Sound insulation, building and architectural acustics

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1st CYCLE STUDY PROGRAMMES	2nd CYCLE STUDY PROGRAMMES	3rd CYCLE STUDY PROGRAMMES
CIVIL ENGINEERING (BA)	CIVIL ENGINEERING (MA)	BUILT ENVIRONMENT (PhD)
CONSTRUCTION MANAGEMENT (BA)	BUILDINGS (MA)	ENVIRONMENTAL PROTECTION (PhD)
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2nd Cycle: Buildings MA

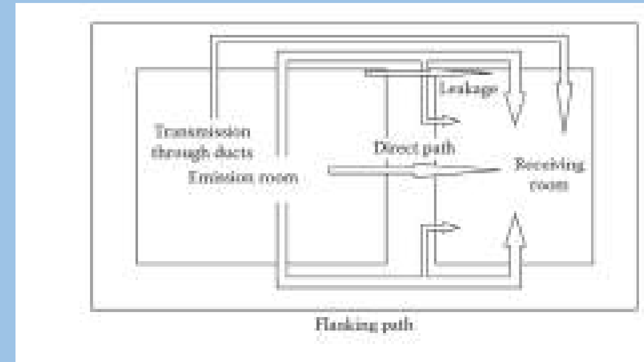
The second cycle master study program **Buildings** consists of two years (four semesters) and amounts to 120 credit points. After the studies graduate acquires the professional title **MASTER ENGINEER OF BUILDINGS.**

The study program Buildings focuses on buildings – their design, construction, use and removal.

The study program Buildings is adapted to the needs and requirements of our dwelling and working environments. The basic condition and rule for the functioning of ecological systems is rationality and balance of their parts and complexes. The same is also true for socio-ecological system, part of which are also built environment and man. Architectonic artefact is an interface between natural environment and man-made environment. Building as part of the ecosystem that harmonizes different influences and conditions in the system using high technology, is the goal of all efforts of the contemporary bioclimatic design dealing with dwelling and living environment.

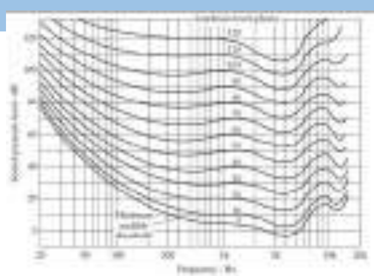
Acoustical living and working environment

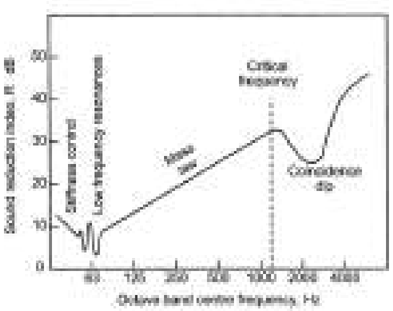
- **Sound insulation of buildings**
- **Sound insulation against airborne sound**
- **Sound insulation against impact sound**
- **Environmental (municipal) noise**
- **Vibrations in buildings**
- **Acoustics of interior space – reverberation noise**

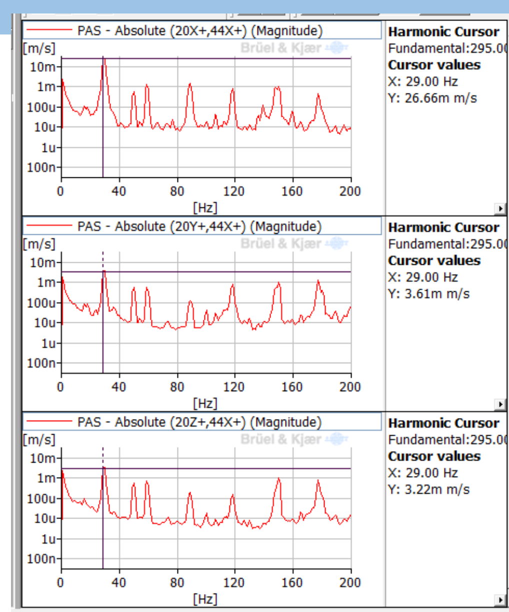


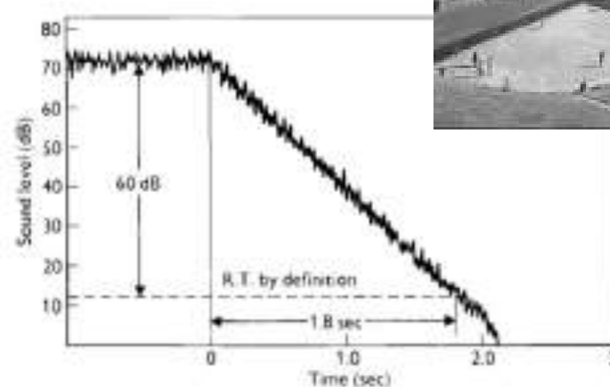
Acoustic transmission paths between spaces.

- **Design of building envelopes and interior barriers against environmental and building users noise**
- **Design of interior space against reverberation noise and exterior space against traffic noise**









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Contents:

1. Fundamentals of sound propagation

- 

Sound is longitudinal vibration

$$c \ (m/s) = f \ (Hz) \cdot \lambda \ (m) = \text{const.} = \sim 340 \ m/s$$

Speed of light is ~ 300 000 000 m/s i.e. 880 000 x more

$$\text{Wavelength (ft)} = \frac{\text{Speed of sound (ft/sec)}}{\text{Frequency (Hz)}} \qquad (1\text{-}1)$$

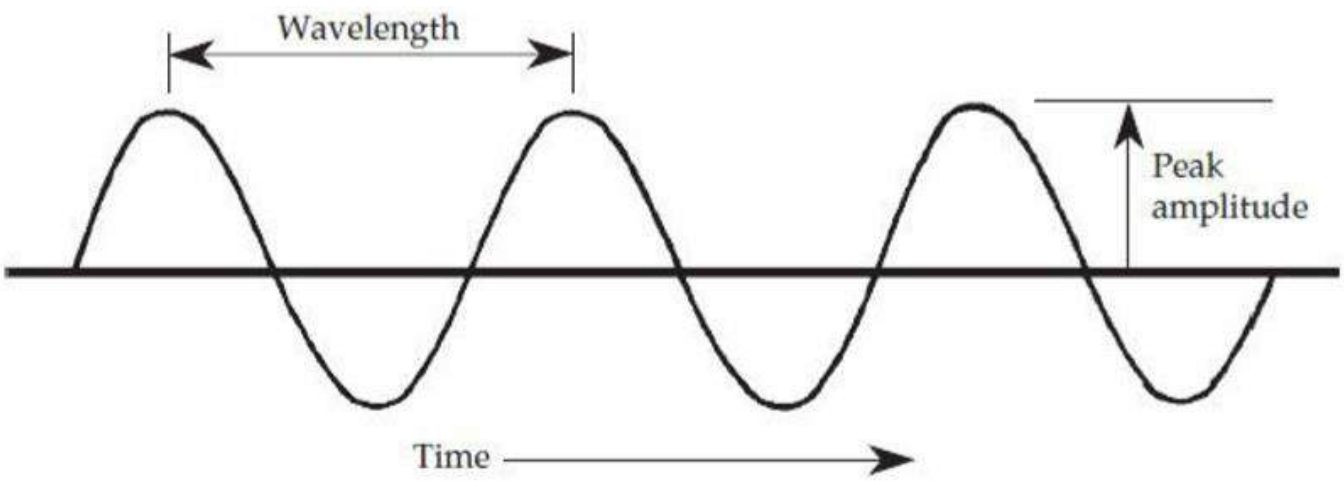


FIGURE 1-7 Wavelength is the distance a wave travels in the time it takes to complete one cycle. It can also be expressed as the distance from one point on a periodic wave to the corresponding point on the next cycle of the wave.

Changes in atmospheric pressure

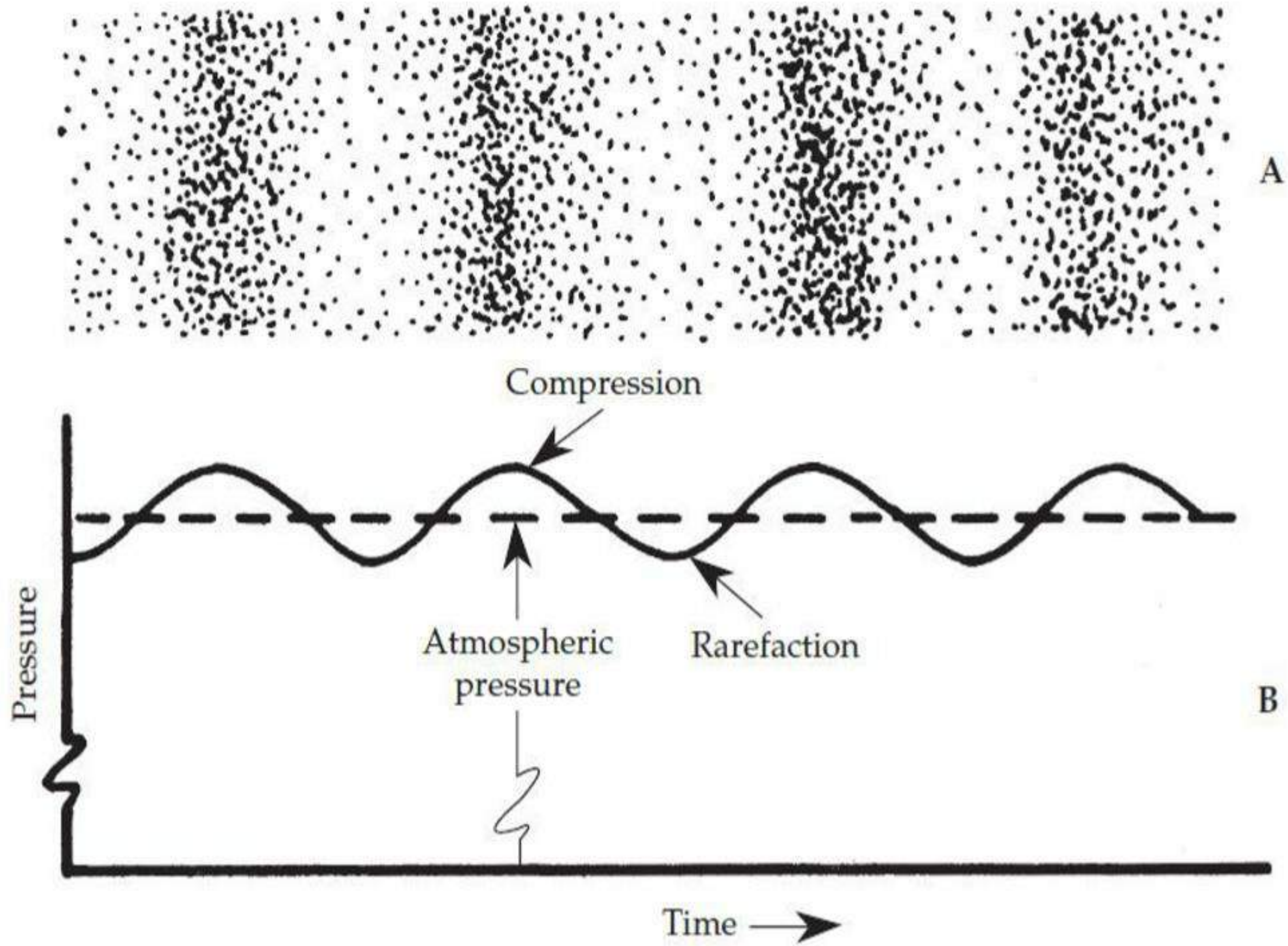


FIGURE 1-6 Pressure variations of sound waves are superimposed on prevailing barometric pressure. (A) An instantaneous view of the compressed and rarefied regions of a sound wave in air. (B) The compressed regions are very slightly above and the rarefied regions very slightly below atmospheric pressure.

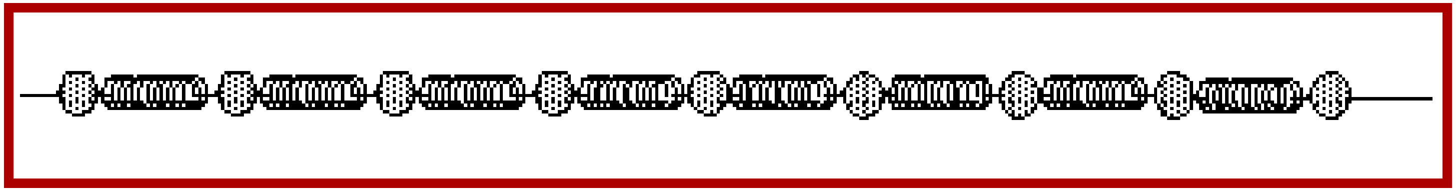
Definition of sound:

Time dependent mechanical deformation of the elastic medium

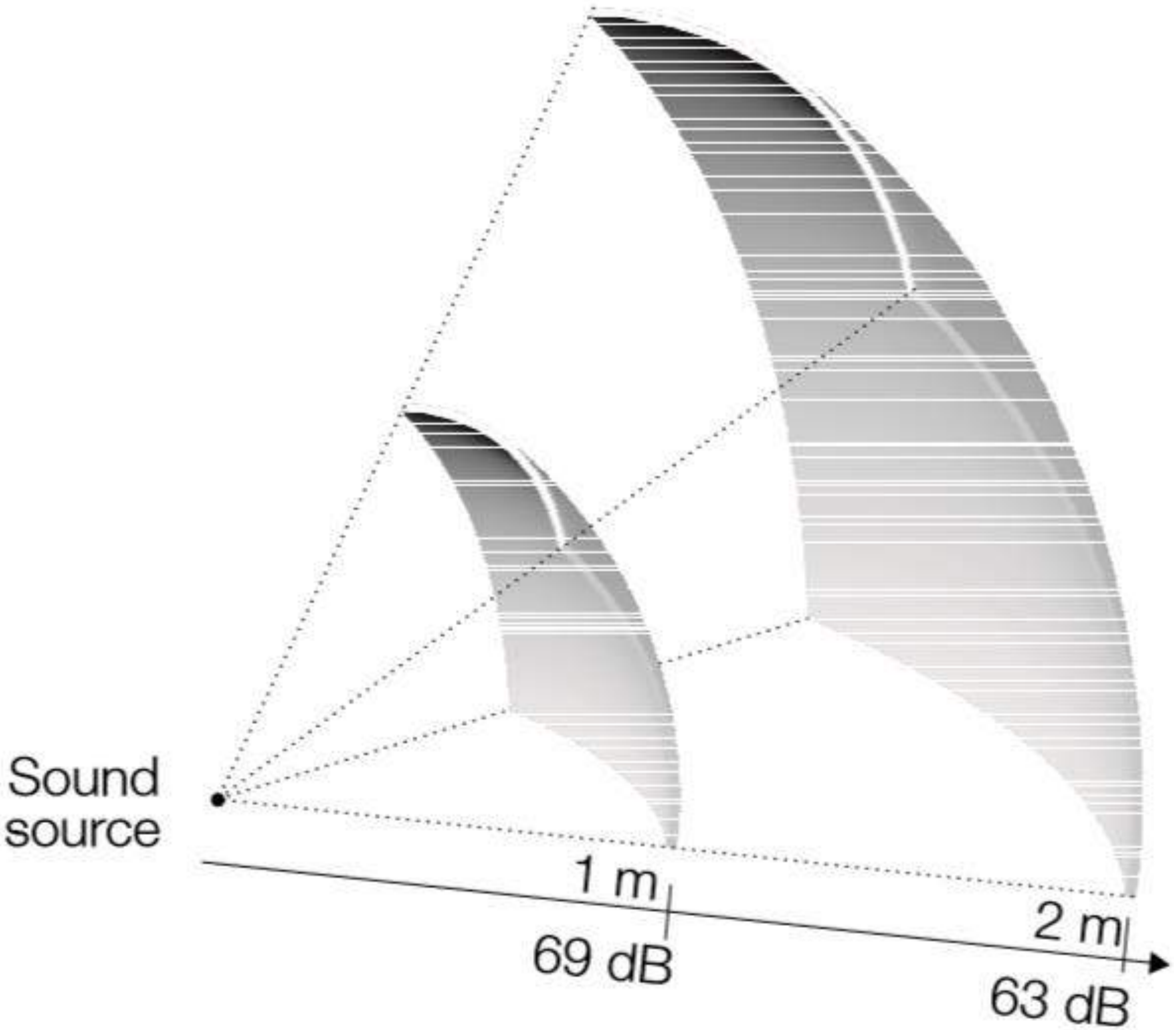
Understanding the physical and psychic properties of the nature of sound propagation is essential for designing, troubleshooting and analyzing noise protection

Prevention of the transition of the sound energy, i.e. sound insulation, can be achived in two ways:

- by energy loss (conversion of mechanical energy into heat), or
- with return of sound energy (reflection)

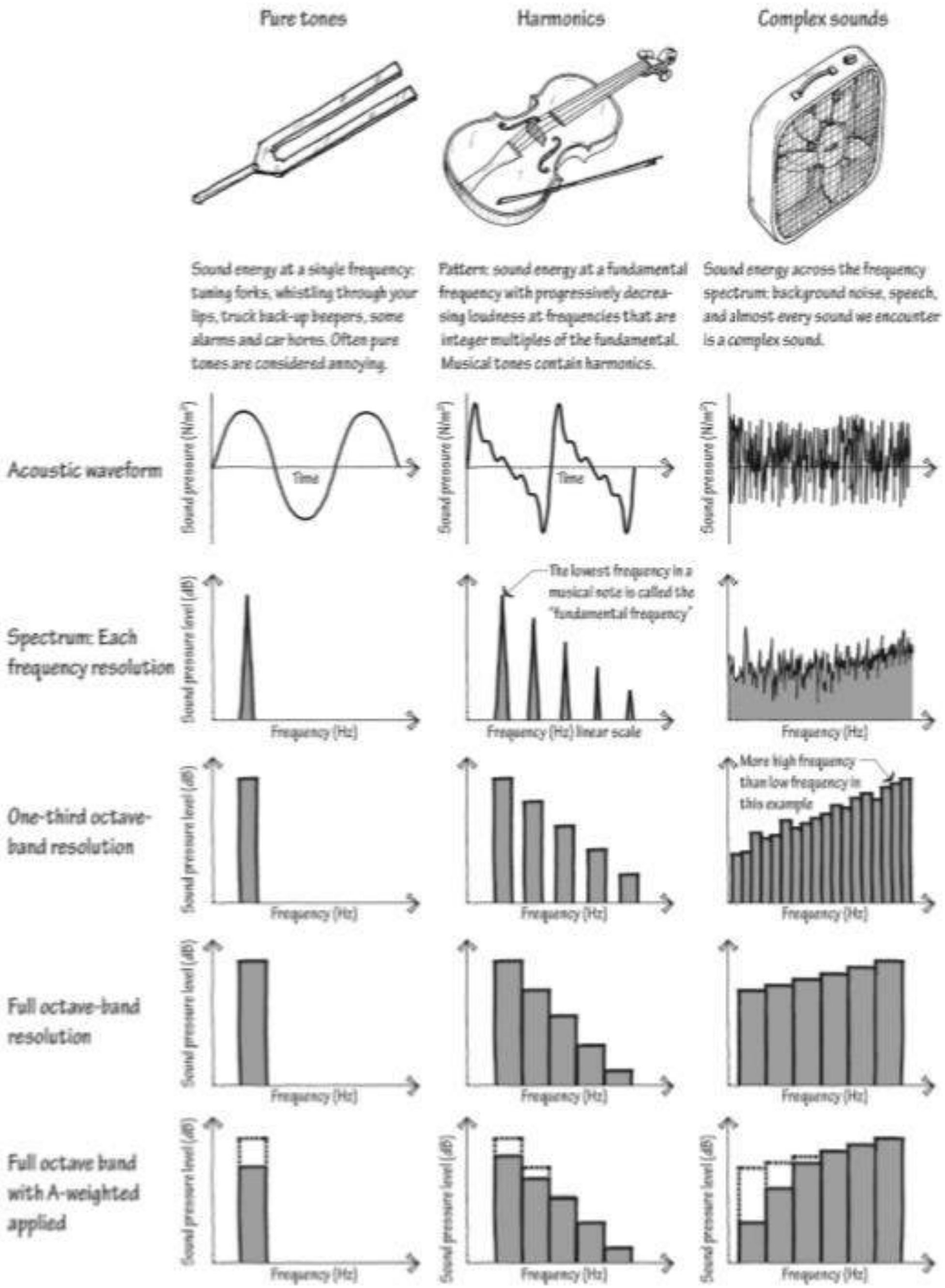


Sound propagation in free air (outdoors)



- 6 dB / double d

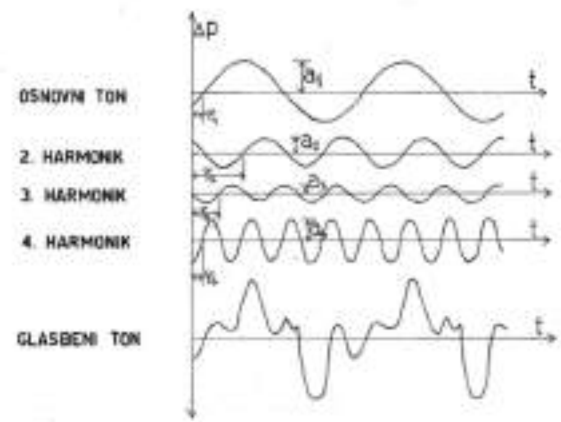
Sinus sound, sound and noise



1.17 Glasbeni ton

Je sestavljen iz osnovnega tona - čisti sinusni ton (ta določa tonsko višino) in iz višjeharmoničnih tonov - večkratniki osnovnega tona (ti pa določajo barvo tona).

Glasbeni ton lahko sestavimo iz čistih sinusnih tonov :



Matematična obravnava je možna s pomočjo Fourierjeve vrste.

Fourier transformation

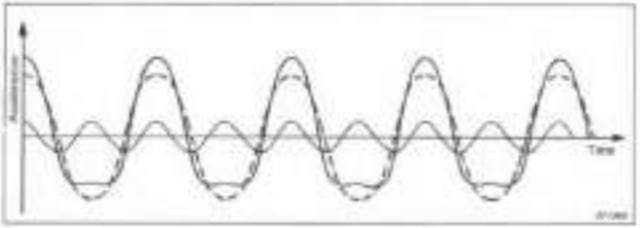


Fig.2.4. Illustration of how the waveform shown in Fig.2.3 can be "broken up" into a sum of harmonically related sinewaves

The number of terms required may be infinite, but in that case as the number of elements in the series is increased it becomes an increasingly better approximation to the original curve. The various elements constitute the vibration *frequency spectrum*. In Fig.2.4 the nonharmonic periodic motion of Fig.2.3 is redrawn together with the two most important harmonic curves representing its frequency spectrum. A somewhat more convenient method of representing this spectrum is shown in Fig.2.5 b, while Fig.2.6 shows some further examples of periodic time functions and their frequency spectra. A specific feature of periodic vibrations, which becomes clear by looking at Fig.2.5 and 2.6 is that their spectra consist of *discrete lines* when presented

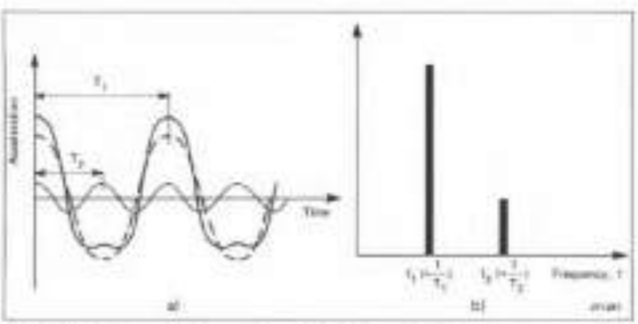


Fig.2.5. Illustration of how the signal, Fig.2.3 can be described in terms of a frequency spectrum
a) Description in the time domain
b) Description in the frequency domain

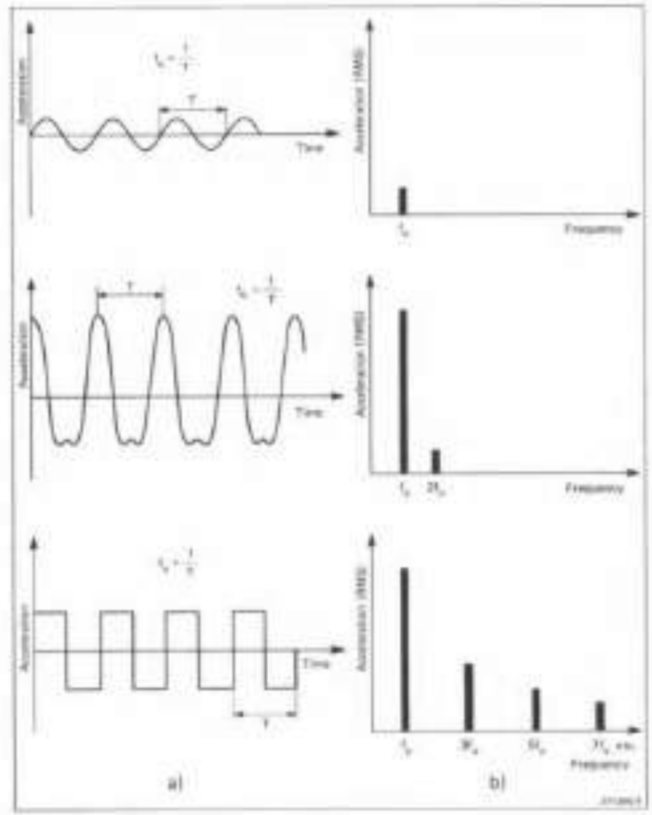


Fig.2.6. Examples of periodic signals and their frequency spectra
a) Descriptions in the time domain
b) Descriptions in the frequency domain

in the so-called frequency domain (Figs.2.5 b and 2.6 b). This is in contrast to random vibrations which show continuous frequency spectra (section 2.2, Fig.2.12).

Analysis, calculation and sound / noise measurements are using Fourier transformations

Sound Pressure Level: SPL = 20 . log (p_{RMS} / p_o)

Reference pressure: p_o = 20 μPa = 0.00002 Pa = 20 . 10^{-6} N/m^2

Sound Source	Sound Pressure (Pa)	Sound-Pressure Level* (dB, A-Weighted)
Saturn rocket	100,000	194
Ram jet	2,000	160
Propeller aircraft	200	140
Riveter	20	120
Heavy truck	2	100
Noisy office or heavy traffic	0.2	80
Conversational speech	0.02	60
Quiet residence	0.002	40
Leaves rustling	0.0002	20
Hearing threshold, excellent ears at frequency maximum response	0.00002	0

*Reference pressure (these are identical):
20 μPa (micropascals)
0.00002 Pa (pascals)
2×10^{-5} N/m^2
0.0002 dyne/cm^2 or μbar

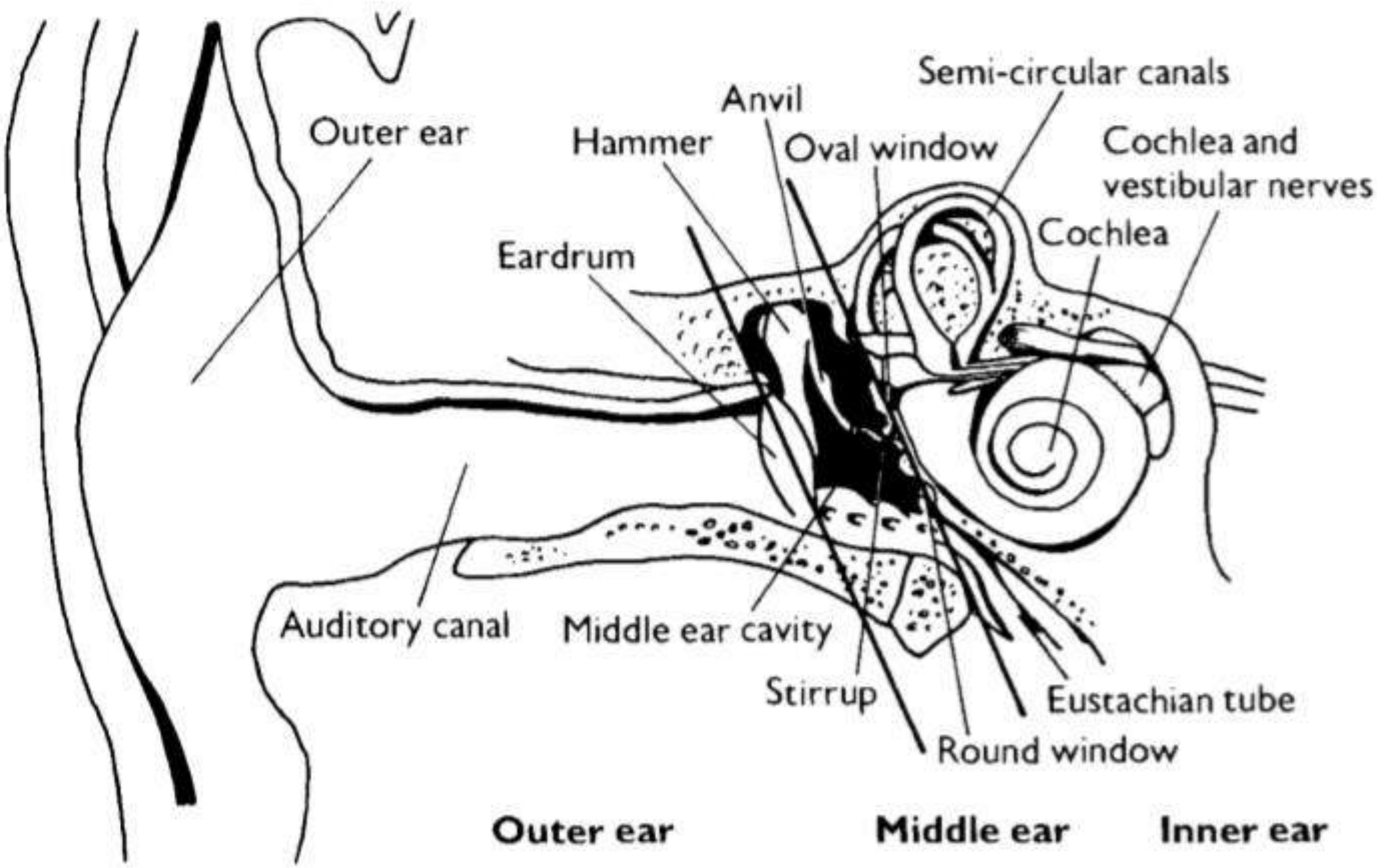
Sound Power Level:

SWL = 10 . log (W_{RMS} / W_o)

Reference power: W_o = 10^{-12} W

TABLE 2-5 Examples of Sound Pressures, and Sound-Pressure Levels

2. Psychophysical response of humans on noise



What is dB

Because the relationship between values in acoustics are extremely high (from the most silent to the most noisy, intensities of sound or source powers are in relation even up to 1 : 10^{12}) and because the human response to sound is in approximately logarithmical relation, the following relationship is used:

dB is a logarithmic ratio of two values

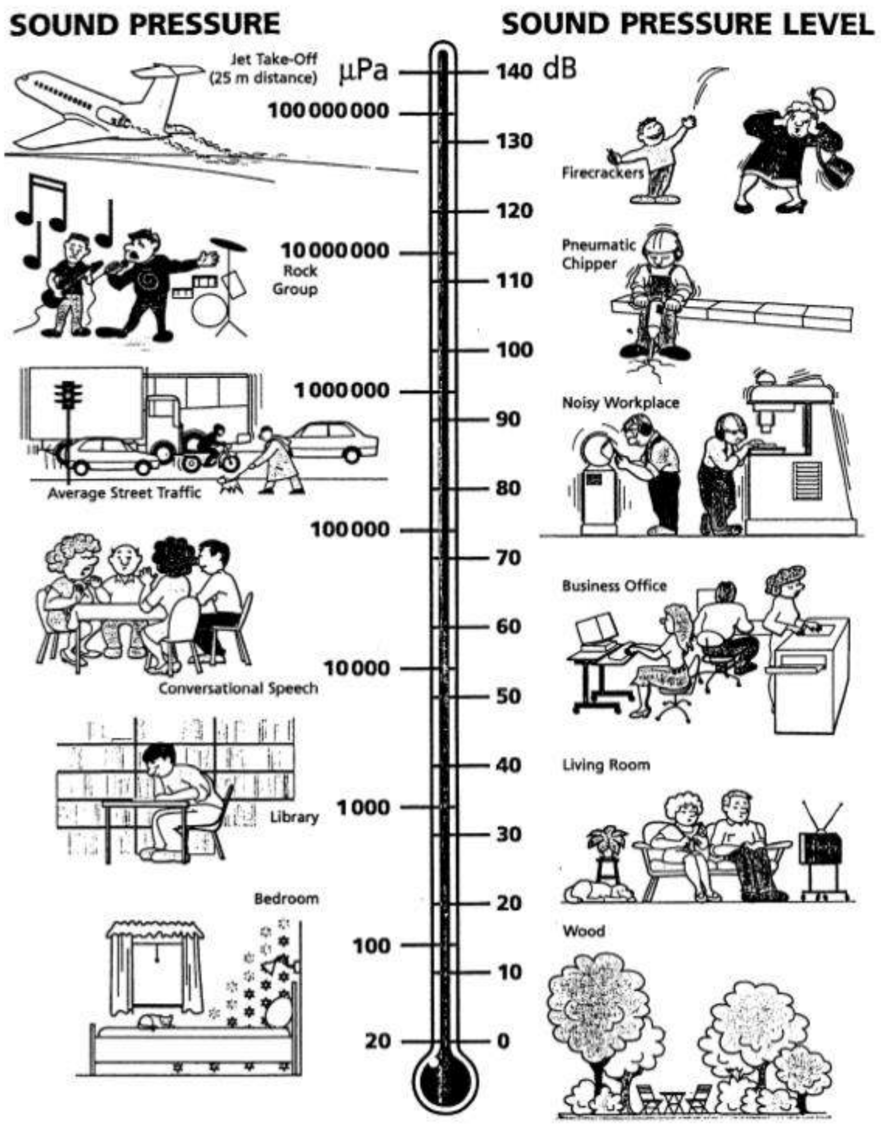
(values in dB are always related to reference values of pressure, power, intensity…)

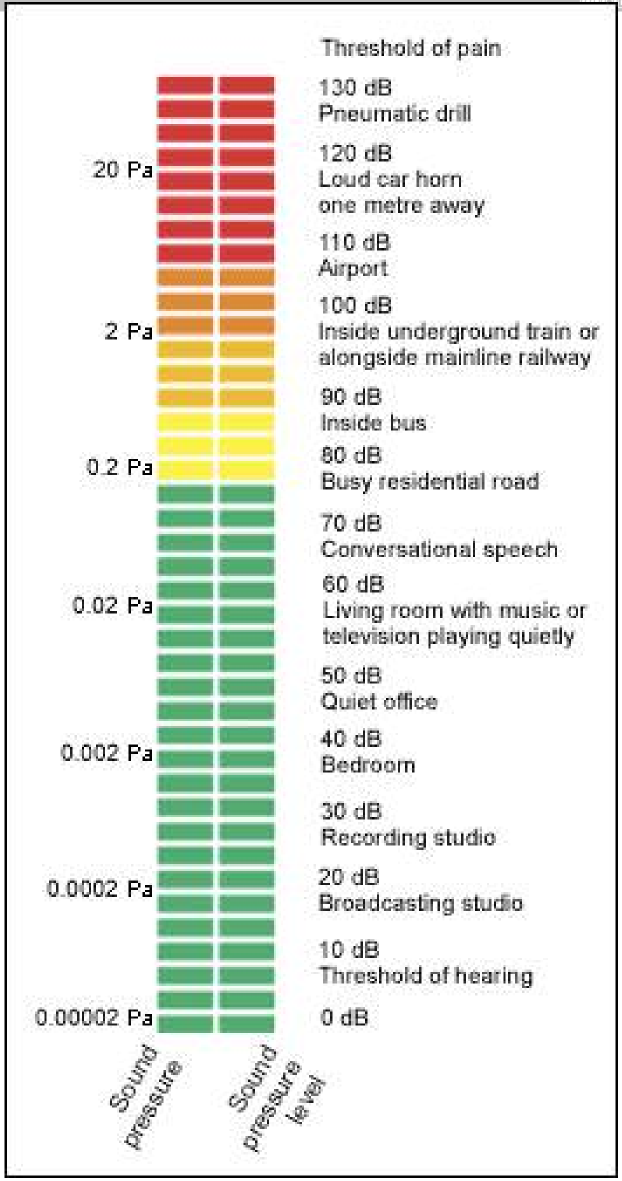
$n = 10 \log I_1 / I_2$ — I …. Intensity of sound / noise (W/m^2)

$n = 10 \log P_1 / P_2$ — P …. Power of source (W)

$n = 20 \log v_1 / v_2$ — v …. Speed of (air) particles (m/s)

$n = 20 \log p_1 / p_2$ — p …. Sound pressure ($N/m^2 = Pa$)





Sound Pressure Level: $SPL = 20 \,.\, \log (p_{RMS} / p_o)$

Reference pressure: $p_o = 20\ \mu Pa = 0{,}00002\ Pa = 20 \,.\, 10^{-6}\ N/m^2$

Speed of sound in different materials

Medium	Speed of Sound ft/sec	m/sec
Air	1,130	344
Seawater	4,900	1,500
Wood, fir	12,500	3,800
Steel bar	16,600	5,050
Gypsum board	22,300	6,800

l Examples of Speed of Sound in Different Materials

Equal-loudness contours of the human ear response for pure tones

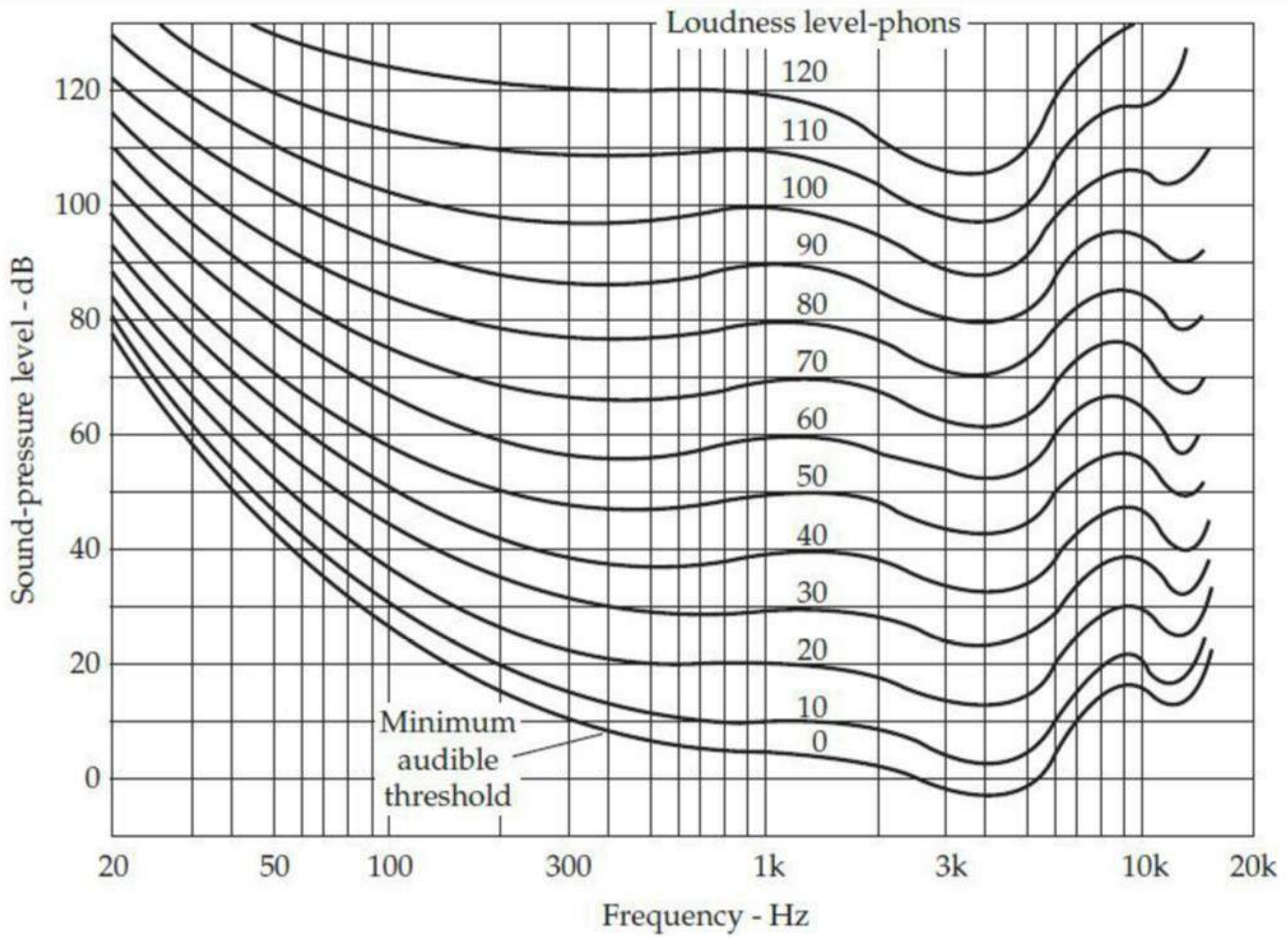


FIGURE 4-6 Equal-loudness contours of the human ear for pure tones. These contours reveal the relative lack of sensitivity of the ear to bass tones, especially at lower sound levels. Inverting these curves gives the frequency response of the ear in terms of loudness level. These data are taken for a sound source directly in front of the listener, pure tones, binaural listening, and subjects aged 18 to 25. (*Robinson and Dadson.*)

Phon = dB (1000 Hz)

Difference between dB in Phone curves

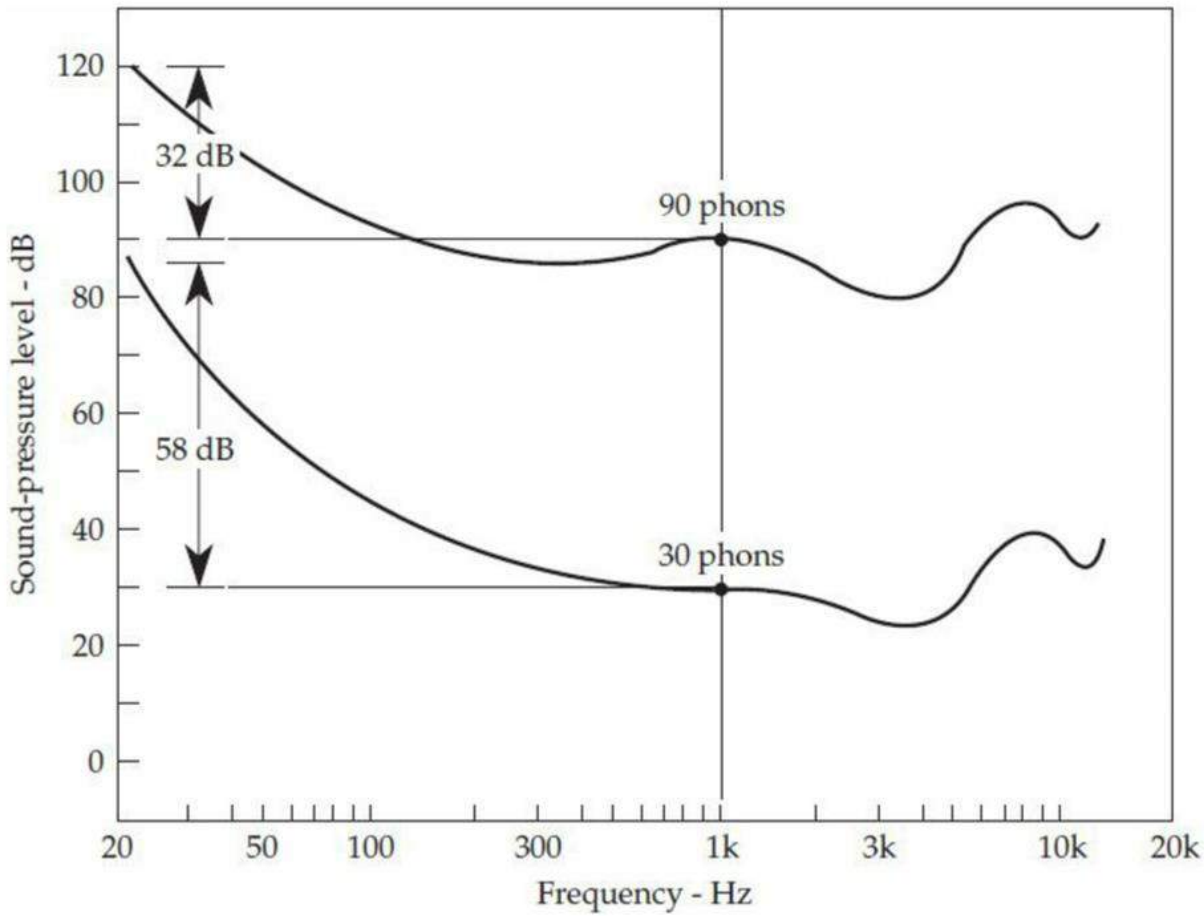


FIGURE 4-7 A comparison of the ear's response at 20 Hz, to the response at 1 kHz. At a loudness level of 30 phons, the sound-pressure level of a 20-Hz tone must be 58 dB higher than that at 1 kHz to have the same loudness. At a 90-phon loudness level, an increase of only 32 dB is required. The ear's response is somewhat flatter at high loudness levels. Loudness level is only an intermediate step to true subjective loudness.

A, B & C weighting

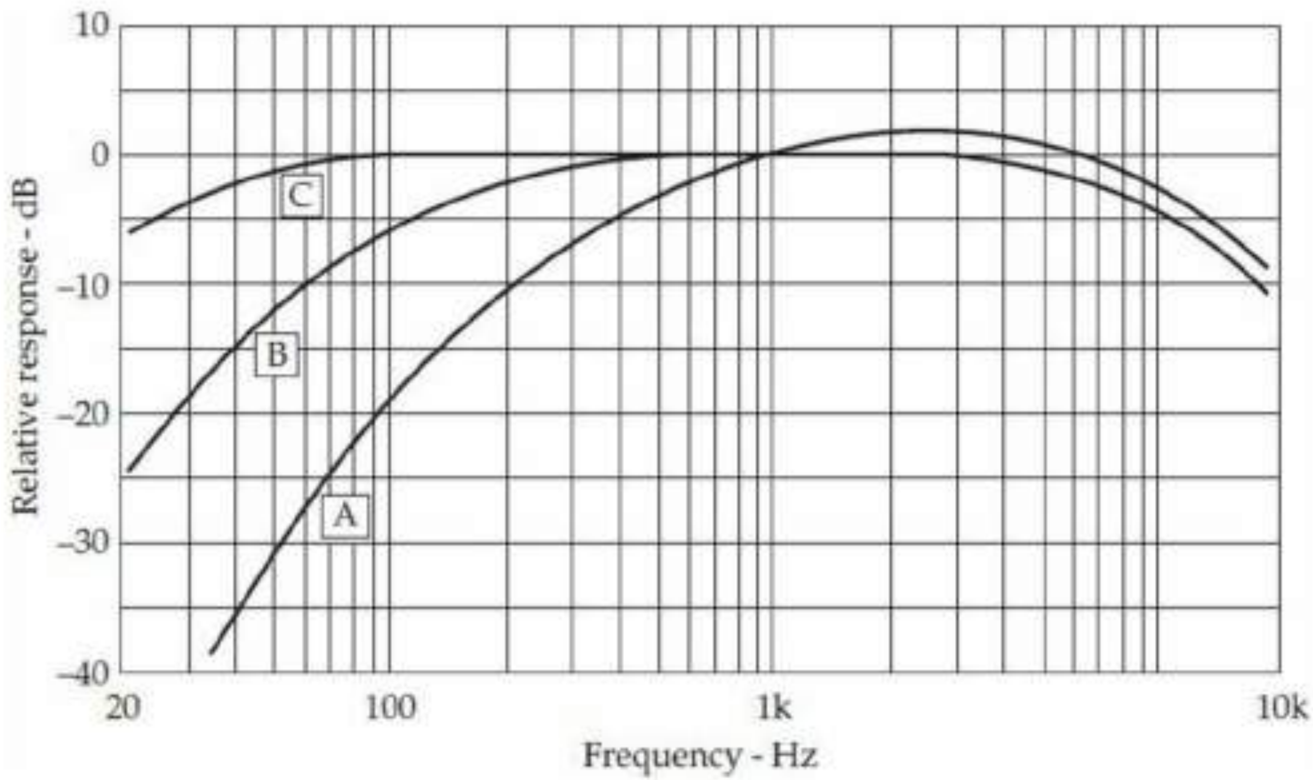
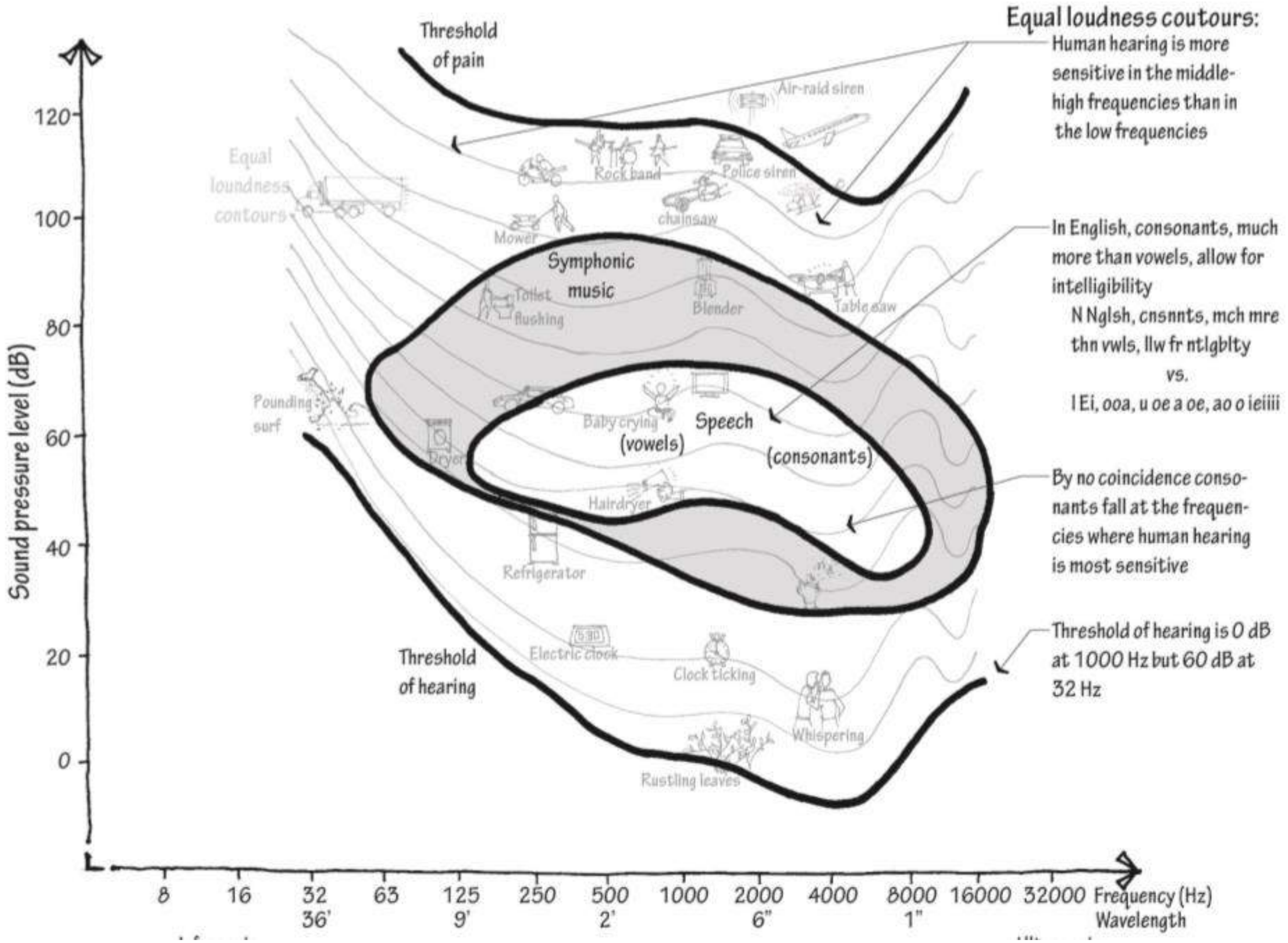


FIGURE 2-3 The A, B, and C weighting response characteristics for sound-level meters. (ANSI S1.4-1981.) A weighting is most commonly used.

- For sound-pressure levels of 20 to 55 dB, use network A.
- For sound-pressure levels of 55 to 85 dB, use network B.
- For sound-pressure levels of 85 to 140 dB, use network C.

dB(A)
dB(B)
dB(C)

Sound pressure level in relation to frequency of sound, for speech, music, thresholds of hearing and pain



White & Pink Noise

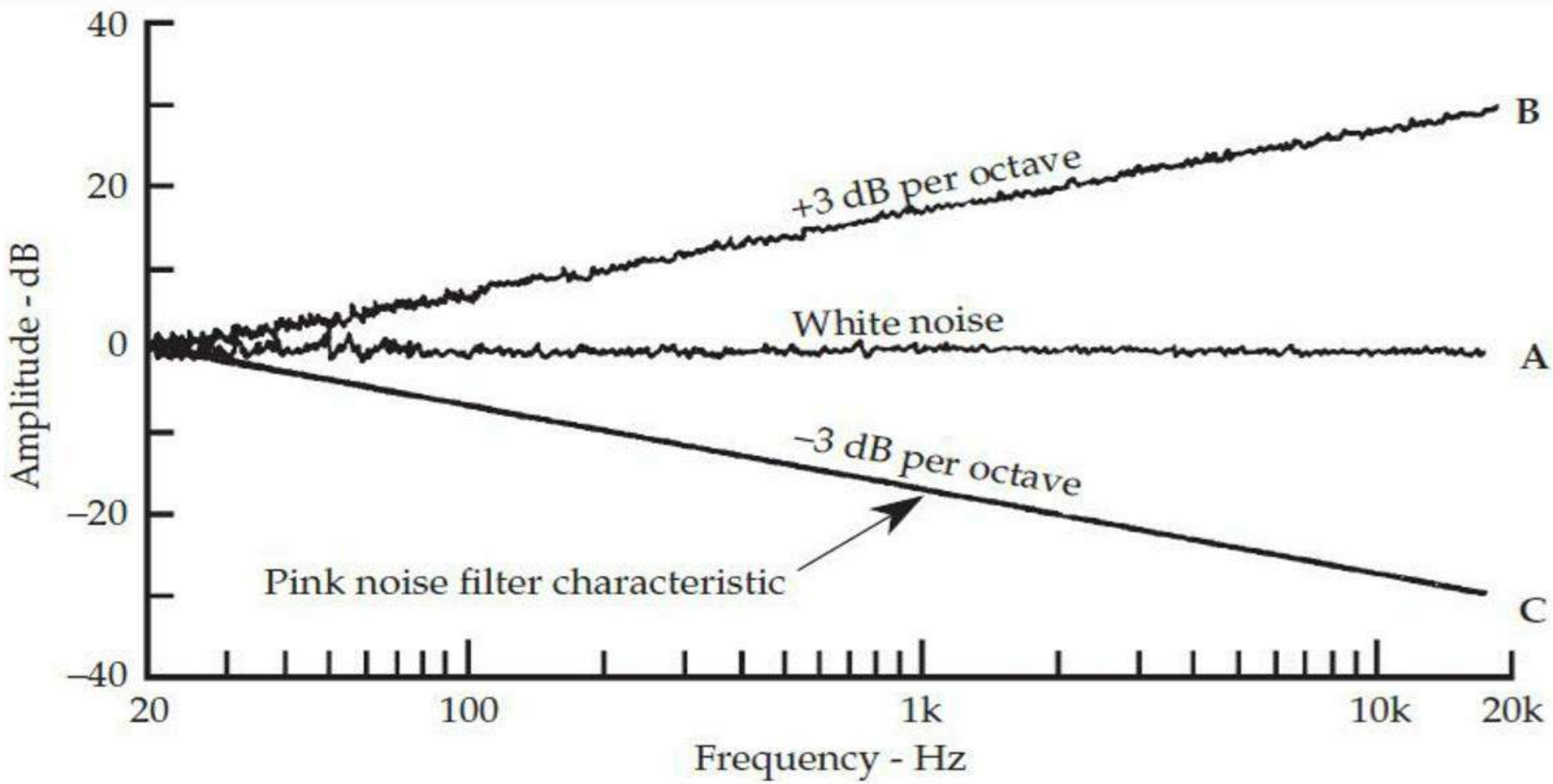


FIGURE 5-16 (A) Random white noise has constant energy per hertz. If the spectrum of random white noise is measured with an analyzer of fixed bandwidth, the resulting spectrum will be flat with frequency. (B) If white noise is measured with an analyzer whose passband width is a given percentage of the frequency to which it is tuned, the spectrum will slope upward at 3 dB/octave. (C) Pink noise is obtained by low-pass filtering white noise with a characteristic that slopes downward at 3 dB/octave.

