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Volume Diffusers in the Reverberation Room

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ABSTRACT

The random incidence absorption coefficient is measured in a reverberation room according to the ISO354 or ASTM C423-09. According to these standards, the diffusivity of a reverberation room is usually obtained with panel diffusers. Besides the fundamental problem that a reverberation room with a highly absorptive specimen is not diffuse, these panel diffusers introduce a number of uncertainties in the resulting acoustical effective volume and the total boundary surface of the reverberation room.

As a part of more investigations with the aim to reduce the difference in measurement results between different laboratories, the possible use of volume diffusers instead of panel diffusers is investigated with the aid of a 1:10 scale model, the real reverberation room at the Peutz laboratories and raytracing calculations.

From this investigation it can be concluded that volume diffusors can be used instead op panel diffusors to enhance the diffusitivity in a reverberation room. Besides the advantage that with volume diffusors the real volume and boundary area of the room are known, these investigations show that the use of volume diffusors might even result in a higher degree of diffusitivity than the use of panel diffusors. This is shown by comparing the spread of measurement results between different source and microphone positions in the reverberation room. Furthermore, the relative standard deviation between the different source – microphone positions might be a good test for the qualification of the diffusitivity of a reverberation room, especially with highly absorptive specimen present in the room.

INTRODUCTION

The random incidence absorption coefficient is measured in a reverberation room according to the ISO354 or ASTM C423-09a [1,2]. It is known that the inter laboratory reproducability of these results is not very well, which leads to the undesired "shopping" phenomenon: material suppliers try to find the laboratories who produce the highest absorption coefficient of their material [3]. The main difference between the laboratories that already fulfill the requirements of the standards, is expected to be found in the form and mainly the diffusivity of the different reverberation rooms.

According to the mentioned standards, the decaying sound field in the reverberation room shall be "sufficiently" diffuse. An "acceptable" diffusivity of a reverberation room is usually obtained with panel diffusers, as described in both standards.

The term "diffusitivity" is not specified in one of these standards. Generally a sound field is considered diffuse if the energy density is the uniform at all positions. This definition does not given a criterium when it is "sufficiently" diffuse either. Several investigations have been performed on this subject, but at the moment no consensus has been found.

The tests for diffusitivity in both standards seem to imply, that panel diffusers, rotating or not, are a necessity to gain sufficient diffusion, because only panel diffusors are incorporated in the test procedure for the facility. The ISO 354 A2 method to check for diffusivity is based on adding panel diffusors untill a maximum of absorption for an absorptive specimen is reached. Aiming for the maximum might not be the same as aiming for the right value.

Besides the fundamental problem that a reverberation room with a highly absorptive specimen of a certain size is not diffuse, these panel diffusers introduce a number of uncertainties. Due to all these panels, the acoustical behaviour in the room is much more complicated, and it's not easy to determine the real acoustical effective volume, nor the total boundary surface of the reverberation room. Either a panel shields a particular corner of the room, or it is a barrier in the room. It's therefore not easy to describe or predict the acoustical behavior of a reverberation room, while in the meantime we use this same room to measure a material constant which is used for the prediction of the acoustical behaviour of not yet build rooms.

But also in a much more practical sense these uncertainties are unwanted. It is clear that an uncertainty in volume results directly in uncertainties of the the measurement results of the total specimen absorption present in the room. The equivalent absorption area is calculated trough [1]:

$$A_T = A_2 - A_1 = 55.3V\left(\frac{1}{c_2T_2} - \frac{1}{c_1T_1}\right) - 4V\left(m_2 - m_1\right) \quad (1)$$

in which:

A is the equivalent sound area absorption in m²

V is the volume of the reverberation room in m³

c is the propagation speed of sound in m/s

m is the power attenuation coeffecient according to ISO 9613-1 in m^{-1}

sub 1 is the situation of the empty reverberation room

sub 2 is the situation of the reverberation room with speciman

sub T property of the specimen

The uncertainty in the volume is therefore proportional to the uncertainty in the absorption.

