Title

Acoustical Case Study: AIASF Headquarters Lecture Hall

Authors

Salter, Charles

Nash, Anthony

Publication Date

2026

Acoustical Case Study:
AIASF Headquarters Lecture Hall

Authors

Salter, Charles
Nash, Anthony

Project Contributors

Charles M. Salter Associates Inc. (Salter)

Center for the Built Environment (CBE)
University of California, Berkeley

Abstract

This case study summarizes our efforts to optimize speech intelligibility in a medium-sized lecture hall. In addition to describing the acoustical design, we also interpret the results of our acoustical measurements. Speech intelligibility in the hall was assessed both subjectively and objectively using natural as well as amplified speech.

We determined that natural speech could be clearly understood at the rear of the hall (about 50 feet from the speaker) without electronic amplification. Thus, one of our design goals was achieved.

Adding sound-absorbing materials on the ceiling and selected walls reduced the reverberation time to 0.4 seconds, thereby meeting a project design goal. Due to the distributed sound absorption and low background noise level, exceptional speech intelligibility has been achieved in the room.

Key Words

Acoustics, Conference Rooms, Meeting Rooms

Table of Contents

Acoustical Case Study: Lecture Hall

Introduction

Meeting rooms need to be designed so speech is clearly understood within the listening area. LEED[1] has developed requirements to achieve acceptable speech intelligibility[2] in meeting rooms. The acoustical design considerations are reverberation time[3], ventilation system noise, and isolation from noise in adjoining areas.

Our 2023 CBE paper[4] established that a properly designed acoustical environment is critical to achieving acceptable speech communication in small rooms. That study compared predicted reverberation times to measured values and assessed speech intelligibility, both before and after sound-absorptive treatments were added on the ceiling and certain wall surfaces of the room.

That case study was presented at the October 2020 CBE meeting by Felipe Tavera. He promised that a corresponding case study would be conducted at the AIASF Headquarters, which was being designed at the time. The 106-seat lecture hall within the AIASF Headquarters would be the focus of our study.

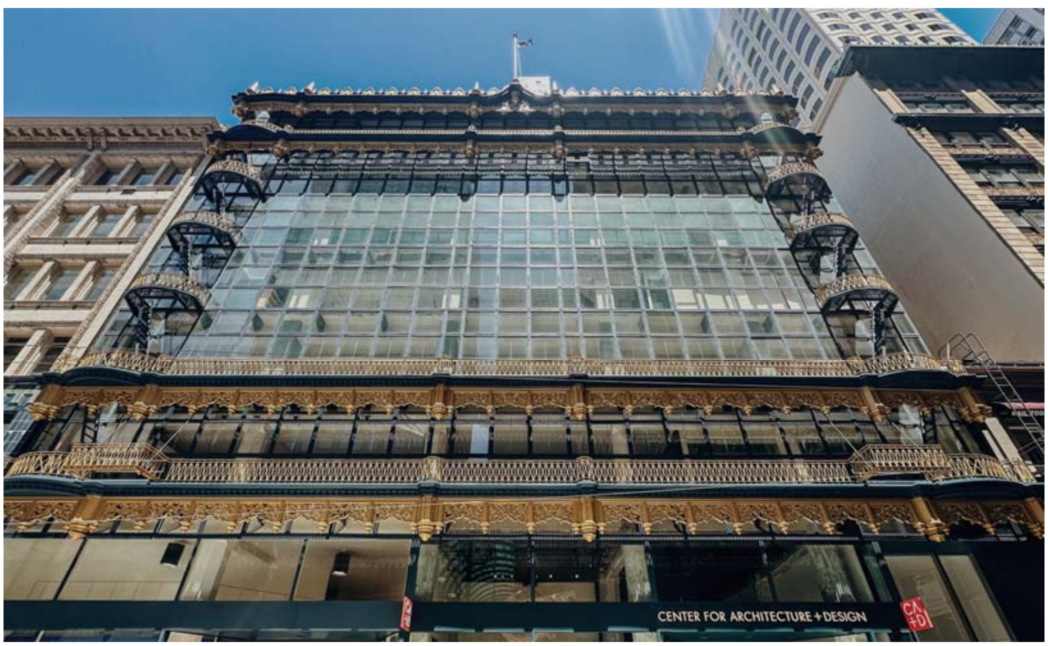

Figure 1: The AIASF Headquarters occupies the ground floor of the Hallidie Building. This 1918 building is on the National Register of Historic Buildings because it was one of the first glass curtain wall buildings. Photo Credit: H. Scott Roth

---

[1] LEED (*Leadership in Energy and Environmental Design*) is a globally recognized green building rating system. Other organizations, including the Acoustical Society of America (ASA) and the American National Standards Institute (ANSI), have prepared similar requirements. The LEED acoustical requirements are summarized in the Appendix.

[2] See Appendix for discussion of speech intelligibility.

[3] See the Appendix for a discussion of reverberation time.

[4] https://escholarship.org/uc/item/6rg5j7hn

Overview

Part I of this acoustical case study presents our analysis and recommendations during the design phase of the lecture hall. Part II summarizes the results of our measurements and assessment.

Achieving excellent speech intelligibility was the focus of our design efforts. The principal acoustical factors were 1) sufficient loudness of the speech signal relative to the background noise, and 2) the interfering "noise" resulting from excessive reverberation. We define excellent speech intelligibility as clear unambiguous speech that is natural sounding. A high degree of speech intelligibility reduces the cognitive effort needed to understand a talker's communication.

Speech signals decrease as distance from the talker increases. Hence, the intelligibility perceived by a listener degrades as the sound level of the speech signal approaches the background noise level (i.e., the speech signal is "masked" by the background noise). In general, speech sound levels should be at least 10 decibels[5] (dB) above the background noise level to achieve satisfactory intelligibility.

Excessive reverberation blurs the consonants in speech. This "blurring" causes a listener to struggle when trying to distinguish between similar-sounding words such as *which* versus *wish*.

Part I: Project Design

Figure 2 shows a partial layout of the AIASF Headquarters.

