



MODERN SCHOOL ACOUSTICS

SPEECH ROOMS

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Part 1: Building Better Schools

- There is a renewed interest in effective and sustainable school design
- AIA is focusing attention on the subject
- USGBC is focusing attention on the subject, because sustainable school design has produced unacceptable acoustical results
- International studies have shown poor student performance in reading comprehension, calculus, and natural science

Importance of Acoustics in Education

Architecture
Dec-2003
pg 122



BUILDING BETTER SCHOOLS

Architects, educators, and experts team up at a series of regional conferences created by ARCHITECTURE magazine

TOP 10 ISSUES IN K-12 SCHOOL DESIGN

- 1 Mold / IAQ
- 2 Cost
- 3 Sustainability
- 4 Enrollment / Utilization Data
- 5 Phased Renovations / Adaptive Reuse
- 6 Acoustics
- 7 Educational Technology
- 8 Multiple Uses
- 9 Lighting / Daylighting
- 10 ADA / Universal Design

Source: Architecture Conferences

TOP 10 ISSUES IN HIGHER EDUCATION DESIGN

- 1 Sustainability
- 2 Educational Technology
- 3 Enrollment / Utilization Data
- 4 Phased Renovations / Adaptive Reuse
- 5 Cost
- 6 Lighting / Daylighting
- 7 Flexible Furnishings / Layouts
- 8 ADA / Universal Design
- 9 Formal / Stylistic Issues
- 10 Acoustics

Source: Architecture Conferences

What does it take for an architect to excel in today's educational market? Aiming to assess the state of the U.S. educational market from an architect's point of view, *Architecture* magazine—in concert with 15 sponsors and scores of educational facility leaders and expert consultants—launched a series of four conferences this year under the banner BUILDING BETTER SCHOOLS. The events in Boston, Los Angeles, Chicago, and metropolitan New York City brought a multidisciplinary discussion to the perennial and varied issues that affect today's K-12 and higher-education administrators and facilities.

The Markets: Still Booming?

Most pertinent to the regional meetings were overviews of design and construction activity planned or currently underway. Against a backdrop of declining state budgets and, in many places, surging student enrollment, the presenters noted robust activity in school bond issues nationwide. According to Dun & Bradstreet, about half of the nation's colleges and universities have projects in planning or underway in 2003, totaling some \$11 billion.

Education have just released a 10-year program for the state's system of universities and community colleges, entailing some \$1 billion in new construction and renovation projects. Likewise, many other school systems and institutions around the country report ambitious long-range capital plans.

Of course, the key for architects is to become active in the markets, and a large part of the BUILDING BETTER SCHOOLS program was devoted to creating winning proposals, presentations, and marketing strategies for educational owners, as well as how to be a more effective service provider. Panel discussions organized by marketing experts such as Boston's Michael Reilly and New Jersey's Sharyn Yorio—and by practitioners like Kimberly Knight of Frederick Fisher Partners, Santa Monica; and Deborah J. Hodges of Plunkett Raysich Architects, Northbrook, Illinois—provided tips and strategies for firms looking to expand their educational practices.

K-12: Smaller and More Innovative

Around the country, much of the upcoming

6. Acoustics →

10. Acoustics →

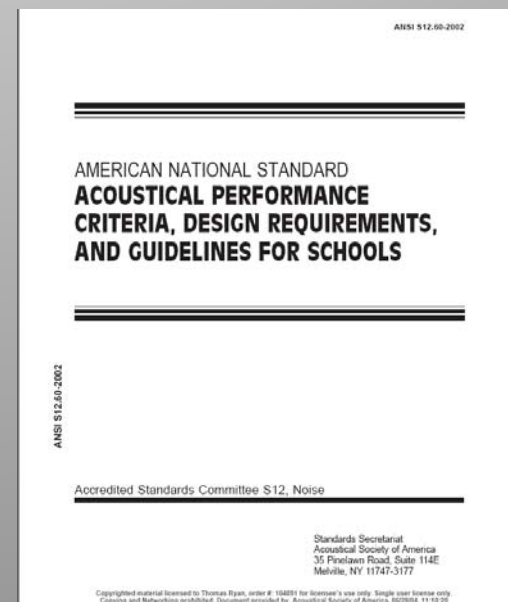
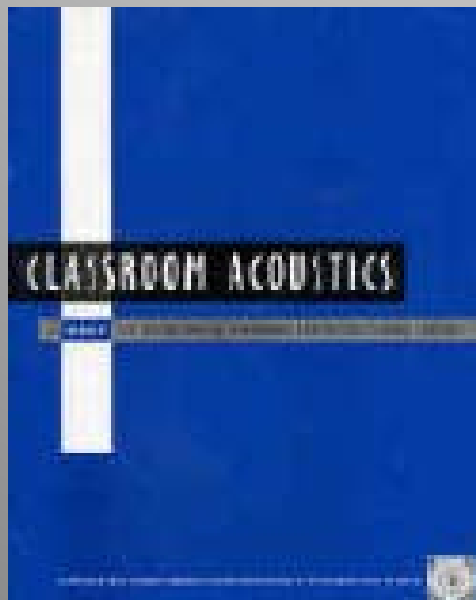


ANSI S12.60-2002

- The ASA's finest hour!
 - Done mostly through unselfish efforts of its members

Provide classrooms that facilitate better teacher-student and student-student communication

- Adopted by USGBC- Enhanced Acoustical Performance
 - Why? Because sustainable designs were presenting significant acoustical problems.



LEED for Schools V3

	ANSI 12.6 ⁽¹⁾	LEED Minimum	LEED Enhanced
Reverberation Time for Core Learning Spaces			
< 10,000 ft ³	0.6	NRC 0.7 *	NRC 0.7 *
> 10,000 ft ³ < 20,000 ft ³	0.7	NRC 0.7 *	NRC 0.7 *
> 20,000 ft ³ (and all ancillary spaces)	< 1.5	< 1.5	< 1.5
* 100% of all ceiling areas (excluding lights, diffusers and grills) in all classrooms and core learning spaces are finished with min. 0.7 materials OR total area of wall panels, ceiling finishes and other sound absorbant finishes equals or exceeds total ceiling area.			
Background Noise (dBA)			
< 10,000 ft ³	35 *	45 (HVAC only)	35 - 40 (HVAC only)
> 10,000 ft ³ < 20,000 ft ³	35 *	45 (HVAC only)	35 - 40 (HVAC only)
> 20,000 ft ³ (and all ancillary spaces)	40 *	45 (HVAC only)	35 - 40 (HVAC only)
* Includes building services AND exterior noise in determining total permissible background noise levels			
Sound Transmission Class (STC) Core Learning *			
Core learning to core learning	50	Not Addressed	50
Core learning to common use and toilet rooms	53	Not Addressed	53
Core learning to corridor, staircase, office or conference room	45 - 50	Not Addressed	45 - 50
Core learning to music room, mechanical room, cafeteria, gymnasium, indoor swimming pool	60	Not Addressed	60

*** 100% of all ceiling areas (excluding lights, diffusers and grills) in all classrooms and core learning spaces are finished with min. 0.7 materials**

LEED for Schools V3

Sound Transmission Class (STC) Ancillary Learning Space *			
Corridor to corridor, staircase, common use and toilet rooms	45	Not Addressed	45
Corridor to music room	60	Not Addressed	60
Corridor to office or conference room	45	Not Addressed	45
Corridor to outside	45	Not Addressed	45
Corridor to mechanical room, cafeteria, gymnasium, indoor swimming pool	45 - 55	Not Addressed	45 - 55
Music room to corridor, staircase, common use and toilet rooms	60	Not Addressed	60
Music room to music room	60	Not Addressed	60
Music room to office or conference room	60	Not Addressed	60
Music room to outside	45	Not Addressed	45
Music room to mechanical room, cafeteria, gymnasium, indoor swimming pool	60	Not Addressed	60
Office or conference room to corridor, staircase, common use and toilet rooms	45	Not Addressed	45
Office or conference room to music room	60	Not Addressed	60
Office or conference room to office or conference room	45	Not Addressed	45
Office or conference room to outside	45	Not Addressed	45
Office or conference room to mechanical room, cafeteria, gymnasium, indoor swimming pool	60	Not Addressed	60

* Windows are allowed an STC-35 rating and core learning doors an STC-30 rating. Doors for entry into music rooms are allowed an STC-40 rating

Note that these are minimum ratings and good design practice increases the STC of the door window assemblies to approach the wall STC rating

LEED for Schools V3

Impact Isolation Class (IIC)			
Floor/ceilings above core learning areas	45 - 50	Not Addressed	Not Addressed
Floor/ceilings above ancillary learning spaces	45	Not Addressed	Not Addressed
Gymnasia, dance studios or other high impact activity rooms above core learning rooms < 20,000 ft ³	70*	Not Addressed	Not Addressed
Gymnasia, dance studios or other high impact activity rooms above core learning rooms > 20,000 ft ³	65*	Not Addressed	Not Addressed
Gymnasia, dance studios or other high impact activity rooms above ancillary learning rooms	60*	Not Addressed	Not Addressed
* Applies to renovations only. New construction the spaces shall not be located above core learning spaces			

(1) ANSI 12.6 Does not apply to: Special purpose classrooms, Teleconferencing rooms, Special Ed rooms and Large Auditoria

PISA:

Programme for International Student Assessment

OECD:

***Organisation for Economic Co-operation and
Development***

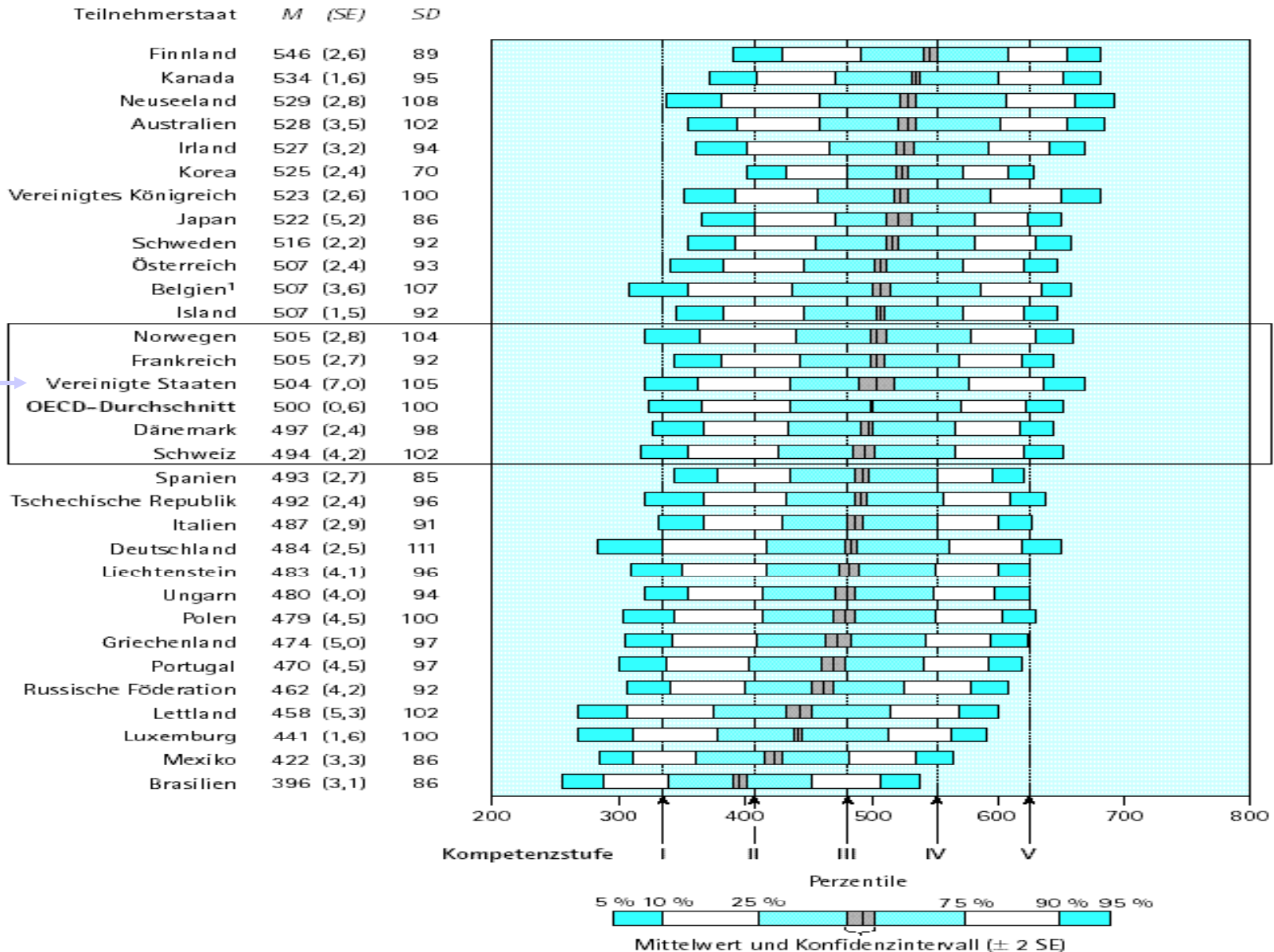
**International comparative trial of student performance
in reading comprehension,
calculus, and natural science**

Student performance in reading comprehension, international comparison

Leistungen und Lesen im internationalen Bereich

Leistungen im Lesen um internationalen Vergleich

Testleistungen der Schülerinnen und Schüler in den Teilnehmerstaaten: Gesamtskala Lesen



¹ Im flämischen Teil Belgiens liegt der Mittelwert bei 532 ($SE = 4,3$, $SD = 96$), im wallonischen Teil bei 476 ($SE = 7,2$, $SD = 111$).

SPEECH ROOMS



What did you say?

- The ear / brain processor can fill in a substantial amount of missing information in music, but requires more detailed information for understanding speech.
- The speech power is delivered in the vowels (**a, e, i, o, u and sometimes y**) which are predominantly in the frequency range of 250Hz to 500Hz.
- The speech intelligibility is delivered in the consonants (**b, c, d, f, g, h, j, k, l, m, n, p, q, r, s, t, v, w**), which requires information in the **2,000Hz to 4,000 Hz** frequency range.

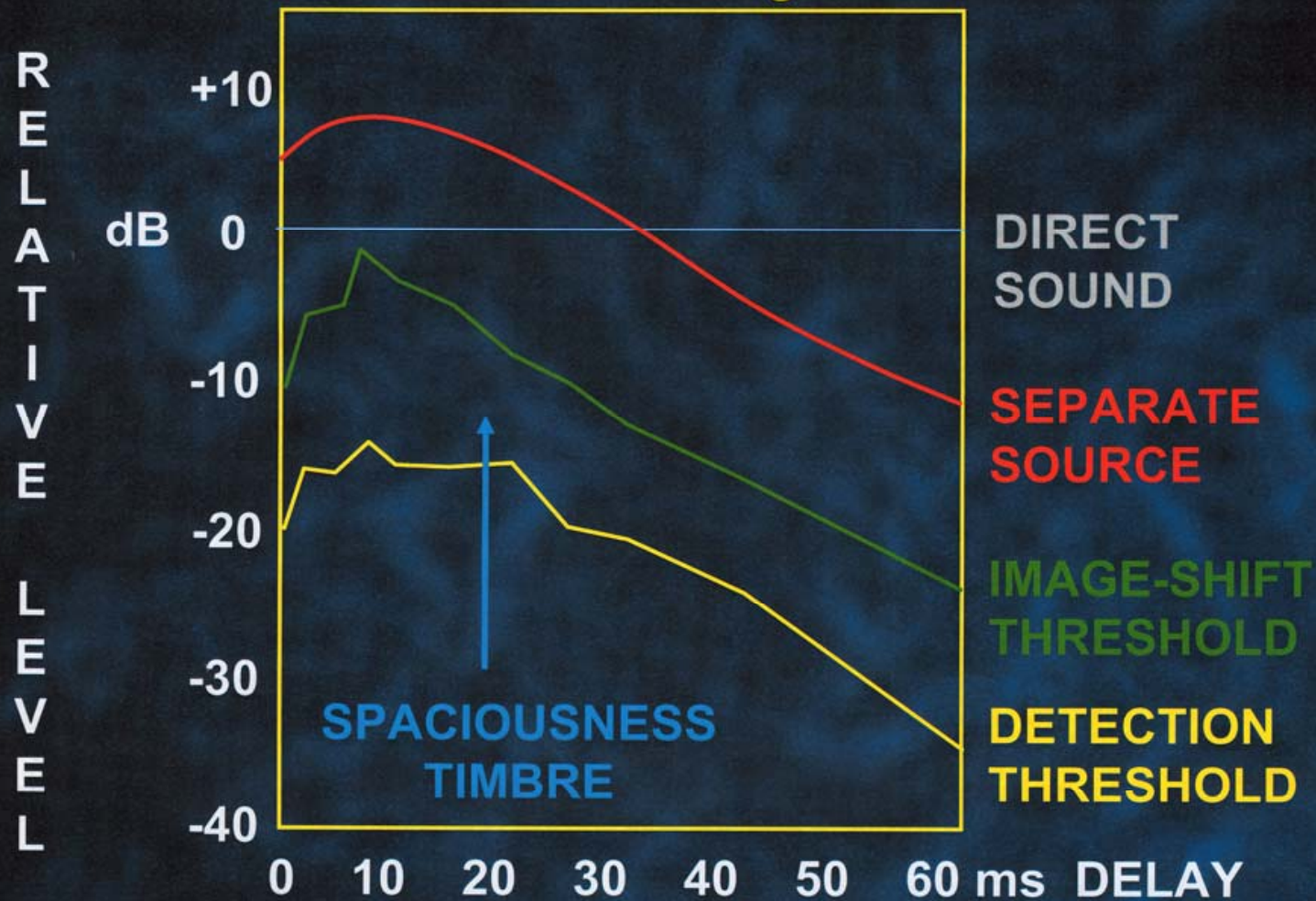
People who suffer from noise induced hearing loss typically have a 4,000Hz notch, which causes severe degradation of speech intelligibility.

