Seeking Architectural Design Guidelines for Improved Speech Communication in School Classrooms

DEAN HEERWAGEN
University of Washington

Contemporary K-12 (and university) classrooms are being constructed without benefit of recently-developed knowledge describing what physical conditions will insure excellent speech intelligibility in classrooms. As a result, speech intelligibility in many new and existing classrooms is inferior. The consequence of poor speech intelligibility is that normal-hearing students, as well as those with hearing impairments, understand speech less well and their academic performances suffer. Students experiencing poor speech intelligibility in classrooms have been shown, through research, to exhibit delayed development in both verbal and mathematical skills.

A need for architectural/acoustical design guidelines for school buildings

During the past few years numbers of school bond and levy issues authorizing the rehabilitation and/or new construction of K-12 schools have been passed in communities in the State of Washington and elsewhere across the United States Thus ends nearly three decades when very little school rehabilitation or construction work was undertaken. The principal reason for this long-term dearth of educational building has been demographic. In the decade from the middle 1950's through the 1960's frenetic school construction occurred to provide adequate educational facilities for "Babyboom Generation" children. But, after these children had passed through the K-12 educational system, most school district administrators found that they indeed had a surplus of educational facilities (and many districts "moth-balled" or even sold off existing facilities.) However, recently as the Babyboomers' children have begun their primary and secondary educations, contemporary administrators are discovering a need for new or rehabilitated school spaces.

For example, the City of Seattle recently passed a levy for $270 million to begin renovations, additions, or new construction for the Seattle School District. Further, the Seattle School District has identified another fourteen primary schools, ten middle schools, and one high school, all of which will require significant rehabilitation. To pay for these improvements further levies will have to be passed. Meanwhile, the school district in Dade County (Florida) is beginning a $920 million program for the construction of twenty-one new schools (and is contemplating building an extra eleven schools at yet-additional costs.)' These two examples — a continent apart — offer an indication of the intensity and scale of the need for school construction. Indeed, based on a report prepared by The Council of Educational Facilities Planners, International, completions of K-12 school construction in the United States totaled $12 billion for the Calendar Year 1996. For 1997 school construction completions are projected to have a total worth of $12.8 billion.?

This recent burgeoning in school construction is occurring while school districts, here in Washington State and elsewhere across the United States, are finding that comprehensive architectural/acoustical guidelines for planning and equipping school buildings are lacking.[3] Instead, school districts, for the most part, rely on largely obsolete design guidelines which, if they existed at all, were used as bases for creating the 1960's schools. Except where design and/or construction practices have markedly changed since the 1960's, little new information is being included in the design requirements furnished by school districts (to building designers.)

Unfortunately, the design and construction professions are mostly unaware of the development of new bodies of knowledge. One such collection of new knowledge concerns what acoustical performance levels are required to insure enhanced *speech intelligibility* in school classrooms. Presently, there are few established *architectural* guidelines for designing K-12 school classrooms, which will assure effective communication between teachers and students. Indeed, the results of recent measurements — either described in the scientific literature or conducted anecdotally by various acousticians — indicate that all too many new and existing classrooms display inferior speech intelligibility.

What factors lead to inferior speech intelligibility in classrooms?

There are at least seven significant parameters that contribute to inferior speech intelligibility in classrooms:
(1) high background noise levels;

(2) weak speech-signal-to-background-noise level ratios;
(3) excessive (too long) reverberation;
(4) too great speaker-to-listener distances;
(5) various speaker idiosyncrasies (e.g., accenting, mumbling, rapidity, using unfamiliar verbiage, etc.);
(6) various acoustical (physical) defects of the classroom, and
(7) faulty amplification systems.

The first three and the sixth parameters involve the acoustic (physical) nature of the classroom. The fourth parameter is strictly a physical dimension, but is made important by the manner and style of the educational process which occurs in the classroom. The fifth parameter depends principally on the characteristics of the various talkers in the classroom. Lastly, the seventh parameter may be relevant if electronic systems have been provided as voice enhancements for talkers in the classroom.

