12th International Conference
ENVIRONMENTAL ENGINEERING
April 27–28, 2023, Vilnius, LITHUANIA

eISSN 2029-7092
eISBN 978-609-476-342-7
Article ID: enviro.2023.915
https://doi.org/10.3846/enviro.2023.915

MODELLING OF SOUND REDUCTION OF SOUND INSULATING ENCLOSURE WITH RECYCLED RUBBER COVERED WALLS

Tomas VILNIŠKIS*, Tomas JANUŠEVIČIUS

Department of Environmental Protection and Water Engineering,
Vilnius Gediminas Technical University, Saulėtekio al. 11, Vilnius, Lithuania

Received 16 January 2023; accepted 20 February 2023

Abstract. The excessive noise of machines and devices could be reduced with the use of acoustic enclosures. Additional requirement for enclosures: free air circulation through construction walls, which is important for device ventilation. The acoustic properties of the construction parts are essential to model their ability to reduce noise. The basic properties of airborne sound insulation of construction walls and absorption of used material should be experimentally tested. In this article, sound reduction modelling of acoustic enclosure with recycled materials covered walls was presented. Sound pressure level reduction of enclosure was modelled with Odeon software. A 3D model was created that includes the acoustic properties of the materials used. The enclosure walls consist of two different constructions. The side walls and roof were made from a single plasterboard covered with recycled rubber material. The back and front walls were constructed as louver construction, which plates were mounted with the ability to change the tilt angle which allows to create an air transparent construction. Acoustic properties of the materials used were tested in different ways. Sound absorption properties of 50 mm thick sample of recycled rubber and transmission loss parameters of used sound insulating walls were measured in the impedance tube. The results of the experimental test of the construction parts were included in the 3D model. The modelling results represented a decrease in sound pressure levels with an increasing distance from the enclosure on different sides. Four different enclosures with different tilt angle of louver plates (0°, 15°, 30°, 45°) were modelled. Results were presented in the 125–4000 Hz frequency range. According to the results, efficiency of enclosure sound reduction with 45° tilted plates could reach up to 12 dB.

Keywords: enclosure, sound absorption, sound insulation, sound attenuation, multi-layered baffles.

Introduction

High sound levels negatively influence human health and cause an increase of annoyance, sleep disturbance (Blume et al., 2022), physical stress, hearing loss, and cardiovascular diseases (Kou et al., 2021; Vienneau et al., 2022). From the physical side, sound and noise are the same thing, but when sound is defined as a noise, it can cause negative health effects (King & Davis, 2003). Nowadays, due to industrialization, many different sound sources in our environment can generate high noise levels. Increasing traffic noise in cities is one of the biggest problems. On the other hand, there are many other sound sources, which generates noise in the environment. Different machines or devices such as HVAC systems (Singh & Mohanty, 2018), electric generators and other systems could generate different sound levels (Farhan et al., 2021), which depends on device properties. Mostly such devices generate the highest sound levels in low and middle frequencies. This is due to engine piston movement inside the cylinder which produce noise through this operation. Engine works at 2000–3000 revolutions per minute, so it generates low frequency noise (30–50 Hz) (Farhan et al., 2021). The human ear reacts differently to sound levels of different frequencies, and there has been some research, which have been done in this scientific field. An example is Fletcher-Mundson measurements. It was stated, that human hearing is less sensitive to low, frequency sounds and it is much more sensitive to middle and high frequencies (Long, 2014).

One of the problems analysed in this article were mobile noise sources, such as portable diesel generators. Such devices are often used at various exhibitions, fairs, in order to ensure power supply to the devices. Generators operating in such places cause a high level of noise, which reduces acoustic comfort in the environment. To reduce noise caused by stationary noise sources, standard solutions such as acoustic barriers, acoustic curtains, etc. are used (Tsouvalas & Metrikine, 2016). However, to reduce the sound of portable noise sources, mobile solutions must be used, enclosures that can be installed in different places. Also it is very important to ensure

---

* Corresponding author. E-mail: *tomas.vilniskis@vilniustech.lt*

free air circulation for device ventilation. For that reason, louvered construction in enclosure could be used. Standard design of the louvers is specified in terms of blade width, blade angle and air gap. Louver construction should be composed with sound absorption material. The main disadvantage of this construction, low sound insulation in low frequencies (Viveiros & Gibbs, 2003). Mobile acoustic enclosures are currently rarely used, so this is a topic that needs to be explored.

Sound-insulating enclosures are mostly constructed from multilayer panels. Control of sound transmission through a multi-layered structure is an interesting topic of research. (Li, 2010) Depending on the area of use, the structural elements can be sound-absorbing or sound-insulating (Kosała et al., 2020). Most often, the baffle construction consists of two sound-insulating panels, which can be steel, wood, gypsum panels, and a sound-absorbing material which is placed between the two panels (Wang & Ma, 2021; Kosała, 2019). In most cases, mineral wool, foam and polyurethane are used, but there have been studies in which recycled rubber has also been used (Julia et al., 2013). In order to investigate the ability of such panels to isolate sound, their acoustic properties must be investigated (Lin et al., 2022). The sound insulation and absorption properties of such panels must be tested under laboratory conditions (Wszołek, 2007). In order to ensure that mobile soundproofing structures provide adequate sound insulation, they must be designed to cover the frequency range of the noise emitted by the sound source. The construction of mobile soundproof enclosures must be light, thin and easily transportable. However, based on theoretical models mass law, Sharp, Davy (Kosała, 2022), such structures better insulate medium and high frequency sound (Tang & Yan, 2017b), and almost do not have sound insulation ability when the wavelengths of sound waves are significantly longer than the thickness of the material (Shao & Yan, 2022; Tang & Yan, 2017a). To ensure low frequency sound insulation, heavy and thick structures must be used.

