Acoustical Characteristics of Ohio State University Classrooms

A Senior Honors Thesis

Presented in Partial Fulfillment of the Requirements for graduation
with research distinction in Speech and Hearing Science in the undergraduate colleges of
The Ohio State University

by

Andrew DeLong

The Ohio State University
June 2010

Project Advisor: Dr. Lawrence L. Feth, Department of Speech and Hearing Science

Table of Contents

Abstract

Learning in a classroom requires that students be able to hear the instructor's speech signal without undue strain or discomfort. In 2002, the American National Standards Institute created a new standard for acoustical variables in K-12 classrooms nationwide. The standard sets forth maximum values for background noise levels and reverberation times and provides suggestions for how best to limit those values during the construction or renovation of a classroom. College students share in the same concerns of parents of school-age children, and nine classrooms were selected from an informal survey of college students about which rooms they had experienced were either "good" or "bad" acoustically. The purpose of our experiment is to test the background noise levels and reverberation times and compare them to the standard and attempt to find a predictive characteristic amongst them that pointed to exceptionally good or bad acoustics. We measured the volume and background noise levels, and calculated the reverberation times in each room at four different spots in the room. Results from the nine rooms show that both background noise levels and reverberation times are within the standard's limits. We have concluded from our data set that there is not a predictive characteristic that can determine whether or not a room will be exceedingly noisy or reverberant.

Introduction

Speech intelligibility in the classroom is of utmost importance for teachers and learners alike. The ability to learn hinges mostly on the student being able to hear the intended message with relative ease and not struggle over competing signals. Crandell and Smaldino (2000) state that the primary acoustical variables in classrooms of concern to teachers, speech pathologists, and audiologists are "(a) level of the background noise, (b) level of the speech signal relative to the level of the background noise, (c) RT [reverberation time], and (d) distance from the speaker to the listener." Of these four acoustical variables, the signal-to-noise ratio and distance between speaker and listener are dependent upon people. Reverberation time and a considerable amount of background noise is at the mercy of the physical learning space and its design. According to Bistafa and Bradley (1999), signal to noise ratios in quiet classrooms can be maximized when the reverberation time is between 0.4 - 0.5 seconds, much of which relies on room design and sound-tempering treatments.

Nelson (2002) says that students under the age of fifteen are still mastering their language and an unimpeded, clear signal allows for maximum listening and comprehension ability. Nelson also goes on to say that in addition to children whose only concern is language mastery, there may be children with hearing impairments, learning disabilities, and or developmental disorders that are mainstreamed in classrooms where they may otherwise require extra attention. From a teaching standpoint, it should not require vocal strain to produce a signal-to-noise ratio (SNR) that is adequate for students to understand the message clearly (Nelson et. al., 2002). With these concerns in mind, the American National Standards Institute (ANSI) was moved to develop a set of standards that would limit the amount of background noise and reverberation time in a learning space based on architectural practices, facility location, and design of the spaces (ANSI, 2002).

While language mastery through adolescence is important, an additional barrier at a university setting is learning in a language that may not be one's native language. The phrasing of the standard itself says that, "Although all those in a classroom, including teachers and adult learners, will benefit, special beneficiaries are young children and persons with hearing, language, speech, attention deficit, or learning disabilities" (ANSI, 2002). There is still a very clear importance as to why college classrooms should adhere to the same standard, and unfortunately, very few buildings on our campus (and likely several campuses) have been built or renovated since the introduction of the standard. There is a proposal to renovate Ohio State University classrooms to include presentation technology in every learning space, and acoustical treatments are not currently a part of the classroom renovation plans. The purpose of this experiment is to test objectively the background noise and reverberation times of nine rooms selected around campus and analyze the results versus the standard requirements. Also, these studies may attempt to determine if there is any sort of predictive factor that unacceptable reverberation time or background noise can be attributed to.

Methods

Description of Procedures

Nine classrooms were selected around campus based on 243 responses to an informal survey. Students were ask to submit classrooms that they felt had "good acoustical characteristics" and "poor acoustical characteristics", explain why it was they felt that way, and what physical aspects of the room stood out to them. Three classrooms each were selected that received a majority of “good” responses, three that received a majority of “poor” responses, and three that received close to half of each. The nine classrooms selected, volumes, and maximum background noise levels and reverberation times according to the standard are listed in appendix A.

