The School Building Association

ISSUETRAK

A CEFPI Brief on Educational Facility Issues

Topic : Classroom Acoustics

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CEFPI BRIEF

TEACHING IN THE DARK

We would never teach reading is a classroom without lights. Why then do we teach in "acoustical darkness?" Speaking to a class, especially of younger children, in a room with poor acoustics, is akin to "turning out the lights."

Architects and facilities planners are quite adept at specifying appropriate lighting levels for classrooms. Required ventilation changes and environmental temperature are always included in any building design. Just as the effect of changes in these design parameters on room occupants can be predicted, the effect of room finishes and ventilation noise on the ability to verbally communicate in the room can be predicted. Teaching in a room with poor acoustics is not only analogous to reading in the dark, inappropriate acoustical design exacerbates the difficulty of communication between teacher and student.

Frequently we hear questions like, "I am an elementary school teacher. It seems the louder I speak, the more noise my students make, so I speak louder, and the students get noisier, and I speak louder… Is there something wrong with my teaching?"

This is classic description of what acousticians call the Lombard effect – the tendency of a talker to maintain a constant relationship between their level of speech and the level of competing sound. In many classrooms there is nothing to limit the build-up of competing sound. The louder the classroom sound, the louder the teacher must speak, and the louder the students will speak to one another. The result is a poor communications environment. It is but one example of what I refer to as "teaching in the dark." Trying to communicate with students in an environment that is hostile to communication also puts the teacher under added vocal (and probably psychological) stress.

Other examples are the classroom where the teacher must choose between using the ventilation system to keep the room cool and turning the ventilation system OFF so teacher and student can understand each other. The classroom located next to the band room where conversation is difficult during band practice is another example of "teaching in the dark."

Although in their most egregious form, these problems present difficulties for students and teachers of any age to communicate, for many years we have known that younger students who have not yet fully acquired language require better acoustical environments for learning than do older students such as those in high school. The Goldman-Fristoe-Woodcock Auditory Skills Test Battery shows improvement in understanding of speech from age 3 to age 16 (Elliott, 1979). In an extensive review of the effect of noise on children, Mills (1975) found that, "Levels of noise that do not interfere with perception of speech in adults may interfere significantly with perception of speech by children."

Children with learning disabilities (developmental articulation expected to be self correcting with age; delayed language development; reading problems, and others) require higher speech levels than normally progressing children to achieve the same performance even in quiet test conditions.

It has been over 100 years since Sabine (1895) developed the basic principles by which the adequacy of the communication environment can be quantified. In the past 70 years these have been refined and standardized by national and international organizations (cf. American National Standards Institute S3.5, Methods for Calculation of Articulation Index). These techniques have been used to design offices, conference rooms, theaters and lecture halls for decades. Perhaps it is time to apply them in schools as well.

Teachers know that the problem exists and acoustical engineers know how to solve the problem. Unfortunately, we have never effectively communicated the scientific basis of the need for or the simple solutions to implement good classroom acoustics.

PREDICTING CLASSROOM ADEQUACY FOR COMMUNICATION

In the context of a classroom, if we can't read the book, the room is too dark. It follows that if we can't understand the speech, the room is "acoustically dark." Speech intelligibility depends on two main factors: the level of the speech (vocal effort) and the level of competing noise, which in turn depends on the level of the competing source itself and the amount of reverberation in the room or reflections which allows the sound to build-up. Experimentally, the relationship between these factors has been developed into a metric that is called the Articulation Index (AI). Articulation Index is a number that ranges between 0 and 1. In an environment with an AI of 1.0, speech will be completely understood. At an AI of 0, no speech can be understood. Data determined empirically that demonstrate this are shown in Figure 1.

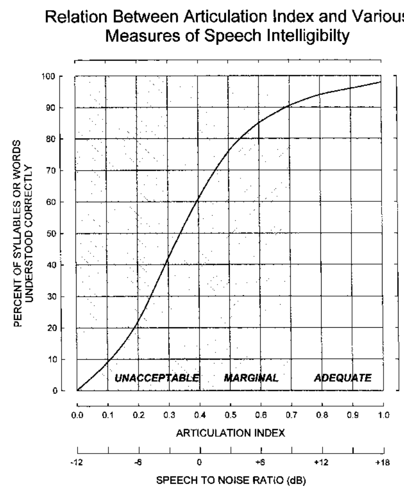

Figure 1 --
Data shows the intelligibility of words not know in context.

