



UNIVERSITY OF HARTFORD ACOUSTICS

A Division of
The Engineering Applications Center
College of Engineering, Technology, & Architecture



Contribution of Non-verbal and Non-ventilation Noise Sources to Background Noise Levels in Elementary School Classrooms Part 1

by

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This report was prepared for Paul S. Veneklasen Research Foundation,
whose support made this student project possible.

Report # EAC-2010-13

May 30, 2010

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Purpose

The purpose of this study was to quantify the contribution of activity noises, such as chairs scraping and footsteps, to the overall background noise level in occupied classrooms and to compare the relative contributions of the activity noises in two classrooms with different floor finishes: carpeting or vinyl-coated tile floor.

Background

Applicable Measurement Standards –ANSI Standard S12.60-2002

In 1997, the American National Standards Institute (ANSI) commissioned a group that included educators, architects, audiologists and acoustical engineers [2, pg. 8] to develop a standard for classroom acoustics. This resulted in the development of ANSI Standard S12.60-2002, *Acoustical Performance Criteria, Design Requirements for Schools*. This standard gives specific room acoustic performance criteria for maximum classroom reverberation times, minimum STC partition requirements between learning spaces, as well as appropriate background noise levels. The intent of these criteria has been to increase speech intelligibility in classrooms and achieve higher reading scores and grades by students [1]. Architects are encouraged to work with acousticians to ensure that classrooms are built with adequate acoustical considerations and located such that mechanical noise will not interfere with learning. Though this standard covers a wide range of potential acoustic problems that can be encountered in a classroom, the background noise criteria only refer to stationary sources such as HVAC noise in unoccupied spaces, and does not account for activity noise such as footfalls and chair scrapes.

ANSI Standard 12.60 provides important acoustic criteria for classroom environments, as described above. The reverberation criterion addresses a classroom's total acoustic absorption, which in turn affects the reverberant field sound levels in the room. In addition, the maximum background noise level criteria of 35 dBA (re: 20 μ Pa) was established "...based on the assumption that a signal-to-noise ratio of at least +15 dB is necessary to ensure that noise will not be a barrier to learning within a classroom" [1]. Appropriate signal-to-noise ratios are important since it has been demonstrated that students under 15 years old are still developing language skills and need appropriate listening environments to understand the spoken message [2]. A related phenomenon is known as the Lombard Effect, which can be described as "the spontaneous tendency of speakers to increase their vocal intensity when talking in the presence

of noise” [3-5]. More recently, researchers have found that the Lombard Effect appears to have a non-linear relationship with reverberation time; i.e., before and after measurements of rooms requiring sound absorption treatment show reductions in speech levels after the room has been treated that are larger than would be predicted by the relationship $10\log_{10}(SA_{\text{before}}/SA_{\text{after}})$ [9 -12].

Health and Safety Issues

Many teachers have reported that working in a classroom with poor acoustic qualities has been detrimental to their voice [2]. This complaint is considered valid, since working in a loud environment with poor speech intelligibility can cause instructors to speak in a raised voice on a recurring basis. Such vocal stress can possibly lead to a strained voice.

Project Goals

One area that has not yet been researched is how much in-class noise, aside from background noise, is detrimental to the learning process. In-class activity noises can include chair scrapes, footfalls from the teacher or students, doors slamming or even a student’s sneeze or cough. Quantifying in-class noise is important, especially in light of ongoing changes in pedagogical techniques. Many K–12 schools no longer use the traditional approach to teaching where the instructor stands in front of the class speaking to everyone (“sage on the stage”), but instead use group learning configurations where the teacher speaks to one or more small groups of students at once (“guide on the side”)[4]. Note, however, that ANSI 12.60’s recommended +15 dB signal-to-noise (S/N) ratio is more feasible in the “sage on the stage” configuration, as the ‘noise’ would most likely be due to the room’s background noise levels. However, it is harder to achieve this S/N ratio with the “guide on the side” configuration, as the noise includes the other students’ voices in addition to their own activity noise. Thus, the goal of this project is to gain a better understanding of the extent to which activity noise contributes to the overall sound level in a student’s learning environment.

Procedure with Theory

Classroom Activity Noise Recordings

To determine the activity noise levels within classrooms, long term calibrated sound recordings were made at the K–5 Magnet School, located on the University of Hartford’s campus. This school’s approach to learning and its variety of classroom floor finishes made it an appropriate choice for this study. First, this magnet school incorporates a ‘collaborative learning’ philosophy, wherein teachers give limited

lecture periods and break the students into groups for in-class learning tasks. The instructor circulates around the room, interacting with sub-groups of students throughout the class period. The students themselves also circulate as necessary while they attend to different assignments. Thus, the classroom environment at this magnet school provided many opportunities for capturing classroom activity noise. Second, students in this school circulate from room to room as they attend each class period. For example, they take Art in one room, and move to another room for Mathematics. Herein the floor finishes were found to be different. The Art rooms use a vinyl-coated tile (VCT) floor, while the Math rooms have rubber-backed commercial short pile carpeting. The Magnet School Math and Art rooms have similar floor area, layout, and room volume. See Figure 1 and 2 below.



Figure 1 - Photo of 2nd grade VCT room



Figure 2 - Photo of 2nd grade Carpeted room

It was decided to compare two different age groups, 5th graders and 2nd graders, in order to include activity noise by a range of student sizes and activity levels in addition to the comparison of the VCT and carpeted floors. A group of 2nd graders and a group of 5th graders were each recorded in two rooms; in separate 2nd and 5th grade Art rooms with tiled floors, and in 2nd and 5th grade Math rooms with carpeted floors during the same school day. Note that University of Hartford Human Subject Committee approval was obtained before measurements commenced, see Appendix A.

