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Section: Environmental protection

Investigation of the variation of noise spectrum behind noise barriers made of different materials

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Abstract

Motor transport is one of the main sources of noise pollution. Each year, the number of people who are exposed to increased noise levels grows, especially in large cities. To reduce the spread of noise, noise barriers are built. Noise barriers are manufactured using a variety of materials. The paper analyzes how the noise level and spectrum is changed by aluminium, "Durisol" block, wooden and brick noise barriers. The change of noise level at low, medium and high frequencies is also analyzed.

Keywords: aluminium; brick; "Durisol" block; wooden; noise barriers; noise spectrum.

Nomenclature

Δ_A	corrections (dB)
L_A	sound pressure level (dBA)

1. Introduction

Noise is an environmental problem, which in recent years, attracts more and more attention. The main sources of noise are road, rail, air transport and industry [3, 14, 20]. The problem of noise pollution is particularly relevant in densely populated cities. Recent studies have showed that urban forms can affect traffic flows and thus the level of traffic noise [22; 24), and a number of studies have showed that traffic noise is the major source of noise in urban areas [15; 16–17]. For the urban areas in Lithuania, it has been found that traffic flows contributed around 80% of all noise sources (1; 13)."

Traffic flows constitute around 80% of all noise sources operating in urban areas (1; 13). Recently, the growth of number of cars is observed, therefore noise emission conditioned by these means of transport also increases. Agreeably to the statistics of 2009, about 55% of the population of major European cities during the day is exposed to noise levels that exceed the permitted levels (23).

Noise has a negative impact on people's health and can be the cause of various health problems and illnesses. People, who live or spend a large part of the day at high noise areas, usually, complain of headaches, sleep disorders and feel irritated (26). Scientific studies have revealed that the increased level of noise in the residential and working environment increases the irritability of the nervous system and icreases the risk of heart attack (6–7; 27).

Noise absorbing or reflecting barriers are widely used to protect populated areas from the traffic noise (8; 11). The main advantage of a noise barrier over other collective noise suppression measures (green hedges, sanitary zones) is that they require little space (2; 19). The reduction of noise level is observed immediately behind the barrier; thus, residential buildings located near a road or highway can be protected.

The effectiveness of a noise barrier is affected by three basic groups of parameters. The first group of parameters is the characteristics of the emitted noise, which depend on the noise source (for example, the noise spectrum). The second group is the environment in which sound waves are emitted. This group of parameters includes occupation of building area, meteorological conditions, characteristics of a surface over which sound waves are emitted. For example, a surface covered with grass absorbs the noise, and paved surfaces reflect it, which may increase the noise level. The third group includes parameters of a noise barrier. The main parameters of a noise barrier that determine its effectiveness are dimensions, the distance to the noise source, the barrier mass per area unit as well as material from which the barrier is made (5; 12).

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With increasing frequency, the insulation of a noise barrier also increases (21). Insulation is worsened by resonant and critical frequencies (8). Resonant frequencies are overlapping frequencies of sound waves and barrier's own vibrations. Resonant frequencies take place within the range of low frequencies and are usually below the lower limit of the normed range (100 Hz).

Noise barriers can be single- or double-layered, with the gap of air or layer of sound absorbing material. The main parameter of a single-layered barrier is the mass of a structure. With the increasing mass of the structure, the noise insulation improves. Double-layered barriers consist of two parts with the air gap or layer of sound absorbing material between them. The air gap helps to increase the insulation of the structure without changing its mass. The air gap improves the noise insulation only in terms of frequencies higher than the resonant frequency of the structure (10).

The aim of this paper is to analyze and compare how the noise level is reduced behind noise barriers made of different materials.

2. Case study

Four noise barriers made of different materials: aluminium, "Durisol" blocks, brick and wood, were used for the purposes of the analysis. All barriers are located near busy roads; however, traffic flows on one of the roads are controlled by means of a traffic-light, while traffic flows on the rest of the roads are not controlled.

