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Evaluation of the impact of a leak on the sound transmission loss of a building partition using sound intensity measurements

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Abstract For partitions in existing buildings with potential leaks, a leak identification method and, above all, a way of assessing the impact of such a leak on sound transmission loss are needed. In this paper, a new method was proposed to evaluate the impact of leakage on the resultant sound transmission loss based on measurement of the sound intensity distribution over a partition. Measurements were carried out in down-scaled reverberation chambers with a scale 1:4. A homogeneous MDF board with leakage in the form of holes of a specific diameter was used. The measurement results were also compared to the values obtained by calculation using well-known models of sound transmission loss of the homogenous partition with an aperture. Measurements and calculations confirmed the possibility of determining the impact of leakage on the resultant sound insulation based only on the measurement of the sound intensity level distribution on the surface of the tested partition.

Keywords: sound insulation, buildings partitions, sound transmission loss of leaks.

1. Introduction

Leaks in building partitions, e.g. at the point of their connection or in the form of poorly filled joints, can significantly affect the resultant sound transmission loss.

The topic of the influence of a leak on the acoustic insulation of building partitions has been considered by various authors [1-4]. In most cases, computational models were used based on the determination of the acoustic impedance of round holes or rectangular slits [1-3] and its effect on the resulting wall impedance. Currently, the most widely used calculation models are Gomperts [1] and Mechel [2]. In the work [4,5], the acoustic insulation of hole-shaped and slit-shaped apertures was measured, among others, by the sound intensity method, and an attempt was made to verify the computational models developed by Gompert [1] and Mechel [2]. However, these models do not allow us to determine the sound insulation of a leak with any geometry. In addition, in practice, leaks in partitions can be partially covered by finishing layers, e.g. a thin layer of plaster or wallpaper, and thus it is practically impossible to determine their geometry without significant interference in the wall.

Therefore, for partitions in existing buildings with potential leaks, a leak identification method and its impact on sound transmission loss are still needed. In this paper, a new method was proposed to evaluate the impact of leakage on the resulting sound insulation of the partition based on sound intensity distribution measurements. The tested building element is represented by a two-element partition: a tight element and a leak of a certain area and sound insulation. The relationship between the sound transmission loss of a tight partition and the leak is determined on the basis of the measurement of the distribution of the sound intensity level on the surface of the tested element. Once the relationship is defined, it is possible to predict the recovery of sound transmission loss of the partition as a result of the removal of the leak.

2. Methodology

Sound insulation R of the building partition is defined by sound transmission coefficient τ:

$$R = -10\, lg\, \tau,$$
$$\tau = \frac{W_t}{W_i}. \tag{1}$$

The sound transmission coefficient τ is a ratio of transmitted acoustic energy W_t through the partition with the surface S_t to incident acoustic energy W_i on the partition with S_i. In a case of a simple, plane wall these surfaces are the same $S_i = S_t$. Moreover, the acoustic energy W can be calculated on the basis of the surface normal sound intensity I_n:

$$\tau = \frac{W_t}{W_i} = \frac{I_{n,t}S_t}{I_{n,i}S_i} = \frac{I_{n,t}}{I_{n,i}}. \tag{2}$$

This means that sound transmission loss R can be calculated by measuring the distribution of sound intensity on the surface S of the partition in source ($I_{n,i}$) and receiving room ($I_{n,t}$).
A partition S_p with a leak can be treated as two-elements wall: tight element with S_1, R_1 and the leak with S_2 and R_2 (see Fig.1). The resultant transmission coefficient of such two-elements partition can be calculated as the sum of transmitted energy through each element:

$$\tau_p = \tau_1 + \tau_2 = \frac{I_{n,1}S_1 + I_{n,2}S_2}{I_{n,i}S_p}. \tag{3}$$

When there is diffuse field in the source chamber, the sound intensity $I_{n,i}$ over elements 1 and 2 is the same, so:

$$R_p = -10lg\left(\frac{\frac{I_{n,1}}{I_{n,i}}S_1 + \frac{I_{n,2}}{I_{n,i}}S_2}{S_p}\right) = 10lg\left(\frac{S_p}{S_1 10^{-0,1R_1} + S_2 10^{-0,1R_2}}\right), \tag{4}$$

$$R_p = 10lg\left(\frac{S_p}{S_2\frac{I_{n,2}}{I_{n,1}} + S_1}\frac{I_{n,i}}{I_{n,1}}\right) = 10lg\left(\frac{S_p}{S_2\frac{I_{n,2}}{I_{n,1}} + S_1}\right) + R_1 . \tag{5}$$

