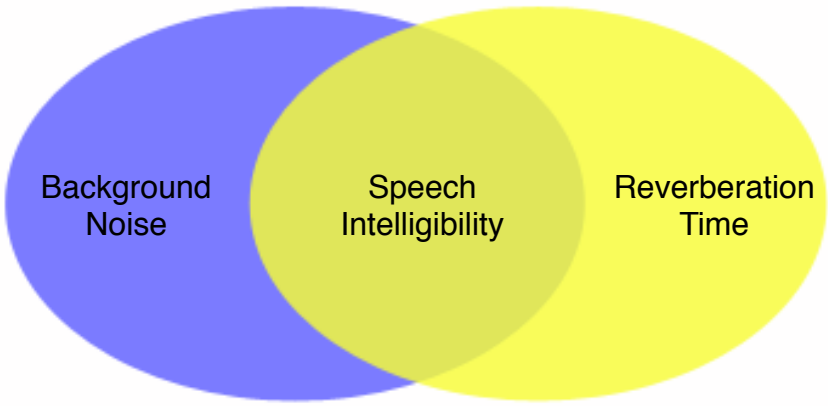


Figure 2.1: Achieving speech intelligibility in classrooms. The target of good speech intelligibility requires attention to both background noise levels AND reverberation time.

Comprehension and the resulting academic achievement require concentration and focused attention.

To eliminate noise and distraction, it's important that the designer to understand how sound is transmitted into and throughout the classroom in order to minimize distraction caused by background noise and to support audible speech.

Section 3: Background noise

"Noise in and around buildings affects 100 percent of the population all or most of the time."

-Technology for a Quieter America 2010

What is "Background Noise?" It's the average sound level created by any combination of nearby noise sources as measured in the classroom of interest.

All of these possible noise sources defined below can contribute to background noise and should be considered in the placement of classrooms, and in the wall type for exterior walls and partitions between rooms:

- Outside environmental noise from traffic, aircraft, and industrial sources should be considered during site evaluation and selection.
- Schoolyard and maintenance noise need to be considered, and they can be addressed in the design stage as well as mitigated through appropriate scheduling policy.
- Inside noise from adjacent spaces (classrooms next door, corridors, restrooms, mechanical rooms, etc.) should be considered in the design stage and noise from these spaces can be reduced or abated by careful placement in the first phases of planning.

All of these sources of noise can be addressed by proper noise and vibration control, including placement of mechanical equipment, proper design of walls, floors, and ceilings, vent layout/HVAC design and plumbing design. Selection of quiet devices or building systems (HVAC, plumbing, lighting) can also play a critical roll in noise reduction.

Note: the unwanted sounds from other people speaking in the room such as a disruptive student are not addressed in this booklet

Background noise is the average sound level measured in decibels, or dB. The human ear filters sound somewhat and is less sensitive to low frequencies; this is approximated by weighting the measurement mathematically. The resulting weighted and averaged sound level is called A-weighted decibels or dBA and is an approximation of the human perception of sound level at normal listening levels. As sound levels increase, the human ear filter changes, and at higher levels the filter approximation is called C-weighted or dBC.

Note:

In this booklet and most commercial literature, dB and dBA are used interchangeably. dBC is only referred to as “dBC”.

Let’s take a look at a table from the ANSI/ASA S12.60 standard that lists allowable levels to get an idea of the numbers.

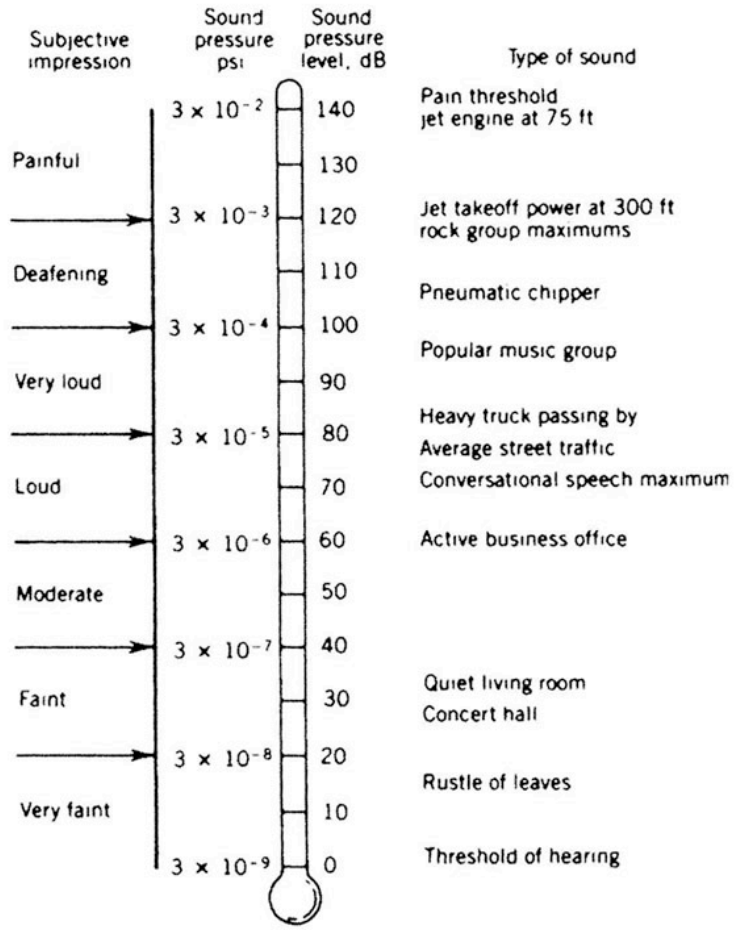
Learning Space	Greatest allowable one-hour-average A- and C-weighted background noise level (dB)
Core learning space with enclosed volume ≤ 283 m^3 (≤ 10 000 ft^3)	35 / 55
Core learning space with enclosed volume > 283 m^3 and ≤ 566 m^3 (> 10 000 ft^3 and ≤ 20 000 ft^3)	35 / 55
Core learning spaces with enclosed volumes > 566 m^3 (> 20 000 ft^3)	40 / 60
Ancillary learning spaces (any volume)	40 / 60

Specific notes for this table are found in the ANSI/ASA S12.60 standard as Table 1 in Section 5.2.1.3.

Table 1: Greatest allowable background noise

So what is 35 dBA? 40 dBA? Before we get much further, let's take a look at sound levels that you may be familiar with ...

These examples should shed some light on sound levels for a few sources of “noise” we have all experienced.



From William J. Cavanaugh “Acoustics-General Principles” in Encyclopedia of Architecture: Design, Engineering, and Construction, ed. Joseph Wilkes, Wiley & Sons, Inc.1988. Graphic used by permission.

Section 4: Bringing the outside in? A bit about site selection

Outdoor noise and selection of sites for learning facilities: Site background noise levels should be measured by a qualified professional.

The noise level evaluation should consider all current and future sources. It is critically important that learning facilities not be located at sites where, depending on the anticipated construction method, the greatest outdoor one-hour average A-weighted sound level, herein called "background noise level" exceeds the following limits:

<55 dBA

1. Where the outdoor background noise level is less than 55 dBA, conventional construction methods may be used, provided the external walls are designed to have an OITC rating not less than 30 dB

55 - 60 dBA

2. Where the outdoor background noise level is between 55 dBA and 60 dBA, conventional construction methods may be used, provided the external walls are designed to have an OITC rating not less than 25 dB below the greatest outdoor one-hour average A-weighted sound level [e.g. if the greatest outdoor one-hour average A-weighted sound level is 60 dB, the OITC rating must not be less than 60 - 25 or 35 dB]

61 - 65 dBA

3. Where the outdoor background noise level is between 61 dBA and 65 dBA, the external shell must be designed to provide adequate noise isolation and to conform to the limits for background noise levels (as listed in Table 1 in the previous section.) The external walls should be designed to have an OITC rating not less than 26 dB below the greatest outdoor one-hour average A-weighted sound level. Construction techniques are not typical and construction workmanship must be carefully monitored.

Note:

OITC is the abbreviation for "Outdoor-to-Indoor Transmission Class" and is a single number descriptor (similar to STC or "Sound Transmission Class") that rates the airborne sound attenuation qualities of a building element (roof, wall, door, window). A higher OITC indicates a greater ability to reduce airborne sound, from outdoors, through the assembly. As with the STC rating, it is measured in accordance with procedures specified by ASTM Standards. See Clause 3.2.5.2 in ANSI/ASA S12.60, Part 1, for further details.

STC will be covered in detail in section 11, 13, and 16. We will briefly revisit OITC in Section 11.

**Note*:

In determining the greatest outdoor one-hour average A-weighted sound level , current and future levels must be considered, including a margin for safety for an increase in level in the future and other uncertainties. Widely accepted models of industrial and transportation noise are available from environmental planners and acoustical consultants.

***Note*:

Sound pressure level in the ANSI/ASA S12.60 Standard is measured in A-weighted decibels and is often expressed as dB.

66 - 70 dBA

4. Where the outdoor background noise level is between 66 dBA and 70 dBA, the external shell must be designed to provide adequate noise isolation and to conform to the limits for background noise levels (as listed in Table 1 in the previous section) and the external walls designed to have an OITC rating not less than 27 dB below the greatest outdoor one-hour average A-weighted sound level. Construction techniques are not typical and construction workmanship must be carefully monitored.

71 - 75 dBA

5. Where the outdoor background noise level is between 71 dBA and 75 dBA, the external shell must be designed to provide adequate noise isolation and to conform to the limits for background noise levels (as listed in Table 1 in the previous section) and the external walls designed to have an OITC rating not less than 28 dB below the greatest outdoor one-hour average A-weighted sound level. Construction techniques are not typical and construction workmanship must be carefully monitored.

76 - 80 dBA

6. Where the outdoor background noise level is between 76 dBA and 80 dBA, the external shell must be designed to provide adequate noise isolation and to conform to the limits for background noise levels (as listed in Table 1 in the previous section). Construction techniques are not typical and construction workmanship must be carefully monitored and the external walls designed to have an OITC rating not less than 29 dB below the greatest outdoor one-hour average A-weighted sound level but not greater than 50 dB.

> 80 dBA

7. Where the outdoor background level is greater than 80 dBA, do not build. Another, quieter site should be selected as allowable noise levels will be extremely difficult to achieve regardless of construction method or workmanship.

A detailed table of the above design requirements is in the ANSI S12.60 Standard, Part 1 under Table 3 in section 5.4.1.4.

Section 5: Background noise-How much is OK?

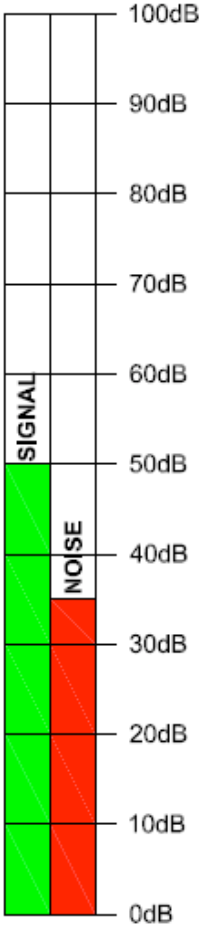


Figure 5.1: A signal to noise ratio of 15 dB; at least 15 dB is required for good intelligibility, but not sufficient by itself to guarantee it. A smaller ratio means that speech intelligibility suffers.

A moderate level for a teacher's voice is around 67 dB at 1 meter (3 feet). However, as the sound waves spread, the sound level drops with distance. A well-designed room that provides useful early sound reflections will in turn provide support to an instructor's voice to a level of about 50 dB at the farthest areas, which can cover more than half the room. Without support, 50 dB is not realistic at these farthest points.

To ensure good speech intelligibility, we need to maintain an average differential between speech level and background level (called signal to noise ratio) of about 15 dB, which means the A-weighted background noise level should not exceed about 35 dB (this is the accepted background noise level per the ANSI/ASA Standard for typical classrooms, (volumes less than 20,000 ft^3)).

That is, 50 dB (signal) minus 35 dB (noise) equals a signal to noise ratio (a relative sound level), of 15 dB.

Rather than boost the instructor's voice through electronic amplification (more on that later), we have to work to keep the background noise level inside the unoccupied classroom from exceeding 35 dB. This is where systems detailing and construction techniques come into play.

A closer look at dBA levels: The background noise is reported as a single number (dBA), but acousticians understand that the single number is actually a logarithmic sum of the weighted raw decibel levels for each frequency band (tell your kids that at the breakfast table!). Humans are less sensitive to lower frequencies and the A-Weighting reflects this.

So what are C-Weighted levels? C-Weighted levels are a measure of the sound, which does not attenuate low frequency sounds as the A-weighting does, and they are limited to values not more than 20 dB above those for the A-weighted levels.

This limitation is shown in **Table 1** in **Section 3** above.

To summarize weightings, all people are very sensitive to the speech range frequencies (mid range and high frequencies), and as indicated above, A-weighting emphasizes them over low frequencies while C-weighting does not.

