Measurement of sound insulation in laboratory - comparison of different methods

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Introduction

For measuring the sound insulation of building elements in laboratory three standardized methods based on different acoustic principles are available. According to ISO 140-3 [1] the element under test is installed between two reverberant rooms. The measurements acc. to ISO 140-5 [2] combine free field excitation with a reverberant receiving room and ISO 15186-1 [3] uses sound intensity for determination of transmission loss. All methods assume idealized acoustic conditions that differ more or less from the situation found in practice. In addition to the inherent statistic variation of the measuring results this gives rise to systematic deviations between the different measuring methods.

Since the deviations are so far only partly understood, they were experimentally investigated by means of an extensive series of tests [4]. The tests comprised three different types of building elements (a chipboard, a lightweight double-leaf construction and a membrane partition) and were performed under well-defined conditions in the test facilities of the Fraunhofer-Institute for Building Physics. Apart from comparing the different measuring methods additional investigations on the influence of the most important measuring parameters (reverberation time, number and position of microphones, etc.) are presented. The results of the investigations contribute to a better understanding of accuracy and reliability in measuring sound insulation.

Measuring methods

The sound reduction index of a building element is defined as

$$R = 10 \lg \left(P_1 / P_2 \right) \text{dB}, \qquad (1)$$

where P_1 and P_2 are the incident and the transmitted sound power, respectively. As shown in figure 1, the measurement of sound reduction can be performed by three standardized methods. The main features of these methods are:

- The test facility acc. to ISO 140-3 consists of two rooms separated by the wall under test. A loudspeaker in the source room is used for sound excitation. Inside of the rooms there are reverberant diffuse sound fields. The sound reduction index is determined from the spatially and temporally averaged sound levels L_1 and L_2 in conjunction with the reverberation T_2 (the indices 1 and 2 refer to source room and receiving room, respectively).
- Although ISO 140-5 is primarily intended for in-situ measurements, it can be also used in laboratory. From the different possibilities offered in this standard only the element loudspeaker method is investigated, since it provides results comparable to ISO 140-3. In using the element loudspeaker method the test wall is excited by a loudspeaker emitting sound waves towards the wall at an angle of 45°. The incident sound power is determined from the mean sound level $L_{1,s}$ directly in front of the wall (see figure 2). Analogous to ISO 140-3 for determination of the transmitted sound power a reverberant receiving room is used.