By rearranging the Eq.(5) it is possible to calculate the sound transmission loss of the tight element 1on the basis of the measured sound insulation of two-elements partition R_p and the ratio of I_n on 1 and 2 element:

$$R_1 = R_p - 10lg\left(\frac{S_p}{S_2\frac{I_{n,2}}{I_{n,1}} + S_1}\right) = R_p + \Delta R , \tag{6}$$

$$\Delta R = 10lg\left(\frac{S_2\frac{I_{n,2}}{I_{n,1}} + S_1}{S_p}\right). \tag{7}$$

This means that using the distribution of the sound intensity on elements 1 and 2, it is possible to determine the increase of the wall sound insulation as a result of the removal of the leakage S_2. However, it is necessary also to know the surface area of the leak S_2, which value is not easy to define, as contrary to the total surface area S_p. The surface of tight partition S_1 is determined knowing S_p and S_2.

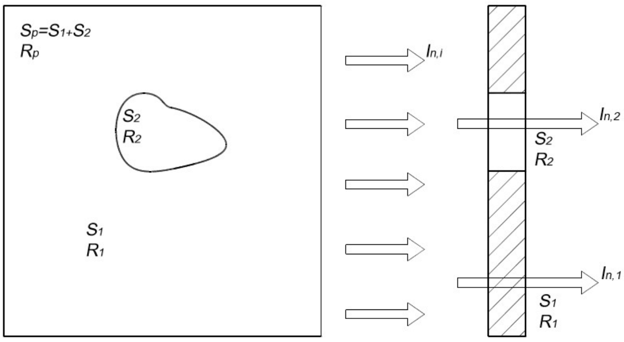

Figure 1. Two-elements partition.

The value of a S_2 of the leak is generally difficult to determine because it is usually not visible, too small or has complex geometry. Therefore, in this paper a method is proposed to determine the surface area of the leak S_2 on the basis of the analysis of the sound intensity level distribution on the partition with the leakage. This methodology assumes that instead of the physical value of S_2, an equivalent surface area $S_{2,c}$ can be used. The $S_{2,c}$ is defined as the area of the region around the leak in which the value of the sound intensity level L_{In} is within the specified range X dB with respect to the maximum value $L_{In,2,max}$ at the center of the leak:

$$L_{I_{n,2}} \geq L_{I_{n,2,max}} - X . \tag{8}$$

In the study three values of parameter X were considered: 3 dB, 6 dB and 10 dB. For example, for X = 3 dB, the equivalent surface area $S_{2,c}$ is the region around the leak where the sound energy decreases by 2 times the value in the center of the leak. Further analysis of the measurement results showed that for all values applied to the parameter X, the equivalent surface area was always greater than the geometric leakage area: $S_{2,c} > S_2$.

3. Measurements

The measurements were carried out using a homogeneous MDF board, in the middle of which there was a round hole with a diameter of 7 mm and 35 mm. All sound insulation tests were performed in the set of two down-scaled reverberation chambers with the scale 1:4. This means that due to the lack of a diffuse field in such small chambers in the low-frequency range, reliable measurement results were obtained for frequencies above 400 Hz. Nevertheless, for research purposes the analysis was carried out in the frequency range of 100-5000 Hz in the 1/3 octave bands. The MDF partition had a thickness of 22 mm and dimensions of 80x40 cm. The partition was simply supported on its edges.

The sound insulation of the partition was measured using the pressure method based on the ISO 10140-2 [6] using the source and receiving chambers and the sound intensity method based on the ISO 15186-1 [7] using only the source chamber. The main deviation from the norms was using down-scaled reverberation chambers, among other smaller distance between microphones was used. Because of that as it mentioned above, the reliable results are achieved above frequency 400 Hz.

The measurement set-up and chambers are shown in Fig. 2–4. In the experiments 1/2" PCB 378B02 measurement microphones, P-P GRAS 50 GI sound intensity probe, BK4205 reference power source and measurement system SAMURAI v3.2.1 from SINUS were used. In the case of the intensity probe, a 25 mm spacer is applied, which means that the sound intensity was correctly measured in the frequency range 120-5000 Hz.

