Reverberation Rooms & Concert Hall Acoustics

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From Lecture 14...

Reverberation Time:

$$T_{60} \propto V$$
$$T_{60} \propto 1/A$$

where T_{60} gives the time required for the sound pressure level to drop by 60 dB

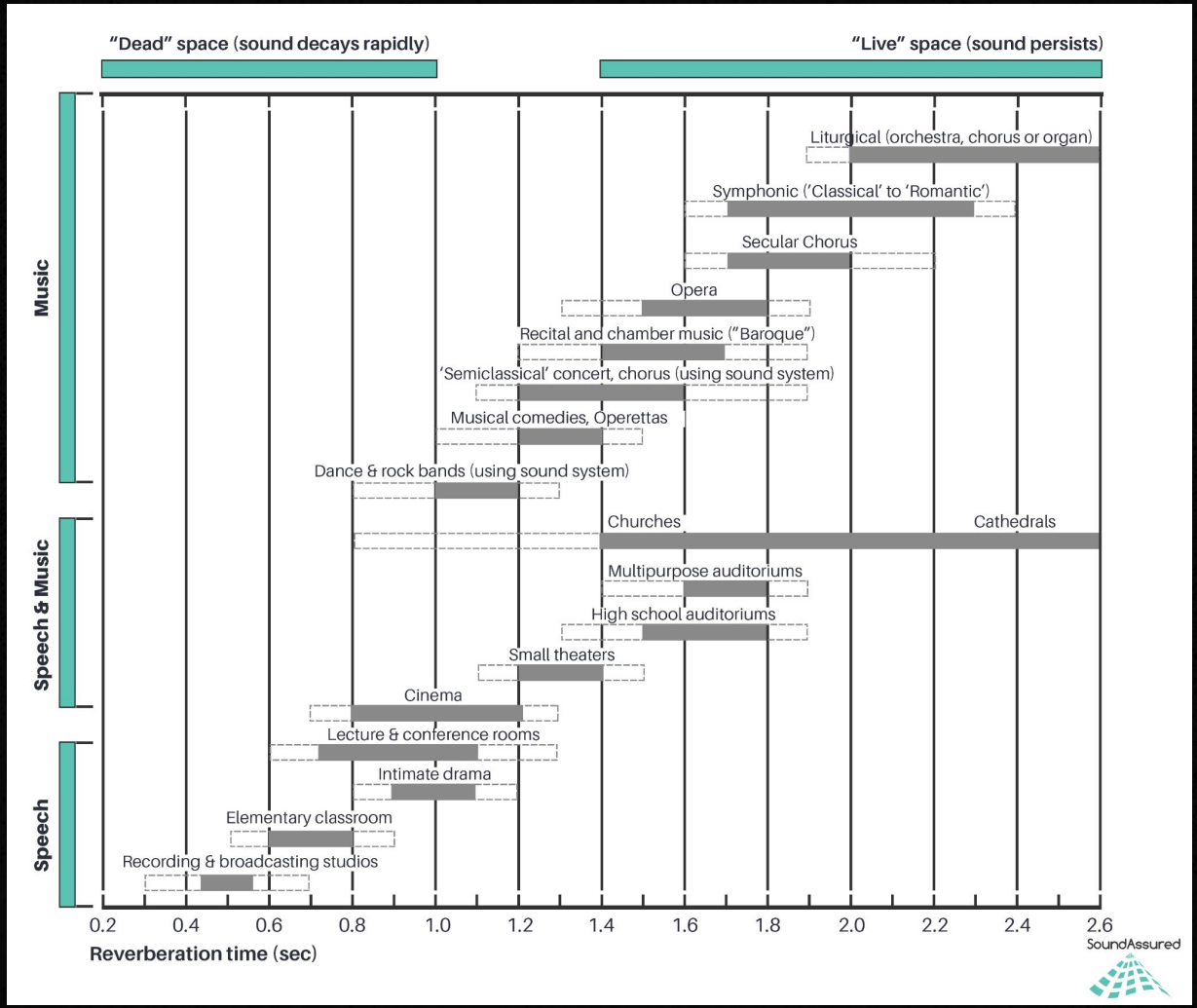
Sound Absorption:

$$A = S \langle a \rangle$$

where $\langle a \rangle$ is the average absorption coefficient of all surfaces in the room

$$a = \frac{\text{absorbed energy}}{\text{incident energy}}$$

Reverberation Time & Space Purpose



Reverberation Time: How Much is Too Much?