In order to evaluate the effectiveness of the enclosures, the reduction of sound in the environment can be modelled. Different programs are used to perform such simulations, which are based on different methods: ray tracing (Løvstad et al., 2014; Rindel & Christensen, 2007), sound attenuation modelling (Rădoi, 2014). The data of acoustic parameters are used to describe sound-absorbing and sound- insulating structures. Modelling of sound propagation in the environment allows to estimate the reduction of sound pressure at different distances from the noise source. The aim of this article was to model the propagation of sound to the environment in the X and Y axes and to evaluate how the sound propagation from the noise source changes, using an acoustic enclosure with different configurations. Enclosure should ensure that sound pressure levels not exceed the values (<65 dB) represented in Hygiene Norm HN 33:2011 (Lietuvos…, 2011).

1. Methodology

The enclosure 3D model was drawn by using Skechup Pro software. Dimensions of the enclosure (Figure 1):

Height – 0.65 m, length – 1.0 m, width – 0.65 m.

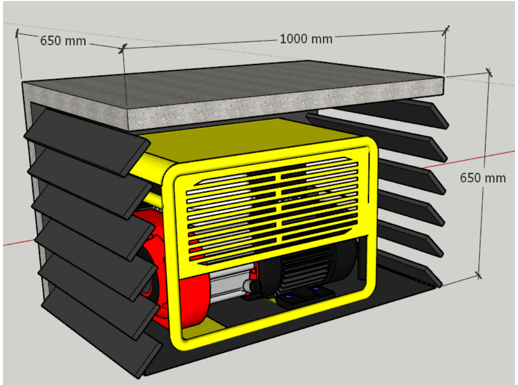

Figure 1. 3D model of the enclosure

The back and front wall of the enclosure was formed as a louvered construction, which consisted of 6 plates, covered with 50 mm thick rubber material. Plates had the ability to change the tilt angle from 0 to 45 degrees. Enclosure constructions, which have different acoustic properties were created as different layers, which allowed to assign different materials to every layer. After that, the model was uploaded to ODEON software.

The first step in ODEON was to create sound sources and receivers. In this article, one sound source was used as a diesel generator. The sound power levels of the diesel generator were presented in Table 1.

Table 1. Sound power level of the diesel generator (British Standard, 2009)

Sound power level in frequencies, dB					
125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
102	97	92	90	86	87
Sound pressure level in frequencies at 10 m, dB					
125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
71	66	61	59	55	56

10 different receiver points were created. The distance between receivers was 1 metre. 1–5 receivers were placed on the X axis, which was along the openings, and 6–10 receivers were positioned in Y axis, which was along the enclosure side wall (Figure 2).

Then, acoustic materials were assigned to each layer. Construction acoustic properties were measured under laboratory conditions. The properties of transmission loss of side walls and sound absorption coefficient of the devulcanized rubber material were measured in an impedance tube. The side walls were created as noise transmitting walls, which transmission loss values were presented in Table 2.

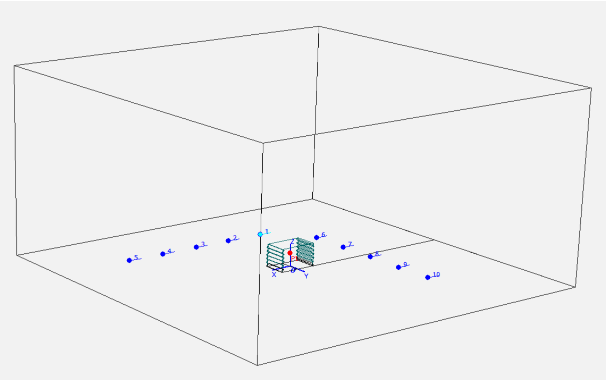

Figure 2. Receiver points on X and Y axis

Opening plates were created as a sound-absorbing construction. Sound absorption coefficient depended on the thickness of the devulcanized rubber layer. Sound absorption results of rubber composite were presented in Table 3.

After layer characterisation, a calculation grid was created. Two different grids were created – horizontal and vertical. Grid size 0.3×0.3 m (Figure 3).

The results were presented as the SPL(A) grid response and the sound pressure levels in the 1/3 octave frequency band of every receiver point were presented as graphs.

2. Results

Modelling was made with construction, which plates were covered with 50 mm thick devulcanized rubber material. The opening plates were angled from 0° to 45° in 15° steps. In addition, sound attenuation was modelled at distance without any enclosure.

