Laboratory facilities for sound transmission measurements – validation by measurement and simulation methods

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ABSTRACT

Test facilities for sound transmission measurements have to be designed according specific international standards. The experience, e.g. of past round robin tests showed, that in spite of the specifications within these standards some differences in the sound transmission measurement occur within different facilities. Some of these differences are related to possible varieties of the room configuration, others may be caused by different mounting conditions of the test specimens, but there are also some effects that are not fully investigated and descripted within these standards.

This paper deals with the validation of such test facilities by measurement and simulation. The combination of these techniques can be helpful to find the right measures for a good diffusity, avoid unwanted resonances and find the right places for diffusors, microphone and loudspeaker positions in a virtual way before realization. Thus, a step by step validation, combining simulation and measurement can help to get the necessary knowledge for a qualified room and equipment design, as it is shown by an example.

Keywords: Laboratory test facility, Sound transmission, Finite element simulation
I-INCE Classification of Subjects Numbers: 73, 73.3, 73.5

1. INTRODUCTION

The sound insulation of building elements (such as components and materials, building elements, technical elements or sound insulation improvement systems) is determined in test benches and laboratory test facilities in accordance with specific international standards prescribed by ISO (International Organization for Standardization). In addition to requirements for the measurement method, there are also detailed requirements for the design of test facilities and equipment (1, 2). To verify these requirements, qualification procedures are defined in international standards. These verifications are carried out during commissioning a new test facility and must be repeated at regular intervals to ensure that there are no issues with the equipment and the test facility.

1.1 Laboratory test facilities for airborne sound insulation measurements

The laboratory test facility shall consist of two adjacent reverberant rooms with a test opening between them, in which the test element is inserted. The reverberation rooms have to fulfil many different requirements. In addition to guidelines concerning the volume, the dimensions as well as the separation of the rooms and the materials used, there are limitations for temperature and humidity, the background noise level in the receiving room, the reverberation time, the structure-borne sound reverberation time and the scattering or fluctuation of the sound pressure levels in the rooms.

When determining the airborne sound insulation, there are also detailed requirements for the airborne sound field that is generated in the source room. This airborne sound field is influenced primarily by the type and position of the sound source and, if possible, should represent a diffuse sound field. Requirements on the sound source with respect to the speaker position and directivity, the direct field at the surface of the test specimen, as well as the distances between the speaker and the room boundaries are also specified in the standards.

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2. Qualification procedure for loudspeaker positions

In this paper a laboratory test bench for the determination of airborne sound insulation with a small test opening having the dimensions of 1250 mm in width and 1500 mm in height (as recommended by international standards for the determination of airborne sound insulation of windows) is treated. Particular attention is put on the qualifying procedure for loudspeaker positions as well as on simulations for the estimation and planning of acoustic modifications of the test chamber to meet the relevant criteria, since the qualification procedure and the associated measurements are quite complex. The test procedure for loudspeaker positions with regard to microphone positions as well as the test procedure for the use of continuously moving loudspeakers is not discussed in this paper.

A dodecahedron loudspeaker with undirected radiation is used as sound source. This loudspeaker with omnidirectional characteristics satisfies the requirements of a single source. The used loudspeaker Norsonic type 270H and its directivity pattern is shown in Figure 1.

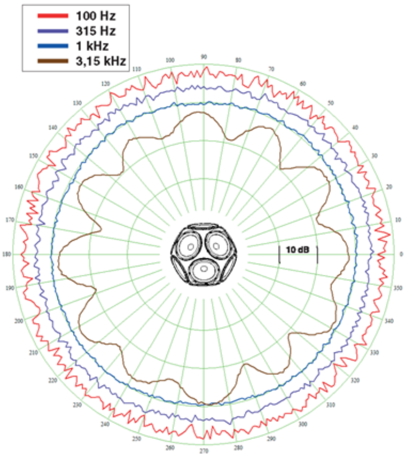

Figure 1 – Dodecahedron loudspeaker Norsonic type 270H and its directivity pattern (3). The graph shows the respons for a sinusoidal signal at 100 Hz, 315 Hz 1 kHz and 3.15 Hz in the horizontal plane through the center of the loudspeaker.

