

Acoustics (VTAN01) – Room Acoustics (2: Properties)

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Parameters: Importance

• T30, EDT: Reverberation

-T60 = 2*T30

- D50: Clarity of speech (C50)
- C80: Clarity of music
- LF, LFC: Spatial impression
- Desired parameters depend on the purpose
 - Optimal T60 for speech: 0,4 -0,6 s

– Optimal T60 for music: > 1 s



- Limiting surfaces (walls, floor and ceiling) are the relevant elements of a room.
- The sound field is influenced by
 - geometry, thus surfaces
 - their absorption properties and
 - their diffusivity.
- To assess the sound field three methods are in use...



(efterklangstid)







Values for RT

Noise recommendations:

Working space
Canteen
Office

Speech inteligibility

Cinema (Bio) Bio, THX Classroom Meeting room (taluppfattbarhet): Small – Big rooms T = 0.6 - 1.2 sT = 0.3 - 1.0 sT = 0.6 - 0.8 sT = 0.6 - 0.8 s

Small – Big rooms

T = 0.5 - 1.5 s

T = 0.5 - 1.0 s

T = 0.4 - 0.8 s



Introduction

• Statistical room acoustics

- a diffuse sound field as a central simplification. The analysis focuses on the ratio of direct and diffuse sound and deals with the reverberation. Walls, floor and ceiling are described by the statistical absorption coefficient α_s .

• Geometrical room acoustics

- models the sound propagation as energy that propagates along straight sound rays.
- high frequency approximation that holds for wave lengths that are much smaller than the dimensions of the elements of the room.
- The reflection properties are defined by an absorption coefficient and a diffusivity to describe the scattering behavior.



Introduction



Introduction

• Wave based room acoustics

- Seeking solutions of the wave equation. The sound propagation is modeled physically correct and considers wave phenomena such as resonance, interference and diffraction.
- However analytical solutions are available for a few simple geometries only.
- In general, specific solutions have to be found with numerical approximations such as the Boundary Element method (BEM) or Finite Element method (FEM). The corresponding computational efforts restricts the application to small geometries or low frequencies.
- The boundary surfaces have to be described with their proper impedances. A difficulty arises as in practice this information is usually not available.



- Sound fields in large rooms are characterized by a high density of room resonances already at relative low frequencies.
 - Statistical room acoustics



- Based on the concept of a diffuse sound field, which means that
 - » the sound energy density in the whole room is constant.
 - » there is no predominant sound incident direction. From that follows that the average intensity is 0 everywhere.



Statistical room acoustics

- Absorption of audience
 - audience contributes significantly or even dominates the absorption
 - exact absorption coefficient depends on different factors such as density and arrangement of the seating, the upholstering of the seats or the type of clothes people are wearing

Hz	125	250	500	1000	2000	4000
upholstered seat, row spacing 1.15 m	0,30	0,35	0,50	0,60	0,70	0,70



Reflection at plane surfaces, specular sources

- If a sound ray hits a surface, it looses a certain amount of its energy depending on the absorption coefficient of the corresponding surface.
- The remaining energy is reflected according to the law of reflection

– angle of incidence = angle of reflection.

• sound path is determined by using mirror sources.



Reflection at plane surfaces, specular sources





Effect of basic reflections



Rectangle: Lateral reflections occur in the entire space



Fan-shape:

Reflections scatter and are directed mainly to the rear part of the space (not in the middle)



Round:

Reflections from concave surfaces cause sound to strongly focus on some parts of the space



Effects of shapes





Reflection from a surface

• Specular reflection: Angle of reflection equals angle of incidence



Absorption coefficient:

$$\alpha = \frac{I_{inc} - I_{refl}}{I_{inc}} = \frac{I_{abs}}{I_{inc}}$$



Reflection from a surface

- Diffuse reflection
 - Scattered in many directions









- Scattering coefficient, *s*
- Fraction of energy which is scattered
- Always between 0 and 1





Absorption and scattering





Sound Example





Reflection at structured surfaces, diffuse reflection and scattering

• *For* $\lambda \gg$ structure dimension *s* \rightarrow the structure has no effect

 \rightarrow specular reflection at an 'average' plane.

• For $\lambda \approx$ structure dimension *s*

 \rightarrow the structure acts as a whole \rightarrow diffuse reflection

• For $\lambda \ll$ structure dimension s

→ the single structure elements act as reflectors

 \rightarrow specular reflection at the structure details.





