Applied Acoustics 92 (2015) 42–46

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

Comparison of sound insulation of windows with double glass units

Kestutis Miskinis *, Vidmantas Dikavicius, Raimondas Bliudzius, Karolis Banionis

Institute of Architecture and Construction of Kaunas University of Technology, Kaunas, Lithuania

ARTICLE INFO

Article history:
Received 22 July 2014
Received in revised form 24 November 2014
Accepted 8 January 2015
Available online 30 January 2015

Keywords:
Double glass unit
Ordinary glass
Laminated glass
Frequency range

ABSTRACT

Level of external noise grows every day in modern cities. New buildings usually have large windows or the whole areas of glass walls therefore protection from external noise is very important. Façade with good sound insulation properties is required to ensure acceptable internal noise level. Sound insulation of façade mainly depends from sound insulation properties of insulated glass unit (IGU). Different IGU with double, triple or even tetra glass could be used. In this paper is presented experimental study of window with three different type double glass units: 1 – two ordinary glass; 2 – one glass ordinary second one laminated; 3 – two laminated glass. The experimental results showed that sound reduction index (R) values are lower than 30 dB below frequency of 315 Hz (first type IGU), 250 Hz (second type IGU) and 125 Hz (third type IGU); sound reduction index (R) exceeds 45 dB above frequency of 4000 Hz (first type IGU), 2500 Hz (second type IGU) and 1600 Hz (third type IGU).

1. Introduction

Every day the level of noise from different sources (cars, trains, planes, industry, lawn mowers, leaf blowers, etc.) grows in both urban and suburban areas of cities [1,2]. Therefore protection from external noise is becoming a top priority to ensure acoustical comfort in buildings [3,4]. We cannot reduce the external noise level but we can reduce internal noise level by choosing appropriate facade construction with good sound insulation properties. Façade design task is difficult because modern buildings as a rule have big windows or even whole glass walls [5]. Façade sound insulation is divided into active and passive façade sound insulation [6,5,7–12]. The best passive sound insulation solutions are double glazing and laminated glazing solutions [4,5,13,14].

If we want to design façades with adequate sound insulation properties, we must know sound reduction index values (R) of windows tested in the laboratory. The sound reduction index of windows depends from various subjects as: type of glass, dimensions of glass, type of joinery, joints and seals in the window-opening system [3]. Windows and walls usually have double or triple glass units [3].

Double-glass IGU use two separate panes of glass with the gas (mostly argon) space between them. Such a double structure has a resonant frequency which depends on the mass of the panes and the distance between them as well as on the stiffness of the gas filling the cavity between panes [4,13]. The sound reduction index of a double glazed system at low frequencies can be considered as two masses acting together as a single pane with the same total mass. As the frequency increases, the airspace separating the glass panes acts as a spring [3].

The experimental results of the sound reduction index for the different types of windows with double glass units are presented. In this experimental study three types of double IGU were tested: first type – two ordinary glass; second – one ordinary and one laminated; third – two laminated glass. The aim of the experimental study was to determine which window has the highest value of weighted sound reduction index (R_w), and which has the best sound insulation at a low frequency range (below 400 Hz).

2. Test methodology, equipment and samples

The measurements of the experimental study were done in 1/3 octave bands from 100 Hz to 5000 Hz according to LST EN ISO 10140 series standards part 1, 2, 4 and 5 [15–18]. Measurements results were evaluated according to LST EN ISO 717-1 standard [19]. A combination of three loudspeaker and six microphone positions were used for measurements. The measurements were performed in the acoustic laboratory at Kaunas University of Technology in the period January–May of 2014. The temperature and relative humidity were kept constant (respectively 18 °C and 50%) and was controlled using a relative humidity and temperature sensor "Testo 615". The measurement system consists of two microphones L&D (Larson & Davis) 2560; two initial microphone

* Corresponding author at: Tunelio 60, LT-44405 Kaunas, Lithuania. Tel.: +370 37 350799; fax: +370 37 451810.

E-mail address: kestutis.miskinis@ktu.lt (K. Miskinis).

http://dx.doi.org/10.1016/j.apacoust.2015.01.007
0003-682X/© 2015 Elsevier Ltd. All rights reserved.

amplifiers L&D PRM 900C; precision integrated noise spectra meter – noise generator L&D 2800B; loudspeaker, power amplifier and rotating microphone system were made at Kaunas University of Technology. The accuracy of the equipment used for the measurements is verified in an accredited metrology laboratory.