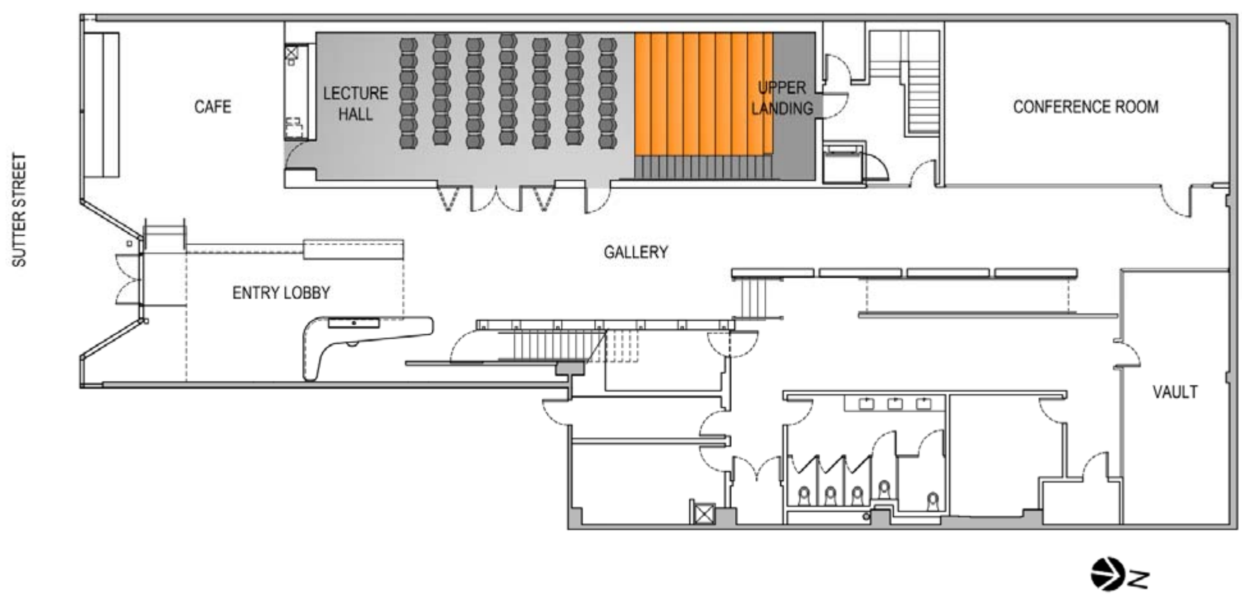

Figure 2: Diagram of AIASF Headquarters

[5] See the Appendix for a definition of the decibel.

Figure 3 depicts the plan and section of the lecture hall. The hall is about 60 feet long, 20 feet wide, and 20 feet high.

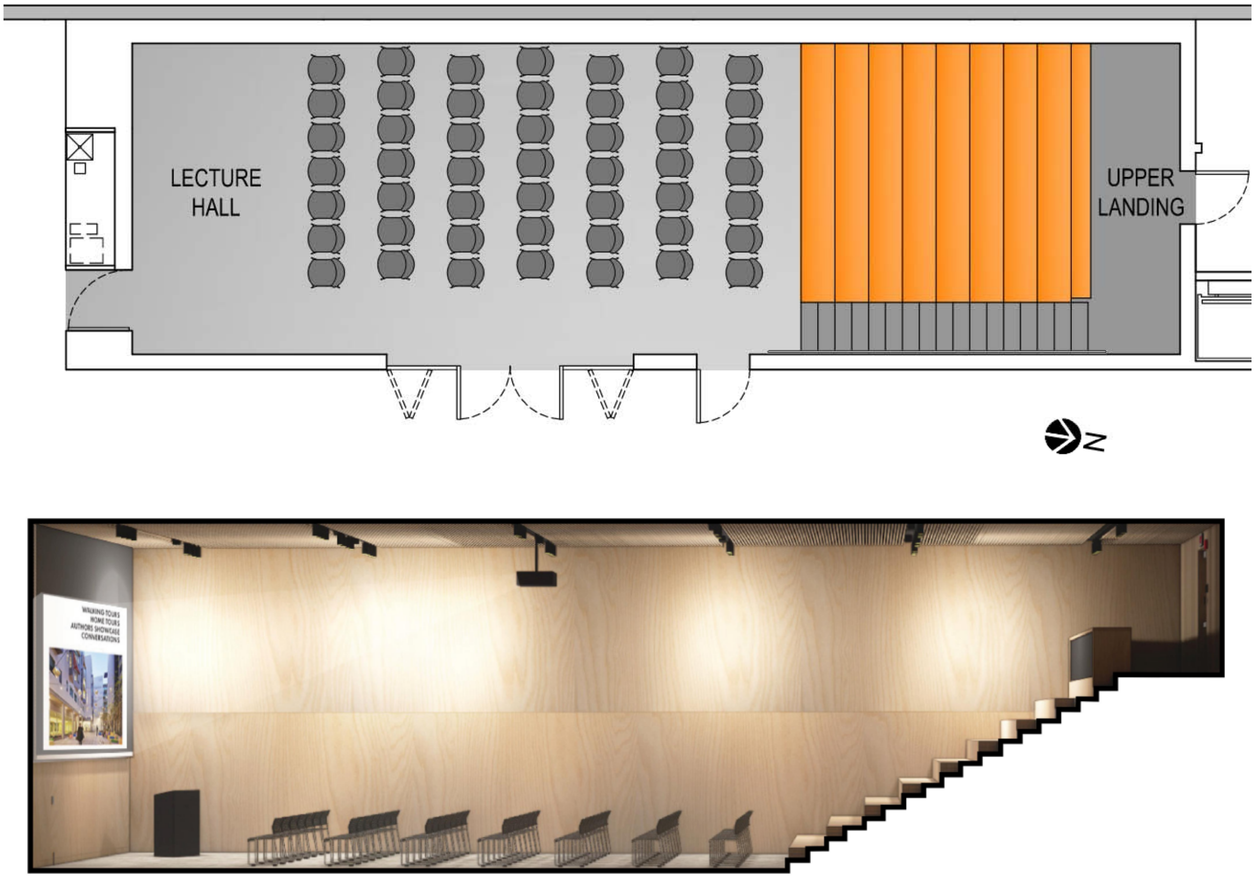

Figure 3: Floor plan (top) and section (bottom) of lecture hall
Bottom Image Credit: Aidlin Darling Design

During design, we worked with the architect, Aidlin Darling Design, to meet the project objectives. The architect stated, "...The design goal was to achieve a unified, intimate room that provides great acoustics without compromising the aesthetics...". Our acoustical design objectives focused on meeting industry standards for a) room acoustics, b) mechanical equipment noise, and c) sound isolation, as discussed below.

In addition, it was decided to include a sound reinforcement system in the room. Its design is described in the Audio System section of this report.

Figure 4: View of lecture hall looking south from the upper landing
Photo Credit: Richard Barnes (edited by Chelsea Hall)

A. Room Acoustics

To reduce reverberation and improve speech intelligibility, certain surfaces were specified to be sound-absorptive. A computer software package called ODEON (https://odeon.dk) was used to construct a mathematical model that enabled the computation of reverberation time. The Sabine[6] formula was also used to predict the reverberation time in conformance with the LEED requirements.

Figure 5 is a rendering of the room with colors representing the sound-absorptive properties of the room surfaces used in the ODEON model. The design details of the acoustical treatment were developed in concert with the architect and Armstrong World Industries, who supplied the materials.

[6] 125 years ago, Wallace Clement Sabine (a physics professor at Harvard University) developed the mathematical relationship between sound absorption and reverberation time. This relationship is known as the Sabine formula (see Appendix).