- **Why would we want to absorb these important frequencies on ceilings of speech rooms and prevents them from fusing with the direct sound and making it louder and more intelligible???**



Effect of early reflections

Factors relevant to understanding small-room acoustics:



Test signal: speech

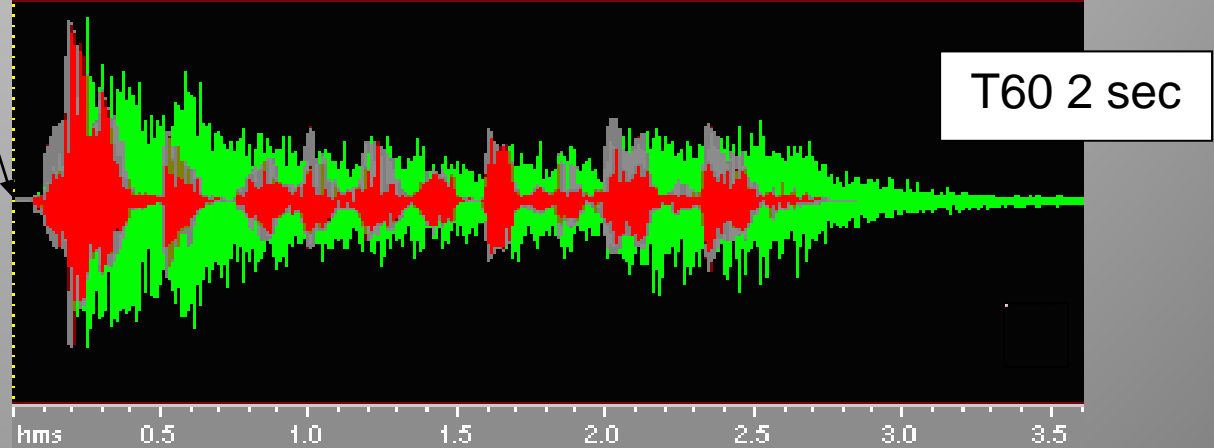
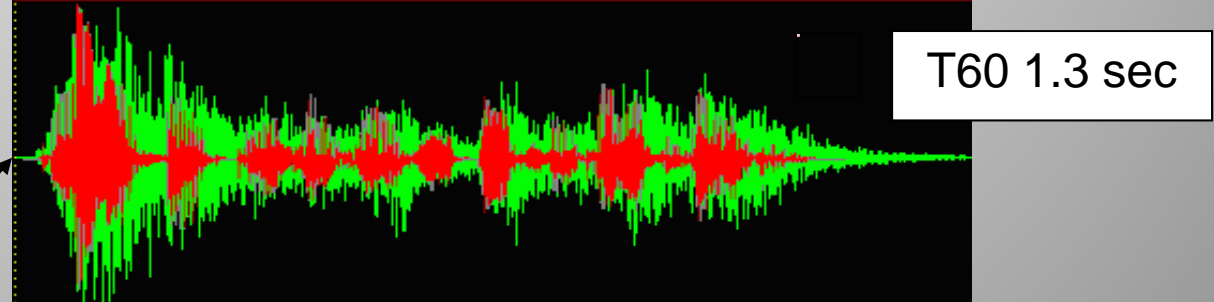
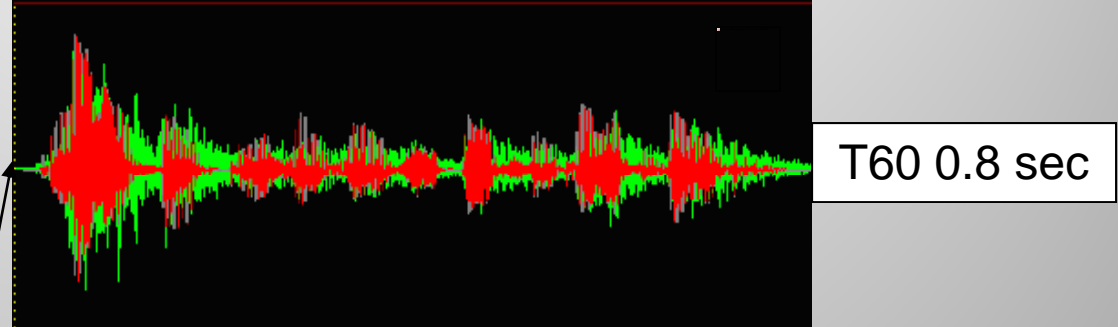
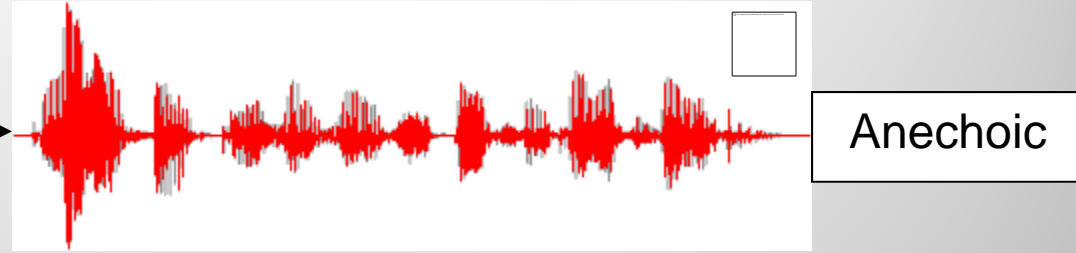
From: Toole, AES 8th Conf. 1990 69



Signal to Noise ~ *Intelligibility*

- Many of the problems that arise in poorly designed speech rooms stem from a low ***Signal to Noise Ratio***.
- ***Signal*** ~ Direct Sound & Early Reflections (50 ms).
- ***Noise*** ~ Reverberation, Occupant Noise, Exterior Noise Intrusion & Noisy MEPF Systems

T60 Corrupts Speech Intelligibility



hms 0.5 1.0 1.5 2.0 2.5 3.0 3.5

Courtesy MC²



Signal to Noise~ Intelligibility

- Normal adults typically require **0 dB** signal-to-noise ratios for high speech intelligibility when listening to simple and familiar speech material for short periods of time.
- An additional **2 dB** is needed to compensate for neurological immaturity
- An additional **5 dB** is required to compensate for sensorineural and conductive hearing losses
- An additional **5 dB** is required for limited English proficiency and language disorders
- An additional **3 dB** is required to compensate for the effects of excessive reverberation.
- These additional requirements for classrooms total 15 dB over that of normal adults, or a signal-to-noise ratio of +15 dB.
- **We can use the passive acoustics of the architecture to provide some of this needed gain.**



Signal to Noise~ Intelligibility

- Most approaches only try to reduce the **Noise** and often simultaneously decrease the strength of the **Signal** as well. The result is no net improvement.
- The best approach is to simultaneously increase the signal by providing useful, early, diffuse reflections and decrease the Noise from all sources including reverberation by using appropriately placed **diffusion or reflection of appropriate level.**

Classroom

ACOUSTICS



CLASSROOM ~ *Basics*

Acoustic Goals

1. ***Quiet*** room, free from distractions.
2. Appropriate Reverberance for ***Speech Intelligibility***.
3. Strong, early, diffuse reflections for ***Loudness, Envelopment & Speech Intelligibility***.

High Signal to Noise Ratio !



CLASSROOM ~ *Basics*

Worst Case Scenario(s)

- Room dividers, curtain dividers or single-layer GWB walls.
- Common doors and other noise flanking paths (central clocks, electrical outlets, light switches, etc).
- Sliding doors, hollow doors, no doors, doors without gaskets.
- No ceiling (open to floor/roof above).
- **Sound absorptive ceiling.**
- **No carpet under student seating.**
- **No wall absorption or diffusion (painted GWB or CMU).**
- Rooftop HVAC units, VAV/FPB box or perimeter heat unit in classroom, roof drain pipes or toilet exhaust fan ducts passing through rooms, unlined ducts, return plenum or transfer grilles, air velocities over 500 fpm, air terminals over NC-25, etc.



CLASSROOM ~ *Basics*

Best Case Scenario(s)

Massive walls (8" CMU or 6" insulated, double-layer GWB)

- No noise flanking paths (offset penetrations, ducts/conduits above corridor ceiling).
- Solid core wood doors with gaskets.
- **Double layer, isolated, insulated GWB ceiling. Diffusion over center/front part of room. Diffusion/Absorption (Diffsorption) along sides and rear.**
- **Carpeted floors under student seating. Hard floor in center/front part of room.**
- **25-50% wall diffisorption ~ Consider soffits treated with diffisorption**
- Maximum NC-25 background noise, HVAC in MERs, duct silencers, lined ductwork, ducted return, VAV/FPB above corridor, air velocities below 500 fpm within 25' of classroom, NC-20 air terminals.

CLASSROOM ~ *Analysis*

Ceiling Treatment Options

Absorption

Absorption: Absorbed sound is removed and doesn't return. Acoustical ceilings absorb most sound.



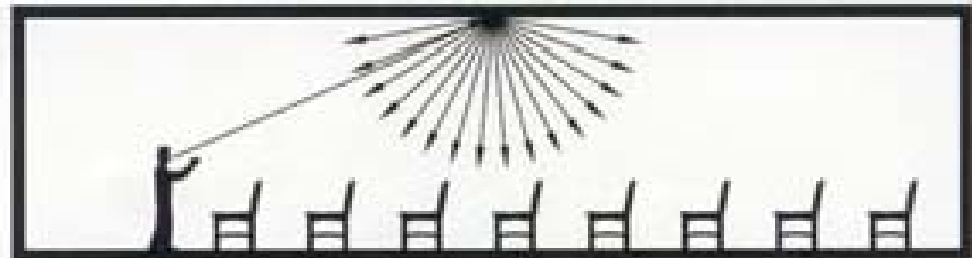
Reflection

Reflection: Reflected sound bounces off a surface and continues on unimpeded in a new direction. Cathedrals with no sound absorption produce echoes that generate long reverberation times and impair intelligibility.



Diffusion

Diffusion: Diffused sound bounces off an irregular surface and scatters it uniformly. Frosted glass creates the same effect with light – no light is removed but it is uniformly scattered in many directions, minimizing glare in any one direction. Sound diffusers act in a similar way.



The combination of diffused sound and absorbed sound is the perfect combination to manage what reaches an individual's ear for high intelligibility. Compare the sense of immersion in listening to music with a monophonic speaker and a fully surround sound system.

Classroom~ Concept Model

Reflective Front Wall/Ceiling

Diffusive Ceiling Over Middle of Room

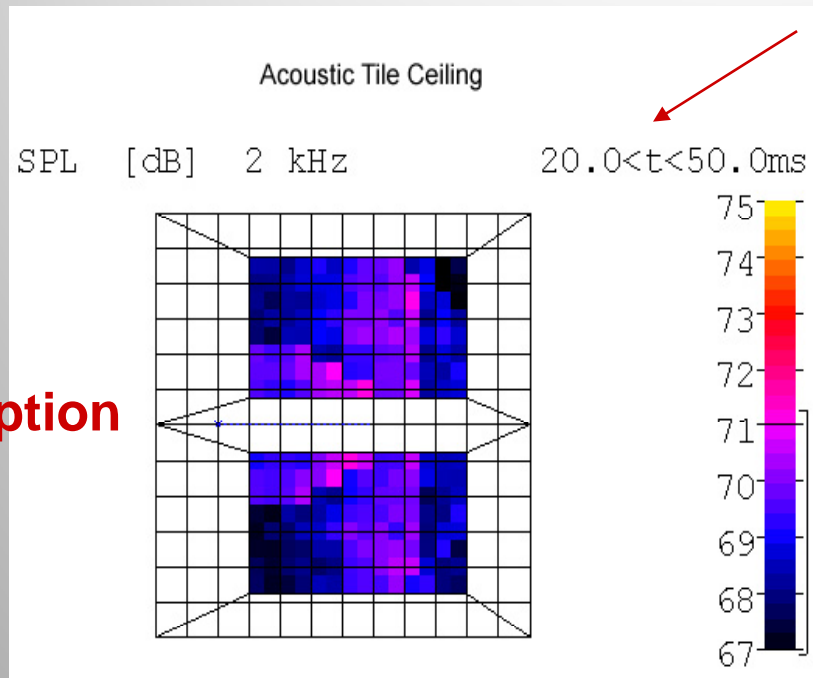


Absorptive
Perimeter
Ceiling

Diffusive Side/Rear Walls

CLASSROOM ~ Analysis

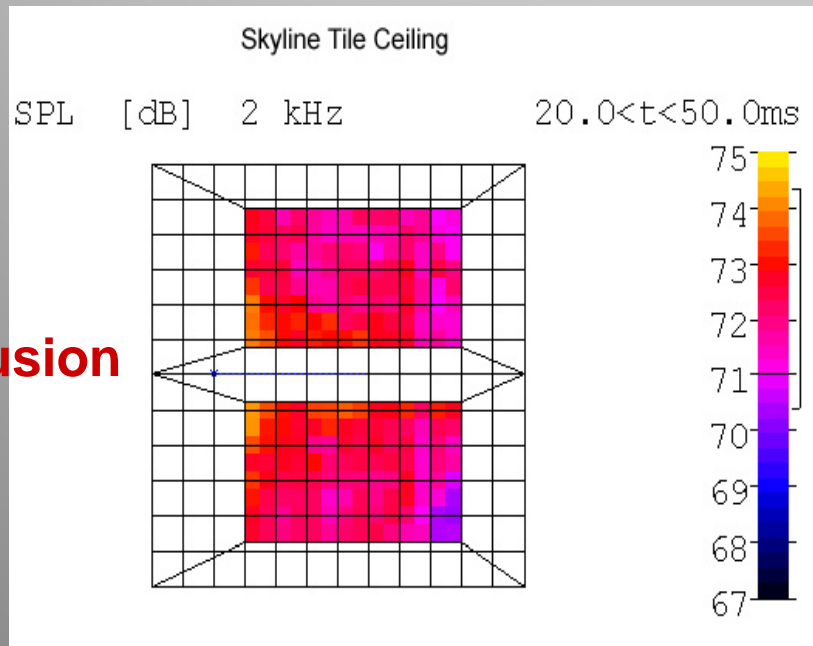
Absorption



20-50 ms Early Signal

The sound pressure level, **SPL**, is rather **low** in the purely absorptive ceiling, making it difficult for the speaker to project causing fatigue

Diffusion

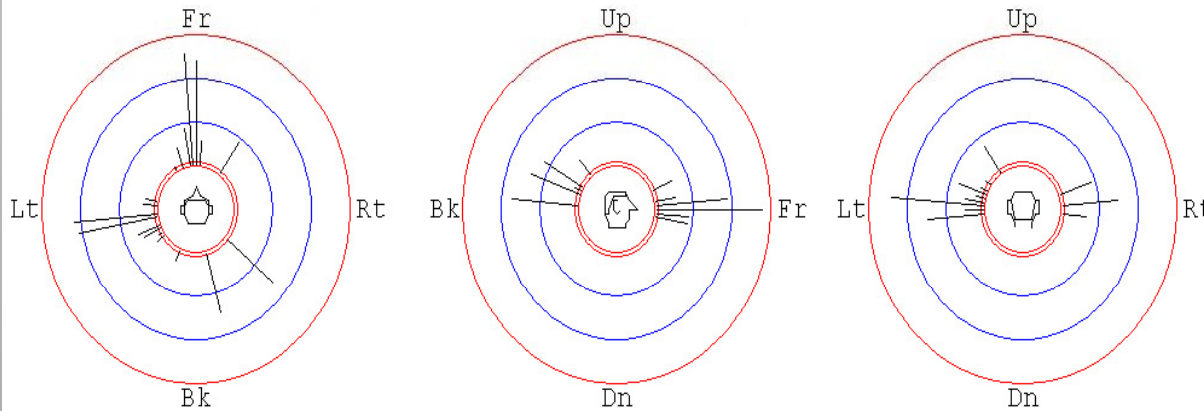


With the diffusive ceiling, **SPL** is **more uniform** and there is **additional acoustic gain** raising the level in the classroom and making it easier for the speaker to project & students to hear

CLASSROOM ~ Analysis

Absorption

ACOUSTIC TILE CEILING

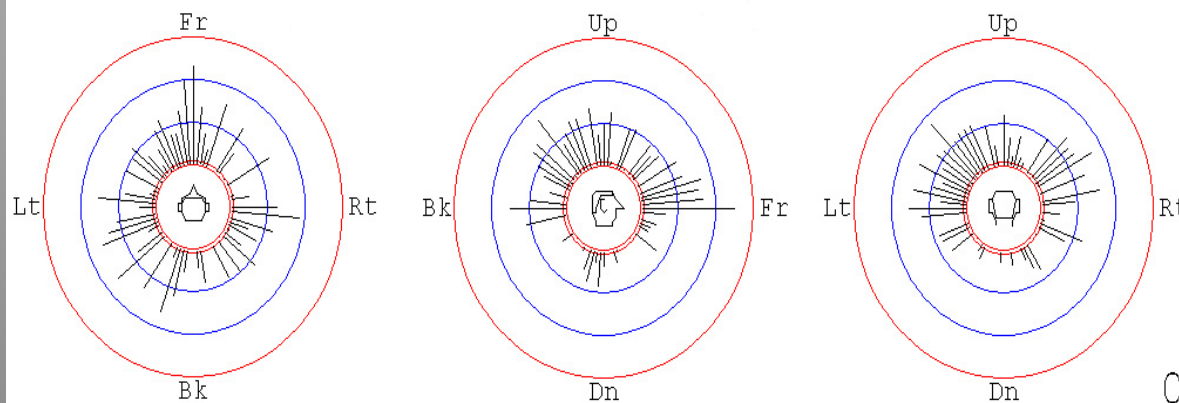


$0.00 < t < 50.0 \text{ ms}$

With the purely absorptive ceiling, reflections are sparse with minimal sound arriving from the vertical plane

Diffusion

SKYLINE CEILING



$0.00 < t < 50.0 \text{ ms}$

With diffusive ceiling, reflection density is greater and sound is arriving uniformly from all directions



CLASSROOM ~ *Conclusions*

- Diffusive ceilings increase the acoustic level and uniformity of coverage without corrupting the speech intelligibility.
- Increasing the acoustic level increases the learning process by extending the attention span and also addresses hearing acuity and hearing impairment.
- The teacher exerts less energy and experiences less fatigue by not speaking into an acoustic vacuum.
- Energy reaches the students from many directions creating a sense of immersion in the learning experience ([surround sound vs mono](#)) for a more intimate, attentive learning experience.
- Diffusion also improves student-student and student-teacher communication (not only teacher to student communication).