Volume and Expected Reverberation Time

- $T = R\,V^{1/3}$
  - where R depends on the space purpose
  - provides a volume limit for different spaces

Example: For a quiet lecture hall where $T_{60} < 0.8$ s, maximum volume is 2.4×10^3 m^3.

Reverberation Time: How Much is Too Much?

Table 12.8.1 Approximate values of $R = T/V^{1/3}$ for rooms used for various purposes

Purpose	$R \pm 10\%$ *(s/m)*	*Range of Volumes Conventionally Encountered* $(m^3)^a$
Concert hall	0.07	$10 \times 10^3 < V < 25 \times 10^3$
Opera house	0.06	$7 \times 10^3 < V < 20 \times 10^3$
Motion picture theater	0.05	$V < 10 \times 10^3$
Auditorium Legitimate theater Lecture hall Conference room	0.06	$V < 4 \times 10^3$
Recording studio Broadcasting studio	0.04	$V < 1 \times 10^3$

Anechoic vs Echo vs Reverberation

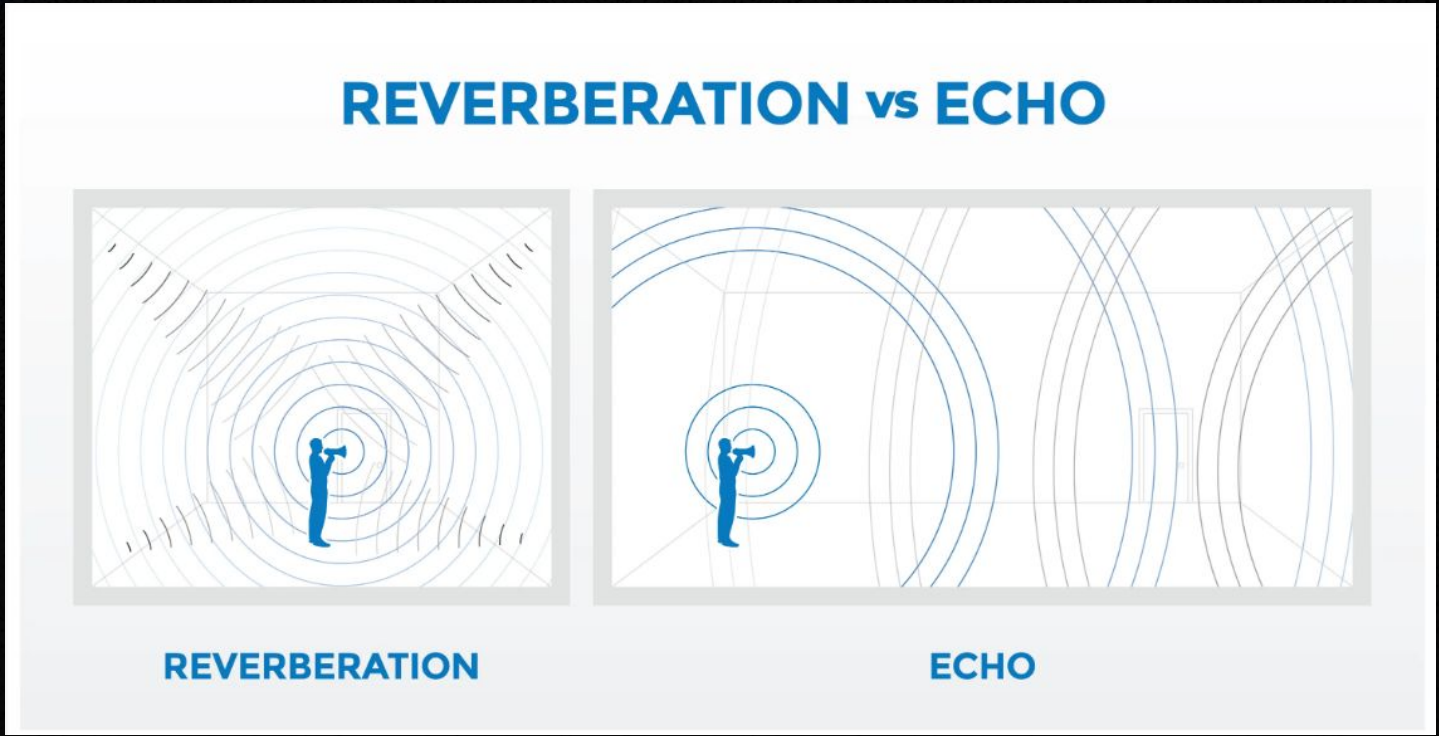
Anechoic Chamber:

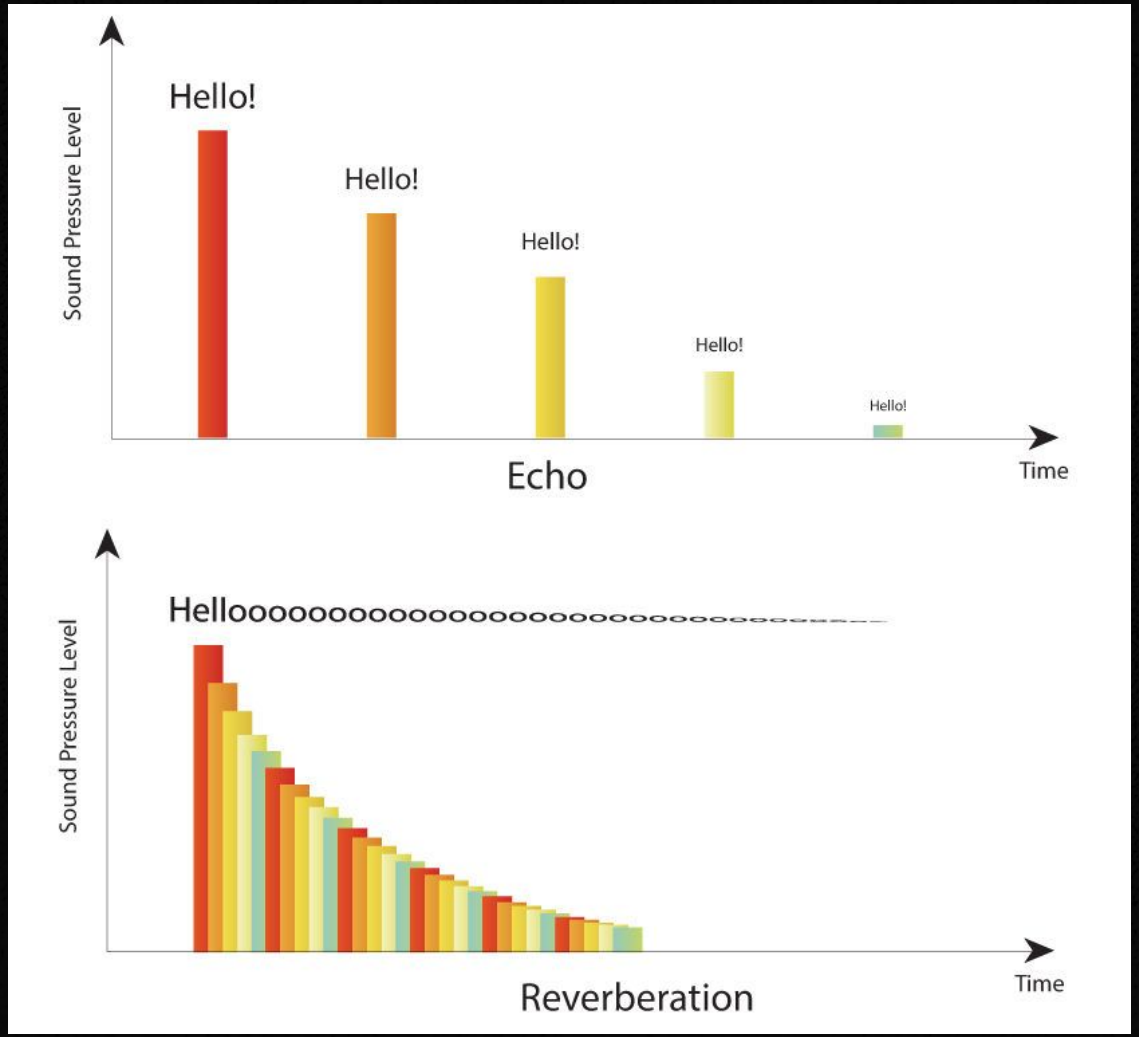
- a space in which sound is not reflected; “without echo”
- creates an acoustically free-field

