The influence of the scattering coefficient on the reverberation time

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The reverberation time is still seen as an important measure of quality in architectural acoustic. The absorption coefficient is to be considered as the largest influencing factor on the reverberation time. The formulas after Sabine and Eyring give us the opportunity to calculate the reverberation time, when the absorption coefficients are known. In contrast to this, is the investigation of the influence of the scattering coefficient on the reverberation time a relatively new field for research. In this study the reverberation time for a “shoebox” was simulated, where the parameters were the values of the absorptions coefficient and the scattering coefficient and the even and uneven distribution of the absorption coefficient. The results of the simulation were compared with the results from the formulas by Sabine and Eyring. The simulations indicate a significant influence of the scattering coefficient on the reverberation time especially at low absorption coefficients. You can see by comparing the results of the simulation with the results of the formulas by Sabine and Eyring, that the theoretical formulas assume a minimum of scattering coefficient. It shows that the variation of the scattering coefficient is a possibly way to influence the reverberation time.

Introduction

If you want to calculate the reverberation time of a room, in many cases you use either the formula after Sabine or the formula after Eyring.

This study has the aim to investigate the influence of the scattering coefficient on the reverberation time. To exclude other influences only the walls of the room will be considered and other influences such as the air absorption or the absorption through audience will be neglected. The advantage of considering only the boundary surfaces of the room is to get a simplified model in which the part of the scattering coefficient comes better out.

The Eq.(1) after Sabine assumes that the only loss of sound energy occurs through the walls of the investigated Room.

$$T = \frac{6 * \ln(10) * 4 * V}{c * \overline{\alpha} * S}, (1)$$

with the Volume V of the room, the sound velocity c, the area of the walls S and the average absorption coefficient of the walls $\overline{\alpha}$.

Instead of $\overline{\alpha} * S$ the total absorption A is often used:

$$A = \overline{\alpha} * S , (2)$$

Inserting in the Eq.(1) the value of the sound velocity and the total absorption, you get the most common equation in practise for calculating the reverberation time:

$$T = 0{,}163 * \frac{V}{A}, (3)$$

If you are calculate the reverberation time after Sabine, you only must know the absorption coefficient of the materials, the area of the walls and the volume of the room.

The formula after Sabine includes the important statement, that the reverberation time only depends on the total absorption area and thus from the average absorption coefficient and not from the distribution and the location of the absorption materials. Also the scattering coefficients of the wall material find no consideration in the formula after Sabine. The statement mentioned above can only be fulfilled, if a diffuse sound field exists in the room.

In real rooms this assumption can not always be accepted and the formula after Sabine can not be applied.

If the surrounding walls have different absorption coefficients, the total absorption can be calculated by

$$A = \sum_i \alpha_i * S_i , (4)$$

and the average absorption coefficient of room surface by

$$\bar{\alpha} = \frac{\sum_i \alpha_i * S_i}{\sum_i S_i} = \frac{\sum_i \alpha_i * S_i}{S}, (5)$$

with S_i as the part surface area of the room and α_i as the associated absorption coefficient and S as the total surface area of room.

The statement of the theory after Eyring is to observe the propagation of a single sound ray. Each single sound ray losses sound energy, when it hits a wall. The higher the absorption coefficient of the wall is the higher the loss of sound energy.

In the formula after Eyring the average absorption coefficient is replaced by the absorption exponent:

$$T = \frac{0{,}163 * V}{S * \alpha^*}, (6)$$

With the absorption exponent

$$\alpha^* = -\ln(1 - \overline{\alpha}), (7)$$

The advantage of the Eyring equation lies in the fact, that the reverberation time becomes zero, if the average absorption coefficient is 1 which describes the reality better.

In practise the formula after Sabine is taken for absorption coefficients under 0.3 and the formula after Eyring is taken, if the absorption coefficients have values above.

Both equations are equal in presupposing a diffuse sound field and that the reverberation time is only depending on the total absorption A and thus from the average absorption coefficient $\overline{\alpha}$.

Recent investigations and considerations[1] have worked out, that the influence of the scattering coefficient on the reverberation time must not be neglected. Also the progresses in the computer simulation moved the scattering coefficient in the centre of interest[2].

In this study a rectangular room with a Volume of $14000m^3$ was simulated, where the average absorption coefficients and the scattered coefficients were varied.