Lecture Hall

ACOUSTICS



LECTURE ROOM ~ *Basics*

Acoustic Goals

1. Appropriate ***Reverberance*** for high speech ***Intelligibility***.
2. Good ***Cross-Room Communication*** so lecturer and audience can engage in dialogue.
3. Good ***Support*** so that lecturer can hear himself.
4. Freedom from ***Flutter*** and ***Echoes***.
5. Freedom from extraneous ***Noise*** from occupants and building systems.



LECTURE ROOM ~ *Basics*

Acoustic Goals

1. Appropriate ***Reverberance*** for high speech ***Intelligibility***.
 - Room Shape (Rectangular Solid or Fan ~ Avoid Circular)
 - Room Volume (150 – 250 cf/seat)
 - Room Height (Low 10' – 20')
 - Absorptive & Diffusive Finish Materials



LECTURE ROOM ~ *Basics*

Acoustic Goals

2. Good ***Cross-Room Communication*** so lecturer and audience can engage in dialogue.
 - Low, Sound Diffusive/Reflective Ceiling (or Reflectors)
 - **AVOID SOUND ABSORPTIVE CEILING!**



LECTURE ROOM ~ *Basics*

Acoustic Goals

3. Good **Support** so that lecturer can hear himself.
 - Specific wall & ceiling surfaces close to and facing back at lecturer location.
 - Sound diffusive rear wall (if less than 35' away)
 - Sound diffsorptive rear wall (if greater than 35' away)
 - Low, Sound Diffusive/Reflective Ceiling (or Reflectors)
 - **AVOID SOUND ABSORPTIVE CEILING!**
 - **AVOID SOUND ABSORPTIVE REAR WALL**



LECTURE ROOM ~ *Basics*

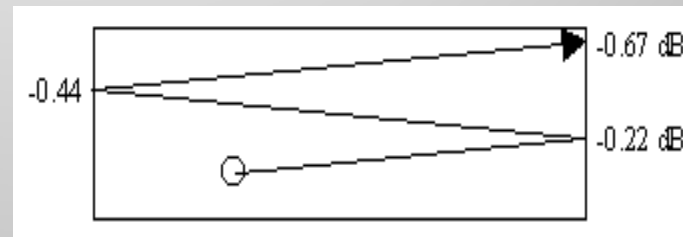
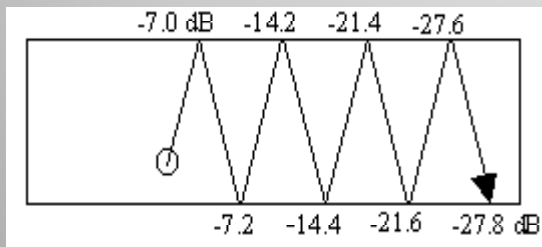
Acoustic Goals

4. Freedom from *Flutter* and *Echoes*.
 - Room Shaping (Avoid Parallel Reflective Surfaces)
 - Diffusive Finish Materials
 - Acoustic Treatment Location (**Avoid S.P.A.S.tic design**)



LECTURE HALL ~ S.P.A.S.

- Single Plane Absorption Syndrome (**SPAS**)
- Absorptive Ceiling & Absorptive Floor
- Reflective Walls
- Lecture Hall, Classroom, Natatorium, Gymnasium



- During the same time period, a vertical sound ray is attenuated by almost 30 dB due to absorption, while a horizontal sound ray is hardly attenuated at all.
- Leads to a non-mixing sound field characterized by different reverberation times in the two planes.
- Makes echoes and flutter more audible and problematic.
- **Diffusion can be used to correct this problem**



Lecture Room



Existing: ACT ceiling, carpeted floor, reflective walls

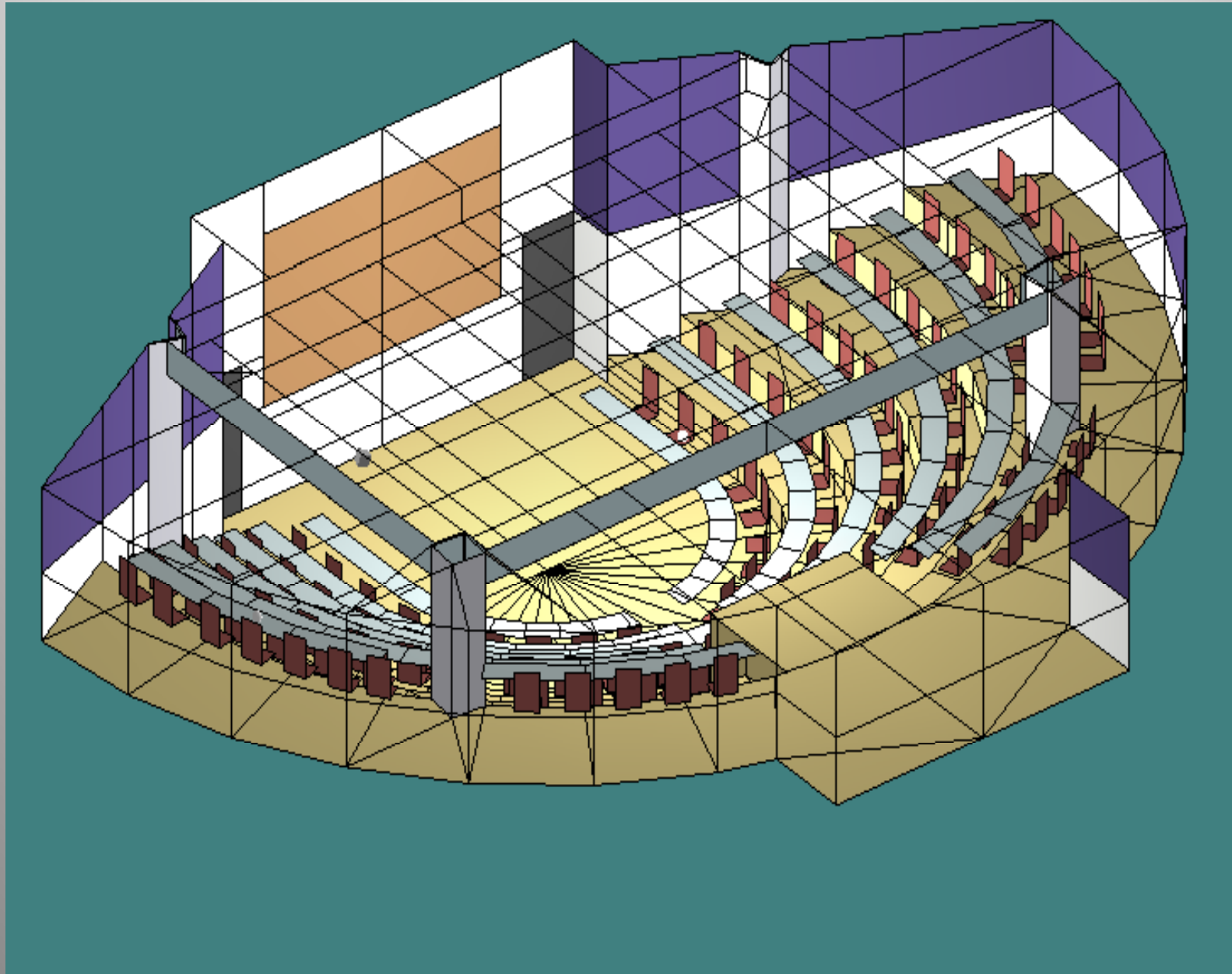
Treatment: Reflective front wall and ceiling, 2D diffusion center of room, ACT on perimeter, diffusive mid third side walls, diffusion rear wall



LECTURE HALL ~ *Example*

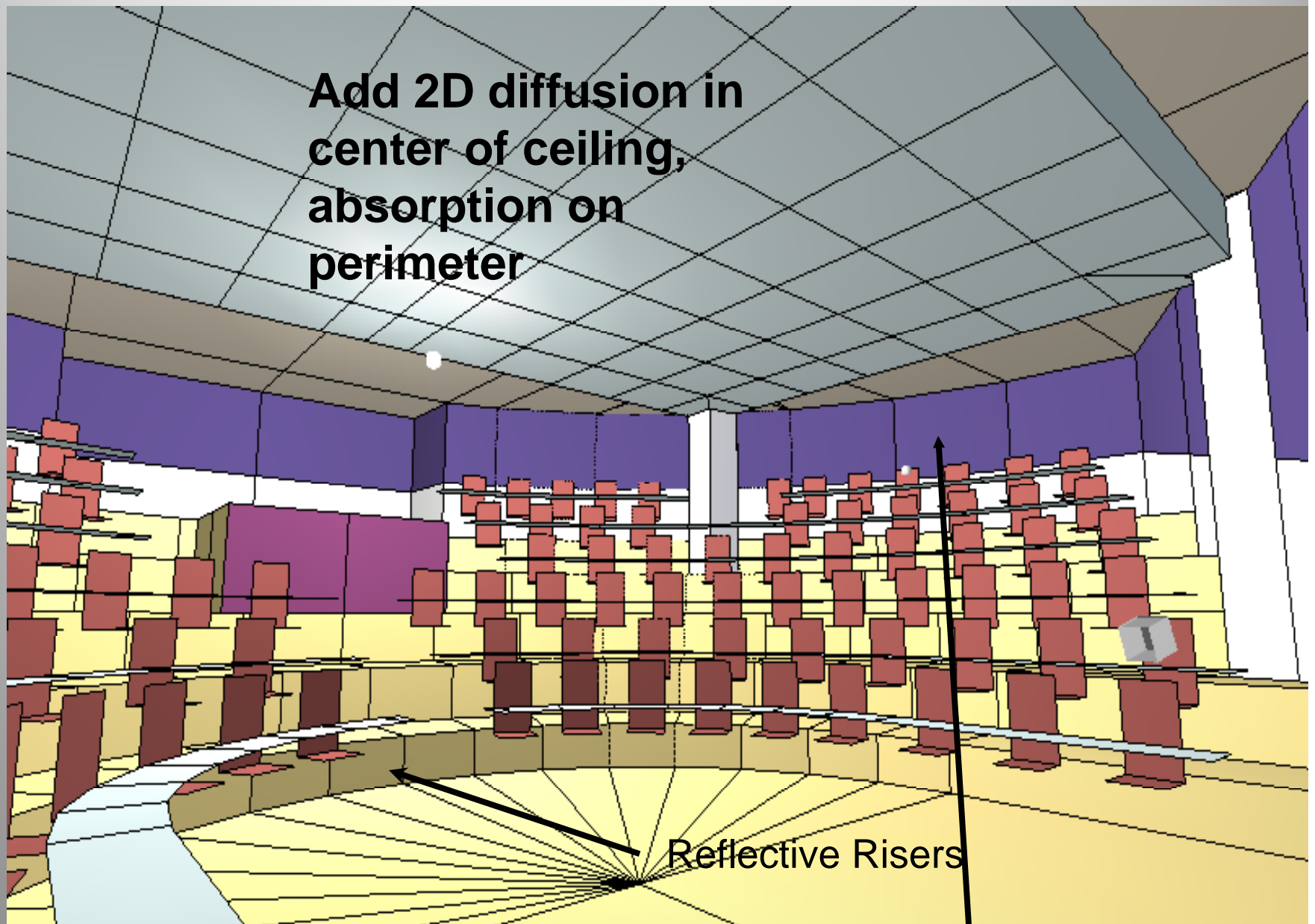


LECTURE HALL ~ *Analysis*



LECTURE HALL ~ *Analysis*

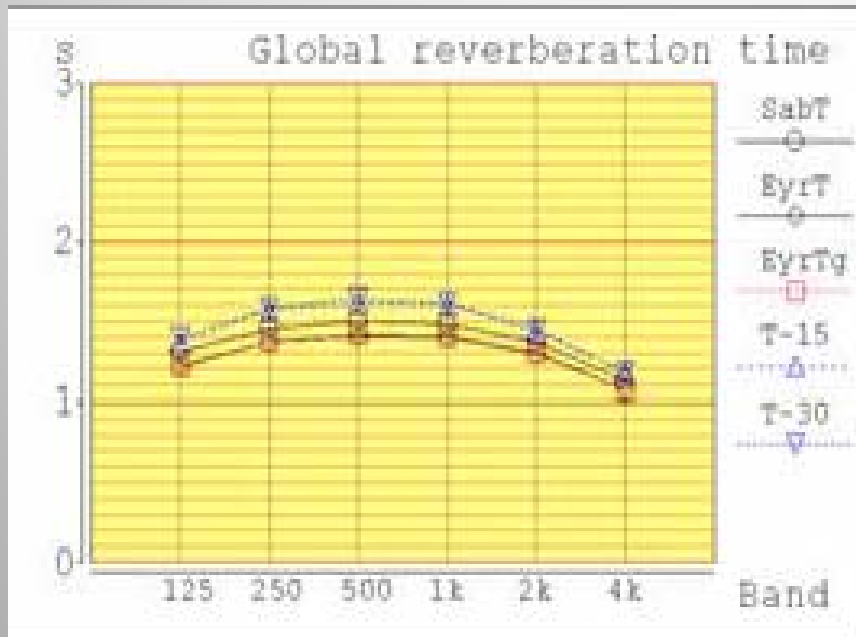
Add 2D diffusion in
center of ceiling,
absorption on
perimeter



Reflective Risers

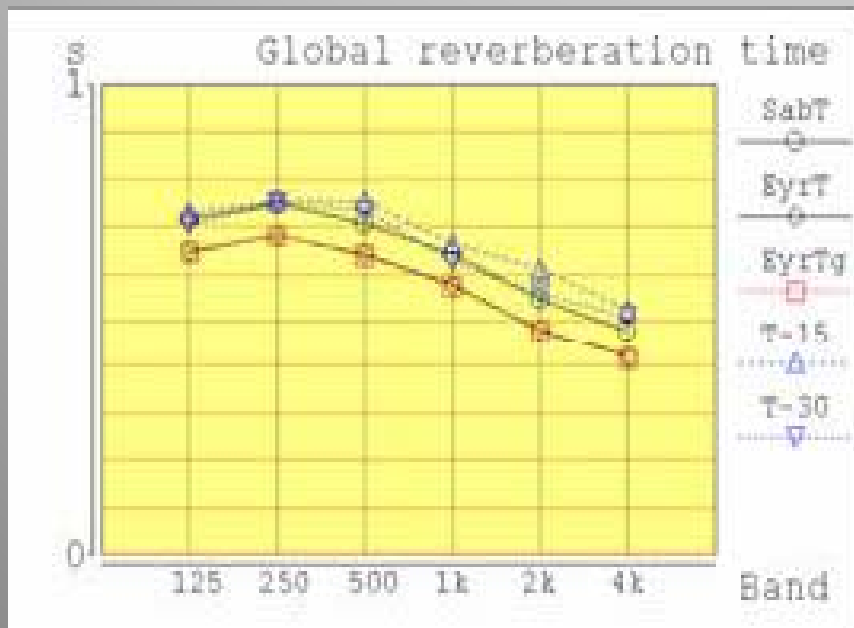
Diffusion on walls

LECTURE HALL ~ *Analysis*



Untreated

T60 > 1.5 sec



Treated

T60 = 0.70 sec





LECTURE HALL ~ *Example*





LECTURE ROOM ~ Checklist

- ❑ Room Shape ~ Rectangular, Fan
- ❑ Room Volume ~ 150 to 250 cf/seat.
- ❑ Low, sound diffusive/reflective ceiling or ceiling reflectors (**Not Absorptive**)
- ❑ Reflective front wall
- ❑ Diffusive/reflective side walls (below 8')
- ❑ Diffusive side walls (above 8')
- ❑ Diffusive rear wall
- ❑ Reflective surfaces close to and facing lecturer
- ❑ Massive boundary construction & quiet building systems

Conference & Meeting Rooms

ACOUSTICS



Conference Room - *Small*



**2D Diffusion
over
conference
table**

Diffisorption

Existing: ACT Ceiling ~ Carpeted Floor ~ Untreated Drywall Walls

Treatment: 2D Diffusion over conference table, ACT around perimeter, diffisorption on mid-third of walls, LF Absorbers if needed above the ACT ceiling