Reverberation Chamber:

- a space in which sound is reflected many times
- creates an acoustically diffuse field

Anechoic vs Echo vs Reverberation




Sound Pressure Level
Hello!
Hello!
Hello!
Hello!
Hello!
Time
Echo
Sound Pressure Level
Hellooooooooooooooooooooooooooooooooo
Time
Reverberation

Reverberation chambers

What is a reverberation chamber?

- Space that creates a *perfectly diffuse sound field*
  - Energy density builds up from source until its sound power balances the dissipation
  - Sound field is independent of location or direction = isotropic energy flow
- Near impossible to create a diffuse sound field

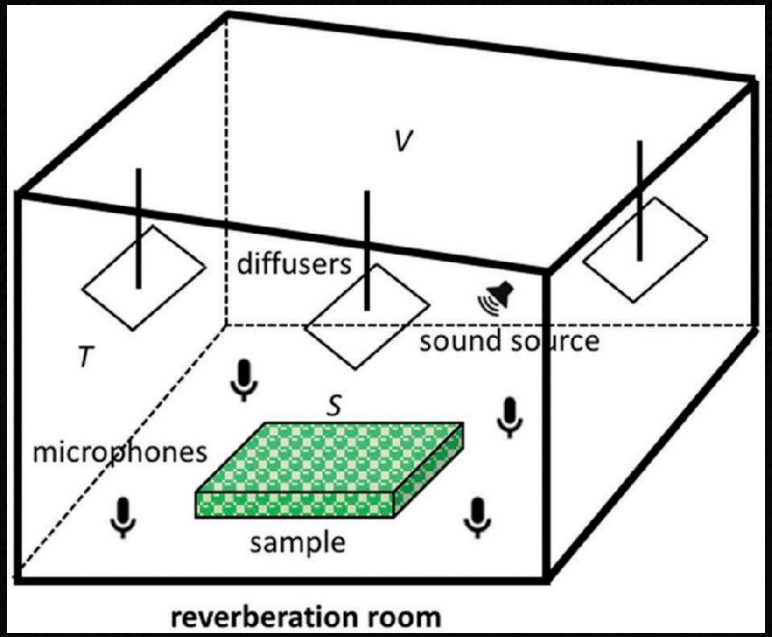
Reverberation chamber applications

What are reverberation chambers used for?

- Recording studios
- Concert halls
- Auditoriums
- Measuring the sound absorption coefficient
- Testing effectiveness of noise barriers

