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Acoustical barriers to communication and hearing

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ACOUSTICAL BARRIERS TO COMMUNICATION AND HEARING

by

Aline Renè Sundeen

**A Capstone Project
submitted in partial fulfillment of the
requirements for the degree of:**

Doctor of Audiology

**Washington University School of Medicine
Program in Audiology and Communication Sciences**

May 16, 2007

**Approved by:
William W. Clark, Ph.D., Capstone Project Advisor**

This study examined the acoustical conditions, including the surface-dimension measurements, background noise levels, and reverberation times in classrooms in a metropolitan area. The data collected in this study will help school administrators realize that appropriate classroom acoustics are necessary for both hearing impaired and normal hearing students.

Acknowledgements

I would like to thank Dr. William Clark, Ph.D. for being my advisor for this capstone project, his leadership, and guidance has been appreciated immensely throughout this process. I would also like to acknowledge my second readers, Dr. Maureen Valente, Ph.D. and Kimberly Ott, Au.D. for all of their help and support during this project. In addition, I would like to give a special thanks to my family for all of their love and constant support throughout the last three years, without them none of this would have been possible. I dedicate this capstone project to my parents, Mary and the late Bernard Sundeen who taught me that in the face of adversity to never give up and keep going.

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Abbreviations

ANSI	American National Standards Institute
ASA	Acoustical Society of America
ASHA	American Speech-Language-Hearing Association
CID	Central Institute for the Deaf
EAH	Educational Audiology Handbook
FM	Frequency Modulation
FT	Feet
HVAC	Heating, Ventilating, Air Conditioning
LCD	Liquid Crystal Display
NC	Noise Criteria
RT	Reverberation Time
SNR	Signal-to-Noise Ratio

Introduction

Presently the United States is in the middle of the largest campaign of school construction and renovation in history. School administrators must take advantage of this opportunity and put a stop to the longstanding practice of building classrooms with sub par acoustics. This dilemma has a vital impact on learning, but can be resolved. Many educators are aware of the importance in improving classroom acoustics for hearing impaired students, but find it unnecessary to do so for students with normal hearing. Populations of students with normal hearing can also reap the benefits of classrooms with appropriate acoustics. These students may be afflicted with learning disabilities, auditory processing disorders, or use English as a second language. More often than not these students are not placed in classrooms with enhanced acoustics, but are mainstreamed with other students. With all of this information at hand it is clear that all students, regardless of hearing status, benefit from improved classroom acoustics (Classroom Acoustics, 2000).

Increased awareness of the importance of good acoustic design is reflected with a standard established by the American National Standards Institute (ANSI) in 2002. ANSI S12.60, Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools provides acoustical performance criteria and design requirements for classrooms and other learning spaces. This document has increased the visibility of audibility in this country; however it is a guideline, not a regulation (Clark, 2006). This comprehensive guideline discusses the most important variables that affect speech perception in the classroom, including the overall background noise level, signal-to-noise ratio (SNR), and reverberation (ASA, 2002). In addition, ANSI S12.60 has been adopted by a few states such as Minnesota, Connecticut, New Hampshire State Board of Education, New Jersey School Construction Board, and Ohio School Facility Commission (United States Access Board, 2007).

Classrooms are auditory-verbal environments that hinge on accurate reception of a verbal speech signal from the teacher or students (Crandell & Smaldino, 2000b). Palmer (1997) discussed the following relevant issues to keep in mind when determining if every student in a classroom can hear the necessary message: the noise, SNR, reverberation, and speaker-to-listener distance in the room. The speech conveyed in any classroom is accompanied by interference in the form of noise and reverberation (Palmer, 1997). Background noise is commonly referred to as any undesired auditory stimuli that interfere with what the student wants, or needs, to hear and understand. Background noise sources in the classroom include external noise (noise that is generated outside the building, such as local construction, automobile noise, and playground noise), internal noise (noise that is generated from within the building, but outside of the classroom, such as gymnasiums, busy hallways, and rooms adjacent to the cafeteria), and room noise (noise that is generated from within the classroom). Room noise sources include the sliding of chairs or tables, students talking, the shuffling of shoes on non-carpeted floors, computers, and liquid crystal display (LCD) projectors. Heating, ventilating, and air-conditioning (HVAC) systems usually also significantly contribute to classroom noise levels. Classrooms often exhibit excessive noise levels due to the complexity of potential noise sources (Crandell & Smaldino, 2000a).

Speech recognition is disrupted by background noise because the noise masks part of the message (Palmer, 1997). In general, background noises in a room mask the weaker consonant phonemes greater than the more intense vowels. A decrease in the consonant information can have a significant impact because approximately 90% of the acoustic information important for speech perception is provided by the consonants (Crandell & Smaldino, 2002).

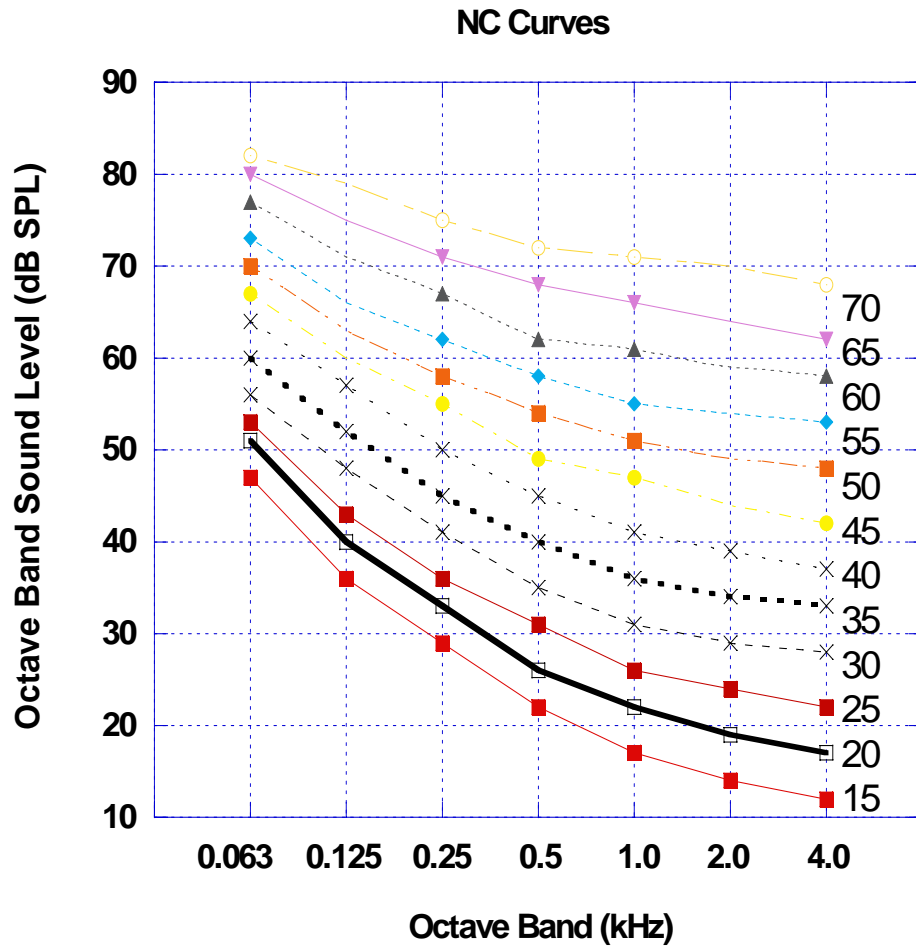
There are a number of acoustical parameters that have the capability of masking the teacher's speech. These parameters include (a) the long-term spectrum, (b) intensity fluctuations of the noise over time, and (c) the intensity of the noise relative to the intensity of speech (Crandell & Smaldino, 2002). Noises with long-term spectra that are similar to the speech spectrum are the most effective maskers of speech because they affect all of the speech frequencies to the same degree. As a result, noises such as children talking (noise generated from within the classroom) produce the greatest reduction in speech perception because the spectral content of the signal (the teacher's voice) is spectrally similar to the spectra of the noise. Noises such as air conditioning units have predominately low frequency energy and are often more effective maskers of high-frequency speech sounds due to the upward spread of masking. This phenomenon involves noise producing greater masking for signals that are higher in frequency than the noise. Continuous noises are generally more effective maskers than impulse or interrupted noises because continuous noises more effectively reduce the spectral-temporal information available in the speech signal. The long-term spectra of children talking, faulty fluorescent lighting, and air conditioning or heating systems are examples of different types of continuous noise sources (Crandell & Smaldino, 2002).

The ANSI S12.60 standard requires that unoccupied background noise levels should not exceed 35 dBA. The ANSI standard does not account for occupied learning spaces. The conventional weighting network for room measurements is the A-weighting network, as it more closely corresponds to the frequency response of the average human ear at moderate listening levels (Crandell & Smaldino, 1994). An examination of past studies that have measured acoustical conditions in unoccupied classrooms suggests that appropriate levels of noise and reverberation are rarely achieved. For example, Crandell and Smaldino (1994) measured the

background noise levels of 32 classrooms used by students with impaired hearing. These investigators found that the mean noise level was 50.2 dBA and none of the rooms were in compliance with the ANSI standard level of 35 dBA (Crandell & Smaldino, 1994). Other investigators measured noise levels in six self-contained classrooms. The unoccupied levels ranged from 35 to 38 dBA, whereas the occupied levels increased by approximately 5 to 15 dB (Crandell & Smaldino, 1994). Hodgson (1999) conducted a study measuring the unoccupied background noise levels in 30 University of British Columbia classrooms and found that the noise levels exceeded 35 dBA in 29 of the 30 classrooms and 45 dBA in 12 rooms (Hodgson, 1999).

