Lecture Hall or Music Hall:

Acoustic Properties of Foellinger Auditorium

PHYS 406 Acoustical Physics of Music Student Project

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1. History

Foellinger Auditorium, not to be confused with Foellinger Great Hall in the Krannert Center for the Performing Arts, is the lecture hall located on the south end of the main quadrangle of University of Illinois at Urbana-Champaign. Designed by Clarence H. Blackall, an architect who graduated from Illinois in 1877, and dedicated on November 4th and 5th, 1907, the auditorium is one of the oldest building on this campus. Initially, the auditorium could not be built exactly as Blackall designed due to budgetary restraints; however, in 1983 a generous donation from an alumna Helena Foellinger allowed the building to be completed as the original plan had it. On April 26th, 1985, the new and expanded auditorium was rededicated and named the Foellinger Auditorium in honor of Ms. Foellinger's dedication to the university.

Since its initial dedication in 1907, the auditorium has hosted many notable musicians for their performances, as well as multiple influential speakers for their lectures. Some speakers include Eleanor Roosevelt, Eve Curie, Amelia Earhart, and Robert Frost; while some major performers include John Phillip Sousa in 1909, Duke Ellington in 1948, Lil Wayne in 2004, and Nick Offerman in 2013. In addition to hosting concerts and student productions, Foellinger Auditorium serves as UIUC's largest lecture hall with over 1,500 total seats.

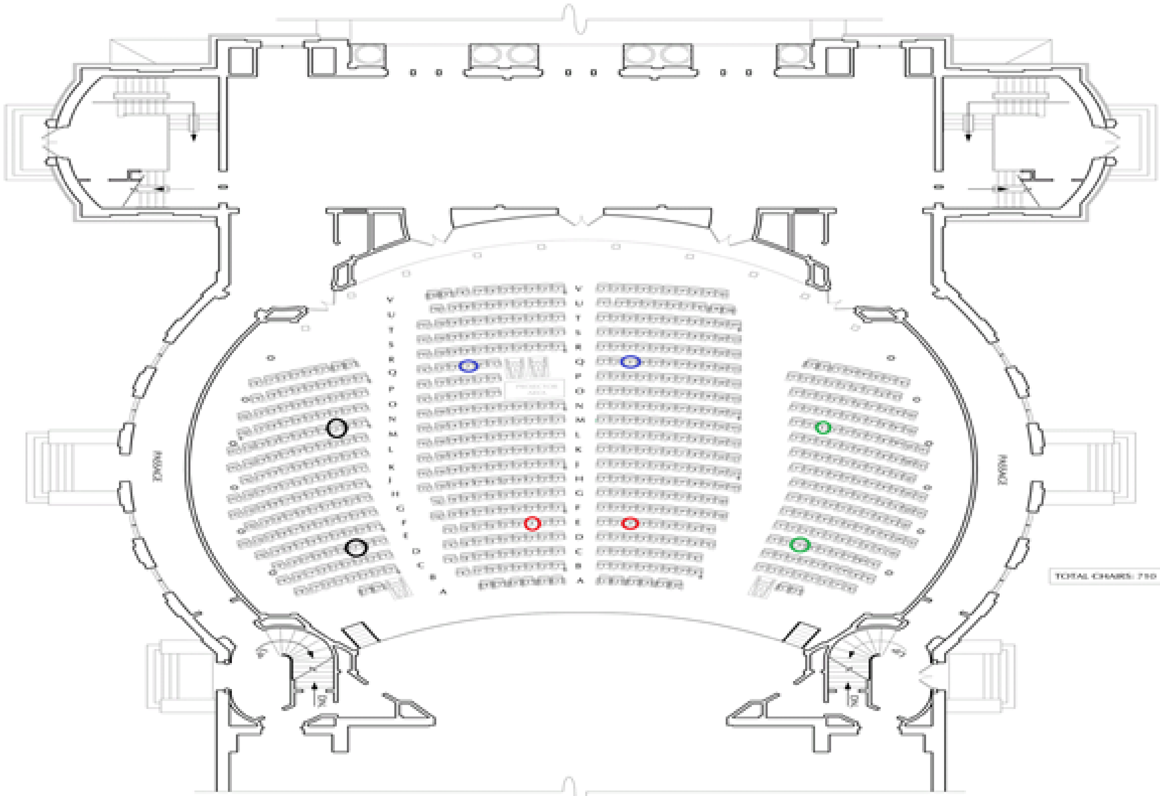
2. Background

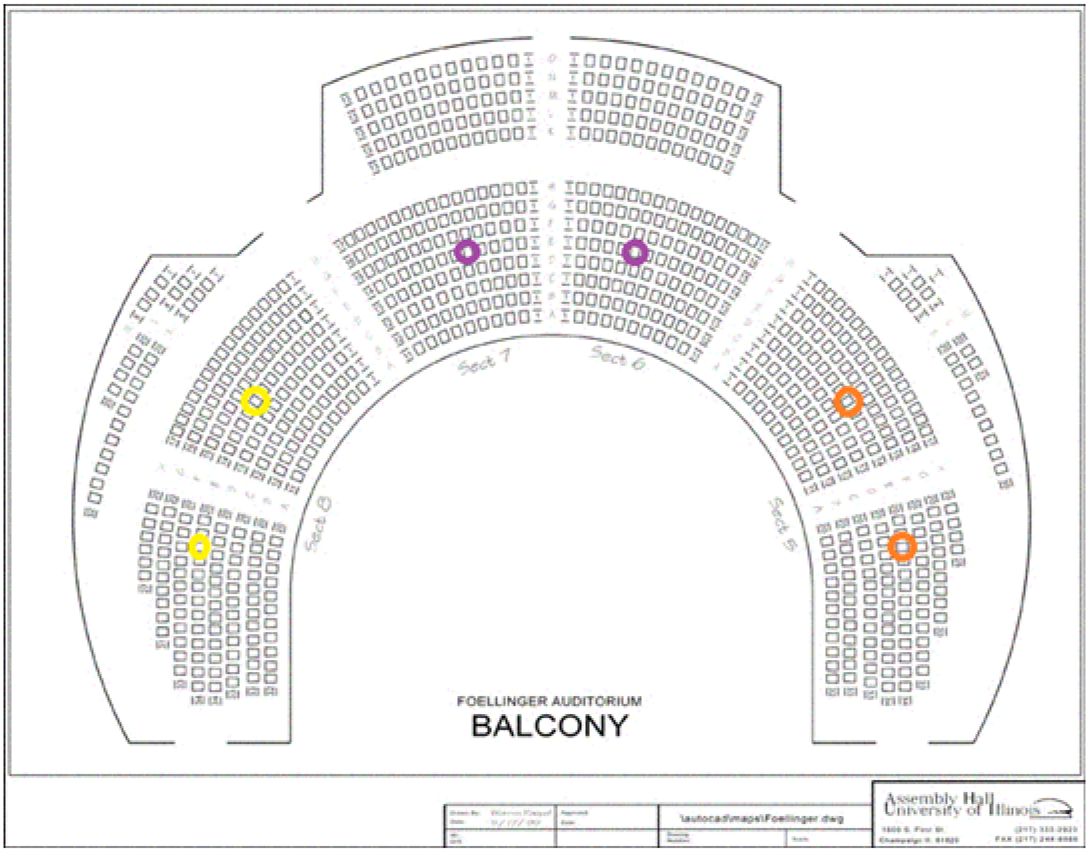
Foellinger Auditorium was initially meant to be dedicated to the school of music and serve as the main concert hall. Due to the construction of the Krannert Center and the Music

Building, the auditorium, while occasionally serving its original purpose, is mostly used as a lecture hall for large classes. However, since a good concert hall and a good lecture halls have different acoustical properties, Foellinger must be better suited for one more than the other. In our project, we decided to take measurements in the auditorium and analyze that data to determine if it is better suited as a concert hall, lecture hall, both, or neither.