The variation of the average absorption coefficient occurs on the one hand by changing the single absorption coefficients of the part surface areas of the wall and on the other hand by altering the values of the part surface areas.

The results of the simulation were compared with the results of the Eq.(1) from Sabine (1) and Eq.(6) from Eyring.

1 Computer Model

The investigated room was simulated with the simulation program CATT-Acoustic v8.0f. As prediction method the full detailed calculation method[3] was taken.

In this method the so called Randomized Tail-corrected Cone-tracing (RTC-II) model is applied. RTC-II assumes that reflection density growth is quadratic. RTC-II employs randomized cone-tracing. RTC-II handles diffuse reflection in generating for each reflection a random number [0,1[and if the number is less than the scattering coefficient of the surface the ray direction is randomized according to Lambert's Law [4] otherwise the reflection is specular.

The shape of the room is a shoebox with a volume of amount $14.000m^3$. The ratio of height to width to length was 1:1,2:2,2, which is the same ratio of the "Großer Wiener Musikvereinssaal[5]".

In the simulated room are 9 receiver determined. The positions of the receiver concentrate on an auditorium location. The results of the reverberation time are averaged over the 9 receiver. As sound source a predefined omnidirectional natural source A0 is used, which is placed at the location where a stage is usually placed (see figure 1).

The sound absorption of air was neglected in the simulation, thus only the surface properties of the walls had influence of the reverberation time.

2 Parameters

In this investigation the influence of the scattering coefficient on the reverberation time is made. In each simulation series the average absorption coefficients after Sabine takes the values 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, 0.45 and 0.55. With the Eq.(1) and Eq.(6) you can calculate the reverberation time after Sabine T_S and Eyring T_E (see table 1).

2.1 Uniform absorption coefficient

In the first simulation series a uniform absorption coefficient for all walls in the model is chosen. For each value of the absorption coefficient $\overline{\alpha}$ the scattering coefficient ρ is altered from 0 to 1 with a step width of 0.1 thus you get 99 results for the reverberation time, each averaged over the 9 receivers in the model room (see table 2).

$\overline{\alpha}$	**0.05**	**0.10**	**0.15**	**0.20**	**0.25**	**0.30**	**0.35**	**0.45**	**0.55**
T_S	12,5	6,2	4,2	3,1	2,5	2,1	1,8	1,4	1,1
T_E	12,2	5,9	3,8	2,8	2,2	1,7	1,4	1,0	0,8

Table 1 Reverberation time in seconds after Sabine T_S and Eyring T_E

2.2 Non uniform absorption coefficient

To investigate the influence of non uniform distributed absorption coefficients two further series are made. In this series the wall surfaces are built of two different areas S_1 and S_2 with different absorption coefficients α_1 and α_2. The average absorption coefficient is calculated after

$$\overline{\alpha} = \frac{\alpha_1 * S_1 + \alpha_2 * S_2}{S_1 + S_2}, (8)$$

In the second series the difference of the two absorption coefficients is always 0.3:

$$\Delta\alpha = |\alpha_1 - \alpha_2| = 0.3$$

and in the third series always 0.8.:

$$\Delta\alpha = |\alpha_1 - \alpha_2| = 0.8$$

To get comparable results you must have the same average absorption coefficients for the investigated room as in series 1. For this purpose the values of the areas S_1 and S_2 were altered for each simulation thus you get the same average absorption coefficient as in simulation with uniform absorption coefficient. In figure1 you can recognized the different areas S_1 and S_2 by different gray shaded and dashed limited rectangles.

3 Results

In table 2 you can see the results for the first series, where only one surface with one absorption coefficient is used. You can see, that the influence on the reverberation time by the scattering coefficient is more significantly for smaller absorption coefficient values. The biggest influence appears when the absorption and the scattering coefficient values are small. For values of the absorption coefficient above 0.55 the reverberation time is independent from the scattering coefficient. Also decreases the influence of the scattering coefficient through increasing values strongly. Therefore only absorption coefficient values till 0.55 are investigated.

