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Testing the airborne sound insulation of reduced size baffles with different dimensions

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Abstract The article discusses the requirements for determining airborne sound insulation according to ISO 10140-2, which involves measuring sound pressure levels in the source (L_1) and receiving (L_2) rooms, as well as reverberation time measurements in the receiving room. The size of the free test opening and the equivalent sound absorption area in the receiving room affect the value of L_2. While ISO 10140-5 specifies the dimensions of a full-size test opening, reduced-size openings can also be used. However, testing reduced-size baffles with specific dimensions may be necessary, and measurements on rectangular-shaped baffles may yield higher sound reduction indices than square-shaped ones. The article presents a comparative analysis of the spectral characteristics of different types of single homogeneous baffles with various dimensions using experimental methods. It examines the measurement methodology's influence on determining sound insulation spectra and the weighted sound reduction index R_w. The article also calculates the combined uncertainty in determining the sound insulation properties and partial uncertainties in determining L_1 and L_2.

Keywords: airborne sound insulation, sound transmission loss, reduced-size openings.

1. Introduction

To determine how well a material can block airborne sound, measurements of sound pressure levels in both the source and receiving rooms and the reverberation time in the receiving room must be taken according to ISO 10140 [1] standards. Many researchers have shown interest in studying and analyzing the soundproofing capabilities of baffles [2-4]. The sound insulation of the receiving room depends on its equivalent sound absorption area and the size of the test opening where the material is installed. ISO 10140-5 [5] specifies a full-size test opening of around 10 square meters, but smaller 1250 mm width and 1500 mm height openings can be used. Sometimes, materials have non-standard dimensions and cannot be tested in compliance with the guidelines. Also, rectangular-shaped baffles may have better sound reduction indices than square ones with the same area. This is confirmed by tests of building baffles carried out under in-situ conditions [6]. Therefore, studies were conducted to determine the possibility of using baffles with reduced dimensions when examining their airborne sound insulation in laboratory conditions. In addition, it was decided to verify the influence of the shape of the tested baffle on the obtained research results.

2. Measurement methodology

The measurement methodology, based on the procedures and requirements contained in [1], is described extensively in [7].

Laboratory sound insulation measurements were carried out in the laboratory equipped with coupled reverberation rooms where the tested material is placed between the rooms. The laboratory meets most of the guidelines contained in the standard [5], except for the reduced dimensions of the measuring window (the required area is 10 m^2) [7, 8] and is described in more detail in [8]. Between the rooms is a measuring hole with dimensions 1 × 2 m. For the needs of testing small baffles, an additional reduction baffles were made, with sizes 0.7 × 0.7 m and 0.7 × 0.84 m (see Fig. 1). Both two reduction baffles are equally constructed, consisting of two parts. The first part (A) is a baffle composed of four OSB boards 0.025 m thick. The second part (B) is also made up of four 0.025m-thick OSB boards, but between them is a 0.001m-thick lead sheet and 0.05m-thick pressed mineral wool. Between the two parts (A and B) is a layer of rubber 0.001 m high.