The acoustic laboratory has masonry walls of ceramic bricks with mineral wool interlayer. There are two chambers: source chamber (volume 79.95 m^3) and receiving chamber (volume 68.56 m^3) (Fig. 1).

Between chambers is a separating wall (area 11.7 m^2) with sound insulation $R_w = 75$ dB. In the wall is an opening for the window (dimensions 1500×1250 mm). The test window (1230×1480 mm) was installed in the opening (Fig. 2).

The frame and sash of the window is wooden (pine) 78 mm thick covered with aluminum from the outside (source chamber); binding GU UniJet; gaskets – SP33 and SP6854; fixing – 8 points (Fig. 3).

The window in the opening was fixed with wooden sticks during the measurements. The perimeter (gap between frame and wall) was sealed using special high density material – Perrenator – from both sides. The same window frame was used for all the tests changing only IGU inside of it.

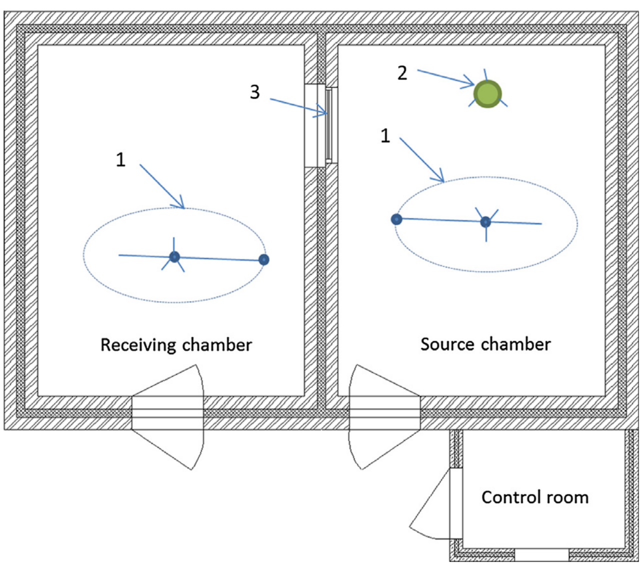

Fig. 1. Plan of acoustic laboratory. 1 – rotating microphone system; 2 – sound source; 3 – test window.

The insulated glass units used for measurements are given in the Table 1.

Twelve double glass units were tested: four were both of panes ordinary glass (WOG2); four with one ordinary and one laminated glass pane (WOLG1); four where both glass panes were laminated (WLG2). The thickness of ordinary glass varied from 4 mm to 12 mm, laminated glass – from 8 mm to 12 mm, the thickness of the air gap from 18 mm to 27 mm and the thickness of glass unit – from 28 mm to 48 mm. All spacers between glasses were metallic except the acoustic one, which was made from rubber. The laminated glass had special acoustical PVB interlayer,–one layer (test samples WOLG1) and two layers (test samples WLG2). All IGU were filled with argon gas. The test samples were made in LLC "Doleta", Lithuania.

3. Test results and discussion

Presented below are the results of the performed experimental study with double glass units described above (Table 1). In Fig. 4 the graphical frequency dependences of sound reduction index in frequency range 100–5000 Hz of IGU with ordinary glass are presented.

From presented curves (Fig. 4) we can see that ordinary glass has poor sound insulation in low frequency range (below 315 Hz). Low values of sound reduction index at a low frequency range are conditioned by resonant effects of the system mass – gas – mass. From Fig. 4 we can see that the curve character in the analyzed frequency range is the same for tested windows with glass units WOG2/1 and WOG2/2 though the gap between glass panes in the second unit is 6 mm wider. By keeping the thickness of the gap 24 mm and increasing the thickness of the second glass pane by 2 mm (test sample WOG2/3) we do not get better sound insulation in this analyzed frequency range. Only for the test sample WOG2/4–6 mm thicker than test sample WOG2/2 we get 1–2 dB improvement of sound insulation. It shows that only three time difference of thickness of first and second glass gives little improvement of sound insulation in low frequency range. In the middle frequency range 400–2000 Hz sound reduction index values (R) are between 35 dB and 40 dB and curves character of all test samples are similar though different thickness glass were used. In this frequency range it (thickness) has no influence. In the high frequency range (above 2000 Hz) we get sound insulation decrement due to coincidence effect. For test samples WOG2/1–WOG2/3 decrement is almost the same (difference is 1–2 dB). While for the test sample WOG2/4 due to the shift of critical

