Rumsakustik

Erling Nilsson, Akustiker
ECOPHON Saint-Gobain

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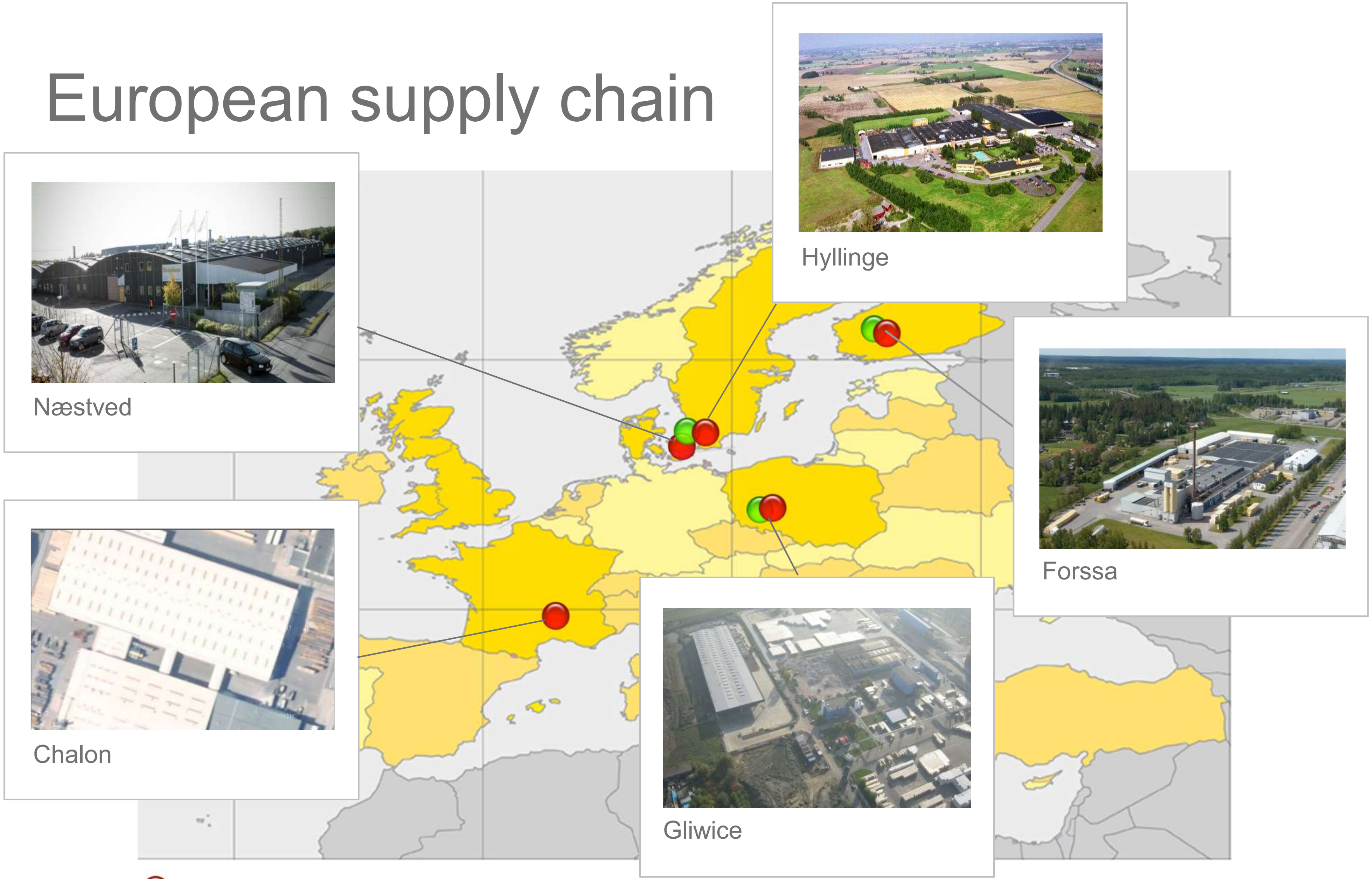
Community school no 15, Gdynia, Poland. Architect: Adam Drochomiercki. Photo: Szymon Polanski.
System: Ecophon Master A/alpha

Ecophon

European supply chain



Production unit
Distribution center

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Saint-Gobain

- One of the world's 100 leading industry groups
- Focusing on habitat and construction
- Established in 1665
- Present in 64 countries
- 190 000 employees
- ~ €40 billion in sales

Spegelsalen i Versailles

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Four market segments

Education

Modern Office

Healthcare

Clean Industry

- Long experience of how sound affects people
- Specialised knowledge about segment specific activities
- Systems developed for specific needs

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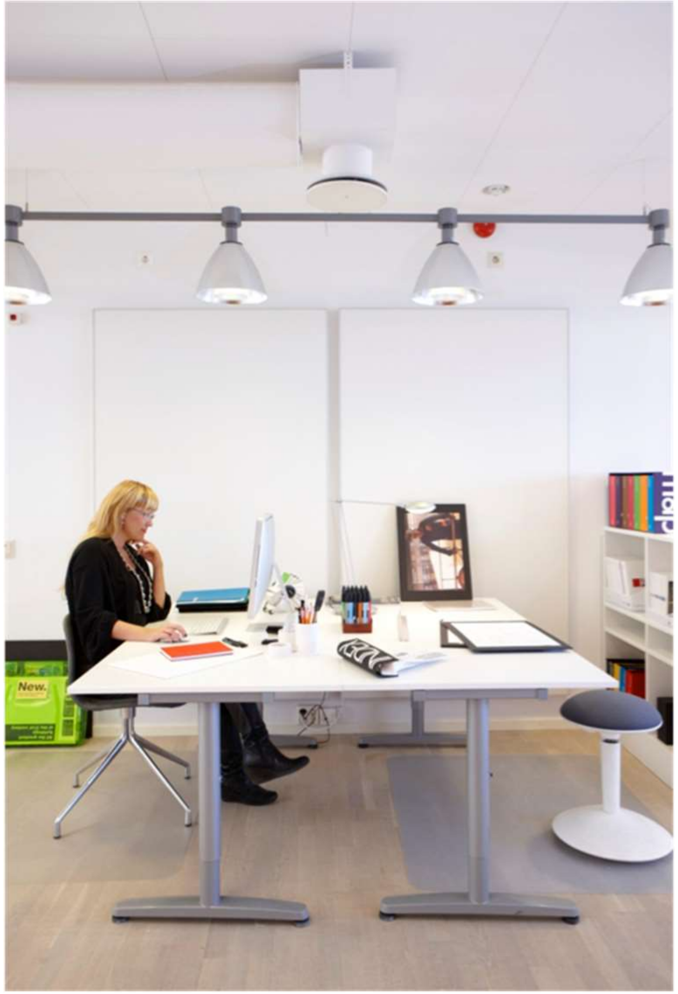
Benefits of good acoustics

- Increased wellbeing and satisfaction
- Less tiredness
- Easier to concentrate
- Fewer errors
- Less stress hormones
- Easier to communicate
- More positive energy
- Increased creativity



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Room Acoustic design in practise



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Innehåll

- Något om Ecophon
- Rumsakustik i praktiken
- Betydelsen av god akustik
- Rumsakustik och ljudabsorption
- “Activity based acoustic design”
- Rumsakustiska mått
- Effekt av akustikreglering I klassrum
- Öppna kontorslandskap
- Några exempel på akustikreglering

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Schools:

Positive effects of a good sound environment in educational premises include:

- Reduced vocal strain and voice disorders for teachers
- Improved concentration
- Reduced tiredness, fatigue and stress levels
- Easier to hear and be heard with improved speech clarity
- Optimised environment for multi-communicational activities such as group work
- Improved student behaviour and reduced burden on school and classroom management

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Healthcare:

Better sound environment contributes to:

- Lowering of blood pressure
- Improving quality of sleep
- Reducing intake of pain medication
- Reducing the number of re-admissions
- Improving the wellbeing of staff and increasing perceived performance

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Open-plan offices:

- In a modern flexible OPO, the creation of a functional work station is a complex process in which acoustic planning is only one part of a series of considerations having to be addressed. The open-plan office should support both communication and concentrated work. Thus, for an OPO to be an efficient and comfortable place of work there are several other requirements than acoustic treatment that have to be fulfilled.

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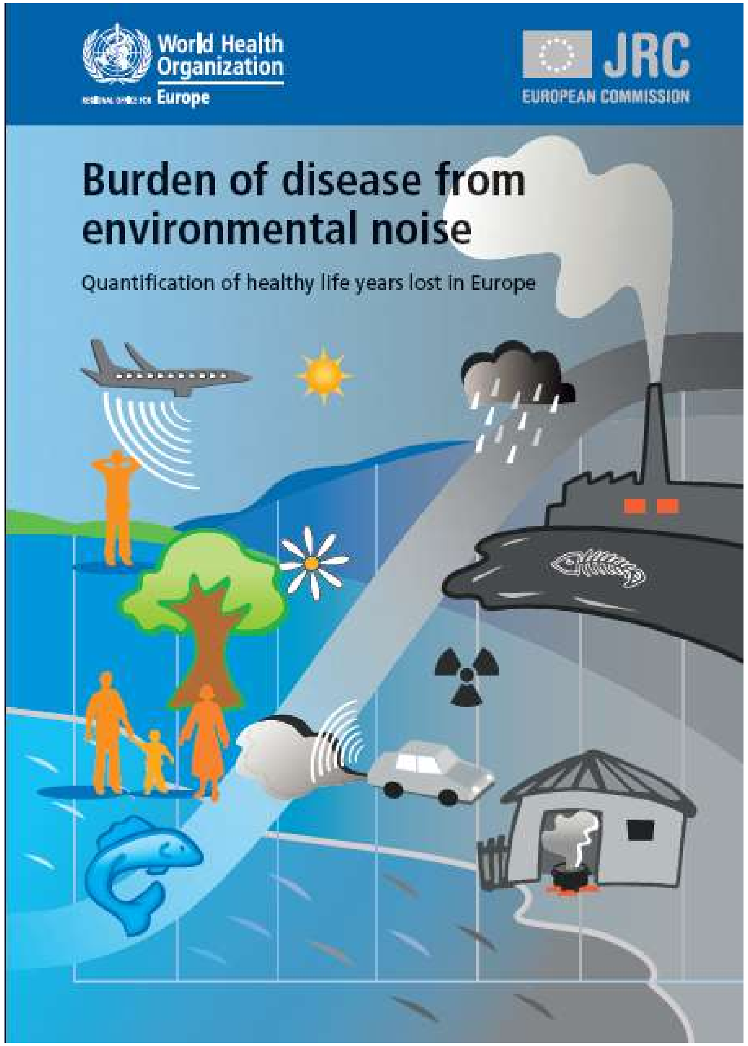
WHO report



Public health experts agree that environmental risks constitute 24% of the burden of disease. Widespread exposure to environmental noise from road, rail, airports and industrial sites contributes to this burden. One in three individuals is annoyed during the daytime and one in five has disturbed sleep at night because of traffic noise. Epidemiological evidence indicates that those chronically exposed to high levels of environmental noise have an increased risk of cardiovascular diseases such as myocardial infarction. Thus, noise pollution is considered not only an environmental nuisance but also a threat to public health.

where

Sabine formula

$$T = 0.16\left(\frac{V}{A}\right) \quad \text{or} \quad A = 0.16\left(\frac{V}{T}\right)$$

where

T=the reverberation time (s)
V=the room volume (m^3)
A=the total equivalent absorption area (m^2 sabin)

The equivalent absorption area A for a surface with area S m^2 is equal to α x S where α is the absorption coefficient for the surface

Acoustic design with Sabine formula

Example: The reverberation time in a room with a volume of 200 m^3 is 2,5 s at 1000 Hz.
Target value for the reverberation time is 0,40 s at 1000 Hz

- A(before treatment)=0,161xV/T= 0,161x200/2,5=12,9 m^2 sabin
- A(needed to fulfil 0,40 s)= 0,161xV/T=0,161x200/0,40=80,5 m^2 sabin
- A(to be added to fulfil 0,40 s)=A(needed)-A(before)=80,5-12,9=67,6 m^2 sabin

If e.g. the absorption coefficient for a ceiling absorber is 0,90 at 1000 Hz we will need S= A/α=67,6/0,90=75 m^2

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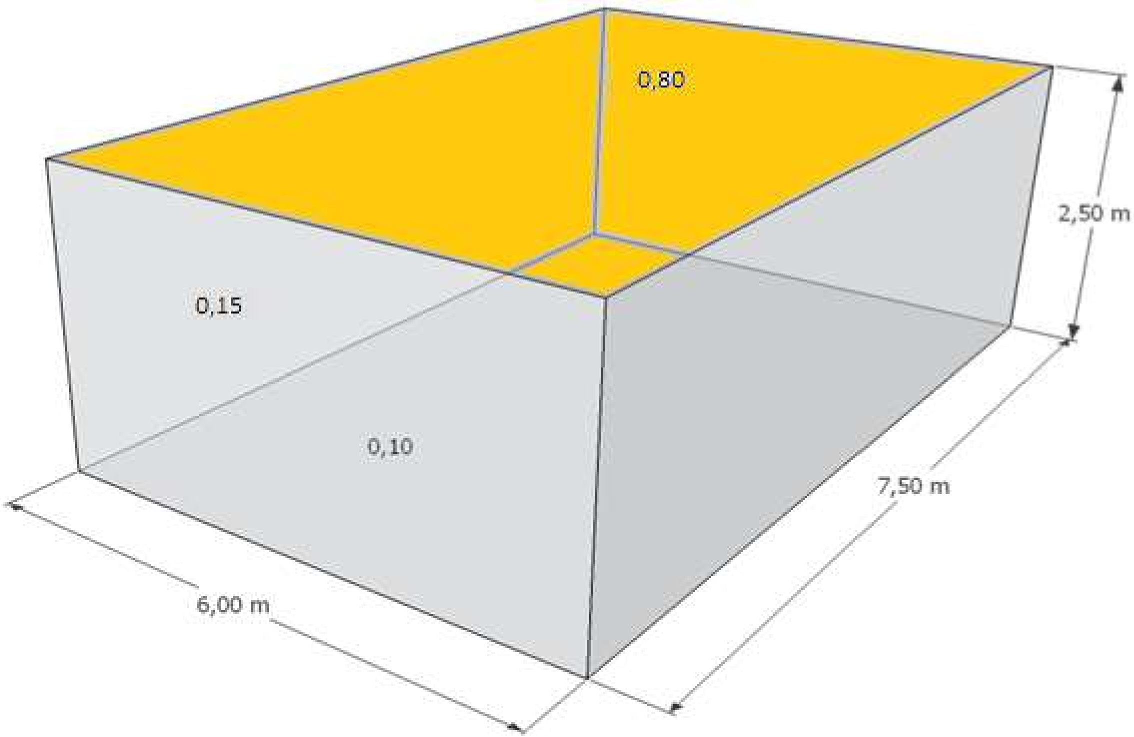
Sabine formula: How it works in theory



Absorption coefficients (500 Hz):

Walls=0,15
Ceiling=0,80
Floor=0,10

Absorption data from EN 12354-6

Table B.1 — Typical values for the absorption coefficient

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; ≤ 5 mm	0,02	0,03	0,06	0,15	0,30	0,40
soft floor covering on heavy floor; ≥ 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 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 ≈ 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.

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Absorption data from EN 12354-6

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

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.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.						

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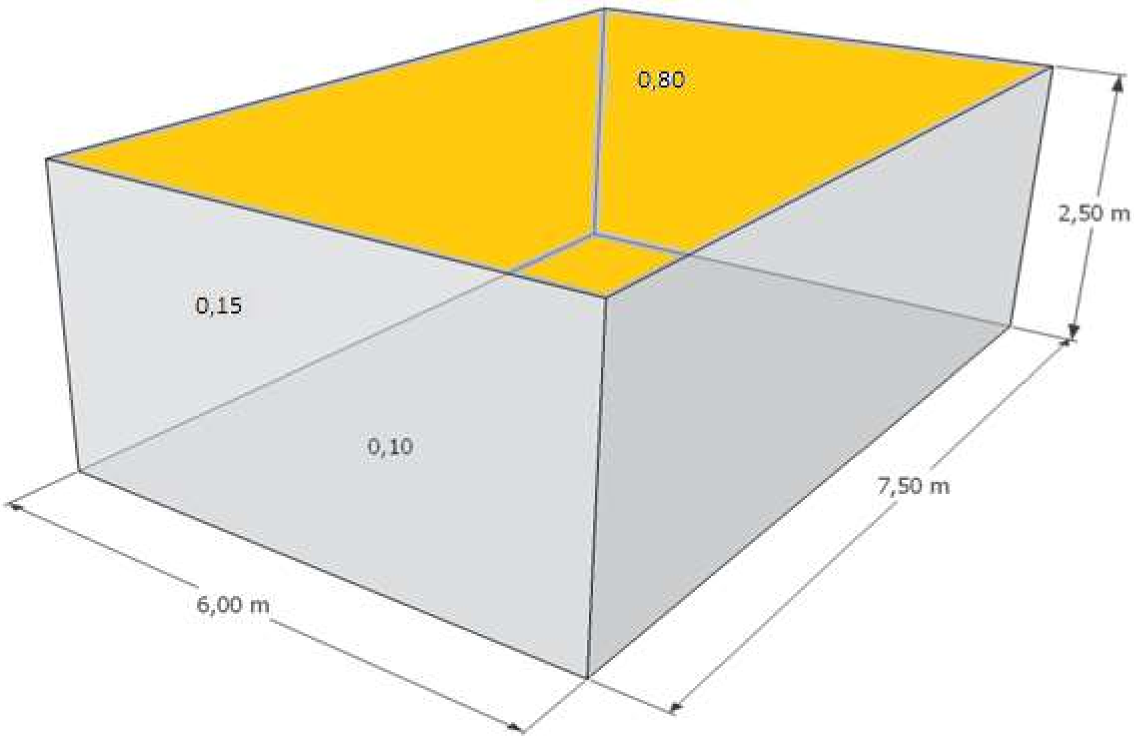
Sabine formula: How it works in theory



Absorption coefficients (500 Hz):

Walls=0,15
Ceiling=0,80
Floor=0,10

$A=\sum \alpha_i \times S_i = 0,10 \times 6 \times 7,5+2 \times 0,15 \times 7,5 \times 2,5+2 \times 0,15 \times 6 \times 2,5+0,80 \times 6 \times 7,5=51\ m^2$ sabin