The background noise in a classroom can be described using a single-number rating called the noise criteria (NC) rating. The ratings are commonly used in ventilating and air conditioning work and in other areas of design acoustics to specify maximum sound pressure levels in rooms (Quirouette & Warnock, 1985). This rating is assigned by measuring the sound pressure level of the noise in each octave band and plotting these levels on a graph and then comparing the results to established NC curves. Figure 1 shows the graph of established NC curves. The lowest NC curve not exceeded by the plotted noise spectrum is the NC rating of the sound (Classroom Acoustics, 2000). Two spectra can have the same NC rating but quite different shapes. The A-weighted level is usually approximately 7 dB greater than the NC value. The NC curves do not describe the spectrum of a neutral sounding noise to be sought after as a design goal. They have been described as both hissy and rumbly. Background noise spectra with less low and high frequency energy are usually found to be less objectionable (Quirouette & Warnock, 1985).

Figure 1: Graph of NC Curves



The most important factor for accurate speech perception is not the overall level of the background noise, but the relationship between the speech level as a function of frequency and the background noise level as a function of frequency. This relationship is commonly referred to as the signal-to-noise ratio (SNR), regardless of the noise or speech level. A positive SNR simply means that the signal is more intense than the competing background noise. For students with a hearing impairment, an enhanced SNR may make it possible to hear a signal that would otherwise be inaudible (Palmer, 1997). A SNR of +15 dB has been recommended by the

American Speech-Language-Hearing Association (ASHA) and the Acoustical Society of America (ASA) (ASHA, 1995; ASA, 2002). Unfortunately, reports of SNRs for various classrooms have been less than favorable, ranging from +5 dB to -7 dB (Crandell & Smaldino, 1994). Hodgson (1999) found poorer SNRs ranging between -2 and +3 dB in a study of thirty classrooms at the University of British Columbia (Hodgson, 1999).

In addition to background noise and SNR, reverberation can also degrade speech delivered in a classroom. Reverberation is dependent upon the contents and physical characteristics of the classroom. Reverberation is commonly defined as the persistence of sound within an enclosed space because of sound waves reflecting off hard surfaces (ceilings, walls, windows, and floor). This reflected energy masks or blurs the direct sound energy.

Reverberation time (RT) refers to the amount of time it takes for a signal, at a specific frequency, to decay 60 dB in intensity after termination of the signal. In general, the larger the room volume, the longer the RT. On the other hand, the more absorptive material in a room, the shorter the RT. Reverberation degrades speech perception by masking subsequent directly transmitted sounds. Reverberant speech energy reaches the listener after the direct energy, overlapping subsequently presented speech sounds. The end result is the “smearing” of the directly transmitted speech signal. As RT increases speech perception tends to decrease. Crandell and Smaldino (2002) asserted that RT should not exceed 0.4 seconds; however ASA has recommended that RT should not exceed 0.6 seconds (ASA, 2002; Crandell & Smaldino, 2002). In a study conducted by Crandell and Smaldino (1995) only 9 of 32 classrooms examined had RTs of 0.4 seconds or less (Crandell & Smaldino, 2002). Brook (1991) asserts that children with a hearing impairment require a shorter RT to maximize speech perception. This

investigator insists that the RT for classrooms used by children with hearing impairment should not exceed 0.3 seconds (Brook, 1991).

Background noise and reverberation combine synergistically to affect speech perception in the classroom environment. The interaction of noise and reverberation negatively affects speech perception to a greater extent than the sum of both effects taken separately. To illustrate this relationship, if a student is listening to a teacher in a quiet room, the addition of a specific noise (e.g., the starting of an air conditioner) might reduce the student's perception by 10%. In a different quiet room, the presence of reflective surfaces, thus reverberation, might degrade perceptual abilities, also by 10%. However, if both noise and reverberation were present in a room, these combined effects on speech perception might equal a 40% to 50% decrease in speech perception. These synergistic effects occur because the combination of background noise and reverberation cause reflections to fill in the temporal gaps in the noise, making it more steady state in nature (Crandell & Smaldino, 2000).

Palmer (1998) asserts that children should be within approximately 6 feet of the teacher for maximum intelligibility. Typical class sizes, however, do not allow for achieving this distance for all of the children in the room. Research has shown that as the speaker-listener distance increases, the listener's speech recognition decreases (Crandell & Smaldino, 2000a). Personal or sound field Frequency Modulated (FM) systems provide a way to create an environment where the child is at a favorable speaker-listener distance.

One might ask why poor classroom acoustics are such an epidemic in this country. The answer does not lie in the lack of funds, but the reluctance of school districts to spend the money to prevent or remedy poor classroom acoustics. The best way to solve acoustics problems is to prevent them from the beginning, not correct them after the fact. In 1998, \$7.9 billion was spent

on school buildings across this country. All of these buildings could have been designed and renovated appropriately for only a fraction more. The slight increase in design or renovation cost is small compared to the deleterious effects poor classroom acoustics can have on the learning of millions of children (Classroom Acoustics, 2000).

Many acousticians feel that achieving the goals is not cost-effective. For example a study was conducted in Minnesota in 2002 that examined the background noise and RT in sixteen schools (48 classrooms) and compared these results to the ANSI S12.60 standard. If the classrooms were not in compliance with the standard the investigators identified potential design solutions and costs were estimated to bring the classrooms into compliance with the requirements of ANSI S12.60. Only one of the classrooms met the ANSI S12.60 requirements. The background noise levels ranged from 36 to 58 dBA with the average noise level being 47 dBA. However, 47 of the 48 classrooms were in compliance with the RT requirements of the standard (Executive Summary: ARI Classroom Acoustical Study).

These investigators concluded that the cost of new construction would increase dramatically in order to meet the ANSI S12.60 standard. The individual classroom cost ranged from 4 to 19%. This percentage increase was dependant upon the baseline construction in addition to the upgrades needed. As a result it may not be economical to implement all design solutions in renovating existing buildings. The cost increase for upgrading these classrooms in renovations is higher than new construction (Executive Summary: ARI Classroom Acoustical Study).

The purpose of this present study was to examine the acoustical environments of educational classrooms in a metropolitan area. The acoustical conditions, including the surface-dimension measurements, background noise levels (unoccupied and occupied), and reverberation

times were obtained and analyzed. Two questions were addressed: (1) are these classrooms in compliance with the ANSI S 12.6 guidelines regarding acoustic conditions in classrooms: and (2) if the classrooms are not in compliance with the guidelines, what recommendations can be made to improve the acoustical environment.

Methods

Classroom Environments

A total of six classrooms were involved in this study. The classrooms were located in three different schools, all of which were part of a metropolitan school district near St. Louis, MO. The classrooms were situated in two elementary/junior high schools and one high school. The rooms fell into the following categories: two were classrooms used by students with impaired hearing, one was a room used by children with special education needs, and three were regular education classrooms. Acoustical measurements were made during regular school hours, while the rooms were vacant and occupied. For the purposes of anonymity the classrooms were arbitrarily assigned numbers 1 through 6.

Surface-Dimension Measurements

In each classroom, a tape measure was used to quantify the dimensions of various surfaces. Some of the larger classrooms had complex shapes with various heights and lengths. Given the complicated shapes of these classrooms, average dimensions were used to compute their volumes. These measurements were recorded on the Deaf and Hard of Hearing Observation Checklist/Interview Form which was modified from an original document in the Educational Audiology Handbook (EAH) (EAH, 1997). Photographs were taken in each classroom and used to compare and contrast the surfaces within each classroom. The following surface types were considered:

- acoustic tile ceiling or non-acoustic tile ceiling;
- hard surfaces – e.g., painted concrete, chalkboard, bulletin board, cabinets, or vinyl tile on concrete;
- carpeted surfaces – e.g., thin carpet covering on concrete floors;
- paneled surfaces – e.g., temporary wall;
- windows – e.g., in internal or external walls, or in doors;
- hard seats – e.g. constructed of wood or plastic;
- fluorescent lighting within the tile ceiling (Hodgson & Scherebnyj, 2006).

Ceiling and floors.

The ceiling surface categories were acoustic tile or non-acoustic tile. In many classrooms the acoustic tile was glued to a concrete ceiling. In one classroom the ceiling was suspended by non-acoustic tile. The floor surfaces were classified as hard surfaces or carpeted surfaces.

Walls.

The surfaces of the walls were classified as either hard surfaces or paneled surfaces. In general, most of the classrooms had walls that were hard surfaces, although one classroom had a temporary wall. The temporary wall or acoustic partition was covered with posters held to the wall by tacks.

Windows.

The windows were categorized as either inside internal walls, external walls, or within doors. All of the classrooms had a small window in the door. In many of the classrooms this window was covered up by a poster or some other piece of paper.

Seats.

The seats were classified as hard seats. All of the furniture in the classrooms was constructed of plastic or wood. Many of the tables were made of wooden tops with metal legs. All of the chairs were constructed of plastic bases and backs with metal legs.

Lights.

The lights were categorized as fluorescent lighting within the ceiling tile. All of the overhead lighting in the classrooms fit into this category. Other lighting was present in the classrooms such as desk lamps and floor lamps.