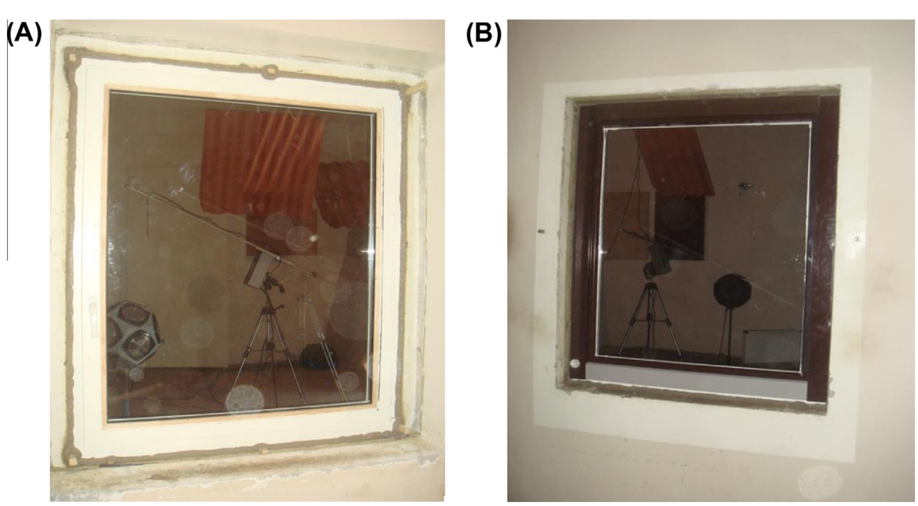

Fig. 2. Test window in the opening: (A) view from receiving chamber (inside of window); (B) view from source chamber (outside of window).

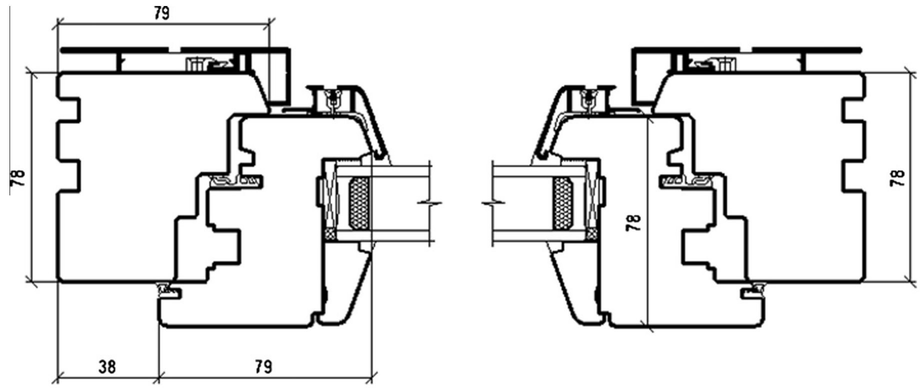

Fig. 3. Horizontal cross-section of test window.

Table 1
Windowglass units.

No.	Glass unit/ test sample	1st glass	Thickness of frame between glass, mm	2nd glass	Thickness of glass unit, mm
1	WOG2/1	4	18	6	28
2	WOG2/2	4	24	6	34
3	WOG2/3	4	24	8	36
4	WOG2/4	4	24	12	40
5	WOLG1/1	44.1ss	24	6	38
6	WOLG1/2	44.1ss	24	8	40
7	WOLG1/3	44.1ss	27	6	41
8	WOLG1/4	44.1ss	24	12	44
9	WLG2/1	66.2ss	27	44.1ss	48
10	WLG2/2	66.2ss	22	44.2ss	42
11	WLG2/3	66.2ss	20	55.2ss	43
12	WLG2/4	66.2ss	20[a]	55.2ss	43

[a] Special acoustic frame.