3. Procedure

To generate the test sounds for the records, we popped balloons. We used 12 inch latex balloons that we popped at stage center, roughly five feet off the ground. With the help of Professor Errede, we recorded 8 total sound files using his digital recorder. We had two microphones per recording; they each corresponded to either the left or right channel connected to the digital recorder. The images below highlight where the microphones were set up for various recordings. The first image is the main floor, and the second is the balcony of Foellinger Auditorium.


TOTAL CHAIRS: 750



Once we had the recordings, Professor Errede had a MATLAB program that provided us with all of the data we could need to analyze the sound files.

Of the data we obtained from the MATLAB program, for our purpose of determining the adequacy of Foellinger Auditorium as a lecture or a concert hall, we decided to focus on T_{60}, D_{50}, C_{50}, C_{80}, syllable intelligibility, and C_7.

T_{60} is the time for the sound to decay to 10^{-6} th of the original intensity, also understood as the reverberation time. For a lecture hall, T_{60} time less than 0.5 seconds is preferable, while concert hall prefers somewhere between 1.7 and 2 seconds.

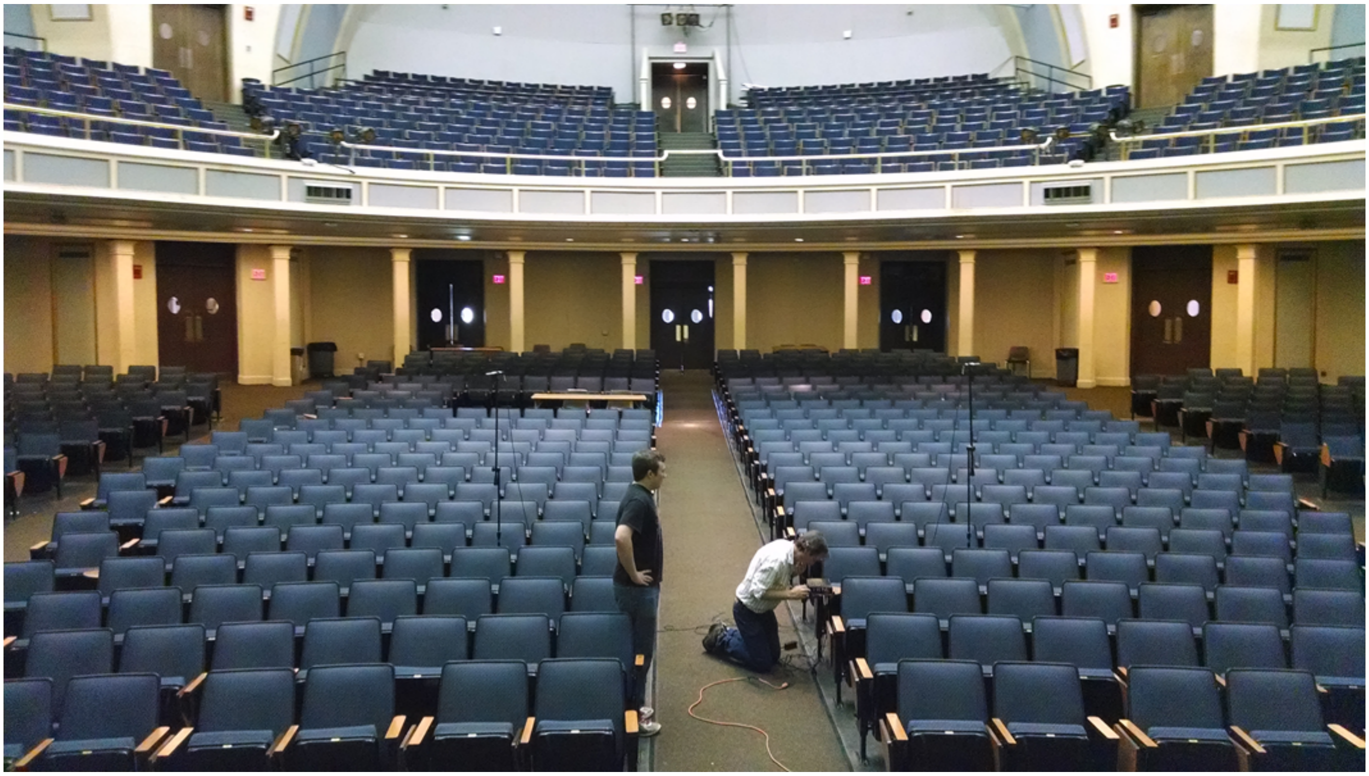
D_{50} is the percentage of total sound reaching the listener within 50 milliseconds after the initial pulse of sound. D_{50} percentage greater than 50% is preferred for both lecture and concert halls.

C_{50}, also known as speech clarity, is the ratio of energy in the first 50 milliseconds compared to the reverberant sounds. C_{50} is for lecture halls; similarly, C_{80}, ratio of energy in the first 80 milliseconds compared to the reverberant sounds, is known as the music clarity. In lecture halls, for syllable intelligibility greater than 80%, C_{50} greater than -2 dB is required, while concert halls requires the value of C_{80} to be at least -1.6 dB, and greater than 1.6 dB for a good concert hall.

