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BUILDING PARTITIONS ACOUSTIC PROPERTIES

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Abstract. In this article the sound insulation index R_w of partitions is analysed.Sound partitions are built from various materials: bricks, ceramsite blocks, clay blocks, which differ in their composition, structure, and mass. Walls from the mentioned materials were constructed in buildings that were under examination. Sound insulation index‘es of the partitions were determined by measuring the insulation of sound under natural conditions, in the buildings where the partitions were constructed. Sound insulation index R_w, were also estimated using the law of weight and international standart LST EN ISO 12354 – 1. Experiments were carried out in newly constructed buildings and in a sound reduction chamber that was constructed in Vilnius Gediminas technical university. The sample under examination was set in the partition between sound transmitting and sound recieving rooms, which were isolated from surroundings. The calculated and measured results were compared and the reasons of mismatches were studied.

Keywords: law of weight, building acoustics, noise, sound insulation index.

1. Introduction

Sound is a serious problem, that encompasses all spheres of human life and work, therefore generation and spread of sound has to be reduced (Vaišis and Januševičius 2008, 2009; Baltrėnas *et al.* 2010). Various sources of sound can not be completely eliminated, so acoustic materials have to be used to reduce it (Rasmussen 2010; Willich *et al.* 2006; Baltrėnas and Puzinas 2009). Acoustic material is a material which can absorb the energy of sound. Material‘s property of sound reduction is especially important to partition of buildings. Sound insulation index R_w (dB) describes the capability of the partition to reduce sound that is spreading through the air (Grubliauskas and Butkus 2009; Butkus and Grubliauskas 2008).

When designing a building it is important to know what is the sound insulation index of the chosen materials. This index can be determined by measuring or by calculating. The sound insulation index of the partition is calculated using the law of weight (Stauskis 2008) or international standart ISO 12354 – 1.

When calculating sound insulation index R_w using the law of weight, the result depends on the following: the speed at which the sound is transmitted density of air, density of the material the partition is built from, surface density and the frequency of sound. At the same time the structure of the material, the form or the roughness of the surface or critical frequency is not considered.

When calculating sound insulation index R_w using international standart ISO 12354 – 1, critical frequency is being considered while the homogeneity of the material is not defined. Therefor a question is raised wether the method of estimating sound insulation index R_w is valid for various partitions of a building (Rasmussen 2005).

Scientists of Coimbra university have performed research on partitions made from two layers of steel, concrete and glass and have come up with a conclusion, that sound insulation index R_w, when calculated according to international standart ISO 12354 – 1 in low frequencies was higher than the actual sound insulation index R_w which was measured in sound reduction chamber (Tadeu *et al.* 2004).

Although the materials chosen by the researchers were smooth and even, sound insulation indexes that were estimated and measured did not match (Tadeu *et al.* 2007). On the ground of the conclusion, that was made by the researchers, a presumtion should be examined: calculated and measured sound insulation index‘es of materials that are not solid should have great errors (Craik *et al.* 1997).

On the purpose to determine wether methodics are reliable for the experiment such partitions were chosen: silicat brick, ceramsite block, ceramic block and wooden log. The density of silicat bricks is 1750 kg/m^3, ceramsite blocks – 662 kg/m^3, ceramic blocks – 850 kg/m^3, pinewood log – 400 kg/m^3. Bricks and blocks were set using building mixture, wooden logs were rigged and battened down.

The purpose of the work is the following: 1) to calculate the sound insulation index of partitions built from ceramsite blocks, ceramic blocks and pinewood logs at frequencies of 1/3 octave, using international ISO 12354

– 1 standart and the law of weight; 2) to compare the obtained results with those measured under natural conditions or in the sound reduction chamber; 3) to analyse the mismatch of the data and the possibilities to perform theoretical calculations of sound insulation index of partitions built from different materials.