2.1. Sound attenuation at distance without any enclosure

First, the sound attenuation was modelled in a free field without any enclosure Figure 4, Figure 5. According to the results of the modelling, the attenuation of the sound pressure level was the same in all sides. According to the literature, sound pressure level decreases 6 dB for every doubling of distance and could be described by the formula:

$$L_p = L_w - 10\lg\left(r^2\right) - 10\lg\left(\Omega\right), \qquad (1)$$

where: L_w – sound power level, dB; R – distance, m; Ω – directivity factor.

Analysing the results, it could be stated, that sound pressure level values matched the formula. Difference between sound pressure level 1 meter from sound source and 2 meters from sound source was 6 dB. The same result was obtained between the measurement

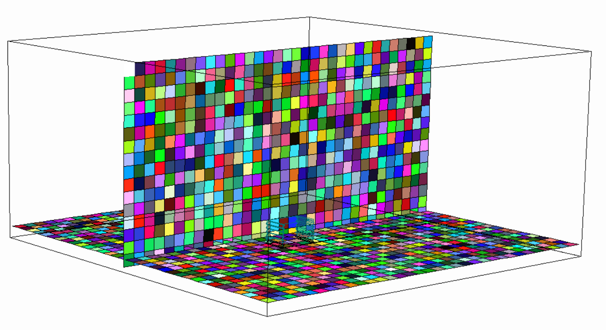

Figure 3. Calculation grid

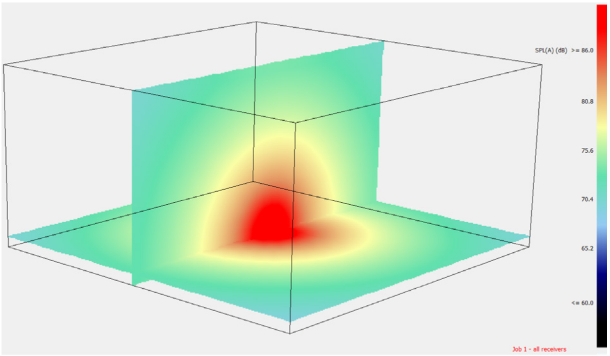

Figure 4. Sound pressure levels without any enclosure

Table 2. Transmission loss values of the side wall

50 mm rubber composite between two gypsum boards								
100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz
32	34	36	37	39	42	48	43	46
800 Hz	1000 Hz	1250 Hz	1600 Hz	2000 Hz	2500 Hz	3150 Hz	4000 Hz	
50	53	53	48	58	62	78	68	

Table 3. Sound absorption values of rubber composite

	Sound absorption coefficient					
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Devulcanized rubber 50 mm	0.07	0.13	0.35	0.92	0.52	0.61

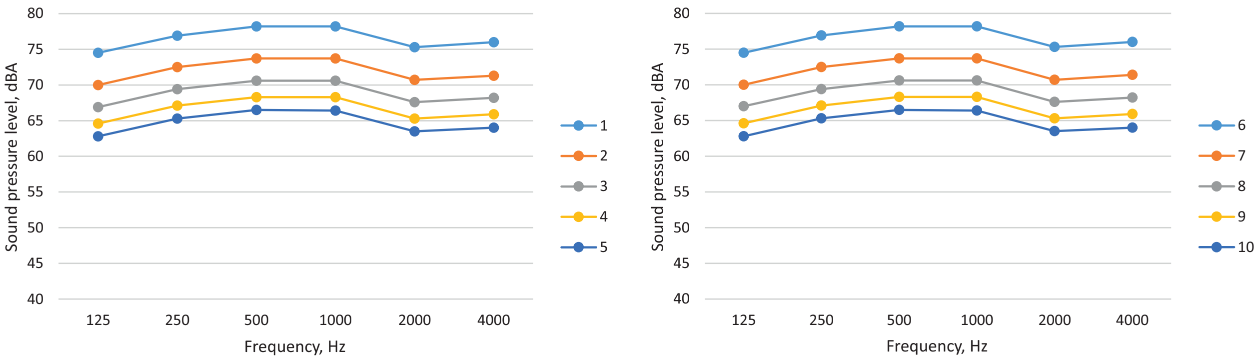

Figure 5. Sound pressure levels in frequencies of every receiver point without any enclosure

points at 2 and 4 metres. Due to the characteristics of the sound source (diesel generator), the highest sound pressure values were at middle frequency and reached up to 78 dB.

2.2. Modelling results of enclosure, which construction was with 50 mm thickness rubber composite

Construction opening plates were covered with 50 mm thick devulcanized rubber. Side wall construction was 15 mm gypsum board, 50 mm devulcanized rubber layer, 15 mm gypsum board. Results were presented in Figure 6, Figure 7.

