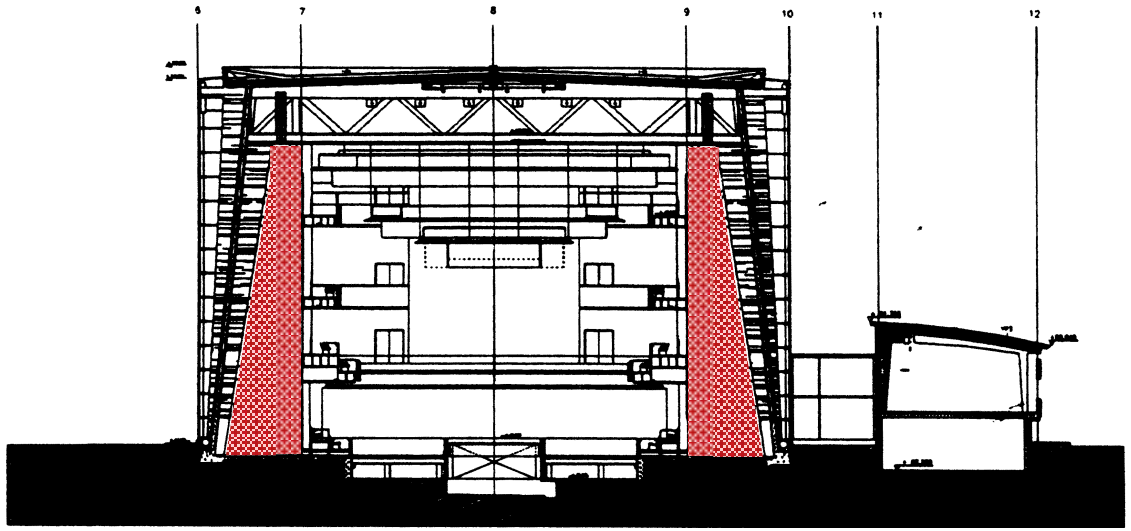
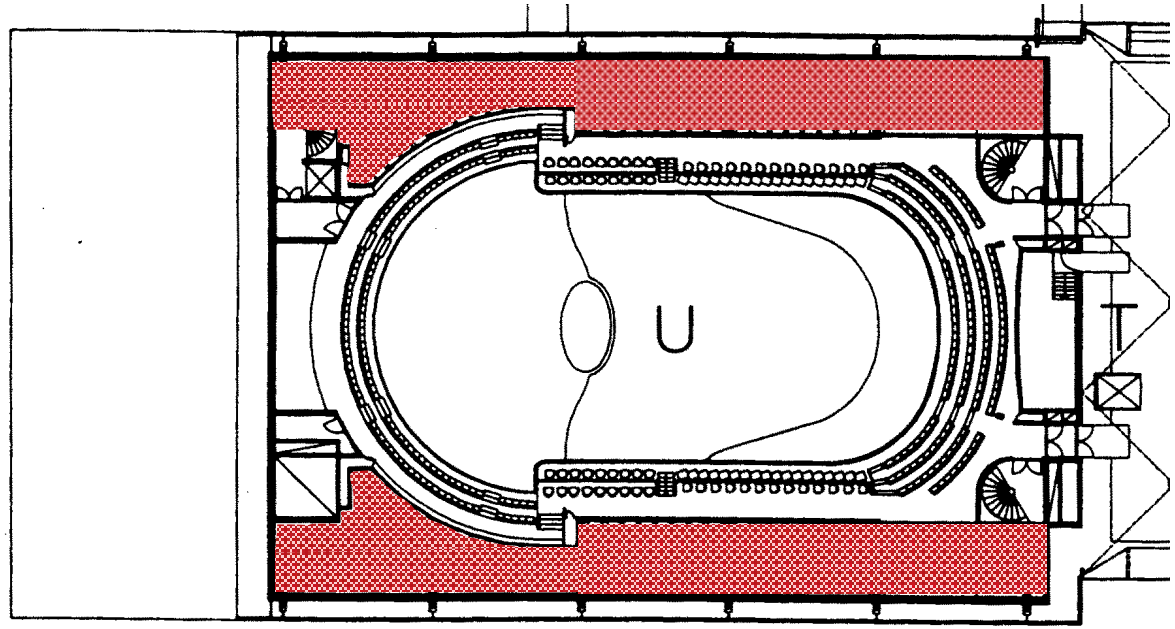
Concert Hall
Lahti, Finland