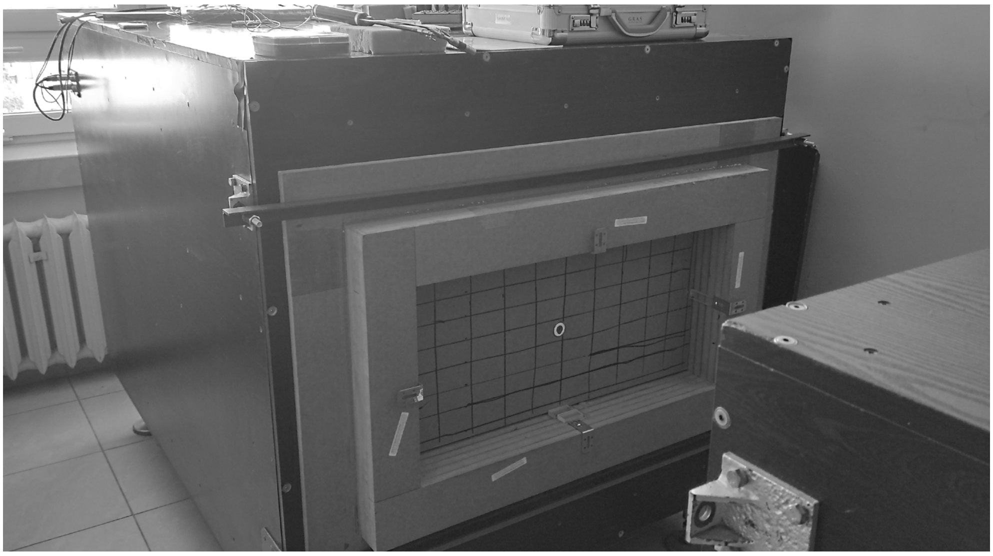

Figure 2. Down-scaled 1:4 source chamber with simply supported 80x40 cm MDF plate.

Pink noise and 6 microphone positions were used in each chamber to measure sound insulation using the pressure method. The reverberation time in the receiving chamber was measured by the interrupted noise method. In the case of intensity method also pink noise, 6 positions of microphones in the source chamber and scanning over the surface of the partition in two perpendicular directions were used. Whereas the distribution of sound intensity was obtained by moving the P-P probe over the partition parallel to its longer side at a distance of about 3 cm from the specimen. It has been discovered that such a relatively small distance of the scanning plane allows us to get more reliable sound intensity maps than maps for at 10 cm as it recommended by ISO 15186-1 [7]. For each measurement, the background noise was at least 10 dB below the emitted signal at all frequencies.

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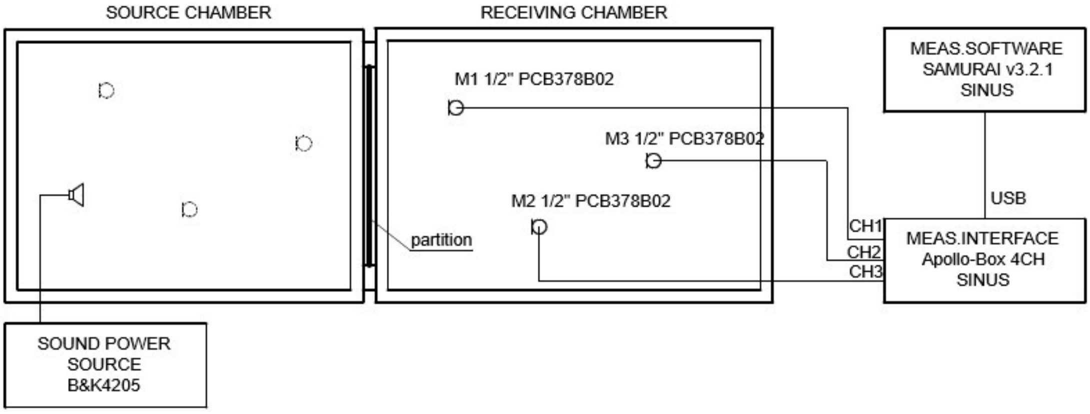

Figure 3. Measurement scheme for sound transmission investigation using the sound pressure method.

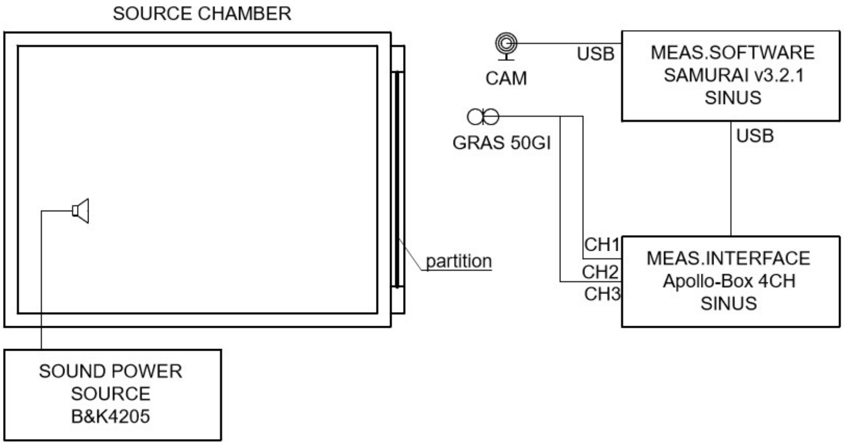

Figure 4. Measurement scheme for sound transmission investigation using the sound intensity method.