Aluminium noise barrier is located at the southern bypass of Vilnius city, which is part of an international IXB transport corridor. This section of the road connects roads E28 and E85. About 33,000 cars pass this road during the day. The road has 8 lanes: 4 of them stretch over the skyway above the Savanorių Avenue. Traffic speed at these lanes is limited to 80 km/h. Traffic speed at the remaining four lanes is limited to 50 km/h. There are no intersections and the traffic is not slowed down at this part of the road. Here, the noise barrier is constructed of two sheets of aluminum (1.00 mm perforated on the road side, and 1.5 mm not perforated on the side of residential buildings), the space between the sheets is filled with 4 cm layer of hydrophobic mineral wool. The barrier is 3.8 m high and 0.13 m thick. In addition, the barrier is placed on a mound with a height of 7 m. The dependence of the airborn noise attenuation index in the case of aluminium barrier on the frequency is shown in Figure 1.

A noise barrier made of "Durisol" blocks is built on both sides of highway E85 (Vievis settlement). The road has four lanes, two in both directions, which are separated by means of a metal guide rail. Speed limit at this stretch of the highway is 70 km/h. Traffic flows are not controlled by traffic-lights, the traffic is not slowed down; therefore, the noise level varies little and is relatively stable. About 21,500 cars pass this section of the road during the day. The height of the noise barrier is 3.5 m and its thickness is 0.22 m. "Durisol" blocks are made of 90% of softwood (spruce wood), 8% of special minerals and 2% of Portland cement. The material's modulus of elasticity is 1500 MPa and the mass of the area unit is 80 kg/m^2.

A noise barrier made of bricks is located in Vilnius, near Žirmūnų street. The street has four lanes with a speed limit of 60 km/h. The traffic is quite heavy on this street. Traffic flows are controlled by traffic-lights, therefore the noise level varies. The barrier at Žirmūnų street is 2.3 m high and 0.7-0.4 m thick, plastered on both sides.

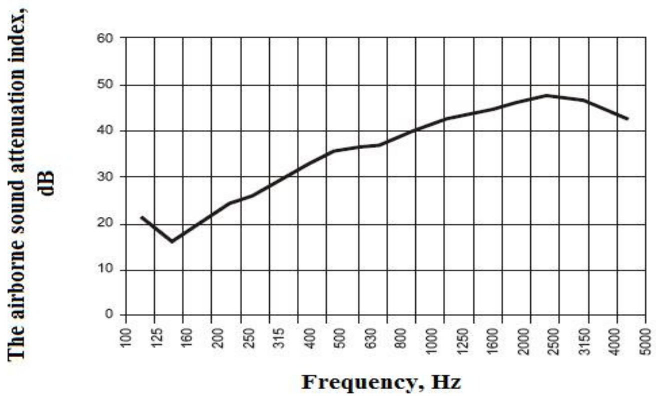

Fig. 1. The airborne sound attenuation index (EN 1793-2 1999) for aluminium noise barrier

A wooden noise barrier is installed near the road E272. Speed limit here is 60 km/h. About 13,000 cars pass this section of the road during the day. The road consists of four lanes. The wooden barrier is 3.5 m high, made of one layer of boards with a thickness of 0.3 m.

At each of the sites of the investigation, the noise level and spectrum were measured in 4 locations. Measurements were carried out opposite the barrier (9.5 m from the central reservation) and at the distance of 1.5 m behind the barrier. Control measurements were carried out at the same roads, at locations that are not covered by the noise barrier, at the distance of 9.5 m from the central reservation and in parallel to the point of 1.5 m behind the imaginary barrier (Fig. 2).

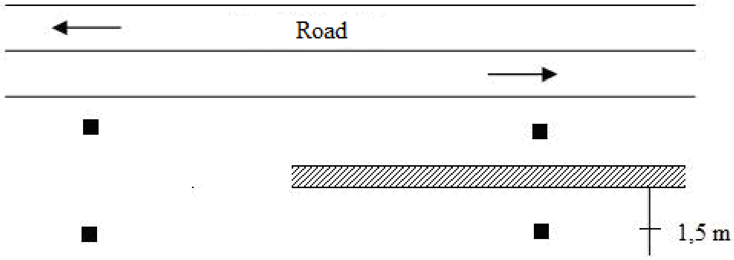

Fig. 2. The scheme of noise measurements place: ■ – measurement place; ▨ – noise barrier

The precision sound level analyser "Bruel&Kjaer 2260" was used to measure the noise spectrum of the traffic. The measurements of the noise level were carried out at frequencies from 40 Hz to 8000 Hz, at one-third octave bands. Values of direct measurements were determined with a margin of error of 1.5%. The measurements were carried out at a height of 1.5 m, at a distance of 0.5 m from the person. The microphone was directed toward the noise source.