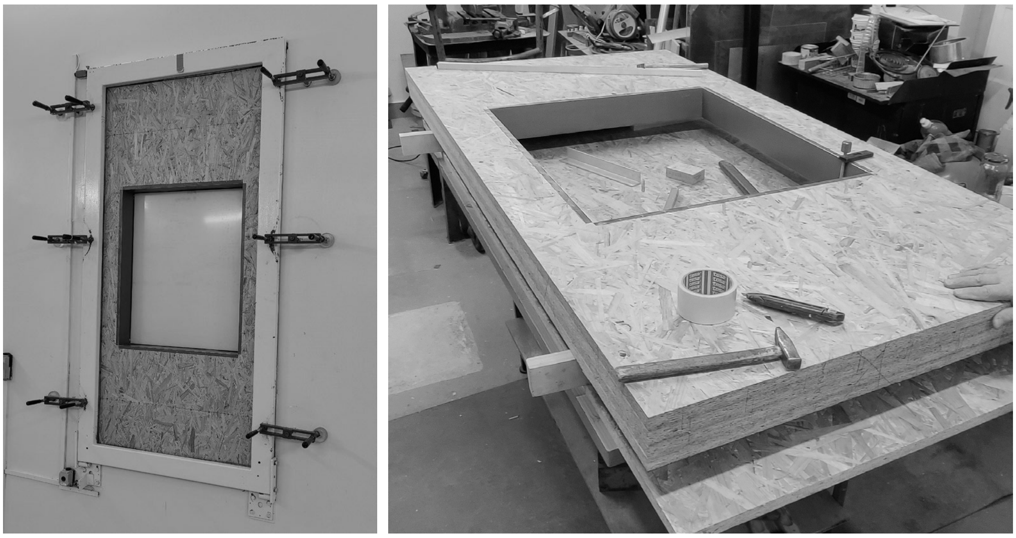

Figure 1. View of partition 0.7 × 0.84 m placed in measuring window and first part (A) of partition during its construction.

The first stage in the construction of the baffle was to build a baffle without a measurement hole to measure the sound insulation of the solid baffle. All those two baffles are characterized by the weighted sound reduction index R_w equal to 50 dB, which allows omitting lateral transmission when analyzing the results. Fig. 2 shows the second part of the baffle (B) without measurement holes.

Figure 2. Second partition (B) without measuring hole.

The measuring path consists of two Norsonic ½" type 1220 pressure microphones, a JBL 2 × 150 VA loudspeaker, the Sound KRAK 200 VA power amplifier and two-channel Norsonic RTA 840 analyzer, which at the same time was used as a measuring signal generator: broadband white noise (in the case of reverberation time measurements the Interrupted Noise Method was used). The meteorological conditions, unchanged during the whole measurements, were temperature 20°C, relative humidity 48%, and atmospheric pressure 994 hPa.

3. Measurement uncertainty

When multiple input parameters affect the outcome of a measurement or prediction, the uncertainty of that outcome can be expressed as a function of the uncertainty of each individual input parameter [9]. If they are not correlated, the uncertainty of the final result can be determined using the law of uncertainty propagation [10]:

$$u = \sqrt{\sum_{i=1}^{n} \left(\frac{\partial f}{\partial X_{in(i)}}\right)^2 u_i^2}\,, \tag{1}$$

where u_i – the partial uncertainty of the i-th parameter of the input function f, in the case of sound insulation tests, $X_{in(i)}$ is the i-th input parameter of the function f defining the sound insulation.

In general, the uncertainty of laboratory measurement of sound insulation will be a function of partial uncertainties specified in the equation

$$u = f\left(u_{L1}, u_{L2}, u_T, u_i, u_a, u_f, u_m\right), \tag{2}$$

where u_{L1} is the partial uncertainty of the sound pressure level measurement in the source room, u_{L2} is the partial uncertainty of the sound pressure level measurement in the receiving room, u_{T2} is the partial uncertainty of the reverberation time measurement in the receiving room, u_i is the uncertainty of the measurement system along with calibration, u_a is the measurement uncertainty (repeatability) of fixing the baffle in the test opening, u_f is the measurement uncertainty of lateral transmission, u_m is the measurement uncertainty caused by the variability of meteorological conditions.

The uncertainties arising from measuring the area of the baffle and the geometrical parameters of the receiving room were excluded from consideration as they are significantly smaller in magnitude compared to other sources of uncertainty [11]. Subsequent calculations did not incorporate the uncertainty stemming from variations in environmental conditions, as the measurements were conducted under nearly identical conditions of temperature, humidity, and pressure, and the impact of any minor fluctuations in these parameters on the results was deemed negligible [12]. The uncertainty introduced by the mounting of the test baffle (u_a) has not been taken into account due to the method of mounting the baffle ensuring repeatability of the mounting for all tested baffles. The uncertainty brought by the measuring system along with the calibration was adopted equal to 0.5 dB in all frequency bands.