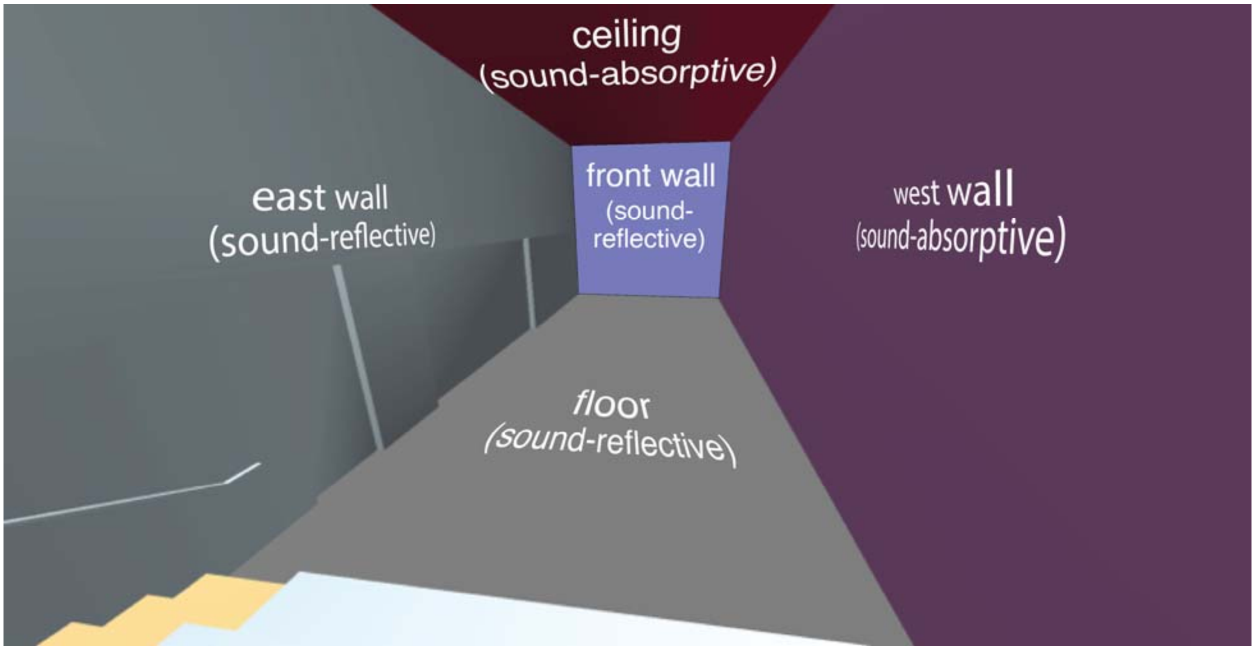

Figure 5: Rendering showing the acoustical treatments used in the ODEON model

The ceiling was made sound-absorptive by using an Armstrong *Woodworks ACGI Grille* which was suspended below ROCKWOOL *AFB evo®* sound-absorptive stone wool batts, as shown in Figure 6.

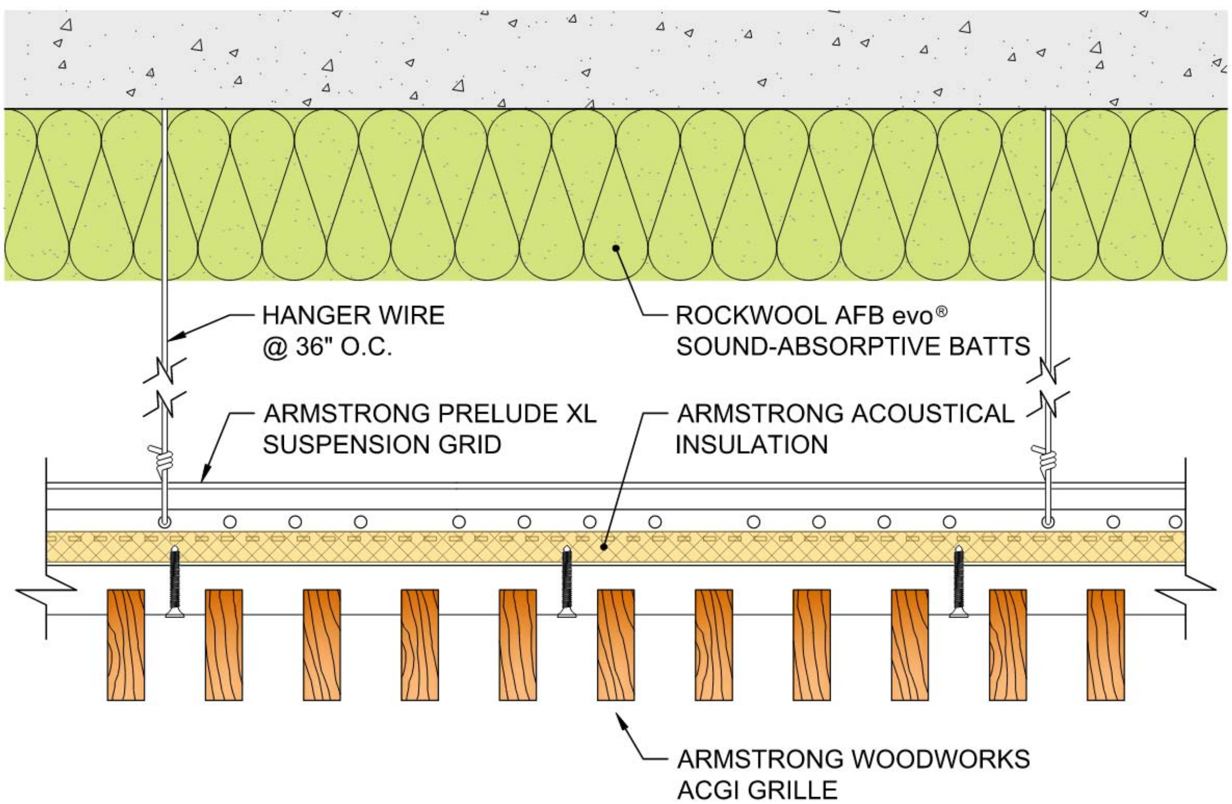

Figure 6: Sound-absorptive ceiling

Figure 7 shows details of the wall treatments as viewed from the front of the lecture hall. The west and north walls were made sound-absorptive using Armstrong's *Woodworks ACGI Encore I* perforated panels installed over sound-absorptive board. The other surfaces of the hall were sound-reflective including: the front (south) wall, the east wall, and the floor. The absorptive surfaces were intentionally placed opposite reflective surfaces.