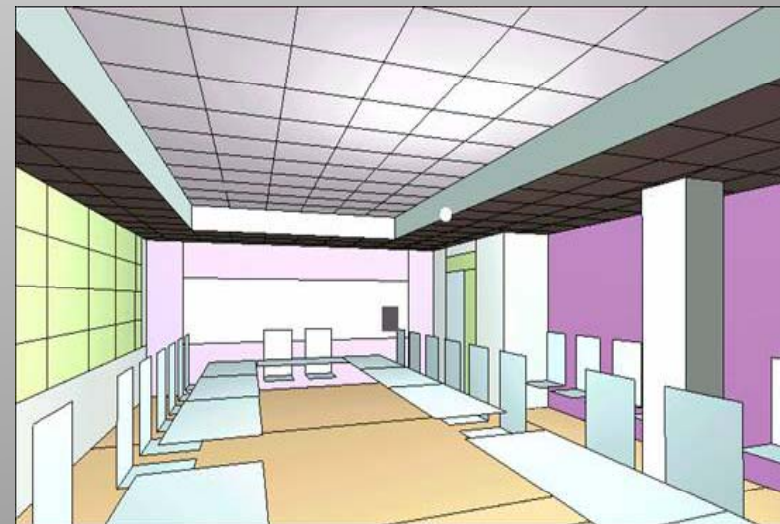
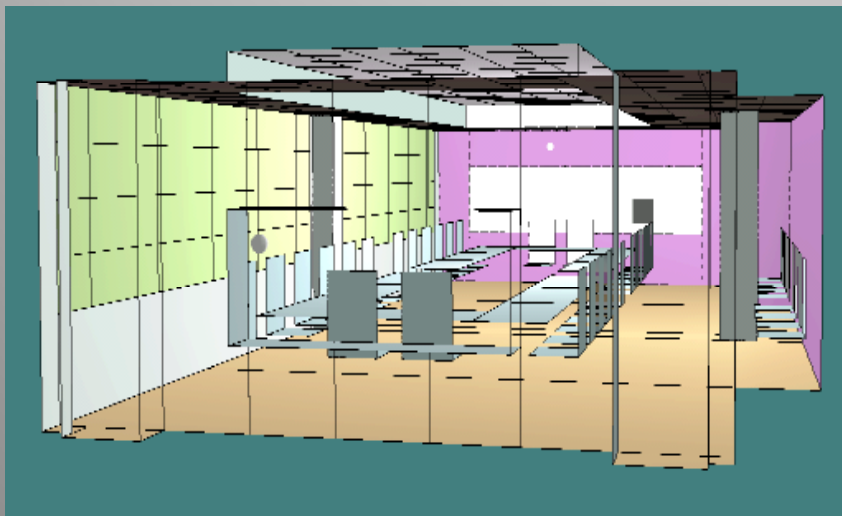
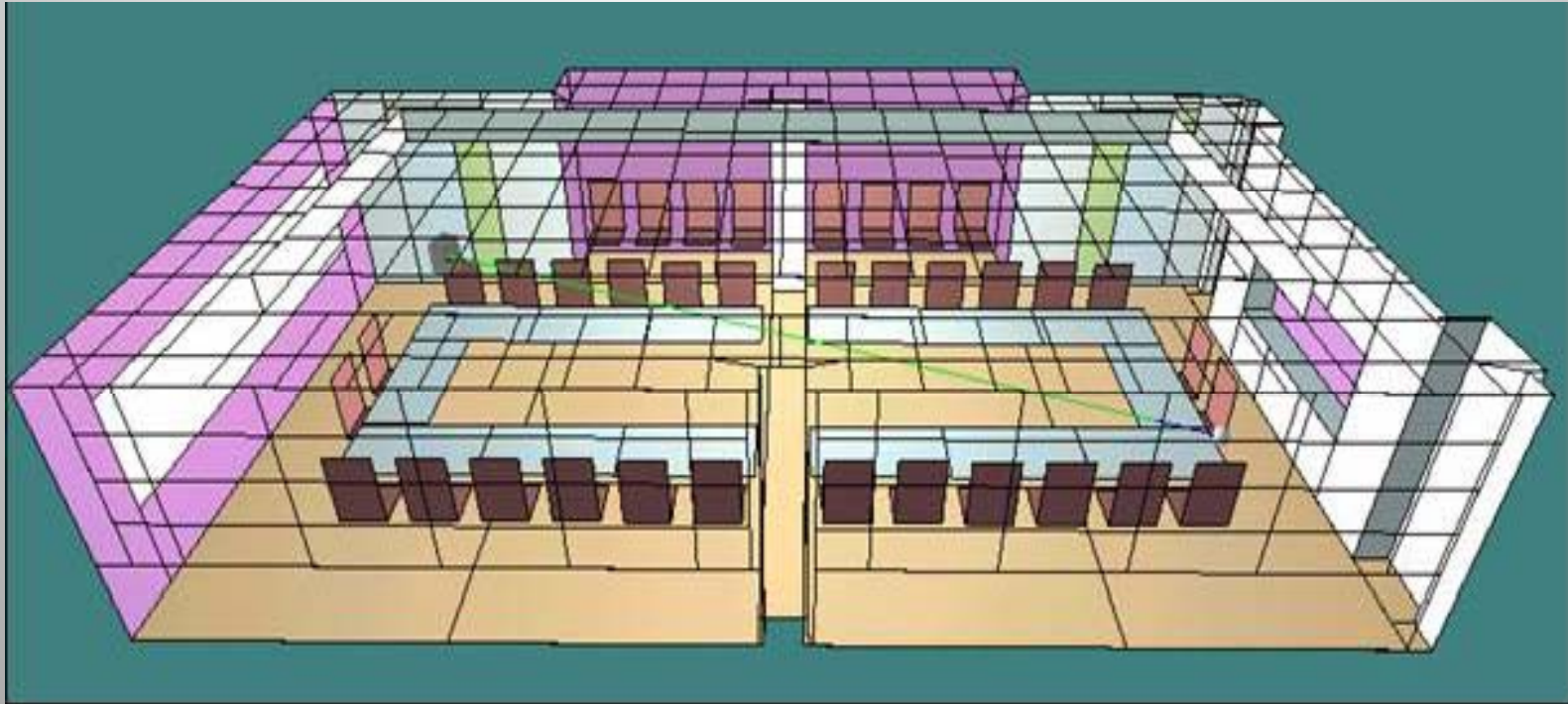
Conference Room



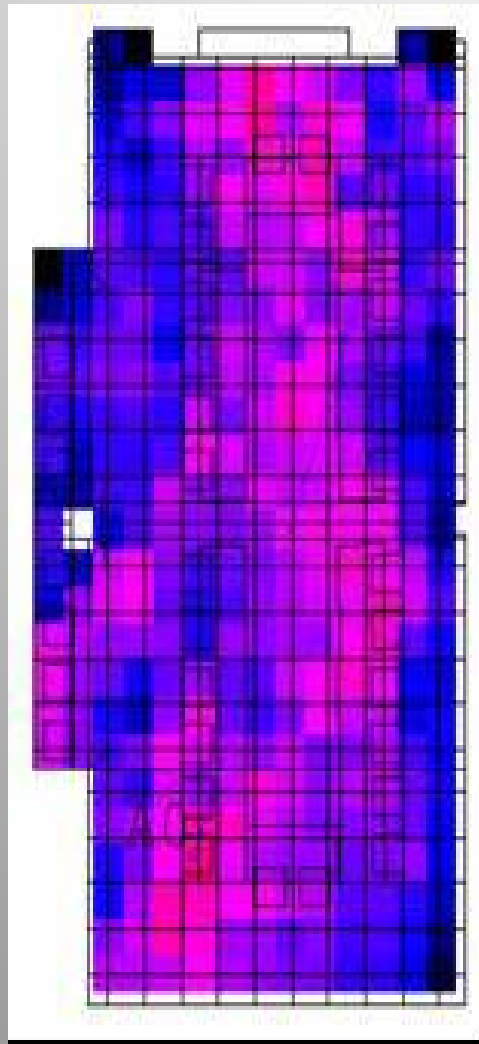
Existing: ACT Ceiling ~ Carpeted Floor ~ Absorptive Panels on Walls

Treatment: 2D Diffusion over conference table, diffusion or diffsrption on mid third of side walls, LF absorption over ACT if needed

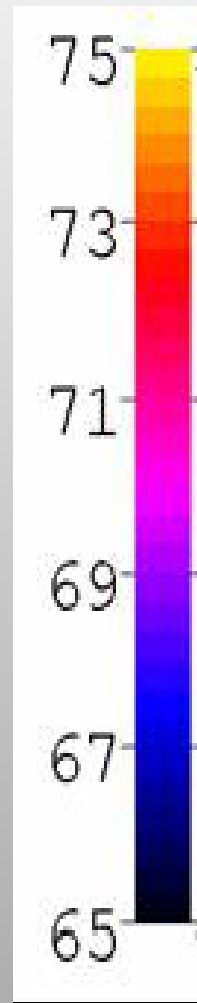
Conference Room - *Analysis*



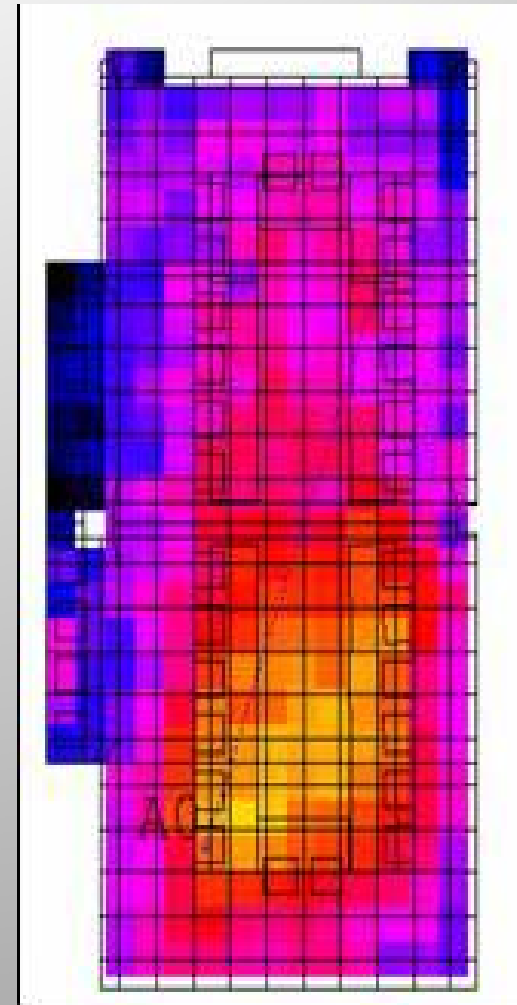
Conference Room - *Analysis*



Typical Treatment



SPL (dB)



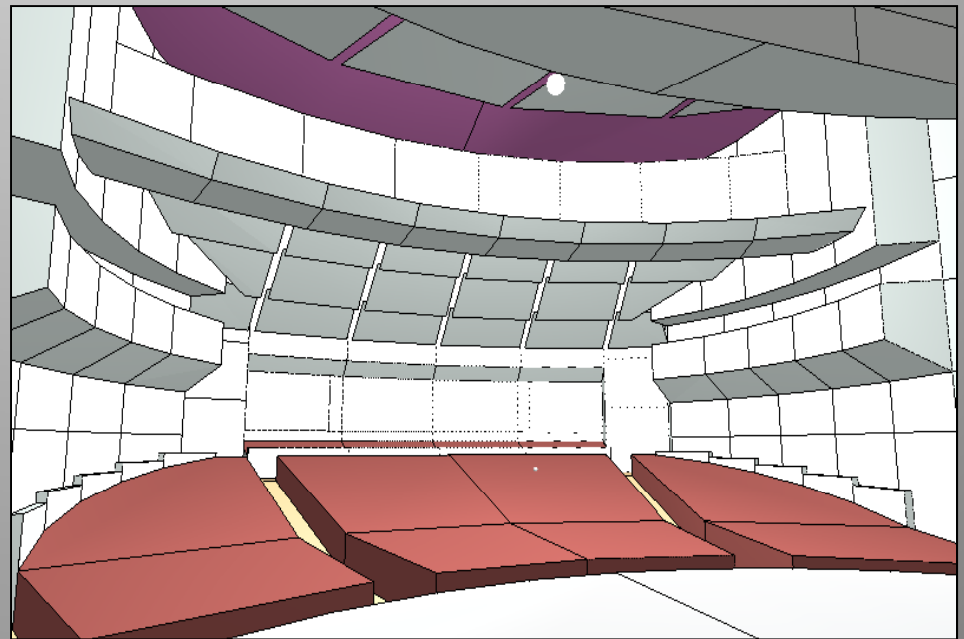
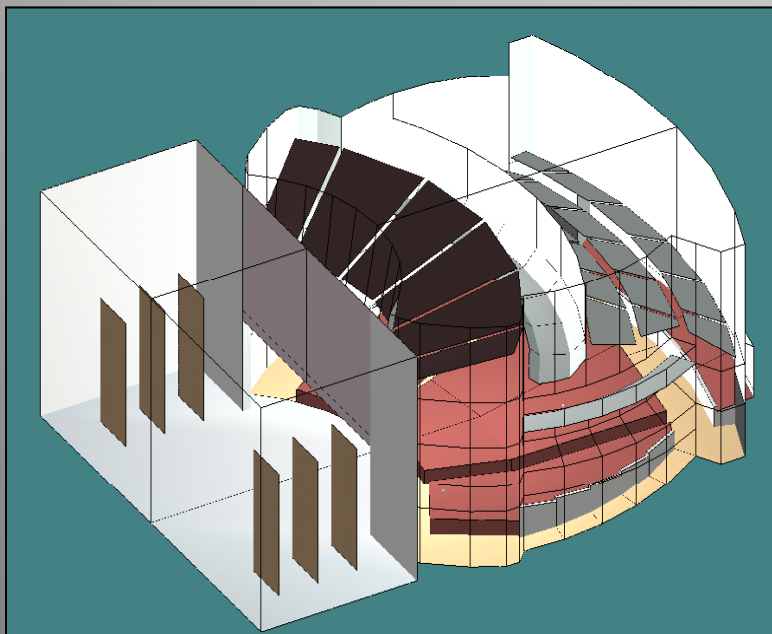
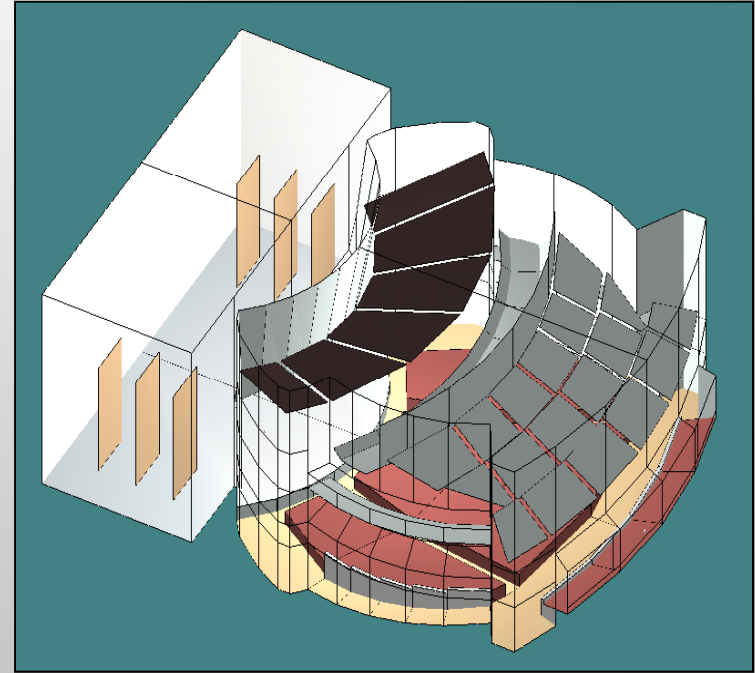
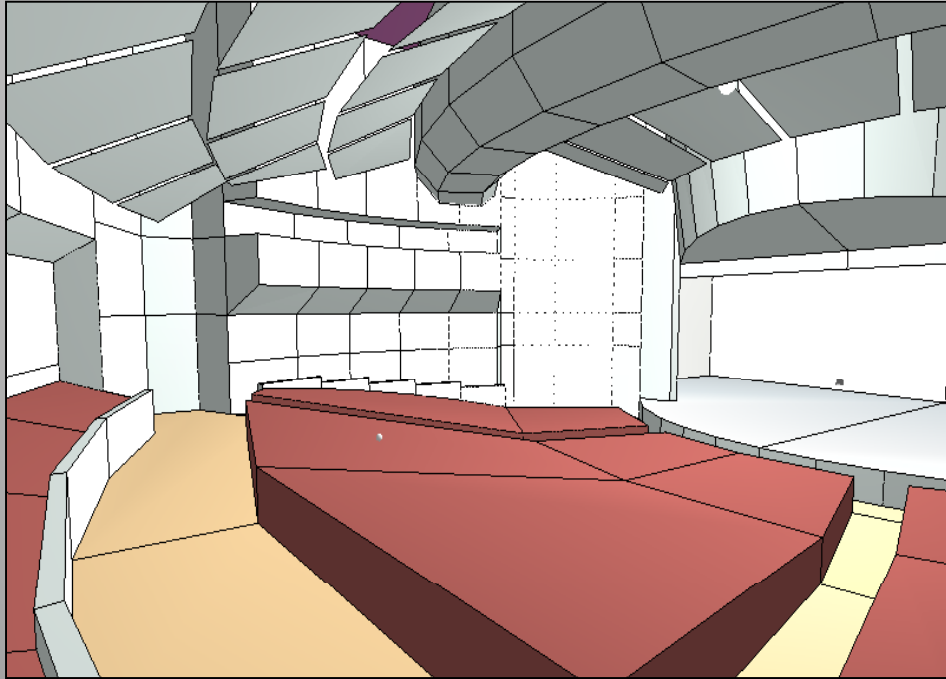
Proper Treatment

