Acoustics of the modern multiple glazing windows

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Abstract

Exterior noise is mainly transmitted into buildings via windows, due to their lower sound transmission loss compared to outer walls. Additionally, the proportion of glass surfaces in modern architecture is increasing. However, when developing modern windows, the focus is on energy efficiency and thermal insulation, while acoustic performance is often ignored.

The acoustic performance of a window is evaluated based on a test certificate, which refers to the standard measurement in a test lab composed of a sending and a receiving room. Since windows in real construction generally have different dimensions, edge connections and mounting conditions, the acoustic performance of the window in the building often differs from the value specified in the test certificate.

This paper focuses on the influences of the window format and the pane configurations on the sound transmission loss. A total of 20 triple glazing units with five different dimensions and four pane thickness configurations were tested according to DIN EN ISO 10140. The analytical method was also used to complement the experimental investigations. Both the experiments and the simulations indicate that the window surface area has a considerable influence on the sound transmission loss.

Introduction

Windows and glazing are playing an increasingly important role in modern housing construction. Current trends are towards larger glass surfaces and narrower frames. Floor-to-ceiling panoramic windows allow plenty of daylight into living spaces and provide an unobstructed view of the surroundings.

In addition to the demands on design, there are also increasing requirements on thermal and sound insulation. The acoustic performance of a window is measured in the laboratory according to DIN EN ISO 10140 [1] with a standardized installation area of W × H = 1.23 m × 1.48 m. A lot of test reports contain measurement data from glass panes with a metal-butyl edge seal. Since windows in construction generally have different dimensions and edge connections, the sound insulation in construction differs from the value specified in the test certificate. When measuring from outside to inside, the deviation may increase even more. According to the available measurement data [2], the differences can be considerable. Particularly with large-format panes, a significant deterioration in sound insulation of more than 5 dB (i.e. more than an entire sound insulation class) is to be expected. Architects and planners therefore often ask about the sound insulation of large-format glazing.

The presented research project includes a systematic investigation of the impact of the dimensions and pane thickness configurations of multi-glazing on sound transmission loss. Insights are presented on how the glazing dimensions that deviate from the respective testing standard can influence the acoustic performance. The developed correction factor of the glazing dimensions can certainly improve in-situ acoustic design and support architects in choosing acoustically suited products.

Physical Arrangement

Experiments

During the project, in total 20 triple glazing units were tested with 5 combinations of pane dimensions and 4 combinations of different pane thicknesses to provide a representative overview. Table 1 summarizes the dimensions of the measured triple glazing. Each glass pane was spaced 14 mm apart and the air gap was filled with argon. All measurements were taken in the frequency range from 50 - 5000 Hz in 1/3rd and 1/24th octave bands in an accredited window testing facility with an installation opening of 1.25 m × 1.50 m (the first three dimensions in Table 1) or in the other building acoustics test facility with an installation opening from 3.20 m x 1.25 m (the last two dimensions in Table 1) due to the limited dimensions of the test object in the accredited window testing facility. To adjust the opening to the respective pane format a double-shell installation mask in lightweight construction with a maximum STL ($R_{w,max}$) ≥ 64 dB was used. (see Figure 1).

Figure 1: A double-shell installation mask in lightweight construction.

Table 1: Glazing Dimensions

L x H [m]	Aspect Ratio	Surface Area [m²]
0,87×1,05	**0,83**	0,92
0,97×1,17	**0,83**	1,13
1,23×1,48	**0,83**	**1,82**
0,67×2,05	0,33	1,37
0,77×2,37	0,32	**1,82**

Analytical Model

To supplement the insufficient number of triple glazing samples, the self-developed analytical tool called TL_ATOMOS, was used to analyze the effect of the single glazing dimensions on the sound transmission loss. A plate is set into an infinite rigid baffle between two areas filled with the gas. The panel can be resiliently supported by linear and rotational springs along its four edges [3]. The complex stiffness of the linear and rotational springs was experimentally determined during the project [4].

When a plane sound wave is incident on the structure, the structure is excited by the net pressure acting on the plate, which is equal to the pressure difference on the sending and receiving sides of the panel. On the sending side, the sum of the incoming and reflected plane sound waves and the sound radiated by the structure act on the structure, while only the radiated sound from the structure is counted on the receiving side. The sound transmission loss under the diffuse field excitation was predicted using the Paris formula, i.e., by the integration of the sound transmission loss over the polar and azimuthal angles of the incident sound wave.

Effect of Glass Thickness

First, the effect of the pane thickness configurations on the sound transmission loss was investigated. Four different combinations of triple layer glass thicknesses have been experimentally examined. The glass has a thickness of either 2mm, 3mm, or 4mm. The thinnest triple glazing consists of 3 mm - 2 mm - 3 mm glass panels (hereafter referred to as 3-2-3), thus in total 8 mm glass thickness, while the thickest glazing has 4 mm - 3 mm - 3 mm (4-3-3), thus in total 10 mm thickness. The other two have the same total thickness of 9 mm, but one has 3 mm - 3 mm - 3 mm (3-3-3) thick glass panels, while the other has 3 mm - 2 mm- 4 mm (3-2-4) thick glass panels.

