ODEON Workshop, Mariehamn, Åland, Finland, 2nd June 2004

ODEON
and the scattering coefficient

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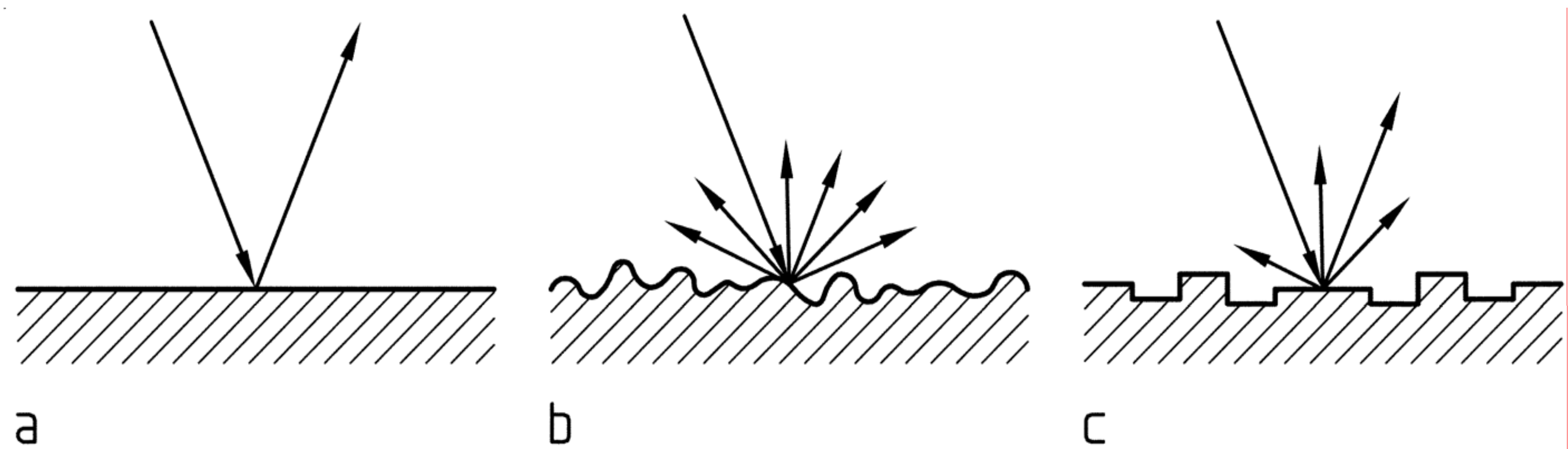
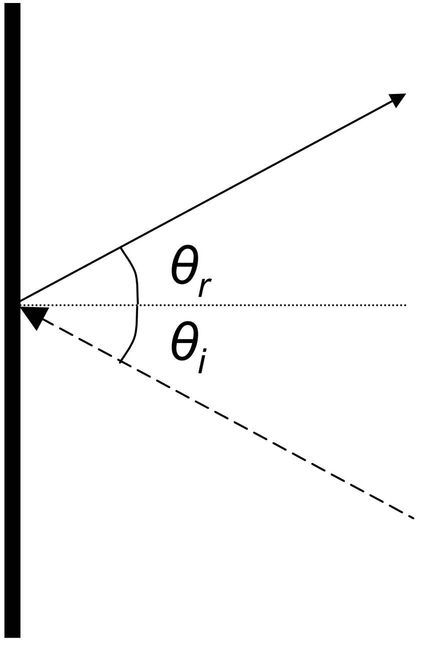
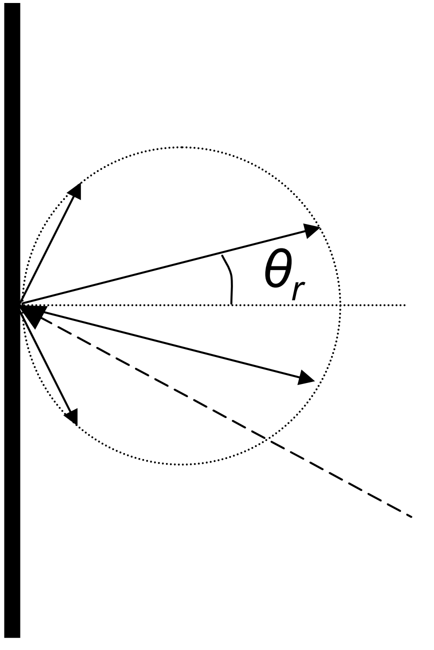
Specular and diffuse reflection



Reflection models
(asymptotic models for short wavelengths)

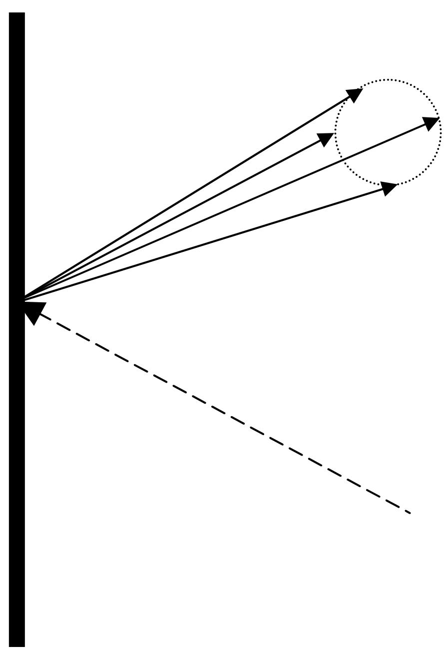




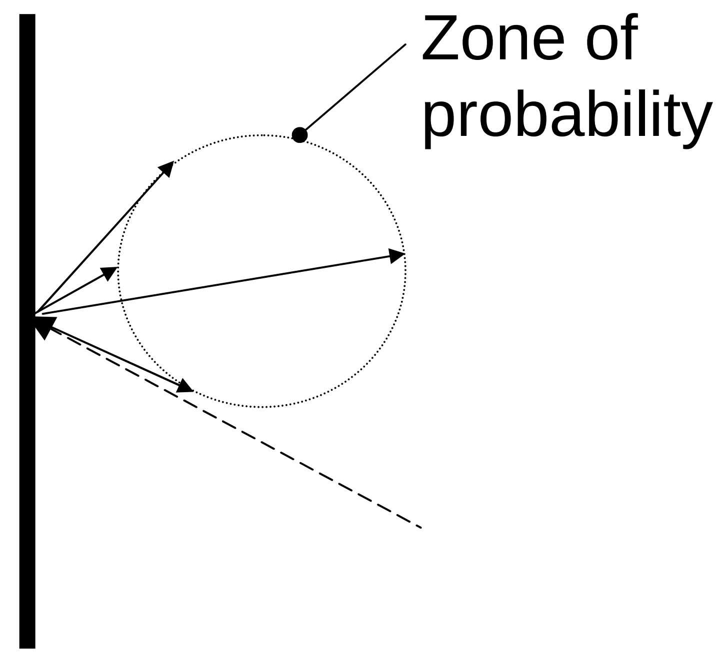
Snell's law: $\theta_r = \theta_i$

Lambert's law:
Probability of diffuse reflection is ~ cos θ_r

Scattering as a weighted vector addition of specular and diffuse reflection



Small scattering,
s = 0,2

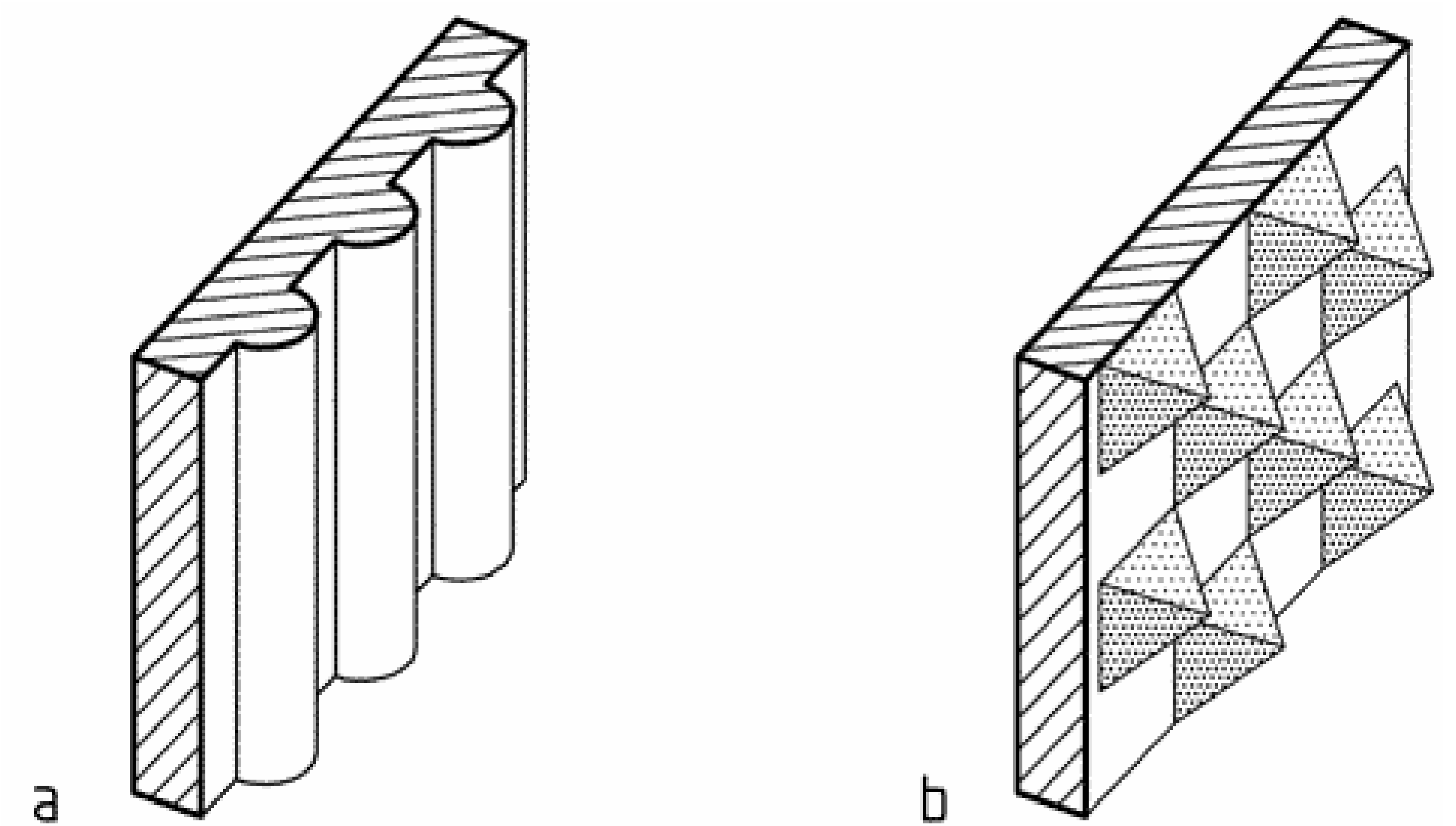


High scattering,
s = 0,8

Sound scattering coefficient, s

- defined as the ratio between the acoustic energy reflected in non-specular directions and the totally reflected acoustic energy
- A sound scattering surface is defined as a surface with $s \geq 0.5$