Uncertainties u_{L1}, u_{L2} and u_{T2}were determined according to the formula:

$$U_i = \frac{s_i}{\sqrt{n}} t_{(n-1;0.975)}, \tag{3}$$

where s_i is the standard deviation of the relevant variable, n is the size of the measurement baffle and $t_{(n-1;0.975)}$ is the Student's t-distribution quantile. Propagation coefficients for u_{L1} and u_{L2}were assumed to be equal one, whereas for u_{T2} as the T function expressed in the formula

$$\frac{\partial R}{\partial T_2} = \frac{10}{T\,\ln 10}. \tag{4}$$

4. Results and discussion

As part of this project, three homogeneous baffles were tested for their sound insulation through measurements. Baffles were made of PMMA (with a thickness of h = 0.015 m), steel (h = 0.001 m) and aluminium (h = 0.002 m), each with dimensions of 1 m × 2 m, 0.7 m × 0.7 m and 0.7 m × 0.84 m. The evaluation was conducted by comparing the results of the measurements of the specific sound insulation (including the weighted sound reduction index R_w, as defined in [13]) as well as the dispersion of the obtained values L_1, L_2, and T. The standard deviation was used to determine the distribution, which was also used to calculate the measurement uncertainty.

L_1, L_2 i T values were determined based on a set of 70 measurement trials. The measurements were conducted with the sound source placed in two different positions, with 35 measuring points for each position. The evaluation of reverberation time T in the case of broadband noise was conducted using the Interrupted Noise Method.

The results of laboratory tests as characteristics of sound insulation are shown in Figs. 3–5. Tables 1–3 presents the measurements results of sound insulation in 1/3 octave bands, the weighted sound reduction index R_w and spectrum adaption terms C and C_{tr} with expanded uncertainty of measurement U_c, taking into account partial uncertainties specified in relation (2). Additionally, in order to facilitate comparison of the obtained results, the calculated values of the R_{A1} i R_{A2} indicators were presented, where:

$$R_{\mathrm{A1}} = R_{\mathrm{w}} + C \qquad R_{\mathrm{A2}} = R_{\mathrm{w}} + C_{\mathrm{tr}} \tag{5}$$

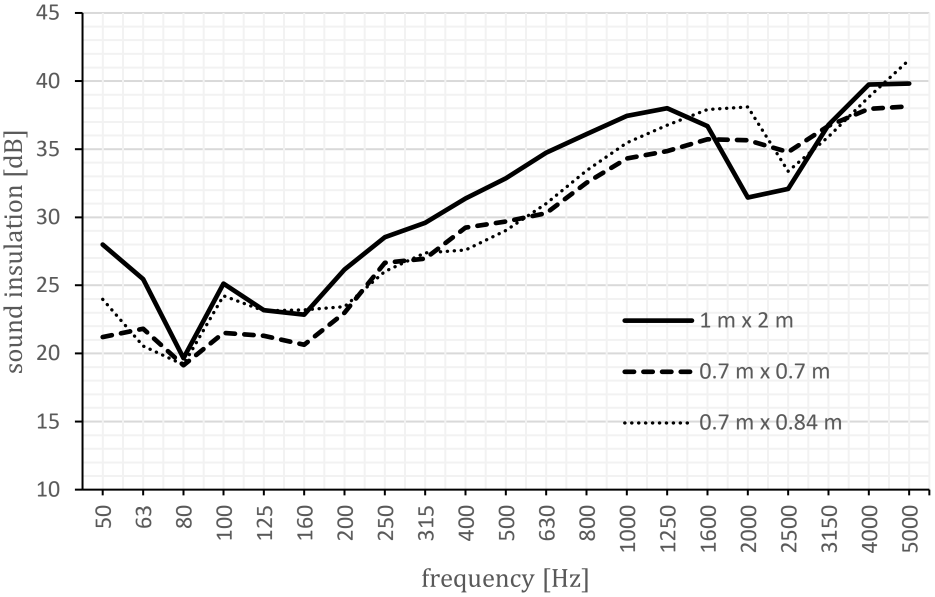

Figure 3. Sound insulation characteristics obtained from laboratory tests of PMMA plates with different dimensions and thickness h =0.015 m.