The suitability of source positions shall be tested with regard to excitation of room modes in order to find positions that lead to results of sound insulation measurement which are as close as possible to the mean value of a large number of positions equally distributed around the room. The number of loudspeaker positions used and a set of optimal positions are found by the following procedure.

At first the level difference between the source room and the receiving room as specified in international standards has to be determined. For this purpose a number of m loudspeaker positions which is greater than

$$m = 152 / V^{2/3} \tag{1}$$

where V is the source room volume in cubic metres must be used. The spatial dimensions including the volume of the source room are shown in Table 1.

Table 1 – Spatial data of the source room

Spatial dimensions	
Length	5.73 m
Width	3.49 m
Height	3.73 m
Volume	74.6 m³

In this example the level difference shall be determined with nine loudspeaker positions. Table 2 shows the minimum clearances the loudspeaker positions must meet. Measurement results on small test elements with relative low sound insulation have been found to be particularly sensitive to variations in the sound source positions. For this reason the test element used at the determination of the sound difference shall not exceed the values for the sound reduction index shown in Table 3. Since in this laboratory test facility mainly windows are examined, the test procedure could also be carried out on a test sample which is representative of those normally used. However, as windows can have different properties and a different sound insulation, and due to the more meaningful results and the ease of simulatability a homogeneous gypsum fibreboard (board thickness = 12.5 mm, density = 1150 kg/m³) was used. The sound pressure level in the source and receiving room was thereby measured with a continuously moving microphone according to international standards and from this the level differences D for each one-third octave band with a center frequency from 100 Hz to 315 Hz were determined. The level difference D of the nine loudspeaker positions shown in Figure 2 are given in Table 4.

Table 2 – Minimum clearances of the speaker positions

Minimum distance between the loudspeaker and the …	
Microphone	1.0 m
Other loudspeaker	0.7 m
Wall	0.7 m
Floor	0.7 m

Table 3 – Recommended sound reduction index R for the test element

Frequency Hz	Sound reduction index R dB
100	27
125	28
160	29
200	30
250	31
315	32

Table 4 – Level differences of the nine loudspeaker positions LP

Frequency Hz	LP1 dB	LP2 dB	LP3 dB	LP4 dB	LP5 dB	LP6 dB	LP7 dB	LP8 dB	LP9 dB
100	26.4	23.7	26.8	23.4	26.2	27.9	24.4	24.0	28.2
125	30.4	33.1	34.6	32.9	33.0	31.0	34.0	33.1	31.8
160	34.2	35.4	33.6	33.1	33.8	32.2	35.2	33.8	32.0
200	32.5	33.2	32.3	30.5	33.9	32.5	33.0	31.6	33.1
250	31.8	32.0	32.0	32.3	34.3	32.4	33.9	32.1	32.3
315	32.3	35.0	32.9	33.6	32.1	31.6	31.9	32.7	33.9

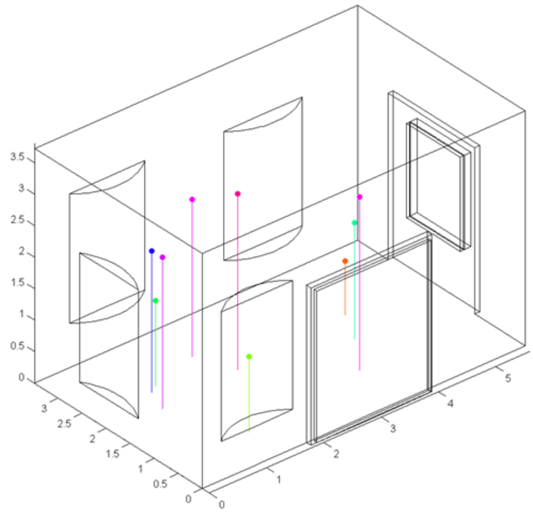

Figure 2 – Loudspeaker positions used in the qualification procedure

Further parameters are the standard deviation s_i of the differences in levels and the prescribed maximum standard deviation σ_i of the mean value for N loudspeaker positions (Table 5)

$$s_i = \left[\frac{1}{m-1} \sum_{j=1}^{m} (D_{ij} - \mu_i)^2 \right]^{1/2} \tag{2}$$

where

D_{ij} is the level difference of the jth loudspeaker position at the ith one-third octave band;
μ_i is the arithmetic mean of the differences in levels in the ith position one-third octave band;
m is the number of loudspeaker positions examined.