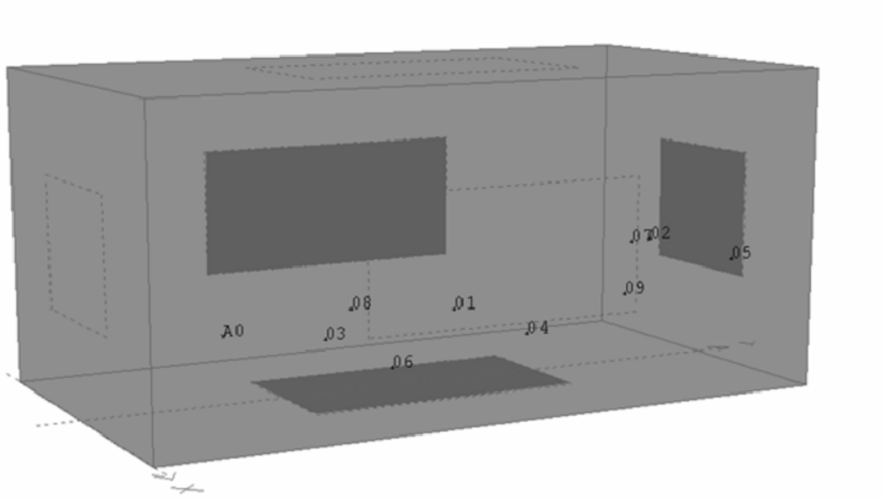

Figure 1: The model of the room used in the simulation

$\overline{\alpha}$	**0.05**	**0.10**	**0.15**	**0.20**	**0.25**	**0.30**	**0.35**	**0.45**	**0.55**
ρ=0.0	15,0	7,6	5,0	3,7	2,9	2,3	1,9	1,4	1,0
ρ=0.1	12,3	6,2	4,1	3,1	2,5	2,0	1,7	1,3	1,0
ρ=0.2	12,1	6,0	3,9	2,9	2,3	1,9	1,6	1,2	0,9
ρ=0.3	12,1	5,9	3,9	2,9	2,3	1,9	1,6	1,2	0,9
ρ=0.4	12,1	5,9	3,9	2,9	2,2	1,8	1,5	1,1	0,9
ρ=0.5	12,1	5,9	3,9	2,8	2,2	1,8	1,5	1,1	0,9
ρ=0.6	12,1	5,9	3,9	2,8	2,2	1,8	1,5	1,1	0,9
ρ=0.7	12,1	5,9	3,9	2,9	2,2	1,8	1,5	1,1	0,9
ρ=0.8	12,1	5,9	3,9	2,9	2,2	1,8	1,5	1,1	0,9
ρ=0.9	12,1	6,0	3,9	2,9	2,3	1,8	1,5	1,1	0,9
ρ=1.0	12,1	6,0	3,9	2,9	2,3	1,8	1,5	1,1	0,9

Table 2 Reverberation time in seconds with uniform absorption coefficient

In table 3 and 4 there are the results for the non uniform distributed absorption coefficients with a difference of 0.3 and 0.8 listed.

$\overline{\alpha}$	**0.05**	**0.10**	**0.15**	**0.20**	**0.25**	**0.30**	**0.35**	**0.45**	**0.55**
ρ=0.0	56,2	10,0	4,5	3,4	2,7	2,5	2,0	1,5	1,1
ρ=0.1	12,6	6,3	4,0	3,0	2,4	2,1	1,8	1,3	1,0
ρ=0.2	12,4	6,0	3,9	2,9	2,3	1,9	1,6	1,2	0,9
ρ=0.3	12,3	6,0	3,9	2,8	2,2	1,8	1,6	1,2	0,9
ρ=0.4	12,3	5,9	3,8	2,8	2,2	1,8	1,5	1,1	0,9
ρ=0.5	12,3	5,9	3,8	2,8	2,2	1,8	1,5	1,1	0,9
ρ=0.6	12,3	5,9	3,8	2,8	2,2	1,8	1,5	1,1	0,9
ρ=0.7	12,3	5,9	3,8	2,8	2,2	1,8	1,5	1,1	0,8
ρ=0.8	12,4	5,9	3,8	2,8	2,2	1,8	1,5	1,1	0,8
ρ=0.9	12,3	5,9	3,8	2,8	2,2	1,8	1,5	1,1	0,9
ρ=1.0	12,3	5,9	3,8	2,8	2,2	1,8	1,5	1,1	0,9

Table 3: Reverberation time in seconds for the non uniform distributed absorption coefficients with Δα=0.3

For the absorption coefficient of 0.05 and no scattering coefficient (ρ=0.0) in the series 2 and 3 you get an unbelievable high reverberation time, which were excluded in the further considerations.

