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Case Study: Four University Law Lecture Auditoria Renovated for Improved Acoustics

First Author: Sarah B. Knight, E.I.T., of JEAcoustics
1705 West Koenig Lane
Austin, Texas; 78756
Phone: (512) 371-0800 & Fax: (512) 371-0825
E-Mail: Knight.atJEAcoustics.com

Other Authors: Jack B. Evans, P.E., also of JEAcoustics; Info<at>JEAcoustics.com

1.0 ABSTRACT

Four university lecture auditoria built in 1961, renovated in 1980, were due for renovation. The auditoria consisted of tiered levels with fixed tables and hinged seating. Users had complained about the acoustics in the spaces; speech intelligibility of students was particularly poor. While there was an adequate square footage of acoustically absorptive and diffusive surface finishes in the spaces, the acoustical treatments were not placed correctly in the room, and they were not effective. The poor acoustics in the spaces were particularly problematic due to the discussion-style teaching employed by several professors who used the spaces.

JEAcoustics (JEA) was retained to provide acoustical recommendations for the space including: architectural room acoustics, sound isolation and mechanical noise control.

JEA visited the auditoria and conducted observations, performed on-site reverberation decay time (T_{60}) and background noise measurements. Ray Diagram Analysis[5] and Classic Sabine Formula Analysis[4] were also conducted, back in the office. JEA developed mechanical noise control, sound isolation and architectural room acoustics recommendations. Some recommendations were employed; others were not. After one auditorium was remodeled, JEA returned to the site and re-measured the T_{60} and background noise in the renovated space.

The results of the renovation will be discussed in terms of the following: background noise level, T_{60}, and user satisfaction with the space.

2.0 INTRODUCTION

Four university lecture auditoria built in 1961, renovated in 1980, were once again due for renovation. All of the auditoria consisted of tiered levels with fixed tables and hinged seating. Three of the auditoria were identical, ~ 1923 usable square feet, seating 138 students, and one auditorium was smaller, seating 117 students. Users of the spaces had complained about the acoustics in the spaces; speech intelligibility of students was particularly poor[1]. Flutter echoes and slap back reflections made voice sources difficult to locate and intelligibility poor.

While there was adequate acoustically absorptive and diffusive surface finishes in the spaces, the acoustical treatments were not placed correctly in the room. They were not effective, and the space was reverberant. In addition to these problems, there was moderately excessive HVAC noise and intrusive corridor noise. The poor acoustics in the spaces were particularly problematic due to the style of teaching employed. See Figures 1, 2, and 3 below (Floor Plan, Reflected Ceiling Plan, and Section). See Figure 4, a photograph of the un-renovated space.

JEAcoustics (JEA) was retained to develop design criteria and provide acoustical recommendations for the spaces, including sound isolation and architectural room acoustics. JEA visited the site and performed on site measurements and objective observation of the spaces during lectures. Ray diagrams[5] were created to determine the nature of the reflective paths of sound within the space. Classic Sabine Formula[4] Analysis results were compared to the measured T_{60}s in the space. JEA developed recommendations, some of which were implemented by the time JEA returned to the site to perform validation measurements. Two of the spaces were renovated, and two of the spaces remained unchanged. This provided an opportunity to conduct noise and reverberation decay time measurements for comparison of the "before" and "after" renovation conditions.

Observations and baseline measurements, project objectives, design criteria, recommendations, design implementation, results and validation measurements, potential improvements, and conclusions are presented below.

3.0 OBSERVATIONS AND BASELINE MEASUREMENTS

While on site, JEA made the following observations:

- ♦ The front wall, behind the speaker was hard and reflective.
- ♦ The floors were hard, reflective terrazzo.
- ♦ The rear and side walls were a combination of absorptive and diffusive. Wall absorption and reflections were compromised by a large number of framed photographs hung on the walls.
- ♦ The ceiling was highly absorptive in the middle, and the perimeters were slightly less acoustically absorptive.
- ♦ Lecture and response audibility varied with location within the space. The sound quality within the room was very "spotty."
- ♦ Student-to-student communication was poor. It was difficult to distinguish the location of the person speaking due to the reverberant quality within the room, and in many cases the students could not understand one another.
- ♦ Reverberant conditions aggravated distraction due to noise sources within the room. Disturbing noise sources within the space included: laptop computer keyboards, paper shuffling, corridor noise intrusions and transient and impact events.