Normal hearing listeners were asked to identify the words presented to them under various conditions of competing noise and the percent that were correctly identified was noted. We see in Figure 1 that for an AI of 0.7 or greater we can anticipate that at least 90 percent of the words will be understood correctly. For an AI of 0.3 or less, fewer that 40 percent of the words will be correctly understood. Generally, it is considered that an AI of 0.7 or better is necessary for good speech communication. In fact, when designing adjacent offices for good speech privacy, an AI between rooms lower than 0.3 is normally required. If the words are known beforehand or if they are included in context, then performance will be better.

Energy contained in speech compared to energy in the competing sound (the speech-to-noise-ratio) is the primary determinant of Articulation Index. This is shown on the lower axis in Figure 1 where we see a speech-to-noise ratio of 0 decibels (speech and noise equal) is equivalent approximately to an AI of 0.4. For acceptable speech intelligibility, a speech-to-noise ratio of approximately 9 dB or greater is required whereas a speech level of 3 dB or more *below* the noise level (S/N = -3 dB) will produce inadequate communication or speech privacy. There are two ways to increase the S/N ratio – raise the speech or lower the noise. The first is very hard on the teacher and has other limitations as well.

Reverberation, the build-up of sound in a room from multiple reflections, also influences the speech intelligibility or the AI in two ways. First, long reverberation times (many reflections) allows a greater build-up of sound level in the classroom resulting in lower speech-to-noise ratios. This is why simply using a sound system frequently is ineffective. Second, long reverberation times don't allow the sound from the phoneme (the smallest element of spoken speech) to decay before the next phoneme is uttered. Therefore, long reverberation time has the effect of "blurring" speech sounds. A reverberation time of as little as 1 second can reduce the Articulation Index by 0.1, a 2-second reverberation time will reduce it by 0.25. Therefore, if a classroom is marginally adequate in terms of the level of competing noise from other sources, a reverberation time of 1 second can render the classroom inadequate. Generally, it is recommended that reverberation times in classrooms be limited to less than ½ second.

Reverberation depends on the volume of the room and the types of materials used on the floors, walls, and ceilings. Acoustically "hard" finishes such as tile and glass do not absorb sound readily and produce long reverberation times. Acoustically "soft" finishes such as carpet, acoustical tile, and curtains are highly sound absorbent and can reduce reverberation times.

HOW CAN WE CALCULATE CLASSROOM ADEQUACY?

Several of the relevant parameters mentioned before can be measured directly: reverberation time and background sound level are the two of importance.

Background sound levels in a room are measured in octave bands using a sound level meter or a real-time analyzer which produces a sound spectrum as shown in Figure 2. Also shown in Figure 2 are a set of parallel curves known as "NC Curves" which are used by acoustical engineers and architects to summarize the sound in a room with a single label, the "NC rating." It is often used to specify the criterion sound level to be achieved in a room. The NC rating resulting from any sound source is the number of the curve not exceeded by the sound spectrum.

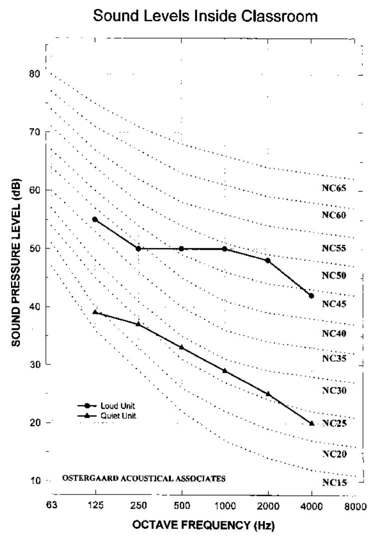

Figure 2 --
Sound spectra for noisy and quiet unit ventilators plotted against room noise criteria. The NC of "Noise Criterion" curves provide an initial metric on which to judge the adequacy of the environment.

In Figure 2, the sound pressure levels in a room produced by two different ventilation systems are shown. One is a typical commercially available unit ventilator, a device that sits on the floor and circulates air from outside the room through an opening in the wall. The second is a specially treated unit that also provides ventilation to a single room through openings in the wall. The units are described as "loud" and "quiet" respectively.