Reported acoustical properties of K-12 classrooms

Unacceptable **background noise levels** in classrooms result from the presence of any of several potential noise sources. These sources may exist in the classroom; they may occur in the school building, but be outside of the specific classroom; and/or the sources can be located external to the school building (and enter the building and classrooms by being transmitted through the building envelope.) For example, common noise sources outside of school buildings include road vehicles and over-flying aircraft, school children exercising on adjacent playgrounds, and construction activities. Sources within school buildings, but which are not in the classroom, are student movement and conversing in hallways, cafeteria noise, wood and metal-working shop activities, band practice, and noise produced in adjacent classrooms as part of normal educational activities. Even within individual classrooms various noise sources can be present: noise can be produced by students talking (or whispering), by the scuffing of shoes on uncarpeted floors, by the dropping of materials onto furniture and floors, and by computers, audio-visual equipment, and, most importantly, ventilation systems (which serve the classroom.)

Measured background noise levels in *unoccupied* classrooms have been found to be in the range of 50-65 dB(A). For instance, Crandell and Smaldino measured background noise levels in thirty-two *unoccupied* classrooms in six different schools of a metropolitan school district.[4] The classrooms were present in four elementary schools, one middle school, and one high school. The average unoccupied background noise level was 50.2 dB(A) with a range of between 34 to 62 dB(A). Measuring the same classrooms on the C-weighting scale, their results showed an average of 65.9 dB(C) with a range of 49 to 78 dB(C). The higher magnitudes found with the C-weighting scale indicate that considerable noise energies were present in these classrooms at lower frequencies. One important result of having such lower frequency noise present in the classrooms is that this lower frequency noise will generally mask (or override) useful higher-frequency speech sounds, which include softer consonant sounds whose audition are particularly necessary for having good speech intelligibility. An earlier study by Bess *et al.* was conducted in nineteen classrooms in another metropolitan school district.[5] When these nineteen classrooms were unoccupied and background noise levels were measured, the results showed a median level of 41 dB(A) with a range of 28 to 50 dB(A), and a median of 58 dB(C) with a range of 52 to 67 dB(C).

Occupied background noise levels in classrooms are usually substantially greater. For instance, in the study cited above, Bess et *al.* reported that the median *occupied* background levels were 56 dB(A) and 63 dB(C) with ranges of 48 to 66 dB(A) and 53 to 71 dB(C), respectively.[6] In another study by Blair, that author found that unoccupied and occupied background noise levels for a typical classroom were, 55 and 65 dB, respectively (note that this author did not specify which weighting scale had been employed.)' Finitzo-Hieber has reported finding, in a series of unoccupied classrooms, background noise levels equaling 36 to 44 dB(A) and 52 to 58 dB(C).[8] When these classrooms were tested while occupied, increases in noise levels of about 15 to 20 dB resulted.

When such high background noise levels are matched against common sound pressure levels for speech, it is not surprising that inadequate **speech-signal-to-background-noise-level ratios** are observed. Pearson et *al.* have reported that the voice levels of average adult female talkers speaking with "normal" amounts of effort have been measured at 55 dB(A) (with a standard deviation of 4 dB(A).)[9] So, contrasting these voice levels with the background noise levels for the previously-cited *occupied* classrooms presents speech-to-noise ratios (for average talkers) which will be near 0 dB (i.e., which indicates that speech and noise levels will have equal strengths!) Indeed, Sanders reported speech-to-noise ratios of +1 to +5 dB;[10] Blair noted speech-to-noise ratios of -7 to 0 dB;[11] and Finitzo-Hieber found speech-to-noise ratios of +1 to +4.[12] Thus, for all these reports the speech sounds of teachers were either less strong or just barely greater than the background noise.[13]

The third principal parameter which adversely affects speech communication is excessive room **reverberation.** Reverberation is the subtle prolongation of sound after the source of a sound has ceased to emit the sound. The prolongation occurs because sound waves moving outward from a source reflect off of room surfaces, and this reflecting sound energy remains audible. Excessive reverberation causes interference with the hearing of *subsequent, useful* direct *sounds* . How long the reverberating sound will continue to be perceptible depends on the nature of room surfaces. When the surfaces are mostly hard and smooth (i.e., reflective), the time period will be longer; when the surfaces are largely soft and fuzzy (i.e., absorptive), the time period will be much briefer.'"

