Measurement and use of scattering coefficients in room acoustic computer simulations

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ABSTRACT: Comparative studies on room acoustic computer simulations have indicated the importance of attributing scattering coefficients to the surfaces, in addition to absorption coefficients. This coefficient is related to the directional distribution of the sound energy reflected from a surface, and can be measured according to the standard ISO17497-1. The procedure adopted for measuring the scattering coefficients of two diffuser surfaces in a studio at the PTB (Physikalisch- Technische Bundesanstalt), Germany, is presented and commented in this paper. The measured coefficients were later used in a computer simulation of the studio, the results of which are compared to those obtained from measured room acoustic parameters performed by a team from the Institute of Technical Acoustics, Aachen University.

1. INTRODUCTION

The standard ISO-17497-1, published in May 2004, describes the standard procedure to measure scattering coefficients of surfaces in a reverberation room, using the method presented in [1]. These coefficients are useful as input data when performing room simulation using Ray-tracing or Ray-Tracing/Image sources hybrid methods. Previous studies [2,3] had already identified the importance of taking such data into account in the simulation (besides absorption coefficients, geometry and atmospheric conditions).
The method described in the referred ISO standard is similar to the well known method for measuring absorption coefficients in the reverberation chamber, as described in ISO 354, in which two measurements of reverberation time must be performed. The difference now is that two further measurements are necessary. Both can be performed while a turntable completes one cycle in the reverberation chamber, first with no test specimen placed on it, and after with the presence of the test specimen. Two main characteristics of the method for measuring scattering coefficients are that Impulse Responses are needed (and not only decay curves) and the test specimen shall have a circular shape. The reason for the latter is to prevent the results

from being affected by scattering caused by reflection from the edges (and not by the rough surface).
The question about the reliability of computer simulations is still not completely answered. In order to define more precisely the conditions under which the acoustic computer simulation gives reliable results, some works, reported in references [2,3,4], were performed in the past 10 years. These studies dealt with large amount of data, using results obtained from simulation and measurements performed by different groups. The present paper describes the contribution from the team of the Institute of Technical Acoustics (ITA), Aachen Technical University, for the most recent of these studies (Round Robin III).
In Round Robin III, a studio located at the Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany, was the test subject. The geometry of the studio, the atmospheric conditions, the absorption and scattering coefficients of the surfaces were distributed to all participants. They calculated several acoustic parameters (Reverberation Time, Early Decay Time, Clarity, Definition, Lateral Fraction and Inter Aural Cross Correlation Coefficient) with their own simulation programmes. The results were collected and compared with each other and with measurements performed by different teams. The ITA team participated measuring the scattering coefficients for the ceiling and wall diffuser (which were later distributed to the participants), performing acoustic simulation with its own simulation program (CAESAR, Computer Aided Evaluation Simulation and Auralization of Rooms, version 0.21, programmed by Oliver Schmitz) and performing measurements of the acoustic parameters in the studio. Next, some of these contributions are described, as well as a comparison between simulated and measured acoustic parameters. Some conclusions and comments are presented, but one should notice that these are only a partial view of the study. A much more complete analysis is to be published by the coordinator of Round Robin III (Dr.Ingolf Bork, at www.ptb.de/en/org/1/14/1401/_index.htm).

2. MEASUREMENT OF SCATTERING COEFFICIENTS

The measurements were performed at ITA in a scale model reverberation chamber with a volume of approximately 1 m^3. Since this reverberation chamber did not have means to substitute the air by another gas, measurements performed only up to 12.5 kHz were considered reliable. The experimental set-up is shown in [5].

2.1 Measuring samples with a non-circular shape

As noted in the introduction, the method for measuring random-incidence scattering coefficients, as described in ISO 17497-1, specifies that the samples shall have a circular shape. By the time the samples of the ceiling and wall diffusers were sent from the PTB to be measured at ITA (see Figure 1), this necessity was not clear, nor well understood. Because of that, or for practical reasons, the samples were constructed with a square and a rectangular shape (wall and ceiling diffuser, respectively). The problem of measuring samples with a non-circular shape is addressed to in [5, 6]. According to these references, one way to minimize the problem is to “hide” the edges, for instance, mounting the squared sample in a square recess of a base plate. The top plane of the sample placed flushes with the base plate. This was the solution found for measuring the samples sent by the PTB.

2.2 Results for the ceiling and wall diffusers of the studio at the PTB

The samples from the wall and ceiling diffusers of the studio at the PTB are shown in Figure 1. They were constructed with 1/50 and 1/10 scale factors, respectively.