Determination of direction of incoming sound

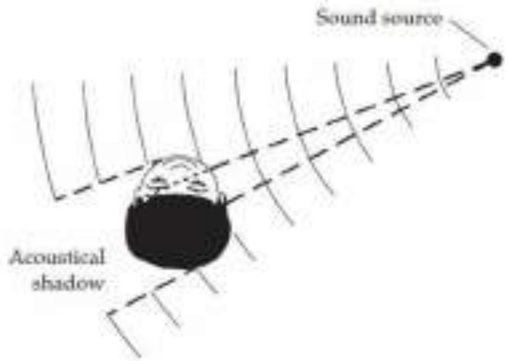
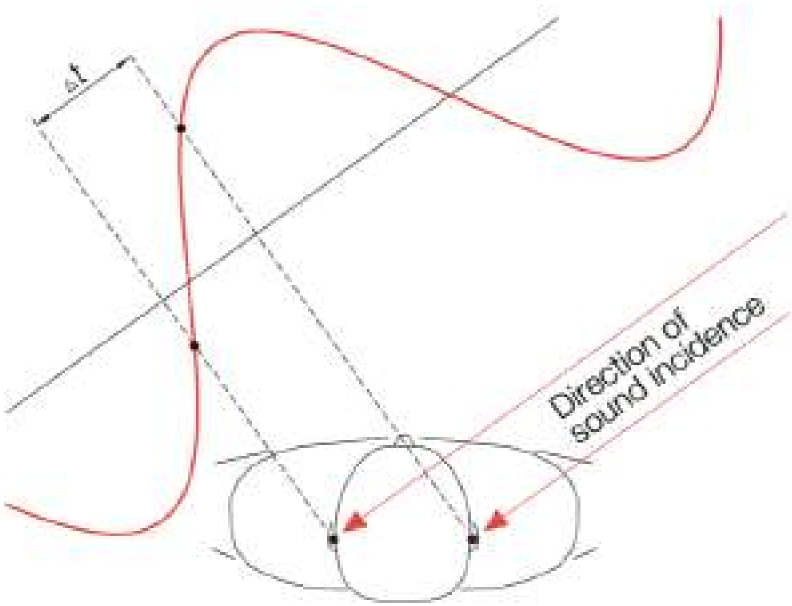


FIGURE 4-17 Our binaural directional sense depends in part on the difference in intensity and time of arrival of the sound falling on two ears.



Problem of noise in EU (source: WHO)

>40% of population is daily exposed to >65dB(A) and through nights >50dB(A)

>20% of working population is exposed to more than acceptable noise levels (more than one half to >80dB(A))

Facts:

Noise **<65 dB(A)** on long period normally **does not lead to permanent hearing failures**. Short exposure generally does not lead to permanent hearing loss. Short exposures do not have detachable effects on temporary hearing loss.

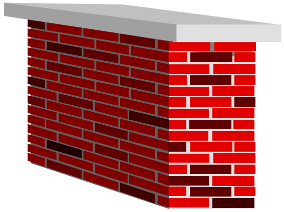
Noise **>65dB(A)** exposure for years **may lead** to problems with hearing loss

Noise **>80B(A)** exposure for many years leads to **great certainty** to permanent hearing loss

4. Sound insulation of buildings

- We distinguish:

- Sound insulation against airborne sound ✓
- Sound insulation against impact sound ✓
- Sound insulation against vibrations of installations ✓
- Sound insulation against environmental (municipal) noise ✓
- Acoustics of interior space (reverberation noise) ✓



Sound insulation against airborne noise:

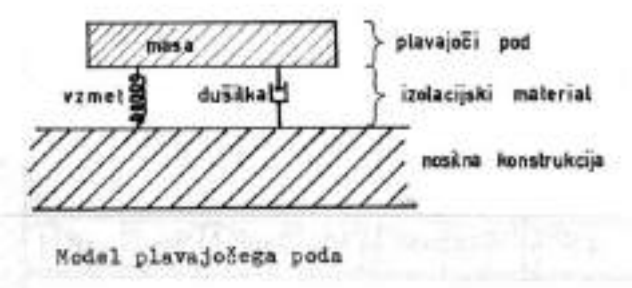
- **Emitter:** sound vibrations in the air (speech, audio speaker, musical instruments ...)
- **Transmitter:** from the air, through solid construction material, partition walls, doors, windows and sound in the air again
- **Receiver:** airborne sound in receiving room (ear, microphone of measuring instrument…)

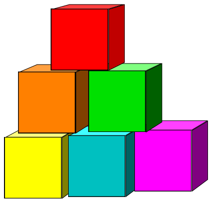
- **Basic rule:** maximizing the mass of the wall, ceiling or intermediate barriers per unit area leads to higher sound insulation values.

Noise reduction insulation materials (mainly porous) do not directly affect the reduction of sound propagation against airborne sound. Those materials are primarily used for lowering noise level by reducing echo effect and to lower reverberation time of the interior spaces

Sound insulation against impact sound:

- **Emitter:** vibrations, walking, different bumps, moving chairs and furniture, various assembly and finishing construction works
- **Transmitter:** massive solid construction material and sound in the air
- **Receiver:** sound in receiving room (ear, microphone of measuring instrument…)

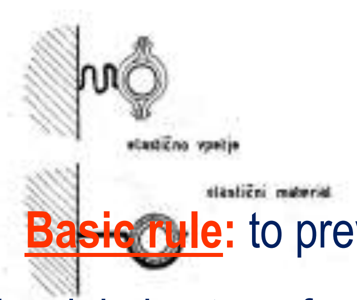




- **Basic rule:** to prevent access of impact sound to enter into massive construction (floor or wall constructions) – all other preventive approaches are much less effective

Sound insulation against vibrations and installations

- **Emitter:** vibrations and forced vibrations of installations and other operating equipment, vibrations transmitted from the air or impact sound into installation lines,
- **Transmitter:** installation lines, direct connections of installation lines into massive bearing constructions,
- **Receiver:** sound in receiving room (ear, microphone of measuring instrument…)



- **Basic rule:** to prevent the access of sound into installations.

To minimize transfer and sources of forced oscillations or vibrations.

All passages of installations through constructions should be sealed with elastic and acoustic insulated materials.

Insulation against environmental (municipal) noise

- **Sources of the noise are usually: transport (road, railway, airplane, sea transport…), industry, children's playgrounds, sport or other events…**

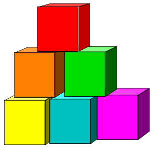
- **Barriers against noise are normally used**

We distinguish between:

- **Active noise protection** (reduction of noise at the source side) – very effective and less costly
- **Passive noise protection** (reduction of noise at the receiver side) – less effective and more expensive

Acoustics of interior space (reverberation noise):

- **A goal is to control (to lower) reverberation time of interior space (indoors)**

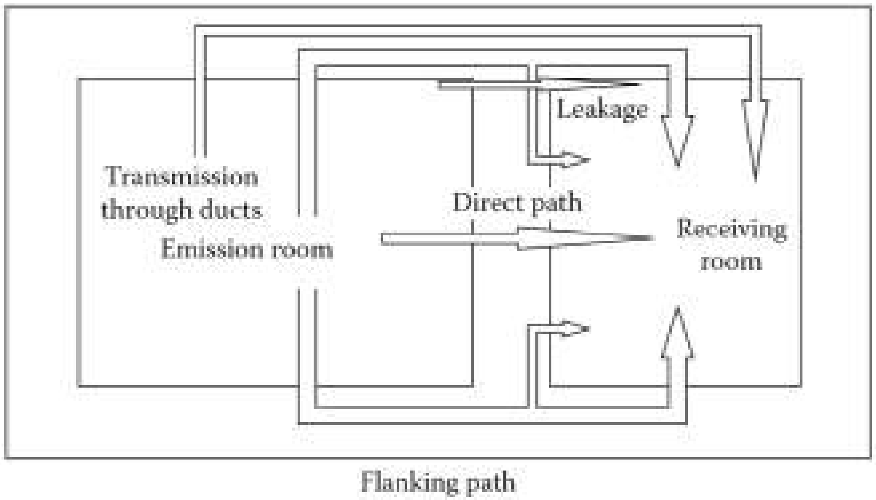


We distinguish between:

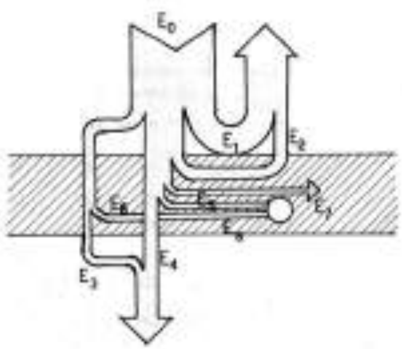
- **Acoustics of spaces intended for speech** (importance of clarity and understanding of human voice or speaker – comprehensibility)
- **Acoustics of spaces intended for music** (importance of various aesthetic and artistic criteria)

Reverberation time is reduced by installing absorbent surfaces on walls, ceilings and floors of interior space

5. Sound insulation against airborne sound



Acoustic transmission paths between spaces.



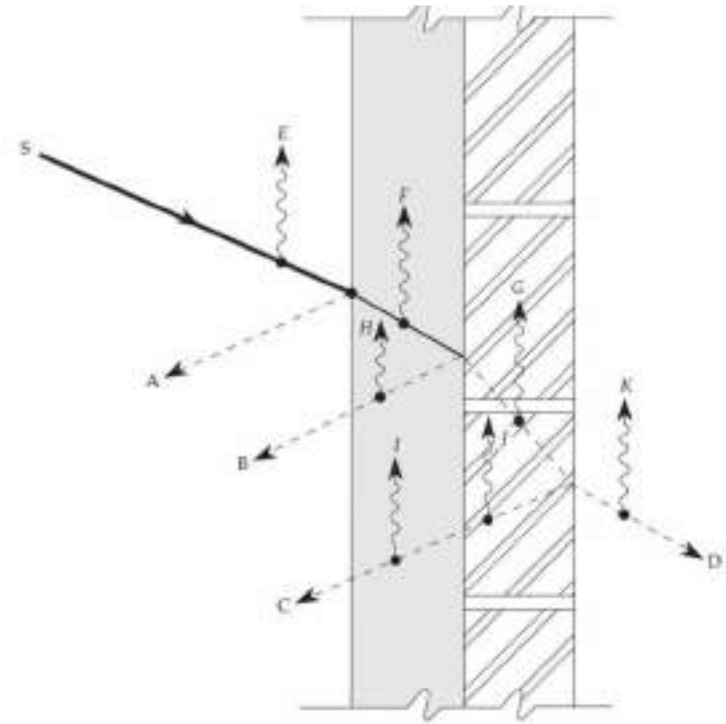
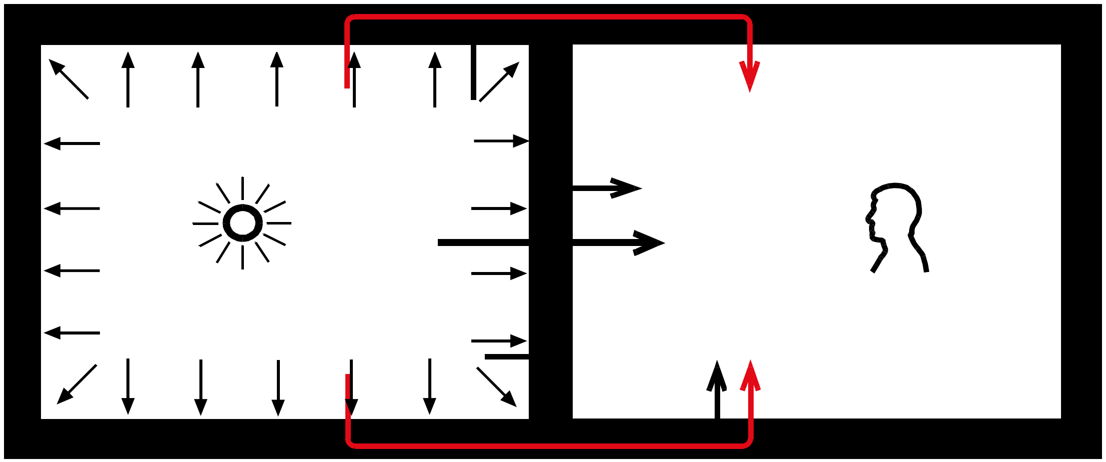


FIGURE 12-1 A sound ray impinging on an acoustical material on a masonry wall undergoes reflection from three different surfaces and absorption in the air and two different materials, with different degrees of refraction at each interface. In this chapter, the cumulative absorbed component is of chief interest.

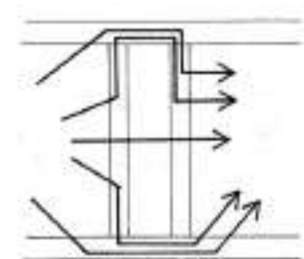
Ways of passing acoustic energy through the dividing wall



The energy of sound is approximately constant in the inner space and penetrates at the same time on all six surfaces

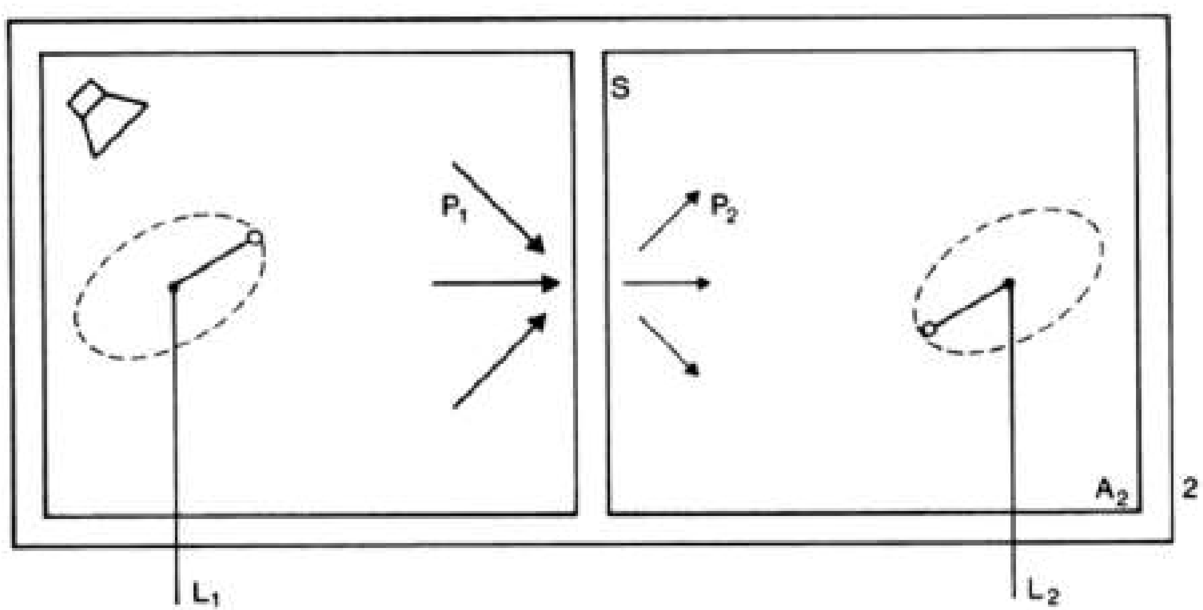
Sound energy passing from inner room into another room :

- Through a wall that separates them – direct transmission,
- Through the side walls – flanking transmission,
- Through combined routes,
- Through openings (windows, doors,)
- Through joints, gaps, dilatations,
- Through installation lines.



Prehod zvoka skozi dvojni zid

Measurements of sound insulation against airborne sound



Sound reduction index (R'_w):

$$R'_w = L_1 - L_2 + 10 \log (S/A) = L_1 - L_2 + 10 \log (RT/RT_0)$$

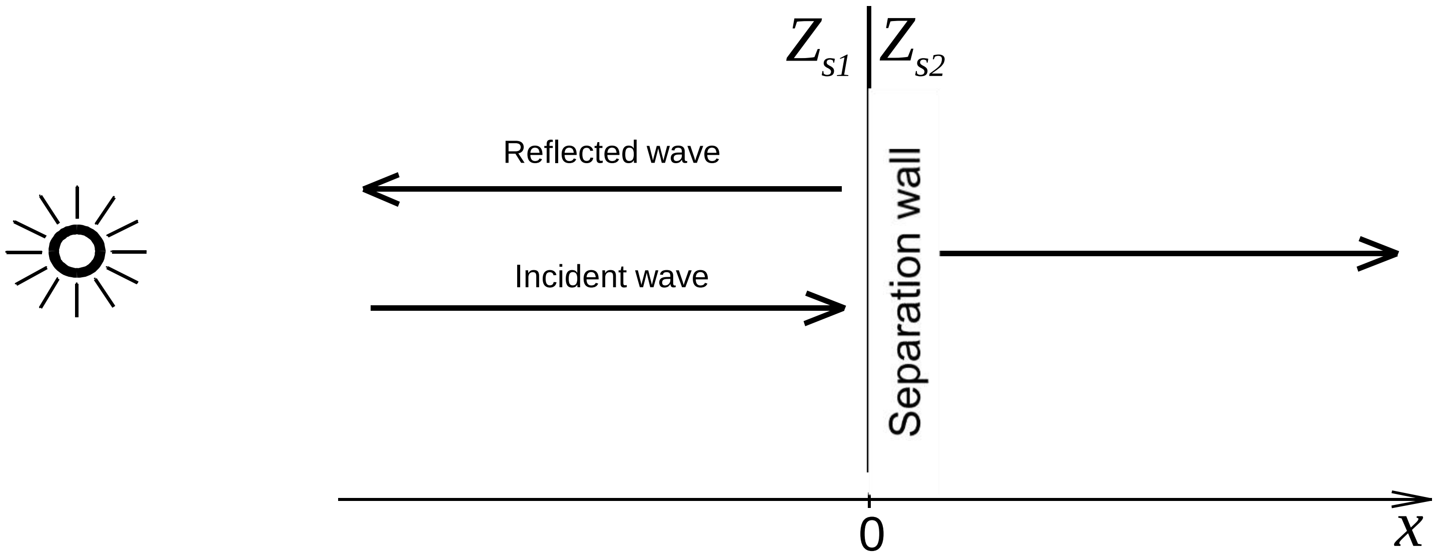
L_1 and L_2 represent the sound pressure level in emitting and receiving room,
S means the area of the separating construction (m^2),
A is equivalent absorption area of the receiving room (m^2),
RT means reverberation time (s),
RT_0 is normalized value of the reverberation time (s)

In order to model the process of transferring energy specific resistance of medium (Z_s) is introduced

$$Z_S = \rho c$$

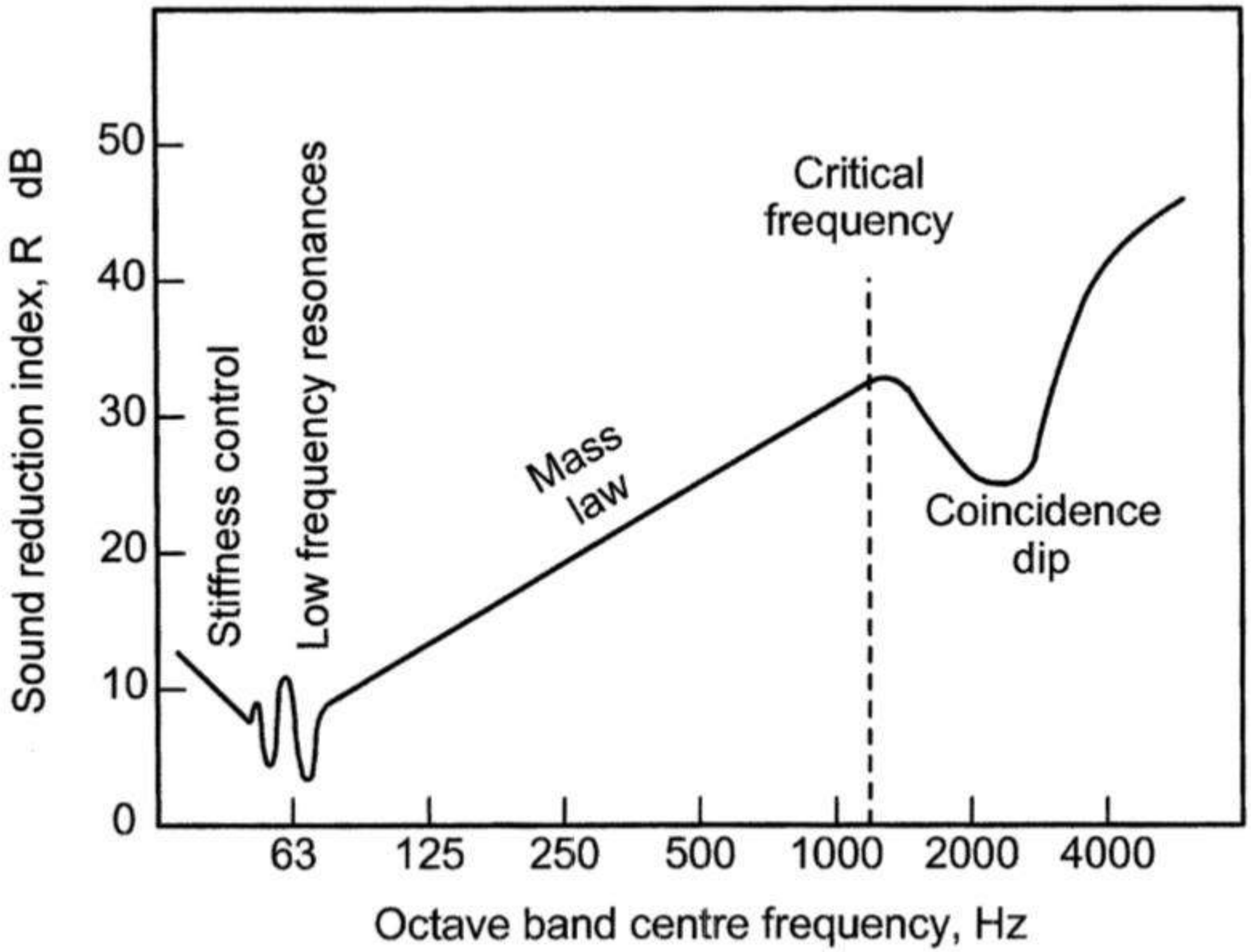
ρ - density of the medium (kg/m^3),
c – speed of sound (m/s)

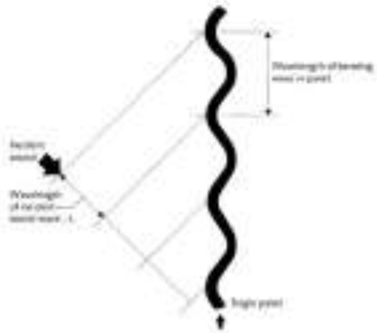
When a sound wave strikes the change in the acoustic resistance causes reflection !



To achieve the sound insulation, on the path of the sound transmission in a certain medium discontinuity isneeded

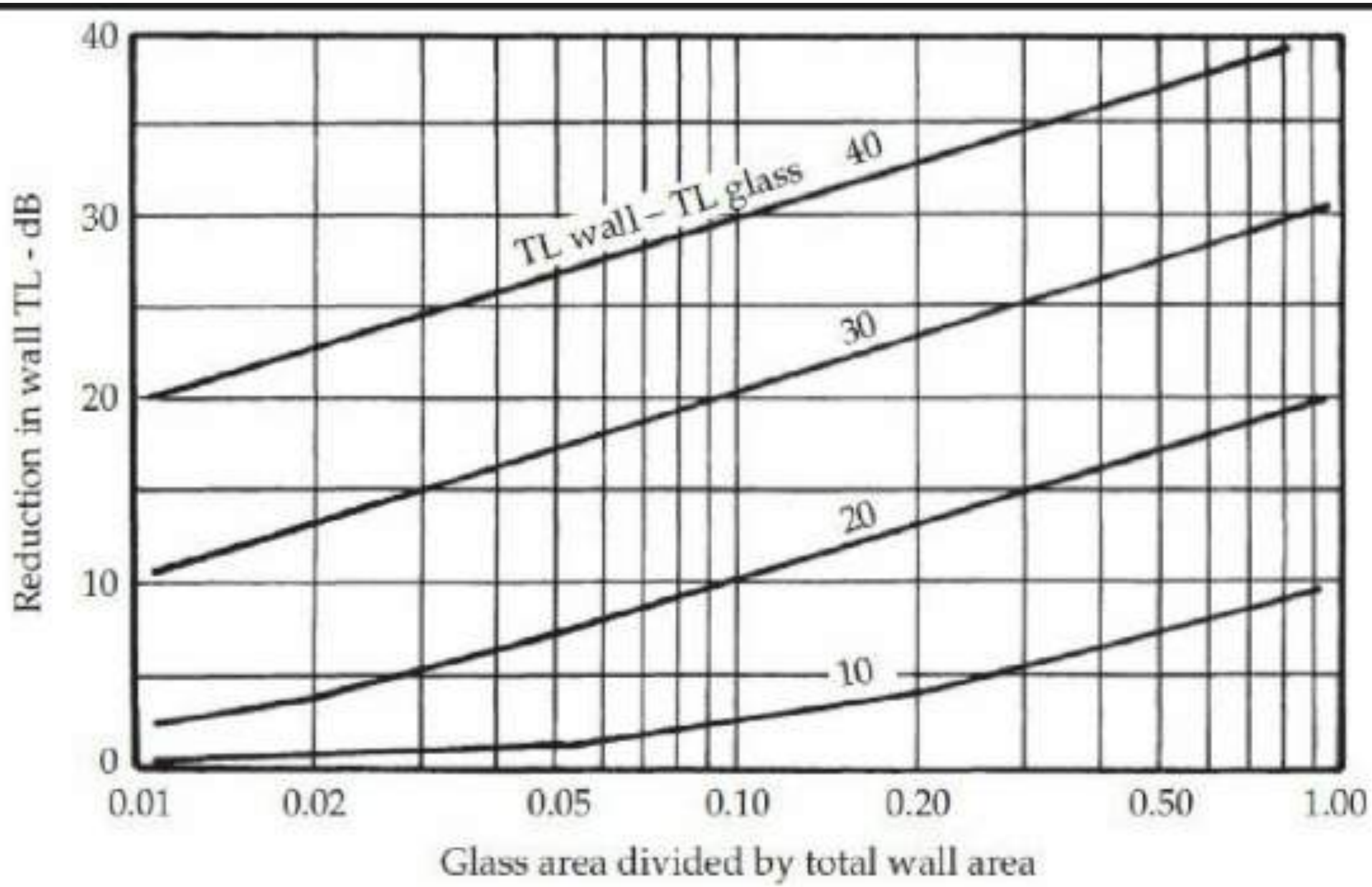
Mass law, resonant and coincidence frequency





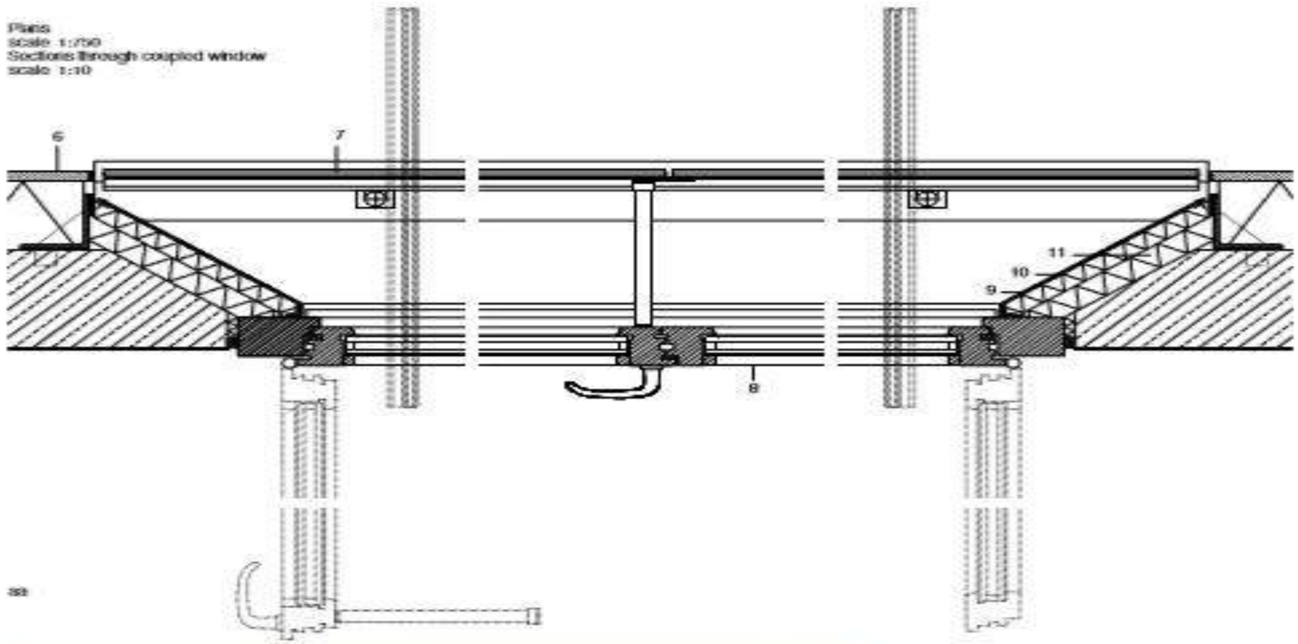
Theoretical variation of sound reduction index with frequency for a single panel.

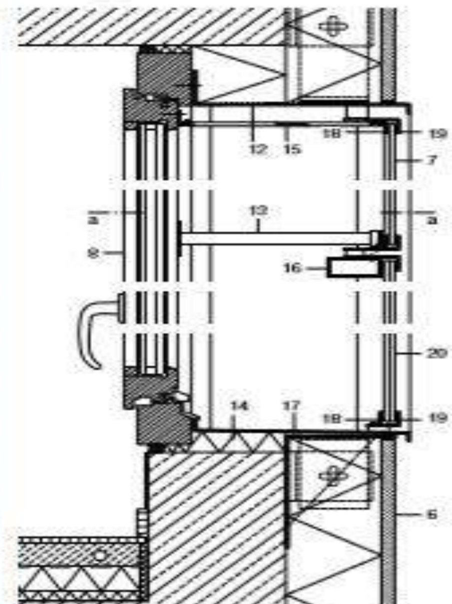
Effects of weak window in a strong insulated wall



RE 18-19 Graphical method for estimating the effect of a weak window in a strong wall.

Case study – housing
Inner-city development, Munich





6. Sound insulation against impact sound

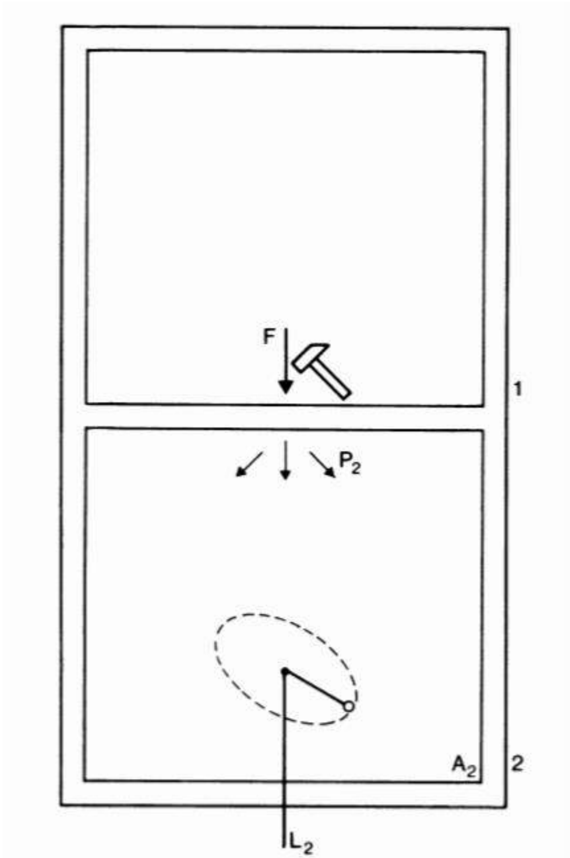


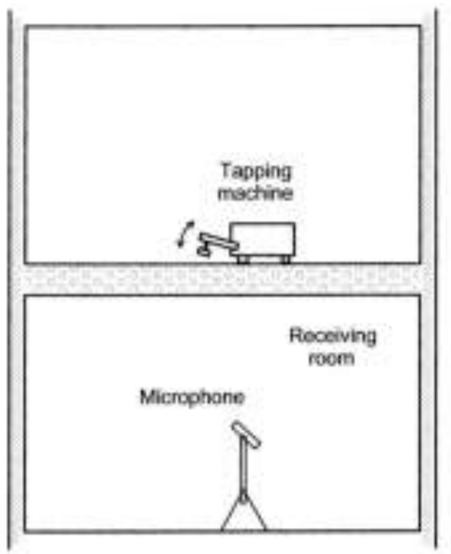
Fig. 5.6.1. Principle of measuring the impact sound pressure level from a floor to a receiving room (2)

To stimulate or create impact sound vibrations, standardized impact sound source (˝knocker˝) is used

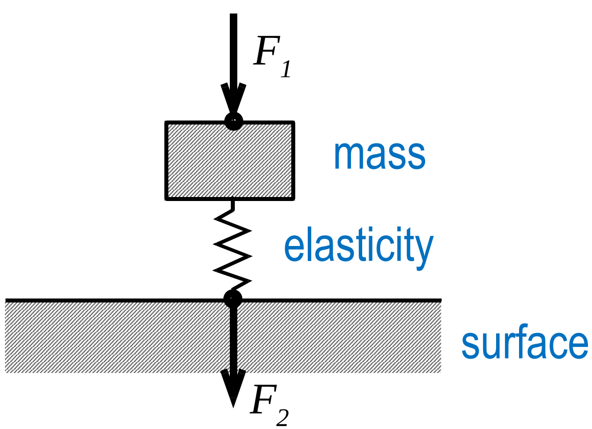
Sound pressure level of impact sound (L'_N) :

$$L'_N = L'_1 + 10 \log (A/A_0) = L'_1 + 10 \log (RT/RT_0)$$

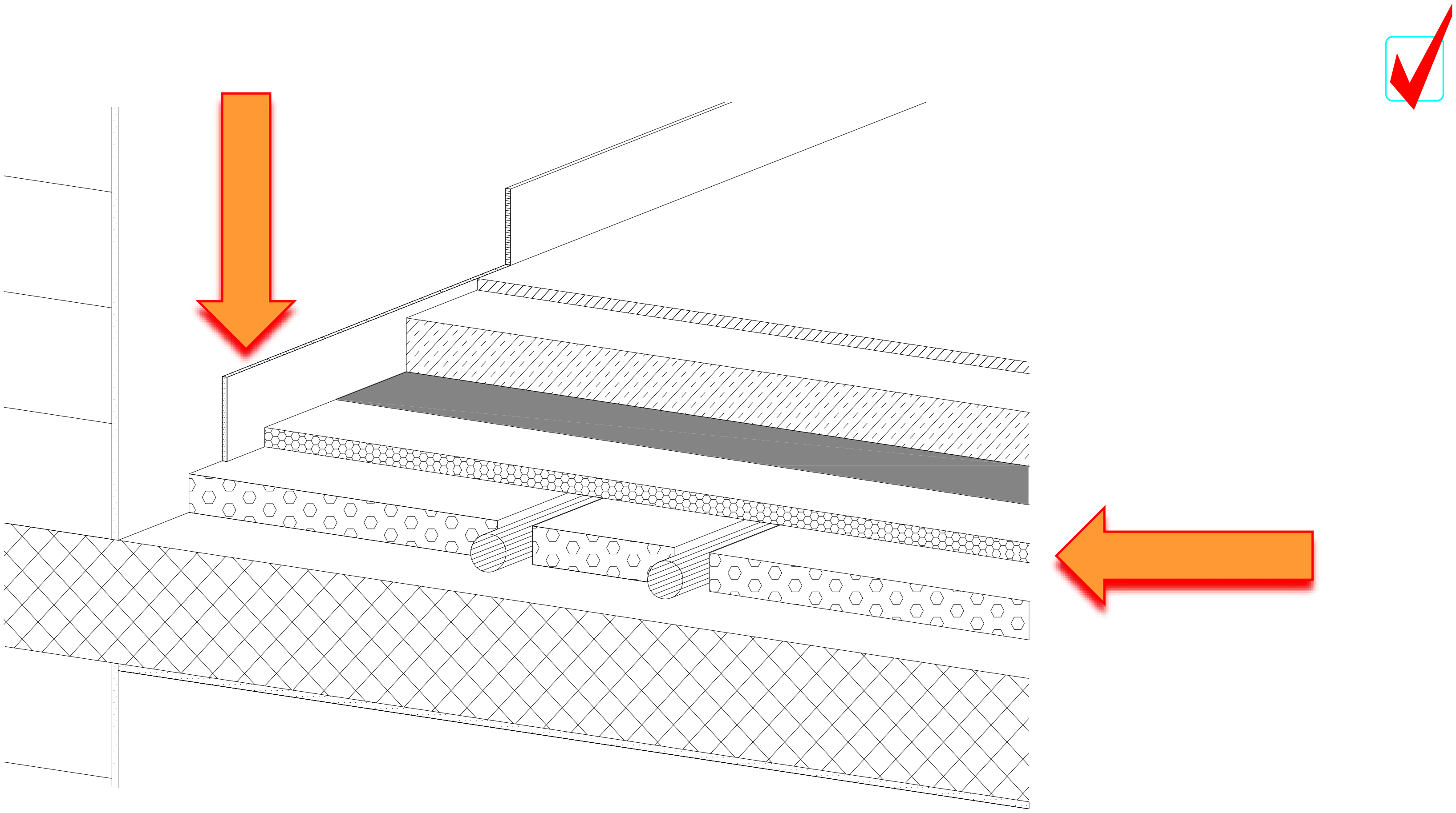
L'_1 …… represents the sound pressure level in receiving room,
A …… is equivalent absorption area of the receiving room (m^2),
A_0 …… means normalized value of the absorption area (m^2)
RT …… is reverberation time (s),
RT_0 .. means normalized reverberation time (s),



Pair of rooms with tapping machine.



Floated floor



6. Sound insulation against environmental (municipal) noise

d

Sound barriers / noise barriers

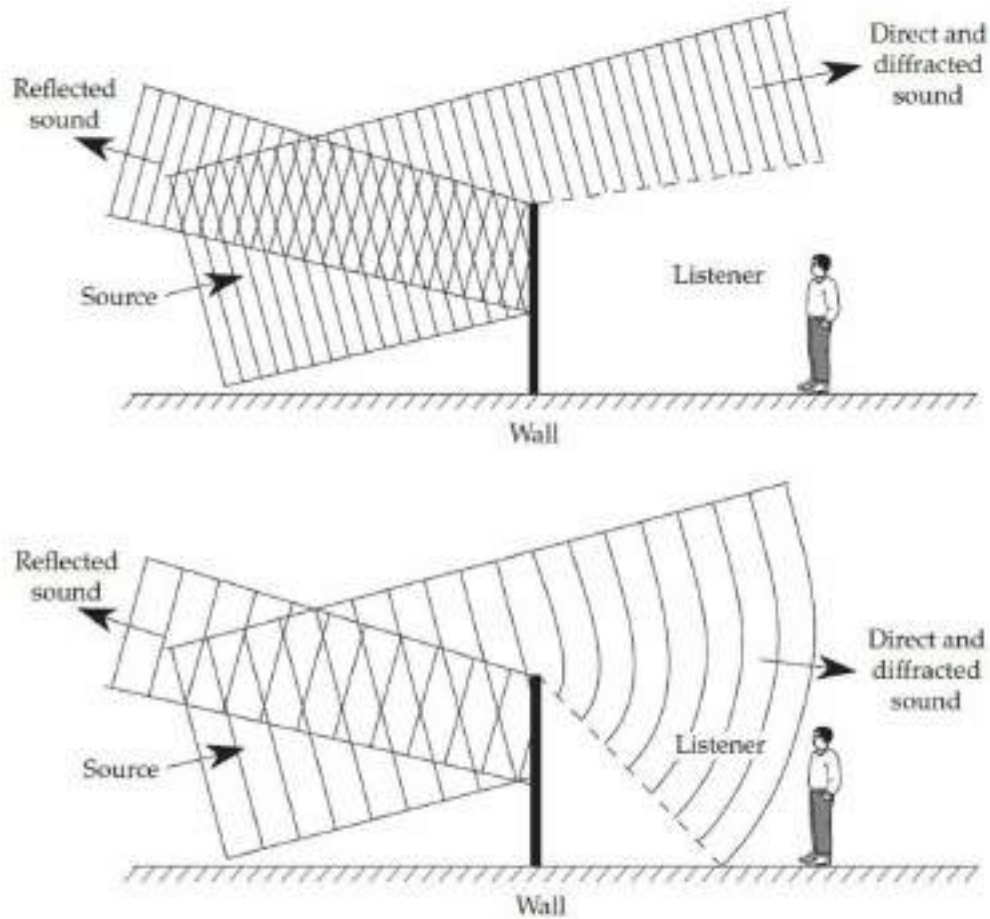
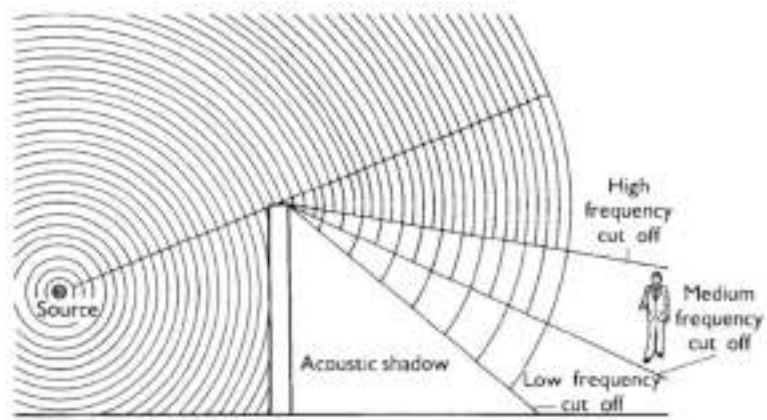


FIGURE 7-3 The sound striking a solid traffic barrier will be partly diffracted and partly reflected. (A) High-frequency traffic sounds are successfully attenuated on the other side of the barrier because of limited diffraction. (B) Low-frequency traffic sounds are less attenuated because of more prominent diffraction. Sound passing the top edge of the barrier acts as though the wavefronts are lines of sources, radiating sound energy into the shadow zone.



Effectiveness of a traffic sound barriers

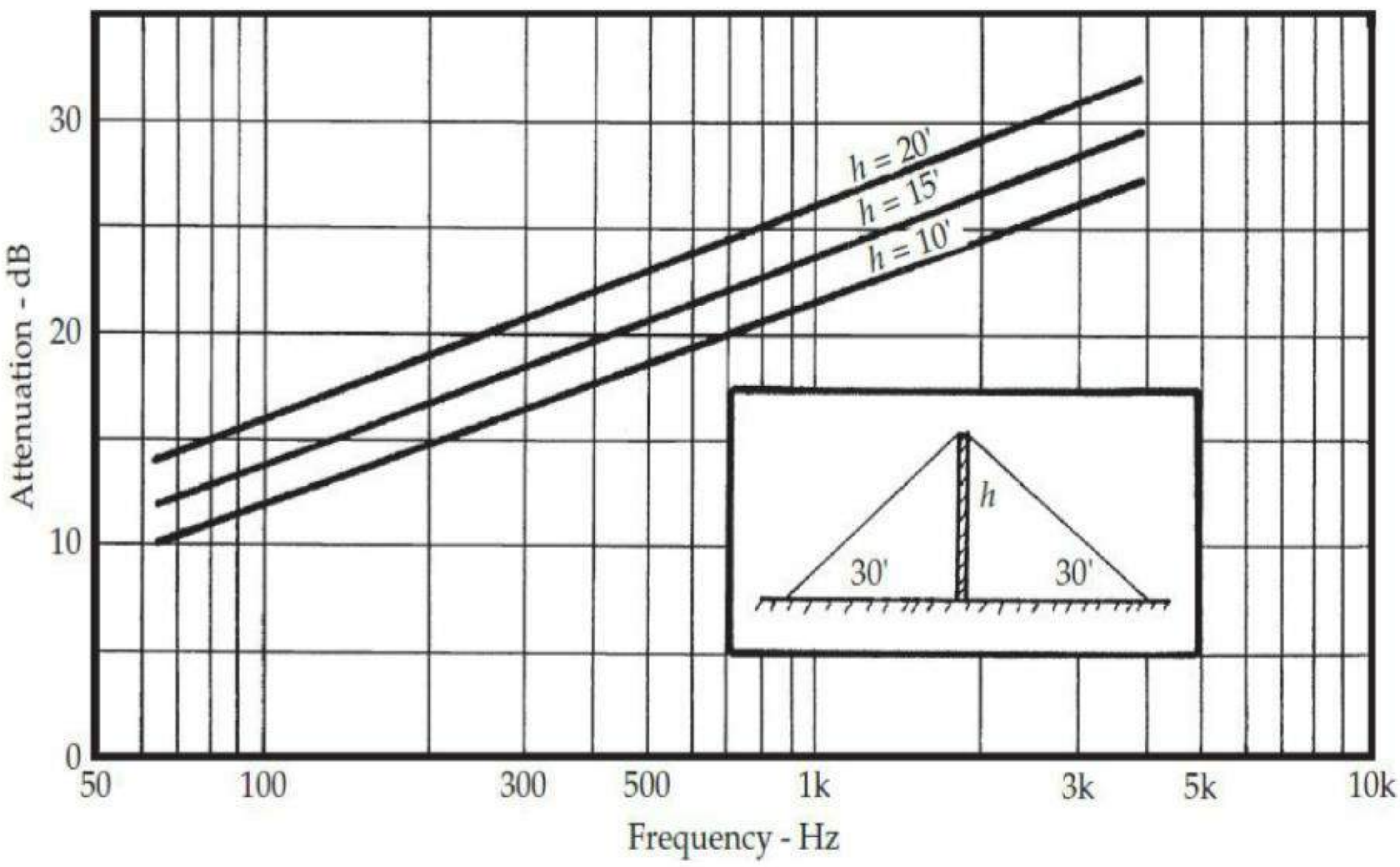
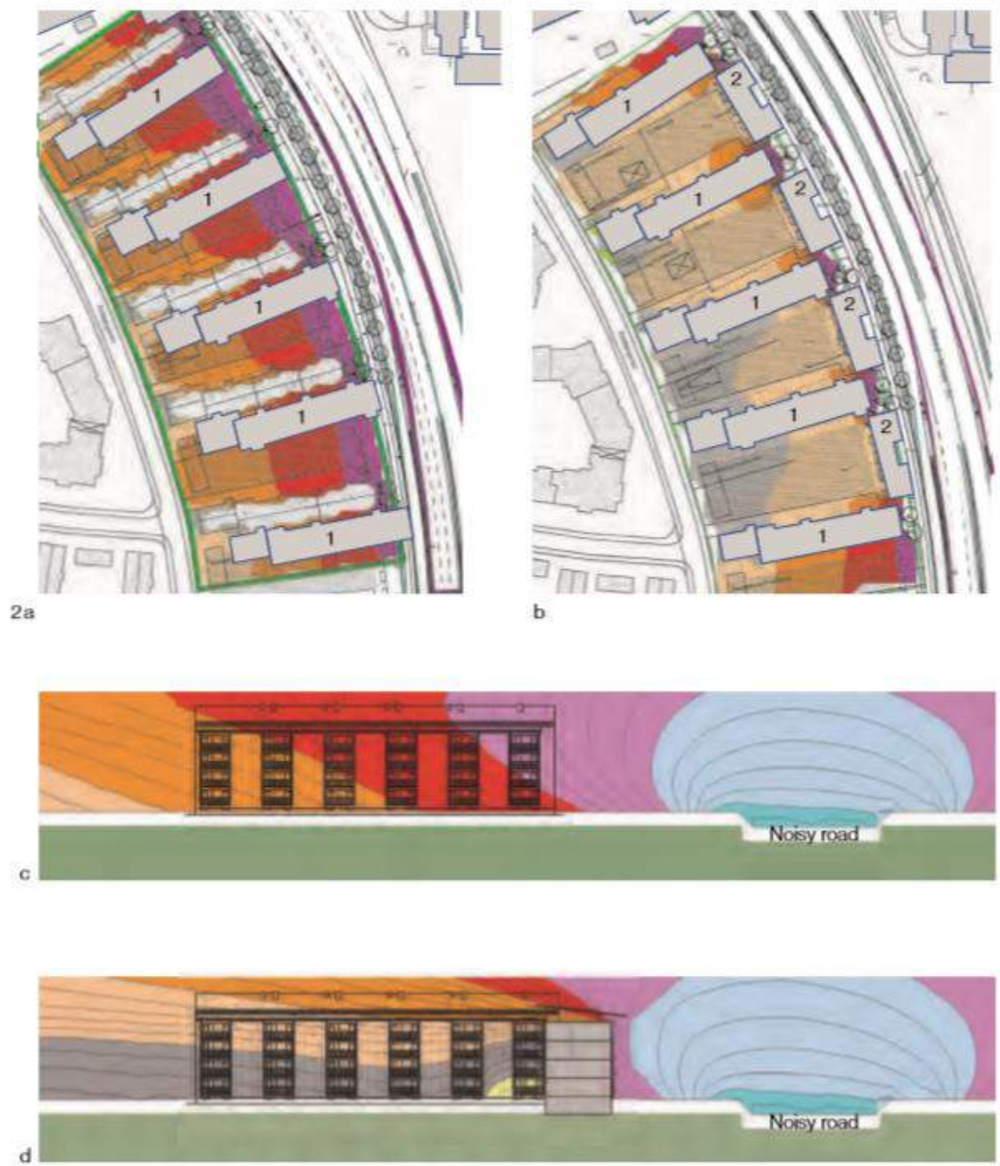


FIGURE 7-4 An estimation of the effectiveness of a traffic barrier in terms of sound (or noise) attenuation as a function of frequency and barrier height. (*Rettinger*.)

Insulation against environmental noise starts with urban design



Case of glass facade designed as a noise barrier for protecting facade of offices and atrium

München

Green facades are also good noise absorbers

Reverberation time is lower and consequently also noise disturbance is lower

7. Sound insulation against vibrations

Testing / verification:

- **Destructive** (during the measurements with load, collapse of specimen is caused)
- **Non-destructive** (the measurement does not cause the collapse of specimen)

For the measurement of sound insulation and vibration only non-destructive testing / verification is used, which is divided into:

- **Systematic** – (measurements on an integrated system, without any additional ˝load˝)
- **Signal** – (measurements with additional load – sound or vibration signal)

Mathematical model of single degree vibrations

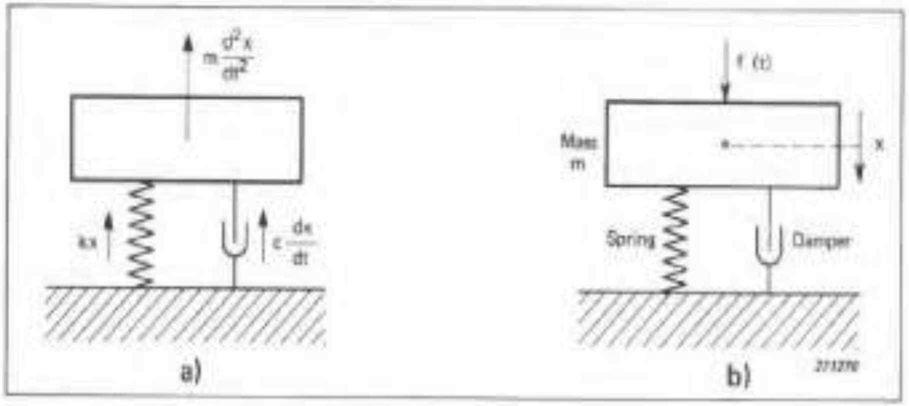


Fig.3.1. Models of a single degree-of-freedom system
a) System in free vibrations
b) System in forced vibrations

Simplified mechanical system representing human body

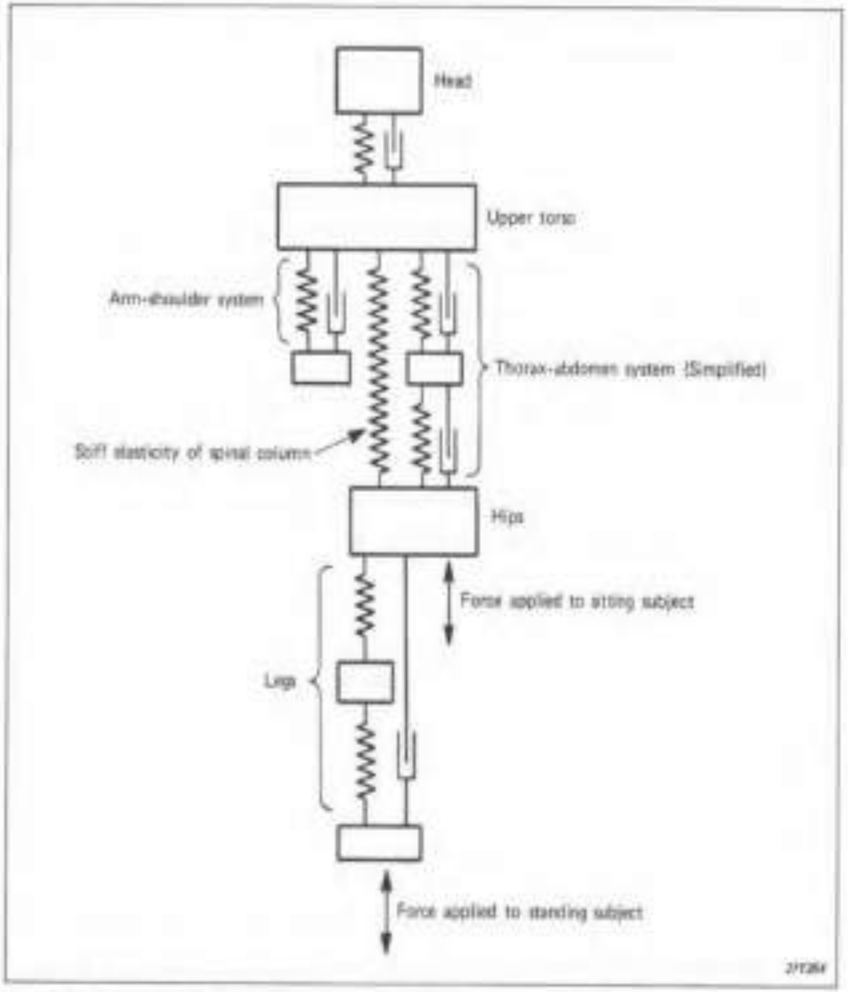
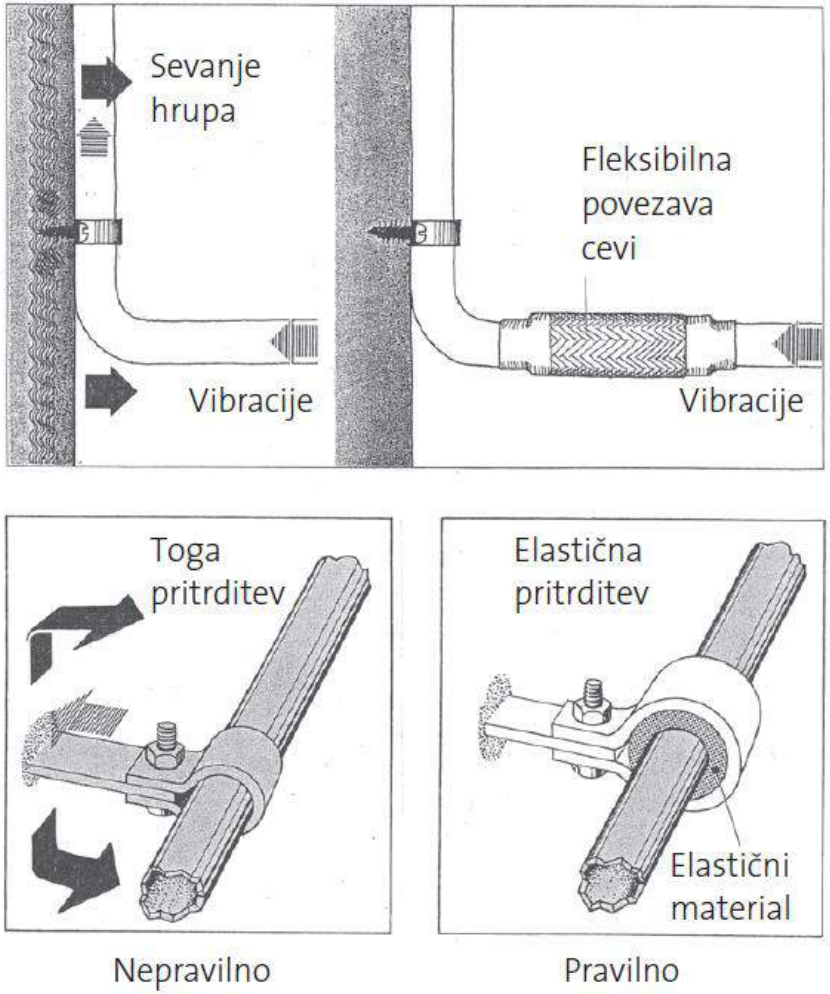


Fig.5.1. Simplified mechanical system representing the human body standing on a vertically vibrating platform. (After Coerman et al.)