When the plates of the enclosure openings were in horizontal position, on Y axis, where was 6–10 measurement points, the reduction of the sound pressure level depended on the distance. 1 metre from the sound source, the sound pressure levels reached 70 dB in the middle frequencies. At higher frequencies, sound pressure levels were lower and reached 57–66 dB. Increasing the distance by 1 m, sound level pressure decreased by 3–5 dB in the whole frequency spectrum. The enclosure reduced sound levels from 4 to 8 dB in low and middle frequencies (63–500 Hz) and from 9 to 11 dB in high frequencies (1000–8000 Hz) compared with modelling result without any enclosure. In positions 1–5, which were along X axis, sound pressure levels in 1 m from

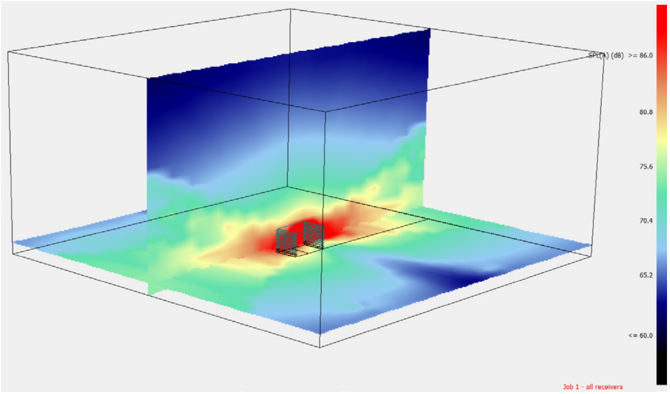

Figure 6. Sound pressure levels of the enclosure with 0° tilted plates

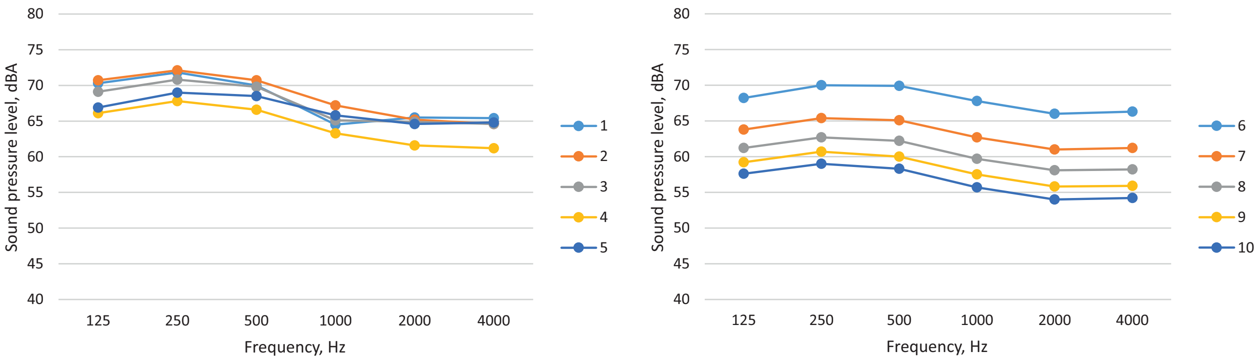

Figure 7. Sound pressure levels in frequencies of every receiver point when plates were tilted at the angle of 0°

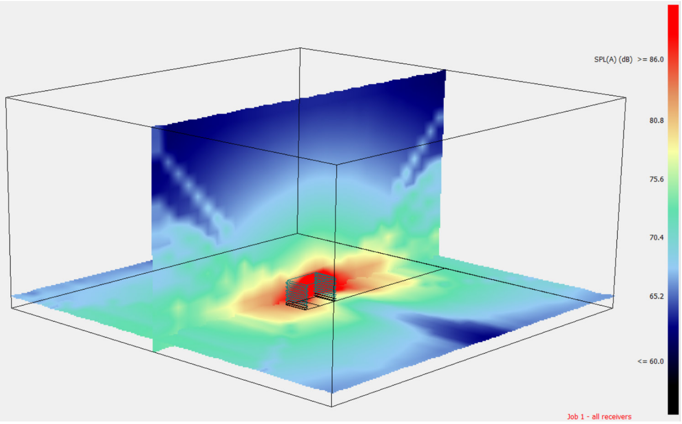

Figure 8. Sound pressure levels of the enclosure with 15° tilted plates

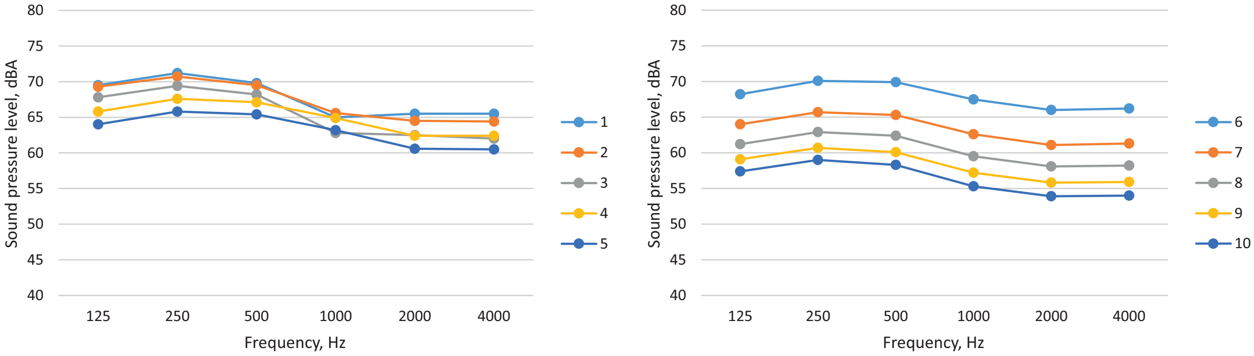

Figure 9. Sound pressure levels in frequencies of every receiver point when plates were tilted at the angle of 15°

the sound source decreased from 4 to 8 dB in middle frequencies and 10–13 dB in high frequencies, compared to the modelling results without any enclosure. Due to resonance, at 2–5 measurement points, sound pressure values increased in low and middle frequencies. The difference between the results with and without enclosure reached 0.5 to 4 dB. On the other hand, enclosure isolates high frequencies quite well, efficiency of sound reduction was from 2 to 7 dB.

