Acoustics, the "black magic" of architecture

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Architectural Acoustics

- What is it?
- Why do we need it?
- Acoustic consultants

Architectural Acoustics

Interior Acoustics

- Acoustic Isolation and Separation
- Room Acoustics

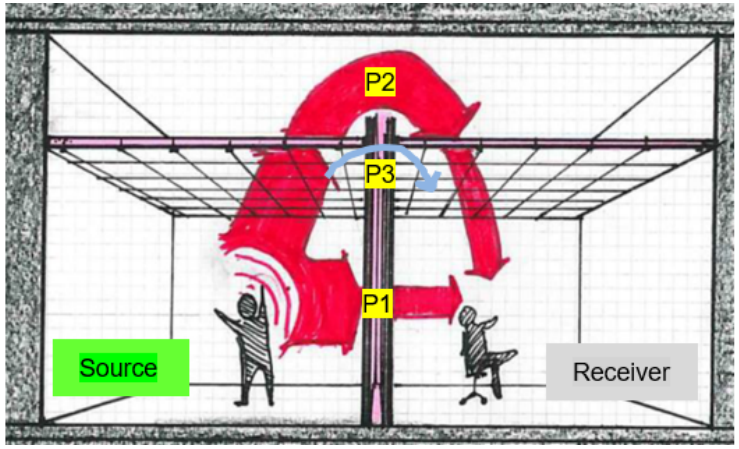
Environmental Noise

Noise Control

Vibration Control

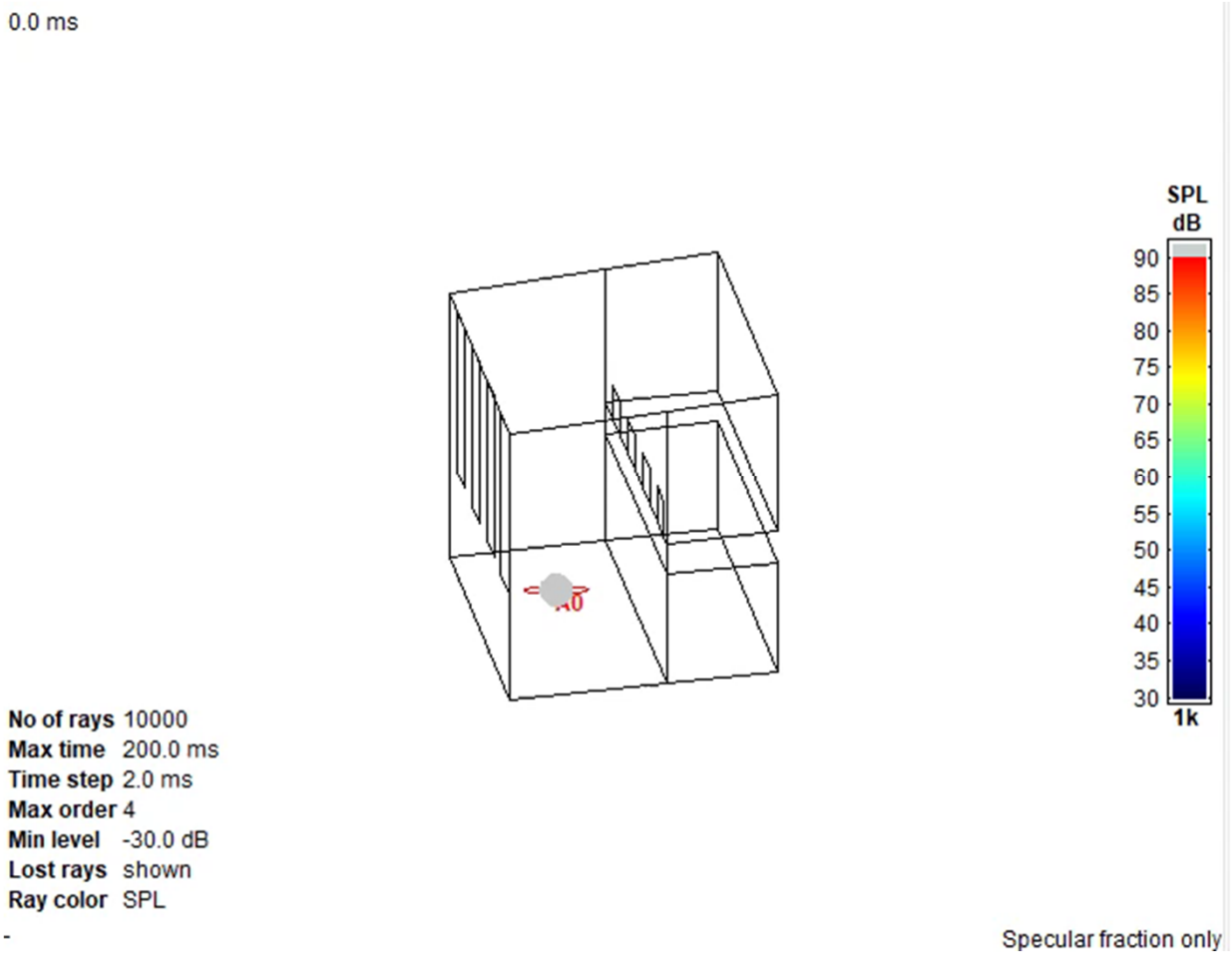
Acoustic Separation

Acoustic Separation

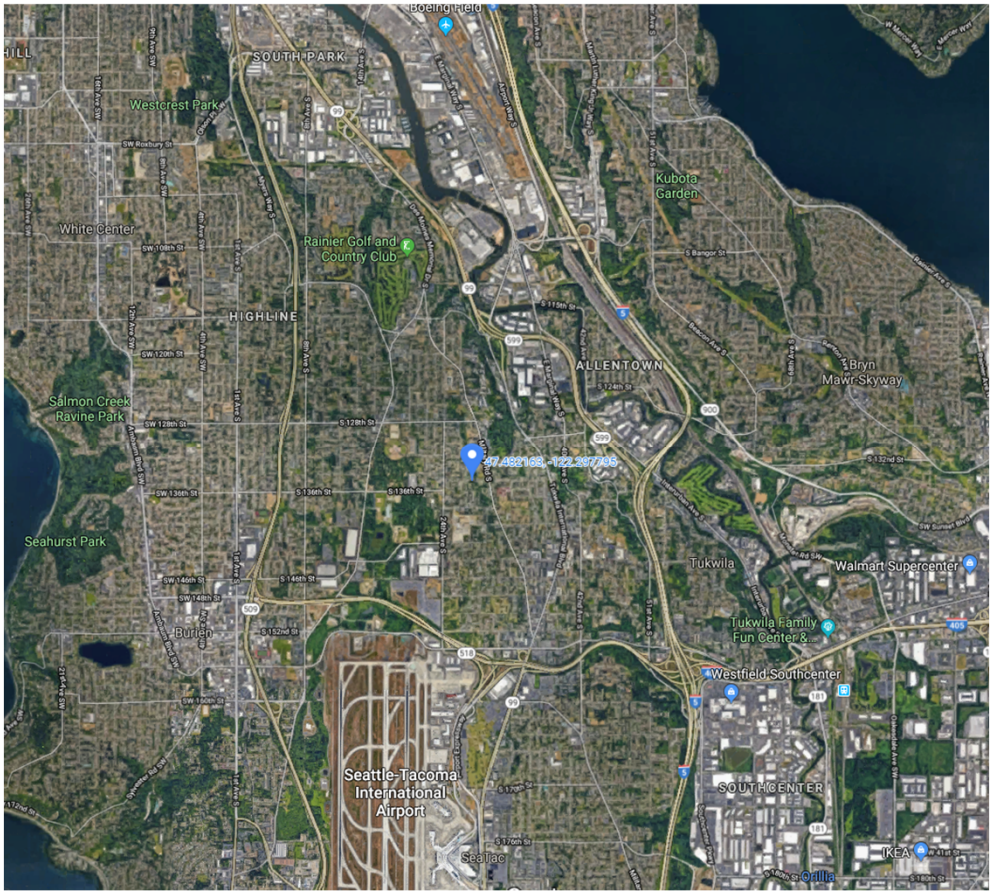


Source	Path	Receiver
Natural Sounds - • Normal vocal effort – one on one conversation or phone call • Raised Vocal effort – Speaker phone conversation or open mic conference call Amplified Sounds - • Audio- caller's voice • Music- part of a presentation	Separating Partition - • Through the body of the wall (P1) • Through the ceiling, over the wall and the through the ceiling in the receiver room (P2) • Through the joint between wall and the exterior mullion • Through the joint between wall and ceiling plane where walls stop at the ACT Ceiling (P3) Other Factors - • Source distance relative to the partition • Source room liveliness • Receiver distance from the partition • Receiver room liveliness • Depth of the plenum above the ceiling • Absorption in the plenum above the ceiling • Return air grilles	• Listener level of sensitivity • Available background noise to reduce the impact of the intruding sounds. Background noise can be the results of the HVAC system or an electronic sound masking system