As a possibility to reduce the measurement uncertainties and to reduce the difference in measurement results between different laboratories, the possible use of volume diffusers instead of panel diffusers is investigated. The investigations have been performed with the aid of a 1:10 scale model of and the reverberation room itself at the Peutz laboratories. Also calculations with raytracing have been performed to investigate the geometric influence of panel diffusors. During this investigation it was tried to find a way how to quantify diffusivity.

The idea of volume diffusors is certainly not new. In the second Round Robin for measuring absorption in the reverberation room, the reverberation room in Braunschweig shows a relative small spread in the measurement results with different configurations. The different configurations are found in different areas of specimen and different number of panel diffusors. The Braunschweig reverberation room had (at the time) volume diffusors on two walls and the ceiling [4].

THE PEUTZ REVERBERATION ROOM

The Peutz reverberation room in the acoustic laboratory has a volume of 214 m³ and a surface boundary of 219 m². The opposite walls have an angle of 10º. The ceiling is under an angle as well, with a heigth of 5,0 to 5,88 m. According to the ISO 354 the diffusivity of the room is provided for with panel diffusors [5], see figure 1.

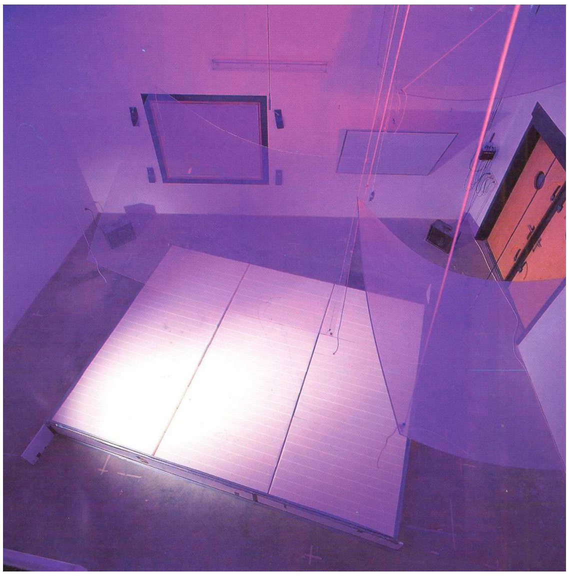


Figure 1. Reverberation Room Peutz, Mook

The reverberation time is measured with the interrupted noise method and is given in octave band values in for the empty reverberation room table 1.

Table 1. Reverberation time empty reverberation room Peutz

	125 Hz [s]	250 Hz [s]	500 Hz [s]	1000 Hz [s]	2000 Hz [s]	4000 Hz [s]
RT	9,84	7,98	8,20	6,81	4,65	2,61

THE 1:10 SCALE MODEL REVERBERATION ROOM

Description scale model and equipment used

The real Peutz reverberation room is duplicated with a 1:10 scale for the scale model reverberation room. The walls, floor and ceiling are made with 40 mm multiplex and 10 mm plexiglass. The wood is sanded and lacquered several times until the reverberation time in the room reached a maximum. Unfortanetly we were unable to realise the same (scaled) reverberation time as in the real Peutz reverberation room. The ISO 354 criteria are (allmost) fulfilled though for the empty reverberation room without diffusors, see figure 2 to for a comparison.

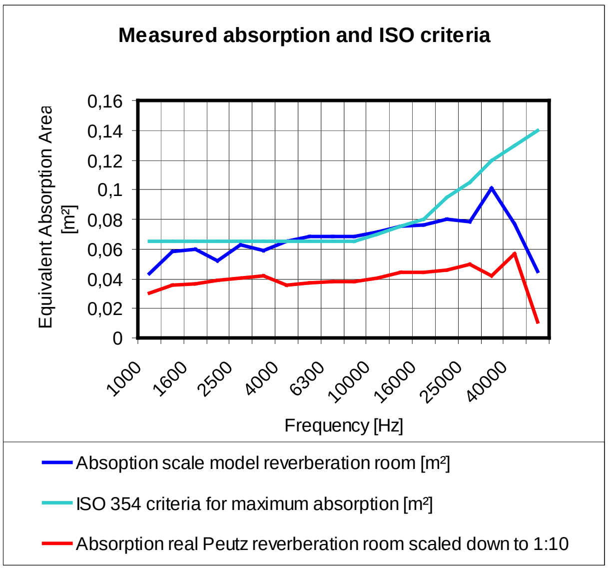


Figure 2. Measured absorption empty reverberation rooms 1:1 and 1: 10 (without diffusors) and ISO 354

Figures 10 and 11 at the end of the article present pictures of the scale model reverberation room.

