COMPARISON OF THE ACOUSTIC PARAMETERS OF DIFFERENT TYPES OF MULTI-USE AUDITORIUMS

by

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Submitted in partial fulfillment of the

requirements for Departmental Honors in

the Department of Engineering

Texas Christian University

Fort Worth, Texas

May 2, 2022

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MULTI-USE AUDITORIUMS

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ABSTRACT

Desired acoustic qualities for auditoriums are dependent on the type of performance that will be housed. In the case of multi-use spaces, acoustic adjustments in the space can be made to ensure the auditorium can accommodate all types of performances. One local high school in particular has received complaints stating that it is difficult to hear past a certain point in their auditorium. Comparisons of acoustic characteristics of three local high school auditoriums in the Dallas-Fort Worth, Texas area, were conducted to quantify perceived quality deficiencies. Each high school auditorium houses a range of different musical and theatrical performances, ranging in size and acoustical qualities. A quantitative analysis using a dodecahedron speaker was performed to gather information on the bass ratio, early decay time, initial time delay gap, clarity, and reverberation time. Background noise levels (noise criteria/room criteria, NC/RC) were also measured from the building mechanical systems. The quantitative data for each auditorium are compared and recommendations are made.

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Introduction

There have been complaints concerning the Creekview High School auditorium which state that it is difficult to hear anything past the cross-aisle, which is the area between the lower and upper seating level. Two similar high school auditoriums within the same district were compared to determine what differences exist between the three auditoriums, and to provide acoustical recommendations for Creekview High School Auditorium.

Analysis of Literature

There are defined acoustical requirements for various spaces including choral, instrumental, orchestral, musical theatre performances, and general speech use spaces. However, spaces that house all types of performances, hereinafter referred to as multi-use spaces, require a compromise of acoustic parameters acceptable to all users. Each acoustic parameter contributes to an understanding of the space's acoustic utility.

Acoustic Parameter Definitions

Clarity

Clarity is the "the ability to hear [speech or] musical detail" (Barron et al., 2010, p. 43) and describes the balances between the direct sound in a hall and the reverberant sound. Two specific measures of clarity are measured in this research, C50 and C80. The first measure, C50, is clarity in speech. The sound energy within 50 milliseconds [ms] includes the direct sound in a hall and early reflections, while the energy after is considered reverberant sound. The second measure, C80, is clarity in music. Like C50, the sound energy within 80 ms includes the direct sound in a hall and early reflections, while the energy after is considered reverberant sound. A negative clarity value indicates the hall being measured has more reverberant energy than direct sound energy. According to ISO (ISO, 2009), any clarity value higher than +1 dB or lower than -1 dB is noticeable by the listeners ear; however, typical clarity values range from -5 to +5 dB. Ideally, no noticeable difference in sound is desired between two areas in an auditorium, therefore clarity values are expected to be within +/- 1 dB.

Reverberation Time

Reverberation time (RT_{30}) is a measure of the length of time required for average sound/noise in an enclosed space to be reduced by 30 dB after the sound source is stopped (i.e., no longer generating any sound) relative to the location of the receiver position, meaning each receiver position would have a separate reverberation measurement which is then averaged (ISO, 2009). Reverberation time is calculated primarily using either the Sabine or Eyring equations, equation (1) and (3), respectively. The Sabine equation assumes that surfaces are impacted by a traveling sound wave on the boundary surfaces sequentially, while the Eyring equation assumes that all surfaces are impacted by the traveling sound wave at the same time, and that "successive simultaneous impacts, each diminished by the average room absorption coefficient, are separated by mean free paths," (Carvalho, 1995). The Eyring equation provides better results than the Sabine equation when predicting reverberation time when the "effect of coupled spaces is not considered," (Carvalho, 1995) where a coupled space is defined as a space with a main volume connected through multiple openings to a second area with a smaller volume.

