IIT KHARAGPUR

NPTEL ONLINE CERTIFICATION COURSES

NPTEL

Architectural Acoustics

Lecture 11: Introduction to Acoustical Absorbers

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Learning Objective

- Room acoustics and role of absorbers

- Types of Absorbers: working principle, target frequency range

- Porous/ Frictional Absorber

Introduction to absorbers

- Room acoustics: surfaces and shape of room

- Purpose of Room- reverberation time

- Role of absorbers

The process by which a material, structure, or object takes in sound energy when sound waves are encountered, as opposed to reflecting the energy is termed as absorption

Part is **absorbed** and a part is transmitted through the **absorbing** body..

Introduction to absorbers

There are two kinds of sound:

1. Direct sound

We use direct sound to gauge direction and general tonal quality.

2. Reflected (indirect) sound, that bounces off the walls, floor and the ceiling

We use this sound to gauge the distance we are from the sound source and the size of the environment we're in.

Introduction to absorbers

Is sound absorption coefficient (α) a true estimator of sound absorption of all frequencies?

Theoretically the Noise Reduction Coefficient 'α' represents the average absorption between 250 Hz to 2000 Hz

Bass and treble refers to the lower and higher frequencies respectively

An architect needs to organise the goals he would like to reach through a clear conceptual framework

Controlling them through absorption is also important

Knowing the source frequencies and also the target frequency to be absorbed specifically is important to get quality sound.

Types of absorbers

How does absorbers work?

Sound energy gets transformed into other forms of energy after hitting the surface

Heat energy due to frictional losses

Vibration losses

Porous absorbers or Frictional Absorbers
Panel absorbers or vibrating absorbers
Resonant absorbers or cavity absorbers

All hard smooth surfaces are reflectors and their absorption coefficient is very low
Absorption coefficient below 0.2 are reflectors

Absorption

The acoustical *impedance, is a measure of the resistance to motion at a given point,* it is one of the most important properties of any material which leads to sound attenuation.

The *specific acoustic impedance,* which is most frequently encountered in architectural acoustics, is defined as the ratio of the sound pressure to the associated *particle velocity at a point*

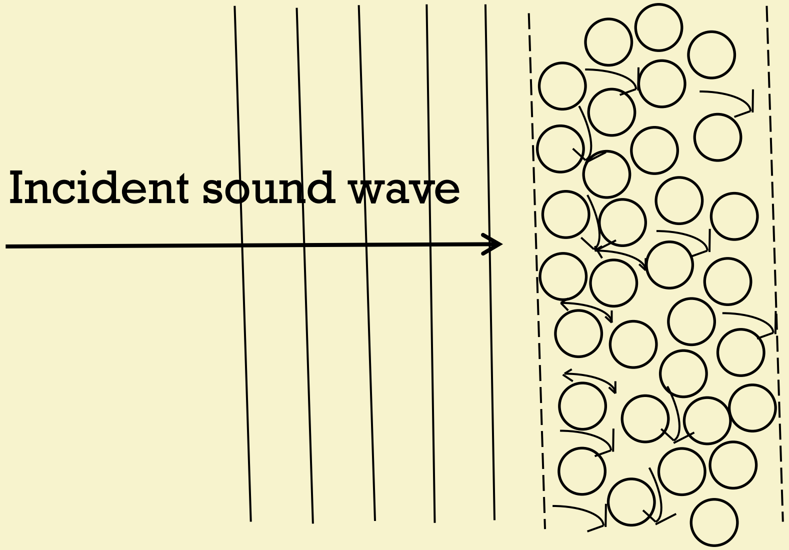
$z = p/u$

where z = specific acoustic impedance ($N.s/m^3$)

p = sound pressure (Pa)

u = acoustic particle velocity (m /s)

Porous absorbers



Local flow velocity increases

Direction changes lead to high frequency losses

Friction with particles lead to heat and low frequency losses

Thicker the absorber, higher is the absorption

Porous absorbers
Examples: fiberglass, mineral fiber products, fiberboard, pressed wood shavings, cotton, felt, open-cell neoprene foam, carpet

Porous absorbers

Fibreboard

(source:Wikimedia commons)

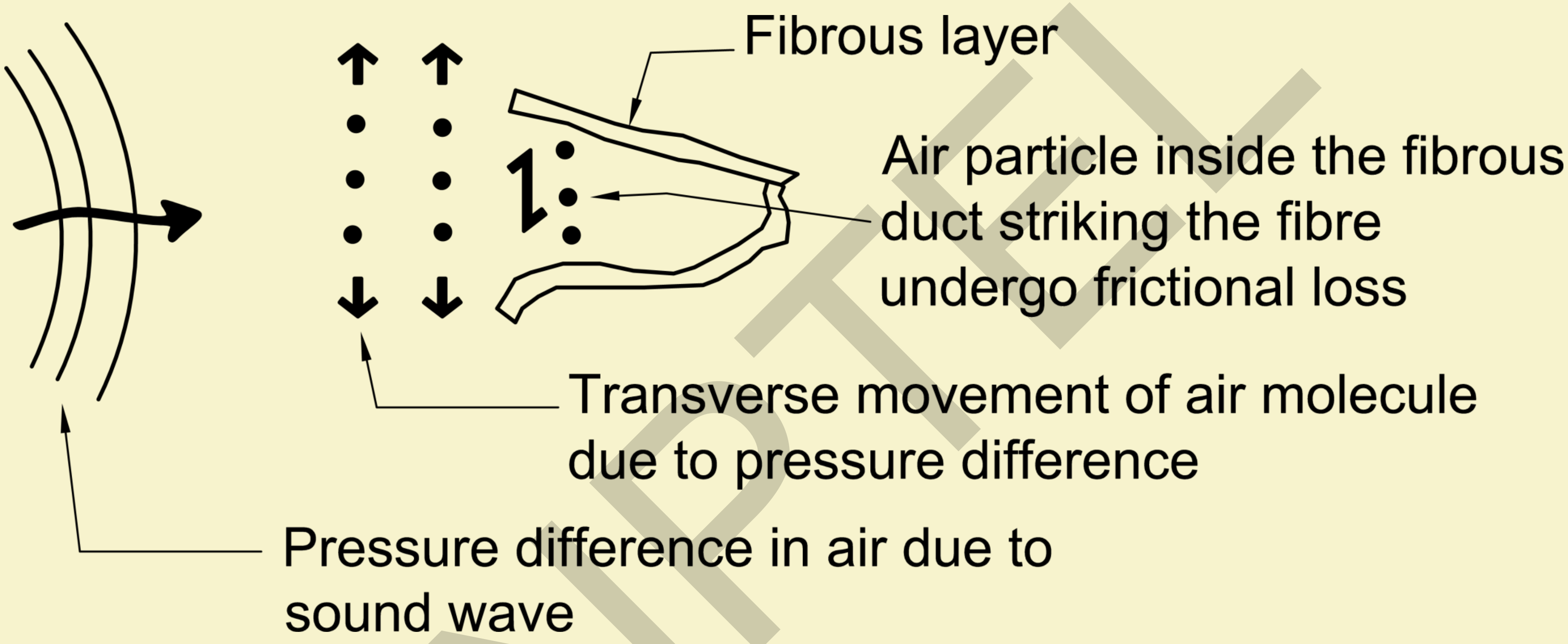
Cork-sheet

(source:Wikimedia commons)

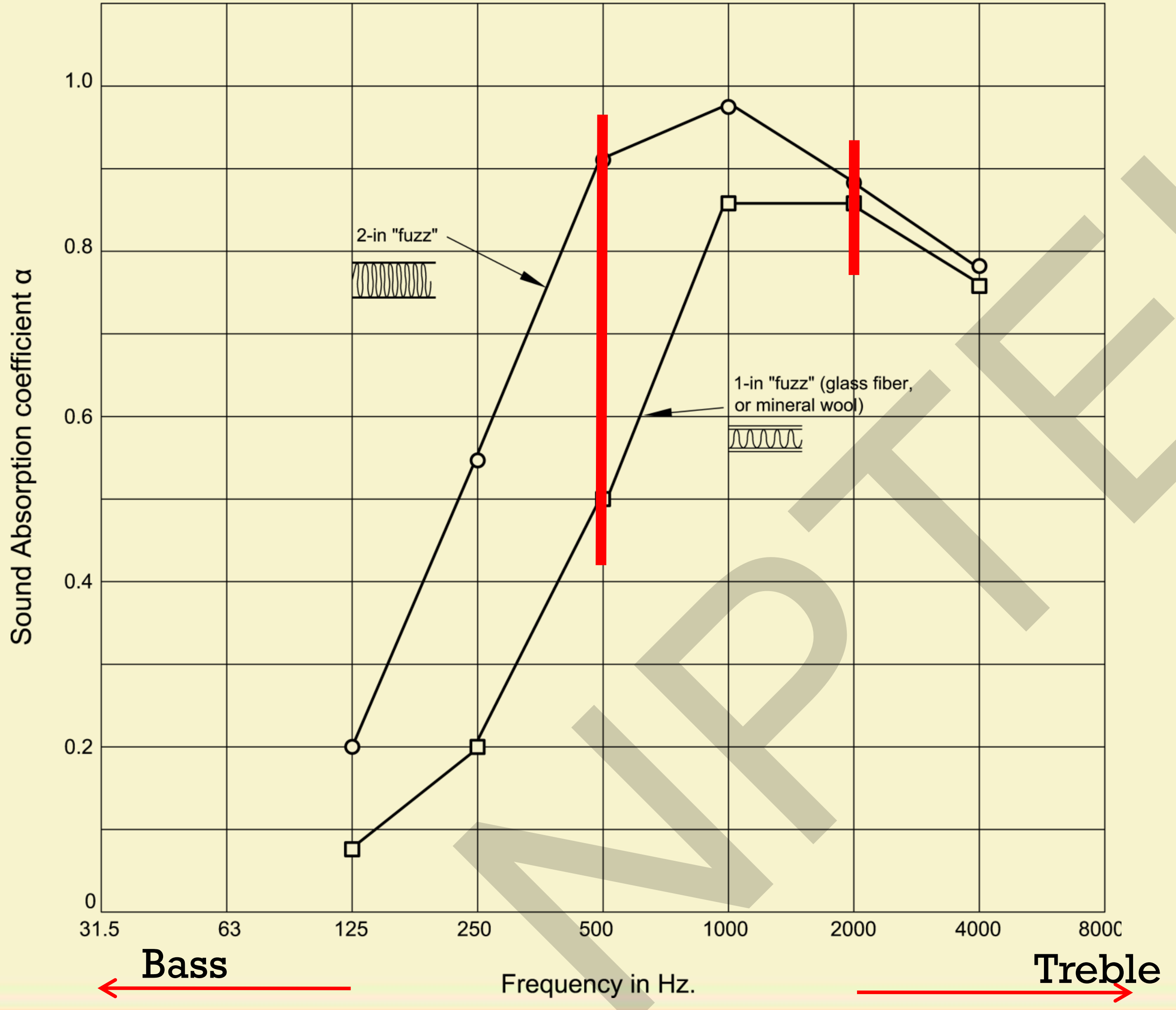
Straw-board

(source:Wikimedia commons)

Porous absorbers



Thickness and absorption by porous absorbers

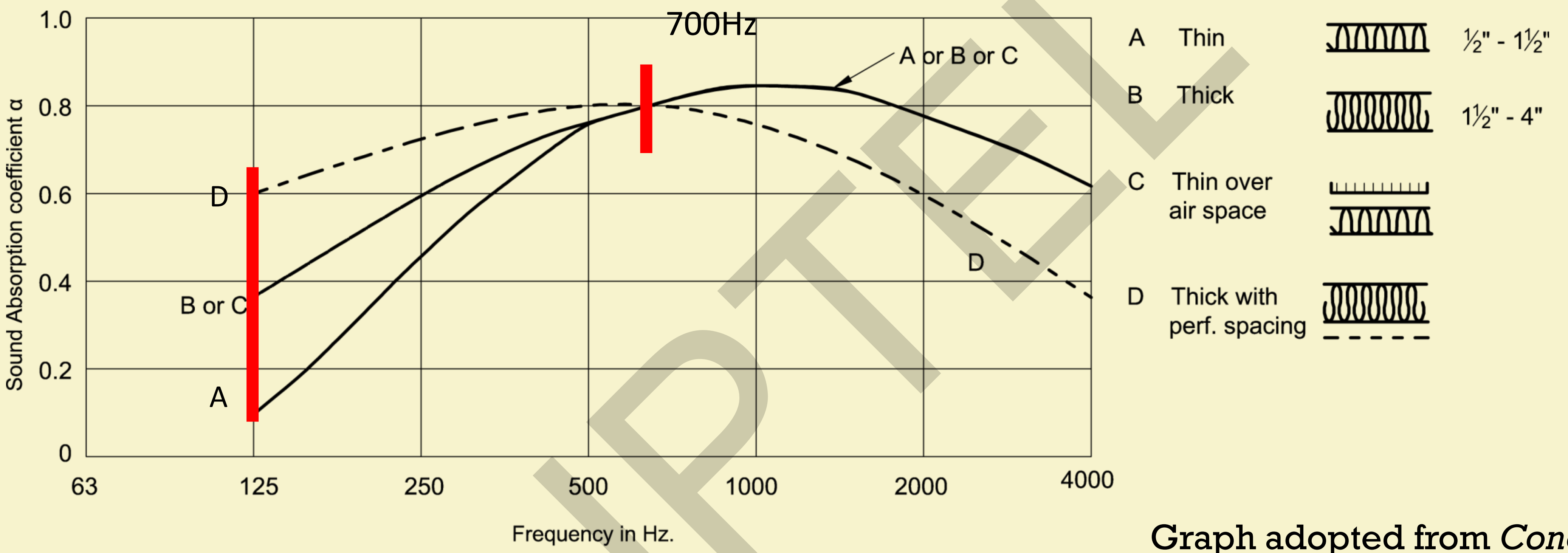


At 500Hz maximum variation in absorption

At 2000Hz and beyond similar absorption diminishing coefficient

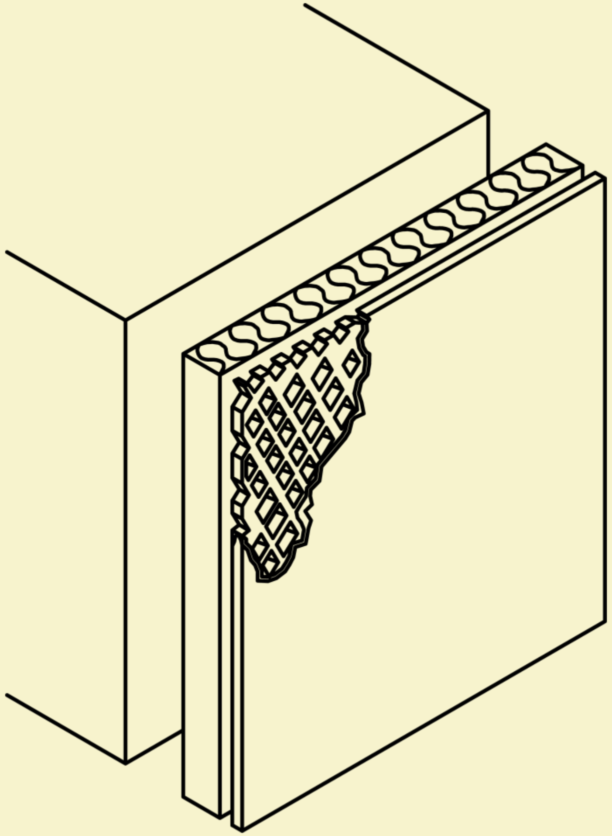
Graph adopted from *Concepts in Architectural Acoustics* by M. David Eagan.

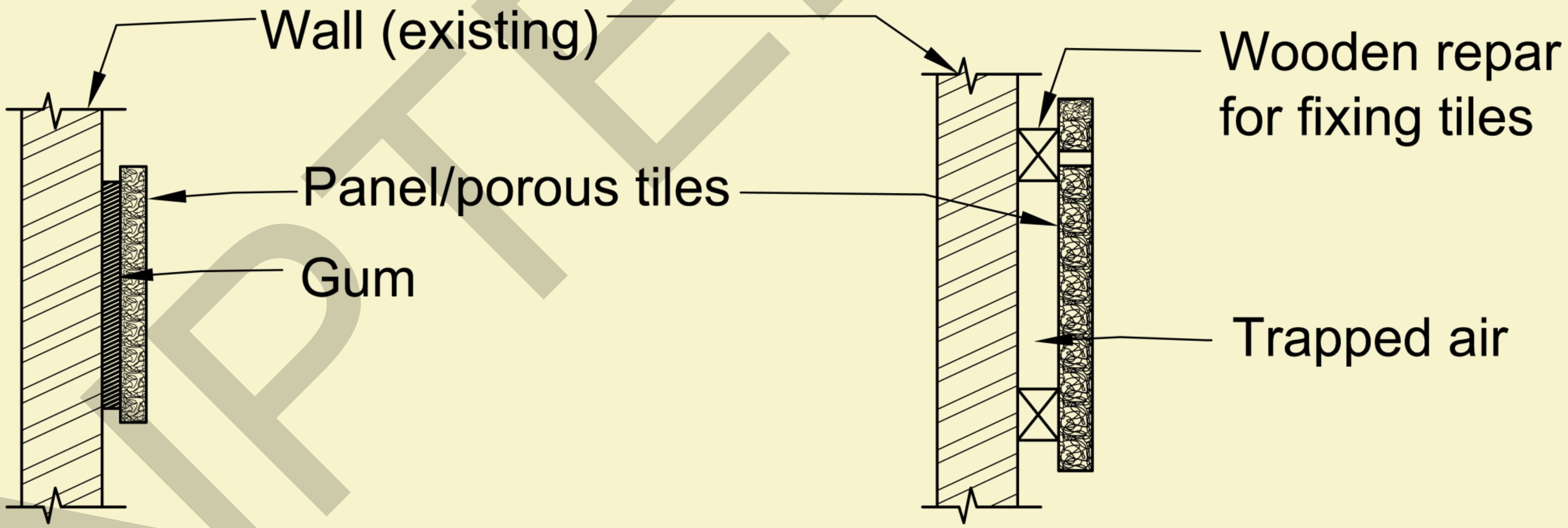
Absorption by porous absorbers



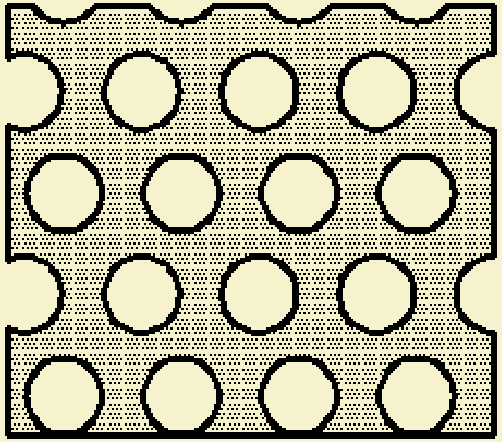
Graph adopted from *Concepts in Architectural Acoustics* by M. David Eagan.