Two Brüel & Kjær Type 2250 portable sound analyzers were used to record the sessions in each of the four classrooms. This model has the capability to perform CD-quality digital recordings that are limited only by the size of the memory card. The microphones from each sound analyzer were hung using 10 meter extension cords at a height of 8 feet above each classrooms floor by suspending them from the ceiling, as seen in Figure 3 and Figure 4. Figure 5 shows a typical plan view of the microphone placements relative to the classroom tables. The two microphone positions were chosen so as to record a broad representation of sound levels that occurred throughout each classroom.



Figure 3 - Microphones mounted in 5th grade Art Classroom



Figure 4 - Microphones mounted in 5th grade Math Classroom

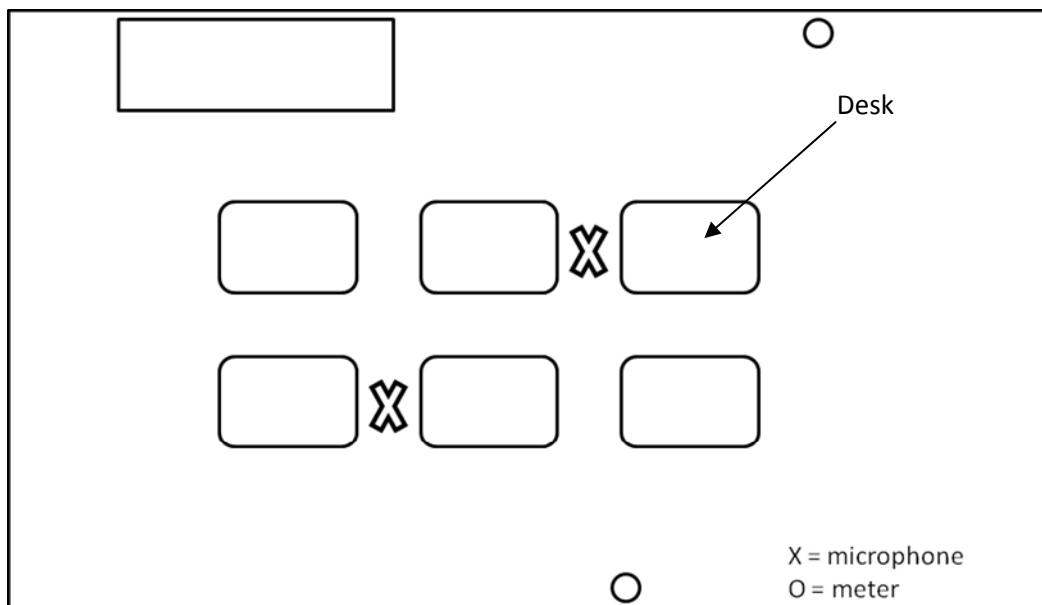


Figure 5 - Plan view of microphone placements in 2nd grade VCT room

A 94 dB calibration tone (re: 20 μ Pa) was recorded on each microphone using a 1,000 Hz Brüel & Kjær Type 4231 sound calibrator at the beginning and end of the recording day to ensure no shift in sensitivity, and to provide a reference level for subsequent sound level analyses. In addition, a time alignment signal was recorded near the beginning of each class (through the use of a bell or hand clap), which was used for aligning the two recorded signals during editing.

Editing and Analysis of Recordings

Using Adobe Audition, version 3.0, the two long term recordings from each class were mixed into a single track to produce an overall level recording of each room. To line up the tracks from the two different microphones, the time alignment signal was located on the recording and one track was adjusted temporally until the two tracks were in unison. Note that one file was panned 100% left and the other 100% right during this procedure. The act of panning resulted in -3 dB sound level decrease for each track, for a total drop of -6 dB. Mixing the tracks into a single file the sound level increased the overall level by +3 dB, leaving a final offset from calibration of -3 dB.

The combined tracks were analyzed and edited into separate uncompressed digital WAV files containing classroom activity noises and speech. This was done by extracting activity noise that contained no speech content and saving it as its own WAV file. The activity noises included such sources as chair scrapes, footfalls, dropped writing implements (on both the floor and desktops), and hand impacts on desktops. The remaining parts of the original track were re-named as a corresponding speech file for that grade and room flooring.

To begin spectral analysis, the recorded calibration tones were input into a Brüel & Kjær PULSE Measurement System, v14.0.1, and the sensitivity settings were adjusted to maintain the 94.0 dB calibration level. The 12 WAV files (unedited, classroom activity noise and speech for each age group and classroom) were analyzed through PULSE to obtain long term spectral averages in both narrow band and 1/3 octaves. Because of the aforementioned decrease in level, +3 dB was added to each decibel level after analysis to maintain calibration.

Room Acoustic Measurements of the Classrooms

The reverberation times (T_{60}) of the unoccupied classrooms were measured after school hours to identify acoustical characteristics of the rooms with and without carpeting, as well as to compare the values to the ANSI standard. Reverberation time (T_{60}) is defined as the time it takes in seconds for a sound to decay 60 dB in a room. Since it is difficult to measure a full decay of 60 dB, the B&K 2260 sound

level meter measures a decay of 30 dB and multiplies the time by two. To obtain an average reverberation time for the entire room, testing was done in eight locations in each room. The sound level meter was pointed away at a 45° angle from the impulsive sound source, which was generated by bursting a 16" diameter balloon. 16" diameter balloons were chosen as the impulsive sound source because their bursts provide approximately equal energy at all measured octave bands.