The volume of the classroom was first measured with a 100’ measuring tape. Acoustical treatments present in the room were noted and mostly consisted of drop-ceiling tiles and wall treatment, and full descriptions of room amenities are also included in appendix A.

Four seats were chosen in the unoccupied room to measure the background noise and reverberation time sound level measurements (excluding Campbell Hall 200, where three seats were chosen on the floor level and three seats were chosen in the balcony). Three seats were chosen as “extreme” positions in the room where students may receive the instructor’s signal. In all cases, one seat was chosen in the front of the room closest to where the professor would likely address the class, and one measurement was made in each of the two farthest corners of the room. A fourth position was chosen in the center of the room to serve as a relative average listening position for the rest of the seats in the room.

Background noise measurements were taken in the unoccupied rooms in the four locations with all lights turned completely on and other presentation equipment or external hardware turned off. HVAC systems were unable to be controlled. Measurements were taken at one-third octave intervals between 125-4000Hz to obtain a better sense of sound levels at each frequency. Those frequencies fully encompass male and female speech frequencies and a vast majority of human's audible range of frequencies. Sound level measurements were documented at each position in the room at each of the sixteen frequencies.

Reverberation times were calculated using the power method instead of the traditionally used decay method. The decay method measures how long a sound signal takes to decay by 60 dB, but the power method considers the volume of the room, absorption coefficient of the wall surfaces, sound pressure level, density of the air, power per bandwidth from a sound source in watts, and the speed of sound in air. The combination of the Sabine and power equations yields the following equation used to determine reverberation times in the rooms (Godfrey, 2003):

$$T = \frac{0.163Vp^2}{4\rho c W_r}$$

Where T is reverberation time (s), V is volume (m^3), p is pressure (N/m^2), ρ is the density of air (Kg/m^2), c is the speed of sound in air (m/s), and W_r is the power per bandwidth (W). To measure data, the sound source was set up in the corner of the room approximately two feet from each wall, turned on, and sound level measurements were taken in each of the same four positions (six in Campbell Hall).