Figure 2 shows the measured sound transmission loss of four triple glazing units with the dimensions of 1230 x 1480 mm. The green (4-2-3) and blue (4-3-3) lines overlap well, while the red (3-2-3) and grey (3-3-3) lines also overlap. The results indicate that the difference of 1 mm in the middle layer thickness has negligible effects on the sound transmission loss. On the other hand, increasing the outer layer thickness by 1mm brings significant improvement of the acoustic performance. The difference between the red (3-2-3) and green (4-2-3), and the difference between the grey (3-3-3) and the blue (4-3-3) lines is larger than 2 dB below 2 kHz. The same tendency was observed for other triple glazing with the different dimensions of glazing.

The effect of the glass layer thickness is more clearly visualized using the weighted sound reduction index according to DIN EN ISO717 [5], R_w, shown in Figure 3. If both outer glass layers have the same thickness, i.e., green (4-2-3) and blue (4-3-3) curves, and red (3-2-3) and grey (3-3-3) curves, the acoustic performance is comparable. The difference of less than 1 dB should be considered as measurement uncertainties. As discussed above, a 1mm difference in the middle layer thickness have a negligible influence on the sound transmission loss. Finally, 3-3-3 (red) and 4-2-3 (black) have the same total thickness of 9 mm, but the 4-2-3 (black) shows a more than 3 dB higher sound reduction index.

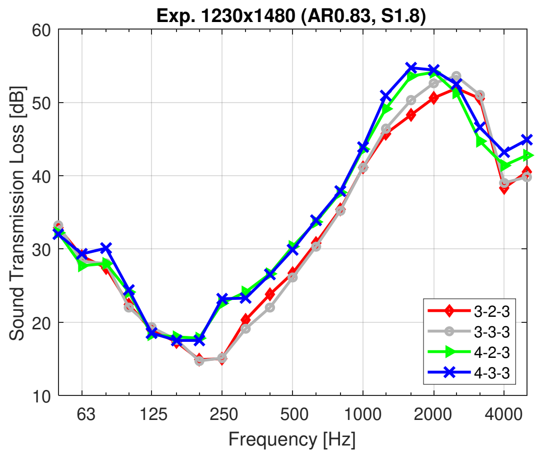

Figure 2: Measured sound transmission loss of the triple glazing with the dimensions of 1230 x 1480 x 3-2-3 mm (red with diamonds), 3-3-3 mm (grey with circles), 4-2-3 mm (green with >), and 4-3-3 mm (blue with x).

Figure 3: Measured weighted sound reduction index of the triple glazing with four pane configurations: 3-2-3 mm (red with diamonds), 3-3-3 mm (grey with circles), 4-2-3 mm (green with >), and 4-3-3 mm (blue with x).

Effect of the Glazing Dimensions

As the next step, the effect of the glazing dimensions on the sound transmission loss was studied. A total of 5 different dimensions of triple glazing were tested during the project. The number of samples is insufficient to draw a general conclusion. Furthermore, the tested triple glazing are smaller or equal to the standard size of 1230 x 1480 mm, and thus the effect of the larger dimensions on the sound transmission loss cannot be examined. Therefore, the analytical model of a single glass panel is used to highlight the effects of the glass dimensions on the sound transmission loss. After the analytical study, the experimental results are examined to determine whether the derived conclusion from the analytical simulation agrees with the experimental results.

Analytical Investigation

Table 2 summarizes the material parameters used in the simulation. The effect of the dimensions on the sound transmission loss is visualized using the weighted sound reduction index, R_w in Figure 4. Both plots show the deviation of the R_w of the glass panel from the reference value, which is the R_w of the 4mm glass plate with a surface area of 1,82 m^2

(top), and with an aspect ratio of 0,83 (bottom). The top plot illustrates the effect of the surface area on the acoustic performance. The surface area varies between 0,8 m^2 and 4 m^2, while the aspect ratio is kept constant as AR=0,33 (red), 0,52 (blue), or 0,83 (green). The bottom plot shows the effects of the aspect ratio. The aspect ratio varies between 0,2 to 1,0, while the surface area is kept constant, S = 1,37 m^2 (red), 1,82 m^2 (blue) and 2,21 m^2 (green).

In both plots, all three curves show the same tendency. In the top plot of Figure 4, the deviation curves continue to decrease with minor oscillations as the surface area increases. This indicates that a smaller glazing tends to overestimate R_w, while the bigger glazing slightly underestimates it. This plot confirms that it is necessary to correct R_w with reference to the glazing surface area. The bottom plot in Figure 4 indicates that the deviation curve is almost unaffected by the change of the aspect ratio, unlike the change of the surface area.