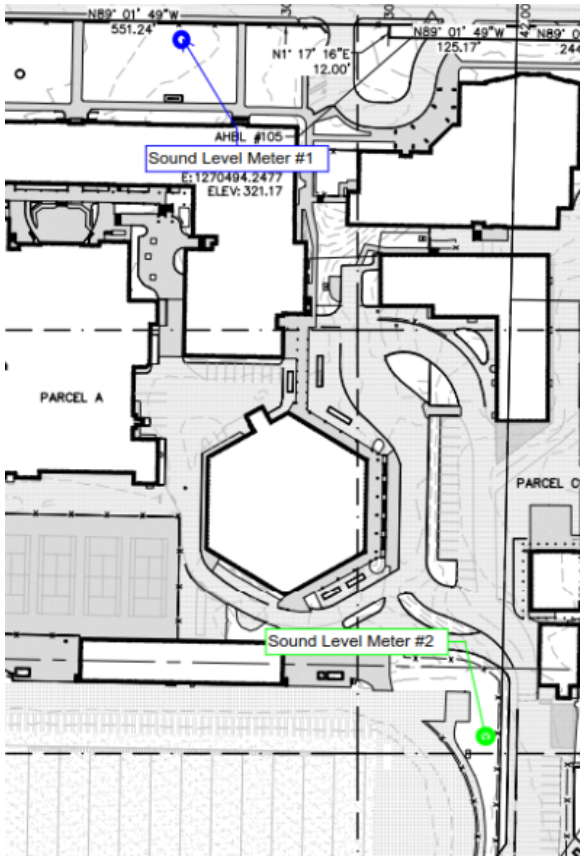
Room Acoustics

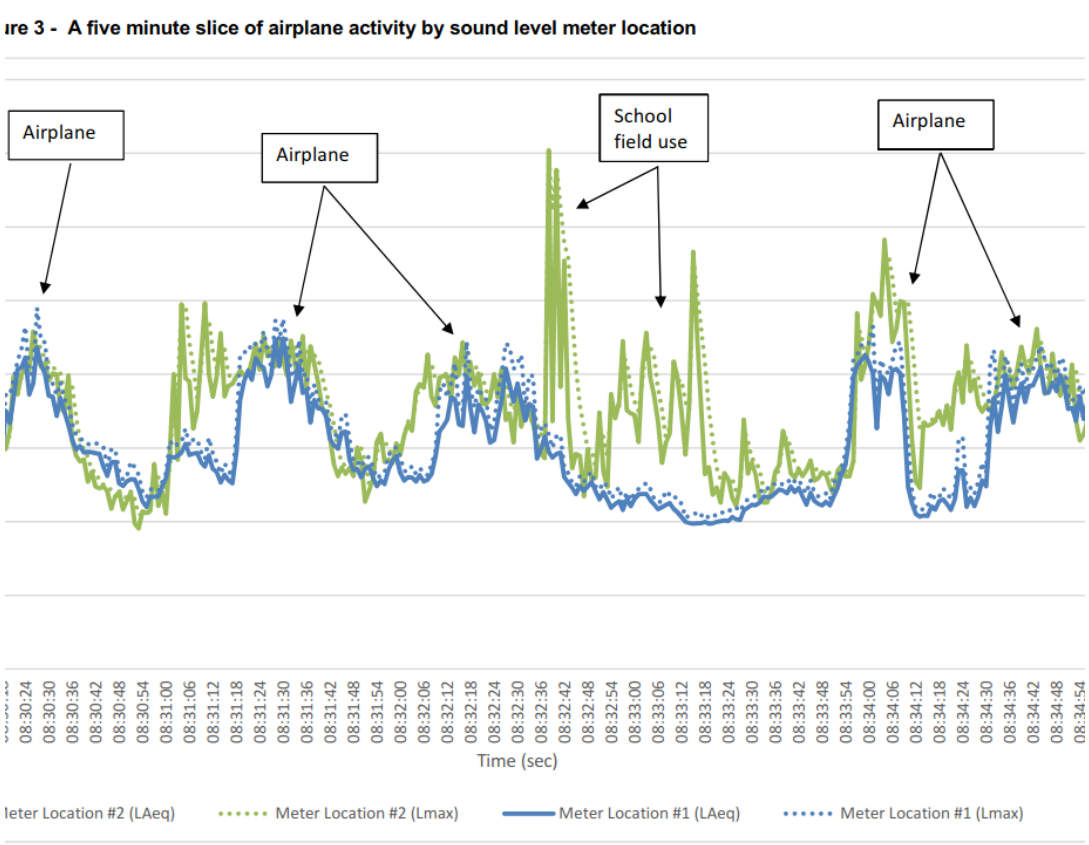


Environmental Noise

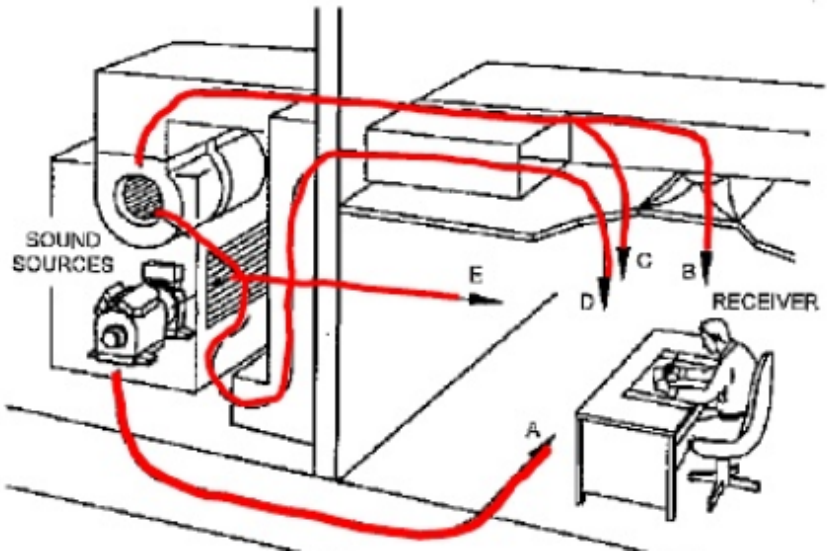


Environmental Noise





Noise Control



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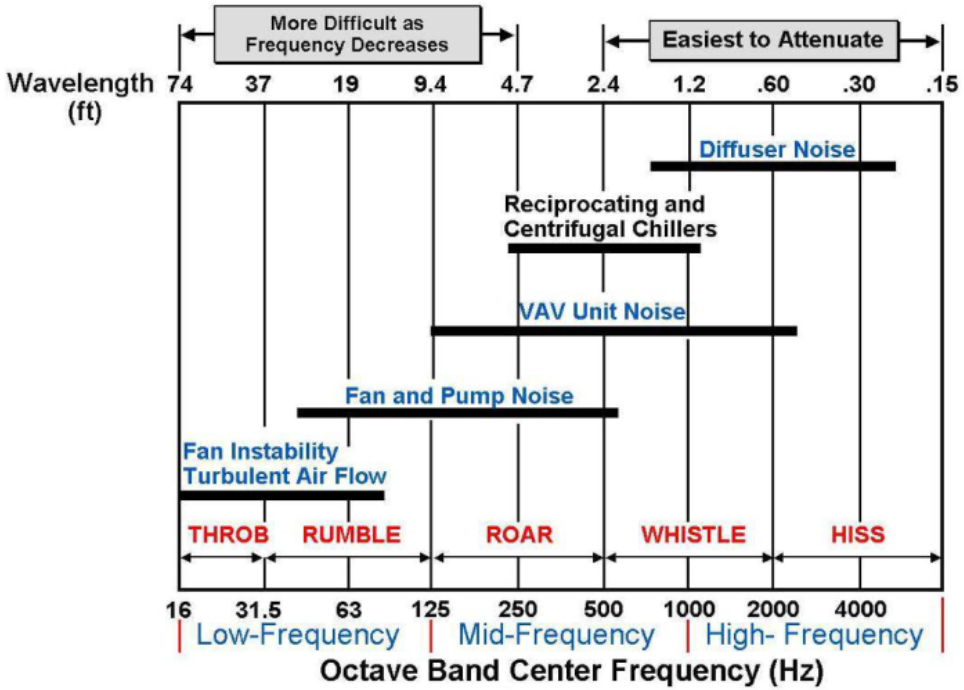


Vibration Control

How to design a building

Project Design

- Pre-design
- Schematic design
- Design Development
- Construction Documents