One- and two-dimensional diffusers

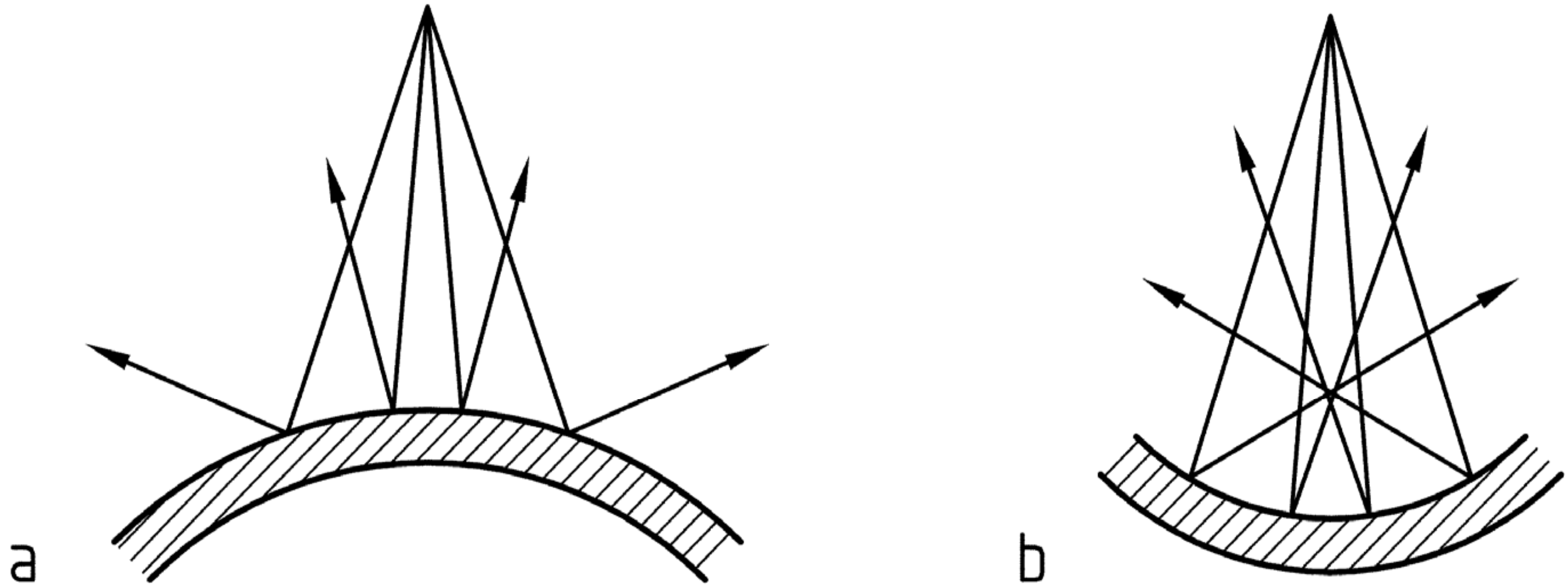


Types of diffusers

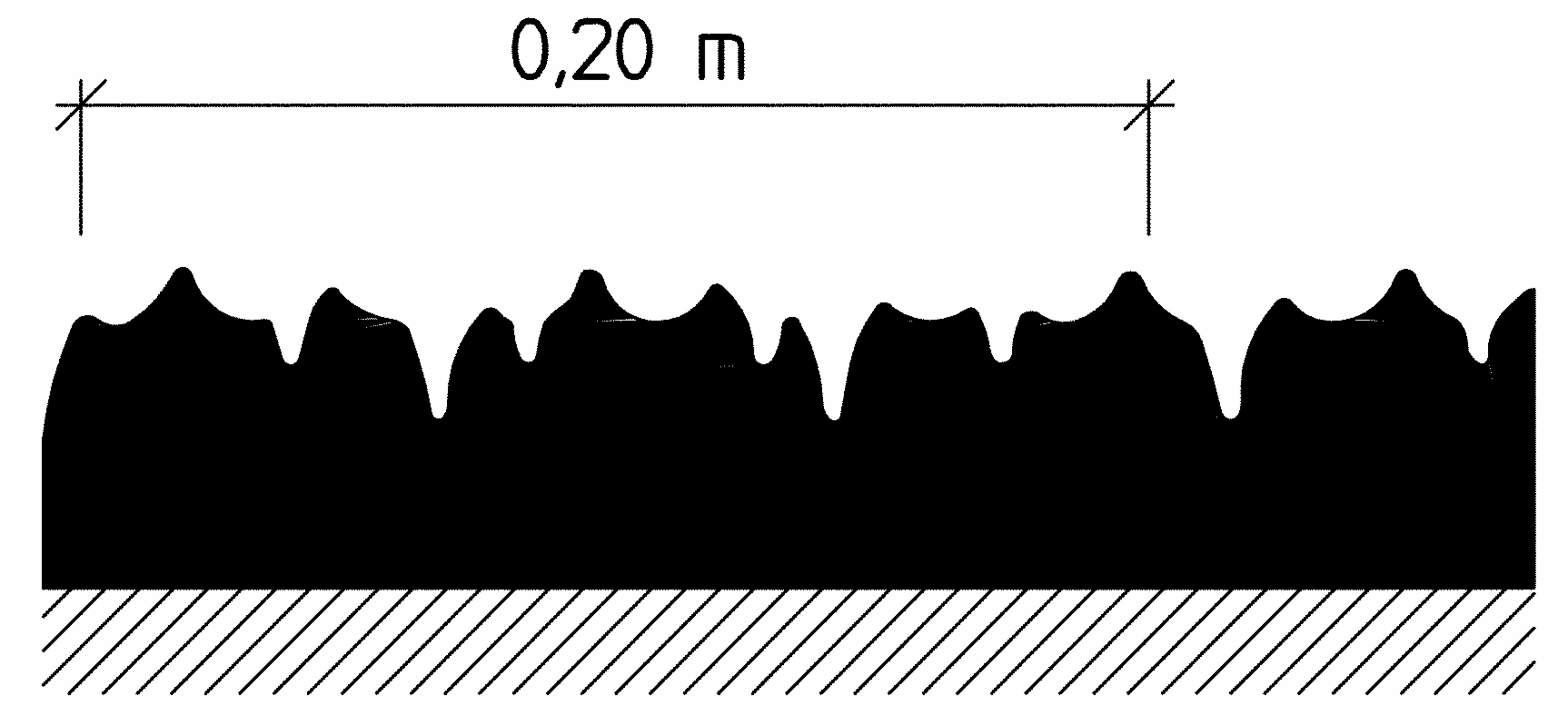
- Geometric diffusers
  - Simple curved surfaces
  - Irregular geometric structures
  - Periodic geometric structures
  - Mixture of absorbing and reflecting materials

- Mathematical diffusers
  - MLS (Maximum Length Sequence) diffusers
  - QRD (Quadratic Residue Diffusers)
  - PRD (Primitive Root Diffusers)
  - Fractal diffusers
  - Curved diffusers

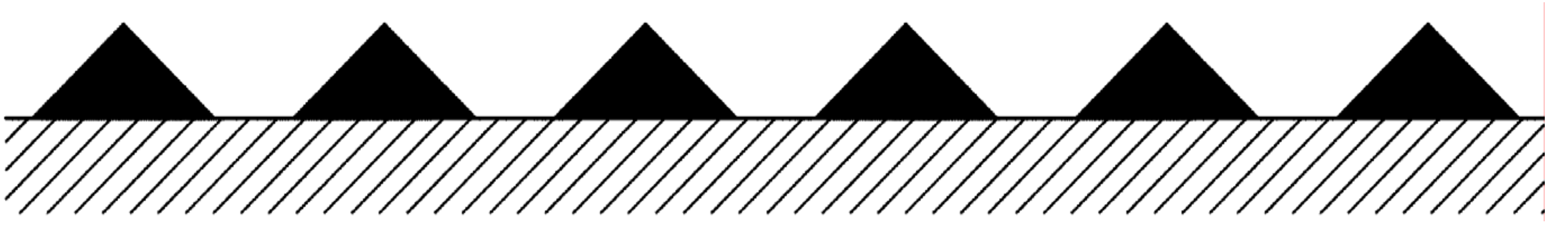
Convex and concave surfaces



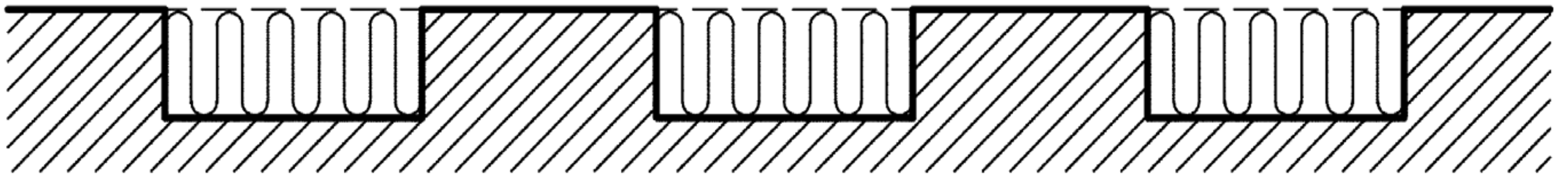
Irregular geometric structure



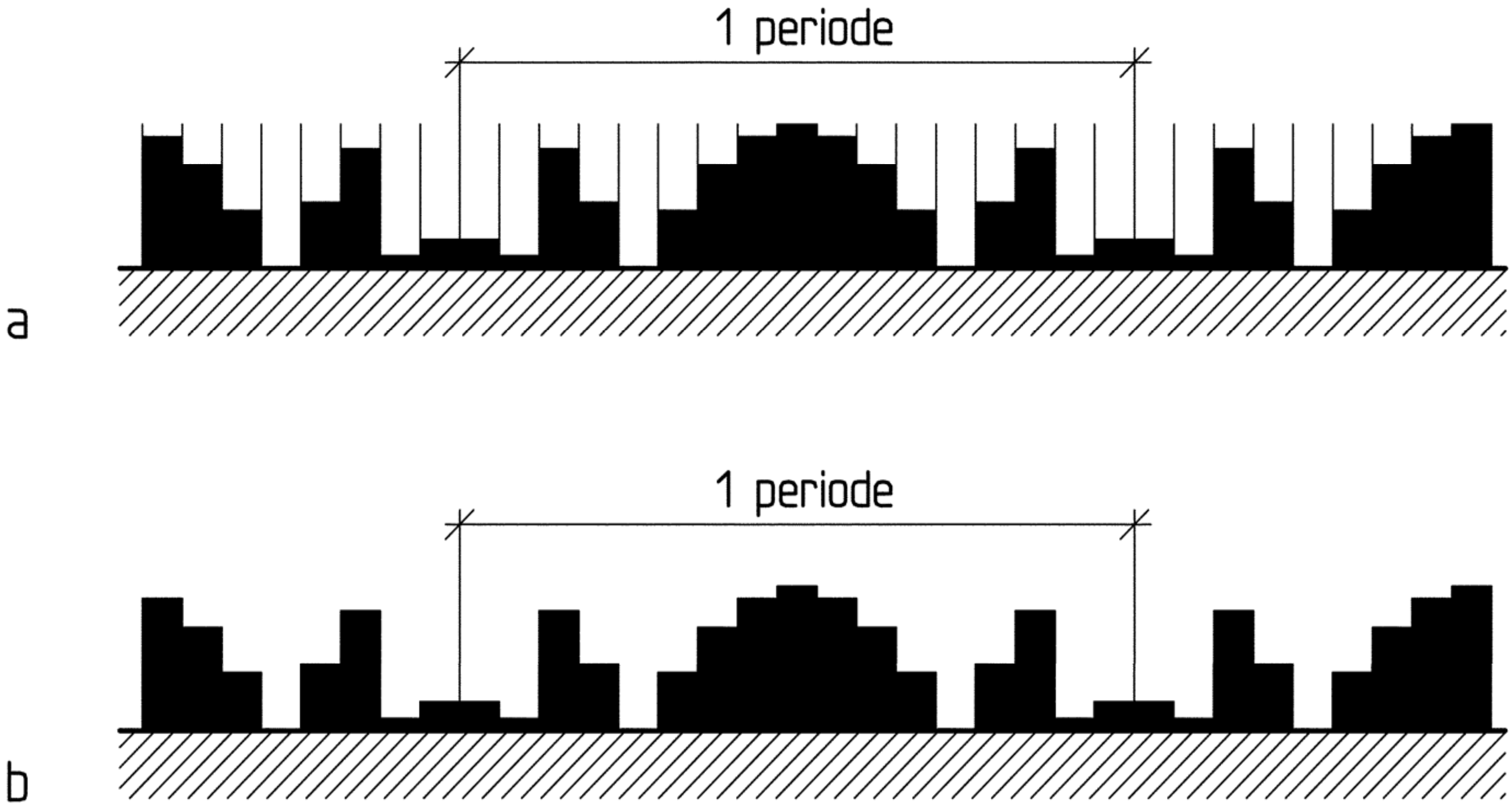
Periodic geometric structure



Alternating absorbing and reflecting structure



QRD
Quadratic Residue Diffuser



Measurement of the scattering coefficient

ISO/FDIS 17497 -1:

