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ACOUSTIC INVESTIGATIONS OF THE EXTERIOR AND INTERIOR WALL OF A LOG HOUSE

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Abstract. With the rapidly changing environment and growing cities and increasing traffic flows the problem of noise pollution is becoming more and more relevant. As street networks continue developing and land prices are rising, houses are more and more often built close to especially noisy suburban streets. Traffic-generated noise accounts for up to 80 % of the prevailing noise level. Many people build private houses from eco-friendly building materials, such as wood. The construction volumes of log houses, roadhouses and guest houses have increased. This article presents acoustic investigations of a log house's $D_{nT,w}$ measured under natural conditions in the natural environment – a constructed log house – and in a noise suppression chamber, analysing an element of the log wall. The log wall concerned was covered with log house heat-insulation materials and the obtained $D_{nT,w}$ results reached up to 58 dB.

Keywords: acoustic investigation of materials, log houses, noise suppression chamber, standardised difference in sound pressure levels.

1. Introduction

Noise has currently become a global problem encountered in all spheres of human life and work. Damage caused by noise should be evaluated in the physiological, economic and sociological aspects on the basis of the most recent scientific achievements (Baltrėnas *et al*. 2007a; Paslawski 2009).

People experience the discomfort of noise not only at noisy workplaces but also in the living environment and at home. Noise negatively affects hearing, the nervous system and the entire organism. A noisy working and recreational environment irritates, causes fatigue, decreases attention, slows down mental reactions and troubles the nervous system (Reinhold and Tint 2009). In a noisy environment, it is difficult to concentrate one's thoughts and memorise important information (Vaišis and Januševičius 2009; Stansfeld *et al*. 2000).

As proved by different kinds of research (Willich *et al*. 2006), an increased level of noise in the living and working environment is related to the increased risk of myocardial infarction (Baltrėnas and Puzinas 2009; Baltrėnas *et al*. 2007b).

Constant noise acts as a factor causing nervous strain and stress; therefore, the World Health Organisation (WHO) attributed noise to the physical factors that entail professional diseases (Butkus and Grubliauskas 2008; Vaišis and Januševičius 2008).

As investigation performed in buildings shows, the acoustic insulation of partitions is typically 3–6 dB lower than that determined in noise research laboratories, which happens due to noise passing via alternative routes Hongisto 2001; Jones 1976; Gerretsen 1979).

Consequently, the sound power transferred via alternative routes must be precisely determined. Indirect measurement of alternative noise routes may be performed by traditional techniques (ISO 140–3:95) by covering structures with additional boards, which block the spread of additional noise. This is, however, a labour consuming technique. Another option is to make direct measurements of vibration in the neighbouring surfaces. Unfortunately, emission efficiency, which is necessary in order to calculate the sound power, is known only if the frequency is above the limit. Thus, this technique is difficult to apply for light structures (Hongisto *et al*. 2000). One more technique is a sound intensity technique.

Literature describes various laboratories, which perform research into acoustic qualities of building materials, structures etc. Chambers of this type consist of two partition-separated rooms where the analysed sample is assembled. These chambers are used to determine the capacity of building materials to absorb or reflect waves of sound as well as establish the suitability of building material compositions for sound insulation (Jagniatinskis 2002).

The aim of the work is to measure the acoustic parameters of log house walls and façade and improve the acoustic properties of the log wall with the help of building materials, which are used in practice.

2. Research methods

Investigations of acoustic properties of materials were carried out in a noise suppression chamber in the Vilnius Gediminas Technical University (VGTU) Department of Environment Protection. The entire surface area (walls, floor, ceiling, partition) of the noise suppression chamber's interior totals 70 m^2 and is covered with a 0.25 m layer of boards consisting of cut acoustic foam (0.15 m cutting step) of a conical form.

A general view of the laboratory and a "window" wherein the specimen was mounted is presented in Fig. 1.