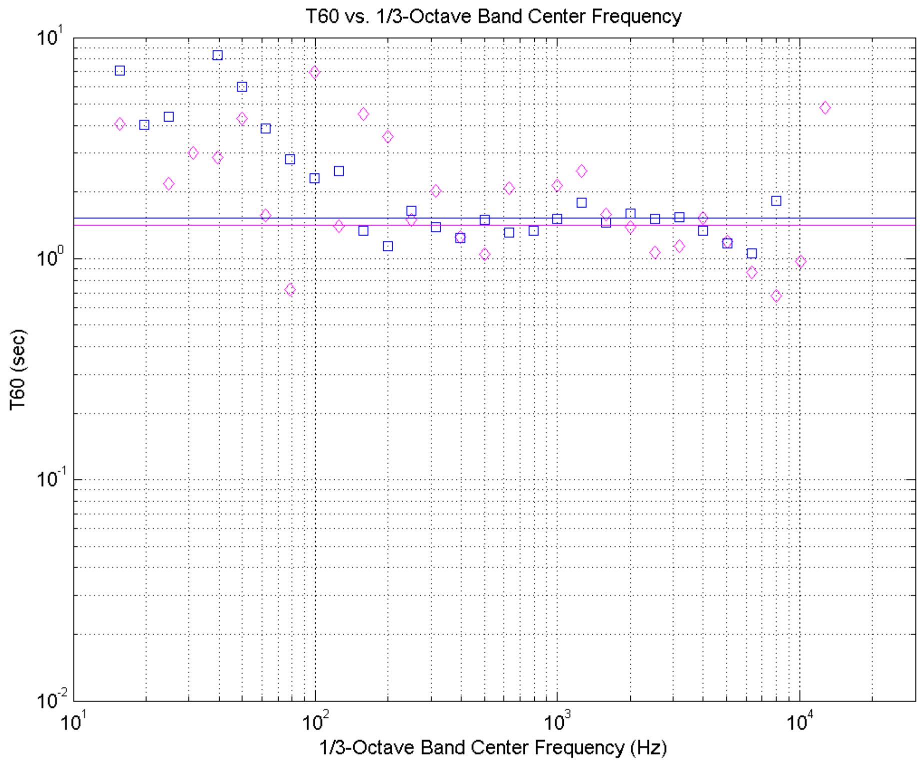
Syllable intelligibility is the percentage of syllables that reaches the audience clearly. Intelligibility greater than 80% is preferred for a good lecture hall.

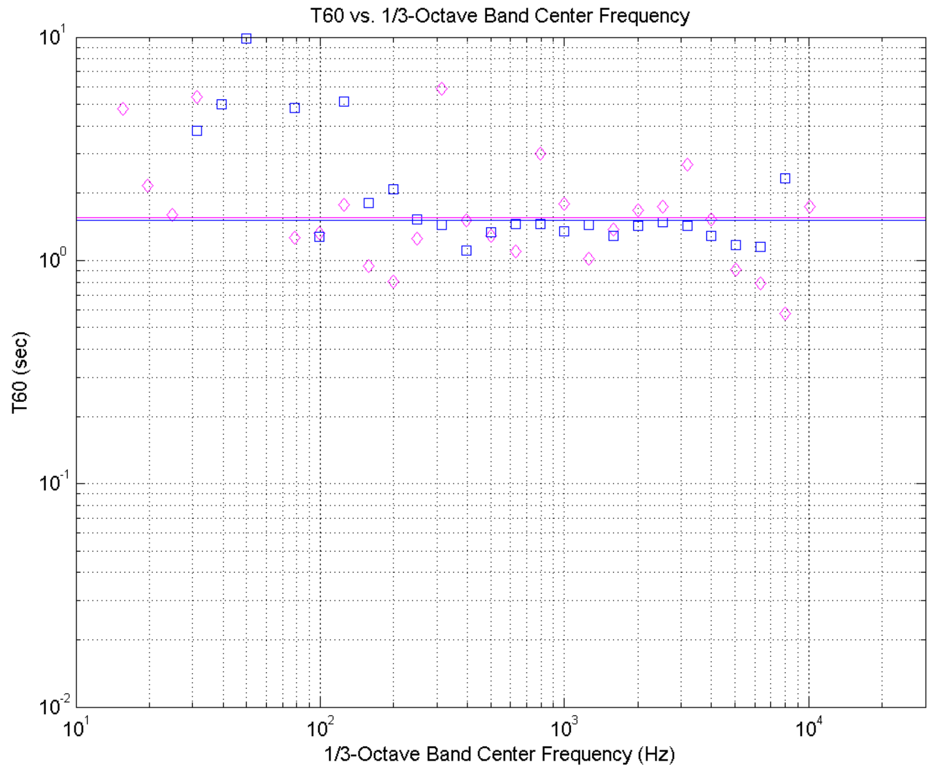
C_7 is the clarity associated with the direct sound level. While it correlates to the distance between the audience and the sound source, C_7 should not fall below -10 dB to -15 dB.

4. Results from Seats E5R/E5L



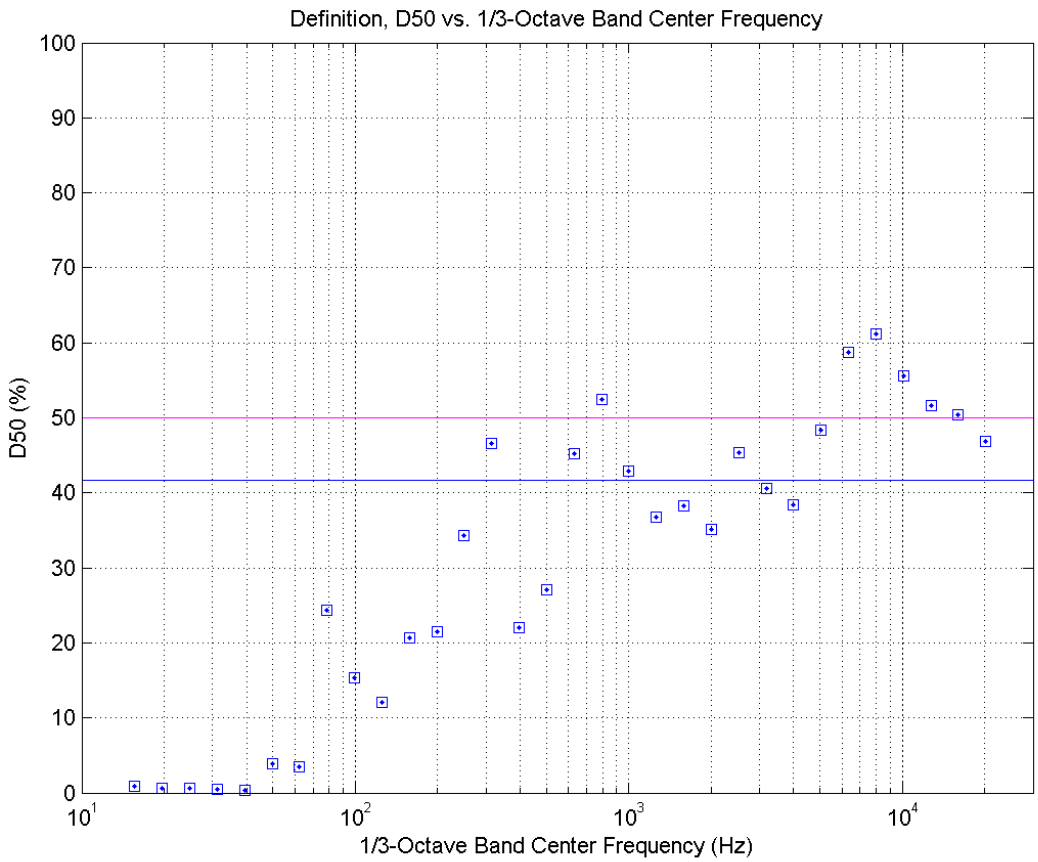
The following graphs were obtained from analyzing the sound data from seats E5R and E5L, which are the seats located in the front center of the auditorium. The first graph is from the sound from the left channel, and the second graph is from the sound recorded in the right channel. The first graphs are the average reverberation time, or $T_{60.}$

