Reverberation time in non-diffuse rooms

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Room Acoustics Software

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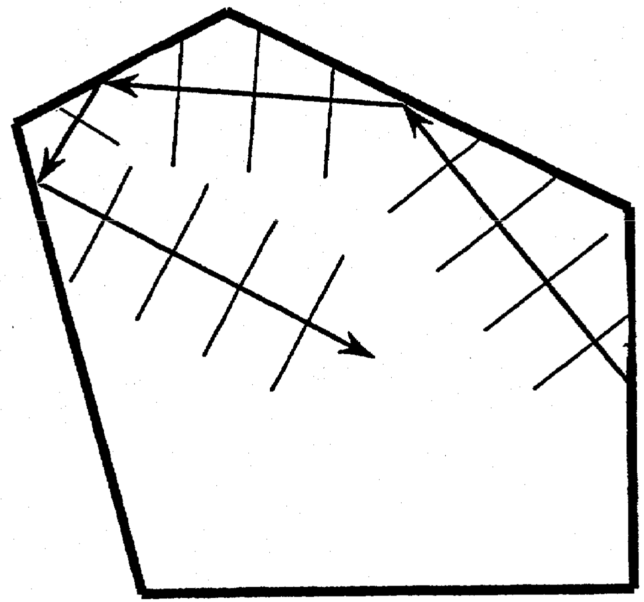
1. Theory: Mean free path and reverberation time

A sound wave represented by a ray



Mean free path,
3D sound field: $l_m = 4V/S$

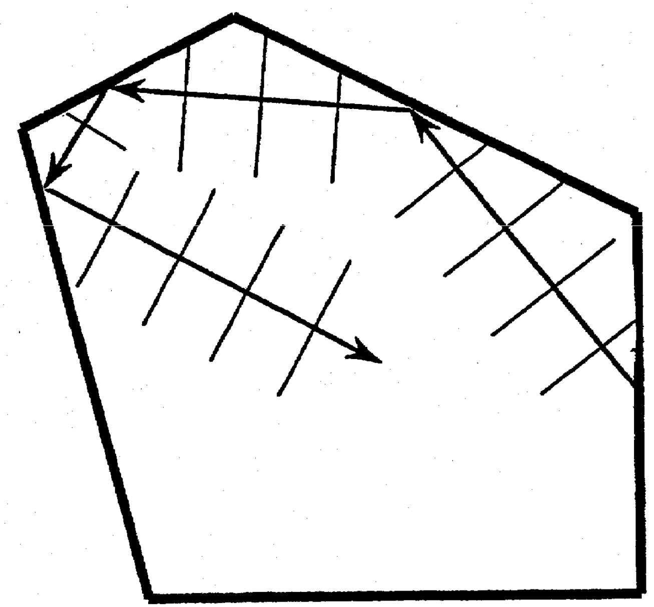
V : Volume
S : Surface area

Mean free path,
2D sound field: $l_m = \pi S_x / U$

S_x : Area
U : Perimeter

A sound wave represented by a ray

NB: It is assumed that all surfaces have the same absorption coefficient α_m



Energy of sound wave is reduced by $(1- \alpha_m)$ after each reflection

Sound pressure after *n* reflections

$$p^2(t) = p_0^2 \cdot (1-\alpha_m)^n \quad = p_0^2 \cdot \mathrm{e}^{n \cdot \ln(1-\alpha_m)}$$

Total path: $\sum_i l_i = c \cdot t = n \cdot l_m$ $\qquad p^2(t) = p_0^2 \cdot \mathrm{e}^{\frac{c}{l_m} \cdot \ln(1-\alpha_m) \cdot t}$

RevTime - 60 dB decay: $t = T_{60} \quad \Rightarrow \quad p^2(t) = p_0^2 \cdot 10^{-6} \quad \Rightarrow$

$$10^{-6} = \mathrm{e}^{\frac{c}{l_m} \cdot \ln(1-\alpha_m) \cdot T_{60}} \quad \Rightarrow \quad -6 \cdot \ln(10) = \frac{c}{l_m} \cdot \ln(1-\alpha_m) \cdot T_{60}$$