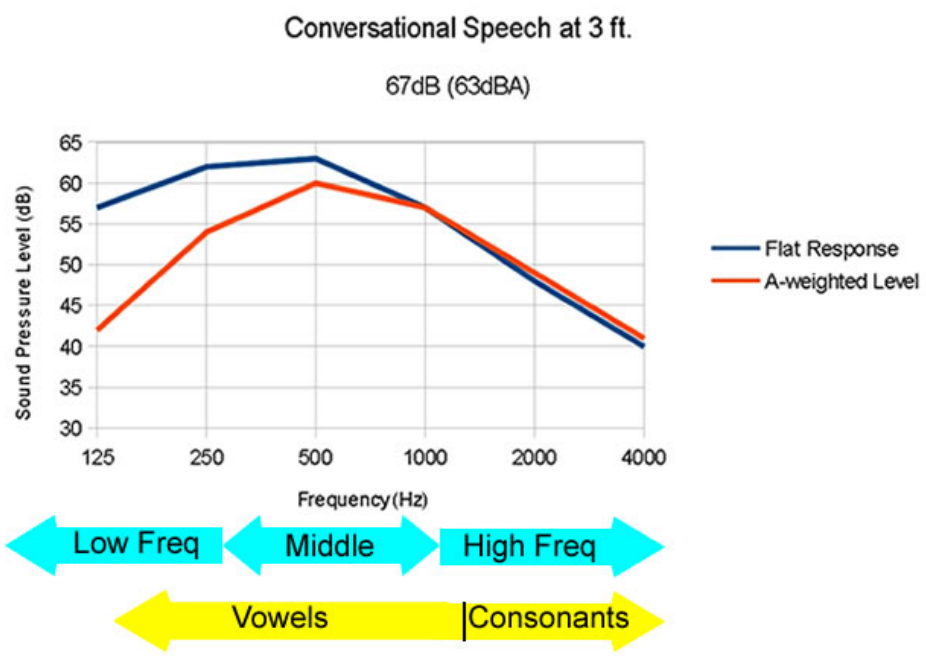
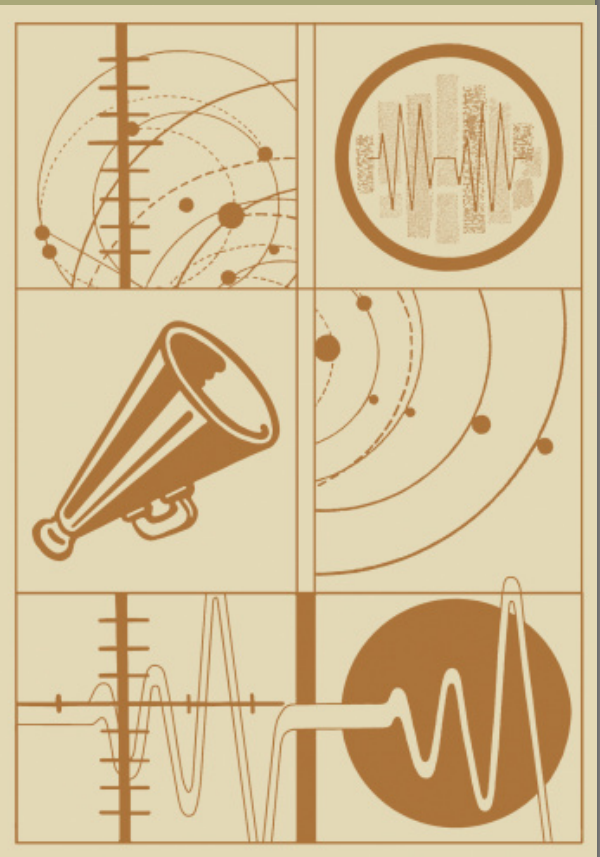
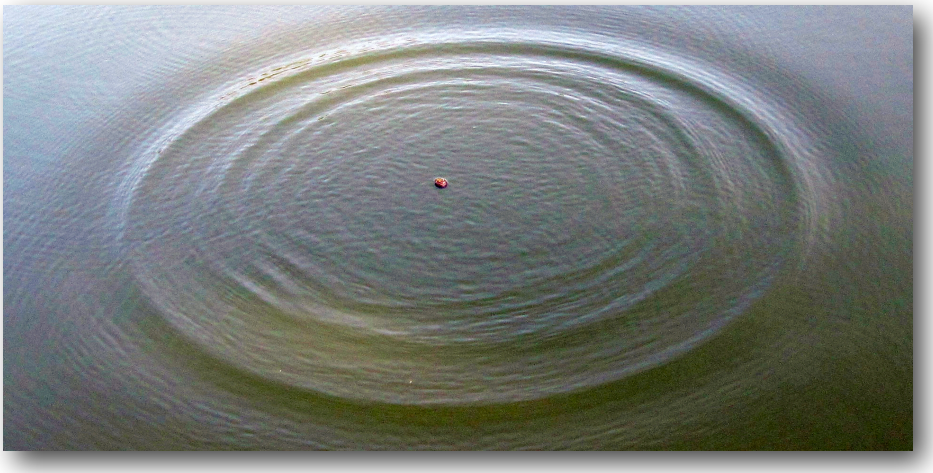


Figure 5.2: Average frequency content of the male human voice. Notice that the A-weighted signal has less low frequency sound pressure (weighted out to simulate the response of the human ear), and that the single number descriptors (67 dB, 63 dBA) are the logarithmic sum of the values on the graph. As you can see, the A-weighted overall level (dBA) is lower than the "flat" or raw signal (dB) due to the weighting of the signal. The C-weighted response curve in this case matches the blue (flat) curve. Also note the low, middle, and high frequencies; speech utilizes predominately middle and high frequencies for intelligibility cues. Data from "Architectural Acoustics" Egan 1988.



We need to talk a bit about sound waves: their frequency, transmission, reflection, reverberation, absorption and about impact sound. In addition we need to discuss how sound travels, what constitutes noise, and suggest some simple control and mitigation strategies.

Section 6: Sound waves 101-What are they?



Different types of sounds each contain a different combination of frequencies - i.e., speech, traffic, equipment fans and motors, aircraft, music, etc. Each has its own frequency signature (a smoothed signature of the male voice is shown in Figure 5.2). All voices have different “signatures” that we can perceive with our own ears–not only can we usually tell the difference between male and female, but sometimes we know who it actually is!

Impact sound is a special case where the waves or vibrations originate from physical impact with a surface like a floor or a wall (footsteps, moving furniture, etc.). The vibrating wall or ceiling becomes a loudspeaker that broadcasts the impact as audible sound.

Like the ripples formed when an acorn is thrown into a pond, sound travels in waves in all directions from a point of origin. The distance between the peaks in the ripples relate to the frequency of a sound – the larger the distance, the lower the frequency of the sound.

Sound travels through the air as a pressure wave that bumps the air molecules s it propagates until it encounters a surface. If that surface is your eardrum, the sound wave excites the eardrum, which sends signals to the brain that allows you to perceive the sound.

In architecture, when the sound encounters a wall or other surface it may be reflected, absorbed, and/or transmitted. That is, some energy comes back (reflected), some is turned into heat (absorbed), and some continues through (transmitted).

See Figure 6.1.

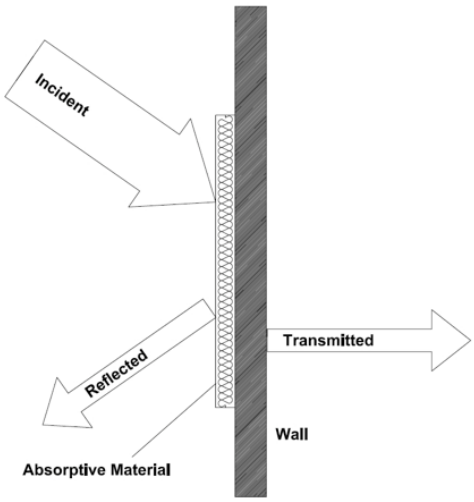


Figure 6.1
Reflection, Absorption and Transmission of sound energy

Section 7: How best to limit sound transfer into spaces

Controlling each type of sound (frequency signature) requires a special strategy.

Transmission of unwanted sounds through an assembly can be reduced with appropriate floor / ceiling and wall details. They are designed to dissipate and / or limit the passage of airborne or impact sound energy by using (for instance) additional mass, staggering double wall studs or adding attenuation blankets (for these and other examples see the section “Simple Initial Mitigation Strategies).

Reflection and absorption of sound energy inside of a room is determined by room finishes; sound absorbing finishes (i.e., acoustical tile or wall panels) can reduce the sound level in a room before it can be transmitted to adjacent spaces.

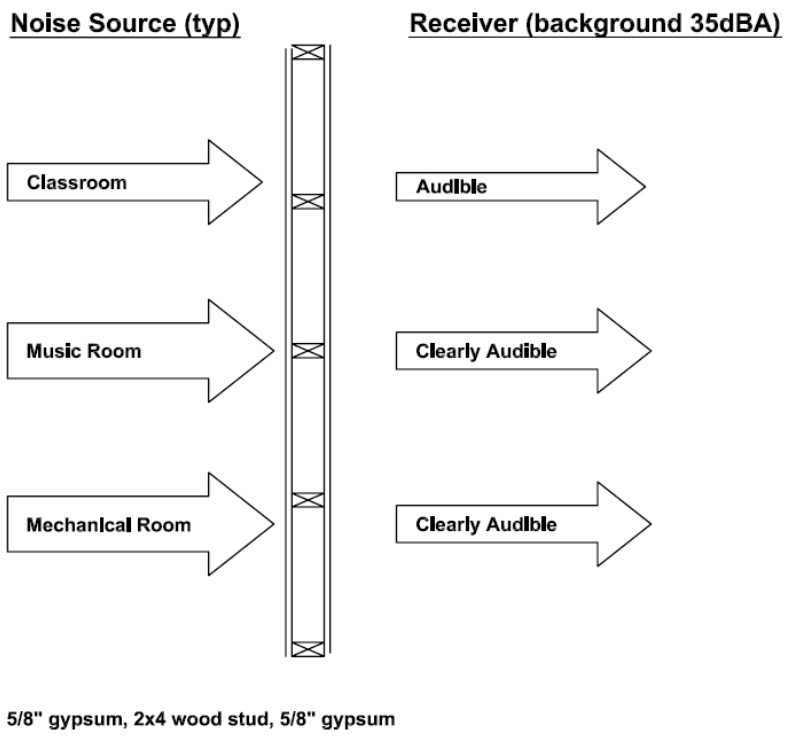
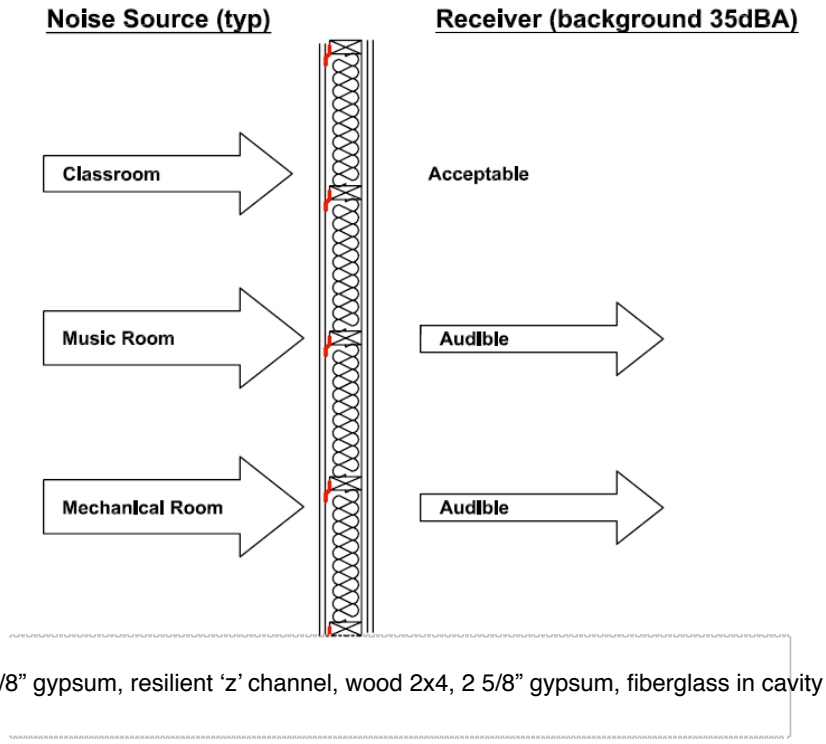
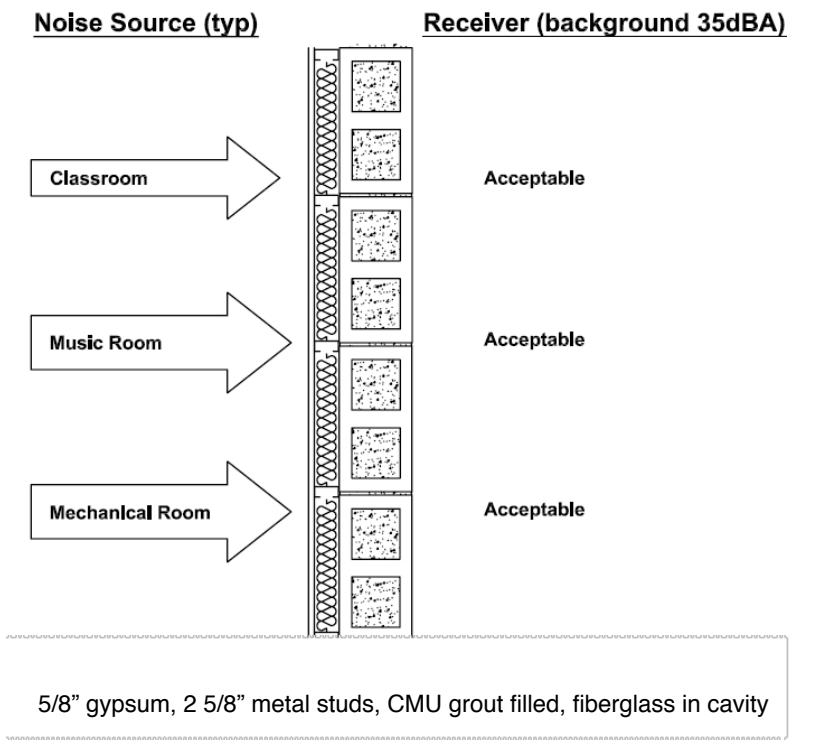


Figure 7.1: Example of wall construction - typical school sources and receiver perception. See next page for additional construction types.

