# Investigations on real-scale experiments for the measurement of the ISO scattering coefficient in the reverberation room

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Lieven De Geetere, Gerrit Vermeir
K.U.Leuven, Laboratory for Building Physics and Laboratory for Acoustics
Celestijnenlaan 200D, B-3001 Heverlee, Belgium
Tel. +32 16 327176
Fax. +32 16 327984
lieven.degeetere@bwk.kuleuven.ac.be
gerrit.vermeir@bwk.kuleuven.ac.be

## ABSTRACT

An ISO working group is preparing a standard for measuring the random-incidence scattering coefficient in the reverberation room [1]. This paper comments on the experiments with the real-scale application of this technique to a sine-shaped surface, a one-dimensional and a two-dimensional diffuser and discusses on several parameters that are related to the measurement quality and reliability.

## I. INTRODUCTION

The proposed ISO measurement technique on measuring the random incidence scattering coefficient in a reverberation room consists of the recording of a series of impulse responses for different angle positions of a circular test sample on a centrally rotating base plate. By synchronous averaging of these impulse responses, a 'virtual' impulse response is obtained that relates only to the specular component of the reflected energy. In case of a diffusing sample the averaged decay will be faster than for each of the single impulse responses [2]. The reverberation time must be obtained from impulse response measurements in four different situations (Table 1). From the differences in reverberation time a scattering coefficient is obtained.

## II. MEASUREMENT PROCEDURE

In numerous experiments, the influence of many measurement parameters has been studied. This experience has led to a final way to implement the method, which will be described next. Later we will discuss some of these choices more in detail.

All measurements are made in a reverberation room with a volume of 197 m³. Diffuser panels are removed. Temperature and relative humidity are continuously monitored. The 3 m diameter base plate is made of multiplex wood, is mounted on wheels (air gap 6.5 cm), has a thickness of 2.1 cm and is driven by an AC-motor at its edge. The source is a high power active speaker. The receiver is a one-inch condenser microphone with random incidence corrector. Two source and three receiver positions lead to six source-microphone combinations. The measurement signal is a 20 s logarithmic sweep from 40 Hz to 18 kHz. For the measurement of $T_3$ and $T_4$, the turntable is continuously rotating with a total revolution time of 9 min., during which 27 sweep responses are averaged in real-time. Reverberation times are estimated from –5 dB to –20 dB, using a linear best fit to the uncompensated Schroeder curves, obtained after filtering the impulse responses in third-octave bands.

| | Test sample | Turntable |
|---|---|---|
| $T_1$ | Not present | Fixed |
| $T_2$ | Present | Fixed |
| $T_3$ | Not present | Rotating |
| $T_4$ | Present | Rotating |

**Table 1.** The four measurement situations

First $T_3$ and $T_1$ are measured for the 6 source-receiver combinations, hereby opening and closing the door of the reverberation room for moving the source or receiver. After putting the test sample on the base plate, at least one hour is needed for the room to stabilise. Then $T_4$ and $T_2$ are measured in the same way. For each source-receiver combination, one scattering coefficient is obtained. The spatial spread of this coefficient is a good estimate for the quality of the measurement. The total time for measuring $T_4$ and $T_2$ for the six source-receiver combinations is approximately 1 hour and 30 minutes (and is the same for measuring $T_3$ and $T_1$).

## III. MEASUREMENT RESULTS

### III.1. Base Plate

To check the quality of the measurement arrangement, the scattering coefficient of the base plate is measured (Fig. 1). This value is limited by maximum values, specified in the draft standard. Also shown is its random incidence absorption coefficient, measured according to ISO 354 (1985). It must be noted that the area of the base plate (7.07 m²) does not meet the minimum required sample size of 10 m².

### III.2. Sine Profile, 1D and 2D Diffusers

The sine profile is made of fibre cement elements, with a more or less sine shaped profile. Its wavelength is 17.7 cm, thickness 6.5 mm and its maximum depth is 5.1 cm (fig. 2a). The 1D diffuser (fig. 2b) and 2D diffuser (fig. 2c) are constructed laying wooden blocks with dimensions 21.2 x 21.2 x 6.0 cm³ directly on the base plate.

Their measured scattering coefficients are shown in figure 3. An indication of the spatial spread of this coefficient for e.g. the 2D diffuser can be found in figure 6, in which the ISO absorption coefficient and the ISO specular absorption coefficient of this diffuser are also shown.

## IV. GUIDELINES ON THE REAL SCALE APPLICATION

### IV.1. Diffusers In Reverberation Room

Diffuser panels in the reverberation room led to less linear Schroeder curves at low frequencies. For this reason, further measurements were made without diffuser panels.