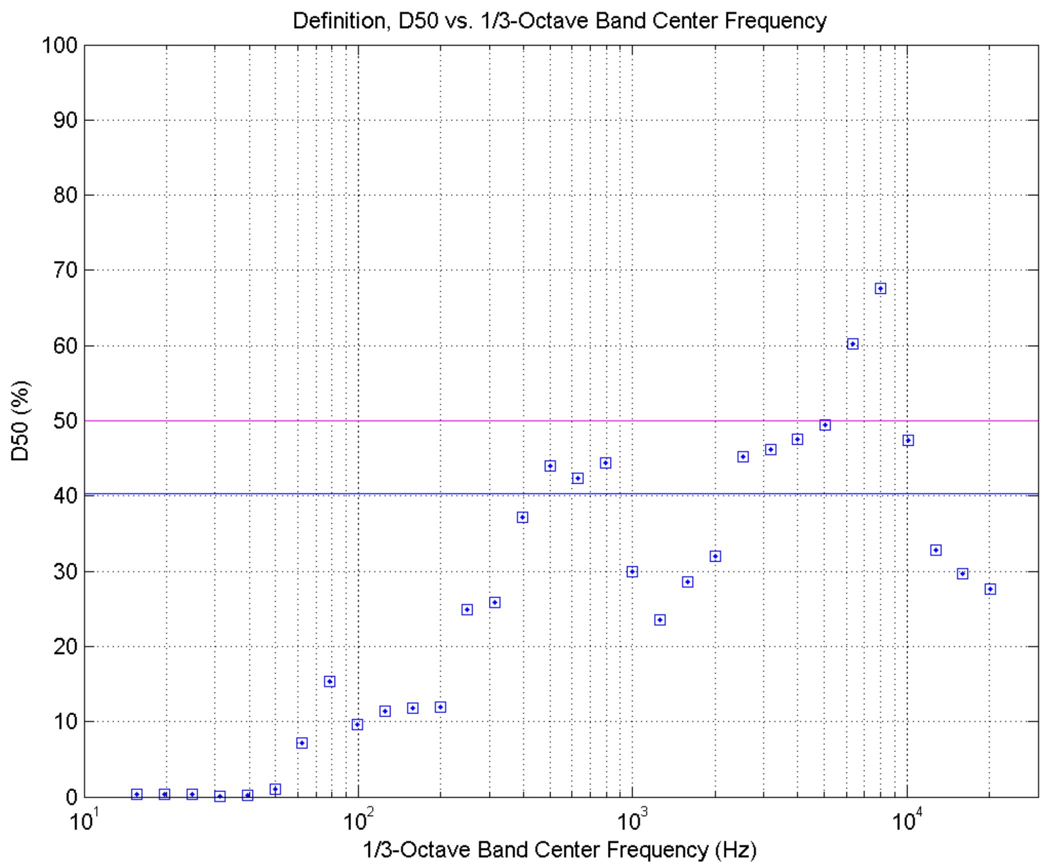

T60 vs. 1/3-Octave Band Center Frequency
T60 (sec)
1/3-Octave Band Center Frequency (Hz)
10^1
10^0
10^{-1}
10^{-2}
10^1
10^2
10^3
10^4



In the graphs above, the blue line is the average T_{60} time of the octave bands. Averaging out the result from both channels, we get the result of 1.6 seconds. For a good lecture hall, T_{60} time of less than .5 seconds is preferable, so the result is not ideal. Things look better for concert halls, which prefers the T_{60} time of 1.7 to 2 seconds.

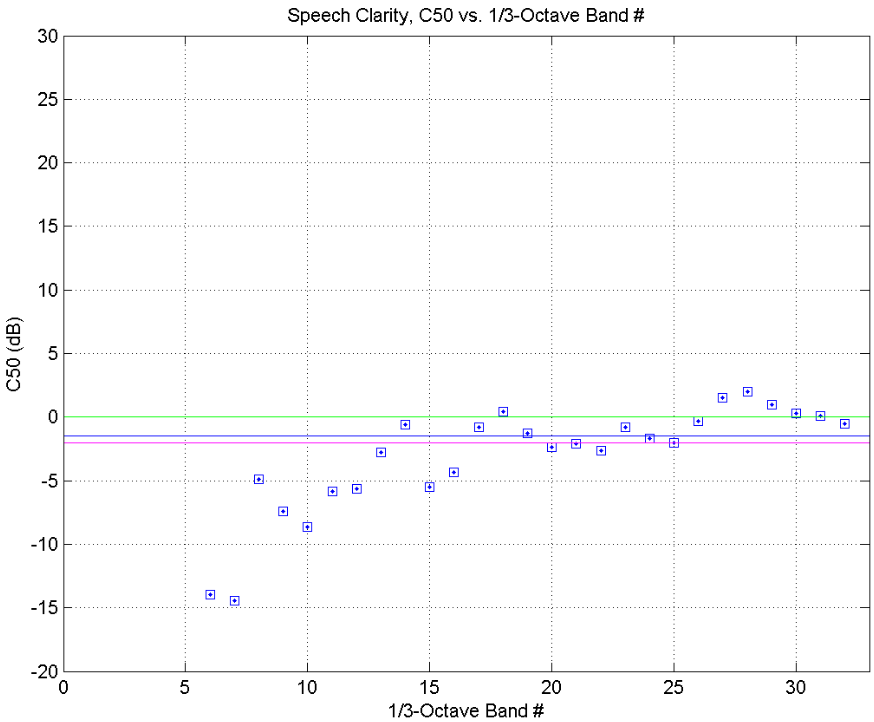
The next graphs show the average D_{50} percentage.