Noise Measurements

The occupied background noise levels were measured in all of the classrooms. The unoccupied background noise levels were measured in two of the classrooms. The measurements were obtained using a Larsen Davis Model 851 sound level meter equipped with a one-inch condenser microphone. The sound level meter was calibrated before and after all measurement sessions. All measuring equipment met ANSI standards for type I precision sound level meters. Noise measurements were obtained on the A-weighting networks. The sound level meter was held away from the investigator's body in the center of the room and measurements were obtained. Each measure was taken for approximately 45 seconds or longer, to allow for meter stability. During the tests in all of the classrooms, the ventilation systems were in normal operation. However, overhead or LCD projectors, common sources of background noise in a classroom, were not in operation. External noise from outside the classroom was not a significant factor. Data were analyzed with BLAZE 5.05 software (Larsen Davis, Provo, UT).

Reverberation Measurements

Room reverberation was defined previously as the amount of time it took for a steady-state sound to decay 60 dB from its initial offset. The RT of each room was determined by presenting a short duration, high level sound source (i.e. slamming a book and a firecracker was lit in the gym) into the unoccupied room and recording decay time with a Larsen Davis sound level meter. All measures were obtained in approximately the center of each classroom. A 20

msec. sample was recorded and the RT was approximated by subtracting 20 dB from the peak LAeq and multiplying that value by 3. That result was copied into a Microsoft Excel spreadsheet and transferred into Kaleidograph to construct graphs of the RT.

Results

Surface-Dimension Measurements

Classroom 1 in this study was a self contained hearing impaired learning environment with approximately 10 students, two aides, and one teacher. The dimensions of this room were 20 ft. in length by 20 ft. in width by 10 ft. in height. The volume of the classrooms in this study was computed by taking the value of the length multiplying that by the width and multiplying that value by the height of the ceiling, in this case, 20 ft. x 20 ft. x 10ft. = 4,000 cubic ft. Figure 2 is a sketch of this classroom illustrating these dimensions.

Figure 2: Sketch of Classroom 1



This classroom had an acoustic ceiling, five hard surfaces (e.g. two concrete block walls, one wall covered with a chalkboard, one wall made of drywall, and a vinyl tile on concrete floor), no windows, hard seats made of plastic, and fluorescent lighting within the tile ceiling.

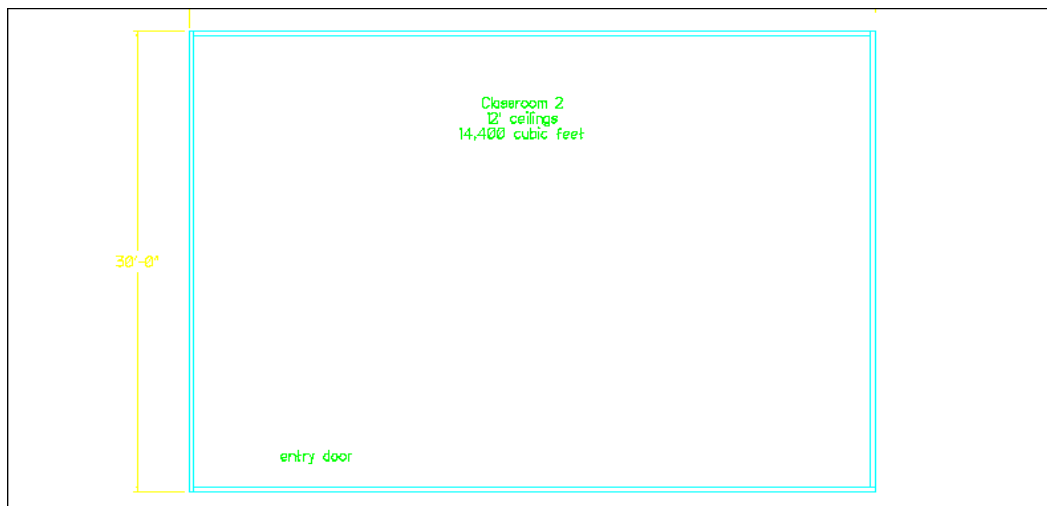
Figure 3 is a photograph that illustrates the concrete block wall, chalkboard, tile floor, and hard seats.

Figure 3: Photograph of classroom 1 illustrating potential computer and LCD projector noise sources



Classroom 2 tested in this study was a self contained special education classroom with approximately six students, three aides, and one teacher. The dimensions of this room were 40 ft. in length by 30 ft. in width by 12 ft. in height. The volume of this classroom was 14,400 cubic ft. Figure 4 is a sketch of the dimensions of classroom 2.

Figure 4: Sketch of Classroom 2



This classroom had a ceiling constructed of acoustic tiles, five hard surfaces (e.g. all of the walls were constructed of drywall with one wall having cabinets spanning the entire length and one wall composed of three windows in an external wall). The floor in this room was half vinyl tile and half thin carpeting on concrete. This classroom also had plastic tables and hard seats made of plastic. The classroom had fluorescent lighting within the acoustic tile ceiling. Figures 5 and 6 depict the materials used in the construction of this classroom.

Figure 5: Photograph of classroom 2 showing the cabinets spanning an entire wall, tile floor, and fluorescent lighting within the acoustic tile ceiling

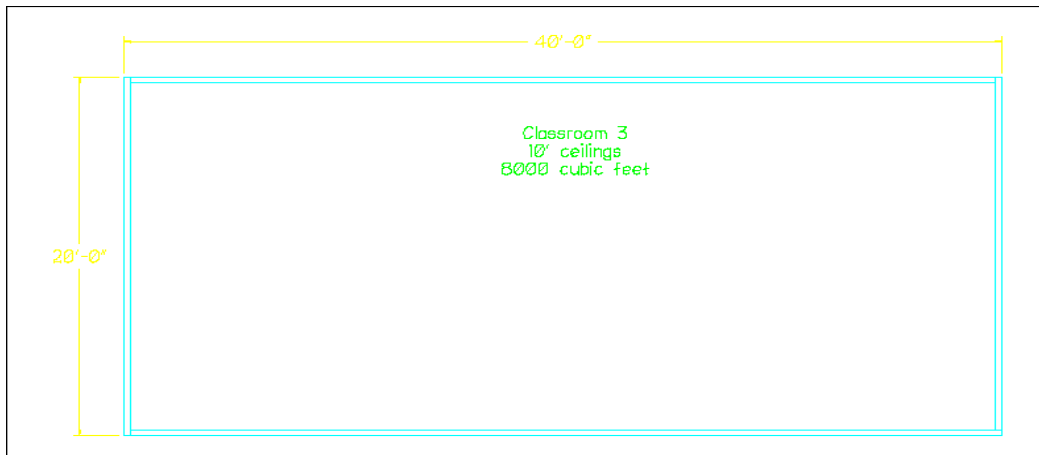


Figure 6: Photograph of classroom 2 illustrating the three windows that span the length of the entire wall and the carpeting on the floor



The next environment tested in this study was a third grade regular education classroom with approximately 25 students and one teacher. The dimensions of this room were 40 ft. in length by 20 ft. in width by 10 ft. in height. The volume of this classroom was 8,000 cubic ft. Figure 7 shows a sketch of the dimensions of classroom 3.

Figure 7: Sketch of Classroom 3



Classroom 3 had an acoustic tile ceiling, four hard surfaces (e.g. three walls were constructed of drywall and one was painted concrete, three of these walls were covered with chalkboards and one with cabinets). The floor was constructed of thin carpeting covering concrete. There were no windows in this room. The tables had wooden tops and the chairs were hard seats made of plastic. This classroom also had fluorescent lighting within the acoustic tile ceiling. Figures 8 and 9 illustrate the materials used in the construction of this classroom.

Figure 8: Photograph of classroom 3 illustrating the chalkboard and cabinets covering the walls, fluorescent lighting in the acoustic tile ceiling, and thin carpeting covering the concrete floor

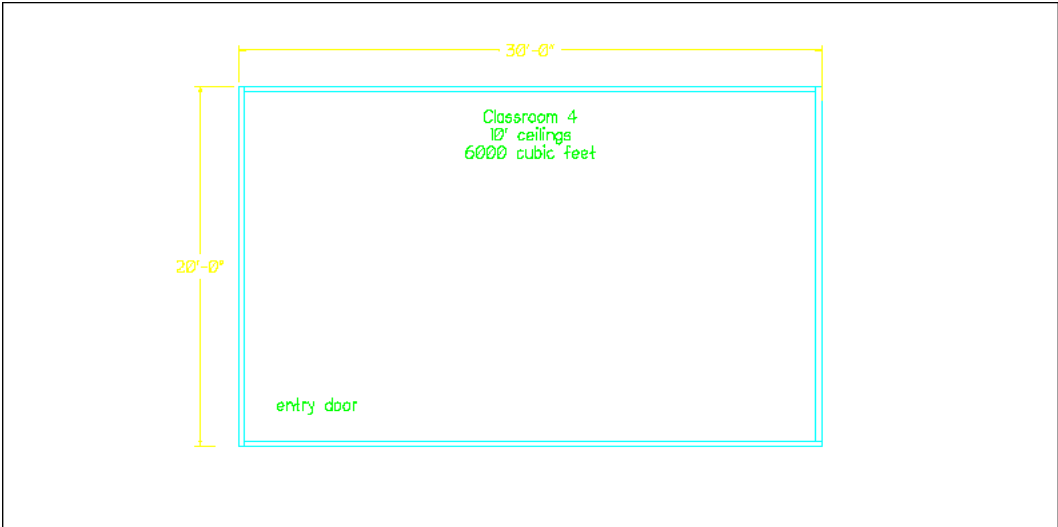


Figure 9: Photograph of classroom 3 depicting the chalkboard covering the painted concrete wall, wooden top tables, and hard seats made of plastic