Structure of a Reverberation Chamber

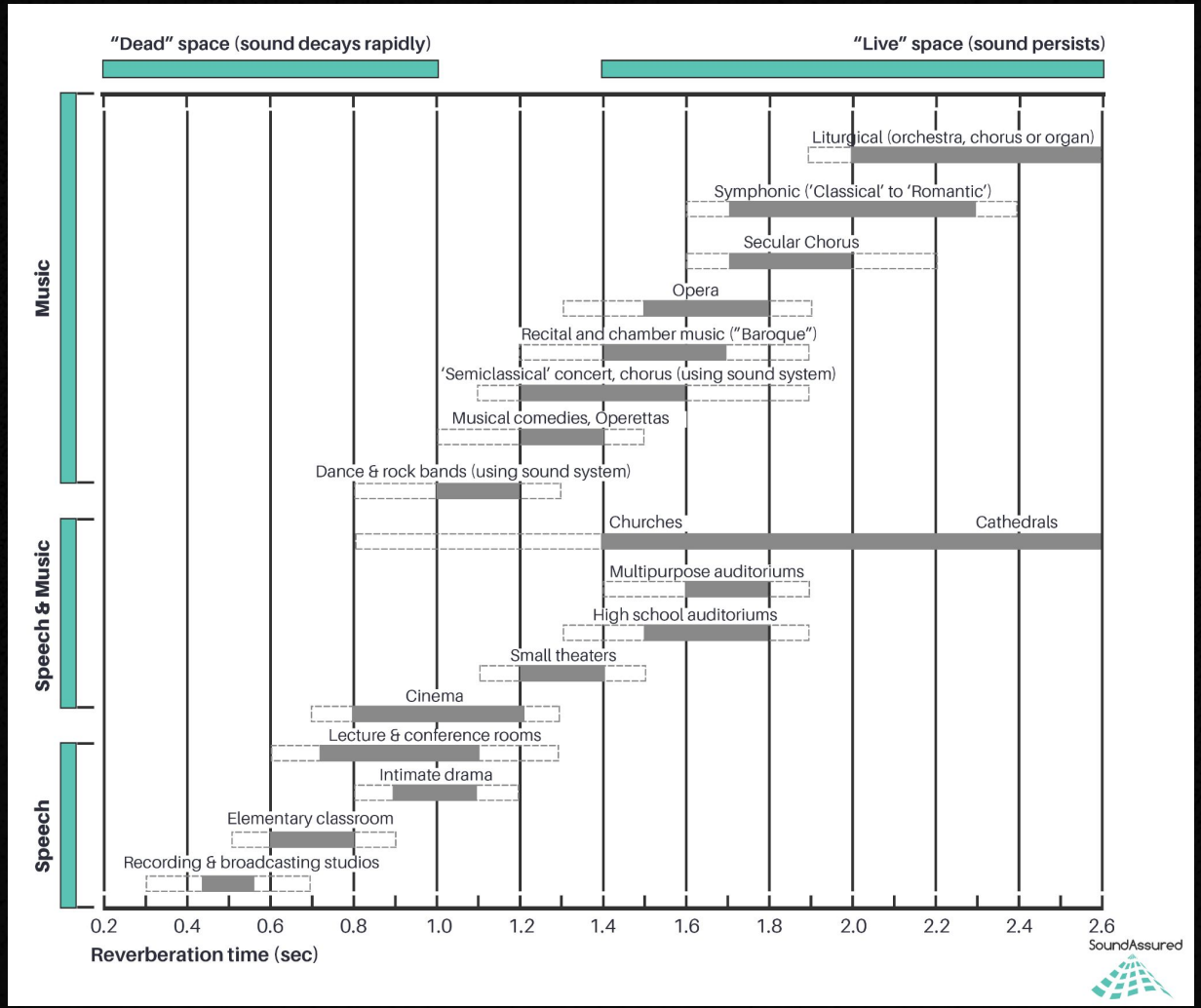
The goal is **reverb** not **resonance**!



Concert Hall Acoustics

For concert halls:

- Sound should reach listeners by direct path within 0.2 seconds
- First reflection: within 50 ms
  - Better to sit off-center for different wall reflection times
- Continuous reflections start at 100-200 ms
- Reverberation time ~ 1.8 seconds


"Dead" space (sound decays rapidly)
"Live" space (sound persists)
Music
Speech & Music
Speech
Liturgical (orchestra, chorus or organ)
Symphonic ('Classical' to 'Romantic')
Secular Chorus
Opera
Recital and chamber music ("Baroque")
'Semiclassical' concert, chorus (using sound system)
Musical comedies, Operettas
Dance & rock bands (using sound system)
Churches
Cathedrals
Multipurpose auditoriums
High school auditoriums
Small theaters
Cinema
Lecture & conference rooms
Intimate drama
Elementary classroom
Recording & broadcasting studios
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
Reverberation time (sec)
SoundAssured

Concert Hall Acoustics

What about the audience?

- Typically, concert hall seats are upholstered to increase absorption
  - For cloth covered seats: a ranges from 0.2 at 125 Hz to 0.65 at 1000 Hz
- Based on the surface area of the floor (audience, orchestra, and chorus) and room volume, T_{60} can be approximated:

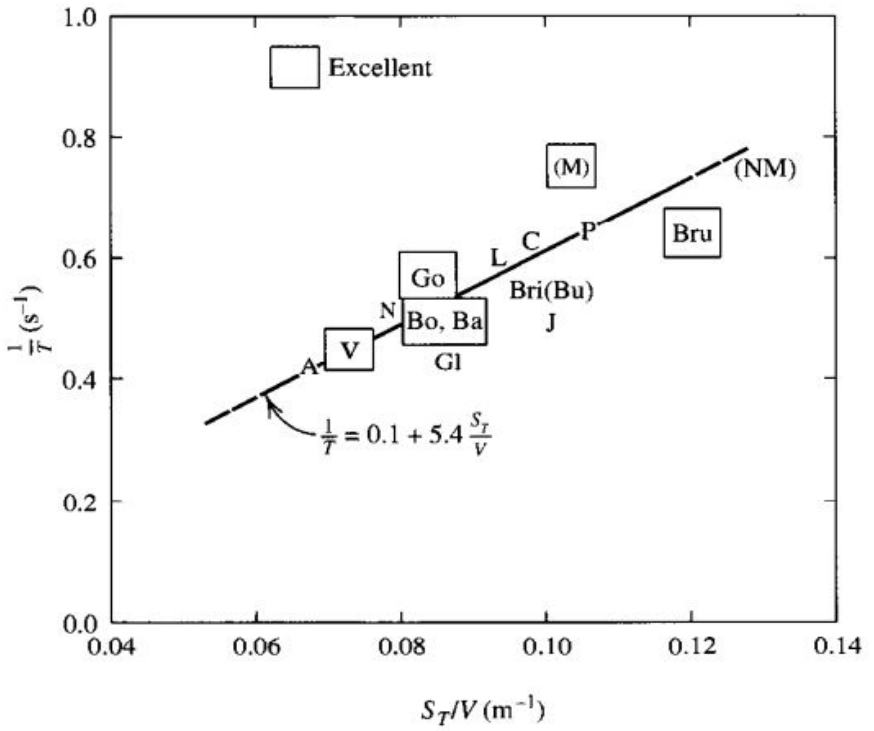
$$1 / T = 0.1 + 5.4\, S_T / V$$

concert hall acoustics

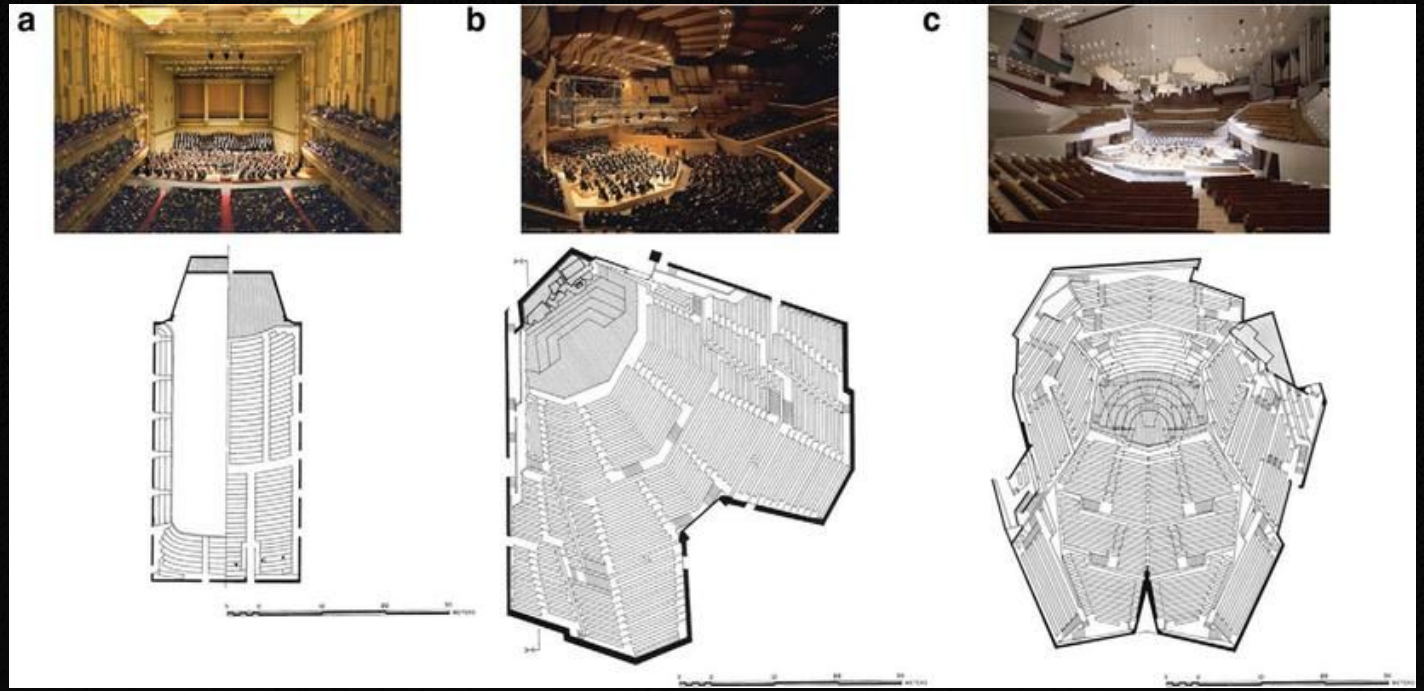
Table 12.8.2 Acoustic environments of selected con