Sabines Formula for Reverberation Time:

$$\text{Reverberation time (seconds)} = \frac{0.16V}{A} \text{ (ISO, 2009)}, \quad (1)$$

in which *V* is the air volume of the room of interest in cubic meters (m^3), and *A* is the total acoustic absorption in the space in squared meters (m^2), calculated using equation (2).

$$A = \Sigma S\alpha = S_1\alpha_1 + S_2\alpha_2 + \cdots + S_n\alpha_n \text{ (ISO, 2009)}, \quad (2)$$

in which *S* is the area of the specified region in squared meters (m^2), α is a dimensionless absorption coefficient of the specified region, and *n* is the number of regions in the room of interest that have sound absorption properties.

Eyring equation for Reverberation Time:

$$\text{Reverberation time (seconds)} = \frac{0.16V}{[A_{air} - S_T \log_n(1-\alpha_{avg})]} \text{ (Carvalho, 1995)}, \quad (3)$$

in which *V* is the air volume of the room of interest in cubic meters (m^3), A_{air} is the air absorption in the space in squared meters (m^2), S_T is the total area of the surfaces in squared meters (m^2), α_{avg} is the average absorption coefficient for all surfaces in the room of interest.

Reverberation time requirements for a particular space are different depending on the primary use of the space, for example, single group use, or multi-use spaces. The following table shows the recommended reverberation times for single-use spaces.

Table 1: Recommended occupied reverberation times in seconds by Barron [1]

Organ music	> 2.5
Romantic classical music	1.8 – 2.2
Early classical music	1.6 – 1.8
Opera	1.3 – 1.8
Chamber music	1.4 – 1.7
Drama theatre	0.7 – 1.0

Reverberation time is a primary parameter analyzed when determining the intelligibility of sound in a particular space. A longer reverberation time associated with echoed sounds, meaning the sounds are repeated as sound waves bounce off hard surfaces, henceforth called an acoustically live room. The sounds in an acoustically live room can be “rendered inaudible (i.e., masked) by an earlier louder sound,” (Barron et al., 2010, p. 18) leading to a lack of definition in speech, therefore making longer reverberation times more suitable for instrumental type of performance groups. A shorter reverberation time is associated with dampened sounds, meaning the sound is not allowed to ring, henceforth called an acoustically dead room. The sounds in an acoustically dead room are “too stark, like listening [to the sound] in the open air,” (Barron et al., 2010, p. 18) therefore making shorter reverberation times more suitable for musical theatre performances and general speech.

Multi-use spaces used for various types of performances, such as grand concert halls, educational auditoriums, and outdoor performance spaces require a compromised reverberation time for all types of performances. Accommodating multiple types of performances often requires a change in reverberation time, as expected from Table 1. These spaces often control reverberation time using additional hardware. The simplest approach to changing the reverberation time in a space introduces sound absorbing materials. Two methods exist to change the reverberation time in a space: an acoustical curtain which could be deployed, or shutter system, such as a “moveable panel/partition … to vary the floor area and with it the seating capacity” (Barron et al., 2010, p. 386). However, introducing sound absorption will also reduce sound level, which may or may not be desired.

Early Decay Time

Early decay time (EDT) measures the rate of sound decay relative to the location of the receiver, similar to reverberation time, but only for the first 10 dB decay of the traveling sound wave. In diffuse spaces, spaces where sound can travel over a large area, the reverberation time and early decay time gap should be identical.

Research Design and Methods

Eight total measurements were performed in each auditorium, consisting of two separate locations for sound source, receiver location, and measurement type. All three multipurpose auditoriums were measured using a dodecahedron loudspeaker as the sound source augmented with a JBL speaker as a subwoofer. The sound speaker was placed either at the front of the stagehouse, or center of the stagehouse. For each hall, two receiver locations were chosen within the main seating areas.