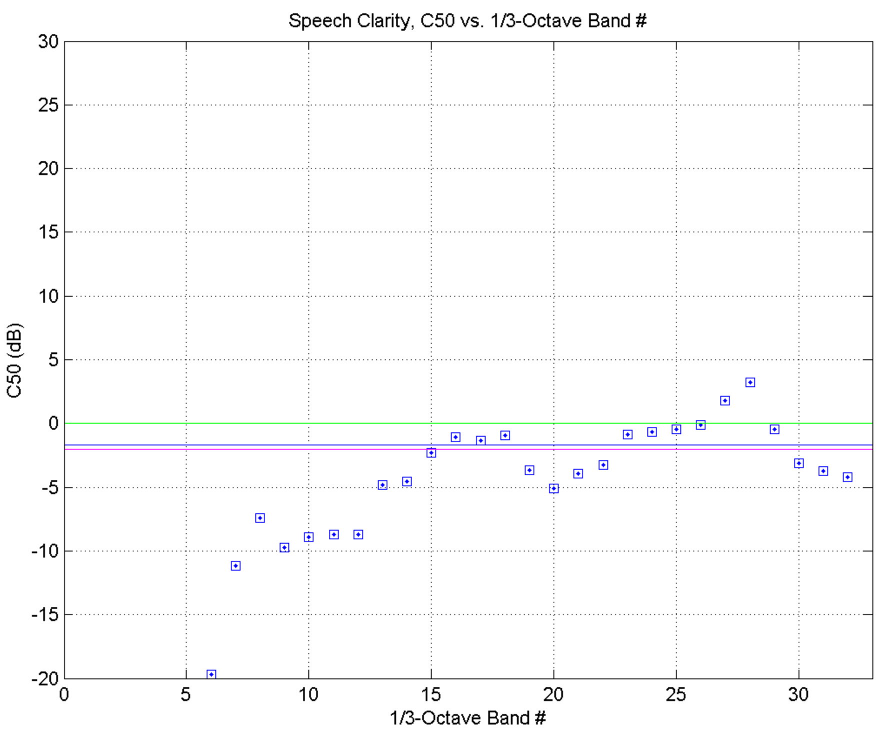

Definition, D50 vs. 1/3-Octave Band Center Frequency
D50 (%)
1/3-Octave Band Center Frequency (Hz)
100
90
80
70
60
50
40
30
20
10
0
10^1
10^2
10^3
10^4

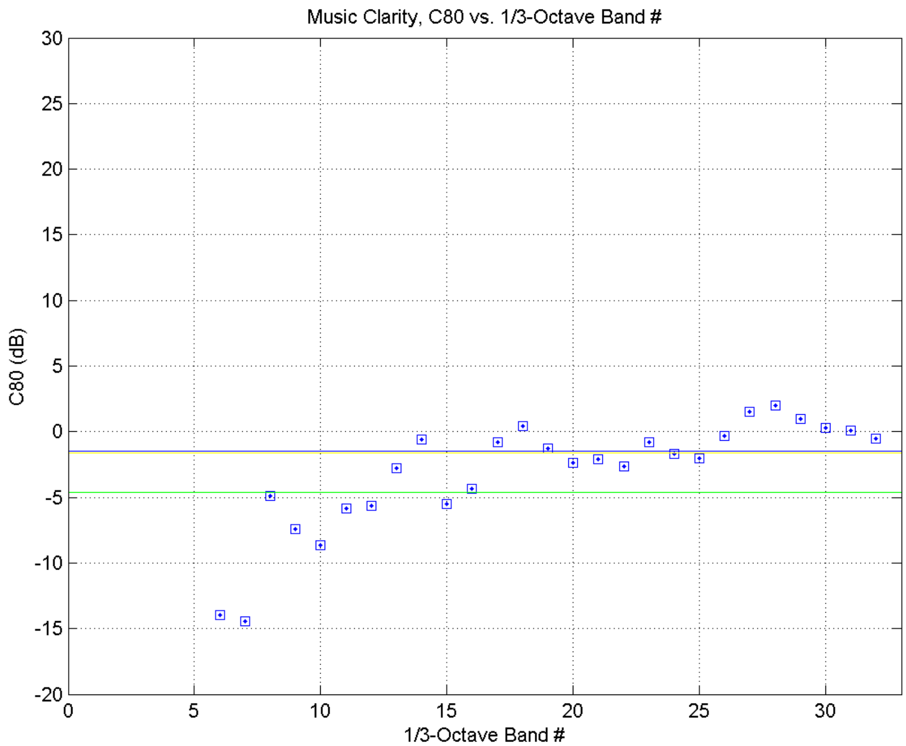


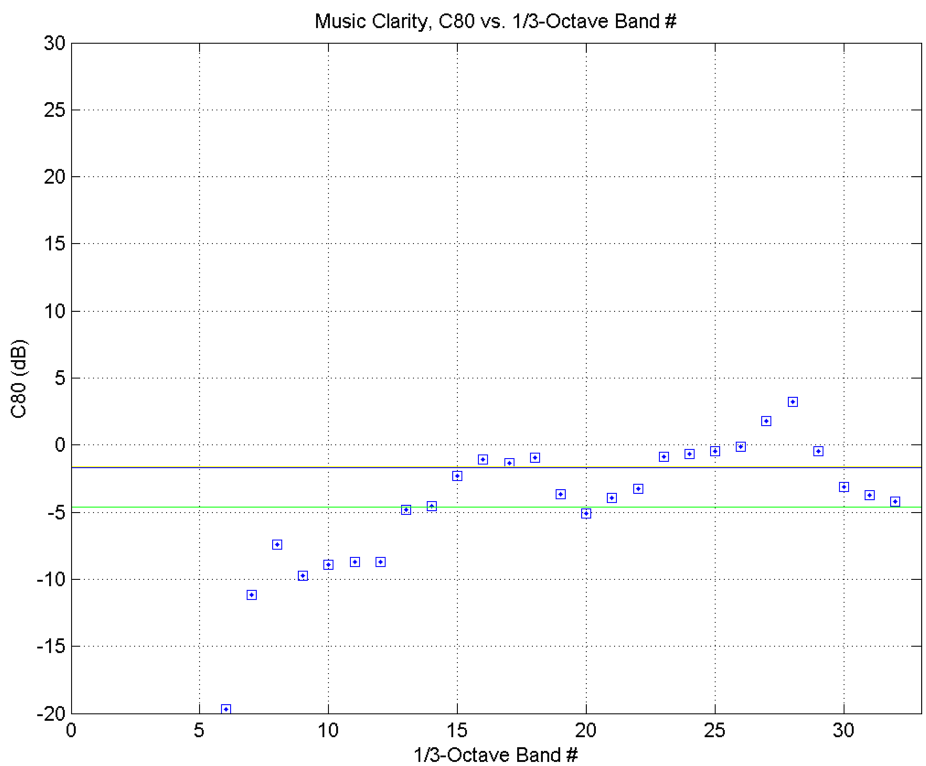
Similar to the T_{60} graphs, the blue line is the average D_{50} percentages of the octave bands. The pink line represents the preferred D_{50} percentage of 50%. It is clear that, in both graphs, the average percentage falls well under the required mark.

Next graphs will be for C_{50} and C_{80}.