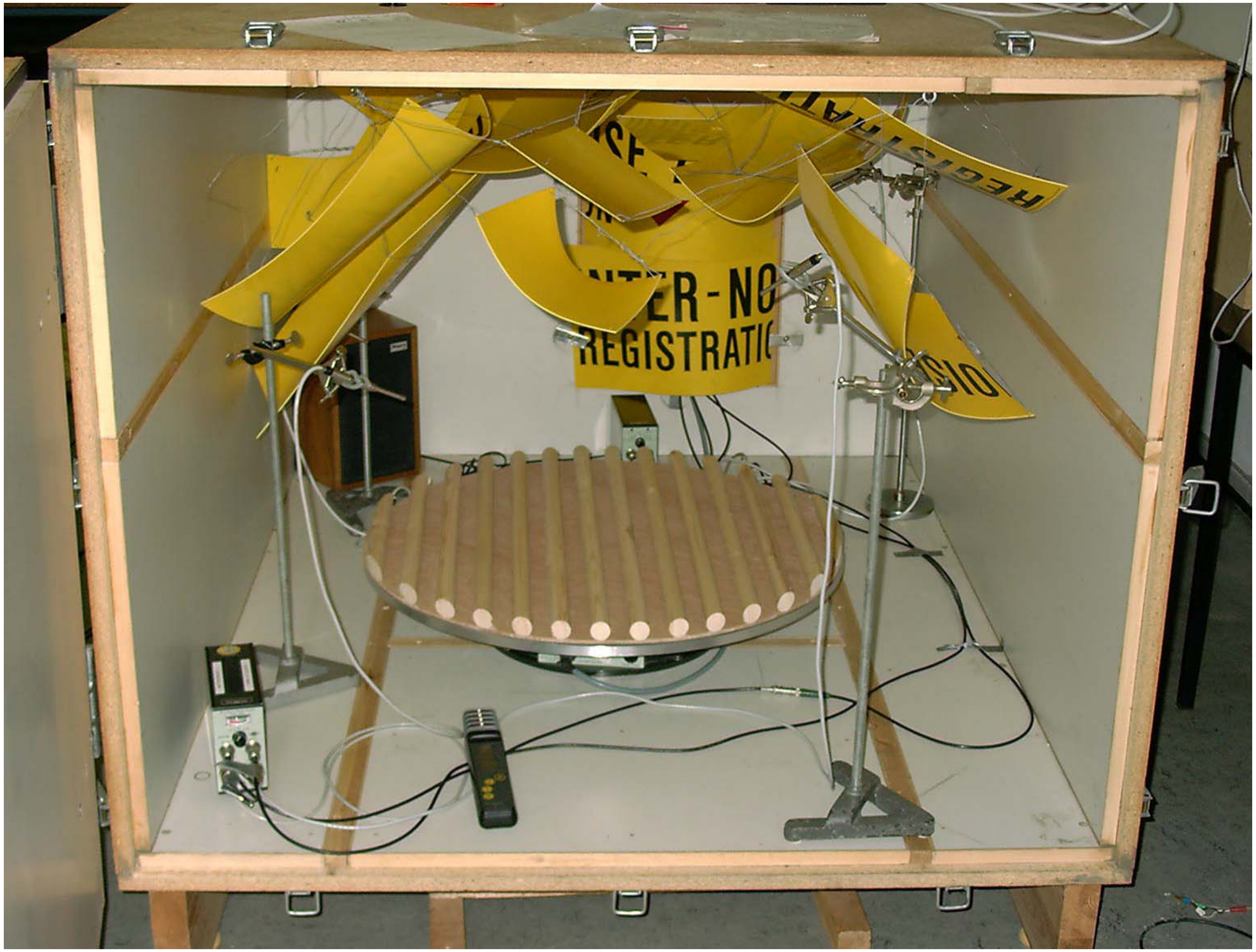
Acoustics – Sound scattering properties of surfaces – Part 1: Measurement of the random-incidence scattering coefficient in a reverberation room

Reverberation room

- The measurements may be done in full scale or in a physical scale model with the scale ratio 1:*N*
- The volume *V* of the reverberation room shall be minimum:

$$N^{-3} \cdot 200 \text{ m}^3 \leq V$$

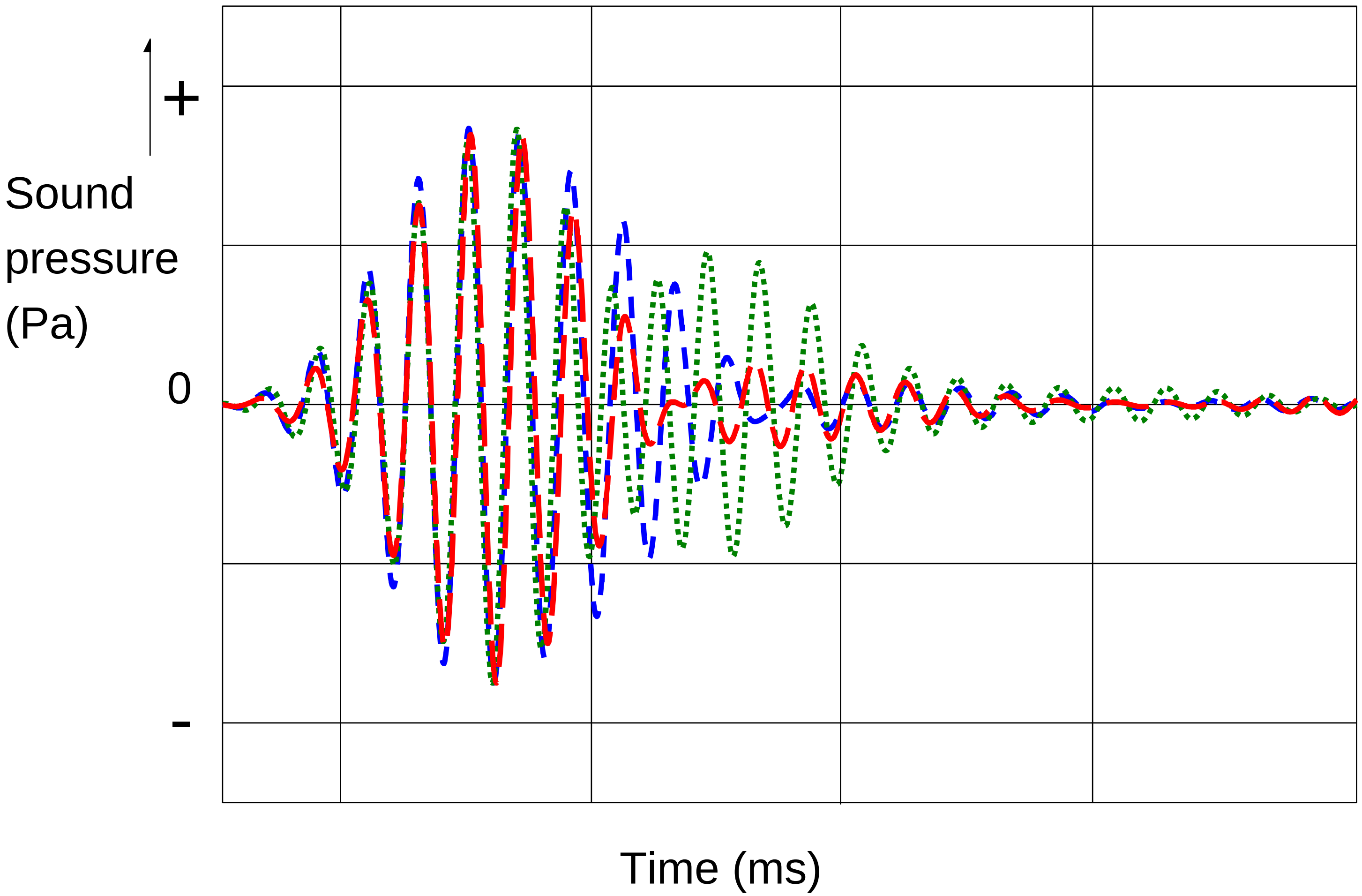
Set-up in a scale model for measurement of the scattering coefficient of a test specimen