### IV.2. Manual Step, Motorised Step Or Motorised Continuous Rotation Measurements?

Three measurement procedures are possible for rotating the base plate: manually rotating over $\Delta\theta$ by entering the room, motorised rotating over $\Delta\theta$ or motorised continuous rotating while

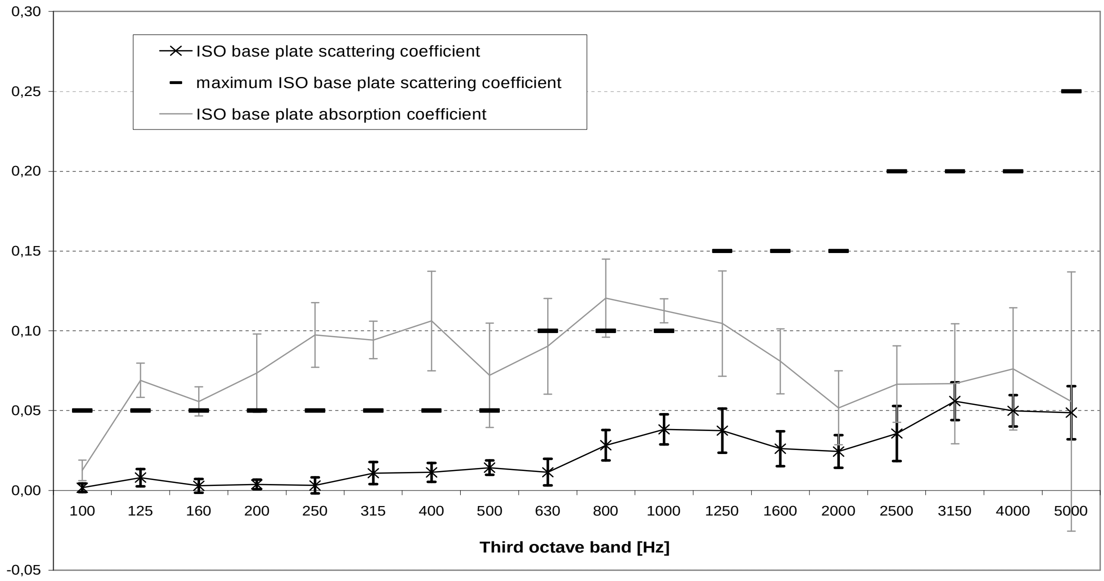


**Figure 1.** Absorption and diffusion properties of the base plate. The error bars indicate the standard deviation for the 6 source-receiver combinations.

**Figure 2**: (a) Sine profile, (b) 1D-diffuser and (c) 2D-diffuser mounted in the reverberation room. The black box at the bottom right is the motor.

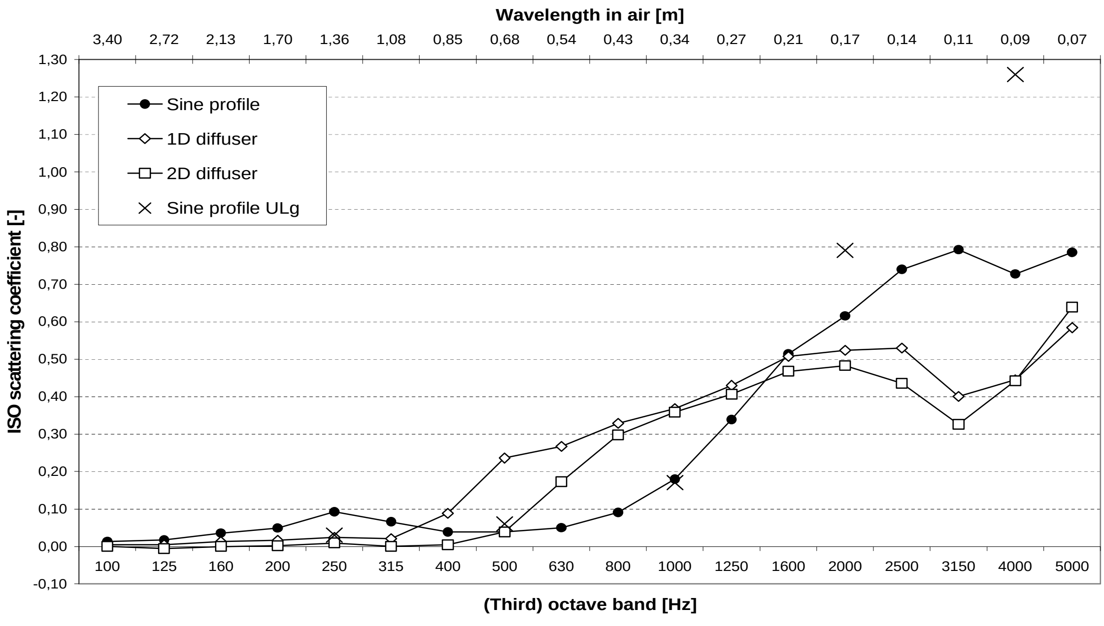


**Figure 3.** Measured ISO scattering coefficients of the 3 diffuser types.

measuring. Using these three procedures, the scattering coefficient of the base plate has been measured for one fixed source-receiver combination, according to the ISO draft [1] (fig. 4).