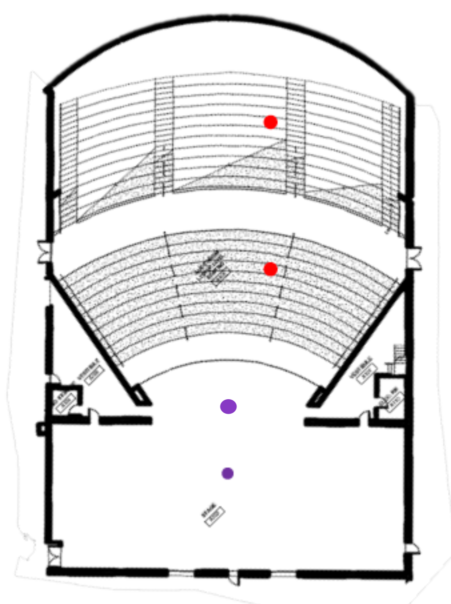


Figure 1: Creekview High School Auditorium: Source and Receiver Locations

The uppermost purple dot in Figure 1 represents the sound source located at the first location, which is at the front of the stagehouse, while the lowermost purple dot represents the sound source located at the second location, the center of the stage house. The lowermost red dot represents the first receiver location placed in the first audience area, before the cross-aisle. The uppermost red dot represents the second receiver location placed in the second audience area, after the cross-aisle. The two other schools had similar receiver locations.

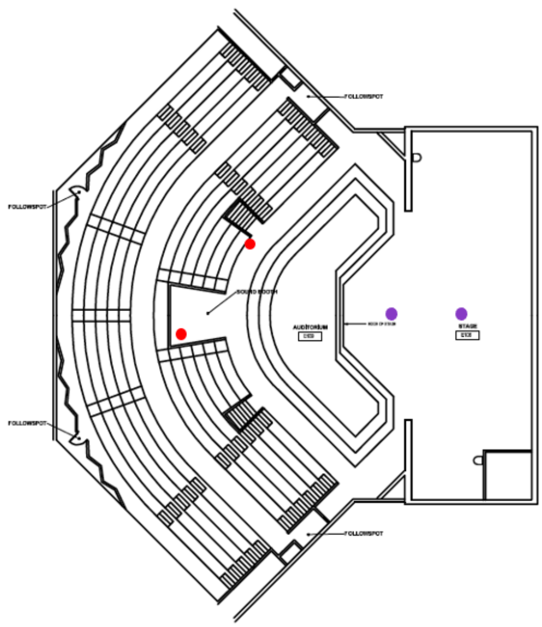


Figure 2: Newman Smith High School Auditorium: Source and Receiver Locations

In Figure 2, the leftmost purple dot represents the sound source located at the first source location, the front of the stagehouse, while the rightmost purple dot represents the sound source located at the second source location, the center of the stagehouse. The leftmost red dot represents the second receiver location, placed within the sound booth of the auditorium, while the rightmost red dot represents the first receiver location, placed within the cross-aisle of the space.

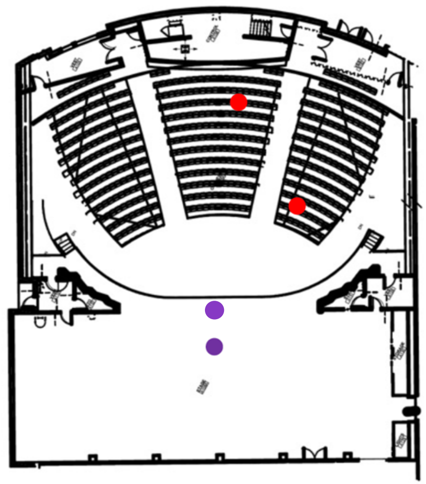


Figure 3: Ranchview High School Auditorium: Source and Receiver Locations

In Figure 3, the uppermost purple dot represents the sound source located at the first location, which is at the front of the stagehouse, while the lowermost purple dot represents the sound source located at the second location, the center of the stage house. The second source location should ideally be placed closer to the center of the stagehouse; however, there was not an electrical outlet close enough for the sound source to be placed more centrally. The lowermost red dot represents the first receiver location placed forward in the right audience area, while the uppermost red dot represents the second receiver location placed rearward in the middle audience area.