Fig. 1. Noise suppression chamber and a "window" wherein the specimen is mounted

The laboratory chamber consists of two rooms, separated by a double wall, and a neighbouring room intended for measuring equipment. For the sake of convenience room 1 is conditionally called a sending sound room (source room), room 2 – a receiving sound room (target room).

Rooms of the noise suppression chamber are acoustically insulated from each other by rock wool boards and the external structures (walls, flooring, ceiling) as well as the frame of the chamber are installed on a rubber base to prevent infiltration of building vibrations to the noise suppression chamber. The rock wool boards limit indirect sound transfer between the rooms of the chamber; besides, these rooms are insulated against the external noise, which minimises the background noise within them.

The measuring method of airborne sound suppression by partitions under laboratory conditions is presented according to LST EN ISO 140-3. Acoustic properties of structures in the noise suppression chamber were analysed using the Danish measuring equipment Bruel & Kjaer comprising:

a real time sound spectrum analyser Bruel & Kjaer mediator 2260;

a microphone 4189 – Bruel & Kjaer (2 pcs.);

a power amplifier – Bruel & Kjaer (300 W power);

an all-direction source with twelve loudspeakers – Bruel & Kjaer (frequency characteristics: 100 Hz – 3150 Hz) with a three-legged stand of regulated height from 1.3 to 2.0 m.

A relative measurement error of the device is ±1.5%. The device records noise within the frequency range of 6.3 20 kHz.

The device has two measurement channels and it can, therefore, record noise in different points using two microphones at a time. One microphone is positioned in the source room, while another – in the target room.

As the device is pre-installed with a processor and specialised software, it statistically processes the measurement results.

To process data received from the performed acoustic investigation, the software BZ 7210 Qualifier from Bruel & Kjaer 2260 was used to calculate the noise reduction index R_w or standardised difference in sound pressure level according to international ISO standards and measured results.

Possible noise passing through possibly emerged spaces between the "window" and structure upon mounting the specimen in the chamber's window was analysed as shown in Fig. 2.

The sound level meter was moved along the edges of the structure and the window as shown in Fig. 1 by observing the instantaneous scale of the sound level meter as shown in Fig. 3. Upon detecting that noise penetrates through spaces in the structure, the structure was dismantled and mounted again.

The standardised difference in sound pressure levels $D_{nT,w}$ (dB) showing the sound insulation properties of the structure was investigated in the noise suppression chamber. The structure's standardised difference in the sound

Fig. 2. Checking noise emission through spaces that emerged in the structure

Fig. 3. Instantaneous sound scale of the sound level meter

pressure level $D_{nT,w}$ was determined according to the formula:

$$D_{nT\,w} = L_1 - L_2 + 10\lg\frac{T}{T_0}, dB, \quad (1)$$

where: L_1 – medium sound pressure level in the source room, dB; L_2 – medium sound pressure level in the target room, dB; T – measured time of reverberation, s; T_0 – reference reverberation duration, $T_0 = 0.5$ s.

The log wall was also investigated in a natural log house by measuring the standardised difference in sound pressure levels $D_{nT,w}$ (dB) according to the formula (1). The obtained results were compared to the results received in the noise suppression chamber.

3. Research results and their analysis

A structure of rectangular logs, 15 cm wide, which are used in the construction of log houses, was assembled in the noise suppression chamber (Fig. 4).

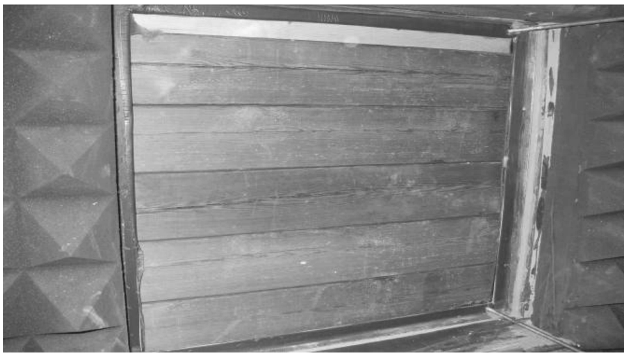


Fig. 4. View of an element of the log wall, 15 cm wide, assembled in the noise suppression chamber