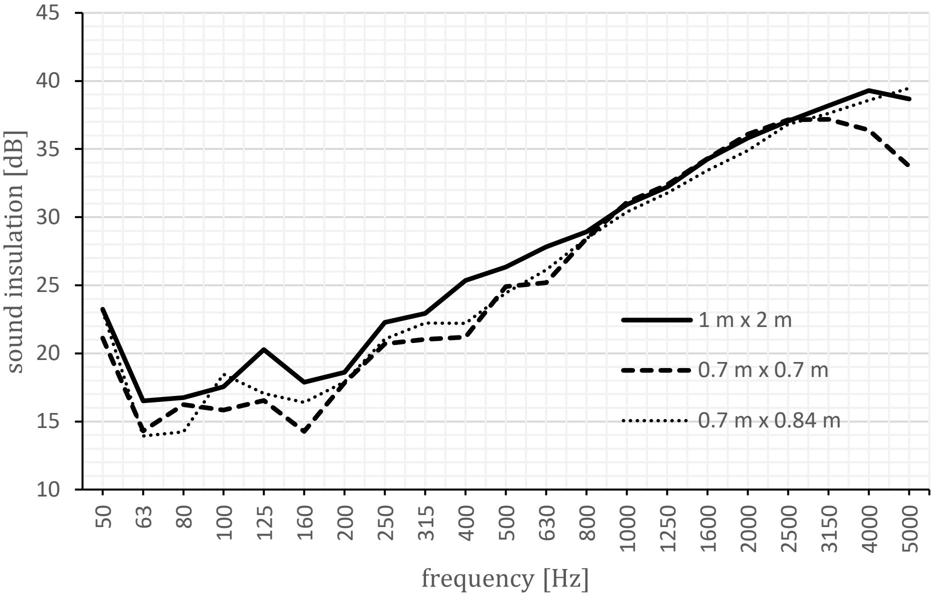

Figure 4. Sound insulation characteristics obtained from laboratory tests of steel plates with different dimensions and thickness h = 0.001 m.

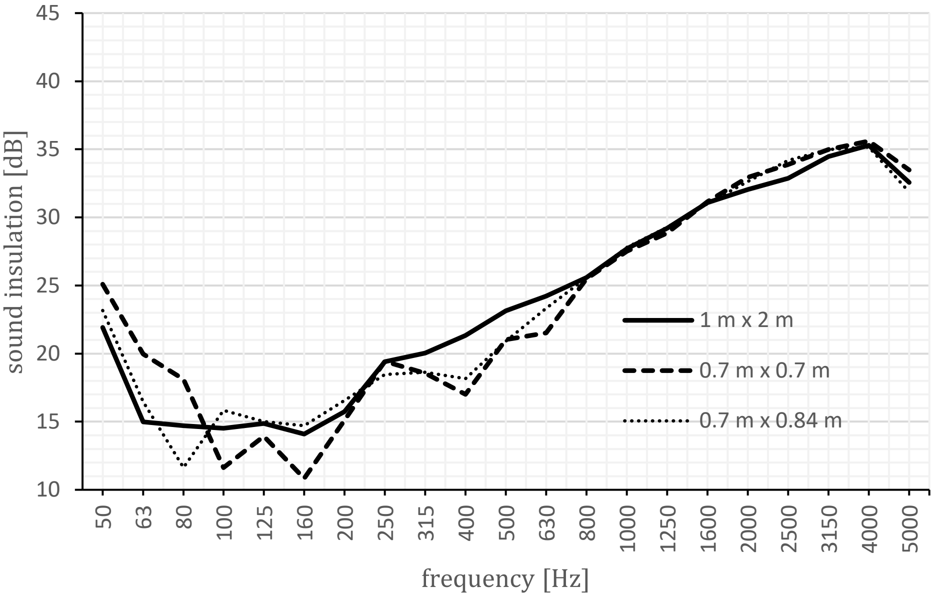

Figure 5. Sound insulation characteristics obtained from laboratory tests of aluminium plates with different dimensions and thickness h = 0.002 m.