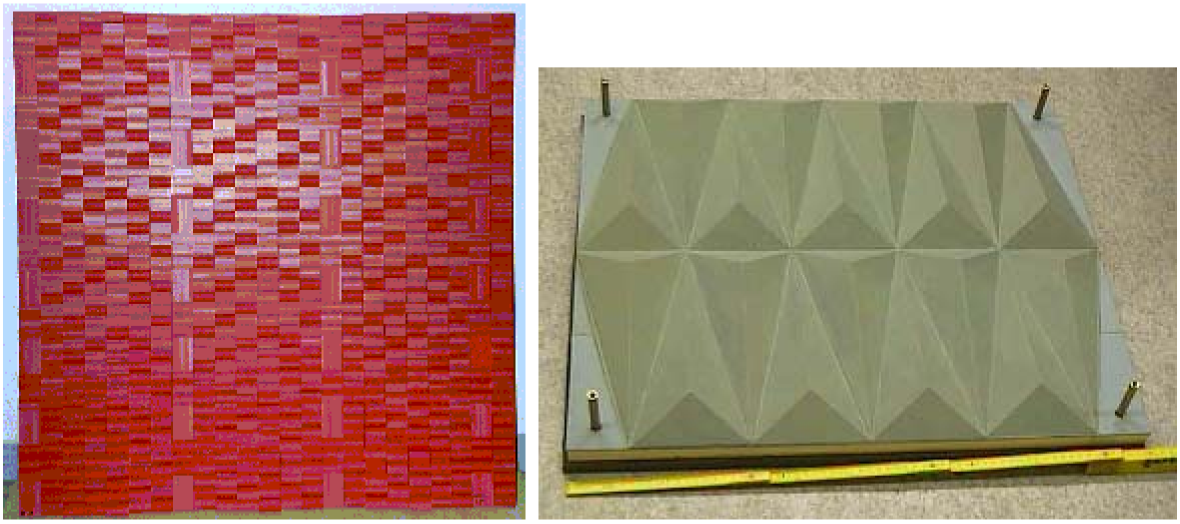

Figure 1 – *Samples from the wall (left) and ceiling diffuser (right) of the studio at the PTB. Picture at the right taken from www.ptb.de/en/org/1/17/173/roundrob3_2.htm.*

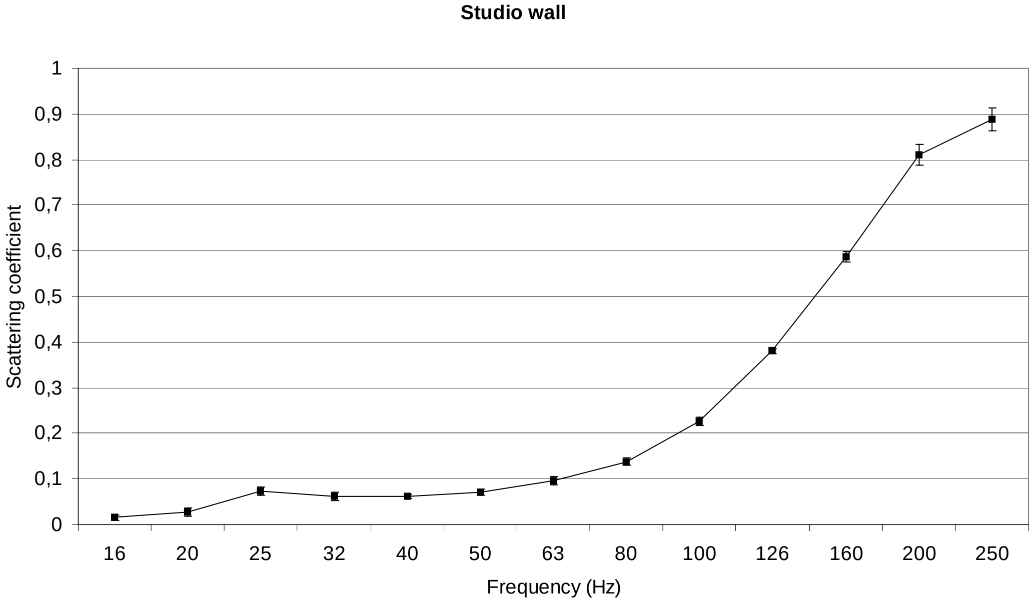

Figure 2 – *Measured random-incidence scattering coefficients of the diffuser on the wall of the studio at the PTB. The results are shown as a function of the full-scale frequency.*

