PHY 103
Room and Auditorium Acoustics

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Reading

- Reading for this week:
  - Berg and Stork, Chapter 8

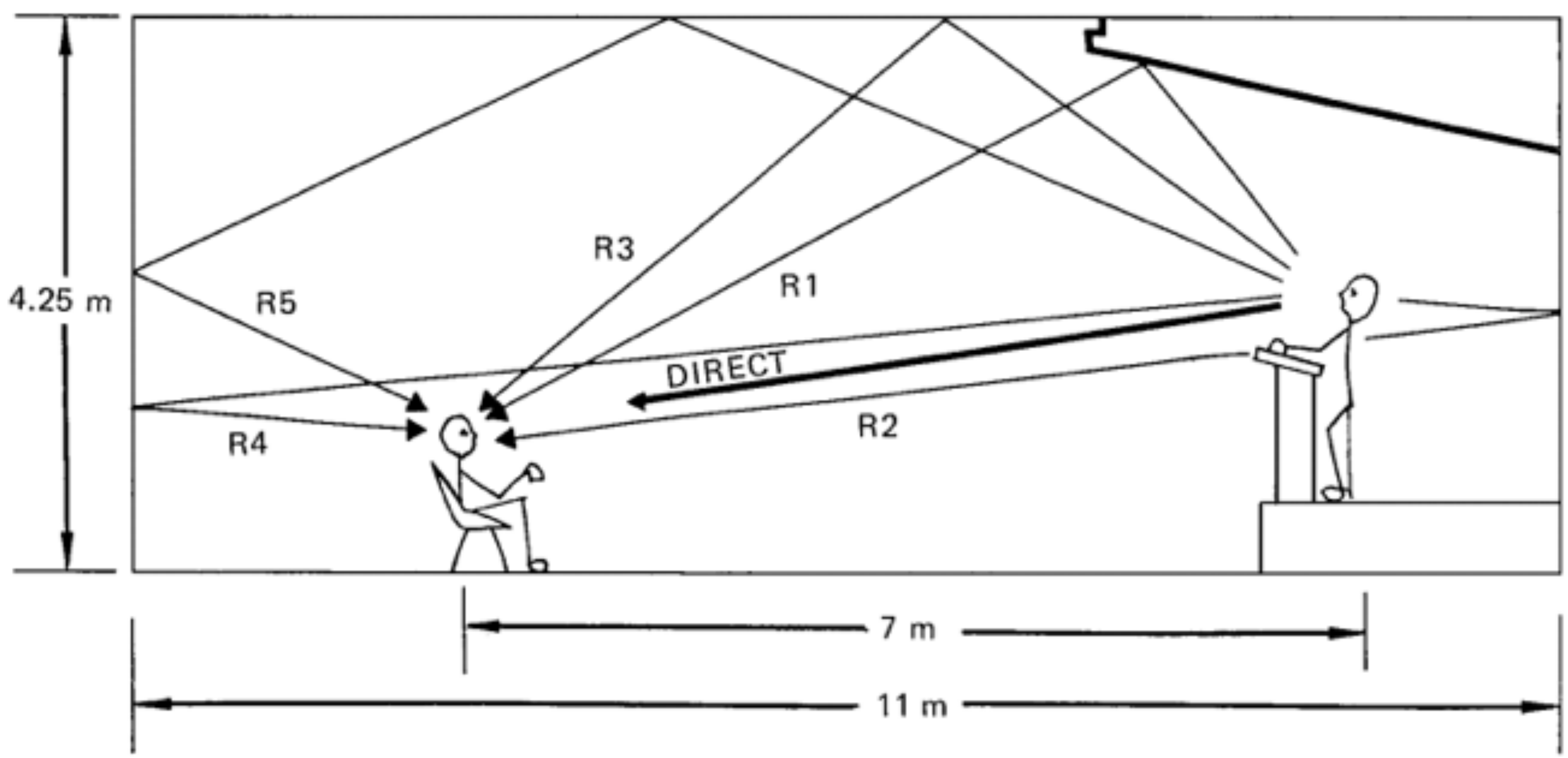
Auditorium Acoustics

- What makes a room sound acoustically "good?"
- What makes a room sound "bad?"
- How are rooms designed to produce a certain quality of sound?