Schematic presentation of vibration transfer between constructions and installations or operation equipment (Slovenian technical guidelines for noise protection in buildings)



Risba 7: Načini pritrditve cevi za vodo na gradbeno konstrukcijo z namenom zmanjšanja hrupa zaradi neposrednega vzbujanja gradbene konstrukcije

Attenuation of vibration at 50 Hz along human body of (A) hand and (B) feet platform

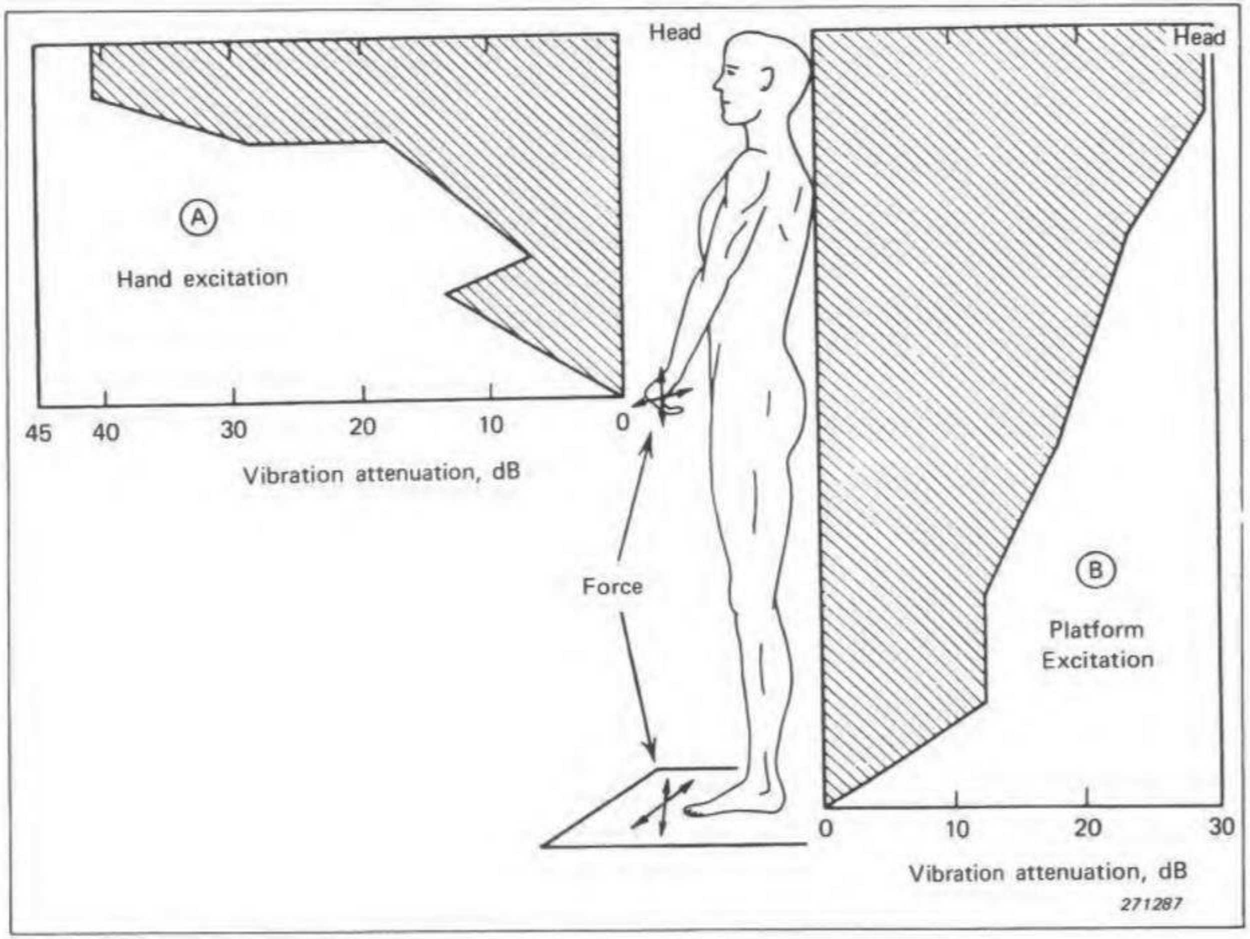
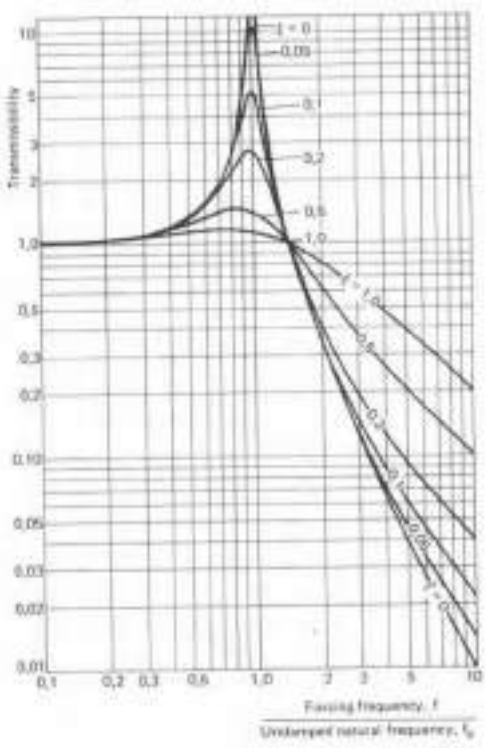


Fig.5.4. Attenuation of vibration at 50 Hz along human body. The attenuation is expressed in decibels below values at the point of excitation. For excitation of (A) hand, and (B) platform on which subject stands. (After von Bekesy)

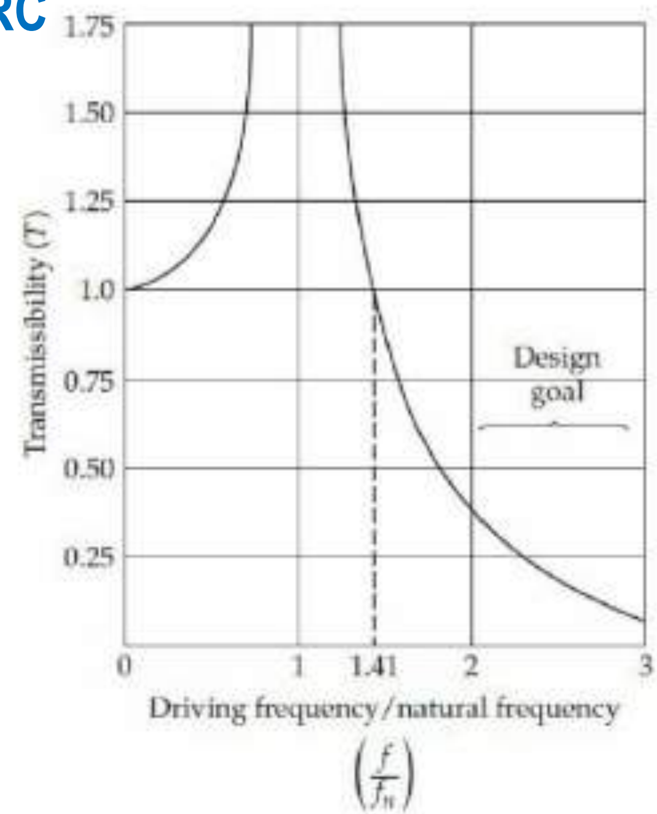
Damping of vibrations

Vibration damping is effective only so far as system's own resonant frequency is much lower than the frequency of the forcing vibration:

$$F_{RES} \leq f_{FORC} / \sqrt{2} = 0.707 \; f_{FORC}$$



Curves showing the absolute transmissibility as a function of the frequency ratio f/f_n for various damping ratios



Graph of transmissibility versus frequency ratio.

Reverberation testing room: diffusors, low frequency absorbers, microphones, noise source (loudspeakers in all directions)

Industrial fan – ventilator is prepared for testing

Vibration measurements: equipment and aims

PRODUCT DATA

General-purpose Triaxial CCLD Accelerometers with TEDS
Type 4535-B and 4535-B-001

Triaxial CCLD Accelerometers with TEDS† Type 4535-B and 4535-B-001 are designed to simplify your testing by covering most of the different needs of a modern test lab with one sensor. Their wide frequency range from 0.3 Hz to 10 kHz and light weight make them excellent general purpose triaxial accelerometers. When only a single- or bi-axis measurement is needed at a location, the small size and possibility of single axis powering supply make Types 4535-B and 4535-B-001 the right choice. TEDS function and the mounting possibilities with an NO slot speed test setup.*

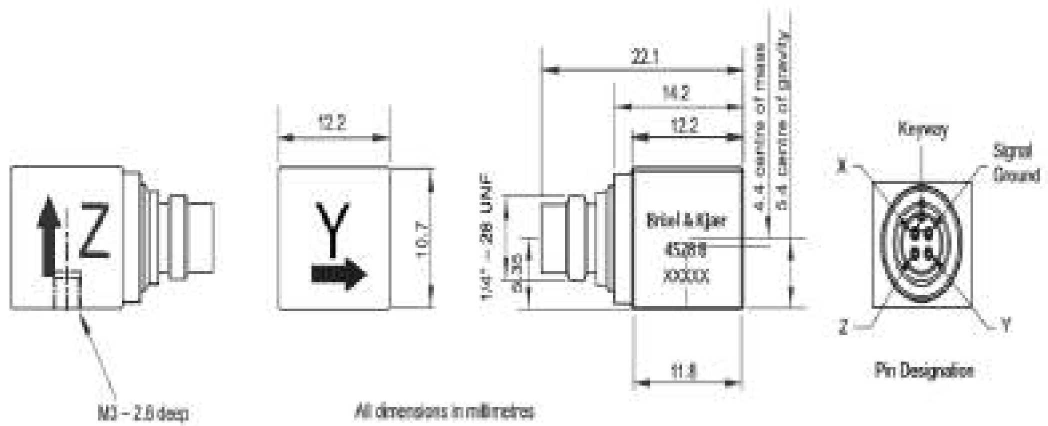
Uses and Features

Uses
- General purpose
- Structural testing
- Automotive body and power train measurements
- Acoustic fatigue testing
- Triaxial measurements in confined space

Features
- Single axis supply makes single- or bi-axial measurement possible to save channels
- Wide frequency range from 0.3 Hz to 10 kHz on all three axes
- Low noise for structural testing
- Possibility for clip mounting with an adaptor speeds test setup
- Titanium construction
- Hermetically sealed
- Transducer Electronic Data Sheet (TEDS) function save the test setup time

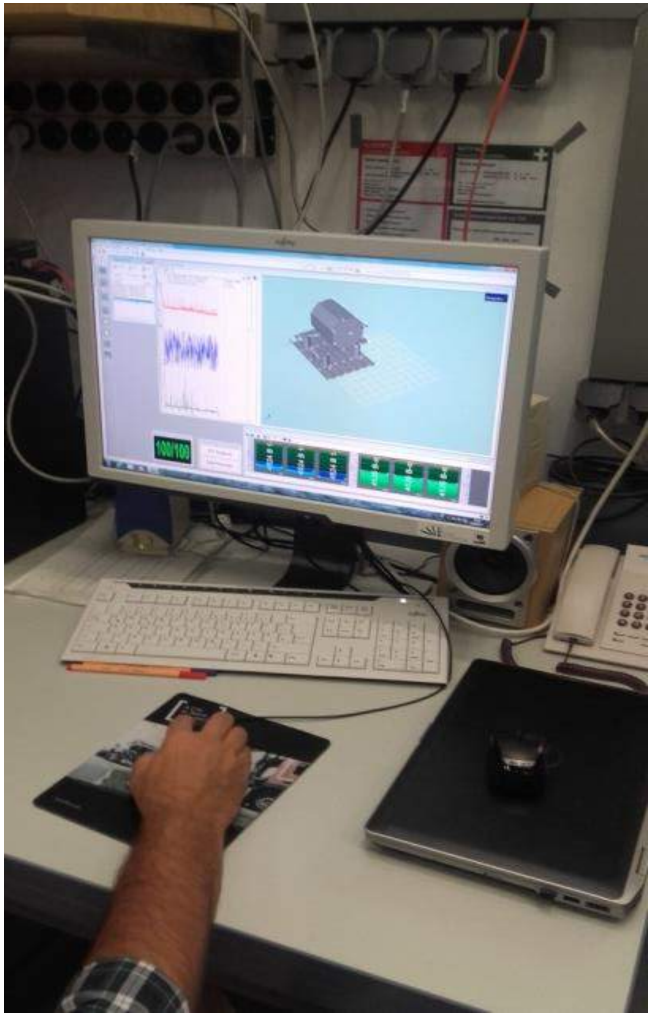
Bruel & Kjaer , Type 4525 B, Triaxial Accelometer, Serial no. 55911

Fig. 3 Physical dimensions and axis orientations of Type 4528-B (also applicable to Type 4528-B-001)



Bruel & Kjaer , Type 7533, LAN Interface Model, Ser.no. 4202202

Bruel & Kjaer , Working with computer program PULSE



Industrial fan – Witt & Sohn –Technical data

Ziehl – Abegg, Type RH 35 F, industrial fan

WITT&SOHN Ventilatoren

Maximal zulässige Lüfterschwingungen gemäß ISO 14694 / ISO 10816-3
Max. allowed fan vibrations according ISO 14694 / ISO 10816-3

Zusammenfassung

Es gibt zwei internationale Standards, welche die Auswuchtgüte und die Schwingwerte von Industrie-Ventilatoren festlegen. In der nachfolgenden Liste werden alle wichtigen Eckdaten für die von WITT & SOHN gefertigten Ventilatoren ausgeführt.

(Der Vergleich von Messwerten über einen längeren Zeitraum hinweg ist sehr wichtig für die Bewertung von Schwingungen an installierten Lüftern: Eine plötzliche Änderung der Schwingwerte kann auf eine dringend erforderliche Inspektion/Wartung hinweisen!)

Conclusion

There are two international standards that specify the balance quality and vibration levels of industrial fans. In the list below we have bundled all relevant data for the fans manufactured by WITT & SOHN

(Historical data is an important factor when considering the vibration severity of any fan installation: A sudden change in the vibration level may indicate the need of prompt inspection / maintenance!)

Tabelle I: Schwingwerte bis zur Inbetriebnahme / **Table I: Vibrations before and at commissioning**

				max. zul. Schwinggeschwindigkeit (Effektivwert) / max. allowed vibration levels (r.m.s.)			
				Auslieferungszustand / in manufacturers shop		Bei Inbetriebnahme / at commissioning	
Lüftertyp / Leistung	Norm	Lüfter-Klasse	min. Auswuchtgüte	fest montiert	flexibel aufgestellt	fest montiert	flexibel aufgestellt
fan type / power	standard	fan application category	min. balance quality	rigidly mounted	flexible mounted	rigidly mounted	flexible mounted
[-/kW]	[-]	[-]	[-]	[mm/s]	[mm/s]	[mm/s]	[mm/s]
alle Lüfter, all fans < 75kW	ISO 14694	BV-3	G 6,3	2,8	3,5	4,5	6,3
Industrielüfter, industrial fans 75 - 300kW	ISO 14694	BV-3	G 6,3	2,8	3,5	4,5	6,3
Tunnellüfter, tunnel fans 75 - 300kW	ISO 14694	BV-4	G 2,5	1,8	2,8	2,8	4,5
alle Lüfter, all fans > 300kW	ISO 10816-3	Gruppe 1	G 2,5	2,3	3,5	4,5	7,1

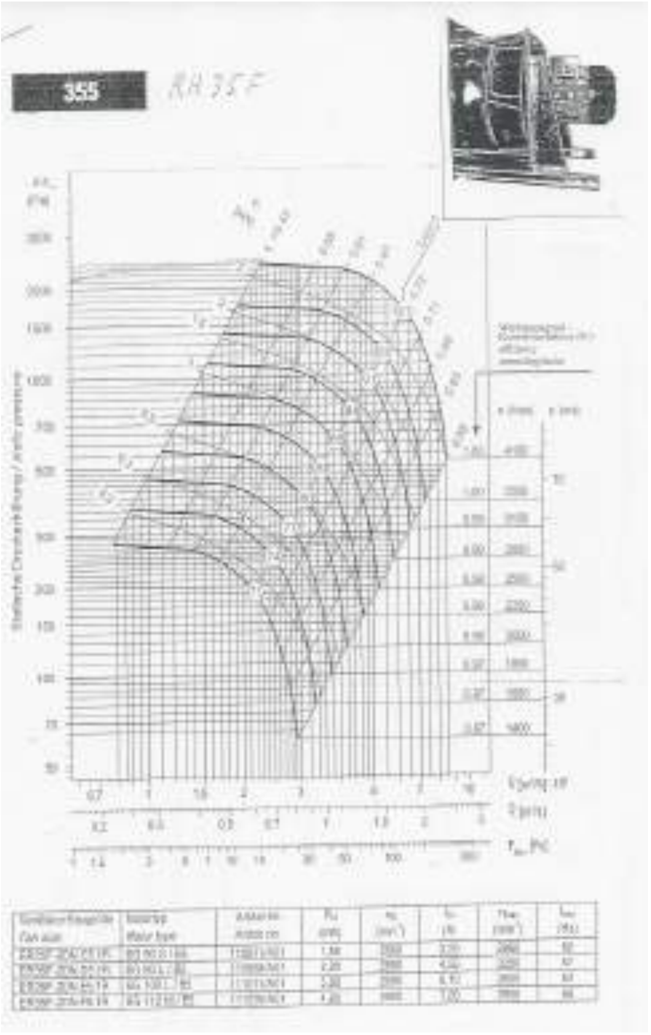
Tabelle II: Schwingwerte nach Inbetriebnahme / **Table II: Vibrations after commissioning**

				max. zul. Schwinggeschwindigkeit (Effektivwert) / max. allowed vibration levels (r.m.s.)			
				Alarm / alarm		Abschalten / shutdown	
Lüfter / Leistung	Norm	Lüfter-Klasse	min. Auswuchtgüte	fest montiert	flexibel aufgestellt	fest montiert	flexibel aufgestellt
fan / power	standard	fan application category	min. balance quality	rigidly mounted	flexible mounted	rigidly mounted	flexible mounted
[-/kW]	[-]	[-]	[-]	[mm/s]	[mm/s]	[mm/s]	[mm/s]
alle Lüfter, all fans < 75kW	ISO 14694	BV-3	G 6,3	7,1	11,8 *)	9,0	12,5
Industrielüfter, industrial fans 75 - 300kW	ISO 14694	BV-3	G 6,3	7,1	11,8 *)	9,0	12,5
Tunnellüfter, tunnel fans 75 - 300kW	ISO 14694	BV-4	G 2,5	4,5	7,1	7,1	11,2
alle Lüfter, all fans > 300kW	ISO 10816-3	Gruppe 1	G 2,5	5,6	8,2	8,9	13,8

*) WITT & SOHN empfiehlt diese Werte auf 9,0 mm/s einzustellen / WITT & SOHN recommend to set these levels at 9,0 mm/s

Schwingwerte werden an den Lagern des Motors / Blocklagers gemessen. Nur wenn diese nicht zugänglich sind, dann wird wie folgt gemessen (hier können aber höhere Werte auftreten !):

Vibration levels are measured on the bearing of the motor / block bearing installed on the fan. Only if the bearings are not accessible measure as follows (then higher levels may occur !) :



Schematic model of vibration measurements of industrial fan

Standard **ISO FDIS 14694** (speed of vibration is limited to maximum peak value of 19.1 m/s and RMS value of speed to 14.0 m/s in all three directions of vibration movement). Our measurements are assumed X-axis in the direction of the rotation axes, perpendicular and horizontal is Y-axis and vertical is Z-axis

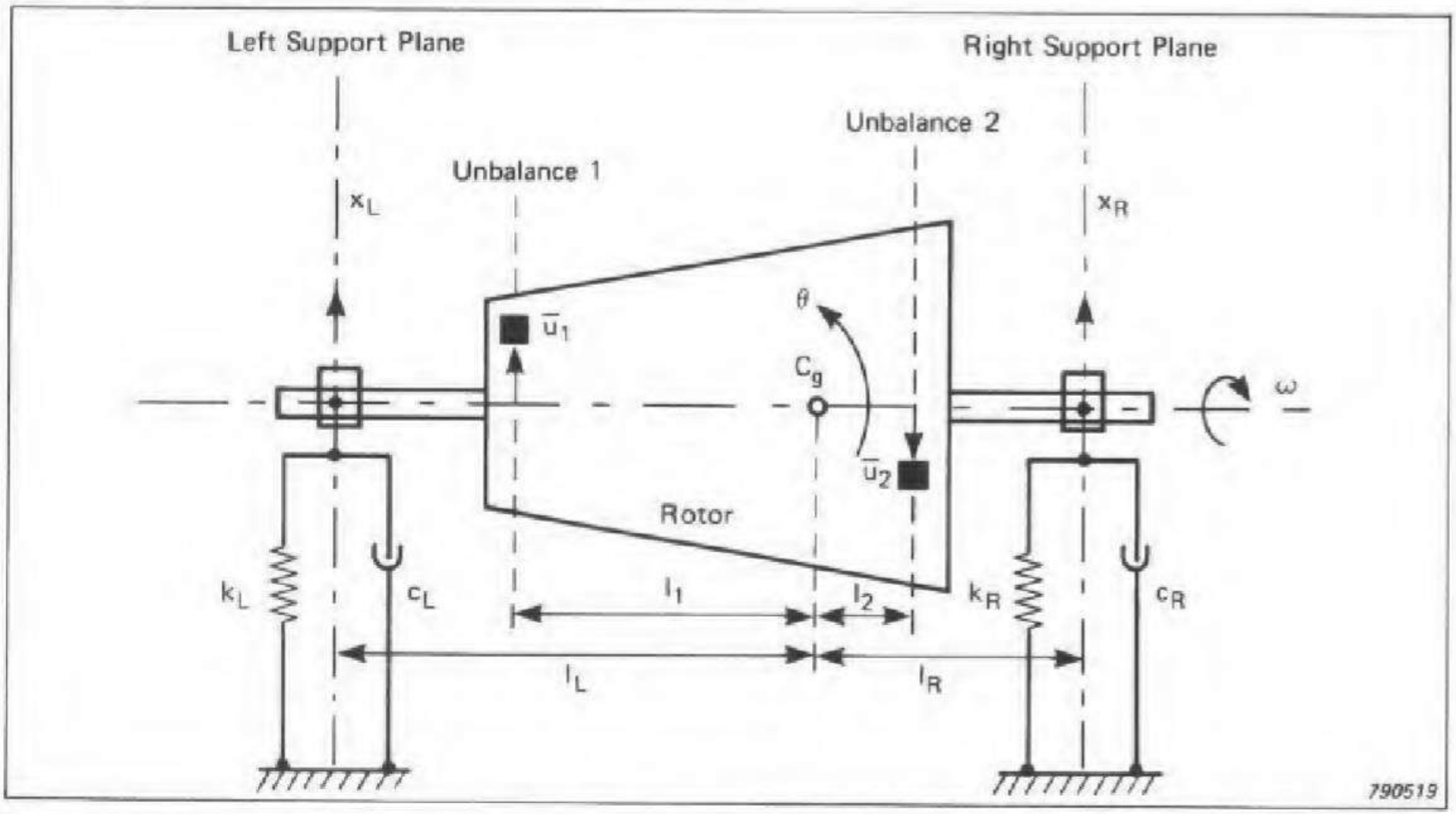
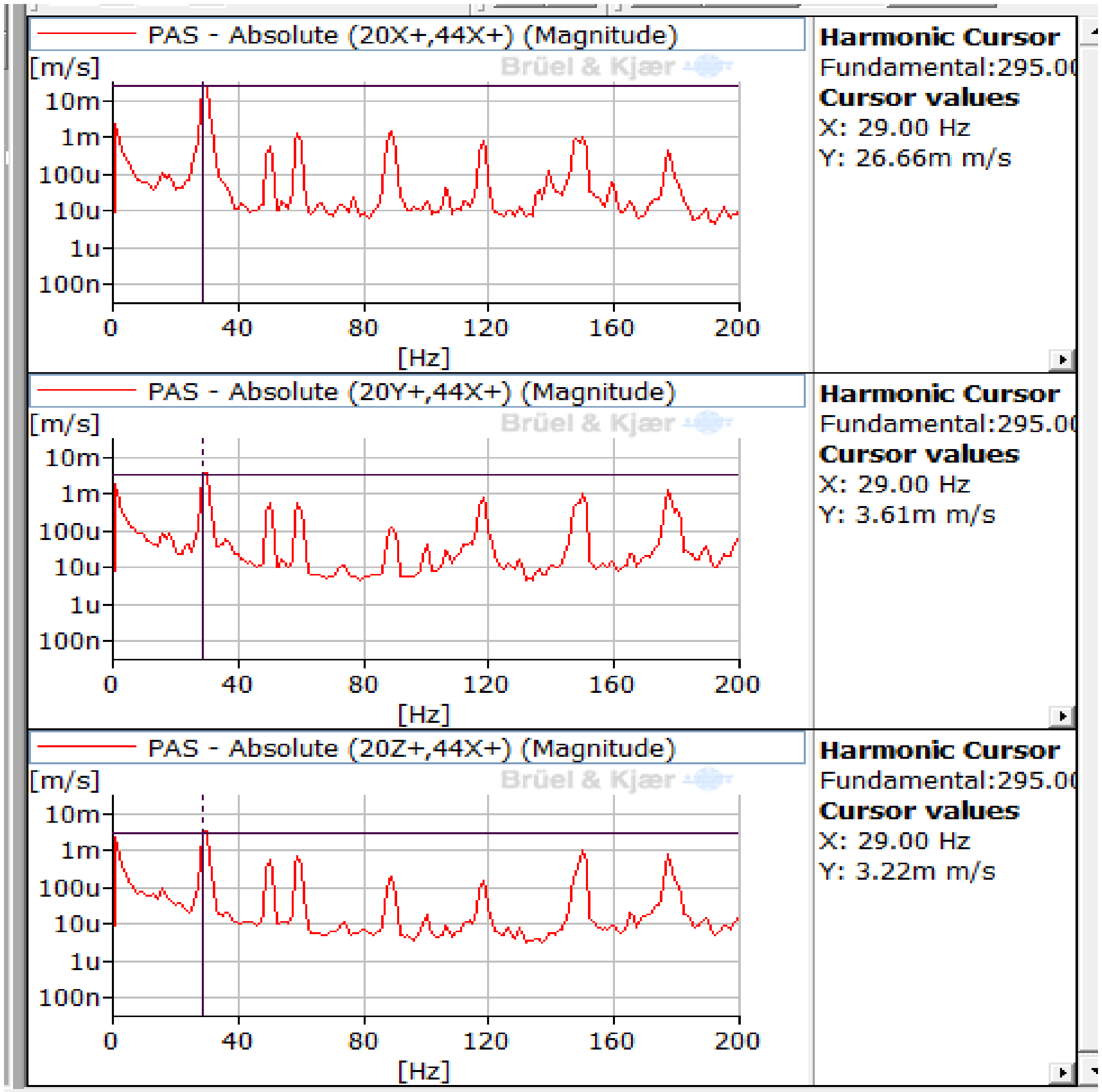
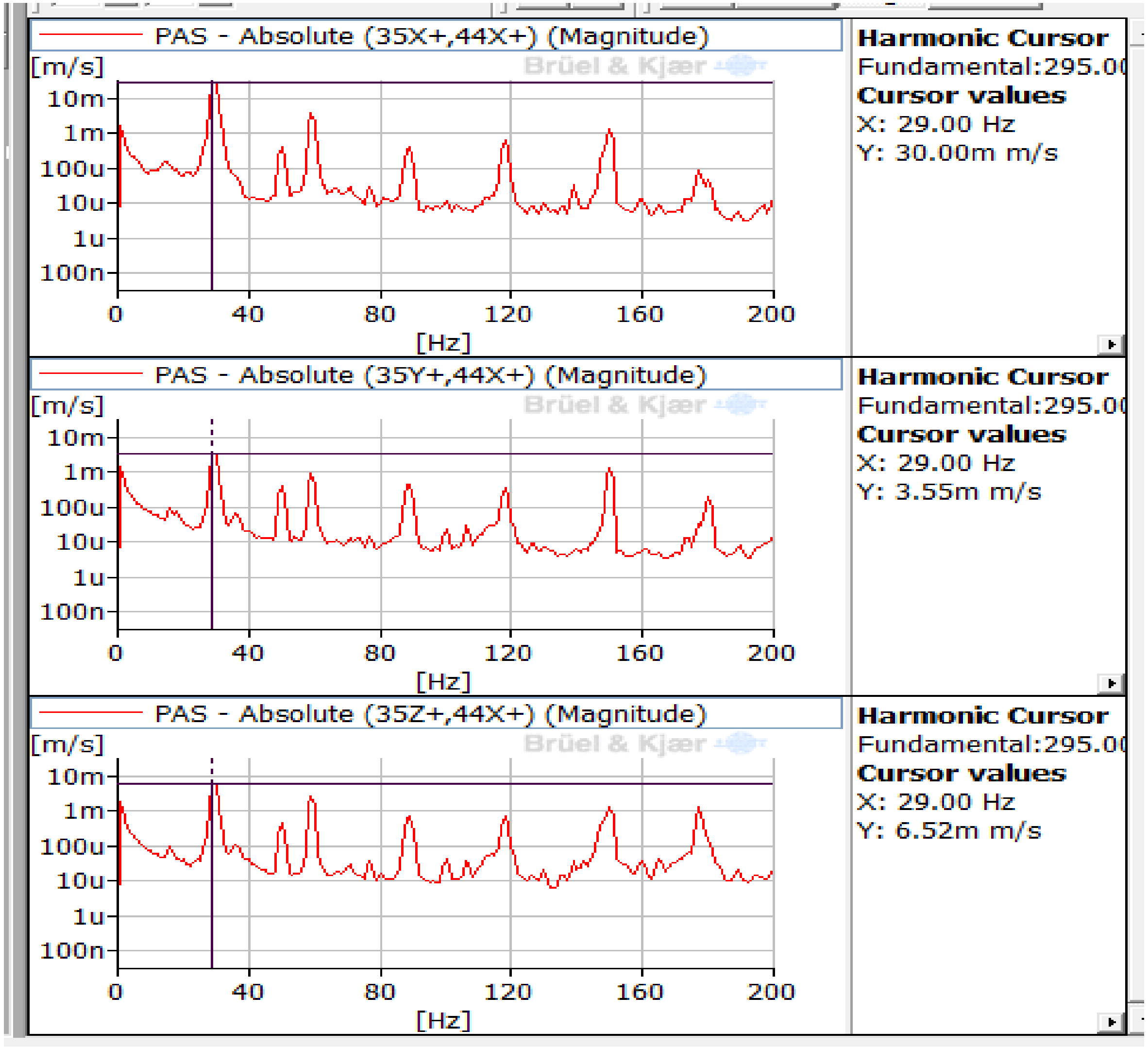


Fig. 11.3. Unbalance of a rotating body vibrating with two degrees of freedom x, θ

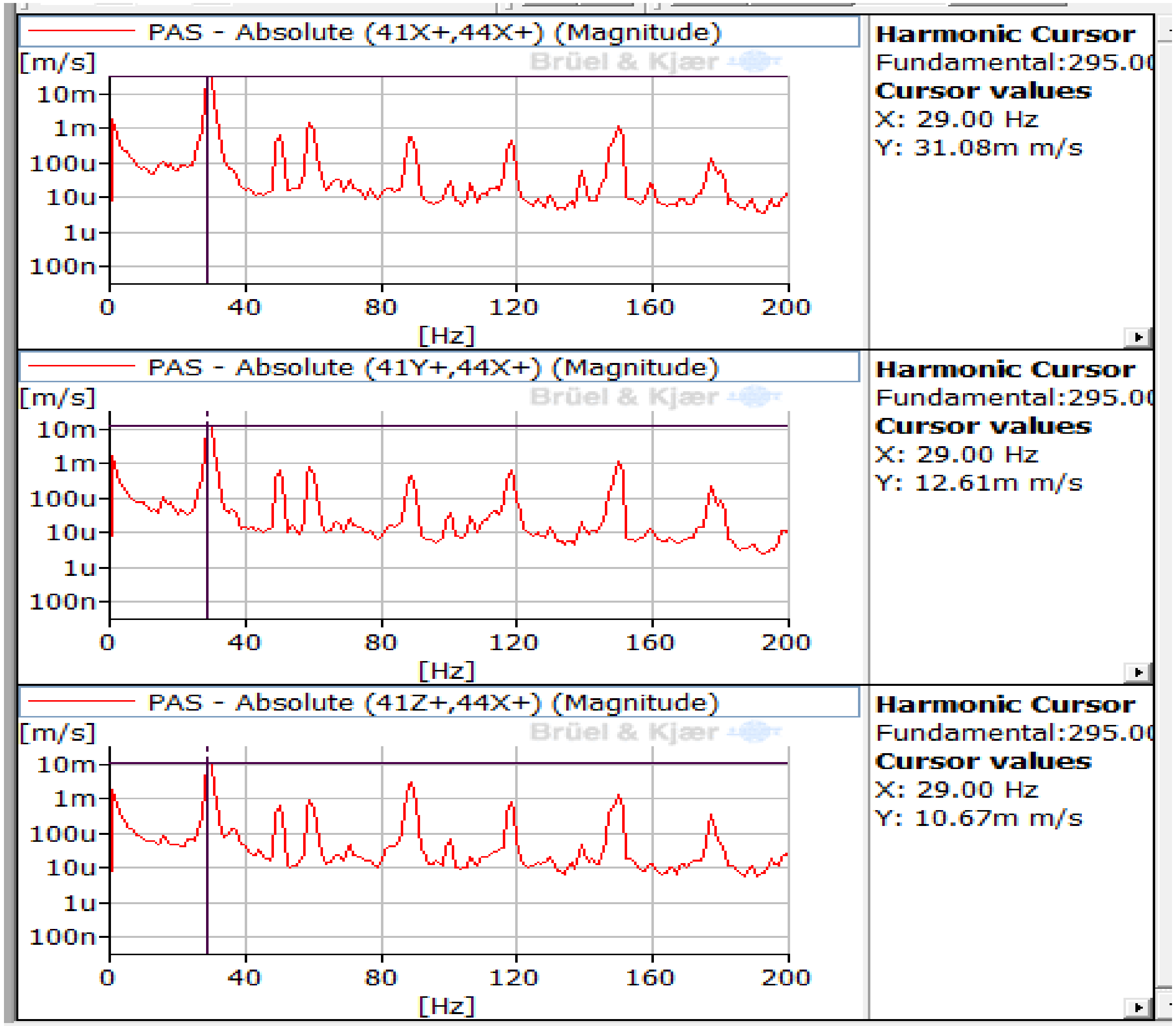
Measurement point 20, velocity in X direction is higher than allowed value, i.e. 26.66 m/s (according to Standard ISO FDIS 14694, where velocities up to peak values of 19.1m/s or RMS up to 14.0m/s are allowed). Velocities in Y and Z directions are bellow allowed limits



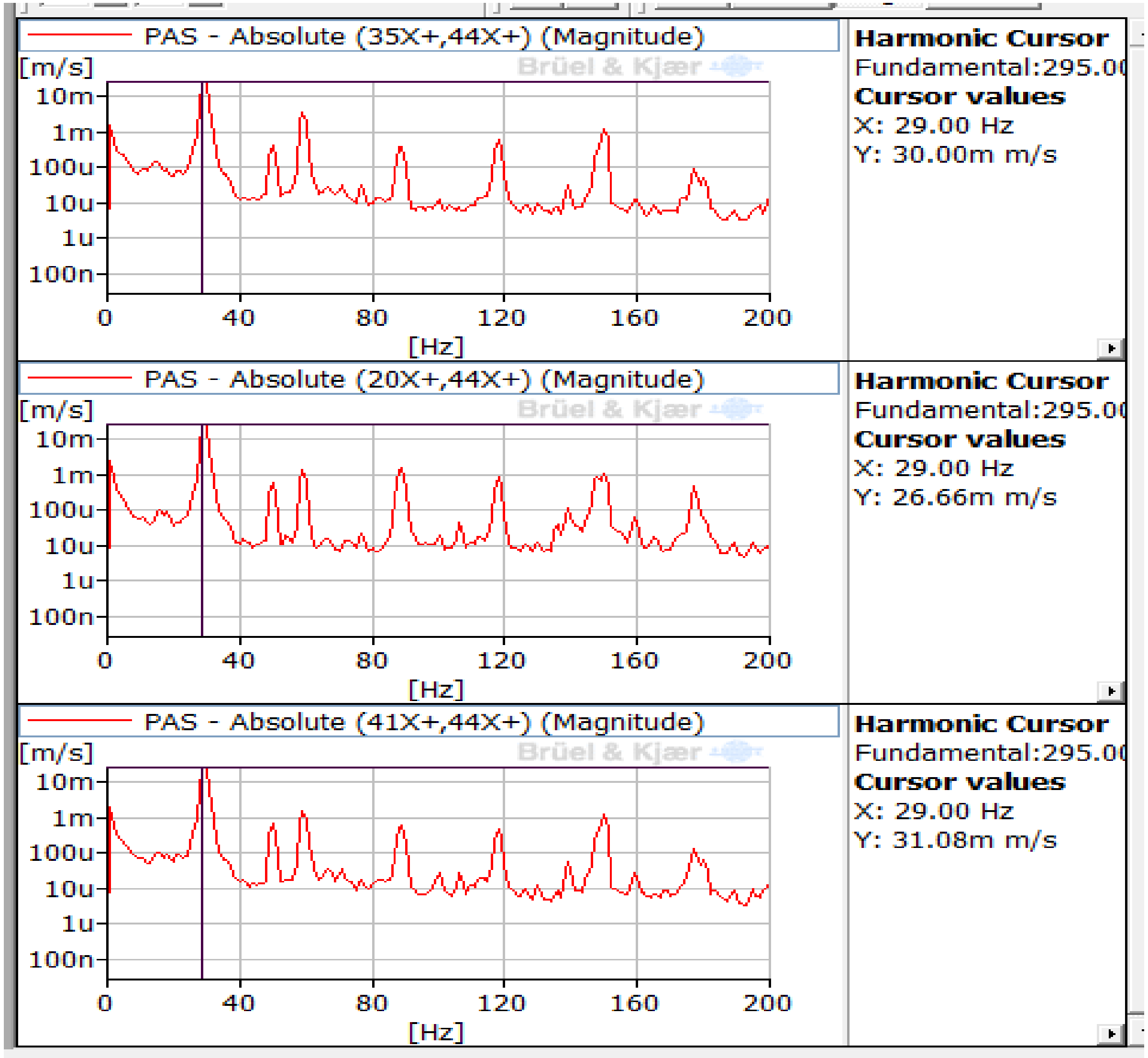
Measurement point 35, velocity in X direction is higher than allowed value, i.e. 30.00 m/s (according to Standard ISO FDIS 14694, where velocities up to peak values of 19.1m/s or RMS up to 14.0m/s are allowed). Velocities in Y and Z directions are bellow allowed limits



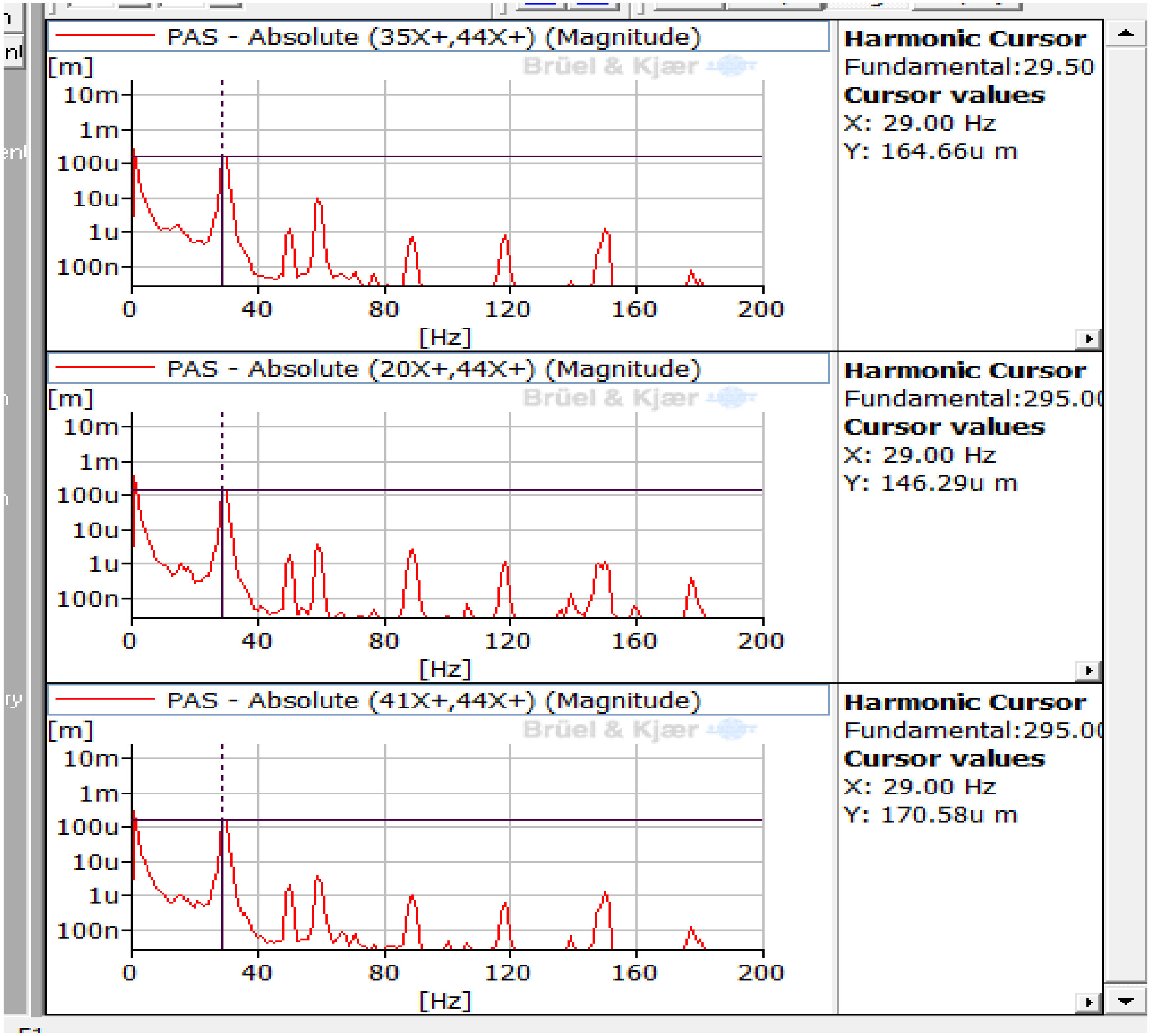
Measurement point 41, velocity in X direction is higher than allowed value, i.e. 31.08 m/s (according to Standard ISO FDIS 14694, where velocities up to peak values of 19.1m/s or RMS up to 14.0m/s are allowed). Velocities in Y and Z directions are bellow allowed limits



Measurement points 35, 20 in 41 only in X direction, velocities of values 30.00, 26.66 and 31.08 m/s are too high (above allowed limits according to Standard ISO FDIS 14694, where velocities up to peak values of 19.1m/s or RMS up to 14.0m/s are allowed).



Displacement of measurements points 35, 20 and 41 (μm)



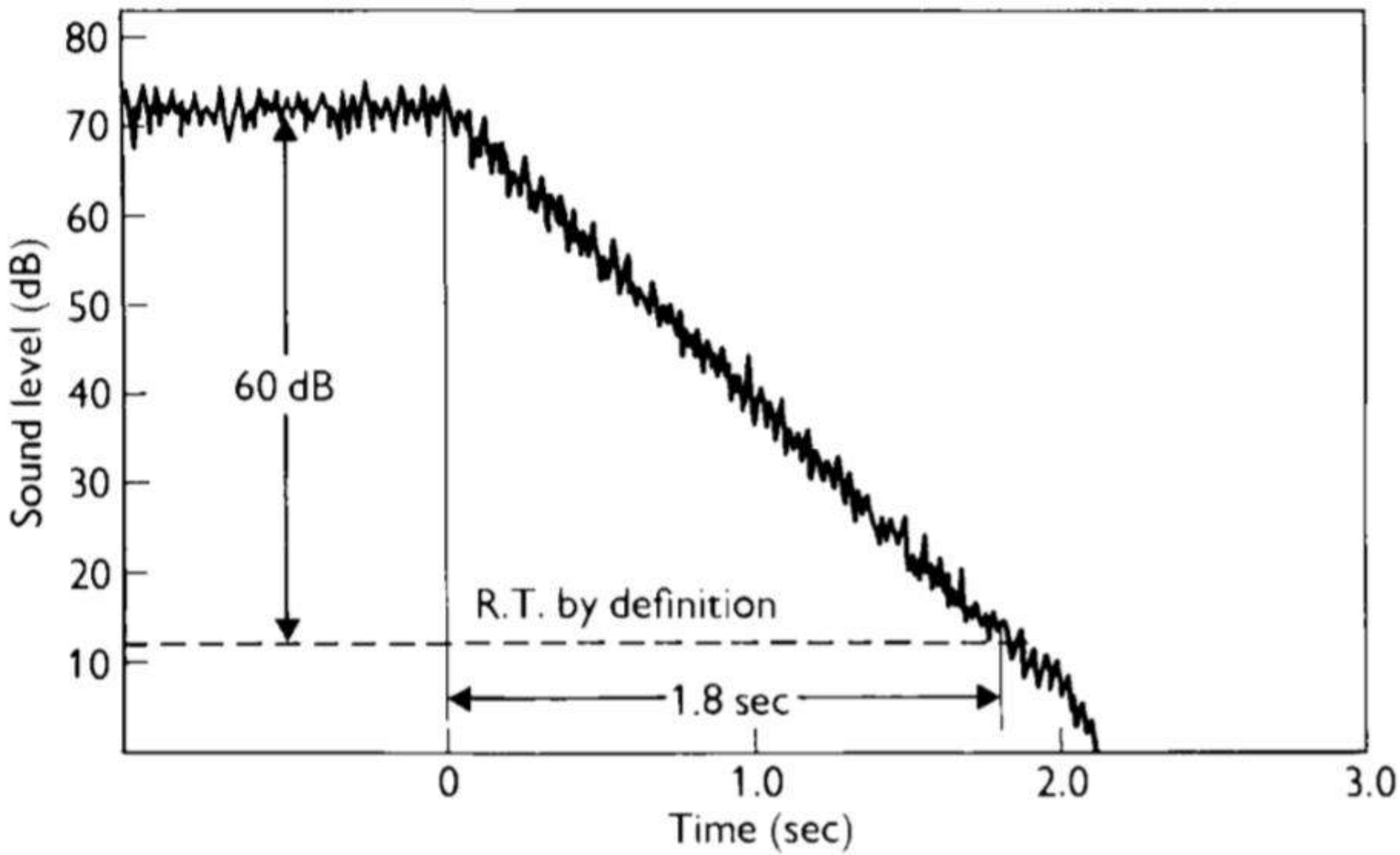
Measurements of vibrations of industrial fan

Vibration limits for tests of industrial fan - Ziehl – Abegg, Type RH 35 F				
According to ISO FDS 14694 – Industrial fans – Specifications for balance quality and vibration levels Category BV2 – peak velocity value = max. 19.1 mm/s and r.m.s. velocity value = max. 14.0 m/s				
Point	Direction	Velocity (mm / s)	True or false	Displacement (mm)
Point 20	X	26.66	NOT O.K.	0.141
	Y	3.61	O.K.	0.019
	Z	3.22	O.K.	0.017
Point 35	X	30.00	NOT O.K.	0.158
	Y	3.55	O.K.	0.019
	Z	6.52	O.K.	0.035
Point 41	X	31.08	NOT O.K.	0.170
	Y	12.61	O.K.	0.069
	Z	10.67	O.K.	0.059

Vibration limits for tests of industrial fan - Ziehl – Abegg, Type RH 35 F
According to ISO FDS 14694 – Industrial fans – Specifications for balance quality and vibration levels Category BV2 – peak velocity value = max. 19.1 mm/s and r.m.s. velocity value = max. 14.0 m/s

Bruel & Kjaer PULSE LabShop file	Point	Direction	Velocity (mm/s)	True or false
AirCon 2 27Hz post analysis 2015 09 25 v1	99	X	3.03	O.K.
	99	X	3.89	O.K.
AirCon 2015 09 04 v11 system post analysis 2015 09 25 v1	35	X	13.03	O.K.
	20	X	0.102	O.K.
	41	X	0.472	O.K.
AirCon 3 29,5Hz post analysis 2015 09 25 v1	92	X	36.88	NOT O.K.
	92	Y	4.02	O.K.
	92	Z	5.51	O.K.
AirCon 4 30Hz post analysis 2015 09 25 v1	92	X	26.82	NOT O.K.
	92	Y	3.25	O.K.
	92	Z	3.25	O.K.
AirCon 5 30Hz Motor post analysis 2015 09 25 v1	92	X	26.82	NOT O.K.
	92	Y	3.25	O.K.
	92	Z	3.25	O.K.
AirCon 5 30Hz Motor 2 post analysis 2015 09 25 v1	92	X	26.98	NOT O.K.
	92	Y	3.24	O.K.
	92	Z	3.26	O.K.
AirCon 5 30Hz Motor 3 post analysis 2015 09 25 v1	92	X	94.85	NOT O.K.
	92	Y	0.10	O.K.
	92	Z	0.10	O.K.
AirCon 5 30Hz Motor 4 post analysis 2015 09 25 v1	92	X	94.85	NOT O.K.
	92	Y	0.10	O.K.
	92	Z	0.10	O.K.
AirCon 2015 09 04 v10 post analysis 2015 09 25 v1	20	X	26.66	NOT O.K.
	20	Y	3.61	O.K.
	20	Z	3.22	O.K.
AirCon 2015 09 04 v10 post analysis 2015 09 25 v2	35	X	30.00	NOT O.K.
	20	X	26.66	NOT O.K.
	41	X	31.08	NOT O.K.

9. Acoustics of interior space (reverberation noise)



Reverberation time TR_{60} (s)

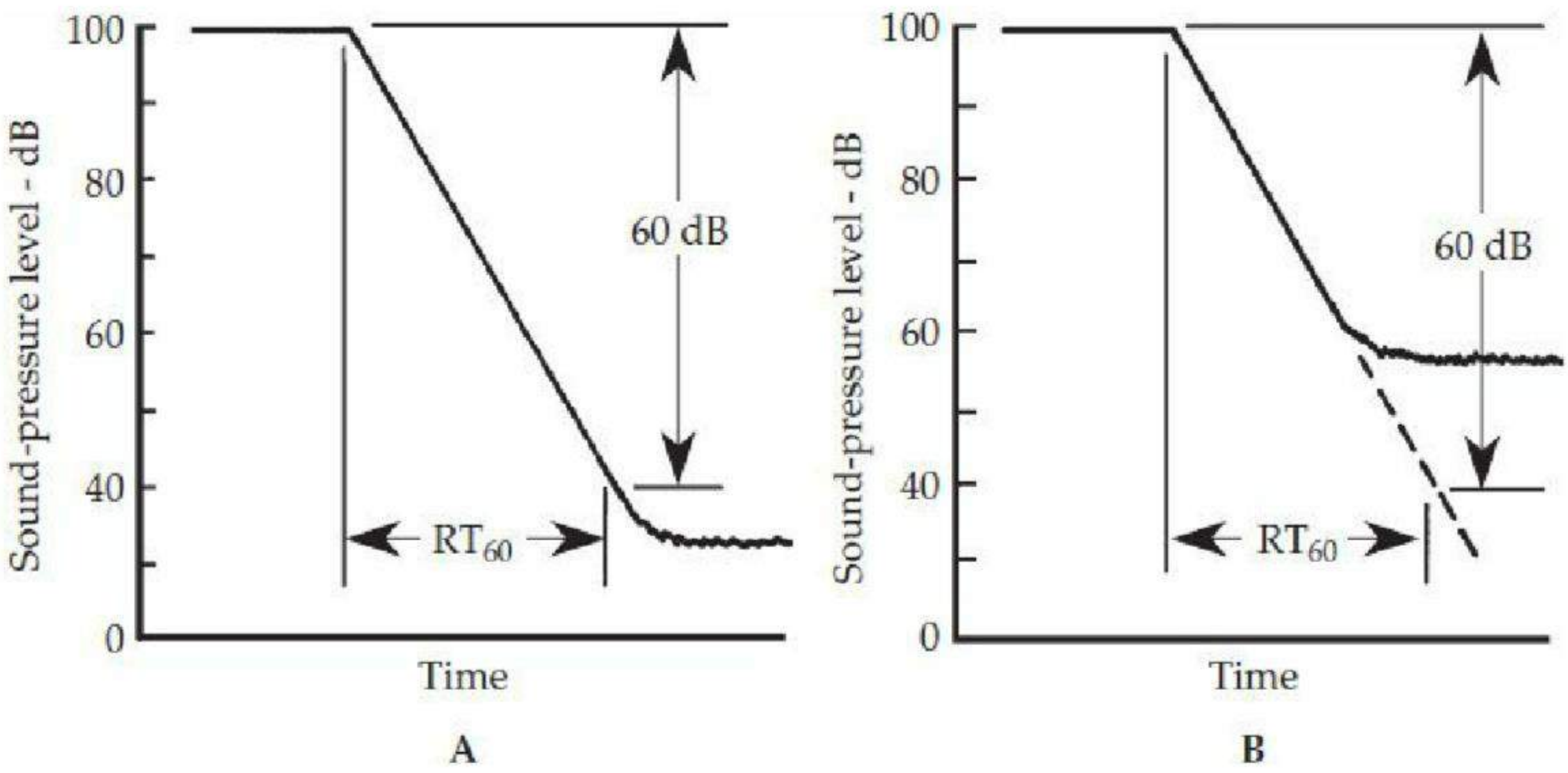


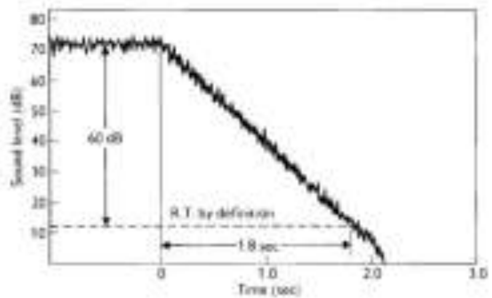
FIGURE 11-3 The length of the decay trace depends on the strength of the source and the noise level. (A) An example of a full 60-dB decay. Practical circumstances rarely allow this. (B) The slope of the limited decay is extrapolated to determine the reverberation time.

Sabin equation for reverberation time of interior space (Wallace Clement Sabine, 1868-1919)

$$RT_{60} = 0.161\ V\ (m^3) / A\ (m^2) \quad (s)$$

also: $RT_{60} = (0{,}163\ V)/ (A + 4mV)$

$$A = \Sigma\, \alpha_i \times S_i \qquad (m^2)$$



V ………………… Volume (m^3)
$A = \Sigma\, \alpha_i \times S_i$ ….. Equivalent absorption area (m^2)
α_i ………………. Absorption coefficient of certain surface (-)
S_i ………………. Absorption area of certain material (m^2)
4mV ………….. Absorption of sound in the air

Eyring formula:

$$TR_{Ey} = (0{,}163\ V)/ (-S * \ln(1- \alpha_{AV}) + 4mV) \quad (s)$$

S ………… sum of all surfaces in room
α_{AV} ………average absorption coefficient of all surfaces of certain room
4mV ……. Absorption of sound in the air

Ideal values of the reverberation time in dependence on the volume of the interior space

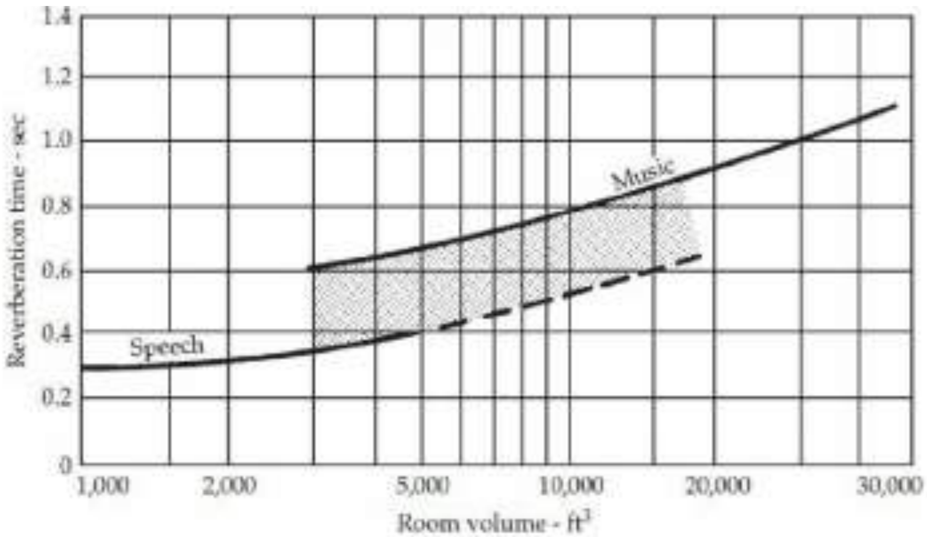
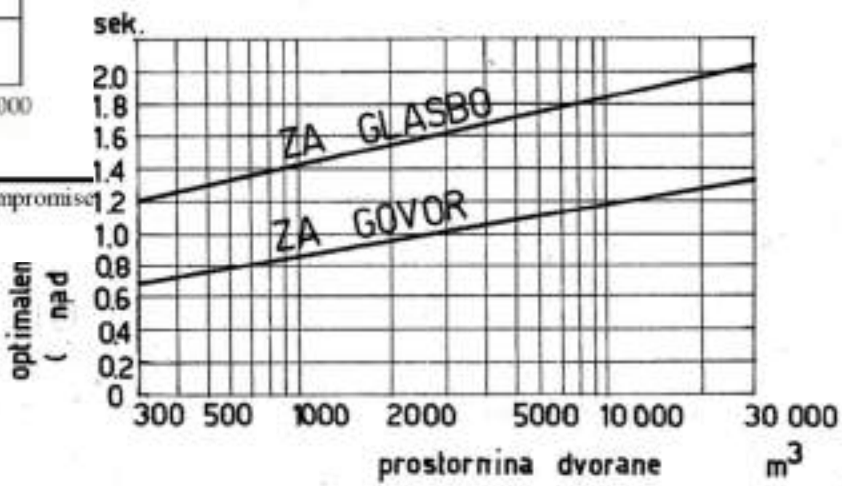
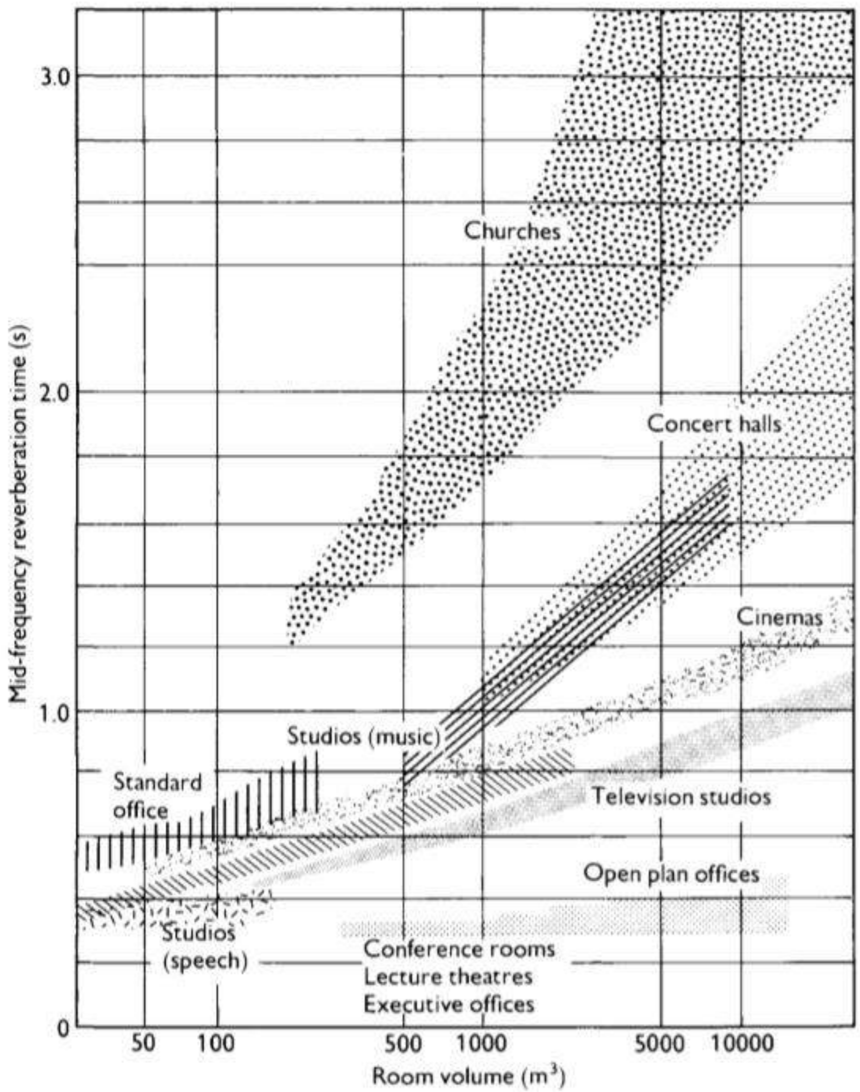
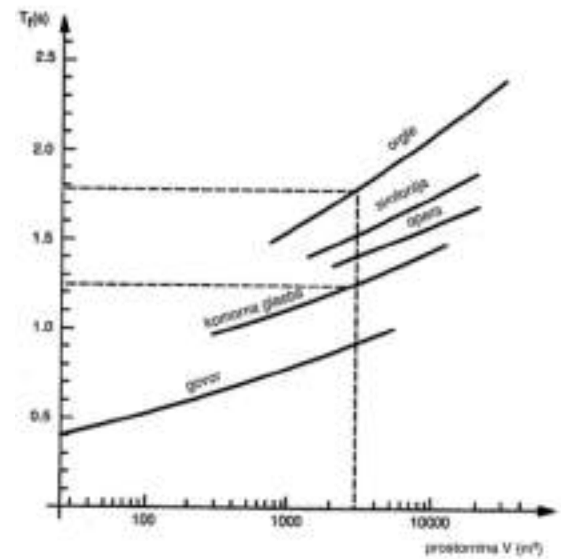


FIGURE 22-3 Suggested reverberation times for recording studios. The shaded area is a compromise region for studios in which both music and speech are recorded.