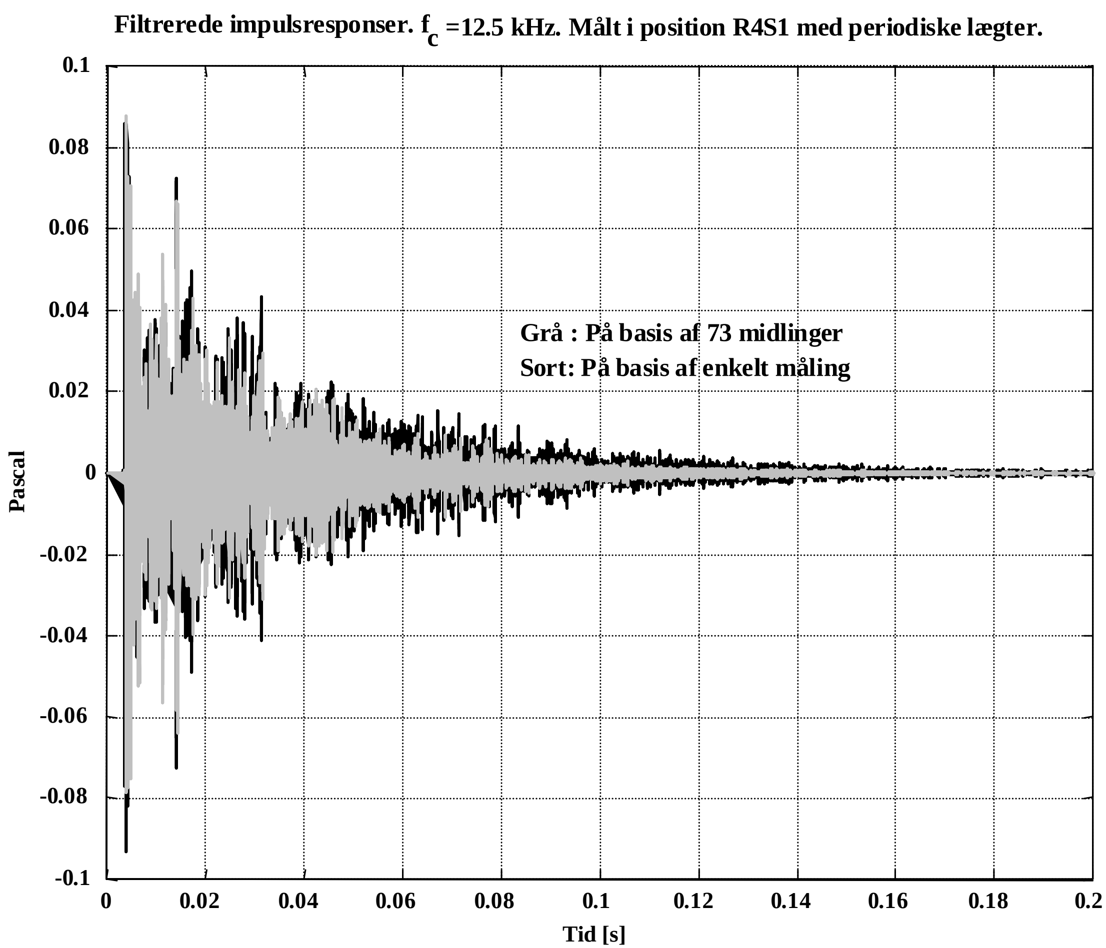
Principle

- Impulse responses are measured for different orientations of a circular test specimen on a turntable
- The specular energy is extracted from the impulse response by phase-locked averaging
- The scattered sound is incoherent and is eliminated by averaging

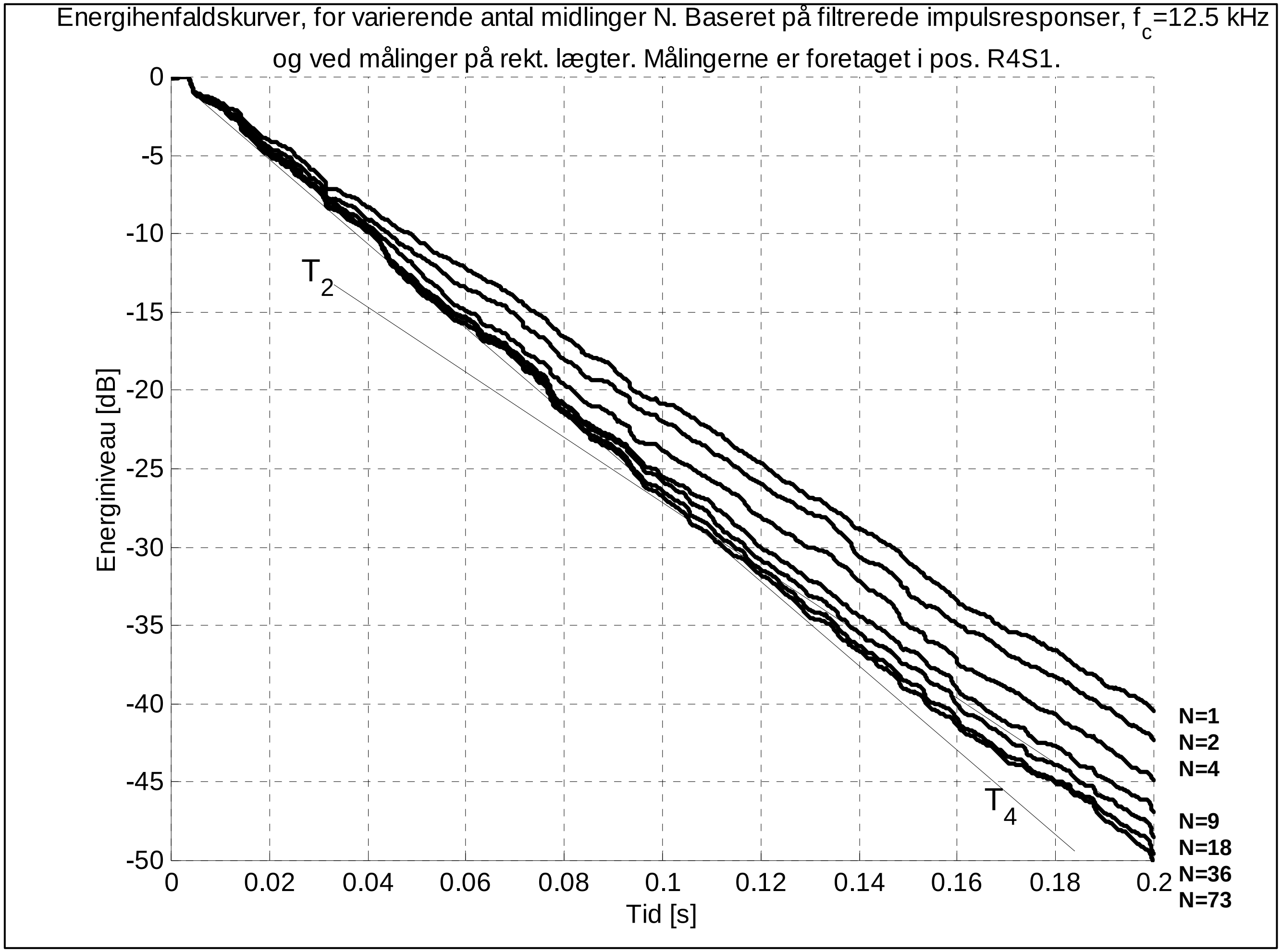
Principle: Three impulse responses measured with rotating test specimen



Impulse responses



Decay curves



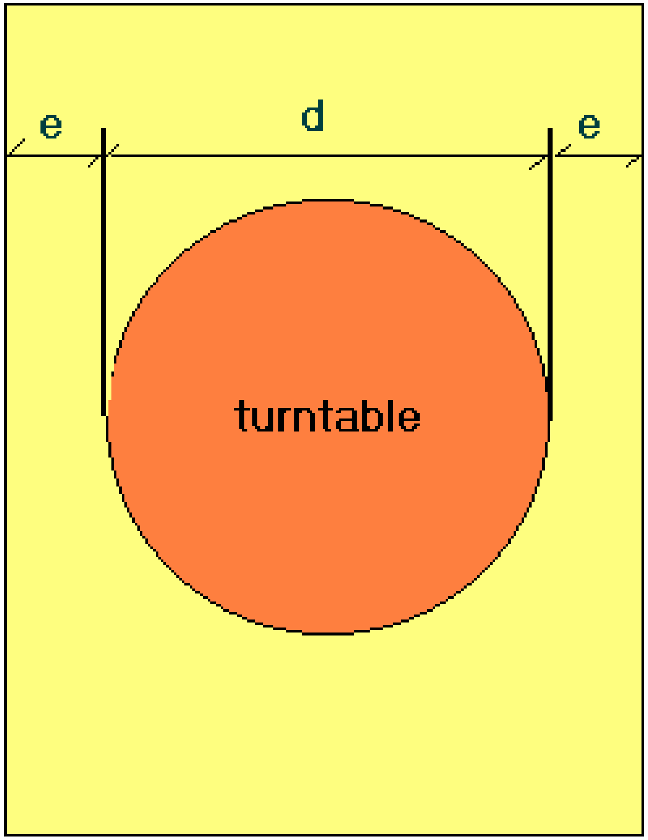
Position of test specimen

- Minimum distance from room boundaries:

$e \geq N^{-1} \cdot 1{,}0$ m

- Diameter of turntable:

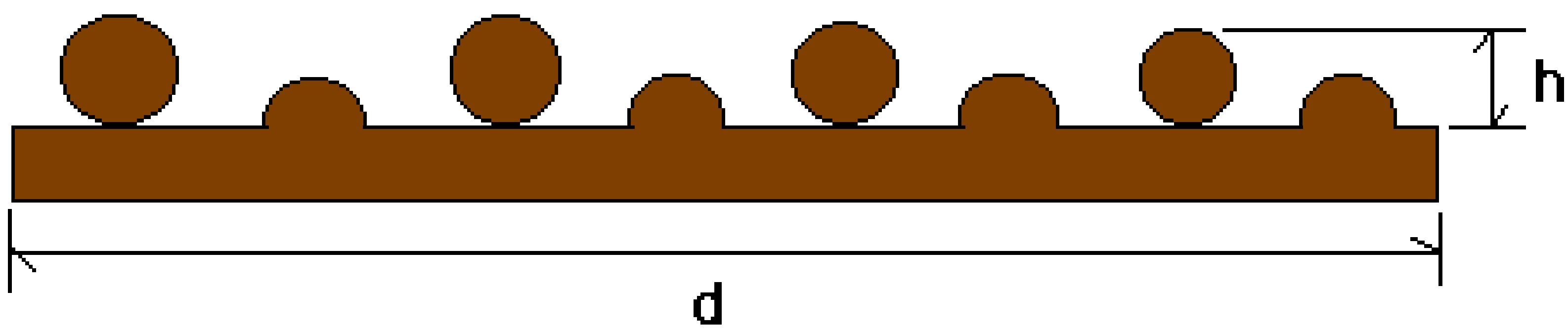
$d \geq N^{-1} \cdot 3{,}0$ m



Plan of room

Test samples

Structural depth of test specimen



The structural depth *h* should be:

$$h \leq d/16$$

where *d* is the diameter of the turntable

Absorption of test specimen

- Measuring accuracy decreases for samples with high absorption
- Sound scattering surfaces should generally be as reflective as possible
- The absorption coefficient should be

$$\alpha_s < 0{,}50$$

Rotation of test specimen

- Number of coherent averages: n

  $$60 \leq n \leq 120$$

- Turn between measurements:

  $$\Delta \varphi = 360° / n$$

  $$3° \leq \Delta \varphi \leq 6°$$

- Preferred number of averages:

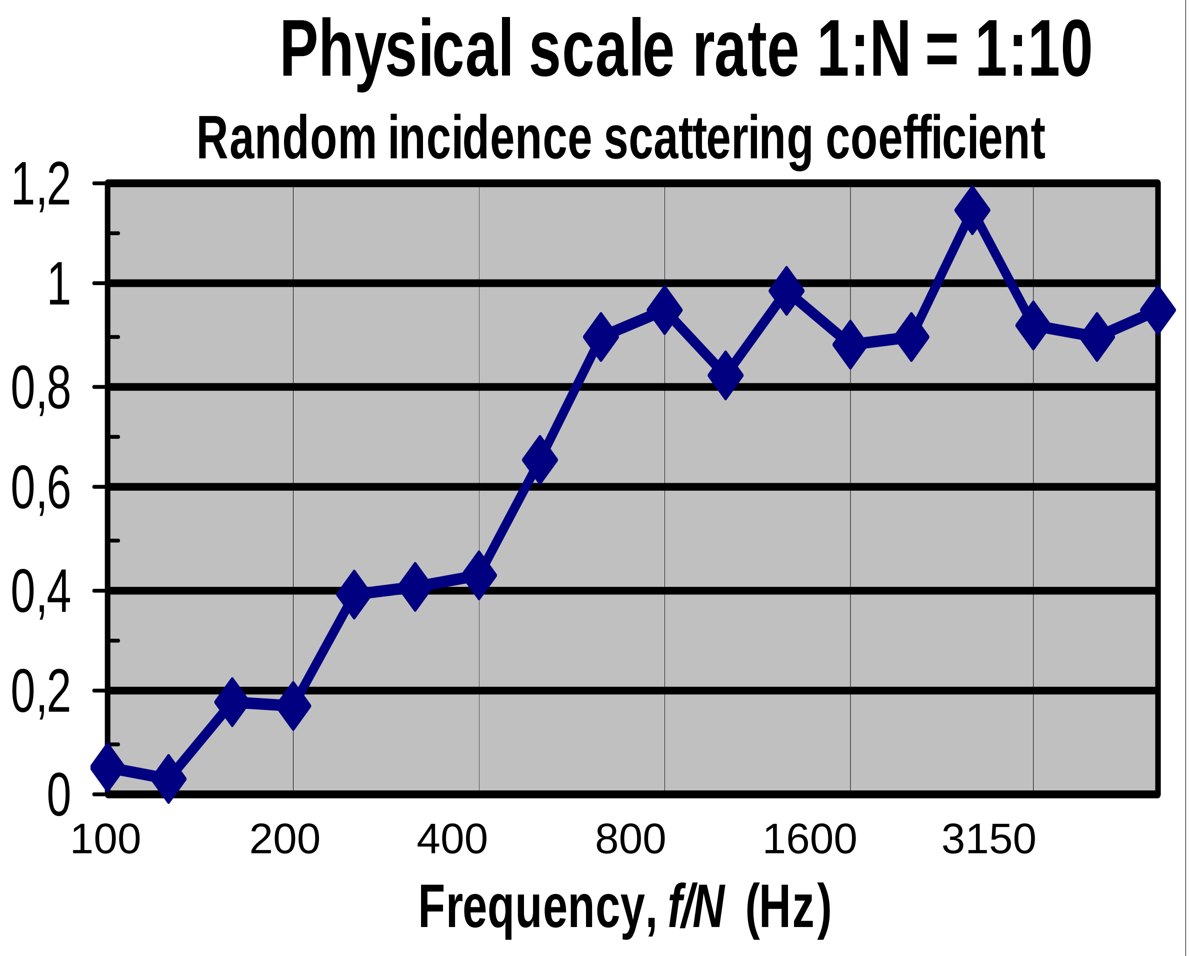
  $$n = 72, \Delta \varphi = 5°$$

Rotation of test specimen

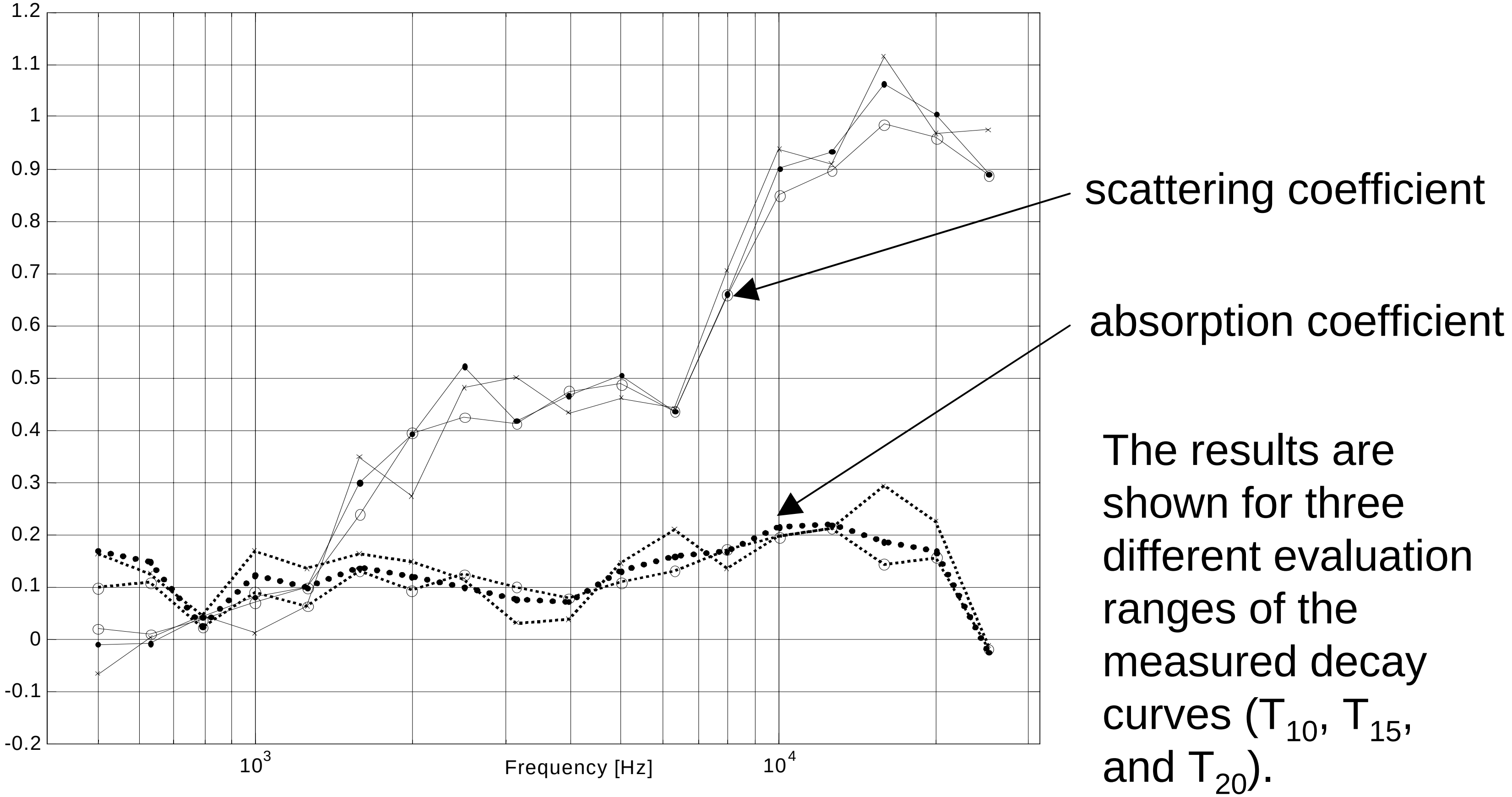
- Continuous rotation may be used
- The total measuring time shall equal a multiple of the revolution time of the turntable
- As a minimum two source positions and three microphone positions shall be used

Presentation of results

f /N (Hz)	s	α
100	0,05	0,01
125	0,03	0,02
160	0,18	0,10
200	0,17	0,05
250	0,39	0,18
315	0,41	0,25
400	0,43	0,20
500	0,66	0,20
630	0,90	0,21
800	0,95	0,20
1000	0,82	0,21
1250	0,99	0,21
1600	0,88	0,17
2000	0,90	0,20
2500	1,15	0,22
3150	0,92	0,24
4000	0,90	0,25
5000	0,95	0,27