- Auditorium designers need to worry a lot about reverberations. Let's find out why…

Direct vs. Indirect Sound

- When you hear a sound in a room, it will travel along many paths. You hear the direct sound and interference from reflections (indirect sound)

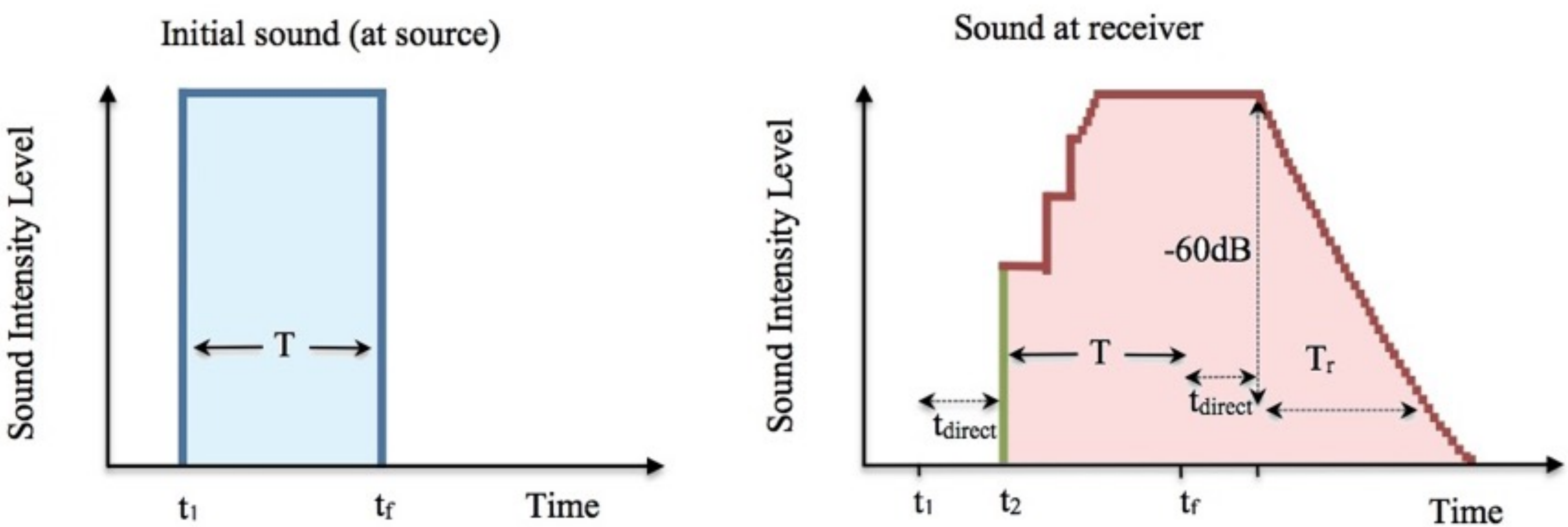


SOUND RAY	DELAY IN MSEC.
DIRECT	0
R1	4.5
R2	9.0
R3	13.0
R4	14.0
R5	18.0

ALL REFLECTIONS SHOWN ARRIVE AT LISTENER'S EAR WITHIN 30 MSEC. AFTER DIRECT SOUND AND, THEREFORE, ARE "EARLY" REFLECTIONS.