2. Methodology

2.1. The calculation of theoretical sound insulation index R_w

Theoretical sound insulation index R_w, based on the law of weight, is calculated according to (1) formula (Ballagh 2004; Stauskis 2007).

$$R=\left(20\lg\frac{\pi fm}{\rho c}-3\right), \tag{1}$$

here: f – the frequency of sound, Hz; m – the surface density of the partition, kg/m^2; ρ –the density of the material the partition is built from, kg/m^3; c –the speed of sound in air, m/s.

Theoretical sound insulation can also be calculated according to international ISO 12354 –1 standard. Calculations using this standard can be used to predict theoretical sound insulation index and can be made according to (2) formula (Gerretsen 1979).

$$R=-10\lg\tau, \tag{2}$$

here: τ – transmission coefficient.

Transmission coefficient τ is calculated according to (3), (4) or (5) formulae, depending on the reading frequency.

When the frequency is higher than the critical frequency ($f > f_c$), τ is calculated using (3) formula:

$$\tau=\left(\frac{2\rho_o c_o}{2\pi fm'}\right)^2\frac{\pi f_c\sigma^2}{2f\eta_{tot}}; \tag{3}$$

When the frequencies in calculation are approximately equal to critical frequency ($f \approx f_c$), τ is calculated using (4) formula:

$$\tau=\left(\frac{2\rho_o c_o}{2\pi fm'}\right)^2\frac{\pi\sigma^2}{2\eta_{tot}}; \tag{4}$$

When the frequency is lower than critical frequency ($f < f_c$), τ is calculated using (5) formula:

$$\tau=\left(\frac{\rho_o c_o}{\pi fm'}\right)^2\left(2\sigma_f+\frac{(l_1+l_2)^2}{l_1^2+l_2^2}\sqrt{\frac{f_c}{f}}\frac{\sigma^2}{\eta_{tot}}\right); \tag{5}$$

here: τ – transmission coefficient; m' –the density of the construction surface of the element, kg/m^2; f – frequency, Hz; ϕ_χ – critical frequency calculated accordingly: $(\phi_\chi=c_o^2/(1{,}8c_L t))$, Hz; η_{tot} – common factor of attenuation, which is determined under laboratory conditions; σ – the factor of radiation of free-bending waves; σ_f – the factor of forced transmission,whitch is calculated using (8) formula; l_1, l_2 – lenghts of the edges of a rectangular element, m.

Common factor of attenuation is calculated according to the data of laboratory research (Craik 1987).

The factor of forced wave radiation, when the value of l_1 is greater than that of l_2, is calculated using (6) formula:

$$\sigma_f=0{,}5\left(\ln\left(k_o\sqrt{l_1 l_2}\right)-\Lambda\right);\ \sigma_f\le 2; \tag{6}$$

Λ is calculated using (7) formula.

$$\Lambda=-0{,}964-\left(0{,}5+\frac{l_2}{\pi l_1}\right)\ln\frac{l_2}{l_1}+\frac{5l_2}{2\pi l_1}-\frac{1}{4\pi l_1 l_2 k_o^2}; \tag{7}$$

here: k_0 – the number of a wave, rad/m; $k_o=2\pi f/c_o$.

The factor of free wave radiation is calculated using Maidanik equations (Maidanik, 1962) ((8) and (9) formulae). The operation of the BASTIAN programme is also based on these formulae:

$$\sigma_1=\frac{1}{\sqrt{1-f_c/f}};\ \sigma_2=4l_1 l_2\left(\frac{f}{c_o}\right)^2;\ \sigma_3=\sqrt{\frac{\pi f(l_1+l_2)}{8c_o}}; \tag{8}$$

$$f_{11}=\frac{c_o^2}{4f_c}\left(\frac{1}{l_1^2}+\frac{1}{l_2^2}\right); \tag{9}$$

If $2f_{11}\le f_c\le f$, then: $\sigma=\sigma_1$;

If $2f_{11}\le f_c$ and $f<f_c$, then:

$$\sigma=\frac{2(l_1+l_2)}{l_1 l_2}\frac{c_o}{f_c}\delta_1+\delta_2;$$

$$\delta_1=\left(\frac{(1-\lambda^2)\ln\frac{1+\lambda}{1-\lambda}+2\lambda}{4\pi^2(1-\lambda^2)^{1,5}}\right);$$

$$\delta_2=\frac{8c_o^2(1-2\lambda^2)}{f_c^2\pi^4 l_1 l_2\lambda\sqrt{1-\lambda^2}};$$

here: $\lambda=\sqrt{\frac{f}{f_c}}$;

If $2f_{11}\le f_c<2f$, then: $\delta_2=0$;

If $f<f_{11}<f_c/2$ and $\sigma>\sigma_2$, then $\sigma=\sigma_2$, but $\sigma\le 2$.