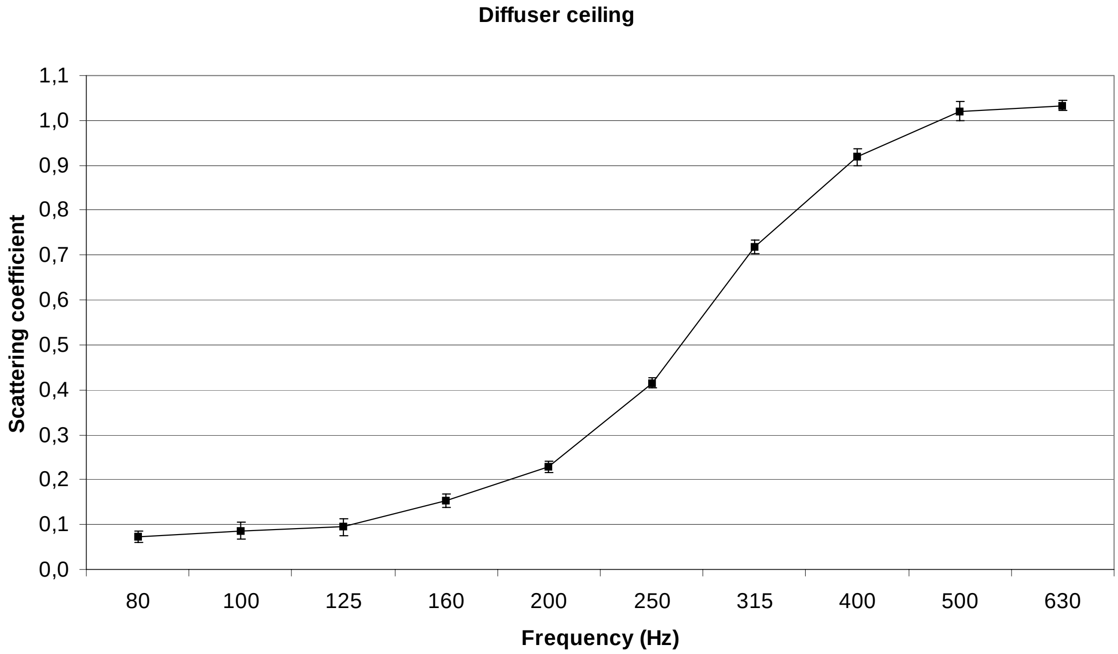

Figure 3 – *Measured random-incidence scattering coefficients of the diffuser on the ceiling of the studio at the PTB. The results are shown as a function of the full-scale frequency.*

Results for scattering coefficients measured for these samples as a function of the full-scale frequency are presented in Figure 2 and Figure 3. Because of the different scale factors of the samples, the results have different frequency ranges when transformed to full-scale frequency. The random-incidence scattering coefficients were obtained after filtering the impulse responses in 1/3 octave bands. Previous investigations have shown that the results obtained when filtering the impulse responses in 1/1 octave bands are approximately the same for the central frequencies. For the wall diffuser, because the scattering coefficient measured for the highest frequency band already shows a high value (0,9), the suggested scattering coefficient for the subsequent frequency bands is 1 for the computer simulations.
Values higher than 1 for the scattering coefficient were measured for the ceiling diffuser. This error may be attributed to reflections from the edges that could not be completely hidden, in this case, because of an imperfection of the used base plate.

3. COMPUTER SIMULATION

3.1 The test room (PTB studio)

The test room is a studio at the PTB, with a volume of approximately 360 m^3 (see Figure 4). The larger wall on the left side of the figure (the one with no windows) has a sound diffuser covering it completely. Another sound diffuser covers the elevated area on the ceiling.

The sound diffuser on the wall also acts as a low-frequency sound absorber, given its construction (large wood-panelled boxes). On the back and right side wall (the one with three windows) there are curtains which may be closed and opened, in order to create two acoustical situations. The representation of the room shown in Figure 4 does not show the details of the sound diffusers and this is actually the model used in the simulations, which did not consider these details. This fact was compensated, in these cases, through the use of the measured random-incidence scattering coefficients of these diffusers. One important characteristic of this studio is that there are no significant areas which provide diffraction of the sound, such as seating areas. Its dimensions, however, can present difficulties for the computer simulations at lower frequencies.