Lowest values are obtained using continuous measurements. The values for the step measurements exceed the maximum values, specified in the ISO draft [2] at high frequencies. Because the correct early slope to the Schroeder curve for the measurement of $T_4$ must be measured, a maximum $\Delta\theta$ of 6° is allowed. We chose $\Delta\theta$ equal to 5°, which means 72 measurements and a total measuring time of more than 1 hour for the step-measurements. On the other hand, the continuous measurement took 9 minutes to complete. Too long measuring times lead to overestimated scattering coefficients at higher frequencies.

IV.3. Waiting After Closing The Door

For changing measurement positions for source and microphone, the door of the reverberation room needs to be opened. In order to avoid measurement errors due to air movements or temperature changes, the ISO draft [1] suggests waiting 15 minutes after closing the door. Comparing measured scattering coefficients for the sine profile with and without respecting this waiting time (fig. 5), reveals that this waiting seems to be less important: all three measured scattering coefficients are within the standard deviation of the two others.

IV.4. Further Considerations On Total Measurement Time

For step measurements, it is recommended to limit the total measurement time (for one source-receiver combination) to one hour. High turntable speeds and short sequence lengths are favourable, however, the output-sequence must be longer than half the longest expected reverberation time. When measuring more than 60 measurement angles, reducing the total measuring time becomes more important than increasing the number of measuring angles.

When measuring $T_3$ or $T_4$ for all source-receiver combinations, it is important to ensure that the room temperature and relative humidity don't change more than 0.1°C and 1 % respectively. If these requirements can't be met, the different source-receiver combinations have to be treated separately in the calculation of the room-averaged scattering coefficient.

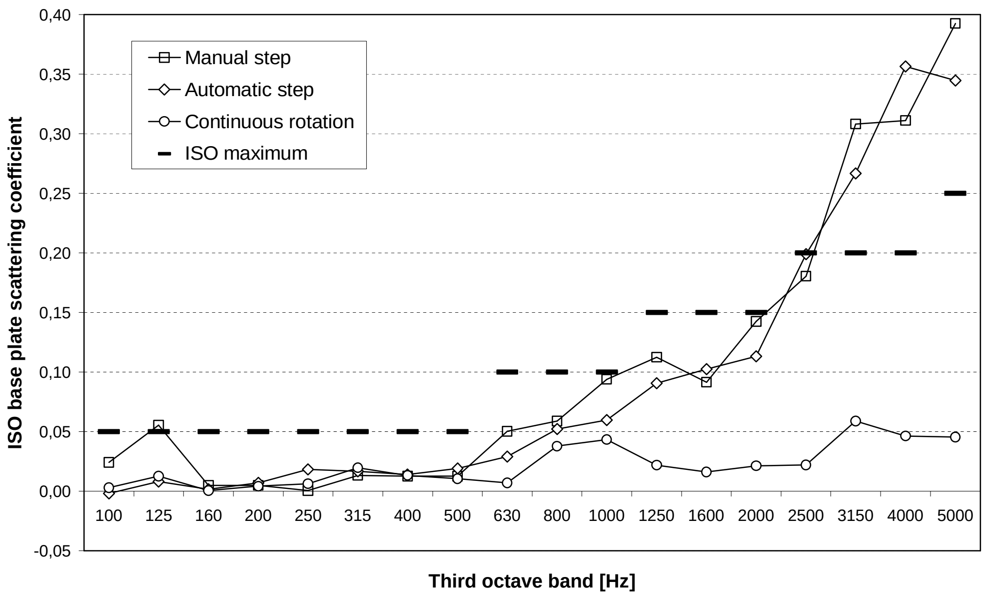


**Figure 4.** The scattering coefficient of the base plate, measured following three different procedures.


**Figure 5**: Scattering coefficient for the sine profile, with and without waiting after closing the door during the measurement of $T_2$ and $T_4$.