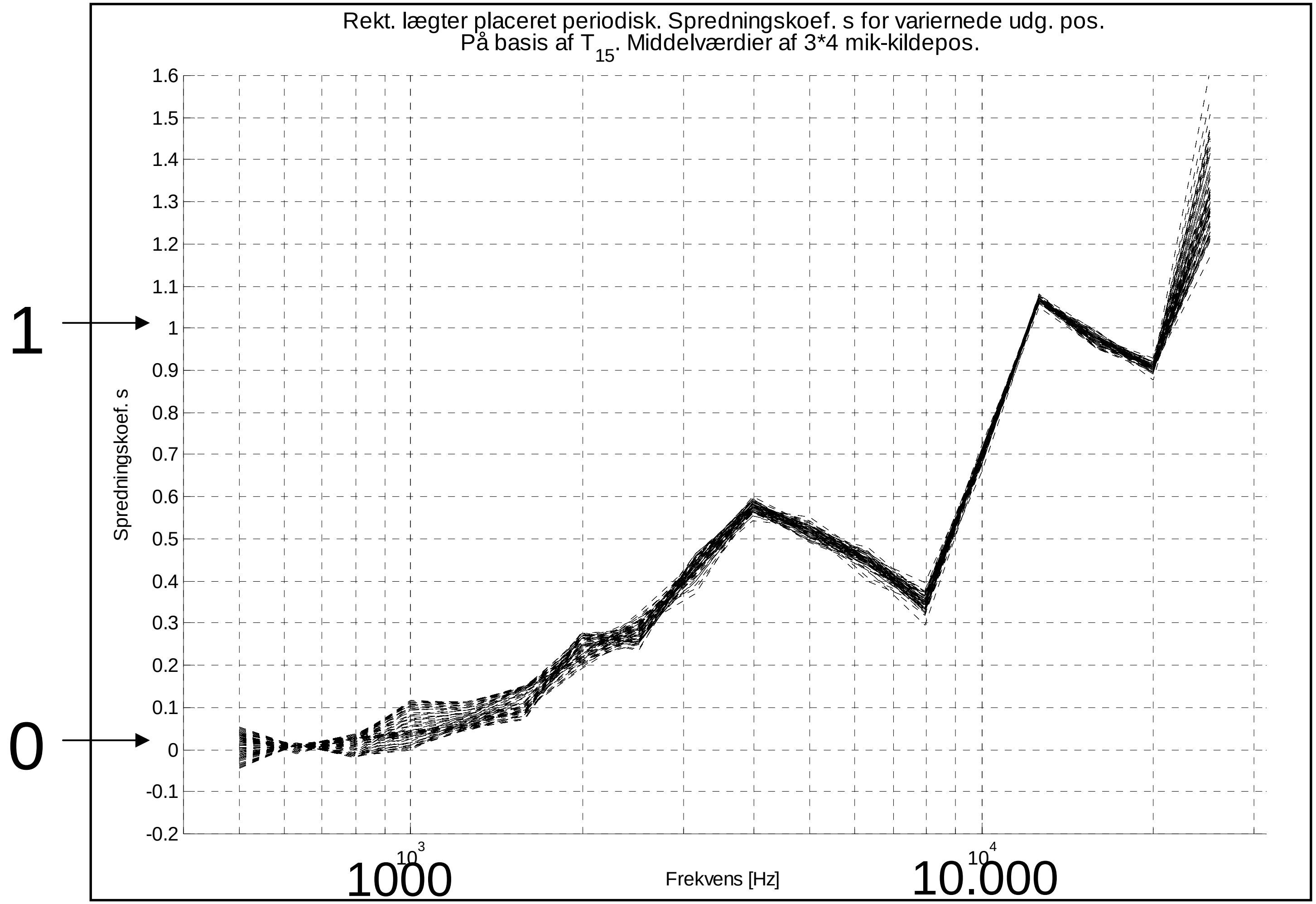


Measurement results

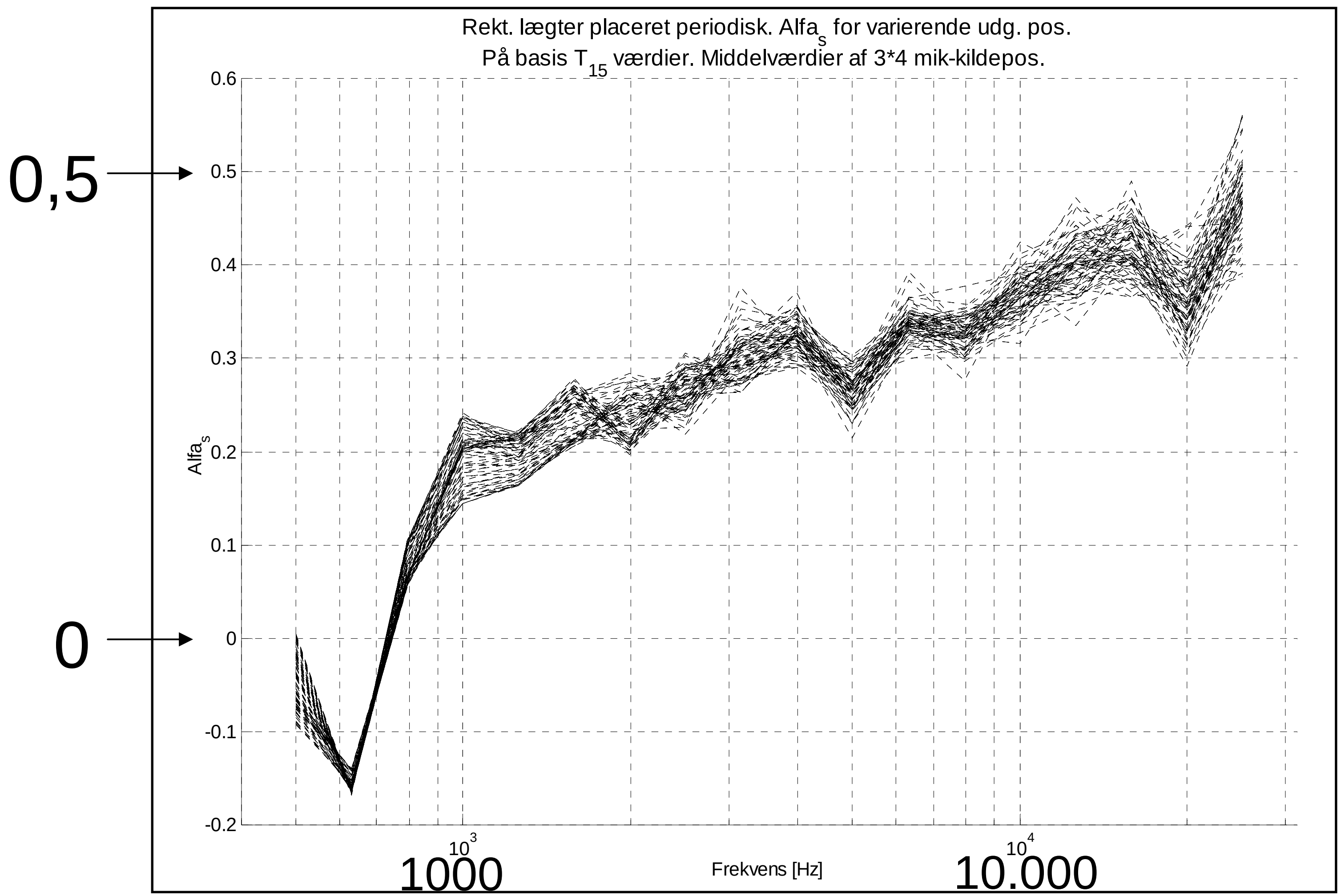


The results are shown for three different evaluation ranges of the measured decay curves (T_{10}, T_{15}, and T_{20}).

s measured for 72 different start positions of the turntable



α_s measured for 72 different start positions of the turntable



Some limitations in the ISO-method

- The absorption of the test sample should be low (< 0,5)
- The attenuation in the air may cause reduced accuracy at high frequencies
- The structural depth must be limited (< 1/16 diameter)
- Variation of the structure along the perimeter may cause values of $s > 1$

Summary of the ISO-method

- The measuring method is an extension of the traditional room-method for sound absorption
- A coherence technique is used to separate the specular reflection
- The measurements may be done in a scale model

Application of ODEON to Workplaces

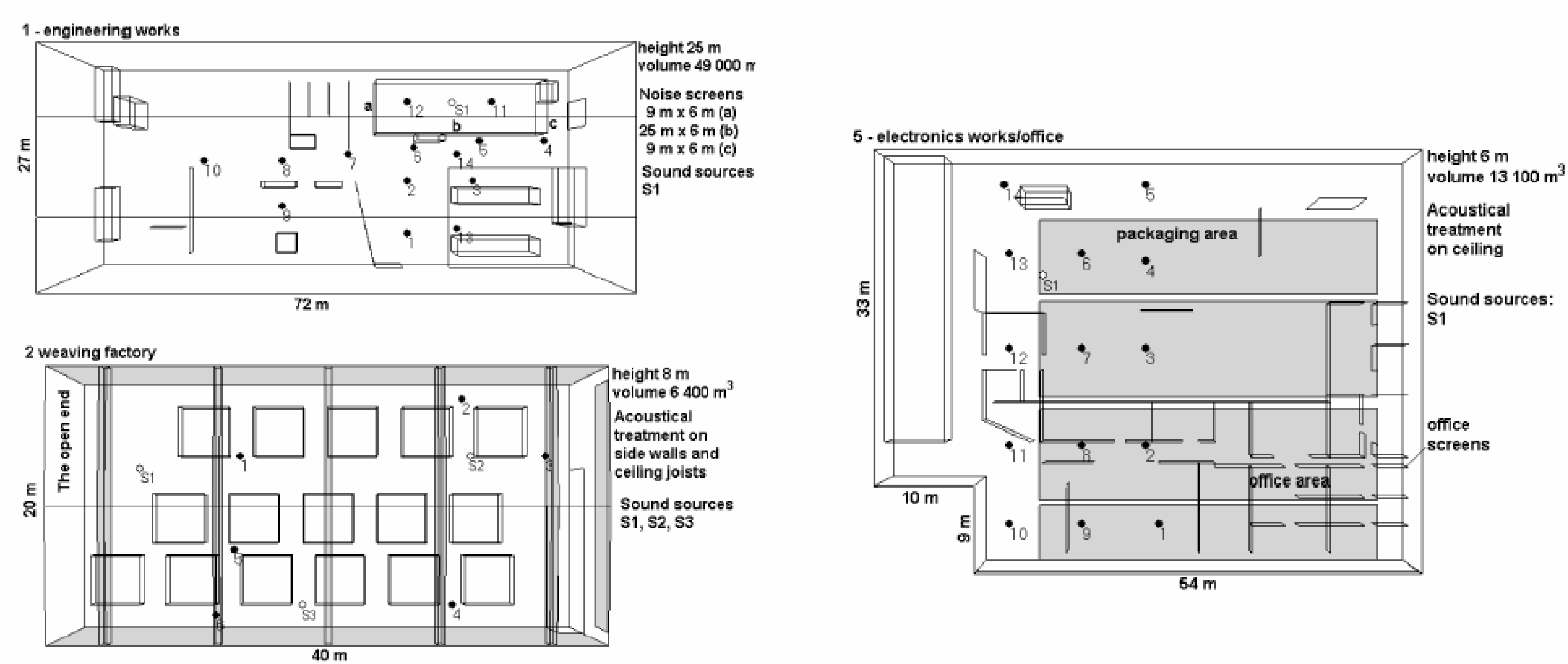
J. Keränen, E. Airo, P. Olkinuora, V. Hongisto
Acta Acustica, vol. 89 (2003) 863-874

The six rooms

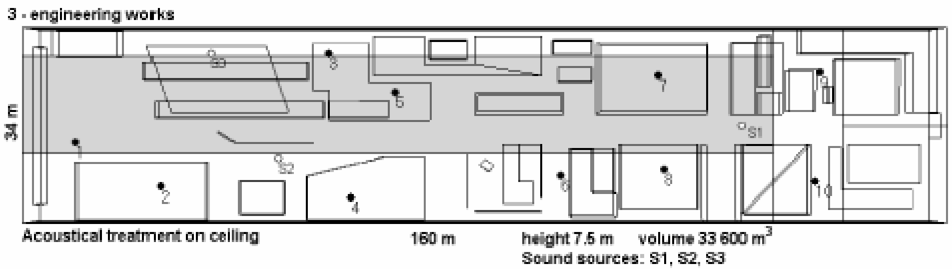
Table I. General information about the workplaces and acoustical models (m= number of sources, n= number of measurement points).

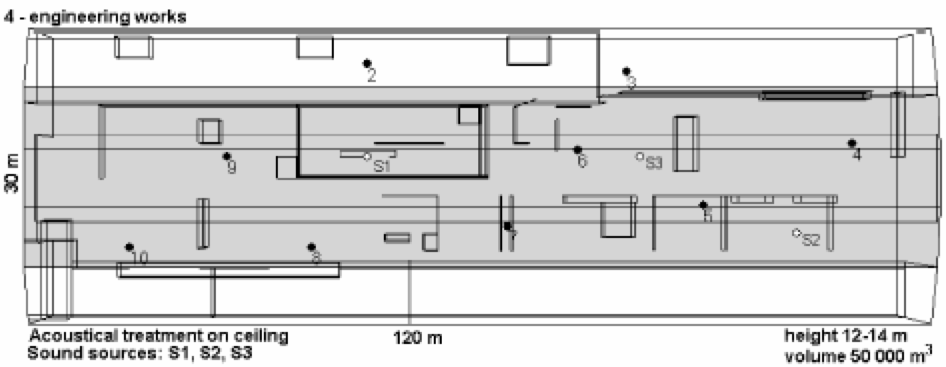
Work place	Type of industry	Volume (m^3)	Surfaces in model	m/n	Number of rays
1	engineering works	49 000	78	1/14	3000
2	weaving factory	6 400	107	3/6	4600
3	engineering works	33 600	134	3/10	10000
4	engineering works	60 000	145	3/9	6000
5	electronics works/ office	13 100	68	1/14	2000
6	knitting factory	33 000	140	6/1	5000

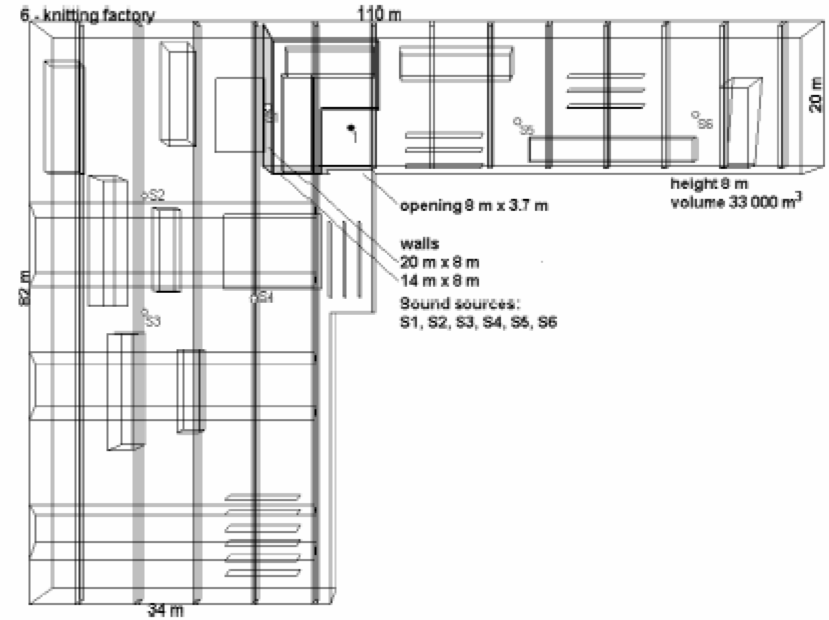
Keränen et al. (2003)



Keränen et al. (2003)







Keränen et al. (2003)

Scattering Coefficients

Table III. Collection of the scattering coefficients (in ODEON) used in the acoustical models.