Absorption vs reflections





Acoustic design simulations of an auditorium



• Acoustic design of a music studio



What is soundproofing?



How to soundproof a home



Mechanical resonance



Soundproofing for home theatres



Soundproofing materials



Soundproofing techniques



• Acoustic design of a music studio



• Office spaces

[Ecophon solutions]



Outdoor acoustics

• Many principles can be applied for open spaces



- The sound field in small rooms at low frequencies is dominated by discrete resonances (Eigenfrequencies) with low spectral density.
- Methods of statistical and geometrical acoustics **are not applicable**.
- The wave nature of sound has to be considered explicitly with help of wave theoretical room acoustics.



Room modes

- The sound field within a room is comprised of room resonances, called room modes
 - Room mode = characteristic resonance of the room
 - Three types of modes: axial, tangential, oblique
 - The amount and spacing of room modes changes with frequency
- At low frequencies there are only a few room modes, sparsely spaced.
 - So the reverberation time and sound level can vary considerably in different points in the room (consider the placement of a subwoofer in a living room)
- At high frequencies the number of room modes gets so high and their frequencies so close to one another
 - indistinguishable resonances
 - sound field approaches the ideal diffusivity



Room modes



Axial – one dimensional



Tangential – two dimensional



Room modes

- The frequency, below which the sound field in a room is not diffuse (so-called Schröder frequency) depends on reverberation time and volume: $f_s = 2000 \sqrt{\frac{T}{V}}$
- Example, typical dewlling room: T = 0.5 s ja V = 30 m³ $\rightarrow f_s = 260$ Hz
- The room modes of a rectangular room can be calculated based on the dimensions of the room (L_x, L_y, L_z):

$$f_{lmn} = \frac{c}{2} \left[\left(\frac{l}{L_X} \right)^2 + \left(\frac{m}{L_Y} \right)^2 + \left(\frac{m}{L_Z} \right)^2 \right]$$

where *I*, *m*, *n* are integers



Room modes: Rectangular rooms

Sound pressure amplitude distribution in a rectangular room for a few modes. The amplitude is gray-scale coded where white stands for maximum and black for minimum amplitudes.

From left to right and top to bottom:

mode (2,0,0), mode (1,1,0), mode (2,1,0), mode (3,2,0).

Ligennequency [12]	n_x	n_y	n_z
36.2	1	0	0
41.5	0	1	0
54.8	0	0	1
55.0	1	1	0
65.7	1	0	1
68.6	0	1	1
72.3	2	0	0
77.7	1	1	1
82.9	0	2	0
83.4	2	1	0
			ORVM-CAROL

Eigenfrequency [U-]



Room modes: Rectangular rooms



Eigenfrequency=74.884 Surface: Absolute pressure (Pa)

Rectangular rooms

The frequency differences between the adjacent Eigenfrequencies are quite large at the low frequency end. For increasing frequency these differences become smaller. The number N_f of Eigenfrequencies between 0 and the frequency f [Hz] in a rectangular room of volume V[m3] is estimated as

$$N_f \approx \frac{4\pi}{3} V \left(\frac{f}{c}\right)^3$$

The density $\frac{dN_f}{df}$ (number of Eigenfrequencies per Hz) at frequency f is then $\frac{dN_f}{df} \approx 4\pi V \left(\frac{f^2}{c^3}\right)$



Room modes: Rectangular rooms



- Control rooms
- Recording studios



Frequency - Hz

In small undamped rooms the following acoustical difficulties are typical:

- At low frequencies the transfer function is very uneven due to the low density of resonances.
- At mid and high frequencies strong reflections lead to comb filter distortions and errors in the stereo image. These effects are irrelevant if there is no other contribution stronger than -15 dB relative to the direct sound within 20 ms after the direct sound .
- At all frequencies the reverberation is too large which leads to low transparency of the acoustical image.



There are two fundamental strategies:

» installation of absorbers

» installation of diffusers

Absorbers

Low frequency absorbers for the low frequency range are typically realized as plate or membrane absorbers. To obtain a broad frequency band of absorption, different modules are necessary with adjusted resonance frequency. In the mid and high frequency range porous absorbers can be used.