Mounting types

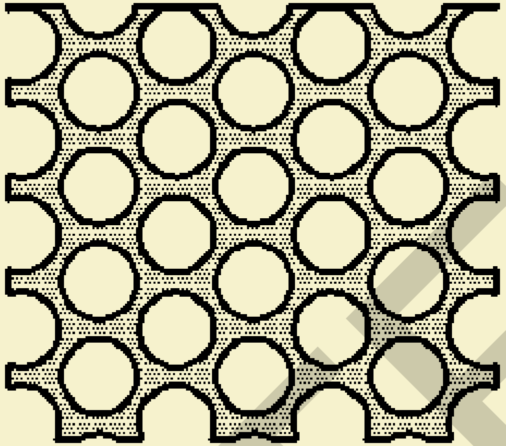




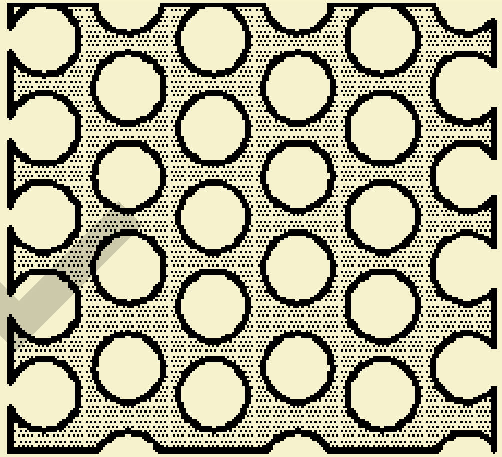
Perforated Panels and porous absorption



$\frac{1}{4}$" Staggered Holes at $\frac{3}{8}$" o.c. -40% open



$\frac{1}{4}$" Staggered Holes at $\frac{5}{16}$" o.c. -58% open

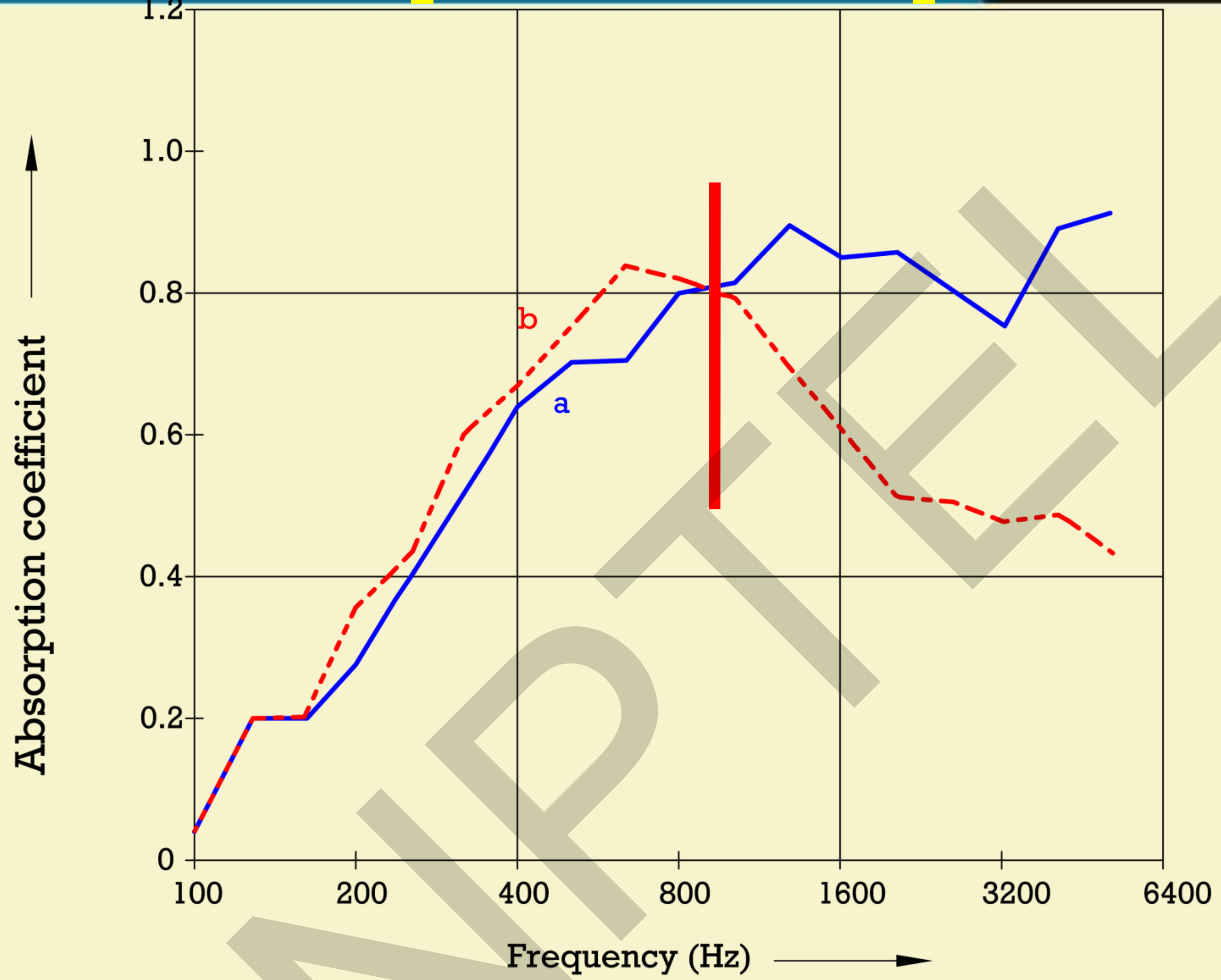


$\frac{17}{64}$ " Staggered Holes at $\frac{5}{16}$ " o.c. -65% open

Perforated At least 15 - 20% of the facing should be open to perform as an absorber - as if it were unfaced

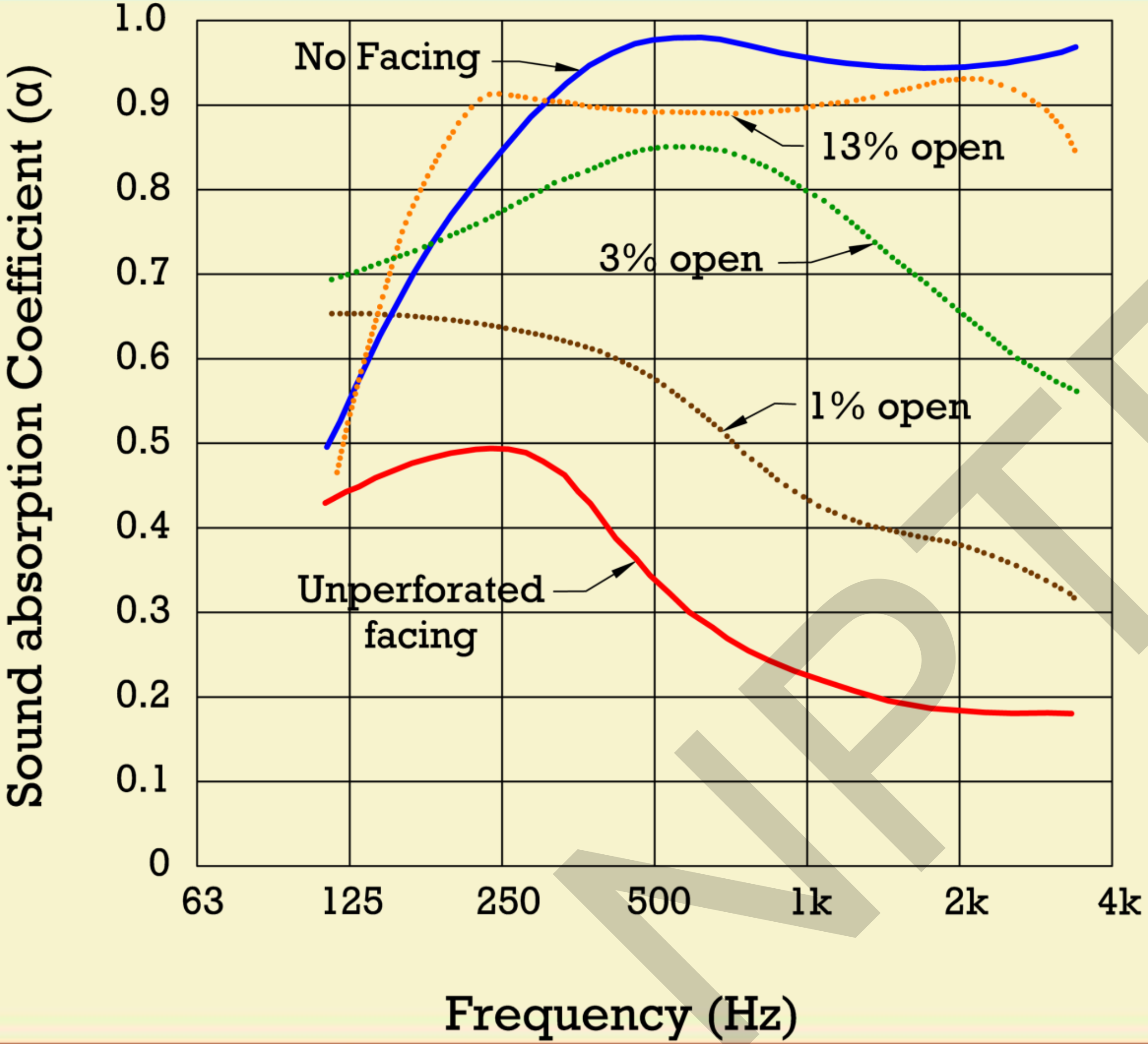
Perforated metals screens are also employed and can be effective as long as there is sufficient open area and the hole sizes are not so large that the spaces between the holes become reflecting surfaces, or so small that they become clogged.

Perforated Panels and porous absorption



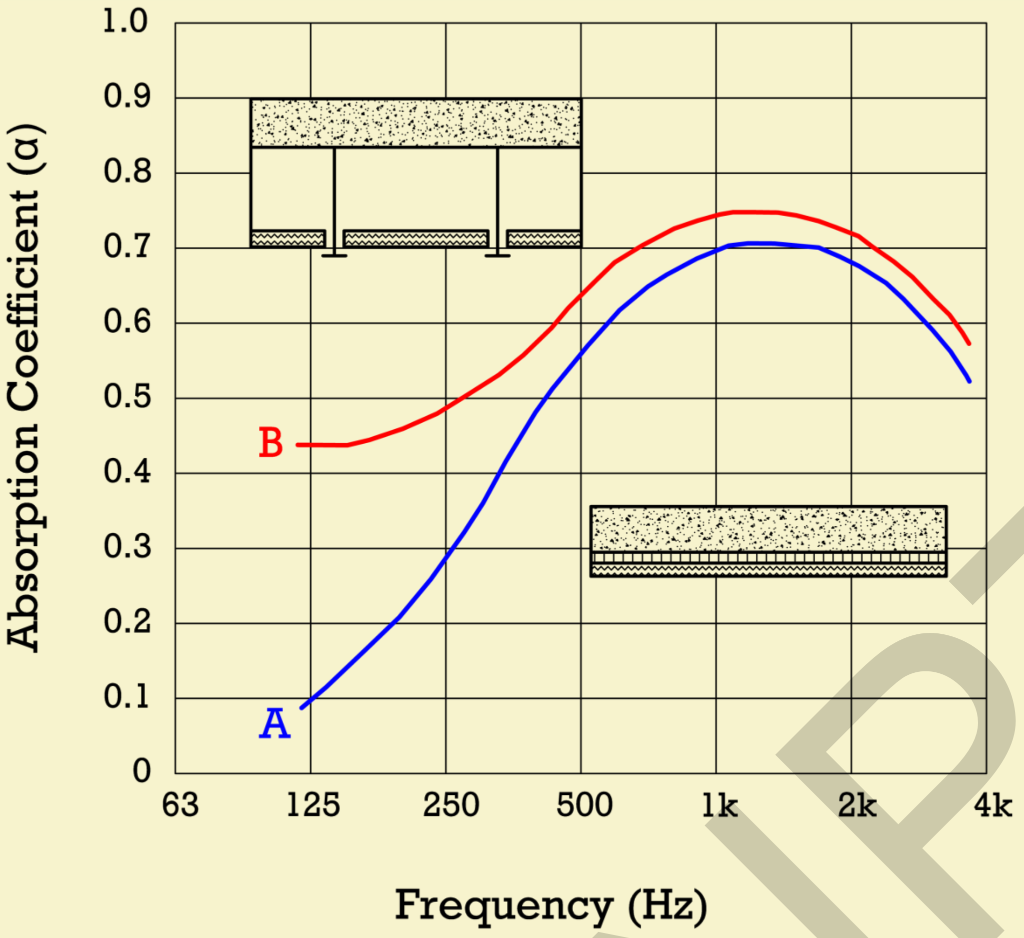
Absorption coefficient of 50 mm glass wool, mounted immediately on concrete:
(a) uncovered
(b) covered with a protective panel, 5 mm thick, 14% perforation

Beyond 1000 Hz there is much difference in absorption.

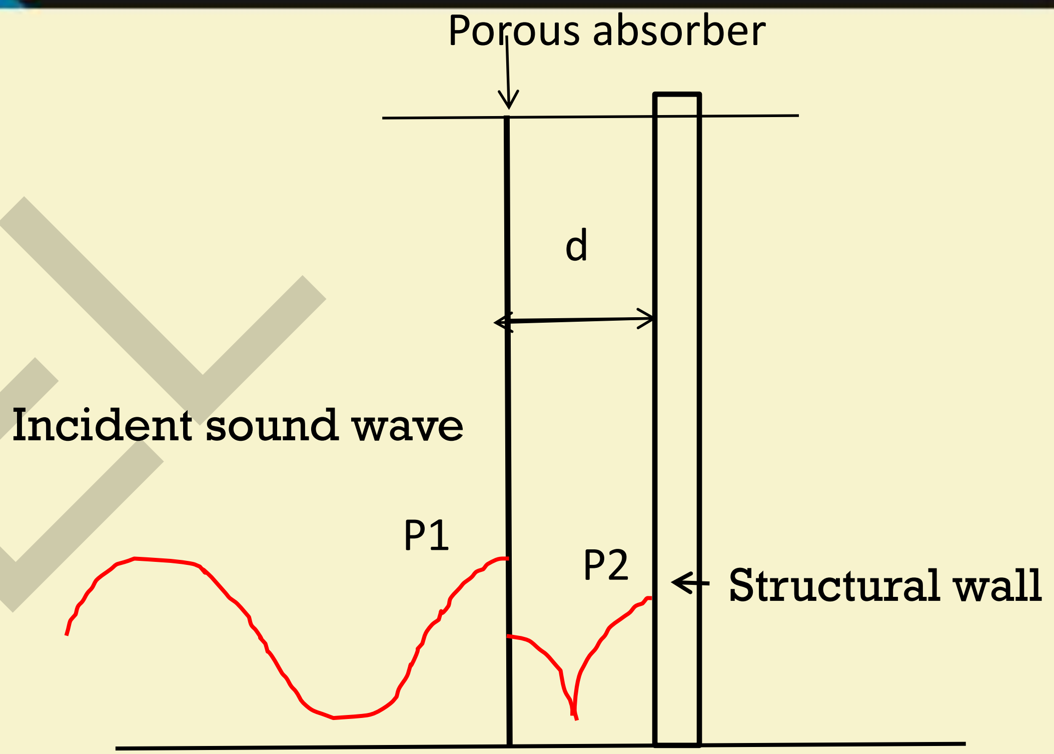


Sound absorption of perforated panel resonators (Doelle, 1972) with an isolation blanket in the air space

Perforated Panels and porous absorption



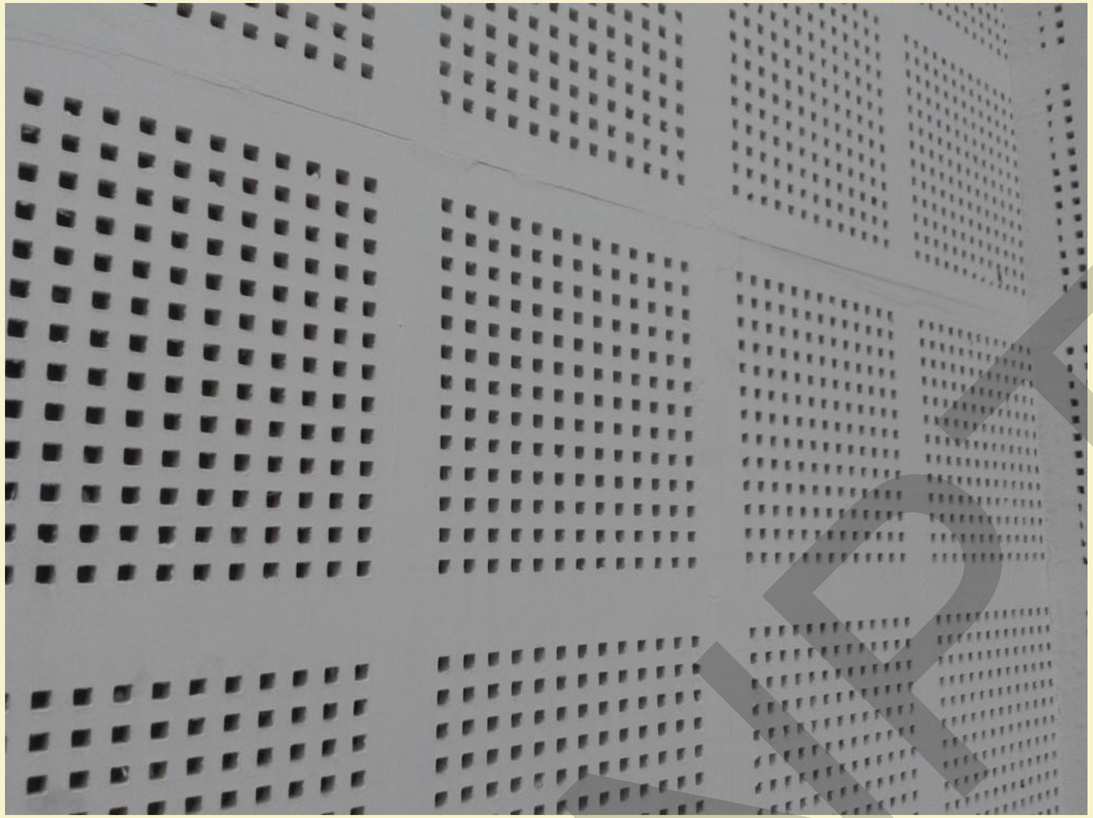
Average absorption of acoustical tiles (Doelle, 1972)
(A) Applied with adhesive
(B) In a suspended grid



Air flows through the absorber creating a standing wave within the cavity
The absorber does not move

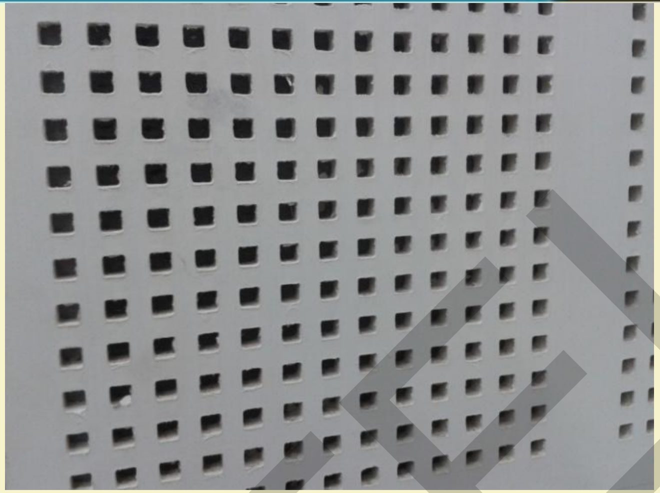
Graph adopted from *Concepts in Architectural Acoustics* by M. David Eagan.