If $2f_{11}>f_c>f$ and $\sigma_2<\sigma_3$, then $\sigma=\sigma_2$,

If $2f_{11}>f_c$, $f>f_c$ and $\sigma_1<\sigma_3$, then $\sigma=\sigma_1$,

If $2f_{11}>f_c$ and $\sigma=\sigma_3$ then $\sigma\le 2$.

These formulae are suitable for calculating the factor of radiation of plates, which are enframed on the condition of infinite screen, that is usual in laboratories. However, construction elements of buildings are often enframed using rectangular elements, which can considerably raise the efficiency of radiation in lower than critical frequency, from 2 (marginal mode) to 4 (angular mode) times. From the data of the latest sources other formulae are also known, by using which radiation factors can be determined.

Taking other types of waves, correspondent to a thin wall and/or higher frequencies into consideration, applying a higher frequency than the critical, the latter frequency is changed into effective critical frequency using formula (10) which is based on Ljunggren‘s (Ljunggren 1991) work:

$$f_p = \frac{c_L}{5{,}5t};$$

If $f < f_p$, then:

$$f_{c,eff} = f_c\left(4{,}05\frac{tf}{c_L} + \sqrt{1+\left(4{,}05\frac{tf}{c_L}\right)}\right); \qquad (10)$$

If $f \geq f_p$, then:

$$f_{c,eff} = 2 f_c\left(\frac{f}{f_p}\right)^3.$$

here: f_p –the frequency reading of sound attenuation, Hz, t – thickness of the element, m; c_L – the speed of a longitudinal wave in a material, m/s.

2.2. Determination of sound insulation index R_w of air by measurements under natural conditions

When carrying out acoustic measurements of the buildings partitions specific conditions of the experiment are followed. The measurements are done in rooms of the same size and shape. If the rooms are not the same size, the bigger one is used as a sound transmitting room and the smaller one as a sound recieving room. In bigger rooms, diffusers are set to form a diffusional field or the furniture acts as a diffuser measurements are carried out at one third of octave range, but can also be carried out at the range of octave frequencies. “White“ noise is used for the measurements in the sound transmitting room (the level of sound is aproximately the same at all frequencies). Prior to measuring, the diffusive properties of the sound field are checked, where the level of sound at one third of octave range can not differ more than 6 dB.

During measurements the generated sound has to be so strong that in the sound recieving room, behind the construction under examination, the level of sound pressure would be at least 10 dB higher than the level of background in every range of frequencies. That is especially important when the elements under examination possess great sound insulation properties.

Locations for the loudspeaker are chosen, in such a way as to make the sound field as diffusive as possible, with at least 0.5 m from the walls being kept to avoid reflection of sound dominating.

While measuring the level of sound in the sound transmitting room, the positions of the microphone and the loudspeaker are constantly changed. At least two positions for the loudspeaker are used and ten for the microphone depending on the size of the room. If the room is smaller than 50 m^2, the loudspeaker is placed at three positions, and the microphone is placed at at least ten positions with consideration to requirements of the distances.

While measuring the level of sound in the recieving room, the average level of sound is determined using the average value of all the measurements. Also the time lenght of sound reverberations is measured. It is measured nine times and an arithmetical average is derived. The strech of the partition and the size of the room are calculated too. Microphones should be positioned at least at: 0.7 m between the microphones; 0.5 m between any other position of the microphone, boundary of the room or a diffuser; 1.0 m between any other position of the microphone or the source of the sound.