Note:

These are shown as conceptual examples; all constructions employed for your design should have performance verified by available lab reports.





Figures 7.2 and 7.3: Examples of wall constructions - typical school sources and receiver perception.

Note:

These are shown as conceptual examples; all constructions employed for your design should have performance verified by available lab reports.

Section 8: Absorbing sound

We have already discussed reducing transmission of sound, to stop noise from entering a space. When sound enters a space, or originates in that space, its behavior is affected by the room finishes. If the room has all hard surfaces (sound reflecting), this will make the room more “reverberant” and sound level in the room can build up due to reflections. Softer surfaces such as acoustic ceiling, wall panel treatments, and carpeting, can reduce noise and reverberation of sound and will increase the intelligibility of speech.

Reverberation time is a measure of the time in seconds it takes for an impulse of sound such as a loud hard clap to decay by 60 dB (become inaudible) in a space. Lower reverberation time yields better speech intelligibility by minimizing the audible blurring of individual speech sounds

Learning Space	Maximum Reverberation Time (in seconds)(a)
Core learning space with enclosed volume ≤ 283m^3 [≤ 10,000 ft^3]	0.6 (b)
Core learning space with enclosed volume > 283m3 and ≤ 566 m^3 [> 10,000 ft^3 and ≤ 20,000 ft^3]	0.7
Core learning space with enclosed volume > 566 m^3 [>20,000 ft^3] and all ancillary spaces	no requirement

Table 2: Maximum acceptable reverberation time in unoccupied, furnished learning spaces. Note that a lower time increases the speech intelligibility in a room.

Note (a) Reverberation times in octave bands with midband frequencies of 500, 1000, and 2000 Hz.

Note (b) Core learning spaces ≤ 283m^3(≤ 10,000 ft^3) shall be readily adaptable to allow reduction in reverberation time to 0.3 sec, typically through the use of added absorptive materials on the walls or ceiling.

Note:

Good sound absorbing materials such as fiberglass typically are not very good as sound barriers, and good sound barriers such as gypsum wall board are not good sound absorbers.

Layering of the two in tandem is an effective solution to achieve both goals, or for noise reduction between spaces.

Section 9: Changes in teaching tools and technology

Filmstrips and overhead projectors have graduated to ‘smartboards’ and video. Student laptops, digital (overhead) projectors, and desktop computers all employ cooling fans; add in cell phones, ipods, lighting ballasts, motors, and mechanical equipment for a classroom cacophony.

Control of in-classroom technology sound buildup is achieved through the use of absorption on the ceiling and walls, and with any groupings of sources such as computer stations, localized absorption is recommended. Line of sight barriers between the source and listener such as absorptive open-office barriers can be employed. Additional information is in Clause 5.5 of the ANSI/ASA standard.

Technology also includes sound amplification; for classrooms under 50,000 ft^3 (all classrooms or core learning spaces covered by this booklet), a properly designed classroom usually does not warrant amplification except for video, recorded audio or internet presentations. There are benefits to employing amplified sound such as saving a teacher’s voice, or temporarily overcoming background noise issues. However, it is important to recognize that without FIRST addressing the background noise and room acoustics, amplification can create new problems (see Section 15 in this booklet on amplification).

Section 10: Audible speech and intelligibility

To summarize so far, designers should focus on providing an acoustic environment that promotes intelligible speech while reducing background noise, reducing impact sound, and providing appropriate reverberation.

How is this achieved?

Background noise must be treated in tandem with room acoustics, because without addressing both, speech intelligibility will suffer, and as a result, students' ability to learn and comprehend will suffer.

Recent studies indicate that younger students require extremely high intelligibility of speech, because they are not able to "fill in the blanks" for garbled sounds or words the way older students can.

Speech intelligibility can be estimated in models for design purposes or measured in existing spaces. A model of a classroom is shown in figures 10.0 to 10.4, and it is evaluated using one of the metrics for measuring speech intelligibility called the Speech Transmission Index (STI). STI is a well-established objective measurement predictor of how the characteristics of the transmission channel affect speech intelligibility.

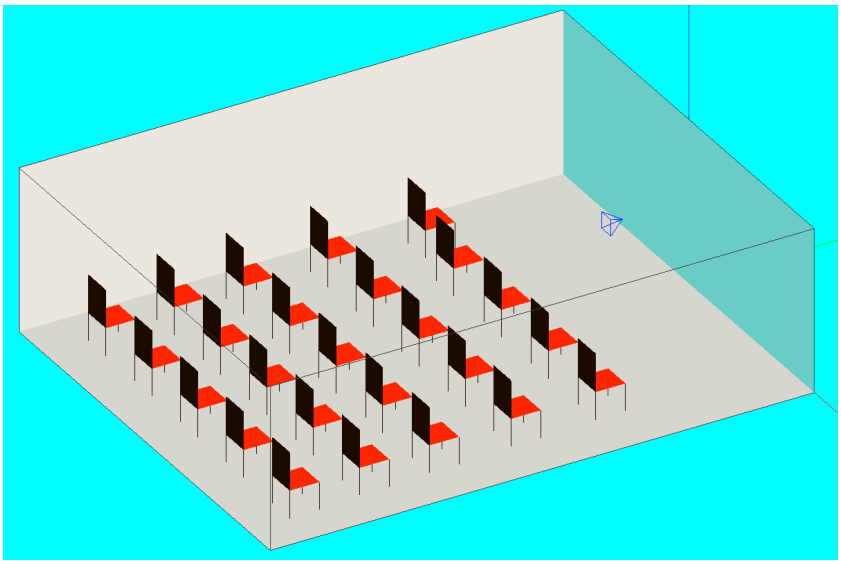


Figure 10.1: An acoustic model of a classroom with a sound source at the front of the room representing a teacher. The floor is hard, the walls are painted concrete block, and the STI is evaluated for an empty room with a gypsum board ceiling and an acoustic tile ceiling.

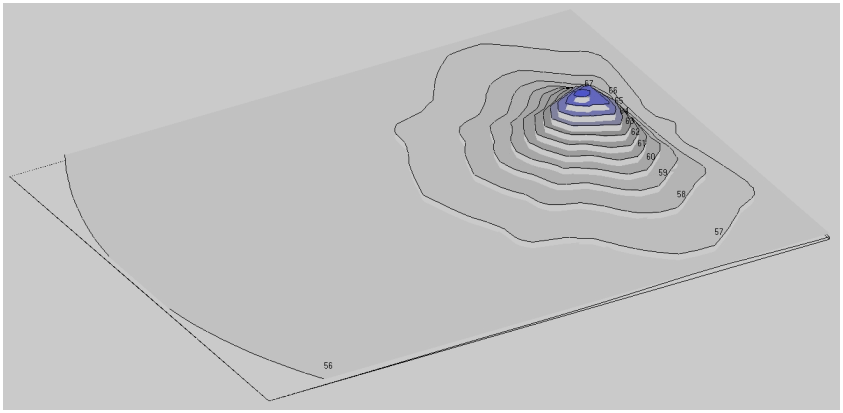


Figure 10.2: Distribution of sound level at ear level in the room with sound emanating from the lecturer position using an acoustic ceiling tile. Here the sound level drops from the lecturer position to the farthest reaches by 12 dB. A larger classroom would see a bigger drop off of sound level at the extremes of the room. Our background noise is set at the ANSI/ASA S12.60 standard of 35 dBA, so we should have a good signal to noise ratio as discussed on page 10, as our level furthest from the source is shown as 56 dBA.

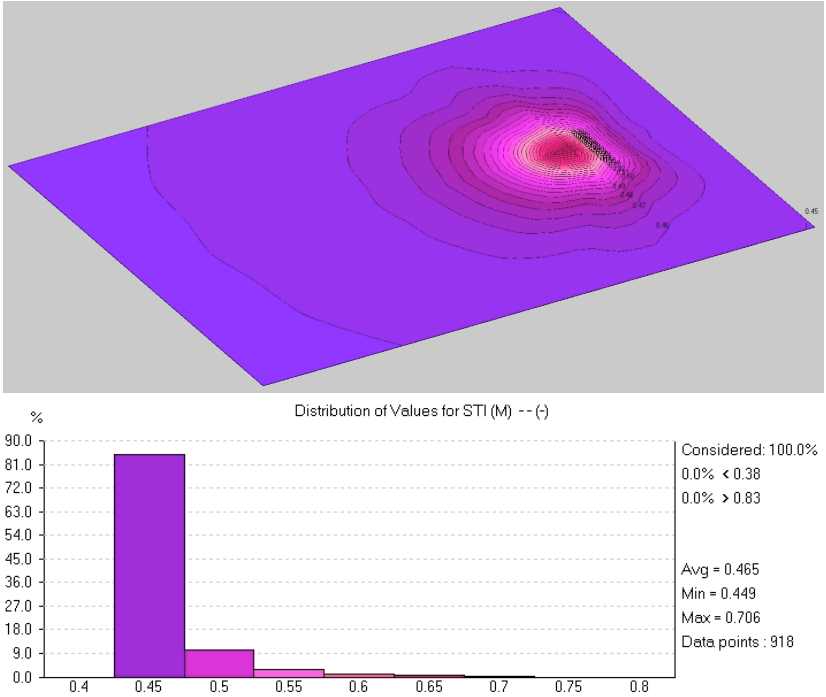


Figure 10.3: STI distribution at ear level of an unoccupied classroom with a gypsum ceiling. Most of the room is considered on the border of “fair” and “poor” (0.45) as seen in the distribution bar graph.

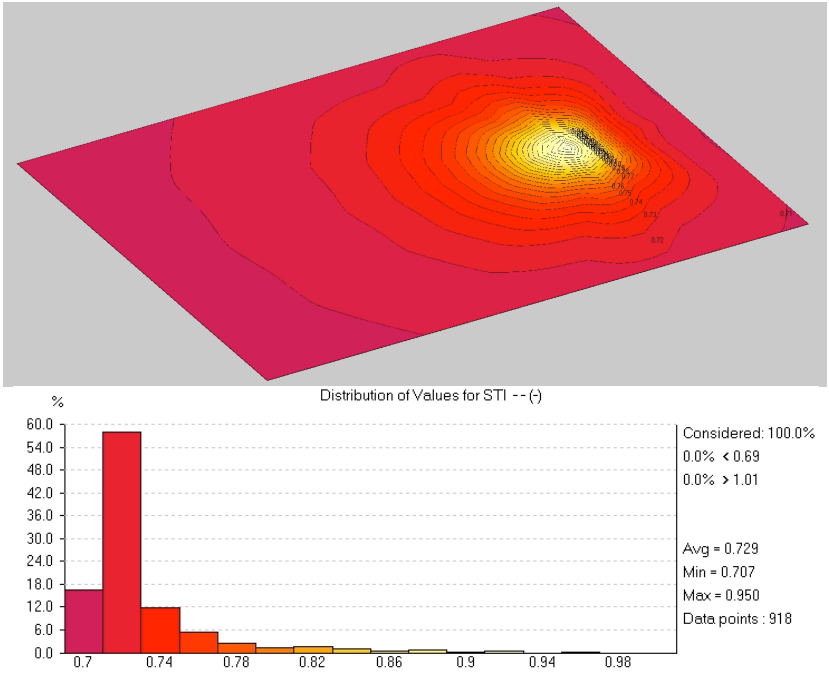


Figure 10.4: STI distribution at ear level of an unoccupied classroom with a 0.7NRC acoustic tile ceiling. Most of the room is considered on the border of “good” bordering on “excellent” (0.72) as seen in the distribution bar graph. This improvement over the STI rating in Figure 10.3 is due to the addition of sound absorptive material in the ceiling. In both cases shown in Figures 10.3 and 10.4, the addition of furniture and people will increase the absorption of sound and further improve the intelligibility somewhat.

Section 11: Decoding STC, IIC, OITC, and composite construction

No perfect world

source	wall STC	receiver (background 35dBA)
conversational sound levels	30	Sentences understood
	40	Effort to understand words and phrases; sound perceived
raised speech sound levels (classrooms)	50	Effort to hear speech
	60	Loud speech not heard. Music faint, some low frequency transfer

Figure 11.1 Perception of speech sound vs. STC
Mehta, "Architectural Acoustics - Principles and Design," Prentice Hall, 1999

Sound Transmission Class (STC) Rating:

Much like fire ratings, different building materials and different wall details provide different sound transmission ratings as a single number descriptor that rates the airborne sound attenuation qualities of a building element (ceiling/floor, wall, door, window, etc.). **A higher STC indicates a greater ability to reduce airborne sound through the assembly.**

Understanding the required STC ratings can help determine what wall type is best suited to what situation (ANSI/ASA S12.60 has specific requirements based on what occupies the adjacent side of a wall or floor).

Different wall construction types yield very different STC ratings. You may be surprised at the low ratings of typical stud wall constructions. But there are subtle changes you can make to your wall types that will enhance their ability to contain sound and limit transmission. While some of these changes will impact construction cost, they will control sound and greatly enhance listening comfort.

Minimum STC ratings for a monolithic or composite wall, floor-ceiling, and roof-ceiling assemblies depend on the adjacent spaces. Example layouts representing core and ancillary learning spaces are shown in **Section 13**, "Isolation- A Strategy to Limit Sound Transmission". Tables 4 and B.1 of ANSI/ASA S12.60/Part 1 further clarify the requirements.

Outdoor Indoor Transmission Class (OITC) rating: Sound from the outdoors incident on a building facade or roof is treated differently than sound transmitted between two rooms inside a building, and the sounds themselves are different. The OITC rating takes this into consideration: OITC ratings are normally less than STC ratings of the same assembly.