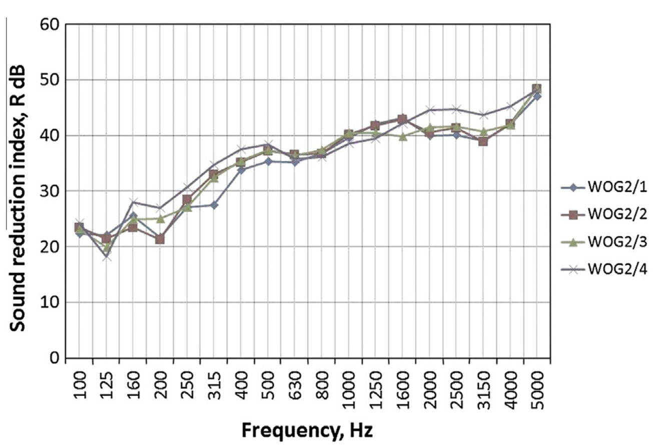

Fig. 4. Sound reduction index frequency dependences of the IGU with both ordinary glass panes.

frequency to lower frequency range of 12 mm glass pane (higher bending stiffness) and composition of two glass panes of different thicknesses (4 and 12 mm) result in smoothed sound insulation curve because when thinner glass coincidence dip occur the more rapid increment of thicker glass compensate it and result in higher value of sound reduction index. From analysis of these test curves we can say that significant difference of first and second glass thickness (in this case three times) enables to reach better sound insulation using ordinary glass in double glass unit.

The Fig. 5 presents sound reduction index (*R*) frequency dependences in the range of 100–5000 Hz for the IGU with two different glass panes: one laminated and one ordinary.

The curves character changes (Fig. 5) in low frequency range (below 315 Hz) changing one ordinary glass with laminated. Thought the resonance occur at the same frequencies (125 Hz and 200 Hz) but sound reduction index values increase comparing with values (Fig. 4) of glass units with ordinary glass. This increment is about 5 dB in average in frequency range of 100–250 Hz and is not noticeable in frequency range of 350–400 Hz. Better results were got for test specimens WOLG1/2 and WOLG1/4. This is influenced by increase of mass of the first glass (thickness increases from 4 mm to 8 mm) and the effect of mass law (doubling of mass increase sound insulation about 5 dB). An increase of air gap by 2 mm does not influence sound reduction index values (samples WOLG1/1 and WOLG1/3). In the middle frequency range 400–2000 Hz sound insulation has not changed. This shows that usage of laminated glass has no effect. In high frequency range (above 2000 Hz) the resonance occurs at 2000–2500 Hz due to composition of two glass panes of different type (laminated and ordinary) with different resonances which compensate one another. The viscoelastic interlayer between two glasses is subjected to shear motion and vibration energy is converted into heat [20]. This effect results that sound reduction index values above 2500 Hz rise about 5 dB comparing with of WOG2 samples sound insulation.

In Fig. 6 is presented sound reduction index frequency dependences (*R*) in the range of 100–5000 Hz when IGU consist of two laminated glass.

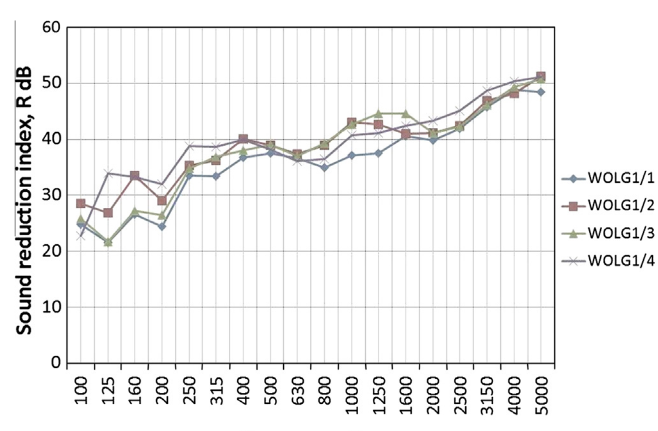

Fig. 5. Sound reduction index frequency dependences of the IGU with one ordinary second one laminated glass pane.