Applications



Pictures of some applications in lecture halls at IIT Kharagpur

Applications


Conclusion

For most architectural applications, a 1” (25mm)thick absorbent fiberglass panel applied over a hard surface is the minimum necessary to control reverberation for speech intelligibility.

High-frequency flutter echoes can be reduced using thinner materials such as 3/16” (5 mm) wall fabric or 1/4” (6 mm) carpet

If low-frequency energy in the 125 Hz. octave band is of concern, then at least 2” (50 mm) panels are necessary

At even lower frequencies, 63 Hz and below different type of absorbers are required.

At even higher frequencies, beyond 2000 Hz porous absorbers are not effective.

Carpet on floor

α 500=0.14, α1000= 0.57, α 2000=0.60

2” shredded wood fiberboard on wall

α_{500}=0.62, α_{1000}= 0.94, α_{2000}=0.64

Tasks

Develop an understanding, find out from books, on the absorption coefficients of different porous absorbers and how effective they are just by assembling differently.

Try to find out compatible materials which when combined can give uniform absorption over a range of frequencies.

Books:
Concepts in Architectural Acoustics, M. David Egan
Architectural Acoustics by M. Long
Room Acoustics by Heinrich Kuttruff

Architectural Acoustics

Lecture 12 : Panel Absorbers and Resonators

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Working Principles of:

- Panel absorbers
- Resonators

- Applications

Panel absorbers

Panel absorbers are nonporous lightweight sheets, solid or perforated,

They may be freely suspended

or

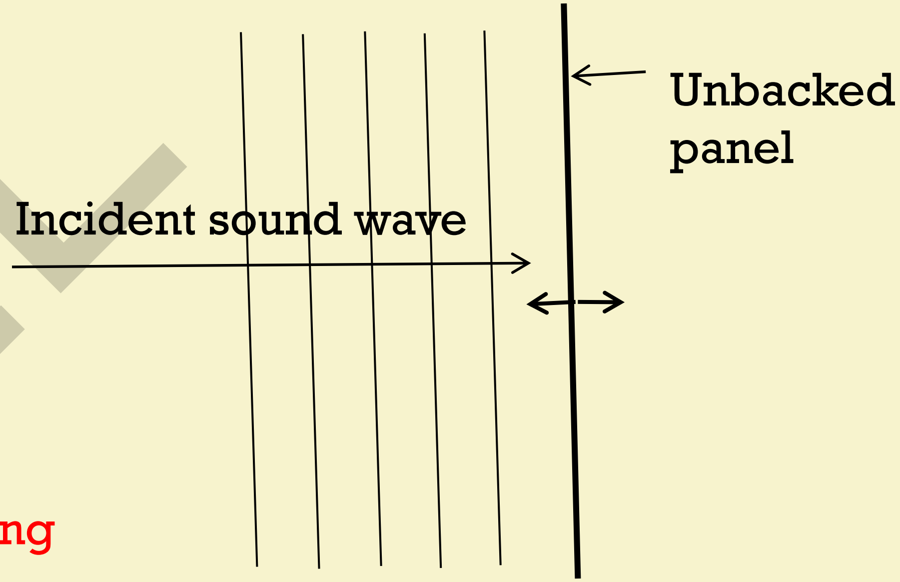
They may be fixed having an air cavity behind them

or

filled with an absorptive material such as fiberglass

Panel absorbers

A freely suspended nonporous panel can absorb sound simply due to its mass reactance that is, its induced motion.



Applications: seen mostly in large open spaces usually hung from ceiling

They can be hung in form of sheets from the ceiling and will vibrate to dissipate sound energy

Acoustic baffles are ideal for areas where sound deflects off hard surfaces.

Acoustic baffles look good and remove the echo effect in large rooms.

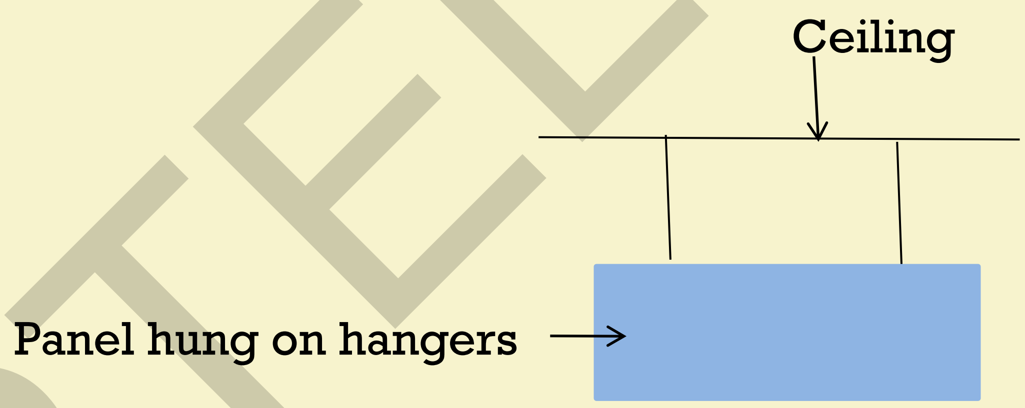
Baffles and Banners

In large volume spaces Baffles and Banners are most economic way to get good sound absorption

Speech intelligibility is improved

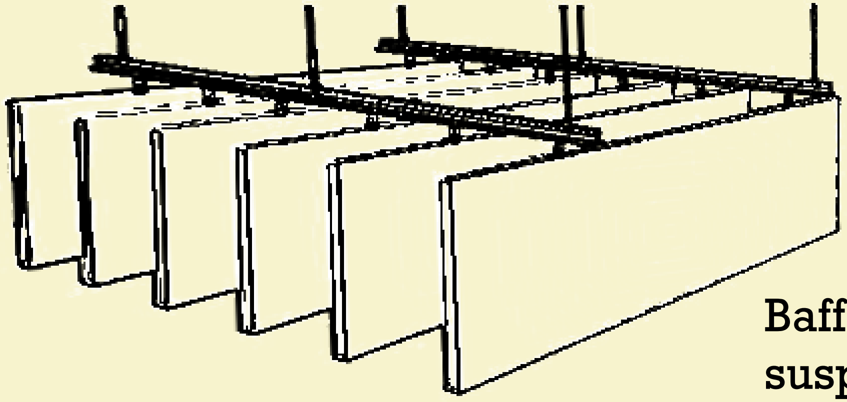
Sound Intensity level reduced

Reverberation Time reduced

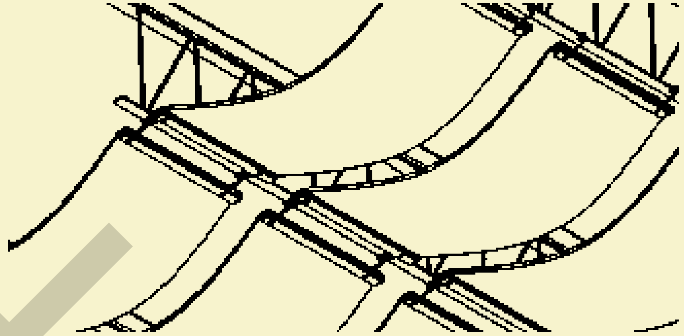


Applications: Arenas, Gymnasiums, theatres, multipurpose halls, auditoriums

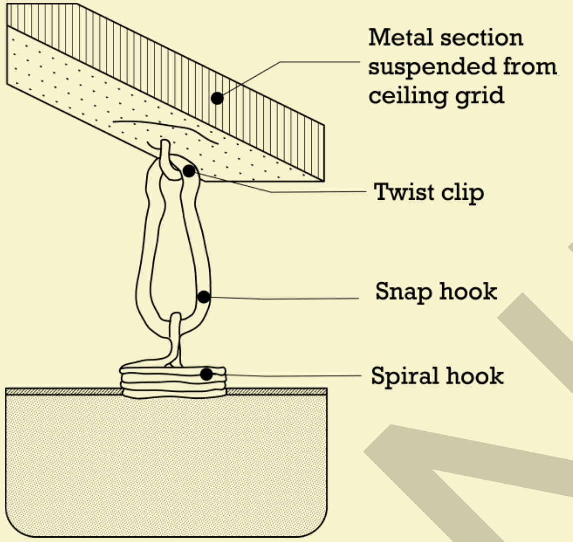
Baffles and Banners



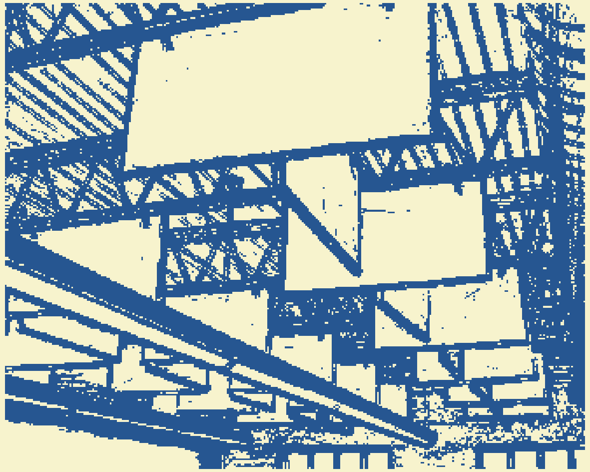
Baffles in suspended grid



Ceiling Banners



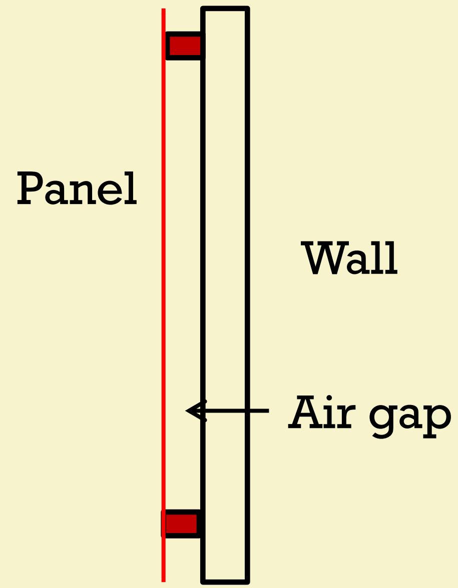
Connection with ceiling



Integration with HVAC systems

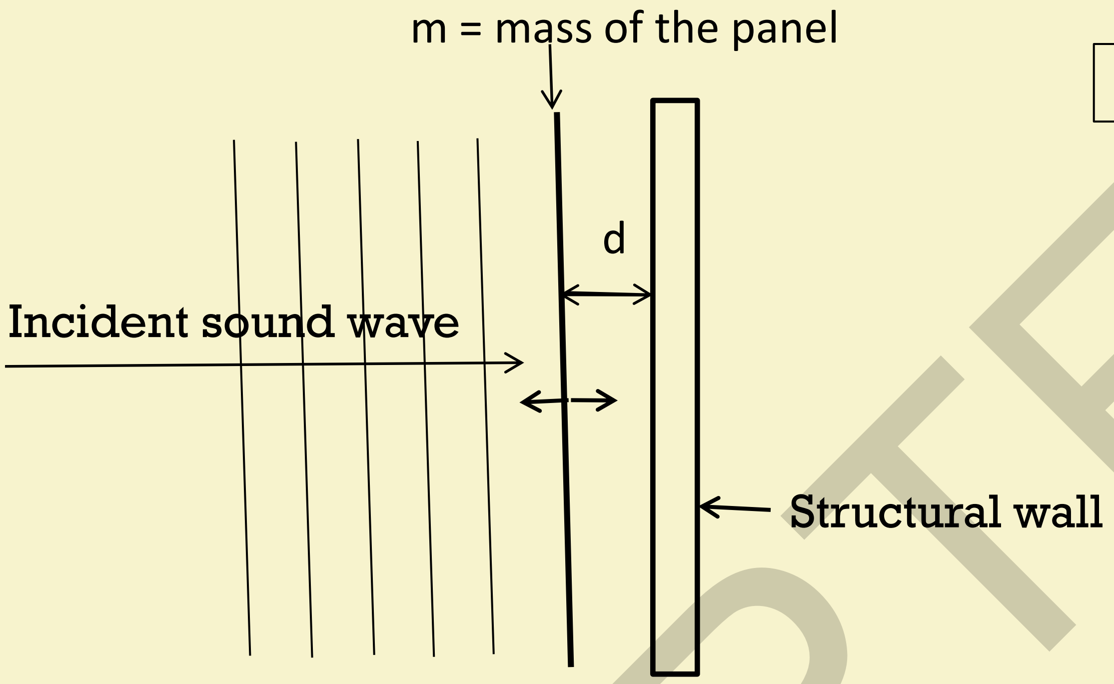
Panel absorbers

When a nonporous panel is placed in front of a solid surface with no contact between the panel and the surface, the panel can move back and forth, but is resisted by the air spring force.

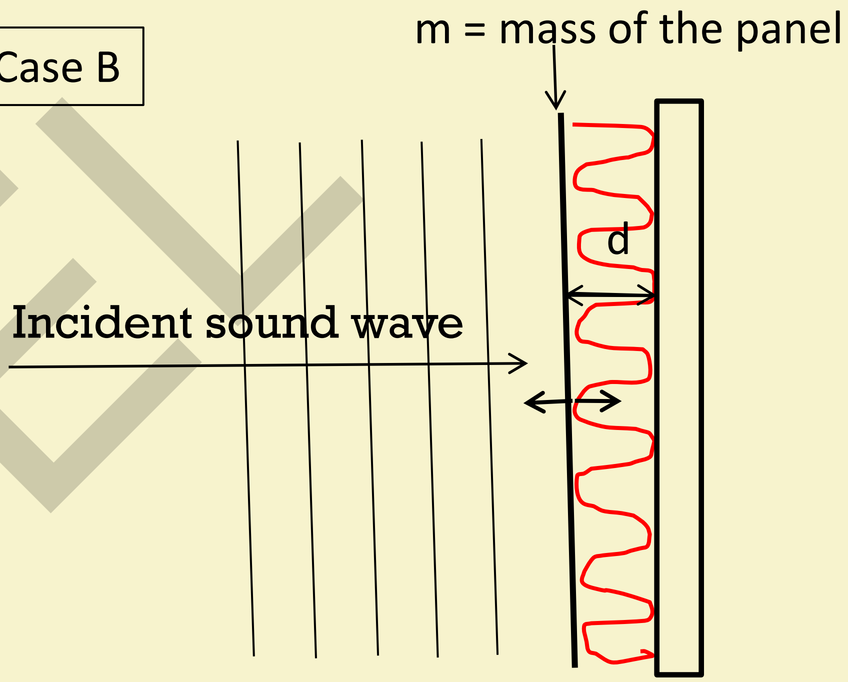


Panel absorbers

Case A



Case B



$f = 600/\sqrt{md}$

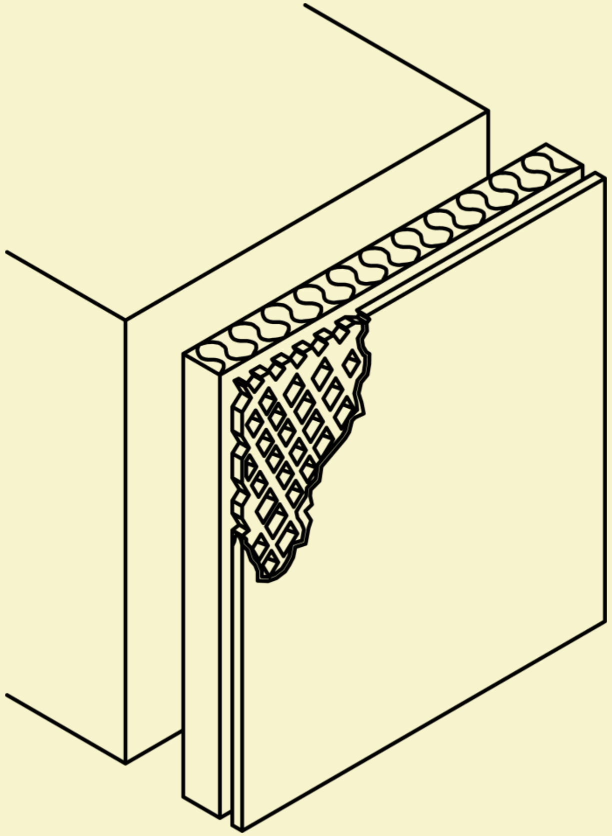
m is lower then target frequency
of absorption is higher
Lesser d more is target frequency