4. Results and discussion

In order to verify the applied measurement systems, the investigation of sound insulation for a homogeneous and tight partition was carried out first. The results of analytic calculations using a commercial program “Insul” and the results of measurements by the pressure method and the sound intensity method of the tight MDF board with a thickness of 22 mm are presented in Fig. 5. Please note that in the figure vertical point line denotes frequency from which the diffuse field condition is achieved. In the useful frequency range, i.e. 400-5000 Hz, the values of R obtained by the calculation, by the sound pressure method and the sound intensity method are similar. At frequencies below 320 Hz, a large dispersion of the measured values can be observed in relation to the calculated ones, especially for the sound intensity method. It confirms the assumptions of the lack of diffuse field in the reverberation chambers below 400 Hz. In Fig. 9.a the sound intensity level map over the tight plate at 5000 Hz band is also shown. The sound intensity level over the tight partition oscillates around 41 dB. It should be noted that the colour scale of maps is always determined by two quantities: the upper value of the scale, which is the highest level of sound intensity level (deep red colour) and the range of the scale, which is always 15 dB in relation to the maximum value.

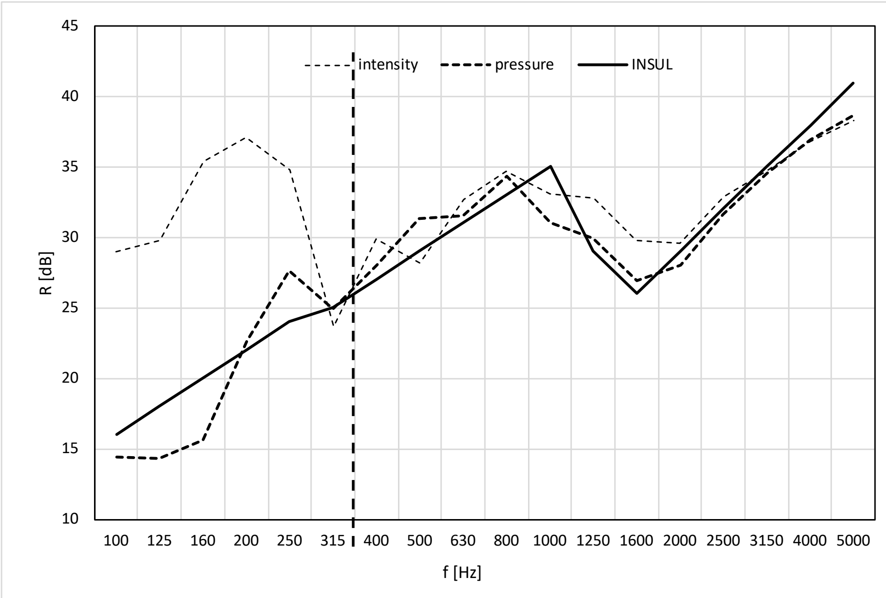

Figure 5. Sound transmission loss of homogenous 22 mm MDF panel obtained by analityc calculation and measurements.

Figs. 6-7 show the measured sound insulation by pressure and sound intensity for an MDF plate with a hole of ϕ7 mm and ϕ35 mm. On the basis of the presented results, it can be seen that the leak with a small, 7 mm diameter affects the resultant insulation of the partition practically only at 5000 Hz band, i.e., it reduces the insulation by 3.5 dB. The influence of the hole with a diameter of 35 mm is much greater and is observed from 500 Hz.

Comparing the results given in Figs. 6-7, it can be seen that the changes in sound insulation due to leakage in the partition obtained by the pressure and the intensity methods are of a similar nature. However, the comparison of the results to the Gompert model [1] is revealed that for the pressure method a slightly better agreement with the calculation is obtained. The pressure method also shows better tendency. Therefore, father calculation of the change R as a result of removing the leak in the partition was verified against the results obtained by pressure method.

Using the Eq. (7) and the measured sound intensity level map on the surface of the partition with the hole, the ΔR was calculated and compared with the results of ΔR obtained by the pressure method. For this purpose, it was also necessary to determine the equivalent surface area $S_{2,c}$ of the leak (hole) on the basis of the sound intensity distribution. This was analyzed for three values of the parameter X in Eq . (8), however the best results were obtained for X=6 dB. An example of sound intensity level distributions at 5000 Hz band with the indication of $S_{2,c}$ for X=6 dB is given in Fig.9b,9c. In Fig.10 an example of determining $S_{2,c}$ for the MDF plate with ϕ35 mm hole and different values of the parameter X: $S_{2,c}$(X=3dB)=54 cm^2, $S_{2,c}$ (X=6dB)=103 cm^2, $S_{2,c}$ (X=10dB)=515 cm^2 is shown.