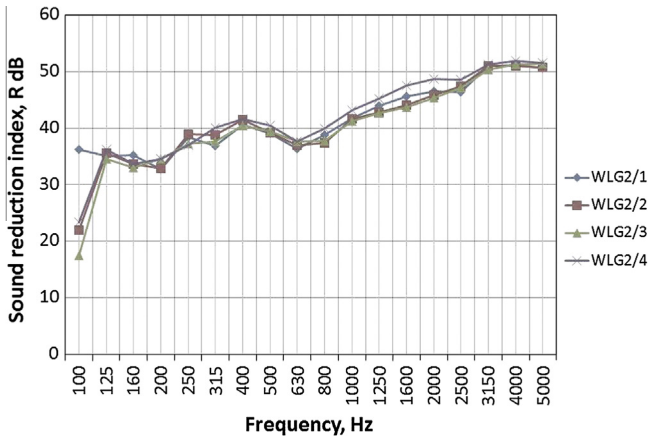

Fig. 6. Sound reduction index frequency dependences of the IGU with both laminated glass panes.

The curves (Fig. 6) of sound reduction index of four test samples in all frequency range are the same character and values are very close. It shows that the thickness of glass and gap do not have significant influence. From the Fig. 6 we can see that using laminated glass resonance effect occur in low frequency at 200 Hz – the same as previous test samples (Figs. 4 and 5). The sound insulation index values increases about 5–10 dB in low frequency range comparing with glass units with first two test samples. From this we can conclude that usage of laminated glass enables to increase sound insulation in low frequency range due to changes of the glass – gas – glass resonant system. Sound insulation increases insignificant comparing with units with different glasses (WOLG1) in the middle frequency range (400–2000 Hz). In high frequency range (above 2000 Hz) sound insulation increases about 5 dB comparing with sound insulation of WOLG1 samples. This is conditioned by higher damping of two viscoelastic interlayers with comparison of one interlayer of WOLG1.

Weighted sound reduction index – R_w – of all tested test samples (Table 2) was calculated using the determined sound reduction index values (R). The values of spectrum adaptation terms C and C_{tr} and $R_w + C_{tr}$ are also given in Table 2.

From the Table 2 we can see that weighted sound reduction index (R_w) value varies from 37 dB up to 39 dB (difference 2 dB) for glass units when both glass ordinary (WOG2); from 38 dB to 41 dB (difference 3 dB) for glass units with different glass (WOLG1) and from 41 dB up to 44 dB (difference 3 dB) for units with both laminated glass (WLG2). From this we can say that using one laminated glass instead of ordinary we get 2 dB better insulation and using both laminated – 5 dB better compared with ordinary glass. For better sound insulation characterization of window it is important to know $R_w + C_{tr}$ values which show how is ensured protection from traffic noise. From the Table 2 we can see that for units with ordinary glass (WOG2) $R_w + C_{tr}$ is from 32 dB to 34 dB (decrement 5 dB adding C_{tr}). For glass units with one ordinary second one laminated (WOLG1) $R_w + C_{tr}$ – from 34 dB to 37 dB (decrement 3–5 dB) and for units with both laminated glass (WLG2) – 35 dB–40 dB (decrement 3–7 dB). From this we can say that transport adaptation term C_{tr} significantly reduces weighed sound reduction index – in average 5 dB. Windows with ordinary glass units have poor sound insulation in low frequencies and this mean that they have worse sound protection form traffic noise. Better sound insulation could be achieved using laminated glass. Summarizing we can say that sound insulation is lower than 30 dB below 315 Hz, 250 Hz and 125 Hz respectively of these three type units (WOG2, WOLG1 and WLG2); sound insulation is higher than 45 dB above 4000 Hz, 2500 Hz and 1600 Hz respectively for these three type glass units (WOG2, WOLG1 and WLG2).

Table 2
Values of R_w, C, C_{tr} and $R_w + C_{tr}$.

No.	Glass unit/test sample	R_w, dB	C	C_{tr}	$R_w + C_{tr}$, dB
1	WOG2/1	37	−1	−5	32
2	WOG2/2	38	−2	−5	33
3	WOG2/3	38	−1	−5	33
4	WOG2/4	39	−2	−5	34
5	WOLG1/1	38	−1	−4	34
6	WOLG1/2	41	−1	−3	38
7	WOLG1/3	41	−2	−5	36
8	WOLG1/4	41	−1	−4	37
9	WLG2/1	43	−1	−3	40
10	WLG2/2	42	−1	−4	38
11	WLG2/3	42	−2	−7	35
12	WLG2/4	44	−2	−5	39

4. Conclusions

From the experimental study we can say that the best chose is window (WOLG1/2) with glass unit 44.1ss/24/8. To second place could be ascribed the window (WLG2/2) with IGU 66.2ss/27/44.1ss. Test window WOLG1/2 has sound insulation 5 dB worse in low frequency range comparing with window WLG2/2, but it is 8 mm thinner, 1 m^2 mass of glass unit is 10 kg less and this glass unit is cheaper to produce. Using these two windows we can ensure good sound insulation (acceptable internal noise level) when high external noise level exist.