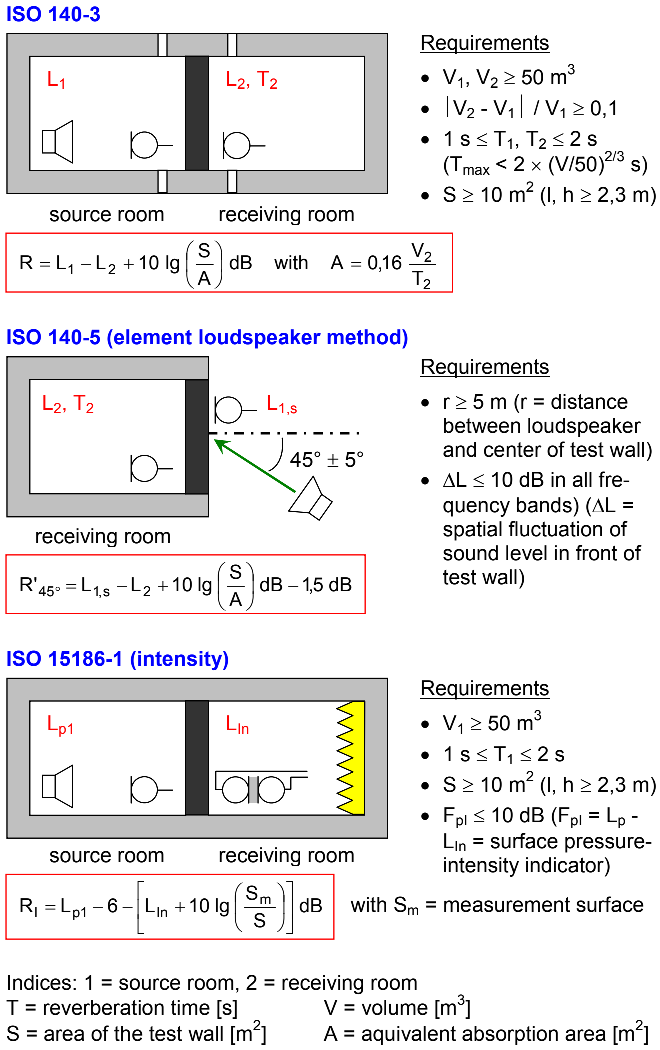

Figure 1: Schematic overview on the three investigated measuring methods. The required measurands are printed in red color.

- According to ISO 15186-1 the test wall is excited by a diffuse sound field produced by a loudspeaker in a reverberant source room. To determine the transmitted sound power the rear side of the wall is scanned using a sound intensity probe. In order to obtain reliable results, the sound radiated from the wall must not be superimposed by disturbing signals consisting of diffuse sound components and background noise. The corresponding signal-to-noise ratio is characterized by the surface pressure-intensity indicator $F_{pI} = L_p - L_{In}$, where L_p and L_{In} are the average values of sound pressure and the sound intensity on the measurement surface, respectively. The receiving room must be designed in such a way (e. g. by incorporating an absorbing back wall) that the condition $F_{pI} \leq 10$ dB is fulfilled. A major advantage of ISO 15186-1 compared to the other measuring methods is, that the test result is not affected by flanking transmission.

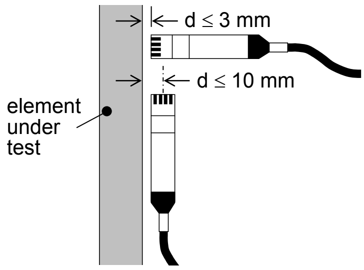

Figure 2: Position of the microphone in front of the surface of the test wall acc. to ISO 140-5. The indicated values denote the distance between the wall and the center of the microphone membrane.

Since the excitation of the test wall takes place under the same acoustic conditions, ISO 140-3 and ISO 15186-1 are expected to provide equal results. However, theory predicts an overestimate of sound insulation by ISO 140-3 due to an underestimate of the sound power transmitted in the receiving room. To obtain comparable results ISO 15186-1 defines the modified intensity sound reduction index

$$R_{I,M} = R_I + K_c \,, \tag{2}$$

where K_c denotes an adaptation term for adjusting the measured intensity sound reduction index R_I to the results of the customary measuring method acc. to ISO 140-3:

$$K_c = 10 \lg\left(1 + \frac{S_{b2}\,\lambda}{8\,V_2}\right) \text{dB} \,, \tag{3}$$

In equation (3) S_{b2} denotes the total inner surface of the receiving room and λ and V_2 are wavelength and room volume, respectively.

Apart from the measuring methods mentioned above the transmitted sound power can also be determined by measuring the mean structural velocity on the surface of the test wall. This method was not included in the presented investigations, since it assumes an radiation efficiency of $\sigma = 1$ and is thus only applicable to heavy solid walls with low coincidence frequency.

Samples

For comparison of the various measuring methods three different samples were investigated. All samples were lightweight building elements and had similar dimensions (3,8 m × 2,4 m) with an area of about 9 m^2. The construction of the three elements is shown schematically in figure 3:

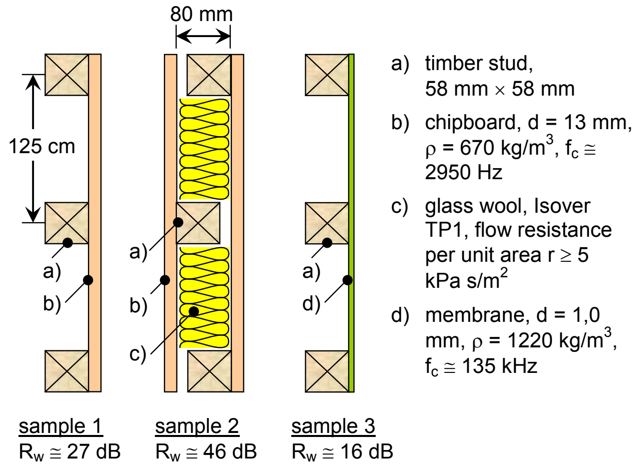

Figure 3: Construction of the investigated building elements: chipboard (1), lightweight double-leaf construction (2) and membrane partition (3). The membrane consists of a flexible foil reinforced by a fabric inlay.