$T_{60}=0,161 \times (V/A)=0,161 \times 112,5/51 \approx 0,36$ s

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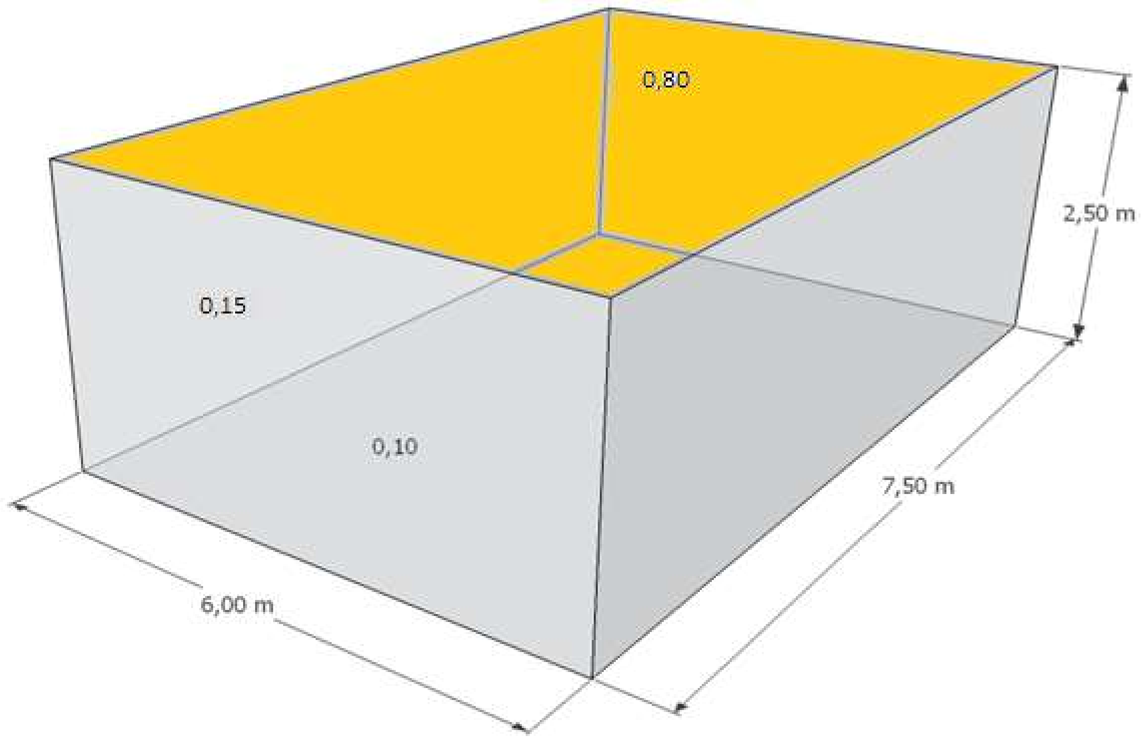
Not a typical classroom



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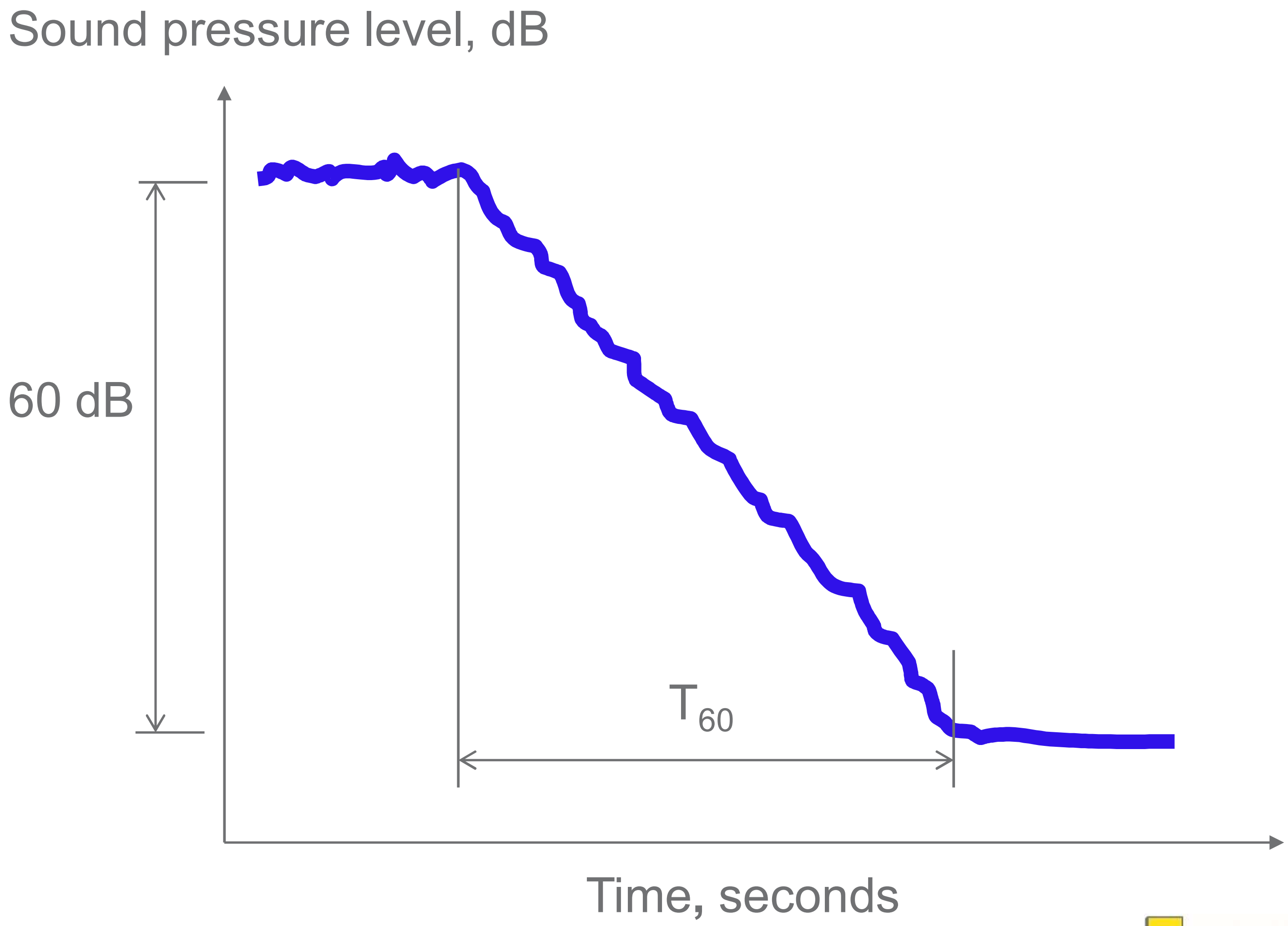
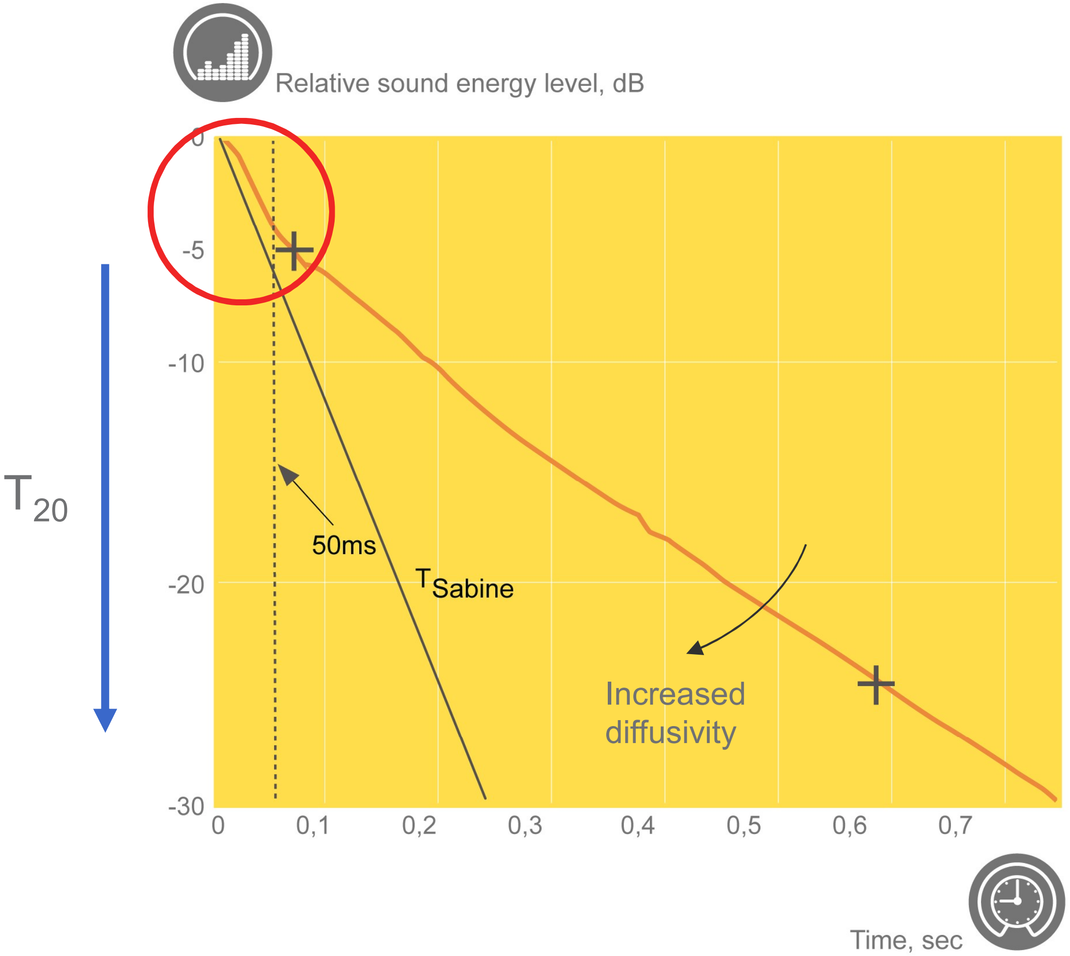
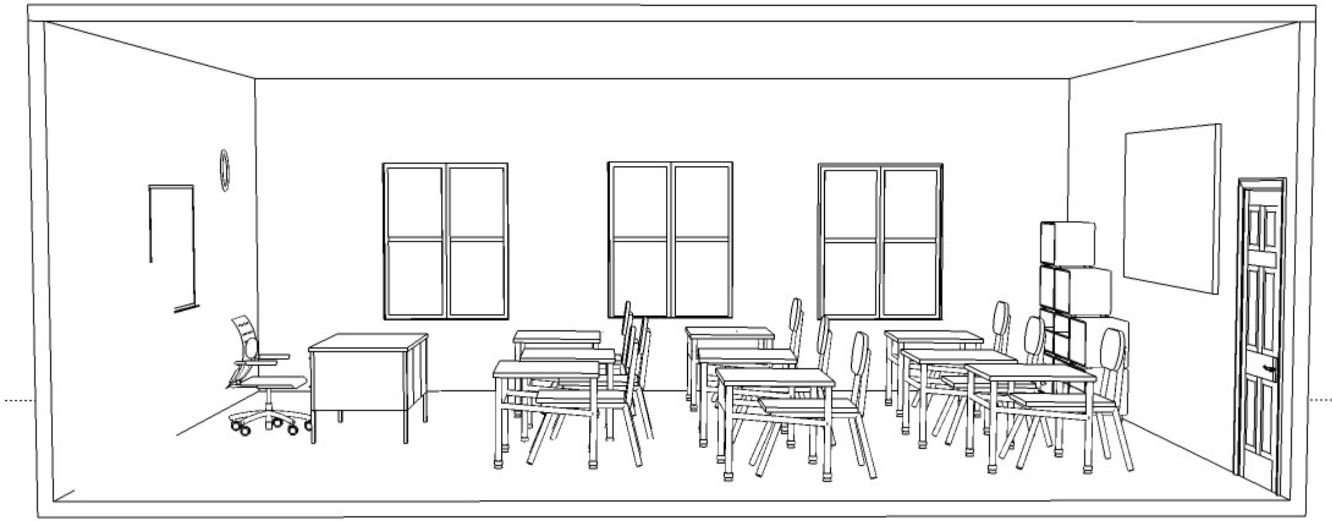
Definition: Reverberation time



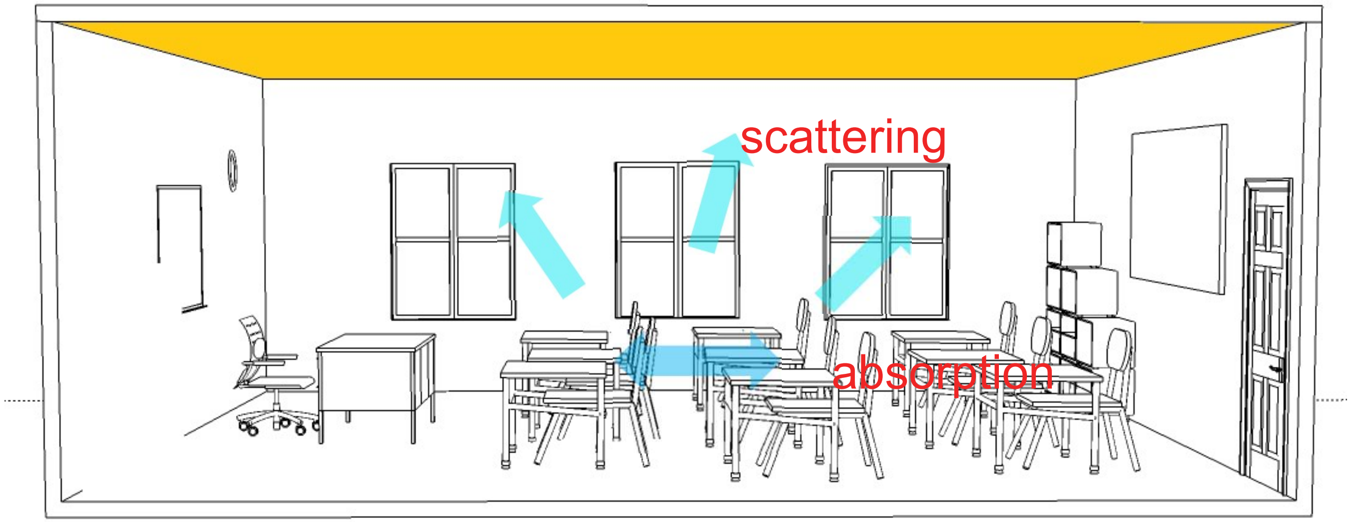
Reverberation decay in rooms with suspended absorbent ceiling



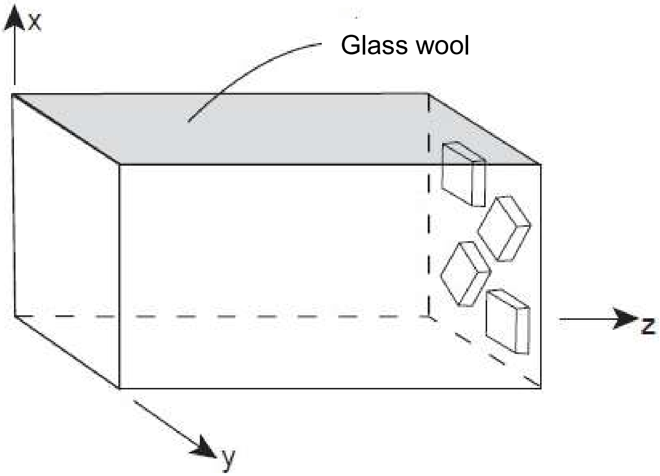
Typical classroom

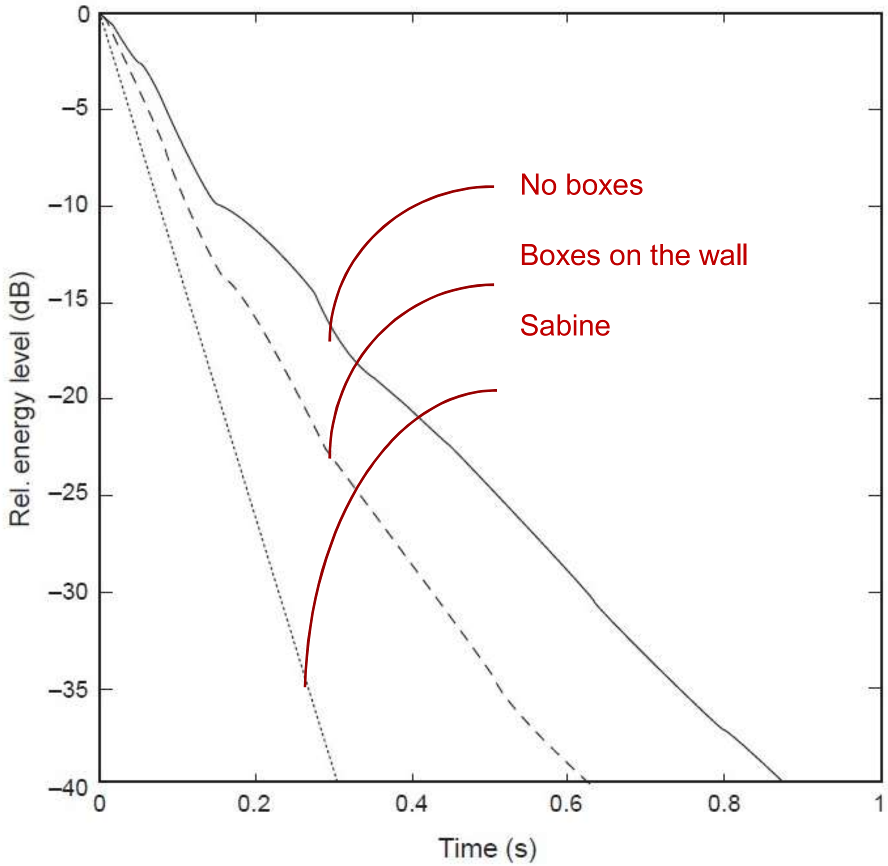


Effect of furniture

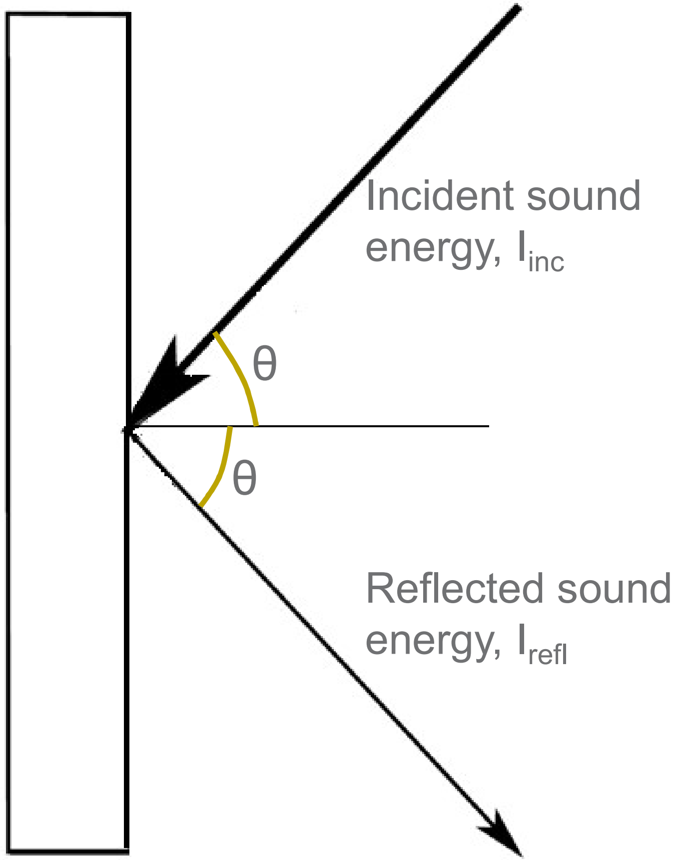


Scattering – why is it important?