By changing the angle of the opening plates from 0° to 15° (Figure 8, Figure 9), any difference between modelling results were not found in Y axis, because side wall construction was the same. Different angle of the opening plates made difference only in 1–5 positions which were along the X axis. When comparing the results of the enclosure with 15° plates and horizontal plates, sound pressure level decreased by about 1–3 dB in 1–3 points in the whole frequency range. In fourth measurement point, due to sound interferation, a higher sound pressure zone occurred and the values were 1–2 dB higher than previous construction. In the fifth position, sound pressure values reached 66 dB in 250 Hz and 60 dB in 2000–4000 Hz, so the sound pressure level was 3–5 dB lower than construction with horizontal opening plates.

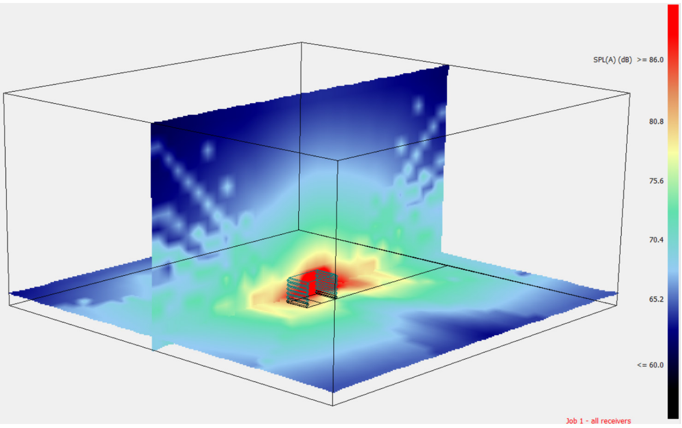

Figure 10. Sound pressure levels of the enclosure with 30° tilted plates

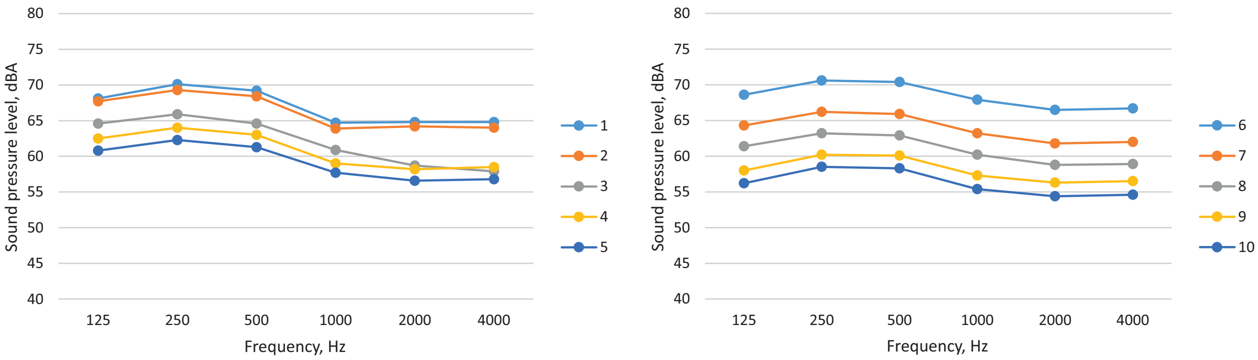

Figure 11. Sound pressure levels in frequencies of every receiver point when plates were tilted at the angle of 30°

When the plates were tilted at 30° (Figure 10, Figure 11), the results on the Y axis were similar to previous results. But the significant difference was determined at 1–5 measurement points along X axis. In all positions sound pressure levels were lower than previous modelling results (15°). At the first and second measurement points, sound pressure levels decreased from 0.5 to 2 dB, compared to the last results. Better efficiency was calculated in 3–5 points. The highest levels of sound pressure reached 62–66 dB in the middle frequencies. By changing the angle of the opening plates from 15° to 30°, sound pressure levels at 3–5 points decreased from 2 to 6 dB in all frequencies.

When the plates were tilted at 45° (Figure 12, Figure 13), there were no significant changes in sound pressure levels on the Y axis, the results were similar to the previous ones. When comparing the modelling results between the enclosure with 45° and 30° tilted plates, sound pressure values decreased slightly in 1 and 2 points, the difference reached 1–3 dB. The highest values of sound pressure were in middle frequencies and reached 68–70 dB. Modelling results showed that in 3–5 positions, sound pressure level values decreased 6–8 dB in middle frequencies and 3–4 dB in high frequencies compared with 2nd measurement point and it was 2–7 dB lower than enclosure with opening plates tilted at 30°.