The standardised difference in sound pressure level D_{nTw} of this wall measured in the chamber, the obtained coefficient was 29±1 dB, whereas the obtained standardised difference in sound pressure level of the natural log wall was 28±1 dB. The obtained difference within the limits of error does not coincide with 1 dB limits. This can be explained by different inter-adhesion of logs in the natural log house and noise suppression chamber. Furthermore, on the basis of other authors' experience, sound insulation coefficients recorded in the chamber and the natural environment differed from 3 to 6 dB.

As both the interior partitions and exterior walls of the log house were made of the same logs, the interior partition concerned was equated to the façade.

Applying the aggregate method for façade noise insulation research formula (2) was used.

$$D_{ls2mnT\,w} = D_{2m} + 10\lg\frac{T}{T_0}, dB, \quad (2)$$

$$D_{2m} = L_{1,2m} - L_2, \quad (3)$$

where: $L_{1,2m}$ – medium sound pressure level at a 2 m distance from the facade, dB; L_2 – medium level of spatial and time sound pressure in the target room, dB.

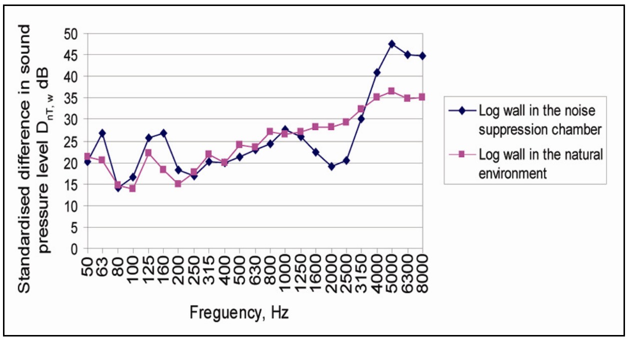


Fig. 5. Insulation coefficients $D_{nT,w}$ converted for each frequency band in the natural and the chamber studies

Fig. 6. A log wall, 15 cm wide, assembled in the noise suppression chamber and covered with cladding, 2 cm wide

There are no essential differences in the calculation results of the noise insulation coefficient of the facade and the partition, and therefore the same partition assembled in the noise suppression chamber was equated to both the facade and the partition.

The results of the log wall research in the natural environment and the chamber were converted into insulation coefficients and presented in Fig. 5. Better noise insulation results were obtained in the noise suppression chamber, but once they were converted into insulation coefficients, the results turned out to be similar with the exception of the frequency range 1250–3150 Hz in the chamber, where the emerged resonance reduced the noise insulation coefficient of the wall, which resulted in a 3 dB variance between the research results obtained in the natural and chamber studies.

As the determined standardised difference in sound pressure levels ($D_{nT,w}$ = 29 dB) is insufficient to satisfy the acoustic class of the partition or the façade, studies in the noise suppression chamber were performed with the aim of finding the best way to improve the log partition or the facade.

The log wall in the chamber was covered with claddings, 2 cm wide, which are often used for log houses; 2 cm air spaces between them were left. View of the wall covered with claddings is presented in Fig. 6.

Tables 1 and 2 show the noise insulation values of the façade depending on the environment class as shown in Table 2. Attribution to the environmental noise class is based on the calculation of L_{dvn}, which is obtained by measuring the environmental noise level and calculating L_{dvn} according to the formula:

$$L_{dvn} = 10\lg\frac{1}{24}\left(12x10^{\frac{L_{dienos}}{10}} + 4x10^{\frac{L_{vakaro}+5}{10}} + 8x10^{\frac{L_{nakties}+10}{10}}\right). \quad (4)$$

Specimens of the log wall are displayed in Figs 7–10. The standardised difference in sound pressure levels $D_{nT,w}$ was analysed.