Background noise level (BNL) measurements were also made in the unoccupied classrooms. BNL is defined as the ambient sound pressure level in an unoccupied space. The measurements were done at three locations in each room. Each measurement was taken for 30 seconds while the meter was slowly moved in a circular pattern to acquire a better spatial average of the room in three dimensions. In addition to the overall A-weighted SPL, Noise Criteria (NC) values were also determined for each space, which provide another means for specifying appropriate background noise levels in a room. They are based on Noise Criteria curves, which indicate background noise levels' dependence on frequency.

Results

Unoccupied Classroom Measurements

The background noise levels for each room, along with the corresponding Noise Criteria (NC) are shown in the following table.

Table 1 - Background Noise Levels

	2 nd Grade Carpeted	2 nd Grade VCT	5 th Grade Carpeted	5 th Grade VCT
BNL [dBA (re: 20 µPa)]	38.0	38.3	43.8	35.2
Noise Criteria (NC)	35	35	45	35

The levels in every room exceed the ANSI standard of 35 dBA. Note that the 5th grade carpeted room is near one of the school's mechanical equipment rooms, which contributed to the high BNL of NC-45.

The T₆₀ measurements are shown in the following table. The values shown are an average of the T₆₀ in the 500 and 1000 Hz octave bands.

Table 2 - Reverberation Times

	2 nd Grade Carpeted	2 nd Grade VCT	5 th Grade Carpeted	5 th Grade VCT
T ₆₀ (s)	0.35	0.46	0.42	0.52

These reverberation times meet the ANSI standard which states that a classroom should have a T_{60} no greater than 0.6 seconds.

Analysis of Recordings

The A-weighted sum of the 1/3 octave band data obtained from the recordings are shown with the corresponding Noise Criteria in the tables below. In each table, the designation “All” refers to the overall unedited recordings, “Activity Noise” refers to the edited portion containing the classroom activities described above, and “Speech” refers to those portions of the recording containing speech alone.

Table 3 - Sound Pressure Levels and NC Obtained From the Recordings of the Two Carpeted Rooms

	5 th Grade			2 nd Grade		
	All	Activity Noise	Speech	All	Activity Noise	Speech
dB(A) (re: 20 μ Pa)	64	56	67	67	65	65
Noise Criteria (NC)	65	50	65	65	65	65

Table 4 - Sound Pressure Levels and NC Obtained From the Recordings of the Two VCT Rooms

	5 th Grade			2 nd Grade		
	All	Activity Noise	Speech	All	Activity Noise	Speech
dB(A) (re: 20 μ Pa)	61	64	61	71	75	70
Noise Criteria (NC)	60	60	60	>65	>65	>65

Note that there is a large difference between the carpeted and VCT rooms for their respective activity noise. For the 5th graders, there is an 8 dB difference between the two (56 vs. 64 dBA) and for the 2nd graders there is a 10 dB difference (65 vs. 75 dBA). While there is also a difference in the speech signals, note that for the second graders the total dBA increases by only 5 dBA from the carpeted room to the VCT room. The 5th graders actually had a lower speech signal in the VCT room because the first 10 minutes of the class consisted of only the teacher talking and explaining the day’s assignment.

The following graph shows a more detailed difference between the carpeted and VCT rooms, for the 5th graders and the activity noise.