The commonly-employed term for indicating the duration of reverberation in a room is the reverberation time (abbreviated as RT).[15] For good hearing of speech sounds, reverberation times should be short, lasting for a fraction of

TABLE 1
Word discrimination scores for tests conducted in noise and reverberation
-- for normal-hearing students -- (after Finitzo-Hieber and Tillman)[20]

Signal-to-noise ratio (in dB)	Reverberation times (in seconds) 0.0	0.4	1.2
Infinite	100.0%	98.7%	82.0%
4-12	94.7	88.3	74.3
+ 6	85.2	76.8	59.7
0	65.7	53.2	35.2

one second. But various researchers have found longer reverberation times. For instance, Kodaras reported reverberations times (measured at 1000 Hz) ranging from 0.4 to 1.1 seconds in eleven elementary school classrooms, which were described as being "typical" and constructed in the post-World War II era.[16] Bradley measured a series of ten middle-school classrooms in Ottawa and found that the reverberation times (at 1000 Hz) for those classrooms ranged from 0.39 to 1.20 seconds (with an average of 0.72 seconds.)[17] Crandell and Smaldino have measured reverberation times in thirty-two classrooms — each one at 500, 1000, and 2000 Hz.[18] They averaged the three reverberation time values for each classroom and then averaged the "average" times for the thirty-two classrooms. The results showed an average reverberation time of 0.52 seconds with a range of 0.30 to 1.12 seconds.

The combined effects of weak speech-signal-to-background-noise-level ratios and excessive reverberation times have been studied by Finitzo-Hieber and Tillman who administered speech intelligibility tests to normal-hearing K-12 students.[19] The results of their tests are summarized in the table above. The signal-to-noise ratio (in the first column) indicates how strong the (recorded) speaker's voice was relative to the background noise level. Second, when the reverberation times are zero (as in the second column), the word discrimination scores are essentially for background noise-only conditions. And, third and most important, this table demonstrates how the combination of low speaking (voice) levels, background noise, and reverberant conditions can severely undermine word discrimination (speech intelligibility) for *normal-hearing* students. The results reported in this table are similar to those found by other researchers working in comparable situations. Indeed, this work by Finitzo-Hieber and Tillman is regarded by many speech and hearing scientists as perhaps the seminal study for showing how reverberation and noise affect speech intelligibility in K-12 classrooms.

Distances between teachers and students in classrooms are usually dictated by class size, the grade level, the natures of the subject matter considered in the classrooms, and whether the classrooms are organized in a standard-lecture or small-group format. What makes distances too great — in terms of speech intelligibility — is that direct sound weakens as the distance from the source increases and reflected sound waves arriving somewhat after direct sound waves do not adequately reinforce this direct sound. Generally, the reflected sound waves will have different compositions than the direct waves (e.g., the intensities, spectral distributions, and temporal patterns of the reflected waves will be altered by the acoustical properties of the room surfaces.) So, particularly-later-arriving reflections — occurring when teacher-student distances are larger — can obscure directly-arriving sound waves. In typical rooms a fraction of the room volume near to the speaker will receive sound energy principally from the direct waves. This volume is identified as the near field. Beyond this near field the reflecting waves can be the more powerful component of spoken communications from the teacher. This volume beyond the near field is called the reverberant field (i.e., the volume in which reverberating sound waves predominate over the direct waves.) The boundary between the near (direct) and reverberant fields occurs at the *critical distance.* Beyond this critical distance, speech intelligibility in a room will be reasonably constant. Peutz has derived an equation for estimating this parameter.[21] In a classroom with a floor area of about 800 square feet (74 sq.m.) and a reverberation time of about 0.70 second, the critical distance from the teacher will be approximately seven and one-half feet (2.3 m).