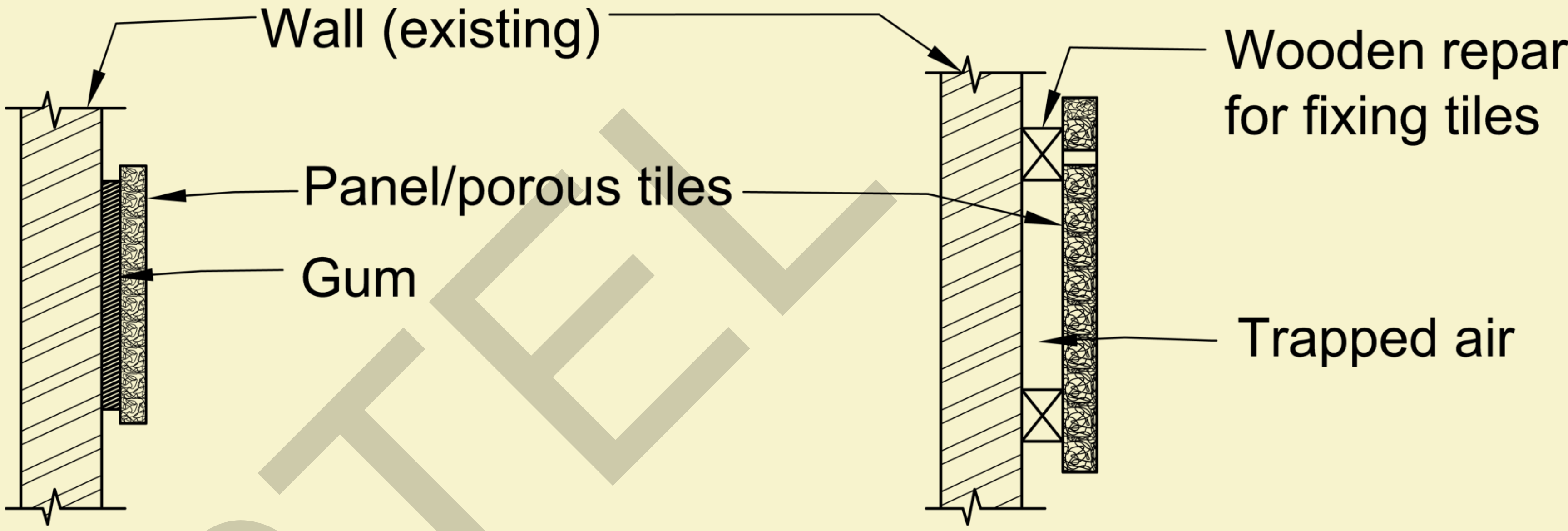
f= frequency
m= Mass in kg/m2
d= distance of airspace in centimeter

$f = 500/\sqrt{md}$

Material remaining unchanged
the target frequency
of absorption is lower than 'A'

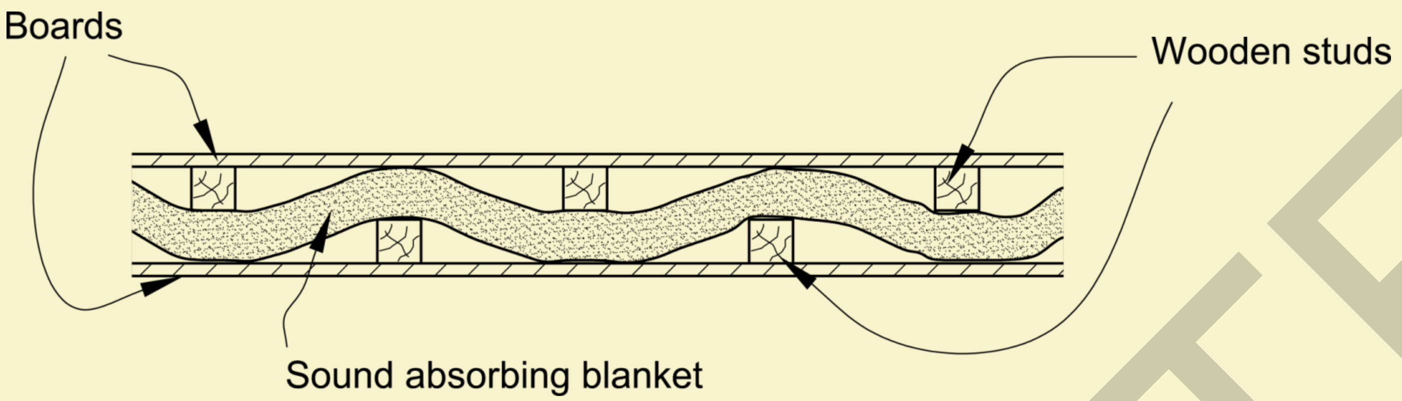
Panel mounting

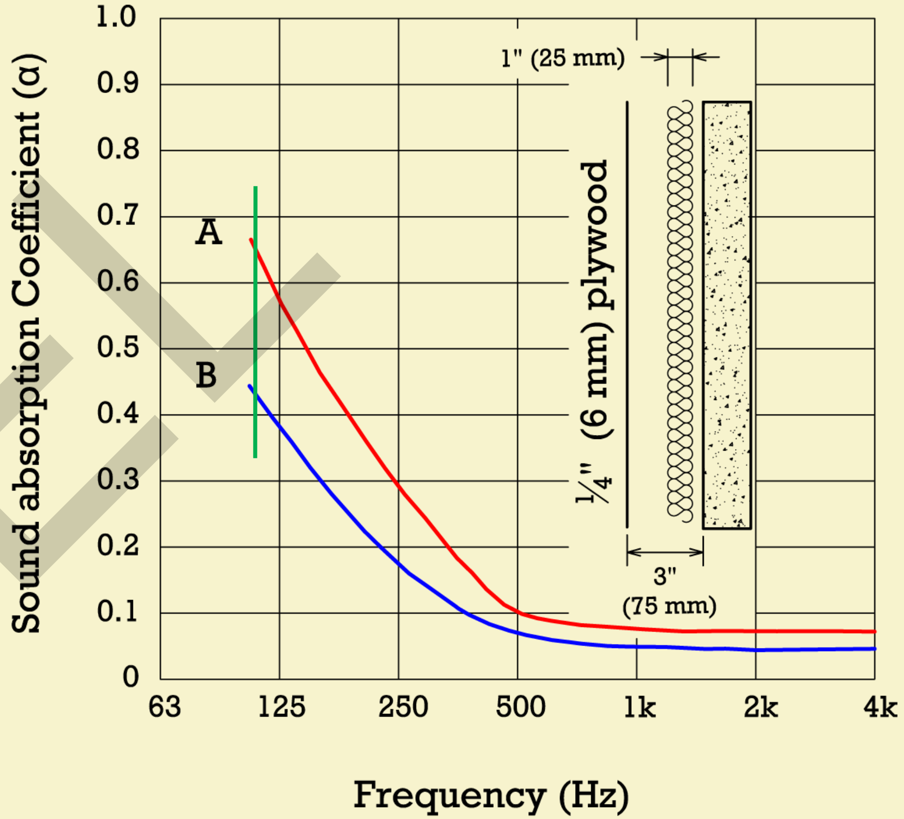




Panel absorbers of this type that are tuned to a low resonant frequency are used as bass traps in studios and control rooms.
Thin wood panels, mounted over an air cavity,
produce considerable low-frequency absorption.

Panel absorbers



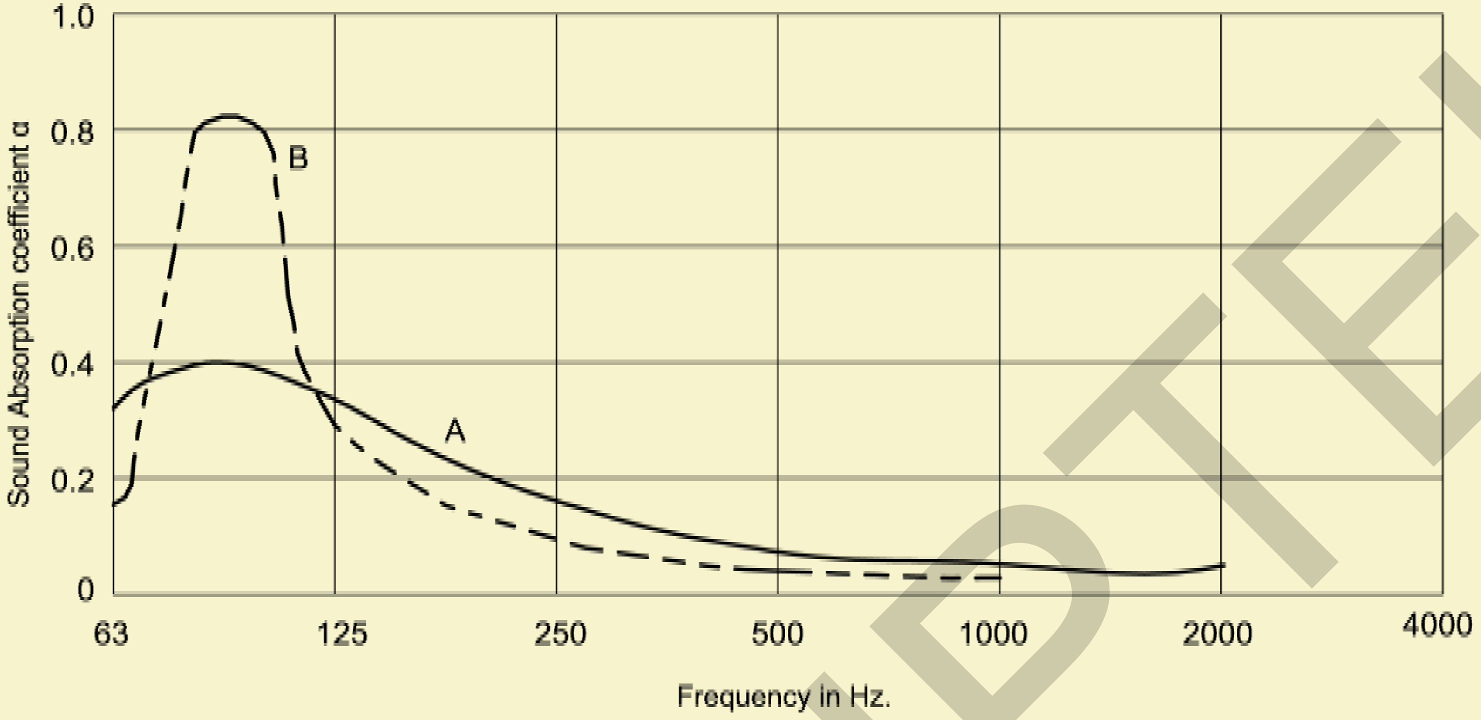


Fiberglass tiles are more effective at high frequencies
Mineral-fiber tiles are not effective at high frequencies

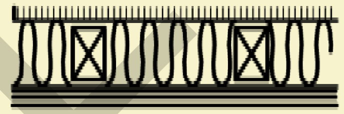
Sound absorption of a suspended panel (Doelle, 1972)

A ¼" (6 mm) plywood panel spaced 3" (75 mm) from the wall (A) with or (B) without an 1" thick fiberglass blanket in the airspace.

Panel absorber



Used to supplement porous absorption or to absorb specific low frequency sound.



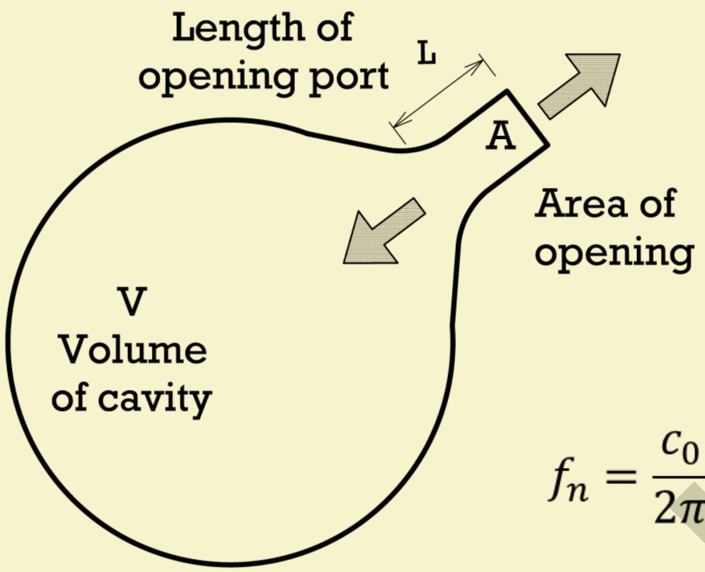
A With porous material in air space

B Without porous material

Resonators

A special type of air-spring oscillator is an enclosed volume having a small neck and an opening at one end.

It is called a *Helmholtz resonator.*



$$f_n = \frac{c_0}{2\pi}\sqrt{\frac{A}{V \cdot L}}$$

It may be noted that the frequency:

- increases with neck area
- decreases with increase in enclosed volume and neck length

Hermann von Helmholtz
Source: Wikipedia

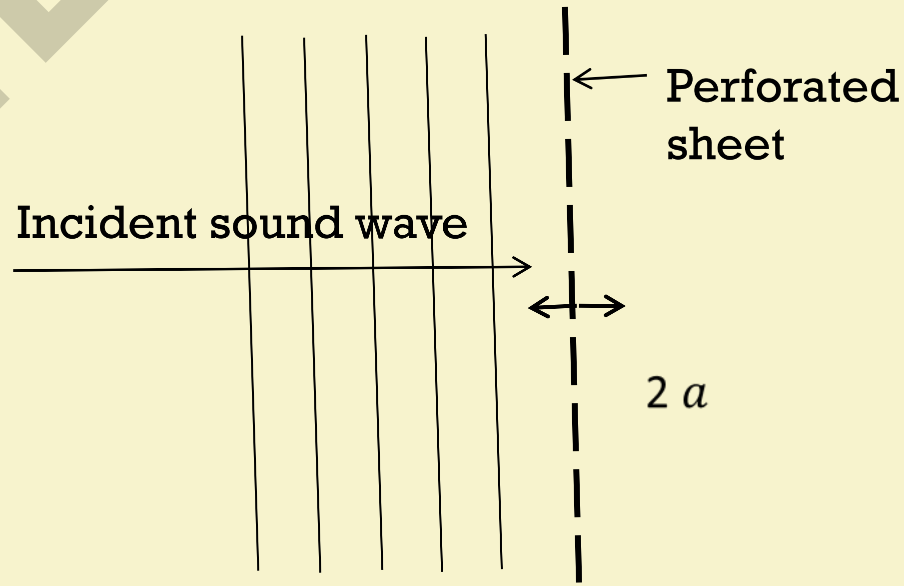
A true Helmholtz resonator must have a volume, a neck, and an opening. The dimensions are to be small compared with the wavelength of sound to be absorbed.

Resonators

In reality we have neckless resonators when there are perforations in a plate against an enclosed volume

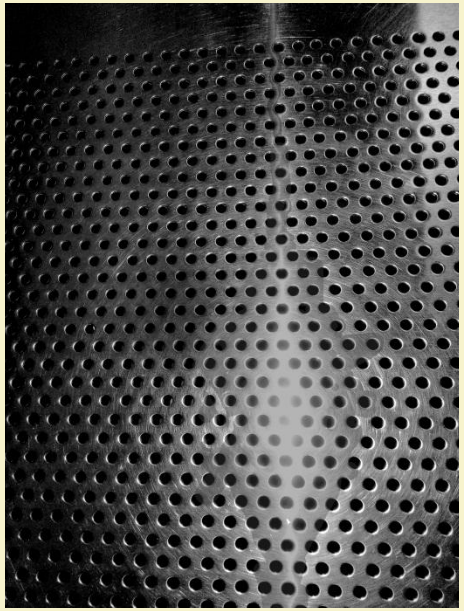
$$f_n = \frac{c_0}{2\pi} \cdot \sqrt{\frac{\pi \cdot a^2}{V \cdot (l_0 + 1.7a)}}$$

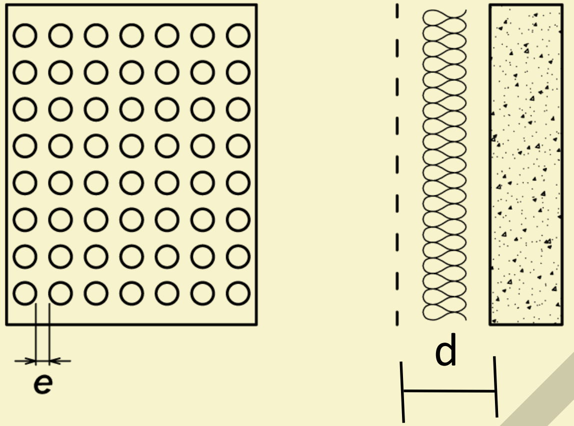
In a perforated plate the perforations form small tubes of air, which have a mass and thus a mass reactance to the sound wave takes place.