Auditorium Analysis

ACOUSTICS

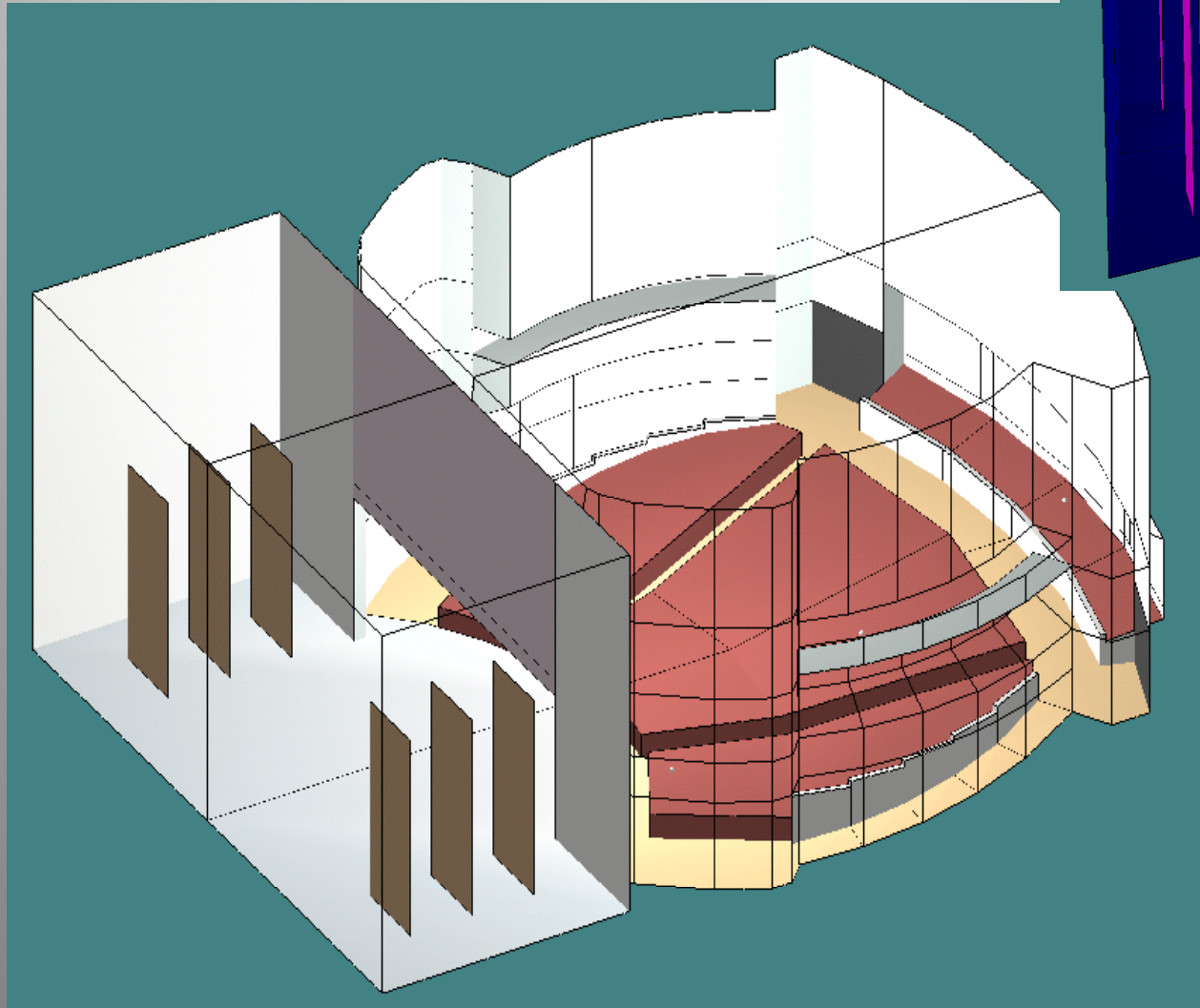
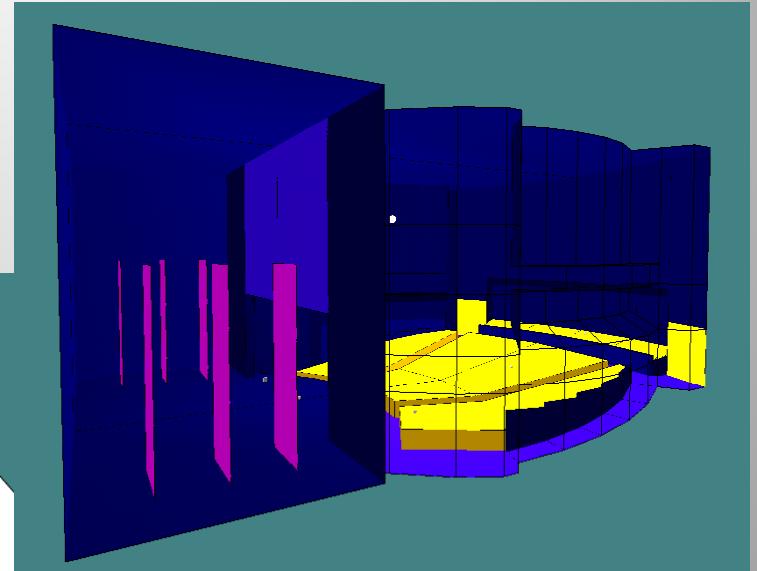


Acoustical Model





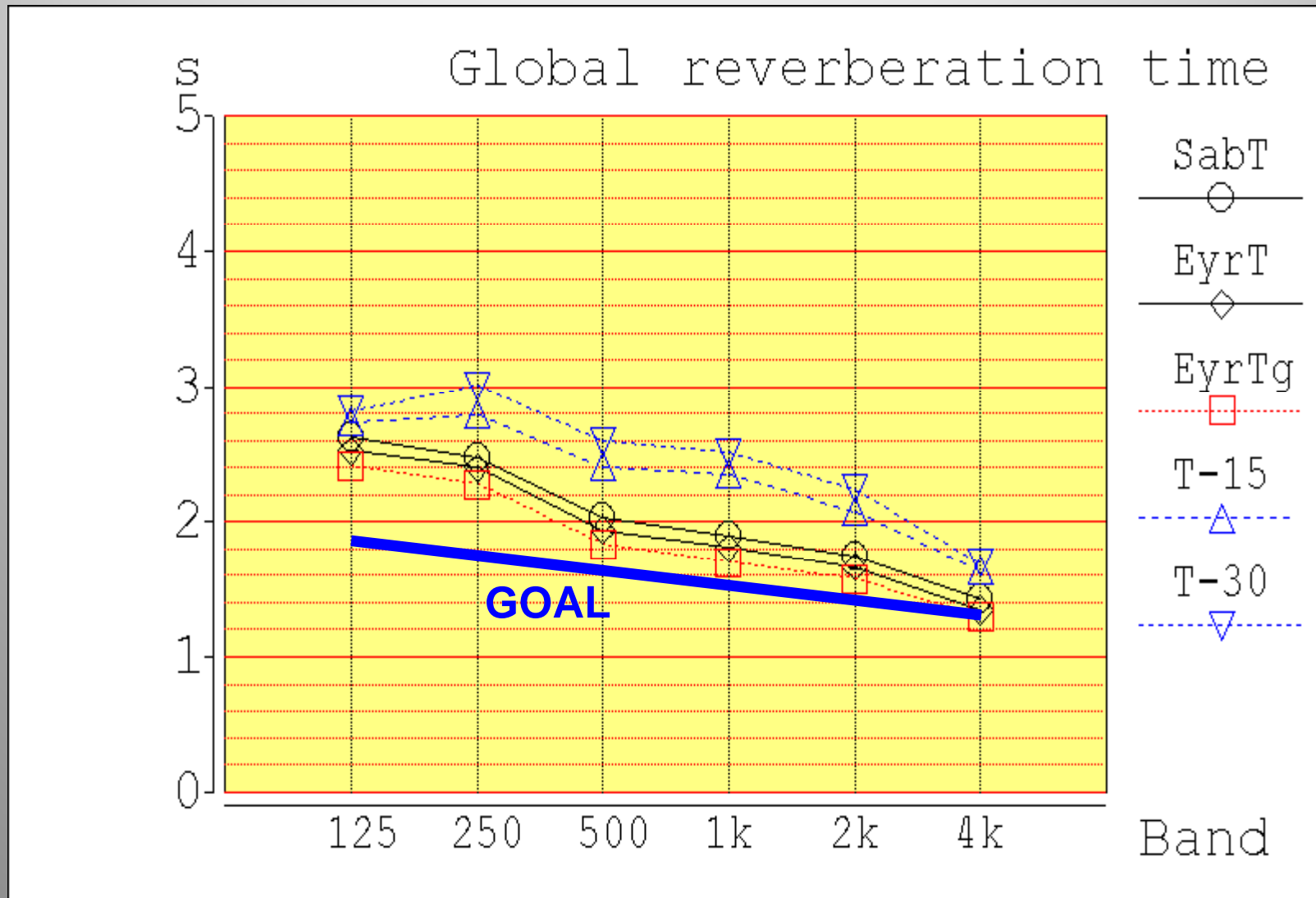
Case 0 ~ No Treatment



ABSORPTION



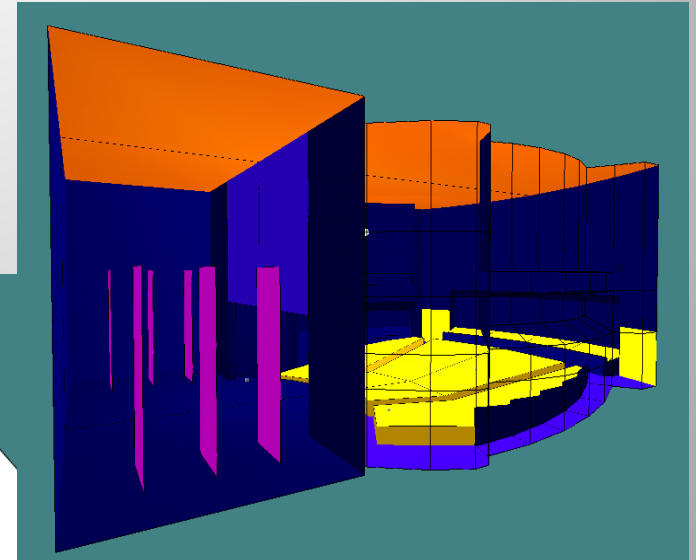
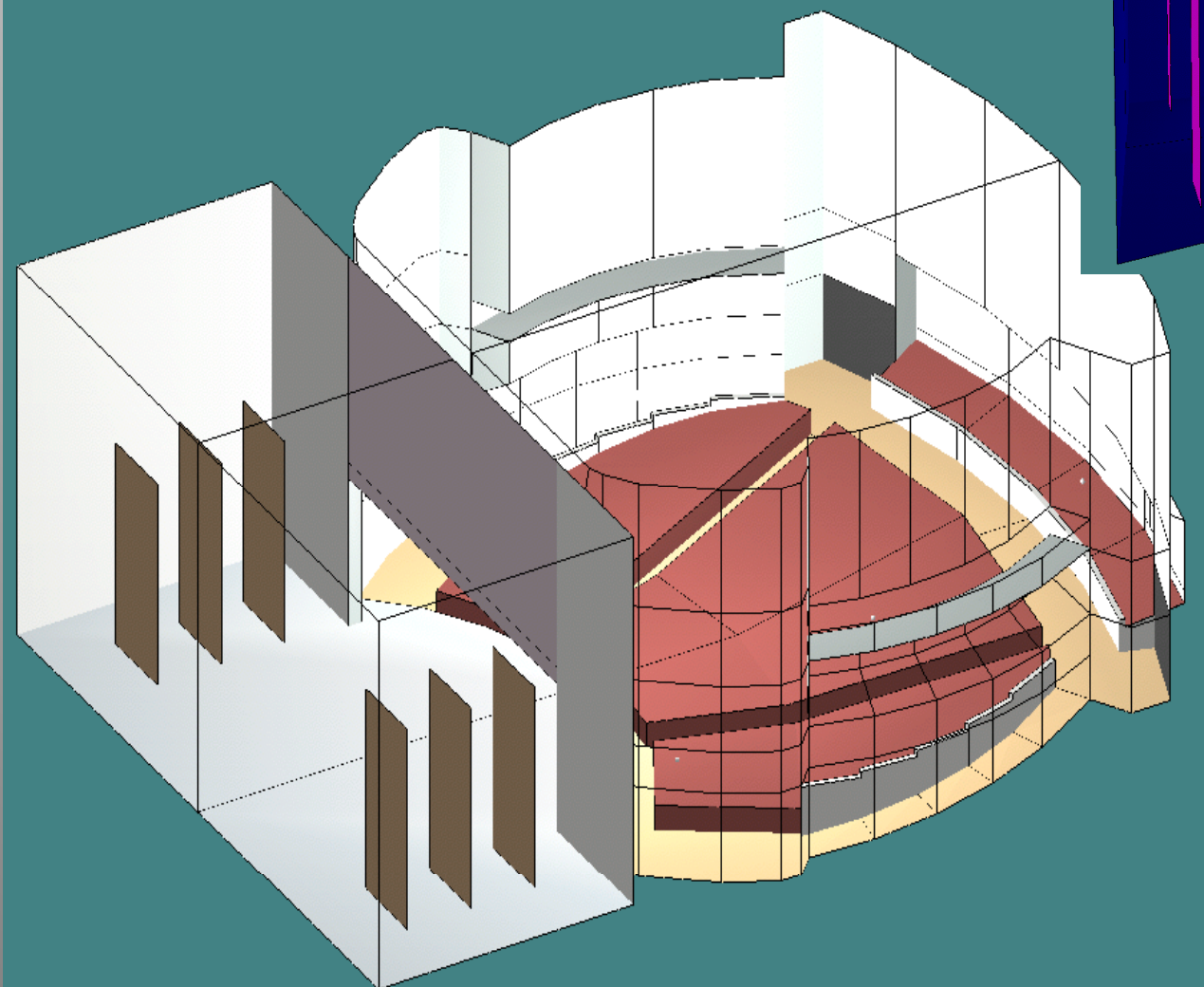
Case 0 ~ Reverberation