Reflection from a surface



Specular reflection

– Angle of reflection equals angle of incidence

Absorption coefficient:

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

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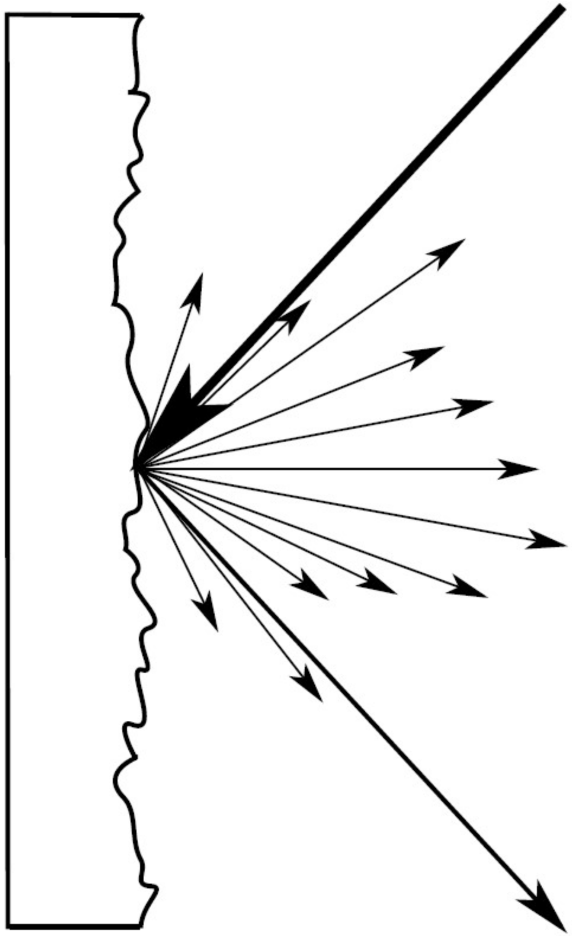
Reflection from a surface



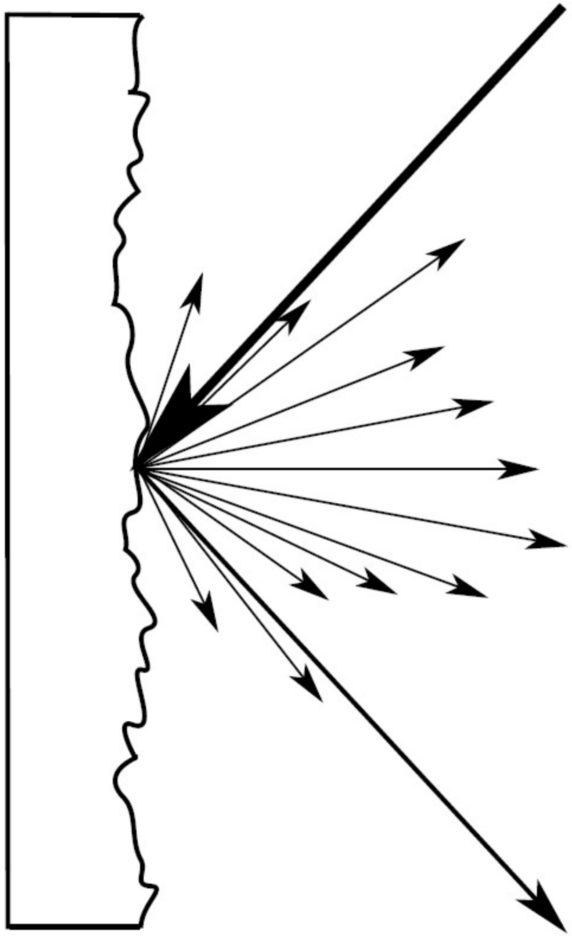
Specular reflection

– Angle of reflection equals angle of incidence

Diffuse reflection

– Scattered in many directions

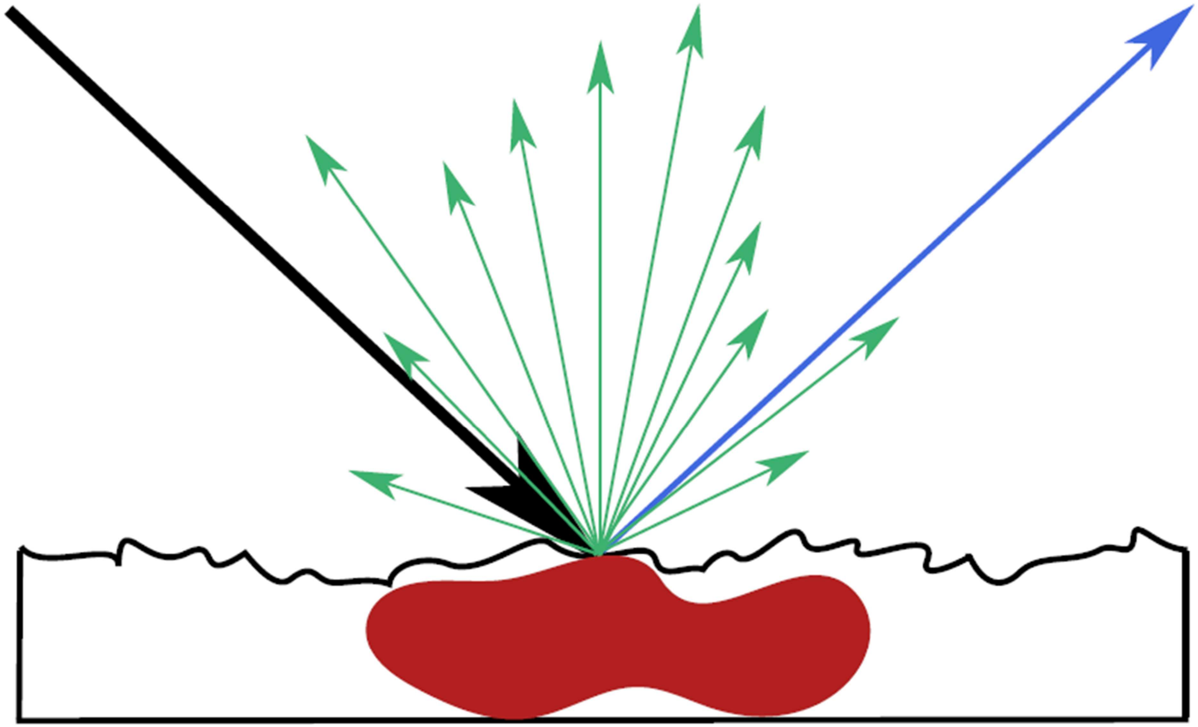
Reflection from a surface



Scattering coefficient, *s*

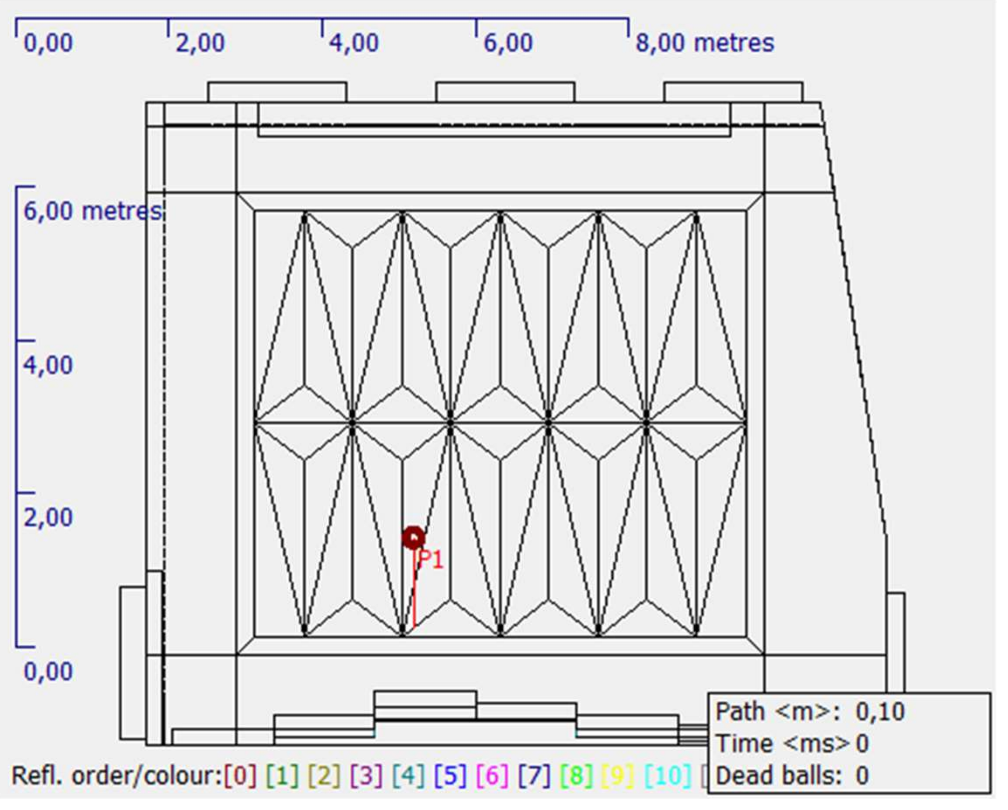
- Fraction of energy which is scattered
- Always between 0 and 1

Absorption and scattering



$$\underset{\text{absorbed}}{\alpha} + \underbrace{(1-\alpha)\cdot(1-s)}_{\text{specularly reflected}} + \underbrace{(1-\alpha)\cdot s}_{\text{diffusely reflected}} = 1$$

Simulation of sound fields



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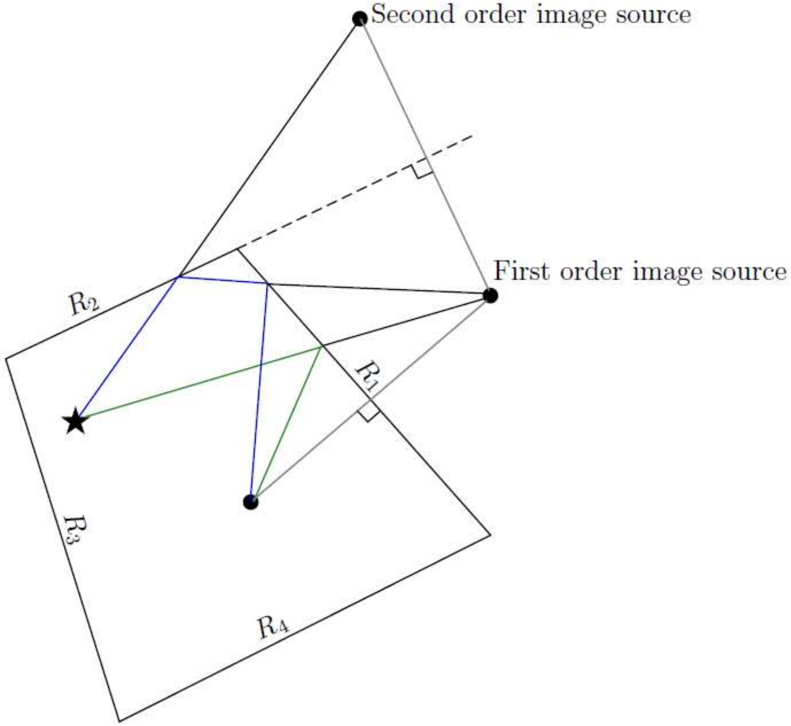
PARISM – simulation tool for ordinary rooms

Industrial PhD project together with DTU

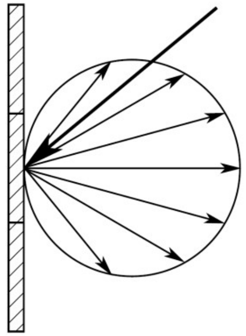
The image source method

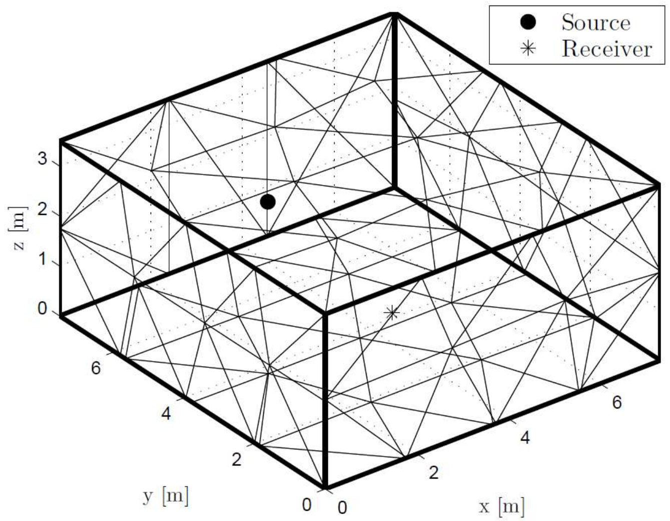


Acoustical radiosity

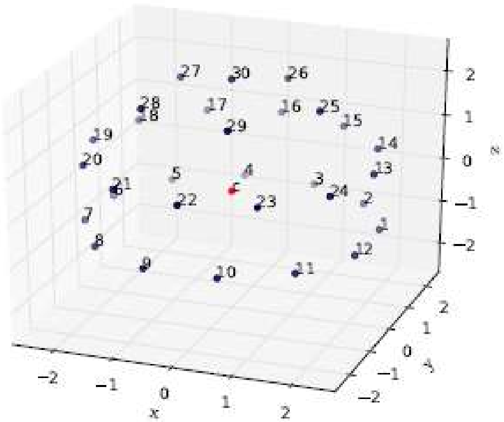
Lambert's law:

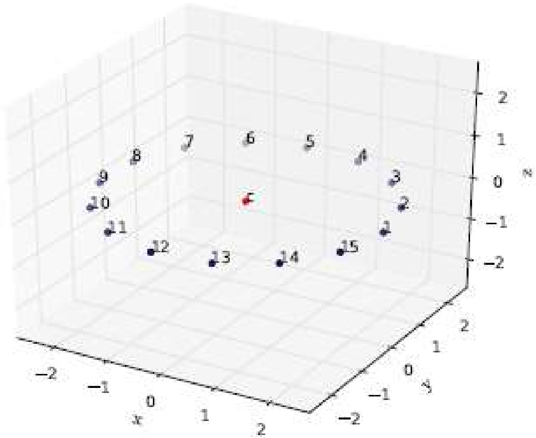
$$I(\theta) = I(0)\cos(\theta)$$



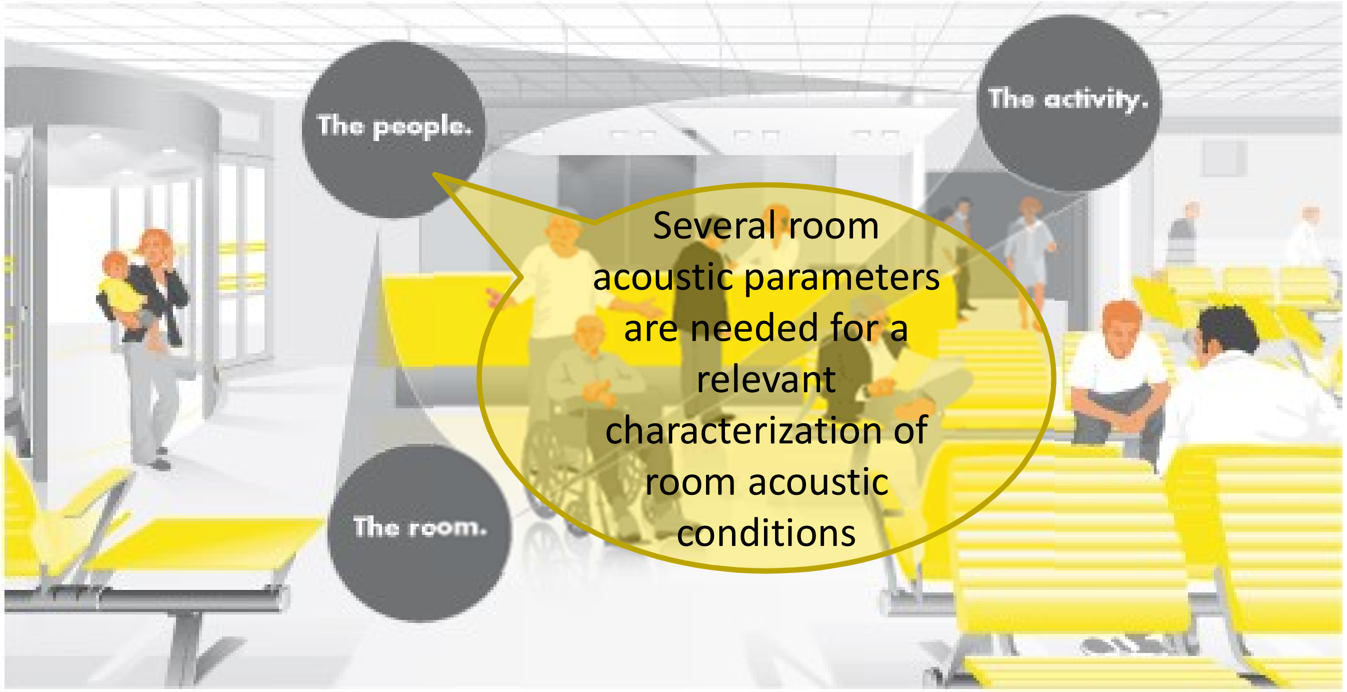


Auralisation with loudspeaker array using higher order ambisonics





Activity based acoustic design – a method to approach room acoustic design



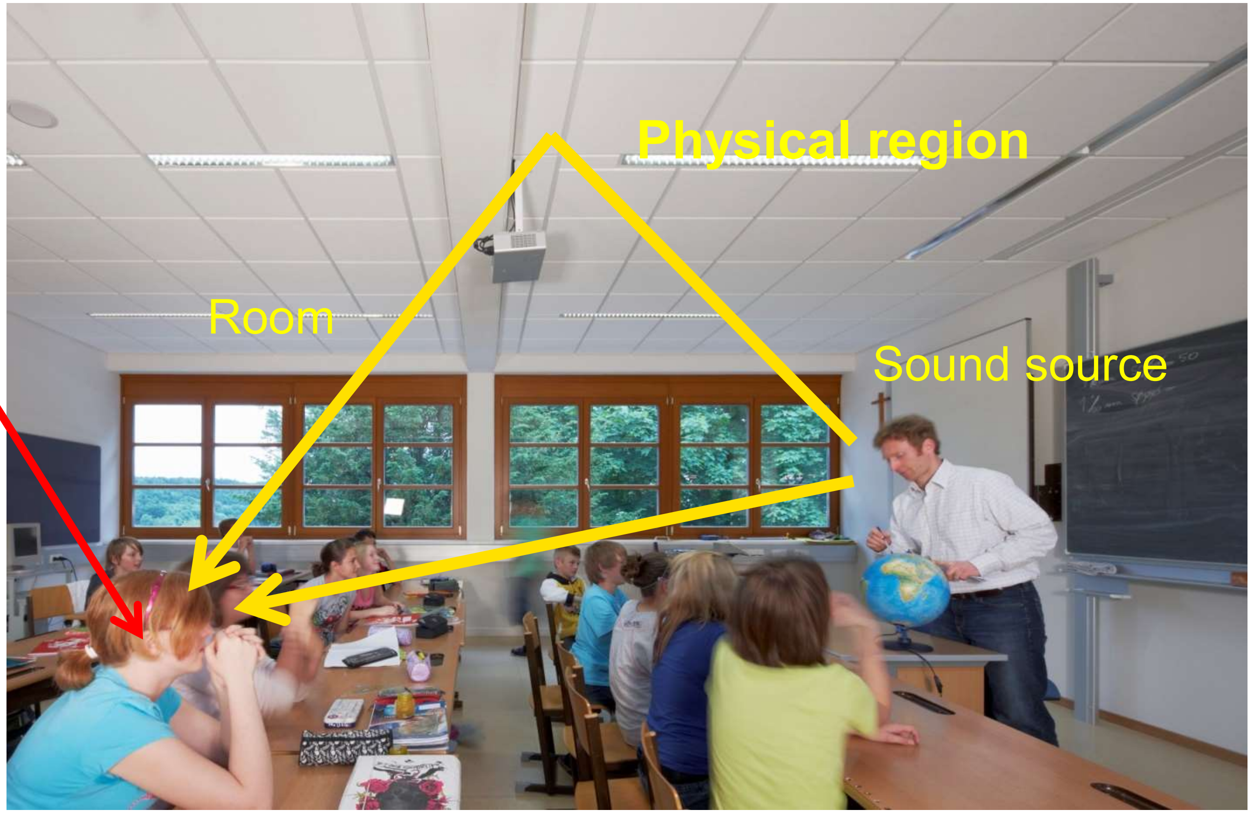
Assessment of sound in rooms

Physiological and psychological region

Sensation

- Sound strength
- Clarity
- Sharpness
- …

Preference



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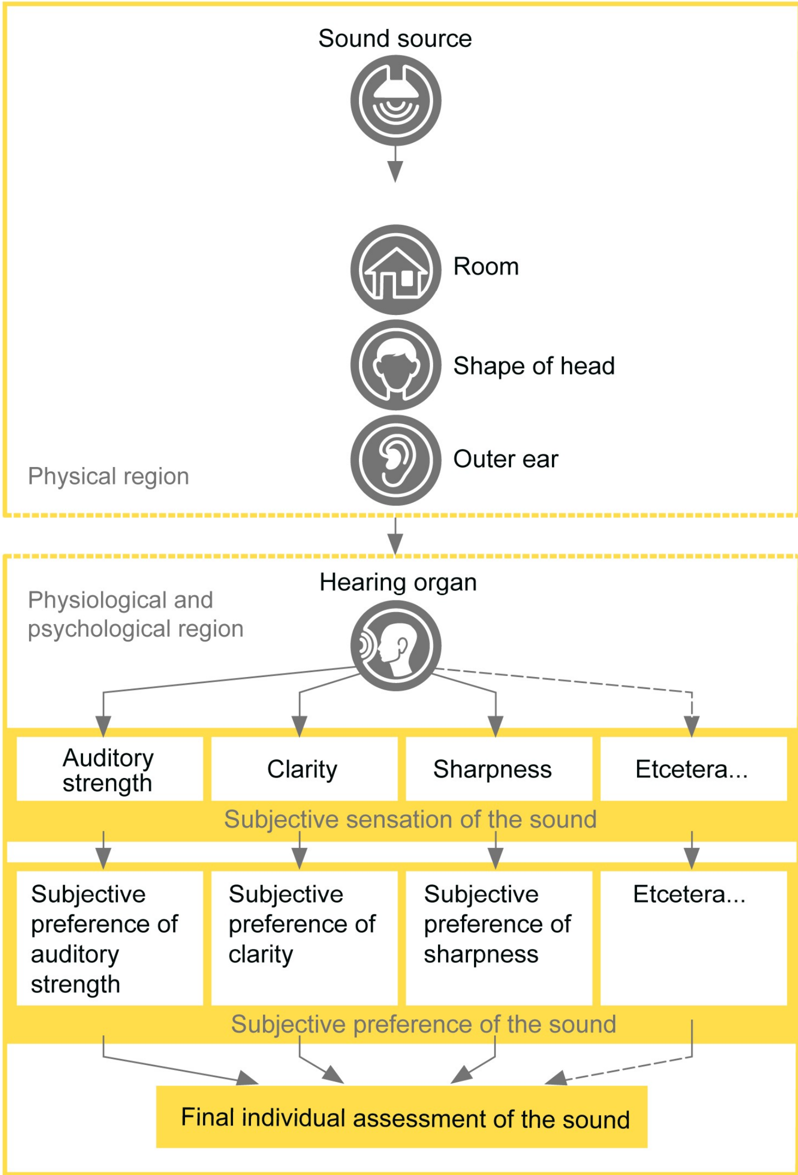
Assessment of sound in rooms



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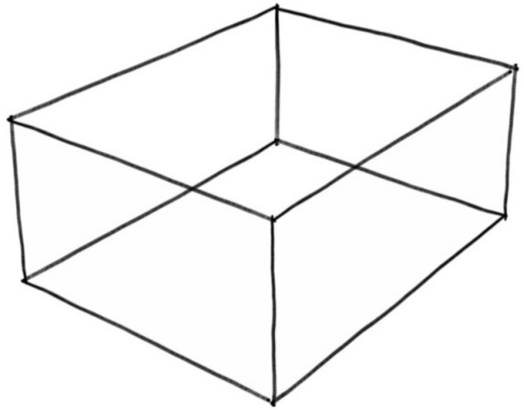
Room types

Reverberant room (Sabine room)

Reverberation time

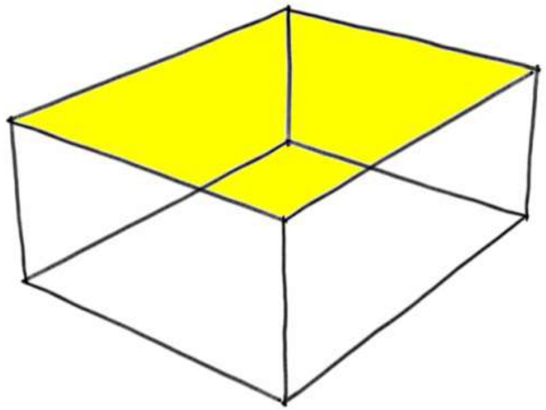


Room with absorbent ceiling

Speech clarity

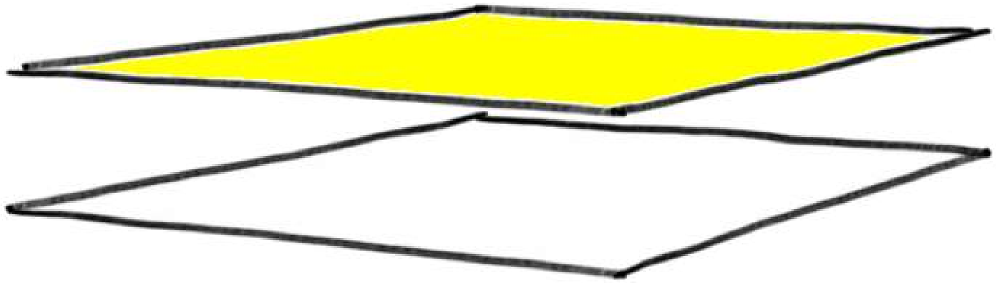
Sound strength

Reverberation time



Open-plan spaces

Spatial decay



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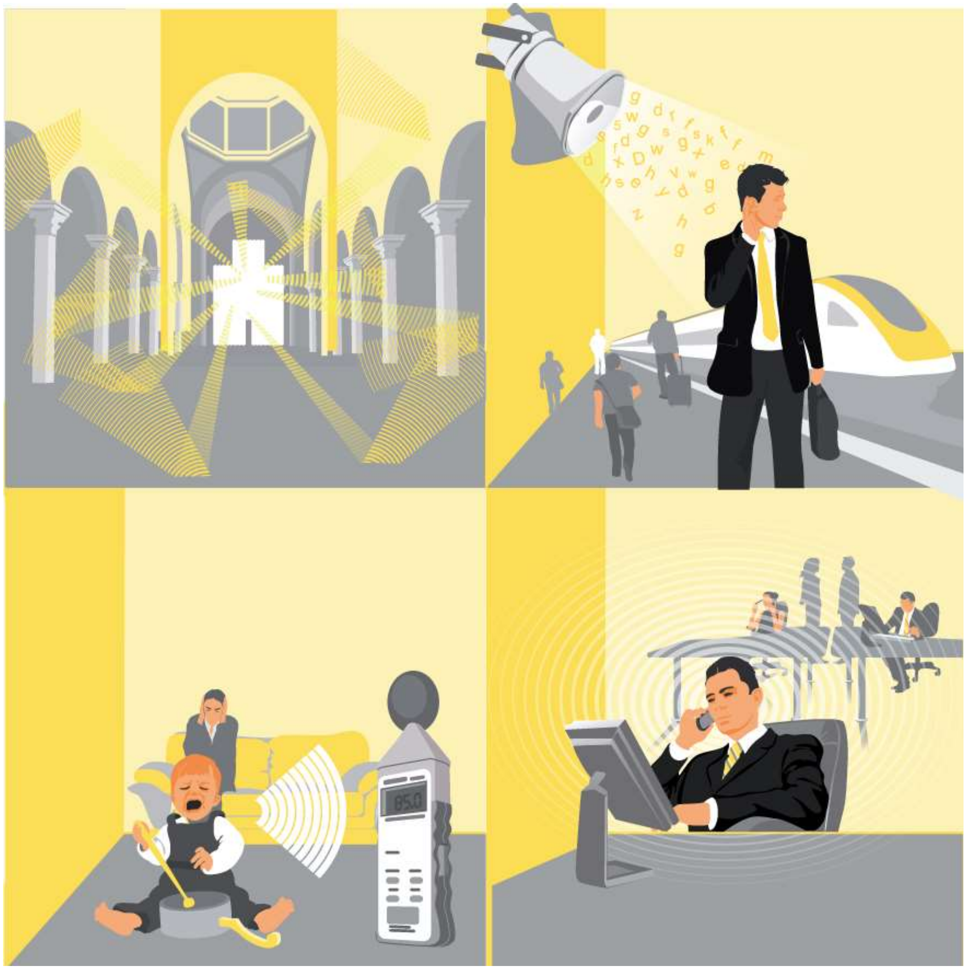
Room acoustic quality aspects

- Reverberation
- Speech clarity
- Auditory strength
- Spatial decay

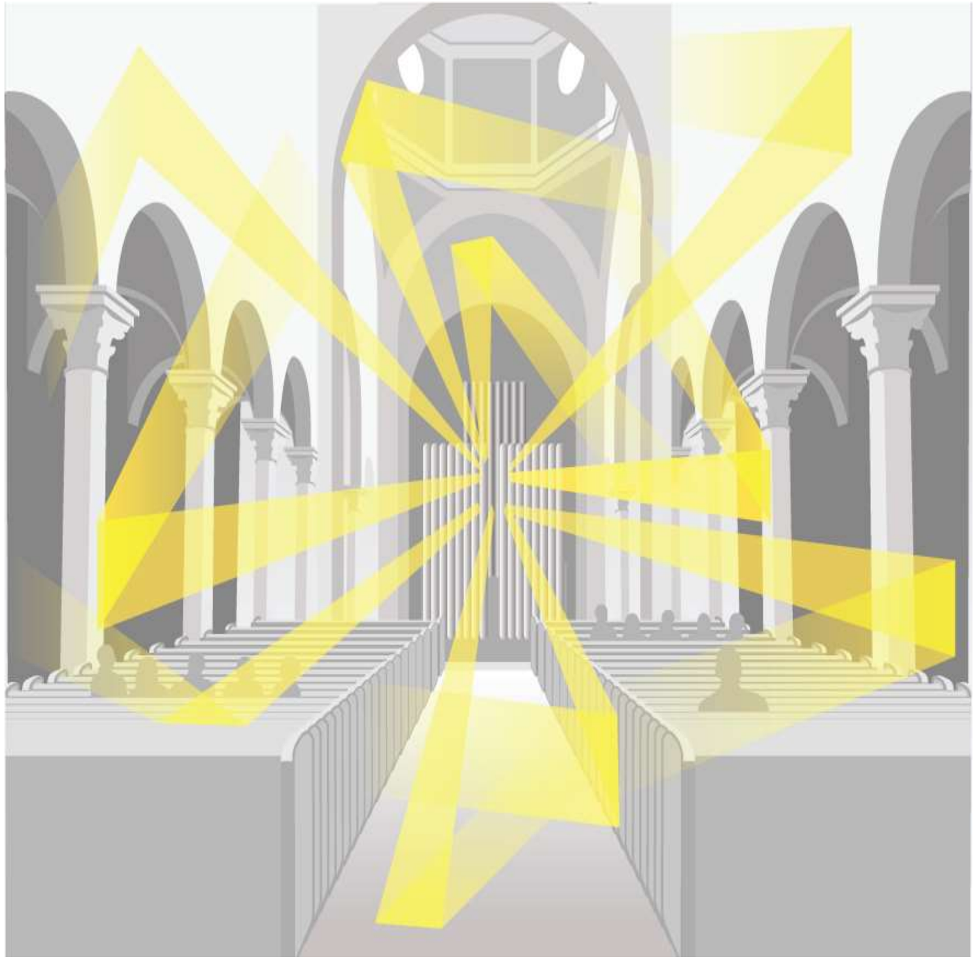


Efterklang

- **Relaterar till hur snabbt ljudenergin försvinner i ett rum**

Lång efterklang

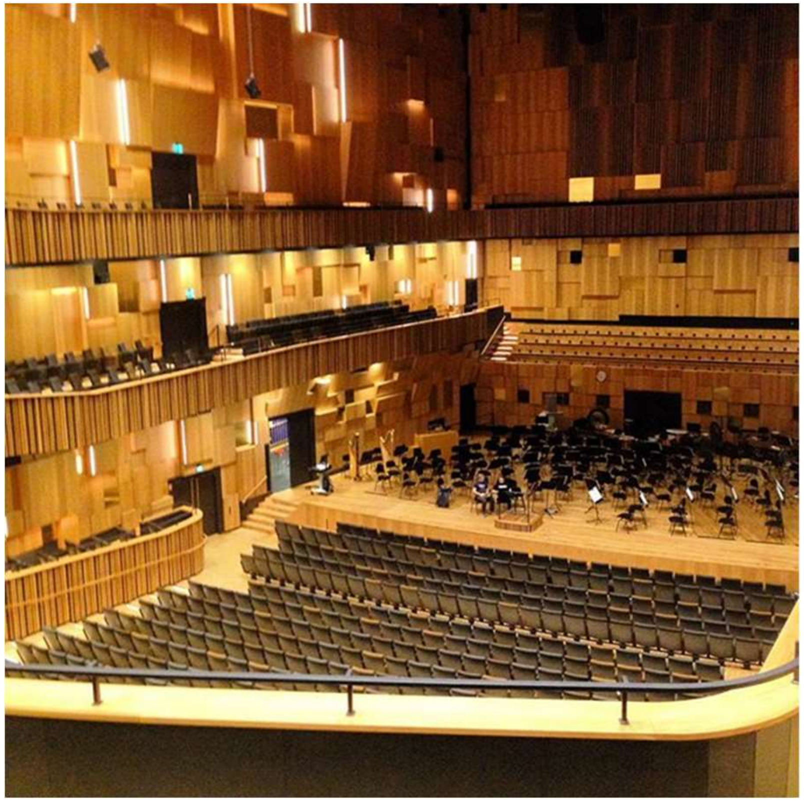
Kort efterklang



Parameters for performance spaces ISO 3382-1

Subjective quality	Objective measure
Clarity	Clarity index (C_{80})
Reverberance	Early decay time (EDT))
Intimacy	Sound strength (level)
Source broadening	Early lateral fraction and strength
Loudness	Sound strength and source-receiver distance

M. Barron, The development of concert hall design – A 111 year experience, Proceedings of the Institute of Acoustics, Vol. 28. Pt. 1. 2006



ISO 3382-2: Reverberation time in ordinary rooms

ISO 3382-3: Open plan offices (T_{20} not included)