Table 5 – Standard deviation and prescribed maximum standard deviation

Frequency Hz	Standard deviation s_i	Prescribed maximum standard deviation σ_i
100	1.8	1.4
125	1.4	1.2
160	1.2	1.0
200	1.0	0.8
250	0.9	0.8
315	1.1	0.8

The number, N, of loudspeaker positions used in practice is determined by the following conditions

$$N \geq 2 \tag{3}$$

$$N \geq (s_i / \sigma_i)^2 \tag{4}$$

$$N \geq \left(\sum_i s_i / 4.8 \text{ dB} \right)^2 \tag{5}$$

In the investigated laboratory test facility N is at most 2 and therefore an excitation with two speaker positions in practice is sufficient.

3. Simulation

If during this initial validation the requirements of the standard are not met or the results are not practicable, the acoustic behavior of the room has to be changed. After these adjustments the suitability of the room needs to be checked with a re-measurement. These empirical measurements for verification and evaluation of the current situation are very time consuming and cost-intensive.

Compared to the past, there are several simulation tools which - with appropriate use - facilitate the design of rooms. Thus, the acoustic effects of changes in geometry (e.g. placing absorbers, reflectors, etc.) can be simulated. As such a tool a finite element simulation with the "Acoustics Module" of COMSOL Multiphysics is performed in this paper. As the first step the test room must be created as a finite element model. Here it is also possible to import CAD models. In addition to precise geometry of the test chamber including any existing reflectors and absorbers, the characteristics and properties of each material have to be implemented in the model. The desired frequency range and the geometry of the room determine the meshing of the model. Since for the qualification procedure for loudspeaker positions only the frequency range up to 354 Hz is of interest, the meshing was carried out accordingly. Figure 3 shows the mesh used at the room.

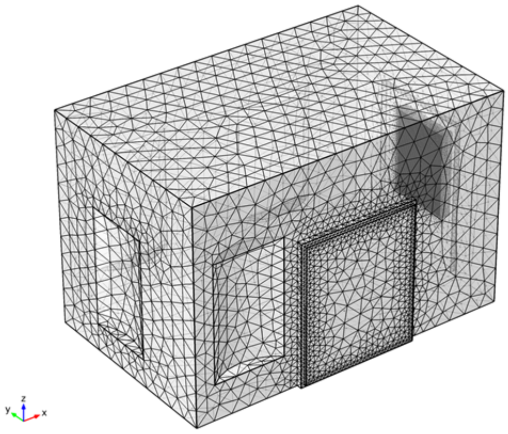

Figure 3 – Meshed room

Now, a simulation of the eigenfrequencies of the room can be performed. Figure 4 shows the eigenmode of the room at 73.6 Hz. The wave antinodes are shown in blue and red, the wave nodes in green. Based on the distribution of the wave antinodes and nodes of every eigenfrequency, a good first impression of the sound field in the test room is given. With this overview you can find the frequency ranges in which acoustic adjustments are appropriate. Even with a pre-approved test facility this simulation can be used to obtain an impression about the excitation of the room at the current speaker positions.

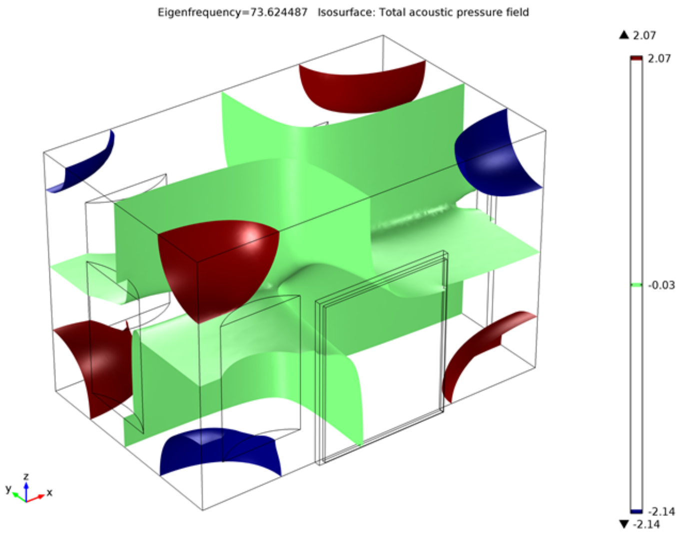

Figure 4 – Eigenmode of the room at 73.6 Hz;