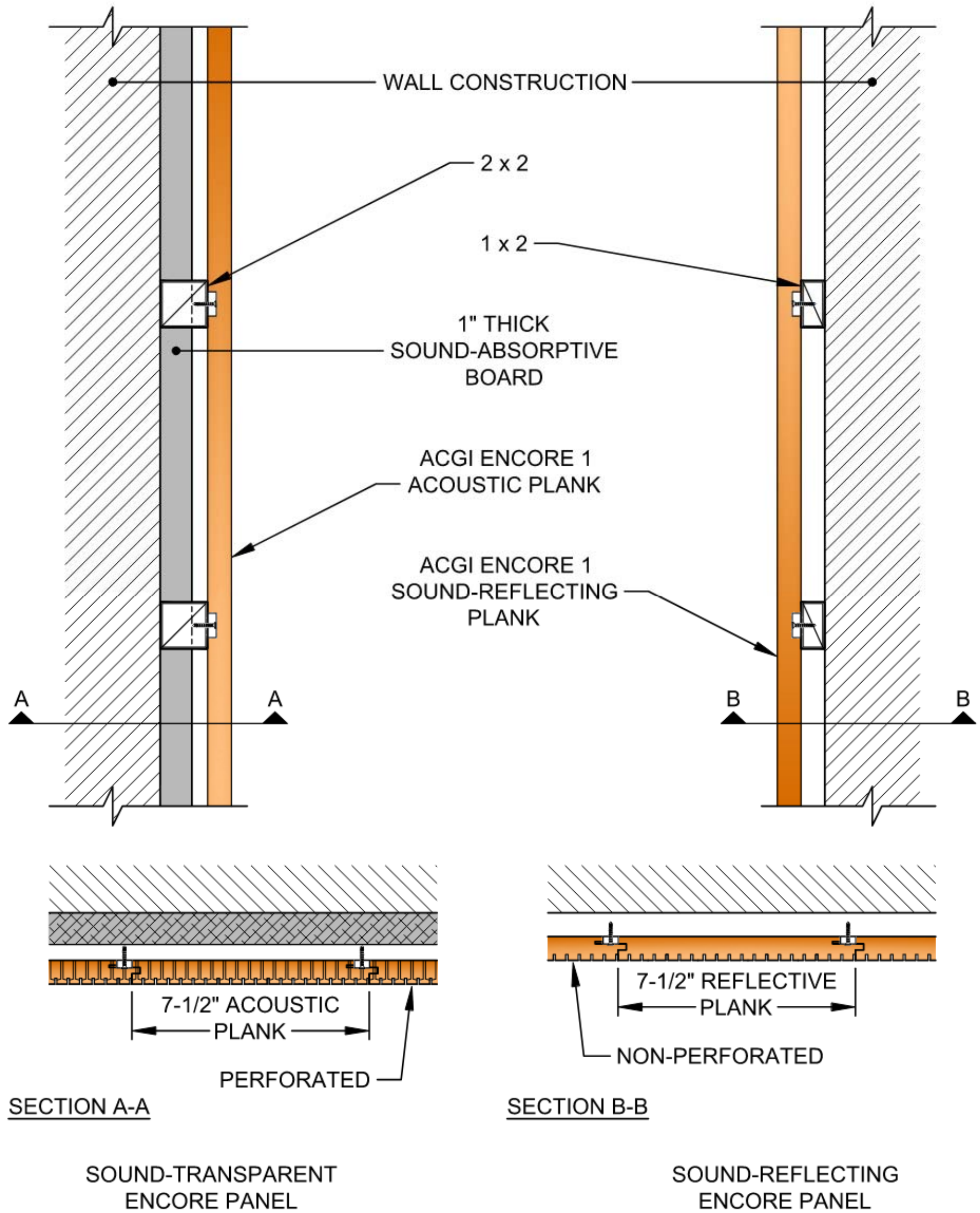

Figure 7: East-west vertical sections of the sound-absorptive and sound-reflective walls in the hall
Credit: Darren T. Osenga

Figures 8 is a close-up photograph of the perforated Armstrong *Woodworks ACGI Encore I* panel on the west wall. Armstrong *Optima PB* sound absorbing panels were placed behind the perforated panels to both help meet the reverberation time requirement and to mitigate “flutter echoes” (i.e., the persistence of sound bouncing back and forth between the parallel wall surfaces).

Figure 8: Perforated ACGI Encore I panel (west wall). The dark elongated slots within the grooves are the acoustical perforations that enable sound to “see” the absorptive material behind the wood surface
Photo Credit: Charles Salter (edited by Chelsea Hall)

The photograph below shows the non-perforated *ACGI Encore I* panel on the east wall.

Figure 9: Non-perforated ACGI Encore I panel (east wall)
Photo Credit: Charles Salter

Visual differences between the perforated and non-perforated panels cannot be detected unless one stands very close and shines a bright light on the panel. Thus, the architects achieved their "unified" design goal for the hall.

B. Ventilation System Noise Reduction

To achieve the LEED requirement for ventilation noise levels, we recommended noise and vibration mitigation for the ventilation equipment and air distribution ductwork. These measures were implemented by PAE Engineers, who designed the system, and Innovative Mechanical, the mechanical contractor. For lecture halls, the upper limit specified by LEED is NC 30.[7]

Initially, we recommended relocating the mechanical equipment so that it would be above the ceiling of the adjacent hallway, outside of the lecture hall. Due to space constraints, the two fan-coil units (FCUs) were installed above the wood-slat ceiling at the rear (north) end of the hall over the upper landing.

Since the fans were within the hall, we suggested incorporating the following measures to achieve the project's acoustical requirements:

- Internally line the air inlet and discharge ducts with sound-absorptive duct board to attenuate fan noise.
- Provide a gypsum board enclosure around the FCUs to attenuate radiated noise.
- Install flexible connectors between the FCUs and the ductwork to reduce transmission of structure-borne noise.
- Use vibration isolation hangers to decouple the FCUs from the building structure.
- Orient the fan inlet ducts so they faced up toward the concrete slab to direct fan noise away from the hall below.

[7] See the Appendix for a discussion of noise criteria (NC).