Scattering coefficient	Description of the surface
0.1, . . . , 0.19	large, plain surfaces
0.2, . . . , 0.39	large partially fitted surfaces
0.4, . . . , 0.59	small or fitted surfaces
0.6, . . . , 0.89	large densely fitted surfaces
0.9, . . . , 1.00	small densely fitted surfaces

Keränen et al. (2003)

Accuracy of Reverberation Time predictions

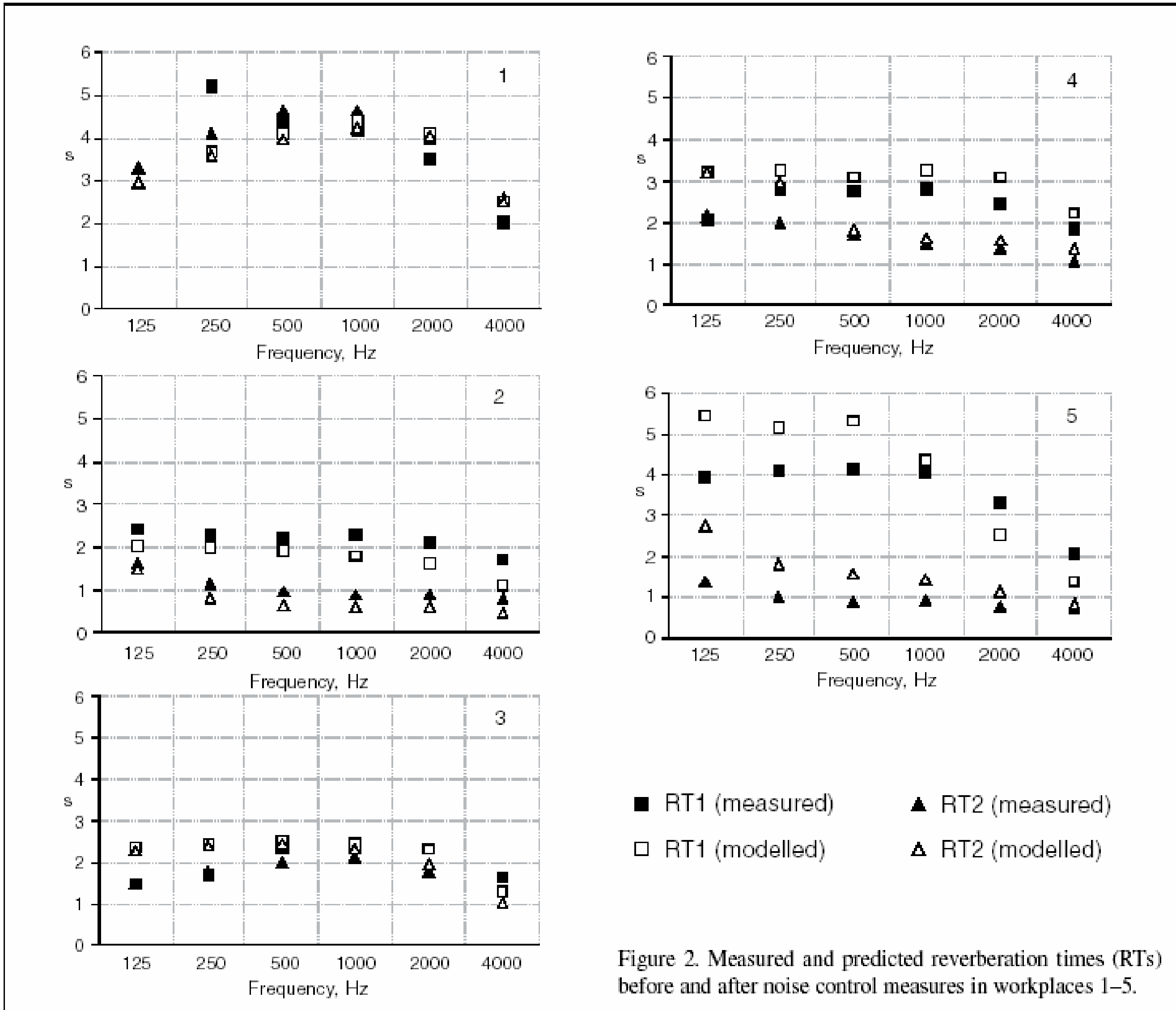
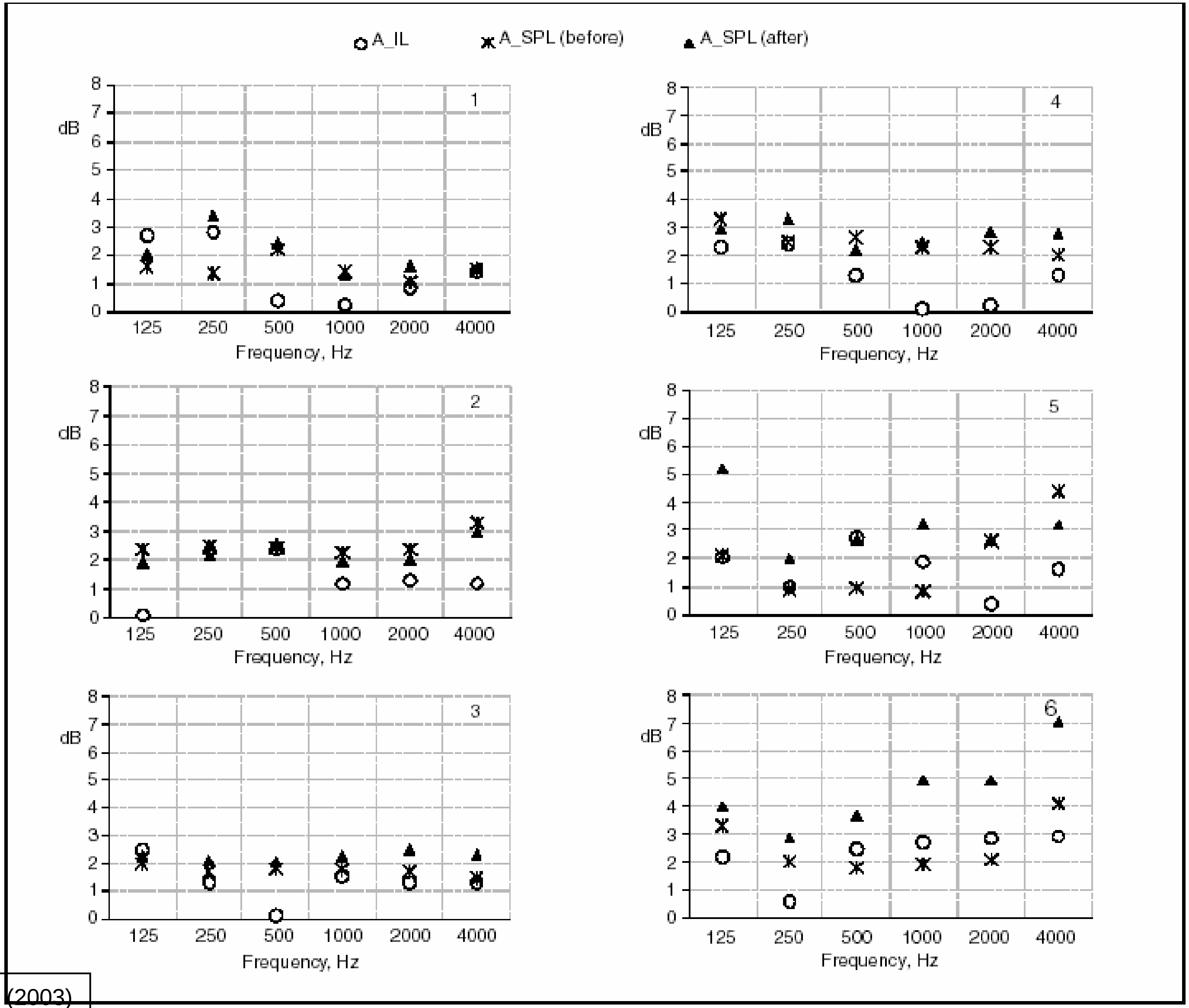


Figure 2. Measured and predicted reverberation times (RTs) before and after noise control measures in workplaces 1–5.

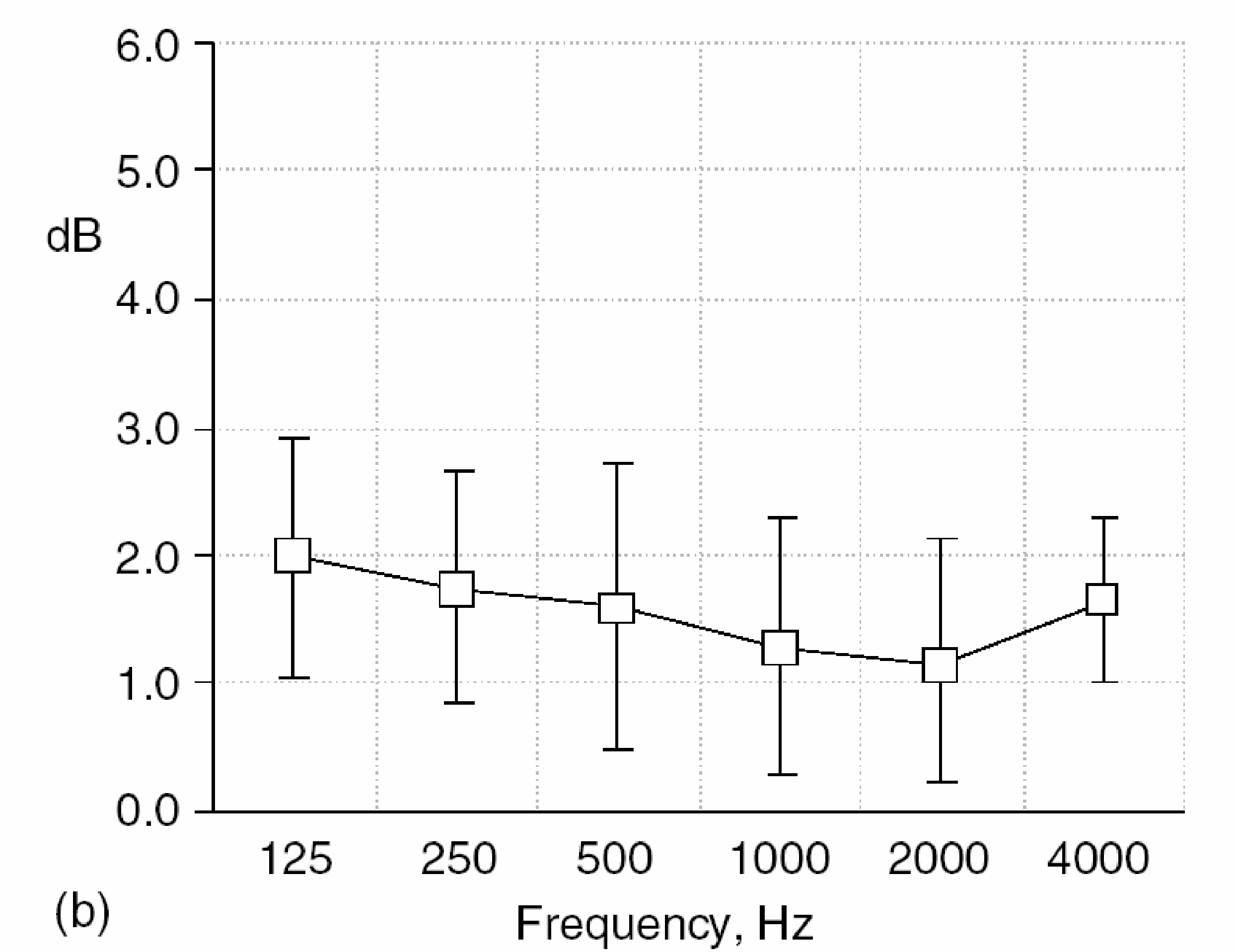
Keränen et al. (2003)

Accuracy of SPL and IL predictions



Keränen et al. (2003)

Accuracy of SPL predictions (Average of six rooms)



Keränen et al. (2003)

Example: Sound scattering walls

J.Y. Jeon, L. Zhu, K. Yoo:
Miral Concert Hall: “Ceramic Palace” for sound scattering. Inter-Noise 2003, Proceedings p. 545 – 552.