wave antinodes are shown in blue and red, wave nodes in green

A more detailed analysis can be achieved using the frequency study. For the frequency study, the frequency range from 89 Hz to 354 Hz in steps of 1 Hz was simulated. Based on this simulation, it can be stated how the sound field behaves at the test opening when excited by different speaker positions. For this purpose, a sound source has to be simulated at each possible speaker position. Due to the high number of possible source positions a lot of simulations and thus a unfeasible computational time is required. For this reason a different approach is used. Since it can be assumed that the room is a linear, time-invariant - and therefore reciprocal - system, source and receiver can be interchanged. Thus, there is only one source and (e.g.) the source level for each point in the room can be calculated by a single simulation. Due to the large reduction of required simulations and, consequently, reduction of computational time and effort, a rapid assessment and evaluation of changes to the spatial characteristics is possible and the influence of wall linings, absorbers and reflectors can be simulated. In this example, the same homogeneous gypsum fibreboard already used in the measurement was used as excitation area in the test opening. Since all the material parameters of the gypsum fibreboard are known, it is quite simple to implement the plate in the model. The excitation of the plate is done in the center of the plate using a point source as shown in Figure 5.

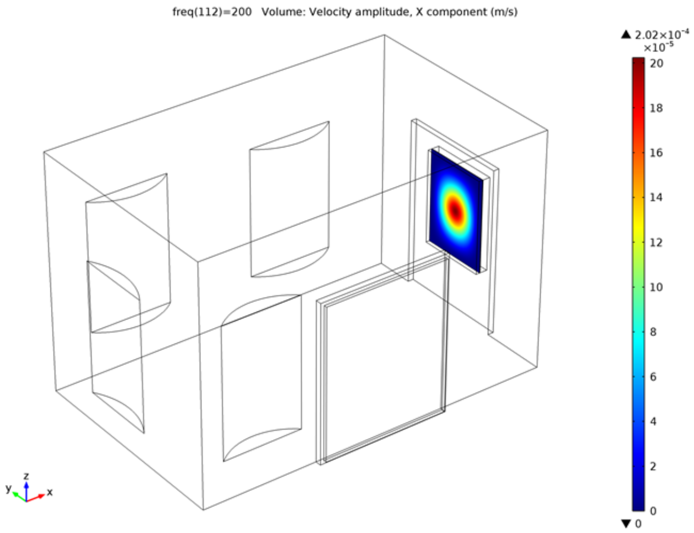

Figure 5 – Excitation of the plate at 200 Hz

Thus the properties of the gypsum fiber board used in the measurement are taken into account in the simulation, which also results in a better match between measurement and simulation. Besides the density of modes in one-third octave band, by comparing the transfer functions a statement about the diffuseness of the sound field of the room can be made. As denominator for the transfer functions the integrated squared velocity related to the surface of the plate was used. As numerator the absolute pressure at all eligible loudspeaker positions was calculated. From the difference between the maximum and minimum transfer function, as well as the dispersion of the transmission functions, a statement about the diffuseness of the room can be made. Furthermore adjustments of the room can be evaluated based on the changes and trends of the transfer functions.

For better illustration the sound pressure level at a slice through the original test facility at 200 Hz was calculated. As a comparison the sound pressure level at the same slice through the room, but with additional reflectors in two rear corners of the test room was simulated. The histograms of the distribution of the sound pressure level at the slices in Figure 6 show, that the diffuseness increases with the installation of reflectors. Considering the entire sound field at all points of all frequencies, an acoustic assessment and evaluation of the room is possible.