Project Construction

- Bid
- Construction Administration

Acoustic Consultant's Role

Design

- Establish project criteria
- Gather project information
- Preliminary analysis and recommendations
- Coordination with other project disciplines
- Project documentation

Construction

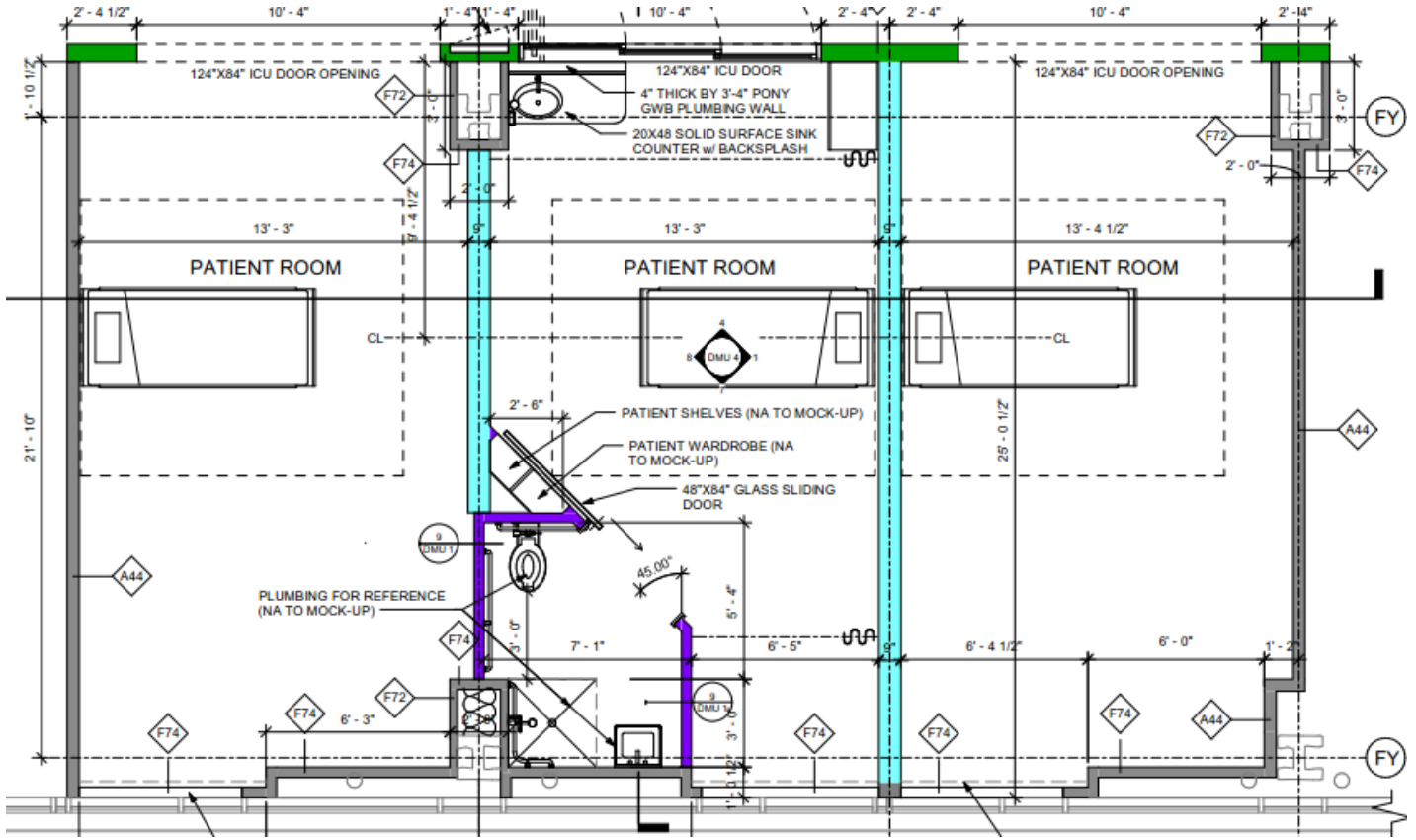
- Review submittals from contractor and answer any questions pertaining to design
- Site visits to observe construction is following design