There were two measurement types used at each location, the first measurement being interrupted pink noise, and the second, sinusoidal frequency sweeps. The measurements were:

1. M01S01R01
2. M01S01R02
3. M01S02R01

4. M01S02R02
5. M02S01R01
6. M02S01R02
7. M02S02R01
8. M02S02R02

in which Mnn stands for measurement type, Snn stands for speaker location, and Rnn stands for receiver location.

The acoustic parameters were calculated using Fast Fourier Transforms (FFT) of the EASERA software. Mid-frequency, 500 Hz, parameters were measured in octave bands.

The M02 measurement types will not be used as a result of an issue that occurred with noise cancelling calculations at 500 Hz.

Table 2: Descriptive characteristics of the measured concert halls

Concert Hall	Volume $[m^3]$	Seats $[m^2]$
(1) Creekview High School Auditorium	18,640	165
(2) Newman Smith High School Auditorium	8,550	130
(3) Ranchview High School Auditorium	4,640	235

Table 2 shows the volume and seating area (absorption) of the three high school auditoriums as estimated from drawings using the measuring tool on Bluebeam Revu PDF software (Version 20.2.70; Bluebeam).

Findings

Creekview High School Auditorium

Creekview High School Auditorium was designed for a wide range of purposes including musical concerts, theatre performances, and any assembly needed. The measurements were performed without any curtains drawn. Unfortunately, some of the data that was recorded at this school is not useful because the room was partially occupied at the time.

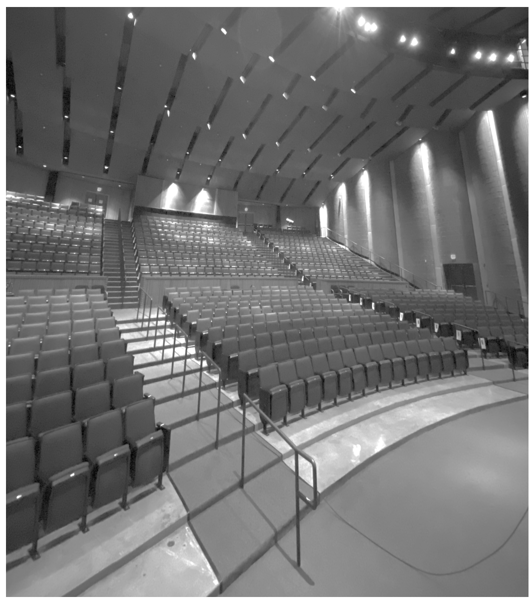


Figure 4. Creekview High School Auditorium

Additionally, the auditorium has a naturally short reverberation time because there is a tectum roof deck above the finished ceiling clouds, which creates an acoustically absorptive plenum above the clouds. The auditorium also has a steep parterre, or seating area.