General equation for reverberation time

$$T_{60} = \frac{13.8 \cdot l_m}{-c \cdot \ln(1-\alpha_m)} \approx \frac{13.8 \cdot l_m}{c \cdot \alpha_m}$$

c : Speed of sound

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Reverberation time equations

General:	T_{60}	$= \dfrac{13.8 \cdot l_m}{-c \cdot \ln(1-\alpha_m)}$	$\approx \dfrac{13.8 \cdot l_m}{c \cdot \alpha_m}$
3D:	$l_m = \dfrac{4\,V}{S}$	$\dfrac{55.3 \cdot V}{-c \cdot S \cdot \ln(1-\alpha_m)}$	$\dfrac{55.3 \cdot V}{c \cdot S \cdot \alpha_m}$
2D:	$l_m = \dfrac{\pi\, S_x}{U}$	$\dfrac{43.4 \cdot S_x}{-c \cdot U \cdot \ln(1-\alpha_m)}$	$\dfrac{43.4 \cdot S_x}{c \cdot U \cdot \alpha_m}$
1D:	$l_m = l_x$	$\dfrac{13.8 \cdot l_x}{-c \cdot \ln(1-\alpha_m)}$	$\dfrac{13.8 \cdot l_x}{c \cdot \alpha_m}$

Eyring and Sabine equations (3D)

Special case for 3D diffuse field

Eyring:

$$T_{60} = \frac{55.3 \cdot V}{-c \cdot S \cdot \ln(1-\alpha_m)}$$

More correct for very high absorption, $\alpha_m \rightarrow 1$

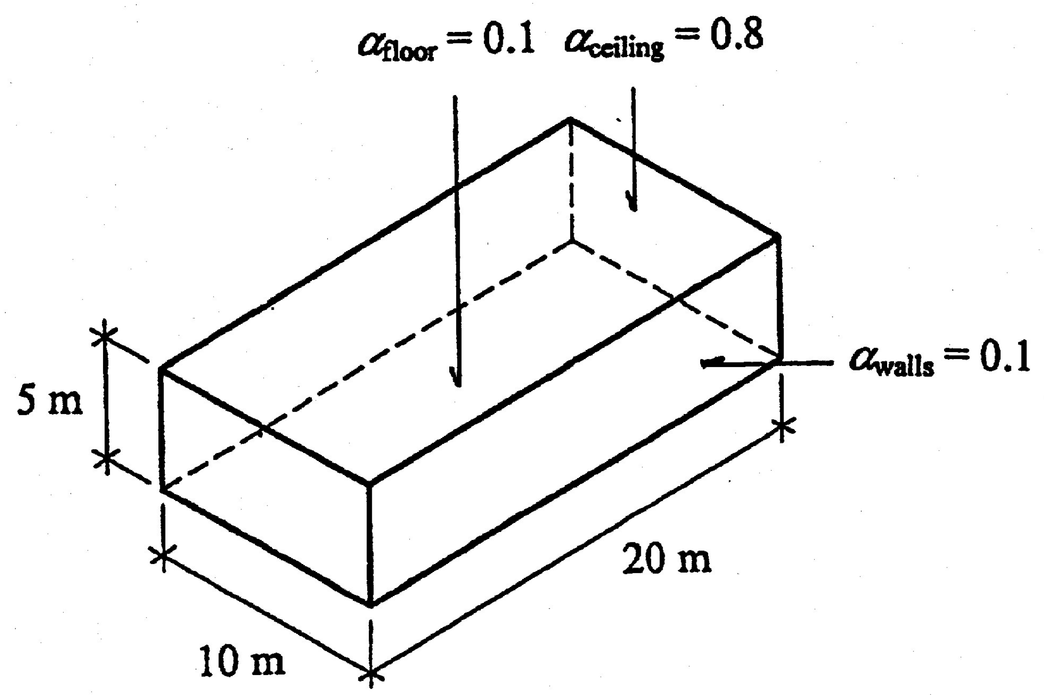
Sabine:

$$T_{60} = \frac{55.3 \cdot V}{c \cdot S \cdot \alpha_m}$$

Approximately the same as Eyring for $\alpha_m < 0{,}3$

2. Reverberation time in non-diffuse rooms – example

Example: Rectangular room



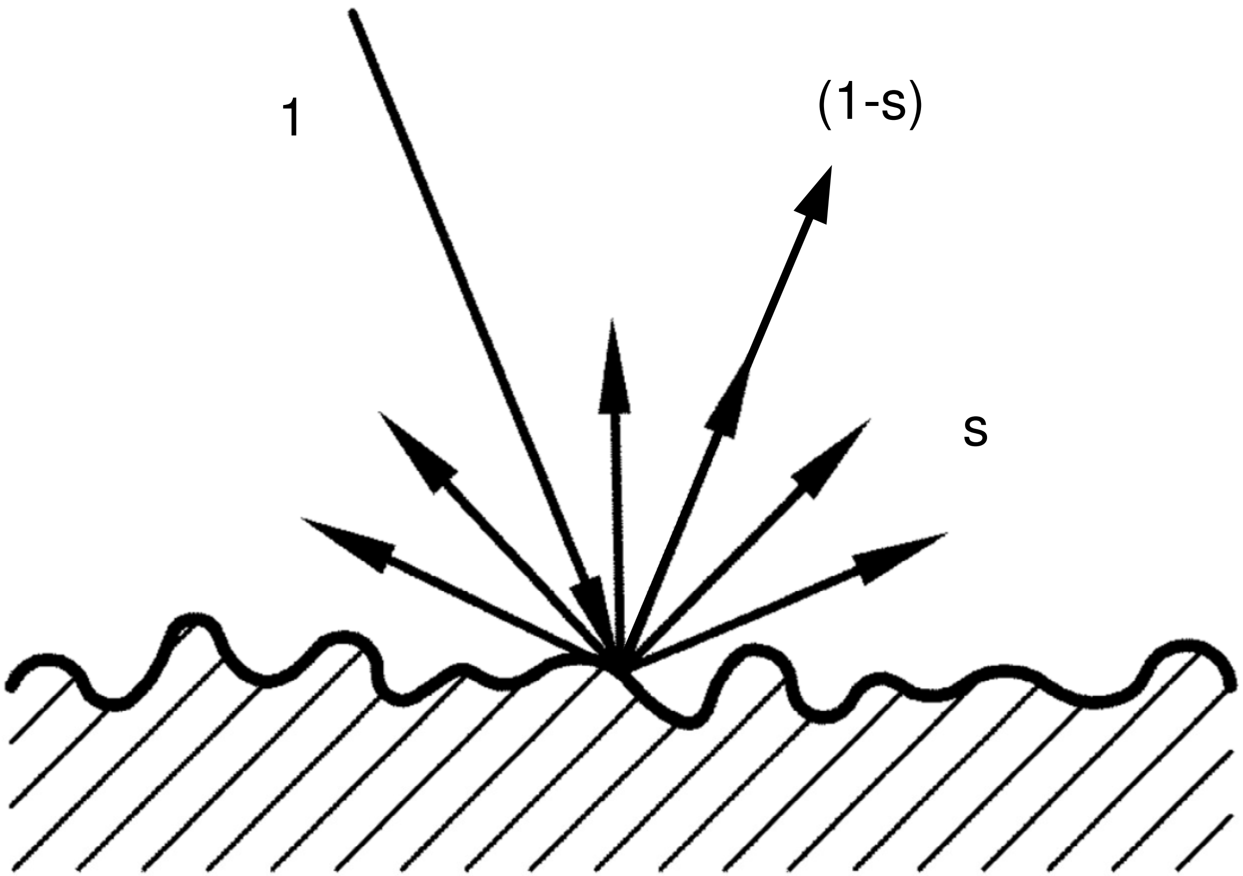
Uneven distribution of absorption – the preconditions for the reverberation equations of Sabine and Eyring are violated