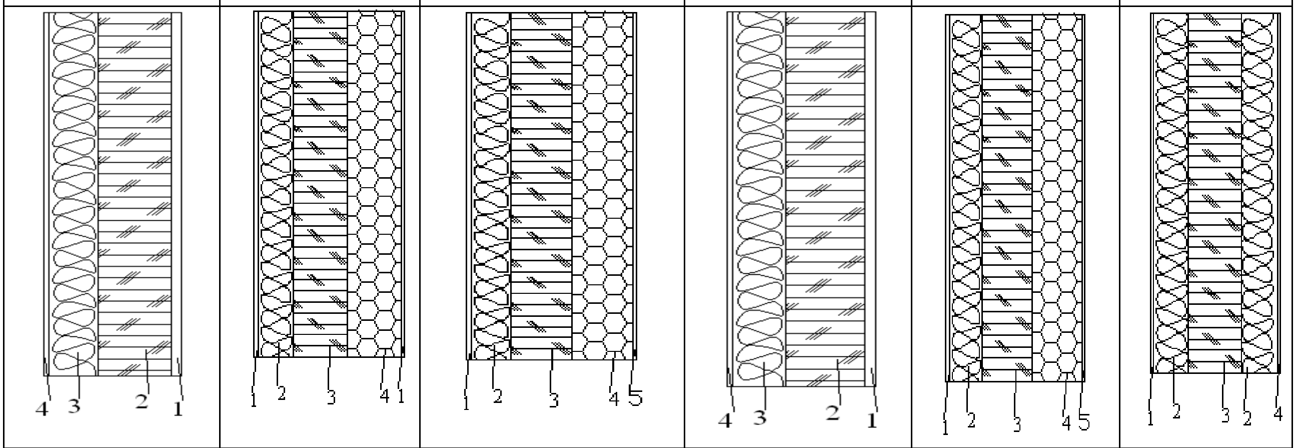
After the log wall was covered with cladding as shown in Fig. 11, the coefficient of insulation improved by a mere 3 dB. After the log wall was covered with cladding from both sides, noise insulation increased up to 36 dB; however, this is not a sufficient level of insulation for the façade. After the wall was covered with a 10 cm layer of rock wool from the noisy side, sound insulation of 45 dB was obtained, which meets sound insulation classes A and B for the façade at the presence of outdoor

Table 1. Classification of airborne sound insulation of exterior walls. The lowest values of the standardised difference in levels index $D_{2m,nT,W}$

	The sound class of exterior partitions				
	A	B	C	D	E
Sound class of the external environment	Index $D_{2m,nT,W}$ (dB)				
A	32	29	24	21	20
B	35	32	27	23	21
C	40	35	30	25	23
D	45	40	35	28	23
E	50	45	40	33	28
Non-classified	55	50	45	38	33

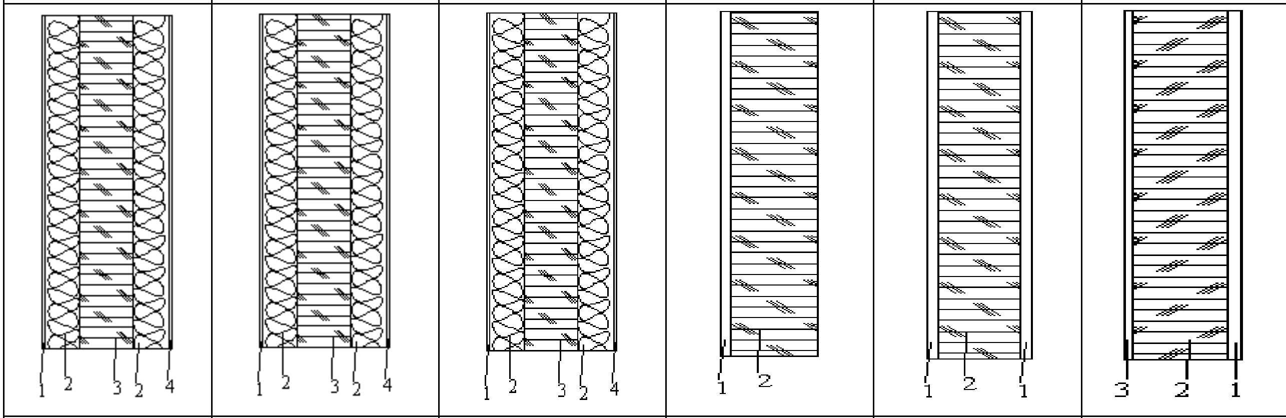
Table 2. Classification of sound pressure levels outside the building originating from traffic. The highest values of A-weighted average long-term noise levels expressed through L_{dvn} (Baltrėnas *et al*. 2010)