In table 3 and 4 you can see, that the influence of the scattering coefficient on the reverberation time increases with increasing difference between the absorption coefficients.

$\overline{\alpha}$	**0.05**	**0.10**	**0.15**	**0.20**	**0.25**	**0.30**	**0.35**	**0.45**	**0.55**
ρ=0.0	49,8	8,4	5,2	3,8	3,4	3,0	2,2	2,0	1,9
ρ=0.1	15,8	6,8	4,4	3,3	2,7	2,3	2,0	1,6	1,5
ρ=0.2	15,4	6,8	4,3	3,1	2,6	2,2	1,8	1,5	1,3
ρ=0.3	15,7	6,8	4,3	3,1	2,6	2,2	1,8	1,4	1,1
ρ=0.4	15,8	6,9	4,3	3,1	2,6	2,1	1,8	1,4	1,1
ρ=0.5	16,3	6,9	4,3	3,1	2,6	2,2	1,8	1,4	1,1
ρ=0.6	15,8	6,9	4,3	3,1	2,4	2,1	1,8	1,4	1,1
ρ=0.7	16,2	7,0	4,3	3,1	2,4	2,1	1,8	1,4	1,2
ρ=0.8	16,6	7,0	4,4	3,1	2,4	2,1	1,8	1,4	1,1
ρ=0.9	16,7	7,0	4,4	3,2	2,4	2,1	1,8	1,4	1,1
ρ=1.0	16,6	7,0	4,4	3,2	2,5	2,1	1,9	1,4	1,1

Table 4: Reverberation time in seconds for the non uniformed distributed absorption coefficients with Δα=0.3

Generally the reverberation time simulation results for zero scattering coefficients are clearly above the values after Sabine and Eyring. In figure 2 and 3 you can see the divergence between the results from the equation after Sabine and the simulation results for uniform absorption coefficient and Δα=0.8. The divergence is given in percentage.

One of the goals of this investigation is to work out at which scattering coefficient the simulation results fits best with the reverberation time after Sabine and Eyring. This comparison is seen in table 5.

	Sabine	Eyring
uniform	0,1	0,6
Δα=0.3	0,1	0,7
Δα=0.8	0,4	0,6

Table 5: scattering coefficients used in the simulation series, which fit best with the results from the equations after Sabine and Eyring

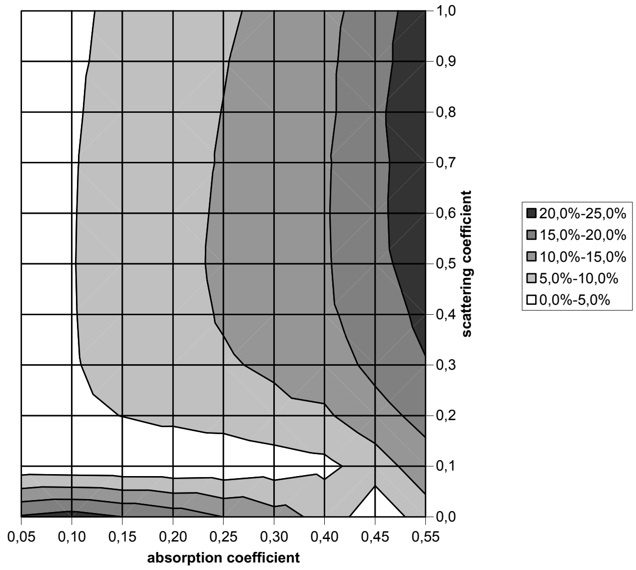

Figure 2: Difference between the Sabine formula and the simulation for uniform absorption coefficient in percentage

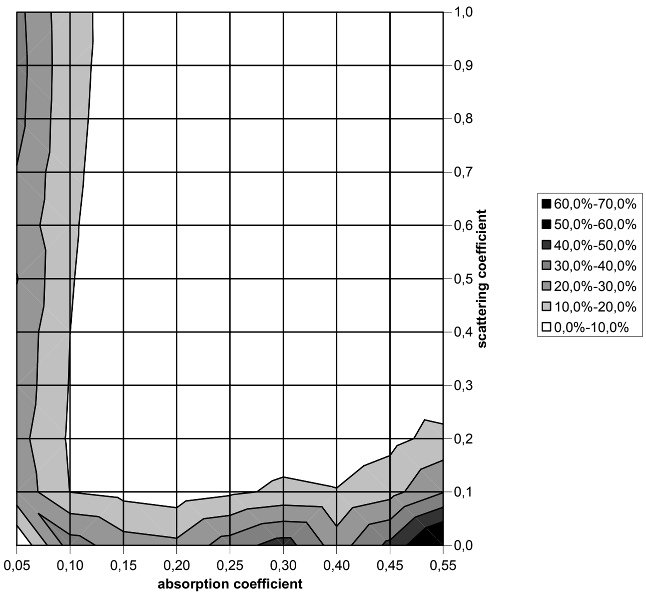

Figure 3: Difference between the Sabine formula and the simulation for $\Delta\alpha$=0.8 in percentage.