The measurements in the 1:10 scale model are also performed with the interrupted noise method (white noise), but in the one third octave bands from 1000 Hz to 50000 Hz. The scale model is fitted with four loudspeakers (type BHT 1004/-08, am-plifier CEC AMP 31) and three microphone (type Esper K4, amplifier RME octamic), all in a fixed position.

All loudspeaker – microphone combinations are measured 4 times, a complete round of reverberation time measurements hase therefore 48 measurements per one third octave band.

The measurements are recorded with a sample rate of 192 kHz, after which the sample is downscaled (stretched) 10 times. The one third octave band reverberation times are then analysed using the "normal" Peutz analyzing software in the 10x downscaled frequency bands.

Description scale model diffusors

The measurements in the scale model are performed without added diffusing elements, with RVS (stainless steel) panel diffusors, with plastic panel diffusors and with volume diffusers. The RVS panel diffusors have a thickness of 1.0 mm and a weight of 7.8 kg/m². The used plastic panel diffusors are made from polystyrene and have a thickness of 0.5 mm and a weight of 0.5 kg/m². (We first made panel diffusors with way too much absorption). The panel diffusors are in the same location and have the same form as in the 1:1 reverberation room (see [5] for more information on that point). The volume diffusors are made of polystyrene, which are stiffened and got a weight increase with the aid of a triple bitumic layer, the resulting weight is 16.3 kg/m². Two different sphere radius' are used: 190 mm and 75 mm. The radius' of the volume diffusers perimeter are 10.85 and 7.45 mm respectively. The volume of the diffusors (14 m³) is distracted from the volume of the reverberation room.

The RVS panel diffusors

Because the first made plastic panel diffusors were an absorbing disaster, RVS was first chosen for the diffusing elements because of their weight in combination with the possibility to polish them very well. The reverberation time measurements of the RVS panel diffusors however were, due to a double decay, hard to interpret, and therefore led to a large spread in measurement results. These occured mainly at the lower frequencies, around 1250 Hz and 4000 Hz (scale model), especially in the empty reverberation room without specimen. The phenomenon is at this point not further investigated, it is not known if this is due to resonance of the panels or that it has a geometric ground. We chose to proceed the measurements also with new panel diffusors with much less weight and not to use the RVS panels. The much lighter plastic panel diffusors did not show this double decay.

With the use of panel diffusors, it might be the case that heavy weight panels lead to less accurate measurements results, while the ASTM only describes a minimum weight.

SCALE MODEL MEASUREMENTS

Overview measurements

The following samples were measured with the three diffusorconfigurations of the reverberation room scale model:

1) Empty reverberation room

2) Empty reverberation room with non-absorptive aluminium frame of 300x400 mm and a heigth of 15mm

3) Reverberation room with specimen:

   a) 10 mm mineral wool 0.118 m² in non-absorptive frame

   b) 15 mm foam, 0.118 m² in non-absorptive frame

   c) ~ 6 mm carpet, 0.118 m² in non-absorptive frame

   d) open "window", 0.108 m² (scale model placed in an absorbing environment: anechoic room)

Measurements with air

The air absorption in (1) is corrected for according to the ISO 9613-1:1993. At the really high frequencies the air absorption is very high. We preferred to perform the measurements with air instead of for instance nitrogen for practical reasons. To test the results with plain air, we compaired the measured absorption coefficient of 10mm mineral wool measured with air with the absorption coefficient measured with nitrogen. Above 31,500 Hz the measurement results with air differ too much from the measurement results with nitrogen, because the air absorption in this range is really high. As for the other frequency bands the comparison is well enough to justify the measurements with air, within the scope of this investigation.