ANSI/ASA S12.60 Section 5.4 establishes the OITC requirements for the building facade based on the loudest known outdoor levels from site monitoring. Not all windows, doors, and building facade elements have an OITC rating, so it is advised that a qualified professional be charged with verifying the design performance to meet the standard.

Impact Insulation Class (IIC) rating: Impact noise from footfalls, rolling equipment, dropped items, or similar sources must also be addressed. It is important to note that the IIC of an floor/ceiling assembly can be very different from its STC; STC addresses airborne sound, while IIC addresses the sound resulting from impacts on the other side of a construction*.

IIC ratings of floor/ceiling assemblies should have an un-carpeted IIC rating of at least 45 if they are located above core learning spaces and a minimum IIC 40 if they are located above ancillary learning spaces.

Gymnasia, dance studios, or other spaces that host high floor impact activity should not be located above classrooms or other core learning spaces for any new construction. If it is unavoidable in a retrofit/renovation situation the following IICs apply:

1. IIC 70 if located above a core learning space <20,000 cu. ft.
2. IIC 65 if located above a core learning space >20,000 cu. ft.
3. IIC 65 if located above an ancillary learning space

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.

For examples of both STC and IIC ratings of various constructions, see Section 16 “Simple Mitigation Strategies”.

***walls are rated with STC while floor/ceiling assemblies are rated with <u>both</u> STC and IIC.**

Composite Construction and STC:

While a wall, roof or floor has a STC rating, it is important to note that the rating assumes that the construction is monolithic with no breaks, and sealed airtight at the edges. If we put a door or a window in the wall, it is considered a composite construction and the STC rating of the wall changes.

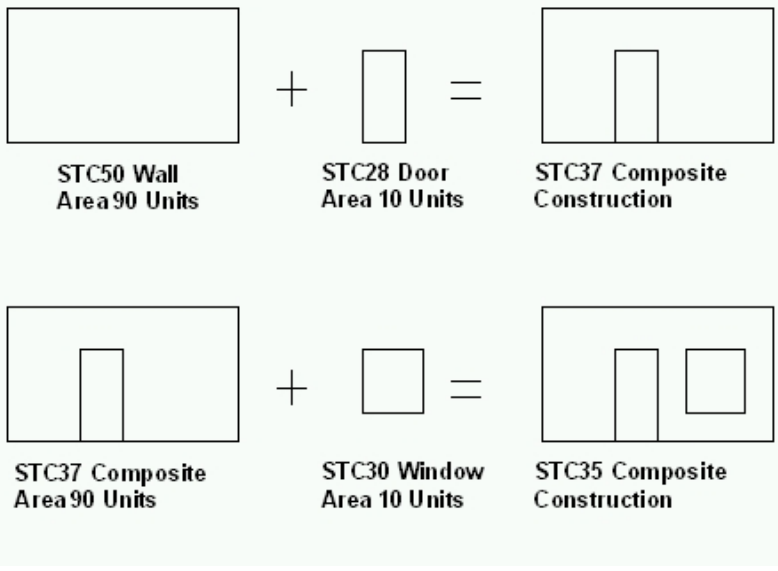


Figure 11.2

Figure 11.2: Composite construction graphic representation

Note that the larger difference of the STC of the elements creates a significant effect on final STC. Better matched elements will save money and effort.

Appendix D contains tables and sample calculations for composite construction as well as a table used to make a rough estimate for OITC of the outer building shell.

Section 12: Reverberation-the persistence of sound

and suggested treatment with absorption

In Section 8 “Absorbing Sound”, the maximum reverberation time for Core Learning Spaces (unoccupied, furnished) in the octave bands 500, 1000, and 2000 Hz were quantified. Why these octave bands? These octave bands are the most important to the intelligibility of speech, and if they are controlled, it is likely that the neighboring octave bands will be similarly controlled. Figure 12.1 below indicates where the majority of speech frequencies lie relative to these critical bands.

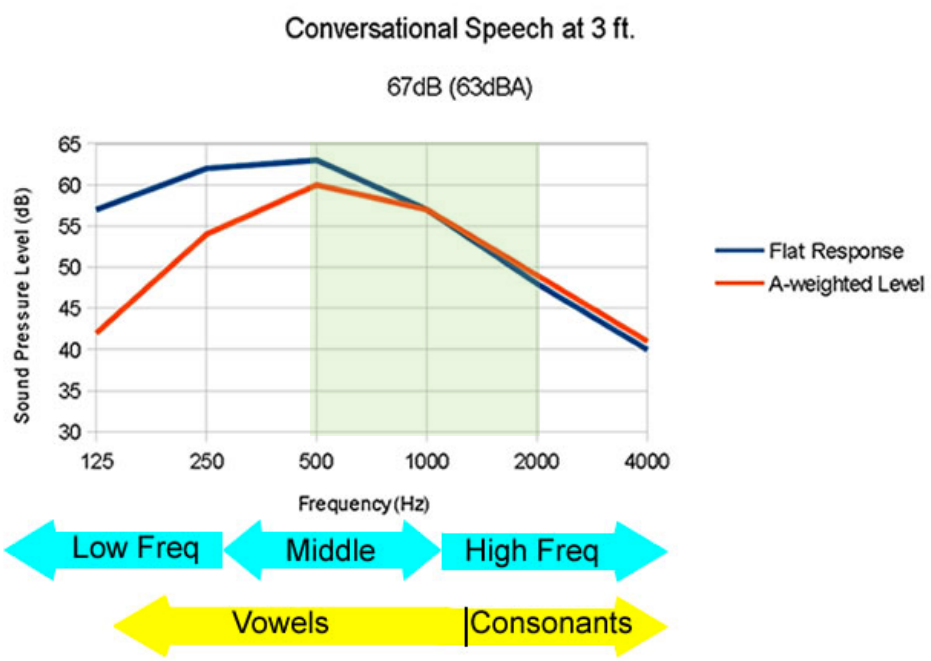


Figure 12.1: Average frequency content of the male human voice.
Data from “Architectural Acoustics” Egan 1988.

Above yet another acronym has been introduced, NRC, or Noise Reduction Coefficient. This is an arithmetic average of the absorption coefficients of a material or surface in the 250Hz, 500Hz, 1kHz, and 2kHz octave bands. It is a good indicator of how the material reacts with speech sound energy; a number closer to 1 indicates that it absorbs most of the energy, and close to zero indicates it reflects most of the energy (the range is 0-1, which correlates roughly to 0-100% of the incident sound energy absorbed). Basic absorptive building finish materials such as ceiling tiles or fiberglass panels will have a NRC rating to help determine their usefulness in absorbing sound and controlling reverberation in the speech frequency range.

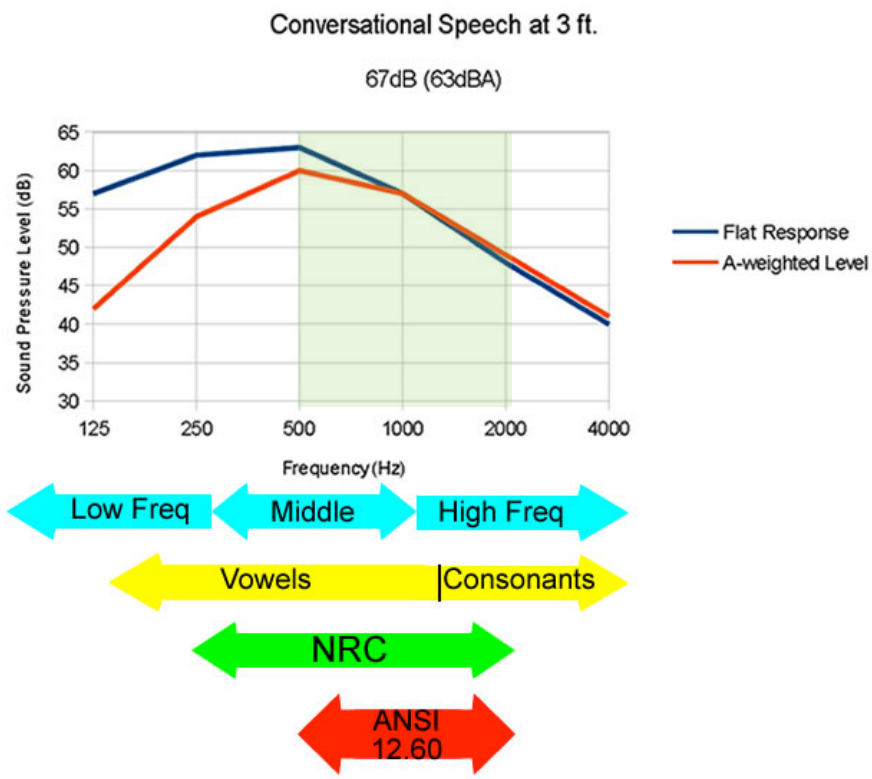


Figure 12.2 Revisiting the frequency (octave) bands for speech in regard to reverberation

Figure 12.2 originally appears earlier in this section, and we have added NRC (noise reduction coefficient) seen as metric for items such as ceiling tiles, and the frequency range utilized by ANSI 12.60 for reverberation time criteria.

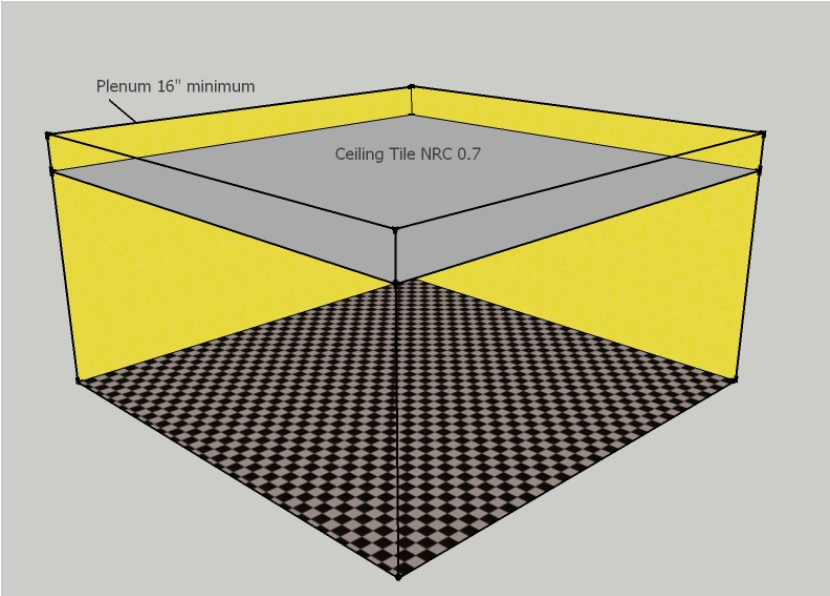
Note: the 125 Hz to 4 kHz bands encompass the majority of speech frequencies. See a definition of the NRC, or Noise Reduction Coefficient.

The following list is meant as a suggested guideline for school absorptive treatments (also see Appendix E):

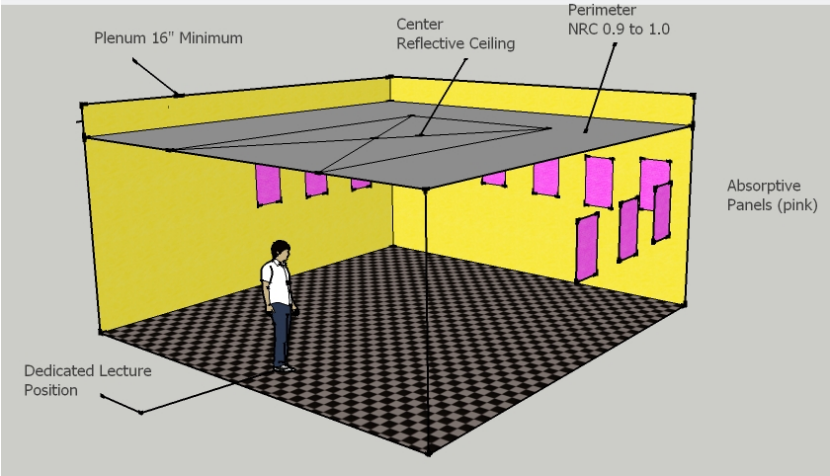
1. Corridors: it is recommended that 75% of the ceiling is treated sound absorbent, and no less than 50%
2. Large rooms (i.e., cafeterias) with ceilings up to 12 ft: the full drop ceiling exclusive of ventilation and lighting should have an NRC of 0.7.
3. Ceilings from 12 ft. to 15 ft. should have an NRC greater than 0.7, and/or walls should be considered.
4. Ceilings higher than 15 ft.: it is recommended that a more detailed analysis be performed by a professional experienced in reverberation control.
5. Wherever permitted wall treatment should be combined with the ceiling treatment, and may allow for a reduced NRC ceiling.
6. Where permitted by sanitation restrictions (See local Health Department Codes & Regulations which may require hard surfaces that can be scrubbed clean,) the same requirements should be applied to food serving and preparation areas.
7. Gymnasiums (very high ceilings) require absorbent wall treatment in order for the ceilings to be effective.
8. Large lecture halls and auditoriums have special requirements that include HVAC noise reduction, specific seat absorption characteristics, and sound reinforcement: it is recommended that a professional experienced in these matters be consulted. (See table E.1 on page 58 of this booklet for more details.)

Location and mounting of sound absorptive material:

- General Classrooms (no fixed lecture position, ceiling @10′) place most if not all absorbing material on the ceiling.
- Lecture Classrooms (fixed lecture position): ring the ceiling and upper walls with absorbent material – exclude absorbing material in the area directly above and in front of the lecturer.
- Drop ceiling airspace should be 16” or larger.