	Hall
J	Jerusalem, Binyanei Ha'oomah
N	New York. Carnegie Hall (before renovation)
Bo	Boston, Symphony Hall
A	Amsterdam, Concertgebouw
Gl	Glasgow, St. Andrew's Hall
P	Philadelphia, Academy of Music
V	Vienna, Grosser Musikvereinsaal
Bri	Bristol, Colston Hall
Bru	Brussels, Palais des Beaux Arts
Go	Gothenburg, Konserthus
L	Leipzig, Neues Gewandhaus
Ba	Basel, Stadt-Casino
C	Cambridge, Mass., Kresge Auditorium
(Bu)	Buenos Aires, Teatro Colon
(NM)	New York. Metropolitan Opera
(M)	Milan, Teatro alla Scala

Source: Adapted from Beranek, *op. cit.*

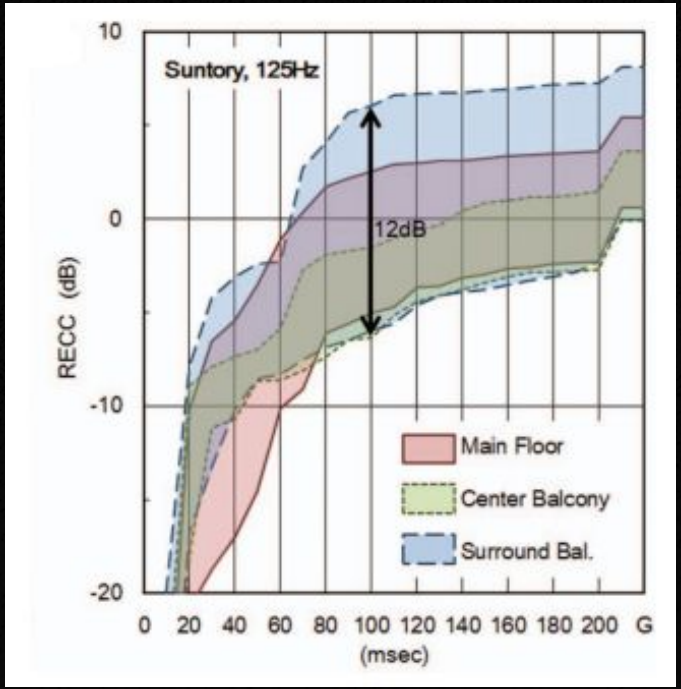


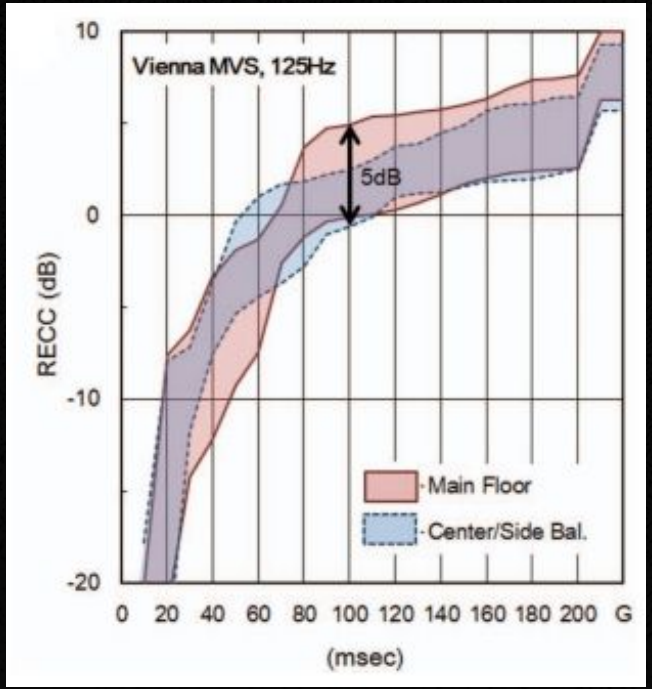
Shapes of Concert Halls



Shoebox | Fan/Spread Shape | Surround

Shapes of concert halls





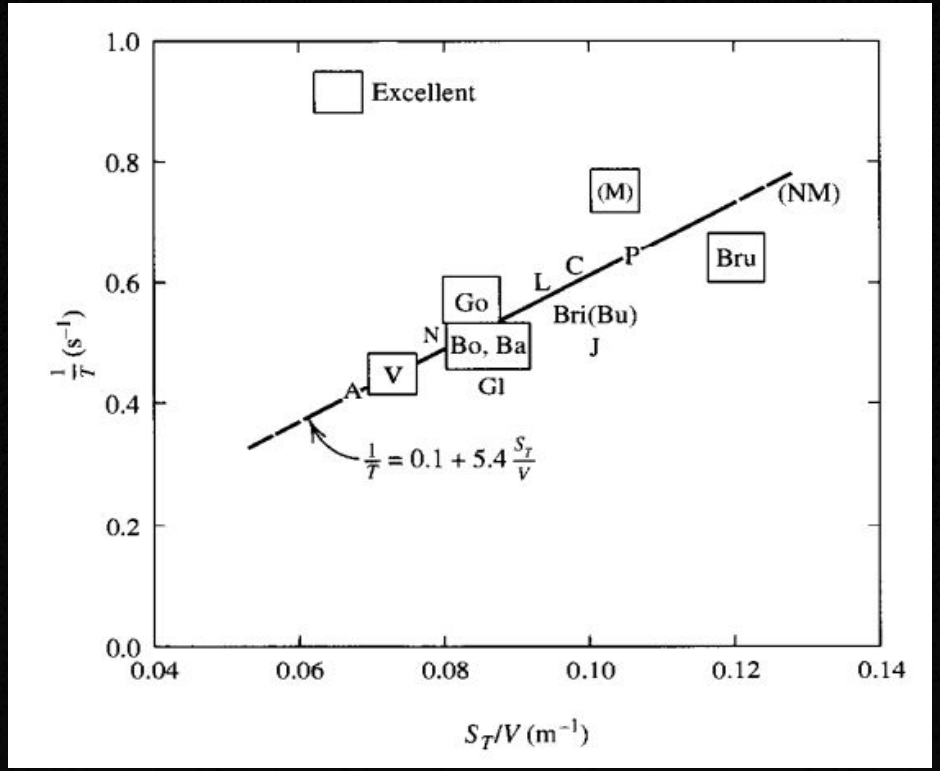
Concert Hall Acoustics

What are the best* concert halls in the world?

- Grosser Musikvereinsaal in Vienna
- Symphony Hall in Boston
- Concertgebouw in Amsterdam
  - All three are shoebox shaped
  - Quality of sound is uniform in 90% of seats

* according to Leo Beranek in 2016

Concert Hall Acoustics



Bo: Boston
Symphony Hall
V: Vienna MKS
A: Amsterdam
Concertgebouw

references

1. Kinsler et al (1982). Fundamentals of Acoustics.
2. L.L. Beranek, “Concert hall acoustics: Recent findings,” Journal of the Acoustical Society of America 139 (2016).
3. M. Nolan et al, “Experimental characterization of the sound field in a reverberation room,” Journal of the Acoustical Society of America 145 (2016).
4. International Organization for Standards, ISO 354: 2003. Accessed 20 February 2023. https://www.iso.org/obp/ui/#iso:std:iso:354:ed-2:v1:en
5. University of Salford Manchester, Acoustics Testing, Calibration, and Consultancy. Accessed 21 February 2023. https://acoustictesting.salford.ac.uk/acoustic-laboratories/reverberation-chamber/
6. T. Hidaka & N. Nishihara, “Acoustical quality in concert halls as related to hall shape: Shoebox, surround, and other,” Psychomusicology: Music, Mind, and Brain (2015).

questions?