Absorption data from EN 12354-6

Material	Sound absorption coefficient α_s						
	in octave bands, centre frequency in Hz						
	125	250	500	1 000	2 000	4 000	
concrete, plastered brick	0,01	0,01	0,01	0,02	0,02	0,03	
brickwork, unplastered	0,02	0,02	0,03	0,04	0,05	0,07	
hard floor coverings (e.g. PVC, parquet) on heavy floor	0,02	0,03	0,04	0,05	0,05	0,06	
soft floor covering on heavy floor; \leq 5 mm	0,02	0,03	0,06	0,15	0,30	0,40	
soft floor covering on heavy floor; \geq 10 mm	0,04	0,08	0,15	0,30	0,45	0,55	
wooden floor, parquet on battens	0,12	0,10	0,06	0,05	0,05	0,06	
windows, glass facade	0,12	0,08	0,05	0,04	0,03	0,02	
doors (wood)	0,14	0,10	0,08	0,08	0,08	0,08	
net curtain; 0 mm - 200 mm in front of hard surface ¹	0,05	0,04	0,03	0,02	0,02	0,02	
curtain, $< 0,2 \text{ kg/m}^2$; 0 mm - 200 mm in front of hard surface; typical minimum ¹	0,05	0,06	0,09	0,12	0,18	0,22	
curtain, woven material \approx 0,4 kg/m^2; folded or ruffled > 1:3, 0-200 mm in front of hard surface; typical maximum	0,10	0,40	0,70	0,90	0,95	1,00	
large openings (smallest dimension > 1 m)	1,00	1,00	1,00	1,00	1,00	1,00	
air grid, 50 % open area	0,30	0,50	0,50	0,50	0,50	0,50	
NOTE These data are based on publications used in Austria, Denmark and the Netherlands.							
¹ in front of a window the values of the combination can increase to the values for such a window alone.							

Table B.1 — Typical values for the absorption coefficient



Absorption data from EN 12354-6

Object	Equivalent absorption area A _{obj}						
	in octave bands, centre frequency in Hz						
	125	250	500	1 000	2 000	4 000	
single chair, wood	0,02	0,02	0,03	0,04	0,04	0,04	
single chair, upholstered	0,10	0,20	0,25	0,30	0,35	0,35	
single person in a group, sitting or standing, 1 per 6 m ² area; typical minimum	0,05	0,10	0,20	0,35	0,50	0,65	
single person in a group, sitting, 1 per 6 m ² area; typical maximum	0,12	0,45	0,80	0,90	0,95	1,00	
single person in a group, standing, 1 per 6 m ² area; typical maximum	0,12	0,45	0,80	1,20	1,30	1,40	
NOTE These data are based on publications used in Austria, Denmark and the Netherlands.							

Table C.1 — Typical values for the equivalent absorption area for some common objects

Table C.2 — Typical vales for the sound absorption coefficient for some common specified arrays of objects

Array of objects	Sound absorption coefficient α_s					
	in octave bands, centre frequency in Hz					
	125	250	500	1 000	2 000	4 000
chairs in a row at 0,9m – 1,2m; wood/plastic	0,06	0,08	0,10	0,12	0,14	0,16
chairs in a row at 0,9m – 1,2m; upholstered; typical minimum	0,10	0,20	0,30	0,40	0,50	0,50
chairs in a row at 0,9m – 1,2m; upholstered; typical maximum	0,50	0,70	0,80	0,90	1,0	1,0
persons sitting in a row at 0,9m – 1,2m (audience); typical minimum	0,20	0,40	0,50	0,60	0,70	0,70
persons sitting in a row at 0,9m – 1,2m (audience); typical maximum	0,60	0,70	0,80	0,90	0,90	0,90
children in a hard furnished class room, 1 per m ² area	0,10	0,20	0,25	0,35	0,40	0,40
NOTE These data are based on publications used in Austria, Denmark and the Netherlands.						



Diffusers

- The use of diffusers aims at replacing reflections by scattering .
- In the best case the scattered sound energy is equally distributed in all directions.
- In small rooms, scattering may help to avoid room resonances. In order to create diffuse reflections a surface has to introduce locally inhomogeneous reflection conditions. This inhomogeneity can be realized by phase or amplitude variation.



Typical classroom





Effect of furniture





Scattering – why is it important?





Furniture absorption

T₀ empty room



T_{furn} furnished



$$A_{furn}=0,163V~(\frac{1}{T_{furn}}-\frac{1}{T_0})$$



Effects of furniture

The reverberation curve in a classroom for

a) empty room,

b) empty room + an absorbent ceiling,

c) b + shelves, cupboards and furnishings along the walls,

d) c + pupil stations, consisting of a chair and small table, distributed across the floor.



Assessment of sound in rooms



Sensation

- Sound strength
- Clarity
- Sharpness
- ...

Preference





Thank you for your attention!

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