The assumed sound insulation index R'_w of the sound in air is estimated by calculating the decuple logarithm of the falling power of the sound on the partition in examination L_1 in proportion with the power of sound that was put through the sample L_2 to power of 10. This value is denoted R'_w and is expressed in decibels using (11) formula:

$$R'_w = L_1 - L_2 + 10\lg\frac{S}{A}, \qquad (11)$$

$$A = \frac{0{,}163 \cdot V}{T}, \qquad (12)$$

here: L_1 – average level of sound in the sound transmitting room, dB; L_2 – average level of sound in the sound recieving room, dB; S – strech of the wall in examination, m^2; A – an equivalent strech of sound absorption in the sound recieving room, m^2; V –volume of sound recieving room, m^3; T –time lenght of the echo in the sound recieving room, s.

2.3. Evaluation of the insulation index R_w of sound in air in the noise reduction chamber

Research on the acoustic properties of a material are carried out in VGTU department of environment protection. General length of the camera is 4.2 m, width – 2.5 m, height – 3 m. All of inner surface (walls, ground, ceiling, partition) make up 70 m^2, all of which is covered in 0.25 m thick carved acoustic foam rubber slices (interval of cutting – 0.15 m.). General image of the laboratory is shown in Figure 1.

The noise reduction chamber is made up from two rooms separated by a double wall, and a nearby room with measuring equipment. The first room is called the sound transmitting „noisy“ room, the second room – sound recieving „silent“ room. The rooms with respect to each other and to the outer structure are isolated with rockwool. This construction allows to reduce the indirect permeability of sound between echoing rooms beside isolating the rooms from outer noise and thus minimyzing background noise. In the partition that separates the rooms there is a 1 m^2 opening in which 1.0 ×1.0 m sample is firmly set.

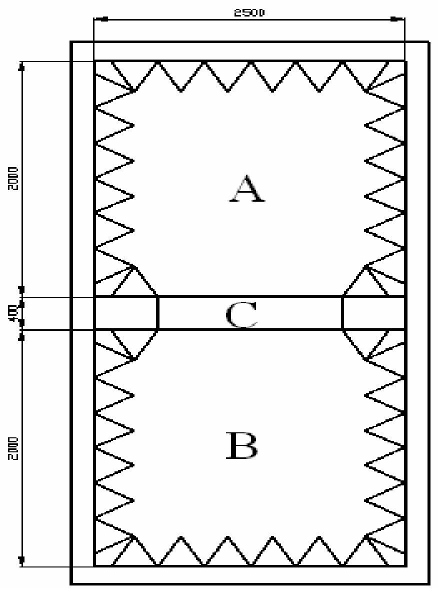

Fig 1. General image of the noise reduction chamber from the top (A – sound transmitting room, B – sound recieving room, C – sample under examination)

The sound is emited from the source which cannot be closer to the wall than 0.7 m.. One microphone is placed in the „noisy“ room, where the source of the sound is, the other is placed in the „silent“ room. Microphones are placed at a hight of 1.5 m from the ground surface of the room, at 1.2 m distance from the sample. The measurements are repeated three times. The level of sound insulation of the material under examination is determined by the difference in the levels of sound, which were measured in the „noisy“ and the „silent rooms, between which the sample is firmly set (Januševičius *et al.* 2008).

Equipment used for acoustic measurements:

- real time sound spectrum analyser „Bruel&Kjaer mediator 2260“ (Figure 2);
- two microphones Bruel&Kjaer 4189;
- microphone calibrator;
- amplifier of power Bruel&Kjaer;
- all-directional twelve-walled loudspeaker Bruel&Kjaer OmniPower Type 4292 (Figure 3).

Fig 2. Real time sound spectrum analyser „Bruel & Kjaer mediator 2260“

Fig 3. All-directional twelve-walled loudspeaker “Bruel&Kjaer Omni Power Type 4292”

3. The results

The results of the measurements under natural conditions and theoretical calculations of the partition constructed from ceramic blocks are shown in figure 4.