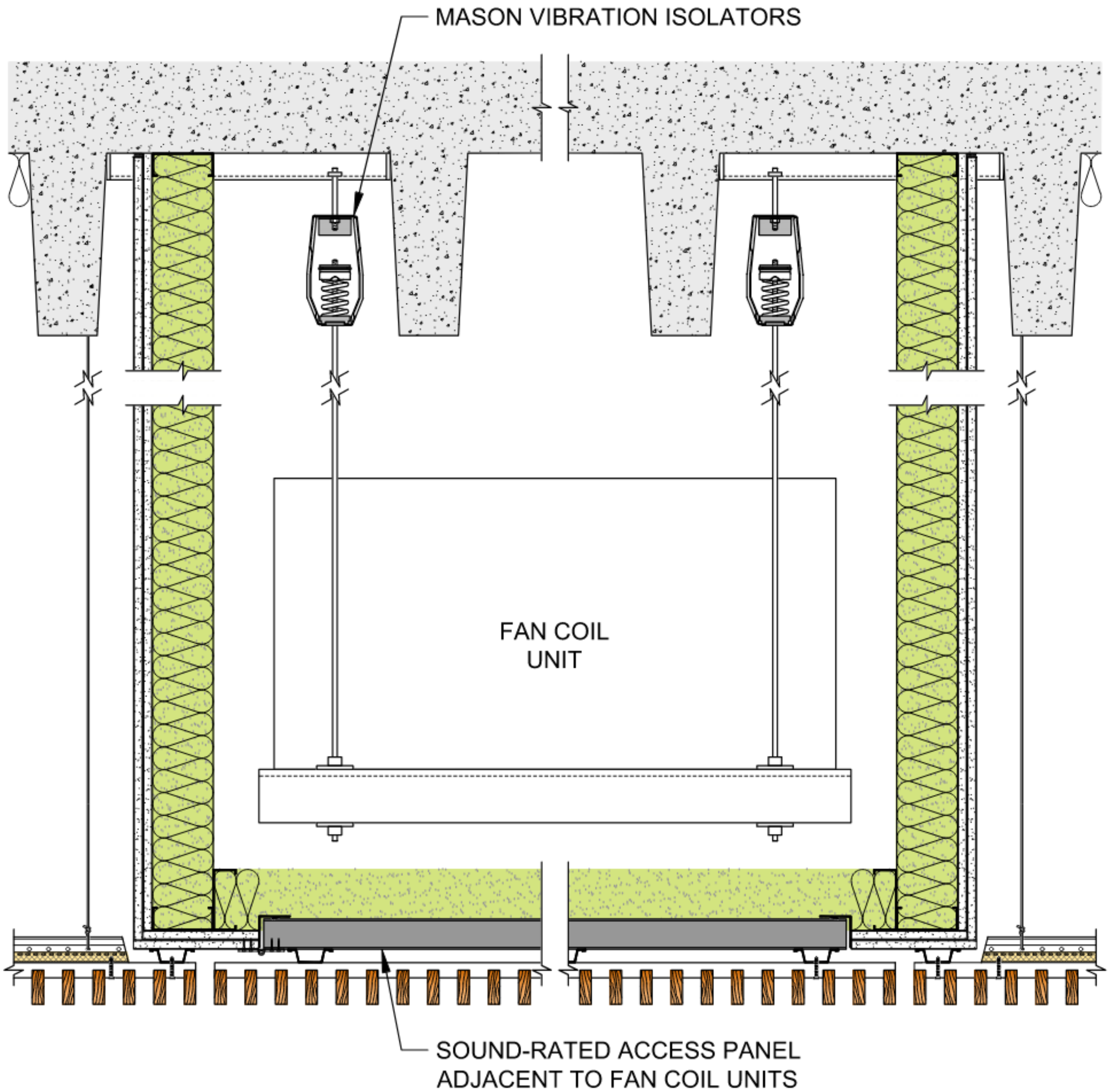

Figure 10: Fan-coil units (FCUs) suspended in enclosures above the finished ceiling at rear of the hall

Sound-rated access panels were fitted in the lower portion of the gypsum board enclosures near the FCUs, as shown in Figure 10. To open these access panels, portions of the spaced wood slats need to be removed. The enclosure design and construction details required a collaborative effort among the acoustical consultant, mechanical engineer, architect, mechanical subcontractor, drywall subcontractor, and acoustical subcontractor.

Beneath the FCUs, one cannot hear any equipment noise nor see the access panels.

C. Sound Isolation

The sound-isolation requirements for the lecture hall were addressed using sound-rated doors and partitions. A quad-leaf sound-rated door was used between the hall and the Gallery. In addition, single-leaf sound-rated doors were installed between the hall and Café, between the upper landing and mezzanine lobby, and between the hall and Gallery (see Figures 2 and 3). The doors are 2.5-inches thick and double-gasketed along the jambs and head, as shown in Figure 11.

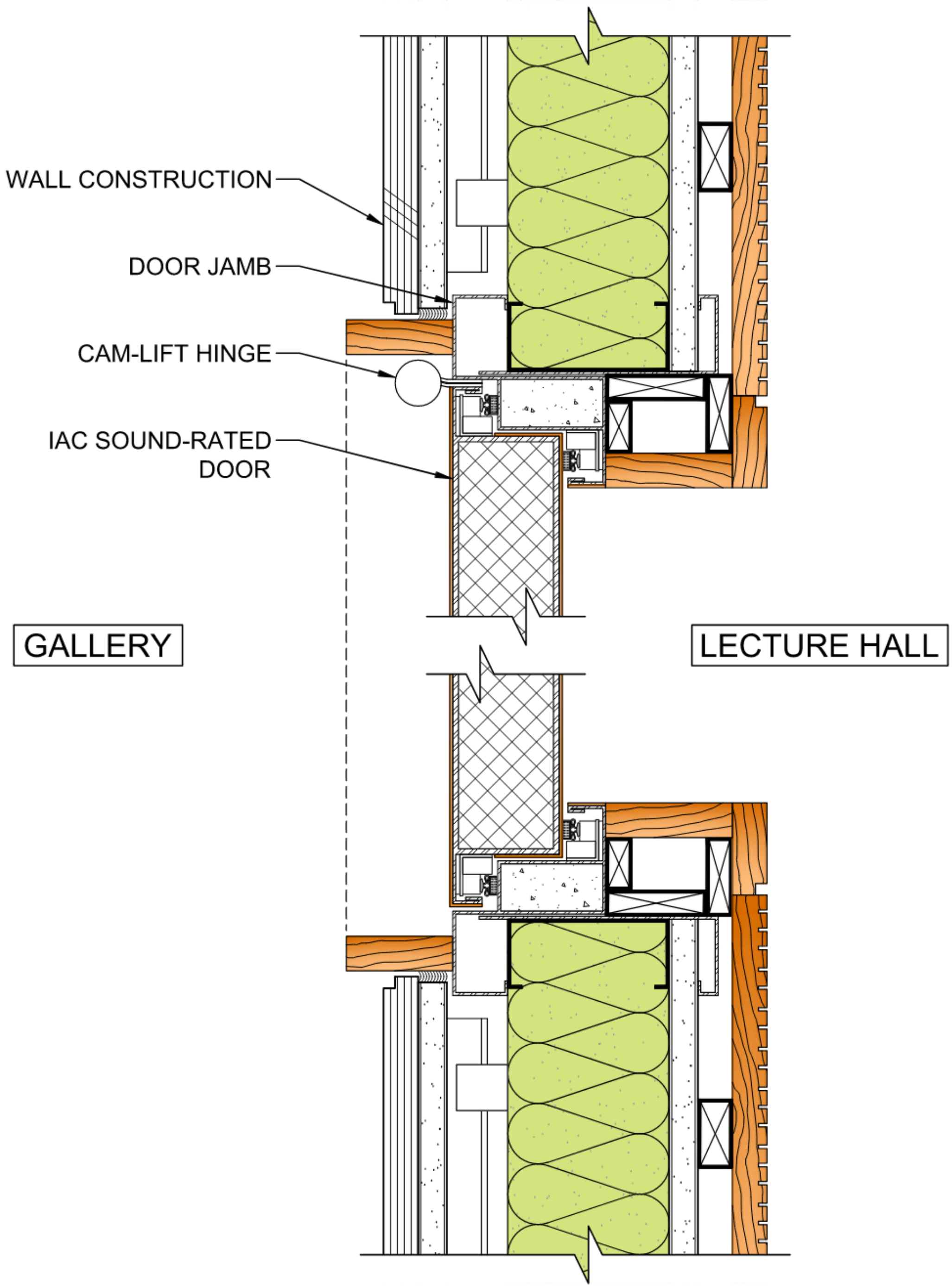

Figure 11: Detail of sound-rated door jambs and head

Figure 12 depicts the partition design including the Kinetics Noise Control *IsoMax* sound-isolation clips and ROCKWOOL *AFB evo®* sound-absorptive batts. The clips decouple the gypsum board on one side of the partition from the studs, which increases the sound isolation. The batts also increase the isolation by absorbing sound within the stud cavity. The partition perimeter was caulked airtight. All electrical boxes were sealed as shown in Figure 13.