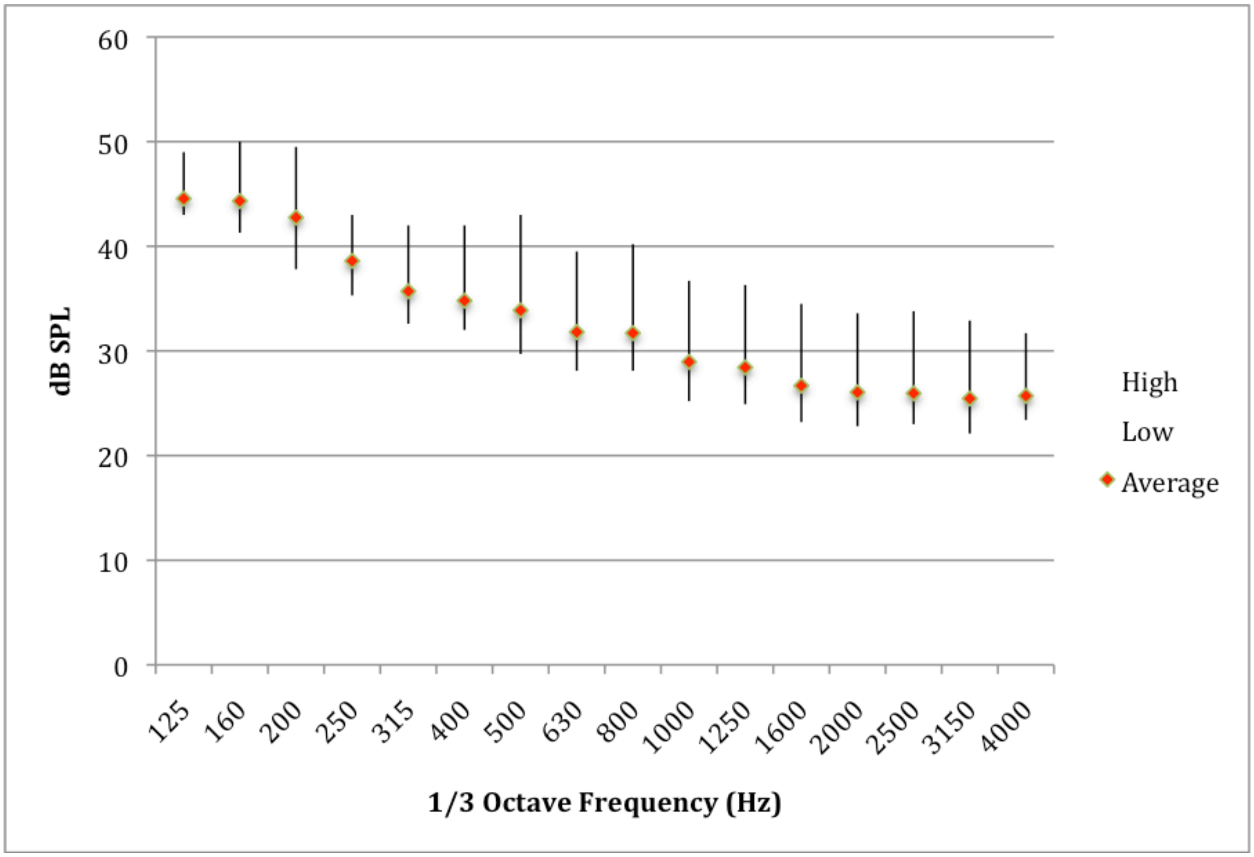
Description of Materials

All sound level measurements were taken using a Larson-Davis System 824 sound level meter and G.R.A.S. ½" pressure microphone, which was calibrated using a Larson Davis Precision Acoustic Calibrator model CAL250. The sound source used to create broadband spectrum noise for the reverberation time measurements is an Acculab Reference Sound Source Model 101 loaned from Owens Corning Acoustics Laboratory.

Results

The sound levels measurements taken in each room for background noise may be found in appendix B, and calculated reverberation times may be found in appendix C. Below are three graphs representing one classroom initially determined by students to be "good" and "bad" acoustically, and one that received mixed reviews.

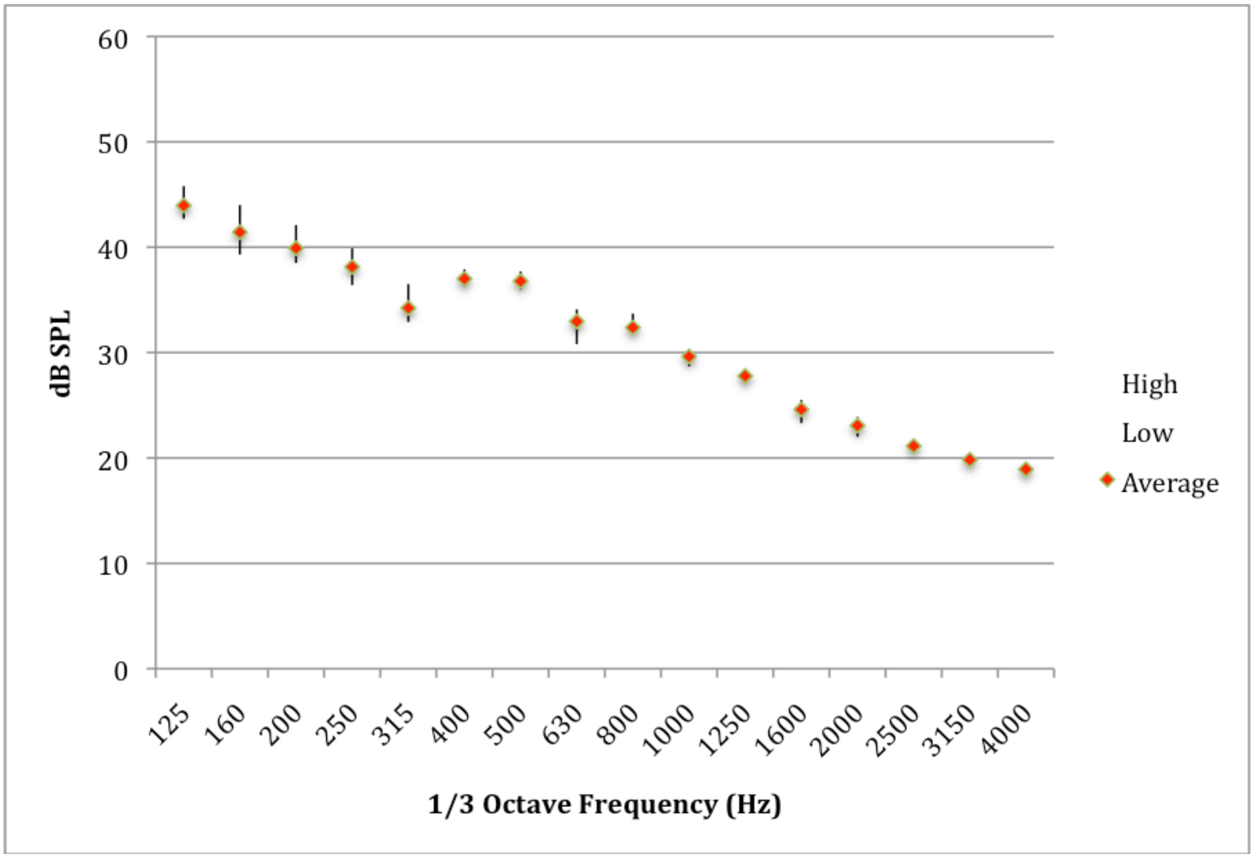
Figure 1. Pressey Hall 40 Background Noise (Good)