Table 1. Sound insulation characteristics in 1/3 octave bands, weighted sound reduction index R_w and spectrum adaption terms C and C_{tr} of PMMA plate with different dimensions and thickness h = 0.015 m.

f [Hz]	1 m × 2 m		0.7 m × 0.7 m		0.7 m × 0. 84 m	
	R [dB]	U_c [dB]	R [dB]	U_c [dB]	R [dB]	U_c [dB]
50	28.0	1.0	21.2	0.9	24.0	1.0
63	25.4	0.9	21.8	0.8	20.5	0.9
80	19.7	0.8	19.1	0.9	19.2	0.9
100	25.1	0.7	21.5	0.6	23.5	0.6
125	23.2	0.6	21.1	0.5	23.1	0.5
160	22.9	0.5	20.6	0.5	23.2	0.5
200	26.2	0.3	23.0	0.3	23.4	0.3
250	28.5	0.2	26.7	0.2	26.0	0.3
315	29.6	0.2	27.0	0.2	27.4	0.3
400	31.4	0.2	29.2	0.2	27.5	0.2
500	32.9	0.2	29.7	0.2	29.1	0.2
630	34.7	0.2	30.3	0.2	31.0	0.2
800	36.1	0.2	32.5	0.2	33.4	0.2
1000	37.4	0.2	34.3	0.2	35.5	0.2
1250	38.0	0.1	34.9	0.2	36.8	0.2
1600	36.7	0.2	35.7	0.2	37.9	0.2
2000	31.5	0.2	35.6	0.2	38.1	0.2
2500	32.1	0.2	34.8	0.2	33.4	0.2
3150	36.8	0.2	36.7	0.2	35.9	0.2
4000	39.8	0.2	38.0	0.2	38.8	0.2
5000	39.8	0.3	38.1	0.2	41.6	0.3
R_w	35(.2)	0.2	33(.5)	0.2	34(.0)	0.2
C	-2	0.2	-1	0.2	-1	0.3
C_{tr}	-3	0.2	-4	0.2	-3	0.3
R_{A1}	33	0.2	32	0.3	33	0.3
R_{A2}	32	0.2	29	0.3	31	0.3

Table 2. Sound insulation characteristics in 1/3 octave bands, weighted sound reduction index R_w and spectrum adaption terms C and C_{tr} of steel plate with different dimensions and thickness h = 0.001 m.

f [Hz]	1 m × 2 m		0.7 m × 0.7 m		0.7 m × 0. 84 m	
	R [dB]	U_c [dB]	R [dB]	U_c, dB	R [dB]	U_c [dB]
50	23.2	1.0	21.1	1.2	23.1	1.1
63	16.5	0.9	14.3	1.2	13.9	1.1
80	16.8	0.7	16.2	0.7	14.2	1.0
100	17.6	0.4	15.8	0.8	18.5	0.8
125	20.3	0.6	16.5	0.6	17.1	0.4
160	17.9	0.5	14.3	0.7	16.4	0.4
200	18.6	0.4	17.8	0.5	17.9	0.4
250	22.3	0.2	20.7	0.3	21.0	0.3
315	22.9	0.2	21.0	0.3	22.2	0.3
400	25.3	0.2	21.2	0.3	22.2	0.2
500	26.3	0.2	24.9	0.2	23.7	0.2
630	27.8	0.2	25.2	0.2	26.1	0.2
800	28.9	0.2	28.4	0.2	28.4	0.2
1000	30.9	0.2	31.1	0.2	30.4	0.2
1250	32.2	0.2	32.4	0.2	31.8	0.2
1600	34.3	0.2	34.3	0.2	33.4	0.2
2000	35.8	0.2	36.1	0.2	34.9	0.2
2500	37.1	0.2	37.1	0.2	36.8	0.2
3150	38.2	0.2	37.2	0.2	37.6	0.2
4000	39.3	0.2	36.4	0.2	38.6	0.2
5000	38.7	0.2	33.8	0.2	39.5	0.3
R_w	30(.9)	0.2	29(.1)	0.2	29(.7)	0.2
C	-1	0.4	-1	0.4	-1	0.3
C_{tr}	-4	0.4	-4	0.4	-4	0.3
R_{A1}	29	0.4	28	0.4	28	0.3
R_{A2}	26	0.4	25	0.4	25	0.3