TOO LONG FOR A MULTI-USE AUDITORIUM



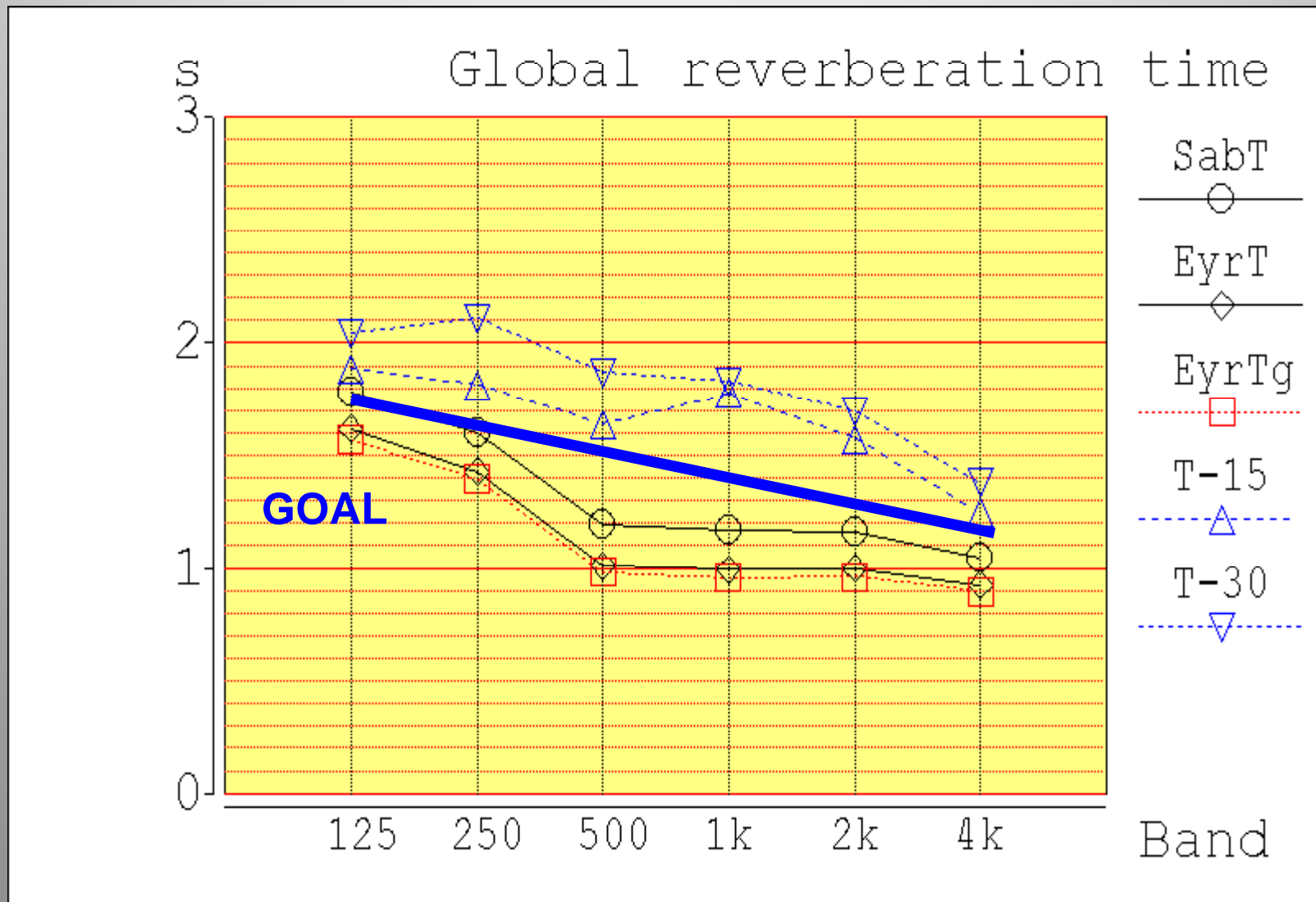
Case 1 ~ Acoustic Deck



ABSORPTION



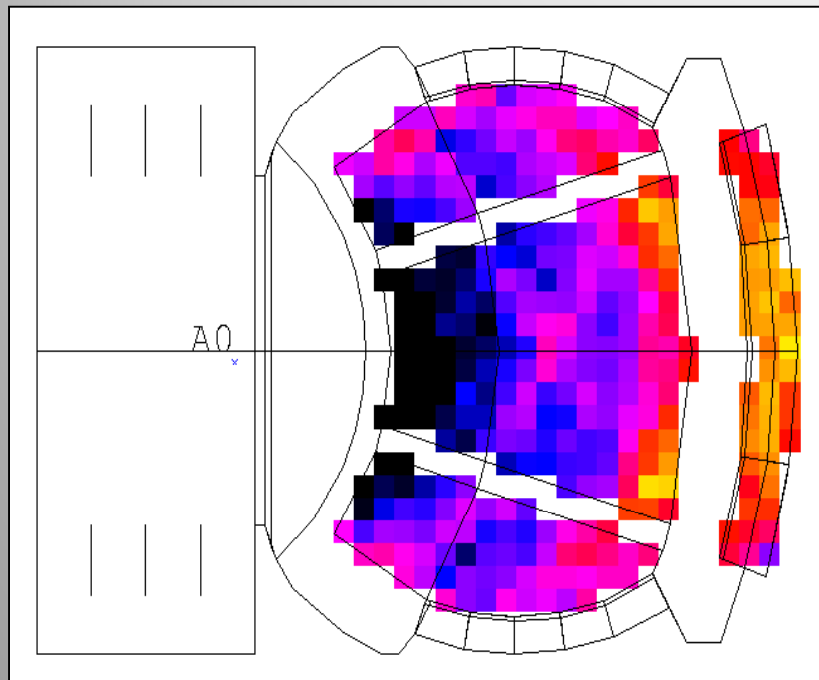
Case 1 ~ Reverberation



TOO LONG FOR A MULTI-USE AUDITORIUM



SPL Non-Uniformity

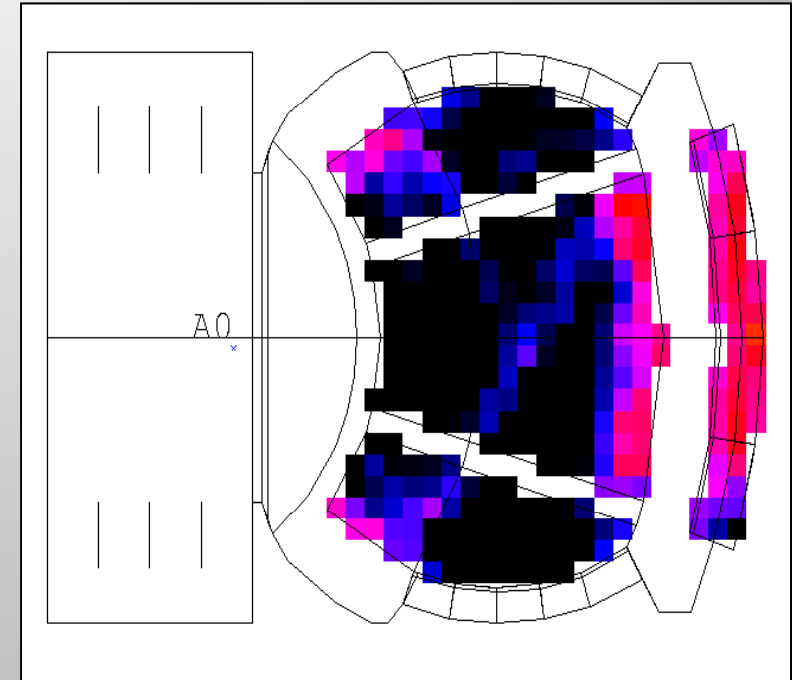
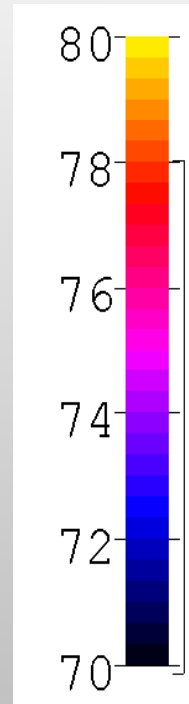


Case 0

Standard Metal Deck

No Treatment or Reflectors

Great Variation & Bad Uniformity



Case 1

'Acoustic' Metal Deck

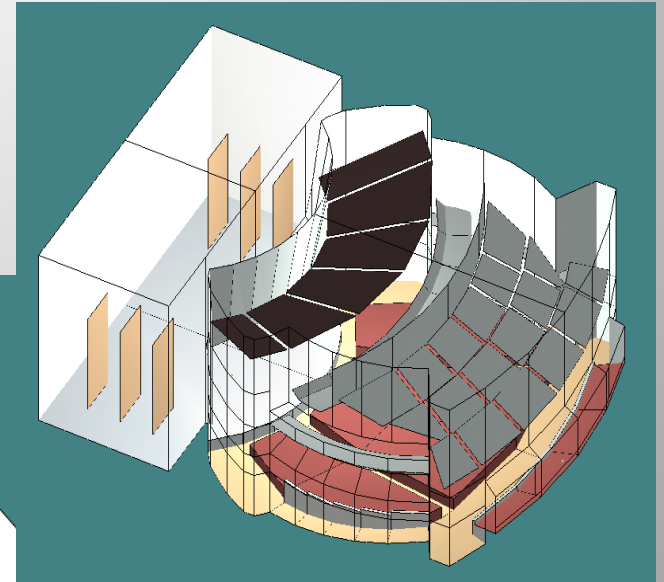
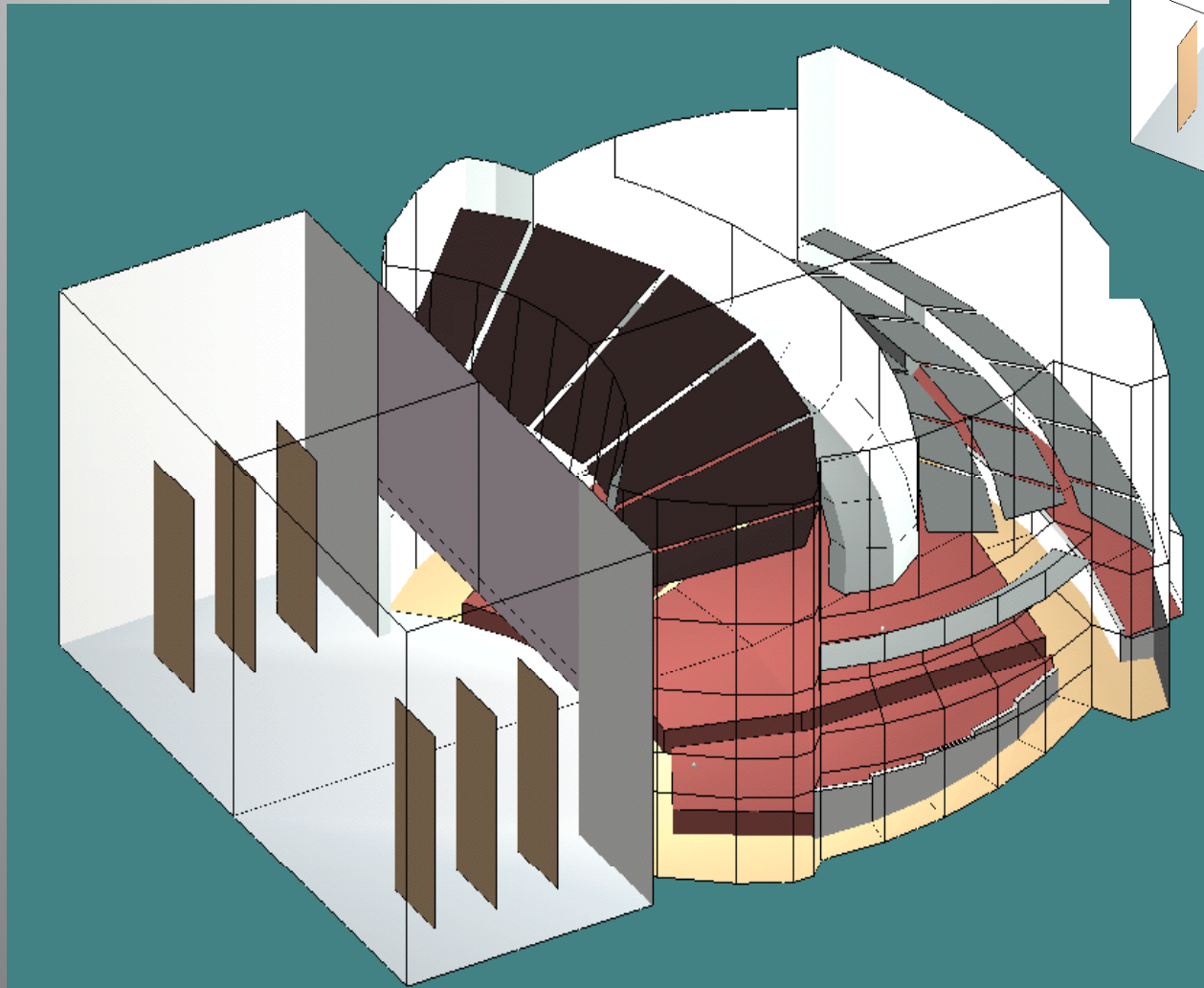
No Other Treatment

Less Variation (Except Rear Seats)

Less Reverberance & More Echoes

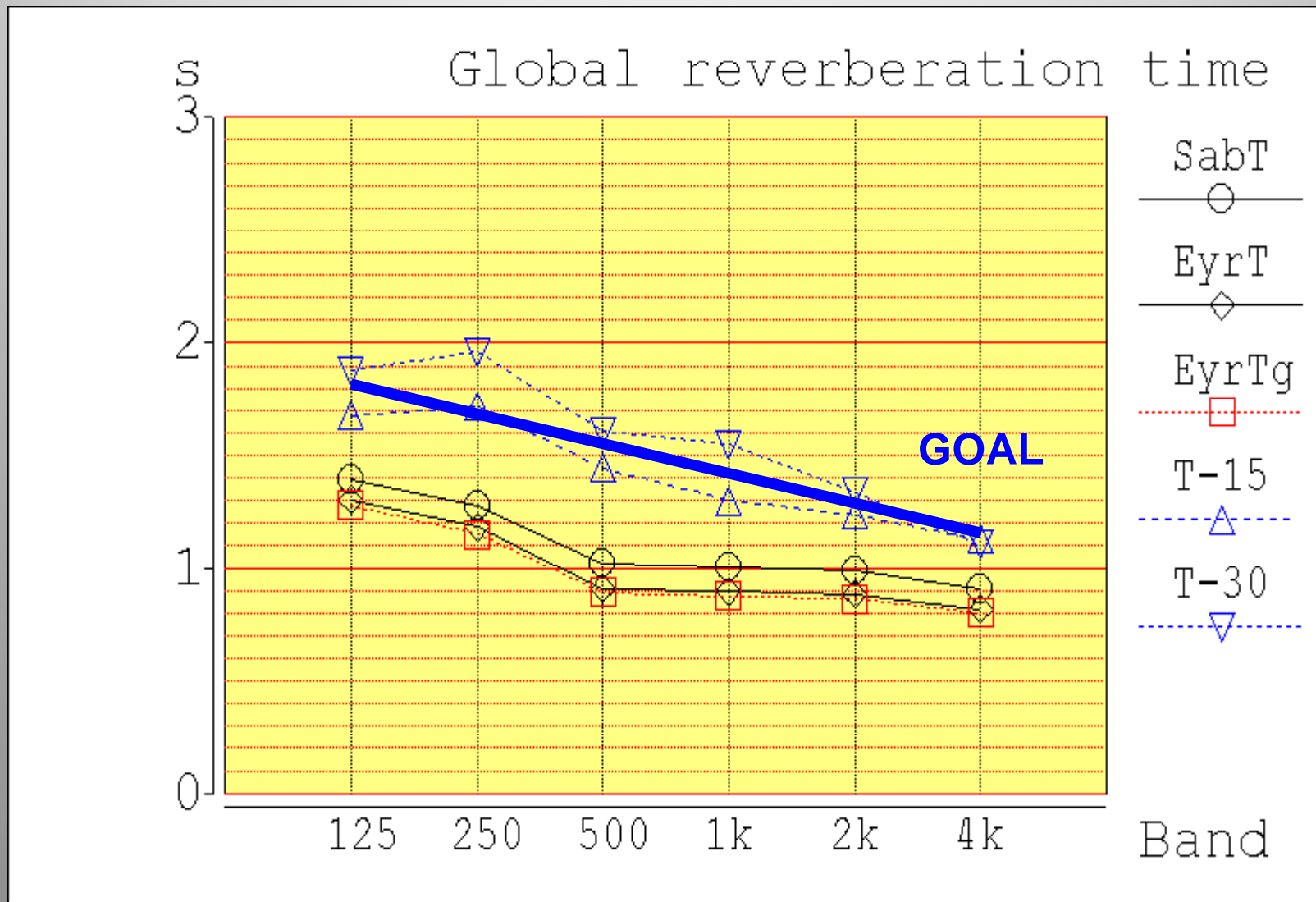


Case 2 ~ Reflectors





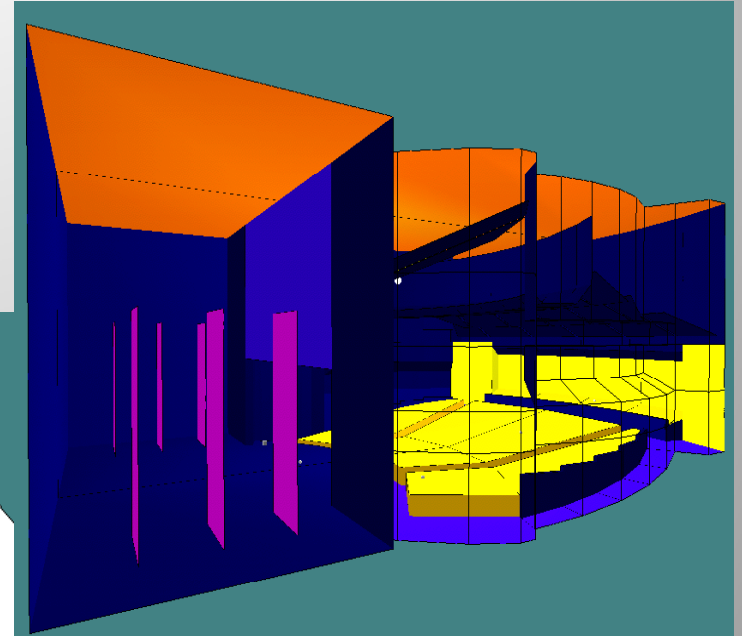
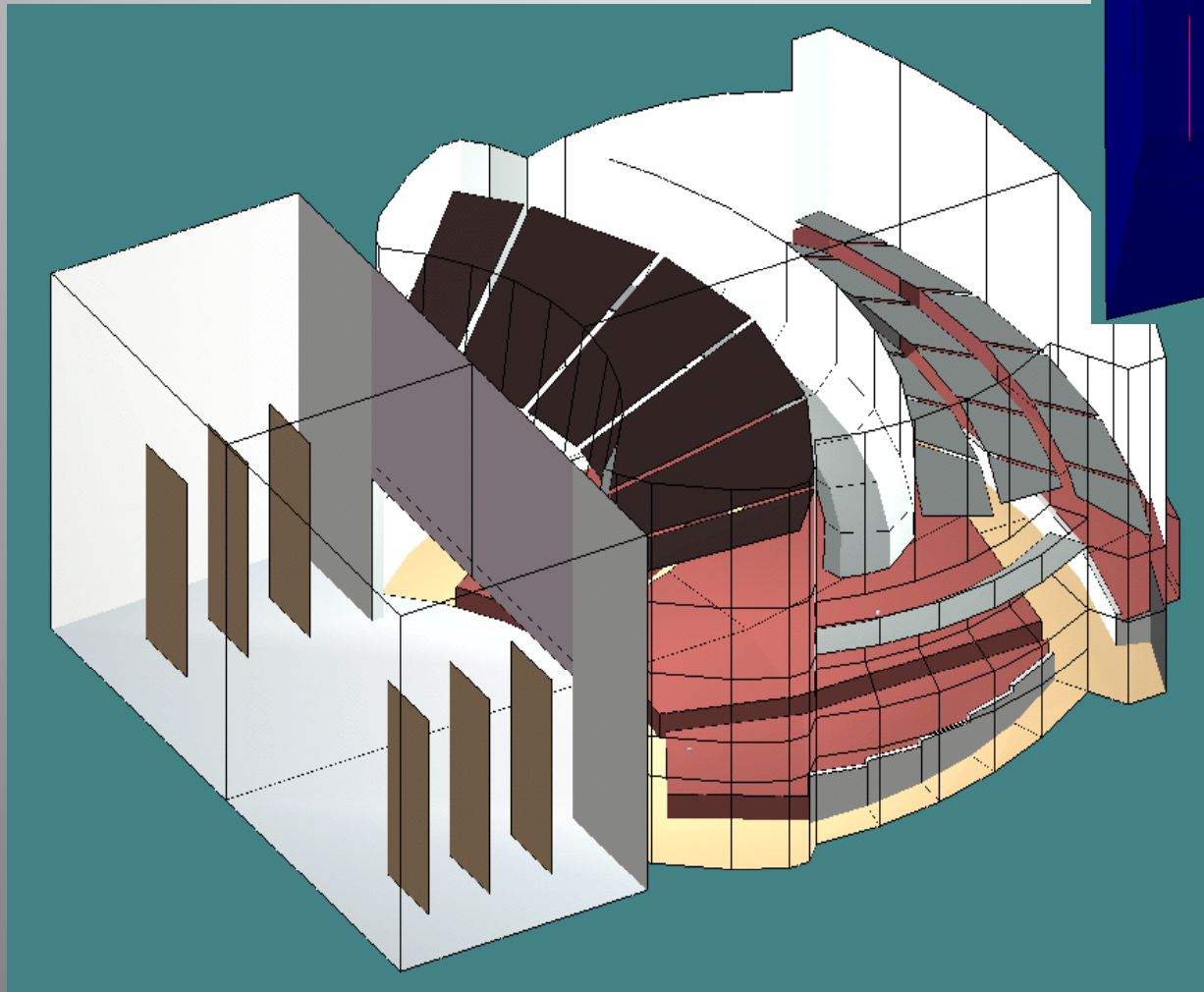
Case 2 ~ Reverberation