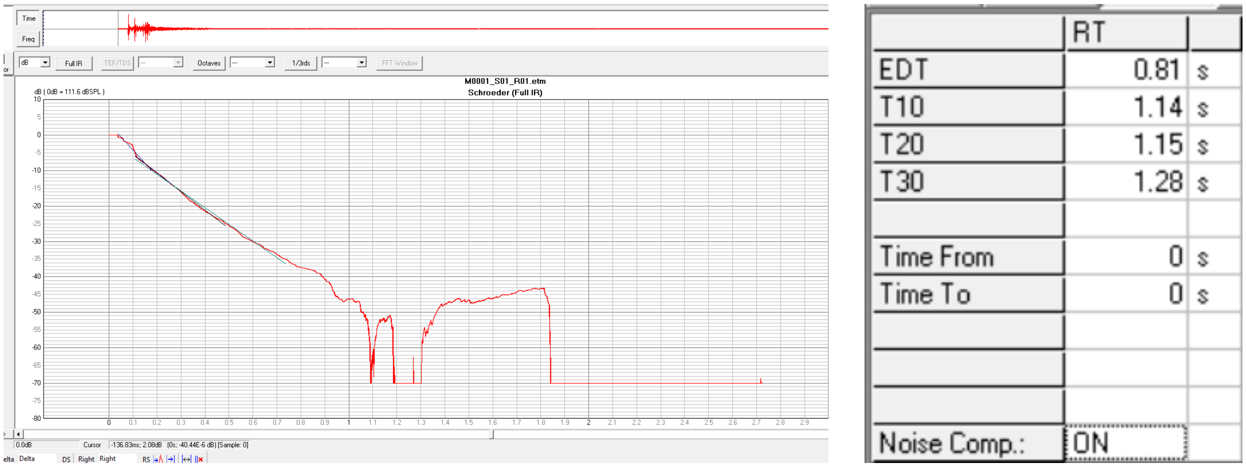


Figure 5. Example Reverberation Time Measurements from Schroeder Curves for Creekview High School Auditorium

The Schroeder Curve, shown on the left of Figure 5, depicts the backward integration from impulse response measurements to obtain a decay curve for finding reverberation and early decay times. The horizontal axis depicts time in seconds, and the vertical axis depicts sound intensity in decibels.

Table 3: Creekview High School Auditorium Acoustic Parameters

Measurements	Reverberation Time, RT_{30} [s]	Early Decay Time, EDT [s]	Clarity, C50 and C80 [dB]
(1) M01S01R01	1.28	0.81	C_{50} = -0.8 dB C_{80} = 1.8 dB
(2) M01S01R02	1.29	0.97	C_{50} = 0.6 dB C_{80} = 2.1 dB
(3) M01S02R01	1.41	1.27	C_{50} = -1.1 dB C_{80} = 1.9 dB
(4) M01S02R02	1.48	0.98	C_{50} = -1.1 dB C_{80} = 4.2 dB

The reverberation time and early decay times were averaged for all measurements. The average reverberation time measured is 1.37 s, the average EDT measured is 1.01 s.

Newman Smith High School Auditorium

Similarly, Newman Smith High School was designed for a wide range of purposes. The measurements were performed without any curtains drawn. This auditorium was unfortunately also partially occupied.

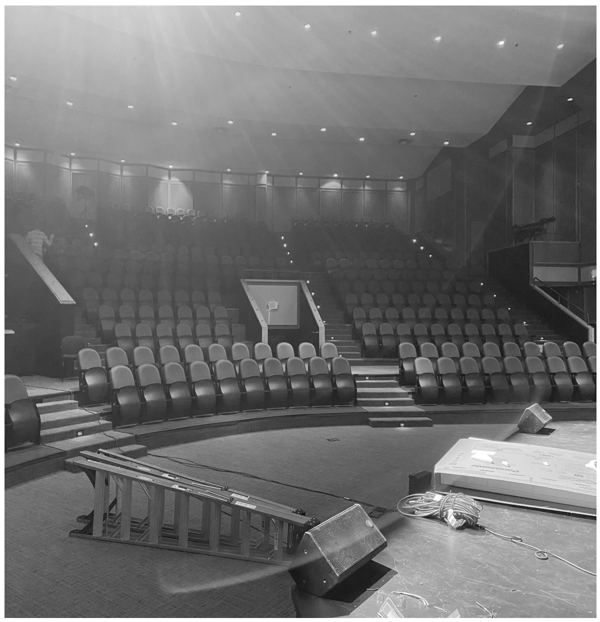


Figure 6. Newman Smith High School Auditorium

Figure 7. Example Reverberation Time Measurements from Schroeder Curves for Newman Smith High School Auditorium

The Schroeder Curve, shown on the left of Figure 7, depicts the backward integration from impulse response measurements to obtain a decay curve for finding reverberation and early decay times. The horizontal axis depicts time in seconds, and the vertical axis depicts sound intensity in decibels.