Schools

Offices

Hospitals

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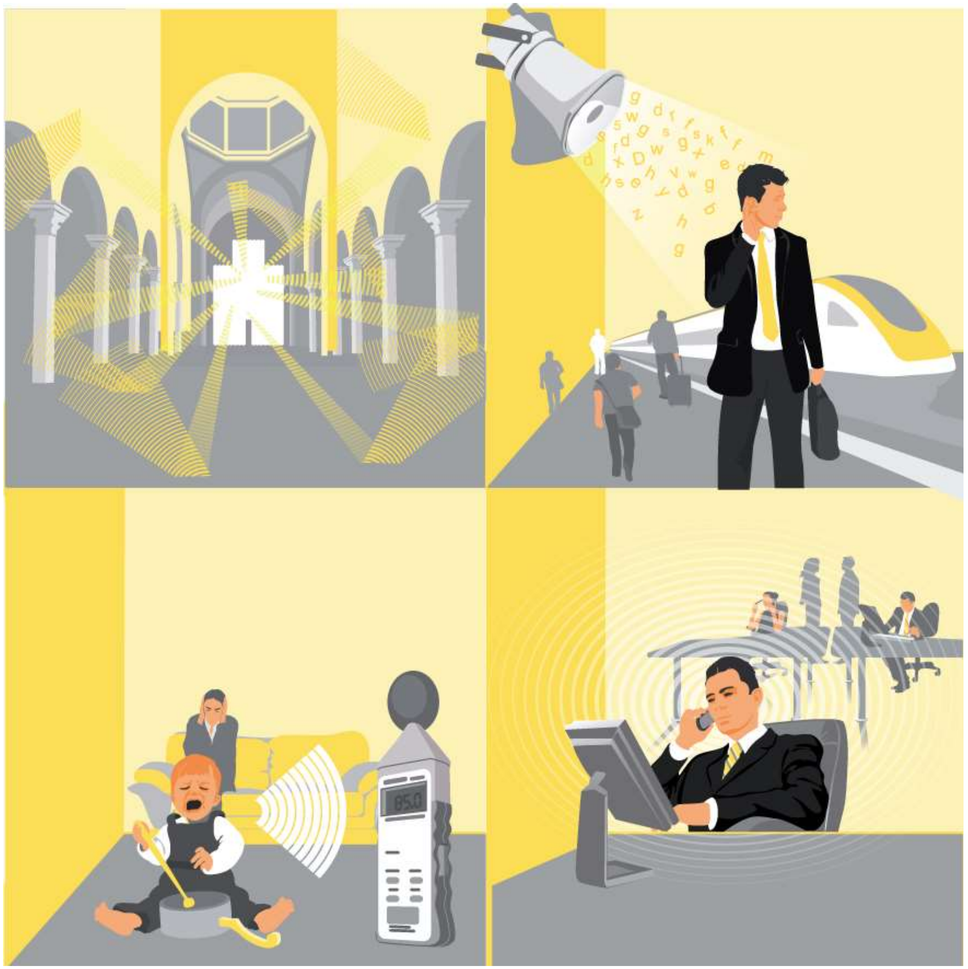
Room acoustic quality aspects and parameters

Ordinary rooms:

- Reverberation: T_{20} (s), ISO 3382-2
- Speech clarity: C_{50} (dB), ISO 3382-1
- Auditory strength: G (dB), ISO 3382-1

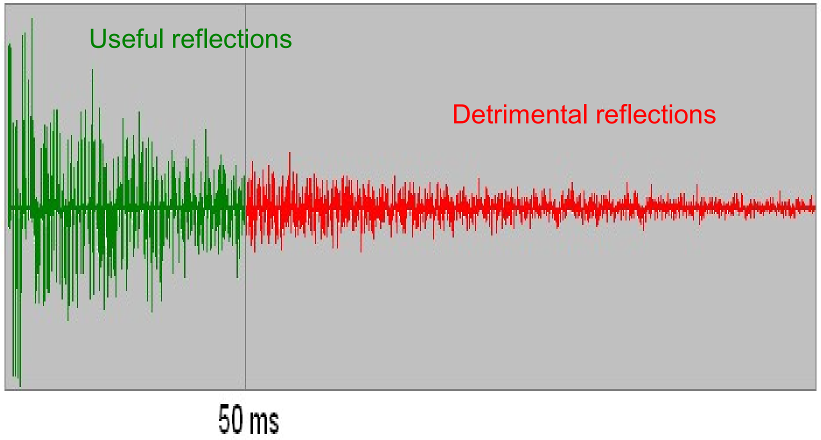
Open plan spaces:

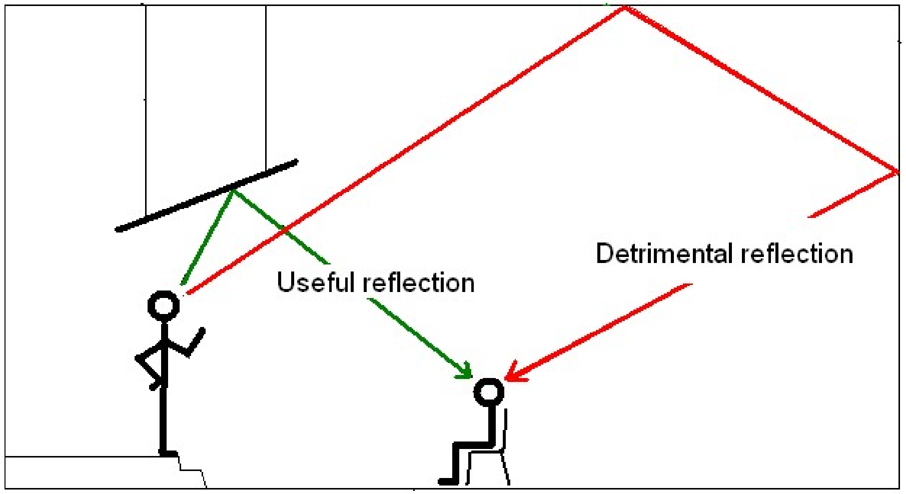
- Spatial decay: according to ISO 3382-3



Definition of room acoustic measures: Speech Clarity C_{50} (dB)

$$C_{50} = 10 \times \log\left(\frac{\text{Energy}(0-50\text{ms})}{\text{Energy}(50-\text{end})}\right) \quad , \text{dB}$$





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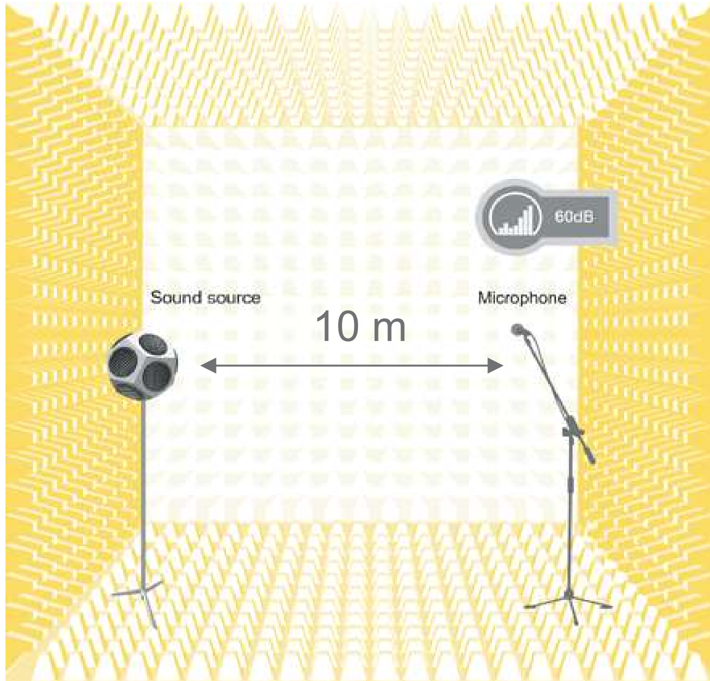
Room acoustic measures: Sound strength G (dB)

$G = Lp_{Room} - Lp_{10m} = Lp - Lw + 31$ dB (omni-directional sound source)



G=70 dB - 60 dB= 10 dB

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Sound Power Source

Norsonic

Certificate No: CAL 022-2014-4810

NORWEGIAN ACCREDITATION CAL 022

Measurement results:

The sound power level of the reference sound source, relative to 10^{-12} W, normalised to the stated reference conditions, is given in the table below. Broadband levels are computed from the summed energy in each 1/3-octave band with midband frequency from 50 Hz to 20 kHz.

Frequency Hz	L_w dB re 1 pW 1/3-octave	L_w dB re 1 pW 1/1-octave	Uncertainty (2σ) dB	Directivity dB
20 *	62,0		2,0	4,4
25 *	65,5		1,8	2,3
31.5 *	66,7	71,5	1,7	2,1
40 *	67,8		1,6	1,9
50	67,8		1,5	2,2
63	71,1	75,8	1,3	2,1
80	72,9		1,0	2,4
100	74,4		0,9	2,1
125	75,2	79,9	0,8	1,8
160	75,6		0,8	2,0
200	74,6		0,7	2,1
250	75,5	80,4	0,7	2,3
315	76,6		0,6	2,4
400	76,9		0,5	2,6
500	77,0	81,9	0,5	2,6
630	77,6		0,5	2,6
800	78,4		0,5	2,7
1 k	78,9	83,7	0,5	1,8
1,25 k	79,4		0,5	2,8
1,6 k	80,4		0,5	2,8
2 k	82,8	87,7	0,5	2,2
2,5 k	84,6		0,5	2,4
3,15 k	83,6		0,5	2,3
4 k	83,0	87,6	0,5	2,9
5 k	81,7		0,6	1,5
6,3 k	80,8		0,6	3,3
8 k	78,3	83,5	0,7	1,9
10 k	75,8		0,8	2,1
12,5 k	73,8		1,0	1,0
16 k	72,5	77,3	1,1	1,9
20 k	70,7		1,2	1,7
Lin	**93,2**		0,4	-
A-weighted	**93,1**		0,5	-

* Values for frequencies marked with * are not covered by the accreditation.

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Sound strength G (dB)

$$G = L_p - L_W + 31 \text{ (dB)}$$

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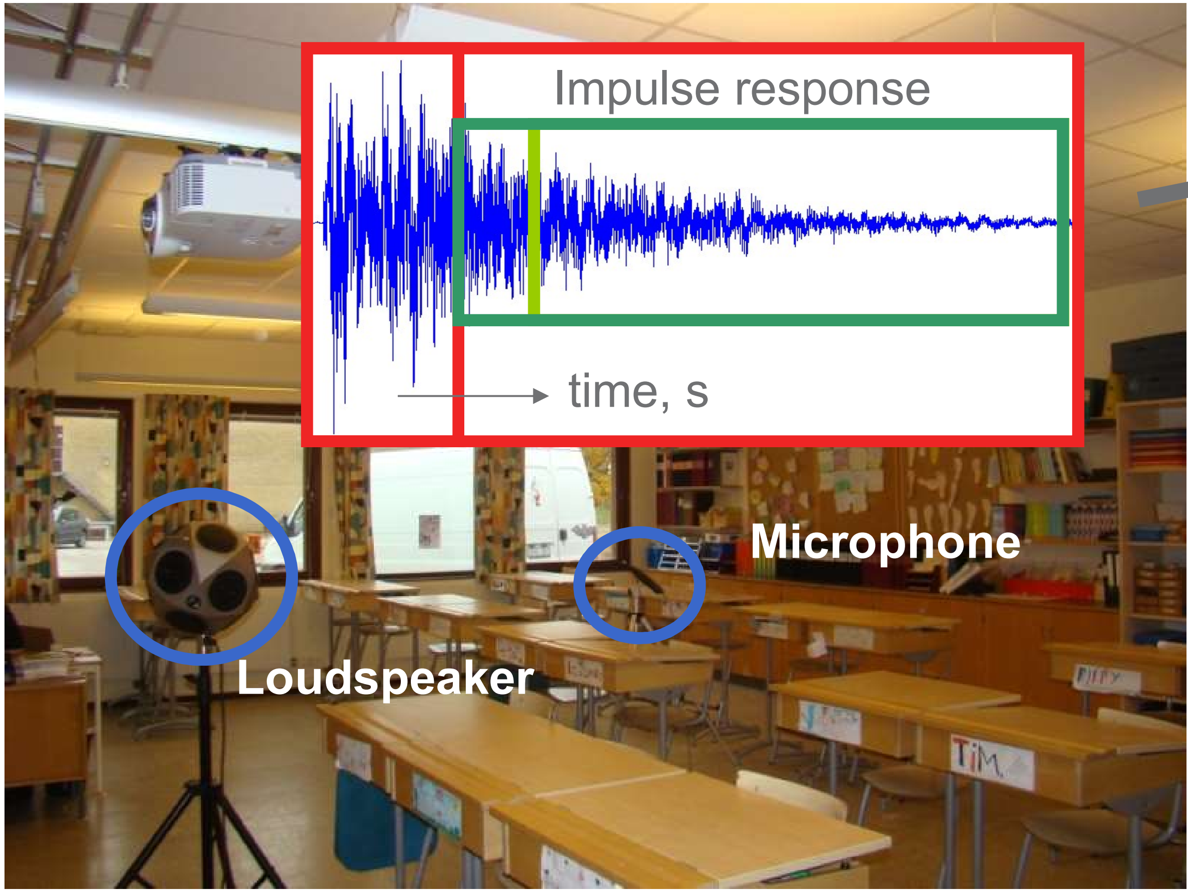
Just noticeable difference of room acoustic quantities according to ISO 3382-1

Subjective listener aspect	Room acoustic quantity	Just noticeable difference
Subjective level of sound	Sound Strength G in dB	1 dB
Perceived reverberance	Reverberation time T_{20} in seconds	5%
Perceived clarity of sound	Speech Clarity C_{50} in dB	1 dB

Room acoustic measurements



Reverberation time, T_{20}
Speech clarity, C_{50}
Strength, G

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Small meeting rooms

Two similar rooms with different ceiling treatment.

Room 1: Ceiling absorber $\alpha_w = 1.0$

Room 2: Ceiling absorber $\alpha_w = 0.1$

Floor area = 12 m^2

Height = 2.7 m

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Semantic differential questionnaires

	Extremely	Very	Fairly	Partly	Fairly	Very	Extremely	
Distinct							X	Indistinct
Pleasant								Unpleasant
Dry								Reverberant
Best possible listening environment								Worst possible listening environment
Best possible speaking environmen								Worst possible speaking environmen

Semantic differential questionnaires

	Extremely	Very	Fairly	Partly	Fairly	Very	Extremely	
Distinct		X						Indistinct
Pleasant								Unpleasant
Dry								Reverberant
Best possible listening environment								Worst possible listening environment
Best possible speaking environmen								Worst possible speaking environmen

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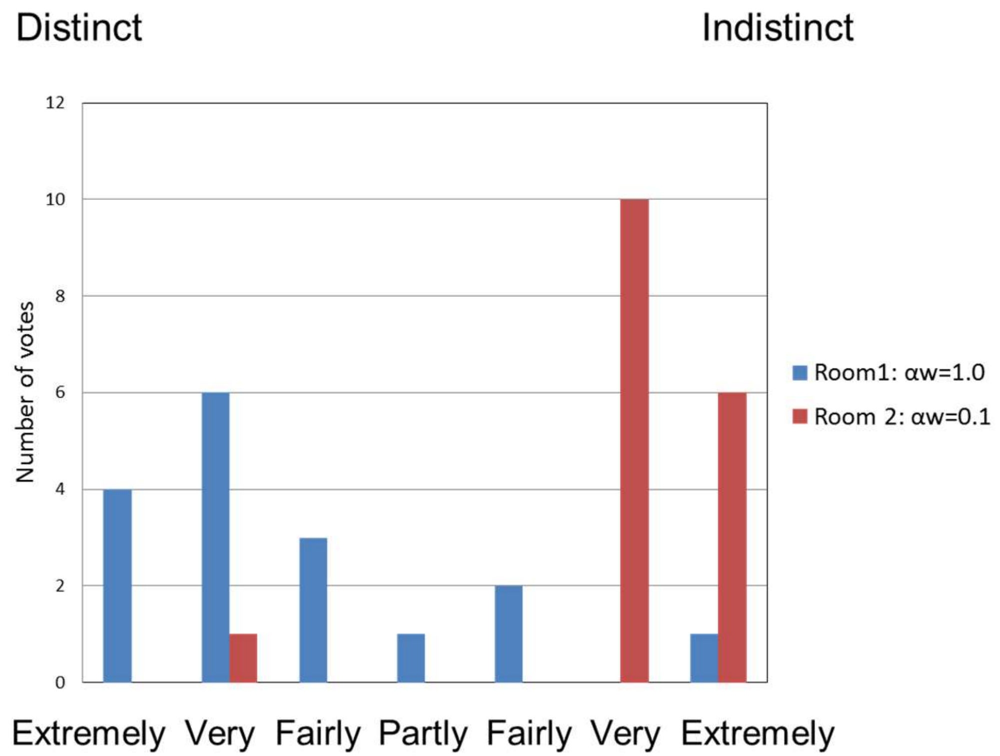
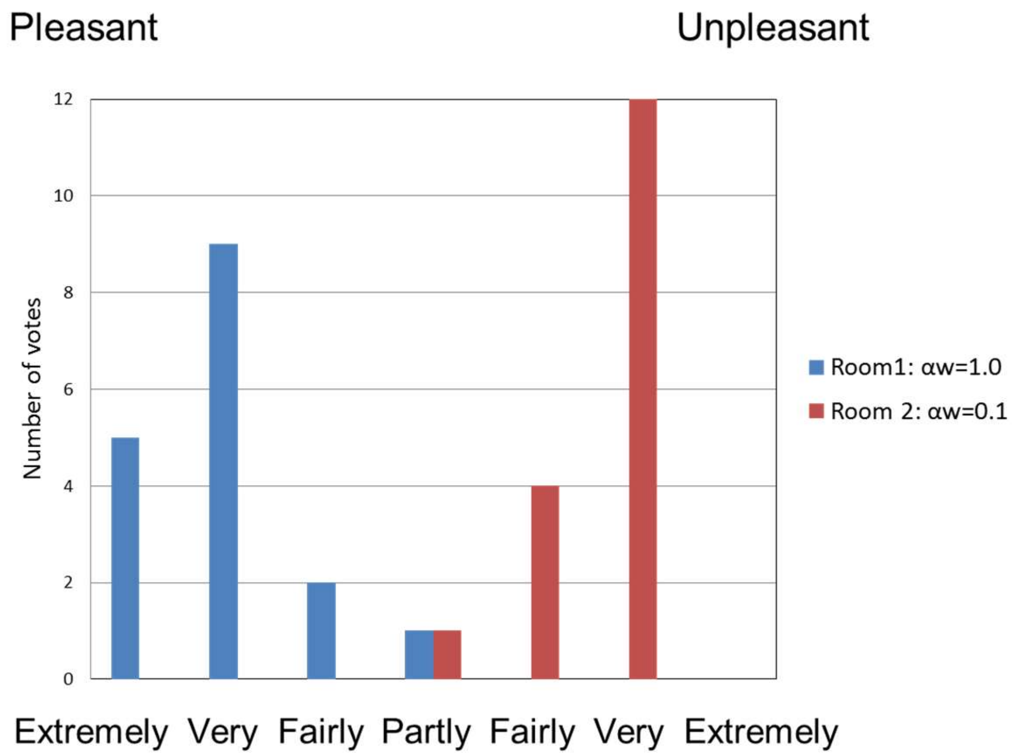
Listening test