How a speaker talks in a classroom can have profound effects upon the speech intelligibility experienced by listeners. For instance, a teacher may speak with an accent that causes the speech seem unfamiliar to the listeners. Or the teacher may speak indistinctly (either too rapidly or faintly.) Or if the speaker uses unfamiliar words — jargon or even slang — making understanding of the speech troublesome.

The types of other room **acoustical defects** that can negatively affect the quality of sound communication in a room are several. Whether any one or more of these defects will exist in a classroom depends upon a number of factors including the size and geometry of the room, the properties of the surface materials, and the layout of furnishings. Examples of these conditions include flutter echo; long-delayed reflections; sound concentrations, voids, or shadows; room resonance (modes); uneven distribution of absorption; and the coupling of adjacent spaces.

Speech amplification systems are rarely present in most conventional K-12 classrooms with floor areas up to about 1000 square feet and commensurate ceiling heights. However, in larger classrooms where audience capacities exceed about fifty or seventy-five students and/or the distance between a speaker and an auditor exceeds about forty feet, an amplification system may be necessary. Amplification systems in classrooms require special attention to insure proper design, installation, and operation (particularly, if these systems are provided for hearing-impaired students.)

Recommendations for establishing good speech communication conditions in K-12 classrooms

Presently, two sets of guidelines define conditions for well-operating classrooms. The first set of guidelines presents two alternative recommendations for **background noise levels.** One component of this set of recommended acceptable noise levels is the Noise Criterion (NC) model that was originally developed by Beranek[22], subsequently was modified by Schultz[2'], and has since been further revised, again by Beranek[24,25]. The purpose of this model is to indicate what background noise level should be maintained in a building interior to minimize noise interference with intended activities. According to design recommendations that accompany this Noise Criterion model, classroom interiors should be designed to have background noise levels not exceeding NC 30-40 (i.e., or, using the related A-weighted scale, background noise levels should not exceed 38 to 48 dB(A).) An alternative guideline has been promulgated by the American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) and specifically recommends acceptable background noise levels in unoccupied classrooms taking into accountwhen the mechanical (HVAC) system is operating. This guideline identifies Room Noise Criteria (RC). The recommended Room Noise Criteria for classrooms are RC-40 for classrooms up to 750 square feet and RC-35 for larger classrooms (whether amplified or not.)[26]

The other major set of guidelines for establishing good speech communication conditions in classroom has been proposed by the American Speech-Language-Hearing Association. These guidelines are based on extensive research conducted by speech and hearing scientists who have tested both normal-hearing and hearing-impaired students to determine what acoustical conditions are needed in K-12 classrooms. The principal recommendations from this large body of research address **background noise levels, reverberation times,** and **speech-signal-to-background-noise-level ratio~.** The specific quantities appearing in these recommendations are as follows, *for* unoccupied classrooms,

- background noise levels should be less than 30 dB(A) (or less than the values found on a NC (Noise Criterion) 20 curve);
- reverberation times should be equal to or less than 0.4 seconds; and
- the speech-signal-to-noise ratio should be at least +15 dB(A).

There are no commonly-specified recommendations for teacher-to-student distances. Direct sound waves from the teacher will be strongest within the radius of the critical distance out from the teacher. But beyond this critical distance the sound level will be relatively uniform (within the reverberant field.) If the educational style in aclassroom can be limited to having the class be divided into a series of small groups so that the teacher may speak to each small group one group at a time (e.g., a teacher talking to a small group clustered around a table), then the voice level of the teacher will be stronger as s/he addresses the group. But, if the teacher speaks to a class of twenty-five or thirty students, who sit conventionally in rows, then some students close to the teacher will experience the stronger direct sound waves and the direct (near) field, and the remaining students will be in the reverberant field (with its comparatively weakerspeech sound level.)