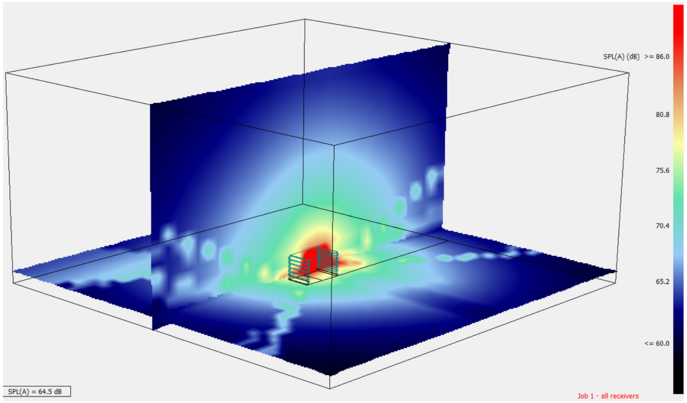

Figure 12. Sound pressure levels of the enclosure with 45° tilted plates

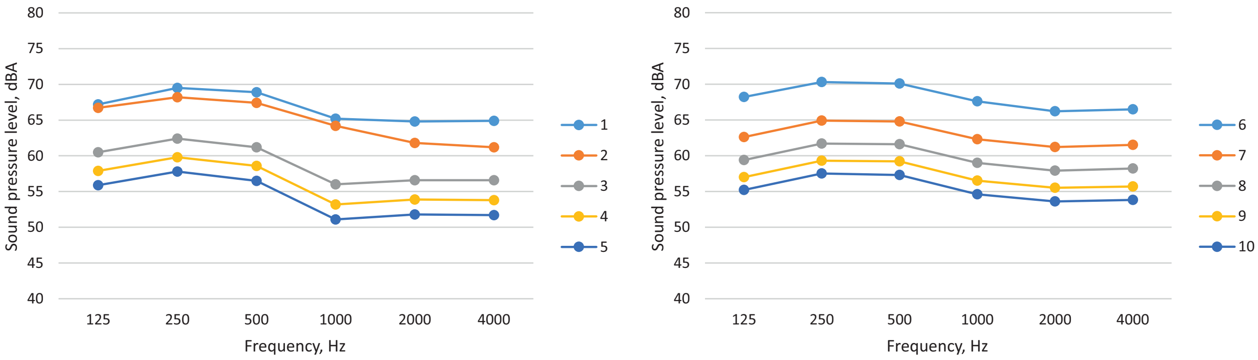

Figure 13. Sound pressure levels in frequencies of every receiver point when plates were tilted at the angle of 45^0

3. Discussion

Diesel generators generate noise mostly in low and middle frequencies. Average sound power level in low frequency of diesel generators is 95–100 dB in low frequency range 63–250 Hz, 90–95 dB in middle frequency range 500–1000 Hz and 80–90 dB in high frequency range (2000–8000 Hz). Quite thin constructions (75 mm), such as baffles used in this research, do not have high efficiency in low frequencies, because due to acoustic theory, thick and heavy constructions should be used, but they work quite well in middle and high frequencies (500–8000 Hz). According to the Flecher-Munson curve, it could be stated that midrange frequencies are loudest or most noticeable. On the other hand low and high frequencies are less noticeable. For that reason, to reduce sound pressure levels of machines, such as diesel generators, is very important to isolate mid frequency noise (500–1000 Hz). Free air circulation inside the enclosure is also very important, because air is required for generator operation. For that reason, the openings were formed as a louvered construction, which plates were covered with devulcanized rubber material. Devulcanized rubber material also worked as an sound absorbing material, so it let to increase sound reduction efficiency, because part of sound energy was absorbed. In this research, the attenuation of the sound pressure level in distance was modelled. 1–5 measurement points were on the X axis along the enclosure opening, and 6–10 points were on the Y axis alongside the wall.

Analysing the results of receiver points 6–10 on the Y axis (Figure 14), it could be stated that sound pressure levels were not dependent on the angle of the louver plates. The sound reduction values of different enclosure configurations were quite similar. The difference in sound insulation only depended on the side wall construction. Also, it could be stated that sound pressure values decreased by increasing distance. 5 meters from sound source sound pressure values was below 65 dB, and this result met the requirements of Hygiene norm.

The results on the X axis, where 1–5 measurement points were placed (Figure 15), sound pressure levels depended on the enclosure configuration. It could be stated that increasing the tilt angle of the opening plates, sound pressure values decreased. In some cases, enclose openings worked as a resonator, so sound pressure values