Healthcare - Hospitals

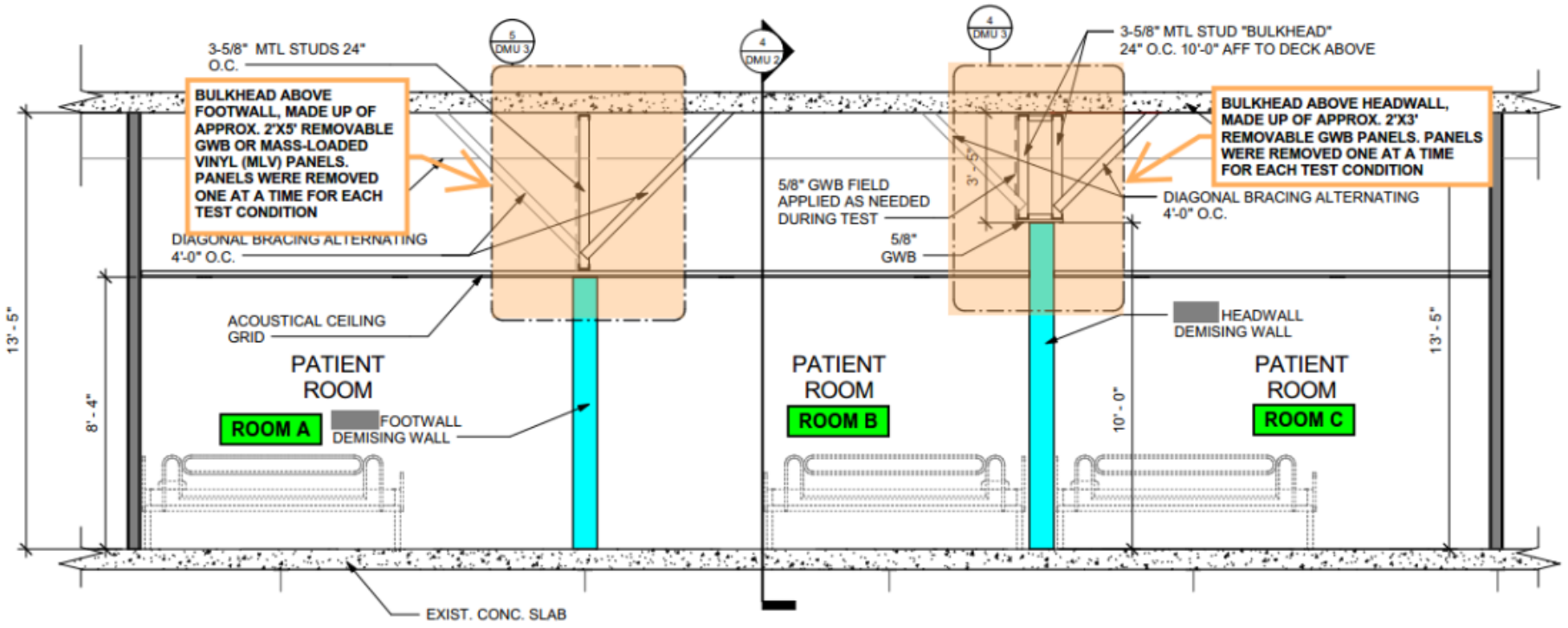
Design considerations:

- Separating partitions designed to give staff and patients adequate speech privacy
- Background noise levels designed to work with the separating architecture to minimize intruding sounds, but not overly loud
- Minimal room response to maintain good speech intelligibility