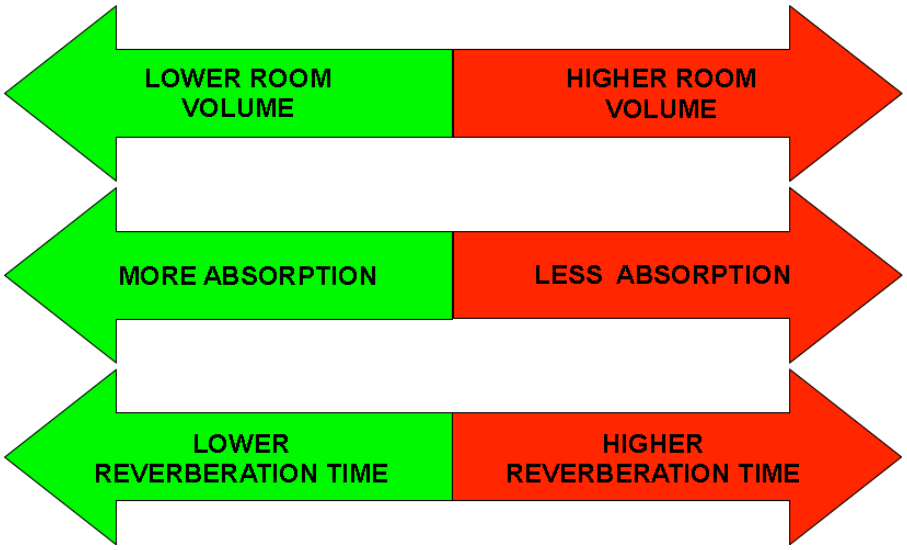


12.3a: Typical Classroom (lecturer roams the room)



12.3b: Dedicated Lecture Position

Figure 12.3: Location and mounting of sound absorbent material
A typical classroom is shown with a NRC 0.7 ceiling tile. For classrooms with a dedicated lecture position, one might consider utilizing useful ceiling reflections as shown, and compensating for lost absorption by supplementing with a more sound absorbent ceiling and additional absorption on the walls. Such a design can be implemented with a basic acoustics knowledge or with the help of an experienced consultant. The reflective surface in the center can be made with gypsum wallboard or a similar hard material. This approach increases the sound level from the teacher throughout the room while maintaining clarity.



Notes:

- Control of reverberation below 500 Hz should be performed by an experienced consultant.
- Manufacturers' recommendations must be followed when installing sound-absorbing wall treatments.

Figure 12.4: Concepts in core learning classrooms
The green colored design goals on the left side should be kept in mind whenever possible.

Section 13: Isolation strategy #1:

Limit airborne sound transmission between spaces

Noise isolation between interior spaces: the STC requirements listed assume a continuous wall from the floor of the room to the floor/ceiling system above, sealed at the perimeter (edges, top and bottom). As noted earlier, composite construction that includes a door or window can have a serious negative impact on the STC rating of the wall construction alone if the door or window does not have a similar STC. Composite wall STC rating must be specified based on composite construction calculations.

Noise isolation of open plan classrooms: While flexible learning spaces are possible when very carefully planned, “open plan” classrooms should be discouraged due to disruptive background levels created by adjacent neighboring classes.

Note:

Meeting the sound isolation rating of a ceiling or wall construction is directly affected by materials, workmanship, and flanking sound from penetrations and at joints. “Composite constructions” (the inclusion of doors and windows with a wall) also compromise the isolation (STC) ratings of walls and are treated in Section 10 and Appendix D of this booklet.

Examples of STC based on layout of adjacent spaces:

The following figures show the STCs for walls based on adjacent spaces as required by ANSI/ASA S12.60. A detailed description of STC and IIC requirements is found in Section 4 of this booklet and Clause 5.4 of ANSI/ASA S12.60, Part 1.

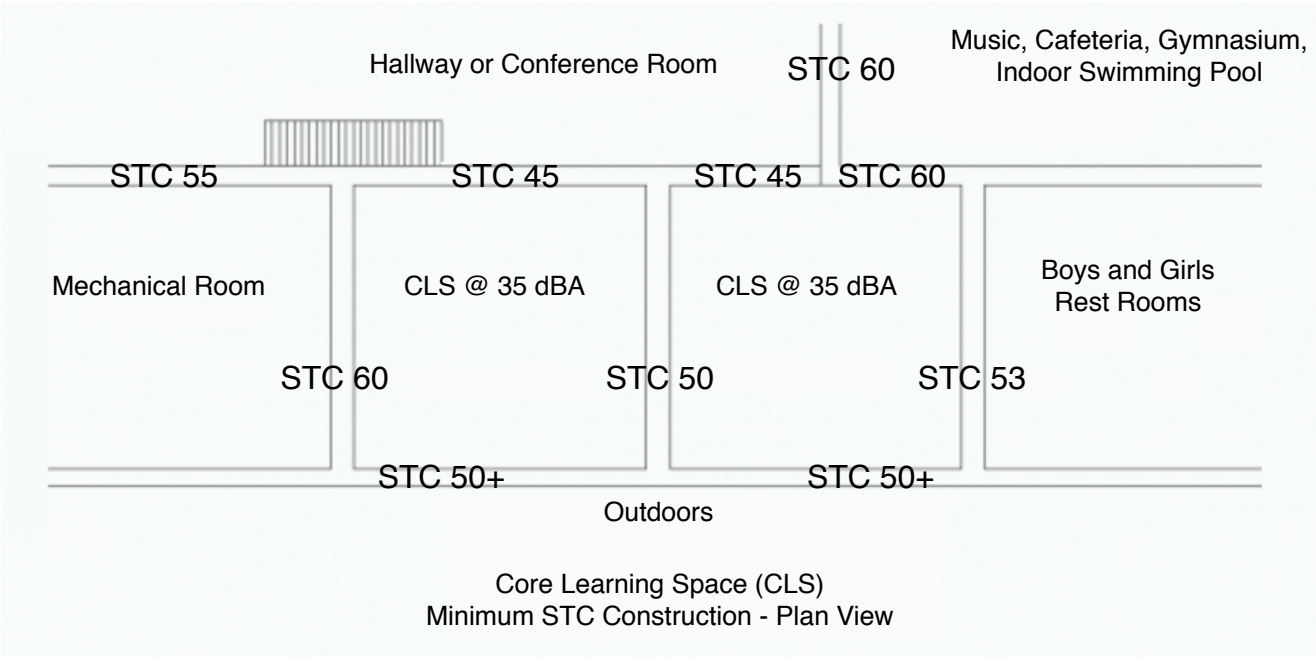


Figure 13.1: Core Learning Space minimum STC ratings for walls and floor/ceiling assemblies in plan view (walls) Ceiling/floor STC-IIC depends on the vertically adjacent space(s).

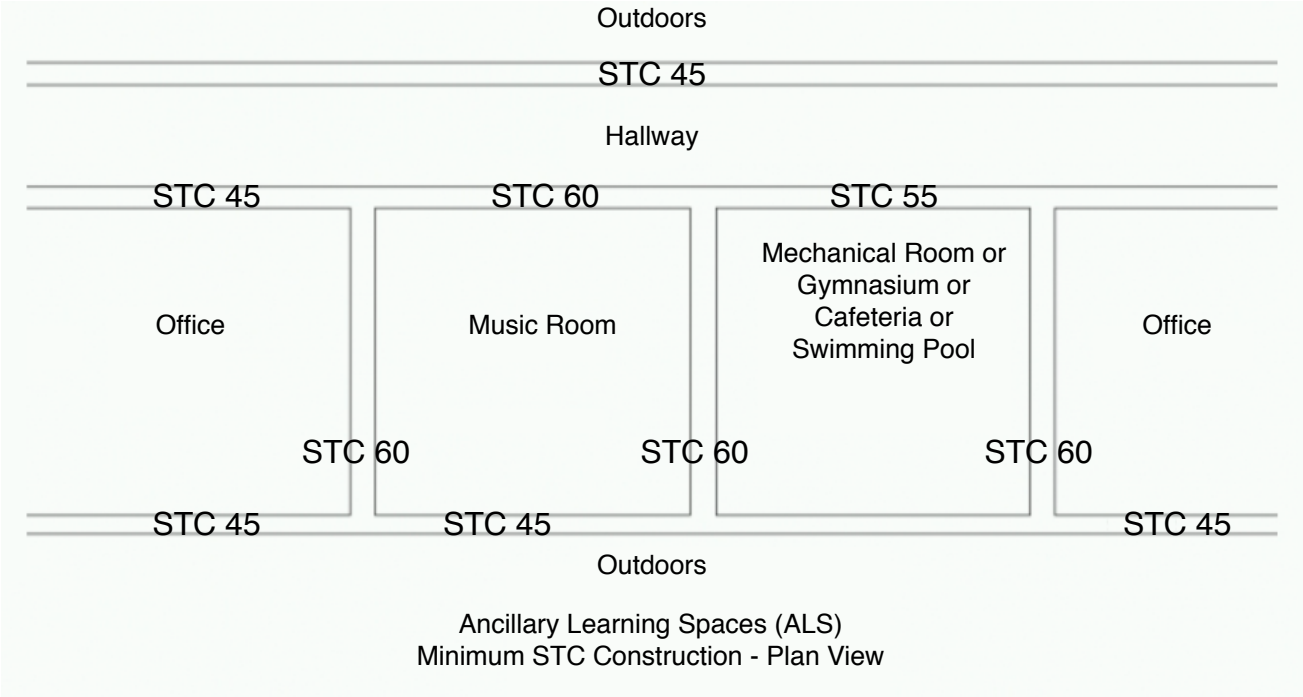


Figure 13.2: An example of ancillary spaces and required STC in plan view (walls) Ceiling/floor STC-IIC depends on the vertically adjacent space(s).

Section 14: Isolation strategy #2: Vibration isolation-

Eliminate vibration transfer (and its potential broadcast as audible sound)

There will be sources of vibration in the building which must be considered for isolation such as machinery, HVAC, plumbing, fans, and pumps. Vibration travels easily through rigidly connected structural members, and can excite other parts of the building such as wall panels, converting the energy to audible sound.

Common strategies employed to eliminate or reduce the effects of a source of vibration:

- Use low vibration-equipment.
- Arrest vibration at the source with isolation including resilient pads and springs.
- Use a housekeeping pad.
- Relocate sources away from the structure.
- Isolate the structural perimeter around the source.
- Install resilient connections (electrical, fuel, exhaust, etc.) to machinery such as springs, pads, or flex connectors.

Note:

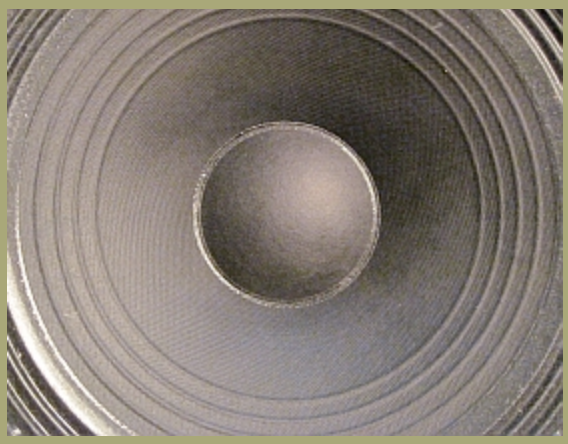
For more specific information on isolation and vibration transfer, see Appendices B and C.

Section 15: Amplification isn't usually an effective long term strategy

Classroom audio distribution systems may be an excellent temporary solution where background noise problems are pending remedy, and may be useful for larger lecture halls to boost the signal source. However, there are drawbacks to such systems because they inhibit spontaneous interaction between students and teachers, which is a core learning activity.

Amplification also produces louder than conversational sound levels. And amplification systems are subject to failure, maintenance, and repair issues. Amplification in one area also contributes to background noise in adjacent spaces, requiring additional mitigation via a more robust wall and ceiling/floor construction for better isolation.

While sound systems do have benefits as mentioned earlier, there are issues that need to be considered beforehand:



1. Sound reinforcement makes the sound louder, and if the sound clarity was not acceptable due to high reverberation time beforehand, it will remain unclear, only louder.
2. If the background noise is too high, the amplified signal becomes too loud as well if you are trying to achieve an appropriate 15 dB signal to noise ratio (as shown in **Section 5**). The classroom can become uncomfortable or noisy.

Additional concerns when relying on sound amplification:

1. The system reduces spontaneous interaction between the teacher and student. Either students must pass a microphone to speak or they may not be heard.
2. The system may employ wireless transmitters which require vigilance in regard to batteries.
3. This is an additional system that requires maintenance.

Section 16: Simple initial mitigation strategies

Consideration should be given to separation walls between classrooms (and between classrooms and hallways) to provide construction details that inhibit transmission through the wall. Strategies can include multiple layers of drywall to increase mass, sound attenuation blankets (insulation) to absorb sound, as well as staggered stud construction and even separating sole and top plates to inhibit the transfer of sound via diaphragmatic action between sides of the separation wall.