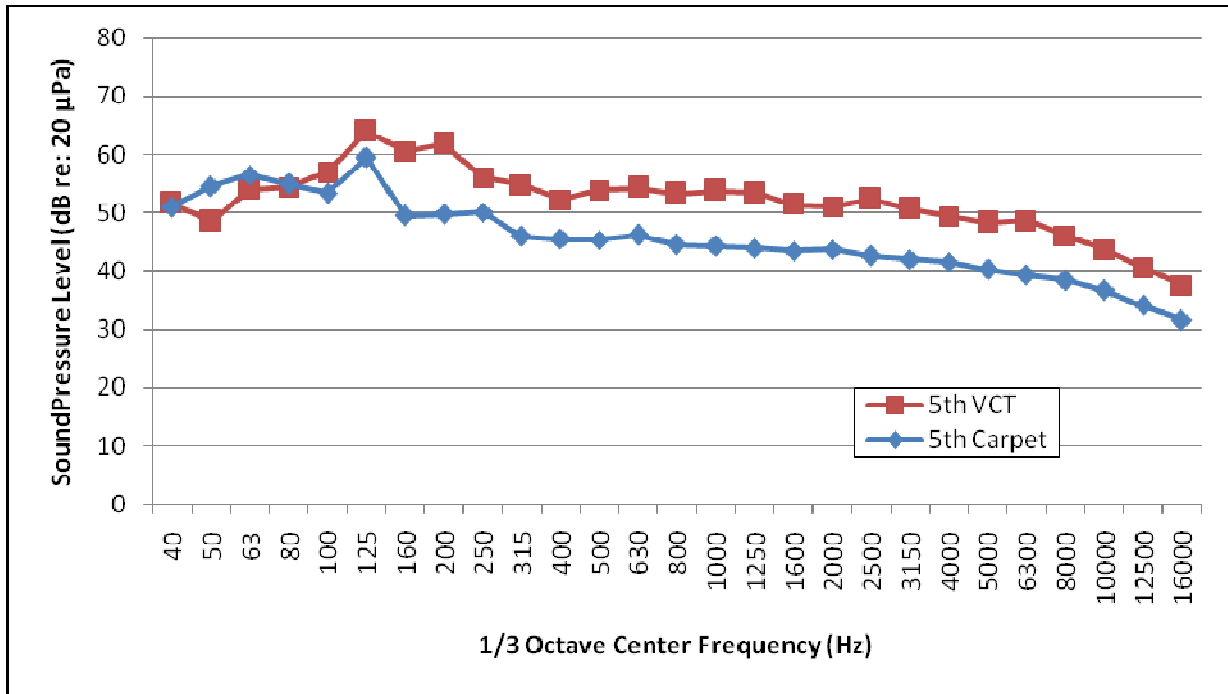


Figure 6 - Plot of 5th grade Activity Noise, Carpet vs. VCT

There is a nearly uniform difference of 8 to 10 dB across most 1/3-octave bands above 100 Hz. A graph with finer resolution can be found in Appendix B, Figure B1. The following graph shows a more detailed difference between the carpeted and VCT rooms, for the 2nd graders and the activity noise.

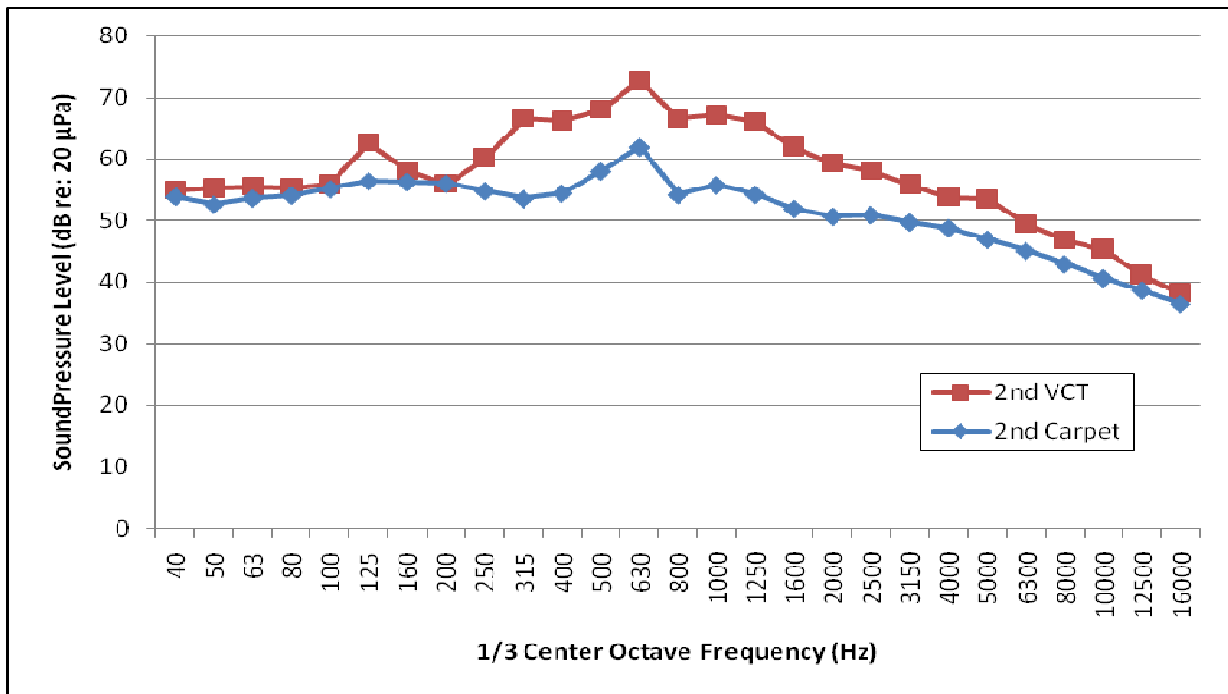


Figure 7 - Plot of 2nd grade Activity Noise, Carpet vs. VCT

There is a nearly uniform difference 10 dB or more across the 250 Hz to 2000 Hz 1/3 octave bands. The difference falls over a smaller range of frequencies than the 5th graders activity noise because more footfalls and chair scrapes were observed for the 2nd graders than in the older age group. A graph with finer resolution can be found in Appendix B, Figure B2.

The following graphs show the speech signals for the rooms with VCT and carpeted flooring, Figures 8 and 9 respectively, comparing the two age groups. In the room with the carpeted flooring (Figure 8), the speech signals are almost identical, which shows that the carpeted environment encourages lower overall speech levels. In the room with the VCT flooring (Figure 9) the 2nd grade speech levels are consistently 8 to 10 dB higher than the 5th grade speech levels above 250 Hz, which is in the speech range.