Type of Protected Space	Noise index	The sound class of the building exterior environment					
		A	B	C	D	E	Unclassified
The building exterior environment at least in one place	L_{dvn}	45	50	55	60	65	>65



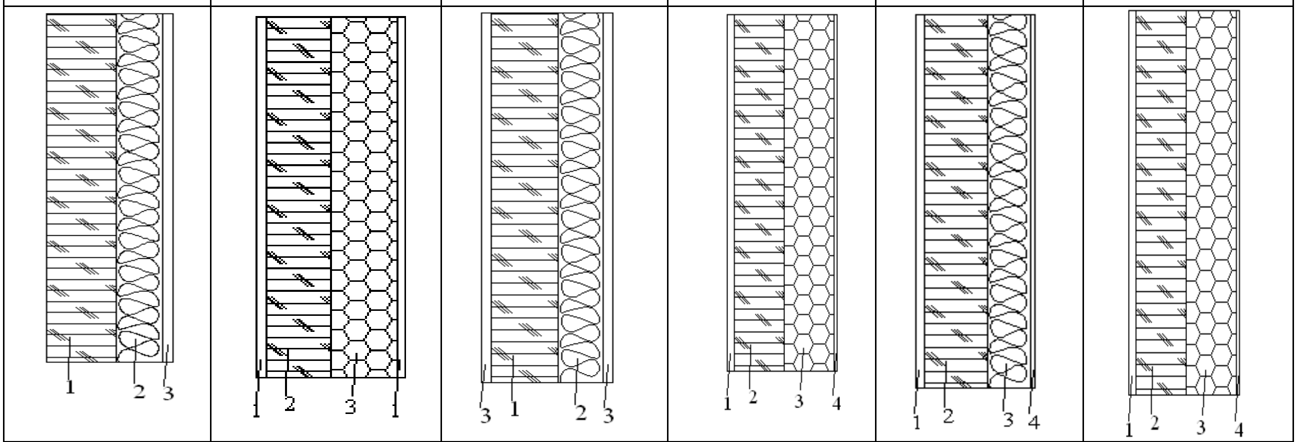
No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
1. gypsum cardboard 2. log wall, 15 cm 3. rock wool, 10 cm 4. cladding, 2 cm	1. cladding, 2 cm 2. rock wool, 10 cm 3. log wall, 15 cm 4. polystyrene, 5 cm	1. cladding, 2 cm 2. rock wool, 10 cm 3. log wall, 15 cm 4. polystyrene, 5 cm 5. gypsum cardboard	1. chipboard 2. log wall, 15 cm 3. rock wool, 10 cm 4. cladding, 2 cm	1. cladding, 2 cm 2. rock wool, 10 cm 3. log wall, 15 cm 4. polystyrene, 5 cm 5. chipboard	1. cladding, 2 cm 2. rock wool, 10 cm 3. log wall, 15 cm 4. gypsum cardboard