Speech Clarity, C50 vs. 1/3-Octave Band #
C50 (dB)
1/3-Octave Band #
30
25
20
15
10
5
0
-5
-10
-15
-20
0
5
10
15
20
25
30

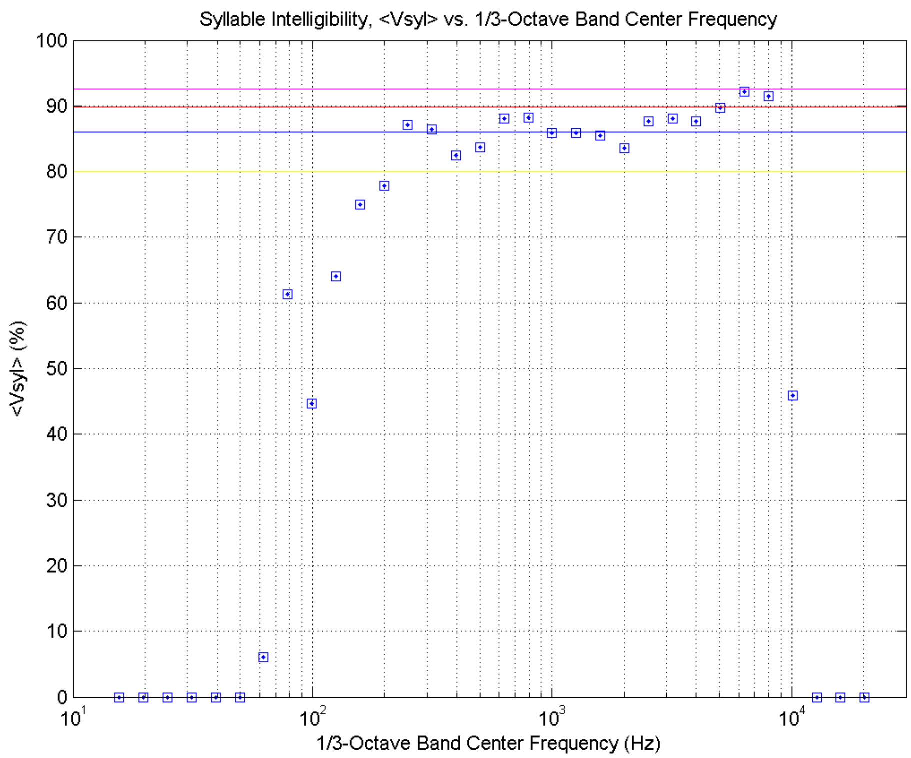

Speech Clarity, C50 vs. 1/3-Octave Band #
C50 (dB)
1/3-Octave Band #
30
25
20
15
10
5
0
-5
-10
-15
-20
0
5
10
15
20
25
30

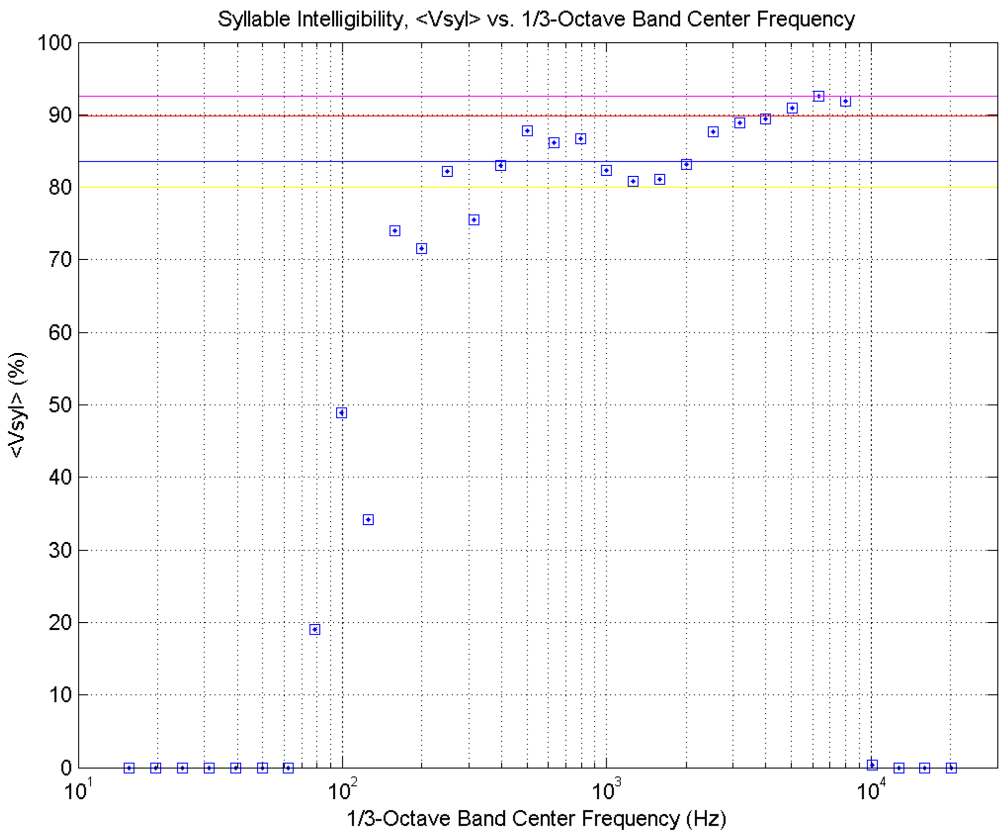

Music Clarity, C80 vs. 1/3-Octave Band #
C80 (dB)
1/3-Octave Band #
30
25
20
15
10
5
0
-5
-10
-15
-20
0
5
10
15
20
25
30


Music Clarity, C80 vs. 1/3-Octave Band #
C80 (dB)
1/3-Octave Band #
30
25
20
15
10
5
0
-5
-10
-15
-20
0
5
10
15
20
25
30

The average C_{50} value between both channels comes out to be about -1.8dB, which is greater than -2dB that the lecture hall must be. The average C_{80} value of the two graphs comes out to be -1.6dB, which is the minimum value a concert hall must have to be acceptable.

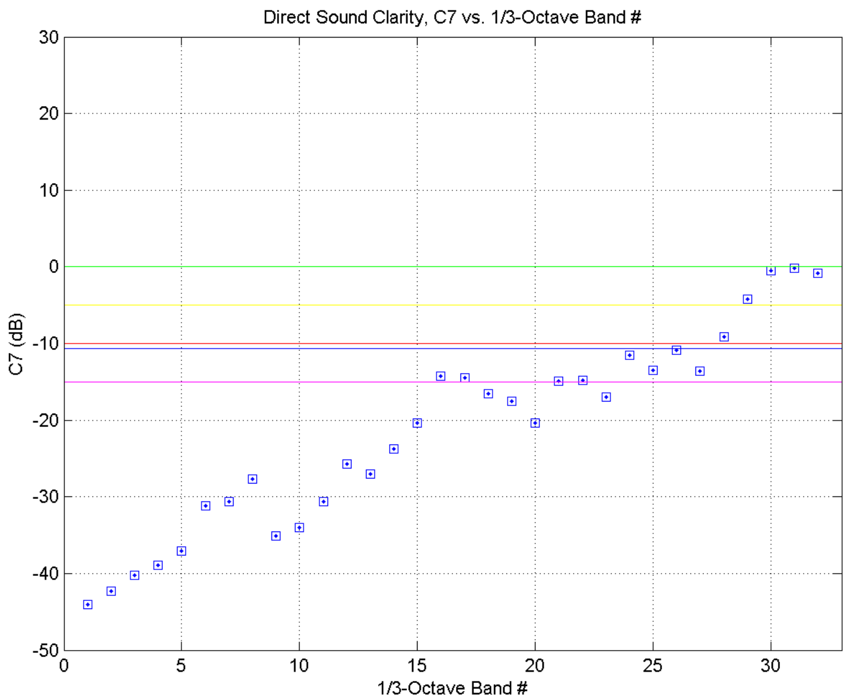
The next graph shows the syllable intelligibility of the octave bands.