Ideal values of the reverberation time in dependence on the volume of the interior space





Odmevni čas, v odvisnosti od prostornine in vrste glasbe [03]

Ideal values of the reverberation time in dependence on the volume of the interior space or frequency of sound

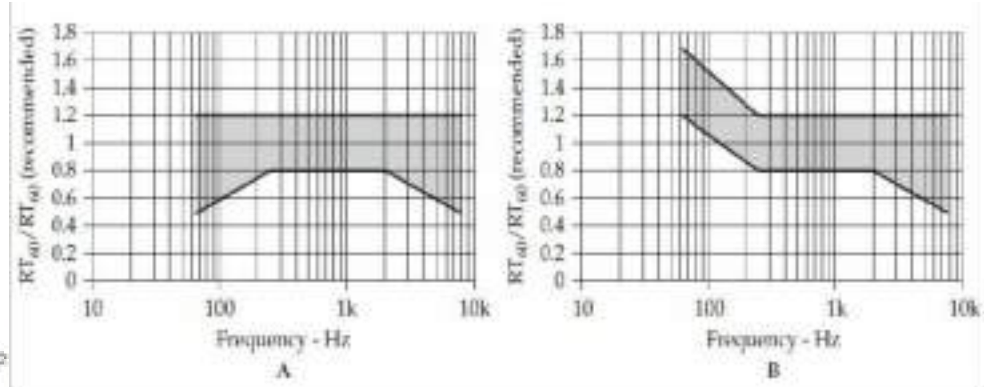
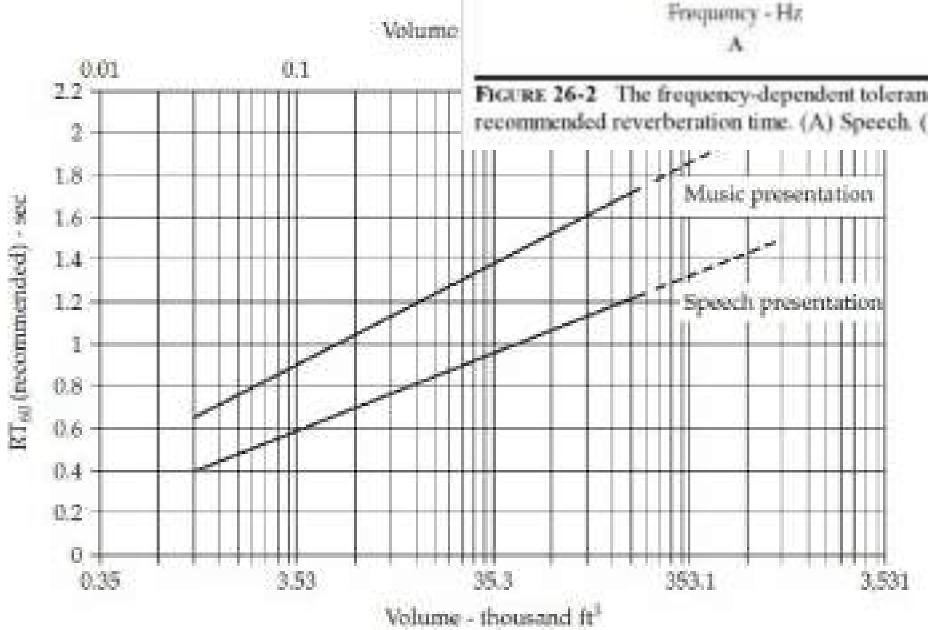
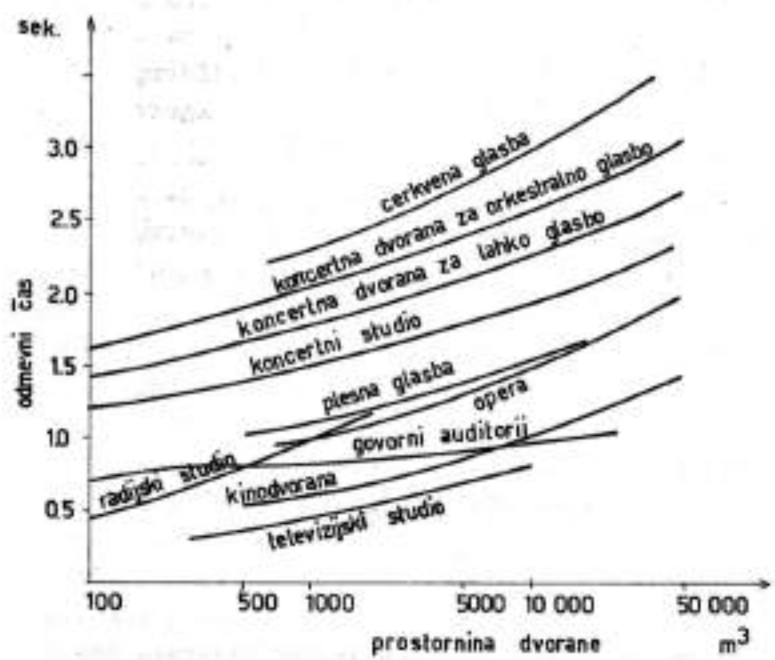


FIGURE 26-2 The frequency-dependent tolerance recommended reverberation time. (A) Speech. (B)



IGURE 26-1 The recommended mean reverberation time between 500 and 1,000 Hz, for speech nd music, with respect to room volume. (*Ahnert and Tennhardt.*)



Ideal values of the reverberation time of interior space for recording are considerably smaller (shorter reverberation time)

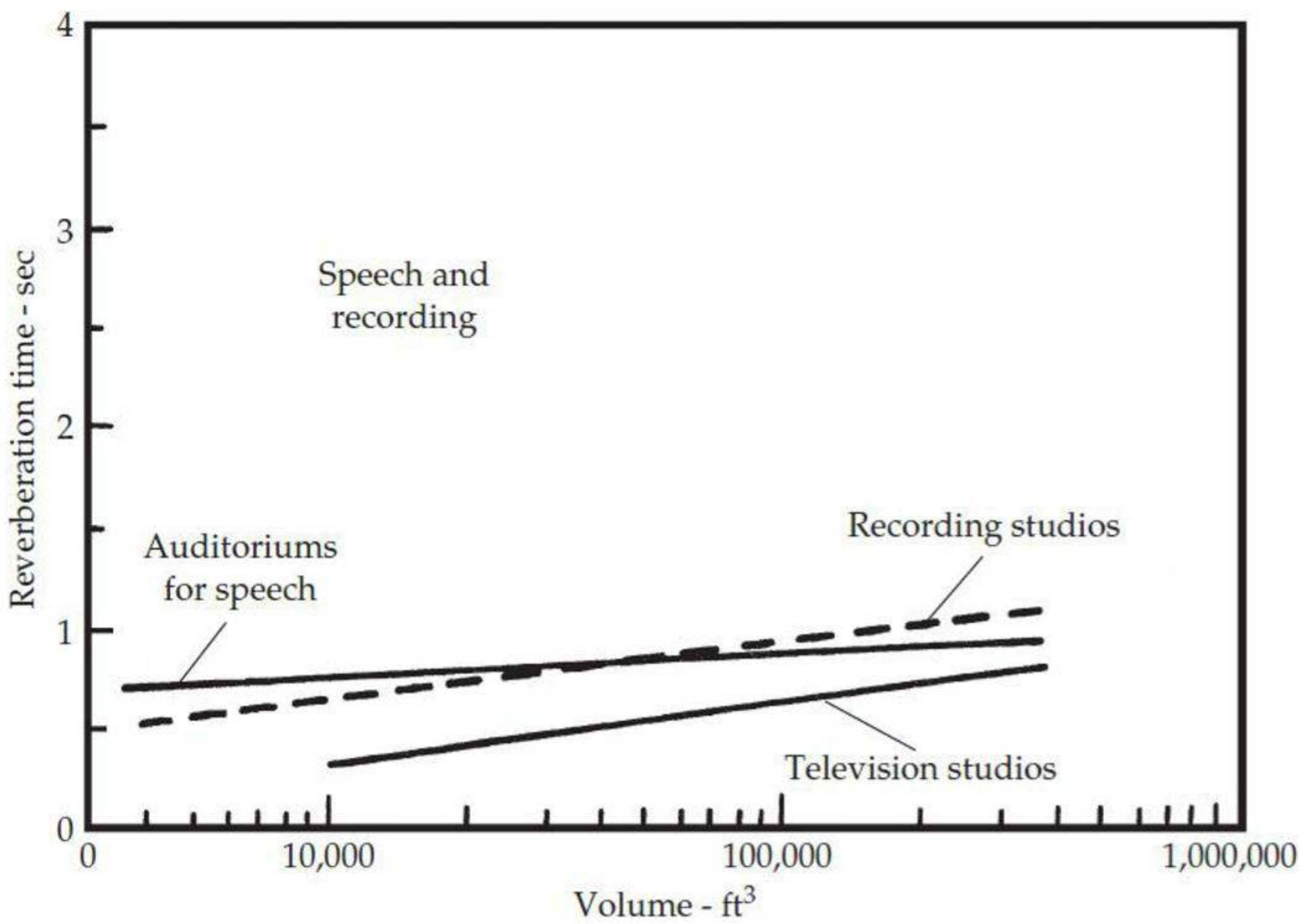
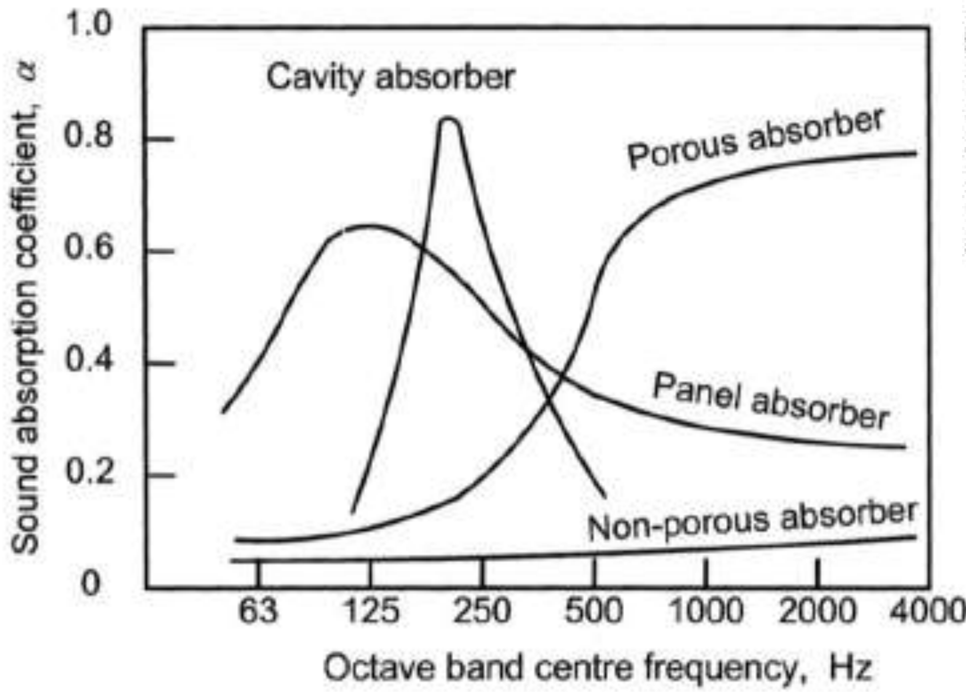
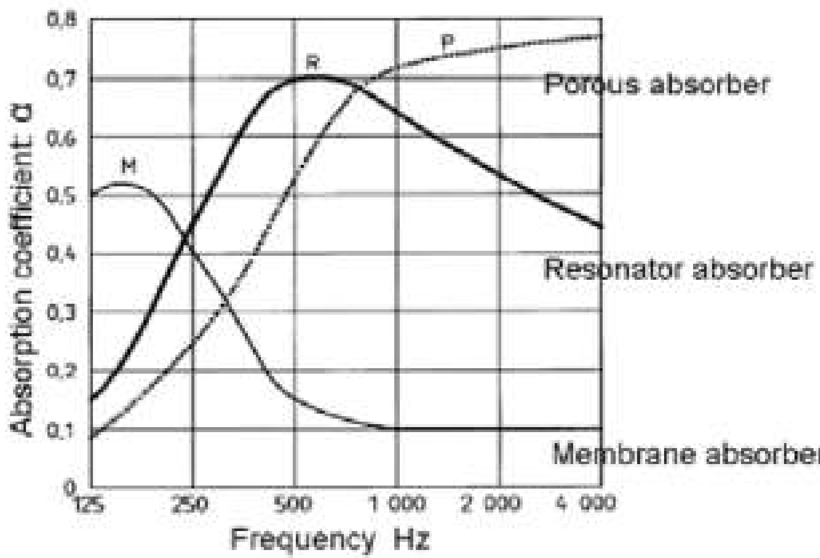


FIGURE 11-15 Spaces designed for speech and music recording require short reverberation times.

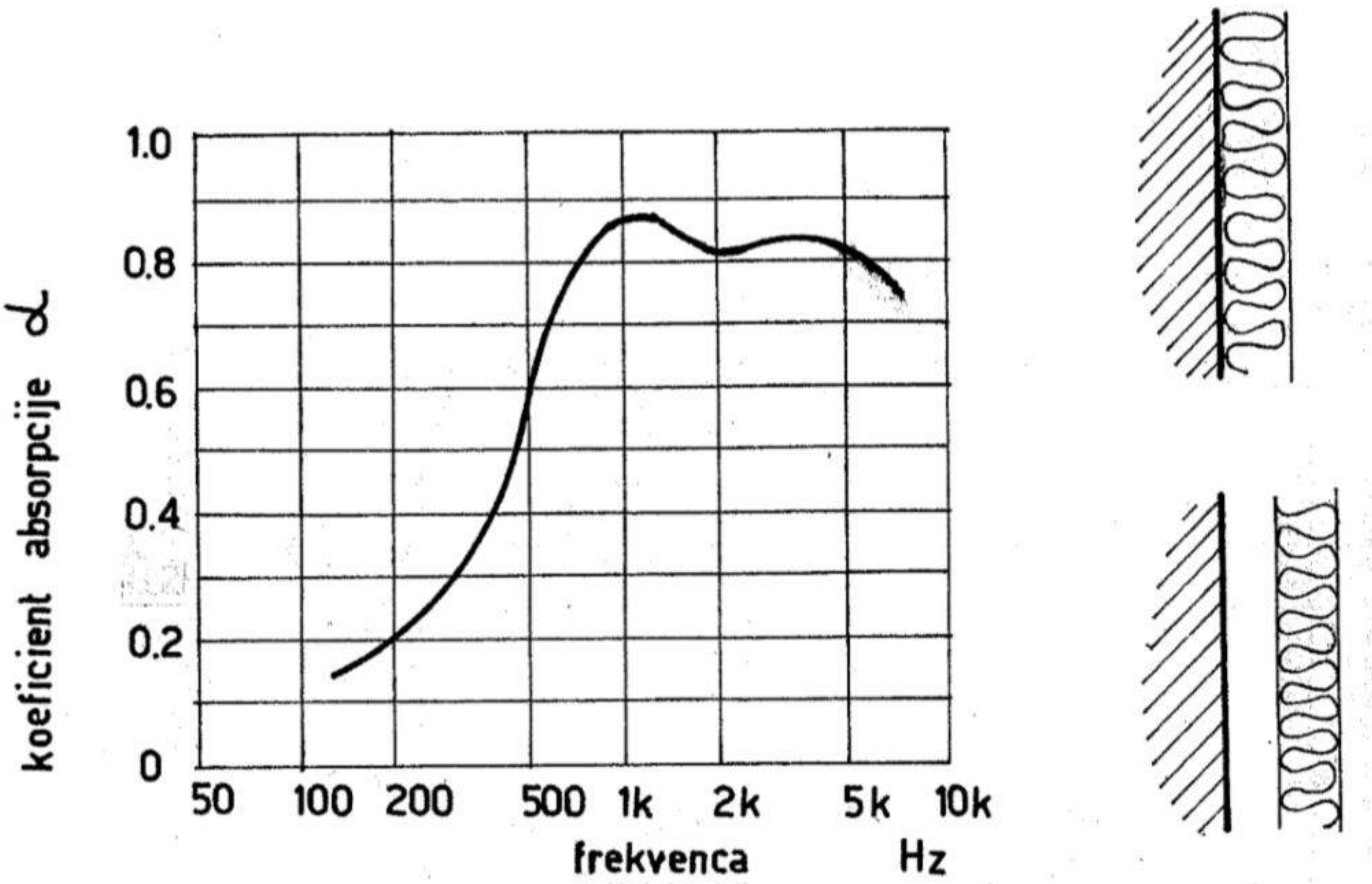
Types of absorbers: porous, membrane, Helmholtz, comprehensive (integrated)

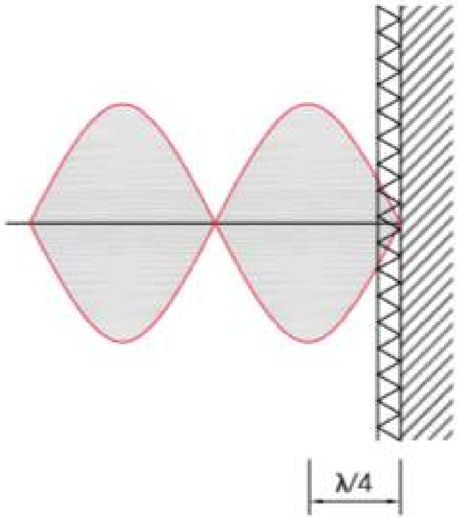


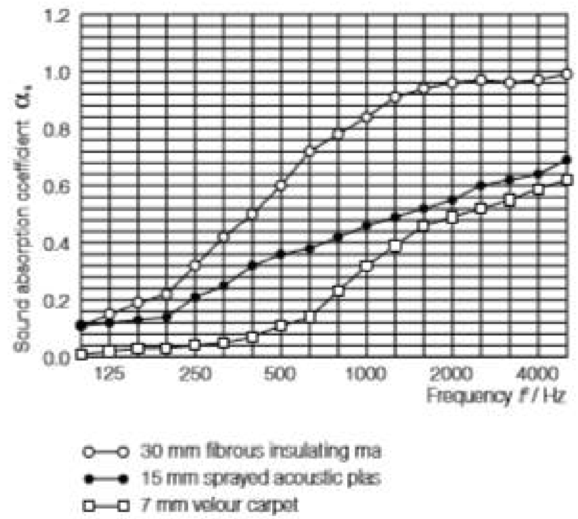
Characteristic frequency absorption curves.

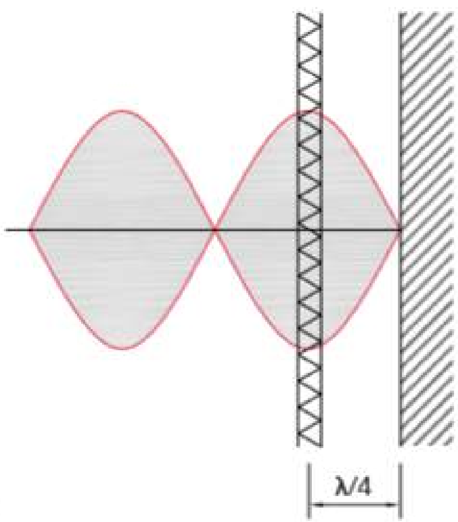


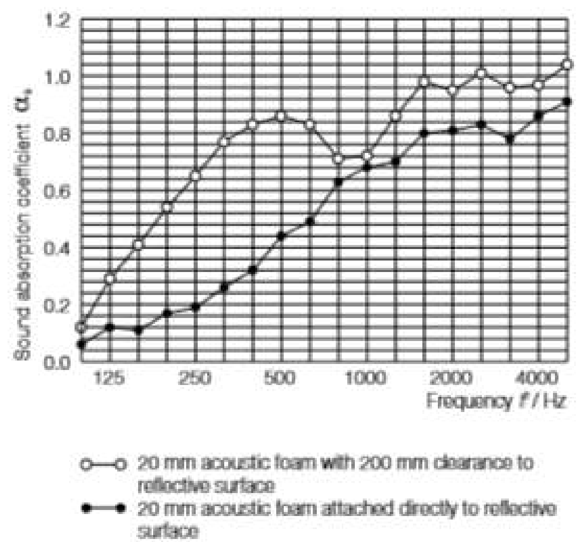
Porous absorber



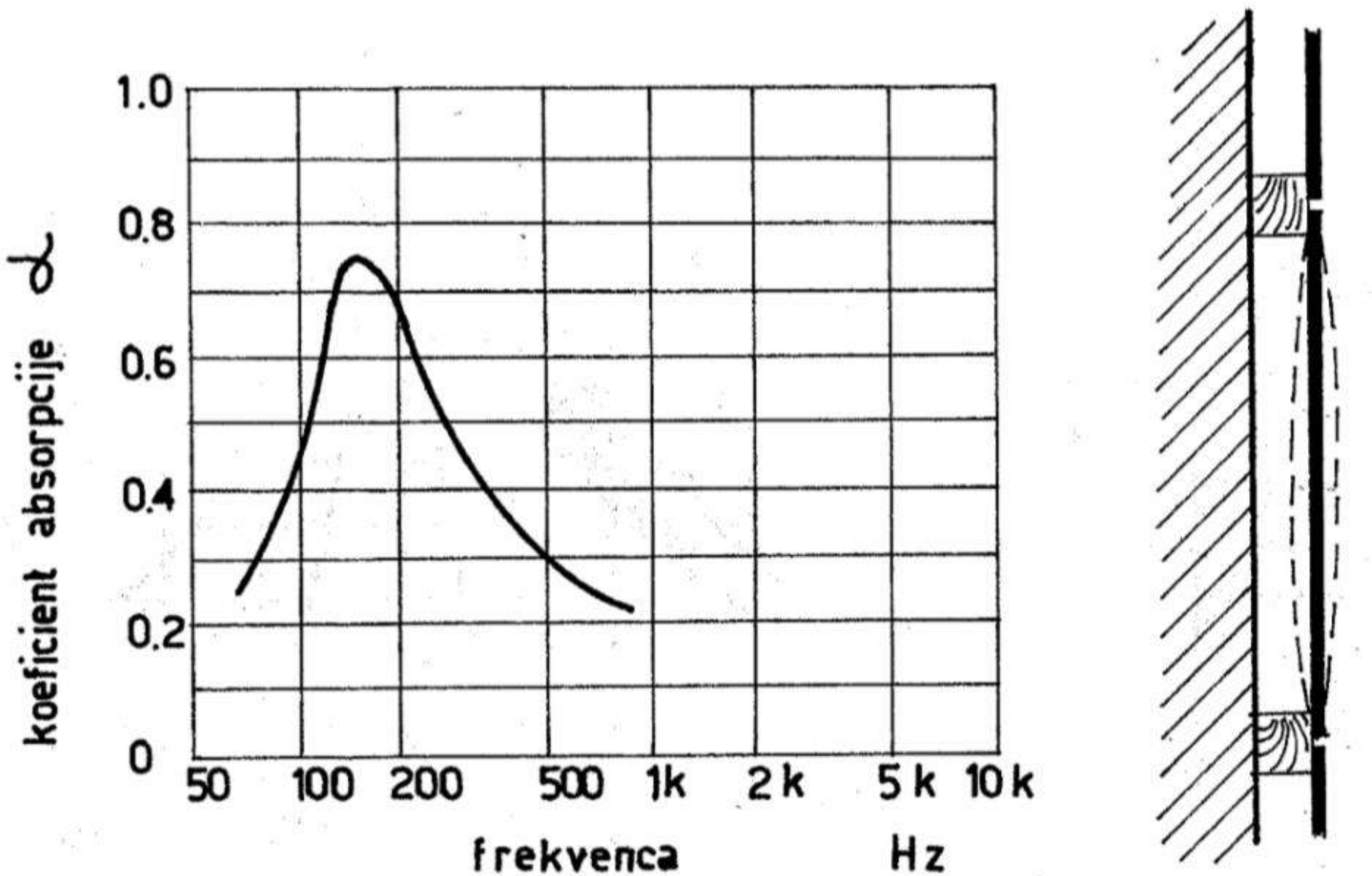

λ/4


Sound absorption coefficient α_s
1.2
1.0
0.8
0.6
0.4
0.2
0.0
125
250
500
1000
2000
4000
Frequency f / Hz
30 mm fibrous insulating ma
15 mm sprayed acoustic plas
7 mm velour carpet

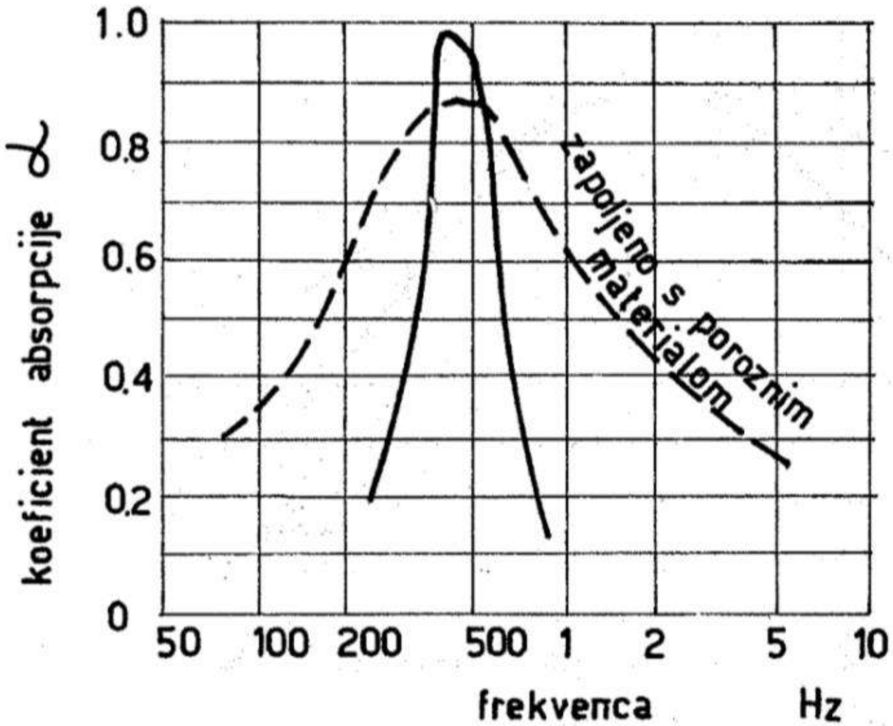

λ/4

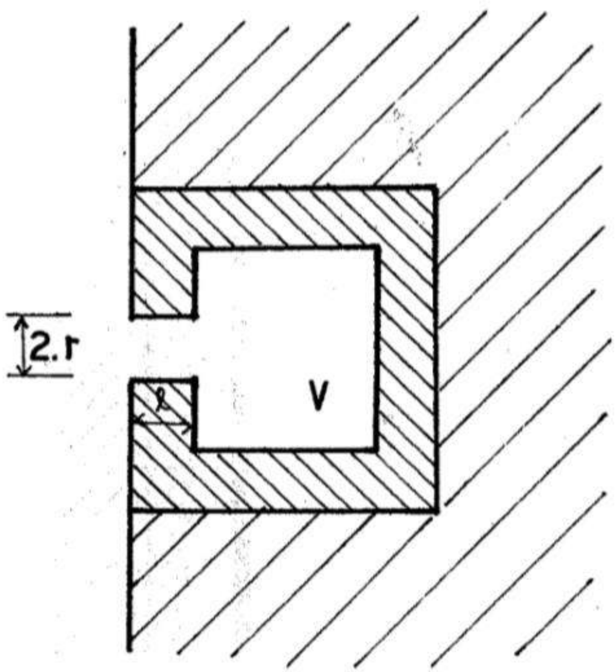

Sound absorption coefficient α_s
1.2
1.0
0.8
0.6
0.4
0.2
0.0
125
250
500
1000
2000
4000
Frequency f / Hz
20 mm acoustic foam with 200 mm clearance to reflective surface
20 mm acoustic foam attached directly to reflective surface

Membrane absorber



Helmholtz absorber / resonator





Helmholtz resonator

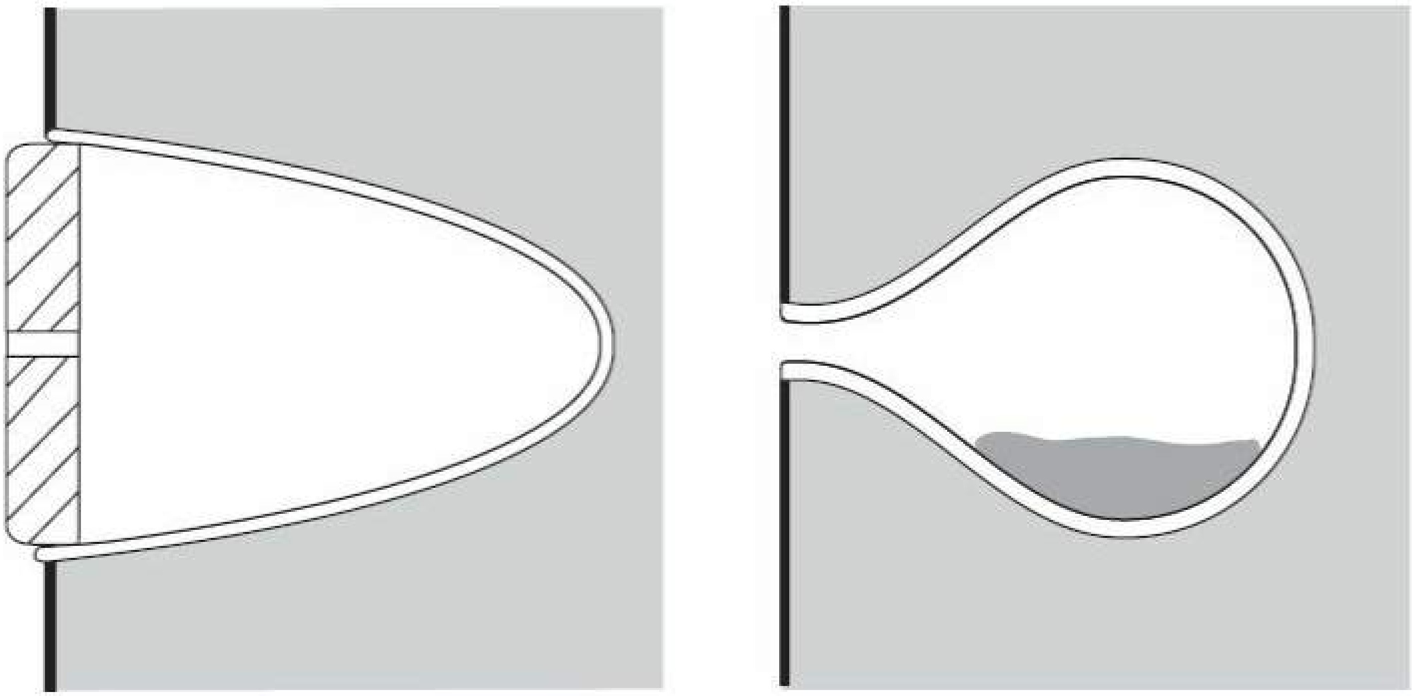


FIGURE 12-30 Pots embedded in the walls of medieval churches in Sweden and Denmark served as Helmholtz resonators, absorbing sound. Ashes, found in some of the pots, may have served as a dissipative agent. (*Brüel*.)

Correction of reverberation time at problematic frequency (around 40 Hz) with Helmholtz absorbers (resonators)

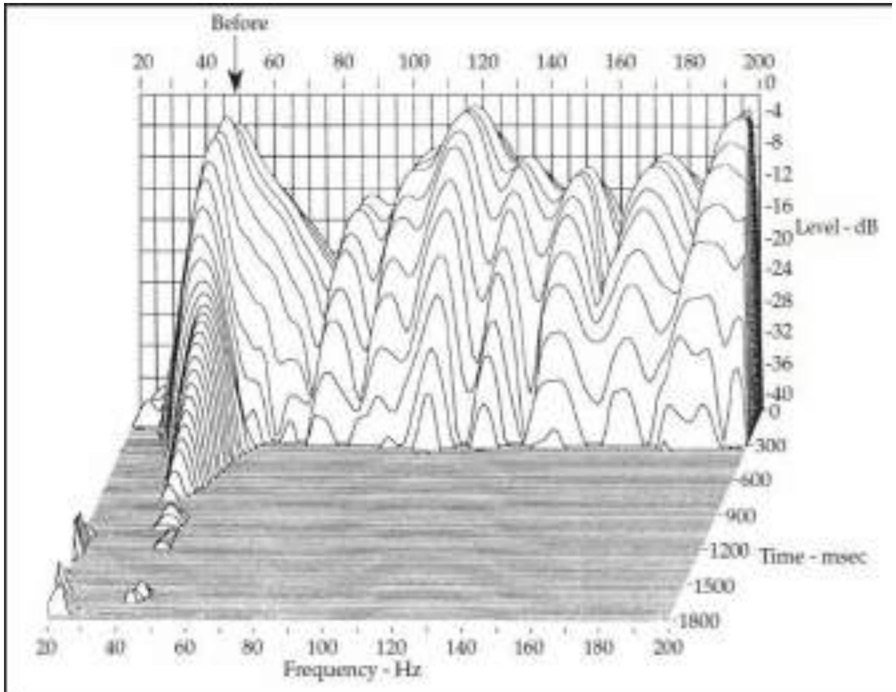


FIGURE 12-38 Low-frequency modal structure of the sound field of a small room before introduction of the tuned Helmholtz resonator absorber.

Before: existing problem with room resonant frequency of 40 Hz

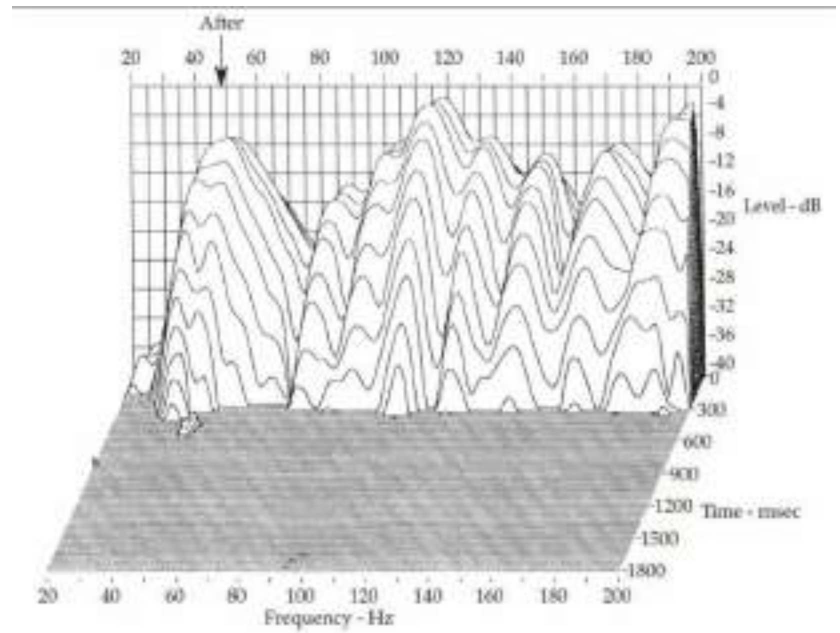
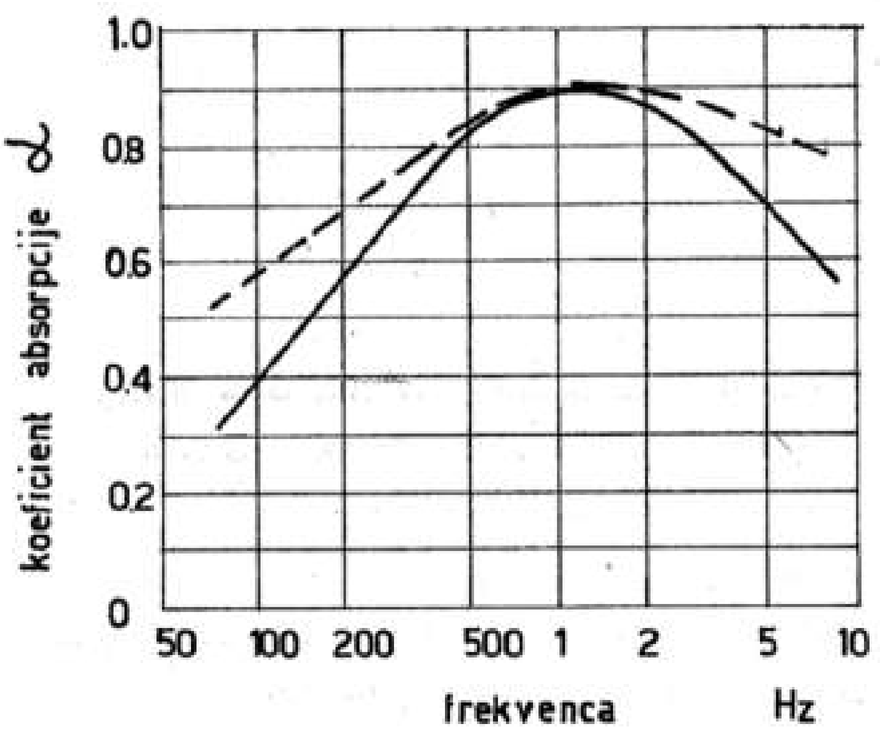
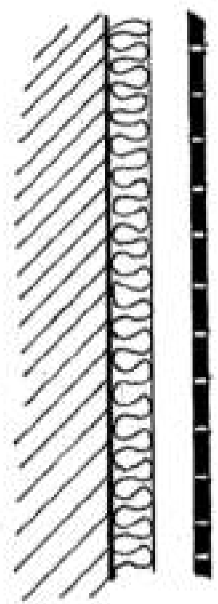


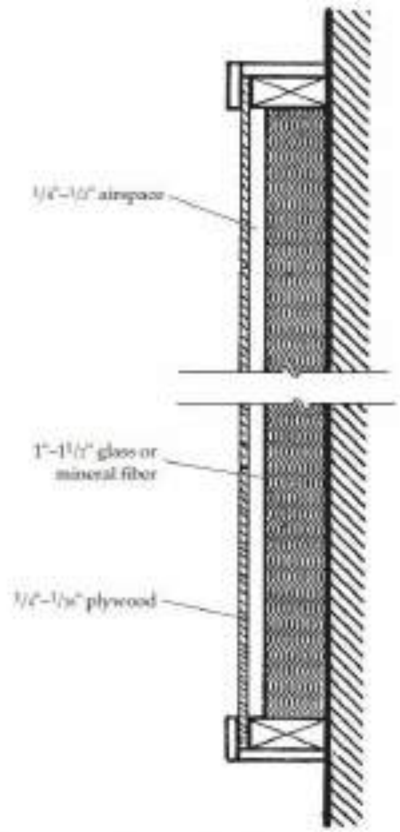
FIGURE 12-39 Low-frequency modal structure of the sound field of the same small room after the introduction of the tuned Helmholtz resonator absorber.

After introduction of Helmholtz absorbers / resonators with tuning frequency of 40 Hz

Comprehensive (integrated) absorbers:
acoustical plates, acoustical panels







Typical resonant panel absorber with wall mounting

Reverberation time before and after acoustic treatment in the interior space in relation to frequency

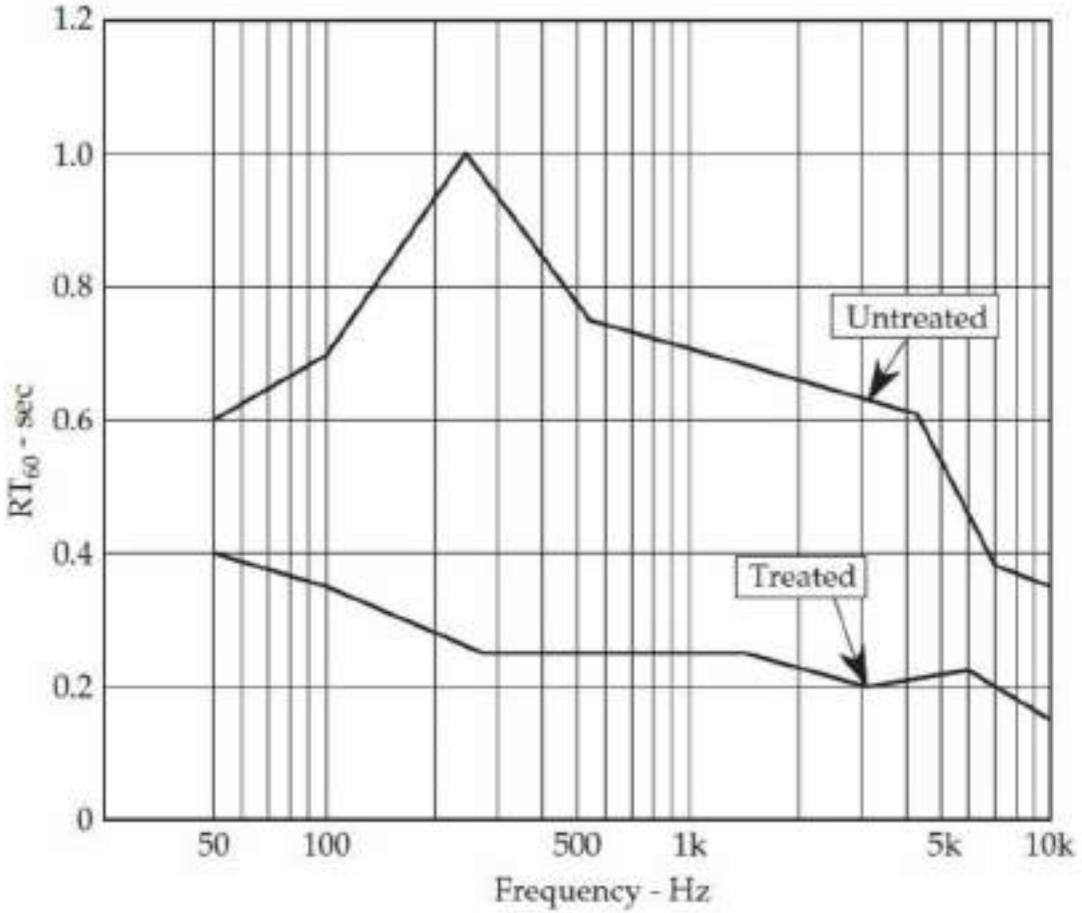


FIGURE 11-10 An example of a room's reverberation characteristic before and after room treatment. A significant rise in reverberation time in the upper bass and lower midrange is changed to a flatter characteristic with a moderate increase in reverberation time at low frequencies.

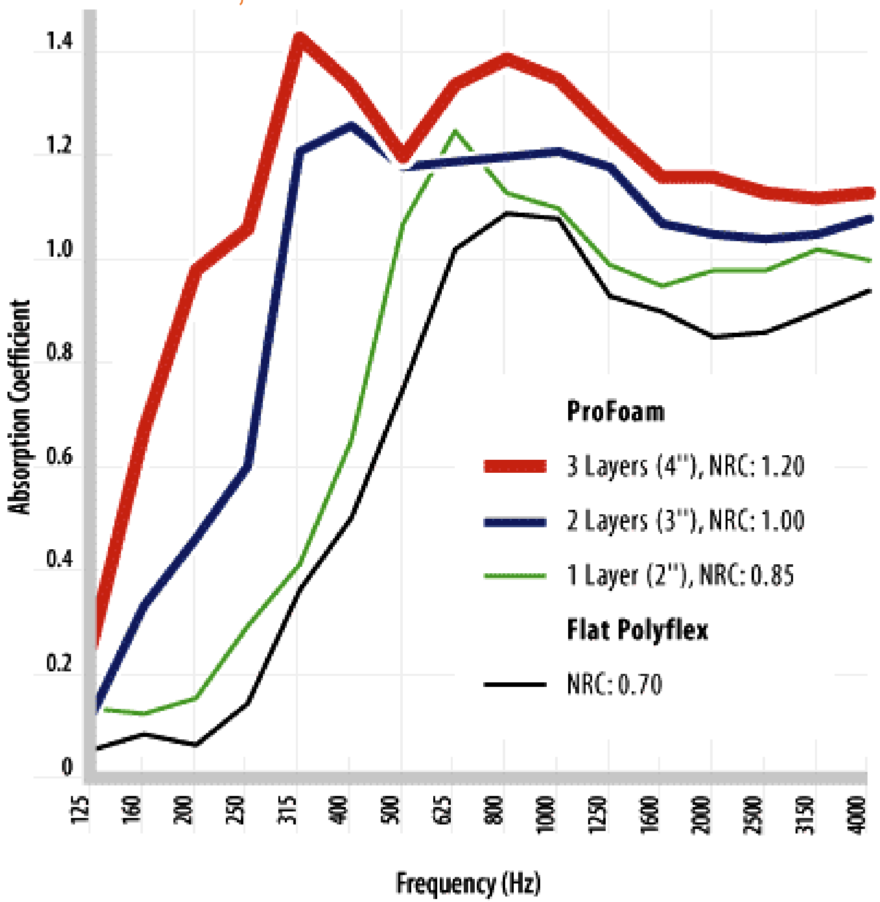
Absorption coefficient α

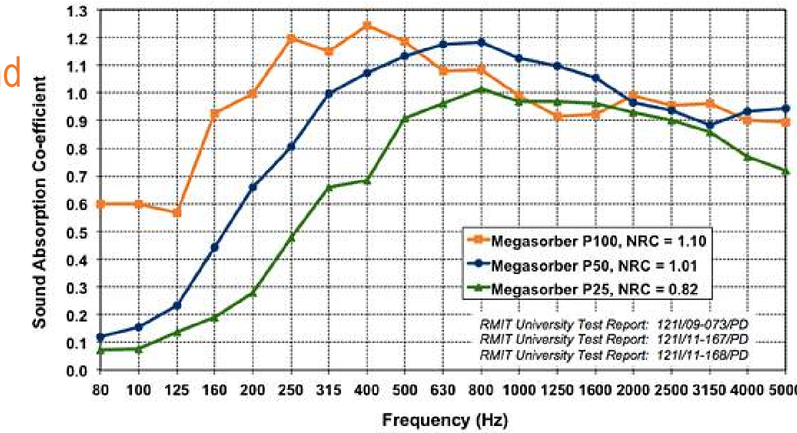
Absorption coefficient α (-)

Means ration between the absorbed and the incident power of sound

Absorption coefficient is normally dependent on the frequency

SIST EN 12354 – 6, SIST EN ISO 11654





Measuring the absorption coefficient (α) of absorbing materials (Kundt tube)

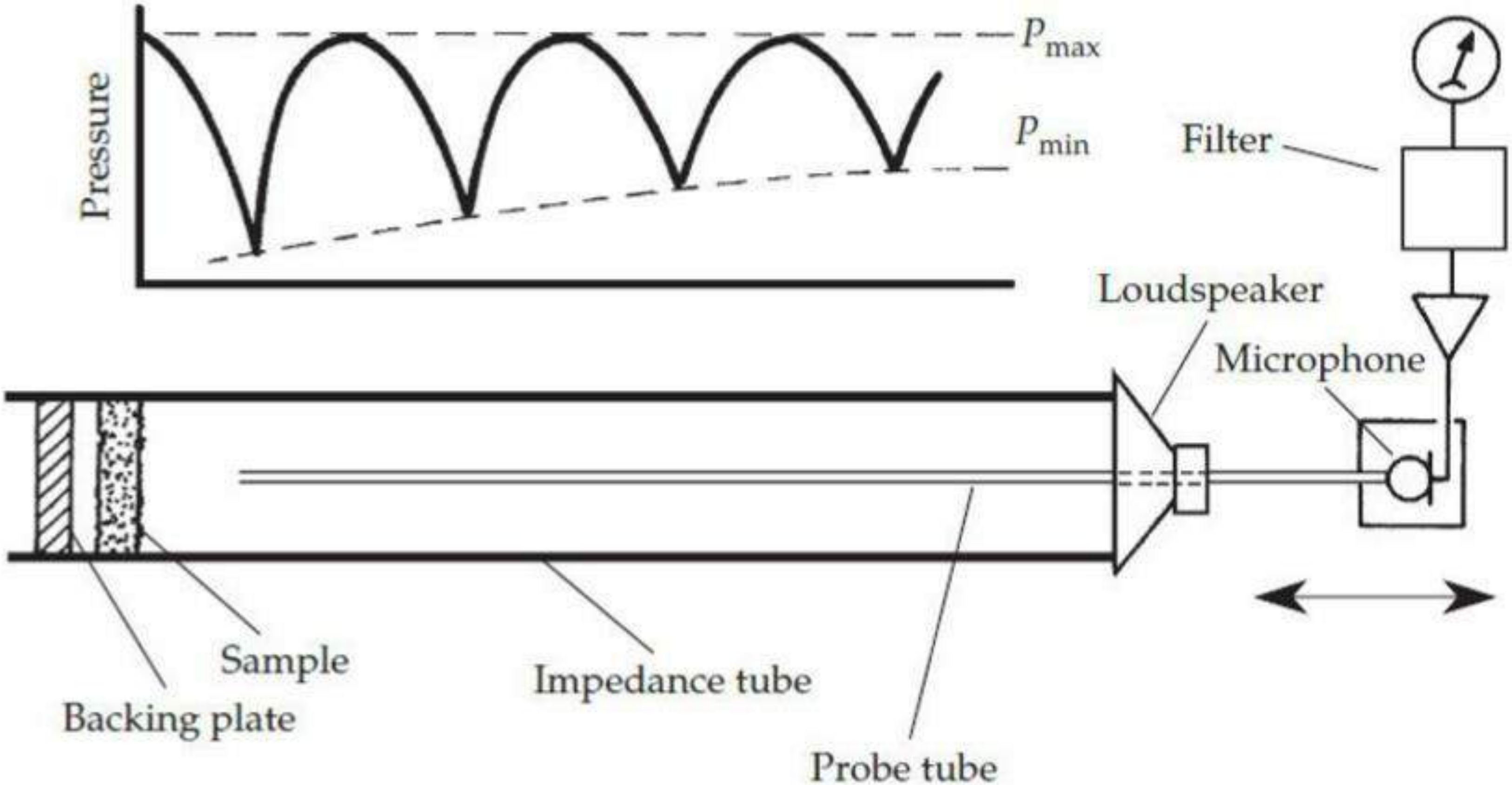
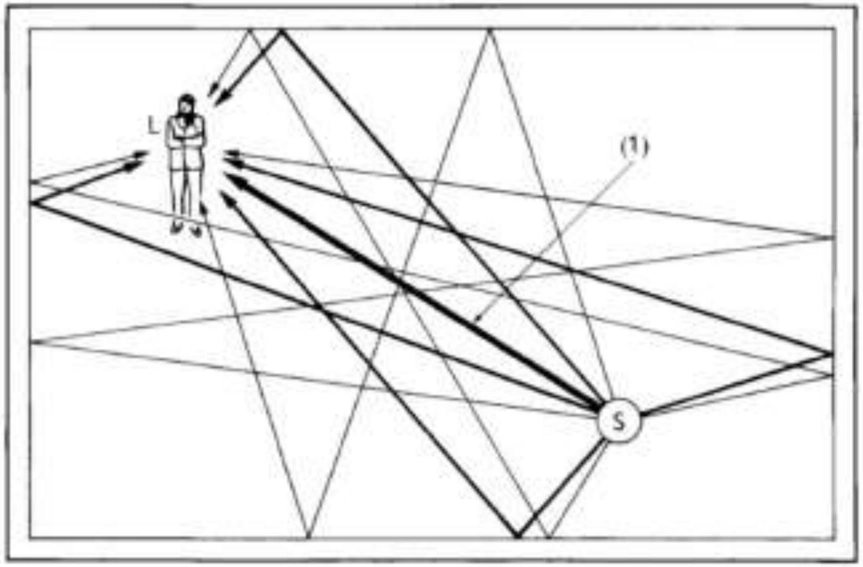
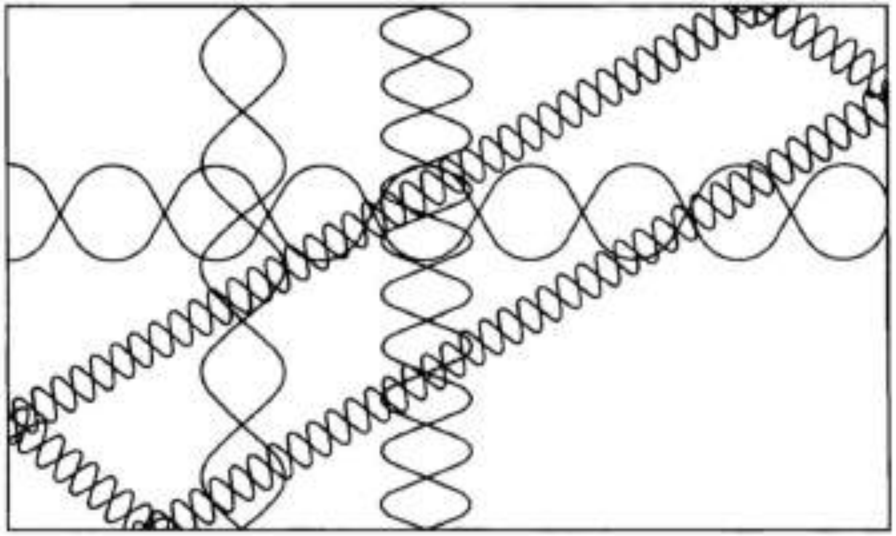


FIGURE 12-2 The impedance tube method of measuring the absorption coefficient of absorbing materials at normal incidence.