Results according to theory

Direction	l_m (m)	α_m	T_{60} (s)
3-dim. (Sabine)	5.7	0.30	0.76
3-dim. (Eyring)	5.7	0.30	0.63
2-dim. (horizontal)	10.5	0.10	4.21
1-dim. (length)	20	0.10	8.02
1-dim. (width)	10	0.10	4.01
1-dim. (height)	5	0.45	0.45

l_m : Mean free path
α_m : Mean absorption coefficient
T_{60} : Reverberation time

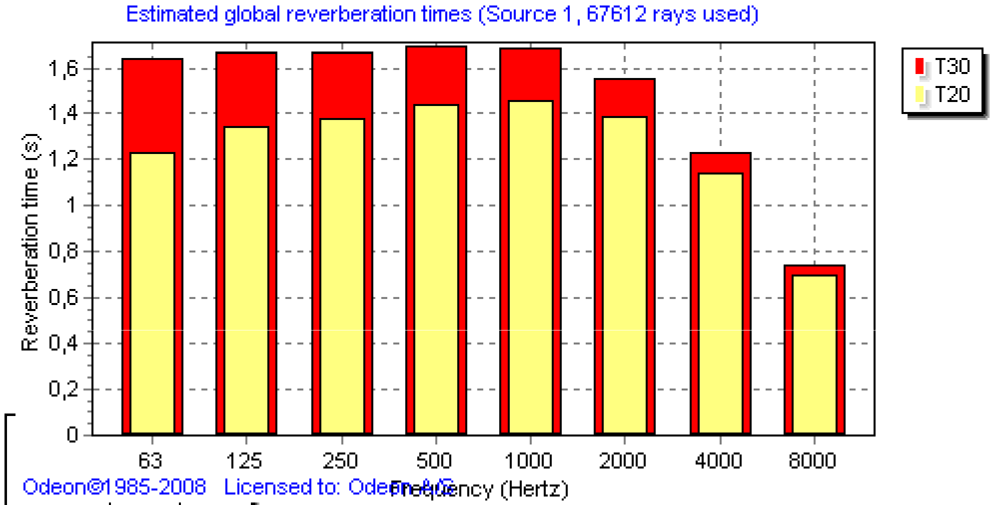
The scattering coefficient, *s*