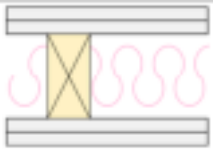
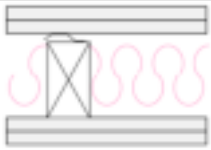
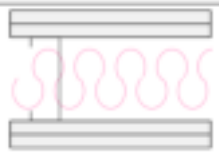
Description		STC
5/8” gypsum, 3.5” wood stud or heavy gauge metal stud, 5/8” gypsum		36
5/8” gypsum, 3.5” light gauge metal stud*, 5/8” gypsum *light gauge is 25 gauge or lighter		38
5/8” gypsum, 3.5” wood stud or heavy gauge metal stud with fiberglass blanket, 5/8” gypsum		40
5/8” gypsum, 3.5” light gauge metal stud* with fiberglass blanket, 5/8” gypsum *light gauge is 25 gauge or lighter		46
2-5/8” gypsum, 3.5” wood stud or heavy gauge metal stud with fiberglass blanket, 2-5/8” gypsum		44
2-5/8” gypsum, 3.5” wood stud or heavy gauge metal stud with fiberglass blanket and resilient channel, 2-5/8” gypsum		53
2-5/8” gypsum, 3.5” light gauge metal stud* with fiberglass blanket, 2-5/8” gypsum *light gauge is 25 gauge or lighter		53

Figure 16.1: STC of stud and 5/8” gypsum constructions. Note that this is intended as a general guide and are not a substitute for reliable field and laboratory test data. Other high STC assemblies can utilize staggered stud, double stud, and cinder block.

Floor/slab and floor/ceiling assemblies can be designed to reduce impact sound. Hanging drywall ceilings with resilient clips or using spring suspended acoustical tile ceilings have a positive effect on reducing impact noise from floors above. And of course,

HVAC equipment must never be placed directly over teaching spaces and must always be installed with vibration isolation curbs to limit vibration and direct sound transmission through structural elements including beams, columns and bar joists. The duct work should be suspended with isolation hangers as needed.

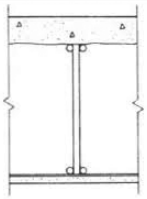
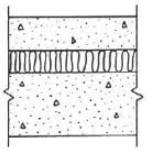
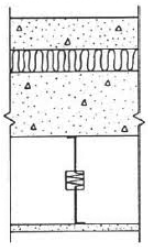
Description		STC/IIC
5 in. reinforced concrete slab, exposed ceiling, vinyl tile floor finish		51/46
Above, with foam backed vinyl tile floor finish		51/50
Above, with 1/4 in. carpet on under-padding		51/70
2 1/2 in. concrete over 12 in. open web steel joists, 5/8 in gypsum board ceiling,		57/45
6 in. reinforced concrete slab with additional 3 in. concrete slab floated on 2 in. fiberglass mat		65/67
Above, with resiliently suspended 5/8 in. gypsum ceiling, 8 in. below slab		75/70

Figure 16.2: STC/IIC of sample ceiling/floor constructions
Note that these are intended as a guide and are not a substitute for reliable field and laboratory test data. From Cavanaugh, "Architectural Acoustics", 1999

Pay Attention to how sound travels

Attention to HVAC duct layout can have a dramatic impact on containing sound within classrooms and minimizing transfer from one room to the next. Running trunk ducts in corridors and branching off to classrooms is far more effective in prevention of "crosstalk" sounds than running trunks lines between rooms where sound can easily be transmitted even through insulated ducts. See the Mechanical Section (Appendix II) for more specifics on limiting the impact of HVAC design on the acoustical environment.

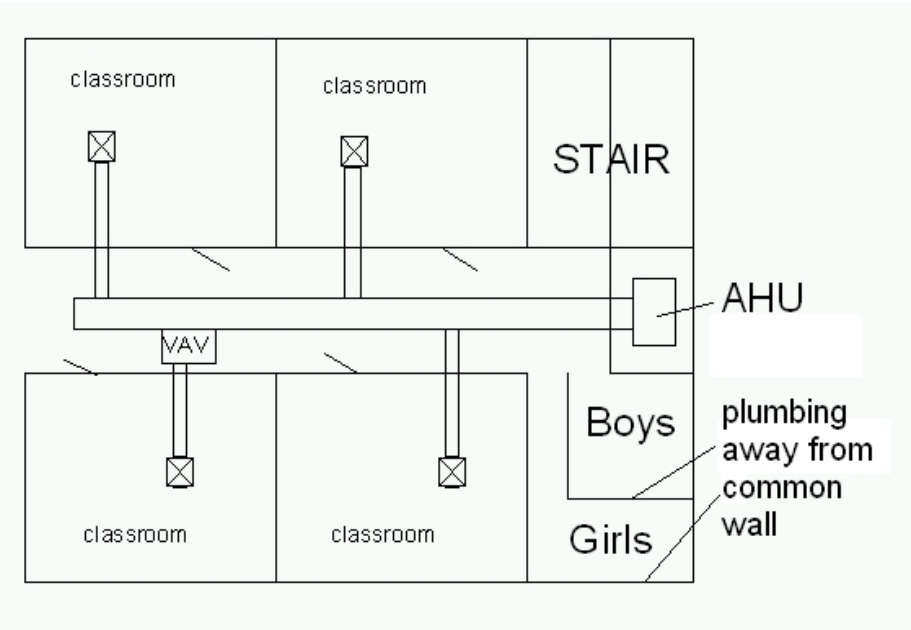


Figure 16.3: HVAC Layout

The main trunk is in the corridor, and branches are offset. Note VAV box in the corridor and offset doors as well.

Consider Absorbent Surfaces:

Acoustical ceiling tiles, fabric-wrapped panels, manufactured acoustical panels, soft seating, drapes, carpeting, blinds (some blinds are designed for sound absorption), etc. all play a role in dampening sound and providing a comfortable acoustical environment.

Consider Diffusive Surfaces:

Breaking up surfaces architecturally by insetting windows, using columns inside a space and other architectural details, bookshelves (with books) and workstations with dividers at ear level will "soften" the sound in the room and provide modest absorption compared to flat hard painted walls. Diffusers are also commercially available.

Section 17: As a final check, examine the envelope for “leaks”

Exterior wall mass plays an important role in acoustical control with respect to limiting background noise from external sources such as traffic, aircraft, schoolyard play, etc. High-efficiency doors and windows with well-maintained seals do as much to control sound comfort as they do to control temperature comfort. As remarked earlier, the inclusion of a door or window with a poor acoustic design can compromise the isolation integrity of the wall construction. Combining mass layers with an air space in between can reduce costs and improve effectiveness with good design. Laminated and double glazed windows and insulated, weather stripped doors can lower heat gain AND reduce transmission of background noise.

Weather stripping, caulking, and gasketing are inexpensive and highly effective mitigations for both air and noise infiltration. It is important to note that all constructions should be caulked and sealed along all edges for the best isolation performance. Think airtight. Also all hollow window and door frames are potential shortcuts or “flanking paths” for sound, and should be insulated or grouted as needed. Certain high performance windows take this into consideration already. Assemblies should be checked to confirm that the manufacturer has performed the appropriate standardized testing to determine STC.

Section 18: Classroom technology and acoustics

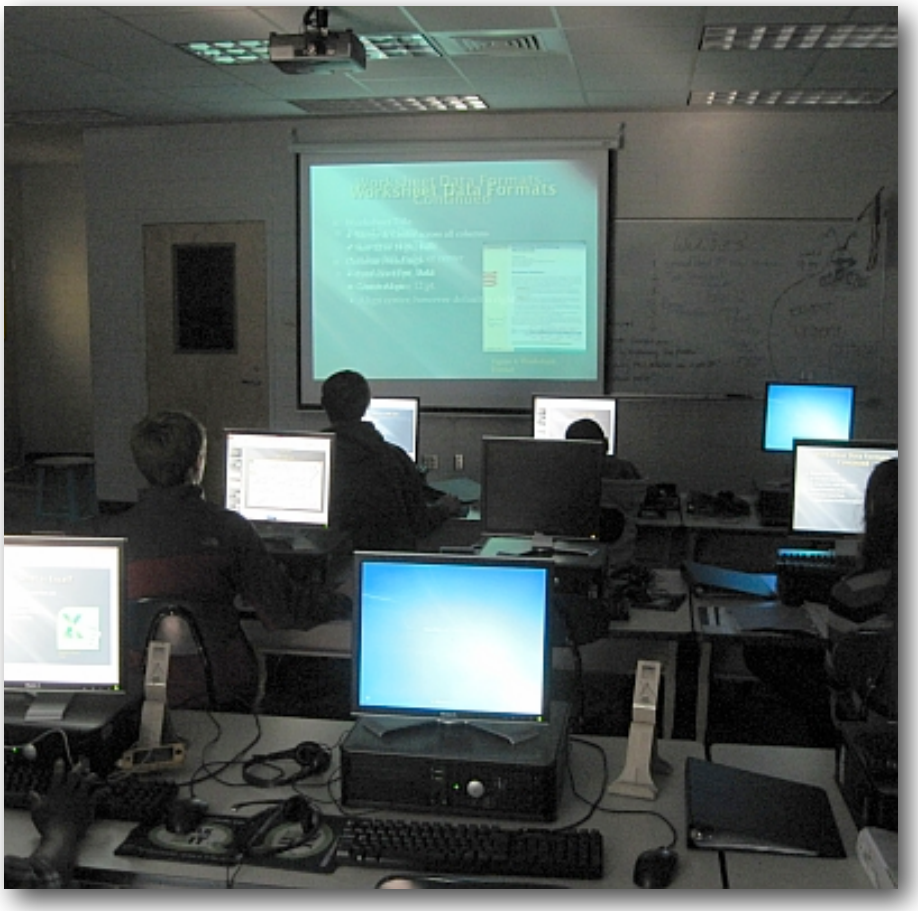
Changes in architectural design have not kept pace with changes in technology. Yesterday's teaching technology was completely different.

Cutting-edge technology in the 1960's included language labs with recording equipment and headphones for every student. Those were the good old days. All the teacher had to worry about was having to cue the tape.

Today's lecture halls support a variety of electronic teaching aids including student laptops, rather than steno pads for note taking.

All of this equipment increases air conditioning loads, leading to larger chillers with louder motors and bigger fans, and often each piece of equipment contains a motor or cooling fan which alone may be quiet, but which collectively can become overpowering. Typical solutions are to utilize higher absorption ceiling tile (NRC>0.9), wall panels, carpets, and open office dividers with absorptive surfaces. HVAC (mechanical) noise is held to the same standard as other classrooms, with additional attention to surface flow rates over the supply registers and return grills.

Today's classrooms often include a variety of audio visual equipment including video projectors, smart boards, monitors, and even desktop computers for each student.



The contemporary "smart" classroom and its tools and equipment

Section 19: Consider probable costs

Begin with the "low-hanging fruit"

Most building envelope strategies support energy conservation as well as reductions in noise, so payback can be quantified in real savings by approaching this in tandem.

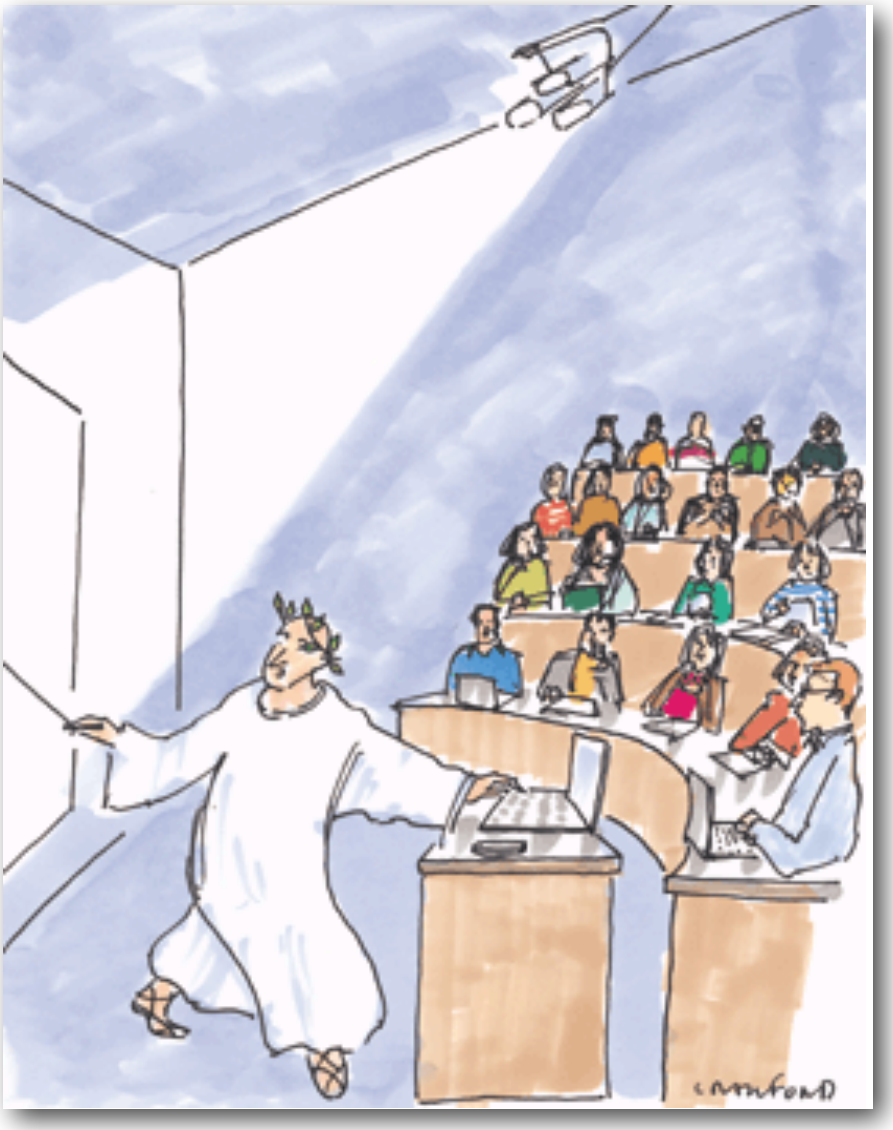
Consideration of layout and building material strategies early in the design phase will help to contain construction costs. You also must educate your client and your contractors. Additional booklets on the ANSI/ASA S12.60 Standard aimed at school districts and general contractors are available through the Acoustical Society of America. The American Institute of Architects can also help.