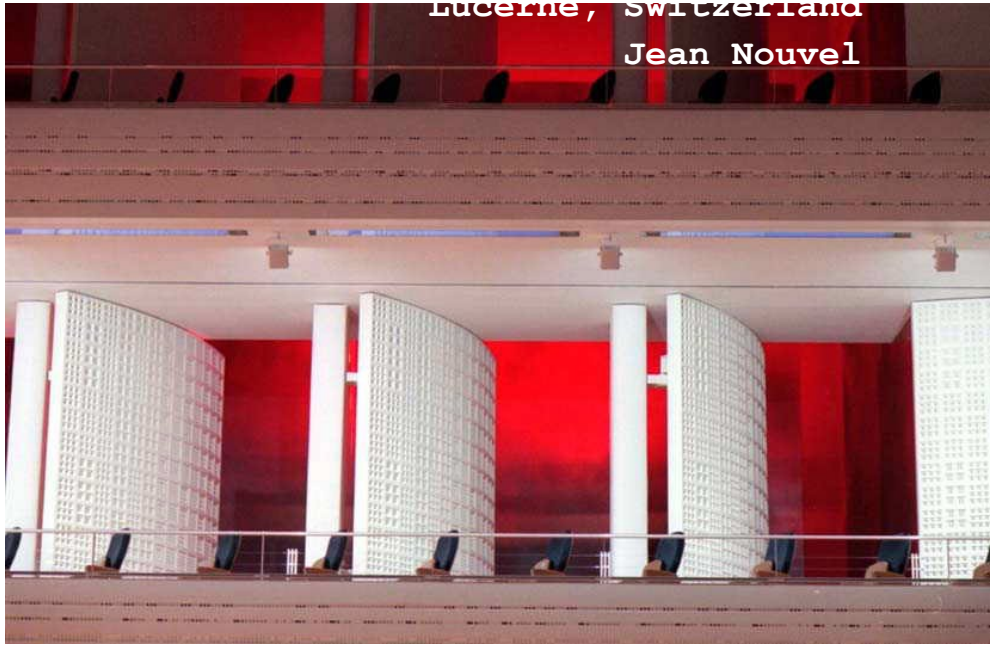
Concert Hall
Lahti, Finland



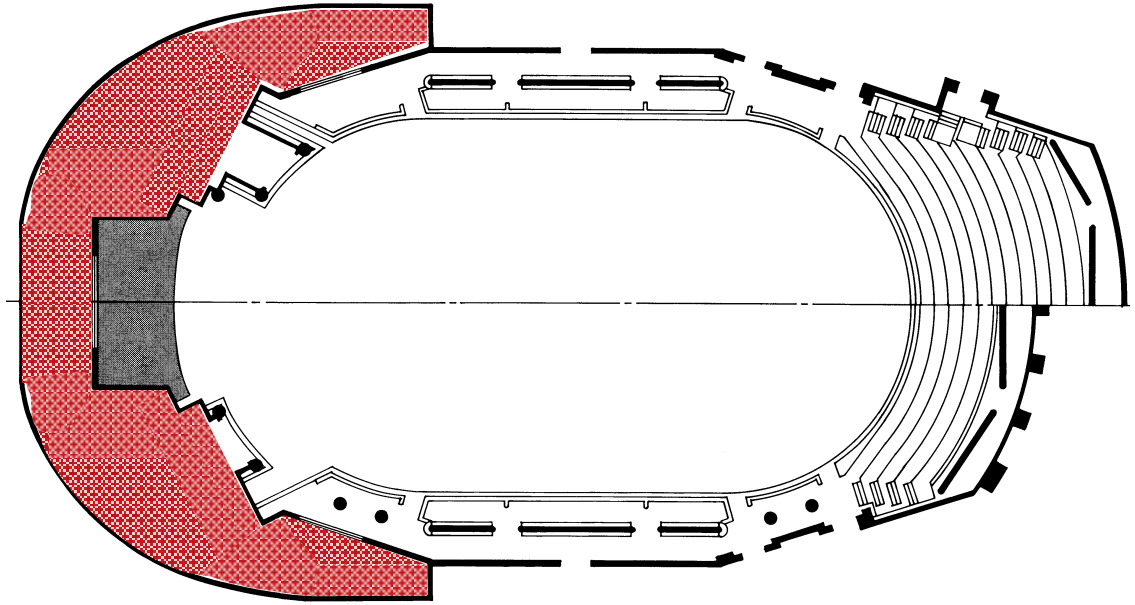

Culture and Congress C

Lucerne, Switzerland

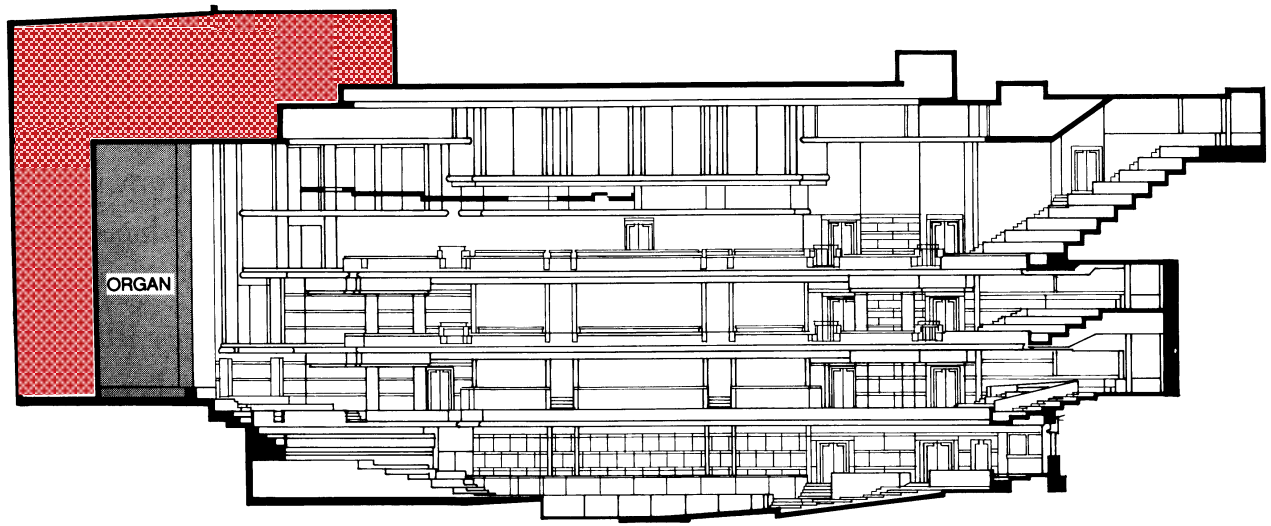
Jean Nouvel

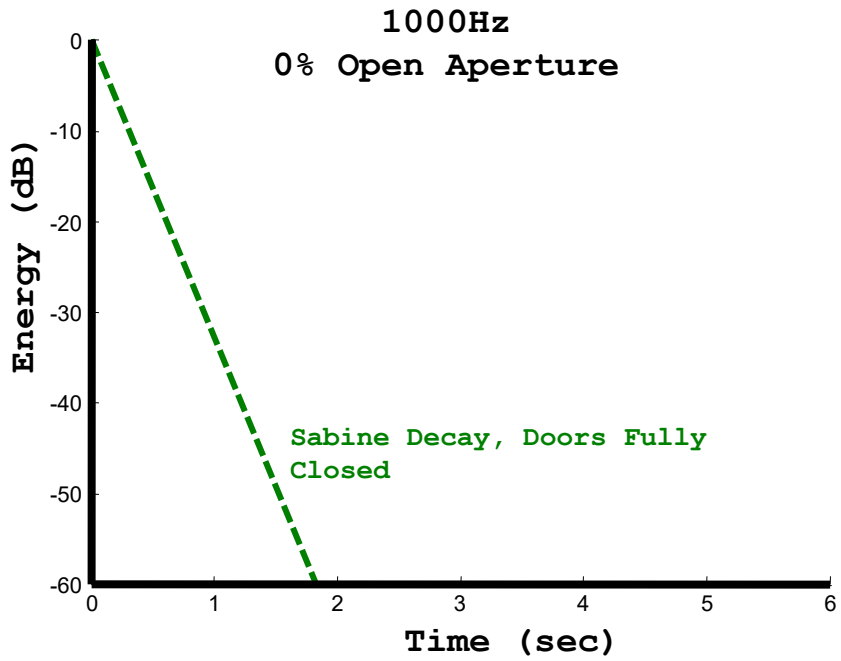


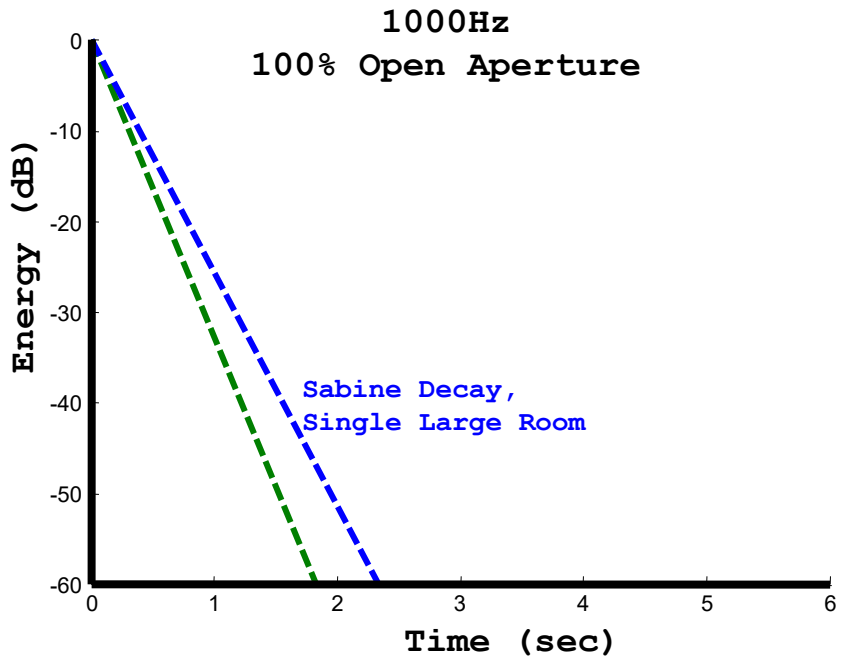
Concert Hall
Birmingham, England

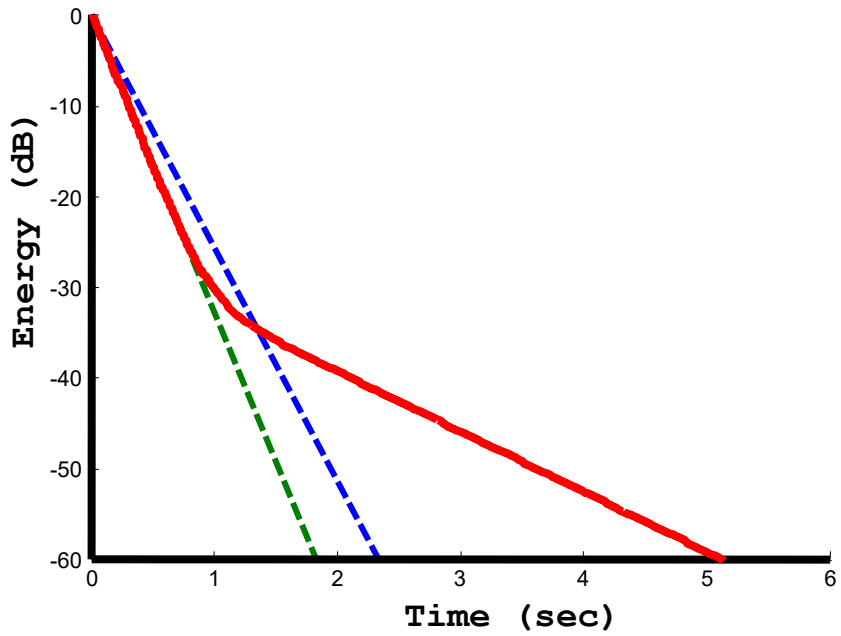


Concert Hall
Birmingham, England

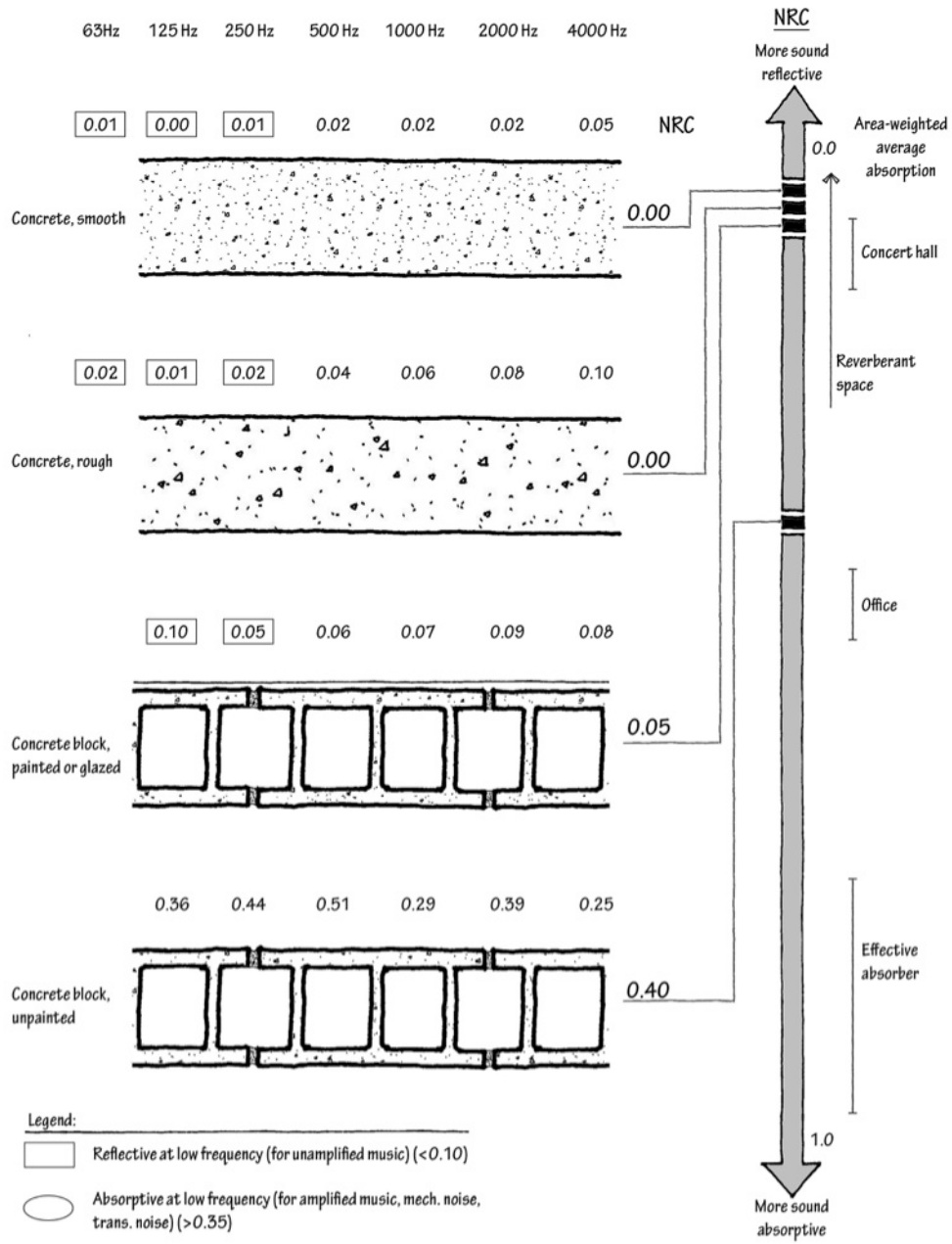



1000Hz
0% Open Aperture
Energy (dB)
0
-10
-20
-30
-40
-50
-60
0
1
2
3
4
5
6
Time (sec)
Sabine Decay, Doors Fully Closed