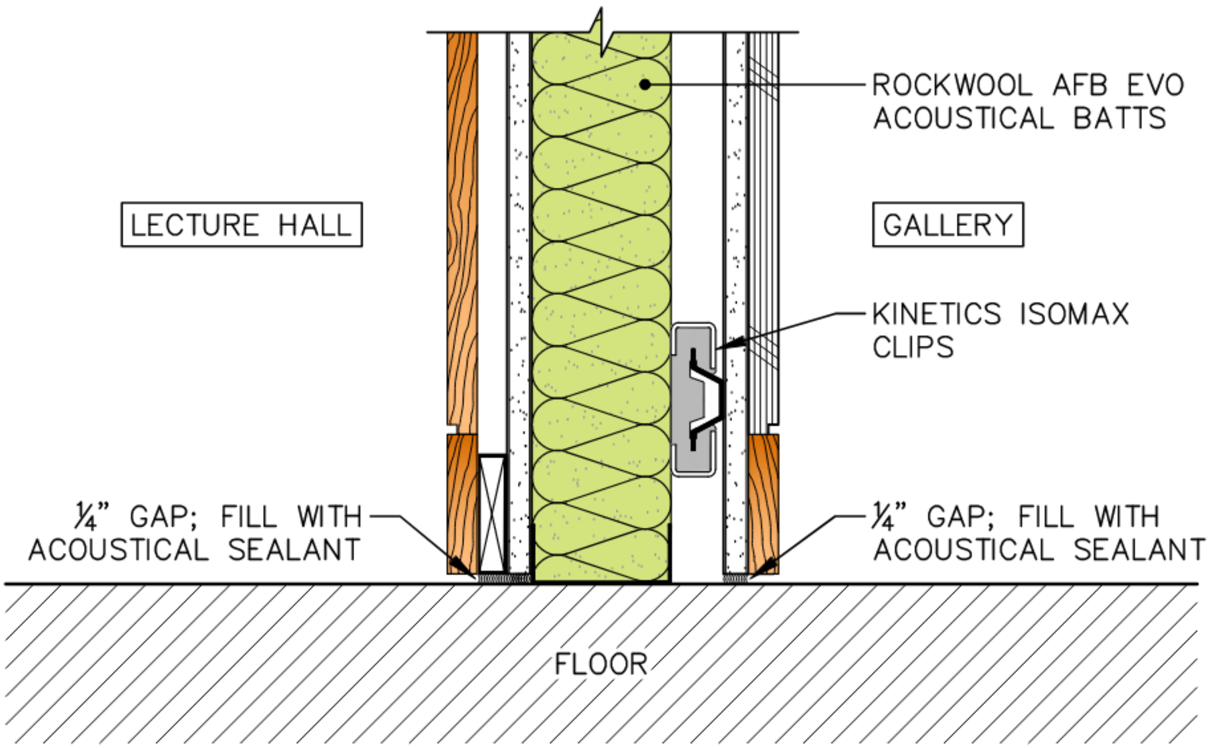

Figure 12: Sound-rated partition

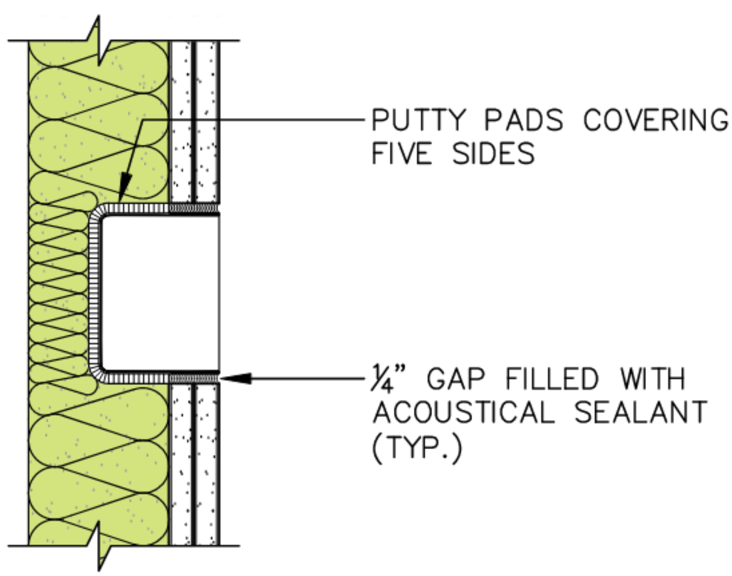

Figure 13: Sealed electrical boxes

D. Audio System

A sound reinforcement system was designed for the hall to enable playback of pre-recorded material and to support presenters who prefer to have their speech electronically amplified. Various options were proposed for the sound system ranging from a simple stereo setup to a full cinema surround system. After considering aesthetics and budget, a distributed overhead loudspeaker layout was selected. This system not only functioned for speech reinforcement but it also featured a wide dynamic range suitable for both the reproduction of music and an immersive movie experience.

Figure 14: Loudspeakers recessed in ceiling of lecture hall (view from rear)
Photo Credit: Richard Barnes (edited by Chelsea Hall)

Meyer Sound Laboratories *UP-4slim* loudspeakers were selected due to their high-quality performance and aesthetic compatibility with the ceiling. They were arranged to provide uniform sound coverage throughout the audience area. We worked with the audio-visual subcontractor (Young AV) during the design process to help coordinate on the fit and functionality of the audio system.

Figure 15: View of Meyer Sound Laboratories UP-4slim Loudspeaker installed in ceiling
Photo Credit: H. Scott Roth

Part II: Room Acoustics and Speech Intelligibility

As part of a post-construction commissioning effort, we conducted acoustical measurements in the lecture hall. Our measurements quantified the four most important attributes for attaining speech intelligibility:

- Reverberation time
- Background noise level
- Sound isolation between the lecture hall and adjacent spaces
- Speech sound levels

A. Test Protocol

Sound levels were measured at four positions in the audience seating area using signals generated by our test loudspeaker, which was placed at the front of the hall (see Figure 16). To assess speech intelligibility, a "dry" (anechoic) speech test signal was reproduced to simulate an individual using a typical vocal effort. The speech signal from the test loudspeaker was also amplified via a wireless microphone connected to the "house" sound reinforcement system.