Fig. 7. Structures of experimental specimens of the log wall



No. 8	No. 9	No. 10	No. 11	No. 12	No. 13
1. cladding, 2 cm 2. rock wool, 10 cm 3. log wall, 15 cm 4. chipboard	1. cladding, 2 cm 2. rock wool, 10 cm/3 cm rock wool with foil 3. log wall, 15 cm 4. cladding, 2 cm	1. cladding, 2 cm 2. rock wool 10 cm/3 cm rock wool with foil 3. log wall, 15 cm 4. chipboard	1. cladding, 2 cm 2. log wall, 15 cm	1. cladding, 2 cm 2. log wall, 15 cm	1. gypsum card-board 2. log wall, 15 cm 3. cladding, 2 cm log wall, 15 cm

Fig. 8. Structures of experimental specimens of the log wall



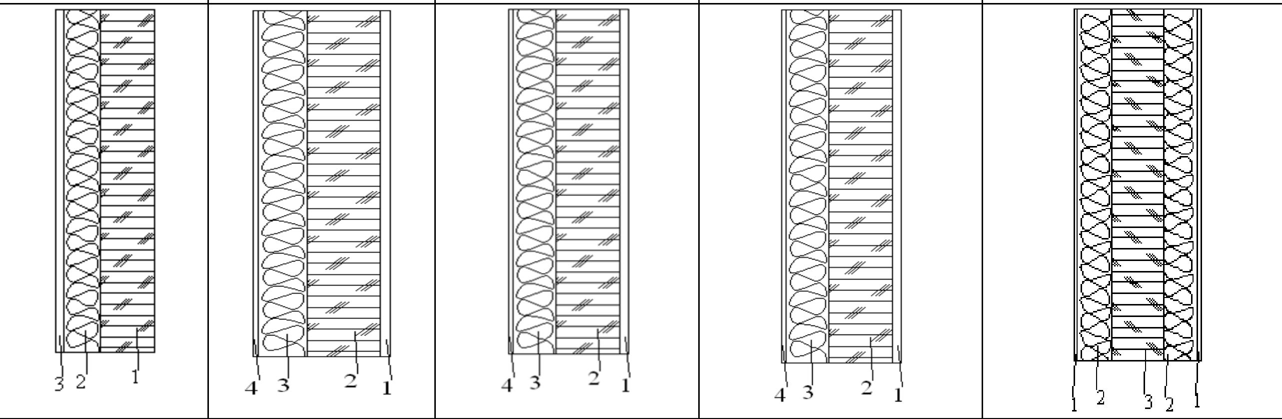
No. 14	No. 15	No. 16	No. 17	No. 18	No. 19
1. log wall, 15 cm 2. rock wool, 10 cm 3. cladding, 2 cm	1. cladding, 2 cm 2. log wall, 15 cm 3. polystyrene, 15 cm	1. log wall, 15 cm 2. rock wool, 10 cm 3. cladding, 2 cm	1. cladding 2. log wall, 15 cm 3. polystyrene, 15 cm 4. plywood	1. cladding 2. log wall, 15 cm 3. rock wool 4. gypsum card-board	1. cladding 2. log wall, 15 cm 3. polystyrene, 15 cm 4. gypsum card-board

Fig. 9. Structures of experimental specimens of the log wall

environment classes D and E. However, partitions do not meet the required class C. After the wall was covered with polystyrene instead of rock wool and covered with cladding from both sides, sound insulation was 46 dB, which is analogous to that of the structure No. 16, where rock wool was used instead of polystyrene and the obtained sound insulation coefficient was 1 dB higher, which proves better noise insulation in the structure when rock wool is applied. As determined by Grubliauskas and others, gypsum cardboard, chip board and plywood are distinguished by good noise insulation properties.

The obtained coefficients of structures No. 18 and. 19 are 50 and 51 dB, but these insulation coefficients do not meet the requirement of 55 dB applicable to a partition dividing rooms. This is important as individual dwellings and lodging houses are currently often constructed out of logs.