CONCLUSIONS AND RECOMMENDATIONS

The preceding discussion indicates that a number of obstacles exist to the successful development and dissemination of useful design guidelines. The principal obstacle is that there is a lack of communication between speech and hearing scientists and acoustical consultants and also between acoustical consultants and architects. These communication problems lead to a host of cascading difficulties commencing with a lack of awareness of the knowledge base generated by speechand hearing scientists; poor coordination of the performance criteria recommendations advocated by various professional societies; and the need for the sharing of existing knowledge and the development of practical, cost-effective, and easy-to-use design guidelines. Clearly better and more informative lines of communication must be created to get relevant information to architects and the architects must begin to work with this knowledge.

In summary, the need for excellent speech intelligibility in classrooms has been well-established by speech and hearing scientists. Further, these scientists have also identified the various parameters that must be satisfied to achieve effective communication between teachers and students. Without the promotion of such effective communication students hear and understand less well and their academic performances suffer. Speech and hearing scientists (and alternative professional societies) have developed guidelines for what acoustic conditions manifest excellent speech intelligibility opportunities. What is now required is that these guidelines be refined, extended to cover all of the major parameters affecting speech intelligibility, and then translated into directives and informational aids that will enable architects to design classrooms so that excellent speech intelligibility will be the rule, not the exception.

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NOTES

1 This information about the Dade County school construction effort was broadcast on the National Public Radio program, *Morning Edition,* on April 23, 1996.

2 These data have been taken from a web page, "1997 Construction Report," found at the address, http://www.cefpi.com/cefpi/1997-cr/index.html .

As one indication of the lack of attention about the acoustical performance of classrooms, three reports have been issued by the U.S. Government Accounting Office documenting the results of a nation-wide survey of schools. In this survey undertaken in 1994, school districts were asked to rate various features of their school facilities. Among these features were *environmental* factors, including ventilation, heating, lighting, indoor air quality, and "acoustics for noise control" in classrooms. Of these factors "acoustics for noise control" was most often cited as being unsatisfactory with 28.1% of the nearly 78,000 schools surveyed identifying this environmental factor. The total numberofstudents that wereaffected by the unsatisfactory "acoustics for noise control" was projected at 11.0 million.

The three reports, all issued by the U.S. Government Accounting Office, were "School Facilities: Conditionof America's Schools," [HEHS 95-61]; "School Facilities: America's Schools Not Designed or Equipped for the 21st Century," [HEHS 95-95]; and "School Facilities: America's Schools Report Differing Conditions," [HEHS 96-103]. The first two ofthesereports wereissued in 1995. The third was issued in 1996. The place of issuance was the GAO office in Gaithersburg, MD.

4 C. Crandell, and J. Smaldino, "An update of classroom acoustics for children with hearing impairment," *The Volta Review, 96*(4), (1994), pp. 291-306.

5 F.H. Bess, J.S. Sinclair, and D.E. Riggs, "Group amplification in schools for the hearing impaired," *Ear and Hearing, 5*(3), (1984) pp. 138-144.

6 *Ibid.*, p. 141.

7 J. Blair, "Effects of amplification, speechreading, and classroom environment on reception of speech," *The Volta Review, 79*(6), (1977), pp. 443-449.

8 T. Finitzo-Hieber, "Classroom acoustics," in Roeser, R. (ed.), *Auditory Disorders in School Children* (New York: Thieme-Stratton, 1981), pp. 221-233.

9 K.S., Pearson, R.L. Bennett, and S. Fidell, *Speech Levels in Various Noise Environments* [prepared by Bolt, Beranek, and Newman, Inc., Canoga Park, CA, for the U.S. Environmental Protection Agency], May 1977.