Healthcare - Hospitals



Healthcare - Hospitals



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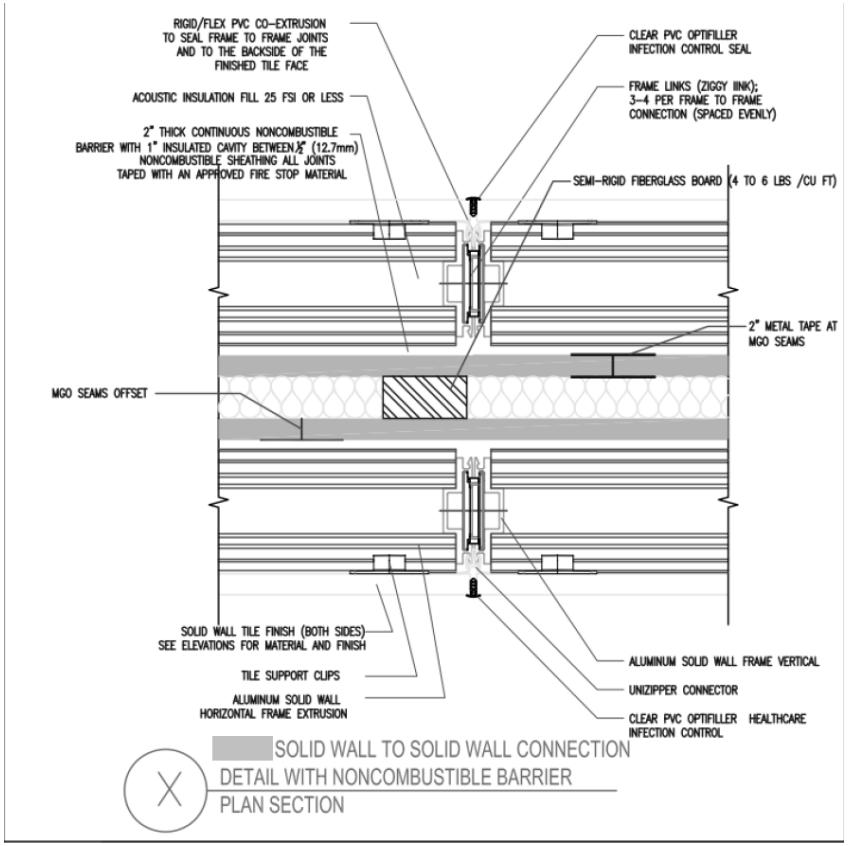
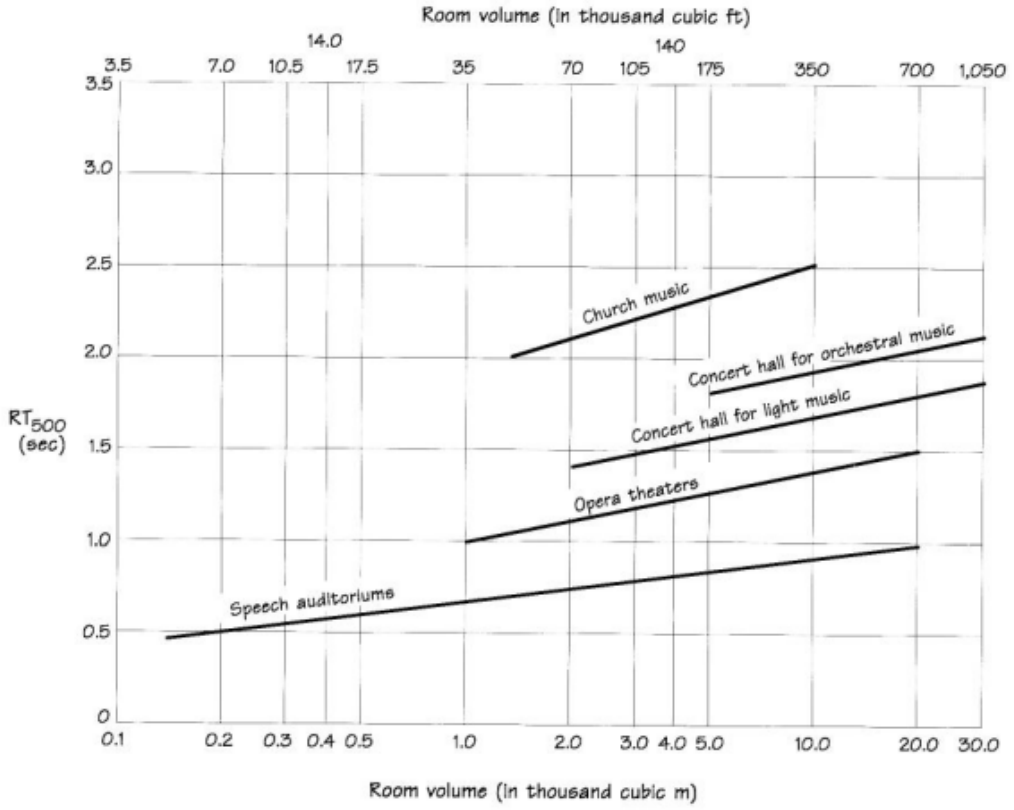