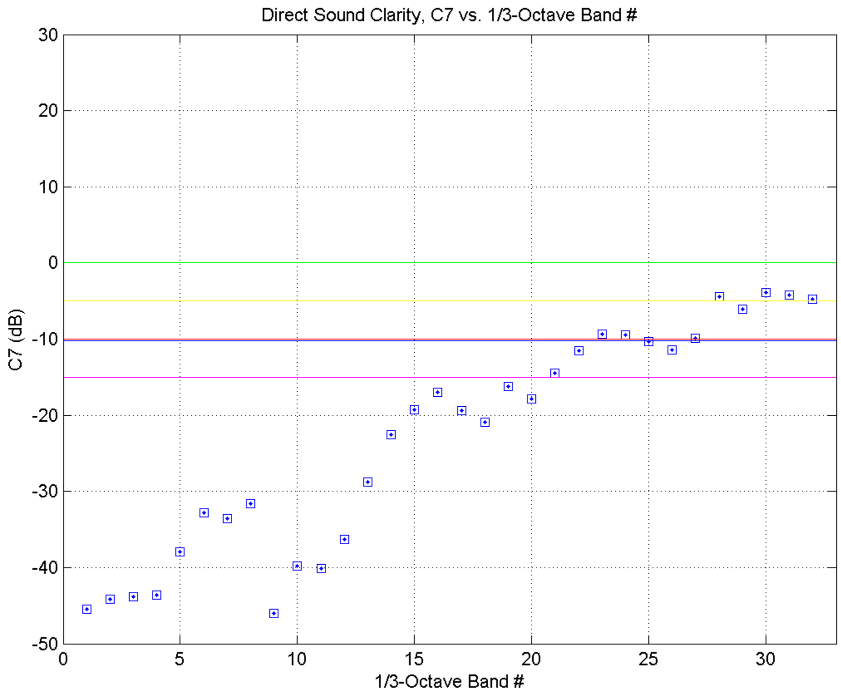




In both graphs, you can see that the average syllable intelligibility is greater than 80%, expressed by the yellow line. Person sitting in this spot will be able to understand the speakers words clearly.

Finally, the last two graphs show the C_7 values.


Direct Sound Clarity, C7 vs. 1/3-Octave Band #
C7 (dB)
1/3-Octave Band #
30
20
10
0
-10
-20
-30
-40
-50
0
5
10
15
20
25
30



The average C_7 values of the two graphs is about -10dB, which is the bare minimum sound clarity for a good auditorium.

The chart below summarizes the results from this sound file. Red X means that it has failed that criterion, yellow triangle is right on the boundary of pass/fail, and the green check mark indicates that it has passed that test.

Measurement	Criteria	Result	Pass/Fail
T_{60} for Lecture Hall (Reverberation Time)	<.5 seconds	1.6 seconds	✗
T_{60} for Concert Hall	1.7~2.0 seconds	1.6 seconds	△
D_{50} (Speech Intelligibility)	>50%	41%	✗
C_{50} (Speech Clarity)	>-2dB	-1.8dB	✓
C_{80} (Music Clarity)	>-1.6dB min, >1.6dB good	-1.6dB	△
T_{ctr}, V_{syl} (Center Time, Syllable Intelligibility)	≤130msec , >80%	103msec, 85%	✓
C_7 (Direct Sound Level Clarity)	>-10 ~ -15dB	-10dB	△

The data in the table shows that these seats are on the border between good and bad as both lecture halls and concert halls. Both speech clarity and syllable intelligibility pass the requirements to be good, and while the speech intelligibility did not pass, 41% is relatively higher than the values at other seats. As for concert halls, T_{60} for concert halls, music clarity, and direct sound level clarity are all on the border between good and bad.

5. Results from Seats Q3L/Q3R

The following table shows the results from analyzing the sounds from seats Q3L and Q3R, middle of the floor seats in the back under the balcony.

Measurement	Criteria	Result	Pass/Fail
T_{60} for Lecture Hall (Reverberation Time)	<.5 seconds	1.7 seconds	✘
T_{60} for Concert Hall	1.7~2.0 seconds	1.7 seconds	△
D_{50} (Speech Intelligibility)	>50%	37%	✘
C_{50} (Speech Clarity)	>-2dB	-2.5dB	✘
C_{80} (Music Clarity)	>-1.6dB min, >1.6dB good	-2.6dB	✘
T_{ctr}, V_{syl} (Center Time, Syllable Intelligibility)	≤130msec , >80%	100msec, 82%	✓
C_7 (Direct Sound Level Clarity)	>-10 ~ -15dB	-12.5dB	△

You could see from this table that this location of the auditorium does not pass the requirements to be considered a good auditorium except for the syllable intelligibility. The

T_{60} is too long for both a concert hall and a lecture hall, speech intelligibility is too low, and both speech and music clarity does not meet the requirements. This could be from the balcony of the auditorium blocking some of the reverberation sounds from reaching the audience, not allowing them to receive all of the sound energy needed for a clear sound reception.

6. Results from Seats E3L/N3L

The following table shows the data obtained from the sound recorded in seats E3L/N3L, the left side (facing the stage) of the auditorium, as the arrow points in the picture above.

Measurement	Criteria	Result	Pass/Fail
T_{60} for Lecture Hall (Reverberation Time)	<.5 seconds	1.8 seconds	✘
T_{60} for Concert Hall	1.7~2.0 seconds	1.8 seconds	✓
D_{50} (Speech Intelligibility)	>50%	38%	✘
C_{50} (Speech Clarity)	>-2dB	-2.2dB	△
C_{80} (Music Clarity)	>-1.6dB min, >1.6dB good	-2.2dB	✘
T_{ctr}, V_{syl} (Center Time, Syllable Intelligibility)	≤130msec , >80%	140msec, 77%	✘
C_7 (Direct Sound Level Clarity)	>-10 ~ -15dB	-11dB	△

While these seats pass the criteria of T_{60} reverberation time for concert halls, it did not pass the requirement for music clarity. The seats did not pass in the requirements for a good lecture hall in the area of reverberation time, speech intelligibility, or syllable intelligibility; syllable intelligibility was especially low compared to other seats.