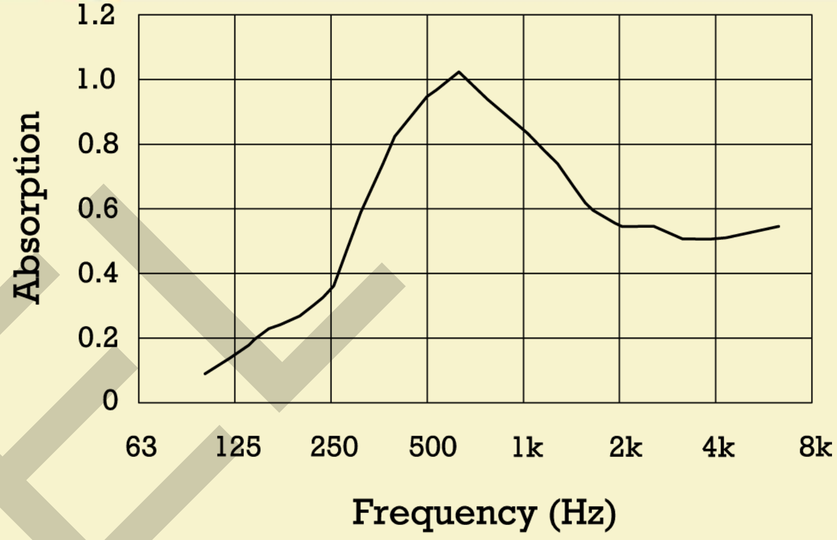


'a' is the radius of perforation

Resonators





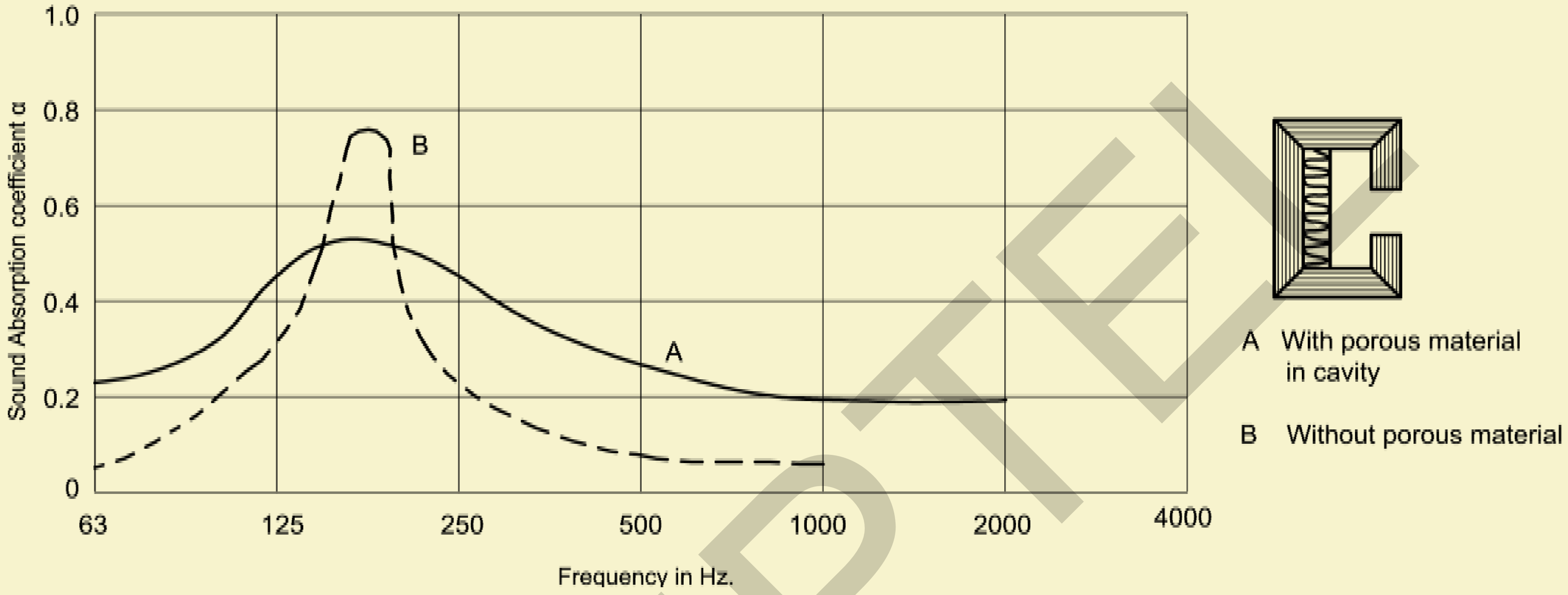


Absorption of a perforated panel (Cremer and Muller, 1982)

$$d = \frac{V}{e^2}$$

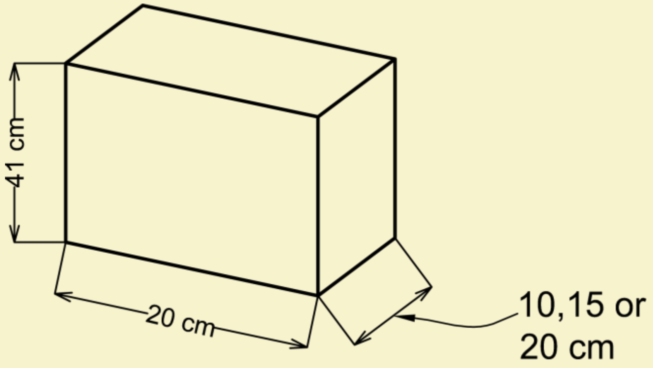
V= volume of room
e= the spacing between perforations

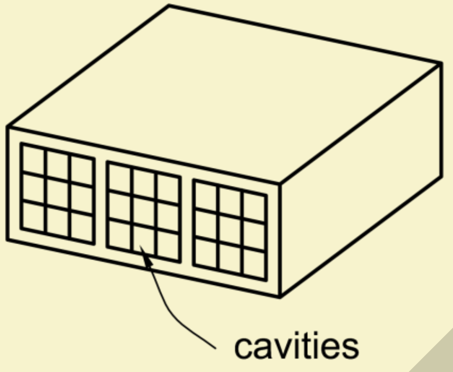
Resonators

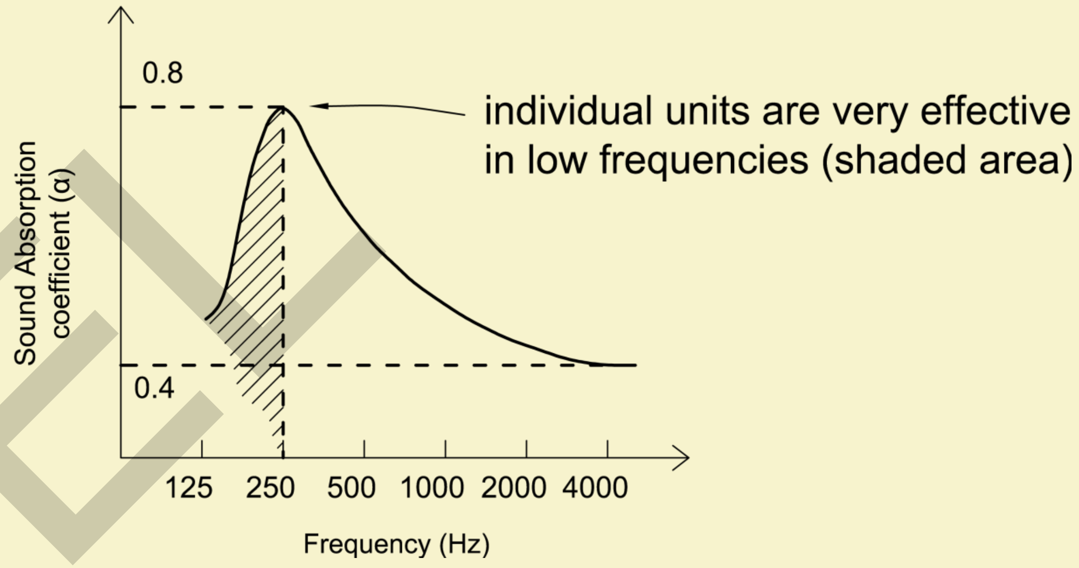


1.0
0.8
0.6
0.4
0.2
0
Sound Absorption coefficient α
B
A
63
125
250
500
1000
2000
4000
Frequency in Hz.
A With porous material in cavity
B Without porous material

Cavity absorbers







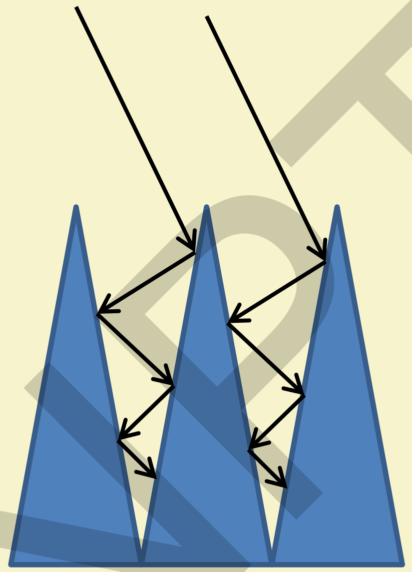
Standard concrete blocks with slotted cavities of same volume and size termed as **'sound box units'**

Products based on the Helmholtz resonator principle are commercially available.
They are available as concrete masonry units with slotted openings having a fibrous fill
or
Metallic septum interior fill.

Anechoic wedge

Anechoic wedge are ideally suitable for entrapment of low frequency sound

Most suitable light weight open cell foam having pyramidal form is appropriate



Applications:
Recording rooms
Anechoic chambers

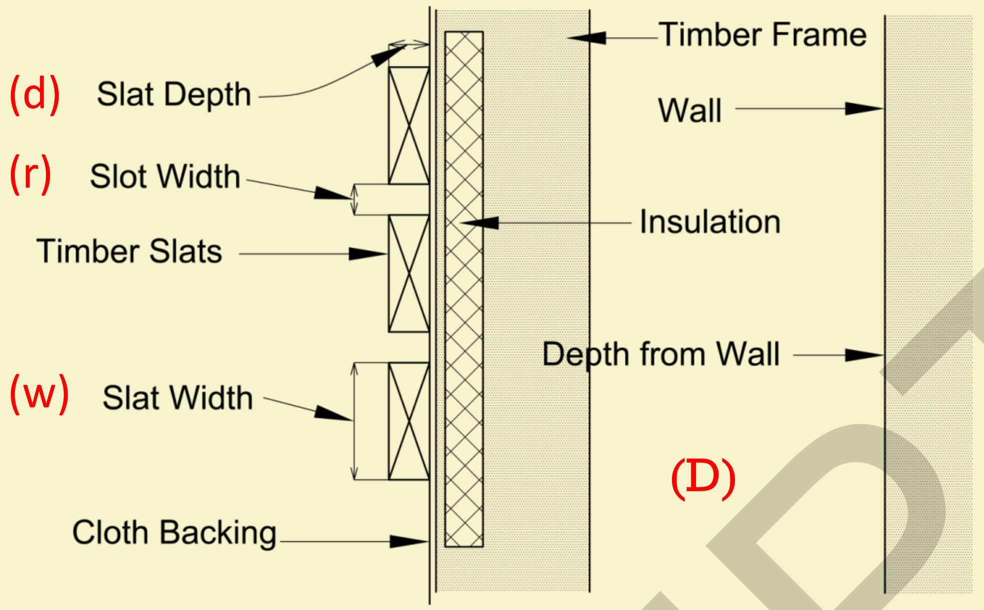
Slit - Slat Resonator

The Slat Resonator is a customized resonator for absorption of specific frequencies.

It can be installed onto the Hybrid Panel.

The slat and groove design creates a broadband mid to low frequency resonator.

Slit - Slat Resonator



A typical slat resonator section

The formula for calculating the Helmholtz resonant frequency is:

$$2160 \times \sqrt{\frac{r}{(d \times 1.2 \times D) \times (r + w)}}$$

Where:
f = resonant frequency in Hertz (Hz)
r = slot width.
w = slat width.
d = effective depth of slot. (1.2 × the actual thickness of the slat)
D = depth of box.

Slat Resonator

Varying r all remaining constant

Frequency	r	d	D	w
112.1416124	10	30	100	100
158.3788842	20	30	100	100
193.7135333	30	30	100	100

Varying 'd' all remaining constant

Frequency	r	d	D	w
188.7200762	10	10	100	100
136.0672103	10	20	100	100

Varying 'D' all remaining constant

Frequency	r	d	D	w
142.0253718	20	30	125	100
129.6531687	20	30	150	100

Inference:

Increasing r, frequency increases

Increasing d, frequency decreases

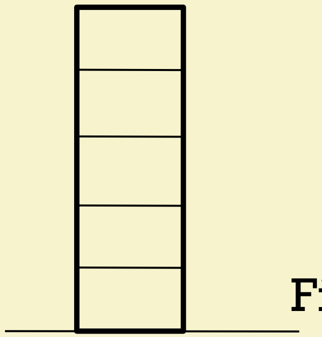
Increasing D, frequency decreases

Increasing w, frequency ?

Frequency of Audible sound and its wavelength in Air

Bass frequency

20 Hz	63 Hz	125 Hz	250 Hz	500Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	160000 Hz	20000 Hz
17m 51ft	5.32m 16ft	2.66m 8ft	1.33m 4ft	0.662m 2ft	330mm 1ft	160mm 6inches	80mm 3inches	40mm 1.5inches	20mm 0.75inch	17mm 11/16th inch



Five storey structure

Challenge : Dealing with sound within closed spaces

- Small rooms
- Large spaces

A small leaf

Continuation lecture……

•Space absorbers/ functional absorbers

•Seats as absorbers

•Human beings as absorbers

•Variable absorbers

•Movable absorbers

Architectural Acoustics

Lecture 13 : Absorption in spaces of different volumes

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Learning Objective

- Deriving the relationship of noise reduction and application of absorption
- in ceiling and walls for different volumes of spaces

- Generating the curves to plot sound reduction

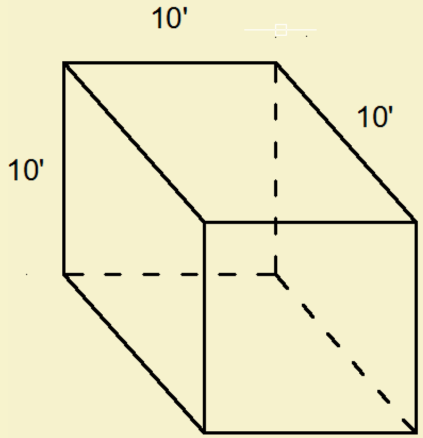


Fig. 1

Fig. 3
All surfaces treated with acoustical tile
coefficient of absorption 0.7
Floor with absorber having 0.02
Total absorption A3 is 500 x (.7) +100x 0.02sabine = 352 sabine

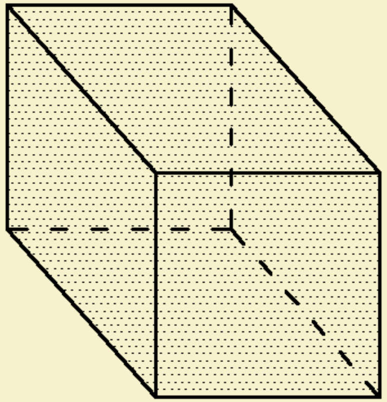


Fig. 3

Fig. 1
All surfaces plastered with coefficient of absorption α1= 0.02
Total absorption A1 is 600 x (.02) sabine = 12 sabine

Noise Reduction between Fig 2 and Fig 1

10 log A2/A1 = 8 dB

Fig. 2

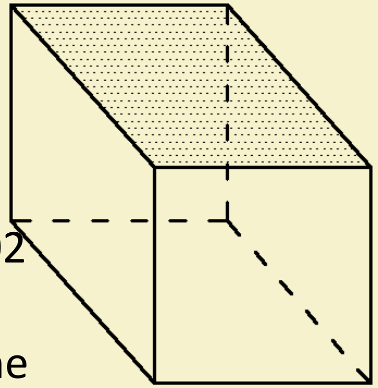


Fig. 2
All surfaces plastered with coefficient of absorption α1= 0.02
Ceiling with absorber having α2= 0.7
Total absorption A2 is 500 x (.02) +100x 0.7sabine = 80 sabine

Noise Reduction between Fig 3 and Fig 1

10 log A3/A1 = 15 dB

Inference is:

When ceiling only covered by absorber there is 8 dB reduction in sound

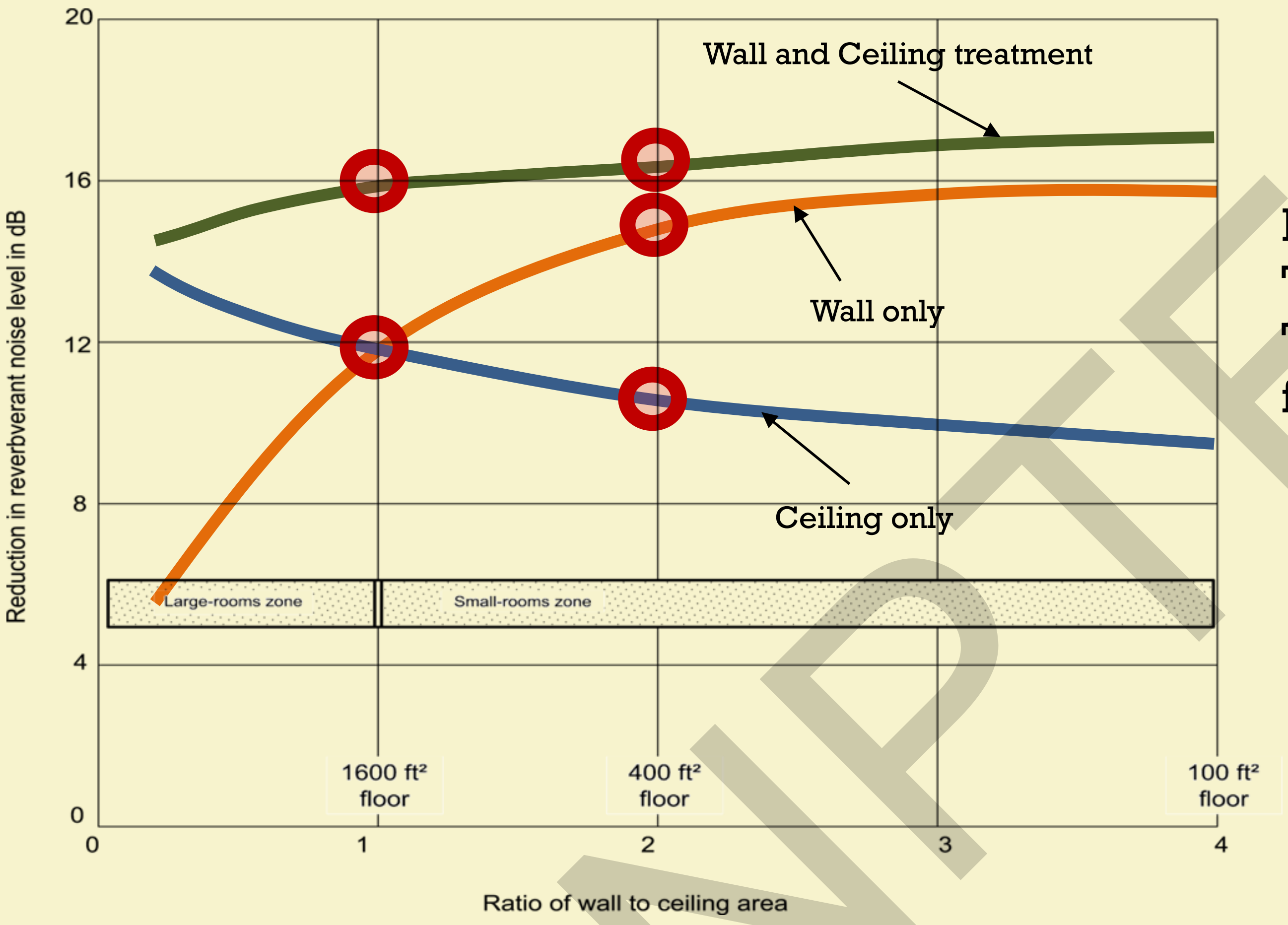
When ceiling and one wall (say back wall) is covered by absorber 11 dB reduction in sound

When ceiling and all walls are covered by absorber 15 dB reduction in sound

Assuming ceiling height to be same, say 10'-0'' let us observe the phenomena of sound absorption with different floor areas

Absorption coefficient (α)= 0.7 in all cases
Height of room =10 ft

Room size in feet (LxBxH)	Wall area	Ceiling area	Absorption with No absorber (α=0.02)	Wall Absorber (α=0.7) only	Ceiling absorber (α=0.7) only	Wall to ceiling ratio	Noise Reduction in dB with walls absorption	Reduction in dB with Ceiling absorption	Total Noise Reduction (Ceiling +floor)
10 x 10 x 10 (V=1000)	400	100	10	282	78	4	14 dB	9 dB	16 dB
15 x 15 x 10 (V=2250)	600	225	16.5	424.5	169.5	2.66	14 dB	10 dB	16 dB
20 x 20 x 10 (V=4000)	800	400	24	296	568	2.0	11 dB	14 dB	16 dB
25 x 25 x 10 (V=6250)	1000	625	32.5	712.5	457.5	1.6	13 dB	11 dB	16 dB
30 x 30 x 10 (V=9000)	1200	900	42	858	654	1.33	13 dB	12 dB	16 dB
35 x 35 x 10 (V=12250)	1400	1225	52.5	1004.5	885.5	1.14	13 dB	12 dB	16 dB
40 x 40 x 10 (V=16000)	1600	1600	64	1152	1152	1	12 dB	12 dB	15 dB
42 x 42 x 10 (V=17640)	1680	1764	68.88	1211.28	1268.4	0.952	12 dB	12 dB	15 dB
45 x 45 x 10 (V=20250)	1800	2025	76.5	1300.5	1453.5	0.888	12 dB	13 dB	15 dB
60 x 60 x 10 (V=36000)	3600	2400	120	2568	1752	1.5	13 dB	11 dB	15 dB



Inferences:

Treating Ceiling is more effective for big rooms.