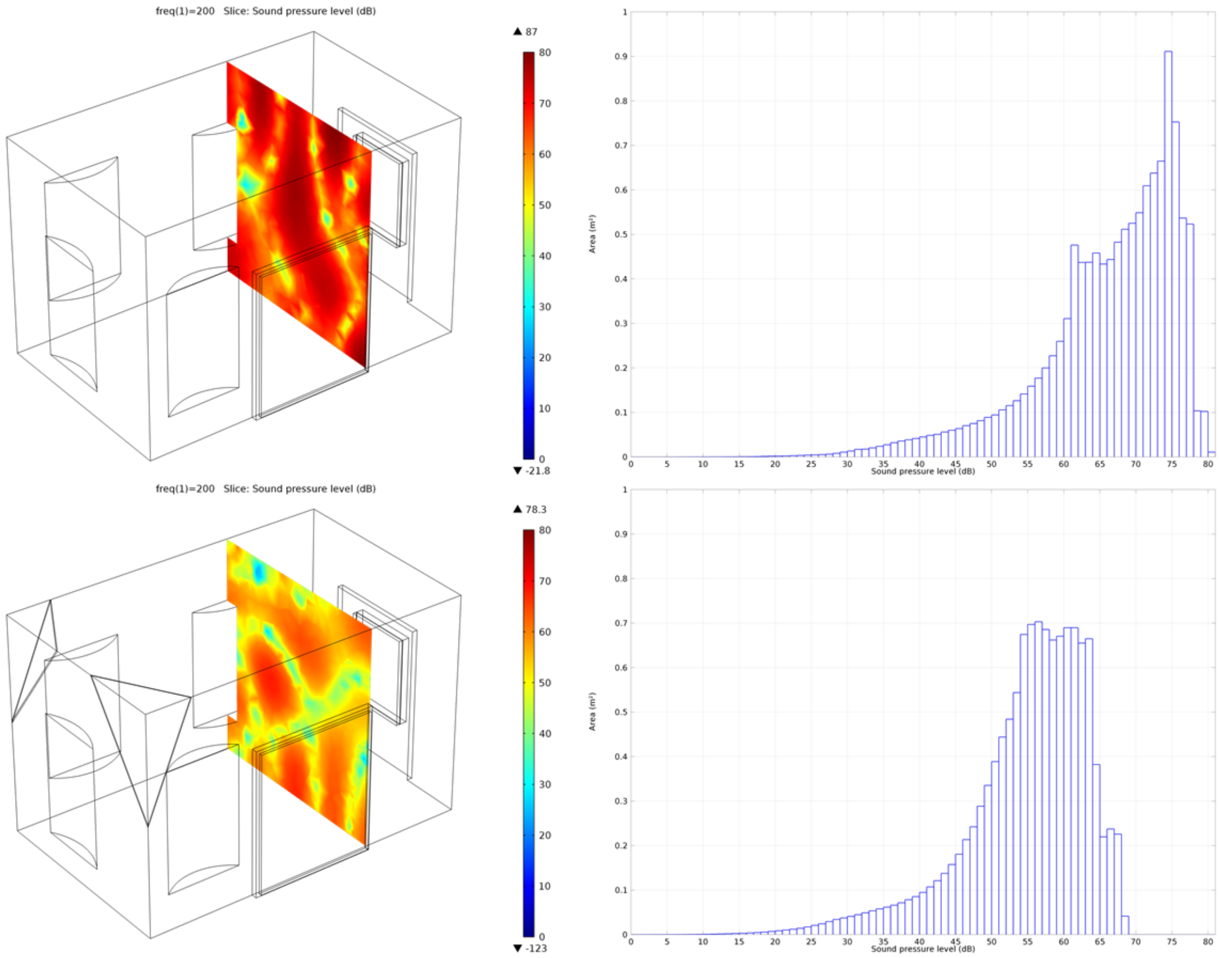

Figure 6 – Distribution of the sound pressure level at 200 Hz at the slice in the original room (upper diagrams) and with additional reflectors (lower diagrams)

4. CONCLUSIONS

The qualification procedure for loudspeaker positions is quite complex and associated with time-consuming measurements. With the help of simulations, a good estimation of the sound field of the room is possible. Due to the relatively low bandwidth and the approach with the reciprocal excitation, as well as the comparison of transfer functions, quick statements about the effects of acoustic modifications of the room are possible. Furthermore, the suitability of speaker positions in compliance with the requirements of international standards can be checked. Thus, only one final measurement for validating the simulation is necessary.

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