Explain to your contractor how carefully you've detailed your drawings and specifications. This level of care has not been used to make their lives more difficult or to create expensive connections or methods – on the contrary, you've spent time and energy figuring out how to maximize acoustical separation between spaces so (s)he won't have to!

Section 20: Would Socrates recognize the classroom of today?

Summary:

- It has been shown that lower reverberation times and good signal to noise ratio increase speech intelligibility, which is critical to the learning environment.
- These are achieved through good acoustic design and attention to noise isolation and control.
- Consider bringing in an acoustic consultant early in the design stage to insure proper design, and if needed, adherence to ANSI/ASA 12.60, or any LEED based acoustic requirements.



Probably not. The fundamentals of teaching have not changed. The goal is still "to kindle a flame…" But today we live in a fast-paced, noisy world and distractions are everywhere.

The designer can control more than the way a space functions and how it looks. (S)he can also control the way it sounds to support learning and promote concentration.

Learn more….

Section 21: Contacts for additional information

Related Websites:

American National Standards Institute

www.ansi.org/

U S Green Building Council

www.usgbc.org/

American Institute of Architects

www.aia.org/index.htm

National Council of Acoustical Consultants

www.ncac.com/

Institute of Noise Control Engineering

www.inceusa.org/

American Society of Heating, Refrigeration, and Air-conditioning Engineers

www.ashrae.org/

Acoustical Society of America

ASA Standards Secretariat

1305 Walt Whitman Road, Suite 300

Melville, NY 11747-4300

1 (631) 390-0215

www.acousticalsociety.org

Electronic copies of the National Classroom Acoustics Standard ANSI/ASA S12.60 Parts 1 and 2 and additional materials are also available at no cost from the Acoustical Society of America Standards Store [click here].

Appendix A: Architects' checklist for meeting ANSI/ASA S12.60

To summarize, this booklet has identified the following issues that require careful examination to achieve an appropriate classroom design to optimize hearing and comprehension of speech:

1. **Outside noise sources must be evaluated and projected.**
    1. Transportation (local/highway, trains, air traffic).
    2. Neighbors (industrial? playground?).
    3. Garbage disposal and deliveries.
    4. Building layout with respect to noise sources (note that a row of screen trees blocks sight, not sound).

2. **Inside Noise Sources and Layout**
    1. Mechanical system noise (HVAC and plumbing noise control).
    2. Adjacent classrooms (all sides).
    3. Hallways.

3. **Isolation Design to Meet Background Noise Level Criteria**
    1. Interior
        1. Space planning and layout.
        2. Wall and ceiling/floor design (STC-primary).
        3. Doors and interior windows.
    2. Exterior
        1. Consideration of the current and projected outside noise sources.
        2. Building shell (walls, windows, roof) (STC/OITC, composite construction).
        3. Entrance doors (composite construction and foot traffic routing).

4. **Room Acoustics**
    1. Design for appropriate reverberation time and speech intelligibility.

Appendix B: Heating, ventilation and air conditioning

Impacts on the acoustical environment

Notify your mechanical consultant that achieving appropriate acoustical performance in classrooms is a primary goal of the project. The basic concepts behind designing a climate control system that does not contribute to acoustical problems in learning spaces are simple:

First, do not locate any HVAC equipment that employs fans or motors near learning spaces. Minimize the number of moving parts (i.e., VAV boxes and dampers in the hallway, and main units away from classrooms).

Second, limit airflows at delivery points and match duct sizes carefully to minimize noise associated with air movement and turbulence.

Third, run major distribution lines in corridors and use offset branches to serve individual leaning spaces.

Additionally:

-Do not allow learning spaces to become connected acoustically through supply ductwork or return plenums.

-Select equipment based on its low operating noise and include any manufacturer recommended attenuation devices in the specifications.

-Isolate mechanical equipment from structure with manufacturer's recommended attachment methods for sound and vibration control.

The following are the specific requirements of which your mechanical consultant must be made aware to ensure that your goal of an appropriate acoustical environment is met in all learning spaces:

1. Un-ducted systems such as window or wall mount units should not be employed.

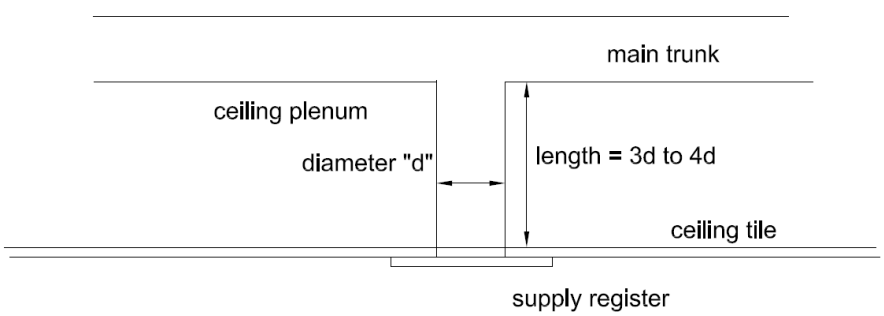
2. Grilles and diffusers should have an NC rating of 18 or less for a single diffuser (the total NC contribution of the HVAC system in the room should be 25-30 NC,) and use no dampers directly behind diffusers.

3. Air flow in the trunk ducts should not exceed 800 ft/min.

4. Branch ductwork to match “devices duct correction size.”

5. A duct silencer should be included in the Air Handling Unit (AHU) or the main supply/return if analysis shows that break out noise or fan noise will exceed 35 dBA in any classrooms.

6. The ductwork should be fabricated and installed as to achieve low static pressure loss; 3-4 duct diameters of straight duct length going to diffuser.

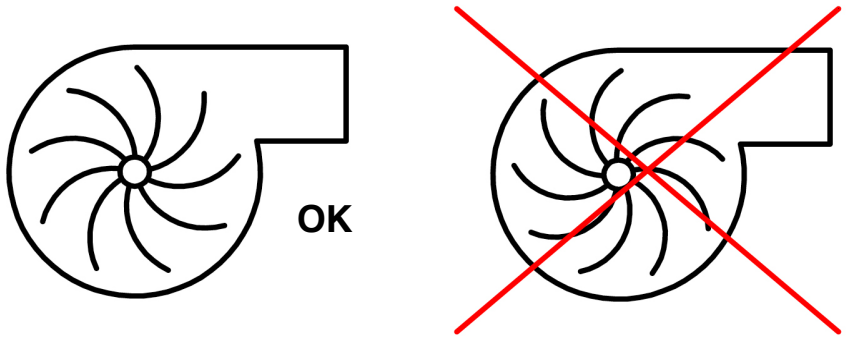


Low static pressure loss for supply diffuser feeds and turbulence reduction. Keep any dampers back toward the trunk to get a quieter laminar flow.

7. All rotating equipment and equipment with static pressure control dampers should be 10 ft or farther from the classroom. If serving more than one classroom, increase the distance.

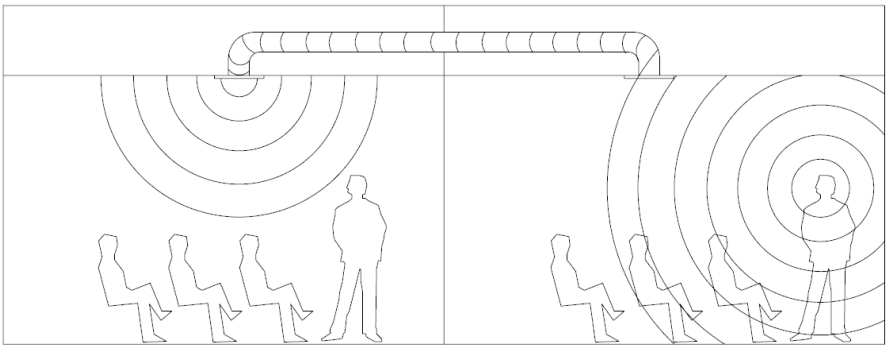
8. Use centrifugal fans with airfoil shaped blades; avoid forward curved blades (see figure below).

9. Where ductwork that connects classrooms is unavoidable, it should include sound attenuators and/or duct liner.



Use Airfoil Shaped Blades Avoid Forward Curved Blades

Airfoil shaped blades for HVAC fans



Crosstalk can occur when two rooms are connected by a duct; sound enters the duct from one room and bypasses the wall/ceiling construction to be re-broadcast in the neighboring space. Ductwork connecting classrooms should be offset, lined, and/or an attenuator should be employed in-line.

Appendix C: Plumbing fixtures,

water supply and waste line impacts

Notify your plumbing consultant that achieving appropriate acoustical performance in classrooms is a primary goal of the project. The basic concepts behind designing a plumbing system that does not contribute to acoustical problems in learning spaces are simple.

First, do not run supply or waste lines near learning spaces – confine them to areas above corridor ceilings.

Second, limit water pressure to minimums necessary for appropriate system function to reduce noise associated with water movement and turbidity.

Third, do not locate restrooms near learning spaces. Select locations which are central and convenient but where walls are not shared with classrooms. Avoid plumbing walls/chases shared with a classroom wall.

Addtionally:

-Select pipe materials, valves and plumbing equipment based on their low operating noise.

-Isolate plumbing lines from structure and wall surfaces, and wrap all lines with attenuating material then enclose in hard wall chases where possible.

-Use flexible pipe hangers and water hammer arresters.

Following are the specific requirements of which your plumbing consultant must be made aware to ensure that your goal of an appropriate acoustical environment is met in all learning spaces.

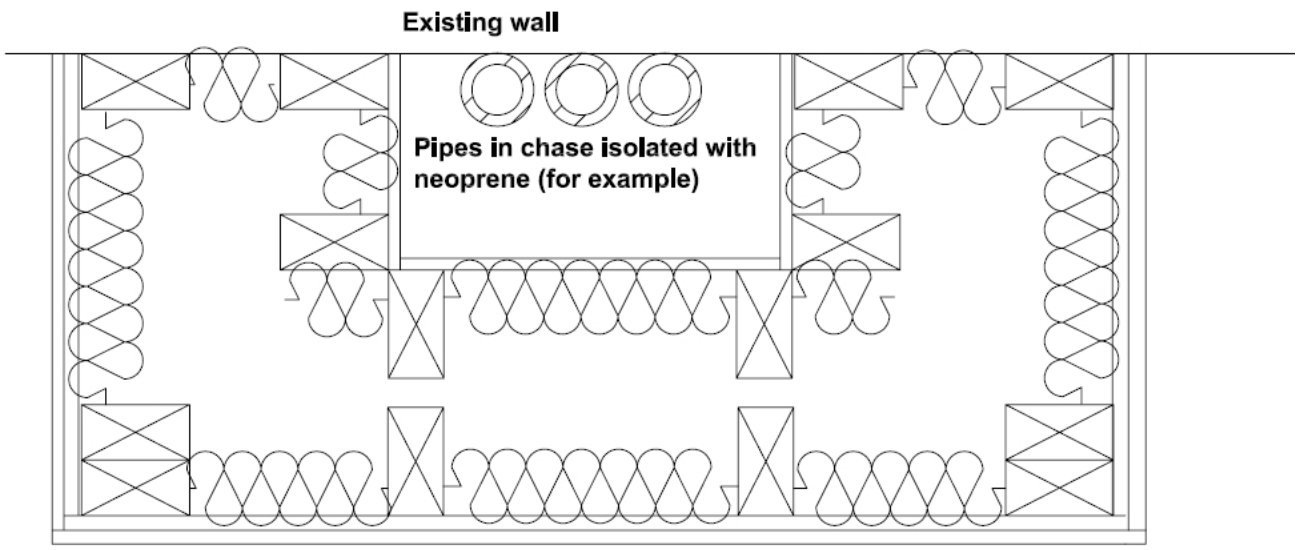
1. Locate restrooms away from classrooms to the greatest extent possible.

2. Only run piping above corridor ceilings, not above learning spaces.

3. Select cast iron for waste pipes over plastic where feasible. Plastic piping may require special care to ensure quiet operation and should be wrapped with one or more layers of sound attenuating material, or wrap all plastic waste pipe with sound absorbing material and box in with gypsum wall board.

4. Do not allow plumbing lines to contact structural components or wall surfaces. Isolate water piping 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 chase wall should employ an isolation wall construction detail, including double stud (1” gap minimum between rows) construction. There should be two layers of gypsum board on the classroom side and sound absorbing batts in both stud cavities.



Plumbing chase adjacent to learning space detail

6. Reduce pressure of supply water as much as possible and employ trapped air water hammer arrestors for supply lines 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 closing the walls.

Appendix D: Design guidelines for noise isolation

Penetrations, cracks, or breaks in a wall can compromise the wall's STC rating significantly and the following should be included or considered in the design:

- All electrical outlets must be acoustically enclosed, or placed at least 1, but preferably 2 stud bays apart.
- All door perimeters must be acoustically addressed with airtight seals and thresholds.
- All seams and wall/ceiling points of intersection should be acoustically caulked.
- All recessed lights must be insulated, or treated with an acoustical baffle.
- All duct or pipe penetrations must be acoustically sealed at and through the penetration.
- All in-wall or in-ceiling speakers must be acoustically backed with a speaker can or box.

The following detailed design guidelines are from an earlier version of the ANSI/ASA S12.60 standard and are included for those that wish to engage in a more detailed analysis during noise isolation planning. All references are to the ANSI/ASA S12.60 Part 1 standard.

1. 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.

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.

2. Noise isolation

2.1 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.