Treating the walls with absorbers is good for rooms of smaller volume.

Task:

Generate similar curves changing the height from 10 ft to 20ft. Absorption coefficient may be changed to 0.8.

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Architectural Acoustics

Lecture 14: Acoustical Absorbers

Dr. Sumana Gupta

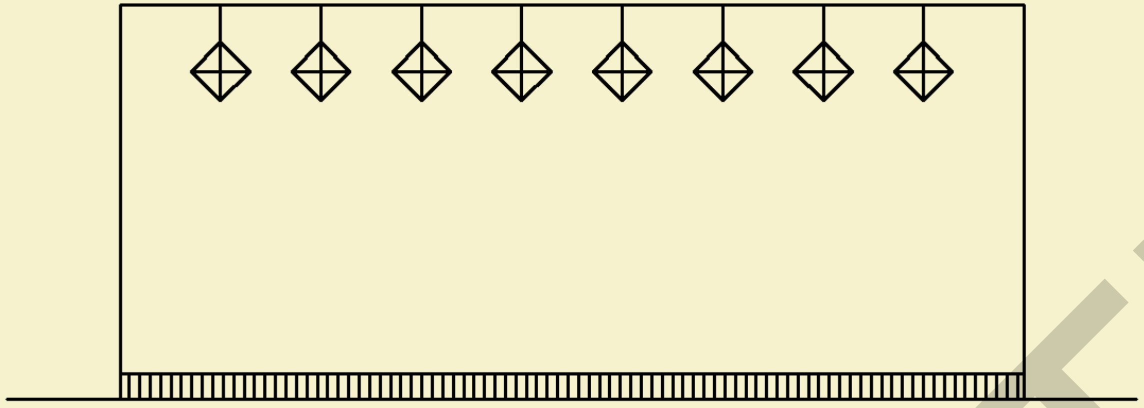
Department of Architecture & Regional Planning

Continuation of absorbers……

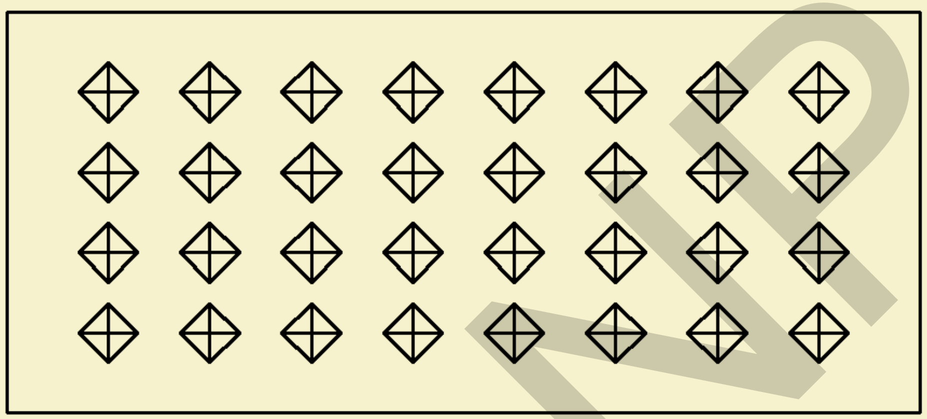
Learning Objective

- Space absorbers
- Variable absorbers
- Movable absorbers
- Area effect
- Seats and Human beings as absorbers
- Grazing attenuation

Space absorbers



Section



Reflected ceiling plan

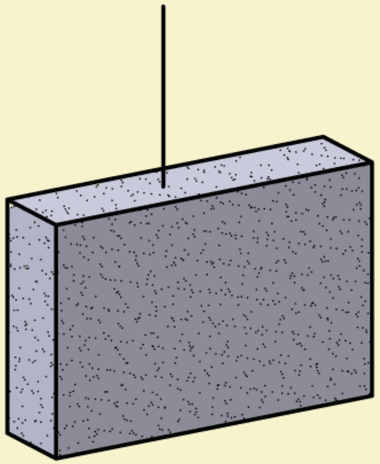
When large spaces are to be treated with absorbers Absorbers covering three dimensional shapes are suspended from ceilings.

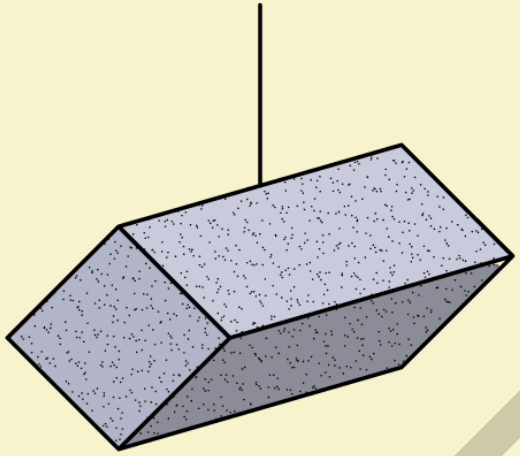
These are added when boundary of the enclosure do not provide a convenient condition to install acoustical treatments.

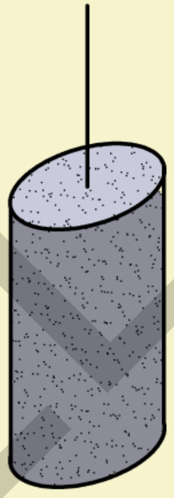
Advantages:

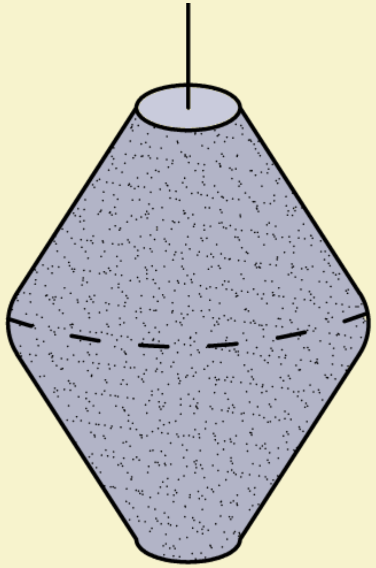
- Provides additional area of absorber
- Independent of mounting on ceiling or walls
- Can be spread wherever required