Using lightweight elements instead of solid walls offered the following advantages:

- Costs and effort for building of the elements were much smaller.
- The elements could be easily dismantled and transported to other test facilities, so that all measurements were performed on almost identical samples. This improved measuring accuracy and reduced deviations due to differing specimens.

Experiment

All investigations took place in the test facilities of the IBP under well defined conditions. The measurements acc. to ISO 140-3 were performed in a test facility for walls without flanking transmission (room volume $V_1 = 66$ m^3 and $V_2 = 76$ m^3) meeting the requirements of ISO 140-1 [5]. For the measurements acc. to ISO 140-5 and ISO 15186-1 the sample was mounted in the opening between a reverberation room ($V = 392$ m^3, reverberation time adjusted to $T = 1 - 2$ s by insertion of absorbers) and a semi-anechoic room.

The measurements acc. to ISO 15186-1 were additionally performed in the above mentioned test facility for walls. To this end the receiving room of the test facility was equipped with an absorbing back wall. Comparison of the measurements carried out in the reverberation room / semi-anechoic room and in the facility for walls revealed almost identical results.

For the measurement of sound intensity a conventional pp-probe (consisting of two equal condenser microphones facing each other and separated by a spacer) were used. For comparison some of the measurements were repeated by means of a Microflown pu-probe, comprising a miniature microphone in conjunction with a special sensor for direct measurement of sound particle velocity. Photographs of the two probes are shown in figure 4.

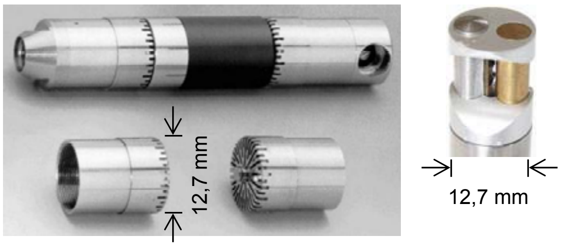

Figure 4: Conventional pp-probe (left) and Microflown pu-probe (right) used for measuring sound intensity.

Results

Comparison of the measuring methods

Experimental data determined with the measuring methods described above are shown in figure 5 to 7, each figure treating another sample. Examination of the data leads to the following results:

- In case of the membrane, characterized by small mass per unit area and very low bending stiffness, all measuring methods coincide quite well.

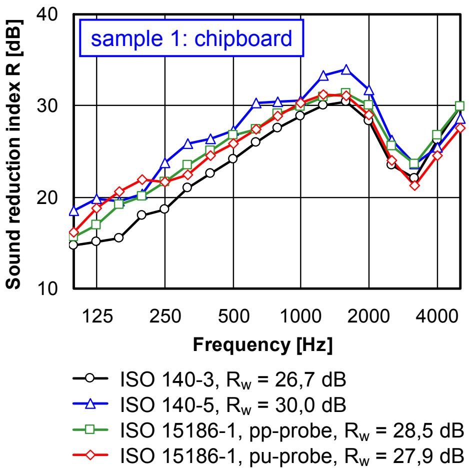

Figure 5: Sound insulation of the chipboard determined by different measuring methods.