1:10 scale reverberation chamber for measuring the scattering coefficient

Jeon et al. (2003)

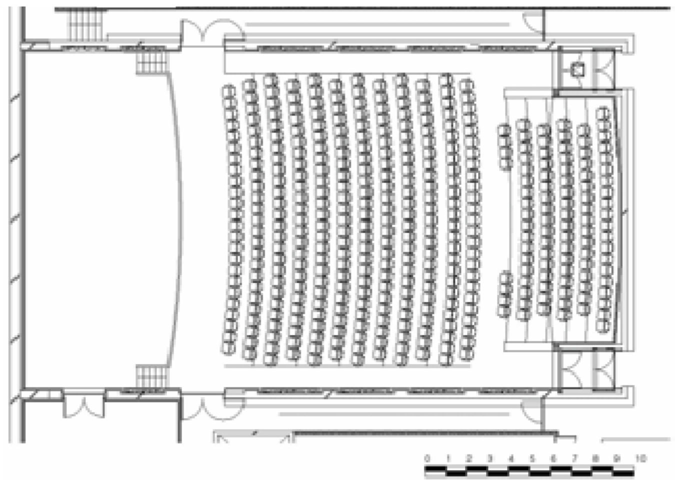


Fig. 6 Miral concert hall floor plan

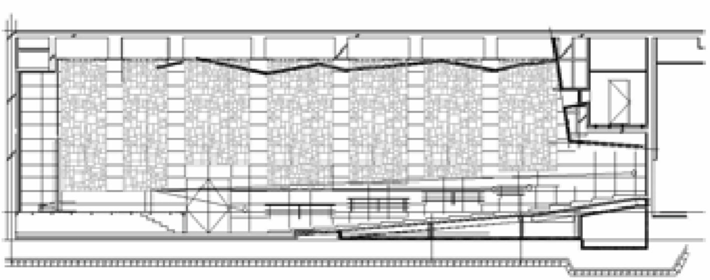


Fig. 7 Miral concert hall main section

Jeon et al. (2003)

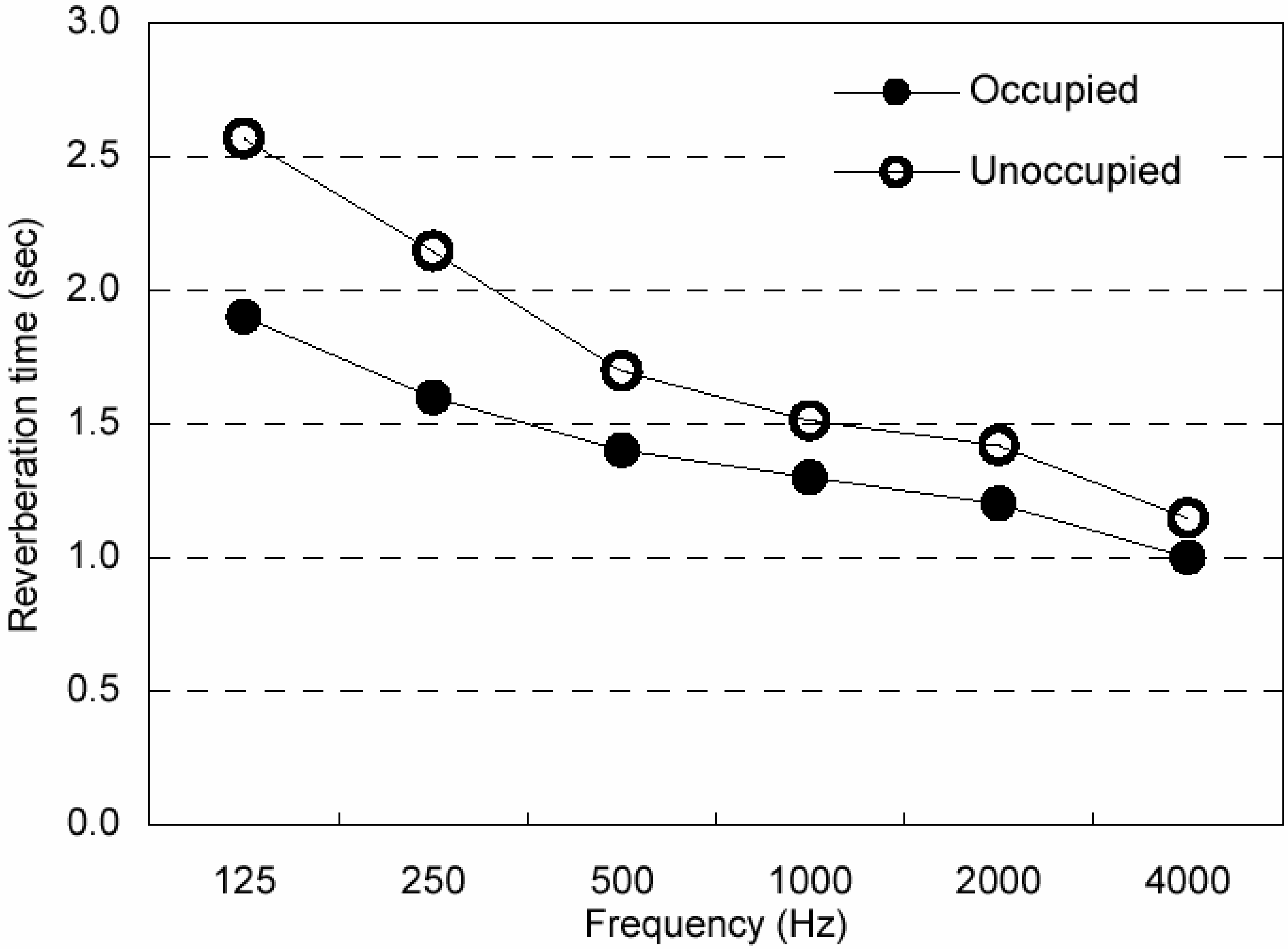


Fig. 10 Reverberation time

Jeon et al. (2003)

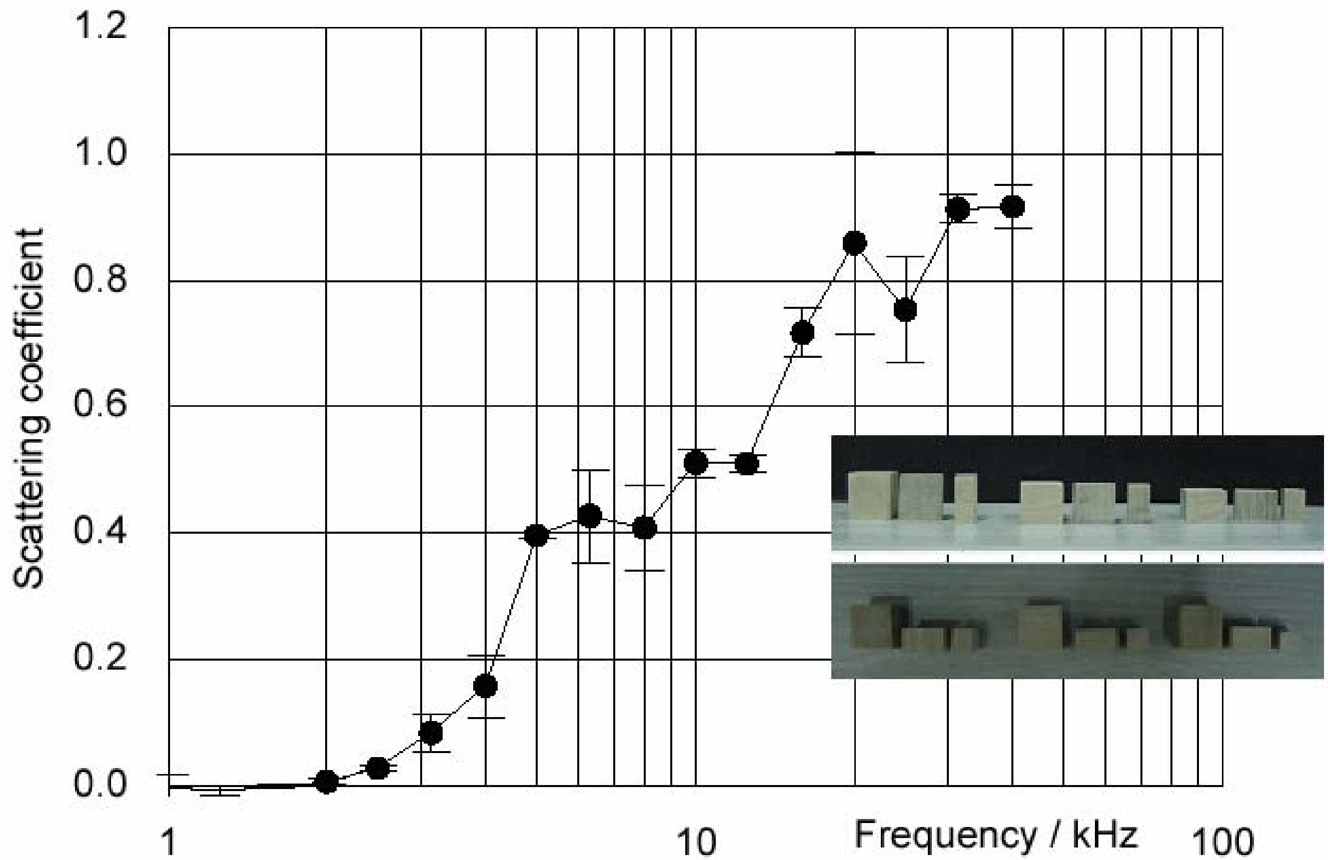


Fig. 4 Ceramic box-diffuser model & Scattering coefficients of a ceramic diffuser model

Jeon et al. (2003)

Max. height: 20 cm
Absorption coeff: α = 0,01 – 0,03
Scattering coeff. s = 0,4 (500 Hz) – 0,8 (2000 Hz)

Fig 5. Finalized shapes of ceramic diffusers

Jeon et al. (2003)

Guide to scattering coefficients

The scattering coefficient *s* should be chosen from depth of the structure and from the width of the surface.

The suggested graphs may be used as a rough guide.

The higher of the two values should be used for *s.*