Acknowledgement

This experimental study was performed with the contribution of windows manufacture LLC "Doleta", Lithuania.

References

[1] Díaz C, Pedrero A. An experimental study on the effect of rolling shutters and shutter boxes on the airborne sound insulation of windows. Appl Acoust 2009;70:369–77.
[2] Novakova K, Mokry P, Vaclavik J. Application of piezoelectric macro-fiber-composite actuators to the suppression of noise transmission through curved glass plates. IEEE T Ultraso Ferr 2012;59(9).
[3] COST Action TU0901 E-book "Building acoustics throughout Europe". Volume 1: Towards a common framework in building acoustics throughout Europe, 2014, [http://tu0901.eu/tu0901-e-books/volume-1/separated-chapters/05-Volume-1-Ch05.pdf/at_download/file]. Ch05 Proposal for an Acoustic Classification Scheme for Housing.
[4] Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise – Declaration by the Commission in the Conciliation Committee on the Directive relating to the assessment and management of environmental noise [http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32002L0049].
[5] Naticchia B, Carbonari A. Feasibility analysis of an active technology to improve acoustic comfort in buildings. Build Environ 2007;42:2785–96.
[6] Zhu H, Yu X, Rajamani R, Stelson K. Active control of glass panels for reduction of sound transmission through windows. Mechatronics 2004;14:805–19.
[7] Mao Q, Pietrzko S. Experimental study for control of sound transmission through double glass window using optimally tuned Helmholtz resonators. Appl Acoust 2010;71:32–8.
[8] Pietrzko SJ, Mao Q. New results in active and passive control of sound transmission through double wall structures. Aerosp Sci Technol 2008;12:42–53.
[9] Hu S, Rajamani R, Yu X. Directional cancellation of acoustic noise for home window applications. Appl Acoust 2013;74:467–77.
[10] Kaiser OE, Pietrzko SJ, Morari M. Feedback control of sound transmission through a double glass window. J Sound Vib 2003;263:775–95.
[11] Kwon B, Park Y. Interior noise control with an active window system. Appl Acoust 2013;74:647–52.
[12] Hu S, Rajamani R, Yu X. Invisible speakers in home windows for simultaneous auxiliary audio playback and active noise cancellation. Mechatronics 2012;22:1031–42.

[13] Garg N, Kumar A, Maji S. Parametric sensitivity analysis of factors affecting sound insulation of double glazing using Taguchi method. Appl Acoust 2013;74:1406–13.

[14] Akrout A, Hammami L, Tahar MB, Haddar M. Vibro-acoustic behaviour of laminated double glazing enclosing a viscothermal fluid cavity. Appl Acoust 2009;70:82–96.

[15] LST EN ISO 10140-1:2010. Acoustics – laboratory measurement of sound insulation of building elements – Part 1: Application rules for specific products (ISO 10140-1:2010).

[16] LST EN ISO 10140-2:2010. Acoustics – laboratory measurement of sound insulation of building elements – Part 2: Measurement of airborne sound insulation (ISO 10140-2:2010).

[17] LST EN ISO 10140-4:2010. Acoustics – laboratory measurement of sound insulation of building elements – Part 4: Measurement procedures and requirements (ISO 10140-4:2010).

[18] LST EN ISO 10140-5:2010. Acoustics – laboratory measurement of sound insulation of building elements – Part 5: Requirements for test facilities and equipment (ISO 10140-5:2010).

[19] LST EN ISO 717–1:2013. Acoustics – rating of sound insulation in buildings and of building elements – Part 1: Airborne sound insulation (ISO 717–1:2013).

[20] Ross D, Ungar EE, Kerwin EM. Damping of plate flexural vibrations by means of viscoelastic laminate. Structural damping. New York: ASME Publication; 1959. p. 49–88.