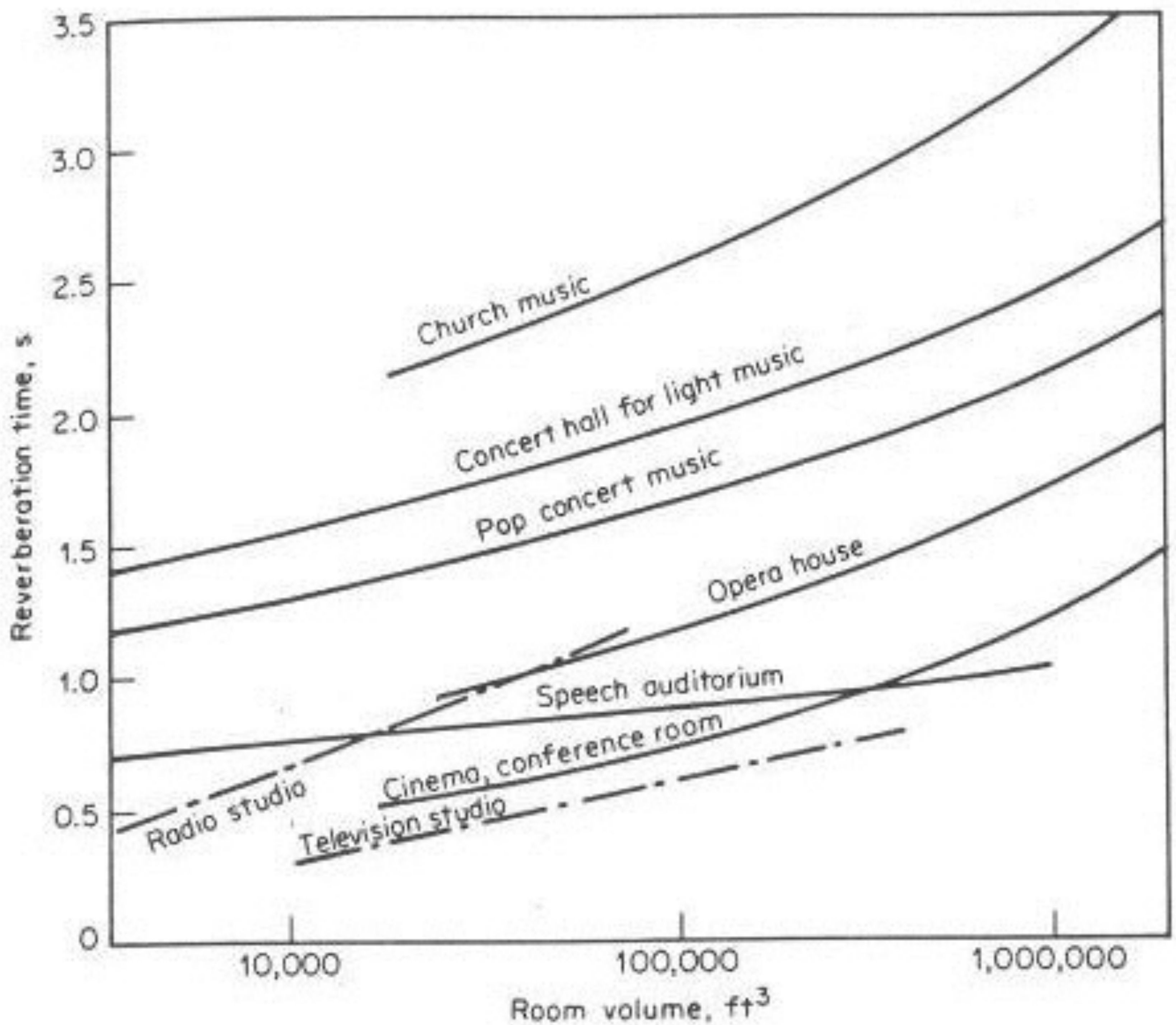
Reverberation Time

- When a musical tone is attacked, the listener hears the direct sound and then reflected waves. The sum might exceed the initial intensity; then it decays
- Reverberation time (t_R) is the time it takes for the sound to decay 60 dB from its maximum intensity; i.e, the sound drops by a factor of 1,000,000 in time t_R



Ideal Reverberation Time

- Different t_R works best for different applications



Acoustical Characteristics

- Liveness: qualitative measure of t_R; a "live" room has a long t_R
- Intimacy: an "intimate" room has first reflected sound reach listener <20 ms after direct sound
- Fullness: amount of reflected sound w.r.t. direct sound. A "full" hall has lots of reflected sound. Good for chamber music, some classical music
- Clarity: the opposite of fullness. Good for speech
- Warmth: a "warm" hall has longer t_R for low frequencies than for high frequencies. Ideally, below 500 Hz t_R is 1.5x the value >500 Hz

Acoustical Characteristics

- Brilliance: opposite of warmth, i.e., t_R is longer for high frequencies
- Texture: time structure of patterns in which reflections reach the listener. Good texture = at least 5 reflections <60 ms after direct sound, resulting in a continuous decrease in intensity
- Blend: mixing of sound from all instruments. Bad blend means that at a given location, one instrument sounds louder than the others
- Ensemble: ability of performers to hear each other during the performance. Good ensemble: t_R for strong reflections is less than the duration of the fastest notes played