The lowest resonant frequency of noise barriers made of a single material was calculated by means of the following equation:

$$f_r = 0,454 \cdot h \cdot c \cdot \left(\frac{1}{x^2} + \frac{1}{y^2}\right) \tag{1}$$

where h is the thickness of the noise barrier, m; c is the speed of sound in the noise barrier, m/s^2; x, y – dimensions of the noise barrier, m (Guidelines on...)

The range of audio frequencies from 40 Hz to 8000 Hz (at 1/3 octave bands) was divided into ranges of low (40–200 Hz), medium (200–800 Hz) and high (800–8000 Hz) frequencies. The average sound pressure level for each range was calculated by means of the following equation:

$$L_A = 10 \lg \sum_{I=1}^{N} 10^{0,1 L_i} \tag{2}$$

where L_A is sound pressure level, dBA; L_i – sound pressure level with Δ_A correction, dBA (21).

The errors were calculated by the following equation:

$$\pm \Delta L = \sqrt{\frac{\sum_{i=1}^{n} (\overline{L} - L_i)^2}{n(n-1)}} \tag{3}$$

where $\overline{L}$ is the average sound pressure level, dB; L_i is sound pressure level in frequency, dB; n is number of measurements (4).

Correction of each measured sound level was carried out in accordance with the frequency characteristics of these sound levels (Table 1).

Table 1. Δ_A corrections

Frequency, Hz	63	125	250	500	1000	2000	4000	8000
Δ_A, dB	–26	–16	–9	–3	0	+1	+1	–1

In the process of the assessment of the equivalent noise level of the individual ranges of the noise spectrum, the errors were calculated.

3. Results and discussion

Noise level reduction within the low-frequency range behind noise barrier made of different materials is shown in Figure 3.

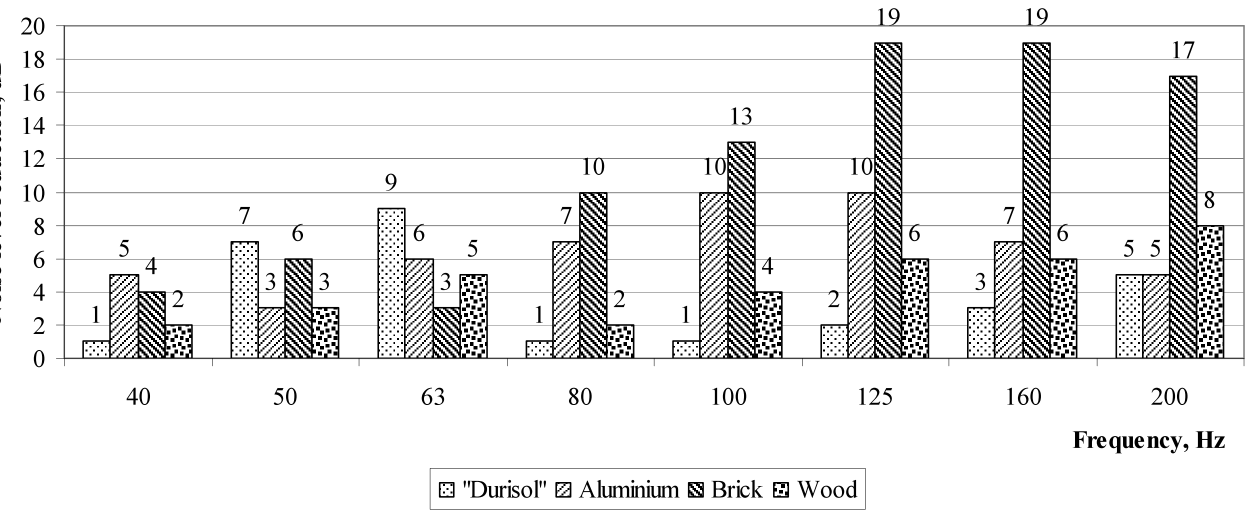

Fig. 3. Noise level reduction behind noise barriers of different materials in low frequency range