Maximum background noise level allowed in standard – 35 dB at 500, 1000, 2000 Hz

This graph reflects the range of background noise measurements across four locations with the average highlighted in red.

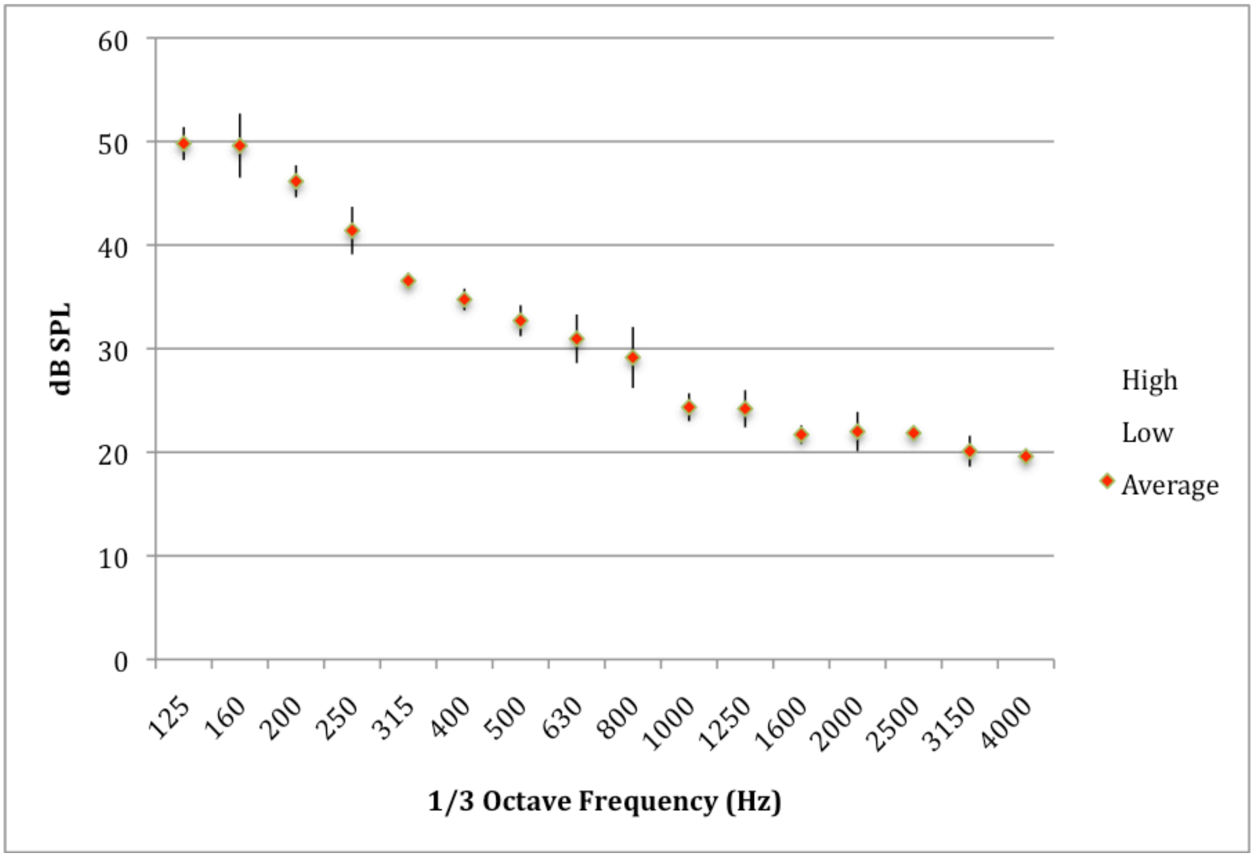
Figure 2. Independence Hall 100 Background Noise (Mixed)



Maximum background noise level allowed in standard – 40 dB at 500, 1000, 2000 Hz

This graph reflects the range of background noise measurements across four locations with the average highlighted in red.