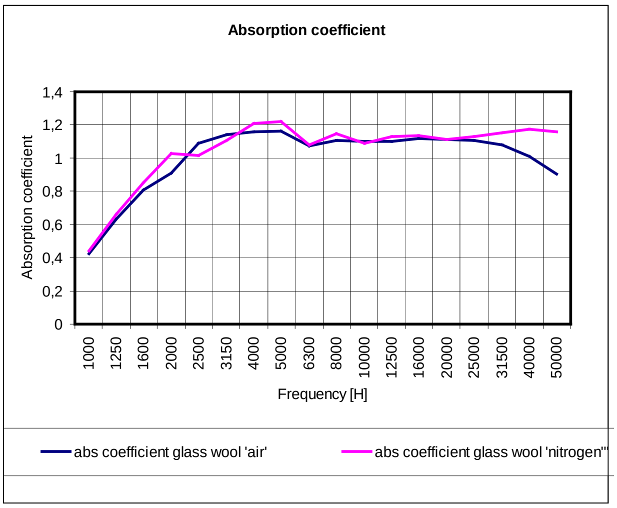


Figure 4. Comparison measured absorption coefficient reverberation room filled with air and with nitrogen

Calculation procedures measurement results

The reverberation times for the different source – microphone combinations are measured and analyzed seperately. From this, the standard deviation over all 48 RT's per measurement is calculated through:

$$StDev_{RT} = \left(\frac{1}{N-1} \sum_{i=1}^{N} \left(RT_i - < RT > \right)^2 \right)^{-\frac{1}{2}} \quad (2)$$

in which:

$StDev_{RT}$	Standard deviation RT in 1/3 octave band
N	Number of measurements over all mics and sources
RT_i	RT of *i*th measurment [s] in 1/3 octave band
<RT>	Average RT in 1/3 octave band

The standard deviation is not calculated per microphone position (then we should have had more microphone positions) but over all measurements.

In analogy with the ASTM 423, also the relative standard deviation for all frequency bands is calculated for all measurements by means of (3). In the ASTM not the RT but the decay rate is used to calculate the relative standard deviation. Also the results per microphone are averaged first. We took the relative standard deviation over all measurements.

$$R.StDev_{RT} = StDev_{RT} / < RT > \quad (3)$$

The equivalent absorption area (A_T) of the specimen is calculated from the difference between empty room with frame and room with specimen. The absorption of the open window is calculated from the difference between empty room and room with open window. Both according to (1). The absorption coefficient α_S is then $A_T/Area_S$.

The repeatability* of the absorption coefficient (with reference to the ISO 354:1985) is calculated through (4):

$$2.83\left(\begin{array}{l} 0.161V\dfrac{StDev_E}{\sqrt{N}}/\left(RT_E\right)^2 + \\ 0.161V\dfrac{StDev_S}{\sqrt{N}}/\left(RT_S\right)^2 + 4V\cdot 0.05\left|m_S - m_E\right| \end{array}\right)/A_S$$

In which E stands for "empty" and S for "specimen".

In this case, the specimen is not really taken out in placed back in the reverberation room. Instead, the repeatability calculation is used to specify a measure of the difference between the different source – microphone positions, therefore the '*'. The corrections for specimen volume and area, are judged as negligable for the calculation of the repeatability*.