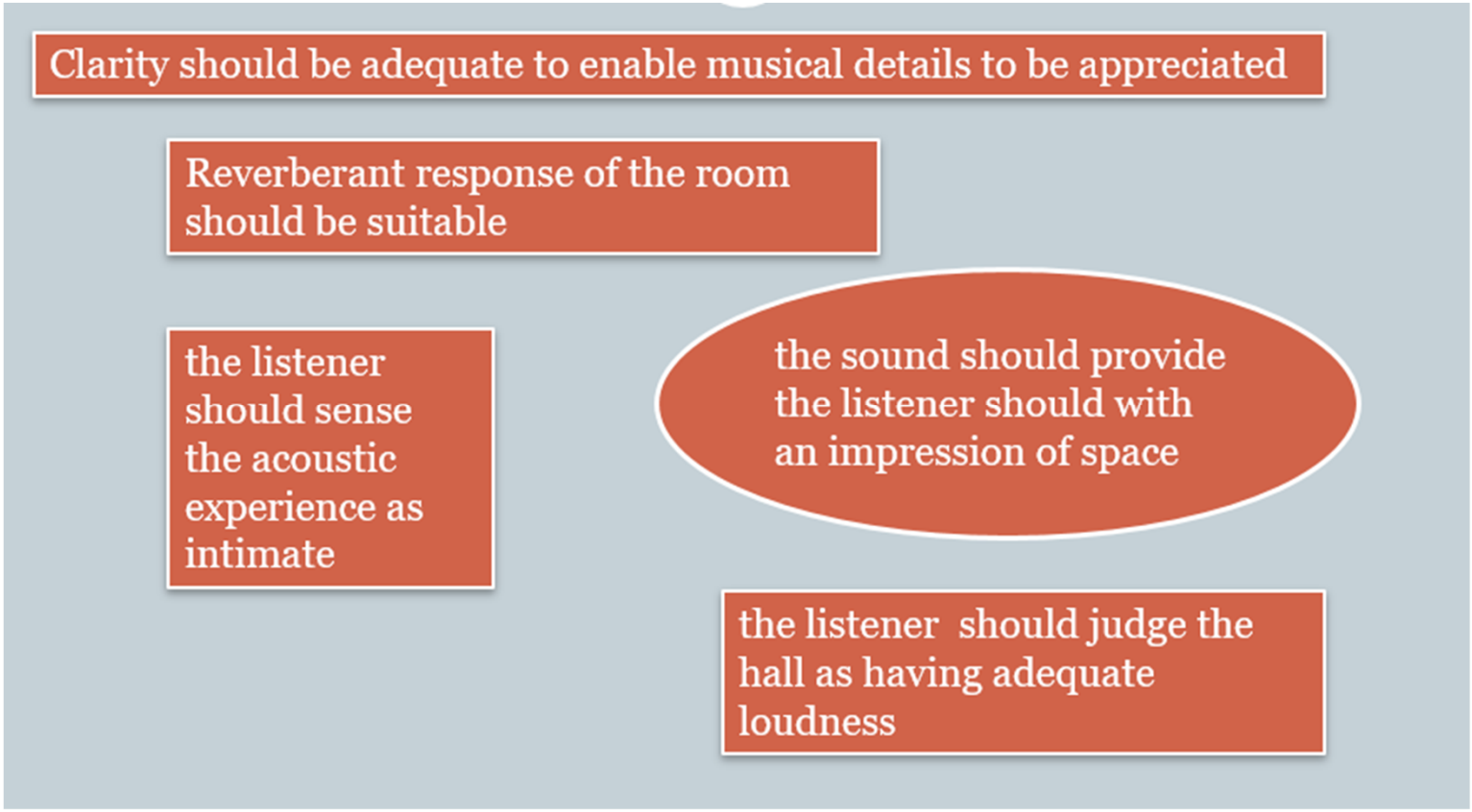
Healthcare - Hospitals

Healthcare - Hospitals

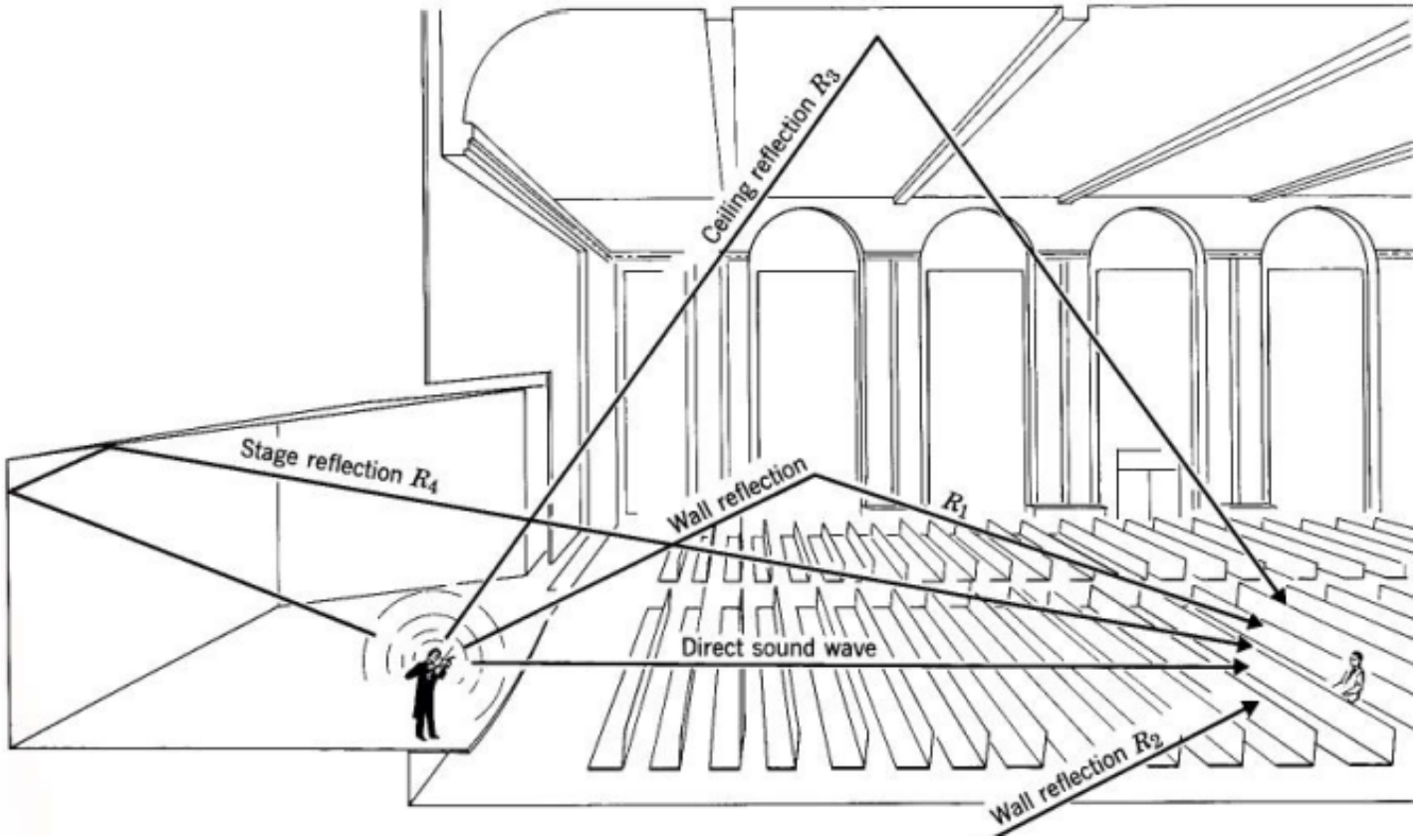
Performance Halls - Auditoriums



Performance Halls - Auditoriums



Performance Halls - Auditoriums



Performance Halls – Design Criteria

- **Reverberation Time (RT)** - Reverberation time is the time in seconds that it takes for a sound to decay 60 dB after it has been cut off. RT provides the sensation of "liveness" to music. An acoustically dead room will have a low reverberation time and an acoustically lively room will have a high reverberation time. For multi-purpose theatres, reverberation time goal ranges between 1.4 seconds to 1.8 seconds.

- **Clarity (C_{80})** - Clarity refers to how clear the sound quality is. It is the degree to which separate notes can be distinguished from one another during a musical performance and one of the indicators of intelligibility for speech and drama performances. Clarity is described by the early-to-late arriving sound energy ratio, where early sound energy is heard up to 80 milliseconds after the arrival of direct sound and late sound energy is heard beyond 80 milliseconds. For orchestral music a C80 of 0dB to -4dB is often preferred, but for rehearsals often conductors express satisfaction about a C80 of 1dB to 5dB, because every detail can be heard. For singers, all values of clarity between +1 and +5 seem acceptable. C80 should be generally in the range of -4dB and +4dB.

- **Definition (D_{50})** - Definition has a direct relationship to the speech intelligibility of a space. Definition is described as the early to total sound energy ratio, where early sound energy is heard up to 50 milliseconds after the arrival of the direct sound. A D_{50} value if 0.65 or higher indicates that 95% of all speech will be intelligible to listeners in the audience. Higher D_{50} values indicate more definition and better speech intelligibility.

- **Center Time (Ts) -** Is another acoustical measure for clarity, and is a comparison of the early and late arriving reverberant energy. The smaller the Ts, the more clear the sound. Greater values of Ts show greater amounts of late, reverberant energy in a room. Center time is calculated by taking the center of gravity of a squared impulse response.