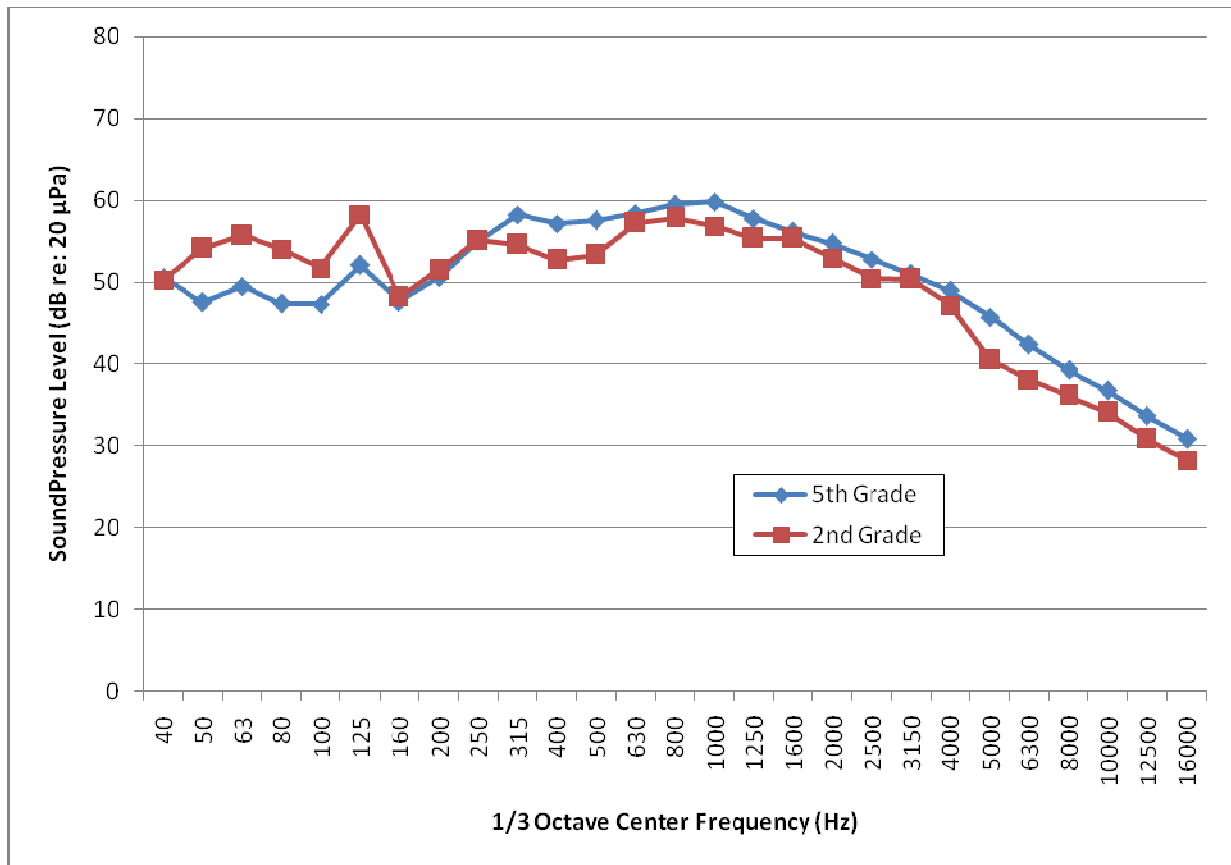


Figure 8 - Carpet Speech, 5th vs. 2nd

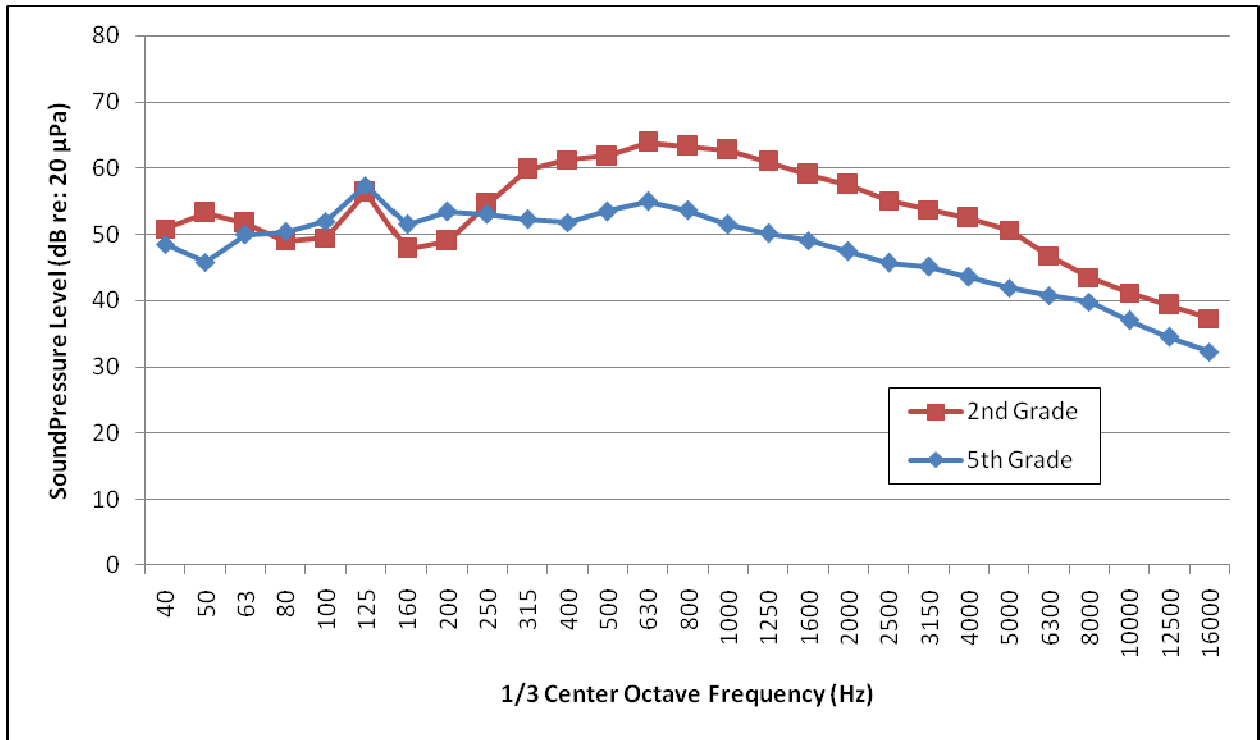


Figure 9 - VCT speech, 5th vs. 2nd

The next set of plots shows the difference in activity noise between the two age groups for each flooring type across 1/3 octave bands.