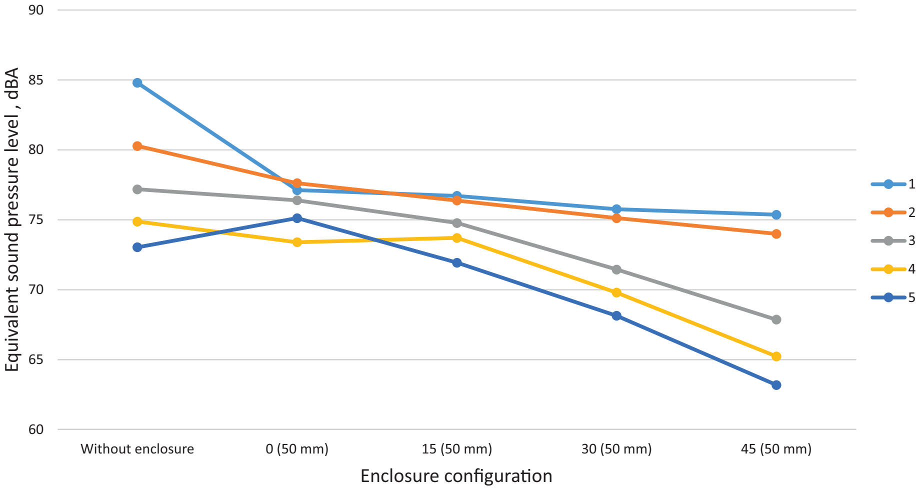

Figure 14. Equivalent sound pressure level of Y axis receiver points, of every enclosure configuration

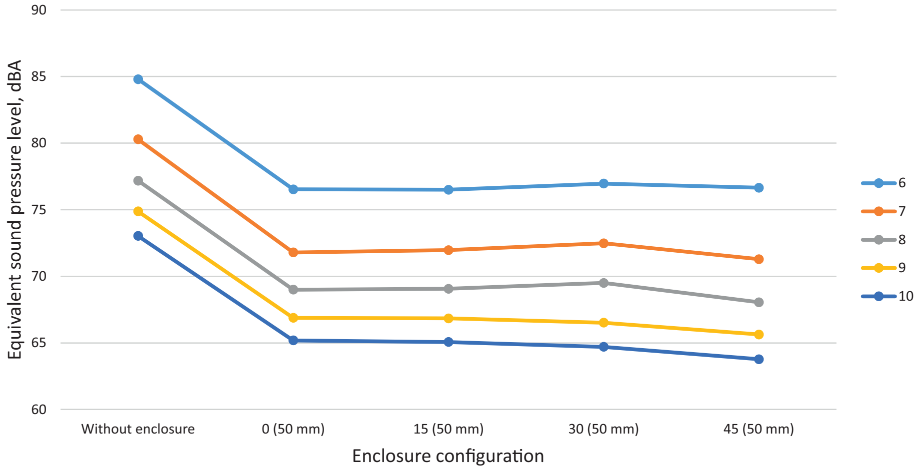

Figure 15. Equivalent sound pressure level of X axis receiver points, of every enclosure configuration

increased. Sound pressure levels decreased by increasing the tilt angle of the opening plates. Just one configuration, which plates were tilted at 15° due to sound resonance, sound pressure levels increased compared with construction which plates were in horizontal position. To reach less than 65 dB of equivalent sound pressure level 4 meters from sound source, opening of the enclosure should be tilted at 45° and covered with 50 mm thickness devulcanized rubber material.

Concluding modelling results, it could be stated, that there was dependence of the angle of opening plates – the bigger inclination angle, the better sound reduction was. It was because a larger area of absorbing material was in the path of the sound when angle of the plates increased, so efficiency of absorbing material was better. Also, thickness of sound absorbing material was also important. 50 mm thick devulcanized rubber sound absorption and sound insultation had high values in mid ranges, what allowed to have good sound insulation results in mid frequencies.

Conclusions

1. Based on modelling results, it could be stated, that sound attenuation depends on the direction from enclosure. In receiver points, which were positioned on the Y axis, sound reduction was mainly influenced by the side wall construction and was not dependent on the angle of louver plates. The sound pressure values at different receiver points decreased by increasing distance.
2. On the X axis, where 1–5 measurement points were placed, sound pressure levels depended on the enclosure configuration. It could be stated that sound reduction values depended on the tilt angle of the enclosure opening plates. Sound pressure levels decreased by increasing the tilt angle of the opening plates. The difference of sound pressure level reduction by increasing the angle by 15° reached 1–5 dB depending on the receiver point distance from sound source.
3. To meet the requirements, equivalent sound pressure level should not exceed 65 dB. According to the modelling results, it could be reached with the enclosure, which side wall construction was with 50 mm rubber between two gypsum boards and opening plates were covered with 50 mm thickness rubber material and tilted at 45°. This configuration of enclosure reduced sound pressure level to 65 dB at a distance of 4 m from the enclosure.

References

Blume, C., Schoch, S. F., Vienneau, D., Röösli, M., Kohler, M., Moeller, A., Kurth, S., & Usemann, J. (2022). Association of transportation noise with sleep during the first year of life: A longitudinal study. *Environmental Research*, *203*, 111776. https://doi.org/10.1016/j.envres.2021.111776

British Standard. (2009). *Code of practice for noise and vibration control on construction and open sites – Part 2: Vibration* (BS 5228-2:2009).