Figure 3. MacQuigg Labs 264 Background Noise (Bad)



Maximum background noise level allowed in standard – 35 dB at 500, 1000, 2000 Hz

This graph reflects the range of background noise measurements across four locations with the average highlighted in red.

Overall results show that of the nine classrooms measured, only two yielded background noise levels above the prescribed maximum above 500 Hz, which is generally considered the lower boundary of speech frequencies. Raw reverberation time data show the longest reverberation time of any classroom was 0.63 seconds in Scott Lab 040 at 125 Hz, which is not even a significant frequencies for human speech. For a room with its volume, that is still within the standard limit. No average reverberation times exceed the established maximum laid out in the ANSI standard (2002) or even came within 0.1 s of the maximum.

Discussion

The purpose of this experiment was to test objectively the background noise and reverberation times of nine rooms selected around campus, analyze the results versus the standard requirements, and also to attempt to determine if there is any sort of predictive factor that unacceptable reverberation time or background noise can be attributed to.

The results of this experiment show that within the speech spectrum (generally considered 500-2000Hz), the primary frequencies of concern with speech intelligibility, there are no sound pressure levels that are outside the bounds of the national standard for classroom spaces. In-class measurements of other studies show that in classrooms that exceed the background noise requirements, teachers speak at approximately 60-65 dB on average (Nelson et al, 2002). If those teachers taught in even the loudest of classrooms measured in this study at a frequency of around 125 Hz, the signal-to-noise ratio would be at approximately +9 dB; Nelson, Soli, and Seltz prescribe a +15 dB signal-to-noise ratio (2002).

Despite student claims of the rooms used in this experiment as being too loud or not conducive to effective learning, background noise levels and reverberation times both lend evidence to the contrary. There is not enough information that can be gleaned from the results that would lend evidence to a predictive room characteristic that causes high background noise or high reverberation time. Crandell and Smaldino did suggest signal-to-noise ratio and distance between listener and speaker as two other primary acoustical variables that may contribute to poor speech intelligibility as well (2000).

This raises several possible questions about the student experience in classrooms. It seems the objective values that stem from room design and technical layout are not to blame in these Ohio State University classrooms, which would leave the subjective measures of signal-to-noise ratio and distance between speaker and listener as the variables. Does a student that sits in the back of an over 1900 cubic meter classroom struggle to hear the instructor as much as someone sitting in the front? Does student noise, such as coughing, shuffling papers, or scooting chairs raise the noise level beyond that of the professor's signal? Is there access to an amplification system in the room? It would appear with the results of this experiment that the struggles students are having with understanding the instructor stem from each individual's experience in the room, not the room itself.

This experiment gathered subjective data from a volunteer-based, limited sample size of students. The informal survey did not gather supplementary information from the students that would have aided in data collection where the students sat in a classroom, if the professor spoke loudly enough to even overcome background noise levels within the standard limits, or what time of day the classes in question were being held.

Future research in this area may consider formalizing how the rooms are selected rather than student volunteering. One may also want to investigate the thought of measuring background noise levels in occupied classrooms and assessing other variables dependent upon a classroom full of people. Future research may also include a longitudinal approach to assessing the background noise levels in classrooms instead of a one-time measurement.

Classroom acoustics are only recently becoming a significant point of concern for parents, instructors, students, and researchers. The ANSI standard is a positive step toward ensuring students will have a classroom experience conducive to learning, but it will take a longer, in-depth look at both the technical facets of classroom spaces and the social aspects of what happens in classrooms while the students are in session to truly better the student experience.

Bibliography

American National Standards Institute. (2002). Acoustical performance criteria, design requirements and guidelines for schools. ANSI S12.60.

Bistafa, S. & Bradley, J. (1999). Reverberation time and maximum background-noise level for classrooms from a comparative study of speech intelligibility metrics. *Journal of the Acoustical Society of America.* 107(2), 861.

Crandell, C. & Smaldino, J. (2000). Classroom Acoustics for Children With Normal Hearing and With Hearing Impairment. *Language, Speech, and Hearing Services in Schools*. 31, 362-370.