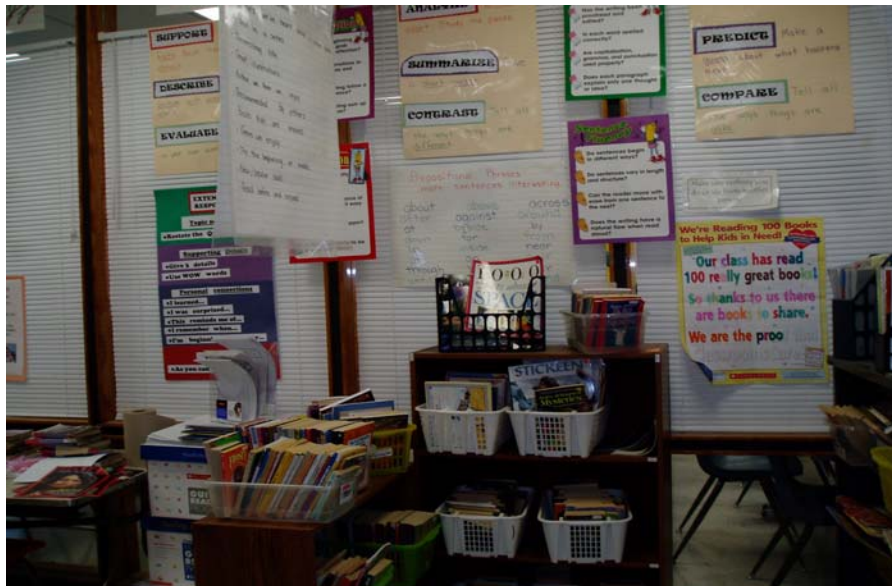
Classroom 4 was a regular education class with approximately 25 students, one hearing impaired student, and an interpreter. The dimensions of this room were 30 ft. in length by 20 ft. in width by 10 ft. in height. The volume of this classroom was 6,000 cubic ft. Figure 10 shows a sketch of the dimensions of this classroom.

Figure 10: Sketch of Classroom 4

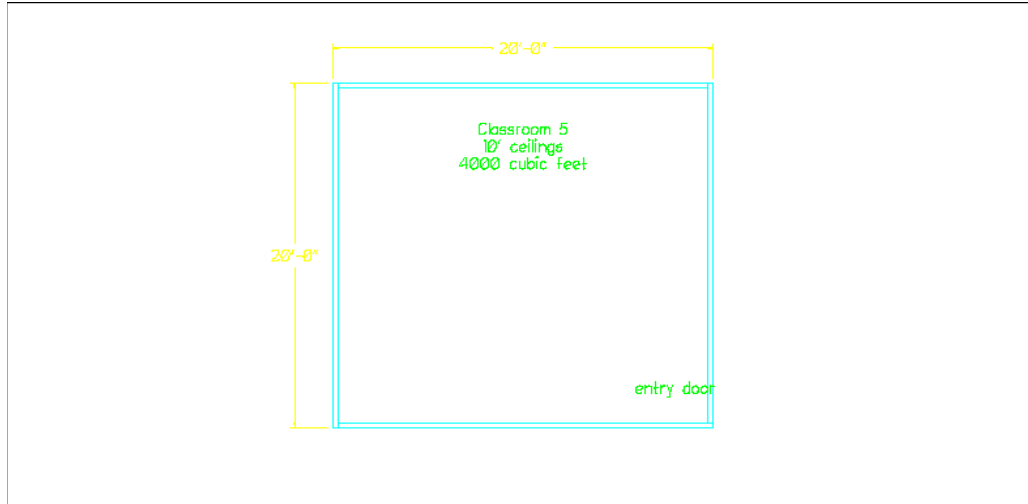


This classroom had an acoustic tile ceiling, four hard surfaces (e.g. three walls were painted concrete with two of the walls covered with chalkboards and one with cabinets, one wall had windows spanning the entire length in an internal wall). The floor was composed of vinyl tile on concrete. The tables were plastic and the chairs were hard seats made of plastic. This classroom also had fluorescent lighting within the acoustic tile ceiling. Figure 11 shows the windows spanning the entire length of an internal wall.

Figure 11: Photograph of classroom 4 showing the windows spanning the entire length of the internal wall



The next environment tested in this study was a self contained hearing impaired classroom with approximately 10 students, two aides, and one teacher. The dimensions of this classroom were 20 ft. in length by 20 ft. in width by 10 ft. in height. The volume of classroom 5 was 4,000 cubic ft. Figure 12 illustrates the dimensions of this classroom.

Figure 12: Sketch of Classroom 5

The classroom had an acoustic tile ceiling, three hard surfaces (e.g. three walls were made of drywall, two of them were covered with chalkboards, and one was covered with a bulletin board). One wall in this room was paneled surface and constructed as a temporary wall. The floor was vinyl tile on concrete. The tables had wooden tops and the chairs were hard seats made out of plastic. This room had fluorescent lighting within the acoustic tile ceiling. Figures 13 and 14 depict the materials used to construct this classroom.

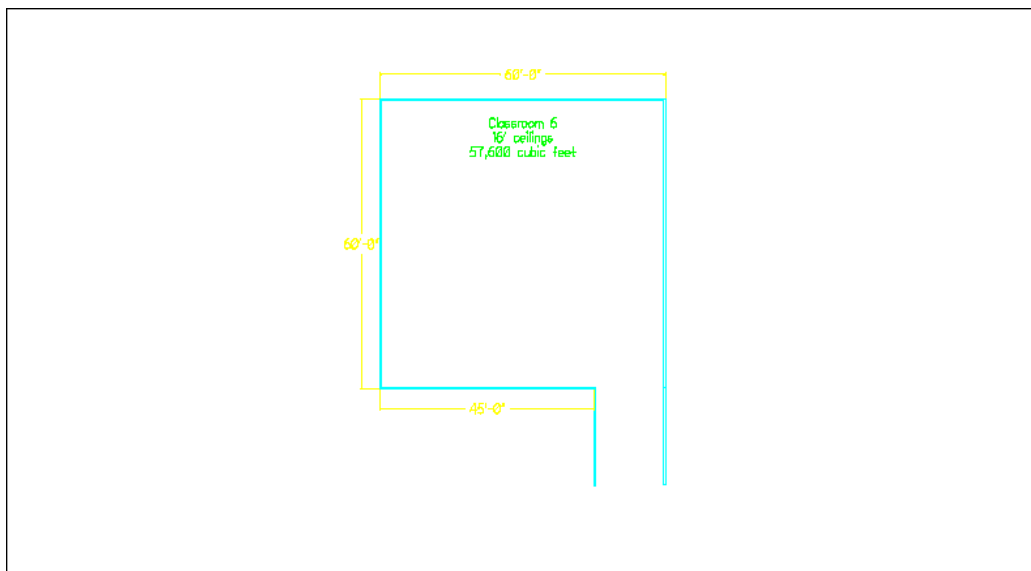
Figure 13: Photograph of classroom 5 showing the paneled surface (e.g. temporary wall)

Figure 14: Photograph of classroom 5 illustrating the chalkboard covering drywall and the paneled surface (e.g. temporary wall).



Classroom 6 was a regular education girls bowling class with approximately 20 students and one teacher. The dimensions of this environment were 60 ft. in length by 60 ft. in width by 16 ft. in height. The volume of this room was 57,600 cubic ft. Figure 15 depicts the dimensions of this classroom.

Figure 15: Sketch of Classroom 6



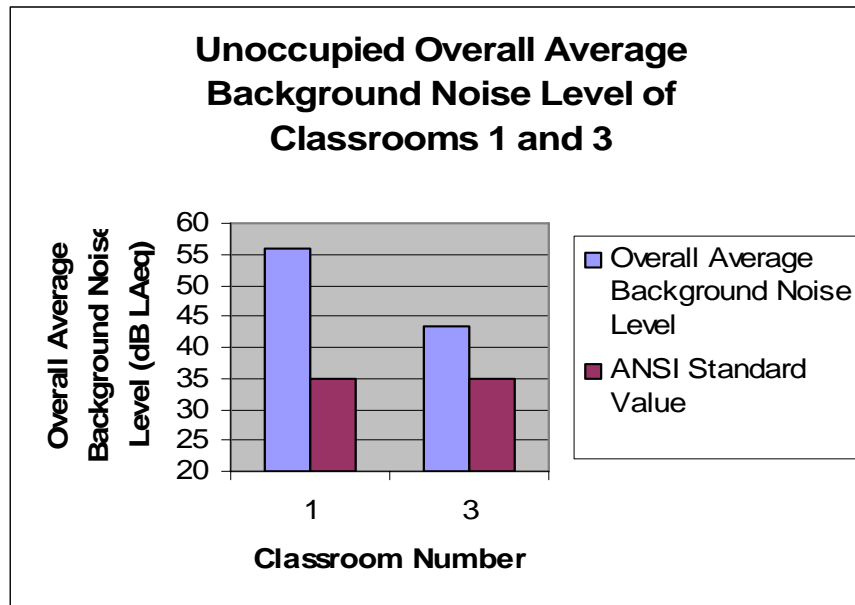
The ceiling was non-acoustic tiles and there were four hard surfaces (e.g. all four walls were painted concrete). The floor was vinyl tile on concrete. There were not any windows, tables/desks, or chairs in this room. The classroom had fluorescent lighting within the ceiling tile. Photographs were not able to be taken of this room.

Noise Measurements

Background noise.