Within the low-frequency range, the barrier made of “Durisol” blocks reduces the noise by 1–9 dB, depending on the frequency. The noise barrier made of “Durisol” blocks demonstrated the best results of the noise level reduction at the frequency of 50 Hz and 63 Hz. Meanwhile the reduction of the noise level at the frequency of 40, 80 and 100 Hz amounts to only 1 dB. The deterioration of the sound insulation at the low-frequency range is determined by the barrier’s own vibrations and resonances (21). Usually, it is possible to identify the range in which several resonant frequencies evidenced as the deterioration of noise insulation are observed. The calculation of the possible resonant frequency by means of the equation 1 revealed that the first resonant frequency of the “Durisol” block barrier is about 33 Hz. The calculated resonant frequency is close to the measured deterioration of noise insulation at the frequency of 40 Hz. Noise level reduction behind the “Durisol” block barrier starts to increase from 125 Hz.

The aluminium noise barrier reduced the noise level at the low-frequency range by 3–10 dB. The deterioration of the noise level reduction is observed at 50 Hz and 160–200 Hz frequencies. The second deterioration of the noise level reduction may have occurred due to the technical characteristics of the aluminium structure. The manufacturer presents the assessment of the index of the airborn noise attenuation behind this barrier (Fig. 1). The graph shows that the index deteriorates at 125–160 Hz. The resonant frequency may occur at these frequencies.

The brick noise barrier reduced the noise level at the low-frequency range by 3–19 dB. Deterioration of 3 dB and 2 dB of the noise level reduction was observed at the frequency of 3 Hz and 200 Hz, respectively. Significant increase of the noise level reduction was observed at 80 Hz and 125 Hz frequency (7 dB in the first case and 6 dB in the second).

The wooden noise barrier reduced the noise level at the low-frequency range by 2–8 dB. With increasing frequency, the noise level reduction behind the barrier also increases, except for the 80 Hz frequency octave. The noise level reduction at this octave fell by 3 dB. The resonant frequency calculated by means of the equation 1 is 84 Hz. The resonant frequency may be the reason of the deterioration of the noise level reduction.

The noise level reduction at the low-frequency range varies behind the noise barriers made of different materials. Deterioration of the noise level reduction behind the four barriers was recorded at different frequencies. Moreover, several resonant frequencies were recorded for each of the four barriers, except for the wooden barrier. The deterioration of the noise level reduction for each of the four barriers was observed in only one octave, while the second deterioration was observed in one octave (behind the brick barrier) or it extended over several frequency octaves (behind the “Durisol” block barrier and the aluminium barrier).

The highest reduction of the noise level at the low-frequency range (when comparing the noise reduction behind the barriers made of different materials) was determined at different frequency octaves. The “Durisol” block barrier presented the best results of the noise reduction at 50–63 Hz, the aluminium barrier – at 100–125 Hz, the brick barrier – at 125–160 Hz, and the wooden barrier – at 200 Hz frequency. However, the brick barrier has the exceptional noise insulation at the low-frequency range, where the best noise reduction is observed at 80–200 Hz (compared with the other barriers).

The reduction of medium-frequency noise behind the noise barriers made of different materials is shown in Figure 4.

The “Durisol” block barrier reduced the noise level at the medium-frequency range by 7–14 dB. With increasing frequency, the noise level reduction behind the barrier also increased. The frequency of 630 Hz is the only exception, where 1 dB lower noise level reduction was determined.

The aluminium noise barrier reduced the noise level at the medium-frequency range by 10–17 dB, depending on frequency. At the frequency of 315 Hz, the deterioration of 13–10 dB of the noise level reduction was observed. The noise level reduction of 13 dB is reached again only at 500 Hz frequency octave. From this octave onward, the noise level reduction starts to increase and reaches 17 dB at 800 Hz frequency octave.