While on site, JEA collected the following measurements:

- ♦ Reverberation Decay Time (T_{60}): The T_{60} of the Un-Renovated Space indicated that the space was "boomy" (excessive low frequency reverberation decay time) and did not have a smooth frequency response[2].
- ♦ Continuous Background Sound Levels due to HVAC and building systems noise (NC): The background sound level was louder than recommended, in the 250 Hz- 1000 Hz octave bands[2].
- ♦ Sound isolation measurements were made (STC, NR, and NIC): No sound isolation measurements were made.

4.0 DESIGN OBJECTIVES

JEA developed design criteria with the following design objectives in mind:

- ♦ Improve Diffusion
- ♦ Mitigate Poor Reflection Patterns
- ♦ Reduce Reverberation
- ♦ Isolate Exterior Noise
- ♦ Attenuate HVAC Noise

5.0 CRITERIA

Acoustical design criteria were established for amplified and non-amplified speech presentation as the principal function of the auditoria, with tolerances to accommodate pre-recorded tracks as a part of presentations. Design criteria and goals were as follows:

- ♦ Surface Reflections: Surface finishes should be specified to encourage beneficial (reinforcing) reflections (particularly student-to-student) and diminish reflections that negatively affect speech intelligibility in the room. Beneficial (reinforcing) reflections are characterized by short paths and directness from the speaker to the receiver. Negative reflections are characterized by long paths (3rd and 4th reflections) and/ or directness from the speaker back to the speaker ("slap-back" paths). The flutter echoes and corner reflections, in particular, need to be eliminated.

- Reverberation Decay Time: The reverberation decay time, T_{60}, should be approximately 1.0 second in the 500-2000 Hertz octave bands (the speech frequencies). See Figure 5.
- Background Sound Levels: The continuous ambient background sound level from mechanical noise in auditoria should meet the ASHRAE recommended criteria for a classroom or auditorium, NC-30[3].
- Sound Isolation between the lecture auditoria and the corridors: Corridor noise in the auditoria < 5 dB above ambient auditoria level, with short transient disturbance or possible annoyance < 10 dB above ambient (serious reaction expected when intrusive noise is more than 10 dB above ambient). Furthermore, the STC rating of the devising partition between the corridor and the auditoria with the doors included should be STC 55 or greater.

6.0 RECOMMENDATIONS

A. Surface Finish Recommendations

The following recommendations were made for the walls of each space:

- Although the room width is greater than the depth of the space, which is generally not a preferred layout, the sidewalls could be used for some beneficial reflections of natural sound. It was recommended that the front and sidewalls of the lecture auditoria be hard, reflective surfaces (NRC less than 0.50).
- It was recommended that the rear walls and immediately adjacent diagonal corner walls of the lecture auditoria be acoustically absorptive (NRC greater than or equal to 0.75). The existing splays on the rear walls could remain. See Figures 1 and 4. The absorption should be installed on the walls from 30" AFF or 36" AFF (above wainscoting) up to ceiling level, if the perimeter ceiling is reflective. If the perimeter ceiling is absorptive, the rear wall absorption should be from 30" AFF or 36" AFF to door head height. It was recommended that a minimum of 85% of the indicated surface area should be covered.
- It was recommended that some articulation or skewing of sidewalls to make them non-parallel. The intent of this recommendation was to prevent the build up of standing waves between the two parallel surfaces. If the walls are skewed, they should be a minimum of 5 degrees included angle, narrower at front and diverging toward the rear of the auditorium, to direct sound back to the absorption on the rear wall.