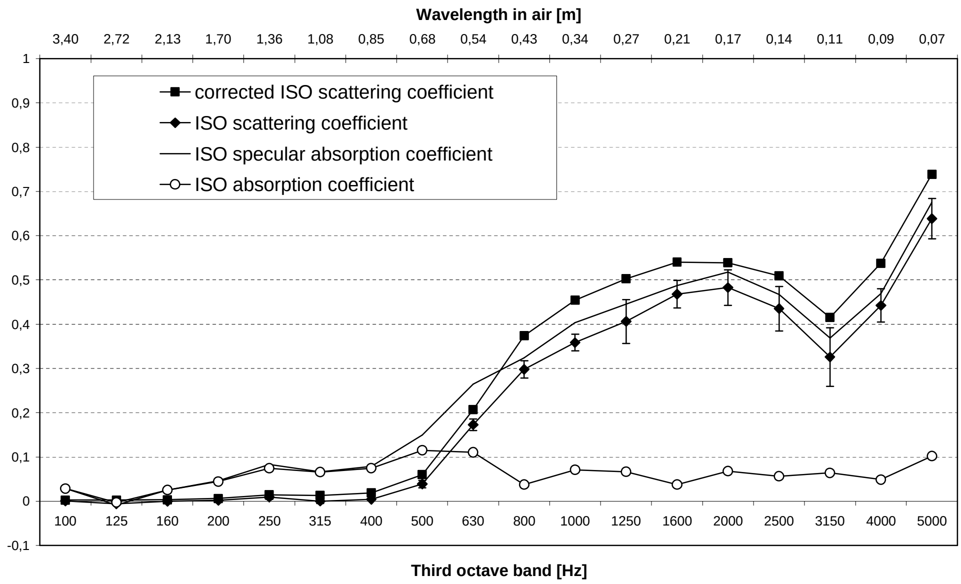


**Figure 6.** Corrected scattering coefficient of the 2D-diffuser. The error bars indicate the standard deviation for the 6 source-receiver combinations.

## V. CORRECTED ISO SCATTERING COEFFICIENT

The ISO draft [1] checks for the scattering coefficient of the base plate but neglects it for the calculation of the scattering coefficient of the test sample. The absorption of the base plate is assumed zero as well. Since the absorption of the base plate is in the same order of magnitude as the (extra) absorption of the samples (compare e.g. fig. 1 with fig. 6), this assumption might underestimate the measured scattering coefficient significantly. It can be shown that, by doing one more measurement ($T_0$, the RT of the empty room), the scattering coefficient can be measured more precisely, taking into account the absorption and scattering of the base plate. This leads to a corrected calculation of the scattering coefficient.

$$s_{corrected} \equiv \frac{a_{spec} - a_s}{1 - a_s} = \frac{a_{spec,ISO} - a_{s,ISO} + s_{base,ISO}}{1 - a_{s,ISO} - a_{s,base}}$$

Here, $a_s$ is the random incidence absorption coefficient of the test sample and $a_{spec}$ is its apparent absorption coefficient, when the losses include the scattered as well as the absorbed acoustic energy. The influence of this correction on e.g. the 2D diffuser, can be seen in figure 6. In general, the corrected scattering coefficients are slightly higher than the ISO scattering coefficients.

## VI. CONCLUSIONS

Real scale measurements of random incidence scattering coefficients are very sensitive to reverberation room conditions. Special attention must be drawn to temperature and relative humidity stability. Most reliable scattering coefficients are obtained using short total measurement times, preferably using motorised continuous rotation measurements. Best results were obtained using logarithmic sweeps. Waiting after closing the door of the reverberation room between two different source-receiver combinations, seemed to be less important than expected.

Finally, it is shown that the base plate absorption and diffraction can be included in the calculation of the sample scattering coefficient.

## VII. FUTURE INVESTIGATIONS

The applicability and reliability of the measurement method cannot be proved until similar test samples are measured in different reverberation rooms using different measurement set-ups. Therefore, a similar test set-up has been constructed in the reverberation room of the University of Liège (ULg). Comparison measurements are going on. A first result for the sine profile is shown in figure 3 (average of two motorised step measurements for one source-receiver combination, $\Delta\theta$ equal to 6°, total measurement time for $T_2$ and $T_4$ about 80 minutes, results displayed in octave bands).

Further attention must be paid to the edge effect, which introduces apparent scattering. The influence of sample size and shape, and how to (possibly) compensate for this edge diffraction, are to be studied more in detail. Perhaps scale models are more suitable to study these effects.

Of course, comparisons with analytical or numerical models could be interesting to study these effects as well. First results will be presented.

## REFERENCES


1. ISO/DIS 17497-1, *Acoustics – Measurement of the sound scattering properties of surfaces, Part 1: Measurement of the random-incidence scattering coefficient in a reverberation room* (2000)
2. M. Vorländer, E. Mommertz, *Definition and measurement of random-incidence scattering coefficients,* Applied Acoustics **60**, 187-189 (2000)