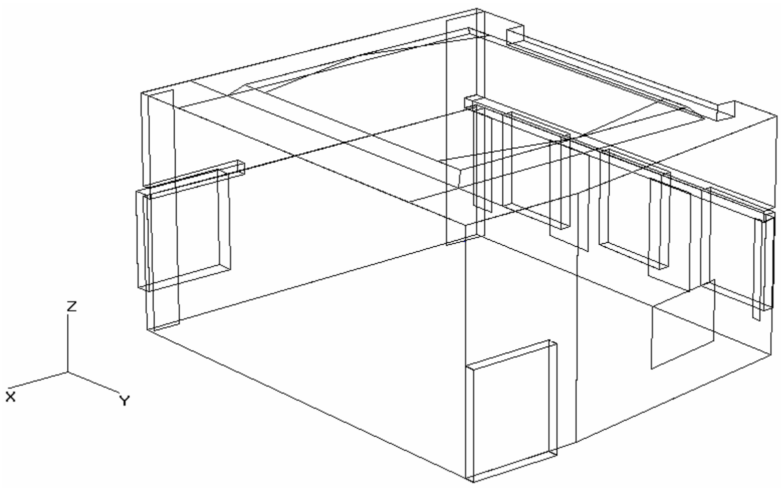

Figure 4 – *Representation of the studio at the PTB, used for measurements and simulations for the third round robin on room acoustical computer simulations.*

3.2 Conditions of simulations and comparison of parameters obtained through measurements and simulations

The simulations were performed with CAESAR. The geometrical model used in the simulations corresponds to the one shown in Figure 4 and the used material properties were those given by the PTB for the second phase Round Robin III. Most of the given absorption coefficients were taken from a database of measured absorption coefficients, but some of them were estimated by the coordinator of the project (see www.ptb.de/en/org/1/17/173/roundrob3_1.htm). The scattering coefficients for all surfaces were also estimated, except for the elevated area on the ceiling and for the left wall in Figure 4. These were measured as described in section 2.

In the program it is possible to set the environmental conditions, number of rays, order of reflections, diameter of the receiver cell, time resolution of the echogram, length of the echogram and directional characteristics of source and receiver. The directional characteristics were left to be omni-directional and the other parameters were set as presented in Table 1.

Table 1 – *Settings of parameters for the computer simulations of the room at the PTB.*

Parameter	Setting
Speed of sound (m/s)	343
Relative air humidity (%)	50
Number of rays	10000
Order of reflections	Automatic
Diameter of the receiver (m)	0,5
Time resolution (1/s)	500
Length of the echogram (s)	1

The simulations were performed for the two source and three receiver positions, as pre-determined by the coordinator of the project, for the curtains opened and closed. With the equipment used, a PC Pentium III, 650 MHz, 128 RAM, they lasted approximately fifty minutes for each source position.

4. COMPARISON WITH MEASURED RESULTS

Measurements of acoustic parameters were performed by the ITA team led by Dr.Gottfried Behler. These were performed using the loudspeaker system described in [7]. The results obtained from simulations were compared to the measurements of EDT, T30, C80, D50 and LF, for a certain source and receiver combination. Figure 5 presents results for T30 as a function of frequency. Although many combinations of source a receiver positions were taken, the results plotted in Figure 5 are typical.
In the figure, the error bars do not indicate the measurement uncertainties, but the subjective limens (or noticeable difference) for the room acoustical parameter in question. So, even though calculated values do not fall within the interval indicated by the error bar, the result still may be considered to be reasonable. Noticeable is the fact that large deviations almost always occur at the frequency band of 125 Hz, a tendency which is also observed for the frequency band of 250 Hz. For frequencies equal or larger than 1000 Hz, the differences between measured and calculated values are smaller and the values fall often within the interval indicating the subjective limens (error bars). The differences at lower frequencies can be explained by the fact that the uncertainties in the measurements are larger in these frequencies. Also, specially for rooms of this size, the geometrical acoustics theory, which is the basis for the ray-tracing and image-source methods, is not able to represent the physical phenomena.