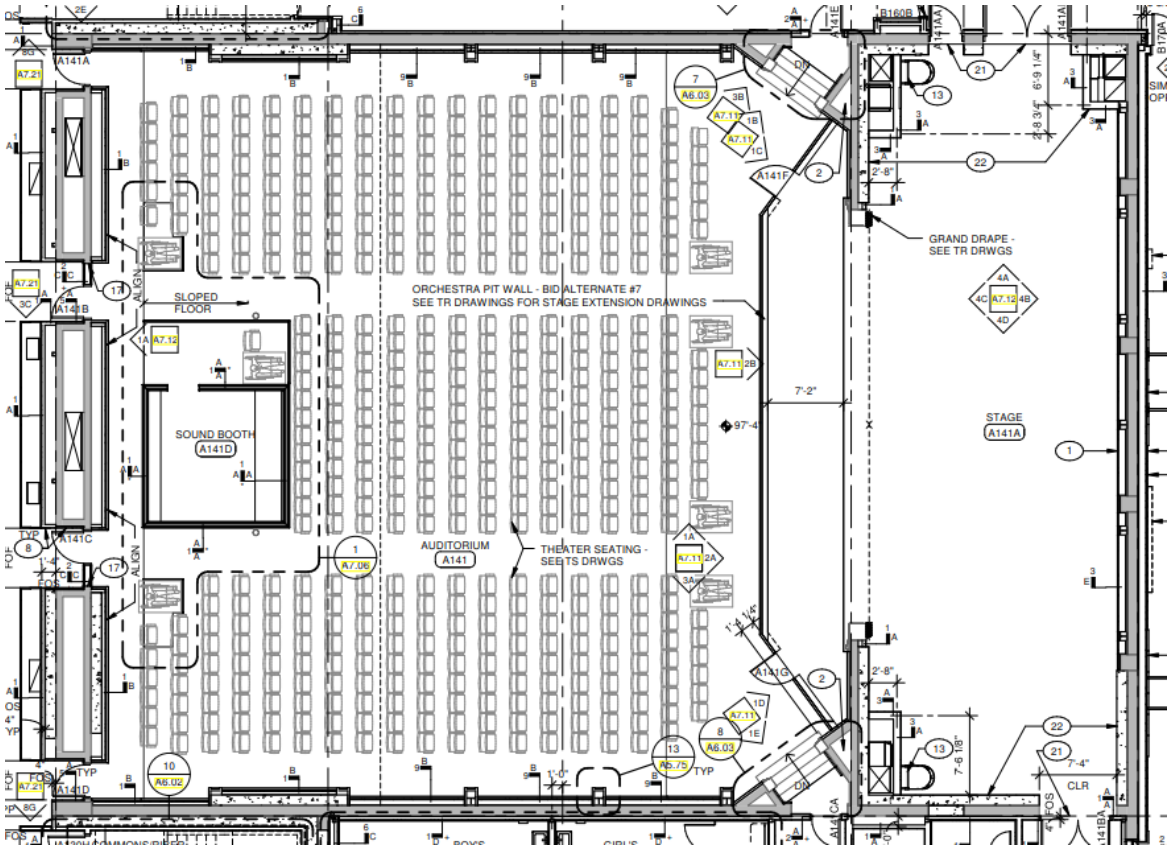
- **Inter-aural Cross-correlation Coefficient (IACC) -** Inter-aural Cross-correlation Coefficient. An acoustical measurement of the similarity of a single sound source arriving at two different points – in this case, the ears of a listener. This measure is highly correlated with a listener sense of spaciousness and envelopment. Typically, lower values of IACC are preferred, approaching 0.3, indicating that the sound arriving at one ear is only 30% correlated to the sound arriving at the other ear.

- **Speech Transmission Index (STI) -** Is a machine measure of speech intelligibility in a room, based on the difference between how much a signal changes or degrades as it passes from speaker to receiver. It therefore cannot be used as a design calculation, but only as a field measurement. A score of 0.00 – 0.30 indicates unacceptable speech intelligibility, 0.30 – 0.45 indicates poor speech intelligibility, 0.45 – 0.60 indicates fair speech intelligibility, 0.60 – 0.75 indicates good speech intelligibility, and 0.75 – 1.00 indicates excellent speech intelligibility.

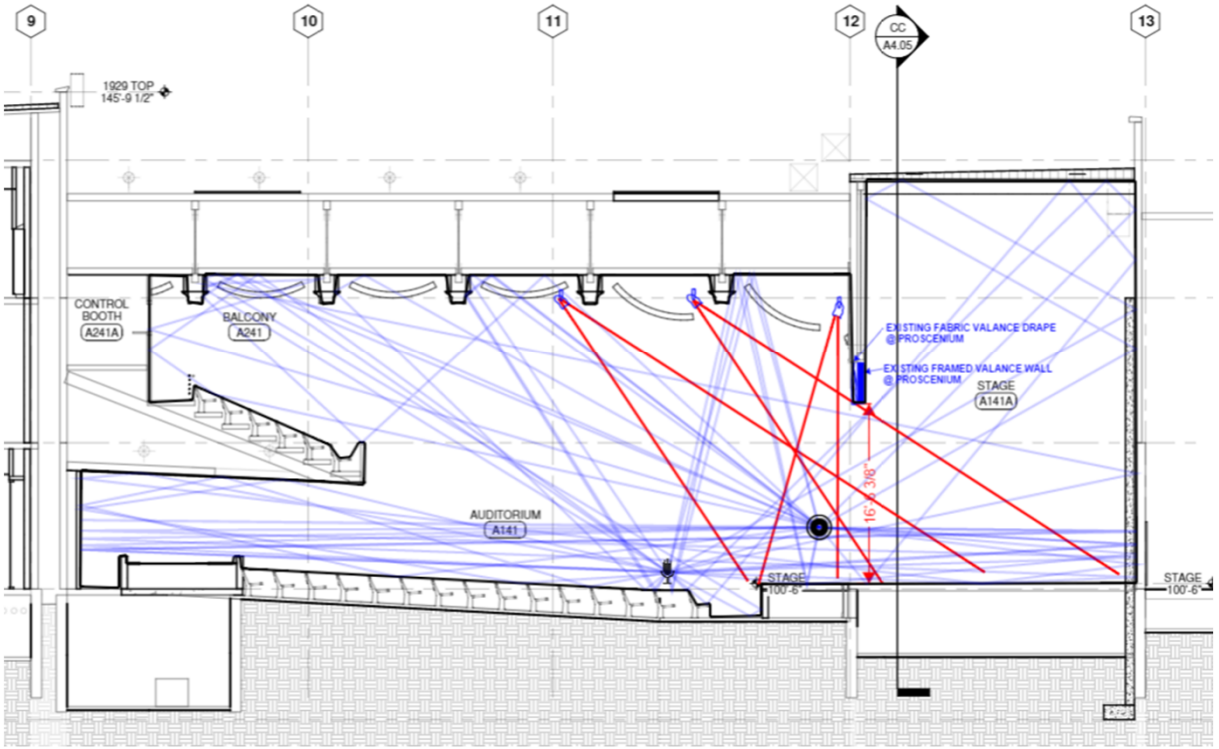
- **Percent Articulation Loss of Consonants (%ALcons) -** ALcons is the number of syllables per 100 syllables that are not intelligible. In other words, smaller numbers indicate fewer missed consonants, which a native listener can usually fill-in easily with contextual clues. Consonants play a much more significant role in speech intelligibility than vowels. If the consonants are heard clearly, the speech can be understood more easily. 0 – 3% indicates no loss of consonants or excellent intelligibility, 3 – 7% indicates good intelligibility, 7 – 15% indicates fair intelligibility, 15 – 33% indicates poor intelligibility, and 33 – 100% indicates unacceptable intelligibility.

- **Support (ST) -** Support is a metric for stages in performance halls/theaters. It is a measurement of how much of the sound is reflected from the surrounding surfaces on a stage back to the musician/performer. This reflects a musician's ability to hear themselves and the other musicians they perform with. The lower the support, the harder it is for the performing musician to hear themselves and others. Preferred values of stage support tend to fall between -11 to -13 dB.