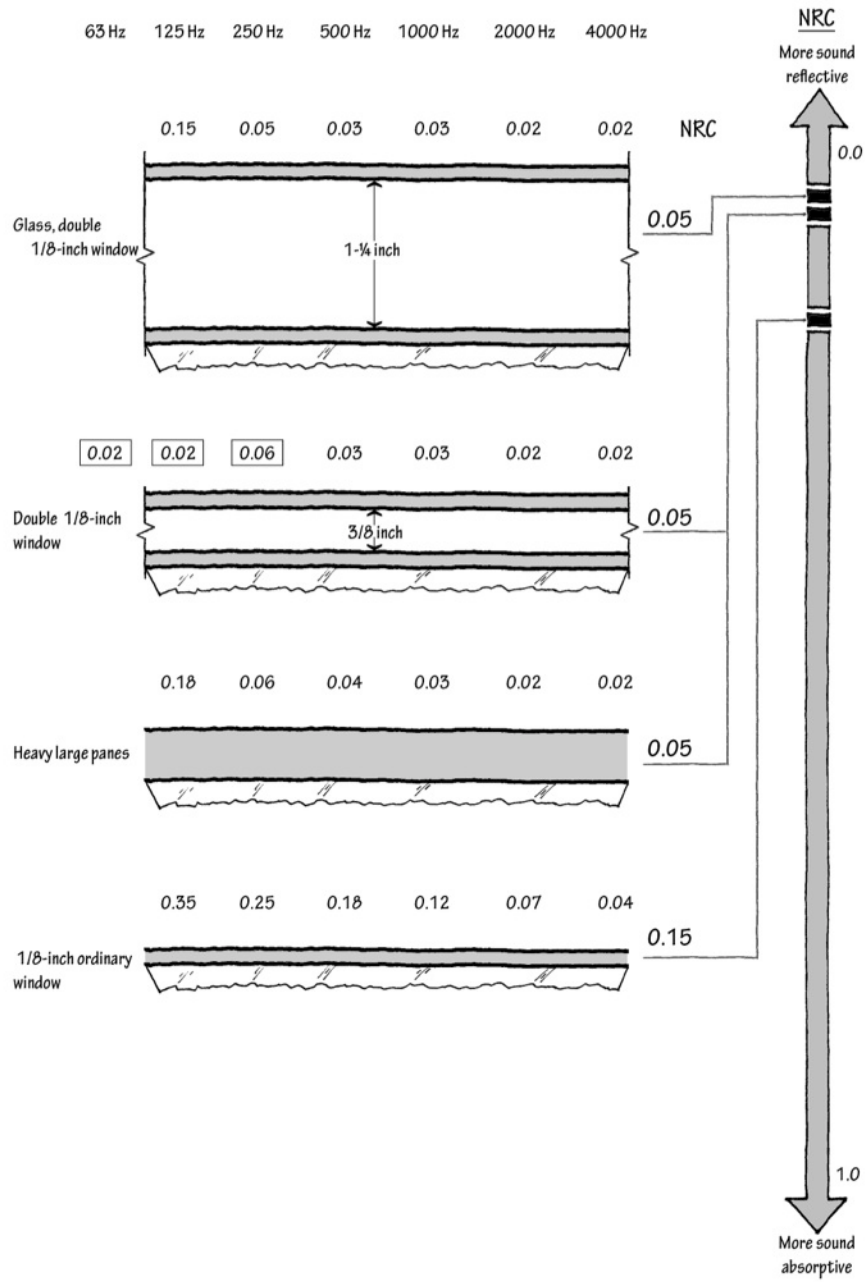

1000Hz
100% Open Aperture
Energy (dB)
0
-10
-20
-30
-40
-50
-60
0
1
2
3
4
5
6
Time (sec)
Sabine Decay,
Single Large Room


0
-10
-20
-30
-40
-50
-60
Energy (dB)
0
1
2
3
4
5
6
Time (sec)