Godfrey, R. (2003, Nov. 11). *Estimating Reverberation Time in Classrooms by the Power Method.* Presented at Owens Corning.

Hodgson, M., Rempel, R., & Kennedy, S. (1999). Measurement and prediction of typical speech and background-noise levels in university classrooms during lectures. *Journal of the Acoustical Society of America.* 105(1), 226-233.

Nelson, P., Soli, S., & Seltz, A. (2002). Acoustical Barriers to Learning. *Acoustical Society of America Publications.* Melville, NY.

Shield, B., & Dockrell, J. (2003). The Effects of Noise on Children at School: A Review. *Building Acoustics,* 10(2), 97-116.

Appendix A – Classroom Parameters

Table A.1. Volume, Background Noise, and RT of classrooms

	Approximate Volume (m^3)	Max. Background Noise (dB)	Max. Reverb Time (s)
Scott Labs 040 (G)	541.8	35	0.7
Campbell 200 (G)	1926.5	40	N/A[1]
Pressey 40 (G)	213.7	35	0.6
Page Hall 10 (M)	513.2	35	0.7
Independence 100 (M)	1791.6	40	N/A[1]
McPherson 1015 (M)	626.3	40	N/A[1]
Parks Hall 107 (P)	403.6	35	0.7
MacQuigg 264 (P)	440.7	35	0.7
Bolz Hall 313 (P)	182.8	35	0.6

[1] Classrooms greater than 566 m^3 do not have an established maximum reverberation time. Rather, the standard offers suggestions for acoustical treatments for areas of this size.

Acoustical Treatments and Amenities

Scott Labs 40: 86 chairs, 9 rows of tables, one freestanding table, tiered
    Acoustical Treatments (AT) – sound directional panel in front of room, ceiling tiles
Campbell Hall 200: 300 upholstered chairs, 2 tables, elevated stage, balcony
    AT – soft-surface wall panels, carpeted aisles, sloped balcony
Pressey 40: 38 upholstered chairs, 20 desks, 20 computers
    AT – ceiling tiles
Page Hall 10: 90 chairs, 8 rows of tables, 1 freestanding table, tiered
    AT – ceiling tiles
Independence 100: 727 chairs, tiered auditorium
    AT – tiered ceiling design, soft-surface wall panels on back wall, stage curtains
McPherson Labs 1015: 115 seats, 1 experiment table, 1 freestanding table, tiered

AT – soft-surface wall panels, ceiling tiles in back ½ of the room
Parks Hall 107: 155 tablet chairs, 1 table, tiered, elevated stage
AT – ceiling tiles
MacQuigg Labs 264: 146 tablet chairs, 3 upholstered chairs, 2 tables, tiered
AT – ceiling tiles
Bolz Hall 313: 43 tablet desks, 1 table, single-paned windows, full-length wall heater
AT – ceiling tiles

Appendix B – Background Noise Measurements*

Table B.1. – Scott Lab 040 Background Noise

	Background Noise at Each Position (dB)			
Frequency (Hz)	A	B	C	D
125	45.1	44.8	44.3	45.6
160	48.5	47.7	49.1	47.2
200	44.4	41.3	42.7	42.9
250	41.9	39.1	41.3	40.7
315	41.3	38.7	38.2	38.2
400	36.8	36.2	35.3	36.0
500	38.7	35.0	34.8	34.2
630	30.4	32.1	32.5	31.8
800	28.9	26.6	29.2	27.2
1000	24.8	24.8	25.0	24.7
1250	20.4	21.2	22.4	21.3
1600	19.2	19.7	20.5	20.1
2000	18.6	18.5	19.6	18.8
2500	19.6	18.2	18.3	17.4
3150	17.8	17.4	18.2	17.9
4000	18.0	17.7	17.7	17.7

Table B.2 Campbell Hall 200 Background Noise

	Background Noise at Each Position (dB)					
Frequency (Hz)	A	B	C[1]	D[2]	E[2]	F[2]
125	48.9	37.5	42.0	47.2	37.0	36.6
160	33.6	34.3	31.8	36.1	34.6	35.1
200	32.5	32.8	30.0	32.8	30.3	34.6
250	40.5	37.5	28.7	37.5	34.2	41.2
315	32.7	31.6	29.3	31.9	30.6	31.4
400	33.6	37.7	30.1	33.2	29.2	34.1
500	36.6	33.8	27.7	31.7	29.6	28.9
630	31.7	30.1	25.9	30.1	26.9	28.1
800	31.4	30.2	25.8	28.7	26.4	26.2
1000	30.9	28.9	24.2	27.2	25.5	25.3
1250	29.8	27.1	23.8	27.4	26.2	24.2
1600	28.5	26.6	23.2	25.9	24.1	24.7
2000	27.2	24.8	21.4	23.8	23.3	22.5
2500	23.8	23.1	20.0	22.1	21.0	20.8
3150	22.6	21.6	18.9	21.2	19.8	20.0
4000	21.4	20.5	18.6	20.3	18.6	18.5