2.2 Noise isolation of open-plan classrooms
The low noise isolation that is inherent with openplan 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 1. 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.

2.3 Outdoor-to-indoor noise isolation
2.3.1 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 regard 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.

2.3.2 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 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 day/night average sound level exceeds, or is predicted to exceed, 75 dB.

2.3.3 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 inD2.3.1 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 — 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
a)
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.
b) 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.

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’’.

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 classroom 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 1 20 or 50. The STC rating of the windows would have to be at least 30 1 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).

2.4 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) and with corresponding surface areas S1 and S2.

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.

S2/(S1+S2) x100%	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

2.5 Isolation from impact noise or vibrating machinery

2.5.1 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.

2.5.2 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).

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

[D1] ASTM E497-99, Standard practice for installing sound-isolating lightweight partitions. [Web site- www.astm.org].

[D2] L.L. Beranek and I.L. Ver, Noise and Vibration Control Engineering, Wiley, NY (1992).

[D3] J.S. Bradley and J.A. Birta, ‘‘Laboratory Measurements of the Sound Insulation of Building Facade Elements’’, National Research Council of Canada, Internal Report, IRC-IR-818, (Oct. 2000).

[D4] R. Coffeen, et al., ‘‘Classroom Acoustics, a resource for creating learning environments with desirable listening conditions’’, Acoustical Society of America, Melville, NY, www.acousticalsociety.org (Aug. 2000).

[D5] R.B. Dupree, Catalog of STC and IIC Ratings for Wall and Floor/Ceiling Assemblies, Office of Noise Control, California Department of Health Services, Sacramento, CA, (Feb. 1980).

[D6] Fire Resistance Design Manual, 16th Edition, (Gypsum Association, Washington, DC, [Web site- www.gypsum.org].

[D7] R.E. Halliwell, T.R.T. Nightingale, A.C.C. Warnock and J.A. Birta, ‘‘Gypsum Board Walls: Transmission Loss Data’’, Internal Report No. 761, National Research Council of Canada, (May 1998).

[D8] C.M. Harris (Ed.), Noise Control in Buildings, McGraw-Hill, NY (1994)

[D9] ASTM E966-99, Standard Guide for Field Measurement of Airborne Sound Insulation of Building Facades and Facade Elements.

[D10] ANSI S12.9-1998/Part 5, American National Standard Quantities and Procedures for Description and Measurement of Environmental Sound, Part 5: Sound Level Descriptors for Determination of Compatible Land Use. [Web Site - www.acousticalsociety.org/standards].

[D11] A.C.C. Warnock and W. Fasold, ‘‘Sound Insulation: Airborne and Impact’’, Chap. 93, Encyclopedia of Acoustics, M.J. Crocker, (Ed), Wiley, NY (1997).

[D12] A.C.C. Warnock and J.A. Birta, ‘‘Detailed Report for the Consortium on Fire Resistance and Sound Insulation of Floors: Sound Transmission and Impact Insulation Data in 1/3 Octave Bands’’, Internal Report, IRC IR-811, National Research Council of Canada, (July 2000).

[D13] A.C.C. Warnock, ‘‘Controlling the Transmission of Impact Sound Through Floors’’, Construction Canada, 42, (5) pp 14-16, (Sept.1, 2000) [Web site - www.nrc-cnrc.gc.ca/ctu-sc/files/doc/ctu-sc/ctu-n35_eng.pdf]

[D14] A.C.C. Warnock, ‘‘Impact Sound Measurements on Floors Covered with Small Patches of Resilient Material or Floating Assemblies’’, Internal Report, IRC-IR-802, National Research Council of Canada, March 1, (2001) [Web site - http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.3.2062]

[D15] ‘‘A Practical Guide to Noise and Vibration Control for HVAC Systems,’’ ASHRAE Special Publication, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA. [Web site - www.ashrae.org.

Appendix E: Design guidelines for controlling reverberation in classrooms and other learning spaces

Note: these design guidelines are from an earlier version of the ANSI S12.60 standard and are included for those that wish to engage in a more detailed analysis during noise isolation planning. All references are to the ANSI S12.60 standard.

E1 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 of ANSI 12.60.

E2 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 [E1]. According to this formula, the minimum total sound absorption A needed to achieve a reverberation time of T60 seconds or less in a room of enclosed volume V is given by:

A] kV/T_{60} (E.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 Si of each such sound-absorbing surface and the sound absorption coefficient ai 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=a1S1+a2S2+a3S3+...+aISi+AR (E.2)

where AR is the residual sound absorption. A default value of AR 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 E3.5). For a carpeted room, a value for AR, of 20% of the floor area is recommended as a conservative default design value.

Alternatively, the designer can set AR 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 E2.1).

Next, the values of a_i and S_i for the proposed materials and surface areas are substituted into equation (E.2). If necessary, the choices of material and material areas are adjusted until equation (E.1) is satisfied. The minimum total sound absorption is calculated from application of equation (E.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 AR 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 Sf and average ceiling height H. Using equations (E.1) and (E.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 S1 as a percentage of the floor area for maximum reverberation times of 0.6 s and 0.7 s from table 1 of ANSI 12.60. The variables in the table are the sound absorption coefficient a_1 of the acoustical treatment and average ceiling height H.

With the assumptions described above, the entries in table E.1 for the minimum surface area of acoustical treatment S1 as a percentage of floor area Sf were calculated from the following expression.

$$100(S_1/S_f)] \; 100\{[(kH/T_{60}) - 0.15] / a_1\} \qquad \textbf{(E.3)}$$

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

As shown in table E.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 x 25 x 9) = 9000 ft^3. From table 1 ANSI 12.60, 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 E.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 x 25 = 1000 ft^2, or 900 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.

> NOTE 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.
>
> NOTE 2. If the manufacturer's sound absorption data are between the sound absorption coefficients listed in the first column of table E.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% x (0.65/0.67) or 87% of the floor area or 870 ft^2 instead of 900 ft^2.

A similar table can be constructed from equation (E.3) for a carpeted floor by changing the default value for AR/Sf 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 E3.1.2, 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 x 900 = 540 ft^2. According to table E.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 ft2 if it were the only material used. However, under the assumptions, only 40% of that area is required or 0.4 x 1.3 x 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 [E2]. 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. 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 of ANSI/ASA S12.60 for each of the three frequencies.

When selecting acoustical materials to meet the reverberation time performance criteria in table 1 of ANSI/ASA S12.60, 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.

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

Sound absorption coefficient, a_1	(a) Reverberation time, T60, of 0.6 s Ceiling height, H, ft								
	8	9	10	11	12	13	14	15	16
	Ceiling Height, H, ft								
	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 tests may be taken as equal to 1.00 for purposes of this appendix.

Sound absorption coefficient, a_1	(b) Reverberation time, T60, of 0.7 s Ceiling height, H, ft								
	8	9	10	11	12	13	14	15	16
	Ceiling Height, H, ft								
	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 tests may be taken as equal to 1.00 for purposes of this appendix.

E3 Further design guidance

E3.1 Location of the absorbing material

E3.1.1 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.

E3.1.2 Lecture-type classrooms. Speech intelligibility studies [E3] 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.

E3.2 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 air space may, or may not, be the same as the 40 cm (16 inch) air space commonly used by manufacturers to achieve the sound absorption coefficients that are measured by a testing laboratory. As long as the minimum air space 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.

E3.3 Reverberation control for ancillary and large core learning spaces

For ancillary spaces, such as corridors, gymnasia, cafeterias and large core learning spaces [volume >566 m3 (>20,000 ft3)] 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), [E4, E5]. For cafeterias and for large core learning spaces with ceiling heights up to 3.7 m (12 ft), a suspended ceiling with an 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 E.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 E5 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. E5, E6, or E7), 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.

E3.4 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. Indoor air quality (IAQ) and multiple chemical sensitivity (MCS) issues for carpeting are beyond the scope of this booklet but should be considered.

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 E.2 for further details.)

E3.5 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 AR in equation E.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 m2 (6.0 ft2) for an adult student and about 20% less for a high school student and 40% less for an elementary grade student [E4].

E4 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 E3.3, 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 [E1, E4-E11] listed in the bibliography.

E5 Bibliography

[E1] R.E. Apfel, Deaf Architects and Blind Acousticians, A Guide to the Principles of Sound Design, Apple Enterprises Press, New Haven, CT, (1998).

[E2] ASTM C423-00, Standard Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method. [Web site - http://www.astm.org]

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[E8] L. Irvine and R. Richards, Acoustics and Noise Control Handbook for Architects and Builders, Krieger Publishing Co., Malabar, FL (1998).

[E9] M. Mehta, J. Johnson, and J. Rocafort, Architectural Acoustics Principles and Design, Prentice Hall, Upper Saddle River, NJ (1999).

[E10] C.J. Rosenburg, ‘‘Acoustic Design,’’ Architectural Graphics Standards, Eighth Edition, J.R. Hoke, Jr., (ed), The American Institute of Architecture, Wash. DC (1988).

[E11] C.M. Salter and Associates, Inc., Acoustics: Architecture-Engineering-The Environment, William Stout Publishing (1998).

Appendix F: Definitions

Absorbent (sound absorbing) - Material which is sound absorbing is usually soft and fibrous or cellular and porous. The small air spaces between fibers or within cells “traps” sound and does not allow it to reverberate back into the open space. Examples of such materials include fabric, draperies, foam, acoustical tile, insulating batts or attenuation blankets, acoustical panels, upholstery, etc.

Acoustics - The science of sound waves that includes (infrasound, audible sound, and ultrasound).

Acoustical panels - Manufactured panels designed to absorb specific frequencies of sound waves by “trapping” the energy of the waves within the material; some of the remaining energy is reflected from the surface back into the space, and some is transmitted to the other side. Panels are available for both walls and ceilings.

Amplification - An artificial increase in sound volume created through electronic means.

ANSI - Acronym for American National Standards Institute.

Attenuation (blanket) - A soft fibrous device, sometimes with a heavy mass layer inside used to reduce sound levels in a space or the passing of sound through it.

Background Noise - Sound in a furnished, unoccupied learning space, including sounds from outdoor sources, building services and utilities. For the purposes of this standard, background noise excludes sound generated by people within the building or sound generated by temporary or permanent instructional equipment. Noise level or sound level is expressed in decibels, unit symbol dB. In this standard booklet, dB refers to dBA.

Decibel or dB - In our case, it is a unit of measurement of the magnitude of the sound level.

Frequency - Distance between waves depending on the pitch of the sound expressed in Hertz, or cycles/second.

IIC - Acronym for Impact Isolation Class.

OITC - Acronym for Outdoor Indoor Transmission Class.

NRC - Acronym for Noise Reduction Coefficient.

Reverberation - Refers to the persistence of sound in and area or space after an impulse such as a balloon popping.

Separation Wall - The wall between classrooms or between classroom and corridor or classroom and another space.

For a more detailed and technical glossary of terms see ANSI/ASA S12.60-2006.

Sound (sound waves) - Fluctuations in air pressure that travel from a source to a listener, where they are perceived via the ear and brain as sound. Sound waves behave like light waves; they can be reflected, refracted, diffracted, transmitted, absorbed, and so on.

Signal to Noise Ratio - The perceived sound level of the desired source relative to the background noise level (location specific). A minimum signal to noise ratio for good intelligibility of a person speaking is 15dB.

STC - Acronym for Sound Transmission Coefficient.

For a more detailed and technical glossary of terms see ANSI/ASA S12.60-2006.

Appendix G: References and resource documents

The following set of references are a sample of available literature on the topic of classroom acoustics:

Maryland State Department of Education: Classroom Acoustics Guidelines (2006) www.marylandpublicschools.org/NR/rdonlyres/FCB60C1D-6CC2-4270-BDAA-153D67247324/10128/ClassroomAcousticsGuidelines.pdf

National Clearinghouse for Educational Facilities: Classroom Acoustics Resource List www.ncef.org/rl/acoustics.cfm?date=4

Ceiling & Interior Systems Construction Association (CISCA): Acoustics in Schools (Design Tool) www.cisca.org/files/public/Acoustics%20in%20Schools_CISCA.pdf

"The effects of environmental and classroom noise on the academic attainments of primary school children", Bridget M Shield[1] and Julie E Dockrell, J. Acoust. Soc. Am. 123 (1), January 2008.

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"Aircraft noise and children's learning," Jones, K. , Environmental Research and Consultancy Department, UK CAA, ERCD Report 0908. Feb. (2010). www.caa.co.uk/docs/33/ERCD200908.pdf

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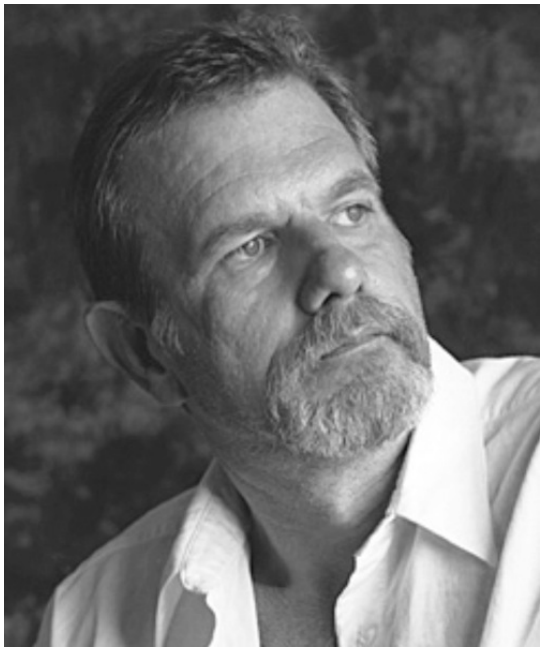

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