10 D. Sanders, "Noise conditions in normal school classrooms," *Exceptional Child,* 31, (1965), pp. 344-353.

11 Blair, J., *op. cit.*

12 T. Finitzo-Hieber, *op. cit.*

13 The consequences of having excessive background noise present in classrooms has been examined by several researchers. In studies where alternative groups of students were compared — some of whom occupied classrooms that were exposed to noisy backgrounds for sustained periods versus other students who occupied quiet classrooms — the students in the noisy classrooms were found to have decreased performances in subjects such as reading comprehension, vocabulary development. and other language skill measures. For example, Bronzaft and McCarthy have reported that students in an elementary school who were exposed to high exterior noisiness from an elevated subway railway performed less well on reading tests than other students at the same school whose classrooms were on the opposite side of the building and faced quiet exterior settings (i.e., when averaged scores for both groups were compared.) The observed decrease in performance was equivalent to a three to four month delay in the development of both vocabulary knowledge and reading comprehension. Cohen *etal.* examined the test performances of third-grade children some of whom occupied classrooms exposed to aircraft noise and others of whom occupiedclassrooms which had been treated for noise abatement. The students present in the noise-abatedclassrooms performed better on both mathematics and reading tests, after adjusting for factors of race, length of occupancy in the respective classrooms, and cognitive ability measures (gathered from the students two years previously.) Lukas *et al.* found similar consequences when they examined students whose classrooms were regularly exposed to road vehicle noise. These students, who were in the sixth grade, displayed an average of a 0.7-year lag in performance on reading tests, when contrasted with students whose classrooms were quiet. Likewise, Green *et al.* have written of similar decreased proficiencies among elementary school students who were regularly exposed to noisy conditions in schools located in the New York City boroughs of Queens and Brooklyn. For this study the researchers performed extensive statistical analyses across a large population of Grades 2-6 students, some of whom occupied classrooms regularly made noisy by aircraft fly-overs and others of whom attended classrooms that were in quieter settings. The major findings in the Green et al. study was that "high levels of environmental noise are inversely related to reading ability in elementary school children."

The references for these previously-cited papers are as follows: A. Bronzaft, and D. McCarthy, "The effects of elevated train noise on reading ability," *Environment and Behavior, 7*(4), (1975), pp. 517-527; S. Cohen, D.S. Krantz, G.W. Evans, D. Stokols, and S. Kelly, "Aircraft noise and children: longitudinal and cross-sectional evidence on adaptation to noise and the effectiveness of noise abatement," *Journal of Personality and Social Psychology, 40*(2), (1981), pp. 331-345; J.S. Lukas, R.B. DuPree, and J.W. Swing, *Effects of Noise on Academic Achievements and Classrootn Behavior,* State of California Report FHWA/CA/DOHS-81/01, (produced at the University of California, Berkeley), September 1981; K.B. Green, B.S. Pastemack, and R.E. Shore, "Effects of aircraft noise on reading ability of school-age children," *Archives of Environmental Health, 37*(1), (1982), pp. 24-31.

14 Note that several studies have documented the contribution of early reflections on developing good speech intelligibility. Papers by Lochner and Burger reported that reflected sound reaching a listener within 95 milliseconds aided intelligibility of speech. Subsequently, Haas found that reflections of speech sounds arriving within 30 milliseconds enhanced the loudness of the sound and positively influenced intelligibility. More recently, Soulodre et al. have repeated and extended the previous studies, finding that the shorter the time delay between the arrivals of direct and reflectedsound, the better intellgibility will be.

The sources for these citations are: and J.F. Burger, "The subjectivemasking of short timedelayed echoes by their primary sounds and their contribution to the intelligibility of speech," *Acustica, 8*(1), (1958), pp. 1-10; J.P.A. Lochner and J.F. Burger, "The influence of reflections on auditorium acoustics," *Journal of Sound and Vibration,* 1, (1964), pp. 426-454; H. Haas, "The influence of a single echo on the audibility of speech," *Journal of the Audio Engineering Society, 20*(2), (1972), pp. 146-158; and G.A. Soulodre N. Popplewell, and J.S. Bradley, "Combined effects of early reflections and background noise on speech intelligibility," *Journal of Sound and Vibration, 135*(1), (1989), pp. 123-133.