Listening test



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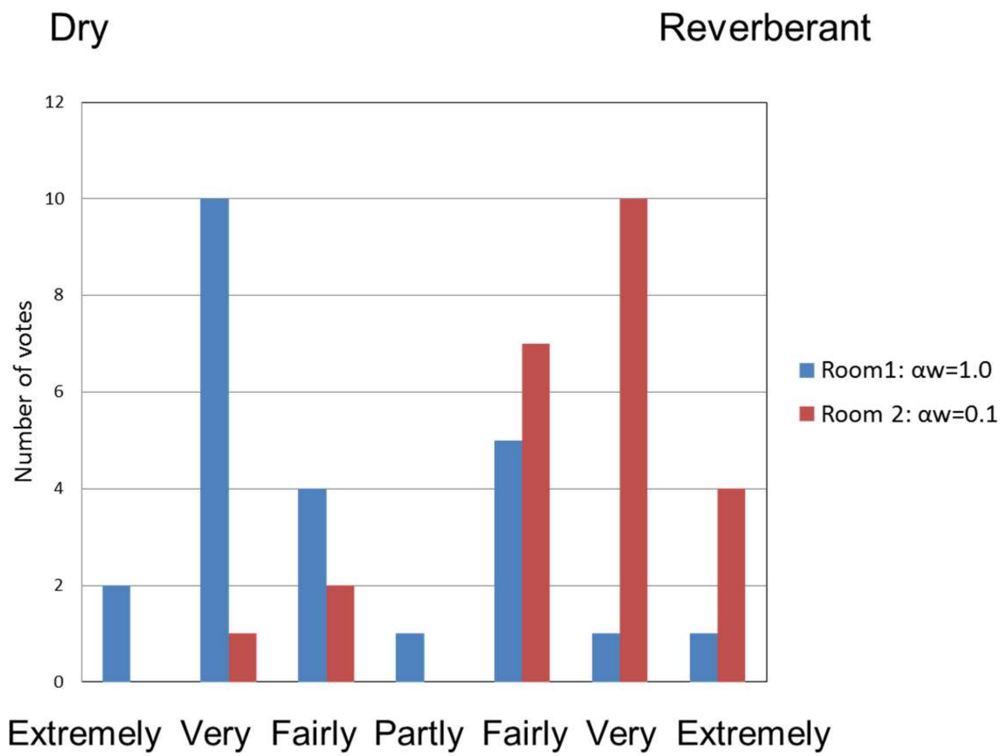
Listening test



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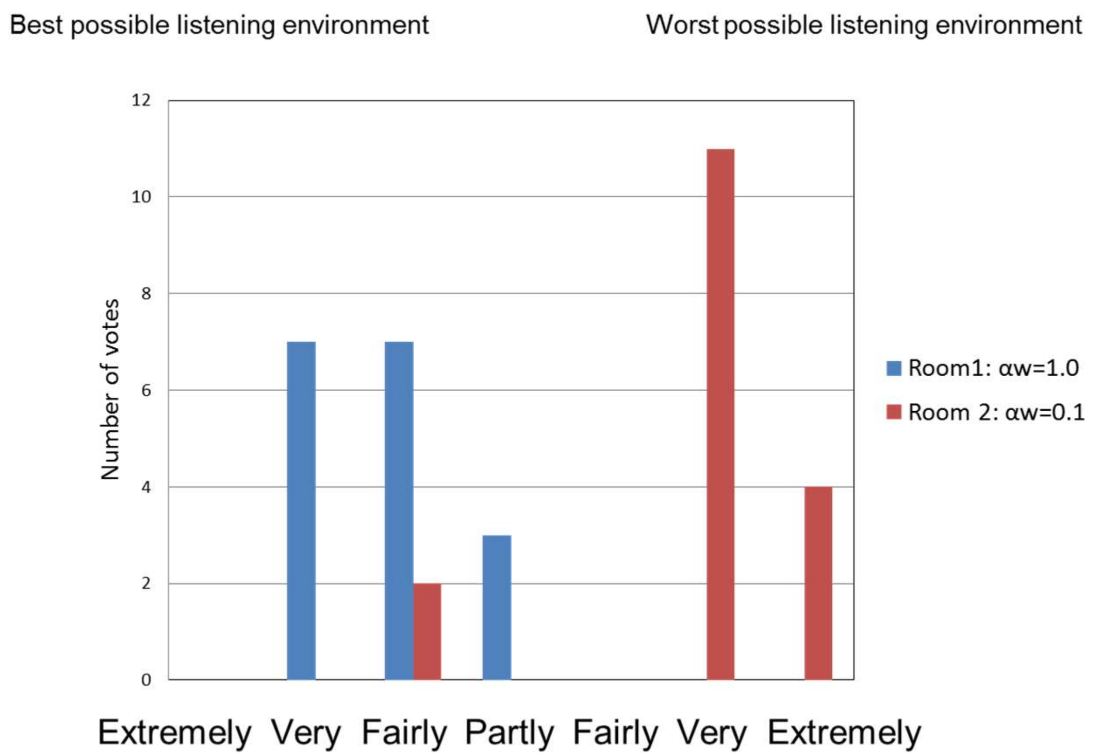
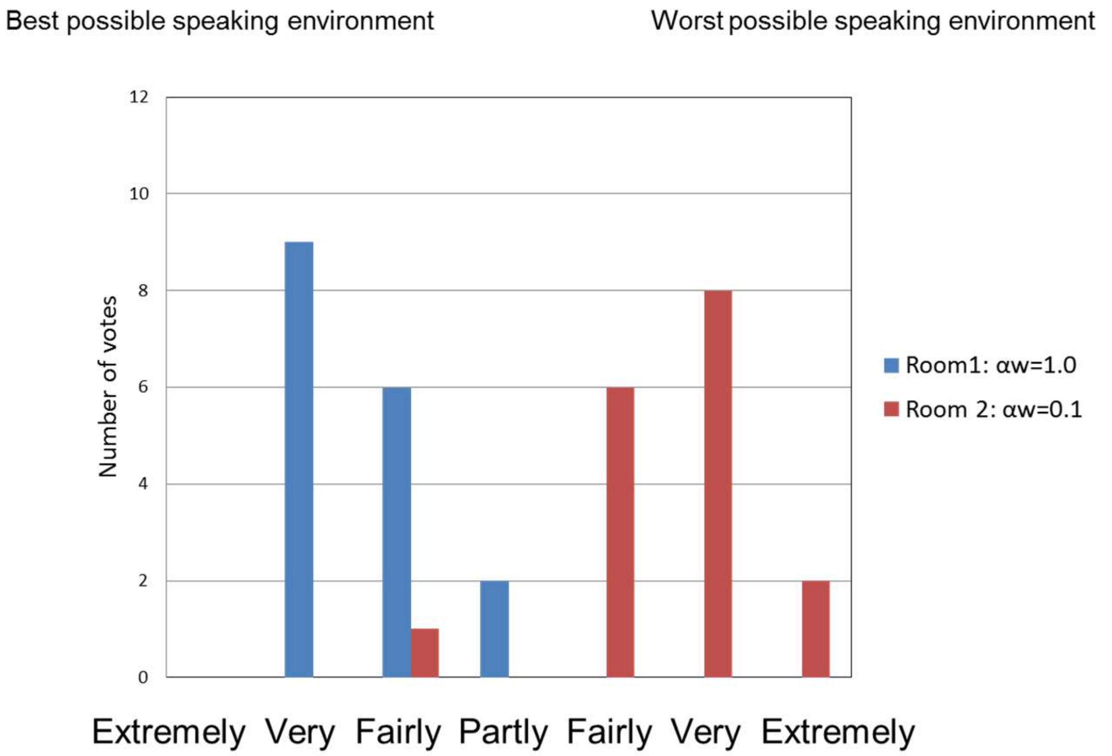
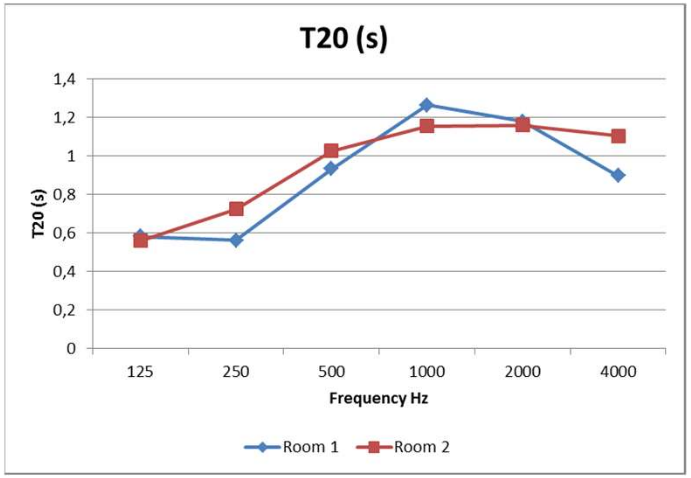
Listening test

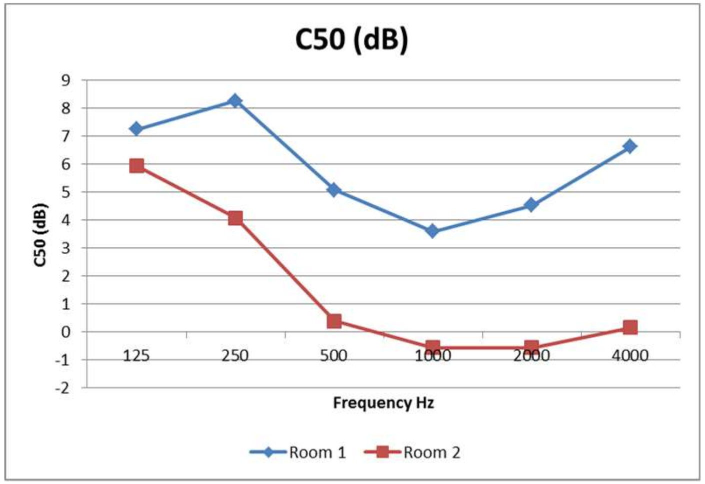


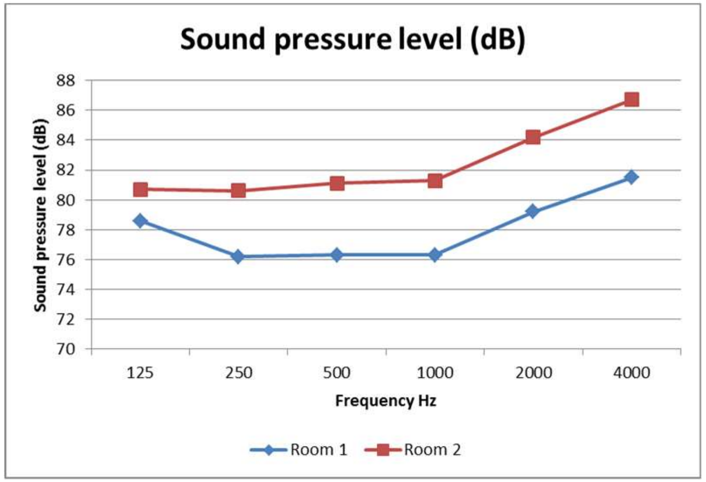
Listening test



Measurement results







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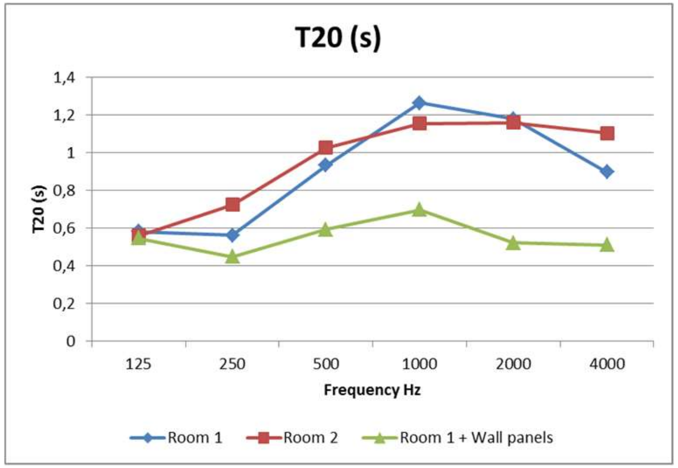
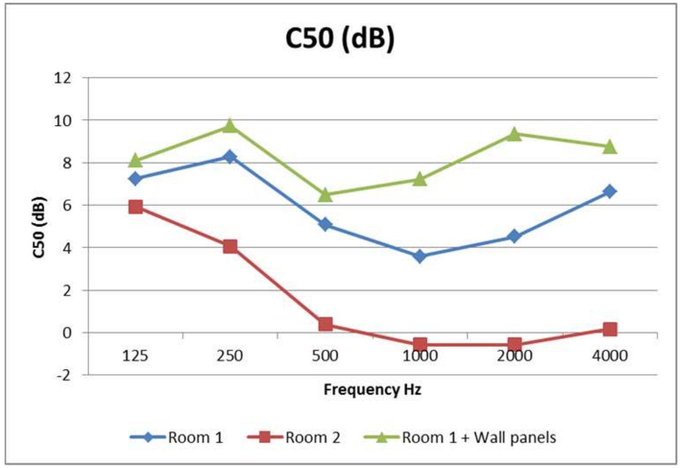
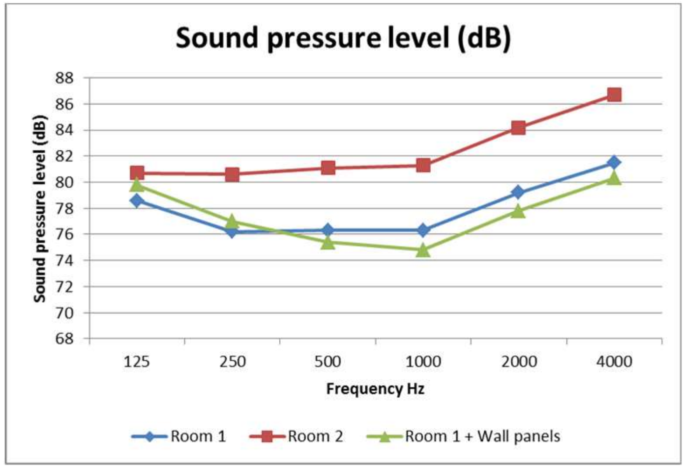
Measurement results, with wall panels







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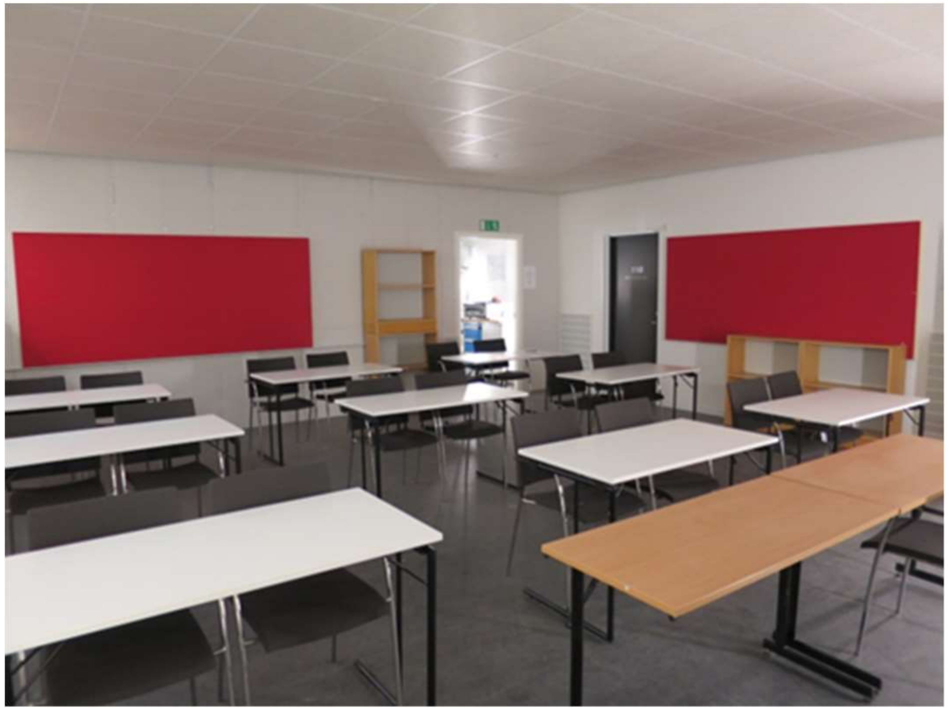
Ecophon recommendation: Schools

Criteria	Parameter*	Target values
Speech clarity	C_{50} (dB)	6 – 8 dB
Sound strength	G (dB)	15 – 17 dB
Reverberation	T_{20} (s)	0,40 – 0,50 s

** Average 125 to 4000 Hz*

The effect of different acoustical treatment



- No ceiling treatment, no furniture
- Ceiling treatment, no furniture
- Ceiling treatment, furniture
- Wall panels
- Extra low frequency absorption