APPROPRIATE FOR A MULTI-USE AUDITORIUM



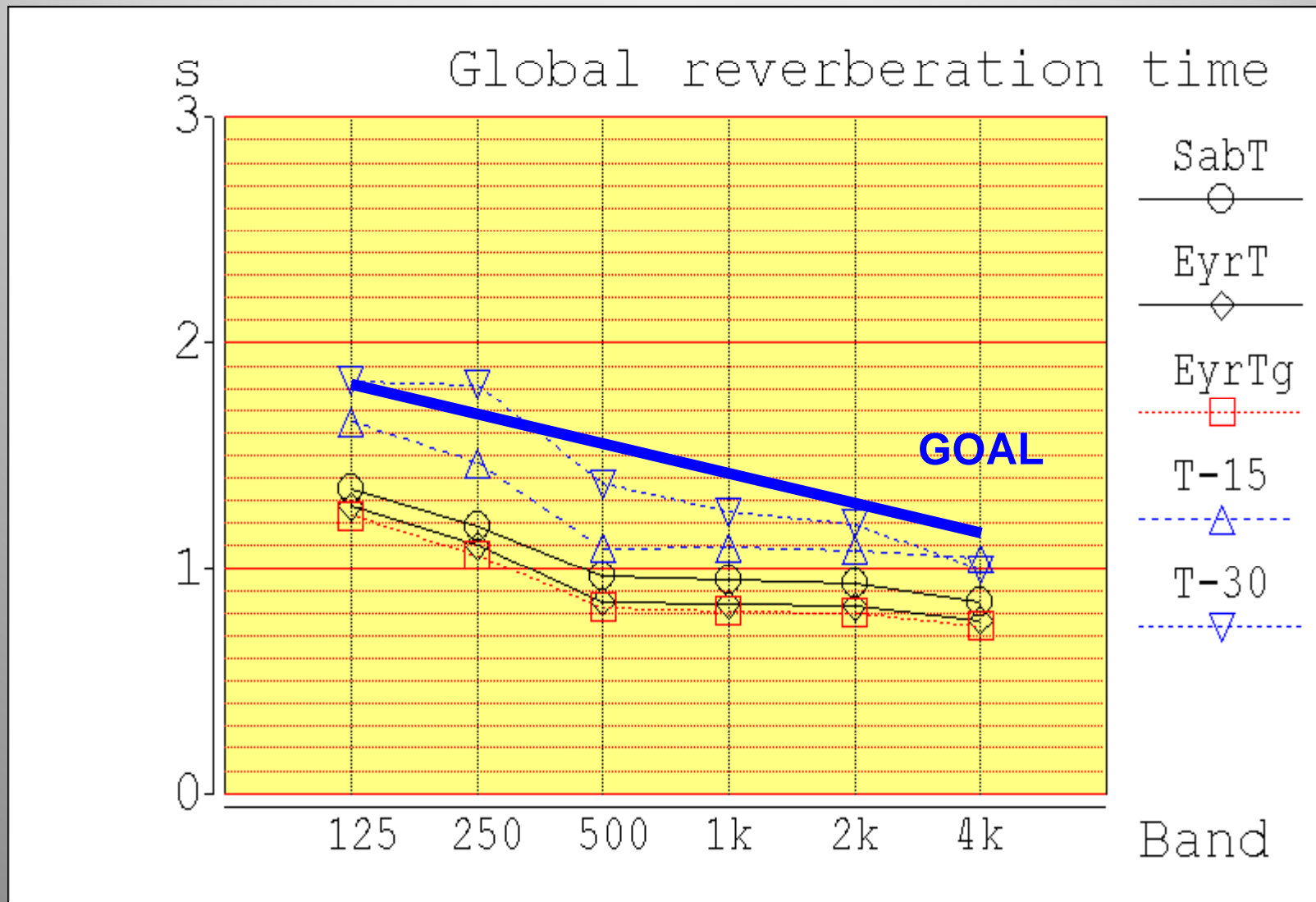
Case 3 ~ Absorptive Rear Wall



ABSORPTION



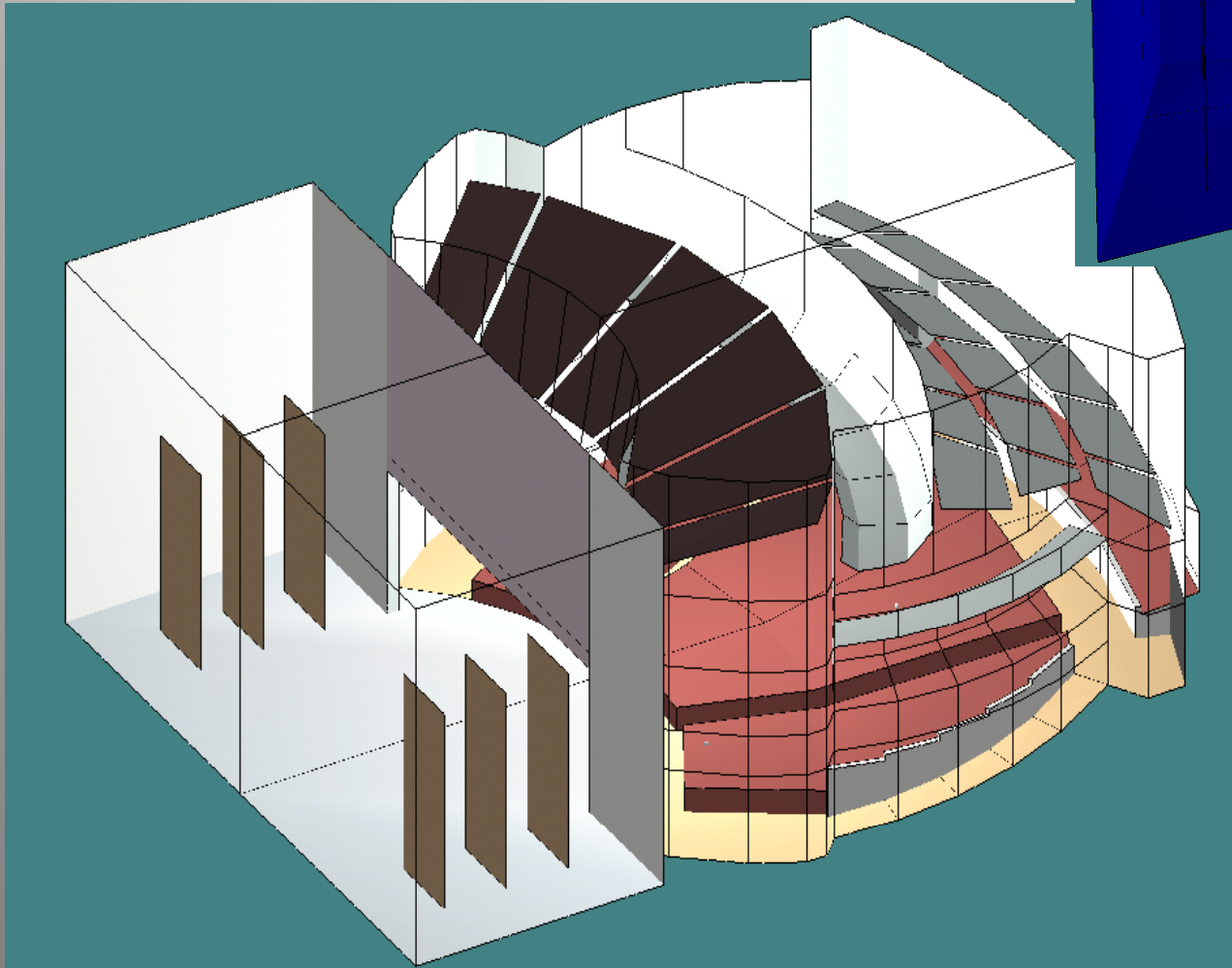
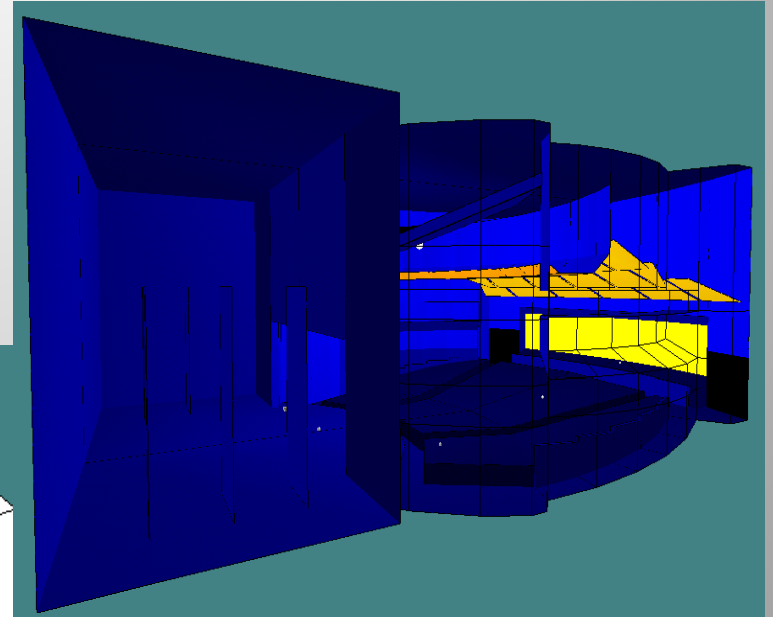
Case 3 ~ Reverberation



TOO SHORT FOR A MULTI-USE AUDITORIUM



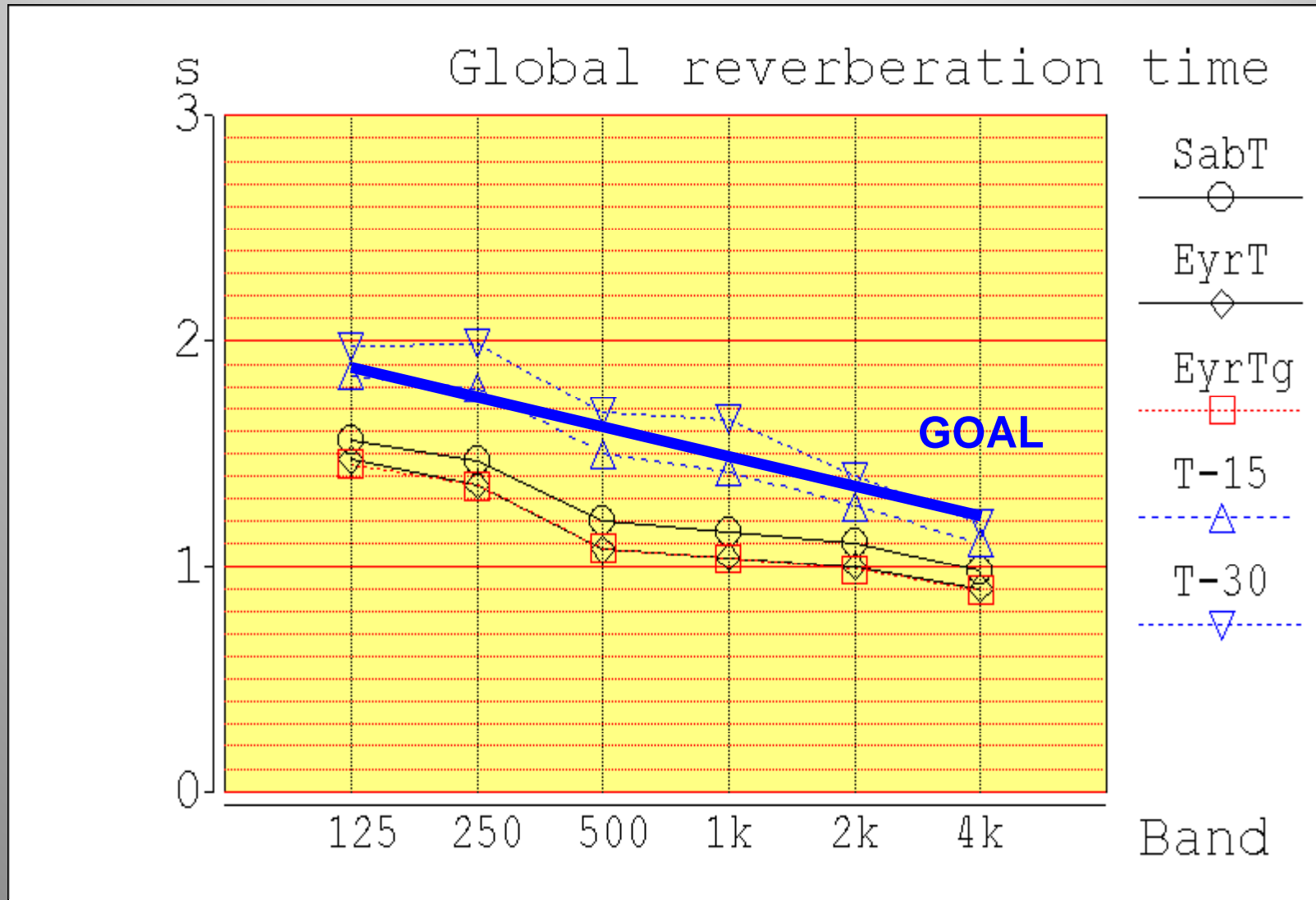
Case 5 ~ Diffusive Surfaces



DIFFUSION



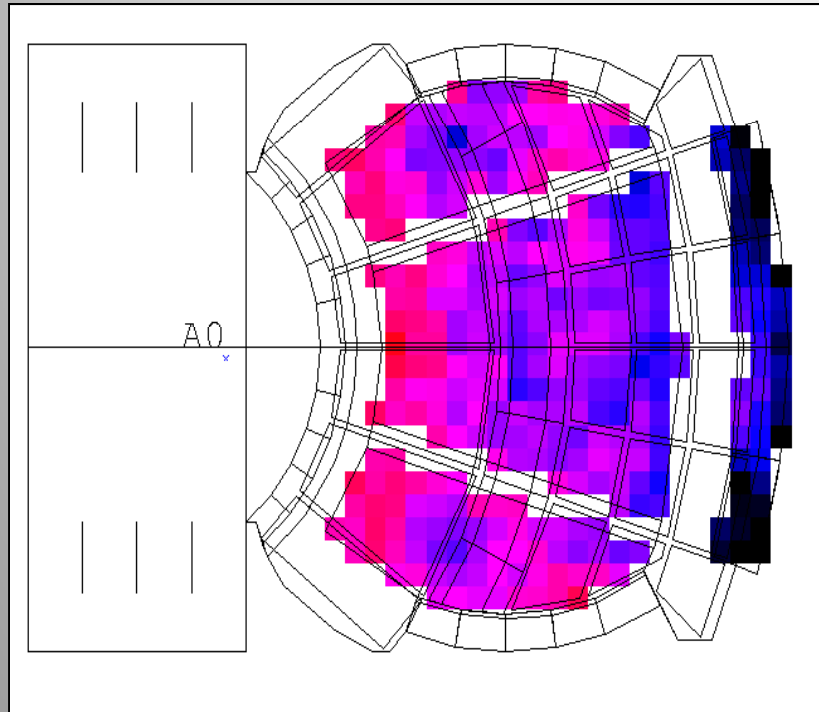
Case 5 ~ Reverberation



APPROPRIATE FOR A MULTI-USE AUDITORIUM



Rear Wall Treatment



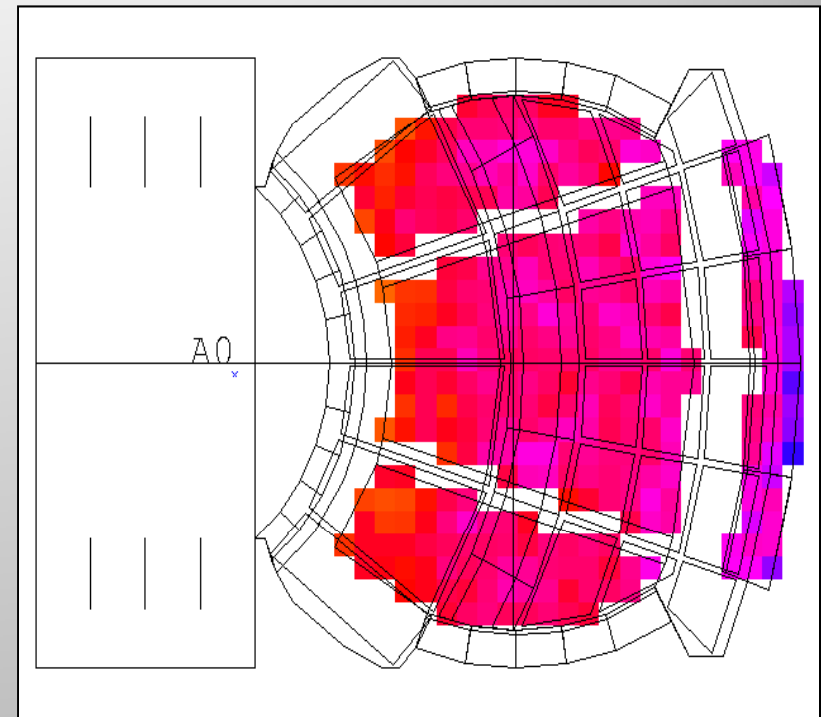
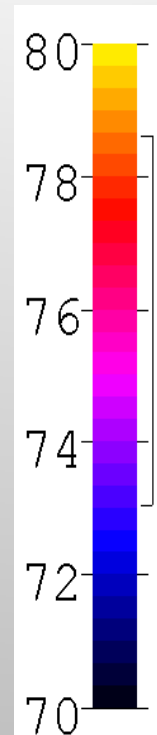
Case 3