For seats E3L and N3L, as well as the following E23L and E10R, we assumed that, because of the bilateral symmetry of Foellinger Auditorium, the results would be similar between the left sides of the auditorium as the right side. Data from E3L and N3L should match the data from E3R and N3R, and E23L and E10R should match the data from E23R and E10L.

7. Results from Seats E23L/E10R

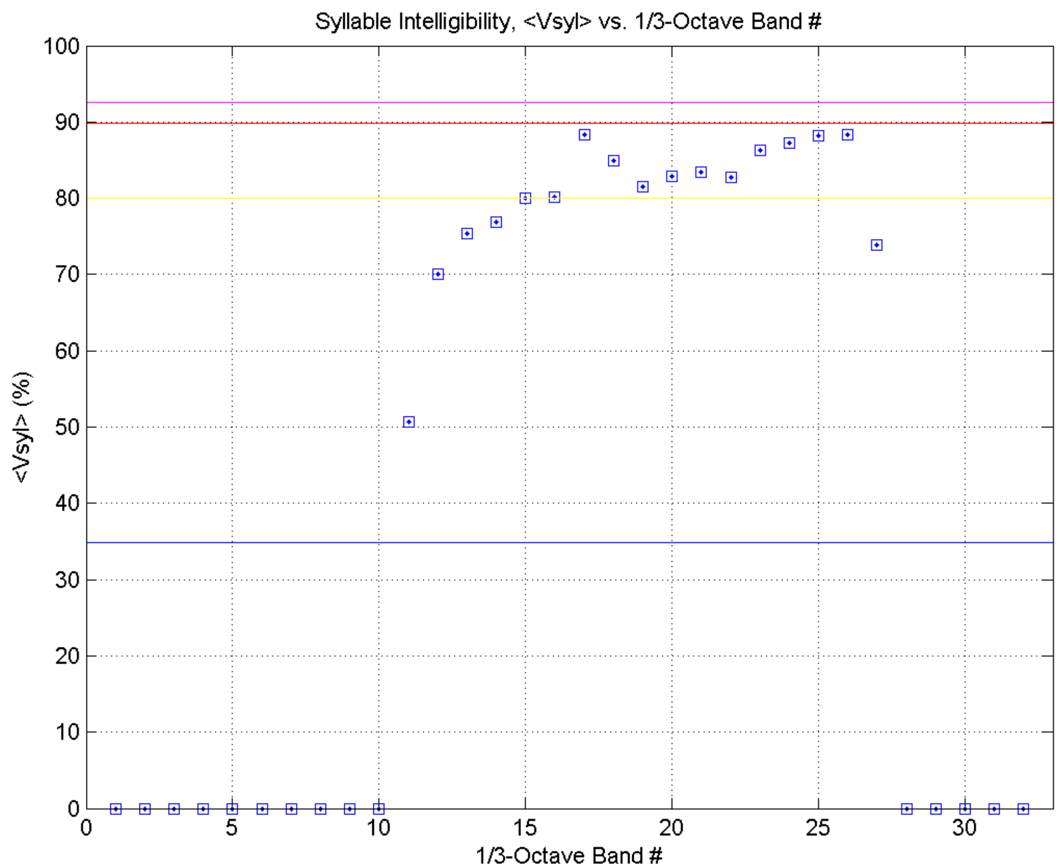
This table shows the results from analyzing the sounds from seats E23L and E10R, the balcony seats on the left side.

Measurement	Criteria	Result	Pass/Fail
T_{60} for Lecture Hall (Reverberation Time)	<.5 seconds	1.65 seconds	✗
T_{60} for Concert Hall	1.7~2.0 seconds	1.65 seconds	△
D_{50} (Speech Intelligibility)	>50%	42%	✗
C_{50} (Speech Clarity)	>-2dB	-1.0dB	✓
C_{80} (Music Clarity)	>-1.6dB min, >1.6dB good	-1.0dB	✓
T_{ctr}, V_{syl} (Center Time, Syllable Intelligibility)	≤130msec , >80%	120msec, 82%	✓
C_7 (Direct Sound Level Clarity)	>-10 ~ -15dB	-11dB	△

Surprisingly, this data shows that the sides of the balcony seats are the best seats in the auditorium. It passed in the criteria of speech and music clarity, and was on the border for direct sound level clarity, which shows that everything will be heard clearly from these seats. The seats passed in syllable intelligibility, and while it did not pass in speech intelligibility, it had the highest value out of all of our data. The T_{60} value was the second lowest of our data, which led us to the conclusion that this would be the best seats in Foellinger, which we found odd that the best seats would be on the sides and not in the middle.

8. Results from Seats E5L/E5R

We analyzed the sound obtained from seats E5L and E5R, the center seats in the balcony. Unfortunately, there was an error, either in the sound file or in the program, which skewed our data. For example, the graph of syllable intelligibility looked like this.



The first 10 1/3-octave bands, as well as the last 5, recorded 0% for the value. While other graphs also had first couple octave bands as 0%, this data had the most and brought down the average syllable intelligibility more than the other graphs. Since we cannot deduce the acoustic properties of this spot from symmetry, the future project must reanalyze the data, or even go back and re-record the sound from this spot.

9. Summary

Finally, this table shows the results from the 4 spots we were able to get good data from.

	Sound 2	Sound 3	Sound 4	Sound 6
T_{60} Lecture Hall	✗	✗	✗	✗
T_{60} Concert Hall	△	△	✓	△
D_{50}	✗	✗	✗	✗
C_{50}	✓	✗	△	✓
C_{80}	△	✗	✗	✓
T_{ctr} , V_{syl}	✓	✓	✗	✓
C_7	△	△	△	△

10. Conclusion

Our main goal was to see if Foellinger Auditorium was a suitable lecture hall and/or music hall. It is immediately clear that the reverberation time, 1.6 seconds, favors a music hall. From our data, we can conclude that this auditorium was built to be a music hall, however it is not a great one. It's reverberation time is close to being ideal for a music hall but only passes the music clarity test about as often as the speech clarity test. With a larger reverberation time, and passing only about half of the lecture hall tests, we can conclude that it is a sub-par lecture hall, and a decent music hall.

Sound reinforcement from speaker systems could solve some, if not all, of the issues seen from the natural sound tests. We took our measurements when the auditorium was practically empty and it would be interesting to do these tests for a full auditorium and compare the results.

Overall, this project was a lot of fun and had some interesting results. A big thanks to Phil Strang for organizing enough time for us in Foellinger to take our measurements. Another huge thanks to Professor Errede for all of his help during this project. Not only did he supply all of the recording equipment, but he was there to help us transport the equipment, record the sounds, and interpret the data from the MATLAB program. It truly was an interesting and fun project, and we are grateful for everyone that was involved.

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