Performance Halls - Auditoriums



Performance Halls - Auditoriums



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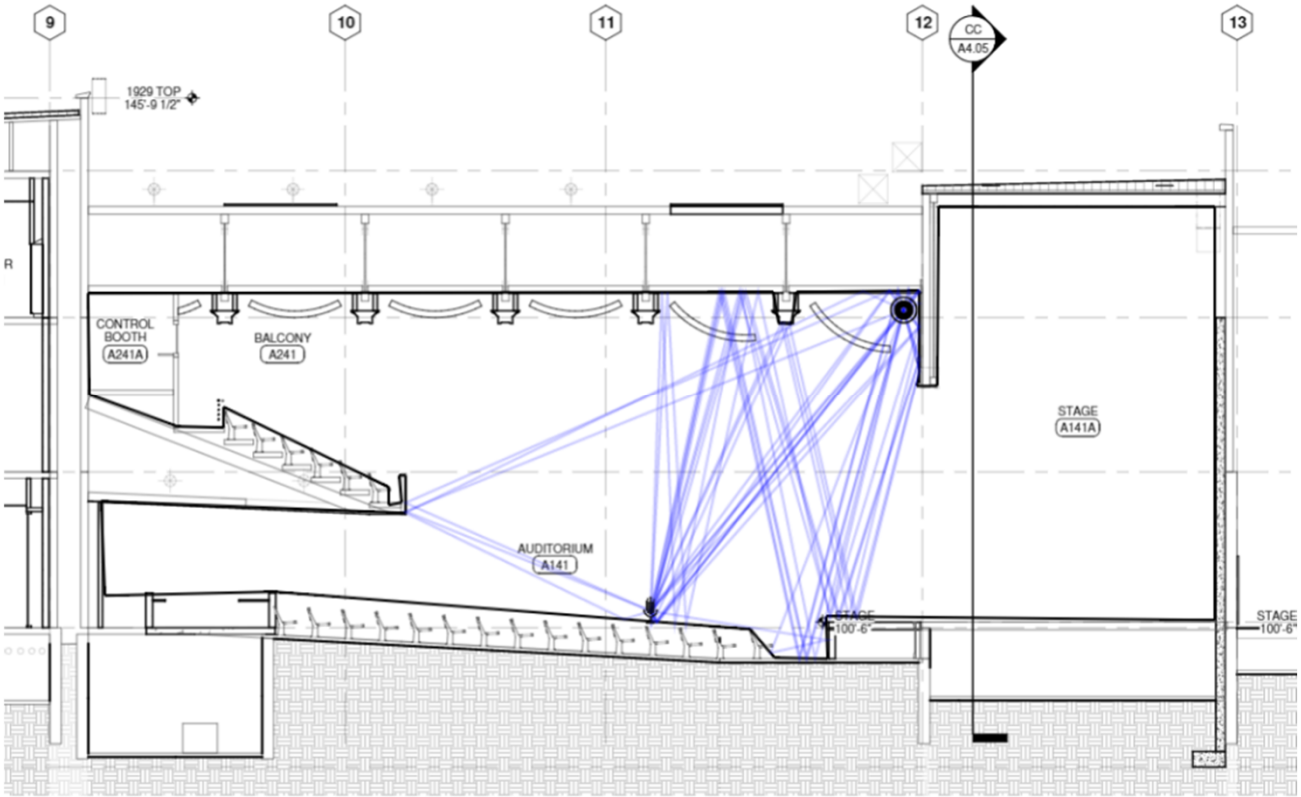
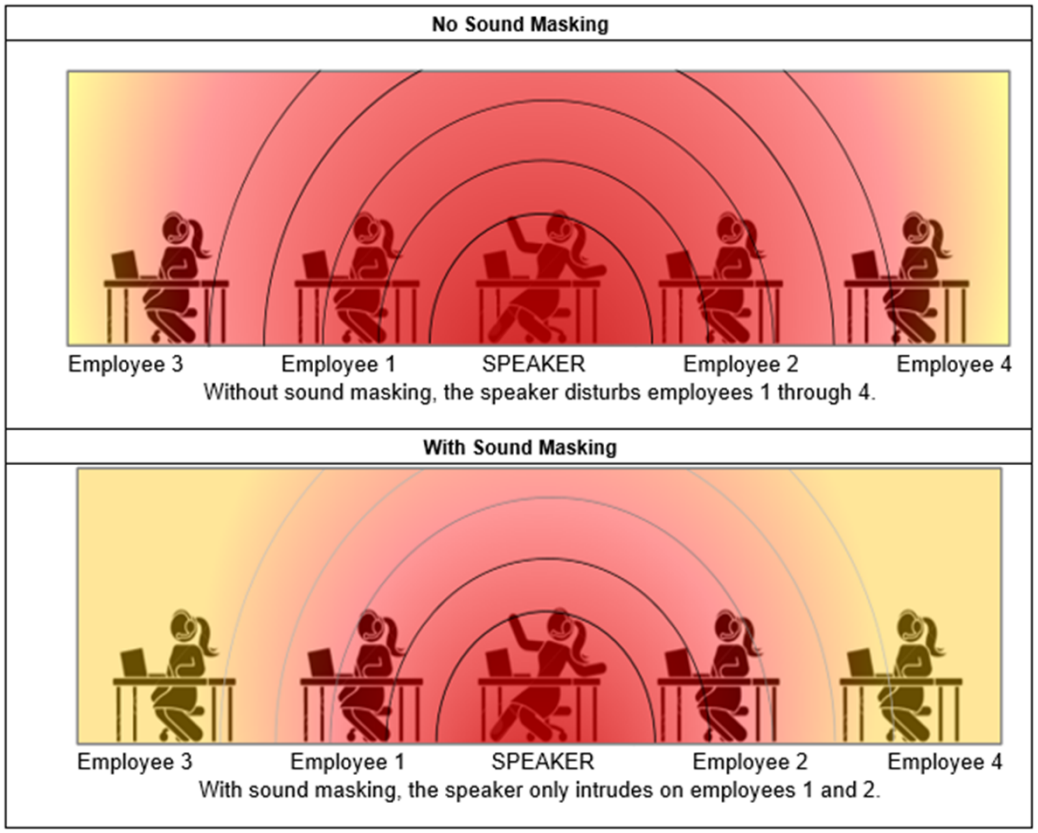


Commercial – Offices

Design Considerations

- Enclosed rooms on project?
- Partitions between workstations
- Overhead absorption
- Background noise – electronic sound masking systems

Commercial - Offices



Further Reading

Architectural Acoustics by M. David Egan
Architectural Acoustics by Marshall Long
Anything by Leo Beranek
Acoustical Measurements and Noise Control by Cyril M. Harris
The Acoustics of Performance Halls by J. Christopher Jaffey
Acoustics of Small Rooms by Jiri Tichy

Questions?