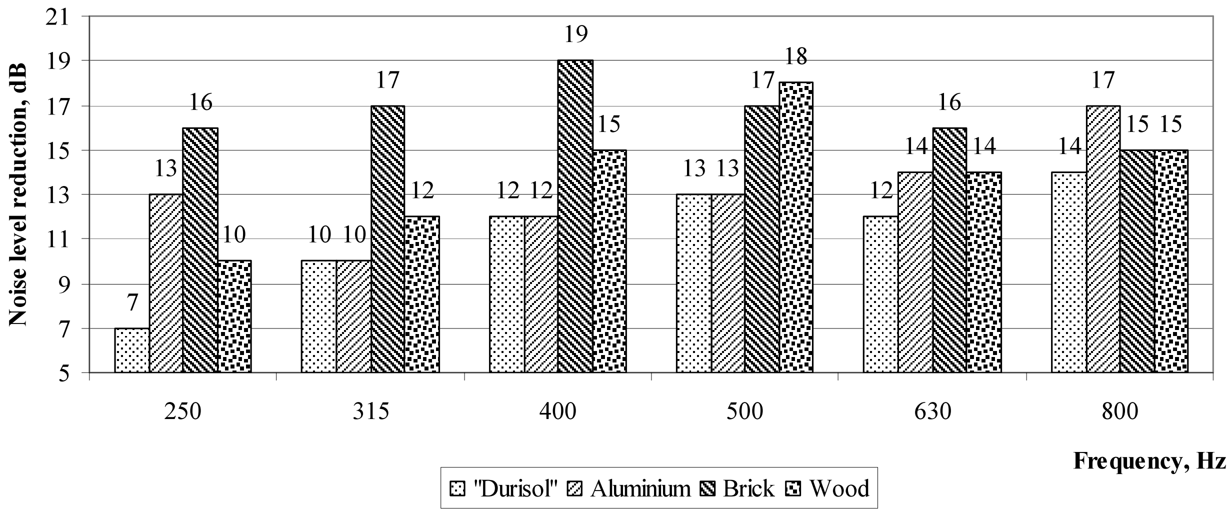

Fig. 4. Noise level reduction behind noise barriers of different materials in medium frequency range

The brick noise barrier reduces the noise level at the medium-frequency range by 15–19 dB, depending on frequency. At this range, the increase of the noise level reduction is observed from 250 Hz to 400 Hz. At 400 Hz frequency octave, the noise level reduction reaches the maximum value (19 dB) at the medium-frequency range, and as the frequency continues to increase, the reduction reaches the minimum value (15 dB) at 800 Hz frequency.

The wooden noise barrier reduced the noise level at the medium-frequency range by 10–18 dB. The increase of the noise level reduction was observed from 250 Hz to 500 Hz. The noise level reduction began to decrease at 500 Hz, and at 800 Hz, the noise level reduction lower by 3 dB than the maximum value at this range was recorded.

The comparison of the noise level reduction behind the barriers made of different materials shows that an increase of frequency does not always result in an increase of the noise level reduction. Behind the aluminium barrier, noise insulation deteriorates by 3 dB at 315 Hz frequency octave, whereas behind the wooden barrier and the “Durisol” block barrier, deterioration of 4 dB and 1 dB, respectively, was observed at 630 Hz frequency octave. The brick noise barrier stands out among the other barriers. Behind this barrier, the noise level reduction has been increasing up to 400 Hz frequency octave and began decreasing from it onward.

The noise level reduction at the high-frequency range behind the noise barriers made of different materials is shown in Figure 5.