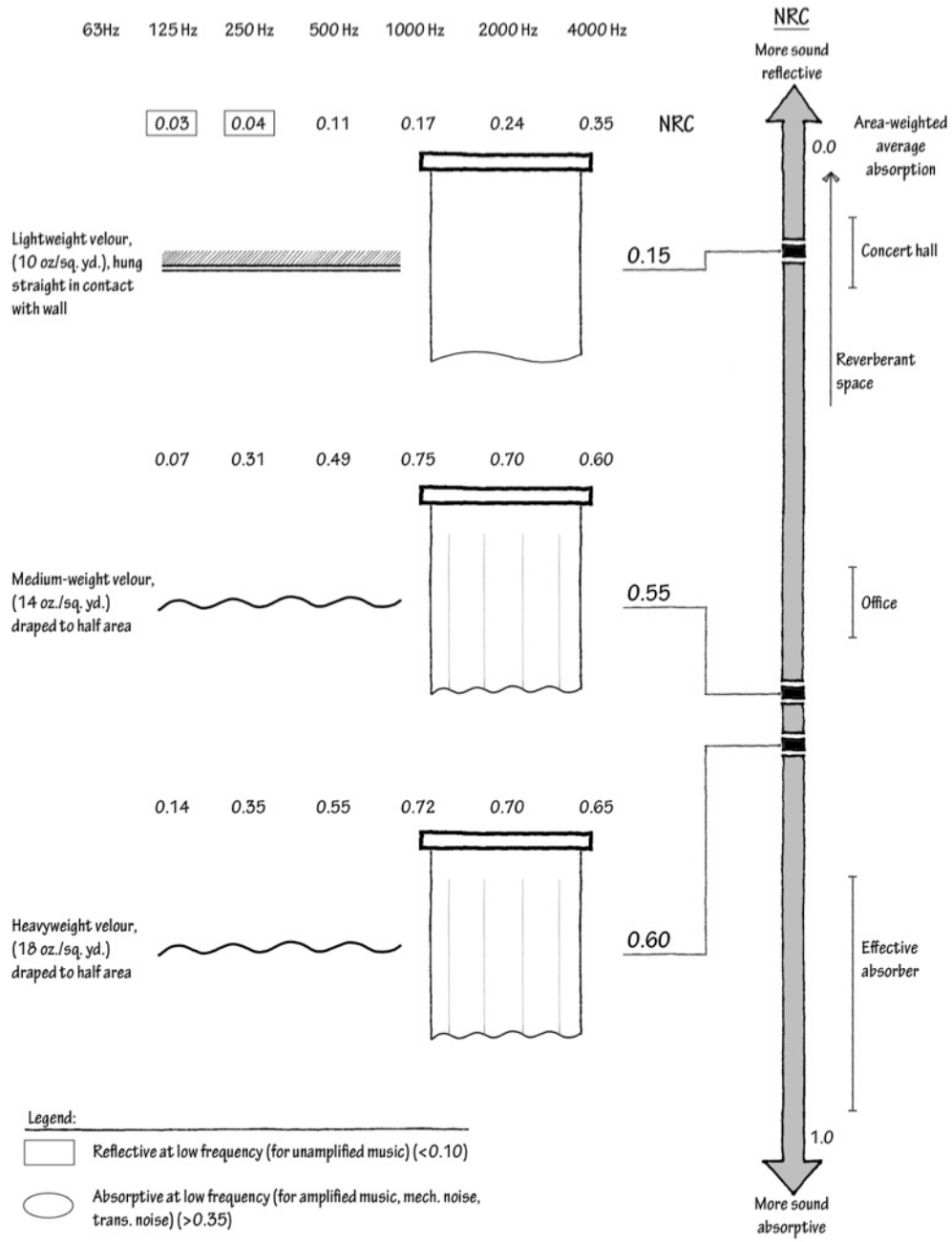
Smooth and porous surfaces



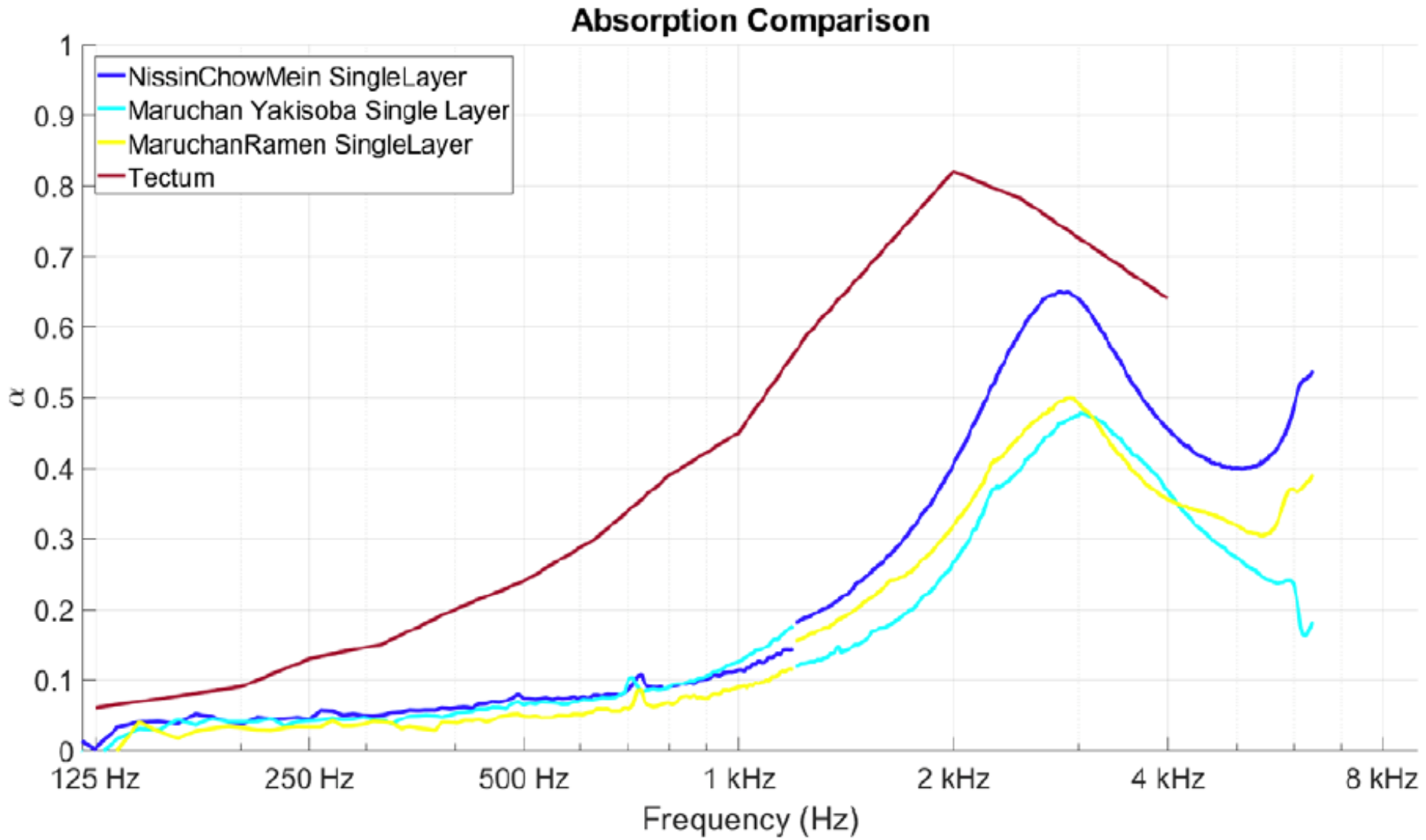
Glass stiffness and mass



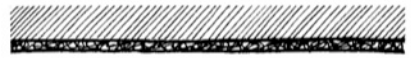
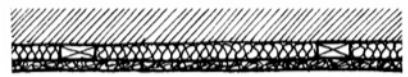
Curtains, furling and weight