Volume= 150 m3, Floor area=55 m2, ceiling height=2,70 m

Classroom in different configurations

Without furniture and ceiling

Without furniture, with ceiling

With furniture and ceiling

With furniture, ceiling and wall panels

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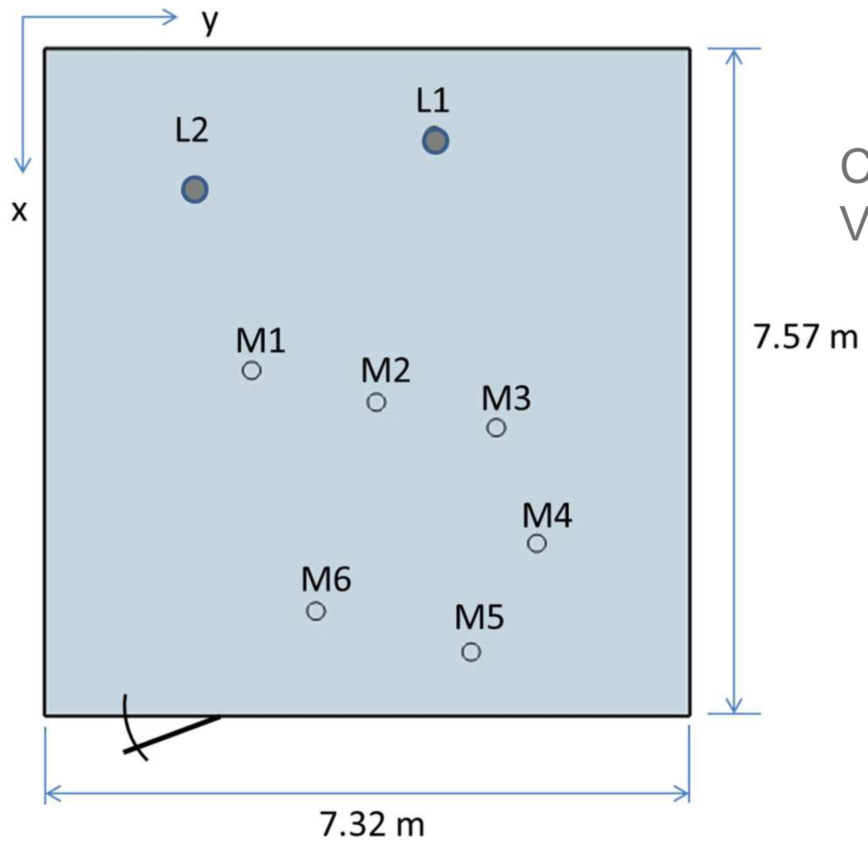
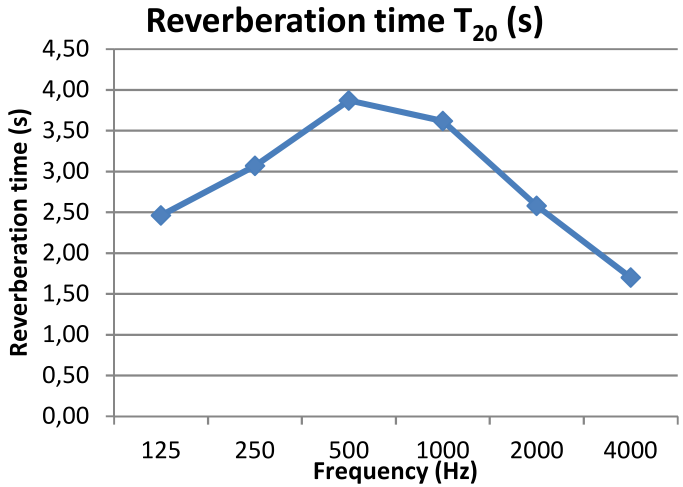
Measurement positions

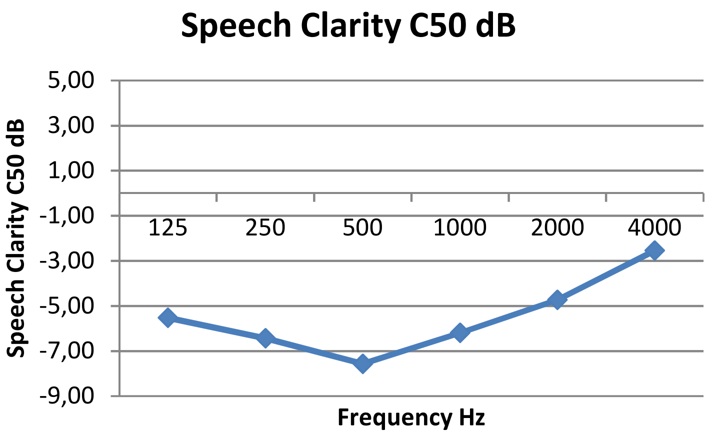


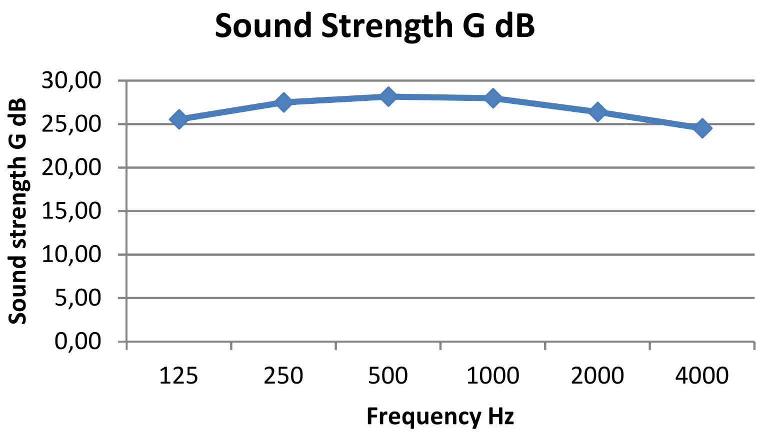
Ceiling height: 2,70 m
Volume: 150 m^3

Without furniture and ceiling

Average absorption coefficient of the room surfaces is 0,05







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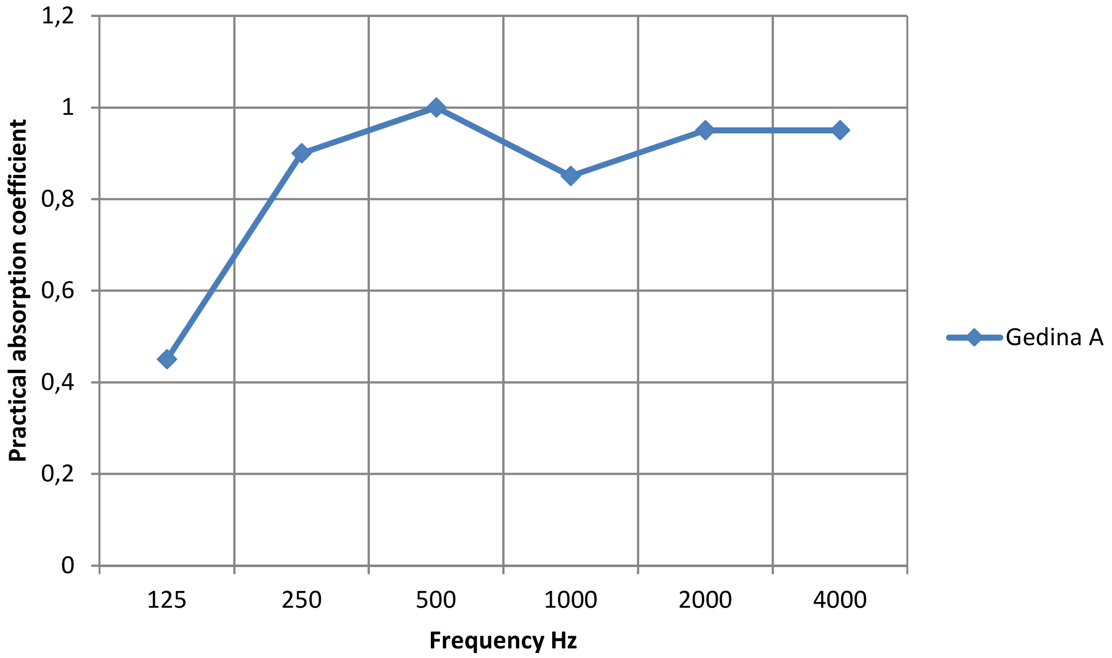
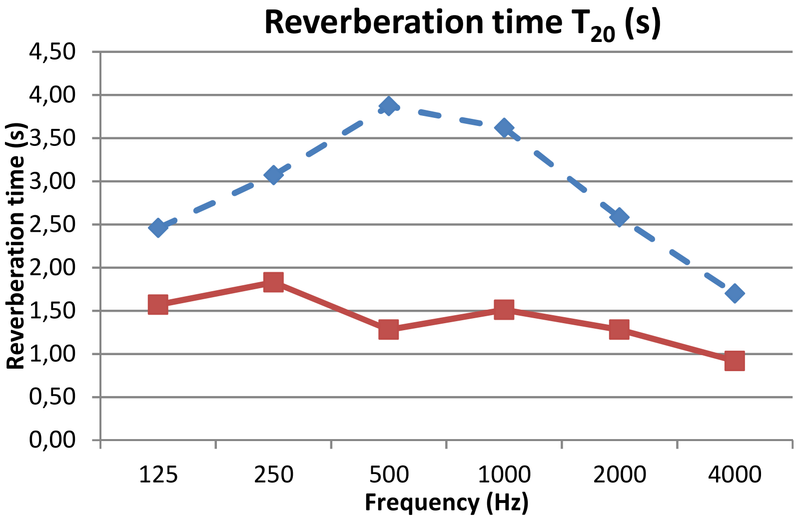
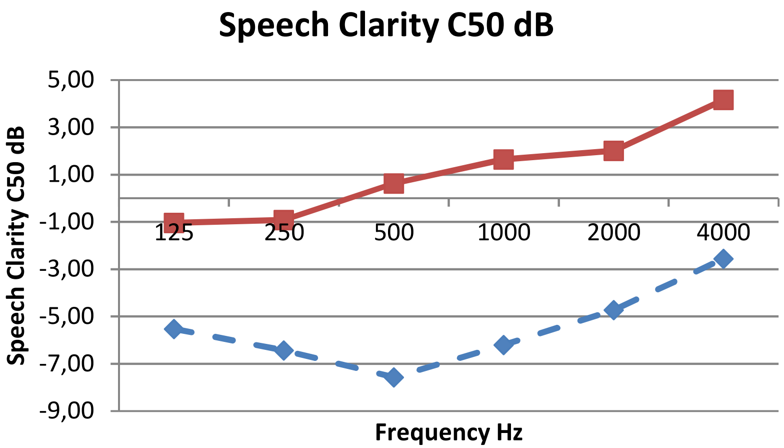
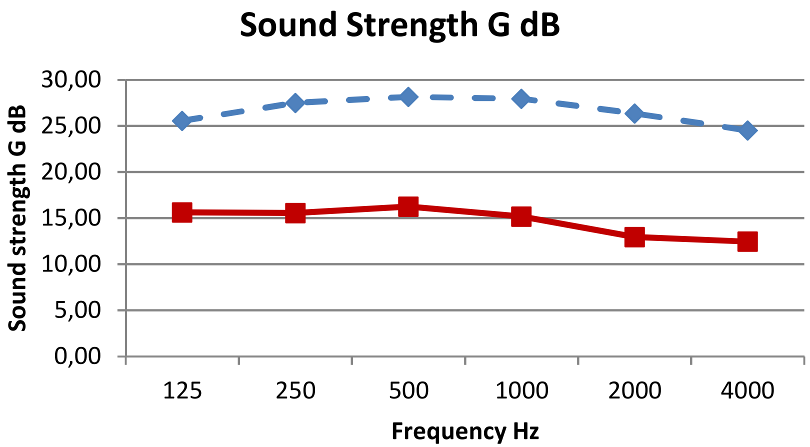
Practical absorption coefficient of Gedina A



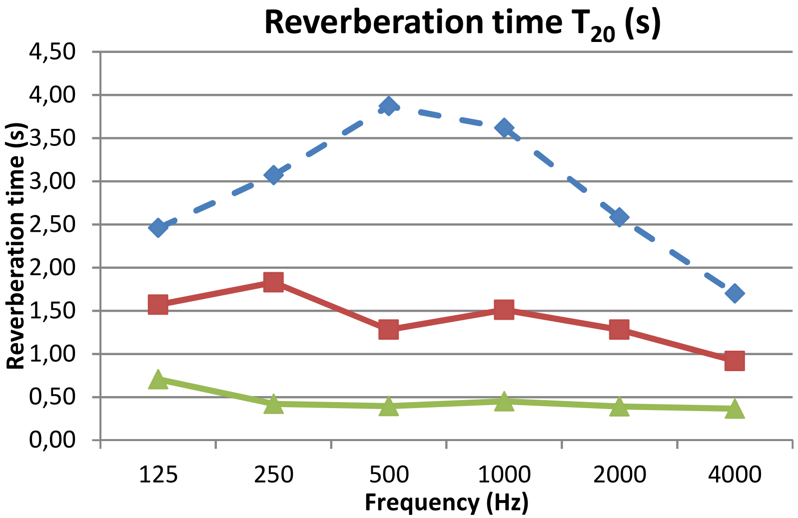
Without furniture with ceiling



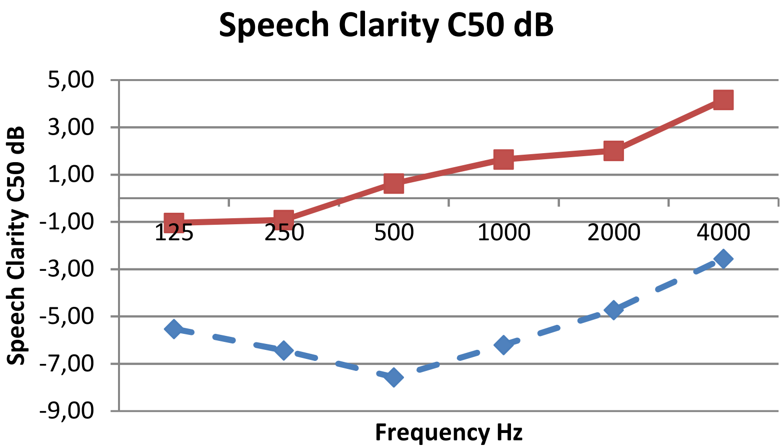


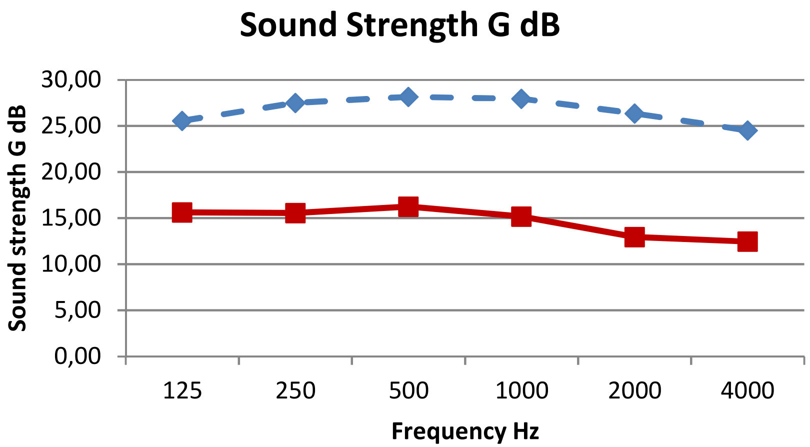


Without furniture with ceiling



Calculation according Sabine formula





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Furniture absorption

T_0 empty room

T_{furn} furnished room

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

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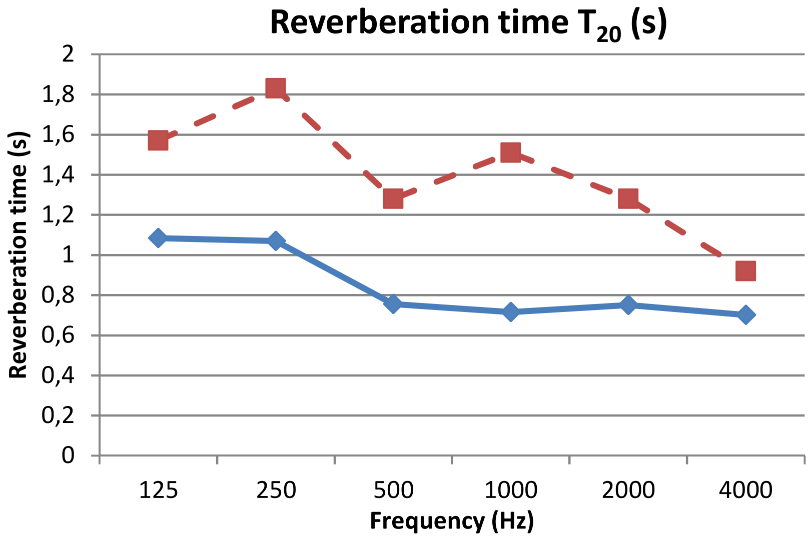
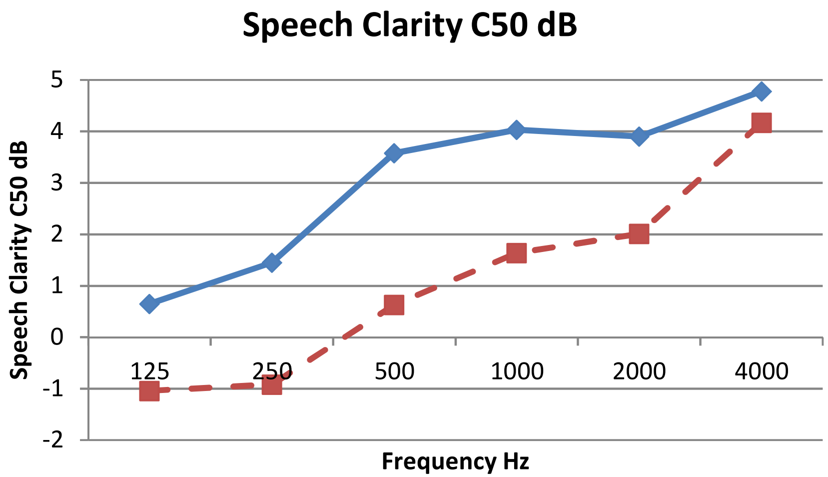
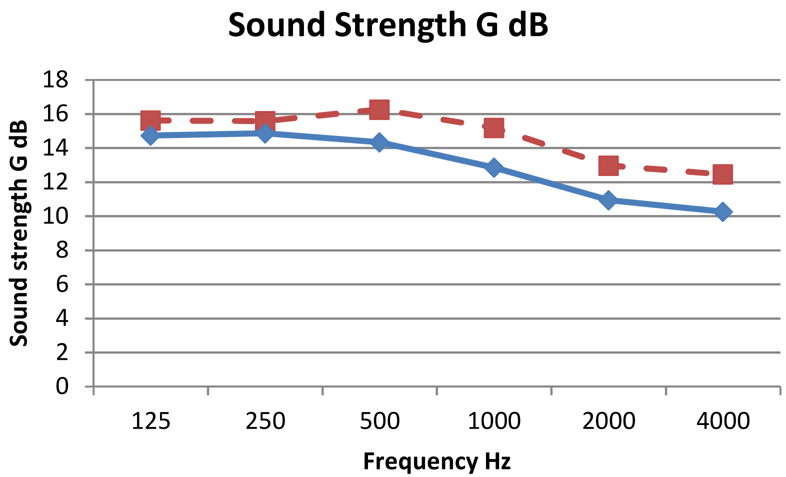
With furniture and ceiling