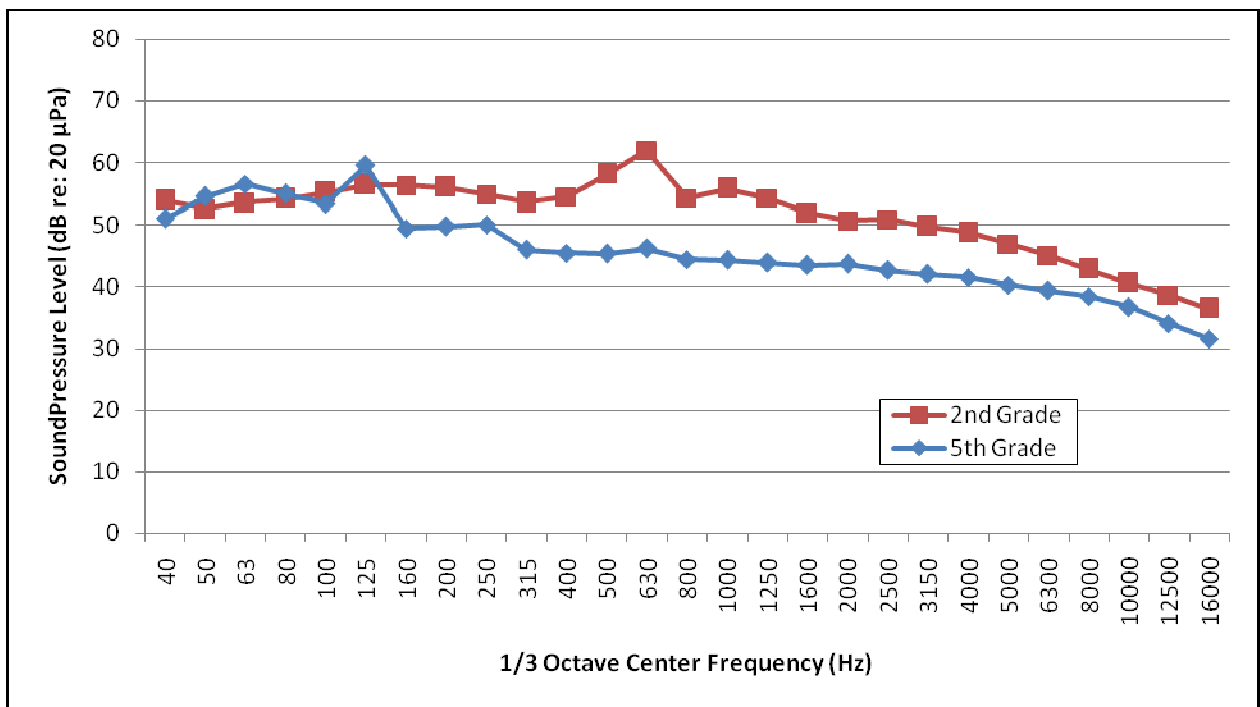


Figure 10 - Carpet Activity Noise, 5th vs. 2nd

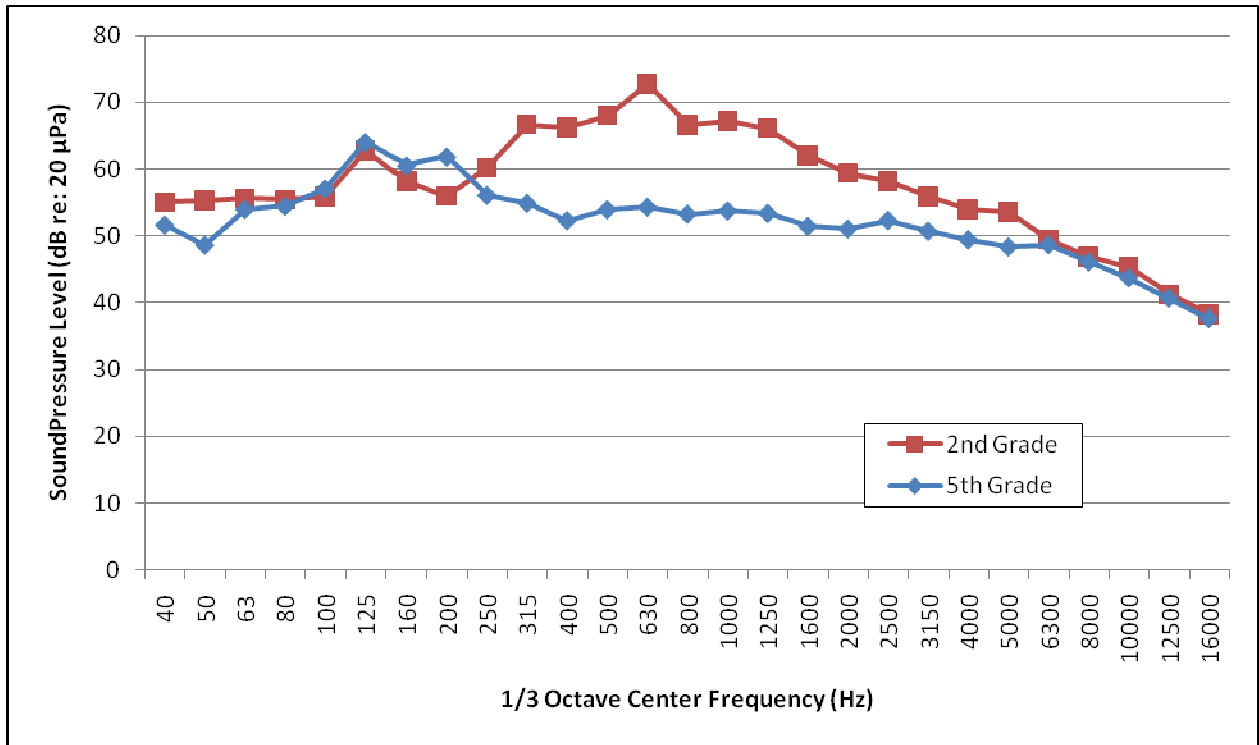


Figure 11 - VCT Activity Noise, 5th vs. 2nd

There is a much larger difference in activity noise between the two age groups in the room with the VCT floor as opposed to the carpeted floor. This can again support the hypothesis that VCT flooring is more reactive to stimulus than carpeted flooring. The other difference seen in these two graphs is that the peaks of the two age groups occur over two different frequency ranges. This can be attributed to the difference in size between the two age groups. A larger 5th grade student will typically be in contact with the floor for a longer period of time than a smaller, lighter 2nd grade student. As shown by the inverse relationship shown below, the longer the period of contact, the lower the frequency produced. This same effect can be demonstrated by the sound of a bounced basketball versus a ping pong ball. The ping pong ball emits a higher pitch when bounced because it is smaller and is in contact with the floor for a shorter period of time. The basketball by contrast is larger and is in contact with the floor for a longer period of time and emits a lower “thud”.

$$f = \frac{1}{T}$$

Discussion/Conclusions

In summary, it was found that classroom activity noise leads to non-speech noise levels well above the recommended 35 dBA BNL set forth by ANSI standard S12.60-2002. It was also found that the type of flooring makes a significant difference in measured activity noise. For both age groups, the room with VCT flooring produced higher activity noise levels than the room with carpeted flooring (up to 10 dBA). The speech signals, however, had a difference of 6 dB at most, when comparing the 5th graders in the different rooms. Thus, the increased levels could be attributed to the interactive effects with the floor types (footfalls, chair scrapes, impacts), rather than differences in total acoustic absorption in the room. Another observation is that based on the relative size of the students, the spectral content of the significant activity noise levels occurred in different third octave bands.