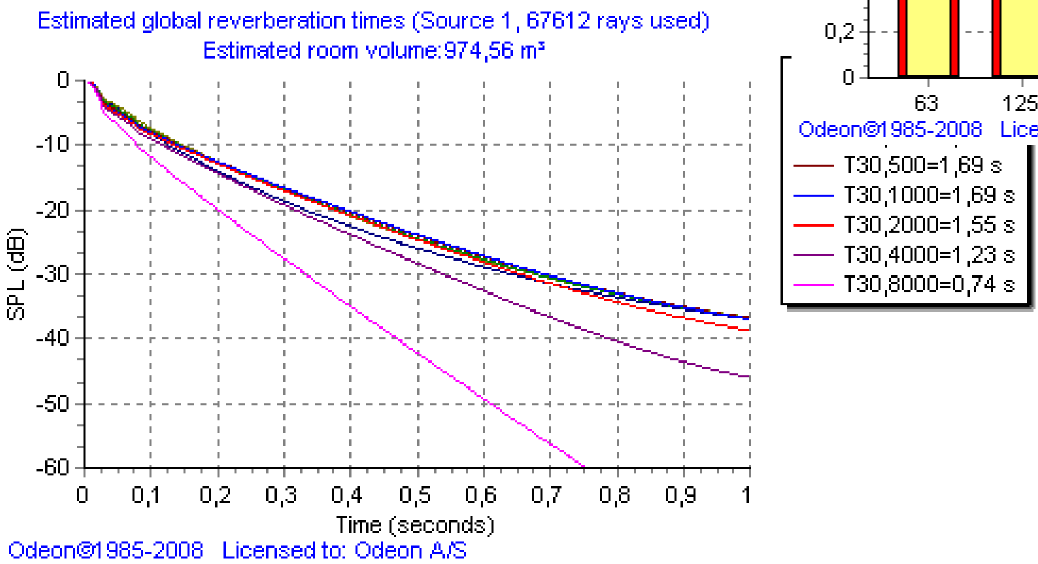


Ratio of reflected energy in non-specular directions

Simulation with ray tracing

Low scattering:
$s = 0.01$

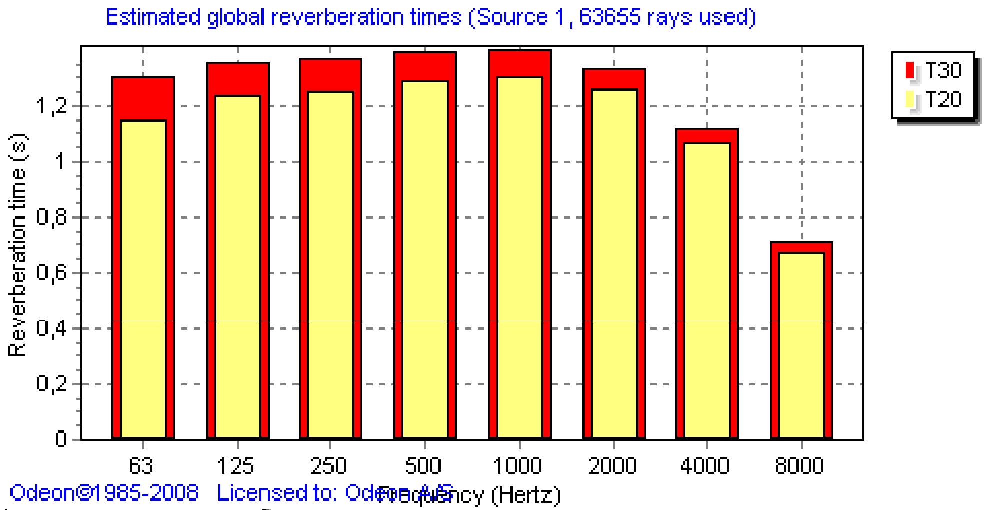


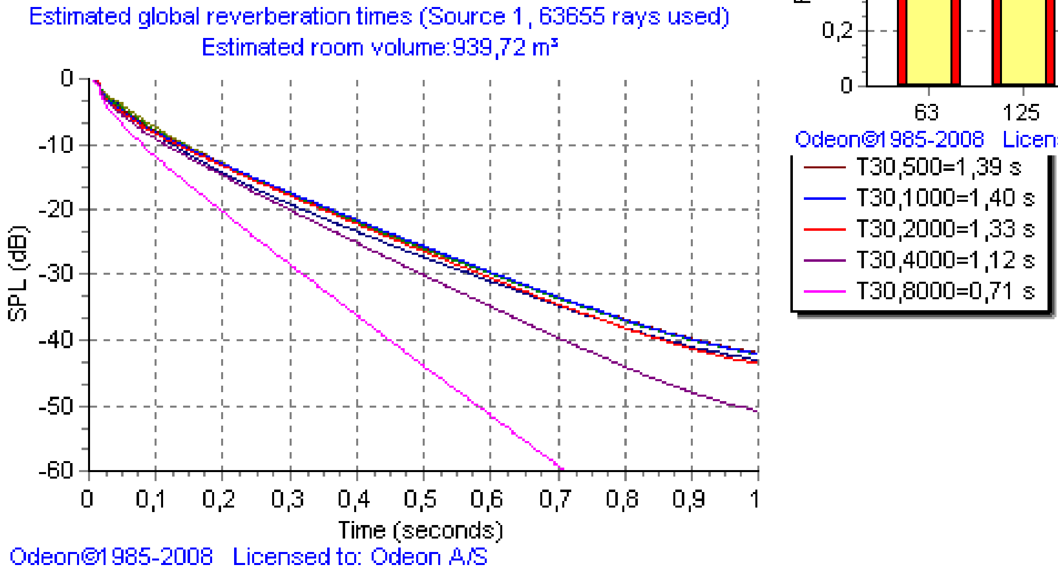


T_{30} = 1,69 s @ 1 kHz

Simulation with ray tracing

Normal scattering:
s = 0.05

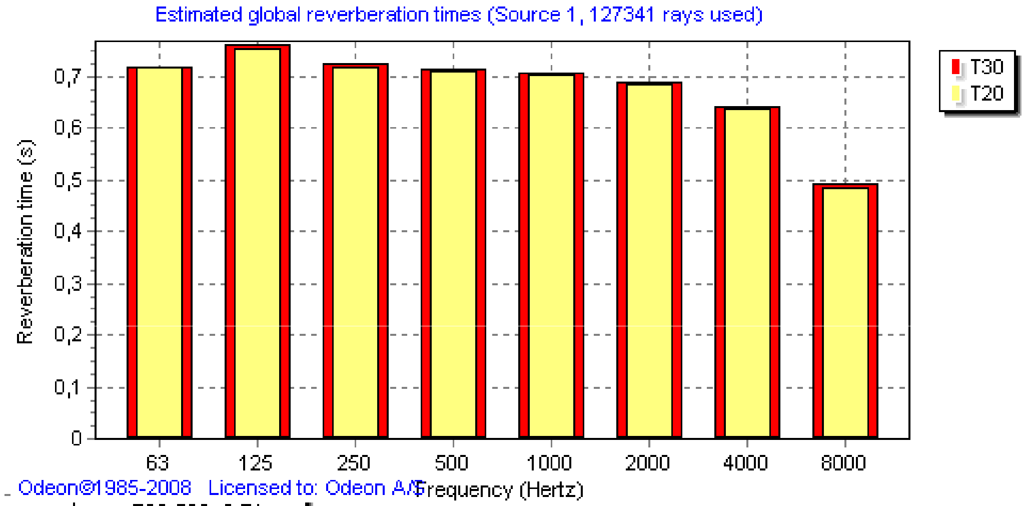


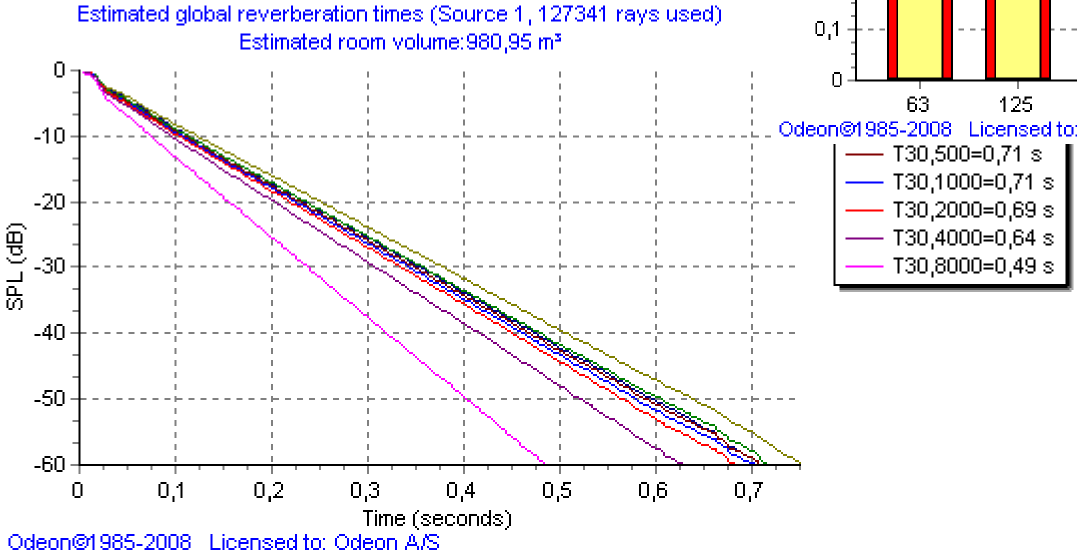