4 Conclusion

The results for the reverberation time of the simulation lie between the reverberation time after Sabine and the reverberation time after Eyring. Exceptions are the results at low scattering coefficient. It is shown, that low scattering coefficients in the simulation generates unbelievable high reverberation times. This fact is increased if the absorption coefficient is not uniform. General the influence of the scattering coefficient on the reverberation time increases at greater differences between the absorption coefficients and declines with greater average absorption coefficient.

Starting from a low scattering and absorption coefficient it seems that the increasing of the scattering coefficient is a proper method to decline the reverberation time in a room.

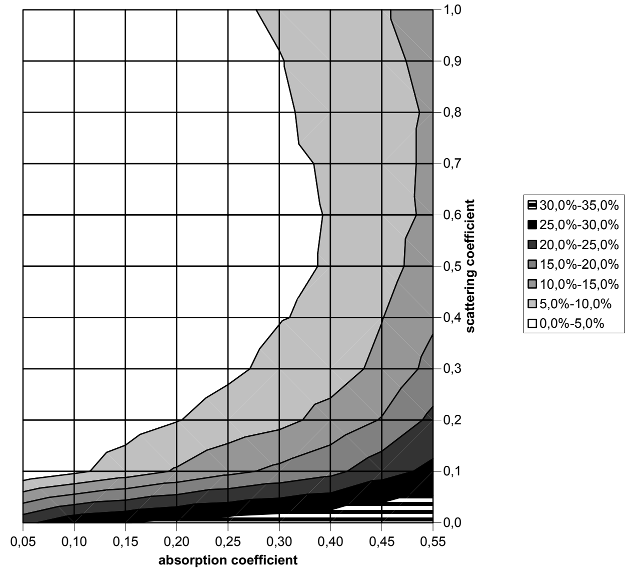

Figure 4: Difference between the Eyring formula and the simulation for uniform absorption coefficient in percentage

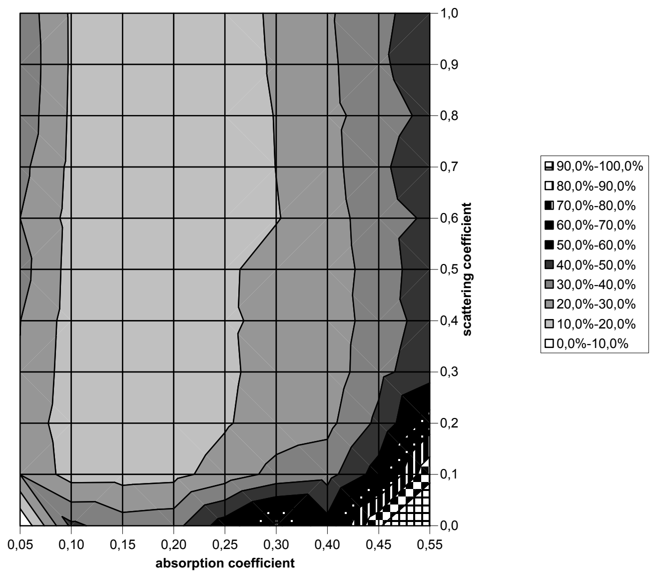

Figure 5**: Difference between the Sabine formula and the simulation for** $\Delta\alpha$=0.8 **in percentage.**

It seems that the formulas after Sabine and Eyring presuppose a minimum of scattering coefficients. Especially for Eyring and non uniform distributed absorption materials it seems, that there is a range for scattering coefficient in which the theory fits best (see figure 5).

The results of this investigation worked out, that the scattering coefficient influences the reverberation time significantly. To set up a definite relation between the reverberation time and the scattering coefficient further investigation are necessary. Many other influences such as the distribution of the absorption materials have to be investigated.

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