On the basis of the presented graphs, several important regularities can be observed. First, the equivalent surface area of the hole is always bigger than the surface area determined by the geometry of the leak, e.g. for a ϕ35 mm hole: 5 times for X=3 and 10 times for X=6 dB. Second, the value of $S_{2,c}$ increases non-linearly with increasing X. Similar regularities were observed for the plate with a ϕ7 mm hole.

In order to determine the ΔR in Eq. (7) It is necessary to know the ratio $I_{n,2}/I_{n,1}$, i.e. the value of the intensity on the leak and on the tight fragment of the partition. In the proposed methodology, these values are determined as follows. The sound intensity in the leak $I_{n,2}$ is defined as the maximum value within the leak, as a rule the value in the geometric center of the hole. The sound intensity on the tight part of the partition $I_{n,1}$ is defined as the average value of the intensity on the surface of the partition, excluding the region around the leakage with an area equal to the equivalent surface S $_{2,c}$. This approach is also partly explained the fact that the equivalent surface is always larger than the geometric one $S_{2,c}$> S_2. It also means that in real situation it is not possible to completely separate field transmitted through the hole and tight fragment of the partition.

In Fig.8 the improvement ΔR of the sound insulation of the panel measured by the sound pressure measurement and obtained using the proposed calculation method as a result of the removal of the leak is compared.

For small leaks, the hole of ϕ7 mm, the agreement between measurement and calculation is very good. In the case of the larger leak, the hole of ϕ35 mm, the tendency of improvement is good, but for higher frequencies ΔR is underestimated.

Analysis of the sound intensity level distributions showed that the main reason for this is the overestimated value of $I_{n.1}$ in Eq. (7). The sound intensity level over the panel, even at a great distance from the leak, is a few dB higher than that for a leak-free partition. In the case of a ϕ35 mm aperture at 5000 Hz band this difference was 6 dB. This means that the sound energy transmitted through the leak is significantly greater than the energy transmitted through the partition itself, even far away from the leak. So proposed methodology for estimating the impact of leakage on the sound transmission loss of tight partition allows one to "safely" determine the effects of removing the leak, because in the worst case the real result will actually be better by a few dB than predict.

It is also possible to modify the developed methodology and determine the value of $I_{n.1}$ on the basis of the sound intensity level distribution over tight partition. This data can be obtained from calculations using existing analytical models for building partitions or by measuring the intensity for a temporarily obstructed leakage, e.g. by simply covering the leak with the operator's hand during measurement. At first glance, such leak cover seems to be a very rough approach, but as research has shown, the method is good to obtain reliable results and very easy to implement in practice. Fig.11 shows the results of the calculation of ΔR for such case (named vs. MDF in figure). It can be seen that the proposed modification of the algorithm to determine $I_{n.1}$ will significantly improve the accuracy of ΔR calculations at frequencies where leakage reduces the insulation of the tight partition by more than 6 dB.

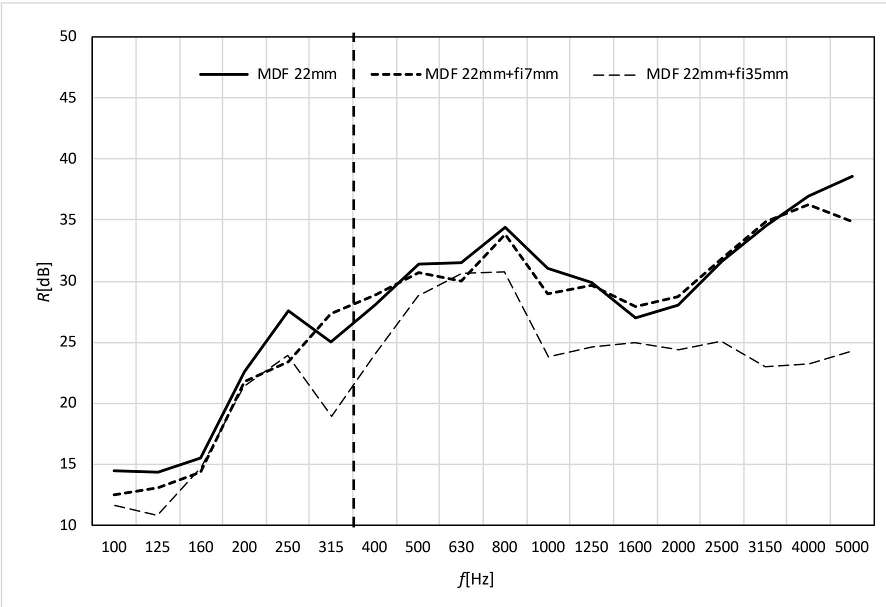

Figure 6. Sound transmission loss of homogenous 22 mm MDF panel and panel with the leaks of ϕ7 mm and ϕ35 mm obtained by the sound pressure measurement.