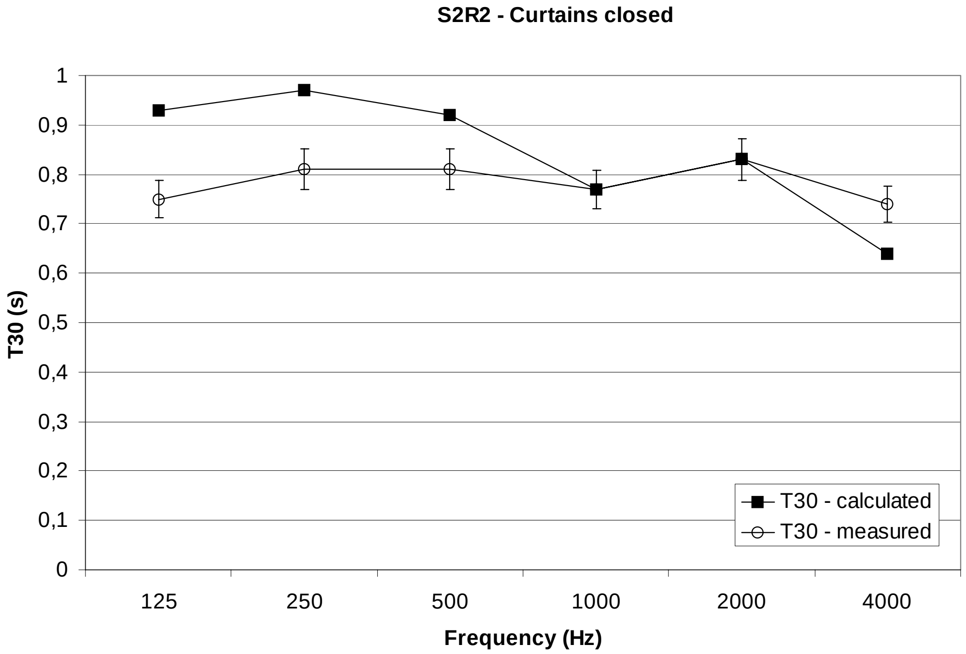

Figure 5 – *Reverberation Time measured and simulated at position S2R2, with curtains closed. The error bars indicate the room acoustical subjective limens for this parameter.*

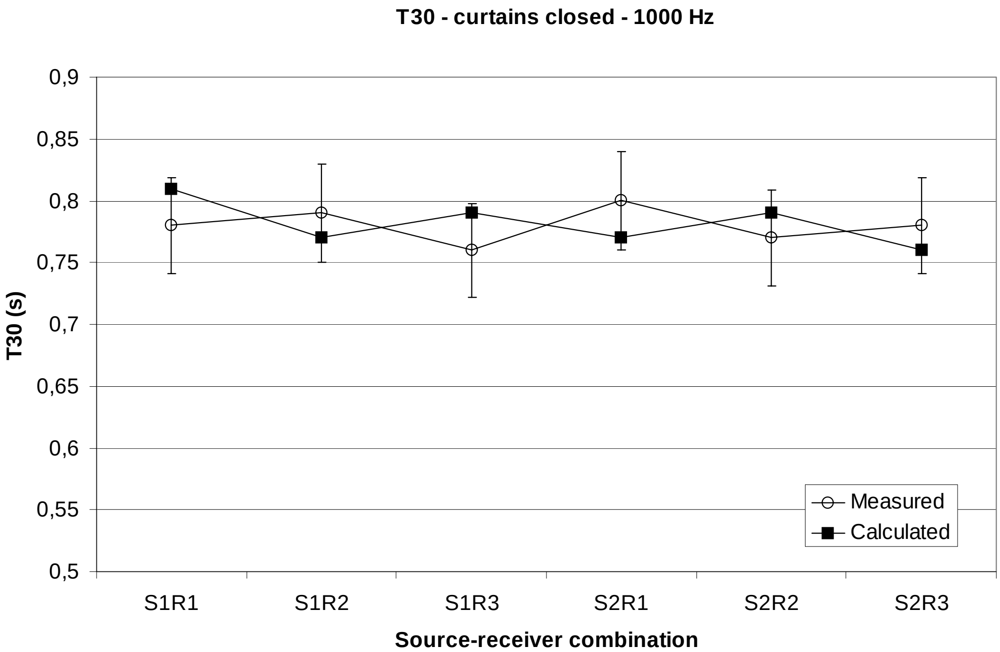

Figure 6 – *Reverberation time (T30), measured and calculated for all source-position combinations at 1000 Hz, with the curtains closed. The error bars indicate the room acoustical subjective limens for this parameter.*

Figure 6 presents the parameters T30 at 1000 Hz, for all source-position combinations. If one observes the spatial distribution of the results, measured and calculated parameters compare very well. A tendency of the differences between measured and calculated parameters to be smaller for the situation when the curtains are closed was also noticeable. No direct explanation, however, can be given for this fact.

From the case studied in this paper, one can have an idea about the ability of a computer program to give coherent results with measured room acoustical parameters. Weaknesses of the measurement technique and of the geometrical acoustics theory can be observed in the lower frequency bands. At higher frequencies, the agreement between measured and calculated results can be considered very good. This good agreement show that the simulations can be effective, provided the input data regarding the acoustical characteristics of the surface materials (absorption and scattering coefficients) are properly given (measured).

ACKNOWLEDGEMENTS

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