[15] H. Kurtovic, "The influence of reflected sound upon speech intelligibility," *Acustica, 33*(1), (1975), pp. 32-39; and J.P.A. Lochner and J.F. Burger, "The influence of reflections on auditorium acoustics, *Journal of Sound and Vibration,* 1, (1964), pp. 426-454.

[16] M.J. Kodaras, "Reverberation times of typical elementary school classrooms," *Noise Control, 6*(4), (1960), pp. 17-19.

[17] J.S. Bradley "Speech intelligibility studiesinclassrooms," *Journal of the Acoustical Society of America, 80*(3), (1986), pp. 846-854.

[18] C.C. Crandell and J.J. Smaldino, *op. cit.*

[19] Results similar to those reported by Finitzo-Hieber and Tillman have been found in parallel studies. For instance, Nabelek and Robinson found comparable data for speech intelligibility tests undertaken in various reverberation conditions. Their principal finding was that the intelligibility test scores increased as the reverberation times decreased to zero seconds. See A.K. Nabelek and P.K. Robinson, "Monaural and binaural speech perception in reverberation for listeners of various ages," *Journal of the Acoustical Society of America, 71*(4), (1982), pp. 1242-1248. Alternatively, Neuman and Hochberg have also found similar results when they tested phoneme discrimination in a series of reverberant conditions. Their findings include that the phoneme discrimination test scores decreased as reverberation times increased. See A.C. Neuman, and I. Hochberg, "Children's perception of speech in reverberation," *Journal of the Acoustical Society of America, 73*(6), (1983), pp. 2145-2149.

[20] T. Finitzo-Hieber, and T.W. Tillman, *op. cit.*, p. 449.

[21] V.M.A. Peutz, "Articulation loss of consonants as a criterion for speech transmission in a room," *Journal of Audio Engineering Society, 19*(11), (1971), pp. 915-922.

[22] L.L. Beranek,, "Revised criteria for noise in buildings," *Noise Control, 3*(1), (1957), pp. 19-27.

[23] T.J. Schultz, "Noise-criterion curves for use with the USASI preferred frequencies," *Journal of the Acoustical Society of America, 43*(3), (1968). pp. 637-638.

[24] L.L. Beranek, "Building noise-criterion (NCB) curves," *Journal of the Acoustical Society of America, 86*(2), (August 1989), pp. 650-664; and L.L. Beranek, "Application of NCB noise criterion curves," *Noise Control Engineering Journal, 33*(2), (September-October 1989), pp. 45-56.

[25] The Noise Criterion curves were derived from studies which Beranek and his associates conducted on office workers whose speech communication was disrupted by the presence of noise. The character of the noises — noting sound pressure levels at particular frequencies — was first established in terms of *speech interference levels* (SIL's). When workers' ratings of noisy conditions were compared with various combinations of sound pressure levels and frequencies, a family of curves resulted similar to those shown in Figure 1. These curves were then identified in terms of a Noise Criterion number which matched the speech interferencelevel. The present Noise Criterion curves have been developed using similar techniques. For further information about the derivation of the NC curves and the linkage between the NC curves and SIL's, see the paper by L.L. Beranek, "Revised criteria for noise in buildings," *Noise Control,* 3(1), (1957), pp. 19-27.

[26] ______, "Sound and vibration control" (Chapter 43) in the *1995 ASHRAE Handbook: Applications*, (American Society of Heating, Refrigerating, and Air-conditioning Engineers, Inc., 1995), pp. 43.1-43.44; see 43.5, specifically.

[27] A primary exposition of these values appears in the American Speech-Language-Hearing Association document, "Position statement and guidelines in educational settings," *Asha, 37*(3)(Supplement 14), (1995), pp. 15-19.

[28] A conference presentation by D. Lubman, "Classroom acoustics: America's need for standards and guidelines to ensure satisfactory classroom acoustics," has recently been offered at the 133rd meeting of the Acoustical Society of America, June 17, 1997, State College, PA. In that presentation Dr. Lubmandiscussed the need for developing design standards and described the work of the Subcommittee on Classroom Acoustics.