In reference to the other part of the ANSI S12.60 standard, the measured classroom activity levels make it impossible to achieve a +15 dB signal-to-noise ratio in these classrooms. The speech and activity noise signals were a maximum of +9 dB apart in the room with the quietest floor (carpet) and the quietest students (5th graders). At their worst, the differences were +3 dB in the VCT room for the 5th graders and +5 dB for the VCT room with the 2nd graders.

A recommendation for further work is to make a controlled study of the sound power levels generated by chair scraping and other classroom activities on different floor types. The 2007 and 2008 footfall sound power studies done at the University of Hartford [7, 8] should also be incorporated with the current results and used in the development of new floor types and styles of mounting. Further studies should be performed to evaluate the effects of new floor types and mountings on signal-to-noise ratios in classrooms.

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Appendix A – Human Subjects Committee Approval



UNIVERSITY OF HARTFORD

Human Subjects Committee

February 22, 2010

Robert Celmer
Department of Mechanical Engineering
University of Hartford
West Hartford, CT 06117

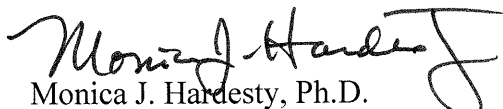
Dear Dr. Celmer:

Upon review of your modifications/clarifications by the Human Subjects Committee, your proposal, *Contribution of non-verbal and non-ventilation noise sources to background noise levels in elementary school classrooms, part 1*, has been approved for one year according to review guidelines established by federal regulation 45 CFR 46. Keep in mind that it is your responsibility to notify and seek approval from this Committee of any modifications to your project, and that it is your responsibility to report to this Committee, any adverse events that occur related to this project. Reporting forms are available online at the HSC website

This institution has an Assurance of Compliance on file with the Office of Human Research Protections (Federalwide Assurance FWA00003578).

Congratulations and good luck.