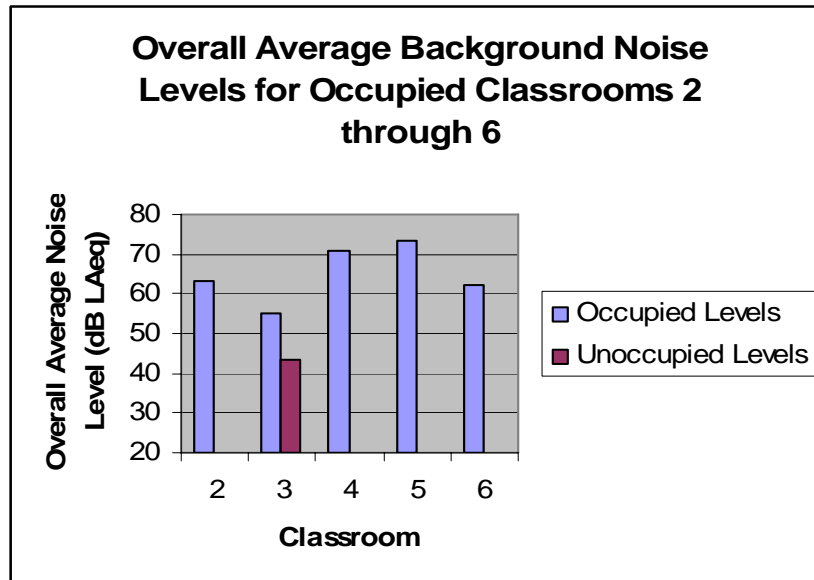
The first question under investigation in this study was whether these environments are in compliance with the ANSI S 12.6 guidelines regarding background noise levels. This standard states that the maximum A-weighted steady background noise levels for unoccupied learning spaces with an enclosed volume less than or equal to 20,000 cubic feet should not exceed 35 dB and should not exceed 40 dB for volumes of greater than 20,000 cubic feet (ASA, 2002). Unoccupied overall average dB LAeq levels were obtained for classrooms 1 and 3. These values were 56.0 dB in classroom 1 and 43.3 dB in classroom 3. Figure 16 shows these levels compared to the ANSI standard value of 35 dB. This figure illustrates that these classrooms are not in compliance with the ANSI standard. The overall average dB LAeq level for classroom 1 is 21.0 dB greater than the standard (e.g. $56.0 \text{ dB} - 35.0 \text{ dB} = 21.0 \text{ dB}$) and classroom 3 is 8.3 dB greater than the standard (e.g. $43.3 \text{ dB} - 35.0 \text{ dB} = 8.3 \text{ dB}$).

Figure 16: Classrooms 1 and 3 Compared to ANSI Standard



Occupied overall average dB LAeq levels were also obtained in five of the classrooms. The ANSI standard does not account for occupied learning spaces; therefore these values can not be compared to the standard. The overall average dB LAeq levels were 63 dB in classroom 2, 54.9 dB in classroom 3, 70.7 dB in classroom 4, 73.6 dB in classroom 5, and 62.3 dB in classroom 6. Figure 17 plots these levels and shows the difference between the unoccupied and occupied levels of classroom 3. The unoccupied and occupied levels were obtained for classroom 3 in which there is a 11.6 dB difference ($54.9 - 43.3 = 11.6$) between these levels.

Figure 17: Classrooms 2 through 6



Noise criteria (NC) rating.

The NC rating was also determined for each classroom. Figures 18 through 24 show the octave band levels for all of the classrooms tested in this study in relation to the NC curve. As stated earlier the lowest NC curve not exceeded by the plotted noise spectrum is the NC rating of the sound. The NC rating for classroom 1 was 50, 55 for classroom 2, 40 for room 3 (unoccupied) and 50 for room 3 (occupied), 65 for classroom 4, 70 for classroom 5, and 55 for room 6.