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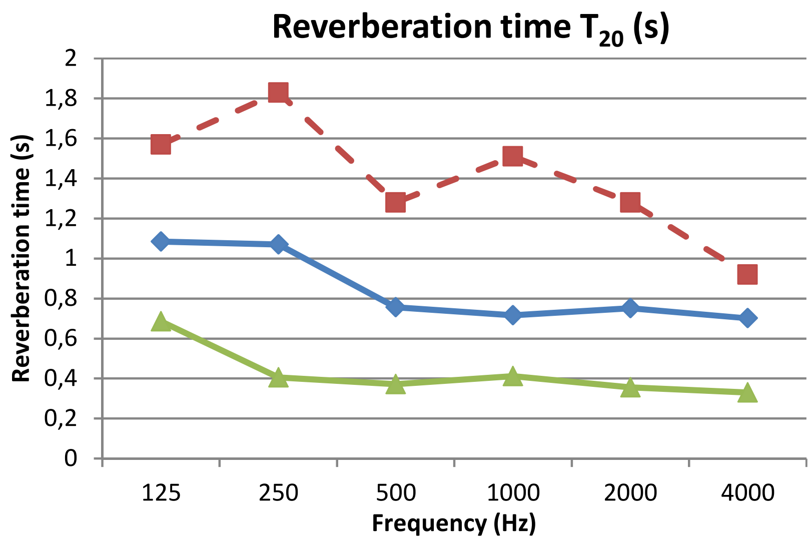
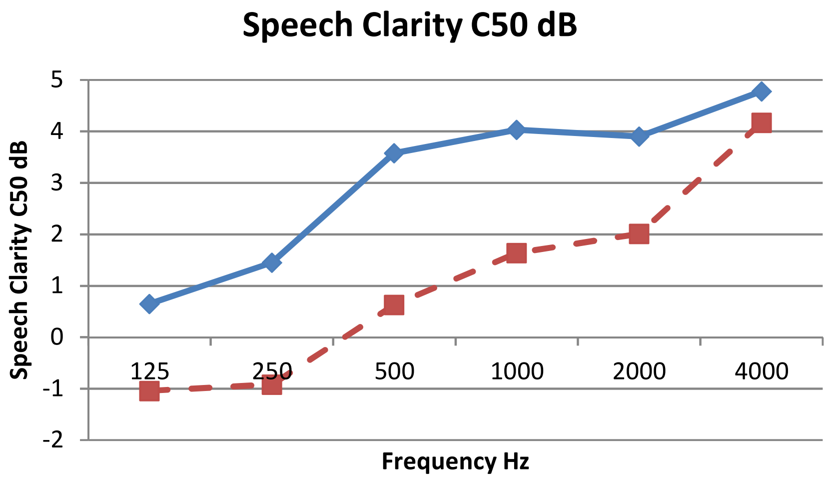
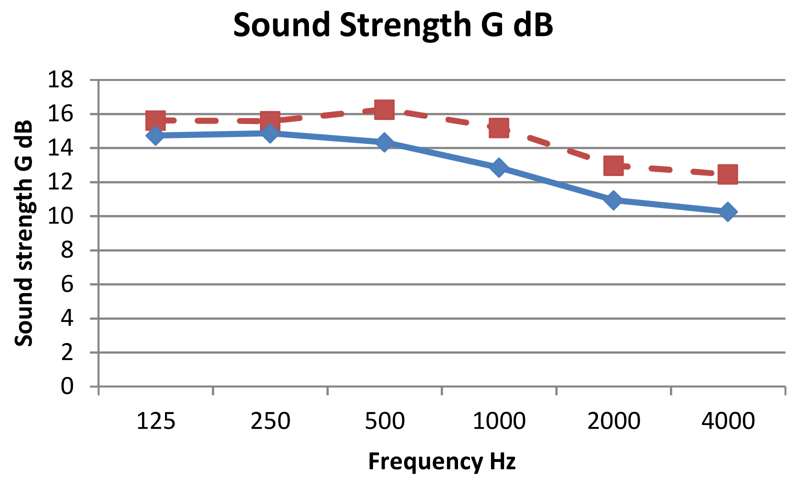
With furniture and ceiling







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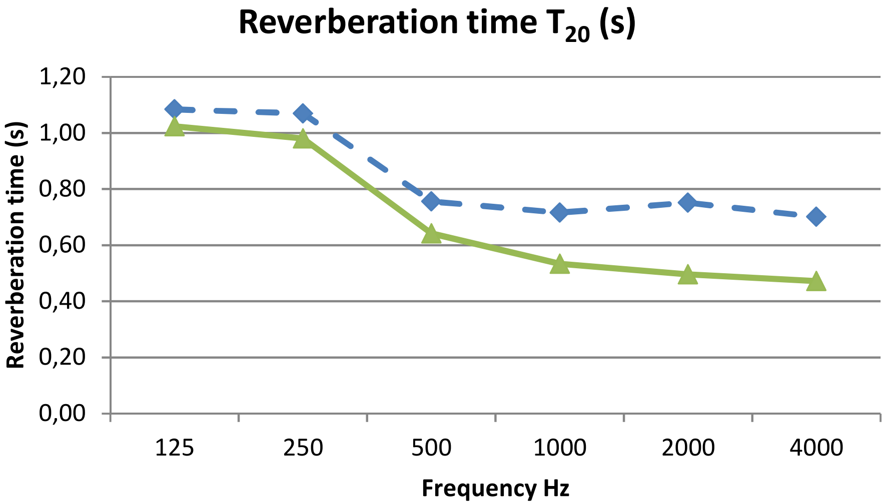
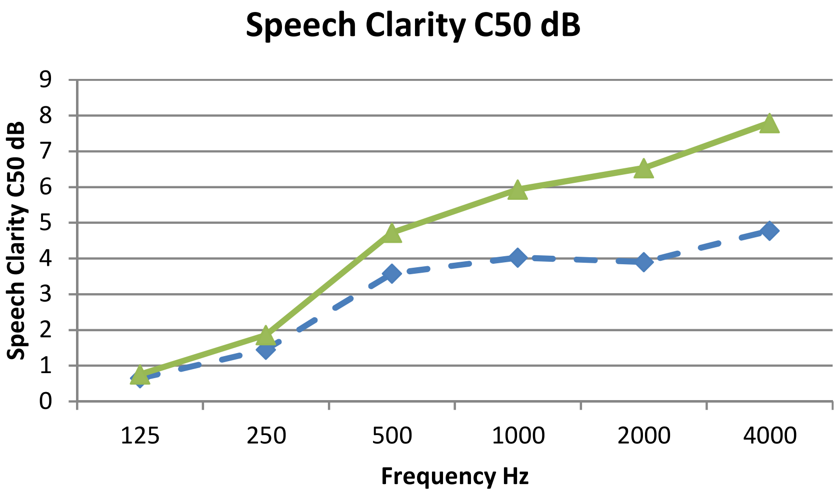
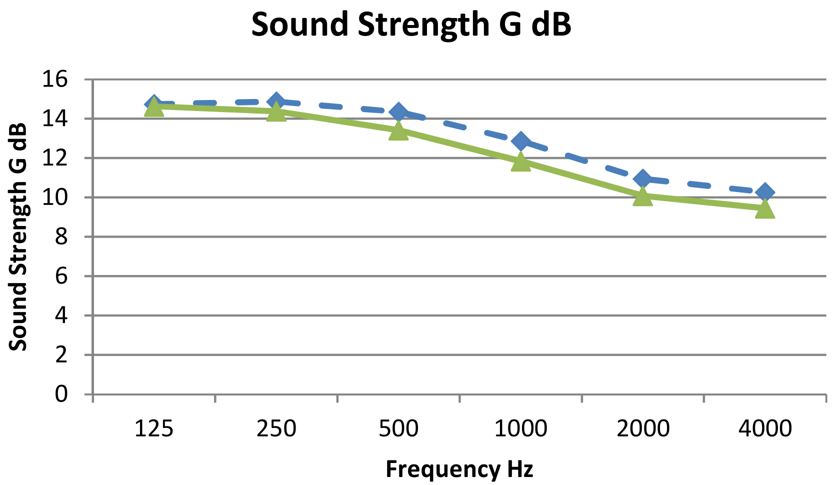
The effect of wall panels







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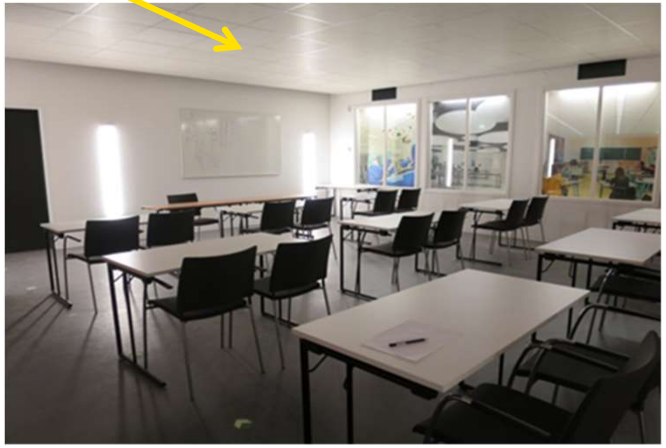
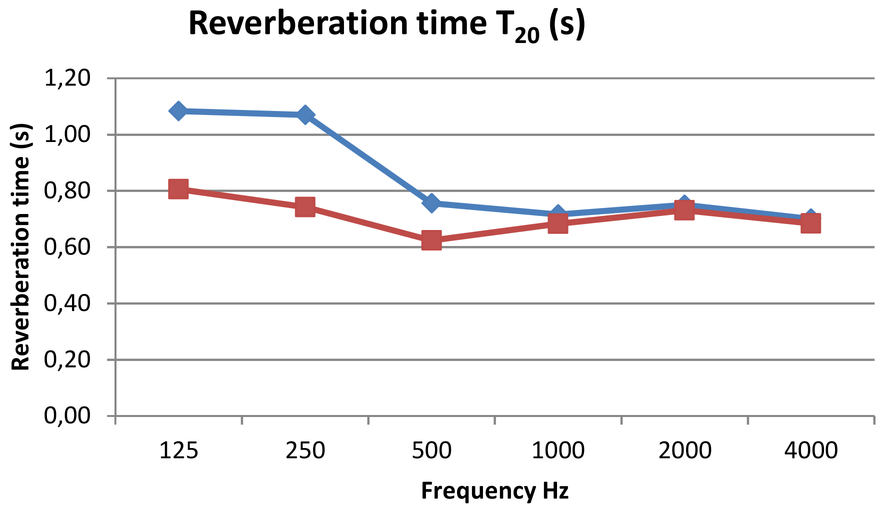
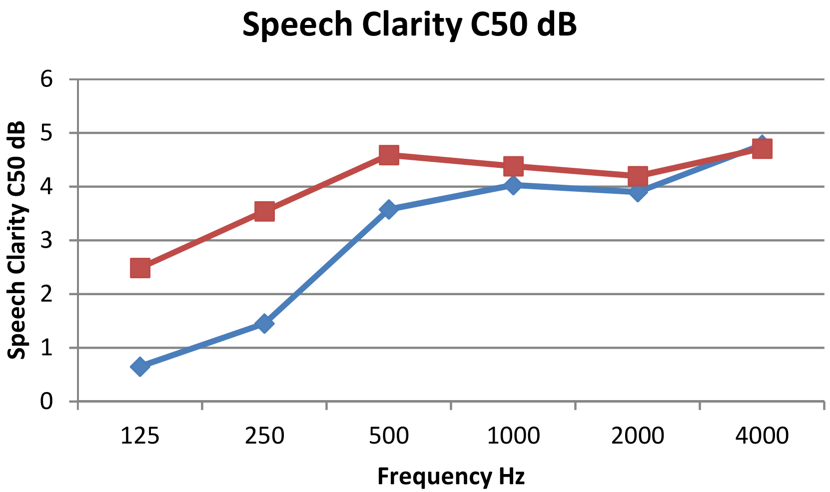
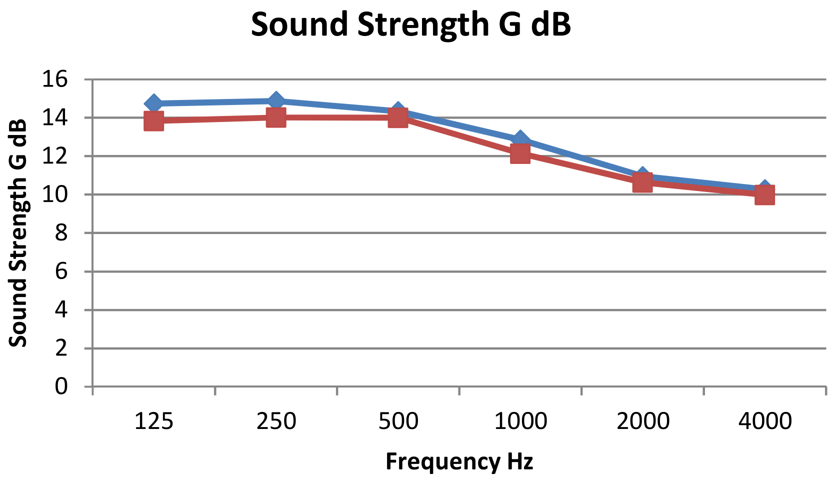
The effect of extra low frequency absorption

With 50% Ecophon Extra Bass









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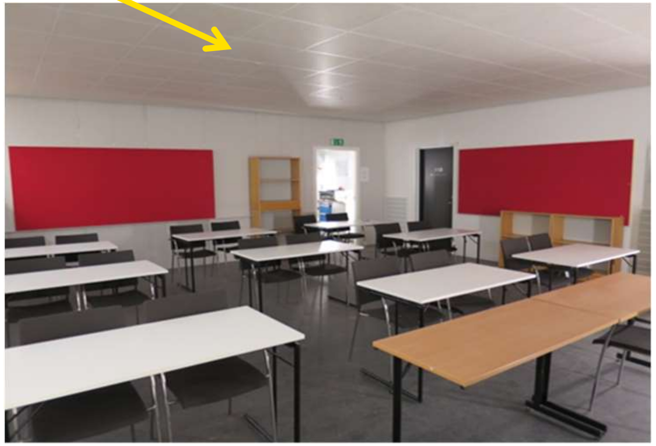
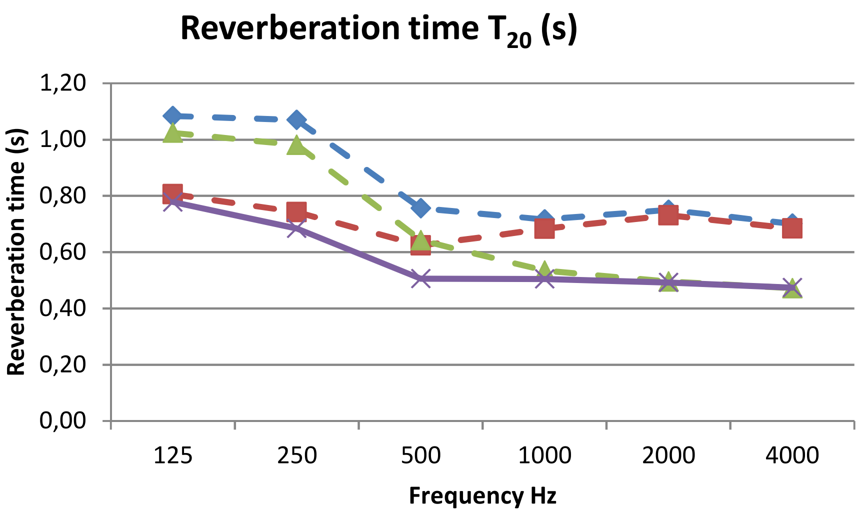
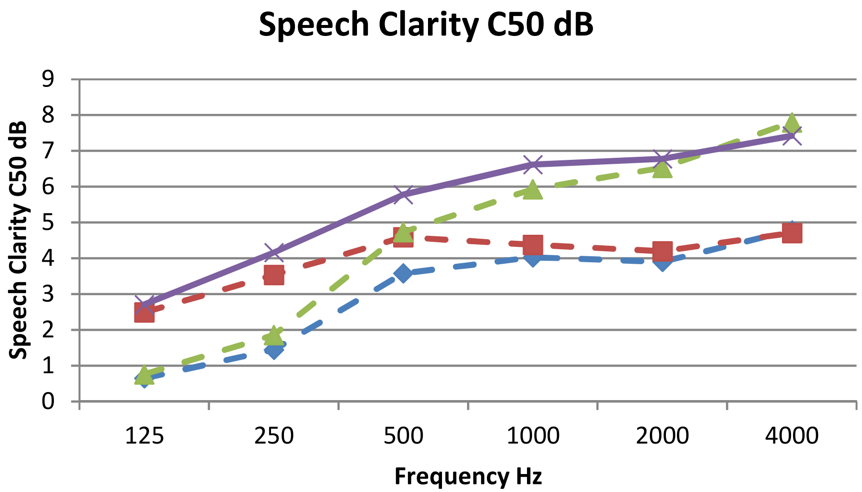
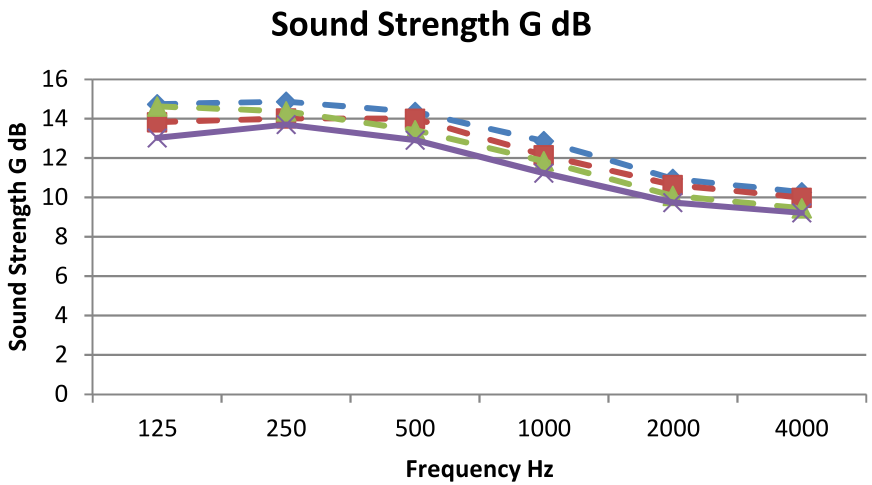
Wall panels and Ecophon Extra Bass

With 50% Ecophon Extra Bass









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