Sabine's Formula

- Model of reverberation time in terms of volume and effective area of a room

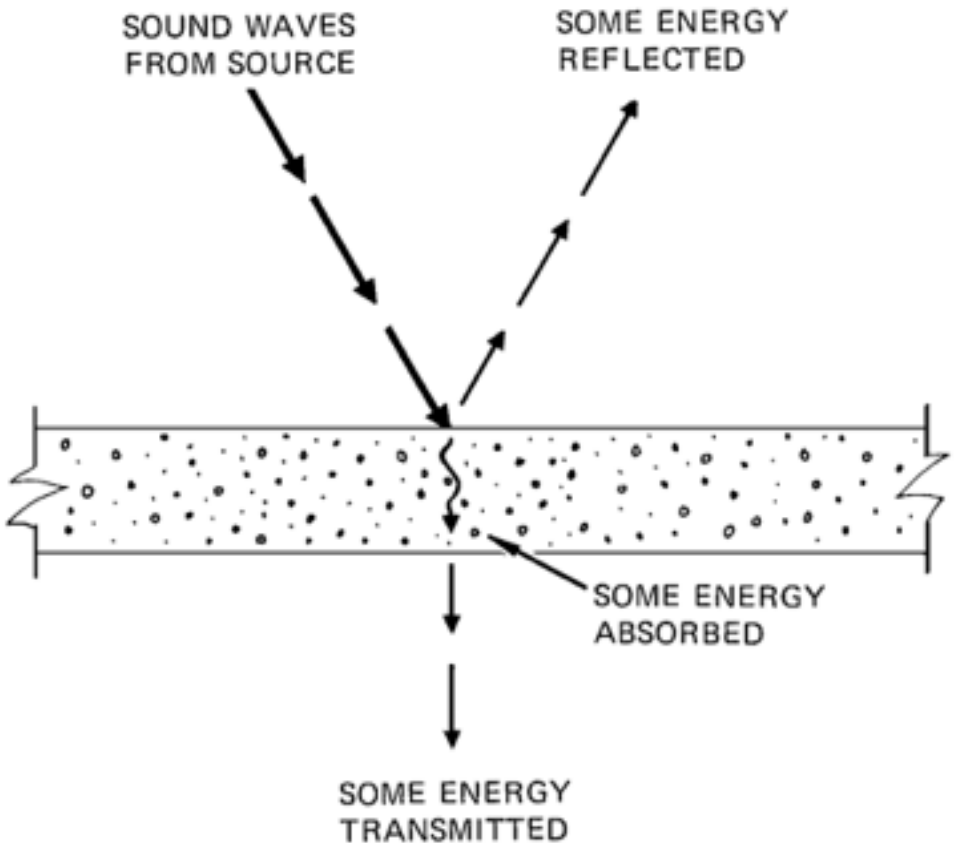
$$t_r \approx 0.16\ \mathrm{s\ m}^{-1} \cdot \frac{V}{S_e} \approx 0.049\ \mathrm{s\ ft}^{-1} \cdot \frac{V}{S_e}$$

- Effective area of each surface in the room is the product of surface area x acoustic absorption
- Total effective area is the sum over all surfaces

$$S_e = a_1 S_1 + a_2 S_2 + \ldots + a_n S_n = \sum_{i=1}^{n} a_i S_i$$

Reflection/Absorption

- When a sound wave strikes a surface, a certain fraction of it is absorbed and a certain fraction is reflected
- The absorption coefficient *a* tells you the absorbed fraction
- Perfect absorber: $a = 1$
- Perfect reflector: $a = 0$
- Frequency dependent!



Absorption Coefficients

Material	Frequency (Hz)					
	125	250	500	1000	2000	4000
Acoustic tile, rigid mount	0.2	0.4	0.7	0.8	0.6	0.4
Acoustic tile, suspended	0.5	0.7	0.6	0.7	0.7	0.5
Acoustical plaster	0.1	0.2	0.5	0.6	0.7	0.7
Standard plaster on lath	0.2	0.15	0.1	0.05	0.04	0.05
Gypsum wallboard, $\frac{1}{2}''$ on studs	0.3	0.1	0.05	0.04	0.07	0.1
Plywood sheet, $\frac{1}{4}''$ on studs	0.6	0.3	0.1	0.1	0.1	0.1
Concrete block, unpainted	0.4	0.4	0.3	0.3	0.4	0.3
Concrete block, painted	0.1	0.05	0.06	0.07	0.1	0.1
Concrete, poured	0.01	0.01	0.02	0.02	0.02	0.03
Brick	0.03	0.03	0.03	0.04	0.05	0.07
Vinyl tile on concrete	0.02	0.03	0.03	0.03	0.03	0.02
Heavy carpet on concrete	0.02	0.06	0.15	0.4	0.6	0.6
Heavy carpet on felt	0.1	0.3	0.4	0.5	0.6	0.7
Platform floor, wooden	0.4	0.3	0.2	0.2	0.15	0.1
Ordinary window glass	0.3	0.2	0.2	0.1	0.07	0.04
Heavy plate glass	0.2	0.06	0.04	0.03	0.02	0.02
Draperies, medium velour	0.07	0.3	0.5	0.7	0.7	0.6
Upholstered seat (empty)	0.2	0.4	0.6	0.7	0.6	0.6
Upholstered seat (occupied)	0.4	0.6	0.8	0.9	0.9	0.9
Wood seating (unoccupied)	0.02	0.03	0.03	0.06	0.06	0.05
Wooden pews (occupied)	0.4	0.4	0.7	0.7	0.8	0.7

Common Problems

- Focusing: sound is louder at one point than at other points (example: whispering gallery)
- Echoes: large single echoes create poor texture in a room
- Shadows: quiet regions due to long overhanging balconies or other structures
- Resonances: affects small rooms where the size of the room is just a few multiples of $\lambda/2$