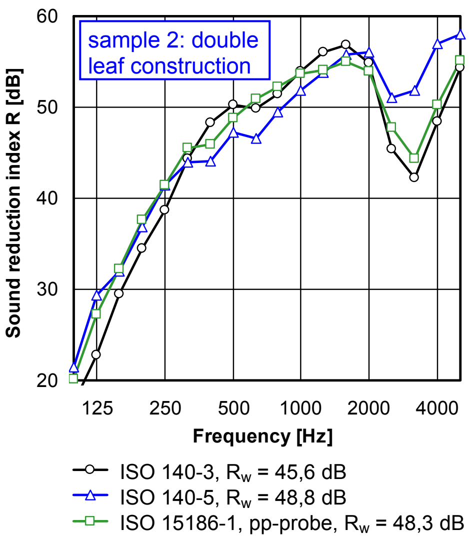

Figure 6: Sound insulation of the lightweight double leaf construction determined by different measuring methods.

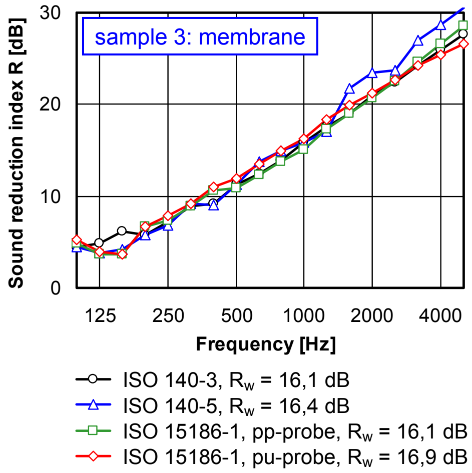

Figure 7: Sound insulation of the membrane determined by different measuring methods.

- For the chipboard and the double leaf construction the differences between the measuring methods are much more pronounced than for the membrane. Although there are deviations in detail the results show a general tendency: On average ISO 140-3 provides the smallest values of sound reduction, whereas ISO 140-5 always yields the largest results. Concerning the weighted sound reduction index the deviations between the three measuring methods amount to maximal ± 2 dB.

- Measurements of sound intensity with the pp- and the pu-probe are in satisfactory correspondence with each other. In using the pu-probe it is sometimes difficult to meet the requirements of ISO 15186-1 concerning the surface pressure-intensity indicator, although this has no noticeable effect on measuring accuracy.

- It is not advisable to use the adaptation term K_c defined in ISO 15186-1, since addition of K_c enlarges the intensity sound reduction index and thus deteriorates the agreement between ISO 15186-1 and ISO 140-3 (for the test facility for walls in the IBP K_c ranges from 3,5 dB at 50 Hz to 0,1 dB at 5000 Hz).

Measurement acc. to ISO 140-5

Since ISO 140-5 still raises several questions additional investigations were carried out to gain better understanding of this measuring method. In the following some of the most important results are discussed:

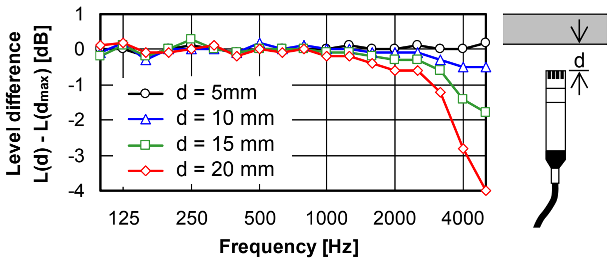

Figure 8: Dependence of the sound level on the distance between microphone and wall for measurements acc. to ISO 140-5. The data refer to the largest permitted distance of d_{max} = 3 mm.

- According to ISO 140-5 the distance between microphone and excited wall must not exceed 3 mm (see figure 2). In practice it is sometimes difficult to meet this requirement. However, the results presented in figure 8 show that an enlargement of the distance to e. g. 10 mm only marginally changes the measurement results. The deviations are solely restricted to high frequencies.
- As can be seen from figure 9 the sound insulation measured by ISO 140-5 considerably depends on the angle of incidence. According to expectation this particularly occurs in the area of the coincidence frequency. Angles below the standardized value of θ = 45° are less critical than larger angles. The requirement of θ = 45° ± 5% as given in ISO 140-5 should be obeyed as far as possible.