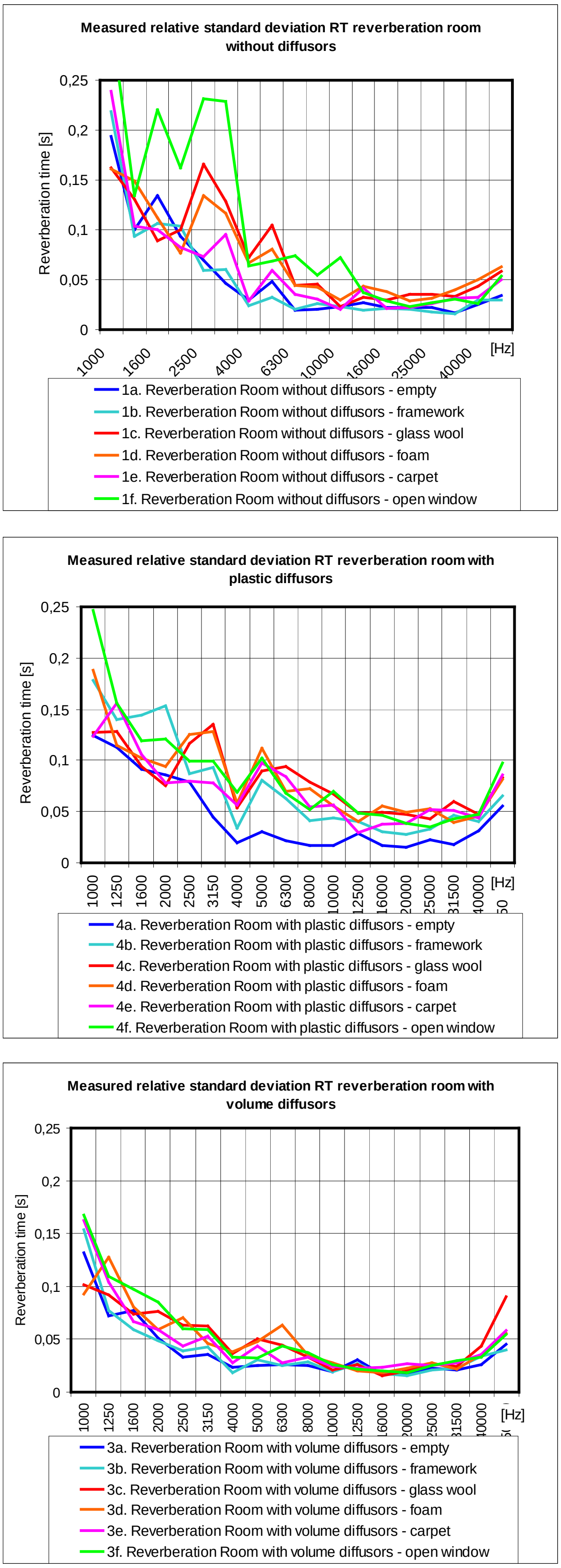
By taking the deviation between different source - microphone positions, information is gathered on the variation of measurement results throughout the room. Especially with absorptive specimen this provides information on the resulting diffusitivity.

Measurement results for different 'diffusivity' configurations

The measurement results for the relative standard deviation of the RT and the repeatability* of the absorption coefficient for the different specimen are presented in the figures 5 and 6. The three reverberation room configurations are:

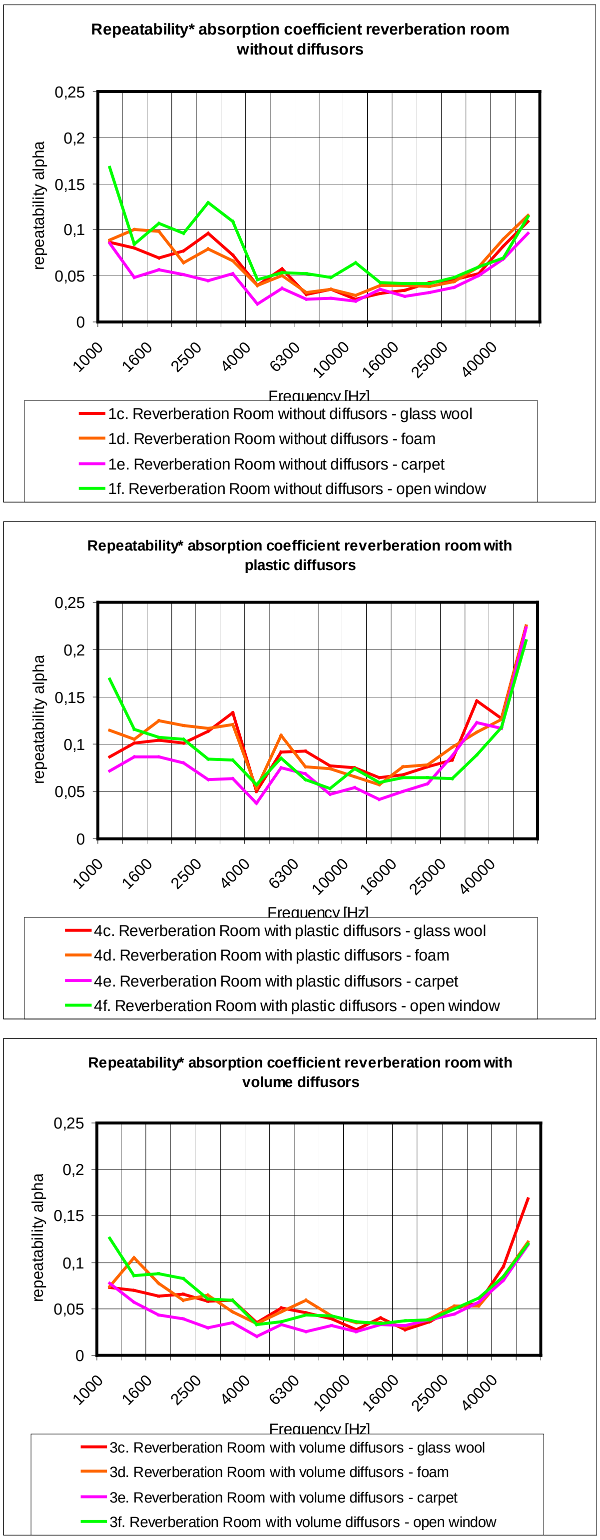
1. Without added diffusors
2. With plastic panel diffusors
3. With volume diffusors

The scale for the comparising graphs is equal.



Figures 5 a to c, from top to bottom the relative standard deviation in measured RT in the scale model reverberation room:

a) without diffusors
b) with plastic panel diffusors
c) with volume diffusors



Figures 6 a to c, from top to bottom the repeatability* for the measured absorption in the scale model reverberation room:
d) without diffusors
e) with plastic panel diffusors
f) with volume diffusors

From these graphs it is quite evident that in all cases the reverberation room with the volume diffusors has the lowest relative standard deviation in RT between measurements and the lowest repeatability* for the absorption coefficient.

Although the repeatability* with panel diffusors is not significantly larger than 0.1 (the required maximum value according to the ISO 354:1985), the repeatability* with the volume diffusors is about half the repeatability of the panel diffusors.

The maximum relative standard deviation for the variation in decay rate as mentioned in the ASTM (not required, attained from unpublished data) is about 0.02 for the variations in decay rate, over the different source microphone positions. With volume diffusors this value seems possible to realise for the RT at higher frequency range. The measured relative standard deviation of the RT measured with panel diffusors is, exept in the empty room, not lower than 0.05.

With the panel diffusors there is a clear difference between the empty room and the room with absorptive specimen with respect to the relative standard deviation of RT. With volume diffusors, the difference with and without absorbtive sample is significantly smaller.

In this scale model investigation, the volume diffusors seem to lead to a higher degree of diffusitivity than the panel diffusors. Furthermore, the relative standard deviation between the different source – microphone positions might be a good test for the qualification of the diffusitivity of a reverberation room, especially with highly absorptive specimen.

Possible further investigation might include the influence of specimen position, basic room shape, mic and source positions, and recommendations on the size and number of volume diffusors.

Measured absorption coefficients and open window

The measured absorption coefficients for the glass wool and foam specimen are well above 1, measured with panel diffusors as well as with volume diffusors. Besides the aim to decrease the difference in measured absorption coefficients between different laboratories, the real goal is of course to measure a material constant within a certain range of accuracy and precision.

The overall opinion seems to be, that the specimen area of 12 m² is large enough for the measurment results being in the neighbourhood of α_∞, the absorption coefficient for an infinite large sample of a locally reacting material (which excludes all kinds of panel absorbers). The edge and area effect as described in [6,7,8,9] is then thought to be most effective at mid-frequencies. Following this opinion this means that at least at the higher frequencies the absorption coefficient should not exceed 1.0.