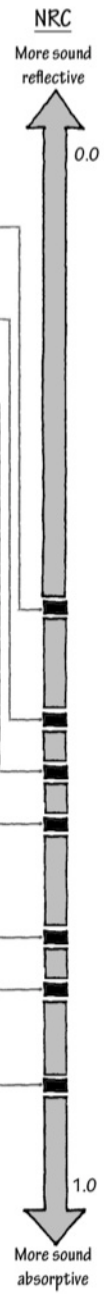


Packaged Noodles

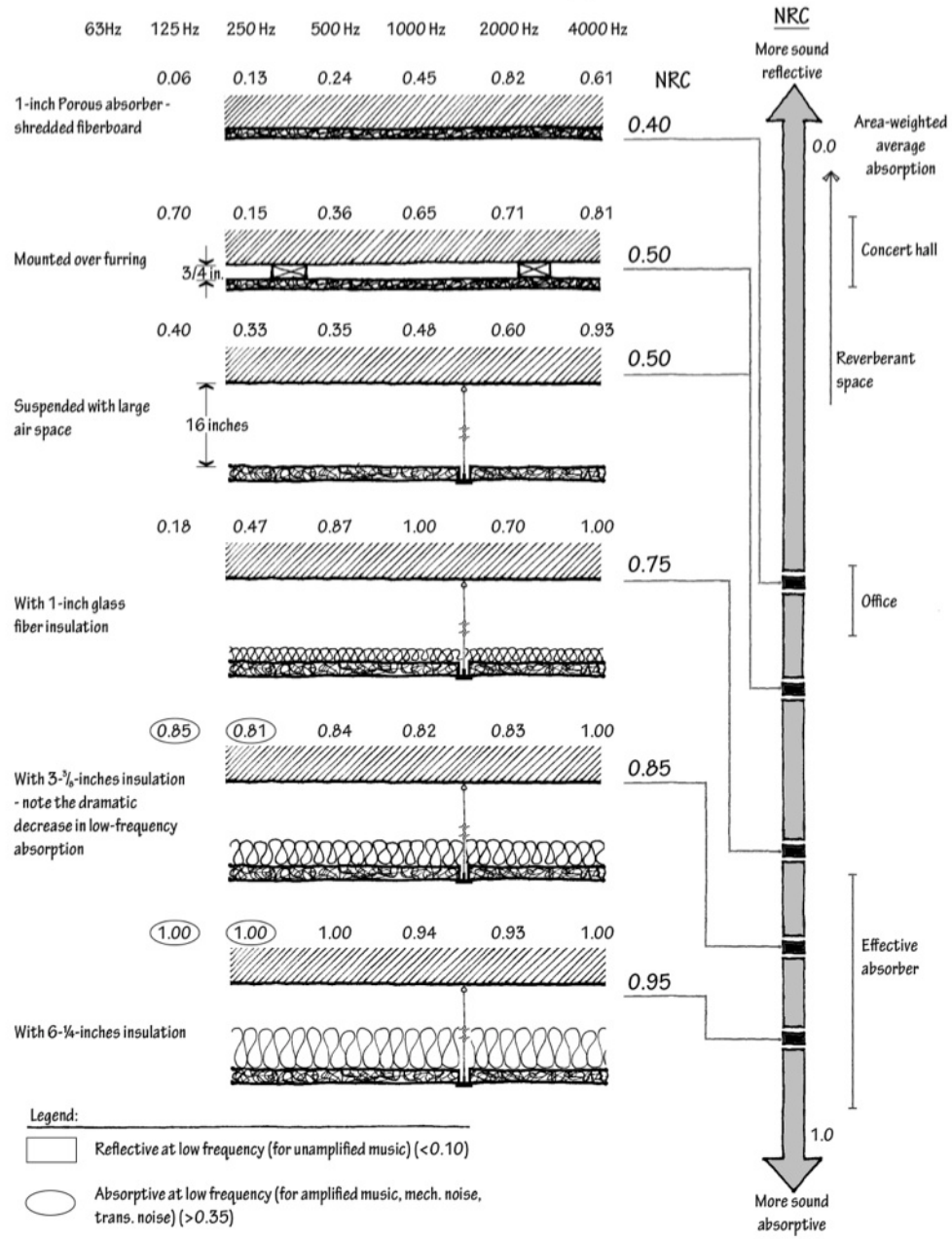


Porous absorbers and thickness

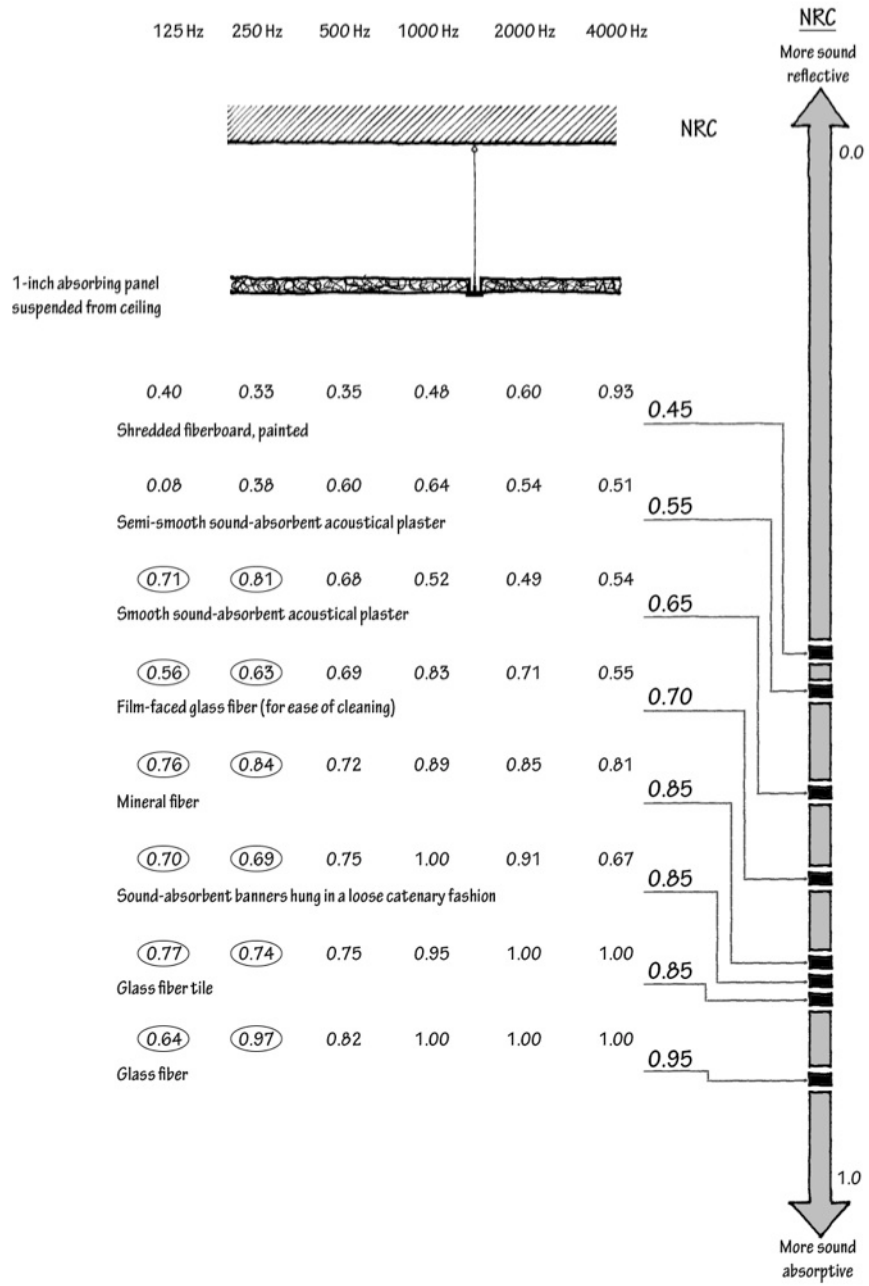
	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	NRC
								
1-inch Thick porous absorber (shredded fiberboard- strands of wood adhered and oriented to promote air pockets)		0.06	0.13	0.24	0.45	0.82	0.64	0.40
1.5-inches Thick		0.07	0.22	0.48	0.82	0.64	0.96	0.55
2-inches Thick		0.15	0.26	0.62	0.94	0.64	0.92	0.60
2.5-inches Thick		0.20	0.31	0.72	0.84	0.77	0.90	0.65
3-inches Thick		0.21	0.41	1.00	0.75	1.00	0.97	0.80
								
1-inch Shredded fiberboard with 1-inch glass fiber		0.16	0.43	1.00	1.00	0.79	0.98	0.80
1-inch Shredded fiberboard with 2-½-inches glass fiber		0.32	0.70	1.00	0.93	0.76	0.94	0.85
2-inches Shredded fiberboard with 2-½-inches glass fiber		(0.42)	(0.89)	1.00	0.85	1.00	0.94	0.95



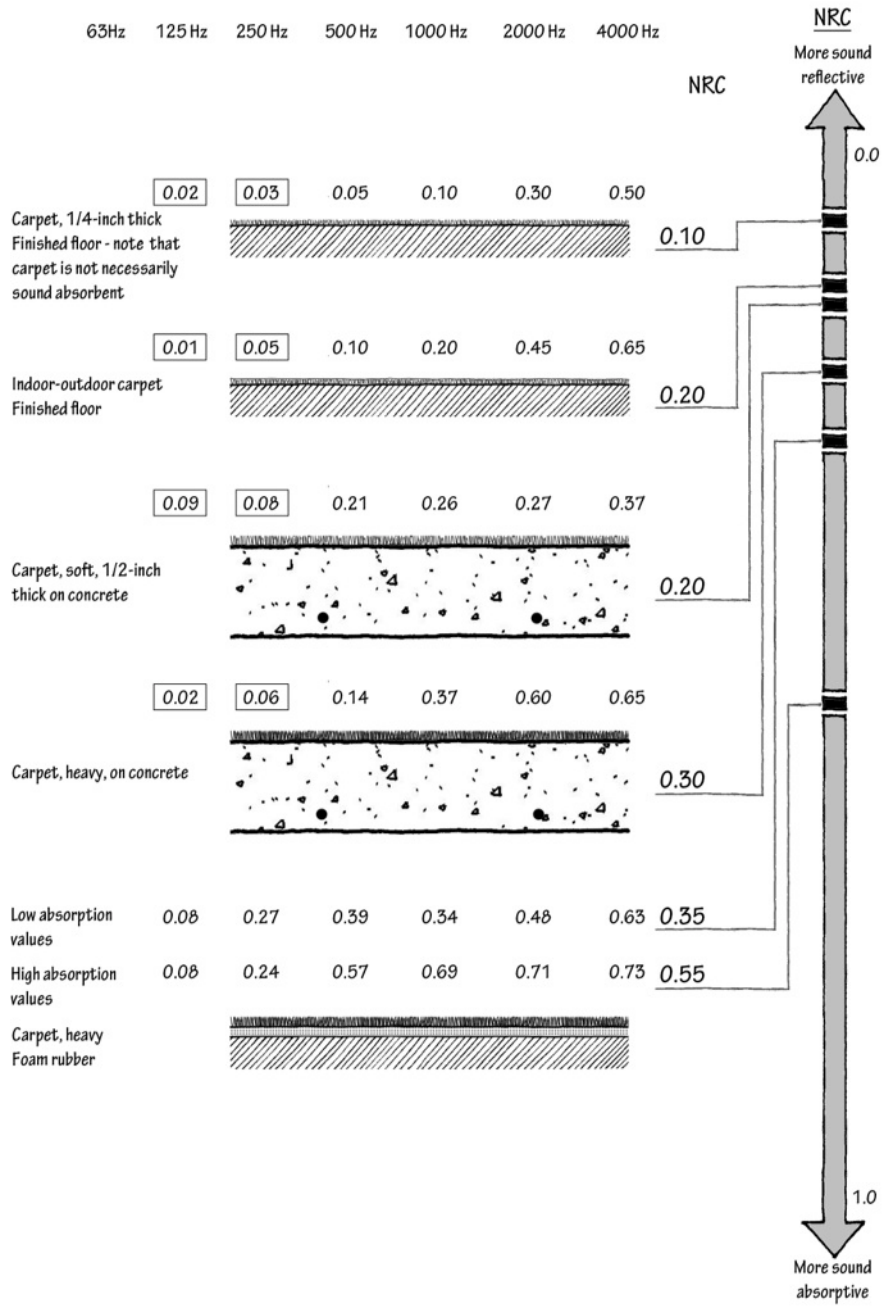
Porous absorbers and mounting over an airspace



Absorbing material comparison

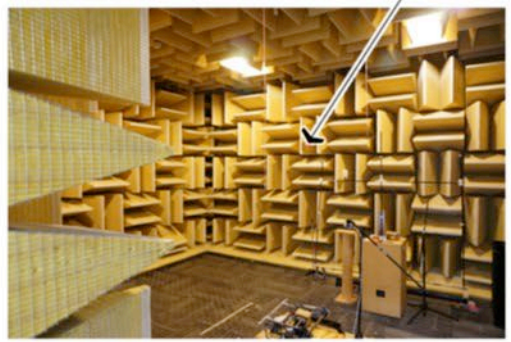


Is carpet very sound-absorbing?




Room average absorption coefficient ($\bar{\alpha}$) area-weighted
Anechoic chamber used for acoustics research
Recording studio for speech
Room with large quantities of absorption
Office with many absorbent surfaces
≥ 0.4 judged a relatively "dead" room
Room with absorbing material on both ceiling and walls
≥ 0.3 eliminates excessive reverberance in restaurants
Room with absorptive furniture or small amount of absorptive material
≤ 0.2 judged a relatively "live" room
Concert hall
Nearly empty room with smooth hard surfaces
Specific material noise reduction coefficient (NRC):
Speech frequency absorption
1.0
0.8
0.6
0.4
0.2
0
Open window: 0% of incident sound energy reflected
The most-absorbent porous absorbers
Snow
Sound-absorbent banners
Thick acoustical ceiling tile
Sprayed-on acoustical plaster
Occupied audience seats, per square foot
Acoustical ceiling tile
Heavyweight curtains
Medium-weight curtains
Least-absorbent porous absorbers
Sand
Unpainted concrete block
Heavy carpet on rubber backing
Heavy carpet on concrete
Carpet on concrete
Lightweight curtains flush to wall
Glass
Gypsum wall board
100% of incident sound energy reflected