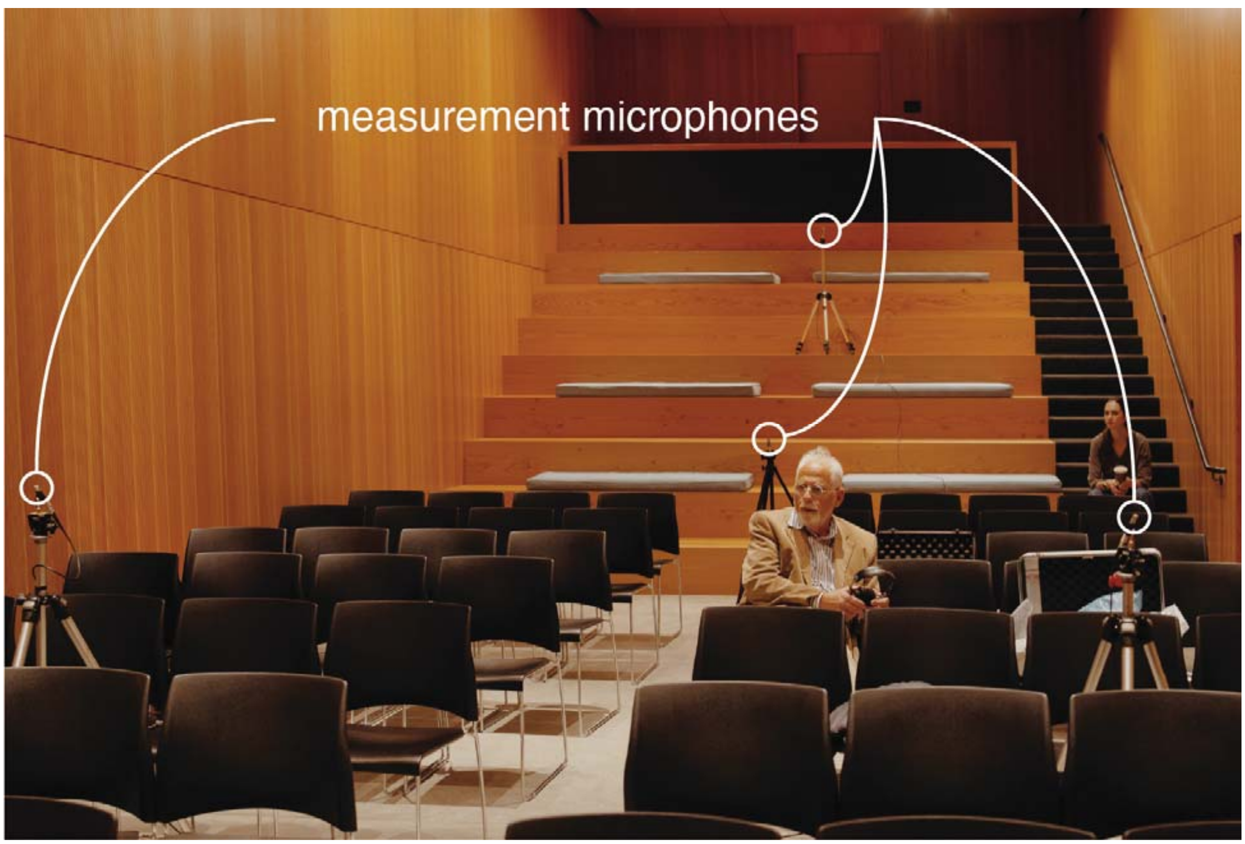

Figure 16: Acoustical testing with measurement microphones at four positions in the audience seating area
Photo Credit: H. Scott Roth

Our testing included reverberation time, background noise, sound isolation, speech sound levels, speech intelligibility, and "house" microphone techniques.

B. Reverberation Time

The following table lists the LEED requirement, the predicted reverberation time for both the Sabine and the ODEON models, and the measured reverberation time (RT60).[8] The two models predicted the same RT60, which matched the RT60 that we measured in the lecture hall. This reverberation time met the project requirement.

RT60 in lecture hall in seconds

LEED Upper Limit[9]	Sabine	ODEON	Measured
< 0.6	0.4	0.4	0.4

C. Background Noise

The measured background noise level in the hall was NC 30, which met the LEED requirement of NC 30 (maximum).

D. Sound Isolation

The minimum LEED sound isolation requirement is NIC 20 between the lecture hall and the Gallery, and NIC 30 between the hall and the Café. [10] The respective measured ratings were NIC 21 and NIC 35. Therefore, the LEED sound isolation requirements were met.

E. Speech Sound Levels

When our test loudspeaker generated the “dry” anechoic speech signal in the front, the words were easily understood at the rear of the hall. Figure 17 shows the sound levels at each microphone position averaged over the speech frequency range. As expected, the sound levels decreased with increasing distance from the test loudspeaker.

When using the audio system, however, the amplified speech was uniform throughout the seating area.

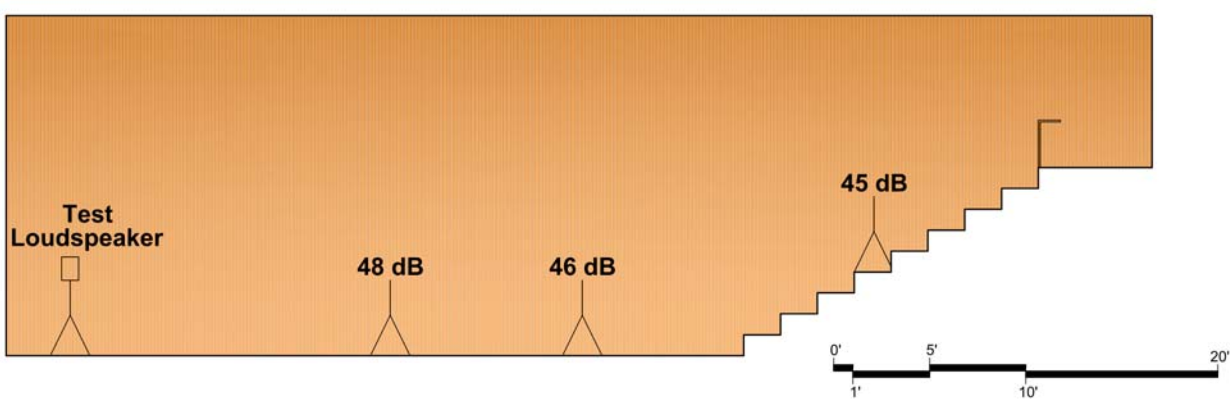

Figure 17: Speech sound levels when our test loudspeaker reproduced the “dry” speech signal

[8] See the Appendix for a definition of RT60.
[9] LEED specifies that the RT60 pertains only to the 500 Hz, 1,000 Hz, and 2,000 Hz octave bands.
[10] See the Appendix for a definition of NIC.

F. Speech Intelligibility Measurements

Aside from our subjective listening assessment, we also measured objective speech intelligibility using a specialized instrument to quantify the so-called speech transmission index (STI)[11]. The STI instrument used for this test was the Nti Audio *TalkBox* (shown in Figure 18).

Figure 18: Nti Audio TalkBox used to measure STI
Photo Credit: H. Scott Roth

Figure 19 shows the measured STI values. An STI of 1.00 is a perfect score for speech intelligibility, while an STI of 0.6 is considered "good".

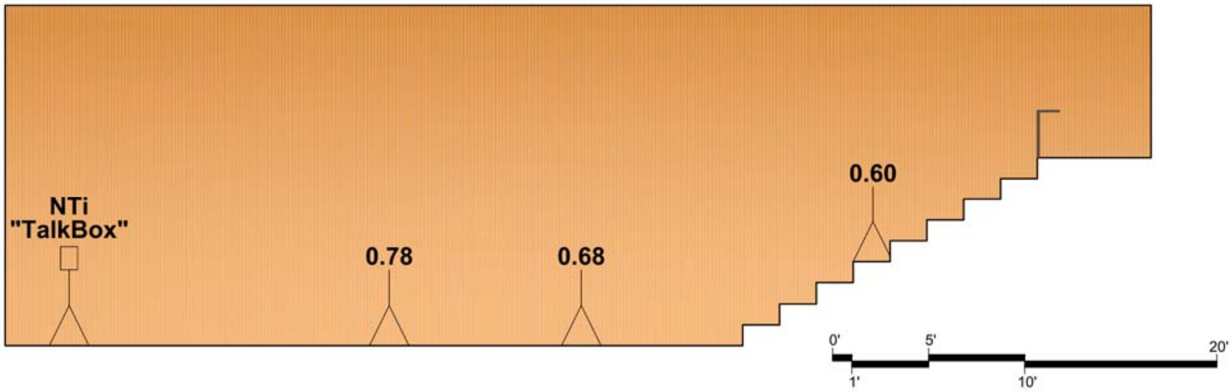

Figure 19: Measured STI values using a calibrated Nti TalkBox

---

[11] See the Appendix for a technical description of STI.