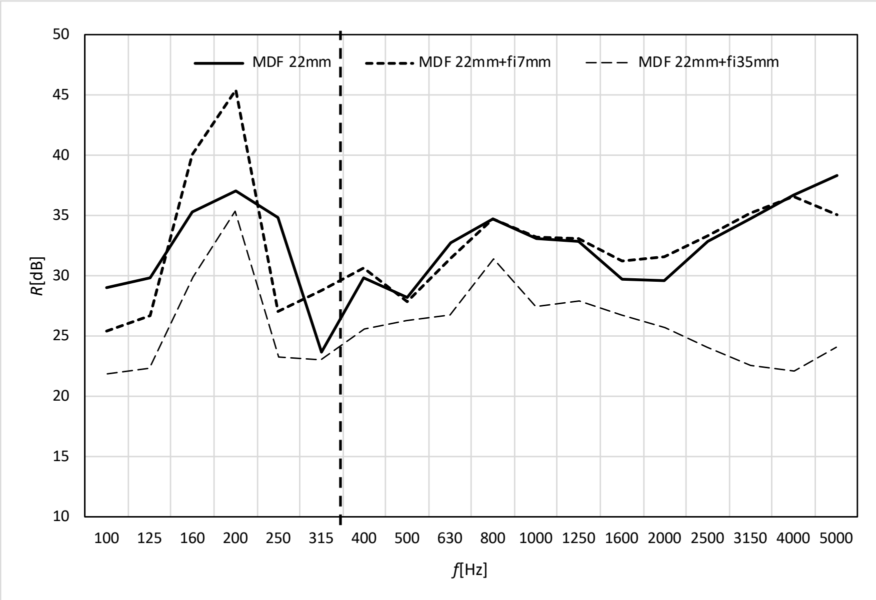

Figure 7. Sound transmission loss of homogenous 22 mm MDF panel and panel with the leaks of ϕ7 mm and ϕ35 mm obtained by the sound intensity measurement.

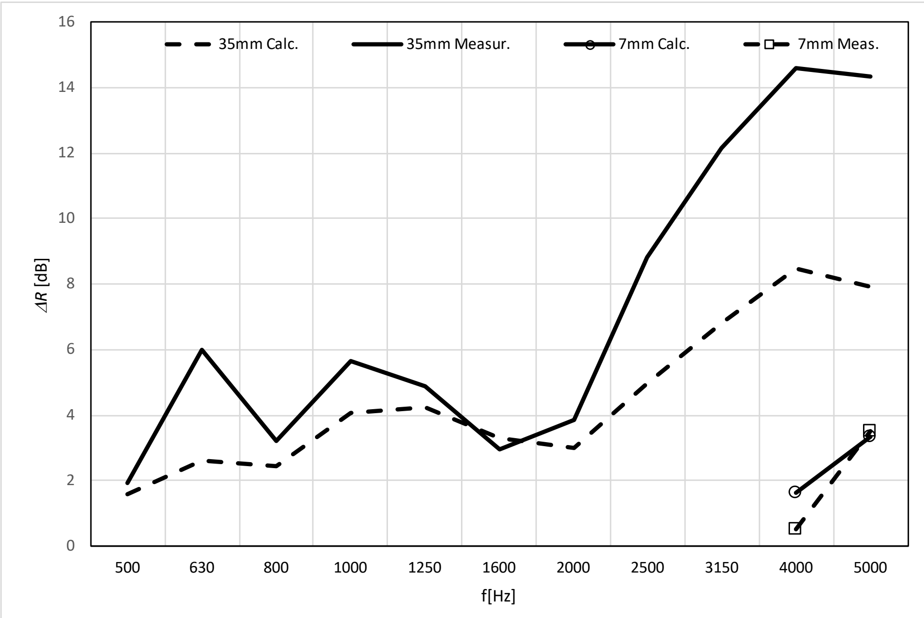

Figure 8. Measured by pressure method (7mm Meas, 35mm Meas) and calculated using proposed approach (7mm Calc, 35mm Calc) sound transmission improvement as a result of hole-leak elimination in the partition.