Rear Wall Sound **ABSORPTIVE**

No Diffusion

Great Variation & Bad Uniformity

Rear 1/2 of Seating Suffers



Case 4

Rear Wall Sound **DIFFUSIVE**

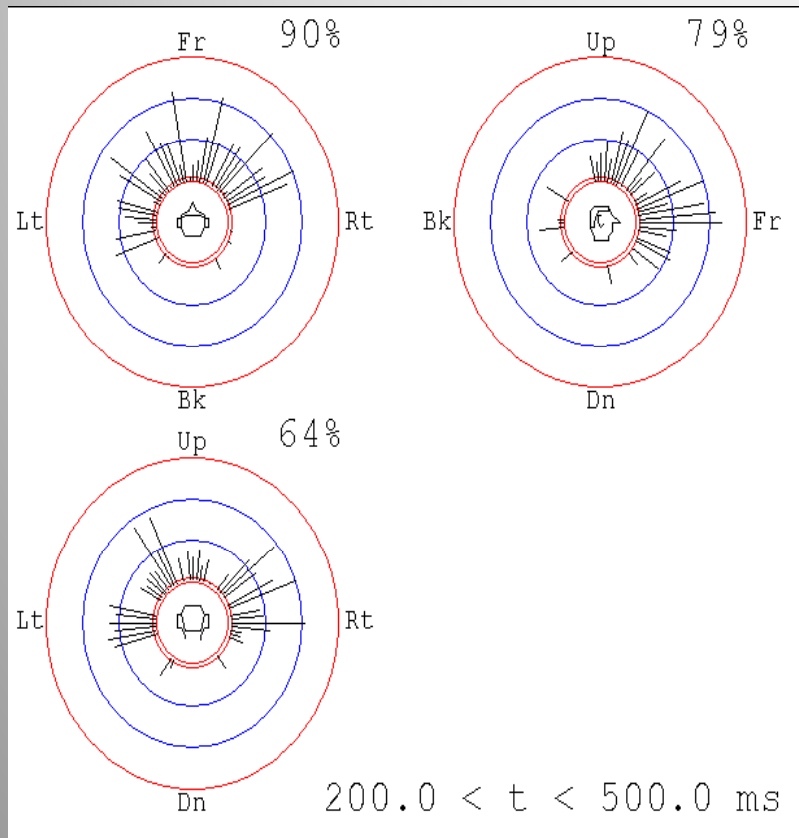
No Absorption

Far Less Variation, More Uniform

Rear 1/2 of Seating Benefits



Case 5 ~ Reverberation

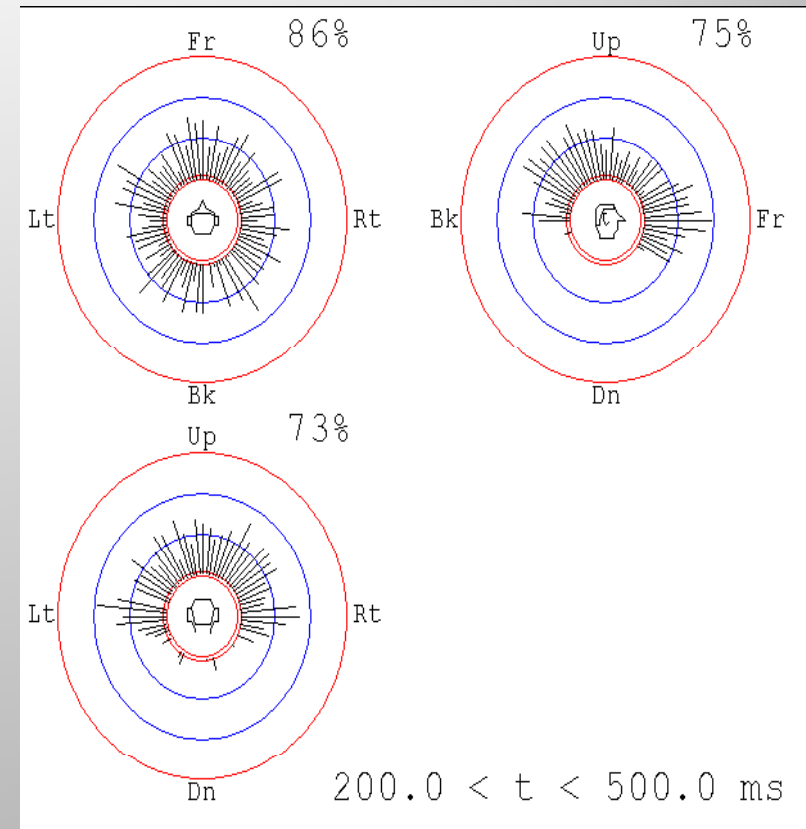


Case 3

Rear Wall Sound **ABSORPTIVE**

No Diffusion

Frontal, Non-Enveloping Sound



Case 4

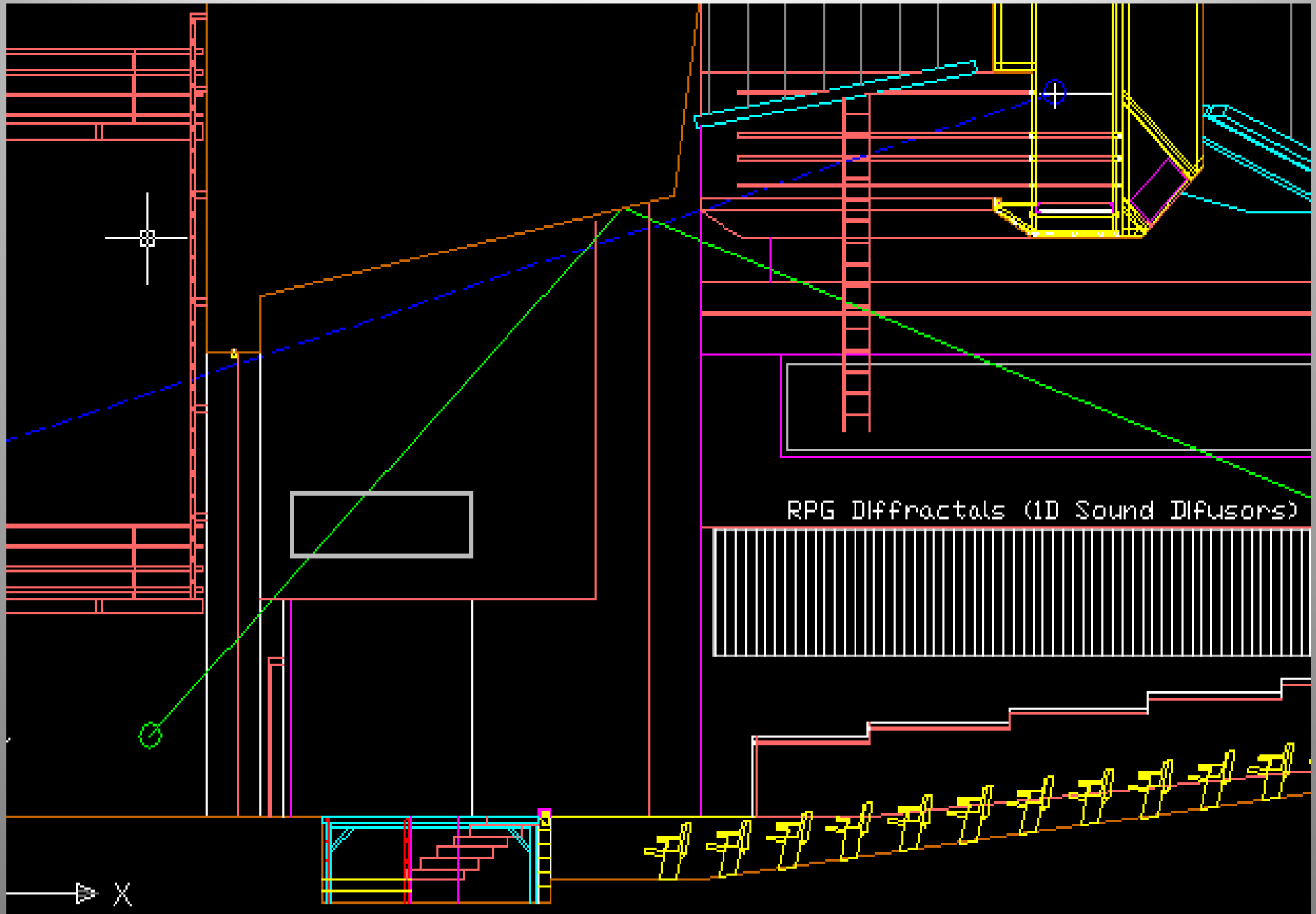
Rear Wall Sound **DIFFUSIVE**

No Absorption

Enveloping, Immersive Sound

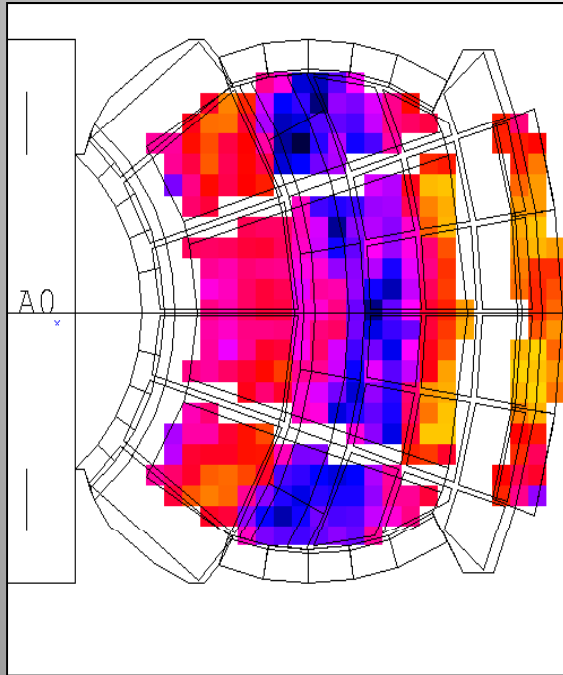


Forestage Redesign





SPL Uniformity ~ Diffusion

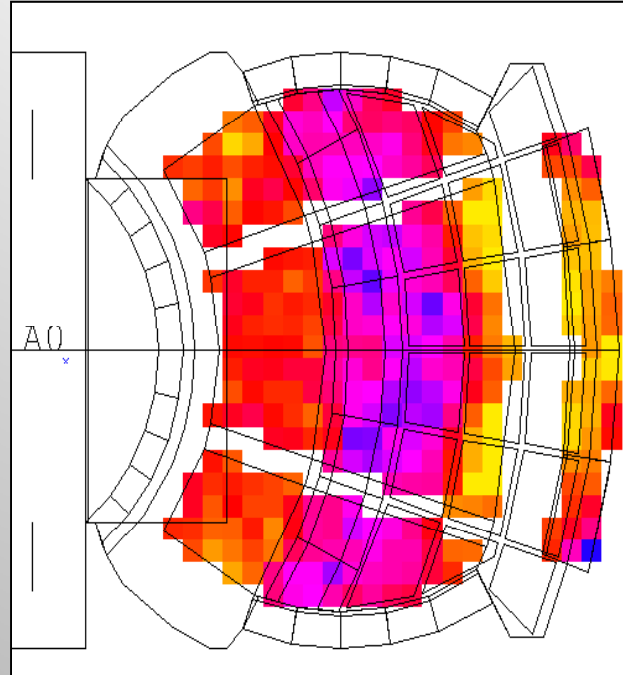
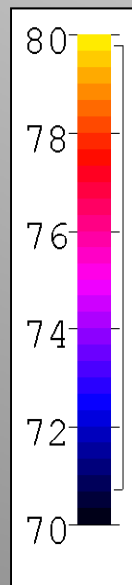


Case 2

Smaller Forestage Reflector

No Diffusion

Great Variation & Bad Uniformity

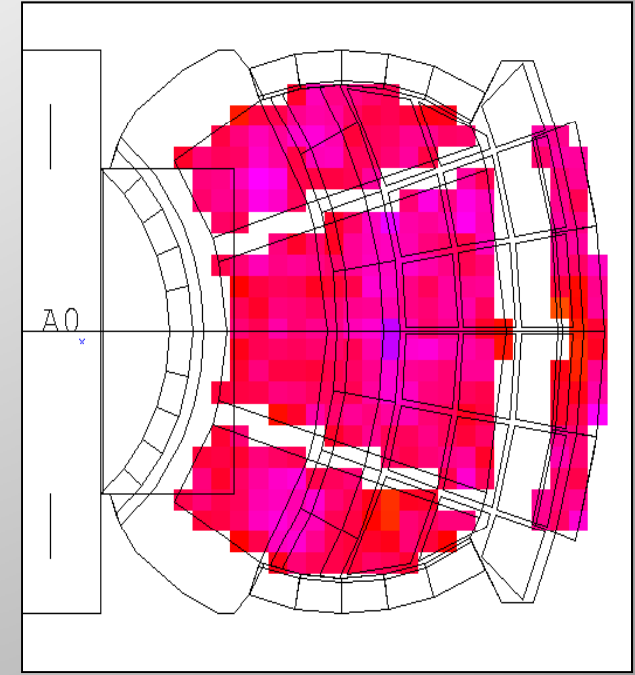


Case 2B

Larger Forestage Reflector

No Diffusion

Still Some Variation & Nonuniformity



Case 6

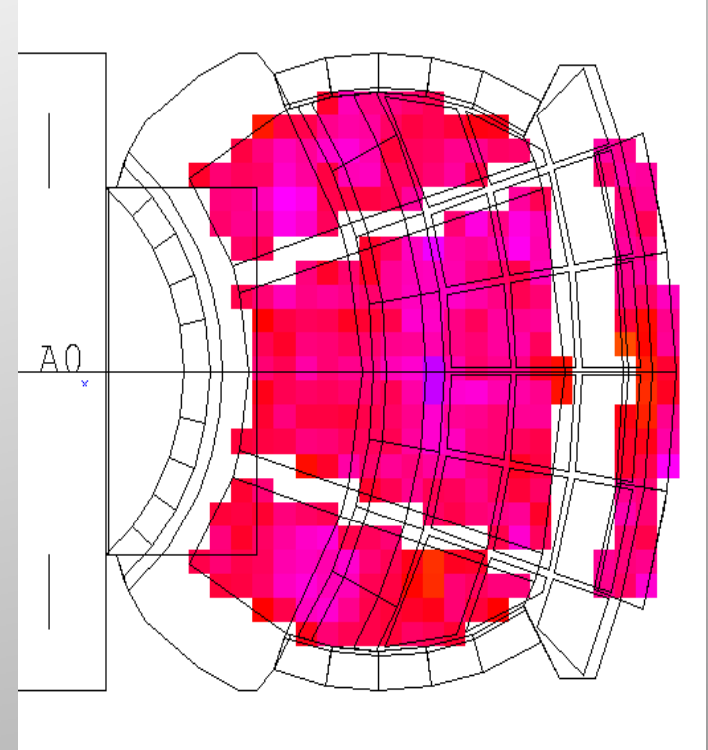
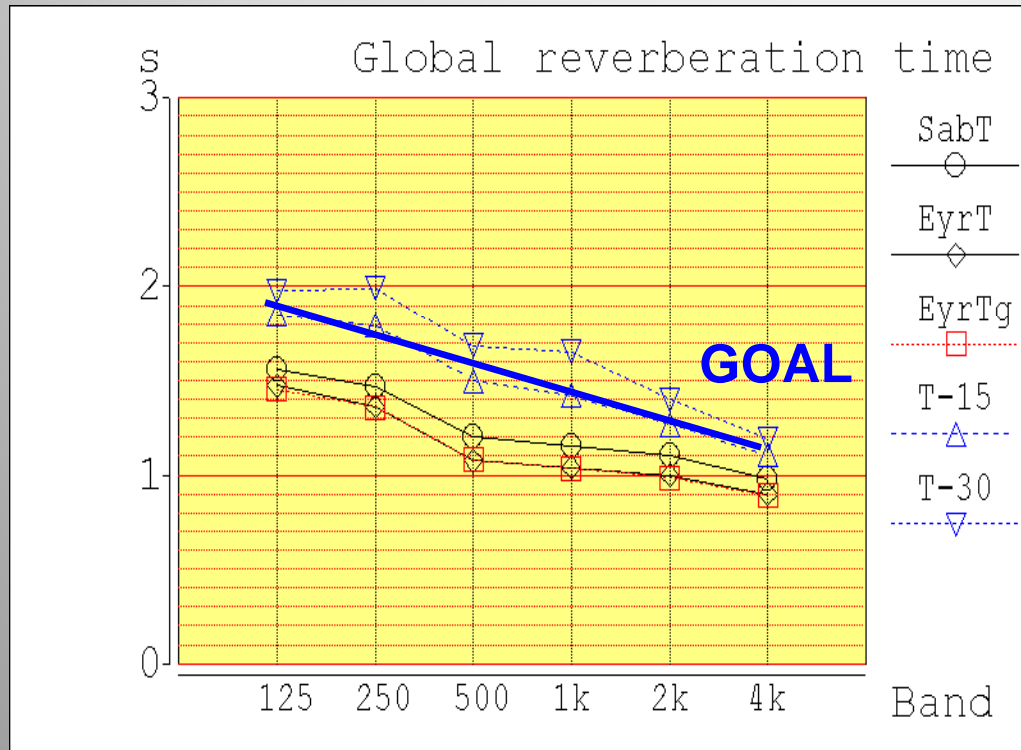
Larger Forestage Reflector

Diffusive Surfaces

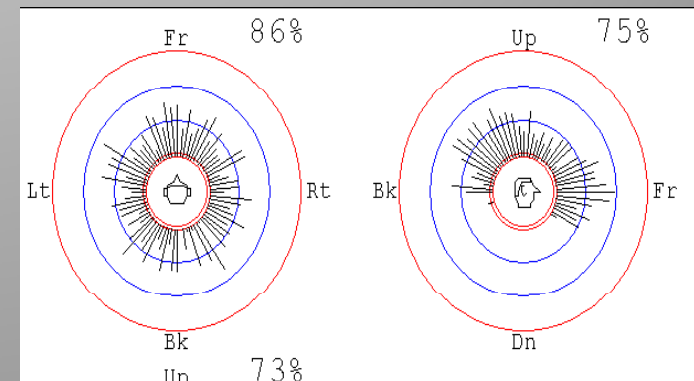
Very Little Variation & Good Uniformity



SUCCESS !



- **Appropriate Reverberation Time**
- **Even Sound Distribution ~ Free From Spatial & Temporal Non-Uniformity**
- **Enveloping Experience**





This is only the beginning.....