Table 4: Newman Smith High School Auditorium Acoustic Parameters

Measurements	Reverberation Time, RT_{30} [s]	Early Decay Time, EDT [s]	Clarity, C50 and C80 [dB]
(1) M01S01R01	2.17	1.67	C_{50} = -1.4 dB C_{80} = 0.6 dB
(2) M01S01R02	2.39	1.65	C_{50} = 1.2 dB C_{80} = 3.6 dB
(3) M01S02R01	1.67	1.19	C_{50} = -1.5 dB C_{80} = 0.2 dB
(4) M01S02R02	1.58	1.17	C_{50} = -1.1 dB C_{80} = 1.7 dB

The reverberation time and early decay times were averaged for all measurements. The average reverberation time measured is 1.95 s, the average EDT measured is 1.42 s.

Ranchview High School Auditorium

Ranchview High School was also similarly designed for a wide range of purposes. The measurements were performed without any curtains drawn. This auditorium was unoccupied.

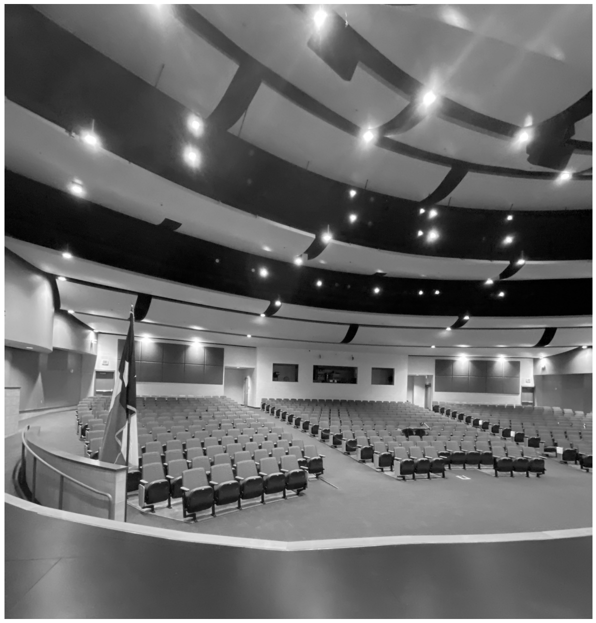
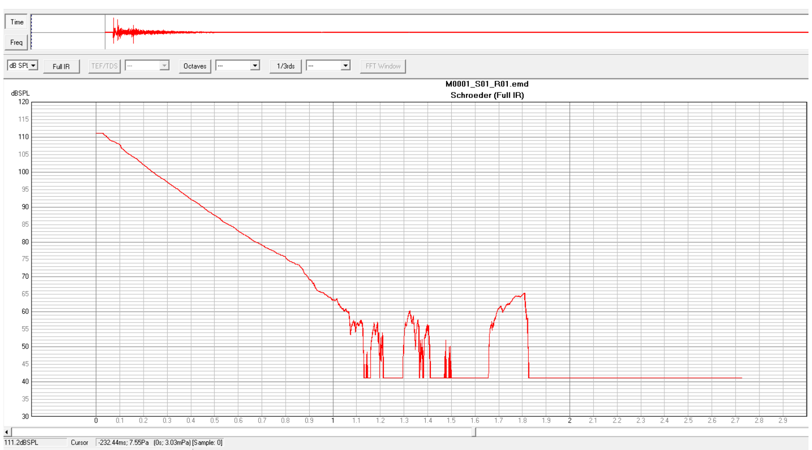


Figure 8. Ranchview High School Auditorium



	RT	
EDT	1.16	s
T10	1.19	s
T20	1.24	s
T30	1.31	s
Time From	0	s
Time To	0	s
Noise Comp.:	ON	

Figure 9. Example Reverberation Time Measurements from Schroeder Curves for Ranchview High School Auditorium

The Schroeder Curve, shown on the left of Figure 9, depicts the backward integration from impulse response measurements to obtain a decay curve for finding reverberation and early decay times. The horizontal axis depicts time in seconds, and the vertical axis depicts sound intensity in decibels.