Space absorbers

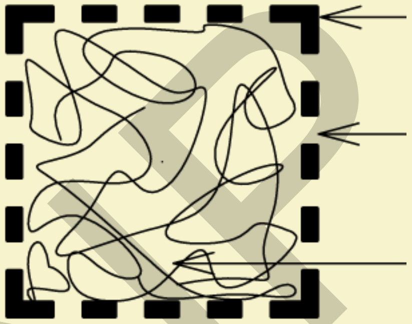








Shapes:
- Cubical
- Conical
- Cylindrical
- Prism



Metal sheet like aluminum, steel or hard board with perforation

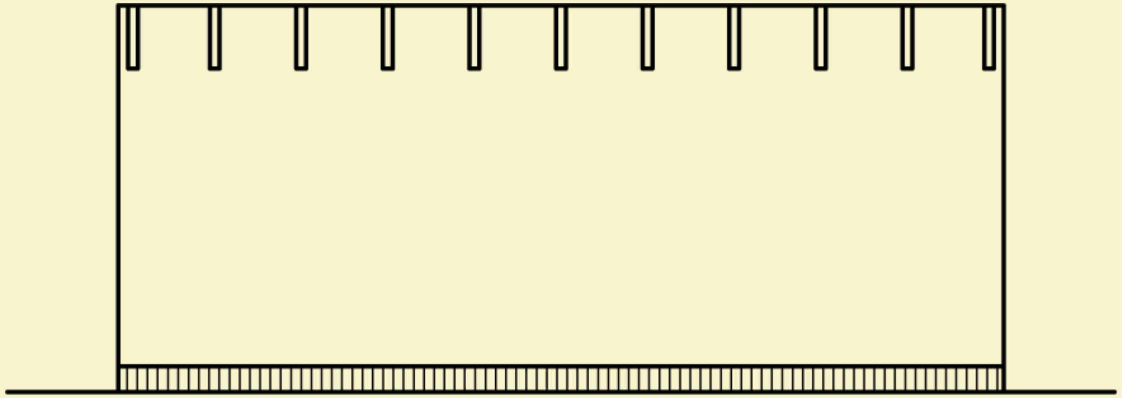
Filled with glass wool etc

Detail

Applications:
- Gymnasium
- Sports arena
- Industrial roofs
- Auditoriums

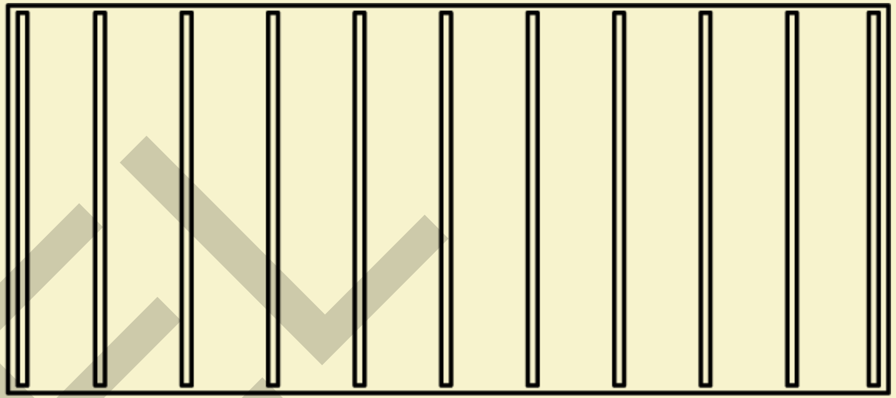
Also called functional absorber

Space absorbers

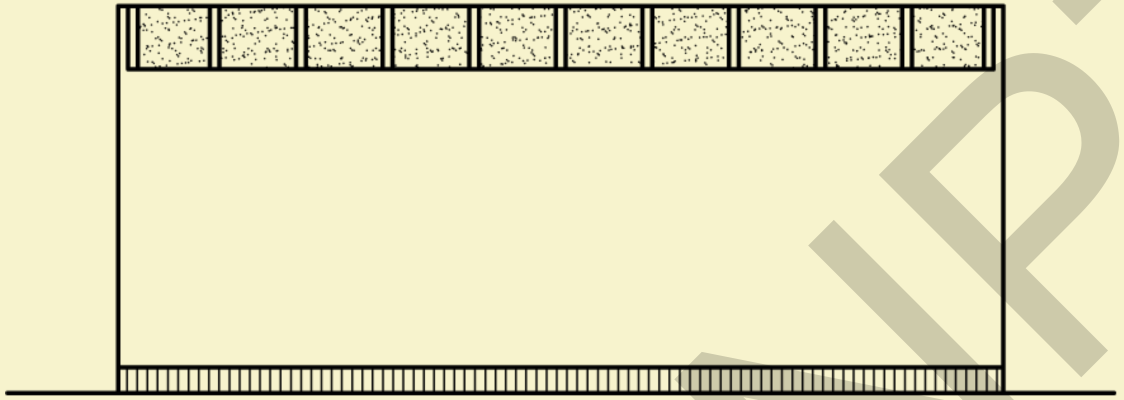


Sound-absorbing louvres

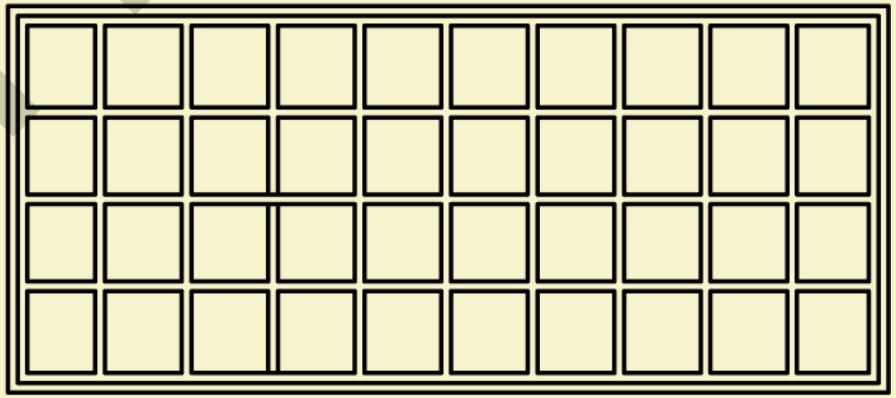
Sections

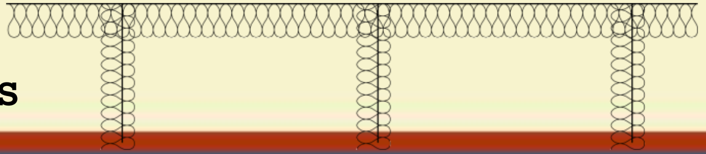


Reflected ceiling plans



"Egg crate" w/sound absorbing treatment on both sides





Hanging absorptive baffles

Space absorbers in ceiling

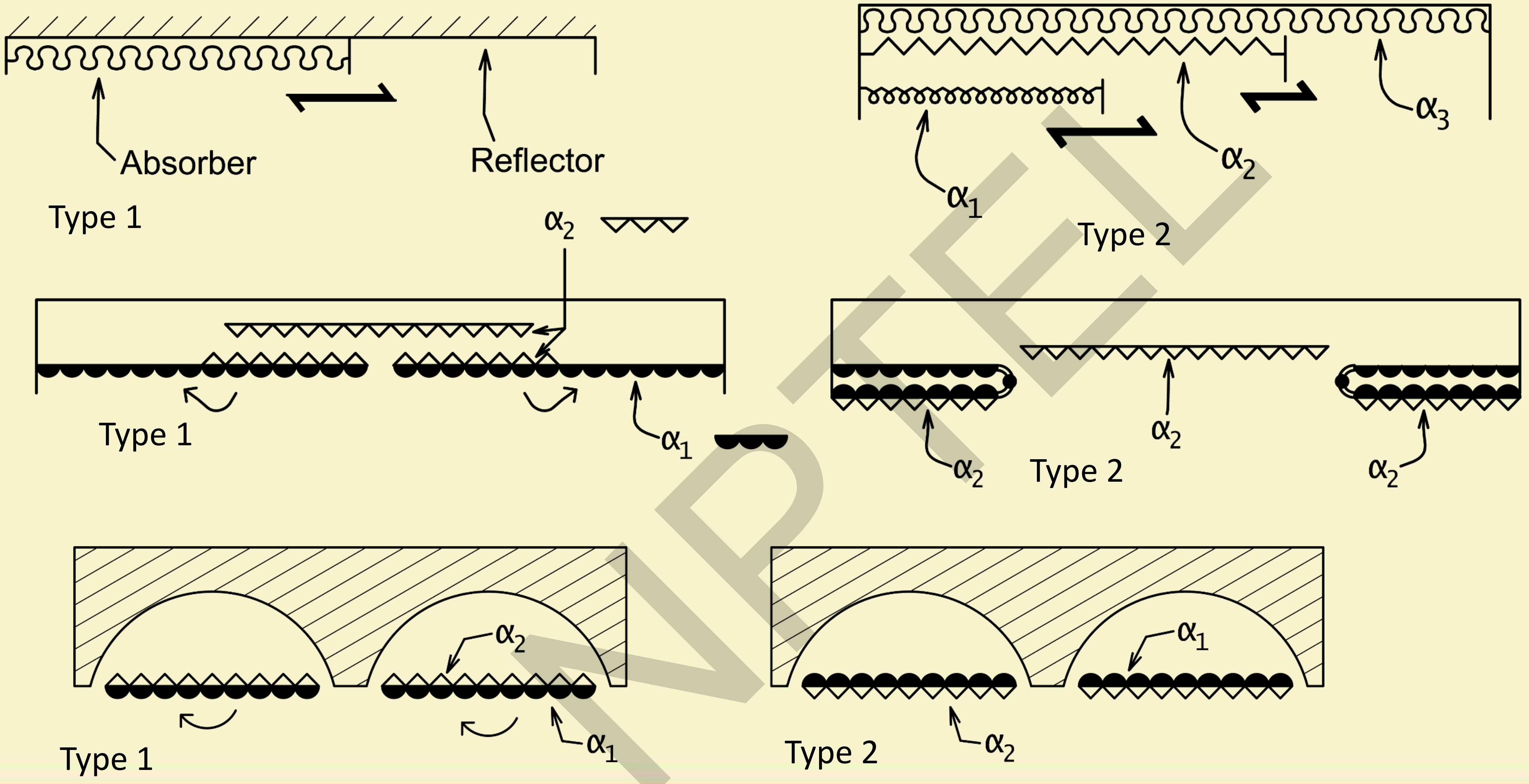
Variable absorbers

- Multipurpose use of a particular space

- Variable Reverberation time to be achieved

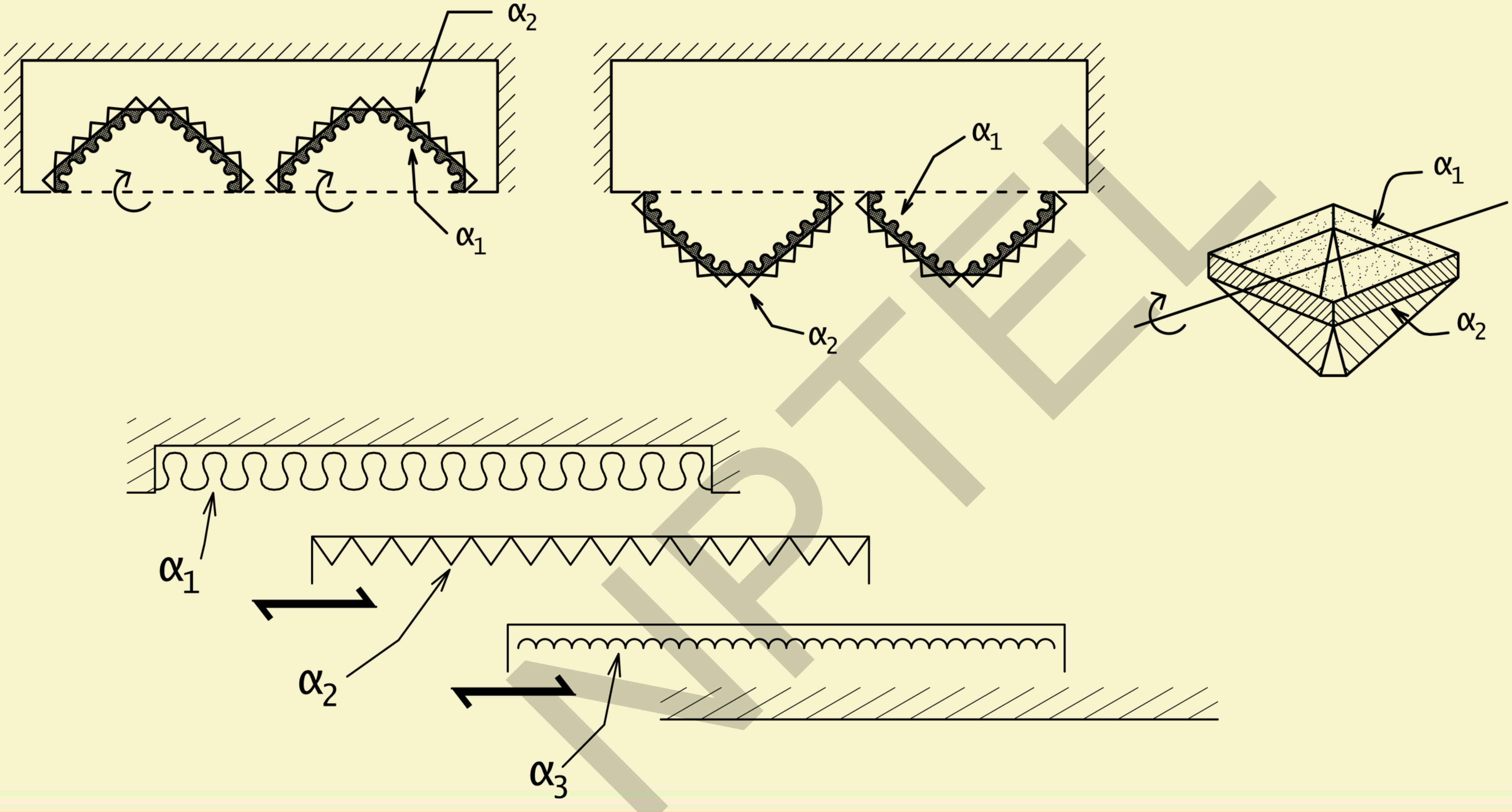
- Changing use can be taken care by variable absorber

Variable absorbers

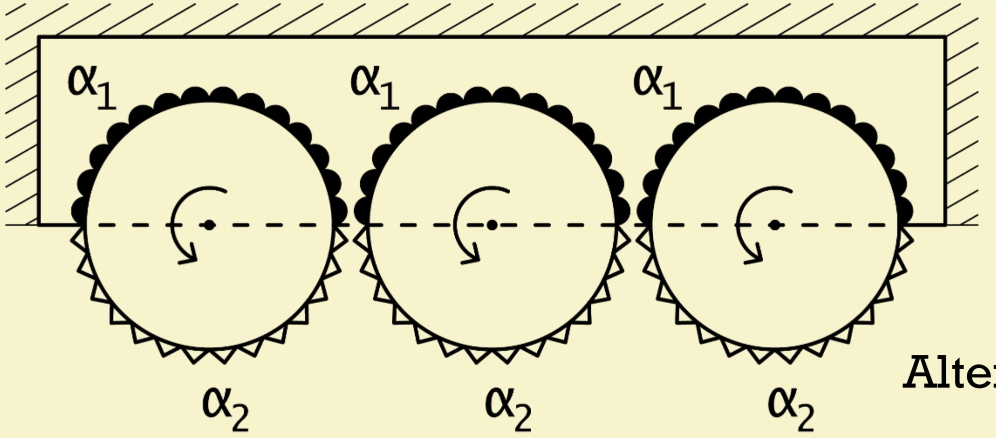


Adopted by:
- Hinge
- By rotation
- By sliding
- By folding

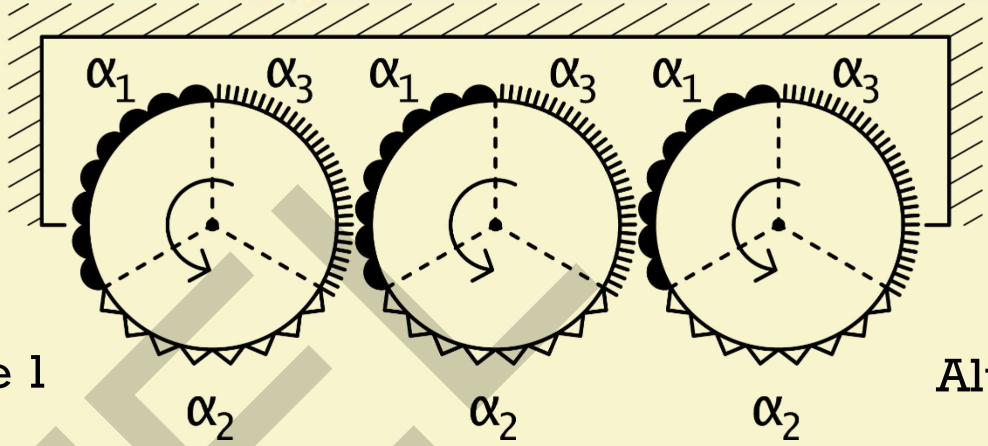
Variable absorbers



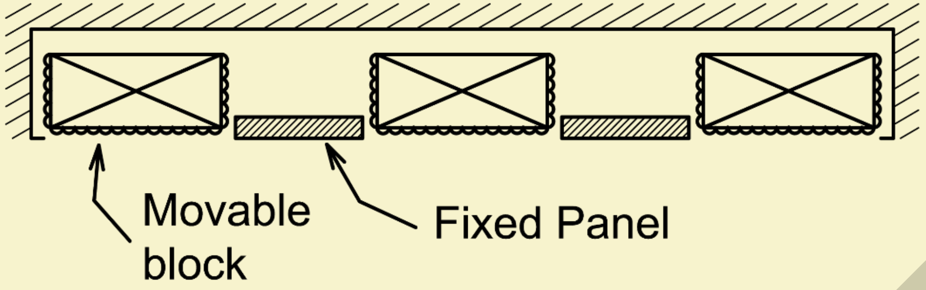
Variable absorbers

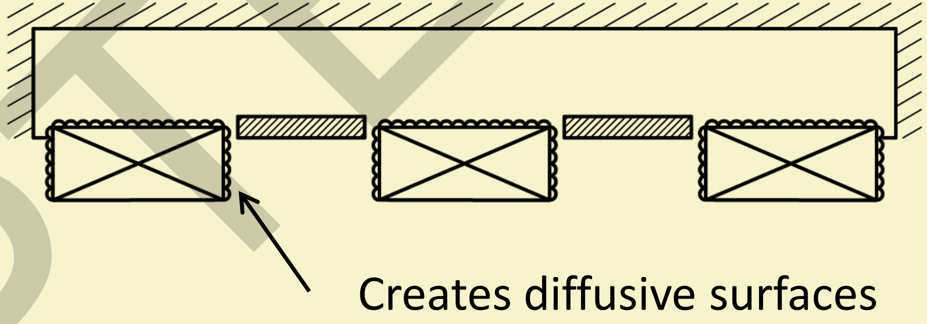


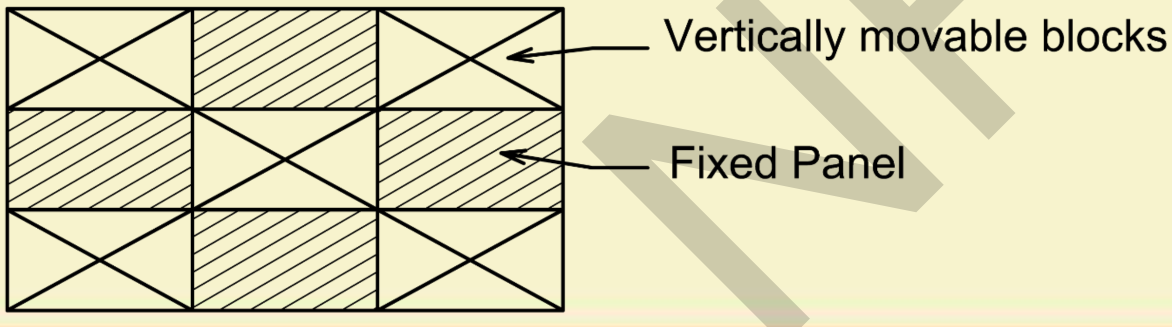
Alternative 1



Alternative 2







Movable absorbers

Stand-mounted portable absorbers
used in an audio recording studio

Area effect

Sound absorption may be affected by its location or distribution in a room

When spaced in a checkerboard manner on a ceiling instead of concentrated pattern it is more efficient.

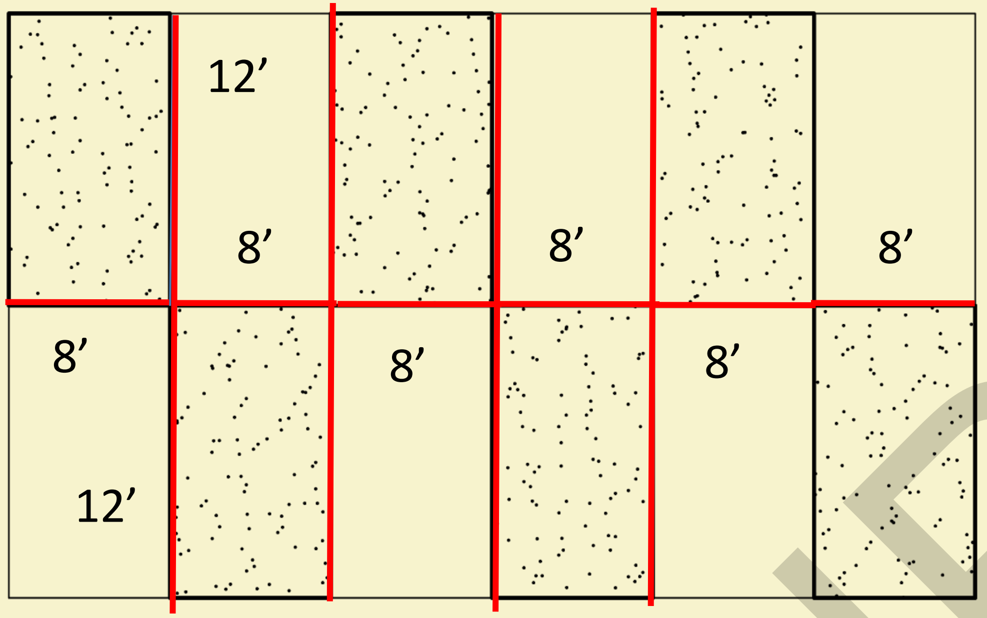
Diffraction from the open edges of the absorbing material takes place

Area of absorption by the edges of the added materials also increase

This increase in efficiency is called the area effect

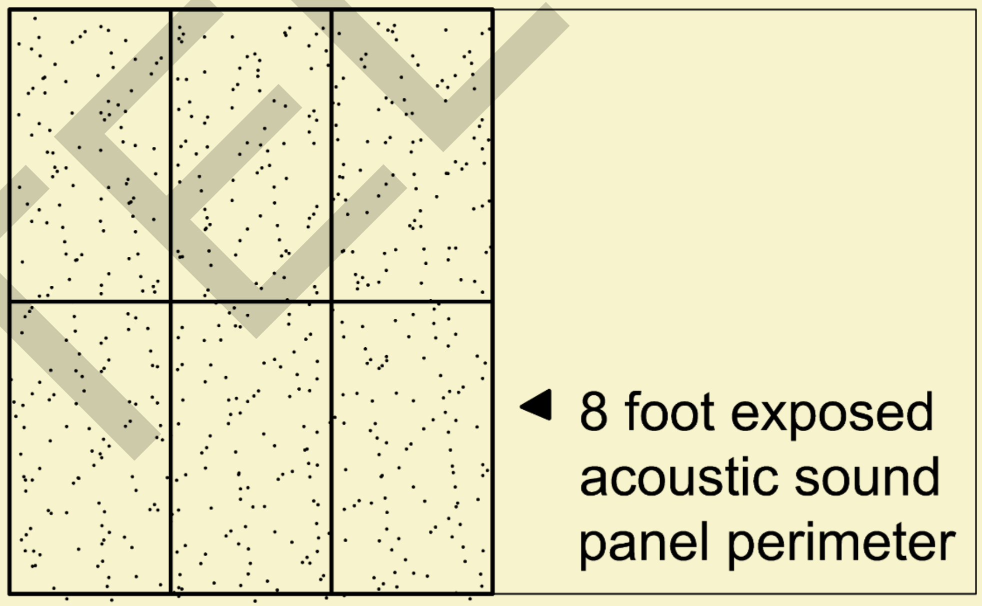
Area effect

Most efficient 8' x 12' acoustic sound panel configuration



Case 1

Less efficient 8' x 12' acoustic panel



Case 2

If we consider thickness of absorber as 1”

The additional area leads to a replacement of 1.5 panels of 8’x12’ dimension due to open edges as in case 1

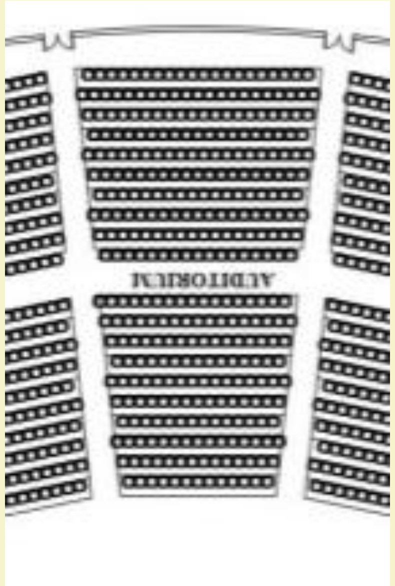
Chairs and human as absorbers

Material	Sound Absorption Coefficient					
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Seats and Audience						
Fabric-upholstered seats, unoccupied	0.19	0.37	0.56	0.67	0.61	0.59
Leather-upholstered seats, unoccupied	0.44	0.54	0.60	0.62	0.58	0.50
Audience, occupied upholstered seats	0.39	0.57	0.80	0.94	0.92	0.87
Metal/wood chair, unoccupied	0.15	0.19	0.22	0.39	0.38	0.30
Informally dressed students seated	0.30	0.41	0.49	0.84	0.87	0.84
Miscellaneous						
Loose gravel(4 in. thick)	0.25	0.60	0.65	0.70	0.75	0.80
Grass (2 in. high)	0.11	0.26	0.60	0.69	0.92	0.99
Fresh snow (4 in. thick)	0.45	0.75	0.90	0.95	0.95	0.95

Chairs and human as absorbers

Direct sound coming from a stage of which 100 - 200 Hz (mostly 125Hz) of the original sound gets weakened.

Padded / wooden chairs in a theater subdivide the floor into a regular lattice having a particular depth and spacing.



Sound wave, coming from the stage, grazes over the chairs.

The basic pattern of the excess attenuation exhibits a steep dip at the frequency whose quarter wavelength is equal to the chair-back height above the floor.

Such low-frequency absorption is known as "seat-dip" effect

Sound scattered from the seats and floor is the main cause of the dip.

With audience the absorption is above 500Hz to 1500Hz

Grazing attenuation

Grazing attenuation is a phenomenon that occurs when an acoustic wave interacts with an absorbing surface at a shallow angle of incidence.
Usually seen outdoor when there is grass or snow.

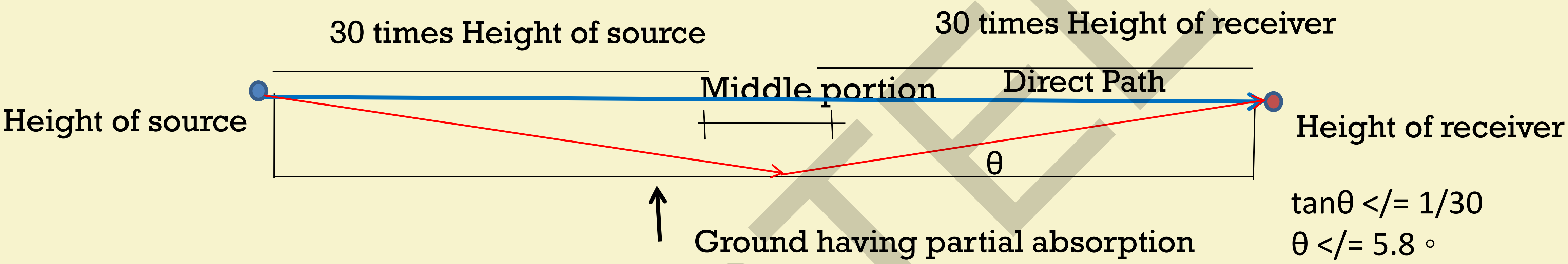
When the surface is very hard, the reflected wave combines with the incident wave at high frequencies to produce an increase in sound pressure.

When the reflecting material is soft the reflected wave is out of phase with the incident wave. Since the two waves are traveling along closely matching paths the combined wave is highly attenuated.

Grazing attenuation is also present in concert halls and theaters, where sounds, emanating from a performer on stage, pass over seated audience or padded chairs and induce losses beyond those expected from geometrical spreading and air absorption alone.

This can happen when audience is sitting on flat floor also.

Grazing attenuation



tanθ </= 1/30
θ </= 5.8 ◦

Grazing attenuation is only present at very shallow angles, less than 5◦

Grazing attenuation can be controlled in auditoriums by raising the talker height and by sloping the floor.