Based on the obtained results, it can be seen that both smaller baffles have lower sound insulation values compared to the larger baffle in the low and medium frequency range (up to about 800 Hz for baffles made of steel and aluminium and up to 1600 Hz for the PMMA baffle). In the case of the PMMA baffle, which has the highest sound insulation among the tested baffles, noticeable discrepancies occur in the range of coincidence frequencies. For the 1m × 2m baffle, the decrease in sound insulation begins at 1600 Hz and reaches its minimum at 2000 Hz. In the case of the 0.7 m × 0.84 m baffle, the coincidence frequency has been shifted – the decrease starts at 2000 Hz, and the minimum is reached only at 2500 Hz. In the case of the 0.7 m × 0.7 m baffle, there is no clear decrease in the coincidence frequency range, but there is some "blurring" observed, consisting of a reduction in sound insulation values in adjacent bands (from 1000 Hz to 2500 Hz), which could create an impression that the coincidence phenomenon almost does not occur in the tested frequency range. The most significant difference between both small baffles is noticeable in the range of the low frequencies (100 – 200 Hz). The rectangular baffle's sound insulation has higher values than the square baffle and is therefore closer to the sound insulation of the large baffle.

Root mean square deviation (RMSD) was used to compare the spectral sound insulation of the large and small baffles. The measurement results of the large baffle in both cases served as a reference value. RMSD was calculated for the primary frequency range (100 Hz – 3150 Hz) and for the extended frequency range (50 Hz – 5000 Hz). The results are presented in Table 4.

Based on the calculated RMSD values it can be observed that the spectral sound insulation results of all small rectangular baffles have better convergence with the results of the large baffle. This is particularly noticeable for baffles with lower sound insulation (steel and aluminium) in both the primary and extended frequency ranges. The calculated RMSD values differ from 0.5 dB to 0.9 dB. The situation is different for the baffle made of PMMA. Here. the calculated RMSD values are significantly higher (2.8 dB to 3.1 dB) and are due to significant differences in most of the tested frequency bands. In addition. this baffle has much higher sound insulation. and the coincidence frequency falls within the range of the considered bands (unlike baffles made of steel and aluminium).

Table 3. Sound insulation characteristics in 1/3 octave bands, weighted sound reduction index R_w and spectrum adaption terms C and C_{tr} of aluminium plate with different dimensions and thickness h = 0.002 m.