The following recommendations were made for the ceiling of each space:

- To improve student-to-student communication and projection of the professor's natural voice throughout the space, it was recommended that the front and center ceiling areas should be diffusive, hard and reflective (CAC greater than 35 and NRC less than 0.50).
- It was recommended that the side and rear ceiling should preferably be acoustically absorptive with a minimum NRC of 0.75. If the side and back walls are acoustically absorptive up to the ceiling the acoustical absorption is not as imperative on the side and rear ceilings.
- JEA recommended sloping the front, side and rear perimeter of the ceiling to assist in orientation of sound paths. See the attached Section and Reflected Ceiling Plan. The center ceiling area should be sloped a minimum of three degrees upwards toward the back of the room to prevent standing wave propagation between the ceiling and floor (and table tops), and to direct sound towards the back of the auditorium. As an alternate to the nominal 3-degree slope towards the rear of the room, the center ceiling area could be sloped up towards the sidewalls to encourage reflection to the sides of the room. Alternately, in lieu of a sloped center ceiling area, a three dimensional, diffuse ceiling could be installed. There are lay-in, diffusive products available from several manufacturers.
- JEA was aware that a uniform ceiling appearance is desired. Also, Sprinkler systems are to be installed in the lecture auditoria when the budget allows, thus the ceiling needs to be on a grid system for easy access to the ceiling plenum space. Both reflective and absorptive ceilings have been recommended in various locations on the reflective ceiling plan. To maintain a uniform appearance of the absorptive and reflective ceiling plans, JEA recommended that they consider wrapping the acoustically reflective tiles in the same fabric (or acoustically transparent finish) as the absorptive ceiling, or that absorptive and reflective ceiling tiles that looked similar be used.

The floors were to remain hard terrazzo, and JEA concurred.

B. Sound Isolation Recommendations

- ♦ JEA recommended that the existing storage spaces between the lecture auditoria be converted to vestibules. As a secondary, less preferred recommendation, JEA recommended erecting an acoustical barrier partition opposite the door with a lower, acoustically absorptive ceiling to block the line of sight between the door and the auditoria.
- ♦ Provide acoustical door seals on the heads, jambs, and astragals. The doors should be solid core wood or insulated metal doors with a minimum 5-lbs/ ft^2 surface weight.
- ♦ The demising partitions are adequate as built; however, ensure that all penetrations of this barrier for electrical wiring or HVAC ducts, etc., are sealed airtight.

C. Ambient Background Level Recommendations

- ♦ For low-frequency fan noise, JEA recommended that either duct silencers be installed in the ductwork or internal duct liner be provided, if permitted by the university.
- ♦ For mid-frequency noise, JEA recommended that the duct airflow velocities be decreased and the duct geometry be improved to decrease turbulence within the ductwork.
- ♦ For high frequency noise, JEA recommended that the duct layouts be improved, that the volume dampers be moved upstream, that insulated flex duct branches be provided, and that quieter diffusers and registers be selected.

7.0 DESIGN IMPLEMENTATION

A. Surface Finish Recommendations

- ♦ Surface finish recommendations were for the most part implemented. The diffusive ceiling elements were added. However, the ceiling was not sloped as recommended. Acoustical absorption was added on the rear walls, above the wainscoting, to the ceiling height. The sidewalls were skewed and acoustical absorption was added to them as well, above the wainscoting. See Figures 6, 7, and 8 below, photographs of the renovated space.

B. Sound Isolation Recommendations

- ♦ At the time the validation measurements were taken, none of the recommendations for sound isolation had been executed, and there are no plans to introduce vestibules or a barrier partition. However, acoustical door seals are planned, as recommended.

C. Ambient Background Level Recommendations

- ♦ The recommendations to improve the background sound levels were not implemented.