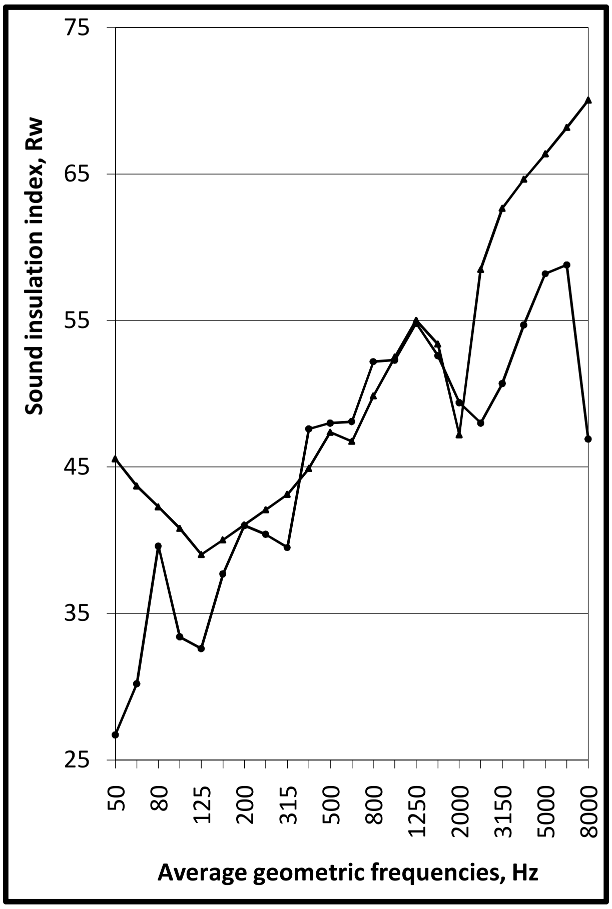

Fig 4. Sound insulation indexes of a partition made from ceramic blocks: —▲— - sound insulation index calculated using 2 formula;—●— - sound insulation index measured under natural conditions

The biggest mismatch between measured and calculated results was attained with clay block partition in low frequencies, from 50 to 150 Hz, where estimated results differed from the measured ones up to 20 dB. Results like these are attained in low frequencies, because low frequencies are best reduced by high mass and thick constructions. Also, low frequency sound travels through sourrounding constructions better at low frequencies, which is the reason why measured values are lower. At the frequency from 160 to 2000 Hz, the difference between measured and calculated results were up 2 dB. When the frequency was high, from 2500 to 6300 Hz, the results differed up to 16 %. The difference between measured and calculated data was attained because the properties of material under examination did not exactly match the properties that were taken into consideration when calculating. The density of the materials may be different as well as the surface density. Also, a portion of the sound may travel through the surrounding constructions.

The results of the measurements under natural conditions and calculations of the sound insulation index of a partition constructed from 520 mm thick bricks are shown in Figure 5.