Figure 18: Octave Band Levels for Classroom 1 Compared to NC Curve

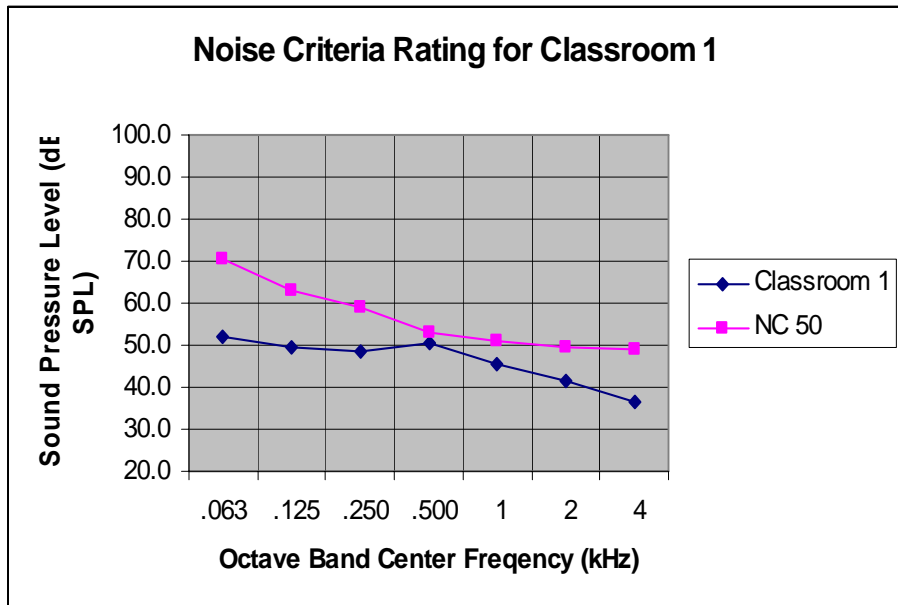


Figure 19: Octave Band Levels for Classroom 2 Compared to NC Curve

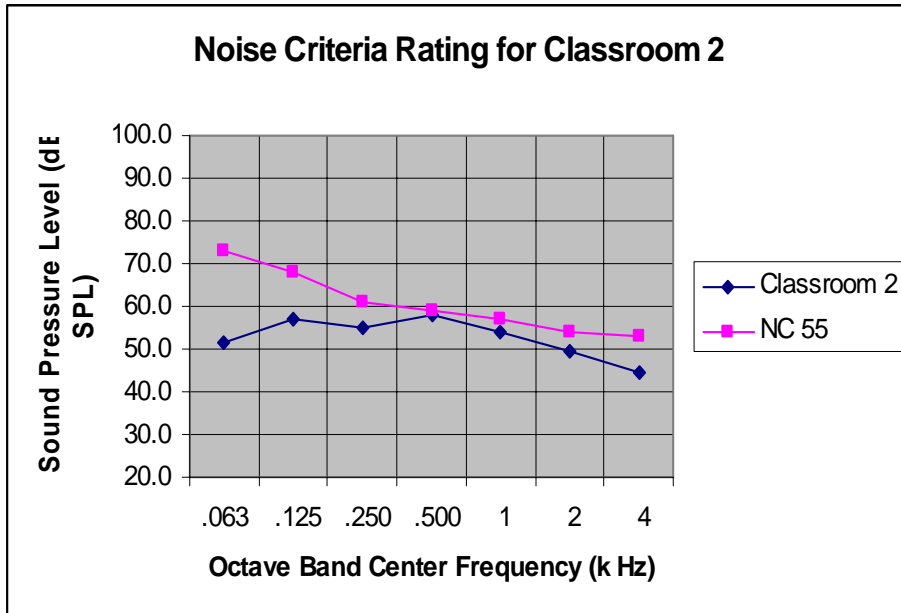


Figure 20: Octave Band Levels for Classroom 3 (Unoccupied) Compared to NC Curve

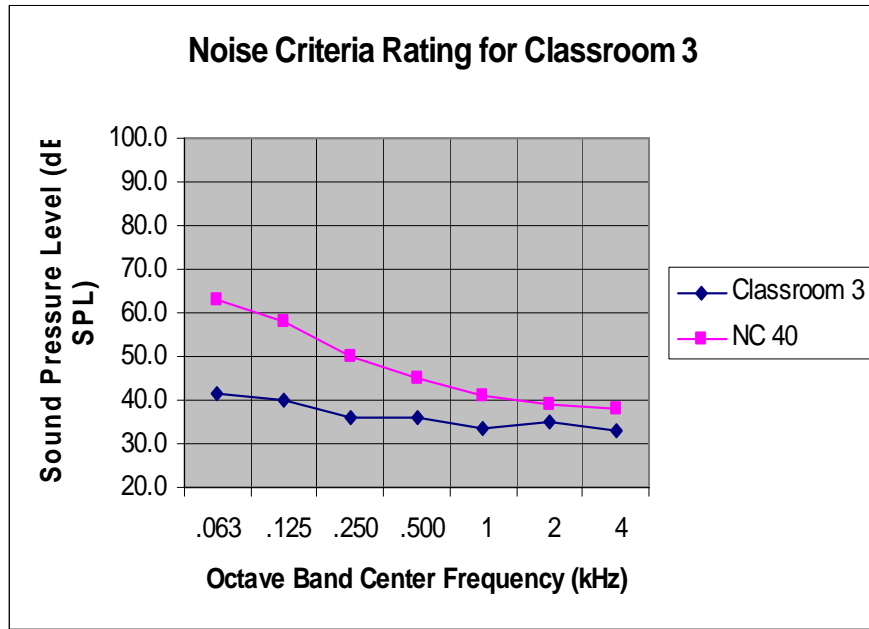


Figure 21: Octave Band Levels for Classroom 3 (Occupied) Compared to NC Curve

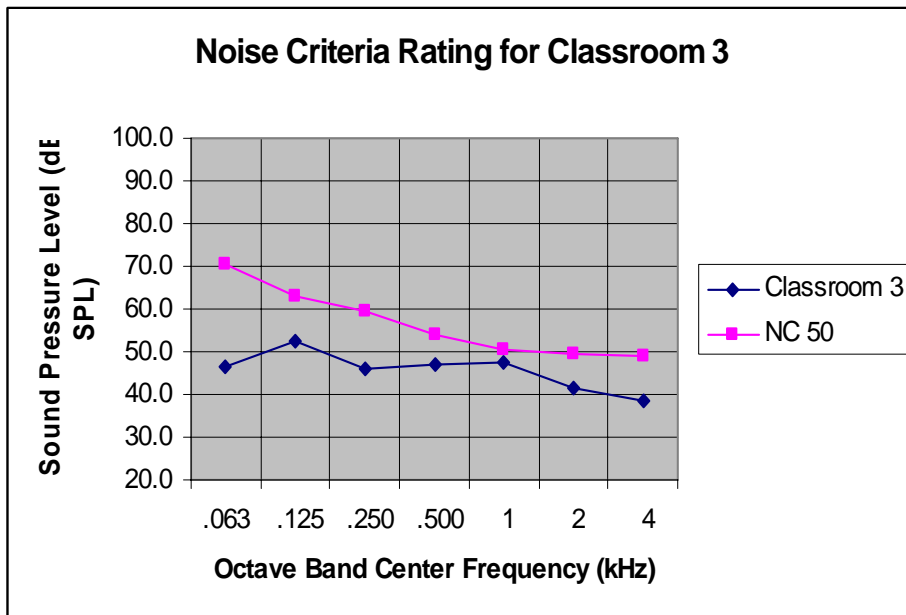


Figure 22: Octave Band Levels for Classroom 4 Compared to NC Curve

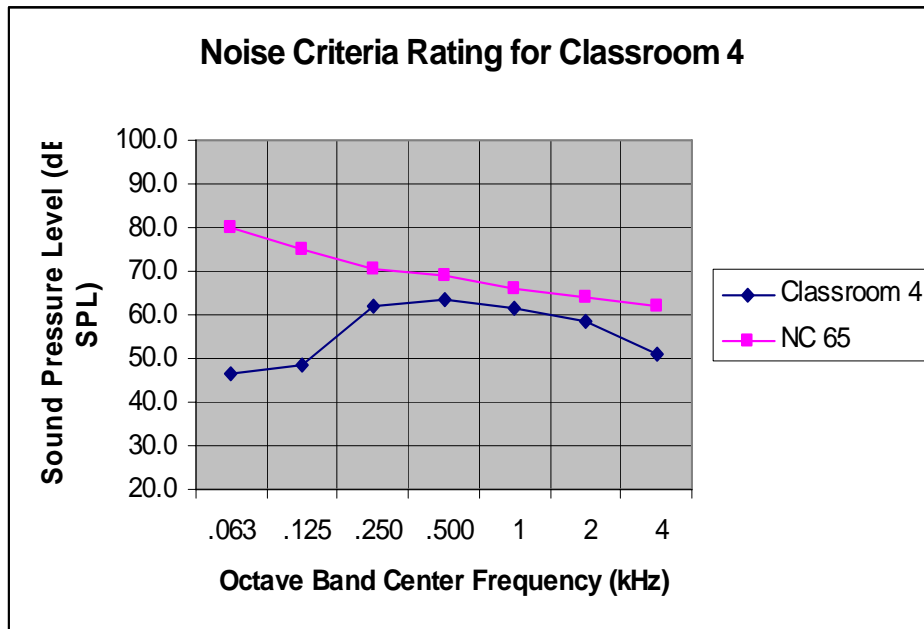


Figure 23: Octave Band Levels for Classroom 5 Compared to NC Curve

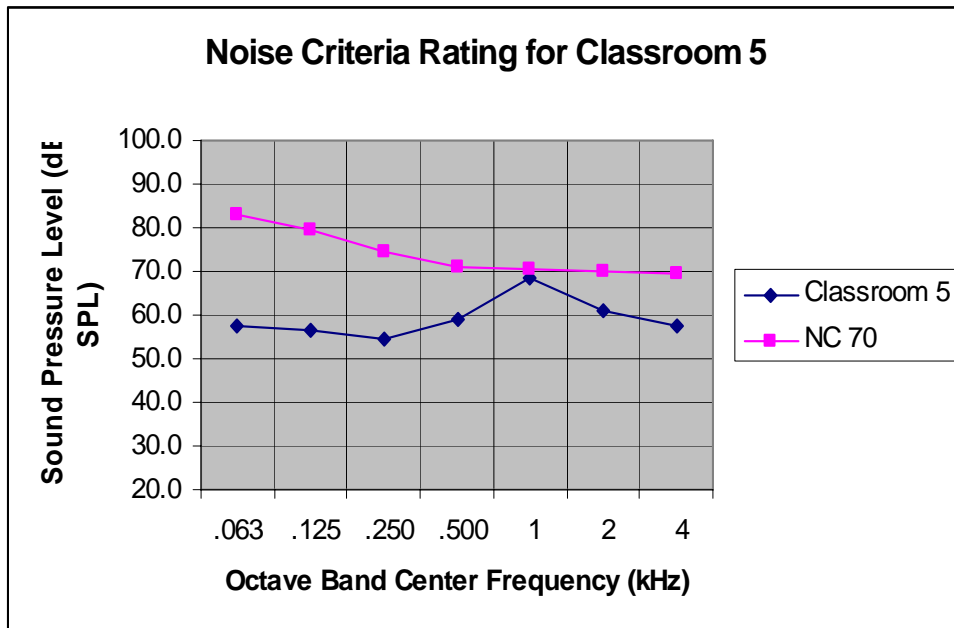
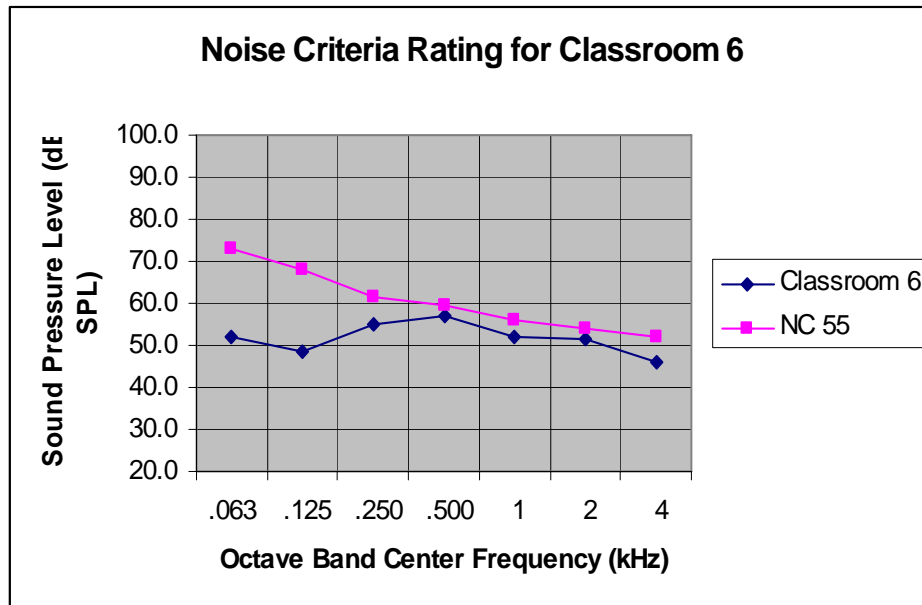
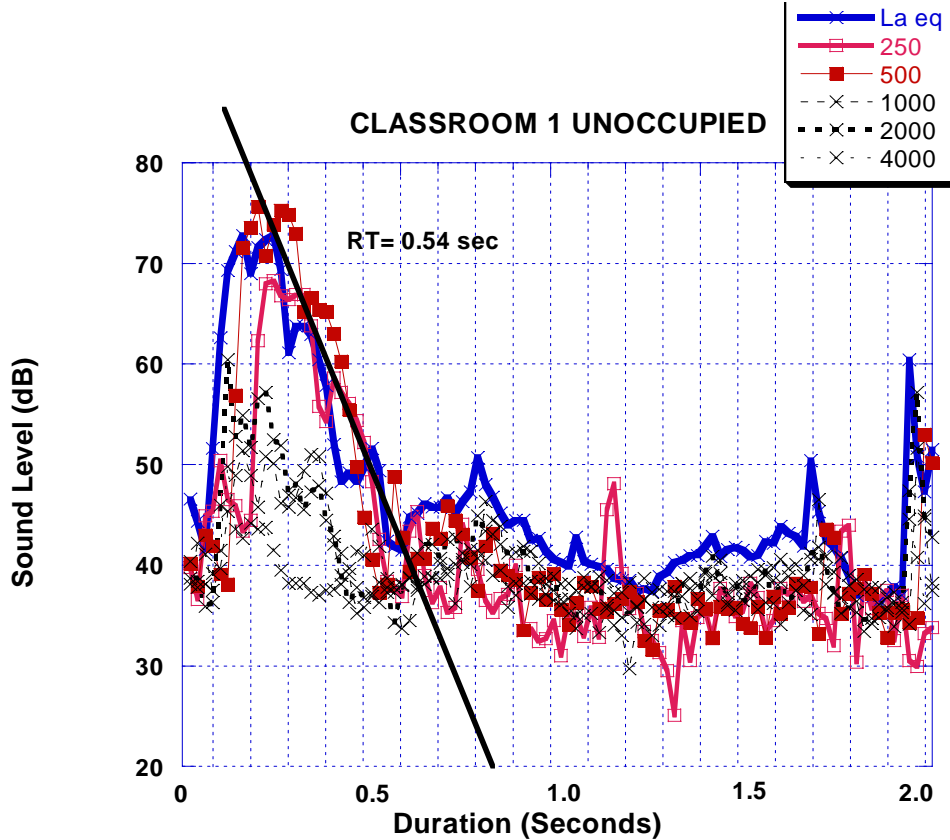


Figure 24: Octave Band Levels for Classroom 6 Compared to NC Curve

Reverberation measurements.