The obtained noise insulation coefficient for structures No. 2, 3 and 4 reached 48–49 dB, which is a sufficient noise insulation level for the facade but insufficient for partitions. The performed experiments with structures No. 5, 6 and 7 produced the standardised difference in sound pressure levels of 52–53 dB, which is close to 55 dB required under class C. The difference between the structure No. 7 and structures No. 5 and 6 lies in the fact that in the first case, the log wall is covered with rock wool from both sides and gypsum cardboard is applied from the silent side instead of chipboard.



No. 20	No. 21	No. 22	No. 23	No. 24
1. log wall, 15 cm 2. rock wool, 10 cm 3. cladding, 2 cm	1. plywood 2. log wall, 15 cm 3. rock wool, 10 cm 4. cladding, 2 cm	1. cladding, 2 cm 2. log wall, 15 cm 3. rock wool, 10 cm 4. cladding, 2 cm	1. 2x gypsum cardboards 2. log wall, 15 cm 3. rock wool, 10 cm 4. cladding, 2 cm	1 cladding, 2 cm 2. rock wool, 10 cm 3. log wall, 15 cm

Fig. 10. Structures of experimental specimens of the log wall

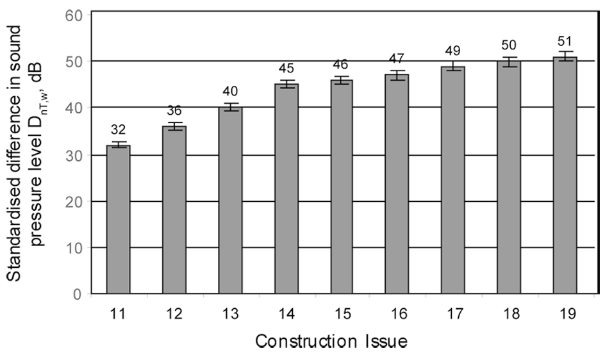


Fig. 11. Results of the standardised difference in sound pressure level $D_{nT,w}$ of structures

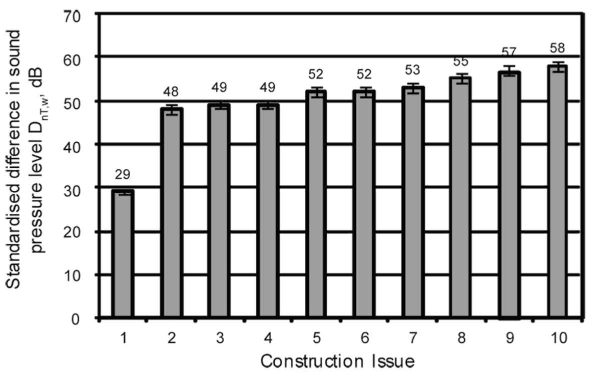


Fig. 12. Results of the standardised difference in sound pressure level $D_{nT,w}$ of structures

Chipboard was used in the structure No. 8, in which case, unlike in the case of gypsum cardboard, the standardised difference in sound pressure level reached 55 dB and this complies with the required sound insulation class C (Fig. 12). The best results were obtained in structures No. 9 and 10, in which 10 cm rock wool from the silent side was replaced with 3 cm rock wool with foil, and

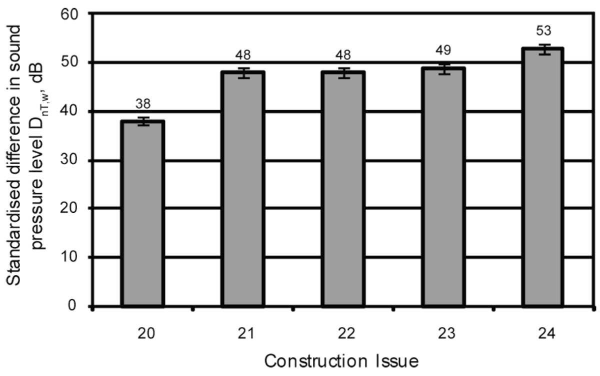


Fig. 13. Results of the standardised difference in sound pressure level D_{nTw} of structures

chipboard or cladding. The highest insulation coefficient, 58 dB, was obtained in the structure No. 10 where cladding from the silent side was replaced with chipboard (Fig. 13).