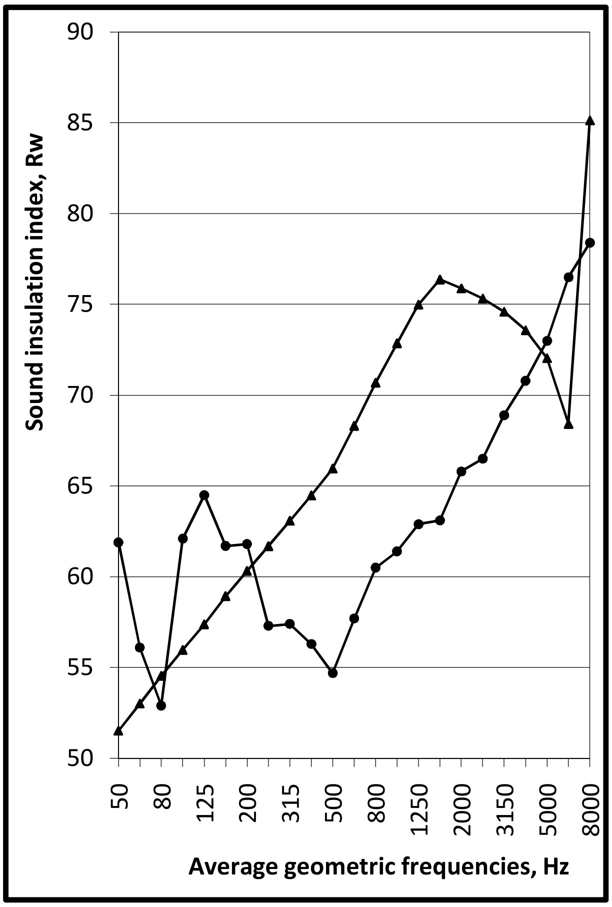

Fig 5. Sound insulation indexes of a partition made from bricks: —●— - sound insulation index measured under natural conditions; —▲— - sound insulation index calculated using (2) formula

In low frequencies, from 50 to 500 Hz, the mismatches were 16 % or 12 dB. In frequencies from 630 to 2000 Hz, the measured results were up to 13 dB 18 % lower than estimated theoretically. In frequencies from 2500 to 8000 Hz the measured and calculated results differed up to 8 dB.

The results of partition made from 15 cm wide wooden logs measurements under natural conditions and standardized chamber research of sound level difference $D_{nT,w}$ and the calculations of sound insulation are shown in Figure 6.

Whith wooden log partition in place, the measured and calculated results differ the most, as compared with other material measurements and calculations. This is determined by the fact that wooden log partition is not solid, it is made from separate shaped and milled 15 cm wide rectangular pinewood logs, which are attached to each other by pressing them together and laying tow in-between. Between the logs various gaps form, which are not considered when calculating. Newertheless, as it can be seen, when the sound insulation level is calculated using the law of wheight (1) formula, it is about 5 dB higher to octave than the one estimated using (2) formula.

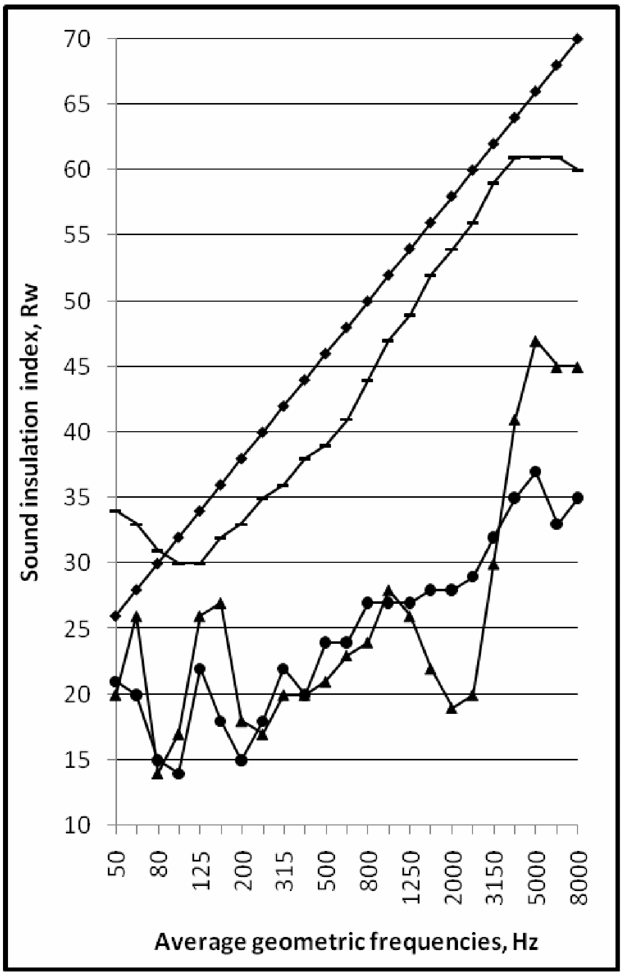

Fig 6. Sound insulation indexes af a partition made from wooden logs: —— - sound insulation index calculated using (2) formula; —◆— - sound insulation index calculated using (1) formula; —●— - standardized difference in sound level measured under natural conditions; —▲— - standardized difference in sound level measured in noise reduction chamber

As it can be seen from experiments that were carried out and their comparison with results obtained from calculating using law of weight and international standard, the measured and calculated results have similar values, therefore when calculating the sound insulation level of a partition, preliminary sound insulation level can be predicted.