Standing waves





Standing waves

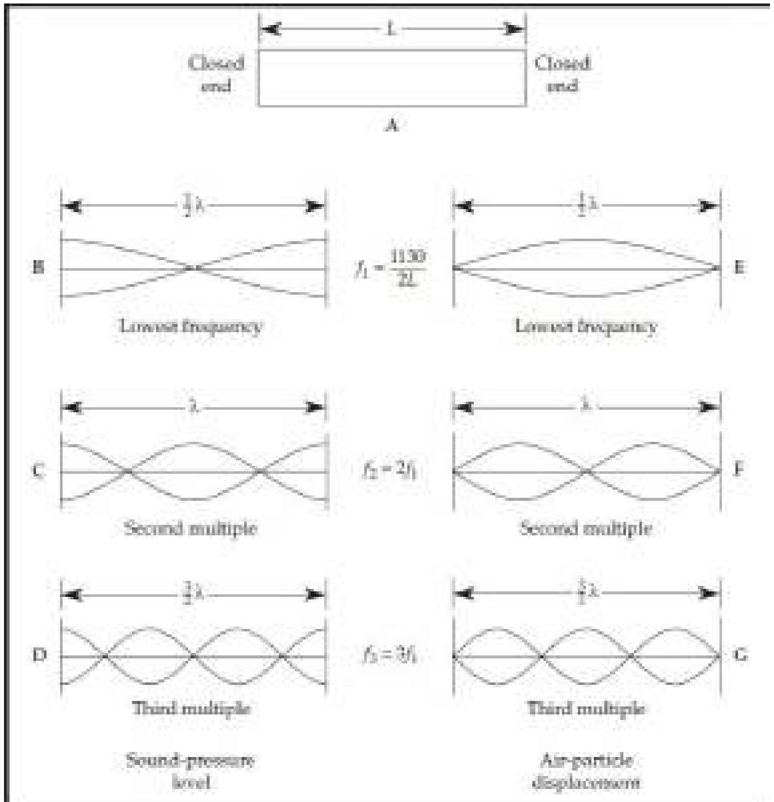


FIGURE 13-1 A pipe closed at both ends demonstrates how resonance occurs between two opposing walls of a room. The length of the pipe (distance between the walls in a room) determines the characteristic frequency of resonance and its harmonics. (A) Closed pipe. (B) Plot of sound-pressure level of f_1. (C) Plot of sound-pressure level of f_2. (D) Plot of sound-pressure level of f_3. (E) Plot of air-particle displacement of f_1. (F) Plot of air-particle displacement of f_2. (G) Plot of air-particle displacement of f_3.

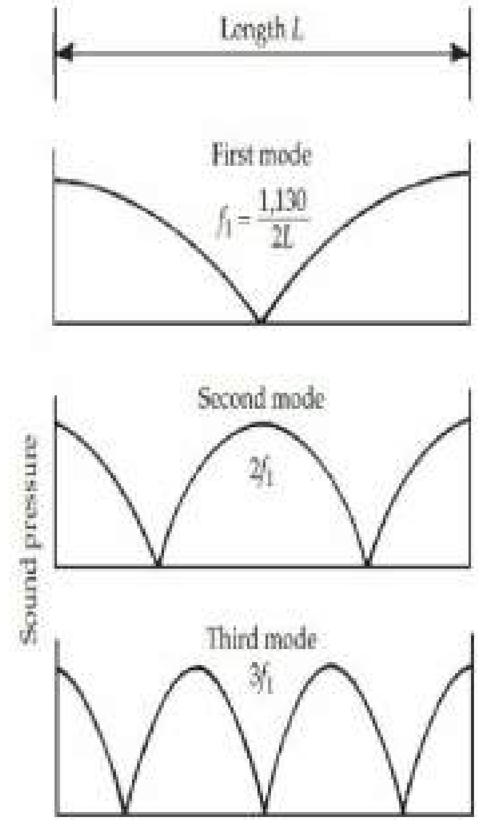


FIGURE 13-4 The space between two parallel, reflective walls can be considered a resonant system with a frequency of resonance of $f_1 = 1,130/2L$. This system is also resonant at integral multiples of

Standing waves

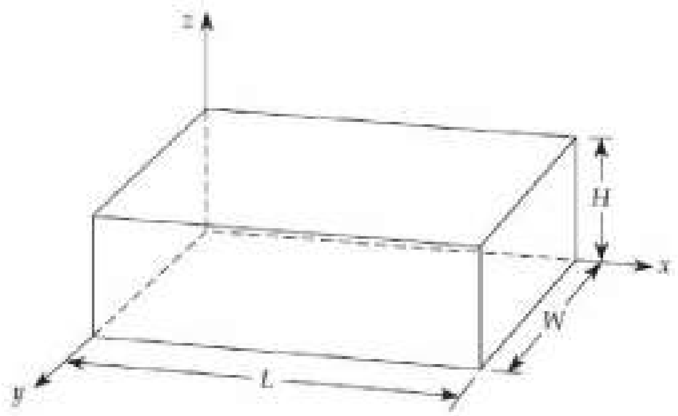


FIGURE 13-7 Orientation of rectangular room of length L, width W, and height H with respect to the x, y, and z coordinates for calculating room-mode frequencies.

$$\text{Frequency} = \frac{c}{2}\sqrt{\frac{p^2}{L^2} + \frac{q^2}{W^2} + \frac{r^2}{H^2}} \quad (13\text{-}3)$$

where L, W, H =
room length, width, and height, ft or m
p, q, r =
integers 0, 1, 2, 3, …
c =

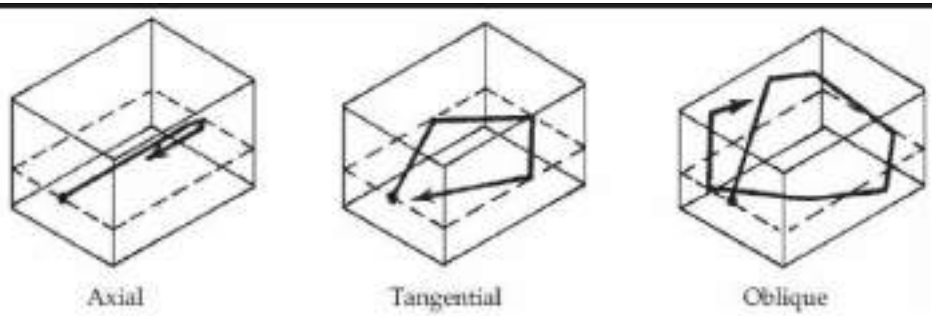


FIGURE 13-5 Visualization of axial, tangential, and oblique room modes using the ray concept.

Bruel & Kjaer, Type 2250, Sound Pressure Meter, Ser.no. 3001735

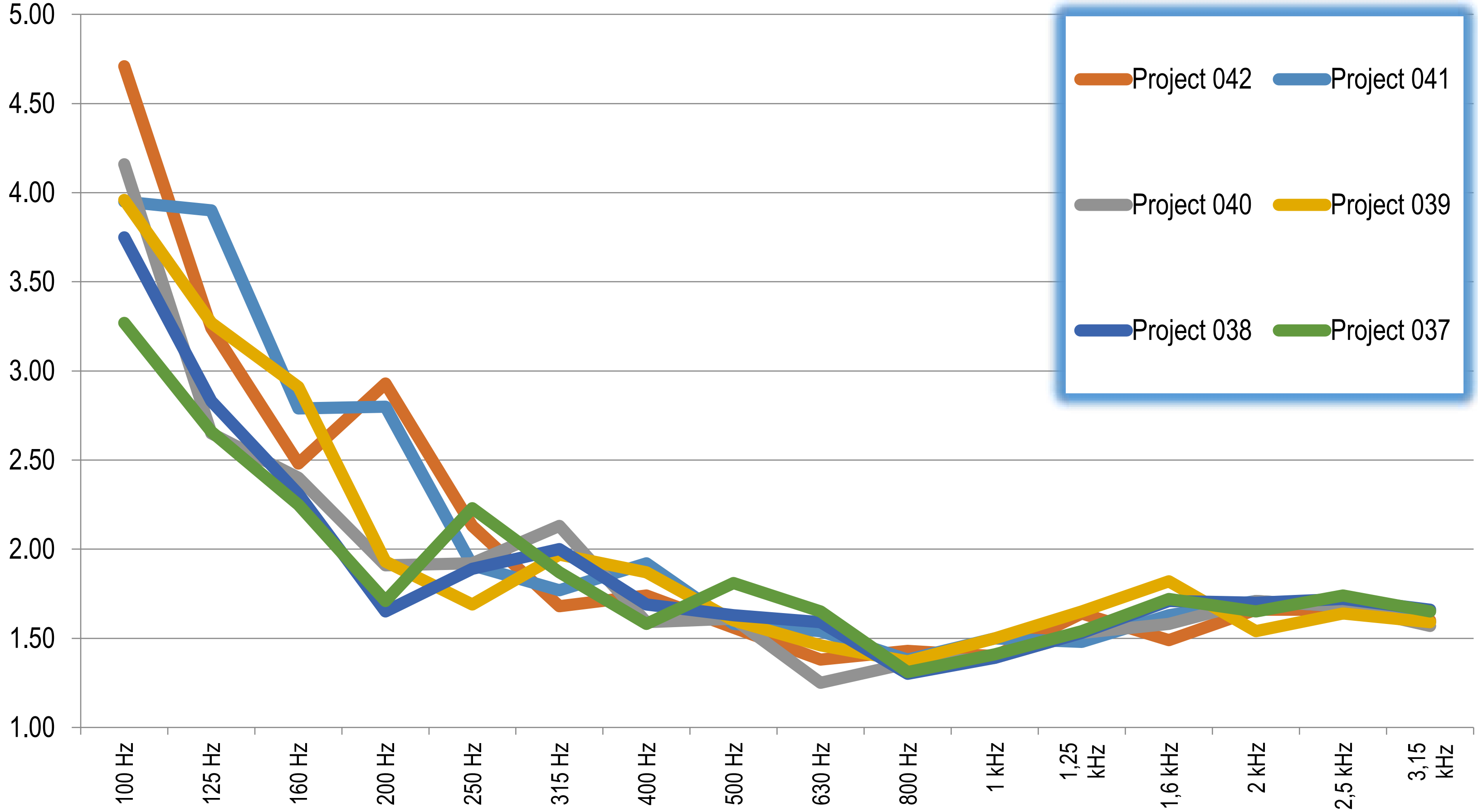
Bruel & Kjaer, Type 4189, ½″ Microphone, Ser.no. 2831973

(+ impact sound source)

HM – Hochschule München, Old building (built around 1930's)

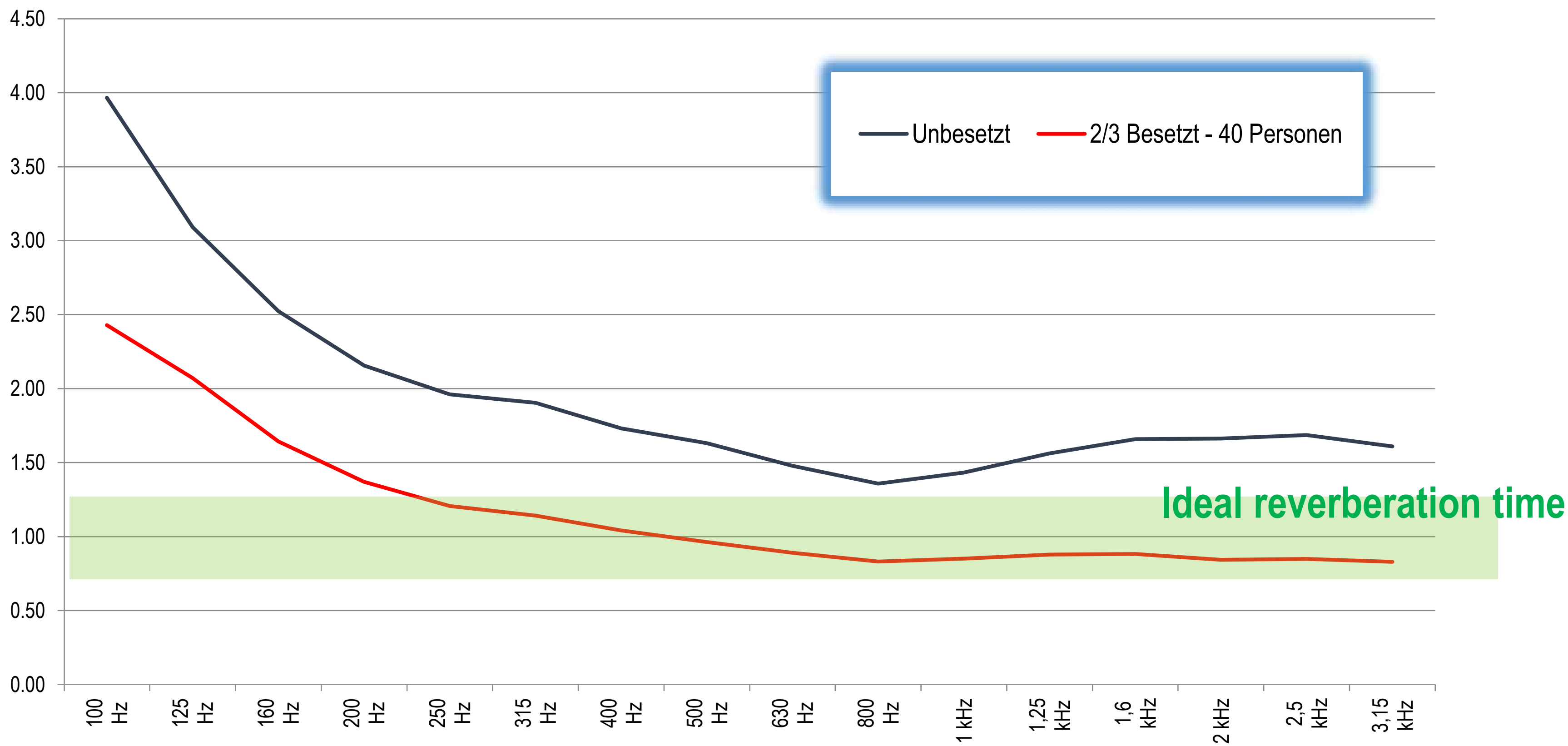
Class A 409 (identical to class A408)

Project 037, Project 038, Project 039, Project 040, Project 041 & Project 042



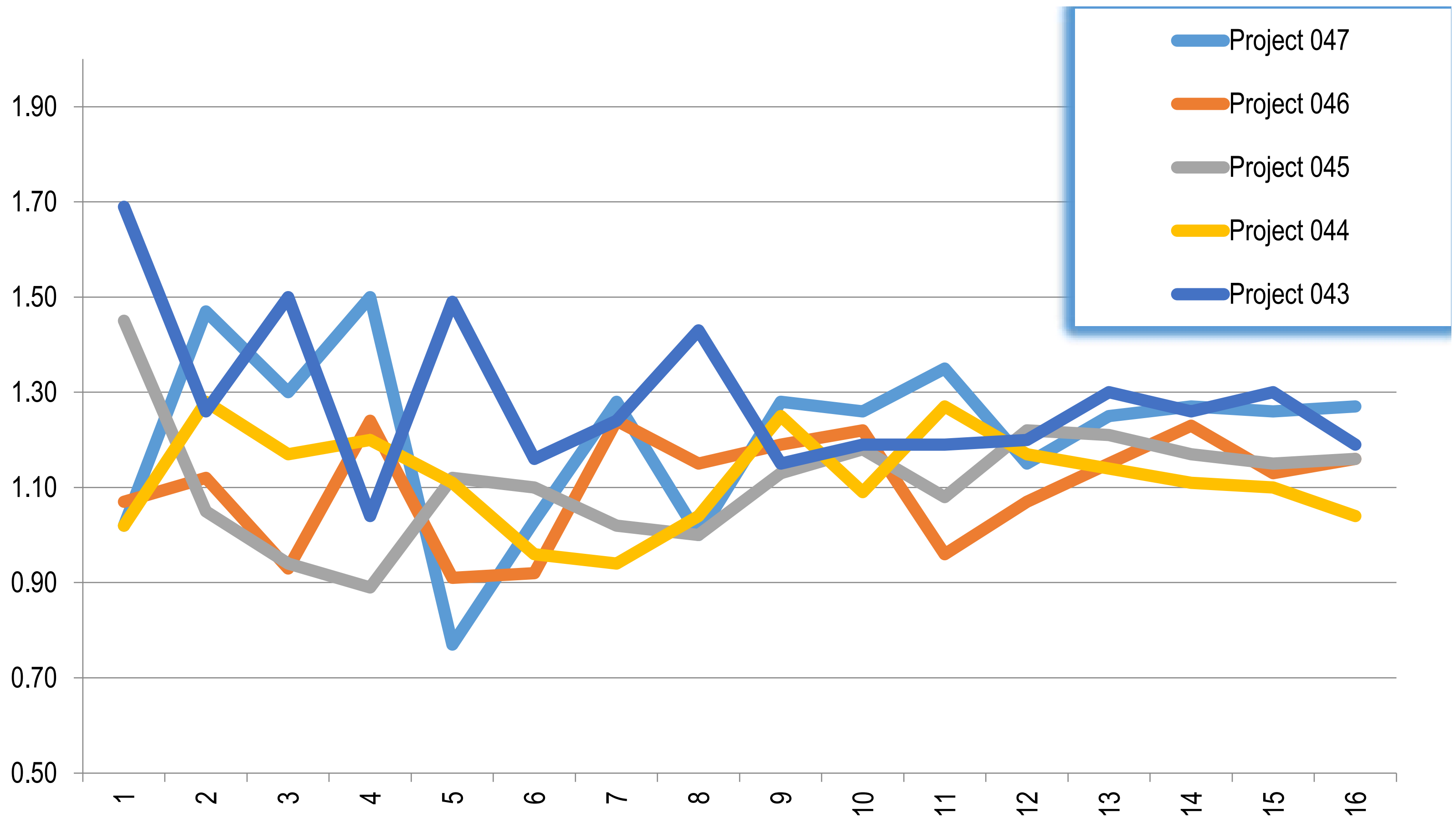
HM – Hochschule München, Old building (around 1930) (A 409 and A 408)

Reverberation time in empty classroom (not occupied by students) is very long and is from minimum 1.38 up to 4.50 seconds.
Average reverberation time in speech frequencies for empty classroom is between 1.50 and 2.50 seconds.
If we compensate this reverberation time with standard DIN 18041, then corrected reverberation time for 2/3 full of students, which represents approx. 40 adult people, is between 0.80 and approx.. 1.50 seconds.
This is higher reverberation time than ideal (ideal reverberation time for partly - around 2/3 - occupied classroom with students – 40 adult people - is from 0.70 to 1.20 seconds).



HM – Hochschule München, New building (built around 1988):

Class G 3.42 - Project 045, Project 046 & Project 047
Class G 3.38 – Project 043 & Project 044



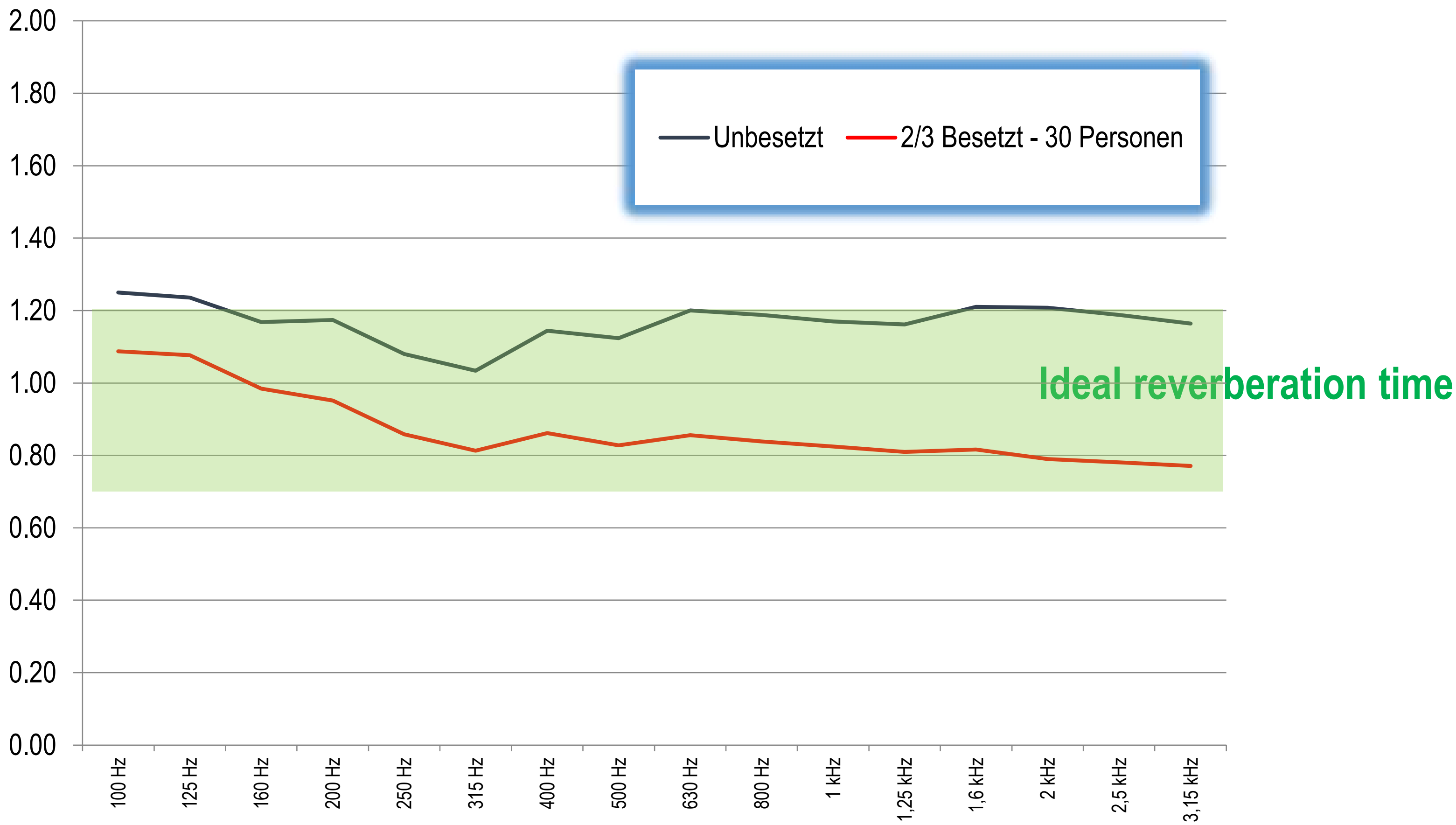
HM – Hochschule München, New building (G 3,38 und G 3,42):

Rooms are acoustically treated with absorbers. Reverberation time in empty classroom (not occupied by students) is from minimum 0.77 up to 1.69 seconds.

Average reverberation time in speech frequencies is between 1.00 and 1.40 seconds.

If we compensate this reverberation time with standard DIN 18041, then corrected reverberation time for 2/3 full room of students, which represents approx. 30 adult people, is between 0.80 and 1.05 seconds.

This reverberation time is in ideal region (ideal reverberation time for partly - around 2/3 - occupied classroom with students – adult people - is from 0.70 to 1.20 seconds).



Sound insulation against airborne sound

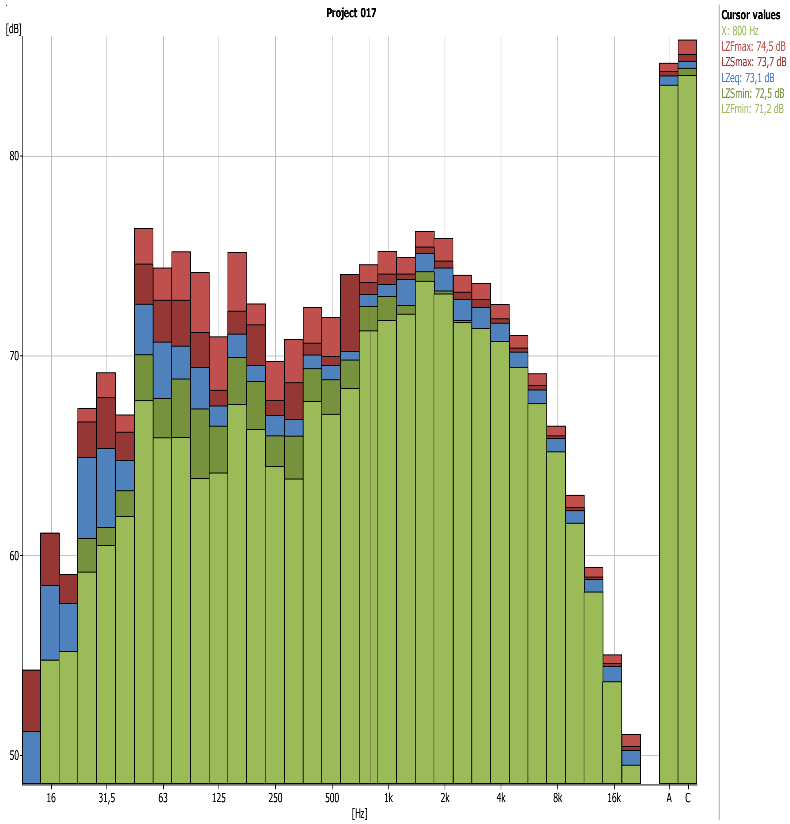
Bruel & Kjaer, Type 4204, Reference Sound Source,

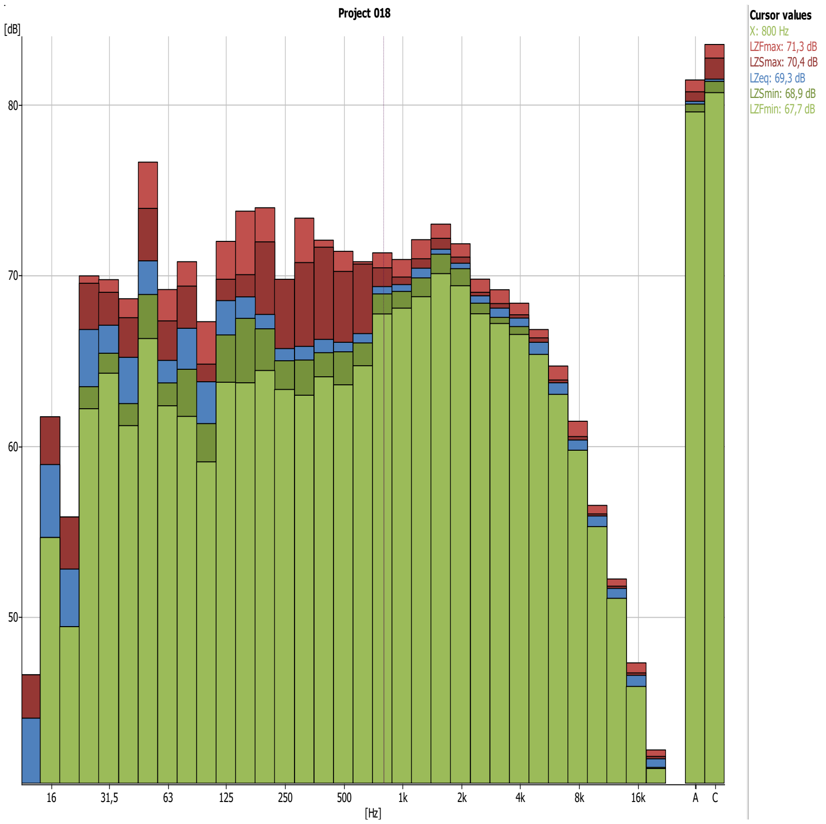
Ser.no. 2334341, 2001

Standardized reference sound source of continuous sound

Old building
1 m from source, oriented to source (74.5 dB(A))

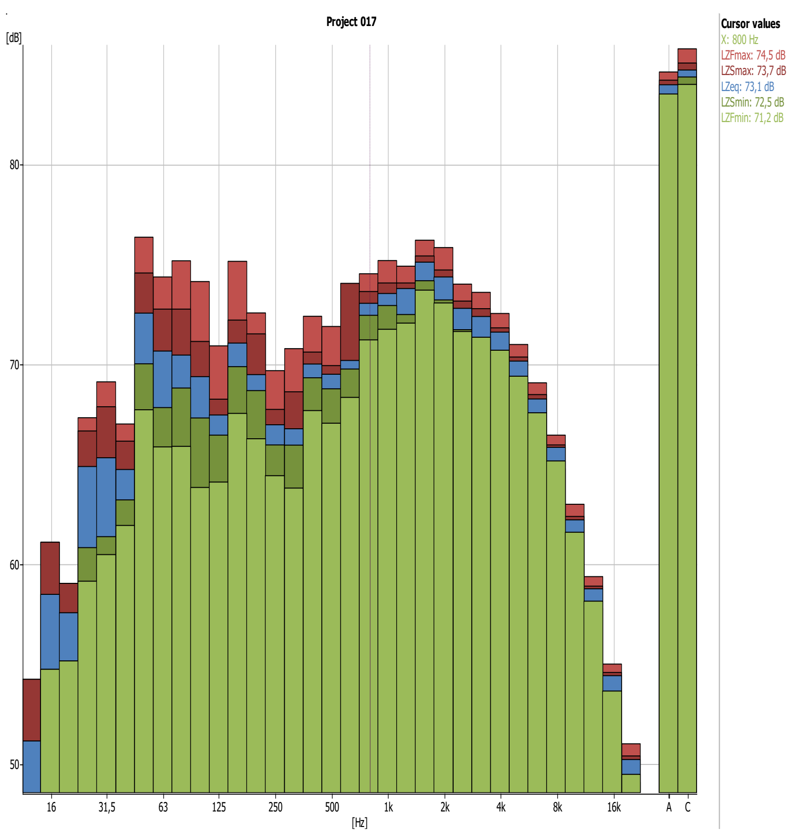
Old building
8 m from source, oriented to source (3.2 dB lower)

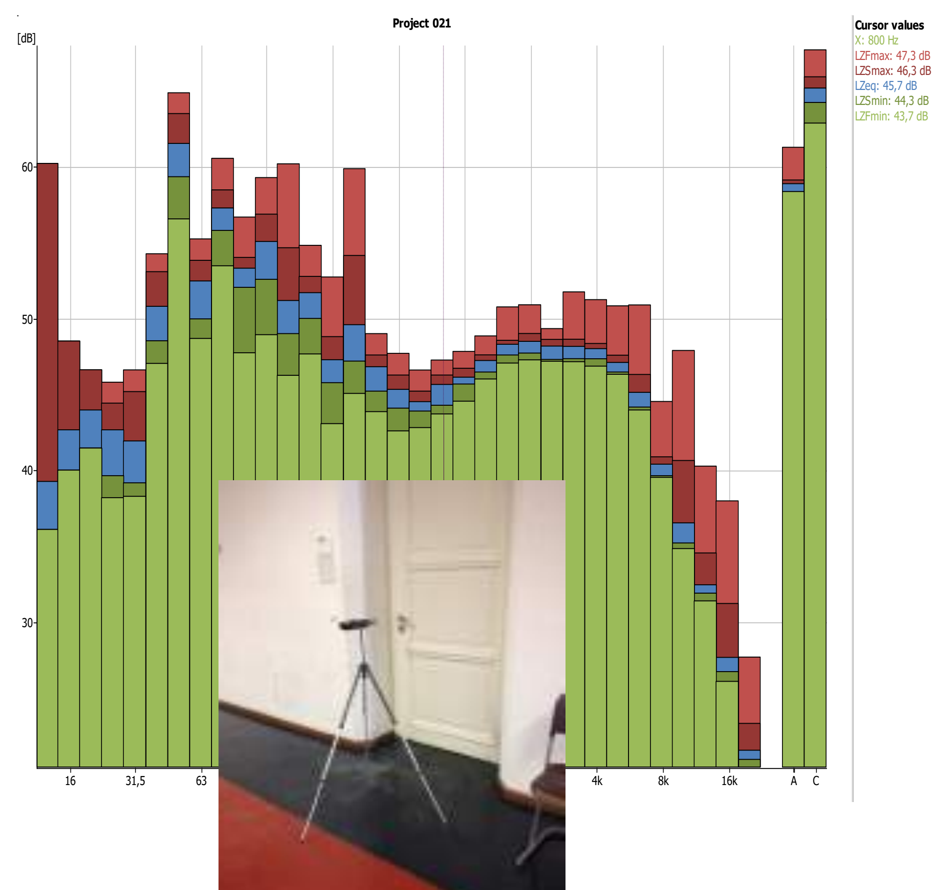




Old building
1 m from source, oriented to source (74.5 dB(A))

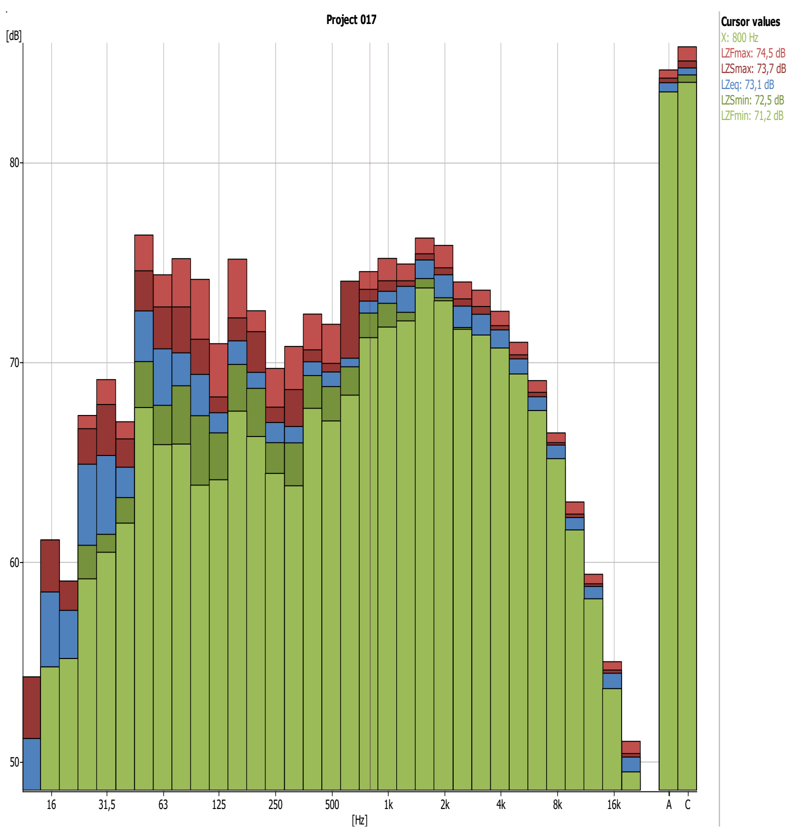
Old building
On the other side of the door,
1 m from the door (27.0 dB lower)

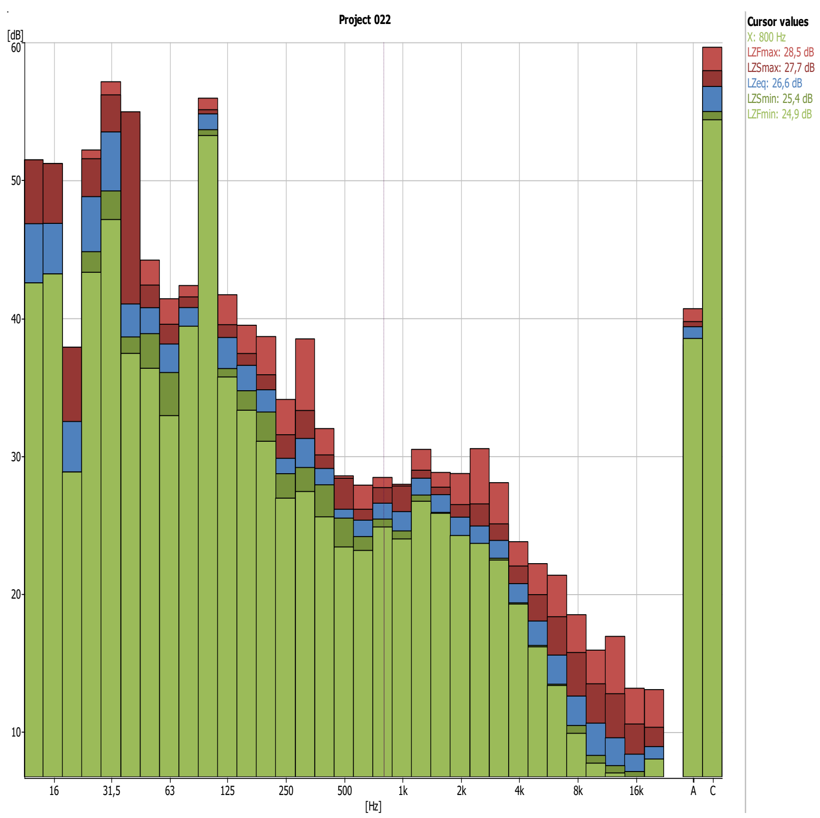




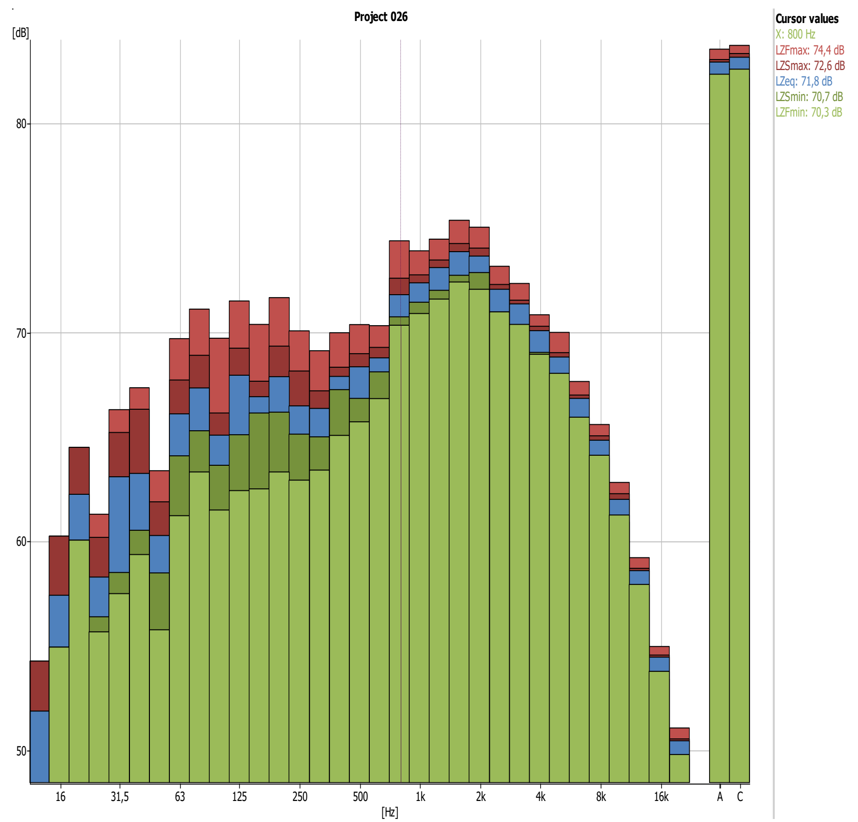
Old building
1 m from source, oriented to source (74.5 dB(A))

Old building
In an other room (A408),
1 m from wall (45.5 dB lower)



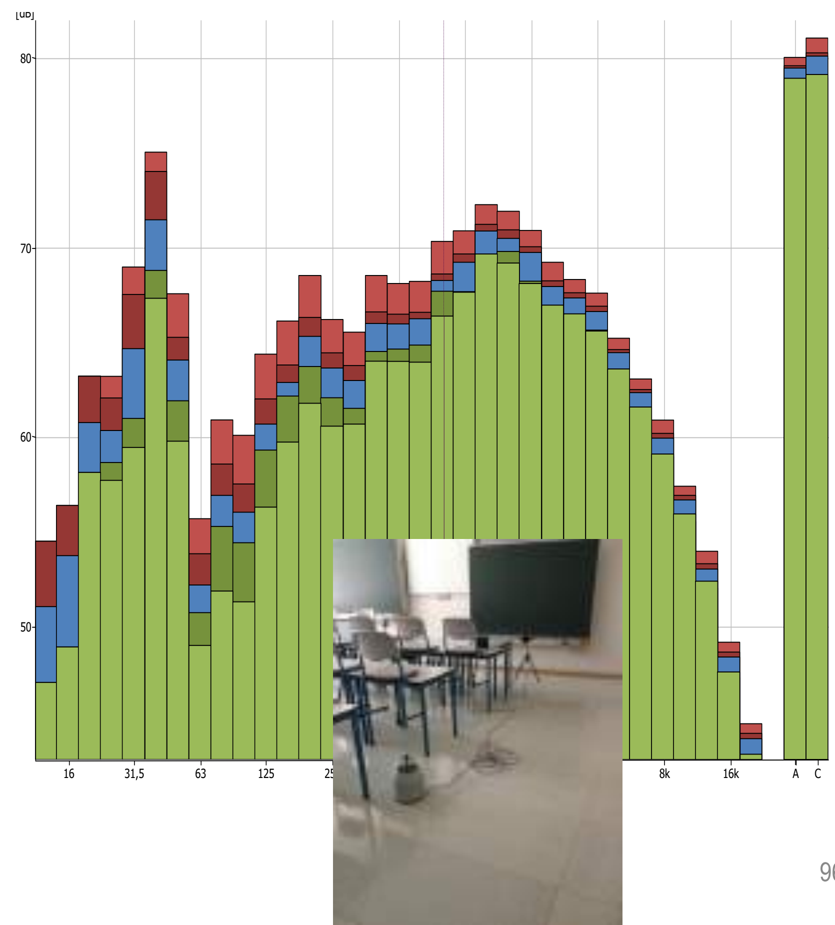


New building
1 m from source, oriented to the source (74.4 dB(A))

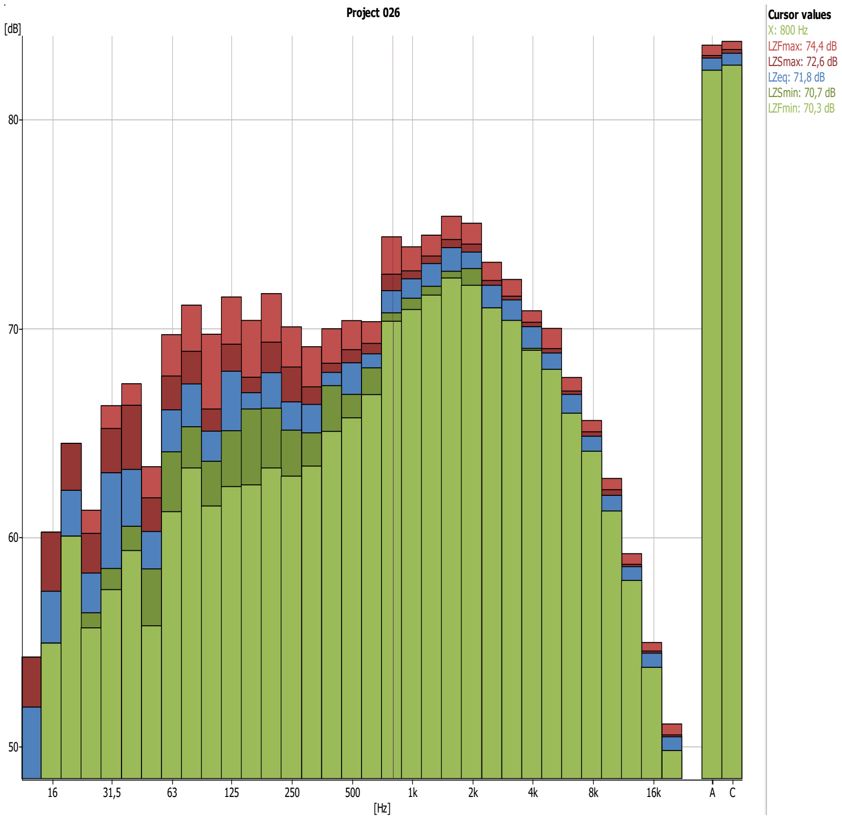


New building
6 m from source, oriented to the source (4.1 dB lower)

(old building 3.2 dB lower / 8 m)

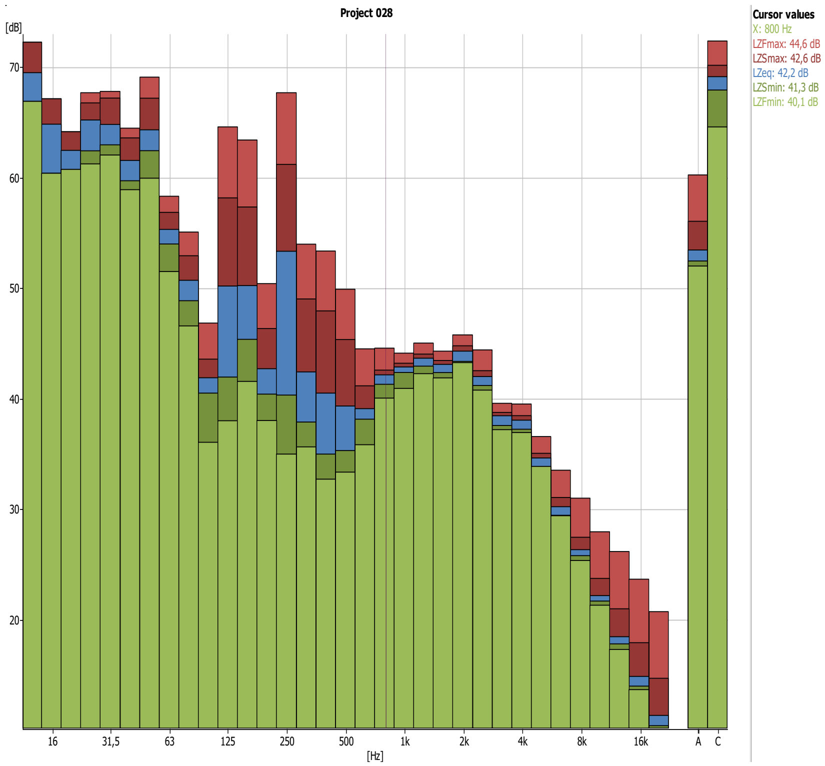


New building
1 m from source, oriented to the source (74. dB(A))

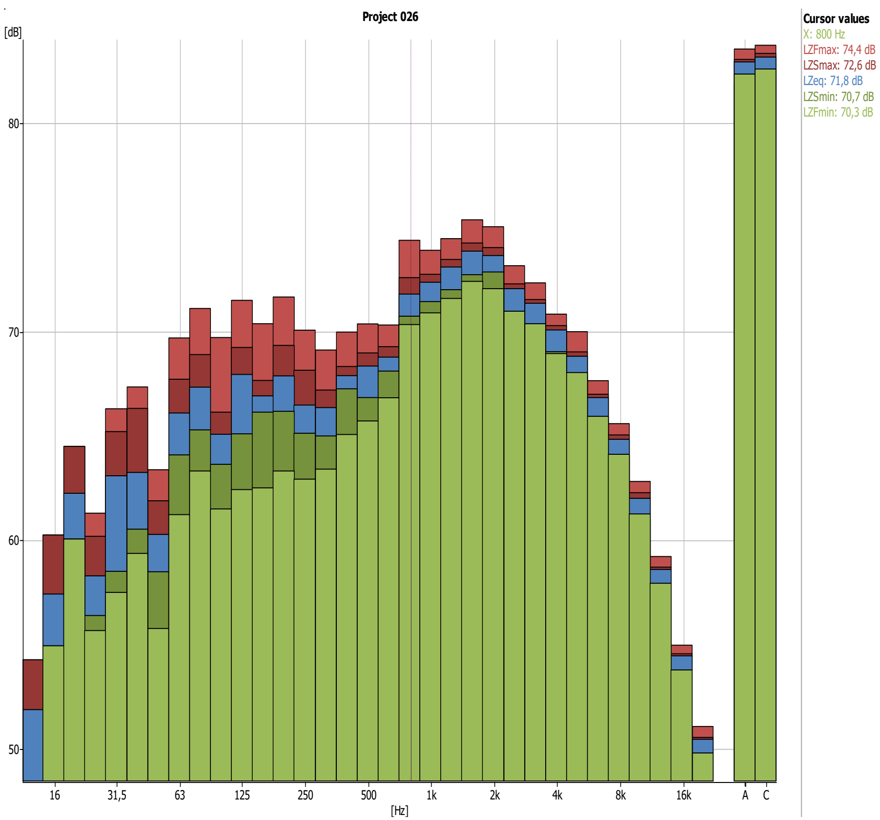


New building
On the other side of the door,
1 m from the door (30.0 dB lower)

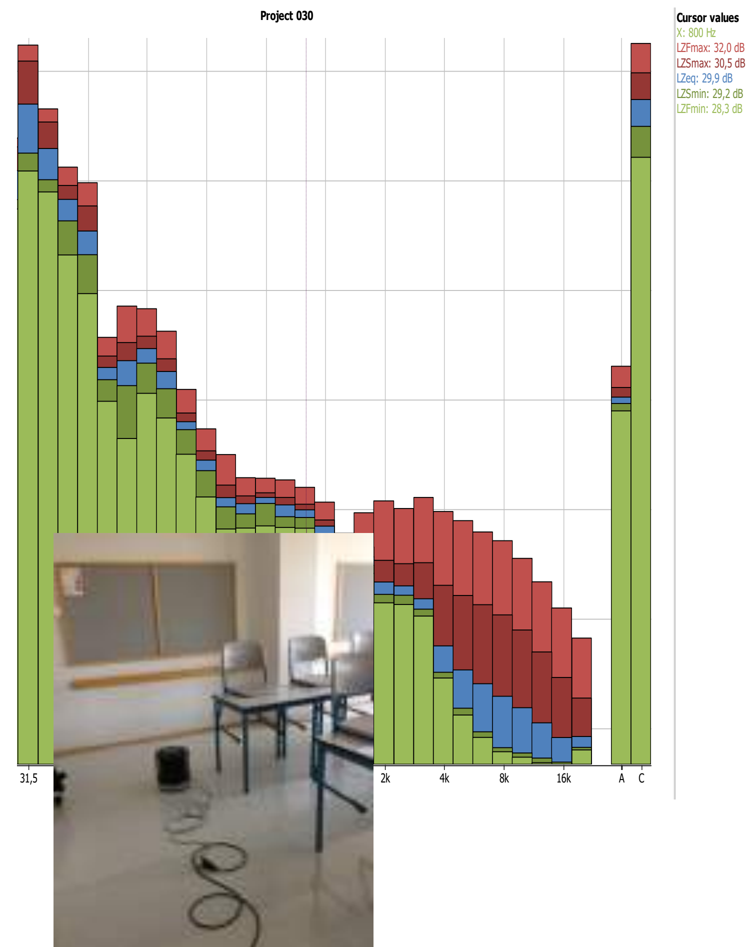
(old building 27.0 dB lower)

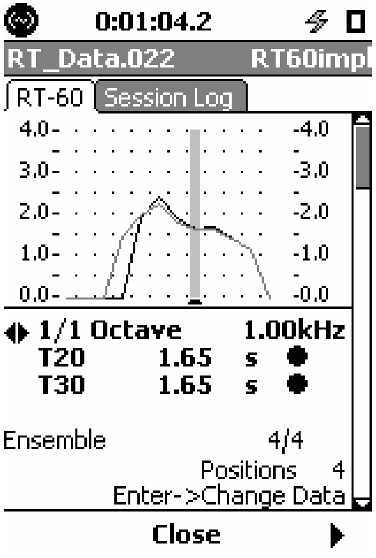


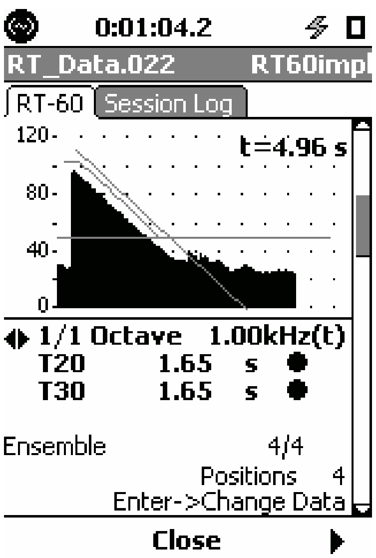
New building
1 m form source, oriented to the source (74.4 dB(A))



New building
In another room (G3.42),
1 m from the wall (42.5 dB lower)
(old building 45.5 dB lower)







Our measuring equipment (at UL FGG):

LARSON DAVIS 831, Sound Level Meter

Sound, noise, sound insulation, acoustics & vibrations

Many thanks !

Any questions?

Roman Kunič

Addition materials!!!

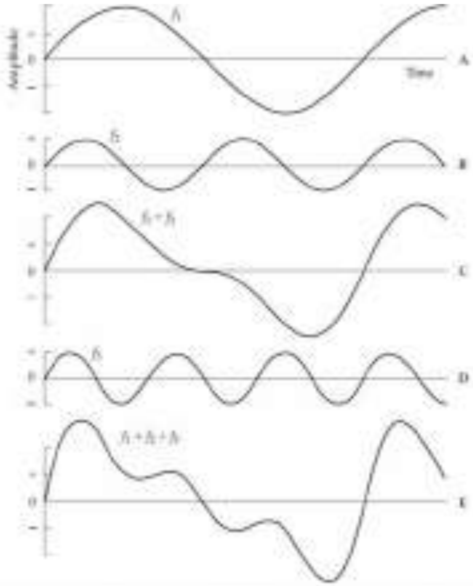


FIGURE 1-9 A study in the combination of sine waves. (A) The fundamental of frequency f_1. (B) A second harmonic of frequency $f_2 = 2f_1$ and half the amplitude of f_1. (C) The sum of f_1 and f_2 obtained by adding ordinates point by point. (D) A third harmonic of frequency $f3 = 3f_1$ and half the amplitude of f_1. (E) The waveform resulting from the addition of f_1, f_2, and $f3$. All three components are in phase; that is, they all start from zero at the same instant.

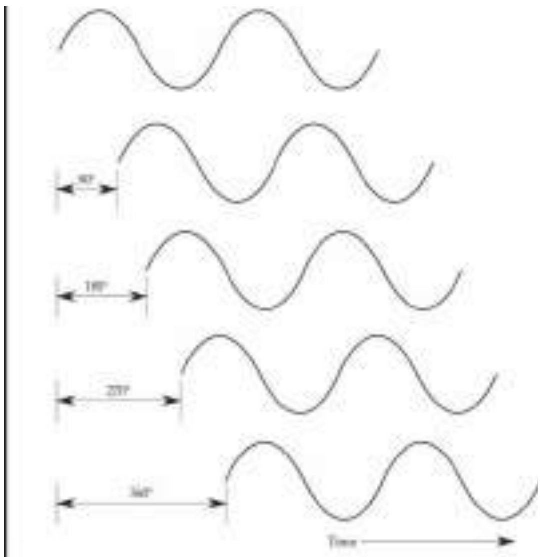


FIGURE 1-10 Illustration of the phase relationships between waveforms with the same ampl and frequency. A rotation of 360° is analogous to one complete sine-wave cycle.

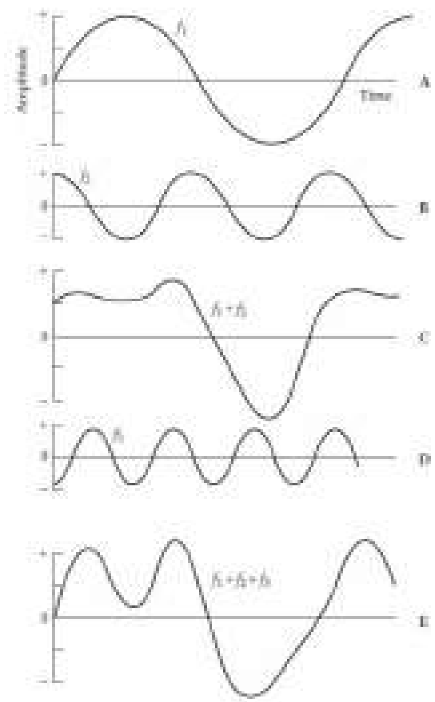


FIGURE 1-11 A study of the combination of sine waves that are not in phase. (A) The fundamental frequency f_1. (B) The second harmonic f_2 with twice the frequency and half the amplitude of f_1 advanced 90° with respect to f_1. (C) The combination of f_1 and f_2 obtained by adding ordinates point by point. (D) The third harmonic $f3$ with phase 90° behind f_1, and with half the amplitude of f_1. (E) The sum of f_1, f_2, and $f3$. Compare this resulting waveform with that of Fig. 1-9E. The difference in waveform is due entirely to the shifting of the phase of the harmonics with respect to the fundamental.

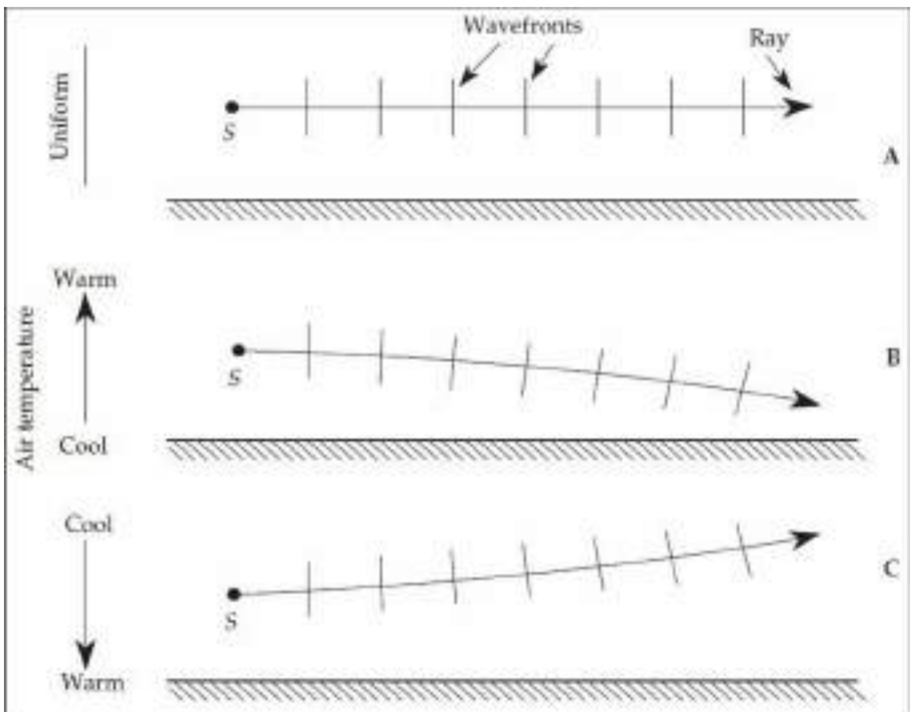


FIGURE 8-3 Refraction of sound paths resulting from temperature gradients in the atmosphere. (A) Air temperature constant with height. (B) Cool air near the surface of the earth and warmer air above. (C) Warm air near the earth and cooler air above.