Table 5: Ranchview High School Auditorium Acoustic Parameters

Measurements	Reverberation Time, RT_{30} [s]	Early Decay Time, EDT [s]	Clarity, C50 and C80 [dB]
(1) M01S01R01	1.31	1.16	C_{50} = 1.3 dB C_{80} = 3.8 dB
(2) M01S01R02	1.30	0.94	C_{50} = -3.1 dB C_{80} = 2.3 dB
(3) M01S02R01	1.29	1.15	C_{50} = 0.4 dB C_{80} = 3.1 dB
(4) M01S02R02	1.29	1.10	C_{50} = -0.1 dB C_{80} = 3.2 dB

The reverberation time and early decay times were averaged for all measurements. The average reverberation time measured is 1.30 s, the average EDT measured is 1.09 s.

Table 6 is a comparison between the three high school auditoriums. To address the main concern at Creekview High School, the two receiver locations were also compared for the interrupted pink noise measurement between the three high schools with the speaker placed centrally in the stagehouse.

Table 6: All High Schools Auditorium Acoustic Parameters for Comparison

Measurements	Creekview HS Aud.	Newman Smith HS Aud.	Ranchview HS Aud.
RT_{30} [s]	1.37	1.95	1.30 s
EDT [s]	1.01	1.42	1.09 s
M01S02R01	C_{50} = -1.1 dB C_{80} = 1.9 dB	C_{50} = -1.5 dB C_{80} = 0.2 dB	C_{50} = 0.4 dB C_{80} = 3.1 dB
M01S02R02	C_{50} = -1.1 dB C_{80} = 4.2 dB	C_{50} = -1.1 dB C_{80} = 1.7 dB	C_{50} = -0.1 dB C_{80} = 3.2 dB

Conclusions and Recommendations

Reverberation times were around 1.3 s for Creekview High School Auditorium and Ranchview High School Auditorium, which is a good compromise value for both band and musical theatre performances, as can be seen from Table 1. However, choir and orchestra require a longer reverberation time. The reverberation time at Newman Smith High School Auditorium was found to be approximately 2 s, which is a good compromise value for band, choir, and orchestra, but may not be the best value for musical theatre performances, as seen in Table 1.

There is a near, just noticeable difference value (within +/- 1 dB), which will be considered within optimum values, for C80 at Creekview High School Auditorium at the first receiver location, and a high positive value for C80 at the second receiver location. A high clarity value corresponds to a high amount of direct sound and a lack of reverberant sound. As a result of the space having a low reverberation time and a steep parterre, the sound wave does not travel well throughout the room, resulting in a loss of sound past the cross-aisle. Additionally, the values for clarity correspond to normal C50 levels at both receiver locations in the auditorium. The clarity for Newman Smith High School Auditorium at both receiver locations for both C50 and C80 are both near the just noticeable difference values for clarity and will therefore be considered within the optimum clarity levels. Similar to Creekview High School Auditorium, Ranchview High School Auditorium has optimum C50 clarity levels at both receiver locations and high, positive C80 values at both receiver locations. Since both C80 values are similar at both receiver locations, there is little difference between clarity in the space as the sound wave travels further throughout the room.

To compensate for the lack of reverberation in Creekview High School and the reverberation time of 1.3 s, an acoustic enhancement system should be added to the audience area to artificially increase the reverberation time for choral and orchestral performances. This system would include loudspeakers mounted throughout the audience chamber ceiling and on the side and rear walls, and microphones over the front third of the audience seating. Additionally, electronic reverberation, an artificial reverberation created using digital algorithms, should be added to the auditorium. No changes are necessary for Newman Smith High School Auditorium nor Ranchview High School Auditorium.

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