G. Placement of “House” Microphone

During our testing of the “house” audio system, we measured the “dry” anechoic speech test signal using an optimum “house” microphone position (held 2 inches from the test loudspeaker). Figure 20 shows this condition.

Figure 20: Optimal placement of “house” microphone (2 inch spacing)
Photo Credit: H. Scott Roth

We also measured the same signal using a non-optimal microphone location (microphone held 12 inches from the test loudspeaker as shown in Figure 21). This comparison was intended to simulate the way that some talkers hold a “house” microphone.

Figure 21: Non-optimal placement of “house” microphone (12 inch spacing)
Photo Credit: H. Scott Roth

We found that speech intelligibility was impaired when the microphone was located 12 inches from the test loudspeaker. This experiment demonstrates the importance of proper microphone placement when using a speech reinforcement system.

Summary of Findings

- Both the Sabine formula and the ODEON model correctly predicted the reverberation time in the hall
- Unamplified speech from a talker at the lectern can be easily understood throughout the hall due to the quiet background noise, the low reverberation, and appropriate sound isolation
- Sound-absorptive treatments were properly distributed within the room, thereby preventing annoying acoustical “fluttering” between parallel surfaces
- The HVAC system noise and vibration mitigation in conjunction with the sound-isolating walls and doors provides an acceptable background noise

Conclusions

- The reverberation time of 0.4 seconds in the lecture hall enhances speech intelligibility and provides a comfortable listening environment
- The low noise environment in the hall enables speech to be easily heard
- The sound-isolating doors and walls prevent outside noise from interfering with speech intelligibility

Appendix

Speech Intelligibility

A term used to describe the ability of a listener to discern speech. There are both subjective and objective means to access speech intelligibility. However, neither is entirely satisfactory due to the complex interaction of so-called cognitive load factors:

- **Talker-related factors**: The talker's clarity, articulation, and ability to use both breath and voice properly
- **Listener-related factors**: The listener's familiarity with the talker's native language and the topic both affect their ability to understand, especially when the talker has a voice disorder or a heavy accent
- **Environmental factors**: Background noise can interfere with the understanding of speech
- **Situational factors**: The context of the speech, its length, and the presence of visual cues

LEED Acoustical Requirements for this Project

Reverberation Time	RT60 of less than 0.6 seconds (500, 1,000, and 2,000 hertz octave bands)
HVAC Background Noise	NC 30 maximum
Sound Isolation	Between the lecture hall and Café: NIC 30 minimum Between the lecture hall and Gallery: NIC 20 minimum
Note: The above NIC ratings are based on the specific categories of use spaces and the desired degree of acoustic privacy.	

Reverberation Time (RT60)

The decay of sound in an enclosed space depends on the acoustical energy lost due to reflections that occur when sound waves encounter room boundaries. If the interior surfaces of the room are treated with a substantial amount of sound-absorptive material, then the decay of sound will be rapid (and vice-versa). RT60 is defined as the number of seconds for sound to decay by 60 decibels.

Rooms having the same reverberation time can sound differently due to both differing volumes and placement of sound-absorptive treatments. For these reasons, reverberation time is a simplified approximation of the room's acoustical qualities.

Decibel (dB)

In acoustics, this term is used to quantify the logarithmic ratio of a sound pressure with respect to a reference sound pressure. When the reference sound pressure is at the threshold of hearing (i.e., 20 micropascals), the ratio is defined as the sound pressure level (SPL), which is always expressed in decibels.

The use of decibels helps to compress the enormous range of sound pressures into a simpler scale extending from the threshold of hearing (0 dB SPL) to above the threshold of pain (120 dB SPL). In the speech frequency range, a 10-decibel increase in sound pressure level is perceived to be twice as loud (and vice versa).

Noise Criteria (NC)

A single-number rating system to quantify the background noise in occupied rooms.

Noise Isolation Class (NIC)

A single-figure rating representing the sound isolation between two spaces separated by a partition. NIC approximates the reduction of speech sound levels expressed in decibels. NIC is a field variant of sound transmission class (STC), which is a single-figure rating obtained under rigorous laboratory test conditions.

Principles of Speech Transmission Index (STI)

Over the past 100 years, acousticians have been concerned with the factors that interfere with the understanding of speech. Various concepts have been proposed to assess speech intelligibility. From a perceptual standpoint, however, none is quite satisfactory since some form of qualitative judgment is always involved.

In 1980, Steeneken and Houtgast proposed an objective measurement technique to help quantify the quality of received speech signals. They considered two characteristics that could interfere with speech transmission: reverberation and background noise. Their proposal involves a standard sound source that emits a set of complex acoustical signals representing human speech. The calibrated acoustical signals are received by a calibrated microphone along with a specialized electronic processor at a listener's location.

The acoustical signals comprise random noise produced at a slow rate to simulate the cadence of speech. This noise sounds like a slow-moving steam locomotive.

STI theory presumes that both reverberation and background noise within the listening space tend to reduce the clarity of the electronically-generated signal. This reduction is then assigned a figure ranging from 0 to 1.00. STI values above 0.6 are considered "good"; values less than 0.5 are considered "poor". The recommended value for small lecture halls is 0.68-to-0.72.

Analogous to reverberation time, two different rooms having the same STI rating can sound differently. For this reason, a room's speech intelligibility quality is only approximated by STI.

Acknowledgments

The authors wish to acknowledge numerous contributors who made this work possible, including Roslyn Cole of Aidlin Darling Design; Stacy Williams, Executive Director of AIASF; and David Lehrer, Gail Brager, and Stefano Schiavon at CBE.

In addition, we'd like to thank the manufacturers that contributed acoustical products: Armstrong World Industries provided *Woodworks ACGI* sound-absorbing ceilings and walls; IAC Acoustics contributed the sound-rated doors; Acousthetics donated the Kinetics Noise Control *IsoMax* sound isolation clips; Mason Industries provided spring isolators for mechanical equipment, and ROCKWOOL™ donated the insulation material used in the sound-rated wall assemblies and on the ceiling.

We wish to thank the following Salter personnel: Sybille Roth provided the room acoustics analysis; Eric Yee engineered the noise mitigation analysis for mechanical equipment; Dylan Mills designed the audio/visual systems; Diego Hernandez led our acoustical measurements and data analysis efforts; Ethan Salter conducted the sound isolation measurements; Jason Duty interpreted the LEED results; Brian Good developed the figure details and drawings; Chelsea Hall enhanced the photographs; and Athena Chan produced this report. In addition, Eric Mori, Aidan Nelson, Durand Begault, and Valerie Smith provided valuable editorial suggestions.

Lastly, a special thanks to H. Scott Roth for his photographs.