Sincerely,


Monica J. Hardesty, Ph.D.
Chair, Human Subjects Committee

Appendix B – FFT Data Plots of Activity Noise

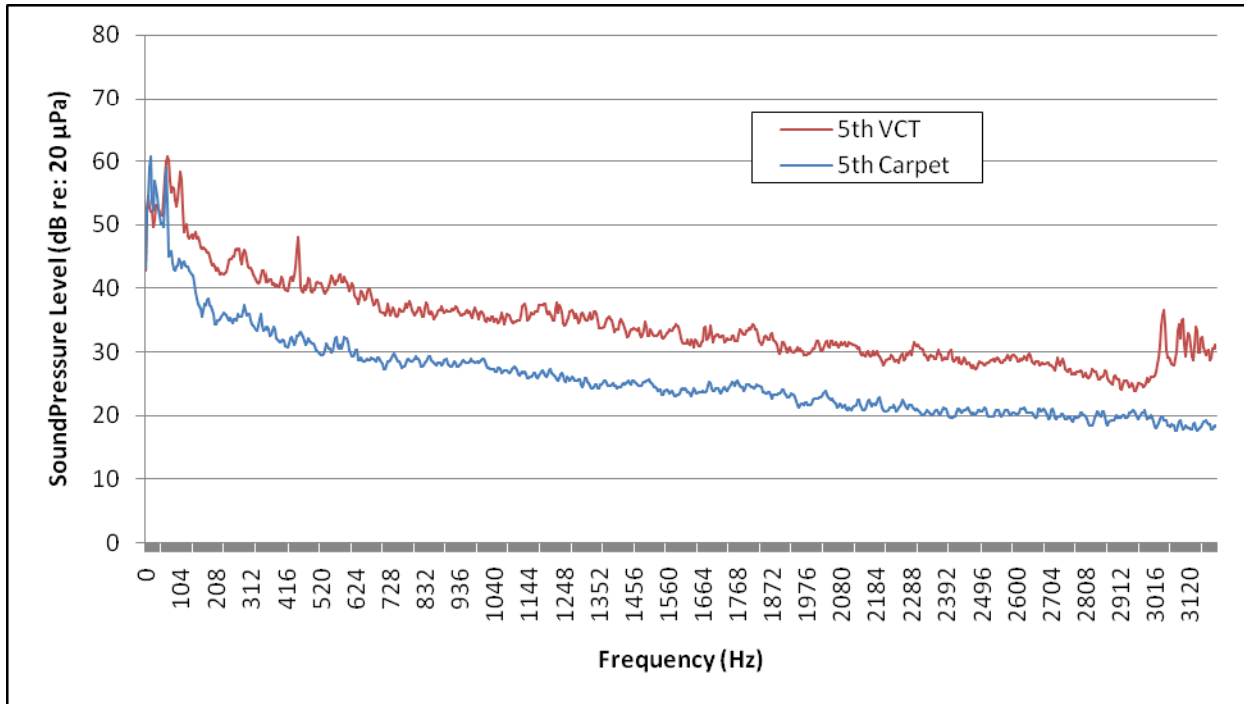


Figure B1 - FFT Plot of 5th grade Activity Noise, Carpet vs. VCT

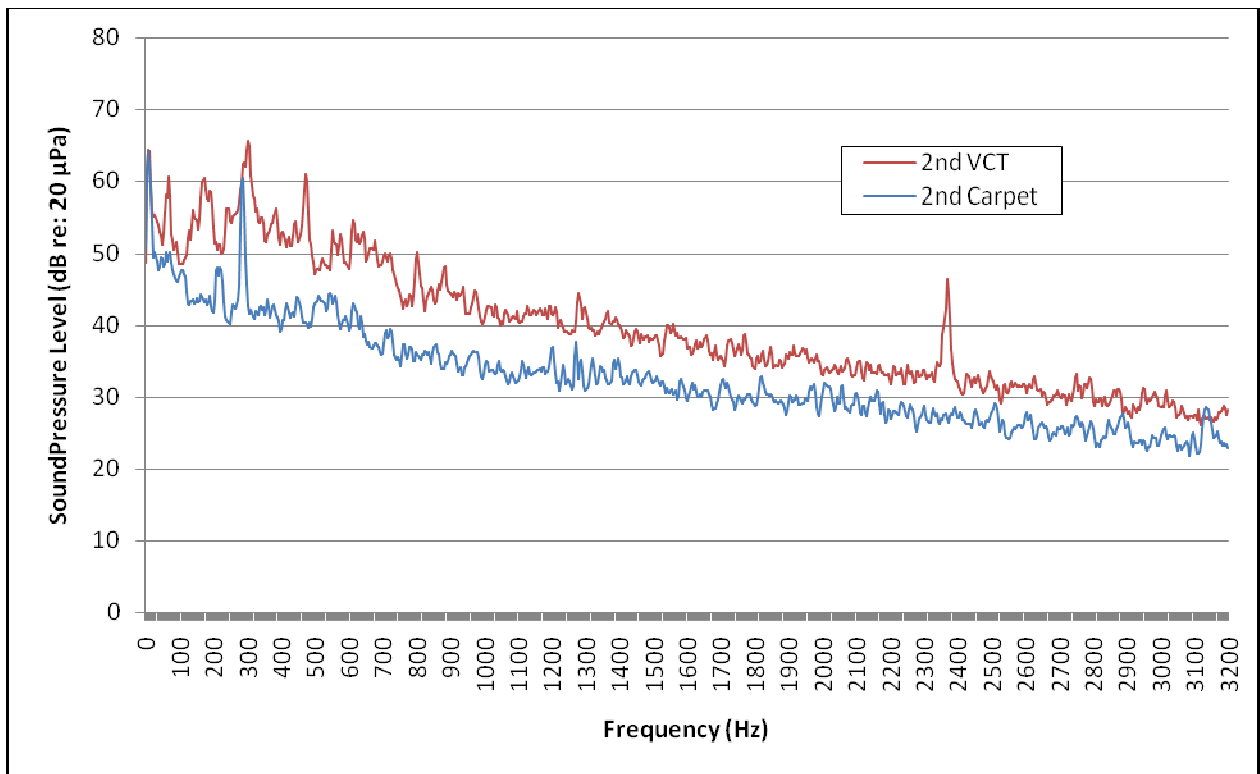


Figure BA2 - FFT Plot of 2nd grade Activity Noise, Carpet vs. VCT