It is recommended to use structures No. 21 or 22 for the façade as they meet the highest requirements for acoustic insulation of the façade irrespective of the environment noise class. A double gypsum cardboard was used from the inner side of the structure No. 23, which increased noise insulation by a mere 1 dB; the structure No. 24 can be used for partitions between rooms as its noise insulation coefficient meets the requirement for class C within the limits of error.

4. Conclusions

1. The standardised difference in sound pressure levels of log house's external and internal wall not covered with any other material, reached 29 dB in the noise suppression chamber and 28 dB in the natural environment –, which does not meet the requirements for noise insulation and minimal acoustic comfort.

2. To achieve the desired noise insulation comfort inside the building, first it is necessary to determine the

environmental noise class and then select the required structure of the façade accordingly.

3. To achieve sufficient noise insulation of the façade, it is enough to cover it with rock wool or polystyrene from the outside and cover with cladding of 2 cm; in order to achieve better noise insulation from the inside, it is recommended to cover walls with cladding, gypsum cardboard or chipboards.

4. Sufficient acoustic insulation of separate rooms was obtained in structures No. 8, 9 and 10, in which the log wall was covered with rock wool and cladding from both sides, and other materials and the obtained standardised difference in sound pressure levels was equal to 55–58 dB.

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RĄSTINIO NAMO IŠORINĖS IR VIDINĖS SIENOS AKUSTINIAI TYRIMAI

D. Butkus, T. Januševičius

Santrauka

Aplinkai kintant, didėjant miestams ir plečiantis transporto srautams, vis aktualesnė tampa triukšmo namuose problema. Plečiantis gatvių tinklams, brangstant žemei, vis dažniau namai statomi netoli užmiesčio gatvių, kuriose aukštas triukšmo lygis. Iki 80 % vyraujančio triukšmo lygio – tai transporto keliamas triukšmas. Daugelis gyventojų statosi individualius namus, o jiems statyti renkasi ekologiškas medžiagas, pavyzdžiui, medieną. Vis daugiau statoma rąstinių namų, pakelės užeigų ar svečių namų. Aprašomi akustiniai rąstinio namo sienos tyrimai, atliki natūroje ir triukšmo slopinimo kameroje. Rąstinė siena dengiama populiariomis rąstinių namų šiltinimo medžiagomis. Tiriamas vidinės sienos triukšmo izoliavimo koeficientas.

Reikšminiai žodžiai: medžiagų akustiniai tyrimai, rąstiniai namai, triukšmo slopinimo kamera.

АКУСТИЧЕСКИЕ ИССЛЕДОВАНИЯ НАРУЖНОЙ И ВНУТРЕННЕЙ СТЕНЫ БРЕВЕНЧАТОГО ДОМА

Д. Буткус, Т. Янушявичюс

Р е з ю м е

В связи с изменением окружающей среды, ростом городов и увеличением транспортных потоков возрастает актуальность проблемы бытового шума. По мере развития уличной сети, роста стоимости земли строительство домов все чаще ведется на загородных улицах, отличающихся высоким уровнем шума. Шум, вызываемый транспортом, составляет до 80 % преобладающего шума. Многие жители строят индивидуальные дома и выбирают для их строительства экологичные материалы, такие, как древесина. Увеличивается строительство бревенчатых домов, придорожных кафе или гостевых домов. В статье описываются акустические исследования стены бревенчатого дома. Исследования проведены в естественных условиях и в шумоподавляющей камере. Бревенчатая стена покрывается популярными материалами, используемыми для утепления бревенчатых домов. Исследуется условный фасад дома и коэффициент шумовой изоляции внутренней стены.

Ключевые слова: акустические исследования материалов, бревенчатые дома, шумоподавляющая камера.

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