Conclusions

Never put absorbers in surfaces near source which help in useful reflection.

Put absorbers in surfaces that can produce echo that is the far ends from source in big spaces

In long, narrow and very high rooms consider using absorbers on walls whereas

Wall absorption is not effective for large rooms and low ceilings.

Proper acoustical planning eliminates many acoustical problems before they are built –Lee Irvine

Books referred:
Concepts in Architectural Acoustics, M. David Egan
Architectural Acoustics by Marshall Long
Room Acoustics by Heinrich Kuttruff

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Architectural Acoustics

Lecture 15: Reverberation time and Intelligibility

Dr. Sumana Gupta

Department of Architecture & Regional Planning

Learning Objective

- Live room, dead room and Reverberation time

- Speech Intelligibility

- Articulation Index

Live room and dead room

The reverberation time has been a useful metric since its discovery by Sabine

A space is said to be acoustically live space when the reverberation time is long.

A “live” room is a room with a dominance of hard, reflective surfaces.

In a very ‘live’ space, the echo that follows the handclap will be fairly loud and quite distinct from the original clap itself.

Example: Notre Dame, Paris RT = 8.5 sec

Live room and dead room

whereas

A dead room is a space with very low reverberation

sound absorption is dominant feature

clear distinct sound is heard

Example : Orfield Laboratories, Minnesota (USA)

Live room and dead room

Live

Auditoriums, theaters (for music)

Obtain proper reverberation time to enhance musical quality.

Provide reflective surfaces near source to reinforce sound; absorptive surfaces toward rear.

Medium Live

Conference and board rooms

Normal speech must be heard over distances up to about 35 ft or 12 m

Allow middle section of ceiling to act as a reinforcing sound-reflector.

Medium live

Cafeterias in schools or offices

Reduce overall noise level.

Use highly sound-absorptive ceiling is suggested; rubberized dish trays etc.

Gymnasiums

Instructor must be heard over background noise

Use acoustical material over entire ceiling to reduce noise; walls remain untreated to permit some reflected sound.

Live room and dead room

Medium Dead

Elementary-grade classrooms

Teacher must be heard distinctly; reduce noise level produced by children.

Acoustical ceiling essential. Supplementary acoustical spaces desirable.

Music rehearsal rooms

Unlike music hall, instructor must hear individual notes distinctly; minimum reverberation desired.

Entire ceiling, sidewalls, and wall facing musicians would be treated; wall behind musicians may be left sound-reflective for proper hearing, outside noise to be avoided.

Dead

Kindergarten

Maximum noise reduction.

Maximum acoustical treatment on ceiling; space units on available wall surfaces.

Vocational classrooms and workshops

Maximum noise reduction.

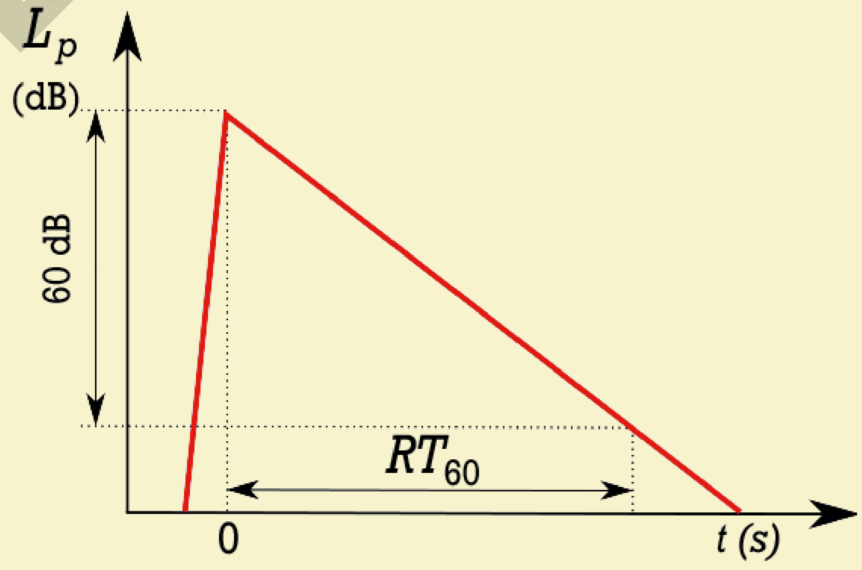
Acoustical tile or lay-in panel ceiling, plus acoustical treatment of available upper wall areas;

locate away from normal use rooms to avoid noise produced here.

Reverberation time

Studies based on the audibility of speech and music reveal that the most **desirable reverberation times** generally fall within the ranges shown below. These values are based on a sound frequency of **500 Hz** (approximate pitch of young male speech).

	Reverberation time in seconds
Speech	
Class rooms/ lecture rooms	0.4 to 0.6
Small offices	0.50 to 0.75
Drama in halls	0.7 to 1.00
Music	
Rehearsal rooms	0.80 to 1.00
Chamber music	1.00 to 1.50
Orchestral/Choral/ Average church music	1.50 to 2.00
Large organ play	>2.00 to 2.25



Reverberation time diagram
(Source: Wikipedia)

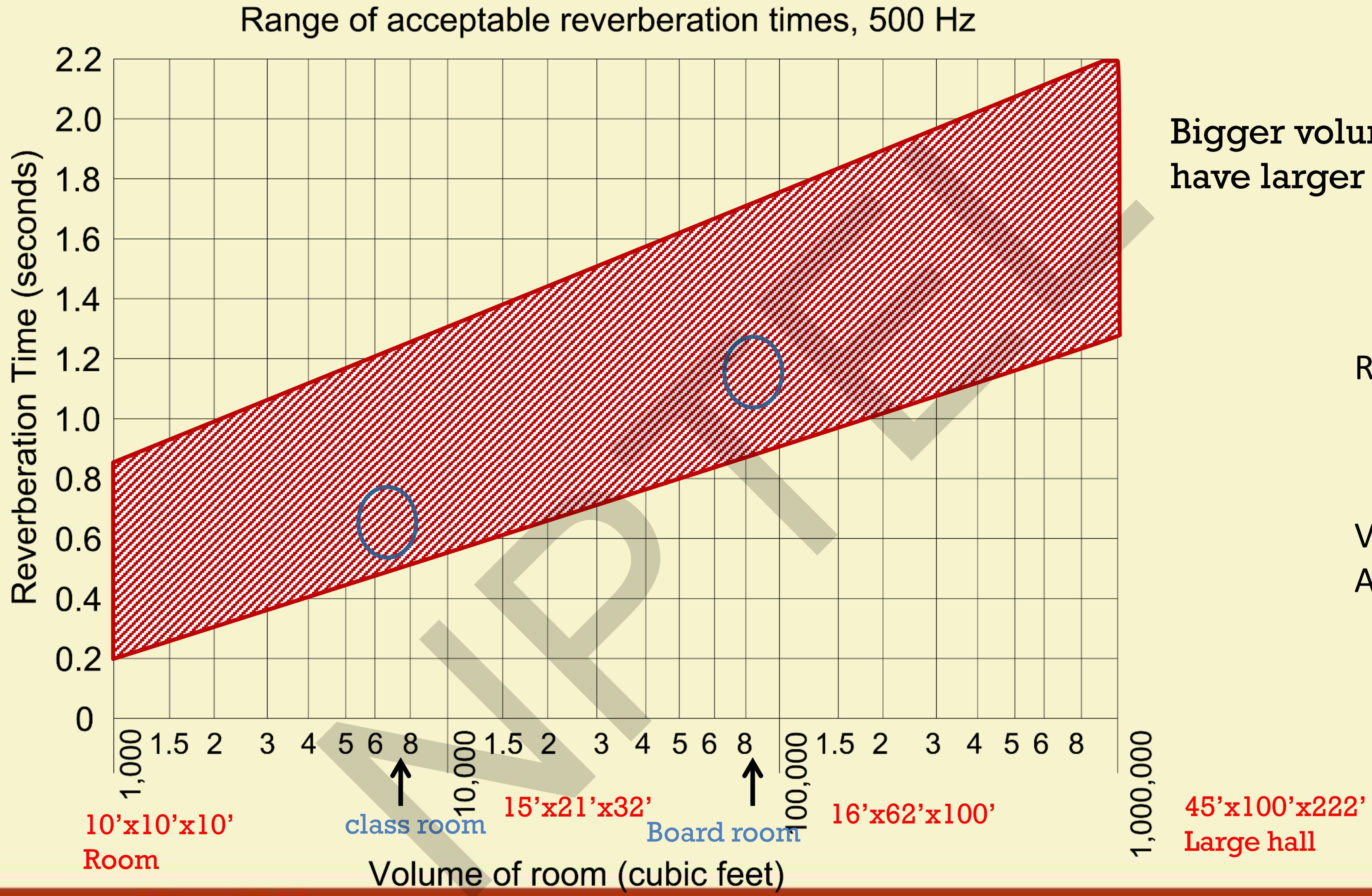
Typical Sound Pressure Level in dB for some frequencies

Source	125 Hz	250 Hz	500Hz	1000Hz
Normal conversation	60	75	78	75
Class room	66	72	77	74
Gymnasium	78	84	89	86
Library, reading room	63	66	67	64
Music practice room	94	96	96	96
Laboratory work spaces	70	73	75	72
Kitchen	85	77	78	79
Thunder	120			

For speech, the reverberation time should be the same at all frequencies,

for music the reverberation at low frequencies should be increased so that the time at 125 Hz is up to 1.5 times the value at 500 Hz.

Reverberation time



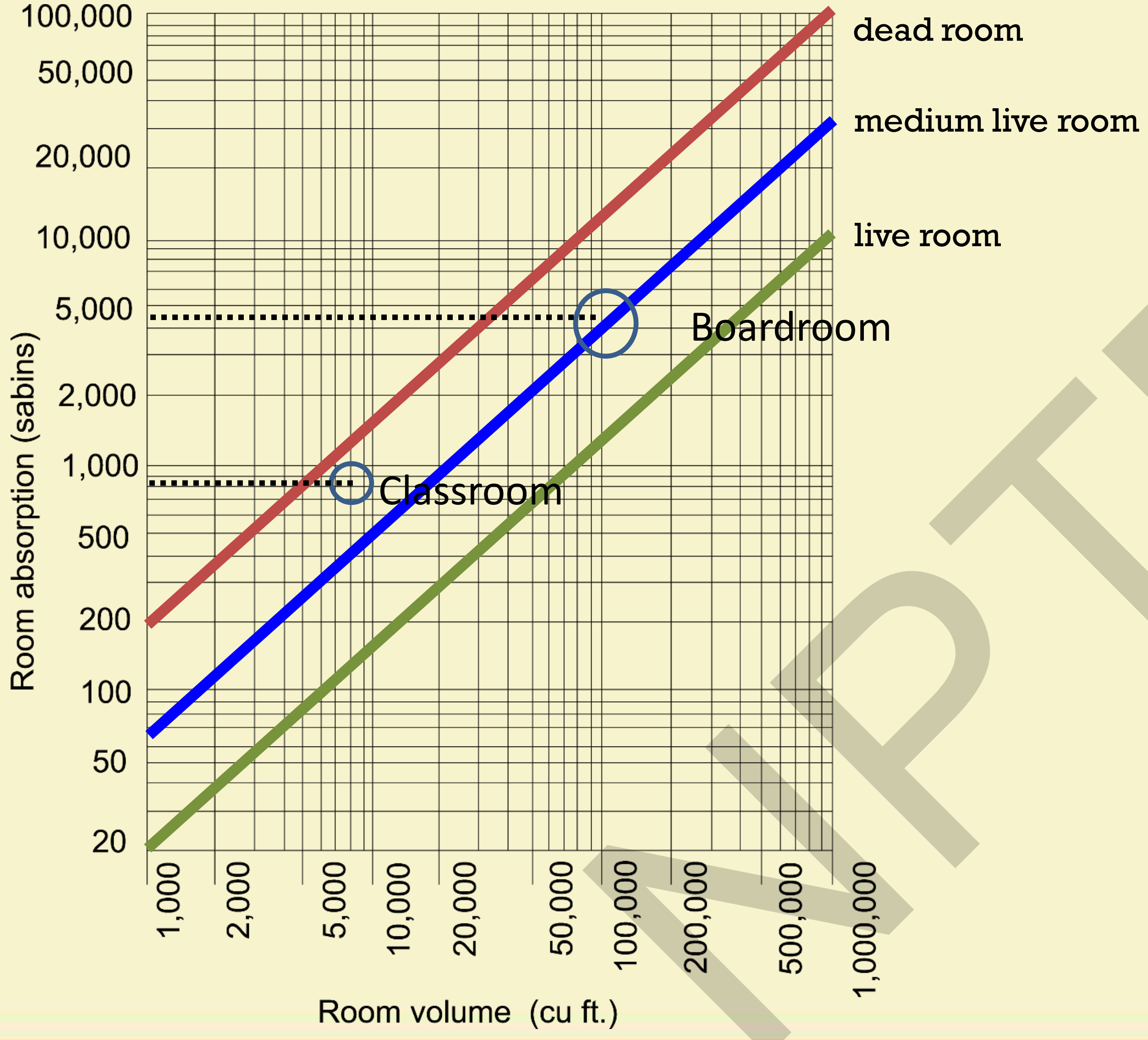
Bigger volume spaces can have larger reverberation time

RT=0.16V/A

V= Volume of room

A= ∑ s α

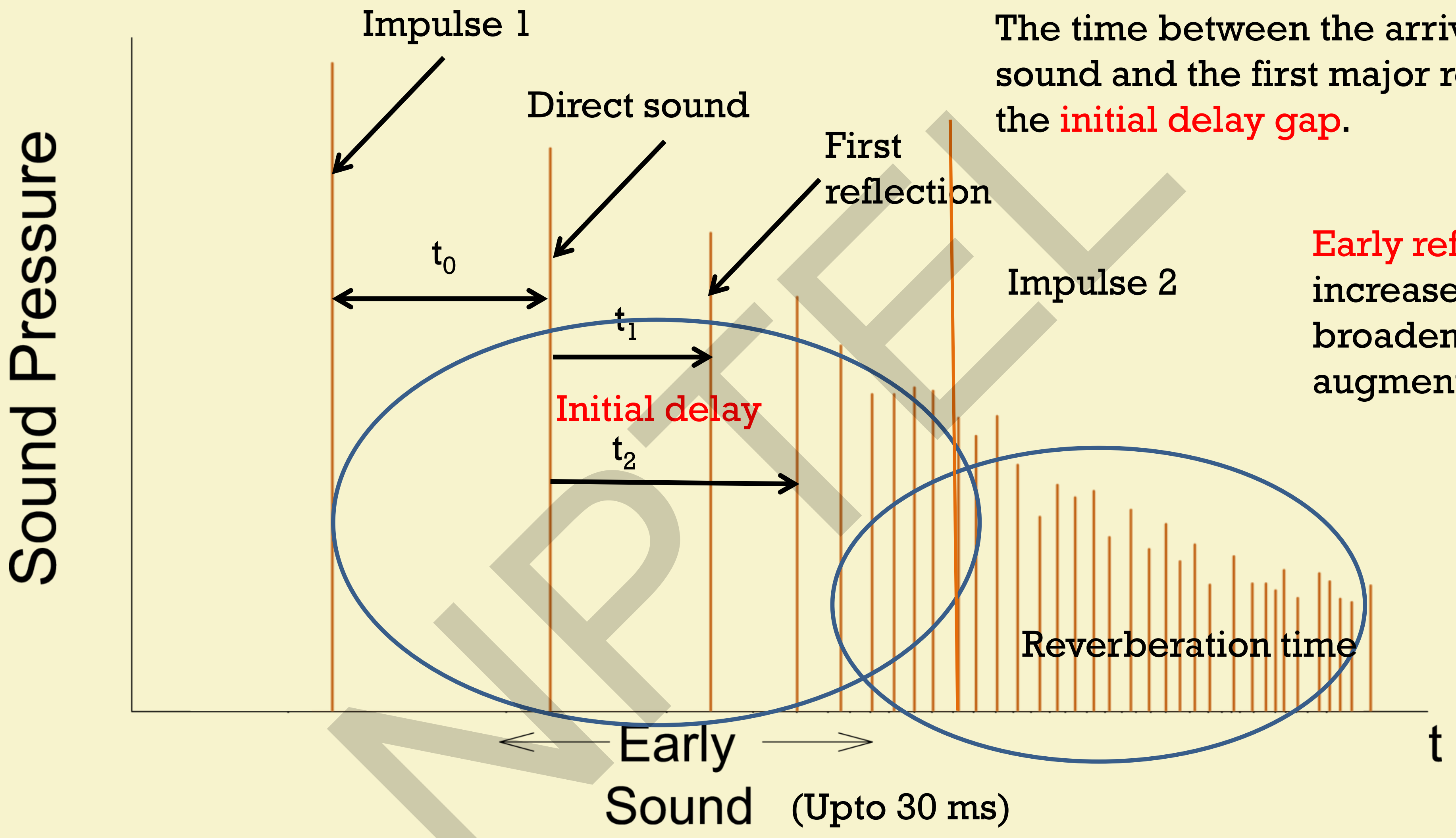
Reverberation time



Higher is the room absorption dead is the room

Higher is the volume higher should be the absorptive surface for lower RT

Speech intelligibility



The time between the arrival of the direct sound and the first major reflection is called the initial delay gap.

Early reflection increases intelligibility, broadens sound image, augments sound level.

Articulation Index

Method of measuring and calculating speech intelligibility

A group of listeners write some non sense syllables from list phonemes for identification

The percentage of correctly noted syllables determine the Articulation Index

Listening condition	% Word understood	AI
Excellent	>84%	above 0.6
Good	62 – 84%	0.4 – 0.6
Fair	42 – 61%	0.3 – 0.39
Poor	below 42%	below 0.3

Speech intelligibility is a direct measure of the fraction of words or sentences understood by a listener.

Intelligibility is dependent on the *signal-to-noise ratio*, it is simply the signal level minus the noise level in dB.

Causes of decreased intelligibility

- Background noise
- HVAC systems, exterior noise sources like traffic, horns
- Electronically generated masking noise
- long-delayed reflections
- persistent reverberation, echoes flutters etc

Tasks

Referring to the graphs find the amount of absorbing surfaces required for some specific room uses like

music rehearsal room (5000 sq ft)

lecture room (100 capacity)

Large auditorium (500 capacity)

Referred Books:

Concepts in Architectural Acoustics, M. David Egan

Architectural Acoustics by M. Long

Room Acoustics by Heinrich Kuttruff