In our measurements the absorption coefficients for glass wool or foam did not decrease above the mid-frequencies to converge to 1 (see figure 7). This leads to the question: "what is the maximum absorption of an absorptive sample of a certain size?" If we are aiming at 1.0 for the higher frequencies, but the maximum absorption of a certain sample size is higher, than we are not aiming for the material constant. More absorption than a real open window will not be realised, as all incomming sound energy escapes completely from the room. A scale model gives the oppertunity to measure the absorption of an open window, by placing the scale model in an anechoic room. The absorption coefficient of the open window appeared to be highest at the higher frequency range of the measurments, reaching a value of 1.16. At the lower frequency range, ths glass wool and the foam strangely exceed the absorption coefficient of the open window, maybe due to a larger length of sample size.

This is of course only a first but interesting excersize. More investigations on this point are necessary to draw conclusions.

The absorption coefficients of the different samples are also measured in the impedance tube. However, the calculation procedure to go from normal incidence to random incidence restricts the value of the absorption coefficient to 0.96 [7]. There's no point in relating our randon incidence measured values to the impedance tube measurement without investigating the side effects as edge and area effects.

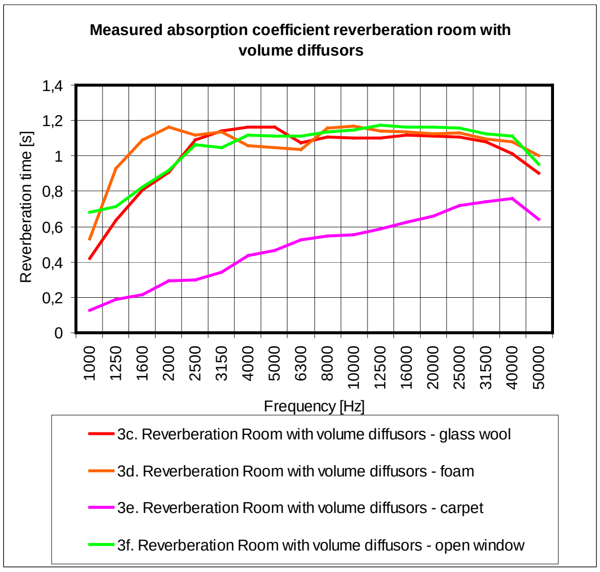


Figure 7. Measured absorption coefficients in scale model with volume diffusors

CALCULATIONS

With the use of a raytracing model (CATT acoustic V08.i) the influence of the different diffusive elements are investigated as well. In a raytracing program, the propagation of sound in air is modelled as rays with a certain amount of sound energy. The wave nature of sound, and therefor interference and deflection are not incorporated. Diffraction due to ending elements and surface roughness is modelled by a scattering coefficient. The interest in these calculations lies mainly in the geometric influence of the panel diffusors on the energy distribution.

The source positions are equal to the scale model reverberation room layout. But for the microphones 11 positions were chosen on a fixed layout, at least 2 m away from the boundary of the reverberation room and each other, and at least 1 m distance to the panel diffusors. The following configurations are calculated for the reverberation room without diffusors, with panel diffusors and volume diffusors, all as a copy of the Peutz reverberation room and scale model.

1. Without specimen
2. Mineral wool 100 mm in non-aborptive frame 11.8 m²
3. Idem but placed in the corner of the room
4. Open window in the wall, 10.8 m²

All the configurations are calculated three times, in order to gain sufficient data relative to the randomness that is incorperated in the energy scattering in raytracing.