8.0 RESULTS AND VALIDATION MEASUREMENTS

- ♦ The users of the space expressed approval of the new space. The students were able to hear the professors and each other better in the new space.
- ♦ The T_{60} was reduced to 0.90 seconds in the speech frequencies and the reverberation decay time chart indicates a smooth (desirable) frequency response in the space. See Figure 9, below.
- ♦ The door seals had not yet been installed at the time that the validation measurements were made, and sound isolation measurements were not performed.
- ♦ The measurements indicate that the background sound level in the renovated space were actually higher than the background sound level in the un-renovated space. This is due to the elimination

9.0 POTENTIAL IMPROVEMENTS

Decrease the background sound levels to ASHRAE recommended levels.

10.0 CONCLUSIONS

In conclusion, the renovation of one of the space was found to be successful, due largely to the elimination of undesirable reflection patterns, the smoothing of the frequency response in the reverberation decay time in the space, and the introduction of beneficial ceiling reflections. JEA has recommended hat the design changes be implemented in the remaining three lecture auditoria.

11.0 ACKNOWLEDGEMENTS

JEAcoustics would like to thank the University of Texas at Austin, School of Law. Special thanks go to Susman Tisdale Gayle (STG) Architects of Austin, Texas (Angela Peterson, Project Manager).

12.0 REFERENCES

Papers:
[1] "Design Program for the University of Texas at Austin School of Law Classroom Renovation," (Susman Tisdale Gale, 2001)
[2] Knight, S.B., "Acoustical Recommendations for UT School of Law Classroom Renovation 2186," (JEAcoustics, 2001)

Books:
[3] *Heating, Ventilating and Air-Conditioning Applications*, American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc., (1999).
[4] Wilson, C.E., *Noise Control*., (Harper and Row Publishers, New York, 1989).
[5] Cavanaugh, W.J. and Wilkes, J.A., *Architectural Acoustics*, (John Wiley & Sons, New York, 1999).