Used for research, sound-absorbent wedges line every surface including the floor



Anechoic Chamber

Fabric-wrapped glass fiber

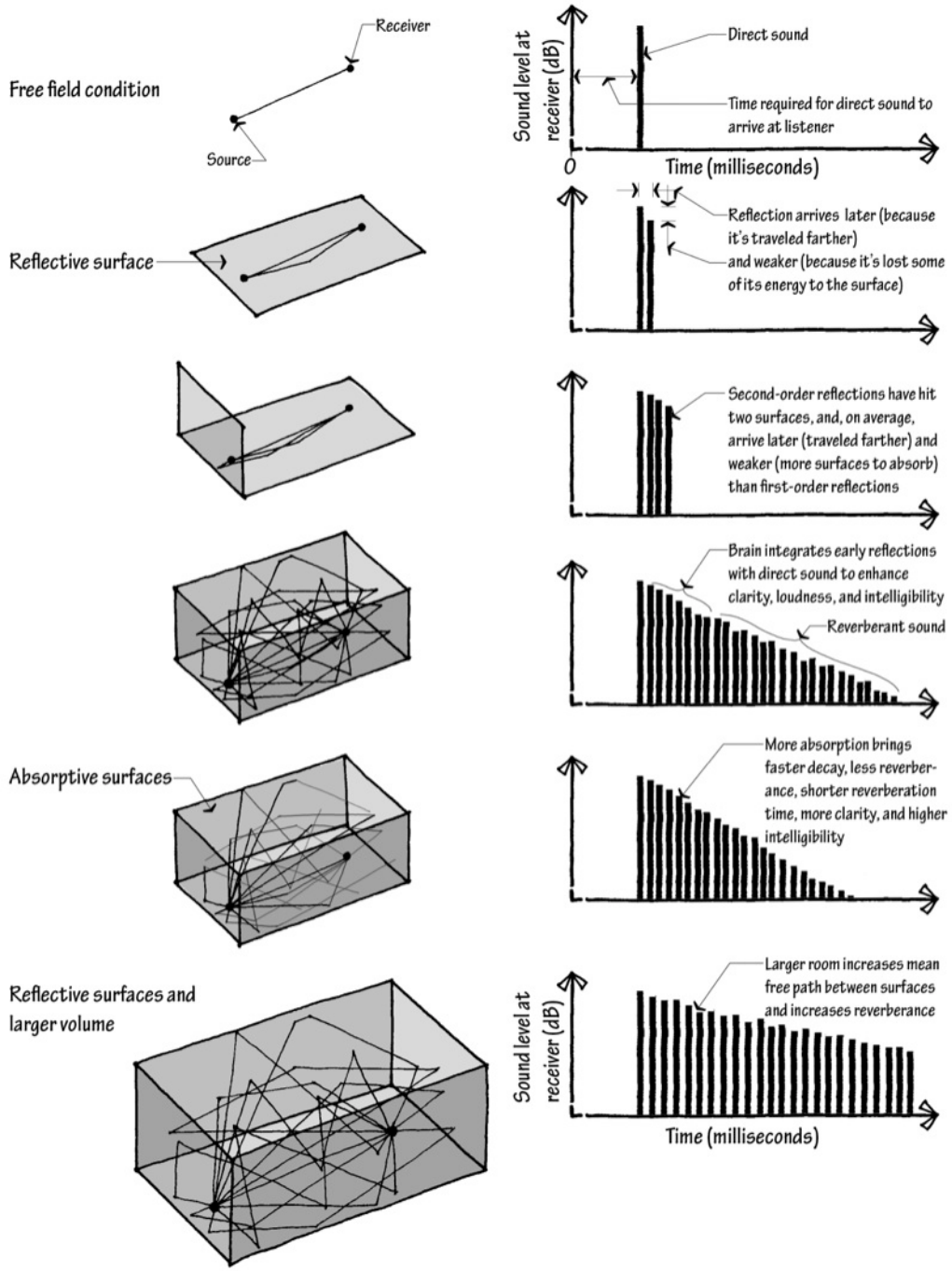
The pores formed by the orientation of the fibers absorb sound

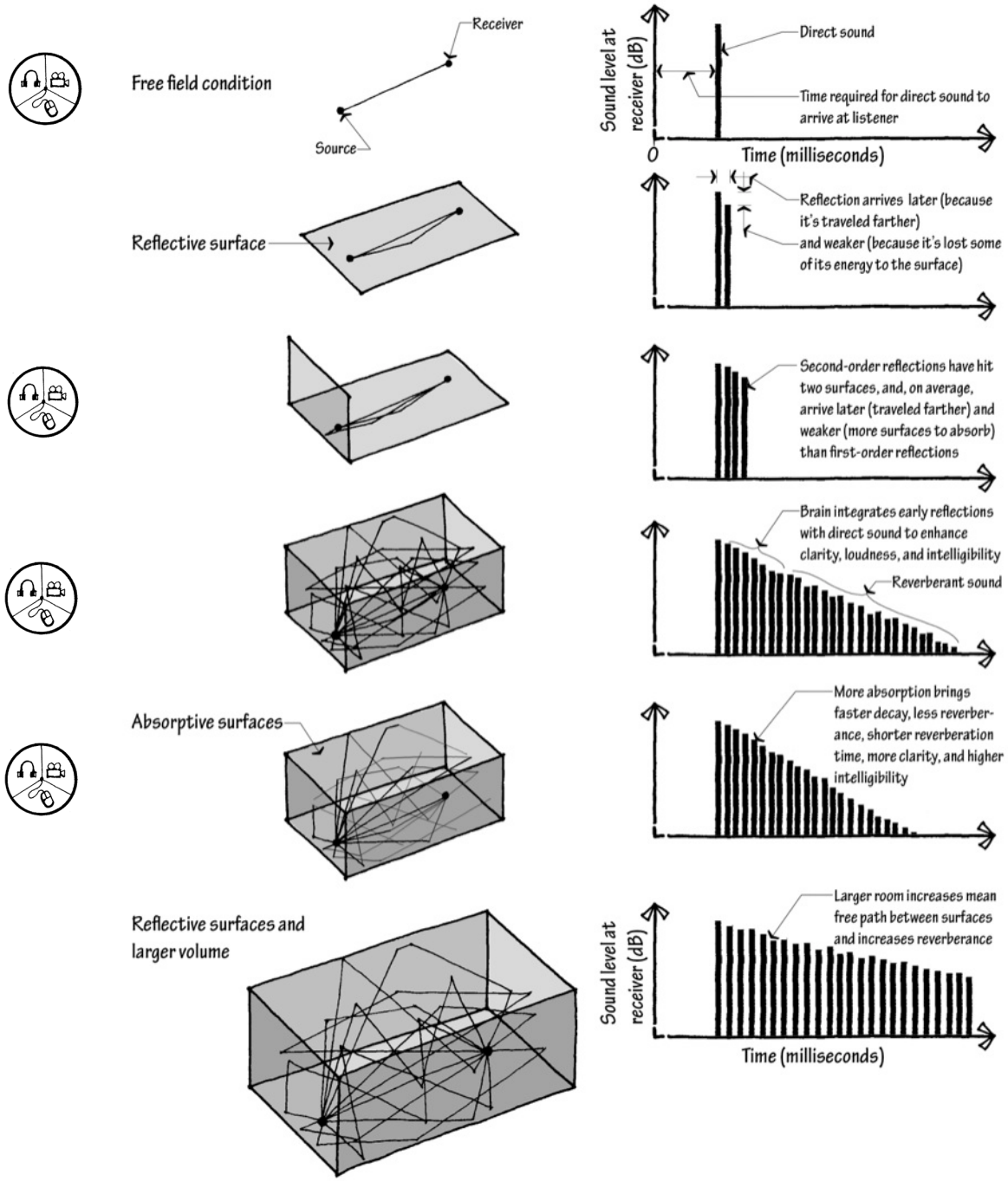
Shredded fiberboard

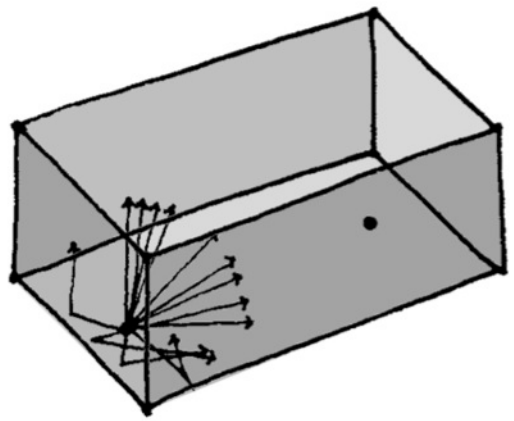
Smooth absorbing plaster

Textured absorbing plaster

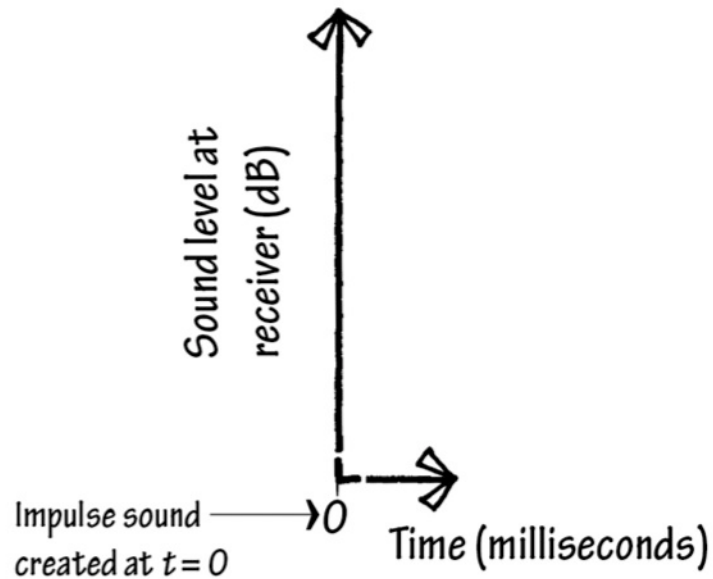
Duct interior insulation

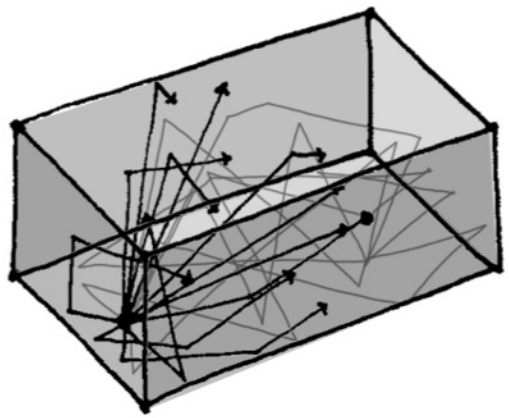

Free field condition
Receiver
Source
Sound level at receiver (dB)
Direct sound
Time required for direct sound to arrive at listener
0
Time (milliseconds)
Reflective surface
Reflection arrives later (because it's traveled farther) and weaker (because it's lost some of its energy to the surface)
Second-order reflections have hit two surfaces, and, on average, arrive later (traveled farther) and weaker (more surfaces to absorb) than first-order reflections
Brain integrates early reflections with direct sound to enhance clarity, loudness, and intelligibility
Reverberant sound
Absorptive surfaces
More absorption brings faster decay, less reverberance, shorter reverberation time, more clarity, and higher intelligibility
Reflective surfaces and larger volume
Larger room increases mean free path between surfaces and increases reverberance
Sound level at receiver (dB)
Time (milliseconds)