T_{30} = 1,40 s @ 1 kHz

Simulation with ray tracing

High scattering:
$s = 0.50$

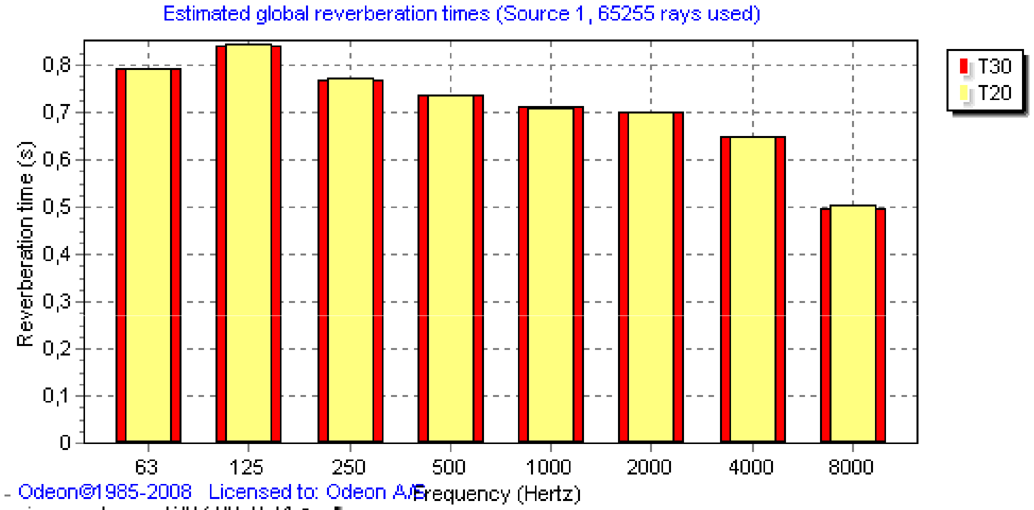


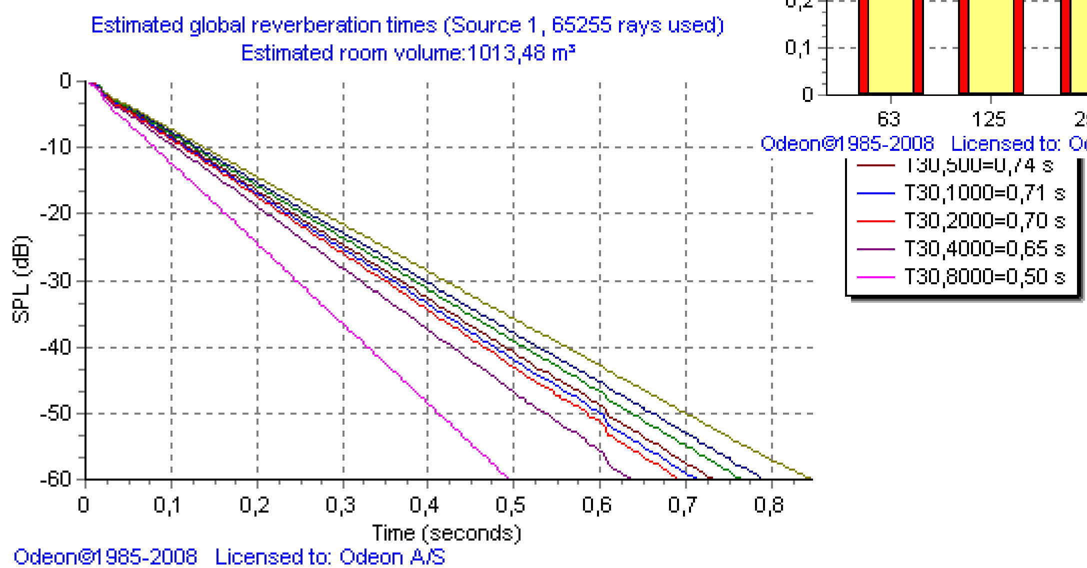


T_{30} = 0,71 s @ 1 kHz

Simulation with ray tracing

Very high scattering:
s = 1.00





T_{30} = 0,71 s @ 1 kHz

Conclusion

- 1-D and 2-D sound fields have longer RT and 3-D sound fields have shorter RT (due to different mean free path)
- The classical equations for reverberation time are based on 3-D sound field and even distribution of absorption
- With uneven distribution of absorption the degree of scattering is most important (RT varies from 1.7 s to 0.7 s in one example)
- The decay curve is not a straight line in case of low scattering and uneven distribution of absorption, i.e. different results for different evaluation range (20 dB or 30 dB)