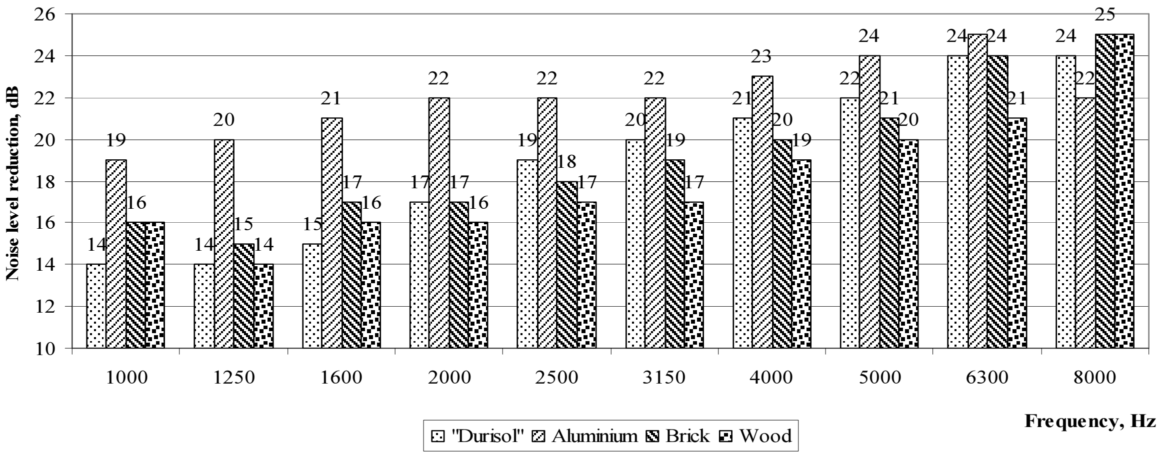

Fig. 5. Noise level reduction behind noise barriers of different materials in high frequency range

The “Durisol” block noise barrier reduced the noise level at the high-frequency range by 14–24 dB. The noise level reduction increased with the increasing frequency or remained stable (as in cases of 1 000 Hz and 1 250 Hz as well as 6 300 Hz and 8 000 Hz).

The aluminium noise barrier reduced the high-frequency noise level by 19–25 dB. As the frequency increased, the increase of the noise level reduction was observed from 1000 Hz to 2000 Hz as well as from 3150 Hz to 6 300 Hz. The noise level reduction remained stable from 2000 Hz to 3150 Hz, and the decrease of 3 dB of the noise level reduction was observed at 8000 Hz frequency octave.

The brick noise barrier reduced the high-frequency noise level by 15–25 dB. With increasing frequency, the noise level reduction also increased. With the exception of 1250 Hz frequency, at which the noise level reduction decreased by 1 dB, and 2000 Hz, at which the noise level reduction remained stable.

The wooden noise barrier reduced the high-frequency noise level by 14–25 dB. The deterioration of 2 dB of the noise level reduction was determined at 1250 Hz frequency. The noise level reduction remained stable at 2000 Hz and 3150 Hz, while with the increase of frequency (starting from 4000 Hz), the noise level reduction also increased.

All noise barriers reduced the noise level at the high-frequency range similarly: by 14–15 dB (aluminium barrier – by 19 dB) and 24–25 dB. The deterioration of 3 dB of the noise level reduction at the high-frequency range behind the aluminium barrier was observed at 8000 Hz. The deterioration of 1 dB and 2 dB of the noise level reduction behind the brick and wooden barrier, respectively, was observed at 1250 Hz frequency.