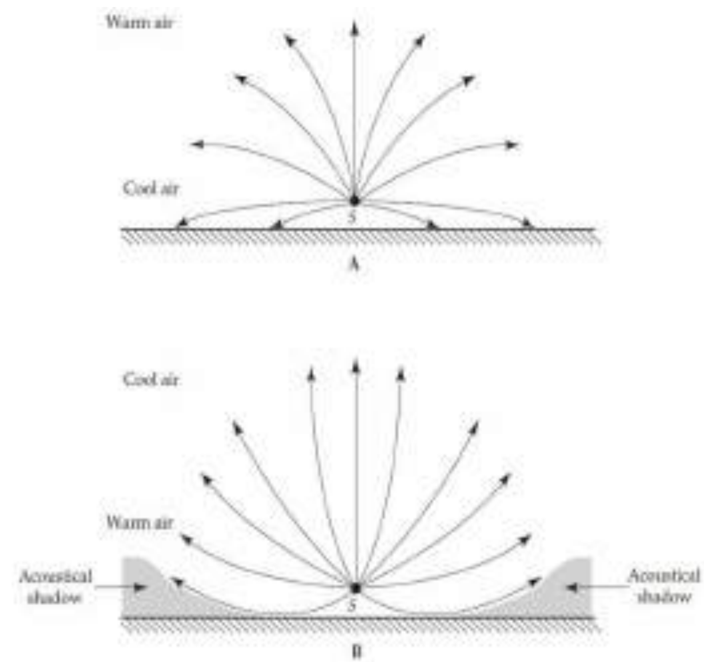


FIGURE 8-4 Comprehensive illustration of refraction of sound from source. (A) Cool air near the ground and warmer air above. (B) Warm air near the ground and cooler air above; note that acoustical shadow areas result from the upward refraction.

T3: Audibility of differences in level

Difference in levels	Audibility
1 dB	Just audible
3 dB	Audible
5 dB	Clearly audible
10 dB	Subjective doubling of loudness
20 dB	Subjective four-fold increase in loudness

T4: Sound power levels of musical instruments and singing voices

Sound source	Sound power level L_{WA} [dB] *pp – ff*
String instruments	55–95
Woodwind instruments	70–100
Brass instruments	70–115
Grand piano	70–115
Percussion instruments	90–120
Organ, whole orchestra	up to 135
Singing voices	80–115

- A
- B
- C
- D

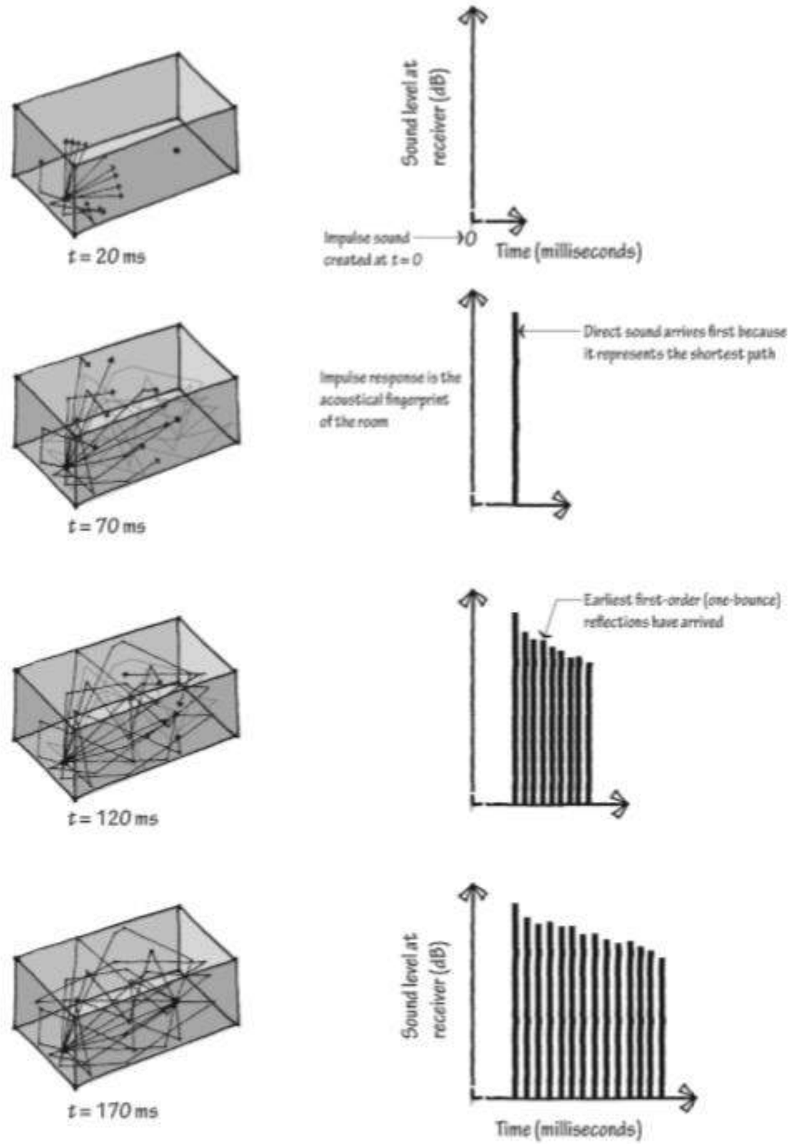
Sound Power Level:

$$SWL = 10 \cdot \log (W_{RMS} / W_o)$$

Reference power:

$$W_o = 10^{-12}\ W$$

Standing Waves



- A
- B
- C
- D

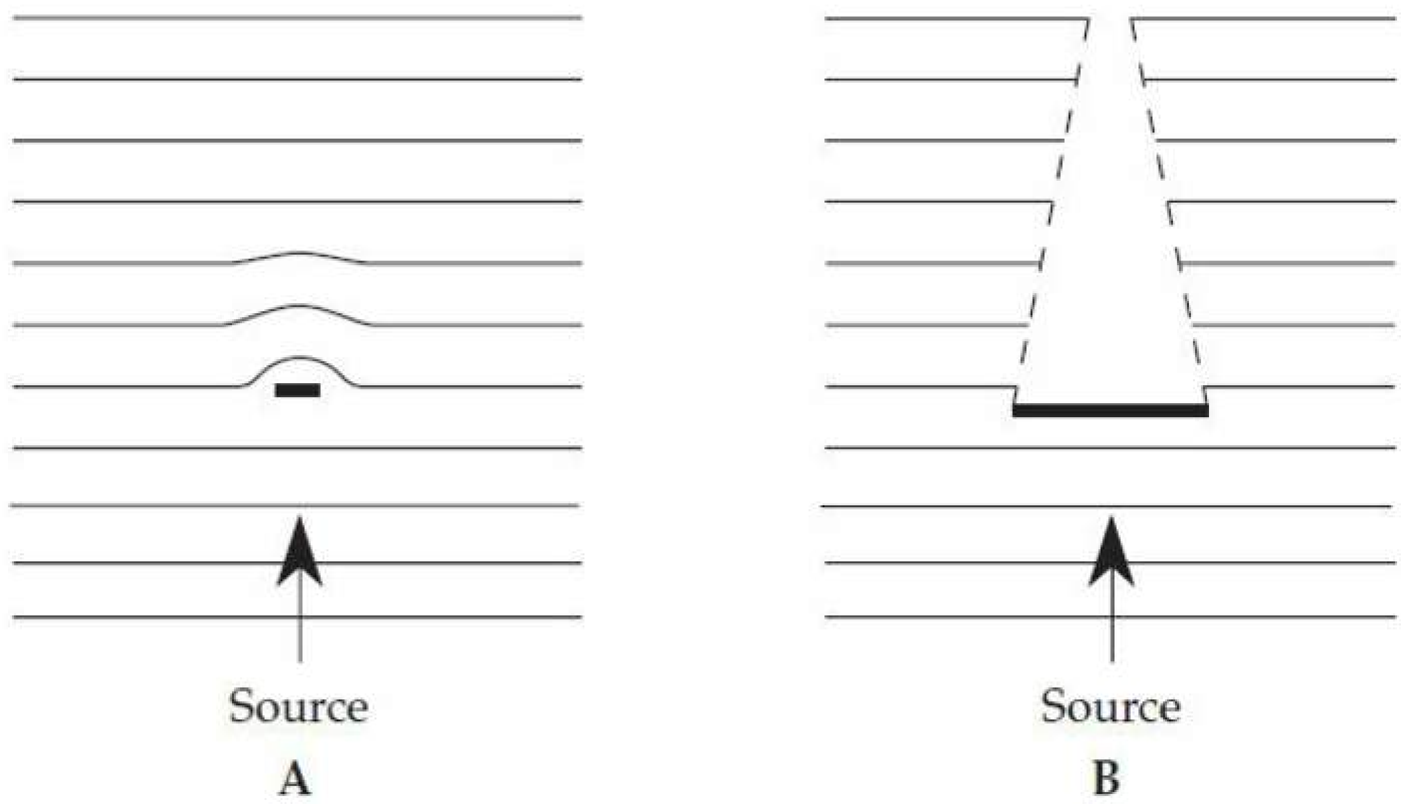


FIGURE 7-1 Diffraction varies according to the wavelength of sound and the size of an obstacle. (A) An obstacle very much smaller than the wavelength of sound allows the wavefronts to pass essentially undisturbed. (B) An obstacle larger than the wavelength casts an acoustical shadow.

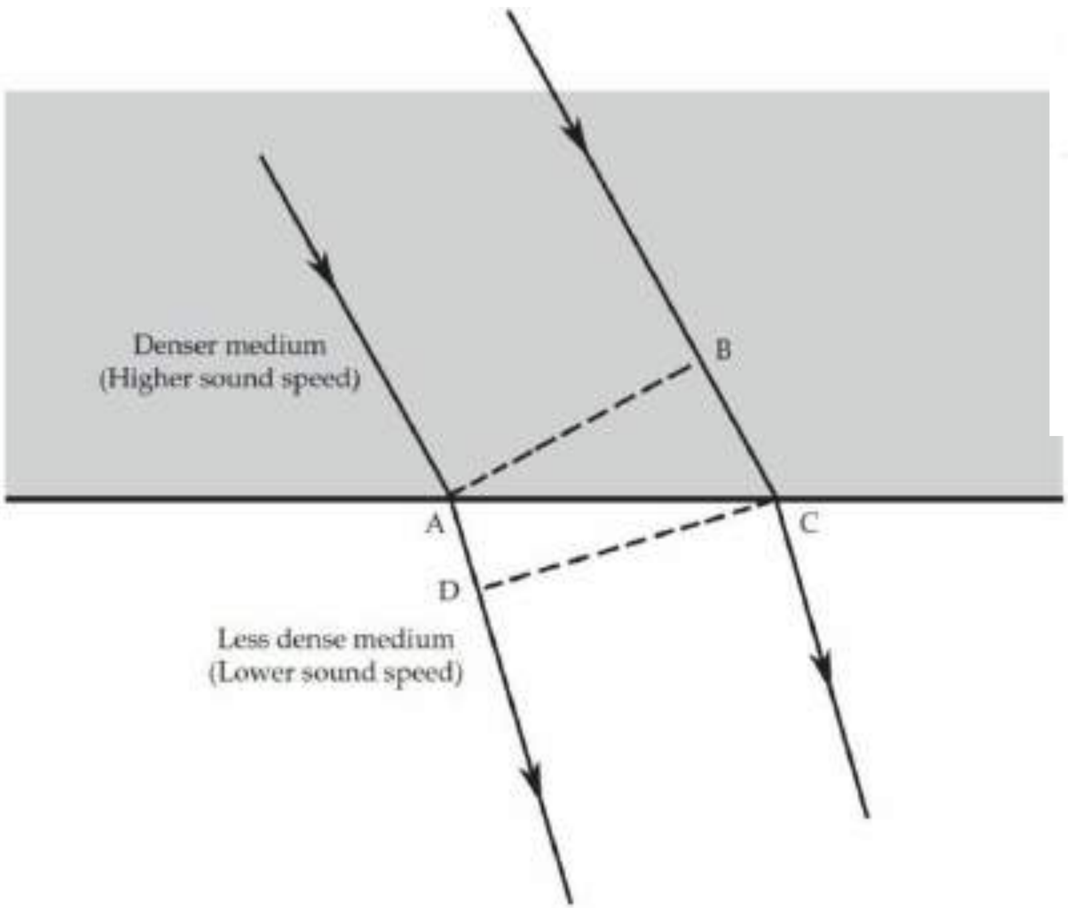
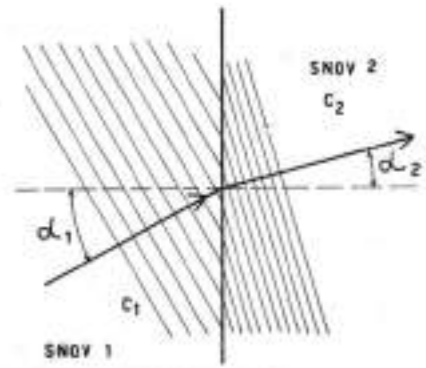


FIGURE 8-2 Rays of sound in this example are refracted when traveling from a denser medium having a higher sound speed into a less dense medium having a lower sound speed. The wavefront A-B is not parallel to wavefront C-D because the direction of the wave is changed due to refraction.

Difrakcija zvoka zelo vpliva na zvočno sliko (viseči predmeti, ornamenti, nepravilne oblike površin ...).

2.04 Refrakcija zvočnih valov



$$\frac{\sin \alpha_1}{c_1} = \frac{\sin \alpha_2}{c_2}$$

ali

$$\frac{\sin \alpha_1}{\sin \alpha_2} = \frac{c_1}{c_2}$$

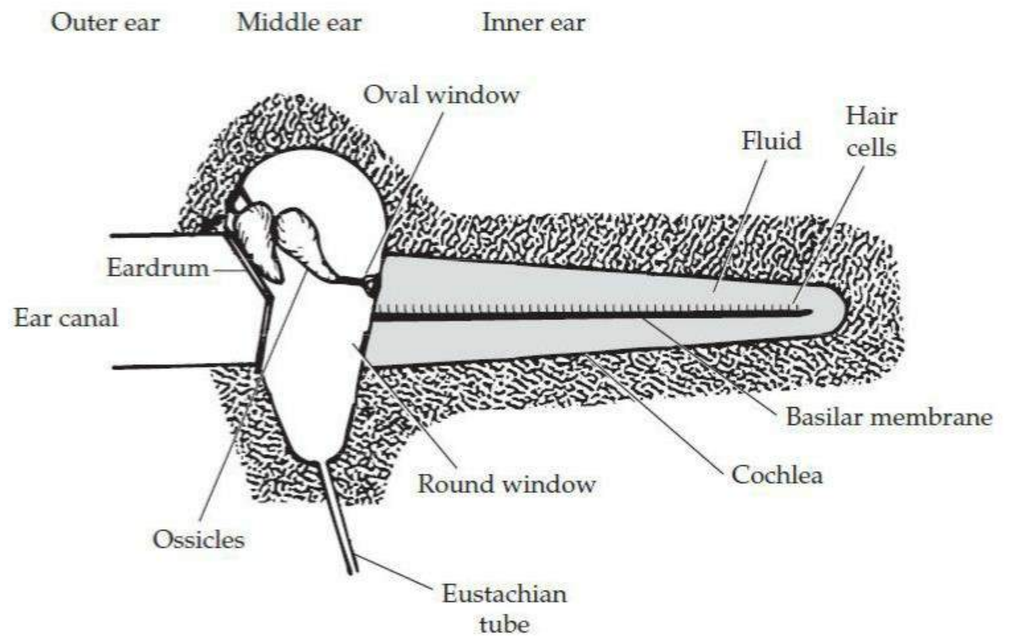


FIGURE 4-5 Idealized sketch of the human ear showing the uncoiled fluid-filled cochlea. Sound entering the ear canal causes the eardrum to vibrate. This vibration is transmitted to the cochlea through the mechanical linkage of the middle ear. The sound is analyzed through standing waves set up on the basilar membrane.

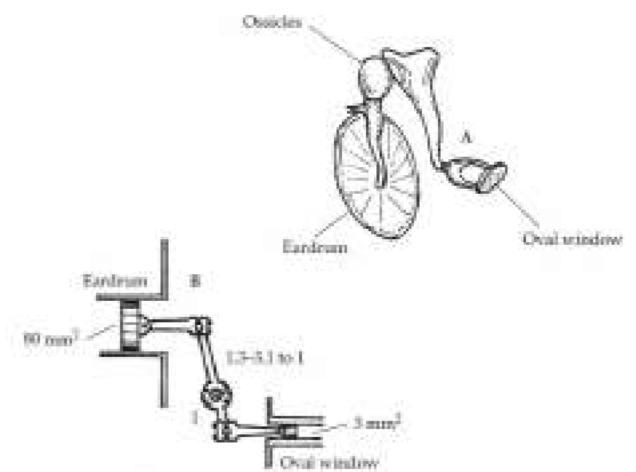
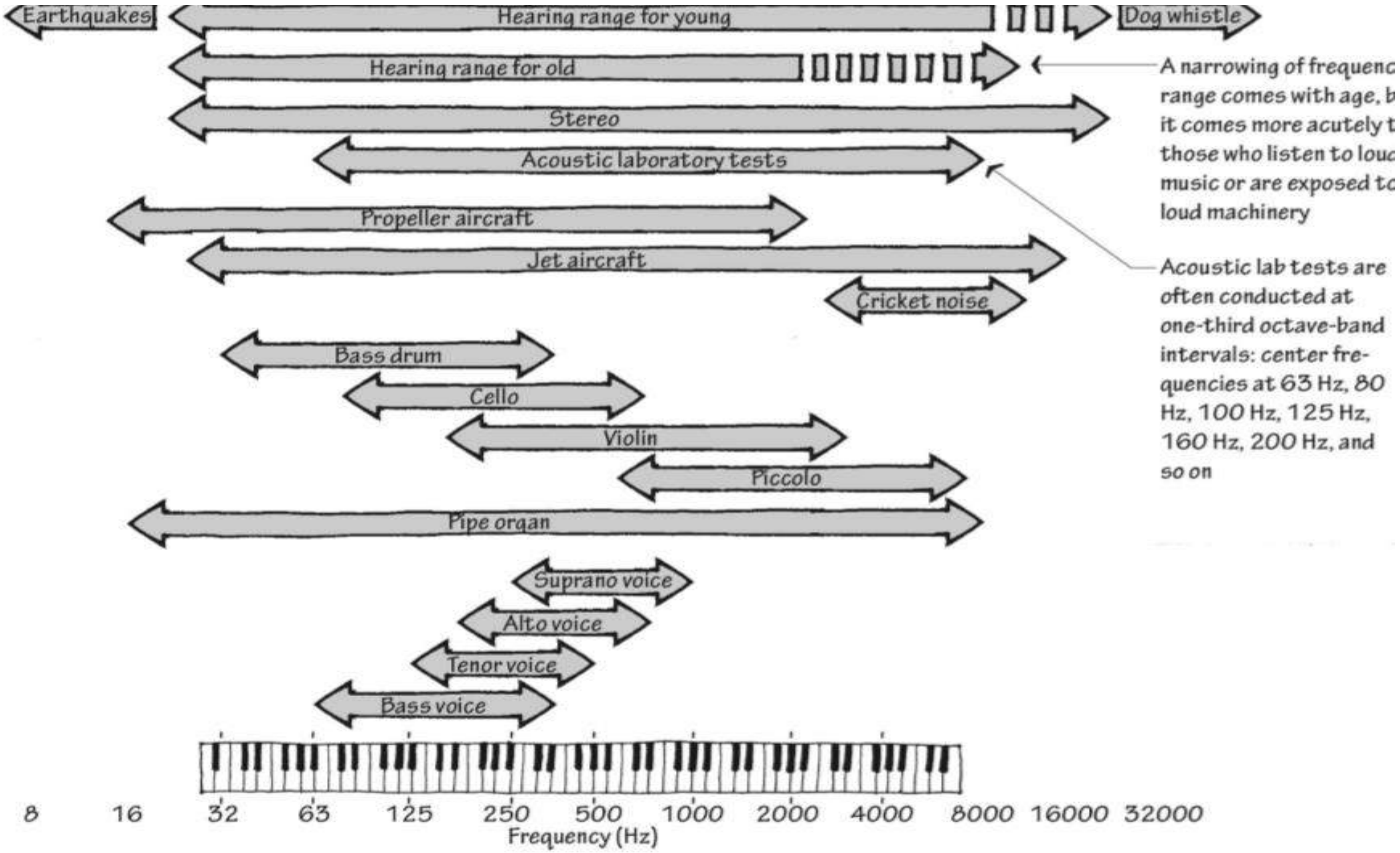


FIGURE 4-4 The middle ear provides impedance matching. (A) The ossicles (hammer, anvil, and stirrup) of the middle ear transmit mechanical vibrations of the eardrum to the oval window of the cochlea. (B) A mechanical analog of the impedance-matching function of the middle ear. The difference in area between the eardrum and the oval window, coupled with the step-down mechanical linkage, matches the motion of the air-actuated eardrum to the fluid-loaded oval window

Abcd



Earthquakes
Hearing range for young
Dog whistle
Hearing range for old
A narrowing of frequenc range comes with age, b it comes more acutely t those who listen to louc music or are exposed tc loud machinery
Stereo
Acoustic laboratory tests
Propeller aircraft
Jet aircraft
Cricket noise
Acoustic lab tests are often conducted at one-third octave-band intervals: center fre- quencies at 63 Hz, 80 Hz, 100 Hz, 125 Hz, 160 Hz, 200 Hz, and so on
Bass drum
Cello
Violin
Piccolo
Pipe organ
Suprano voice
Alto voice
Tenor voice
Bass voice
8 16 32 63 125 250 500 1000 2000 4000 8000 16000 32000
Frequency (Hz)

- A
- E
- (
- [

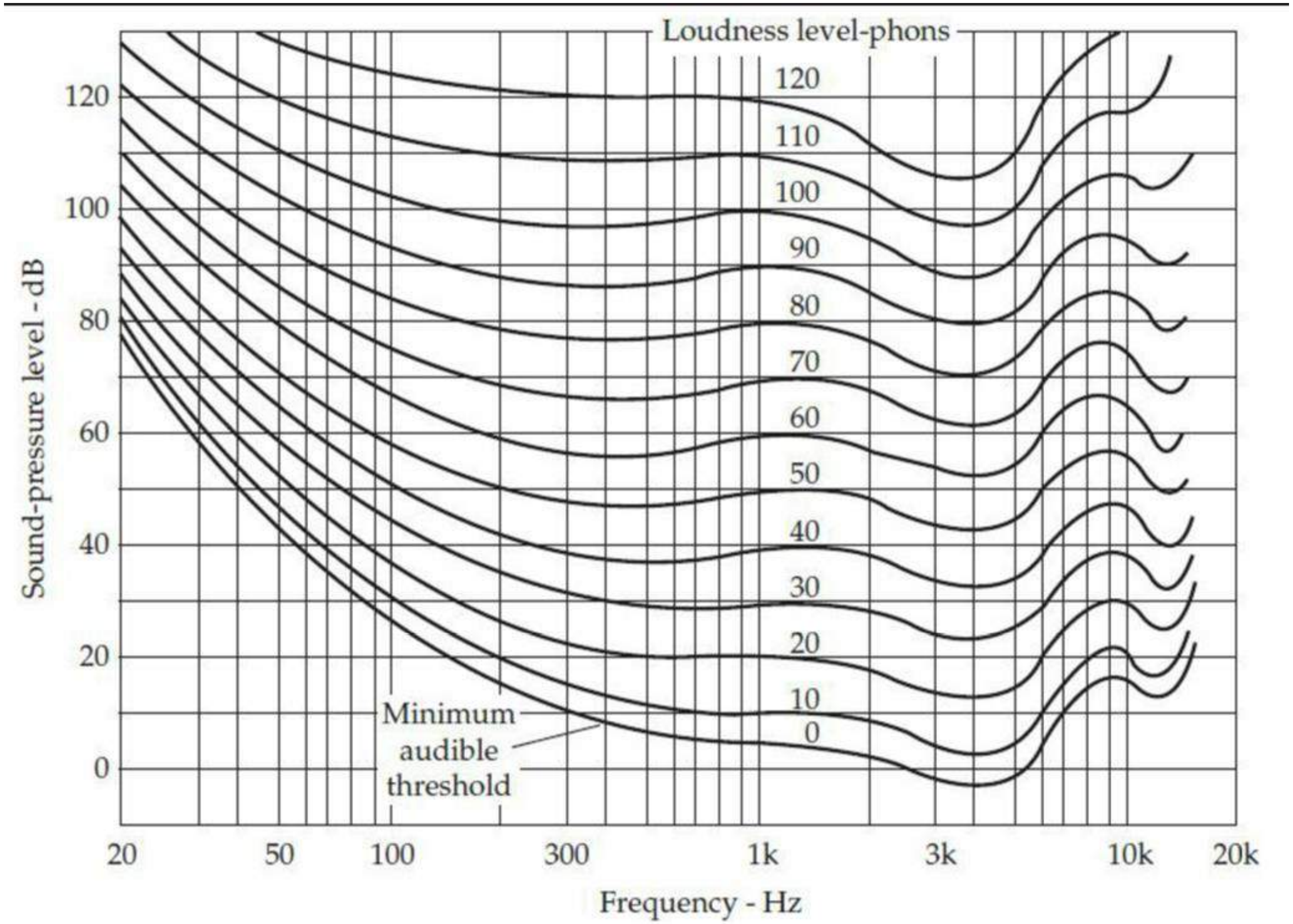


Figure 4-6 Equal-loudness contours of the human ear for pure tones. These contours reveal the relative lack of sensitivity of the ear to bass tones, especially at lower sound levels. Inverting these curves gives the frequency response of the ear in terms of loudness level. These data are taken for a sound source directly in front of the listener, pure tones, binaural listening, and subjects aged 18 to 25. (*Robinson and Dadson.*)

Phon = dB (1000 Hz)

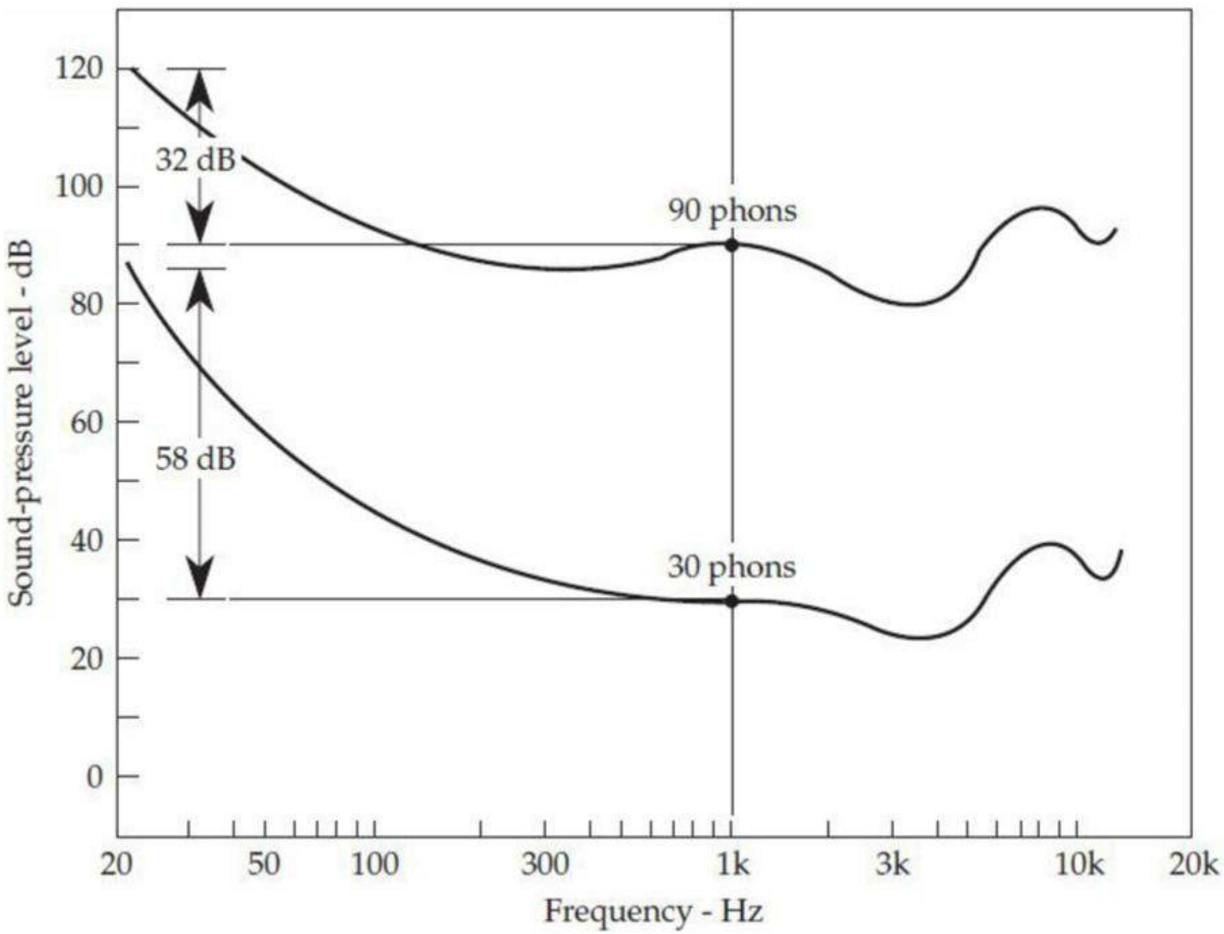


FIGURE 4-7 A comparison of the ear's response at 20 Hz, to the response at 1 kHz. At a loudness level of 30 phons, the sound-pressure level of a 20-Hz tone must be 58 dB higher than that at 1 kHz to have the same loudness. At a 90-phon loudness level, an increase of only 32 dB is required. The ear's response is somewhat flatter at high loudness levels. Loudness level is only an intermediate step to true subjective loudness.

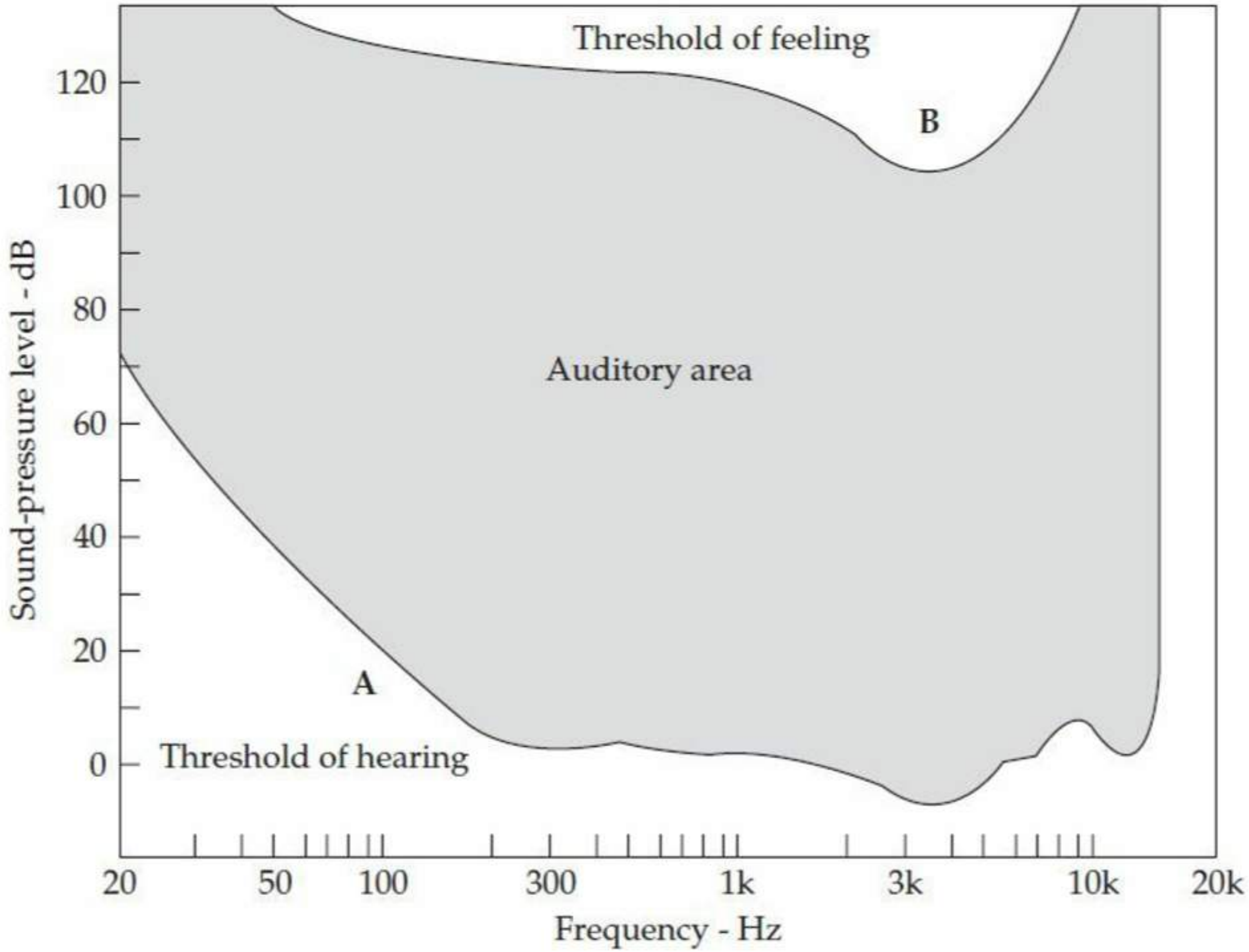
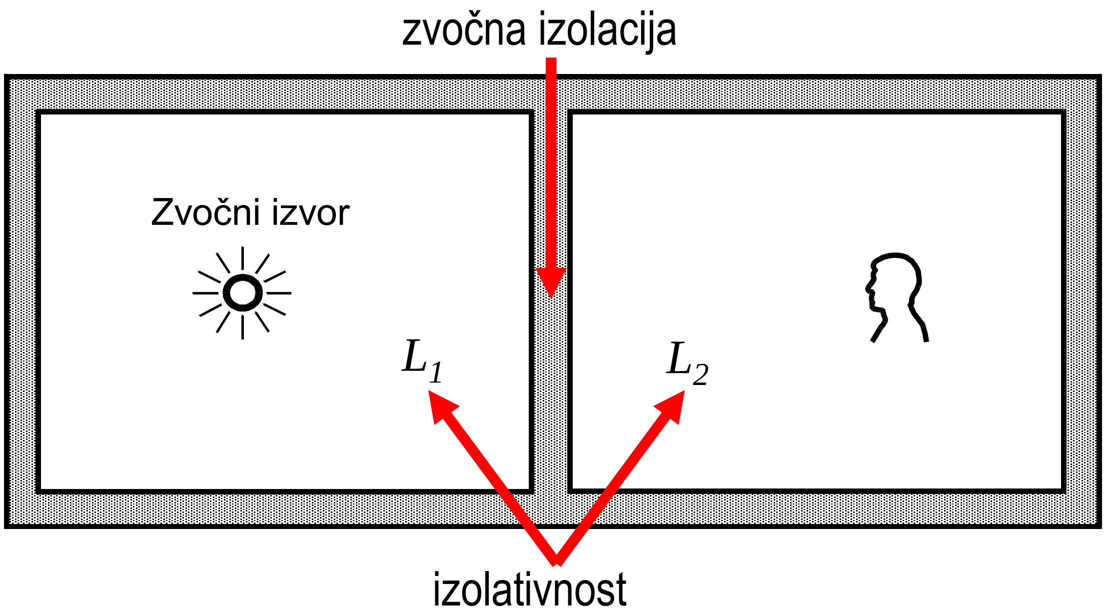


FIGURE 4-8 The auditory area of the human ear is bounded by two threshold contours. (A) The threshold of hearing delineates the lowest level sounds the ear can detect. (B) The threshold of feeling defines the upper extreme. All of our auditory experiences occur within this area.

Cilj zvočne izolirnost je doseganje zmanjšanja zvočne ravni med prostorom z izvorom zvoka in sprejemnim prostorom



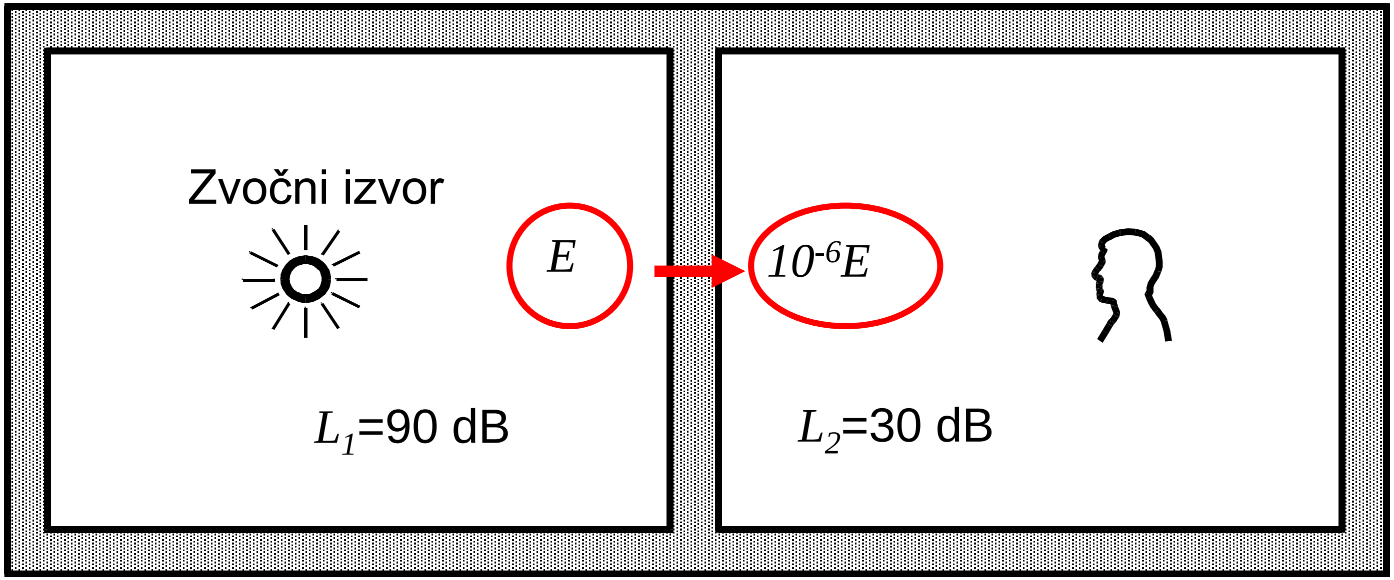
Opredelitve osnovnih pojmov:

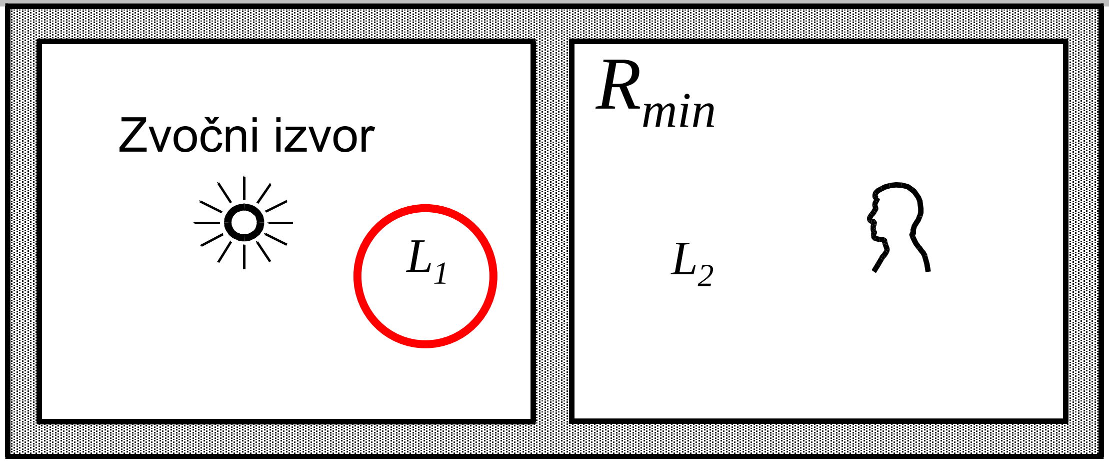
razlika zvočne ravni	*D*	(L_1 - L_2)
zvočna izolacija	*R*	lastnost pregrade da zadrži / oslabi zvok

Zvočna zaščita se ukvarja s prilagoditvijo *D* med prostori v stavbi

Osnovni problem pri doseganju zadostne zvočne izolativnosti je v tem, da ima čut sluha ekstremne zahteve – torej je izredno občutljiv.
Zato se zahtevajo izjemno velika dušenja zvočne energije v pregradnih stenah, medetažnih konstrukcijah…..

Zadovoljiva izolativnost 60 dB predstavlja padec energije na milijonti del prvotne energije.



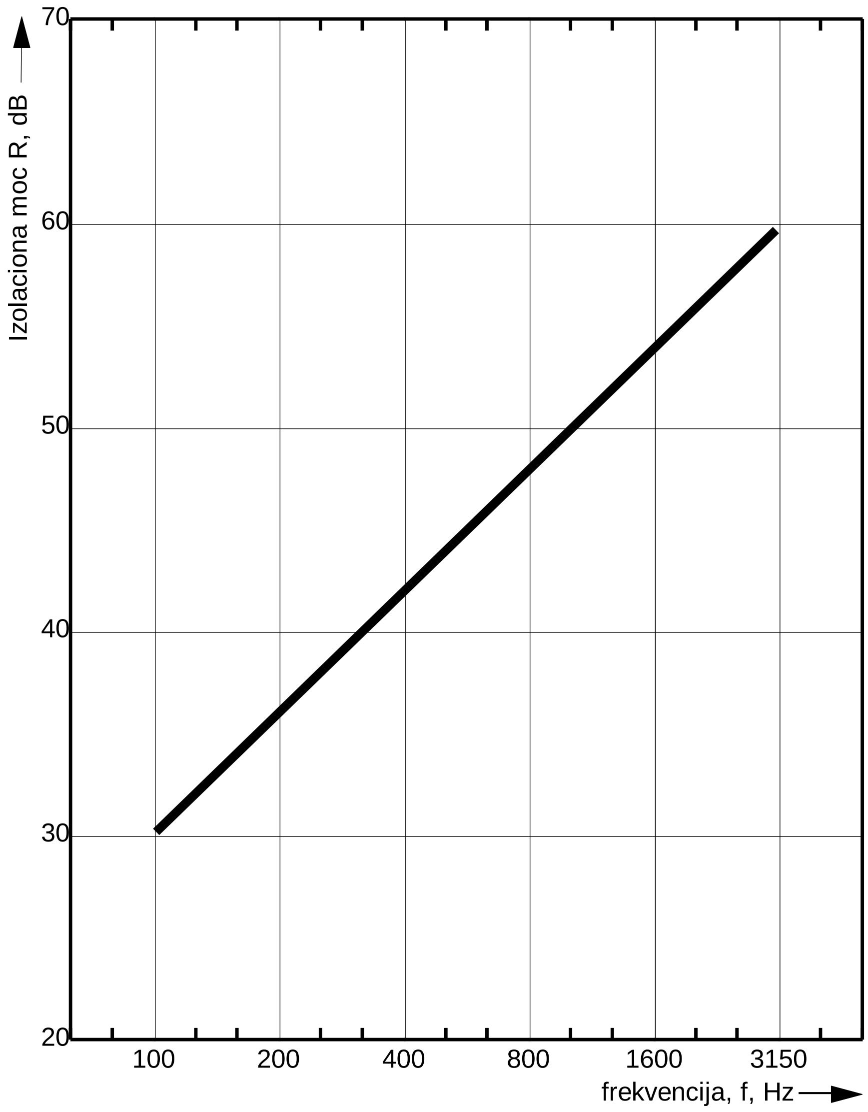


Za primere normalnih okoliščin so v predpisih predvidene pričakovane vrednosti L_1 za prostore z izvorom zvoka, kot n.pr stanovanja, pisarne......

Da bi dosegli določeno akustično udobje v sosednih prostorih, se definirajo minimalne vrednosti izlativnosti za vmesne pregrade R_{min}.

Kadar ne obstaja ena jasno definirana vmesna pregrada izmed dveh prostorov, takrat se definira minimalna izolativnost D_{min}.

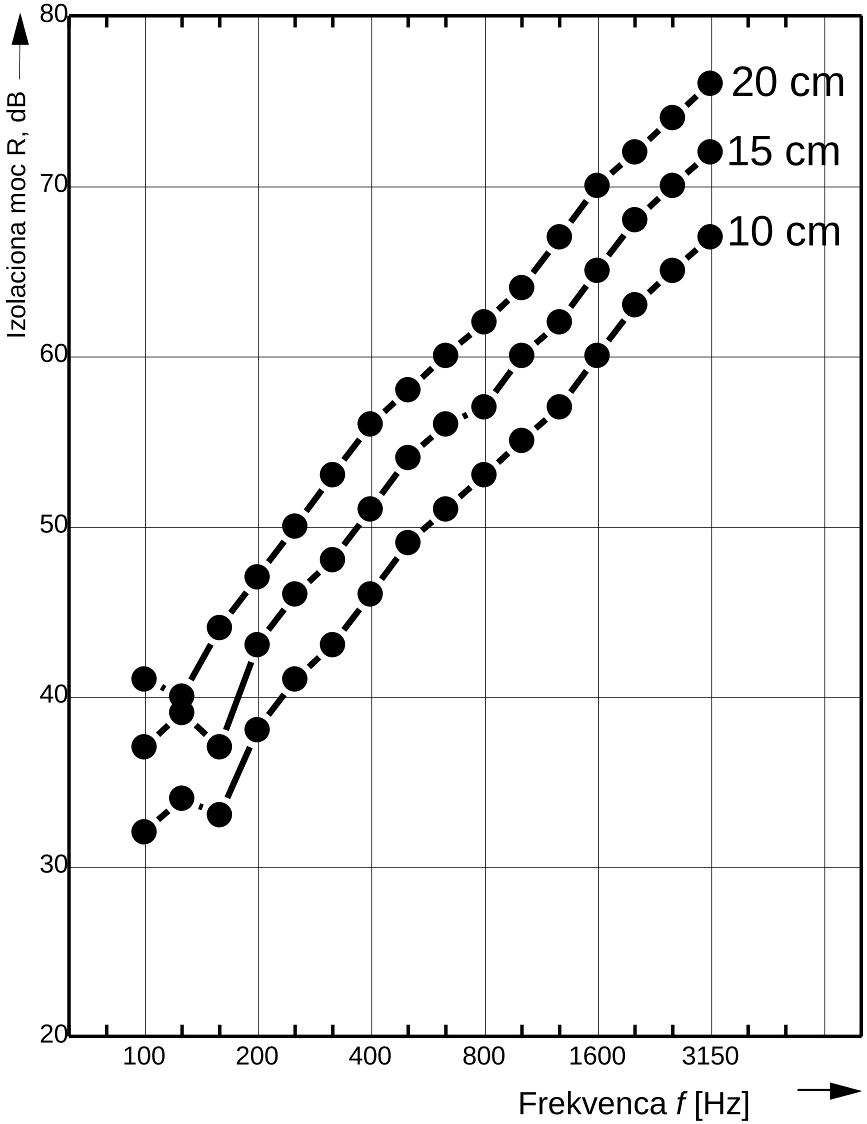
Vpliv frekvence na zvočno izolacijo pregrade



Karakteristični diagram zvočne izolativnosti *R* v odvisnosti od frekvence *f* v skladu z zakonom mase za določeno pregrado mase *m*

Zvočna izolacija vsake pregrade raste s frekvenco zvoka (tudi z lastno maso pregrade)

Vpliv mase pregrade na zvočno izolacijo



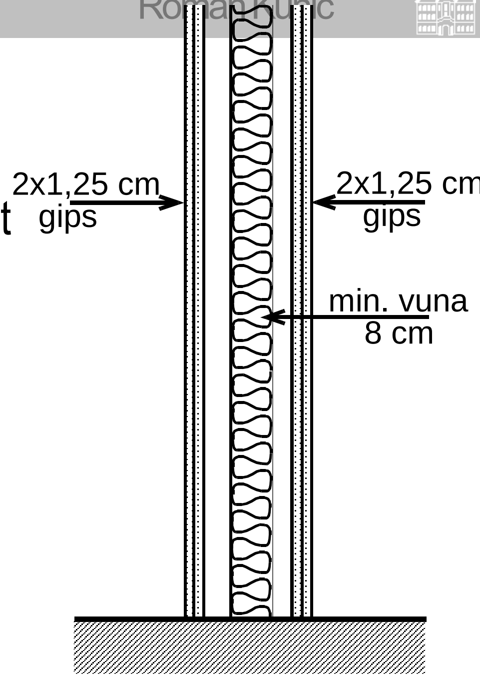
Primer: zvočna izolativnost pregrade iz armiranega betona

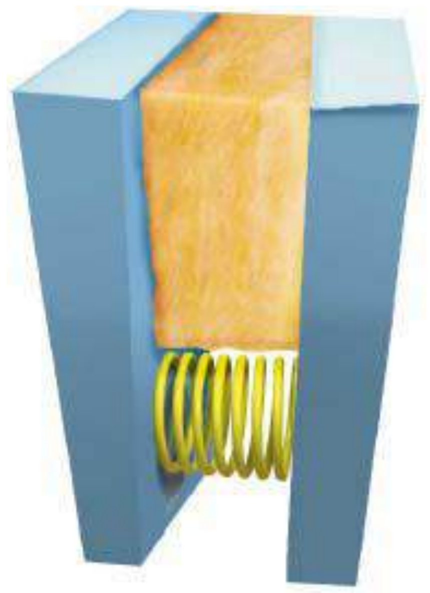
parameter označen na diagramu je debelina pregrade)

zvočna izolativnost stene je neposredno sorazmerna z njeno površinsko maso

Poseben primer večplastnih pregrad so mavčne pregrade (narejene iz mavčno – kartonskih plošč na podkonstrukciji)

Njihov učinek v izolaciji se doseže z več prekinitvami in vmesno izolacijo kot polnilu, ki prinaša izgubo energije zvoka pri prehodu skozi pregradno steno





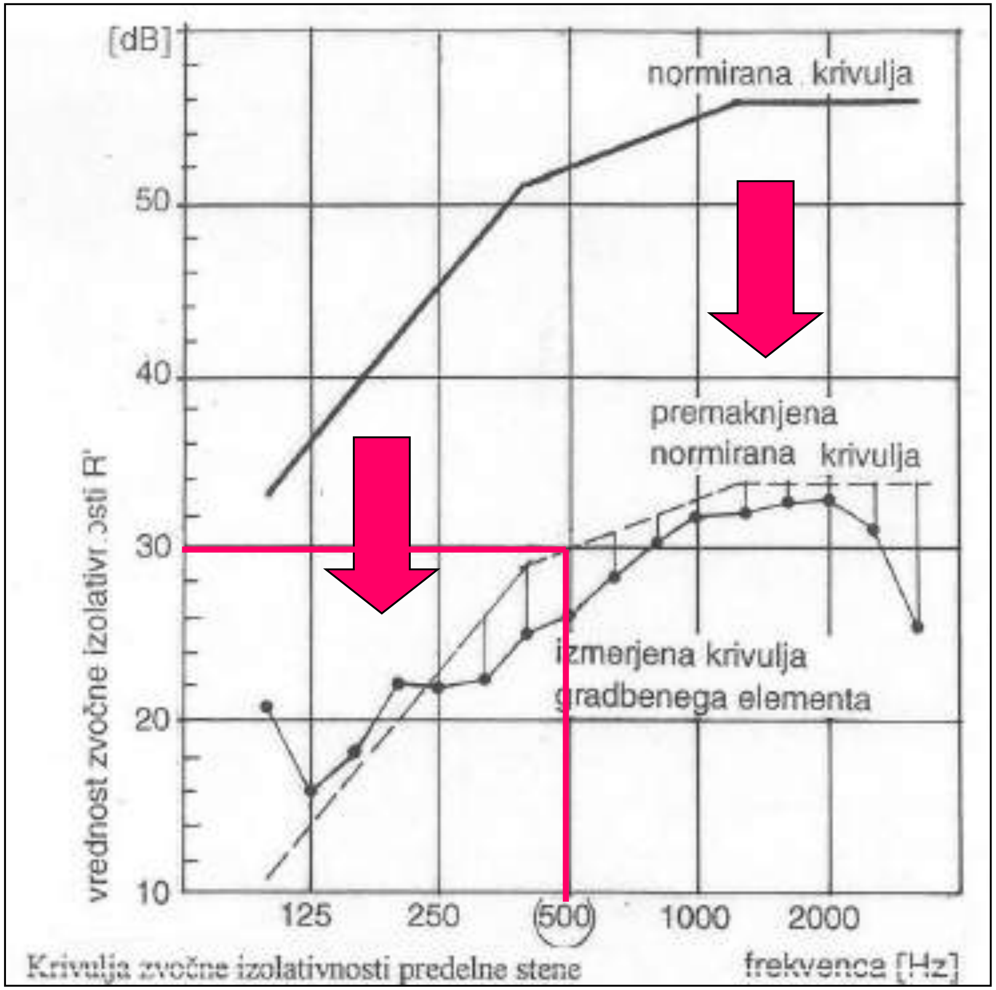
Ideja temelji na zmanjšanju povezave med oblogami. Za to se uporabljajo elastični elementi v stiku s kovinsko podkonstrukcijo..

Večja vrednost zvočne izolirnosti se doseže z ločenima podkonstrukcijama, saj ni togega stikovanja v sami dvojni pregradni steni.