[1] Position located under balcony

[2] Position located in the balcony

Table B.3 Pressey Hall 40 Background Noise

	Background Noise at Each Position (dB)			
Frequency (Hz)	A	B	C	D
125	49.0	43.0	43.2	43.0
160	50.0	42.4	43.6	41.3
200	49.5	44.7	39.0	37.8
250	43.0	37.8	38.3	35.3
315	42.0	33.7	34.5	32.6
400	42.0	33.4	31.8	32.0
500	43.0	32.3	30.5	29.7
630	39.5	30.0	29.6	28.1
800	40.2	29.6	28.1	28.9
1000	36.7	27.6	26.3	25.2
1250	36.3	26.9	25.6	24.9
1600	34.5	25.3	23.2	23.7
2000	33.6	24.2	23.6	22.8
2500	22.8	23.8	23.2	23.0
3150	32.9	23.3	23.5	22.1
4000	31.7	23.9	23.8	23.4

Table B.4 Page Hall 10 Background Noise

	Background Noise at Each Position (dB)			
Frequency (Hz)	A	B	C	D
125	44.2	42.0	42.7	43.2
160	40.9	41.8	41.1	47.8
200	42.7	42.3	40.5	44.7
250	42.9	40.7	39.2	42.1
315	37.1	36.6	35.3	39.2
400	39.4	36.3	35.9	37.0
500	36.3	37.4	32.7	35.0
630	32.5	33.9	31.4	37.2
800	34.7	34.8	33.2	38.4
1000	32.3	29.2	28.6	34.6
1250	28.6	27.1	25.2	30.5
1600	26.0	24.3	24.1	27.8
2000	25.5	24.4	22.8	25.9
2500	23.1	22.7	20.6	21.7
3150	22.4	22.4	21.9	20.8
4000	22.1	21.6	21.2	20.0

Table B.5 Independence Hall 100 Background Noise

	Background Noise at Each Position (dB)			
Frequency (Hz)	A	B	C	D
125	45.8	42.7	42.9	44.4
160	42.6	39.8	39.3	44.0
200	42.1	38.8	38.5	40.2
250	39.9	37.6	36.4	38.6
315	34.5	36.5	32.9	33.0
400	37.9	36.3	37.3	36.5
500	36.8	36.0	37.7	36.6
630	33.1	34.1	30.8	33.8
800	33.7	31.9	32.2	31.7
1000	30.3	29.6	28.7	29.9
1250	28.0	27.6	27.5	28.0
1600	25.5	24.2	23.3	25.4
2000	23.5	23.9	22.0	22.9
2500	21.6	21.4	21.0	20.5
3150	19.9	19.6	19.9	19.9
4000	18.8	18.9	18.8	19.2

Table B.6 McPherson Labs 1015 Background Noise

	Background Noise at Each Position (dB)			
Frequency (Hz)	A	B	C	D
125	38.4	38.6	39.8	46.8
160	31.1	31.4	32.2	31.7
200	33.8	29.4	34.5	34.8
250	26.2	25.5	33.2	26.7
315	23.4	25.0	32.6	29.7
400	30.6	27.5	34.7	33.9
500	19.5	20.9	25.6	22.7
630	19.8	18.7	20.5	18.1
800	18.3	18.4	18.9	16.0
1000	18.2	17.2	17.8	17.5
1250	18.0	18.6	18.2	17.4
1600	18.9	17.1	18.6	16.8
2000	17.7	17.0	17.1	17.1
2500	18.9	18.8	17.6	17.6
3150	20.7	20.0	18.5	18.8
4000	20.5	21.4	19.6	20.0