13.0 FIGURES

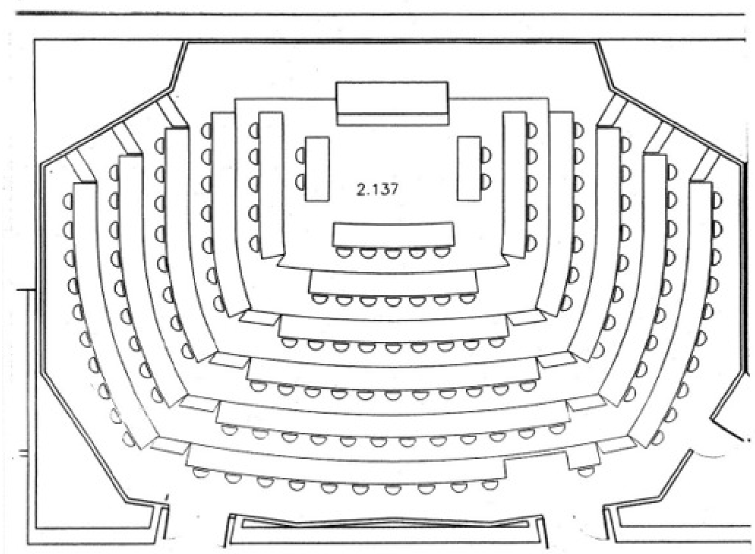

Figure 1: The Floor Plan of the Un-Renovated Space Showing the Furniture Plan

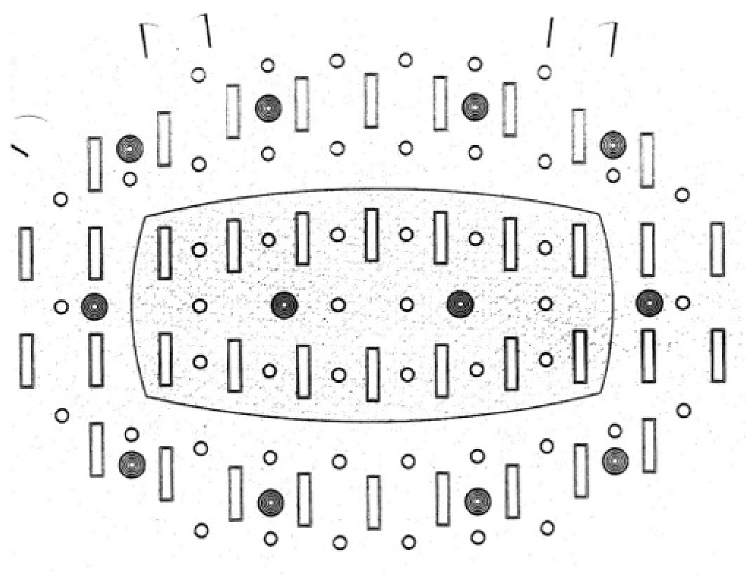

Figure 2: The Reflected Ceiling Plan of the Un-Renovated Space Showing the Furniture Plan

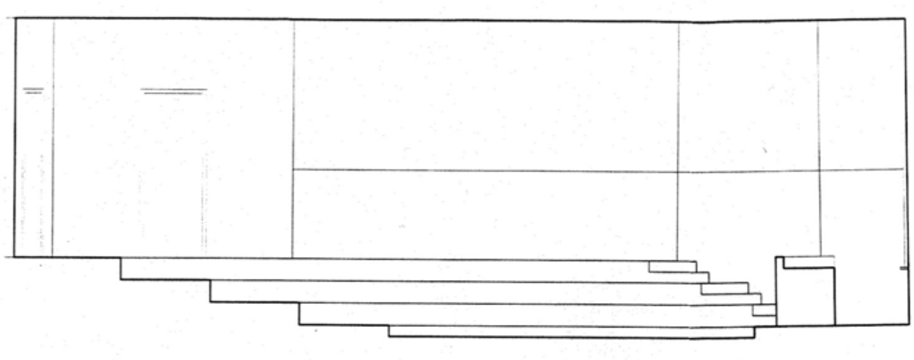

Figure 3: Section of the Un-Renovated Auditoria

Figure 4: Photograph of the Un-Renovated Auditoria, Seating and Sidewall

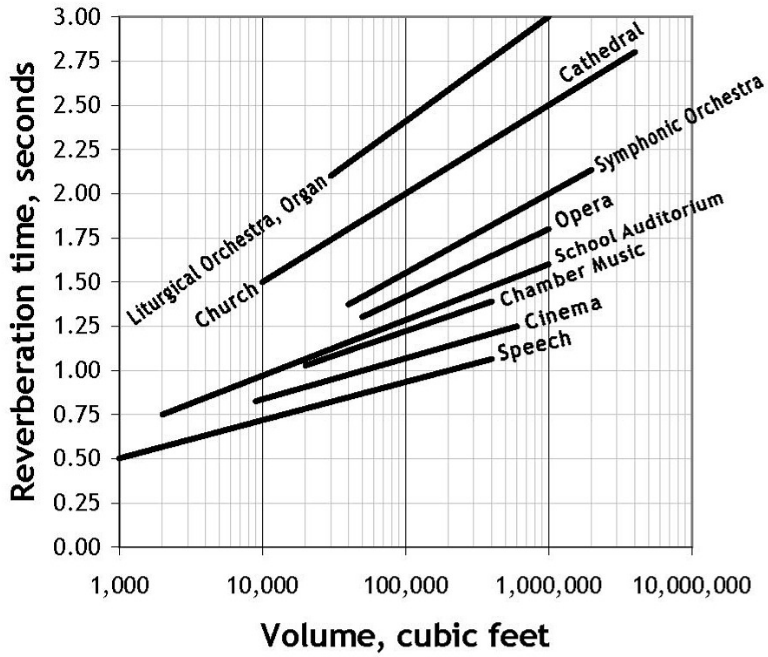

Figure 5: Optimum Reverberation Decay Time Chart


Figure 6: Side view Photograph of Renovated Auditoria


Figure 7: Photograph of Seating, Back and Sidewalls in Renovated Auditoria


Figure 8: Photograph down the Aisle towards Speakers Podium in Renovated Auditoria