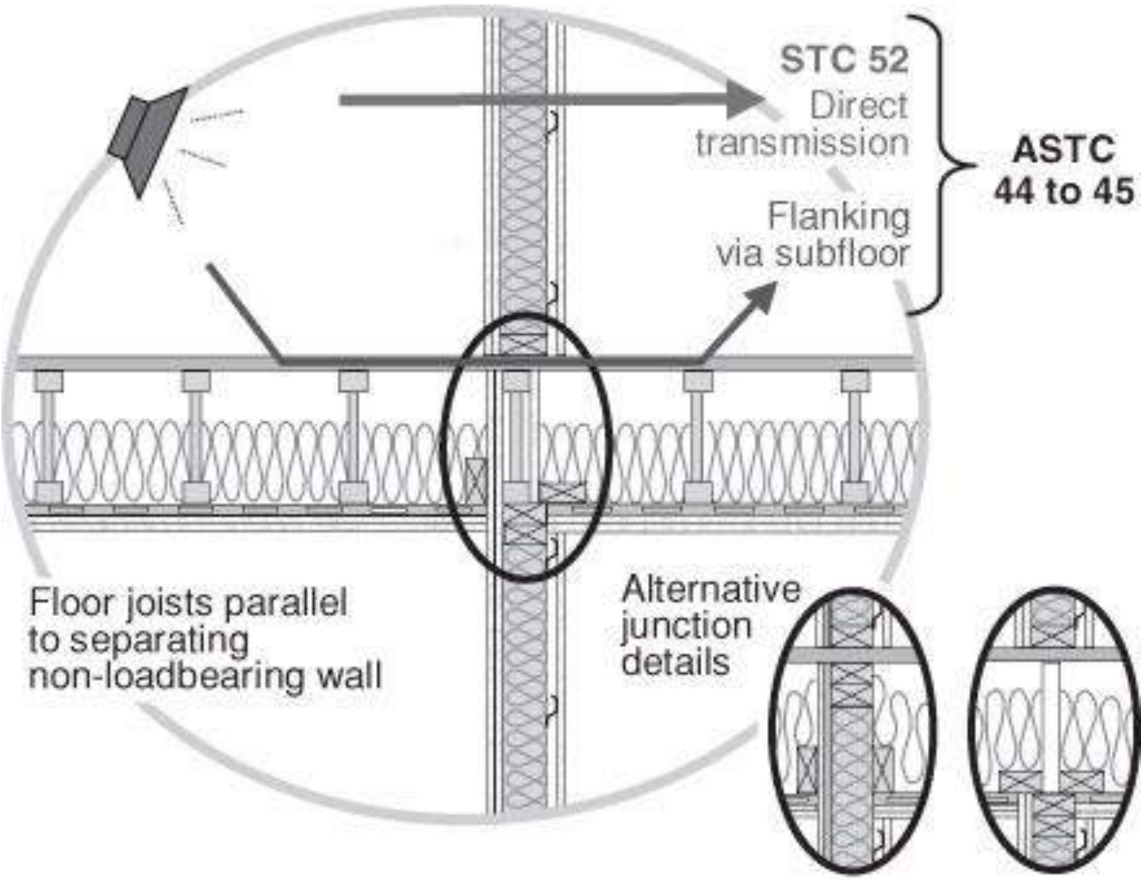
DOLOČANJE ZVOČNE IZOLIRNOSTI R_W

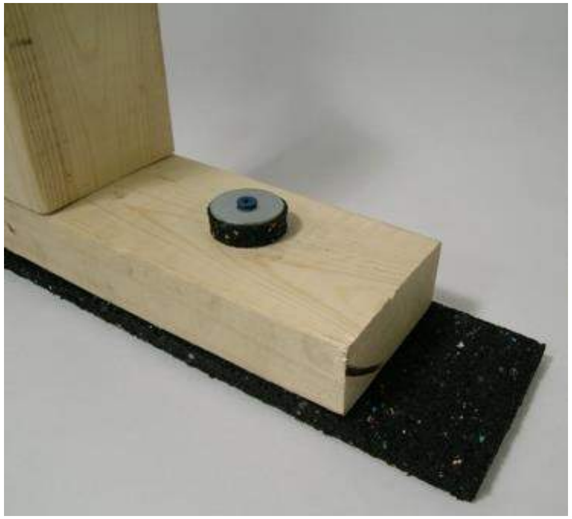
Normirana krivulja (upoštevamo samo vsoto negativnih odstopanj, ki ne sme biti večja kot 32dB)

Rw = odčitamo
LMS = Rw - 52 (SIST DIN 4109)



Tipični problemi s stranskim prenosom zvoka po zraku





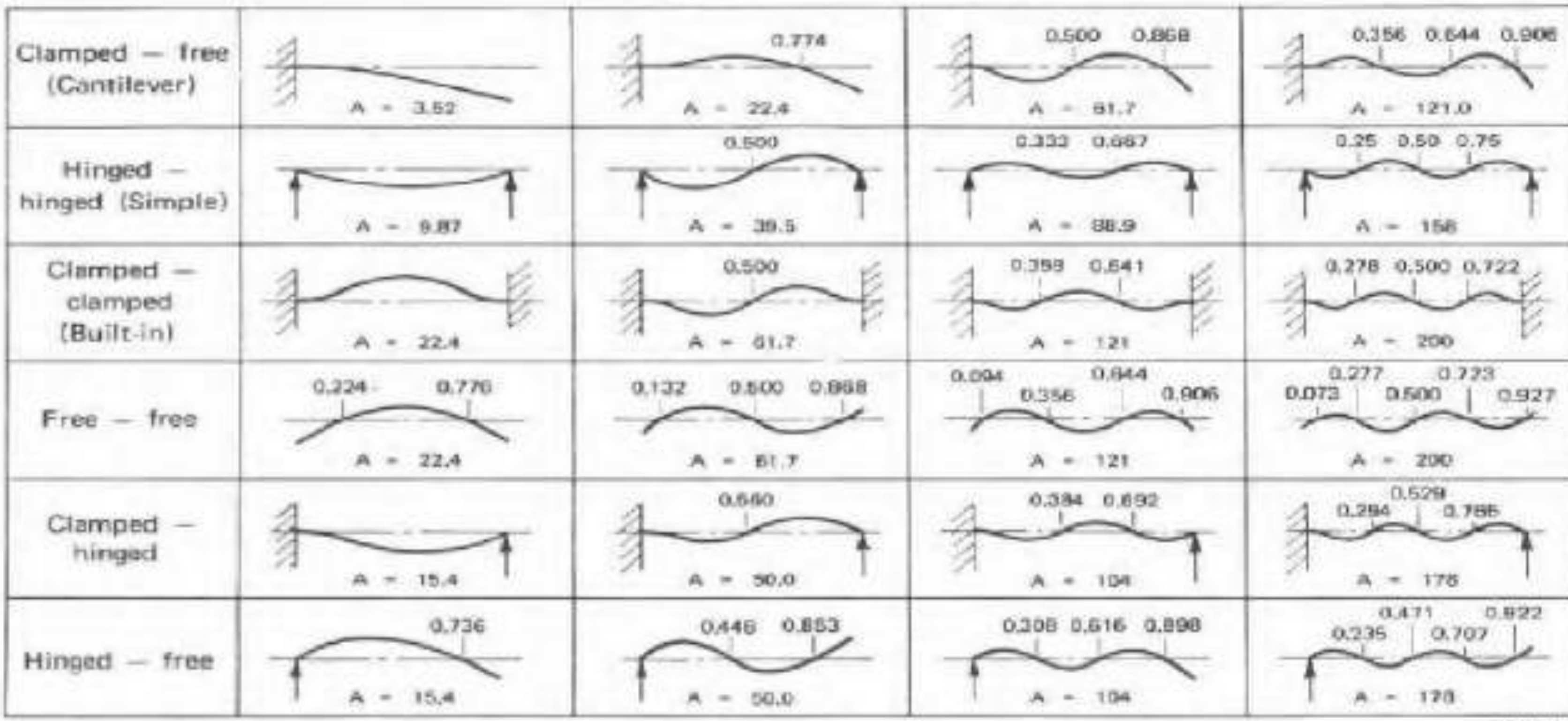
Ko imamo primer udarnega zvoka (npr. koraki) dosežemo zvočno zaščito s plavajočim podom

Plavajoči pod zelo malo prispeva k zvočni izolaciji stropa pri zvoku, ki se širi po zraku

Beams of uniform section and uniformly distributed load

Natural frequencies $f_n = \frac{A}{2\pi}\sqrt{\frac{EI}{\rho S l^4}}$

where E = Young's modulus
I = Area moment of inertia of beam cross section
l = Length of beam
ρ = Mass density of beam material
S = Area of cross-section
A = Coefficient from table below



	Mode 1	Mode 2	Mode 3	Mode 4
Clamped — free (Cantilever)	A = 3.52	0.774; A = 22.4	0.500 0.868; A = 61.7	0.356 0.644 0.906; A = 121.0
Hinged — hinged (Simple)	A = 9.87	0.500; A = 39.5	0.333 0.667; A = 88.9	0.25 0.50 0.75; A = 158
Clamped — clamped (Built-in)	A = 22.4	0.500; A = 61.7	0.359 0.641; A = 121	0.278 0.500 0.722; A = 200
Free — free	0.224 0.776; A = 22.4	0.132 0.500 0.868; A = 61.7	0.094 0.356 0.644 0.906; A = 121	0.073 0.277 0.500 0.723 0.927; A = 200
Clamped — hinged	A = 15.4	0.560; A = 50.0	0.384 0.692; A = 104	0.294 0.529 0.765; A = 178
Hinged — free	0.736; A = 15.4	0.446 0.853; A = 50.0	0.308 0.616 0.898; A = 104	0.235 0.471 0.707 0.922; A = 178

271281

Fig. 3.20. Examples of boundary conditions and mode-shapes for various single uniform beam configurations

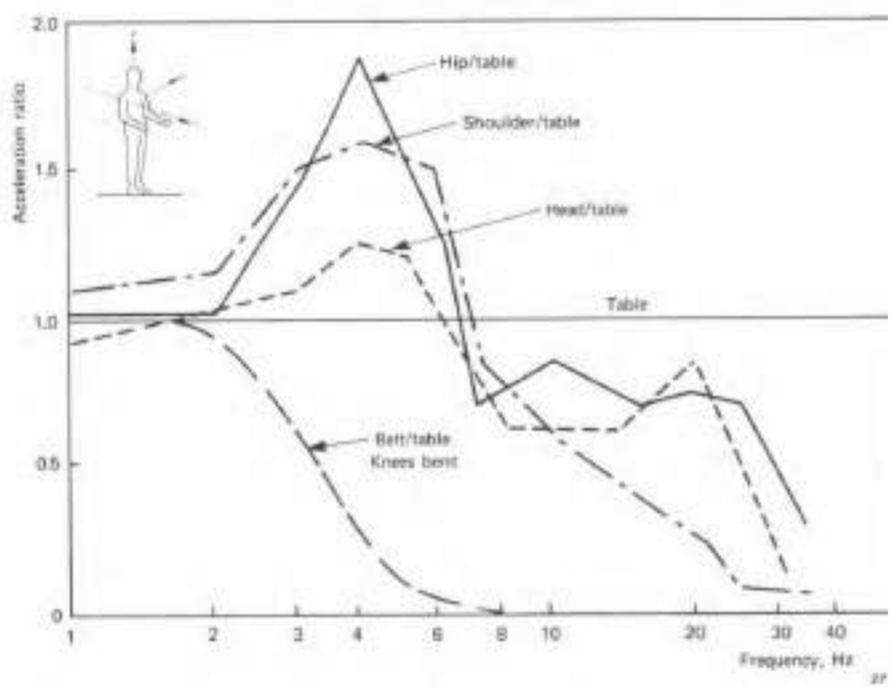


Fig.5.2. Transmissibility of vertical vibration from table to various parts of body of a standing human subject as a function of frequency. (After Dieckmann; data for transmission to belt, after Radke)

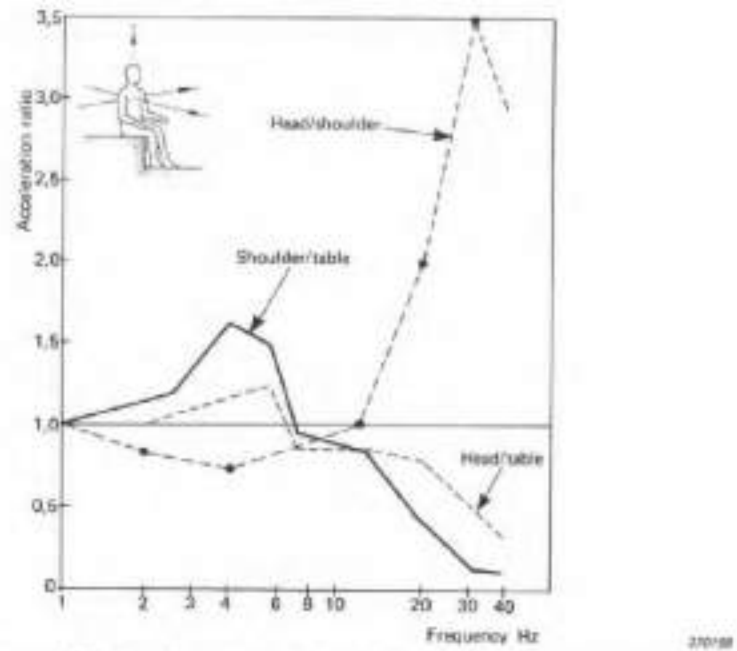


Fig.5.3. Transmissibility of vertical vibration from table to various parts of a seated human subject as a function of frequency. (After Dieckmann)

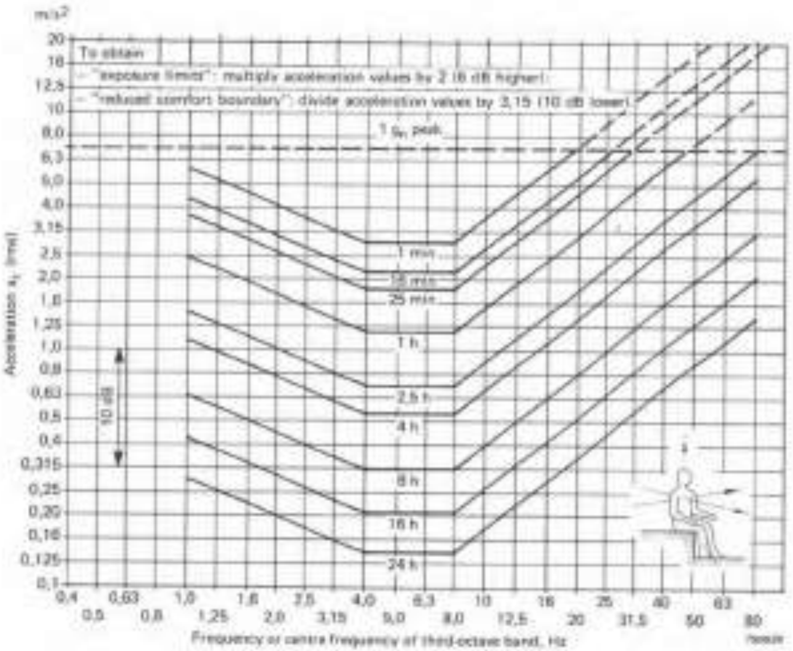


Fig.5.5. Vertical vibration exposure criteria curves defining equal fatigue-decreased proficiency boundaries

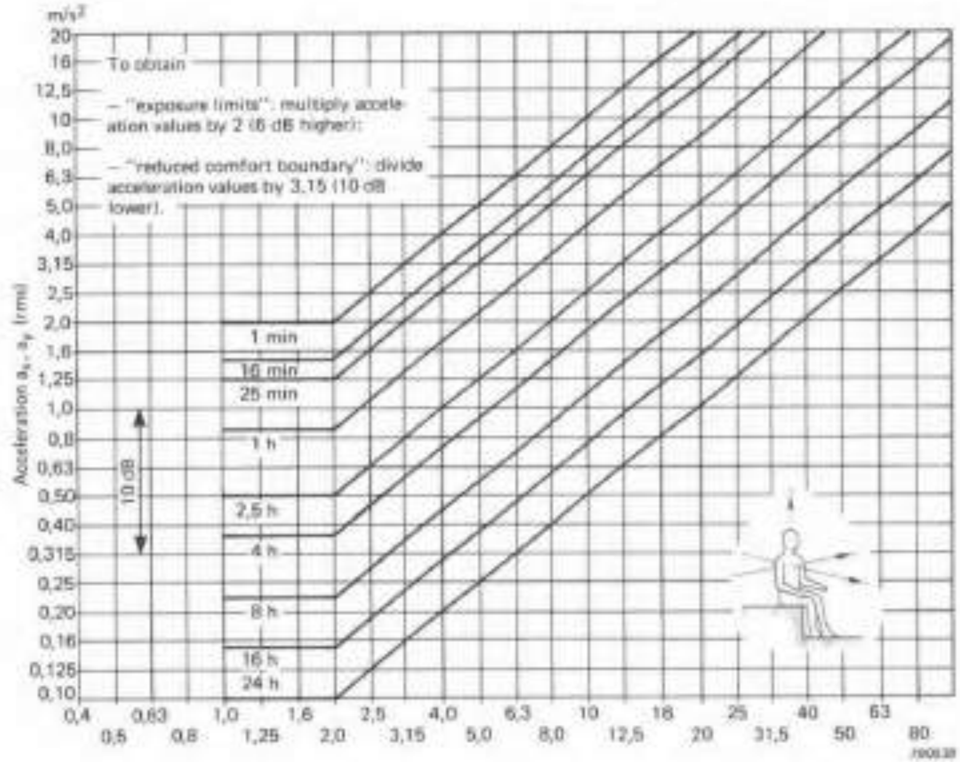


Fig.5.6. Lateral vibration exposure criteria curves defining equal fatigue-decreased proficiency boundaries

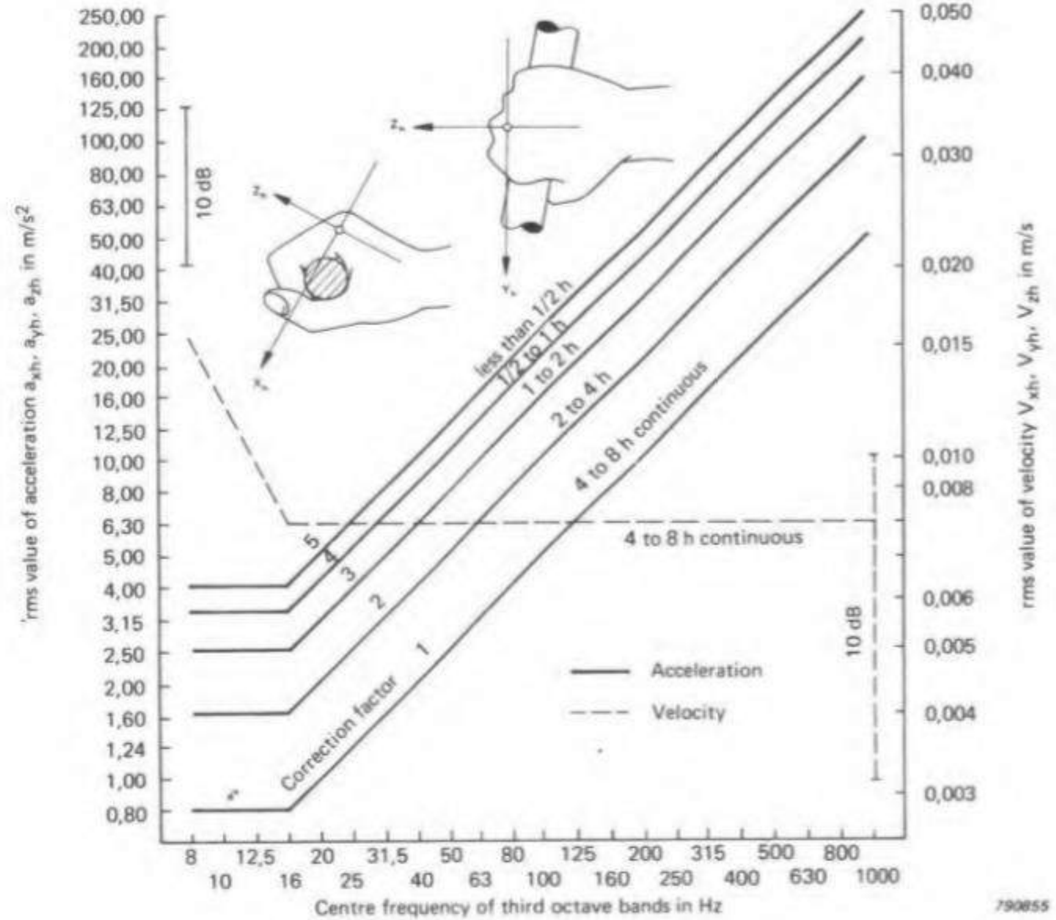


Fig.5.8. Exposure guidelines for vibration transmitted to the hand

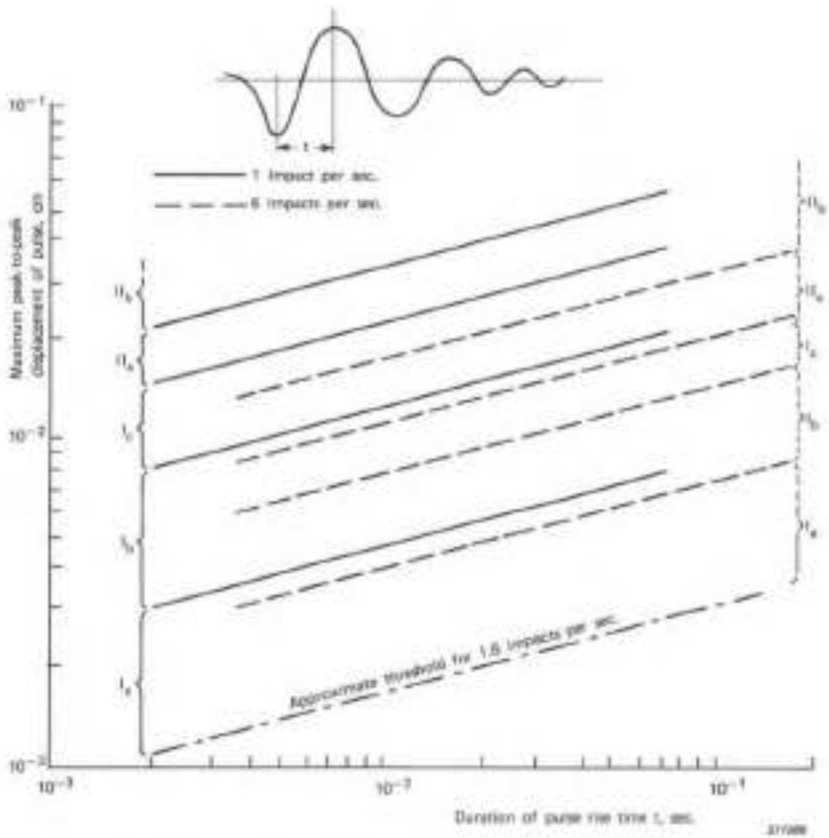
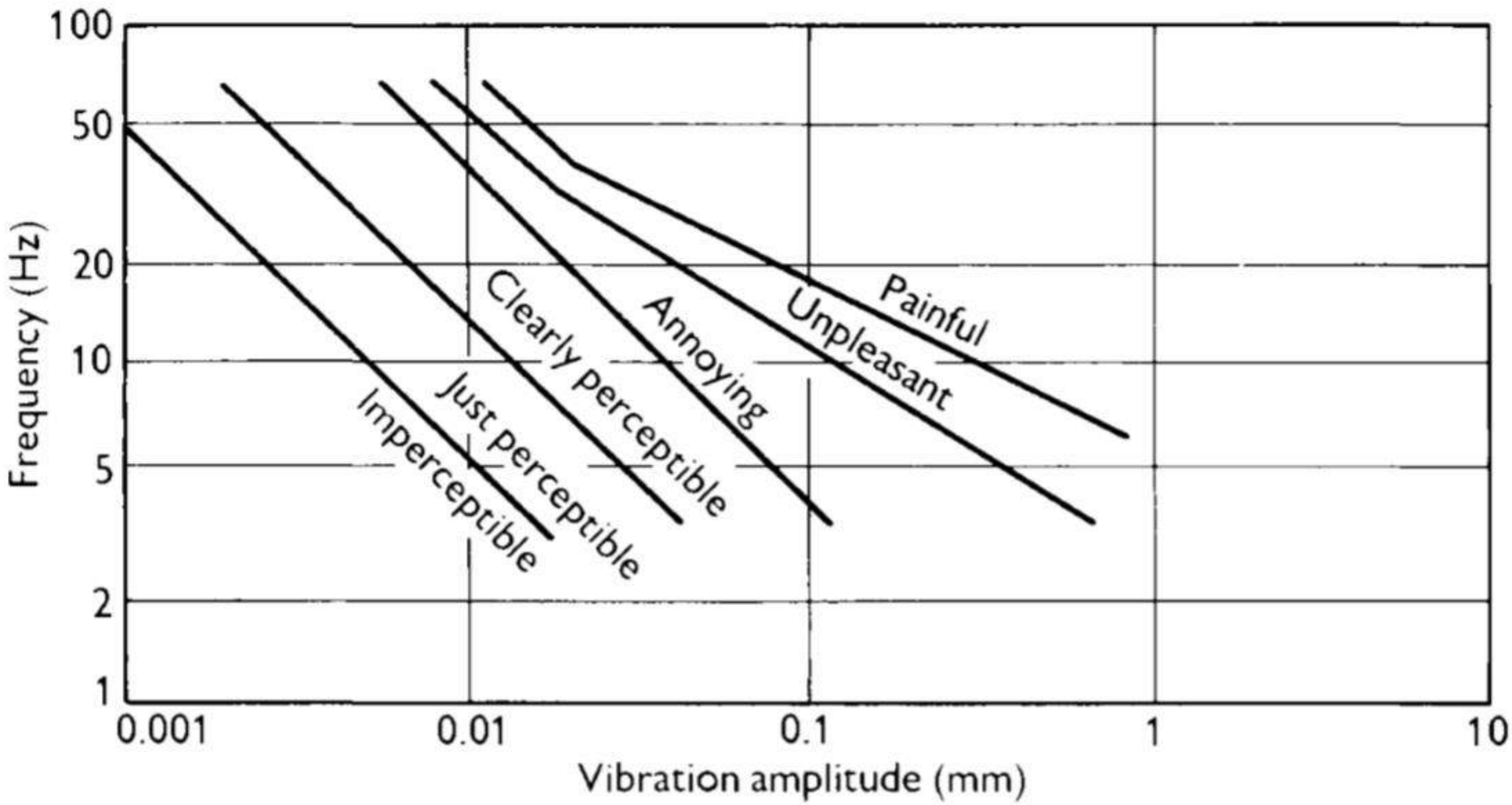


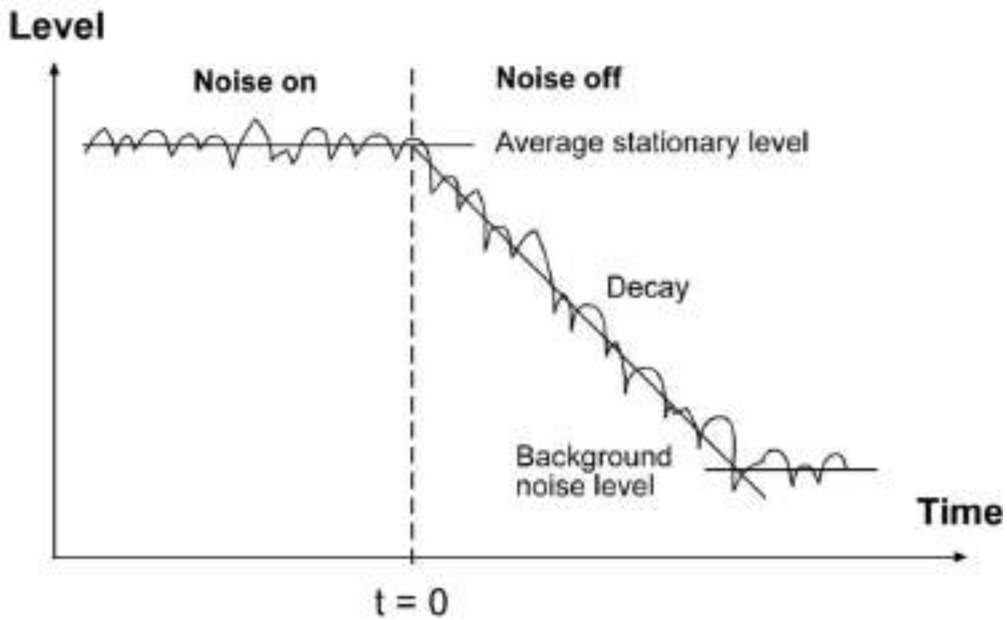
Fig.5.7. Tolerance of human subjects in the standing or supine position to repetitive vertical impact pulses representative of impacts from pile drivers, heavy tools, heavy traffic, etc. Subjective reaction is plotted as a function of the maximum displacement of the initial pulse and its rise time. The numbers indicate the following reactions for the areas between the lines: I a, threshold of perception; I b, for easy perception; I c, of strong perception, annoying; II a, very unpleasant, potential danger for long exposures; II b, extremely unpleasant, definitely dangerous. The decay process of the impact pulses was found to be of little practical significance. (After Reiher and Meister)

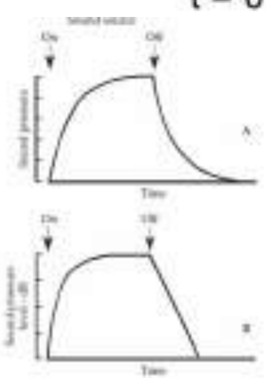
Amplituda vibracij

- A
- B
- C
- D



Abcd





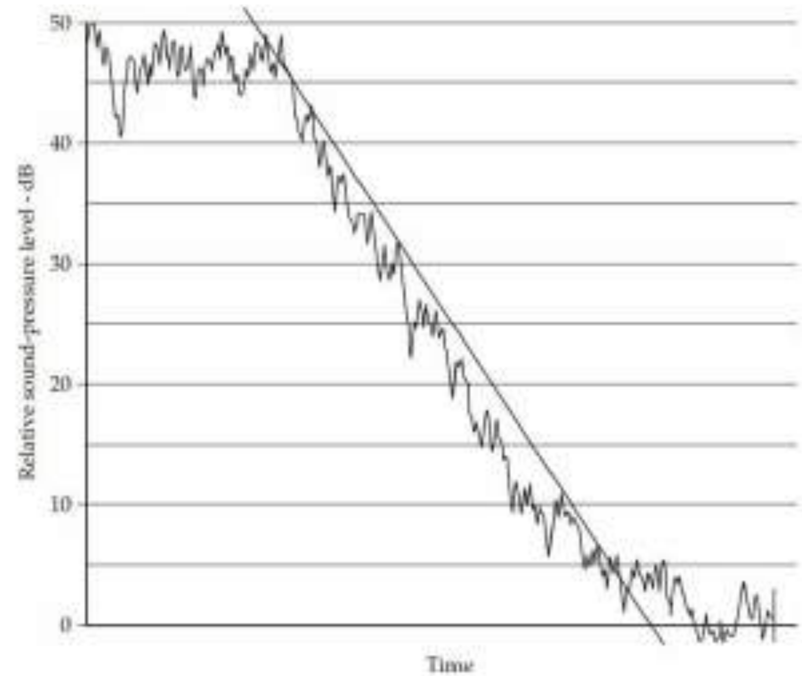


FIGURE 9-3 The nonexponential form of this decay is attributed to acoustically coupled spaces. The absence of a diffuse sound field is indicated.

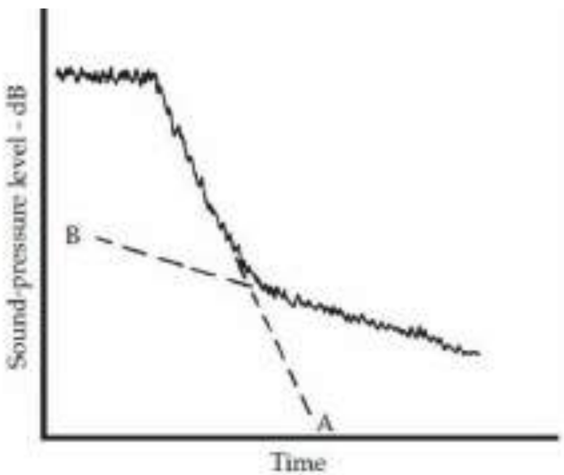


FIGURE 11-11 Reverberatory decay with a double slope due to acoustically coupled spaces. The shorter reverberation time represented by slope A is that of the main room. A second, highly reflective space is coupled through an open doorway; its longer reverberation time is represented by slope B. Those seated near the doorway are subjected first to the main-room response and then to the decay of the coupled space.

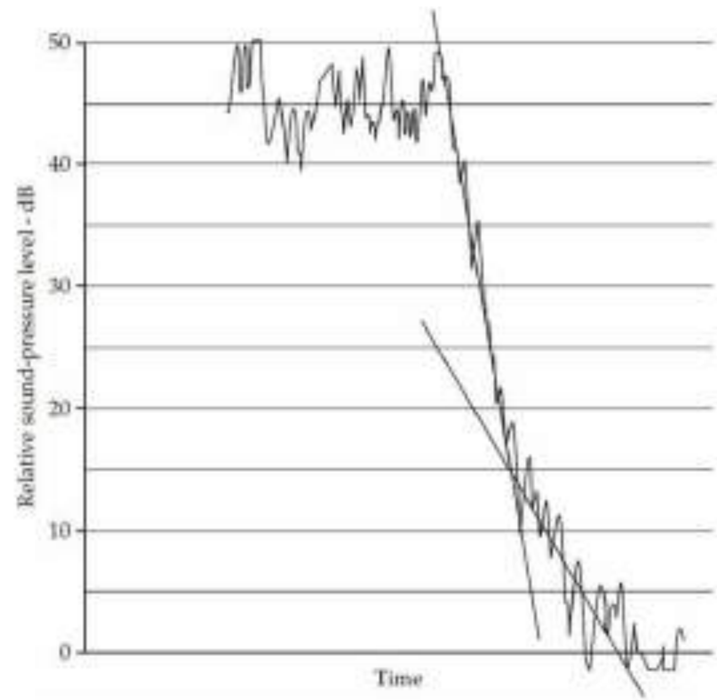


FIGURE 9-2 A typical double-slope decay, showing evidence of a lack of diffuse sound conditions. The slower decaying final slope is probably due to modes that encounter lower absorption.

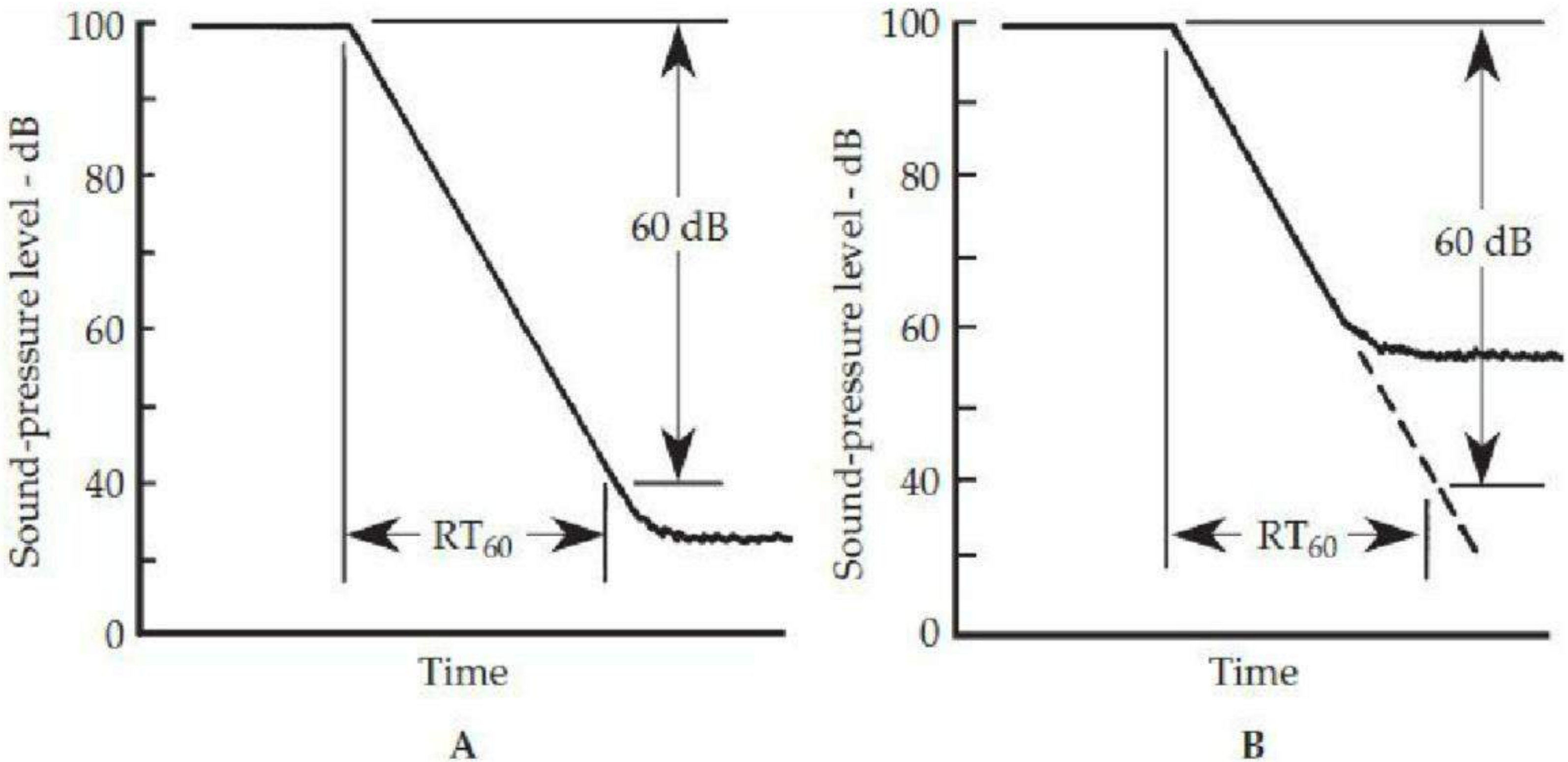
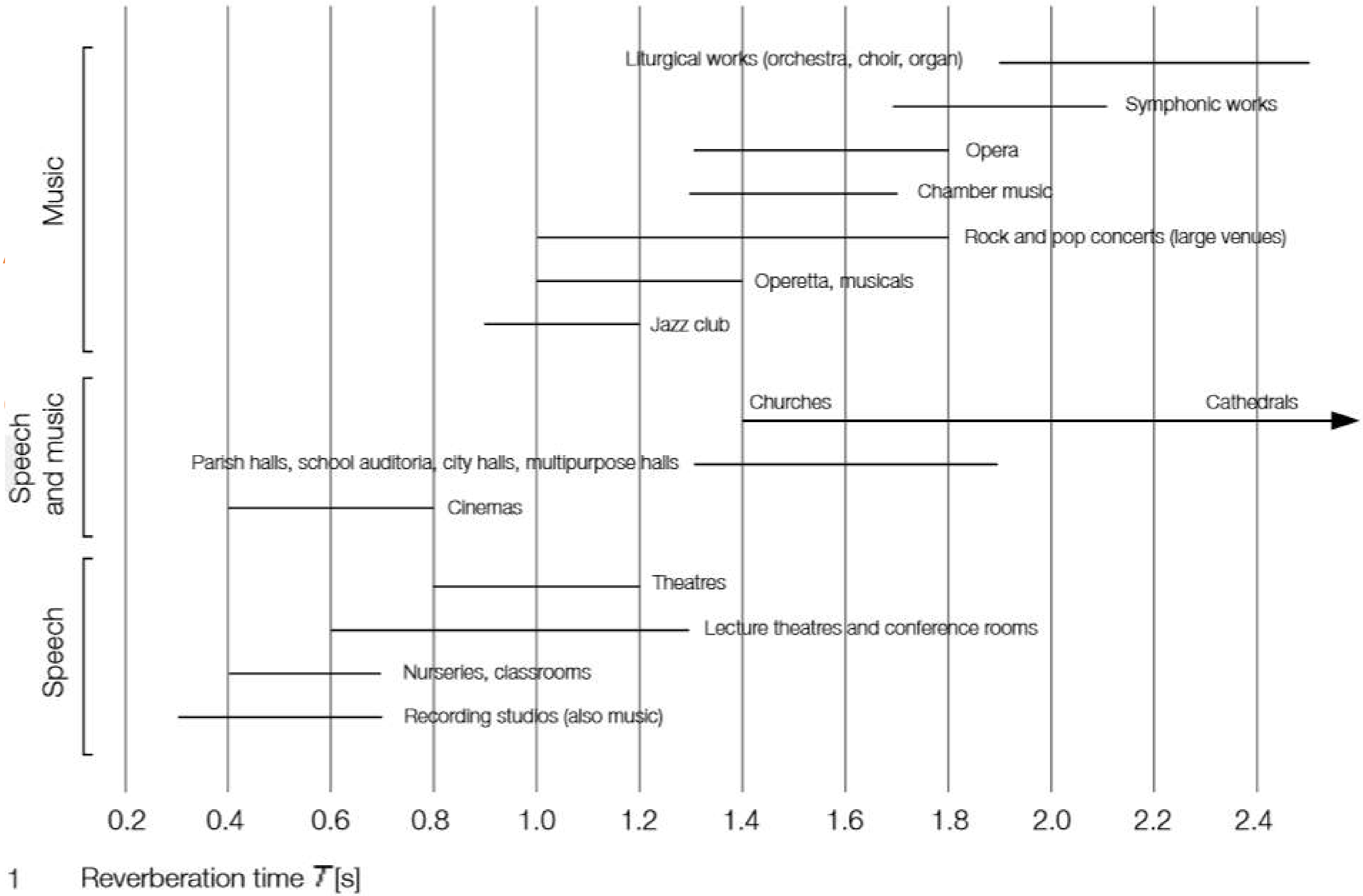


FIGURE 11-3 The length of the decay trace depends on the strength of the source and the noise level. (A) An example of a full 60-dB decay. Practical circumstances rarely allow this. (B) The slope of the limited decay is extrapolated to determine the reverberation time.


Liturgical works (orchestra, choir, organ)
Symphonic works
Opera
Chamber music
Rock and pop concerts (large venues)
Operetta, musicals
Jazz club
Music
Churches
Cathedrals
Parish halls, school auditoria, city halls, multipurpose halls
Cinemas
Speech and music
Theatres
Lecture theatres and conference rooms
Nurseries, classrooms
Recording studios (also music)
Speech
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
1
Reverberation time *T* [s]

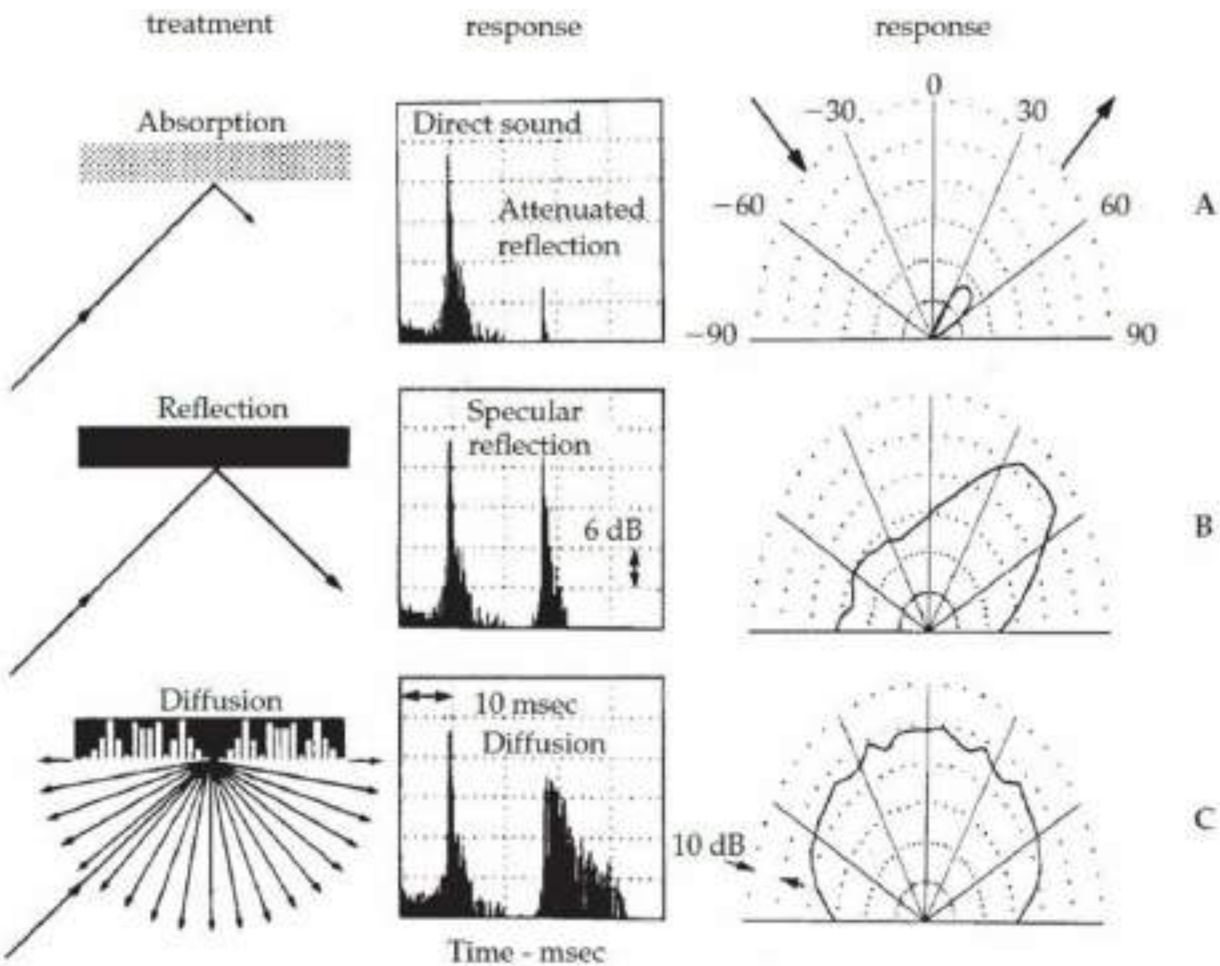
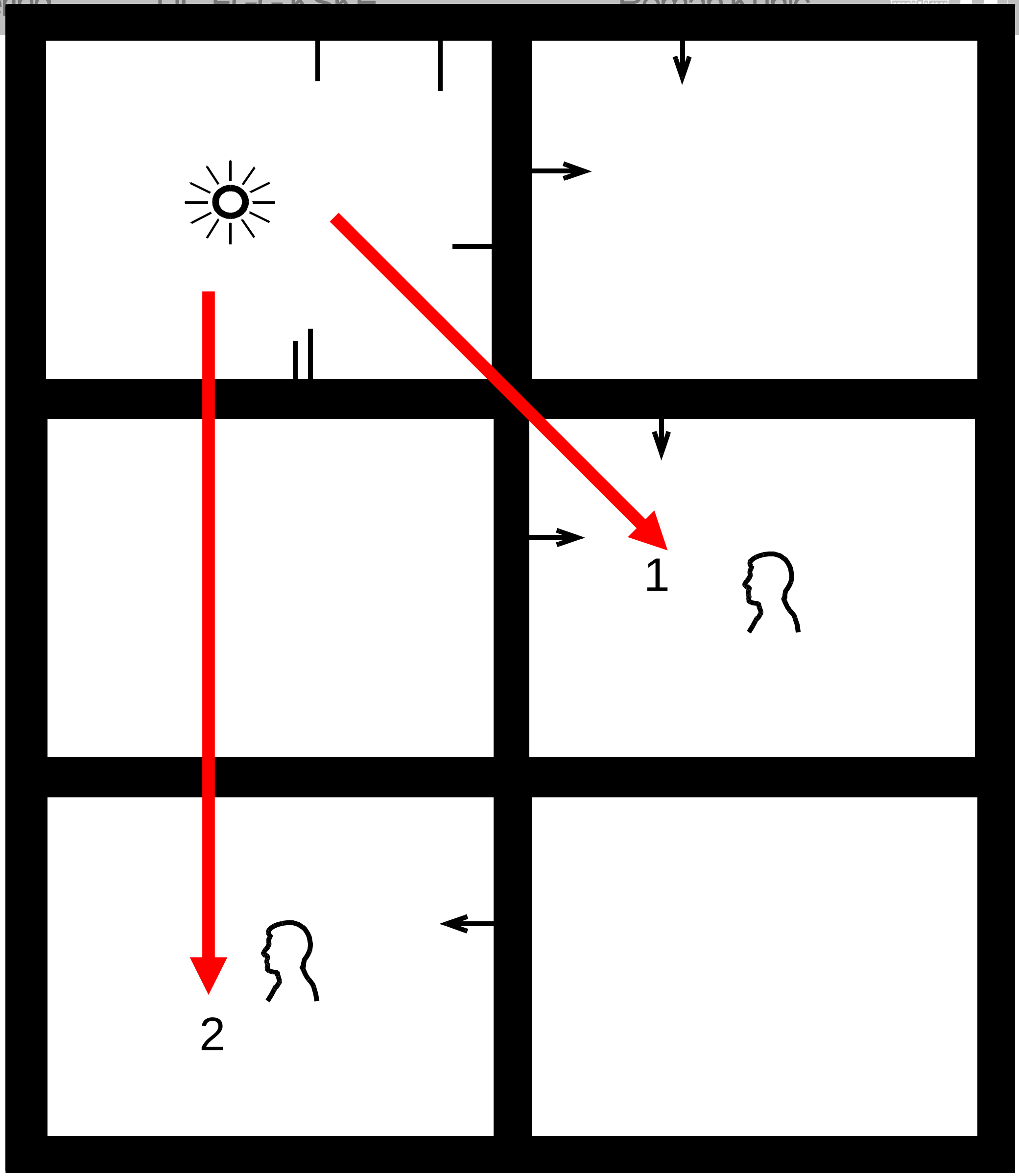


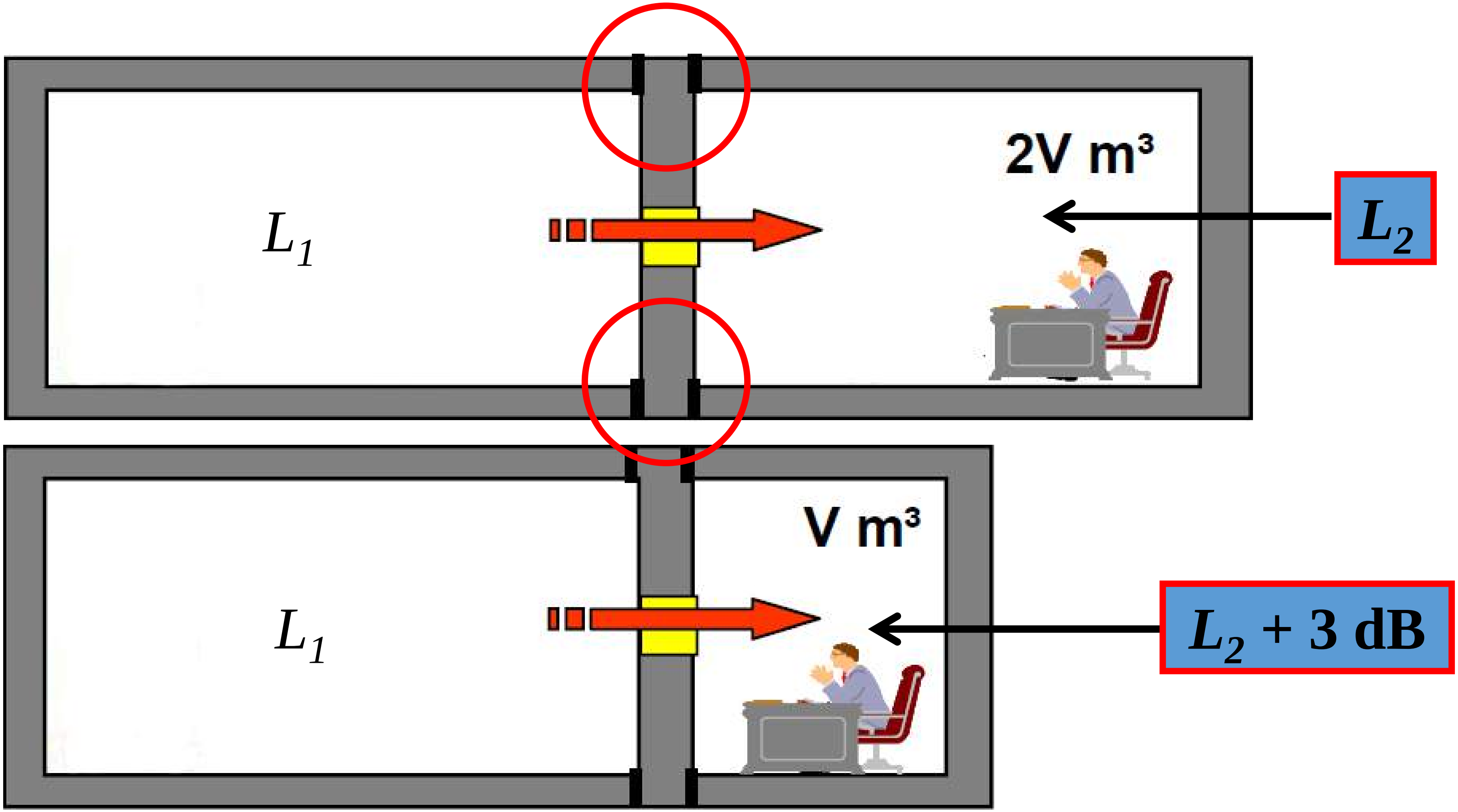
FIGURE 14-6 A comparison of the physical characteristics of three treatments, showing temporal response and spatial response. (A) Absorption. (B) Reflection. (C) Diffusion. (*D'Antonio.*)

Ko pride zvok v gradbene materiale stavbe oz. konstrukcijske sklope, se energije zvoka širi skozi stene in medetažne konstrukcije.



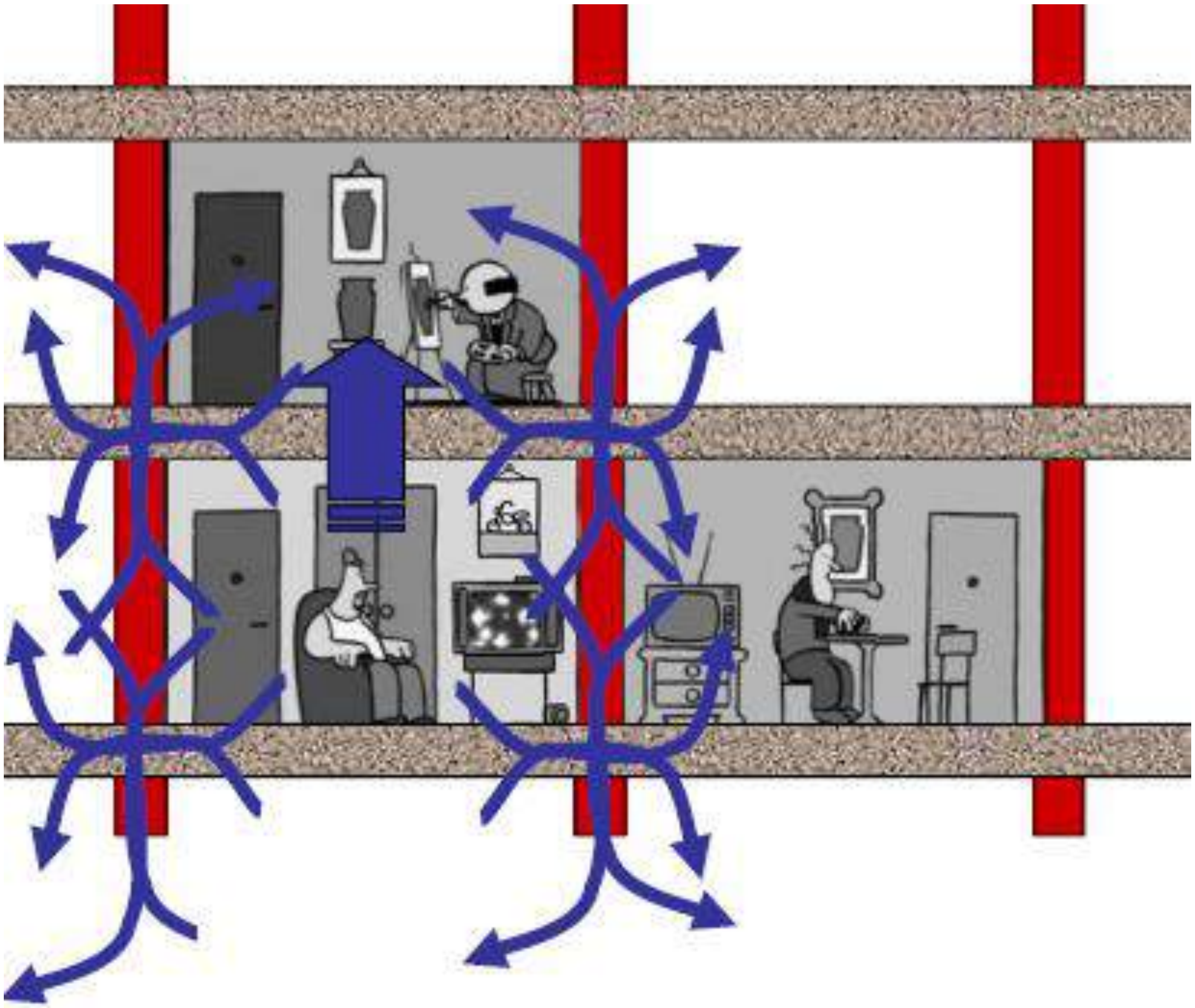
Tako zvok prihaja do diagonalno postavljenih prostorov (1), pa tudi do oddaljenih enot (2)

Kako velikost sprejemnega prostora vpliva na rezultat?

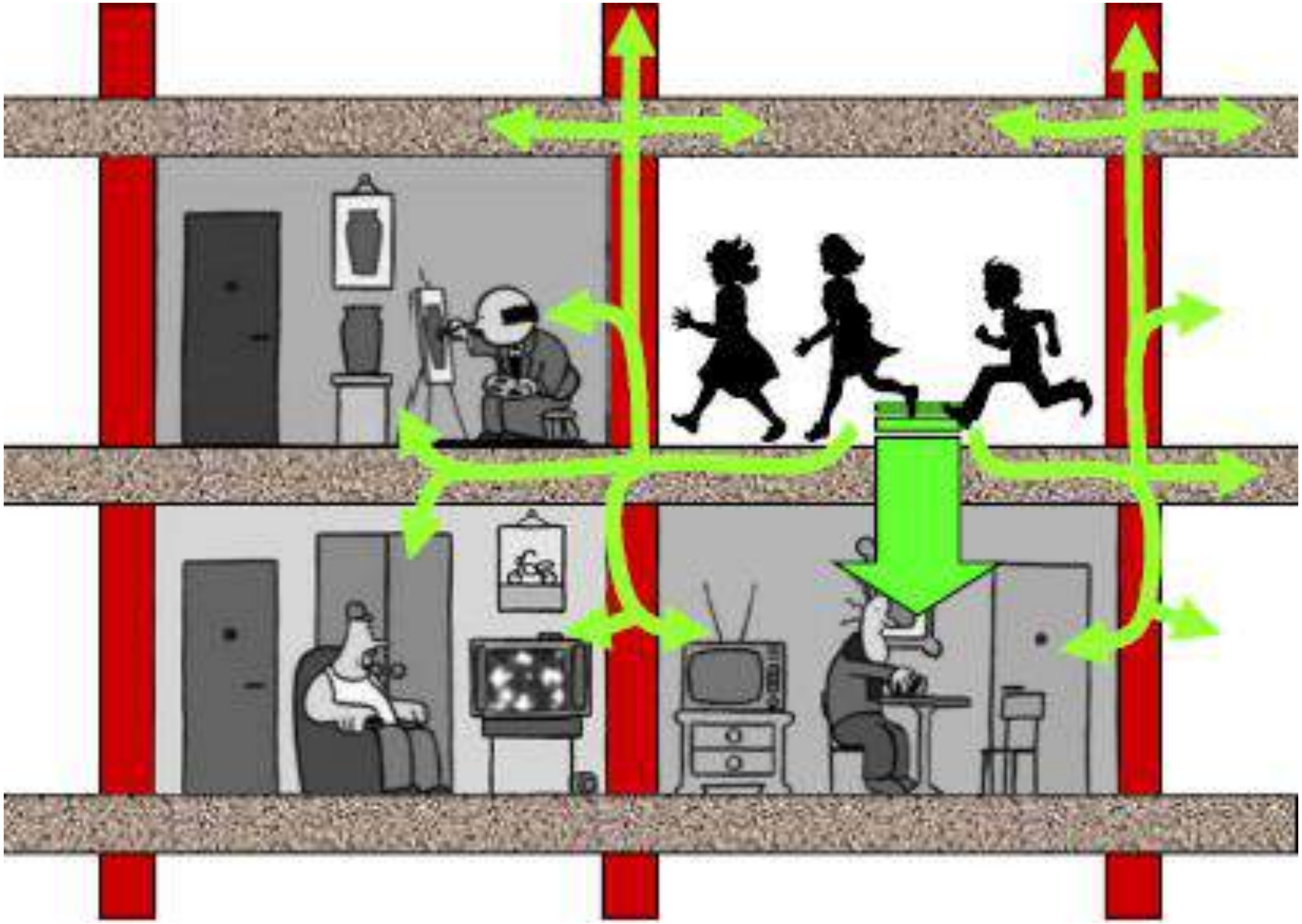


Izolacija je v spodnjem primeru za kar 3 dB slabša / nižja!