The results of a partition made from 100 mm thick ceramsite blocks examination and theoretical calculation are shown in Figure 7.

As it can be seen from Figure 7, in low frequencies, from 50 to 100 Hz, the difference btween measured and calculated results are up to 10 dB. In low frequencies, from 125 to 500 Hz, the difference between measured and calculated results was the lowest, which were between 2 and 10 % or up to 5 dB. In high frequencies, from 1000 to 8000 Hz the difference between measured and calculated results were 23 % or up to 12 dB. In high frequencies from 1250 to 10000 Hz, the mismatches were up to 4 dB.

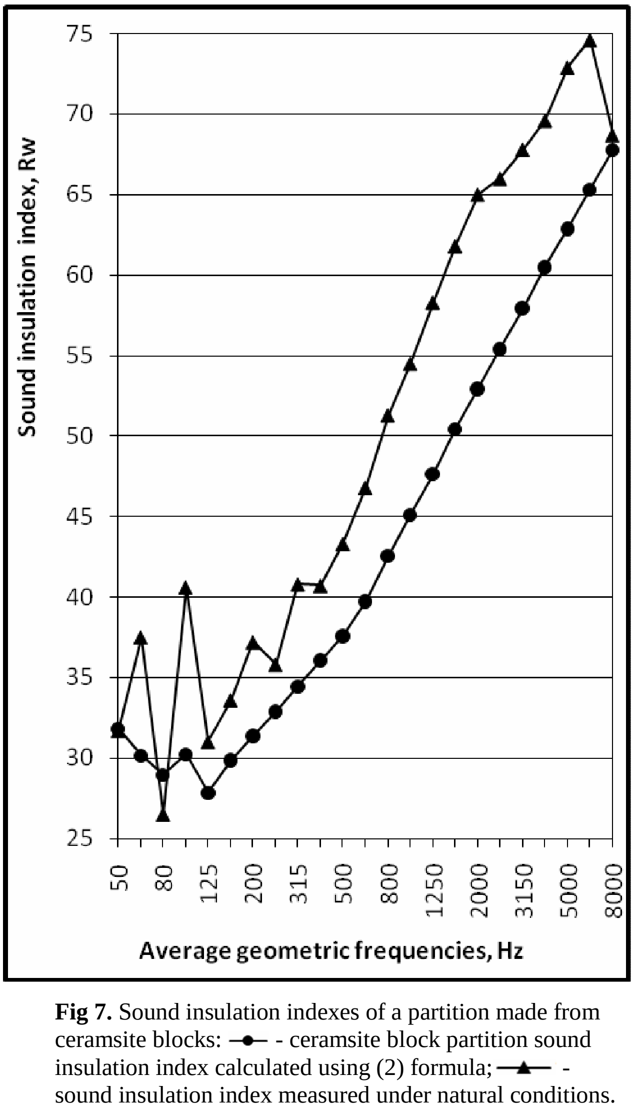

Fig 7. Sound insulation indexes of a partition made from ceramsite blocks: —●— - ceramsite block partition sound insulation index calculated using (2) formula; —▲— - sound insulation index measured under natural conditions.

The mismatches between measured and calculated results are about 10 %, higher values have been attained when measuring sound insulation.

4. Conclusions

1. Theoretical calculations of sound insulation can be accomplished in two ways: using the law of weight or using international standard; although calculations using international standard are more accurate as more properties of a material are taken into consideration.
2. The calculated results of a wooden log partition do not match the measured ones, because a wooden partition is not monolithic and micro-gaps reducing sound insulation form between the logs. Also a wooden log partition is more easily made to vibrate by the power of sound and thus emit the sound to the other room. This can not be taken into consideration when calculating.
3. Mismatches between measured and calculated results are also obtained because the sound partially passes through surrounding constructions and not directly through the construction under examination.

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