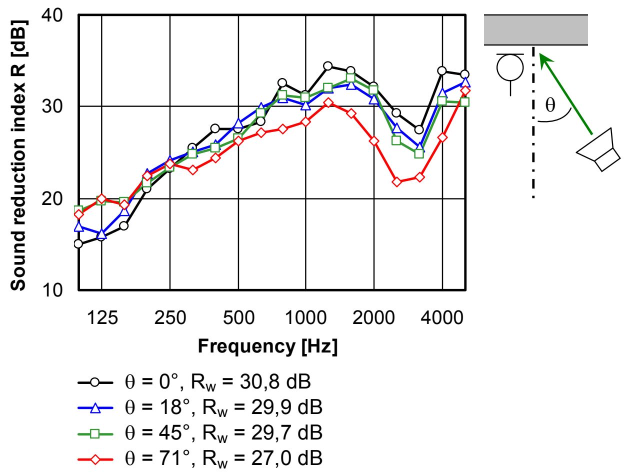

Figure 9: Effect of the angle of incidence on sound insulation for measurements acc. to ISO 140-5.

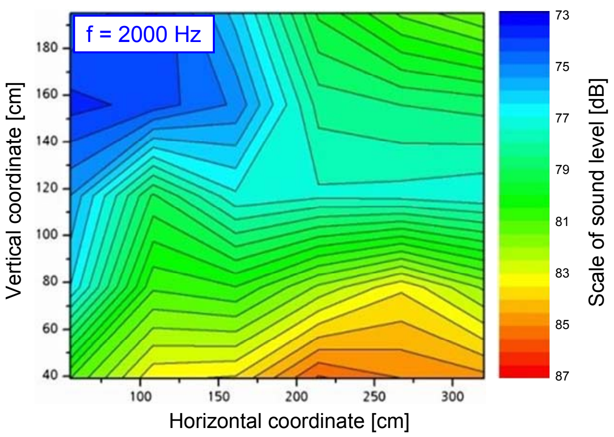

Figure 10: Sound field in front of the excited wall for measurements acc. to ISO 140-5 (example for f = 2000 Hz).

- ISO 140-5 claims the spatial variation of the sound level in front of the test wall to remain below 10 dB. In practice this is often difficult to realize, especially if the sound field is distorted by ground reflections. This also applies even if the requirements of ISO 140-5 concerning the position and orientation of the loudspeaker are fulfilled (see example in figure 10). On the other hand the performed measurements clearly indicate, that moderately exceeding the limit of 10 dB only slightly affects measuring accuracy.

Summary

Laboratory measurements of sound insulation can be performed by three standardized measuring methods: ISO 140-3, ISO 140-5 and ISO 15186-1. The methods differ from each other concerning the excitation of the test wall (diffuse or directed sound field) and the determination of incident and transmitted sound power (sound intensity as well as sound pressure level in diffuse and near field). Each measuring method has benefits and disadvantages so that the choice of the most suitable method depends on the particular field of application.

In spite of their differences all measuring methods provide comparable results. The performed investigations indicate, that ISO 140-3 mostly yields the lowest sound insulation. The values determined by means of ISO 140-5 are the highest ones and ISO 15186-1 takes a middle position. With respect to the weighted sound reduction index the deviations between the three measuring methods amount to maximal $\Delta R_w = \pm 2$ dB.

References

[1] ISO 140-3: Acoustics - Measurement of sound insulation in buildings and of building elements - Part 3: Laboratory measurements of airborne sound insulation of building elements. ISO, 1995.

[2] ISO 140-5: Acoustics - Measurement of sound insulation in buildings and of building elements - Part 5: Field measurement of airborne sound insulation of facade elements and facades. ISO, 1998.

[3] ISO 15186-1: Acoustics - Measurement of sound insulation in buildings and of building elements using sound intensity - Part 1: Laboratory measurements. ISO, 2003.

[4] Schreier, H.: Comparison of various methods for measuring the transmission loss of plate-type building elements. Fraunhofer Institute for Building Physics (IBP) and Hochschule Mittweida (FH) - University of Applied Sciences. Diploma thesis, 2009.

[5] ISO 140-1: Acoustics - Measurement of sound insulation in buildings and of building elements - Part 1: Requirements for laboratory test facilities with suppressed flanking transmission. ISO, 1997.