Free field condition
Receiver
Source
Sound level at receiver (dB)
Direct sound
Time required for direct sound to arrive at listener
0
Time (milliseconds)
Reflective surface
Reflection arrives later (because it's traveled farther)
and weaker (because it's lost some of its energy to the surface)
Second-order reflections have hit two surfaces, and, on average, arrive later (traveled farther) and weaker (more surfaces to absorb) than first-order reflections
Brain integrates early reflections with direct sound to enhance clarity, loudness, and intelligibility
Reverberant sound
Absorptive surfaces
More absorption brings faster decay, less reverberance, shorter reverberation time, more clarity, and higher intelligibility
Reflective surfaces and larger volume
Larger room increases mean free path between surfaces and increases reverberance
Sound level at receiver (dB)
Time (milliseconds)

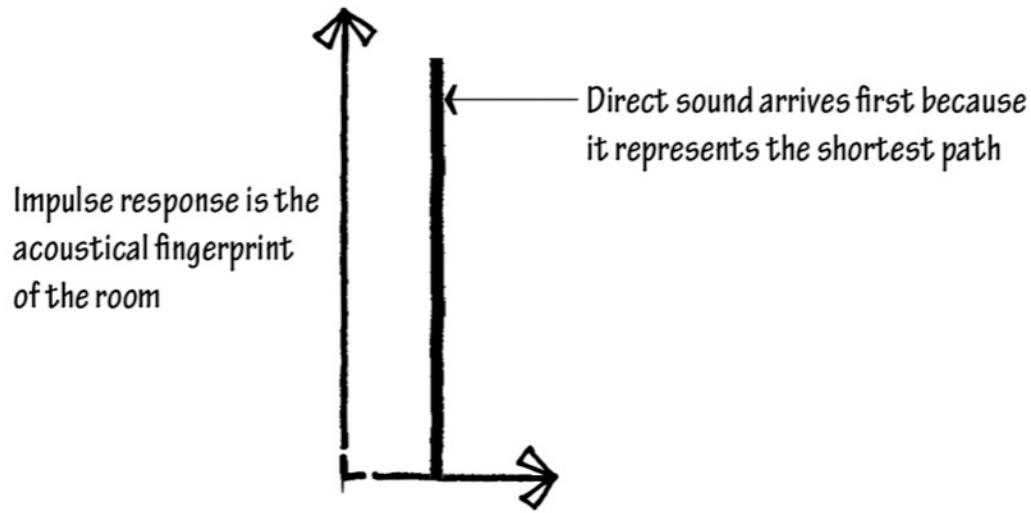


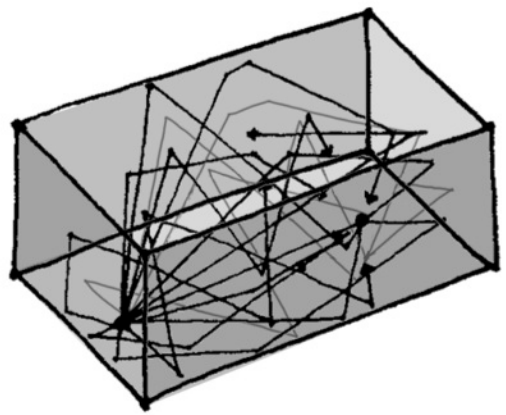
$t = 20$ ms


Sound level at receiver (dB)
Impulse sound created at $t = 0$
0
Time (milliseconds)

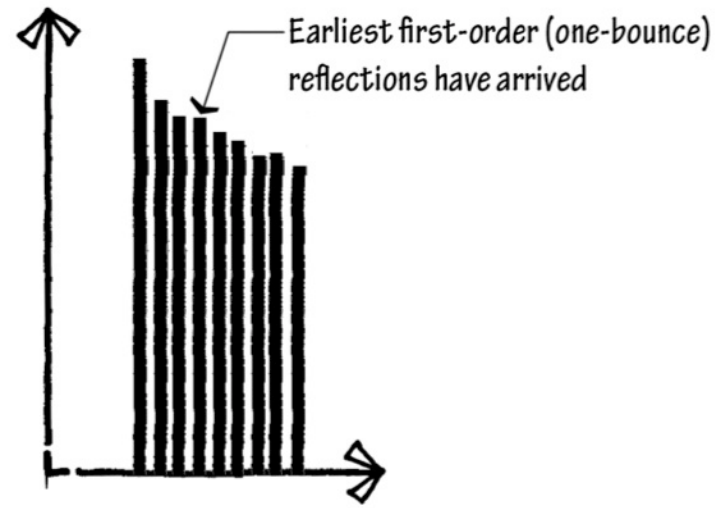


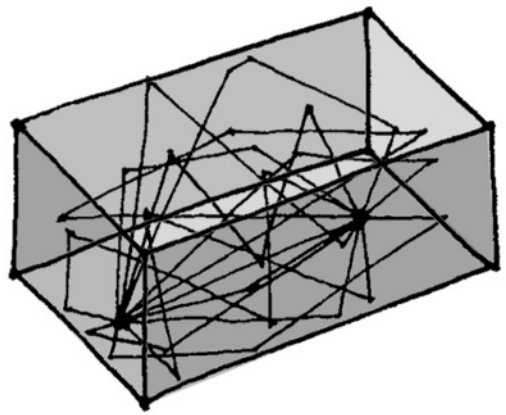
$t = 70$ ms


Impulse response is the acoustical fingerprint of the room
Direct sound arrives first because it represents the shortest path