Table B.7 Parks Hall 107 Background Noise

	Background Noise at Each Position (dB)			
Frequency (Hz)	A	B	C	D
125	47.9	48.4	52.5	50.4
160	43.5	45.0	46.6	48.3
200	46.1	47.4	47.3	47.1
250	43.8	44.8	46.4	44.7
315	39.6	41.8	41.7	42.3
400	36.2	37.7	41.4	38.7
500	33.0	34.4	35.8	35.8
630	29.6	30.8	33.7	32.2
800	27.7	27.6	30.5	29.6
1000	23.9	24.4	26.7	26.8
1250	21.4	23.7	25.4	25.6
1600	19.6	22.1	24.4	23.7
2000	19.7	22.8	23.2	22.0
2500	19.2	20.1	21.8	21.5
3150	18.9	20.2	22.4	21.2
4000	19.6	20.6	22.1	21.0

Table B.8 MacQuigg Labs 264 Background Noise

	Background Noise at Each Position (dB)			
Frequency (Hz)	A	B	C	D
125	48.2	50.5	51.4	51.0
160	46.5	47.3	47.8	52.7
200	47.7	46.6	44.6	46.7
250	39.1	39.9	43.7	41.8
315	37.1	36.4	37.3	35.8
400	35.8	33.8	34.4	33.7
500	34.2	31.6	31.2	32.2
630	33.3	28.6	30.4	30.4
800	32.1	26.2	28.6	27.2
1000	25.7	23.0	25.0	23.1
1250	23.4	23.2	26.0	22.4
1600	20.9	22.6	21.4	20.8
2000	21.7	20.1	23.9	21.4
2500	21.4	19.7	22.3	21.5
3150	21.0	18.6	21.6	20.5
4000	20.3	18.9	20.0	19.4

Table B.9 Bolz Hall 313 Background Noise

	Background Noise at Each Position (dB)			
Frequency (Hz)	A	B	C	D[1]
125	39.7	39.6	38.4	40.1
160	38.5	37.6	36.8	38.7
200	34.8	38.2	37.2	39.2
250	32.0	33.5	36.0	38.9
315	26.6	29.4	29.4	30.0
400	29.4	27.6	28.5	36.8
500	21.7	24.1	22.7	32.4
630	19.6	20.4	21.3	31.5
800	20.8	20.1	19.0	30.1
1000	18.3	18.9	17.4	27.8
1250	18.0	18.8	17.1	26.4
1600	17.7	18.3	16.8	26.3
2000	16.8	16.4	15.4	28.1
2500	16.3	16.9	16.7	28.6
3150	17.1	16.7	16.8	28.2
4000	17.1	17.8	17.2	29.1

[1] HVAC system on during measurements at position D

*All shaded boxes represent measurements that exceed the level established by the ANSI standard (2002)

Appendix C – Reverberation Time Averages

Table C.1. Average Reverberation Times by Frequency in seconds

Freq. (Hz)	SO 040	CM 200	PR 40	PA 10	IH 100	MP 1015	PK 107	MQ 264	BO 313
125	0.36	0.25	0.18	0.10	0.16	0.24	0.26	0.23	0.12
160	0.47	0.24	0.27	0.19	0.08	0.24	0.15	0.22	0.09
200	0.22	0.19	0.21	0.16	0.06	0.21	0.08	0.21	0.12
250	0.16	0.08	0.13	0.14	0.06	0.07	0.08	0.16	0.06
315	0.16	0.16	0.09	0.09	0.06	0.05	0.09	0.11	0.06
400	0.27	0.28	0.12	0.11	0.11	0.13	0.18	0.15	0.16
500	0.18	0.29	0.12	0.14	0.12	0.17	0.12	0.12	0.11
630	0.10	0.19	0.09	0.08	0.08	0.10	0.08	0.09	0.10
800	0.09	0.18	0.06	0.07	0.05	0.07	0.09	0.07	0.07
1000	0.11	0.16	0.05	0.07	0.05	0.09	0.07	0.05	0.07
1250	0.10	0.13	0.04	0.07	0.05	0.08	0.07	0.04	0.05
1600	0.07	0.12	0.03	0.08	0.04	0.08	0.06	0.04	0.03
2000	0.07	0.10	0.03	0.06	0.03	0.07	0.05	0.03	0.03
2500	0.06	0.09	0.03	0.06	0.02	0.06	0.03	0.03	0.02
3150	0.05	0.09	0.03	0.07	0.03	0.06	0.03	0.03	0.02
4000	0.05	0.10	0.03	0.06	0.04	0.07	0.04	0.03	0.02

Maximum possible reverberation time for any room size – 0.7 s