The next question under investigation in this study is whether these environments in compliance with the ANSI S 12.6 guidelines regarding reverberation time. This standard states that the maximum reverberation time for sound pressure levels in octave bands with midband frequencies of 500, 1000, and 2000 Hz should be less than 0.6 seconds for unoccupied learning spaces with a volume less than 10,000 feet and 0.7 seconds for spaces with a volume greater than 10,000 feet, but less or equal to 20,000 feet (ASA, 2002). Classroom 1 had a volume of 4,000 cubic ft. therefore the RT of the room was compared to the ANSI standard value of 0.6 seconds. The RT of this classroom was approximately 0.54 seconds. This classroom is in compliance with the ANSI standard. Figure 25 is a graph of the sound level in decibels at 250, 500, 1000, 2000, 4000 Hz, and overall average dB LAeq as a function of duration in msec. The RT was calculated in classroom 2 (occupied) and was found to be 1.2 seconds. (Data not shown).

Figure 25: Graph of RT of Classroom 1 (Unoccupied)



The RT was not analyzed in classroom 3 (unoccupied) because the peak of the signal could not be extracted from the ambient noise. In classrooms 2, 3, 4, 5, and 6 the occupied RTs were measured and ranged from 0.4 to 1.2 seconds.

Discussion

Background Noise

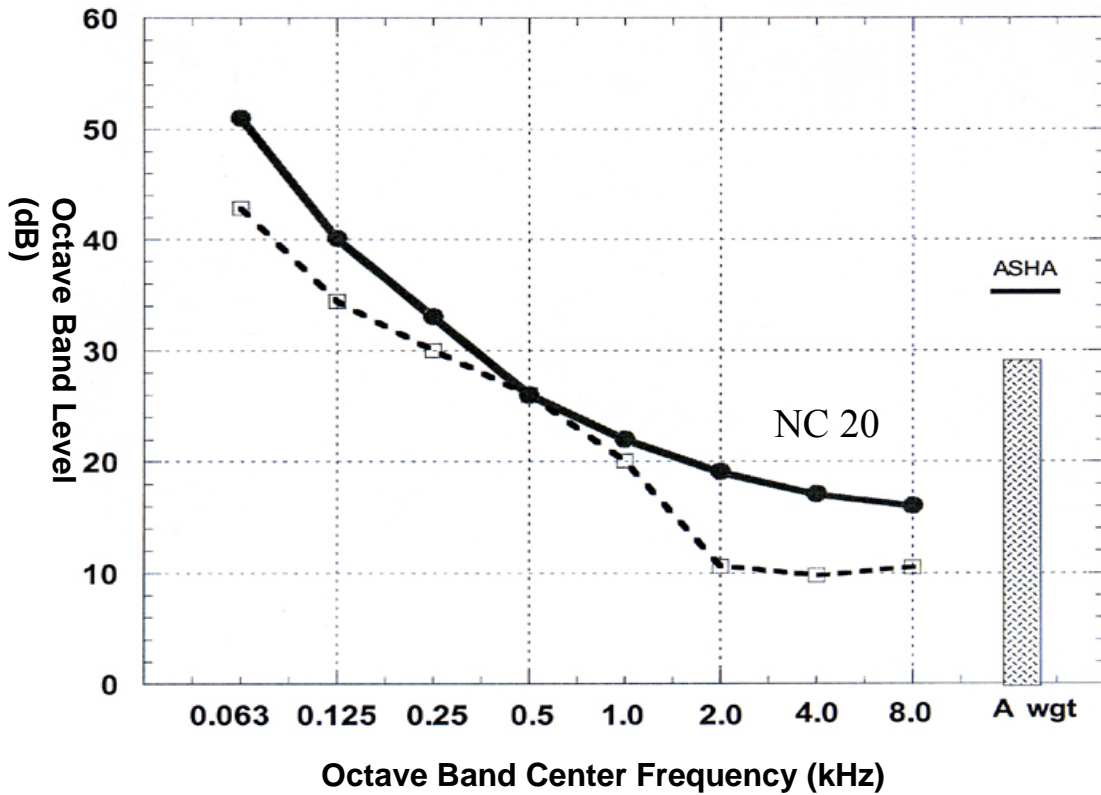
The range of overall average unoccupied noise levels was 43.3 to 56.0 dBA. In a study conducted by Bess, Sinclair, and Riggs (1984) these investigators found a range of 28 to 50 dBA in 19 classrooms. In the present study, the range of overall average occupied noise levels was 54.9 to 73.6 dBA. Similar results were measured in a study examining 23 classrooms which ranged from 52 to 69 dBA (Crandell & Smaldino, 1994). It is evident that the occupied

background noise level will be greater than the unoccupied noise level. Research has shown that occupied classroom noise levels are typically 10 to 15 dB higher than unoccupied levels. In the present study, the difference between the unoccupied and occupied noise level of classroom 3 was 11.6 dB.

The NC rating for the unoccupied classrooms in this study was 50 for classroom 1 and 40 for classroom 3. The average dB LAeq background noise levels for these classrooms were 56.0 dBA in classroom 1 and 43.3 dBA in classroom 3. Figure 26 shows the NC rating and overall average dB LAeq background noise levels for a classroom at The Central Institute for the Deaf (CID) in St. Louis, MO.

Figure 26: NC Rating for CID Classroom

NC Contour Fit for CID School Classroom

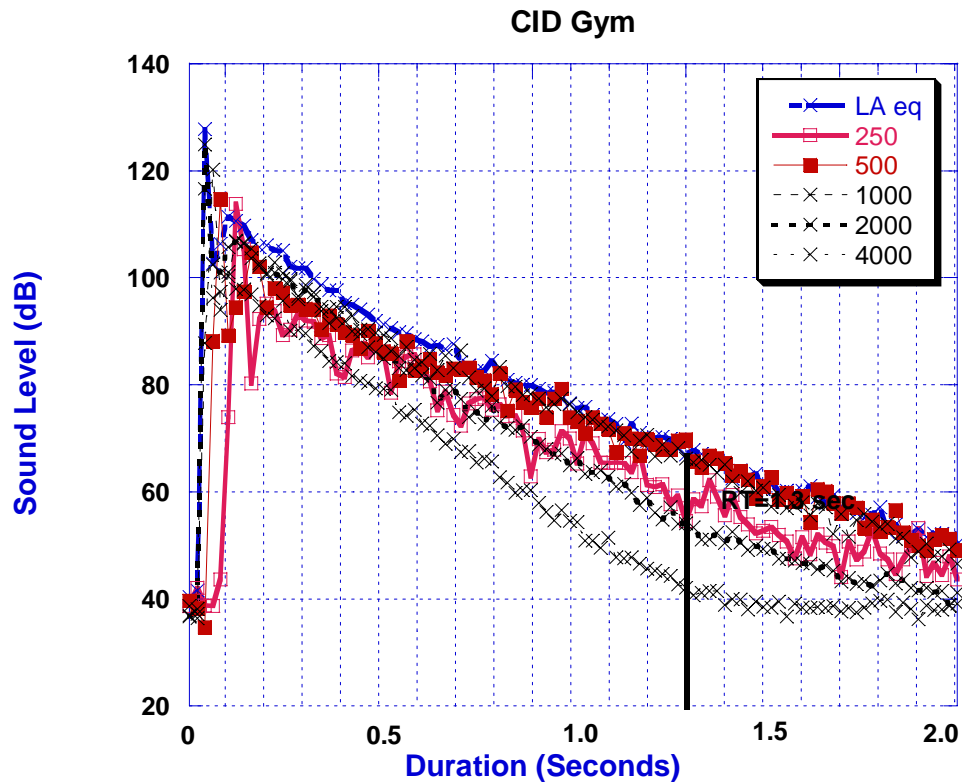


The CID school classroom has been acoustically treated and is an optimal learning environment for children with hearing impairment. The NC rating for this classroom was 20 and the overall average dB LAeq background noise level was 29 dBA. When the quietest classroom in the present study, classroom 3, is compared to the CID school classroom it is evident that classroom 3 is a great deal louder than the CID school classroom. The overall average dB LAeq in classroom 3 is 14.3 dBA ($43.3 - 29.0 = 14.3$) louder than the CID school classroom. One can conclude from this comparison that classroom 3 could benefit from inexpensive design solutions to decrease the background noise level.

The RT for classroom 1 was 0.54 seconds, although classroom 1 is in compliance with the ANSI guideline, Crandell and Smaldino (1999) assert that RTs should not exceed 0.4 seconds. These researchers conclude that RTs for a variety of classrooms range from 0.4 to 1.2 seconds and these acoustical recommendations are rarely achieved in most learning environments (Crandell & Smaldino, 1999). Picard and Bradley (2001) found similar results for RT ranging from 0.5 to 0.7 seconds.

The RT was measured in the unoccupied CID gymnasium and resulted in a RT of 1.2 seconds. Figure 26 is a graph of the sound level in dB at overall average dB LAeq, 250, 500, 1000, 2000, and 4000 Hz as function of duration.