Farhan, A. O., Salman, R. K., & Farhan, S. S. (2021). Studying the effect of diesel Power Generator noise on the publicity in Ramadi city. *Journal of Physics: Conference Series*, *2114*(1), 012078. https://doi.org/10.1088/1742-6596/2114/1/012078

Julia E., Segura, J., Nadal, A., Gadea, J. M., & Crespo, J. E. (2013). Study of sound absorption properties of multilayer panels made from ground tyre rubbers. *Annals of The Oradea University. Fascicle of Management and Technological Engineering*, XXII (XII)(1), 1–13. https://doi.org/10.15660/AUOFMTE.2013-1.2799

King, R. P., & Davis, J. R. (2003). Community noise: Health effects and management. *International Journal of Hygiene and Environmental Health*, *206*(2), 123–131. https://doi.org/10.1078/1438-4639-00202

Kosała, K. (2019). Sound insulation properties of two-layer baffles used in vibroacoustic protection. *Applied Acoustics*, *156*, 297–305. https://doi.org/10.1016/j.apacoust.2019.07.028

Kosała, K. (2022). Experimental tests and prediction of insertion loss for cubical sound insulating enclosures with single homogeneous walls. *Applied Acoustics*, *197*, 108956. https://doi.org/10.1016/j.apacoust.2022.108956

Kosała, K., Majkut, L., & Olszewski, R. (2020). Experimental study and prediction of insertion loss of acoustical enclosures. *Vibrations in Physical* Systems, *31*(2), 2020209.

Kou, L., Kwan, M. P., & Chai, Y. (2021). Living with urban sounds: Understanding the effects of human mobilities on individual sound exposure and psychological health. *Geoforum*, *126*, 13–25. https://doi.org/10.1016/j.geoforum.2021.07.011

Li, Y. Y. (2010). Noise control of an acoustic enclosure covered by a double-wall structure with shallow gap: Design of resonator-like cavities. *Applied Acoustics*, *71*(7), 675–680. https://doi.org/10.1016/j.apacoust.2010.02.008

Lietuvos Respublikos sveikatos apsaugos ministerija. (2011). Lietuvos Respublikos sveikatos apsaugos ministras. Įsakymas dėl Lietuvos higienos normos HN 33:2011 „Triukšmo ribiniai dydžiai gyvenamuosiuose ir visuomeninės paskirties pastatuose bei jų aplinkoje“ patvirtinimo. *Valstybės žinios*, 2011-06-21, Nr. 75-3638.

Lin, C., Wen, G., Yin, H., Wang, Z. P., Liu, J., & Xie, Y. M. (2022). Revealing the sound insulation capacities of TPMS sandwich panels. *Journal of Sound and Vibration*, *540*, 117303. https://doi.org/10.1016/j.jsv.2022.117303

Long, M. (2014). Human perception and reaction to sound. In *Architectural acoustics* (2^{nd} ed., pp. 81–127). Elsevier Inc. https://doi.org/10.1016/B978-0-12-398258-2.00003-9

Løvstad, A., Rindel, J. H., Støen, V., Windsor, A. T., & Negård, A. (2014, September). Measurement and simulation of high sound insulation and identification of sound transmission paths in complex building geometries. *Conference: Forum Acusticum 2014*. Krakow, Poland.

Rădoi, A. M. (2014). *Determination of the noise barriers performance for protected areas*. 7284.

Rindel, J. H., & Christensen, C. L. (2007, July). Odeon, a design tool for noise control in indoor environments. *Conference: Noise at Work 2007*. Lille, France.

Shao, X., & Yan, X. (2022). Sound absorption properties of nanofiber membrane-based multi-layer composites. *Applied*

Acoustics, *200*, 109029. https://doi.org/10.1016/j.apacoust.2022.109029

Singh, S., & Mohanty, A. R. (2018). HVAC noise control using natural materials to improve vehicle interior sound quality. *Applied Acoustics*, *140*, 100–109. https://doi.org/10.1016/j.apacoust.2018.05.013

Tang, X., & Yan, X. (2017a). Acoustic energy absorption properties of fibrous materials: A review. *Composites Part A: Applied Science and Manufacturing*, *101*, 360–380. https://doi.org/10.1016/j.compositesa.2017.07.002

Tang, X., & Yan, X. (2017b). Multi-layer fibrous structures for noise reduction. *Journal of the Textile Institute*, *108*(12), 2096–2106. https://doi.org/10.1080/00405000.2017.1315793

Tsouvalas, A., & Metrikine, A. V. (2016). Noise reduction by the application of an air-bubble curtain in offshore pile driving. *Journal of Sound and Vibration*, *371*, 150–170. https://doi.org/10.1016/j.jsv.2016.02.025

Vienneau, D., Saucy, A., Schäffer, B., Flückiger, B., Tangermann, L., Stafoggia, M., Wunderli, J. M., & Röösli, M. (2022). Transportation noise exposure and cardiovascular mortality: 15-years of follow-up in a nationwide prospective cohort in Switzerland. *Environment International*, *158*, 106974. https://doi.org/10.1016/S0003-682X(03)00008-2

Viveiros, E. B., & Gibbs, B. M. (2003). An image model for predicting the field performance of acoustic louvres from impulse measurements. *Applied Acoustics*, *64*(7), 713–730. https://doi.org/10.1016/S0003-682X(03)00008-2

Wang, Y. Z., & Ma, L. (2021). Sound insulation performance of membrane-type metamaterials combined with pyramidal truss core sandwich structure. *Composite Structures*, *260*. https://doi.org/10.1016/j.compstruct.2020.113257

Wszołek, T. (2007). Uncertainty of sound insulation measurement in laboratory. *Archives of Acoustics*, *32*(4), 271–277.