If we know levels of normal speech (normal vocal effort) and the speech-to-noise ratio required for good intelligibility, an estimate of the appropriate NC value for a classroom could be determined. As an example, normal speech at 3 feet is approximately 65 decibels. At 30 feet, it is 45 dB. From Figure 1, we want a 12 dB speech-to-noise ratio, subtracting 12 dB from 45 means that a maximum sound level in the room of 33 dB is acceptable. Assume that this result is calculated in the 500 Hz octave band, the result is a NC-30 criterion as seen in Figure 2. Clearly, the noisier unit produces an unacceptable acoustical environment.

If the room is designed for NC-30, a child at the rear of the room will be able to hear speech adequately. Just as the teacher would move a child with visual problems closer to the blackboard, a student requiring higher speech levels could be moved closer to the teacher. The actual Articulation Index for a specific location in a specific classroom can be calculated for different ventilation systems and room finishes.

HOW DO WE ACHIEVE THE GOALS?

Since sound level in a room depends on source energy, size of room, and the room finishes, appropriate control of these factors can produce rooms that function well for learning. We can take the children out of the "acoustical darkness". Manufacturers of HVAC equipment typically provide data on sound produced by their equipment or the acoustical engineer can measure the output of similar equipment.

As an example, we calculated the Articulation Index in the center of a room 9 feet high by 20 feet by 15 feet under four conditions. The room is constructed with one glass window wall, three gypsum board walls, a vinyl tile floor, and a painted concrete ceiling.

- The first condition assumed installation of the "loud" ventilation unit.
- The second condition replaces the "loud" unit with the "quiet" unit.
- The third and fourth conditions were the same ventilation units as the first and second. The room finishes in these cases were changed replacing the ceiling with acoustical tile and adding sound absorption on one wall.

In all cases, the teacher speaks with normal voice and we listen in the middle of the room.

*Table 1 – Articulation Index at the center of classroom under four design scenarios. Teacher uses **normal voice** effort.*

	Untreated	Treated
Loud	0.0	0.16
Quiet	0.56	0.85

No amount of treatment can overcome the effect of the background sound produced by the ventilation system. With the quiet ventilator, speech intelligibility is good in the treated room and fair in the untreated room. In addition to producing higher noise levels in the untreated room, the approximately 2-second reverberation time decreased the AI in the room by 0.25.

Even with raised voice effort, as shown in Table II, speech intelligibility is poor in the room with the noisier ventilation system. Of course, and teacher who must use raised voice for a long period of time will end the day severely fatigued.

*Table II – Articulation Index at center of classroom under the same four designs. Teacher uses **raised voice** effort.*

	Untreated	Treated
Loud	0.09	0.37
Quiet	0.74	0.94

Modifications in the treated room include application of sound absorbing panels on one wall and a suspended acoustical ceiling. It is important to note that simply placing these materials in the room is not necessarily a final solution to intelligibility since it is important to control sound reflections to the rear of the room as well. However, in this simple example, we can see the effect of the treatment on reducing the reverberation time, decreasing the background sound level at the center of the room and increasing speech intelligibility.

Note that a combination of the two treatments is required to optimally correct the speech intelligibility in this room. Treating the room without addressing ventilation noise does not produce a sufficient improvement in speech intelligibility. Reducing the HVAC noise without treating the room only increases intelligibility to a fair, not good, environment.

RECOMMENDED APPROACHES TO NEW DESIGNS OR RETROFITS.

Since the principles of acoustical design for good speech intelligibility are well established, it is possible to specify criteria for classroom acoustical environments in the same manner as specifying illumination, temperature, or any other environmental parameter.

Materials for finishes are available in a wide variety of forms. HVAC equipment manufacturers are beginning to develop quiet ventilators for classroom environments. By specifying ambient sound level and reverberation time, the architect, with the assistance of an acoustical engineer, can establish appropriate requirements for HVAC equipment sound emissions and room finishes.

DEFINITIONS

Reverberation time (sec) – The time required for the sound level to decay 60 dB from its original level after the sound source is stopped. Reverberation time is one of the criteria used for occupied spaces.

Octave Band (OB) – A band of frequencies whose upper frequency limit is two times the lower frequency limit. This is comparable to the octave on a musical instrument.

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