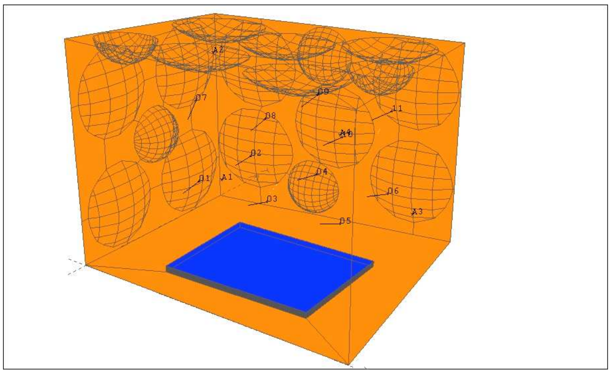


Figure 8. Overview calculation model with volume diffusors and sample

For all configurations the volume diffusors show the least spread in calculated results over all microphone – source combinations. Figure 9 gives an overview of the average relative standard deviation for all microphone – source combinations. The average is the arithmical average over the relative standard deviation of the four configurations

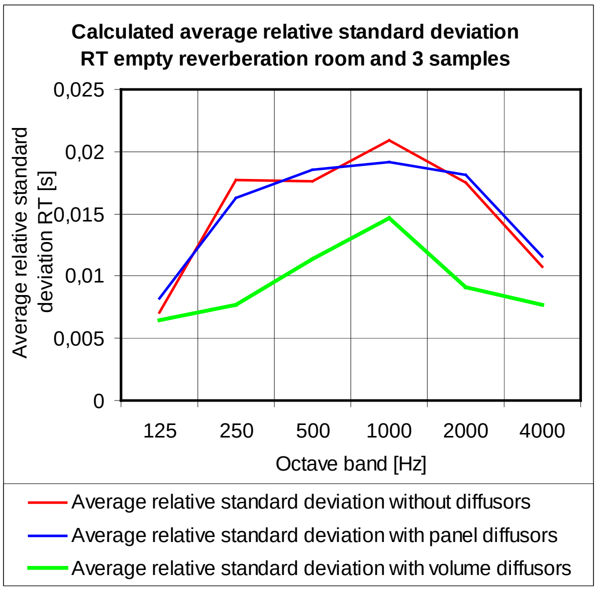


Figure 9. Calculation results of the average standard deviation over all configurations with and without specimen

CONCLUSIONS

From this investigation it can be concluded that volume diffusors can be used instead op panel diffusors to enhance the diffusitivity in a reverberation room. The first advantage is the fact that with volume diffusors the real volume and boundary area of the room are known, contrary to the case with panel diffusors, as required in the current standards [1,2].

From the calculation of the standard deviation of the reverberation time curves at different source and microphone positions in the reverberation room it is concluded that the use of volume diffusors results in a higher degree of diffusitivity than the use of panel diffusors. Furthermore it can be concluded that the relative standard deviation between the different source – microphone positions as indicated in the ASTM might be a good test for the qualification of the diffusitivity of a reverberation room, especially with highly absorptive specimen.

Further investigation might include the influence of basic room shape, the influence of specimen position and recommendations on the size and number of volume diffusors and number and positions of sources and microphones. Also how to quantify diffusivity remains a point for further investigation. Added to that, it is not only very interesting but also nessecery to investigate which value of the total random incidence absorption coefficent of a certain specimen of a certain size really ought to be true.

ACKNOWLEDGEMENTS

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Figures 10 and 11. Scale model reverberation room with panel diffusors and carpet specimen (top) and volume diffusors with foam specimen (bottom).

REFERENCES

1 ISO 354:2003(E)
2 ASTM C423 – 09a
3 M.L.S. Vercammen, "How to Improve the Accuracy of the Absorption Measurement in the Reverberation Chamber", *Nag-Daga proceedings* (2009)
4 C.W. Kosten, International Comparison Measurements in the Reverberation Room, *Acustica* (1960)
5 M.L.S. Vercammen , "The Effectiveness of Diffusors by Determing the Sound Absorption in the Reverberation Room", *Nag Journaal 137* (1997)
6 Ten Wolde, "Measurements on the edge-effect in Reverberation Rooms", 1967
7 A de Bruijn, "The Edge Effect of Sound Absorbing Materials Revisited", *Nag* 2007
8 Y. Kawai, "Estimation of the area effect of sound absorbant surfaces boundary integral equation", *Acoust. Sci & Tech*, 2005
9 T.W. Bartel, "Effect of absorber geometry on abs coefficients measured in rev room", *J. Acoust. Soc. Am. 69*, 1980