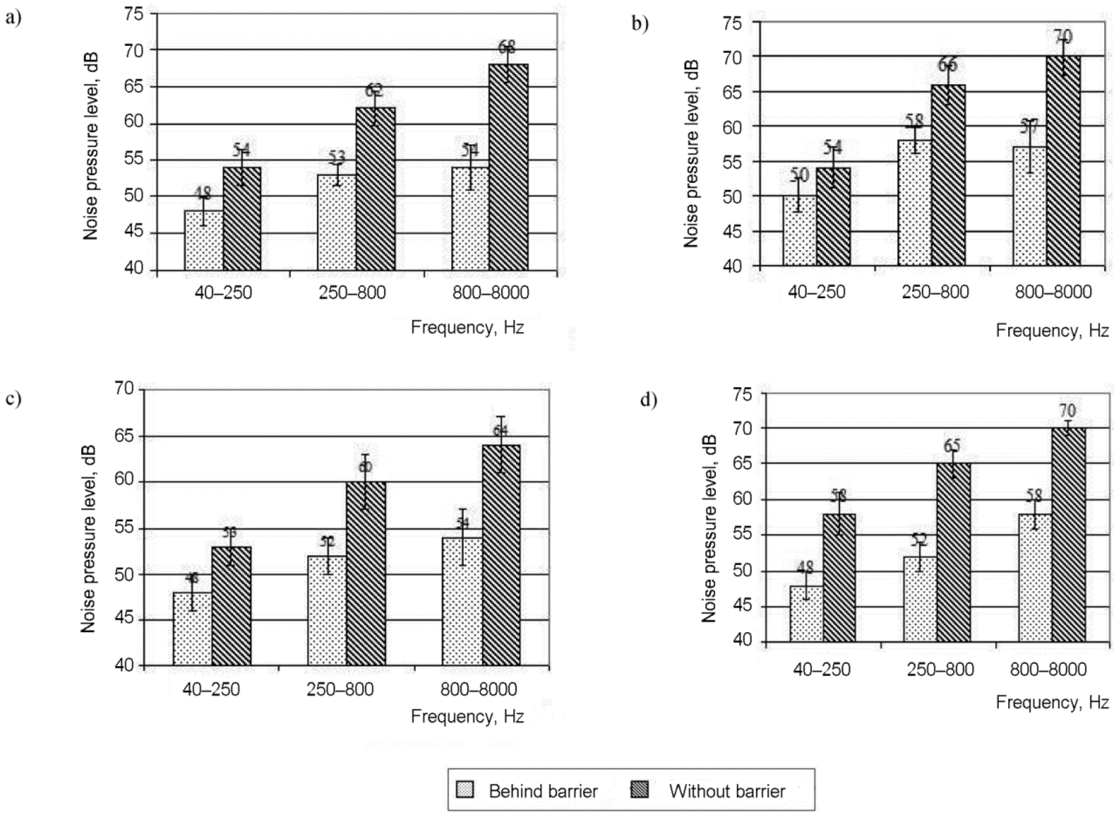

Fig. 6. Noise pressure level in areas behind and without noise barriers (distance is 1,5 m of barrier): a) aluminium; b) „Durisol“; c) wood; d) brick

The extent to which the barriers made of different materials reduce the noise level at low, medium and high-frequency ranges, in comparison with the territory without the barriers, is shown in Figure 6. The figure shows that all the barriers reduce the noise level at the high-frequency range best. Acoustic screens reduced the high-frequency noise level at least by 10 dB. The low-frequency noise level was reduced behind the barriers by 4–10 dB. Among all the barriers, the brick noise barrier behind which the low-frequency noise level was reduced by 10 dB stands out. The other three barriers reduced the noise level by 4–6 dB.

The barriers reduced the medium-frequency noise level by 8–13 dB. At this range, the brick noise barrier showed the best result of the noise level reduction (13 dB). The other three barriers reduced the noise level similarly – by 8–9 dB.

The barriers reduced the high-frequency noise level by 10–14 dB. At this range, as opposed to low- and medium-frequency ranges, the noise level was best reduced by the aluminium noise barrier. Behind this barrier, the noise level was reduced by 14 dB. The “Durisol” block barrier reduced the noise level by 13 dB, the brick barrier – by 12 dB and the wooden barrier – by 10 dB.

The results of the analysis show that noise barriers made of different materials reduce the noise level of different frequency range differently. The barrier should be selected depending on the frequency range of noise level to be reduced.

4. Conclusions

1. The investigated noise barriers reduced the low-frequency noise level least. The low-frequency noise level (at a distance of 1.5 m from the barrier) was best reduced by the brick noise barrier. Its noise insulation reaches 10 dB. The other barriers reduced the low-frequency noise level by 4–5 dB.

2. The medium-frequency noise level (as the low-frequency noise level) was best reduced by the brick noise barrier. The noise level behind this barrier was reduced by 13 dB (at a distance of 1.5 m from the barrier). The other three barriers reduced the noise level by 8–9 dB.
3. The high-frequency noise level is best reduced (by 14 dB) by the aluminium noise barrier (at a distance of 1.5 m from the barrier). The “Durisol” block barrier reduced the noise level by – 13 dB, the brick barrier – by 12 dB and the wooden barrier – by 10 dB.

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