f [Hz]	1 m × 2 m		0.7 m × 0.7 m		0.7 m × 0. 84 m	
	R [dB]	U_c [dB]	R [dB]	U_c, dB	R [dB]	U_c [dB]
50	21.9	1.0	25.1	0.8	23.2	0.9
63	15.0	1.0	20.0	0.8	16.5	0.9
80	14.7	0.9	18.1	0.8	11.6	1.0
100	14.5	0.8	11.6	0.9	15.8	0.7
125	14.9	0.5	13.9	0.2	15.0	0.4
160	14.1	0.4	10.8	0.6	14.7	0.4
200	15.7	0.4	15.1	0.4	16.6	0.4
250	19.4	0.3	19.4	0.3	18.5	0.3
315	20.0	0.2	18.6	0.3	18.6	0.3
400	21.3	0.2	17.0	0.2	18.2	0.2
500	23.1	0.2	21.0	0.2	20.9	0.2
630	24.2	0.2	21.5	0.2	23.3	0.2
800	25.6	0.2	25.5	0.2	25.6	0.2
1000	27.7	0.2	27.5	0.2	27.8	0.2
1250	29.2	0.2	28.9	0.2	29.3	0.2
1600	31.1	0.2	31.1	0.2	31.0	0.2
2000	32.1	0.2	32.9	0.2	32.6	0.2
2500	32.9	0.2	33.9	0.2	34.2	0.2
3150	34.5	0.2	35.0	0.2	35.0	0.2
4000	35.3	0.3	35.6	0.2	35.2	0.2
5000	32.6	0.3	33.5	0.2	31.9	0.2
R_w	27(.6)	0.2	26(.2)	0.2	26(.9)	0.2
C	-2	0.2	-2	0.3	-2	0.2
C_{tr}	-4	0.2	-5	0.3	-4	0.2
R_{A1}	25	0.2	24	0.3	24	0.3
R_{A2}	23	0.2	21	0.3	22	0.3

Table 4. The calculated RMSD values for comparing the sound insulation spectrum results of the large baffle and the small baffles.

Baffle material	**Range of bands tested**	**RMSD [dB]**	
		0.7 m × 0.7 m	0.7 m × 0.84 m
PMMA	Primary bandwidth (100 Hz – 3150 Hz)	2.9	2.8
	Extended bandwidth (50 Hz – 5000 Hz)	3.1	2.8
Steel	Primary bandwidth (100 Hz – 3150 Hz)	2.0	1.5
	Extended bandwidth (50 Hz – 5000 Hz)	2.3	1.5
Aluminium	Primary bandwidth (100 Hz – 3150 Hz)	1.9	1.2
	Extended bandwidth (50 Hz – 5000 Hz)	2.2	1.3

According to the guidelines included in PN-EN ISO 717-1 [13]. values of the single-number weighted sound insulation index R_w and the spectral adaptation indexes C and C_{tr} (Tables 2-4) were determined. For the PMMA material. the rectangular baffle (34 dB) gives results closer to the R_w value of the large baffle (35 dB) than the square baffle (33 dB). In the case of the other two materials (steel and aluminium). the same R_w values were obtained for both small baffles. differing by 1 dB from the large baffle in each case. However. after increasing the result's precision by considering decimal values. we notice that the square baffle has an R_w value closer to the large baffle. After taking into account the spectral characteristics by determining R_{A1} and R_{A2} according to formula (5). we notice that while for R_{A1} the differences are similar to R_w in each case. R_{A2} gives more diverse results. The square baffle gives differences of up to 3 dB in the case of PMMA. while the rectangular baffle gives only 1 dB. The differences are minor for steel and aluminium but still favour the rectangular baffle. This is due to more significant spectral differences in the low and medium frequency ranges considered when determining R_{A2}.

4. Conclusions

Making far-reaching conclusions would require multiple series of measurements and analysing them for discrepancies in the results obtained. Based on the results obtained after testing three samples of different sizes . it can be concluded that both small baffles have lower sound insulation compared to the large baffle. which is visible in the lowest and middle-frequency ranges considered. This trend is also visible in the results of the calculated indicators Rw. R_{A1}. and R_{A2}. At the same time. it should be noted that these differences are more significant in the case of the square-shaped baffle. This is evident in both the calculated indicator values and the convergence of spectra based on the calculated RMSD values. Therefore, it is important to note that the use of reduced size baffles may not be an alternative method of measurement. but rather extends the laboratory's ability to test the sound insulation of smaller baffles. When performing sound insulation measurements on small baffles. one should avoid using square-shaped baffles unless necessary due to the default shape of the tested baffle.

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Additional information

The author 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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