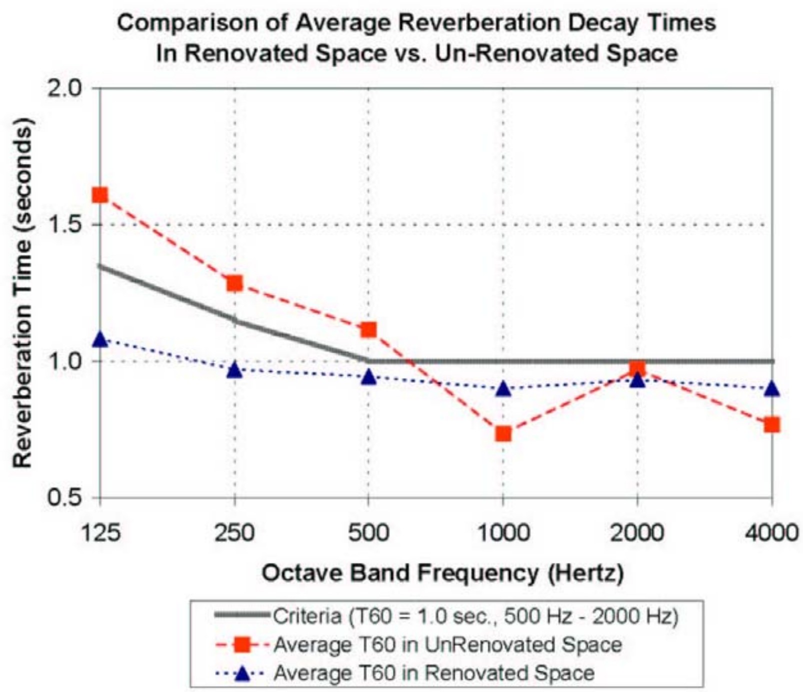

Figure 9: Comparison of Average Background Sound Levels in Renovated Space vs, Un-Renovated Space and Design Criteria

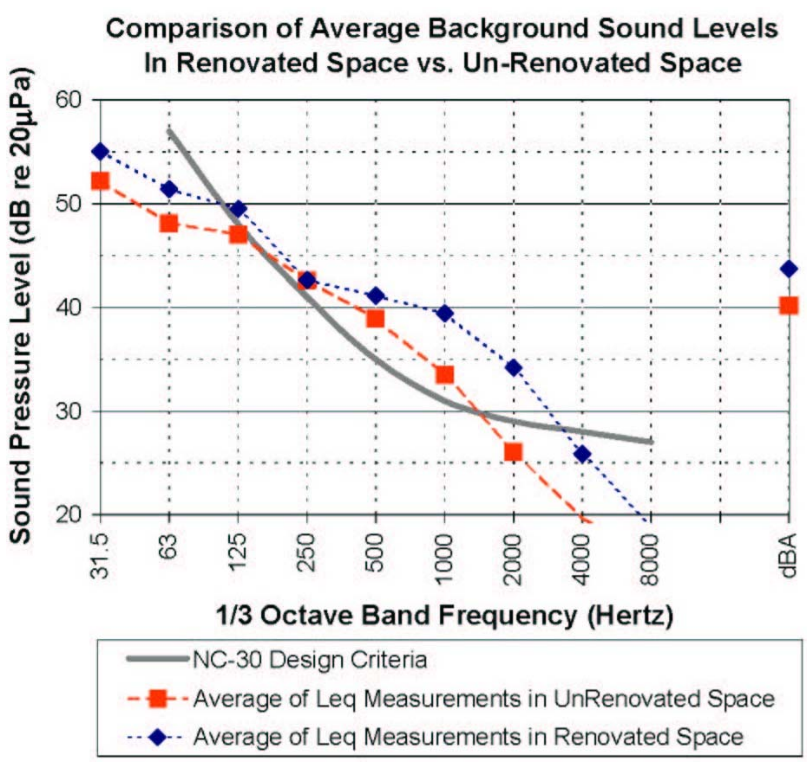

Figure 10: Comparison of Average Background Sound Levels in Renovated Space vs. Un-Renovated Space and Design Criteria