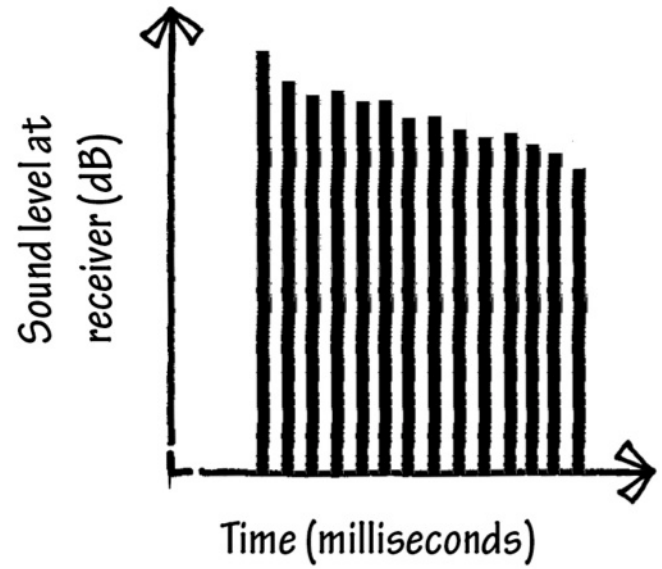


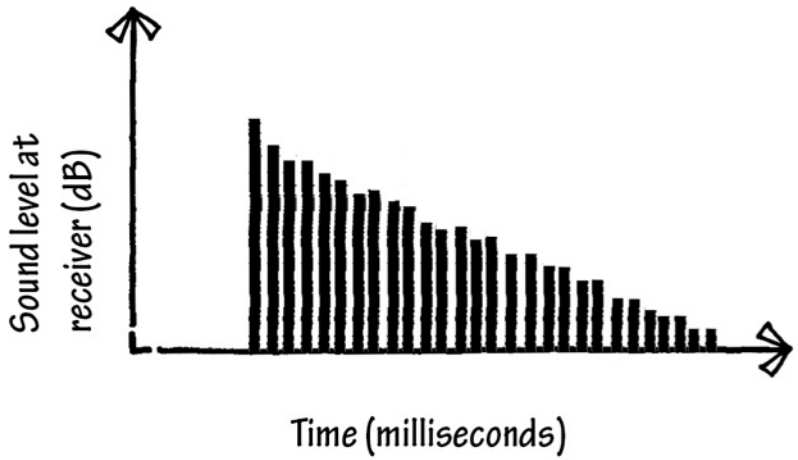
$t = 120$ ms

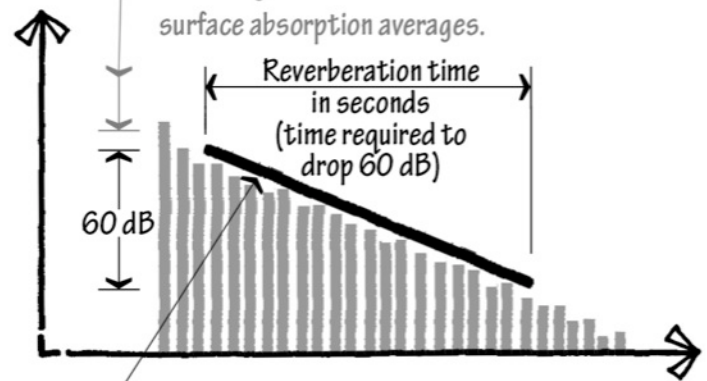




$t = 170$ ms



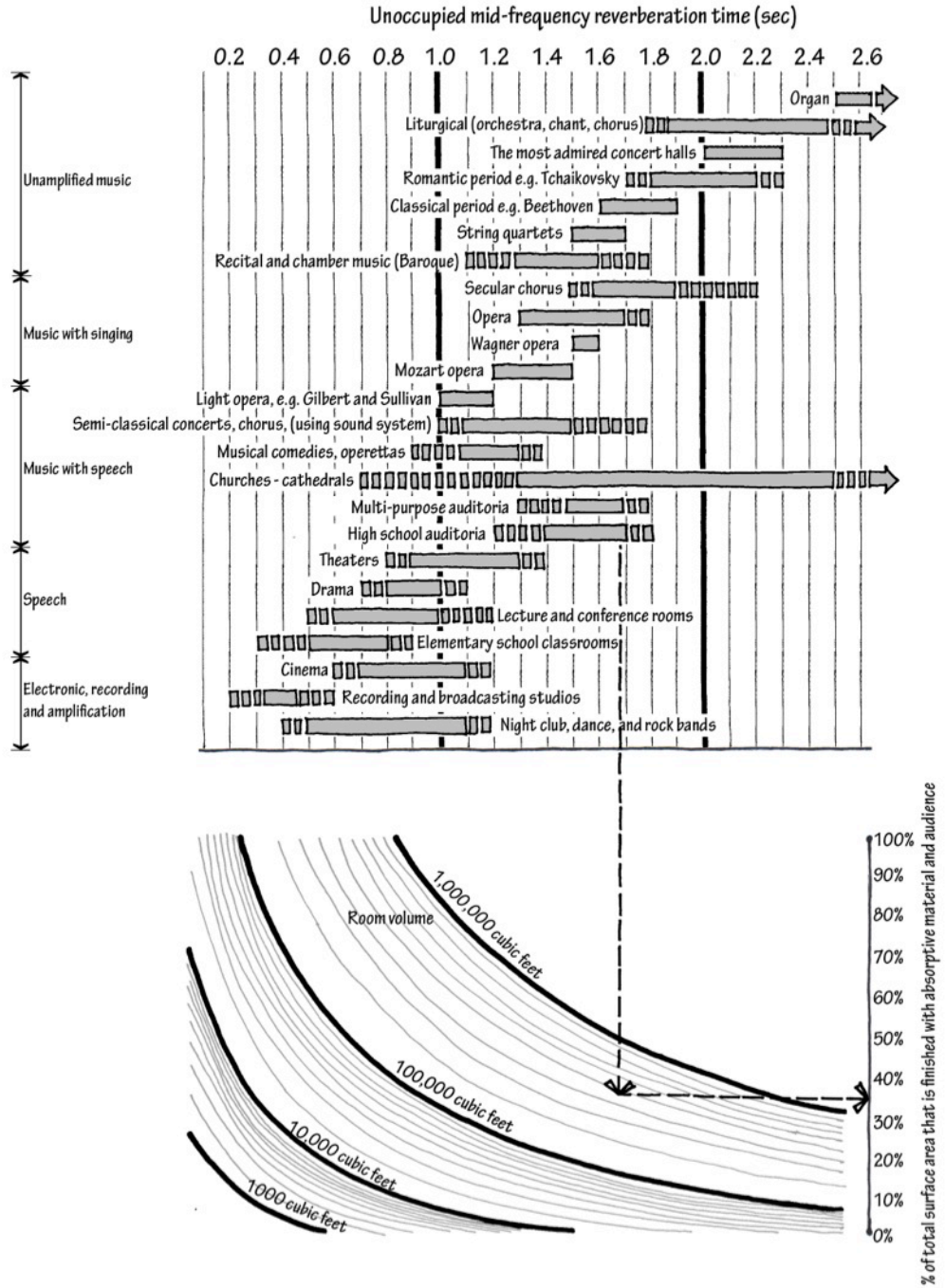


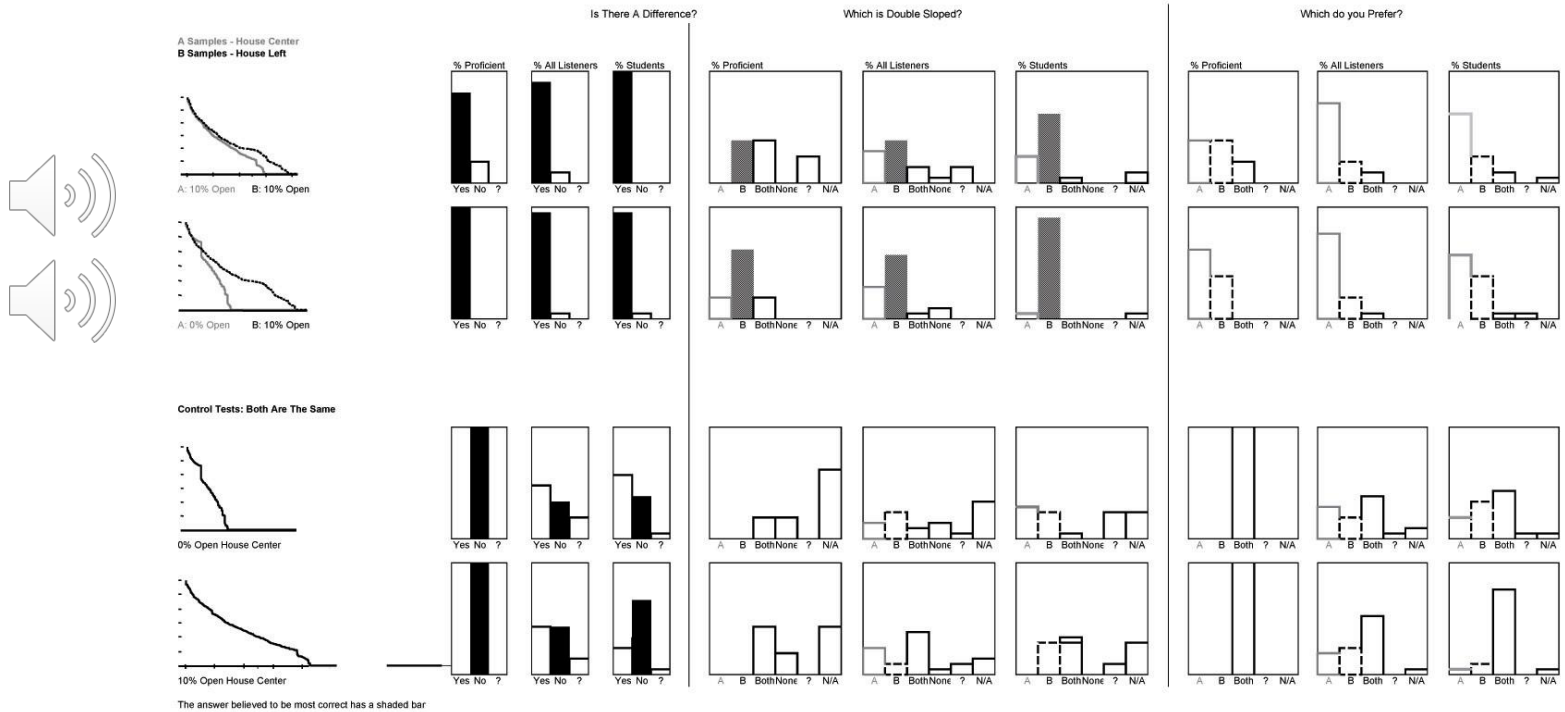


First 5 dB of decay discarded in reverberation time measurement because it is so heavily skewed by the direct sound and the peculiarities of very-early strong reflections. These are more a function of source-path-receiver geometries than statistical room volume and surface absorption averages.

More rapid decay: smaller rooms, more surfaces, fuzzier surfaces, shorter reverberation times

More gradual decay: larger rooms, fewer surfaces, smoother surfaces, longer reverberation times


Unoccupied mid-frequency reverberation time (sec)
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
Unamplified music
Music with singing
Music with speech
Speech
Electronic, recording and amplification
Organ
Liturgical (orchestra, chant, chorus)
The most admired concert halls
Romantic period e.g. Tchaikovsky
Classical period e.g. Beethoven
String quartets
Recital and chamber music (Baroque)
Secular chorus
Opera
Wagner opera
Mozart opera
Light opera, e.g. Gilbert and Sullivan
Semi-classical concerts, chorus, (using sound system)
Musical comedies, operettas
Churches - cathedrals
Multi-purpose auditoria
High school auditoria
Theaters
Drama
Lecture and conference rooms
Elementary school classrooms
Cinema
Recording and broadcasting studios
Night club, dance, and rock bands
Room volume
1,000,000 cubic feet
100,000 cubic feet
10,000 cubic feet
1000 cubic feet
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
% of total surface area that is finished with absorptive material and audience


Is There A Difference?
Which is Double Sloped?
Which do you Prefer?
A Samples - House Center
B Samples - House Left
% Proficient
% All Listeners
% Students
A: 10% Open
B: 10% Open
A: 0% Open
B: 10% Open
Yes No ?
A B Both None ? N/A
Control Tests: Both Are The Same
0% Open House Center
10% Open House Center
The answer believed to be most correct has a shaded bar


Culture and Congress C