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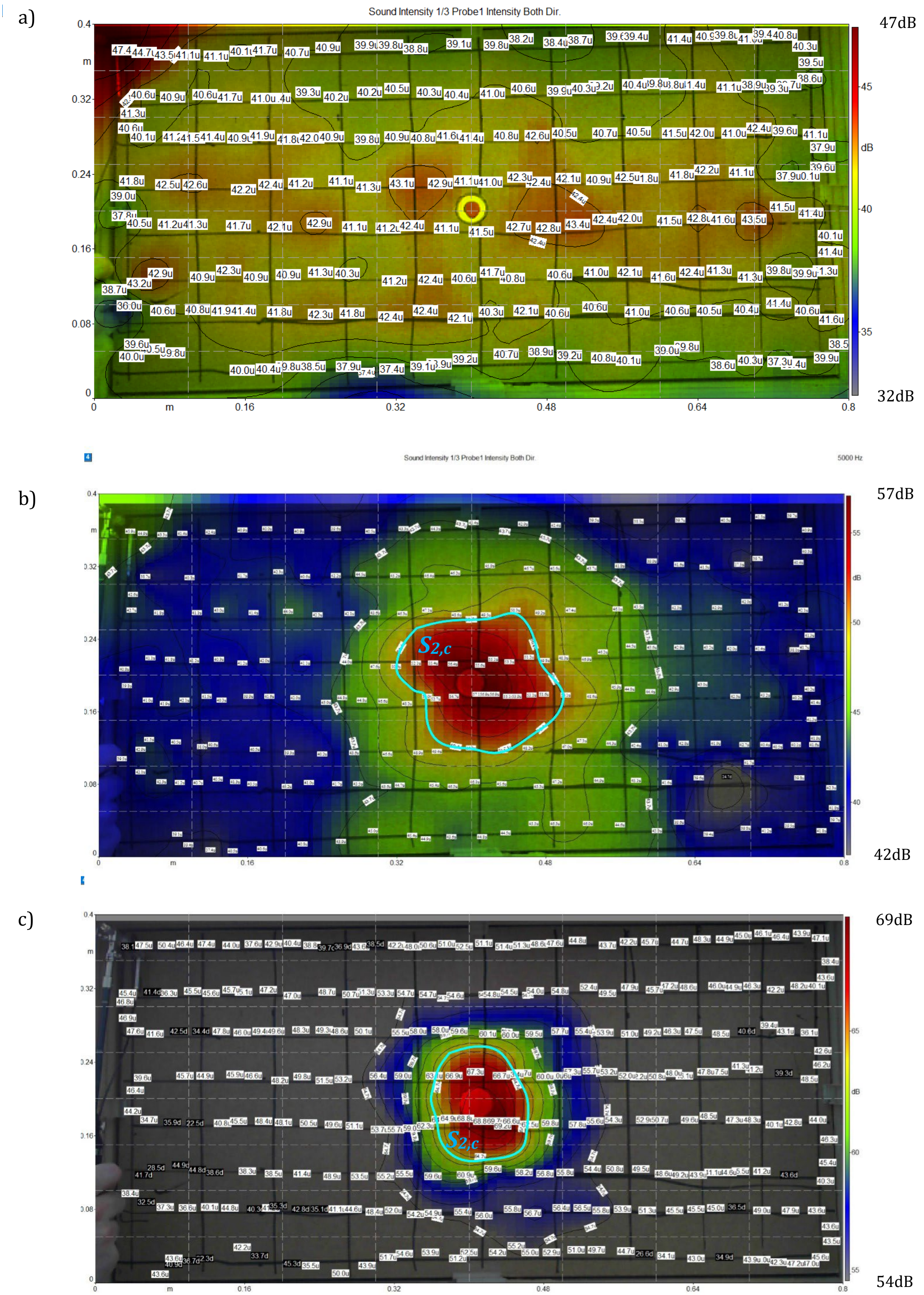

Figure 9. Sound intensity level distribution at 5000 Hz for: a) tight 22 mm MDF panel, b) MDF panel with ϕ7 mm hole, c) MDF panel with ϕ35 mm hole. Please note different maximum values on the scale and constant span of the scale (15 dB).