Figure 27: Reverberation Time for CID Gymnasium



A firecracker with a peak of 127.8 dB SPL was used to measure the RT. The background noise level was low, 40 dBA, before the onset of the firecracker, therefore a measurement of the time it took for the stimulus to decrease by 60 dB was able to be made. If 20 dB would have been subtracted from the peak LAeq and that result multiplied by 3, as used in estimating the RT for classroom 1, would have been used in this instance the RT calculation for CID gym would have been incorrect.

Similarly, the RT for occupied classroom 2 was estimated to be 1.2 seconds. The RT for this classroom was also calculated using the following formula from Durrant and Lovrinic (1995):

$$RT_{60} = 0.049V/A$$

where:

RT_{60} = reverberation time (sec.)

V = room volume (ft.³)

A = absorption = $\alpha_1S_1 + \alpha_2S_2 + \alpha_3S_3 + \dots + \alpha_nS_n$

α = absorption coefficient

S = surface area (ft.²)

The result of this calculation was an RT of 1.25 seconds. Generally occupied classrooms have a shorter RT because of the bodies occupying the space; however in this case that is not true. One would assume that the unoccupied RT for this classroom would be longer than 1.2 seconds.

Recommendations

The high noise and reverberation levels measured in this study indicate the need for improving classroom acoustics for all children, especially those with hearing impairment. Several procedures can be implemented to ensure that classrooms meet acceptable target levels for noise and reverberation. These procedures include acoustical modification of the classroom, reduction of speaker-listener distance, and the utilization of classroom amplification systems, such as personal FM systems, induction loop systems, and sound field amplification systems (Crandell & Smaldino, 1999).

As discussed previously, noise can originate from external and/or internal sources. In this study, external noise sources were minimal; however internal noise sources were present in many of these classrooms. Classroom 2 was located next to an occupational/physical therapy room, classroom 3 was positioned near the cafeteria, and classroom 5 was located next to a

restroom with a hand dryer that was audible inside the classroom. The simplest and often most cost effective procedure for reducing internal noise levels in a room is the relocate the room to a quieter area of the building. If relocation is not an option, acoustical treatments may be implemented such as carpeting of hallways and rooms, acoustically treated doorways and double wall construction between rooms. None of the classrooms utilized any of these acoustical treatments. A significant amount of noise can originate from within the classroom, such as children talking or the sliding of tables and chairs. HVAC systems can also cause a great deal of noise in a room; however the investigator in this study did not observe excessive noise from these systems (Crandell & Smaldino, 1994).

Reverberation can be reduced by covering the hard, reflective surfaces in a room with absorptive materials, such as the placement of cork bulletin boards on walls, acoustic paneling on the walls and ceiling, positioning of bulletin boards at angles other than parallel, curtains on the windows, and carpeting on the floors (Crandell & Smaldino, 1994). Only five of the six classrooms had acoustic tile ceilings. One classroom had a cork bulletin board on the wall and none of the classrooms had bulletin boards positioned at angles other than parallel. One classroom had windows spanning the entire length of an interior wall that were not covered by drapes. Two classrooms had a thin layer of carpet glued to concrete floors. In a study previously discussed by Bess, Sinclair, and Riggs (1984) results indicated that all 19 classrooms studied had acoustic ceiling tile, 68% had carpeting and partitions, 47% contained acoustic wall tile, and 13% had draperies. None of the classrooms in this study had acoustical treated furniture (Bess, Sinclair, & Riggs, 1984).

In the present study, classroom 2 was constructed of hard reflective materials such as drywall, windows, and half of the floor was covered with vinyl tile. In addition, this classroom

had 12 ft. ceilings and the volume was 14,400 cubic ft. Using the previously discussed equation, RT_{60} and the absorption coefficients from Durrant and Lovrinic (1995), the dimensions and the construction materials in classroom 2 were manipulated in the effort to decrease the RT from 1.2 seconds to the ANSI S12.60 required level of 0.6 seconds. The first treatments to the room involved lowering the ceiling height from 12 ft. to 10 ft. and changing the vinyl tile to glazed tile. These changes resulted in the RT decreasing from 1.2 seconds to 0.74 seconds. The second treatment involved adding new carpet to the half of the floor covered with thin carpet. This resulted in a further reduction in RT to 0.66 seconds. The final treatment involved hanging heavy drapes on 200 square ft. of the windows. As a result the RT decreased to 0.60, which is the required ANSI standard value.

In order to overcome the damaging effects of noise and reverberation the listener must receive the speaker's message at the most favorable speaker-listener distance possible. A child with hearing loss should be in the direct sound field, face-to-face with the speaker where the delirious effects of noise and reverberation are less detrimental to speech recognition skills. Researchers have found that speech-recognition scores decrease until the critical distance of the room is reached. Thus, the speaker-listener distance should be as close as possible and should not exceed the critical distance of the room. In order to achieve this recommendation, it may be necessary to restructure classroom activities. For example, small group instruction may be recommended over more traditional classroom teaching styles. Crandell and Smaldino (1994) assert that preferential seating may not be appropriate for a student with hearing loss because the direct sound field is present only at speaker-listener distances close to the teacher. In an average sized room (6 x 6 x 3 meters) with a commonly measured reverberation time of 0.8 seconds, the critical distance would be approximately 3.6 meters. The use of an assistive listening device,

such as an FM system would significantly decrease speaker-to-listener distance (Crandell & Smaldino, 1994).

Conclusion

The preceding discussion has brought to light several points concerning the current status of noise and reverberation levels of classrooms in this country. None of these classrooms was in compliance with the ANSI S12.60 standard regarding classroom acoustics. In addition, few of the classrooms studied had appropriate acoustical treatments to reduce noise and reverberation. Finally, several strategies were discussed to enhance speech recognition for children in inadequate listening environments. These findings indicate a need for a collaborative effort among architectural/acoustical engineers, psychoacousticians, audiologists, teachers, and school administrators to determine the most appropriate and cost effective procedures to reduce noise and reverberation in these classrooms. Future research may investigate repeating measurements after recommendations for changes have been made to decipher if the changes caused a decrease in background noise levels and reverberation times. In addition, continuing research is necessary concerning cost-benefit analyses of renovating existing classrooms and/or school buildings to bring them up to the ANSI S12.60 standard.

References

- Acoustical Society of America. (2002). American national standard, acoustical performance criteria, design requirements, and guidelines for schools. *ASA*, 1–36.
- American Speech-Language-Hearing-Association. (1995, March). Position statement and guidelines for acoustics in educational settings. *ASHA*, 37(Suppl. 14), 15–19.
- Bess, F., Sinclair, J., & Riggs, D. (1984). Group amplification in schools for the hearing-impaired. *Ear and Hearing*, 5, 3–13.
- Brook, R. (1991). Rooms for speech and music. In G. Ballou (Ed.), *Handbook for sound engineers* (pp. 155–197). Indianapolis, IN: Howard W. Sams.
- Clark, W. (2006, June). Sound Advice for Learning in Children. Presentation at the annual A.G. Bell meeting, Pittsburg, PA.
- Classroom Acoustics. (2000, August). *The technical committee on architectural acoustics of the acoustical society of america*. Melville, NY.
- Crandell, C. & Smaldino, J. (1994). An update of classroom acoustics for children with hearing impairment. *The Volta Review*, 96, 291–306.
- Crandell, C. & Smaldino, J. (1999). Improving classroom acoustics: Utilizing hearing assistive Technology and communication strategies in the education setting. *The Volta Review*, 101 (5), 47–62.
- Crandell, C. & Smaldino, J. (2000a). Classroom acoustics for children with normal hearing and with hearing impairment. *Language, Speech, and Hearing Services in Schools*, 31, 362–370.
- Crandell, C. & Smaldino J. (2000b). Classroom amplification technology: Theory and practice. *Language, Speech, and Hearing Services in Schools*, 31 (4), 371–375.

- Crandell, C. & Smaldino, J. (2002). Room acoustics and auditory rehabilitation technology. In J. Katz (Ed.), *Handbook of clinical audiology* (pp. 607–630). Baltimore, MD: Lippincott Williams & Wilkins.
- Durrant, J. & Lovrinic, J. (1995). *Bases of hearing science* (3rd ed.). Baltimore: Williams & Wilkins.
- Educational Audiology Handbook. (1997). Deaf and Hard of Hearing Observation Checklist/Interview Form. Educational Audiology Handbook. San Diego, CA: Singular.
- Executive Summary: ARI Classroom Acoustical Study. (n.d.) Retrieved May 1, 2007 from http://www.ari.org/NR/rdonlyres/0DC867EC-8418-4D26-BC73-76836ADC9520/0/ARI_clsrm_exc_sum.pdf
- Hodgson, M. (1999). Experimental investigation of the acoustical characteristics of university Classrooms. *Journal of the Acoustical Society of America*, 106 (4), 1810–1818.
- Hodgson, M., & Scherebnyj, K. (2006). Estimation of the absorption coefficients of the surfaces of classrooms. *Applied Acoustics*, 67, 936–944.
- Palmer, C. (1997). Hearing and listening in a typical classroom. *Language, Speech, and Hearing Services in Schools*, 28, 212–217.
- Picard, M. & Bradley, J. (2001). Revisiting speech interference in classrooms. *Audiology*, 40, 221–244.
- Quirouette, R. & Warnock A. (1985). Basics of noise control. Retrieved April 26, 2007, from http://irc.nrc-cnrc.gc.ca/pubs/bsi/85-1_e.html
- United States Access Board. (2007, March). Classroom Acoustics. Retrieved May 1, 2007, from <http://www.access-board.gov/acoustic/index.htm>