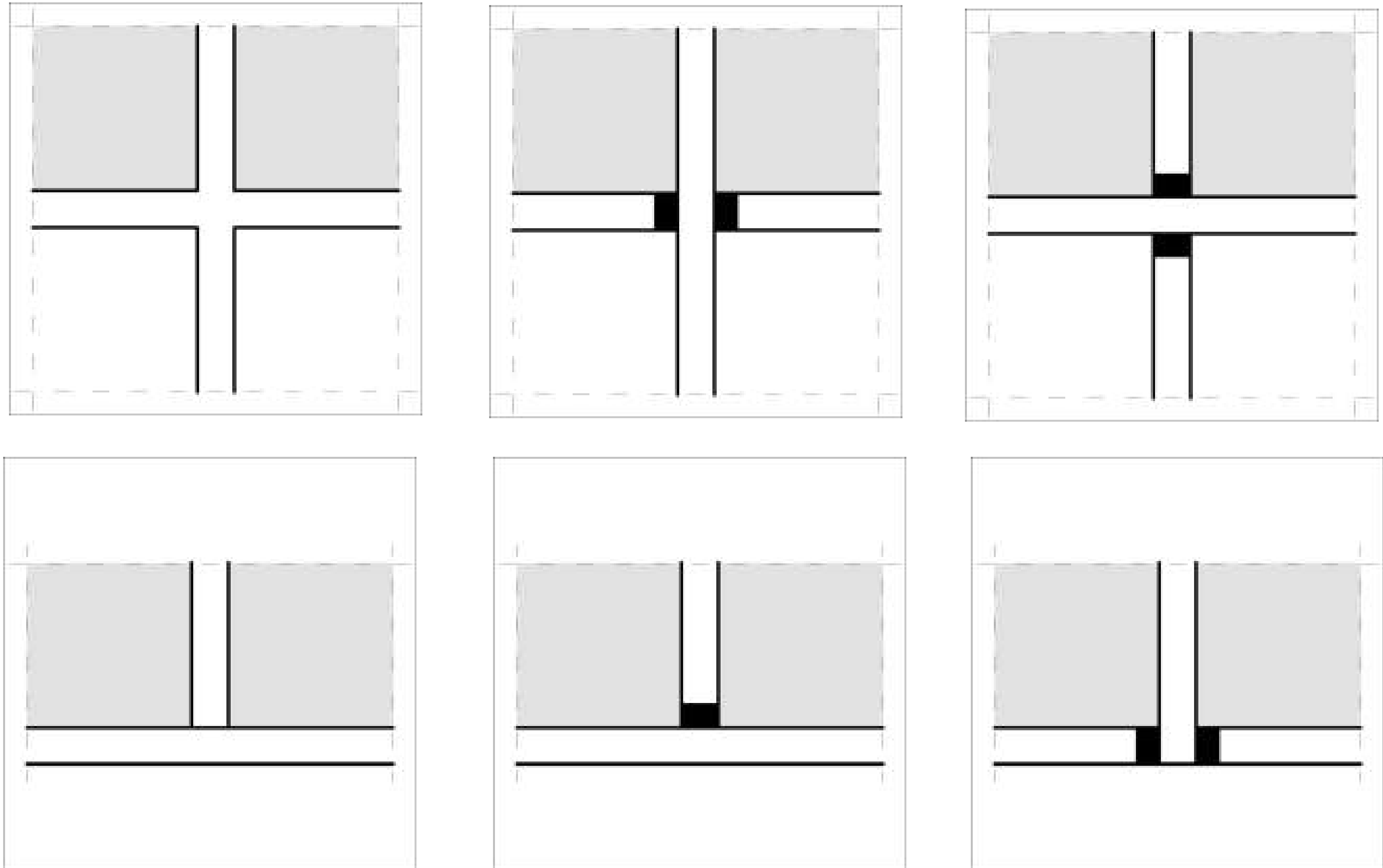
Primer zahtevnosti za vazvušni zvok



Primer zahtevnosti udarnega zvoka

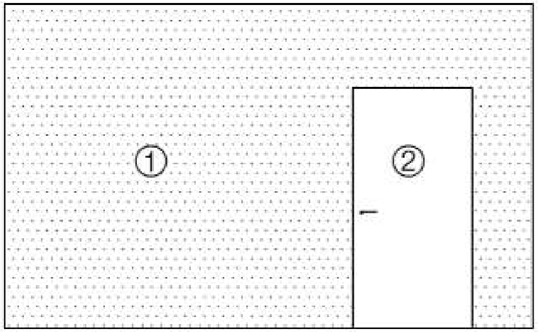


Kakšni so lahko stiki?



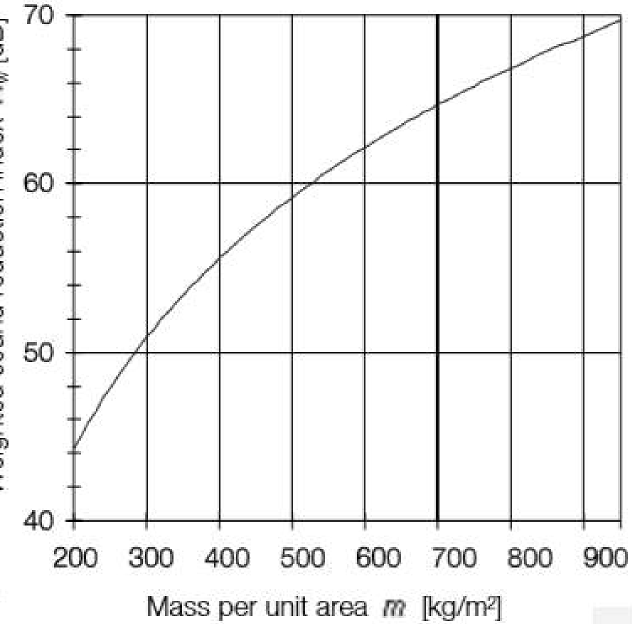
Primer prekinitve v sestavi

Primer prekinitve v sestavi



① Corridor wall	10 m²	R_{w1}	= 42 dB
② Door	2 m²	R_{w2}	= 27 dB
Corridor wall with door	12 m²	$R_{w\,res}$	= 34 dB

2



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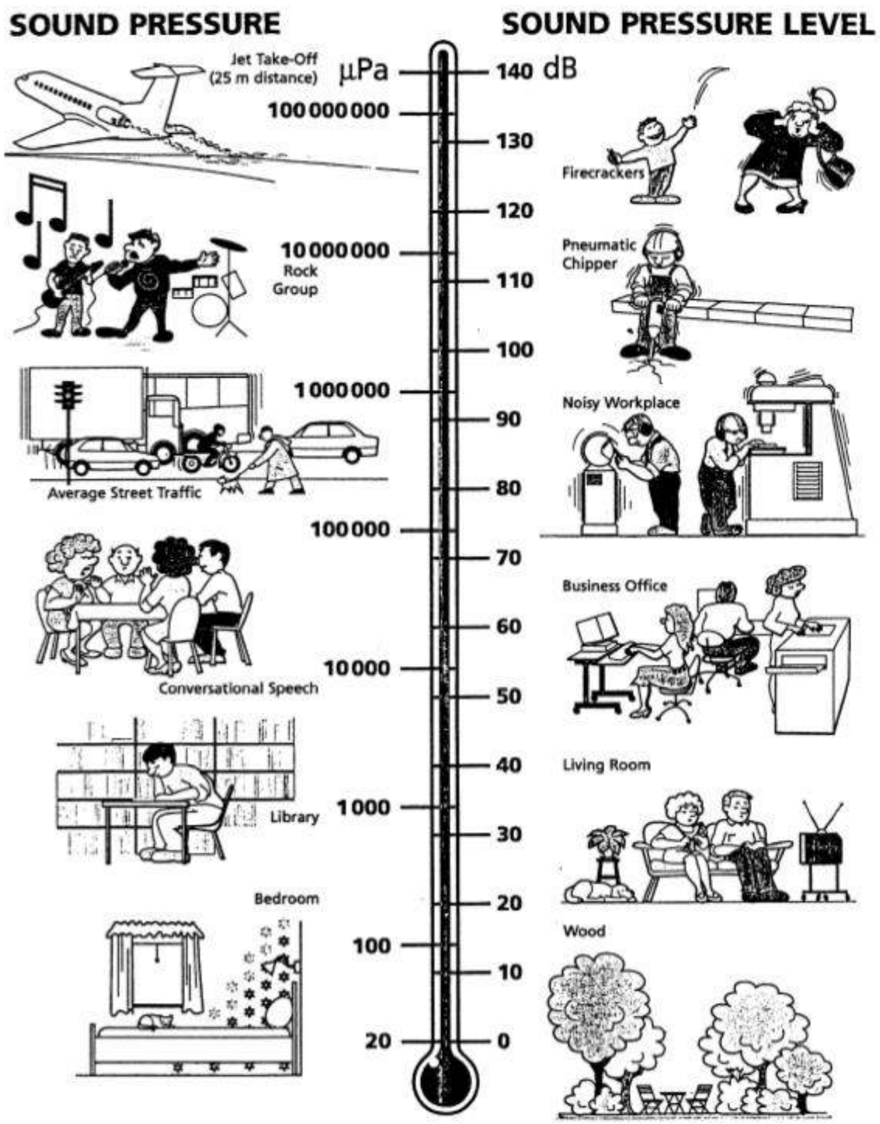
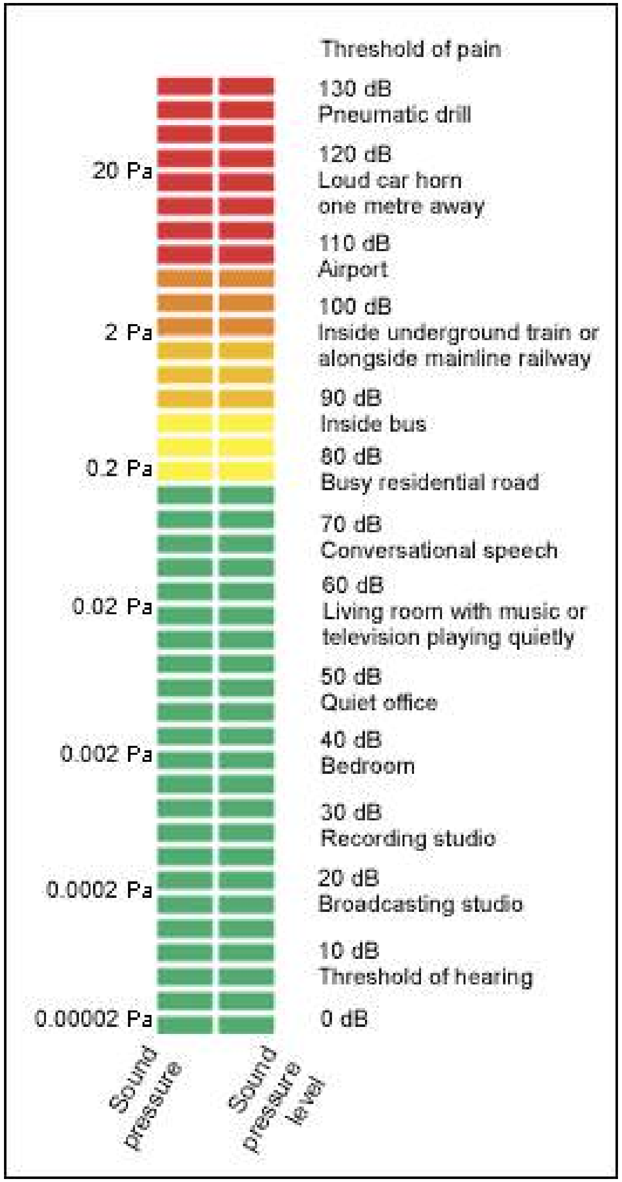




Sound Pressure Level: SPL = $20 \cdot \log (p_{RMS} / p_o)$

Reference pressure: $p_o = 20\ \mu Pa = 0{,}00002\ Pa = 20 \cdot 10^{-6}\ N/m^2$

Problem of noise in EU (source: WHO)

>40% of population is daily exposed to >65dB(A) and through nights >50dB(A)

>20% of working population is exposed to more than acceptable noise levels (more than one half to >80dB(A))

Facts:

Noise **<65 dB(A)** on long period normally **does not lead to permanent hearing failures**. Short exposure generally does not lead to permanent hearing loss. Short exposures do not have detachable effects on temporary hearing loss.

Noise **>65dB(A)** exposure for years **may lead** to problems with hearing loss

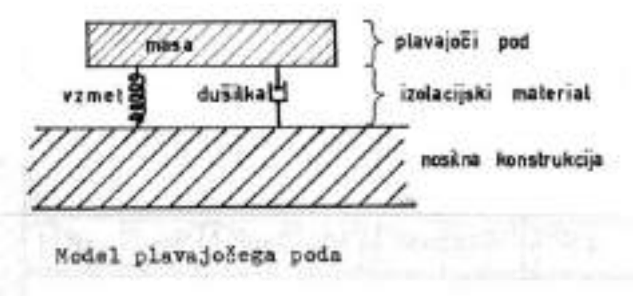
Noise **>80B(A)** exposure for many years leads to **great certainty** to permanent hearing loss

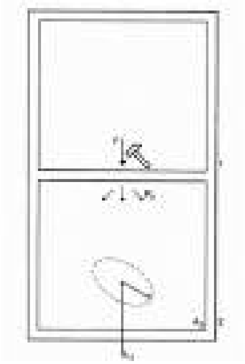
Sound insulation of buildings

- Sound insulation against airborne sound ✓
- Sound insulation against impact sound ✓
- Sound insulation against vibrations of installations ✓
- Sound insulation against environmental (municipal) noise ✓
- Acoustics of interior space (reverberation noise) ✓

Sound insulation against impact sound:

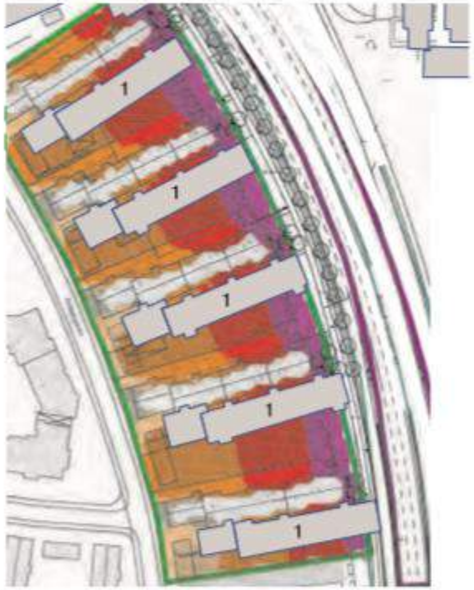
- **Emitter:** vibrations, walking, different bumps, moving chairs and furniture, various assembly and finishing construction works
- **Transmitter:** massive solid construction material and sound in the air
- **Receiver:** sound in receiving room (ear, microphone of measuring instrument…)





- **Basic rule:** to prevent access of impact sound to enter into massive construction (floor or wall constructions) – all other preventive approaches are much less effective

Insulation against environmental noise starts with urban design



2a

b

c

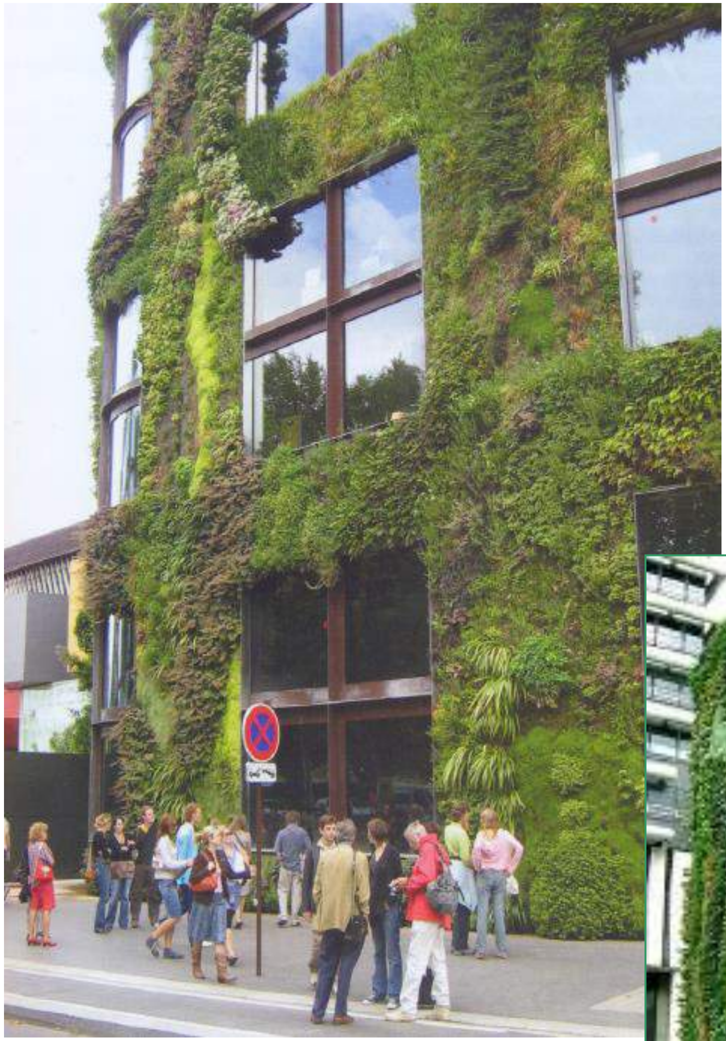
d


d

Case of glass facade designed as a noise barrier for protecting facade of offices and atrium

München

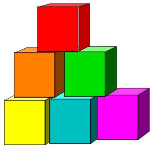
Green facades are also good noise absorbers



Reverberation time is lower and consequently also noise disturbance is lower

Acoustics of interior space (reverberation noise):

- **A goal is to control (to lower) reverberation time of interior space (indoors)**



We distinguish between:

- **Acoustics of spaces intended for speech** (importance of clarity and understanding of human voice or speaker – comprehensibility)
- **Acoustics of spaces intended for music** (importance of various aesthetic and artistic criteria)

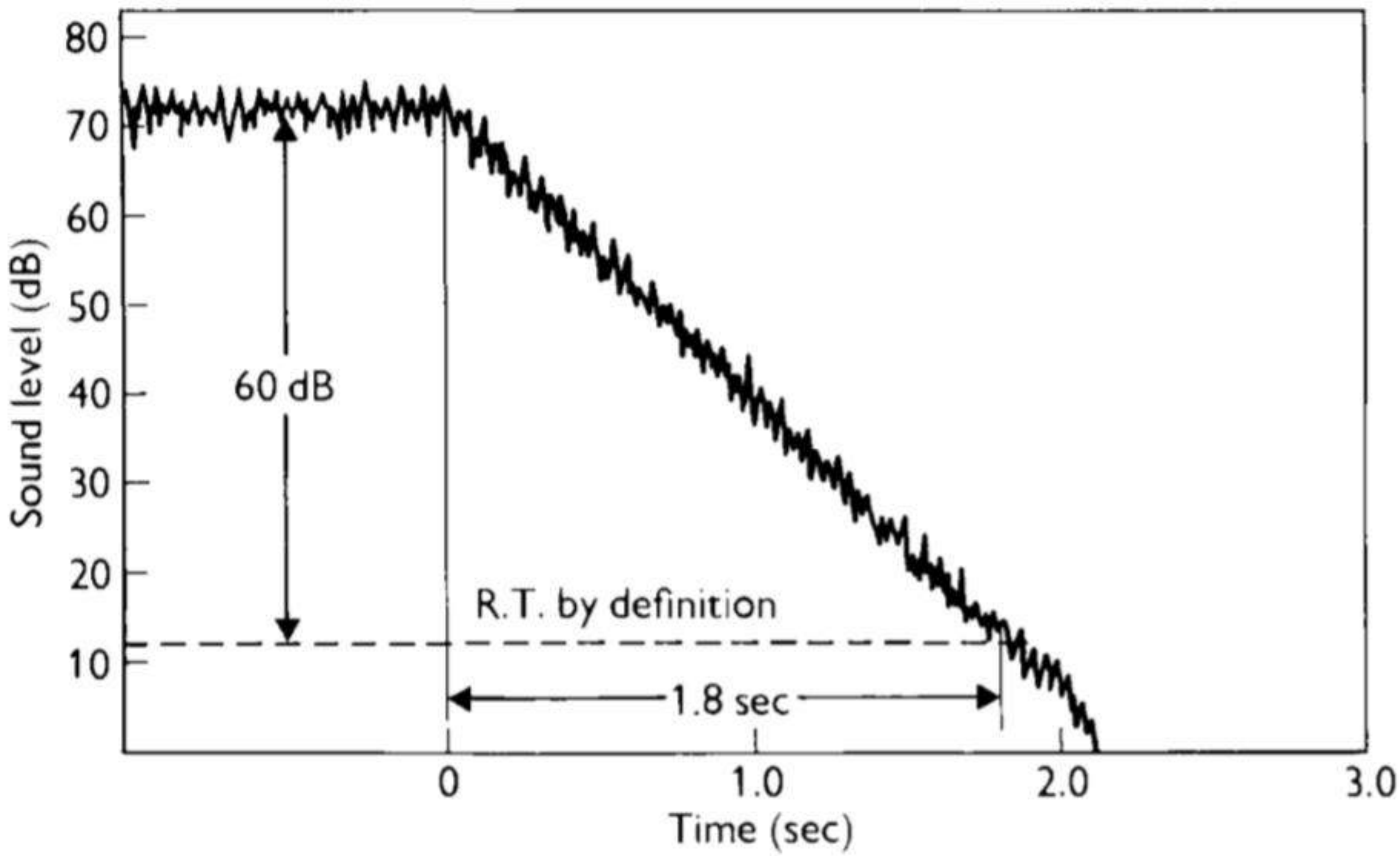
Reverberation time is reduced by installing absorbent surfaces on walls, ceilings and floors of interior space

ARTIE - računalniški program za analizo akustike notranjega prostora

Naš računalniški program za analizo akustike notranjega prostora
ARTIE (**A**nalysis of **R**everberation **T**ime in **I**ndoor **E**nvironments)

pokriva računalniško simulacijo odmevnega hrupa notranjega prostora (ne pa gradbene akustike – torej prehoda zvoka zaradi zvoka v zraku ali udarnega zvoka, komunalnega hrupa...)

Acoustics of interior space (reverberation noise)

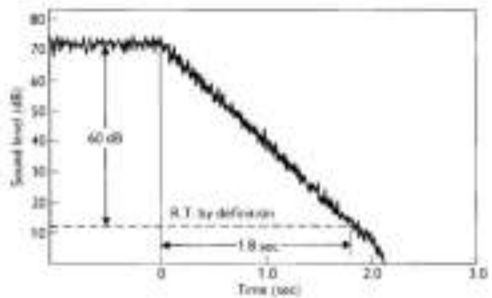


Sabin equation for reverberation time of interior space (Wallace Clement Sabine, 1868-1919)

$$RT_{60} = 0.161\ V\ (m^3) / A\ (m^2) \quad (s)$$

also: $RT_{60} = (0{,}163\ V)/\ (A + 4mV)$

$A = \Sigma\ \alpha_i \times S_i$ (m^2)



V ………………… Volume (m^3)
$A = \Sigma\ \alpha_i \times S_i$ ….. Equivalent absorption area (m^2)
α_i ………………. Absorption coefficient of certain surface (-)
S_i ………………. Absorption area of certain material (m^2)
4mV ………….. Absorption of sound in the air

Eyring formula:

$TR_{Ey} = (0{,}163\ V)/\ (-S * \ln(1-\alpha_{AV}) + 4mV)$ (s)

S ………… sum of all surfaces in room
α_{AV} ………average absorption coefficient of all surfaces of certain room
4mV ……. Absorption of sound in the air

Ideal values of the reverberation time in dependence on the volume of the interior space

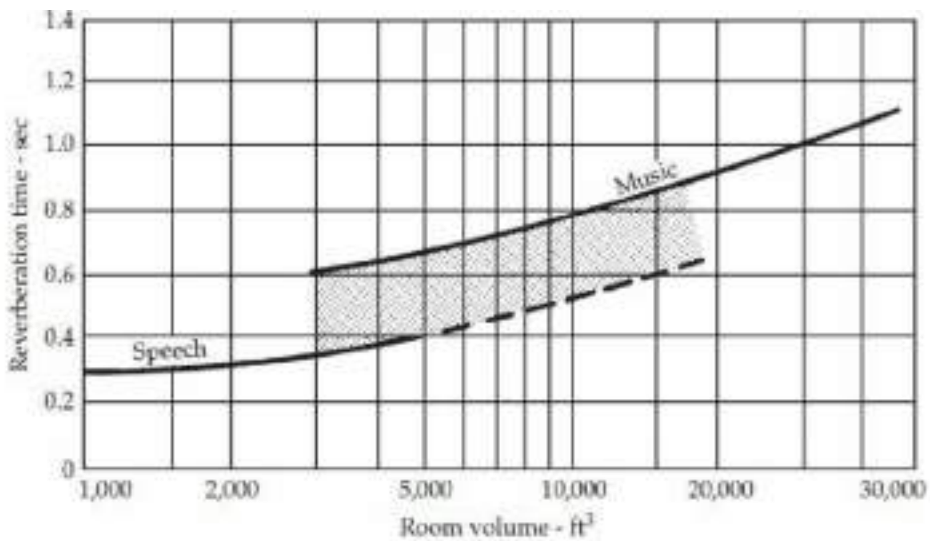
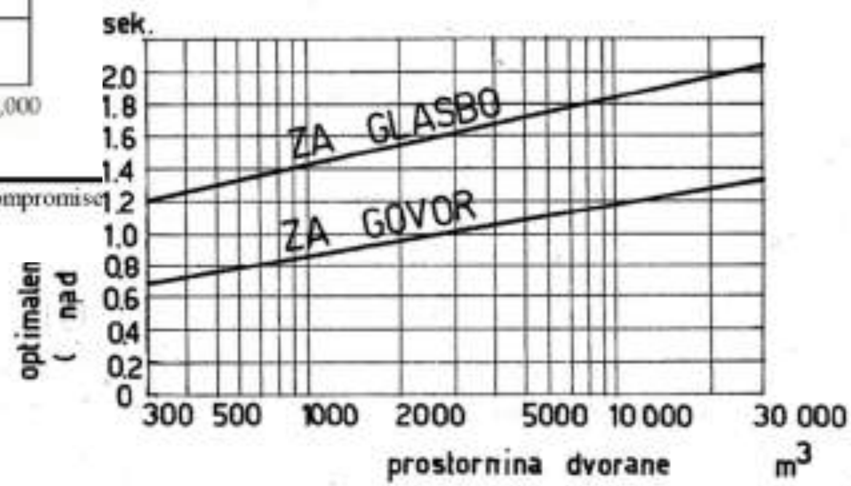


FIGURE 22-3 Suggested reverberation times for recording studios. The shaded area is a compromise region for studios in which both music and speech are recorded.



Ideal values of the reverberation time of interior space for recording are considerably smaller (shorter reverberation time)

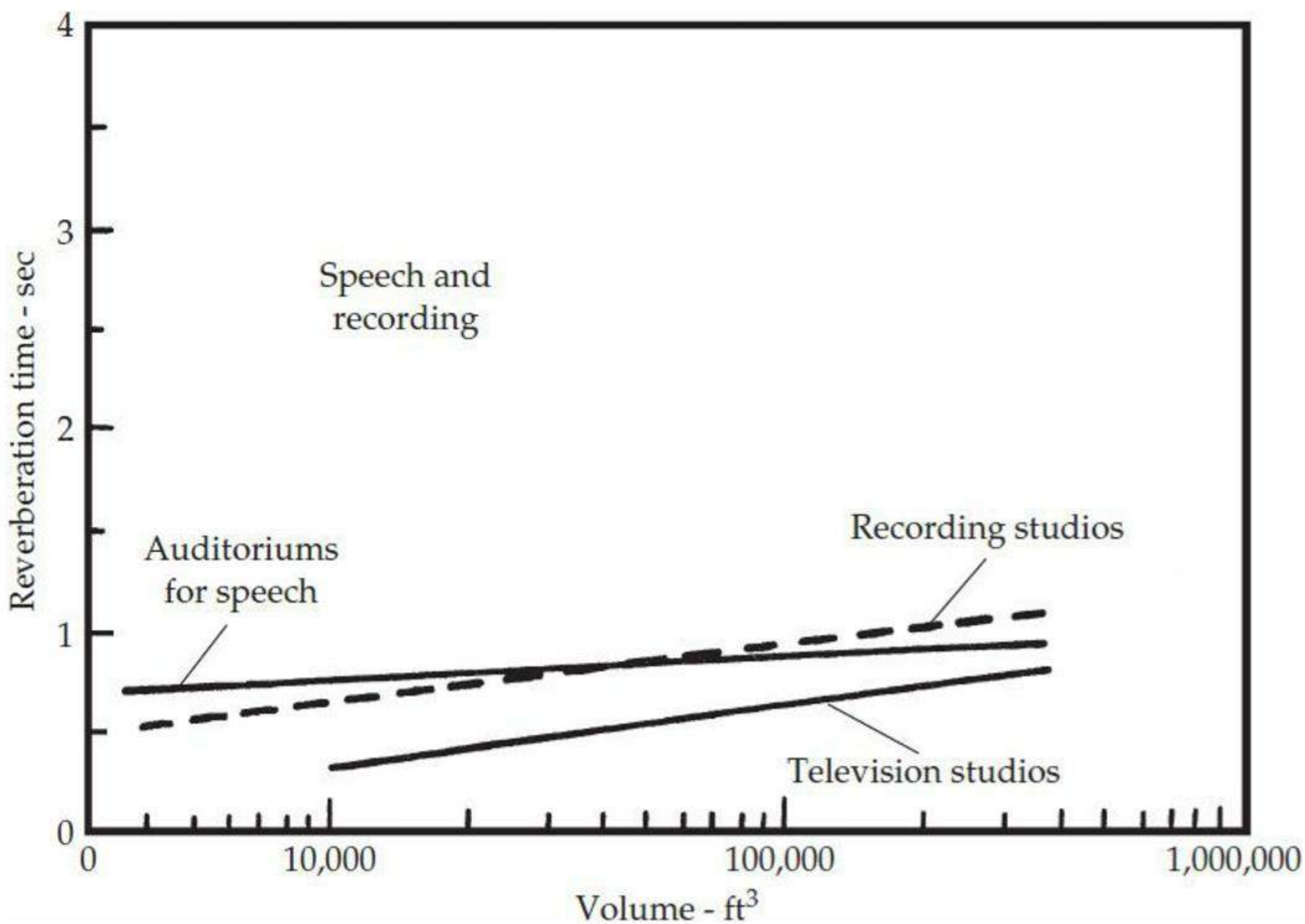
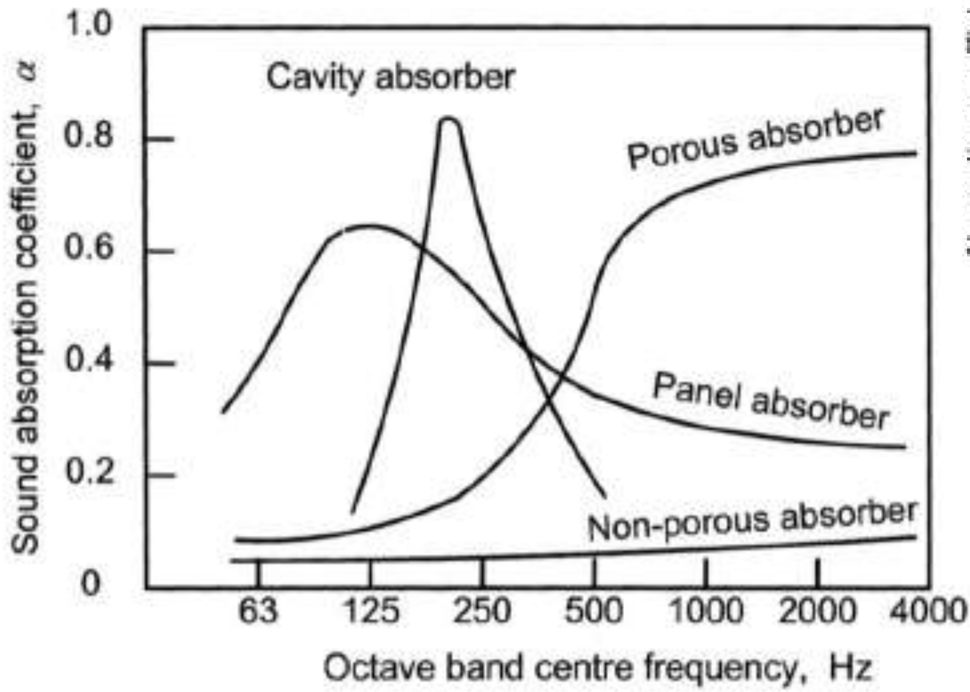
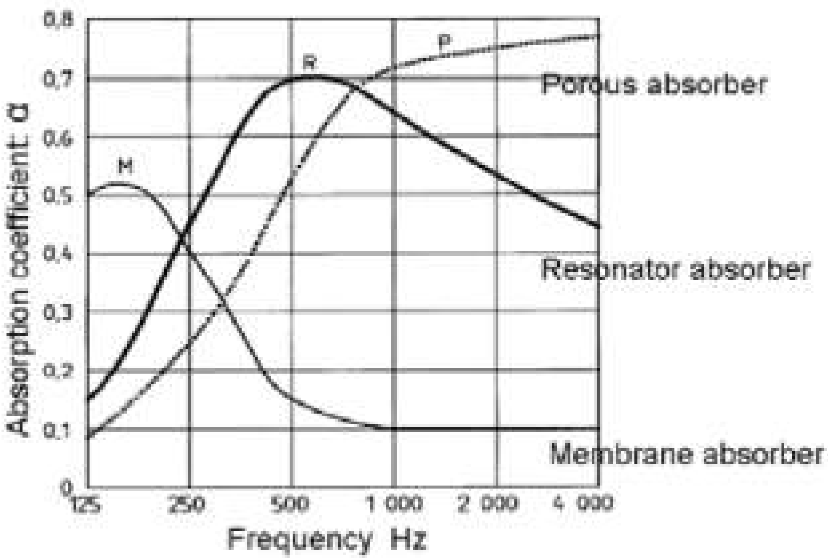


FIGURE 11-15 Spaces designed for speech and music recording require short reverberation times.

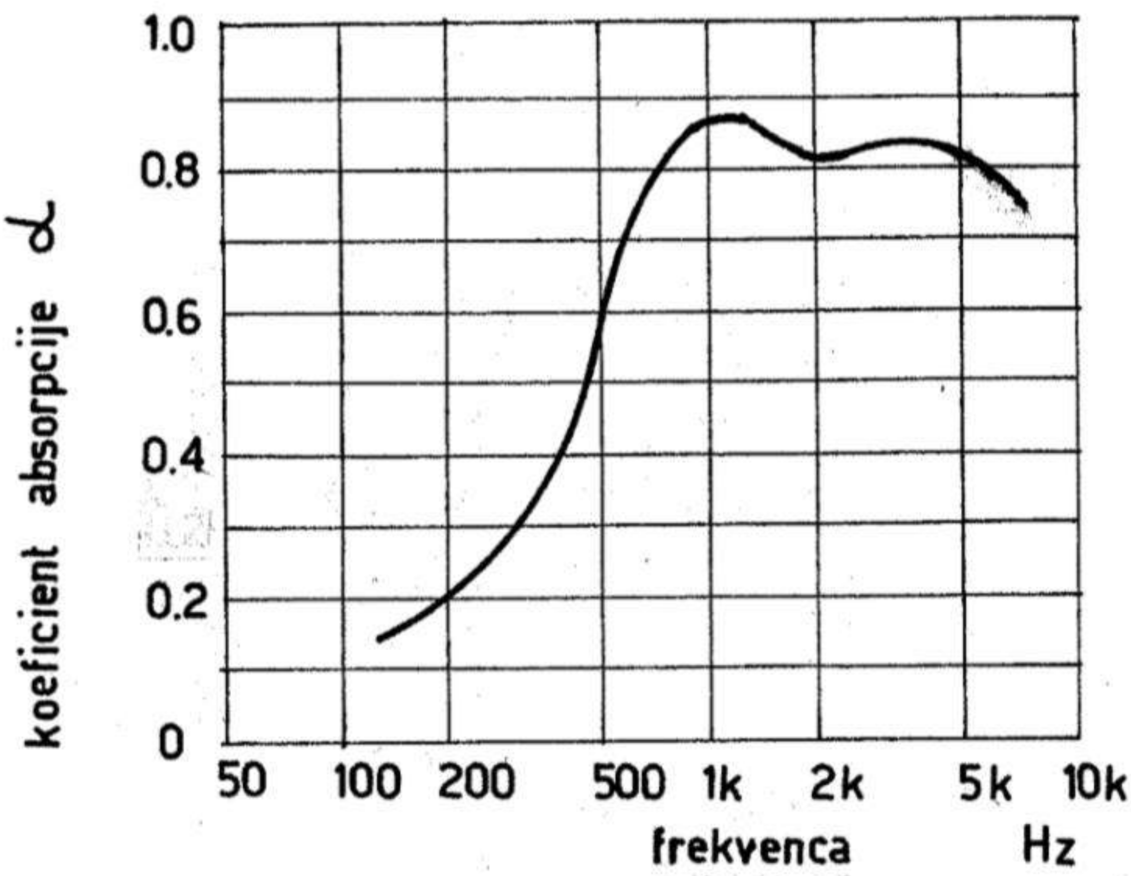
Types of absorbers: porous, membrane, Helmholtz, comprehensive (integrated)



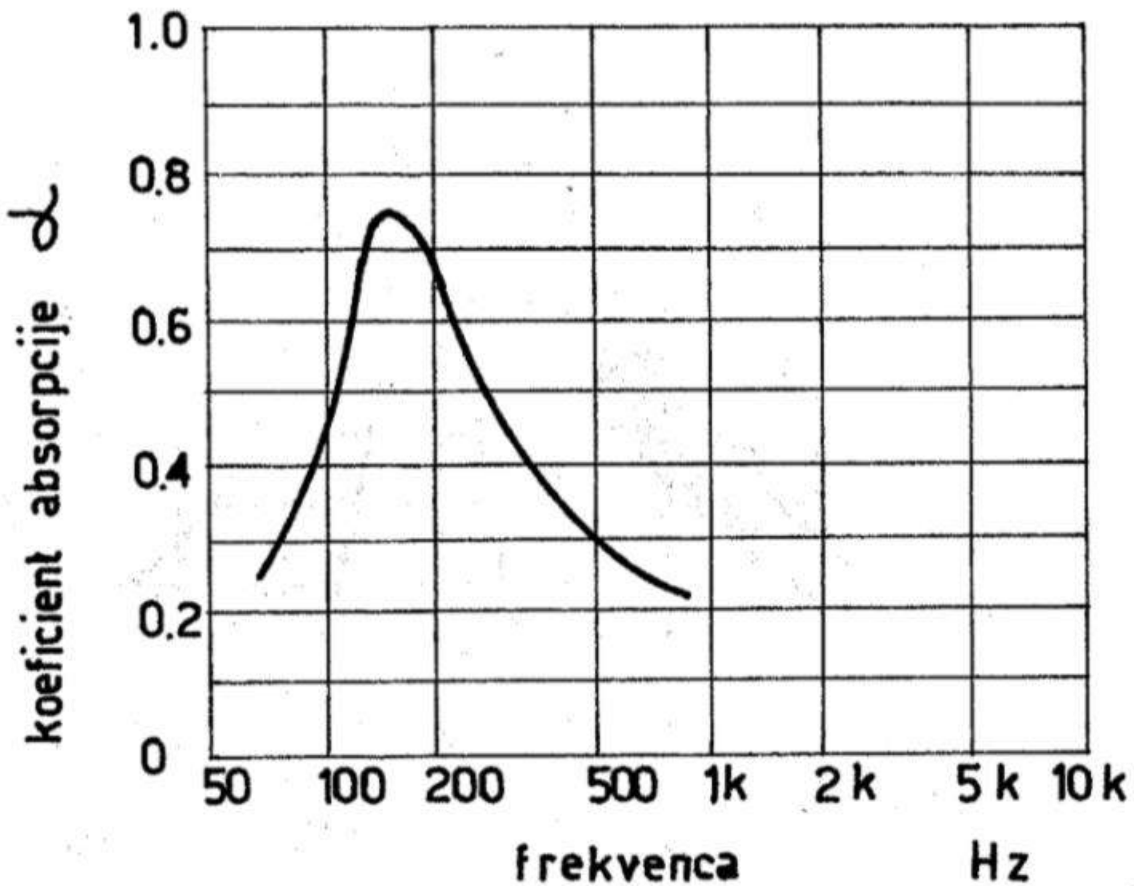
Characteristic frequency absorption curves.

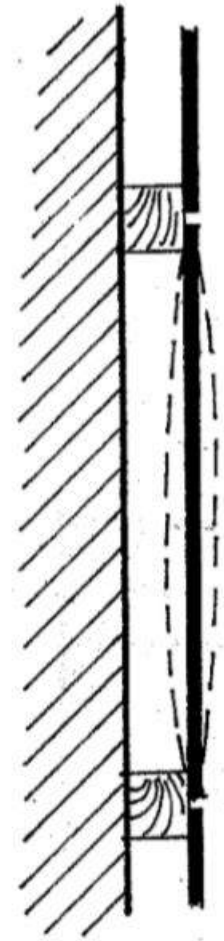


Porous absorber

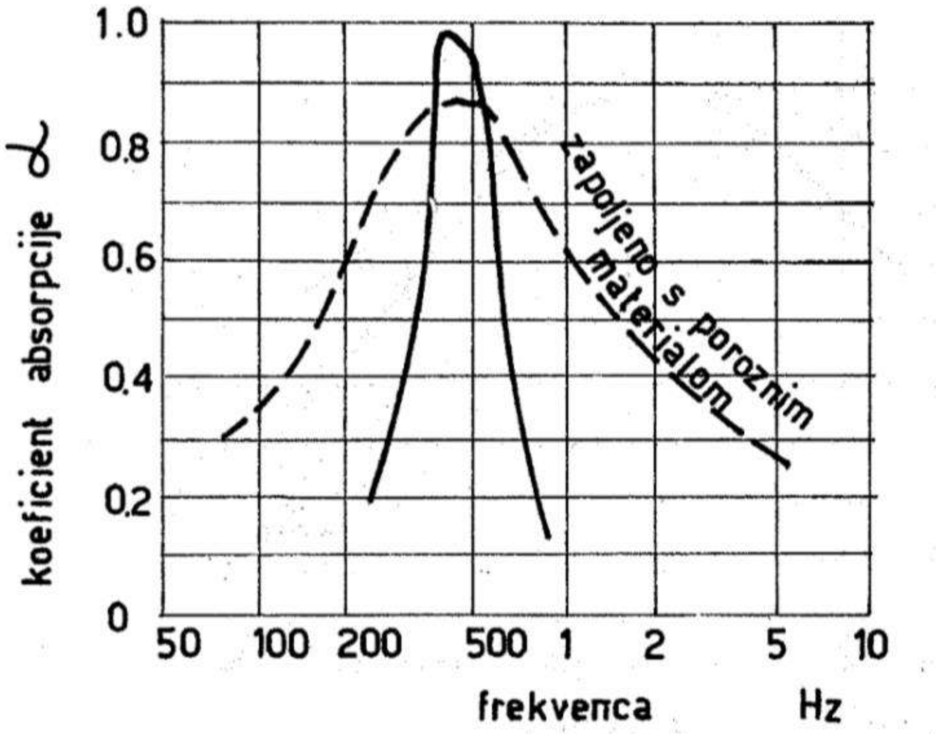


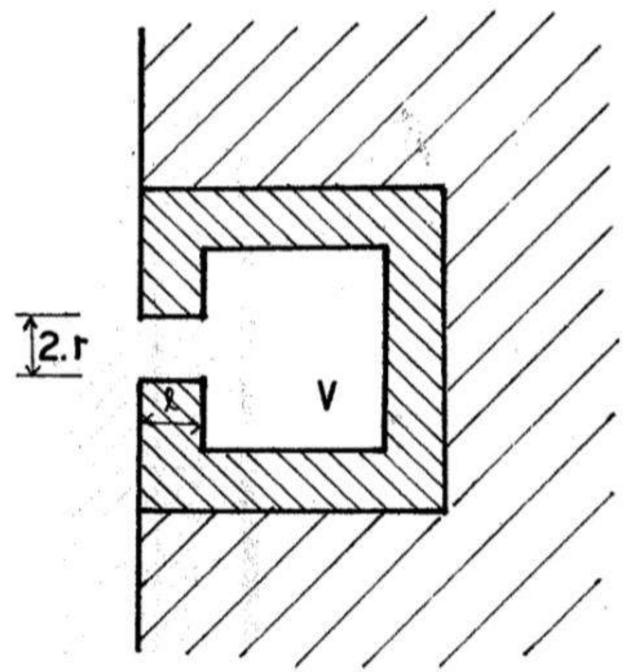
Membrane absorber



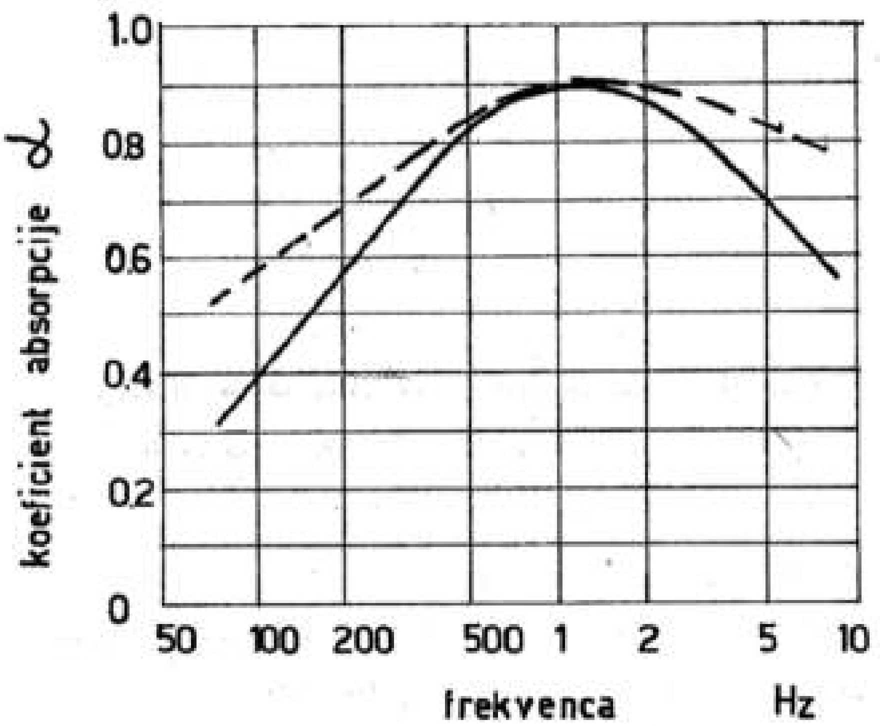


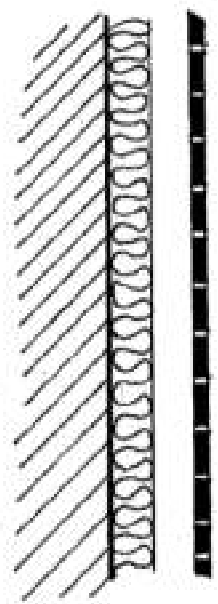
Helmholtz absorber / resonator

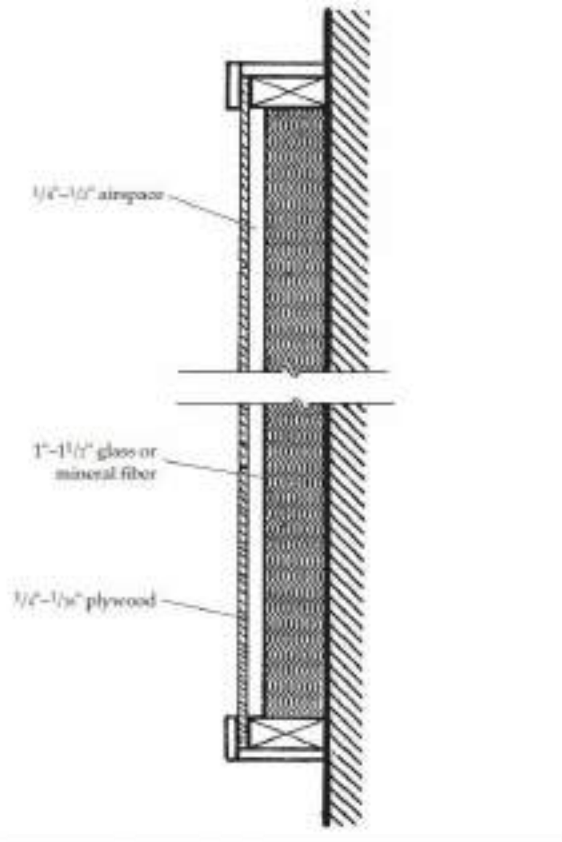




Comprehensive (integrated) absorbers:
acoustical plates, acoustical panels







Typical resonant panel absorber with wall mounting.

Reverberation time before and after acoustic treatment in the interior space in relation to frequency

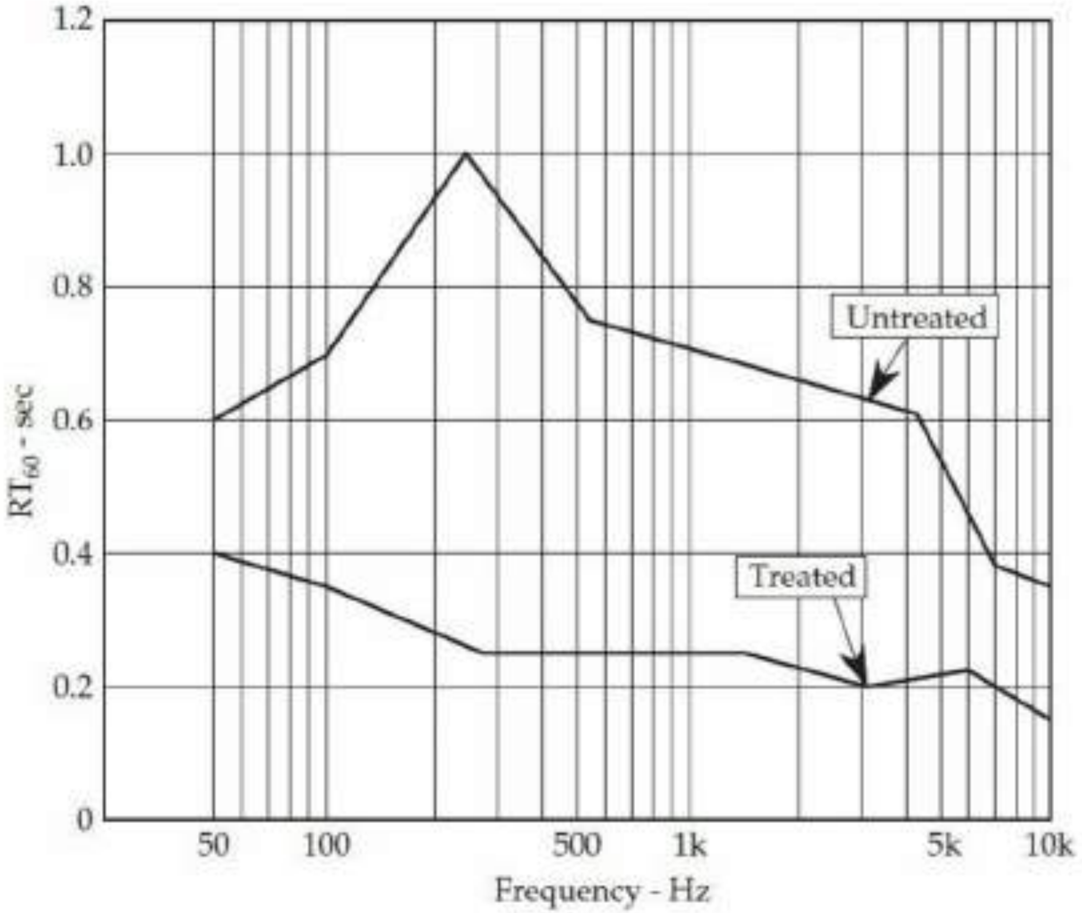


FIGURE 11-10 An example of a room's reverberation characteristic before and after room treatment. A significant rise in reverberation time in the upper bass and lower midrange is changed to a flatter characteristic with a moderate increase in reverberation time at low frequencies.

Acoustical Analysis and Adaptation of a Playroom

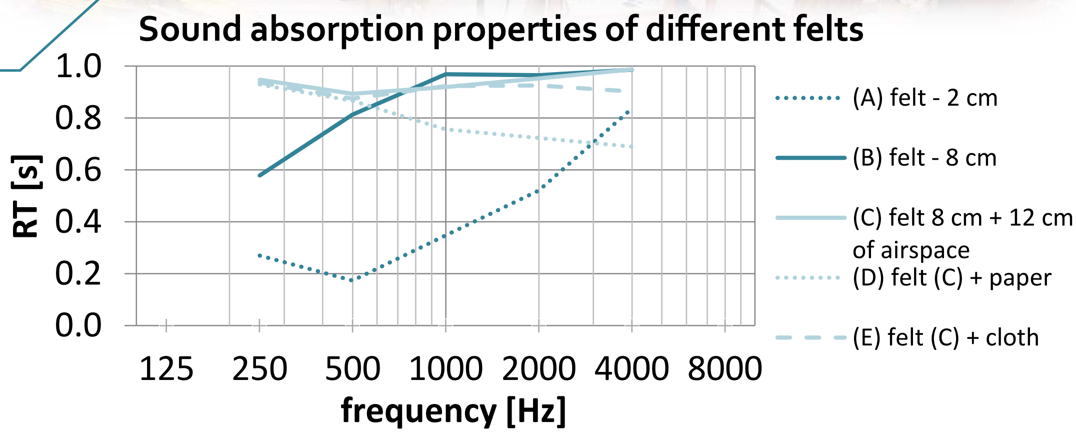
Prototypical Acoustic Elements

Hanging Wall Element
- Felt: 2 + 2 cm
- airspace between layers and behind the element

Ceiling Elements
- Rock wool: 5 cm
- airspace behind the element
- covered with paper

Temporary Elements
- Felt: 2 cm
- airspace behind the element or freely hung
- partly coloured

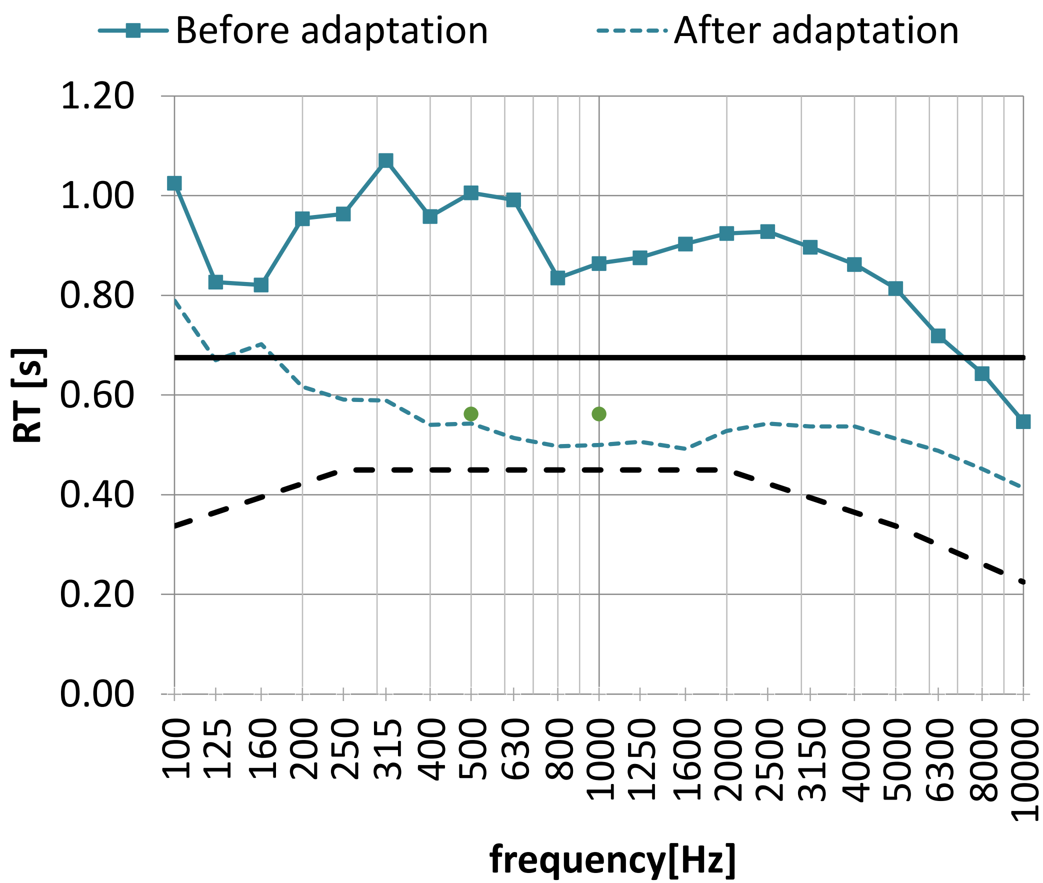
Floor Element
- Felt: 2 + 2 +2 +2 cm
- covered with textile



Acoustical Analysis and Adaptation of a Playroom

Reverberation Time Measurements

- Results:
  - Aprox. 20 m² of acoustic elements
  - Overall drop of 0,31 s (> 35 %)
  - 500 Hz – 4000 Hz: drop of 0,38 s (> 42 %)
  - L_{eq} dops for 2,5 dB
  - Satisfaction of users
  - Low cost
  - Child friendly



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Advanced insulation materials and systems in buildings, and energy savings

Many thanks !

Any questions?

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