10dB

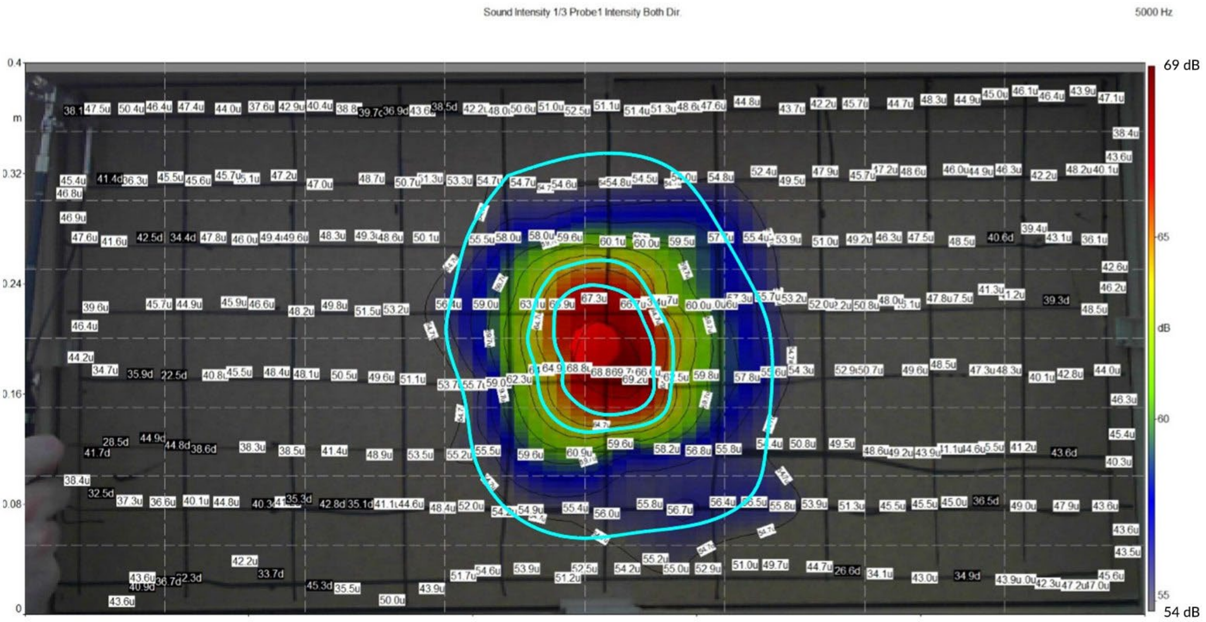

Figure 10. Sound intensity level map at 5000 Hz over panel with ϕ35 mm hole and $S_{2,c}$ for X=3,6,10 dB.

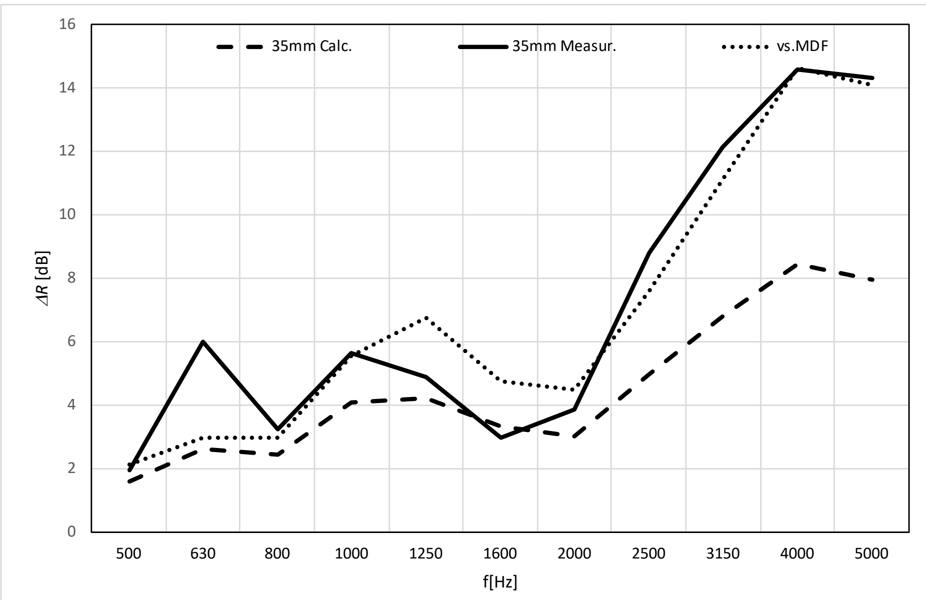

Figure 11. Measured by pressure method (35mm Meas) and calculated using standard (35mm Calc) and modified proposed algorithm (vs.MDF) sound transmission improvement by ϕ35 hole-leak elimination in the partition.

5. Conclusions

In the paper, the method of the evaluation of the impact of leakage on the sound insulation of a building partition using sound intensity level distribution over the partition is presented. In the method, the partition with a single or multiple leaks of any size and geometry is represented as a multi-elements panel with components: a tight partition and leaks. The effect of leakage on the R of the partition was determined by measuring the maximum value of the sound intensity level within the leak, the average sound intensity level over the tight fragment of the partition, and by defining the equivalent area of the leakage. The equivalent area is determined by analyzing the distribution of sound intensity level around the leak. The introduction of the equivalent surface makes it possible to assess the effect of the leak on the resultant R of the partition, even for very small leaks or leakage with complex geometries. It has been shown that the proposed methodology allows quantitative assessment of the improvement in sound insulation of the building partition as a result of the removal of leaks only on the basis of the distribution of sound intensity level on the surface of the tested wall. The proposed methodology allows a correct assessment of the leaks that reduce the acoustic insulation of a tight partition by a few to a dozen or so dB. The research was carried out using a down-scaled reverberation chambers. As an extension of the work, it is planned to verify the proposed methodology through additional in-situ measurements.

Additional information

The authors declare: no competing financial interests and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

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