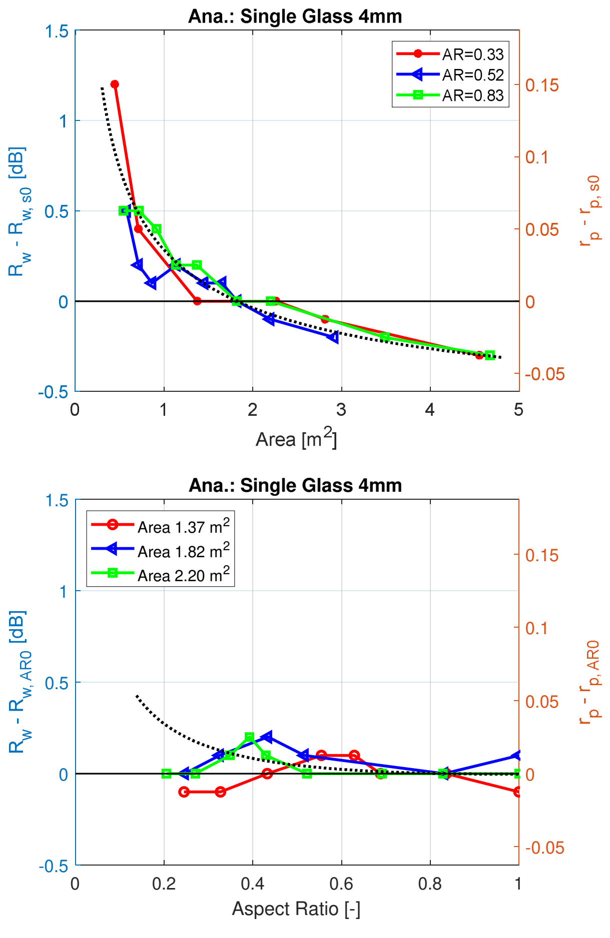

Figure 4: Top: Deviation of the R_w of the 4 mm glass panel with reference to the surface area at a constant aspect ratio of 0,33 (red with circles), 0,52 (blue with <) and 0,83 (green with squares) using the R_w of the 4mm glass plate with the surface area of 1,82 m^2 as a reference. Bottom: Deviation of R_w of the 4 mm glass panel with reference to the aspect ratio at a constant surface area of 1,37 m^2 (red with circles), 1,82 m^2 (blue with <) and 2,20 m^2 (green with squares) using the R_w of the 4mm glass plate with the aspect ratio of 0,83 as a reference. The deviation of the area ratio r_P (black dotted line) from the reference panel with the dimensions of 1230 x 1480 x 4 mm.

Table 2: Material and geometrical parameters used in the simulation.

	Parameter	Unit	Value
Glass	Thickness	mm	4
	Elastic modulus	N/m^2	72 x 10^9
	Poisson ratio	--	0,3
	Loss factor	--	0,005
	Density	kg/m^3	2500
	Linear stiffness	N/m^2	30 (1 + 0,5j) 10^6
	Rotational stiffness	N/m	30 (1 + 0,5j) 10^3
Dry Air	Speed of sound	m/sec	343
	Density	kg/m^3	1,21

Experimental Validation

In total 5 different dimensions of glazing were tested, 3 of which have a common aspect ratio of 0,83 (see Table 1). The effect of the surface area on the STL is visualized in Figure 5 using R_w. The measured results clearly confirm the analytical results: The deviation of the R_w decreases as the surface area increases. In terms of the surface area, only two different dimensions with a constant surface area of 1,82 m^2 were included in the tested objects (see Table 1). It is impossible to draw any general conclusion using only two samples.

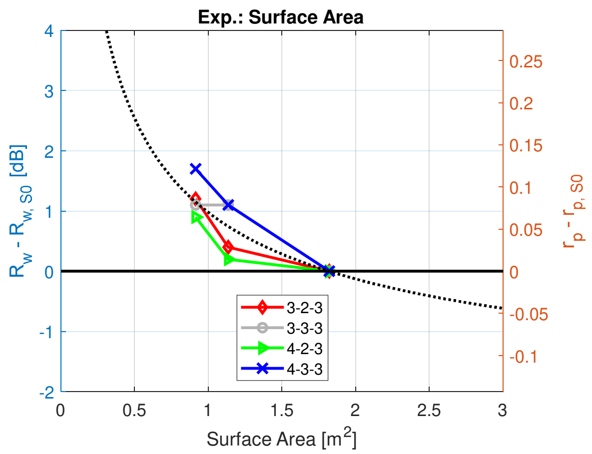

Figure 5: Deviation of the measured $\boldsymbol{R_w}$ from the reference value of the 1230 x 1480 mm with the glass layer thickness of 3-2-3 mm (red with diamonds), 3-3-3 mm (grey with circles), 4-2-3 mm (green with >), and 4-3-3 mm (blue with x) with reference to the surface area (left). Ratio of the perimeter to the surface area of the rectangular plate with an aspect ratio of 0,83. The deviation of the area ratio r_P (black dotted line) from the reference panel with the dimensions of 1230 x 1480 x 3-3-3 mm.

Correction Factor

Both the analytical and experimental results indicate that the surface area affects the sound transmission loss. The aspect ratio has less influence on the STL than the surface area, according to the analytical results. This is probably due to the fixing of the glazing in the testing facility. The glazing is aligned in the opening according to ISO 10140 using strips of hardwood and specific window putty. Figure 6 illustrates the boundary conditions of the double glazing. As glass is generally a very low dissipative material, the incoming sound power can mostly be dissipated by the area covered by the putty.

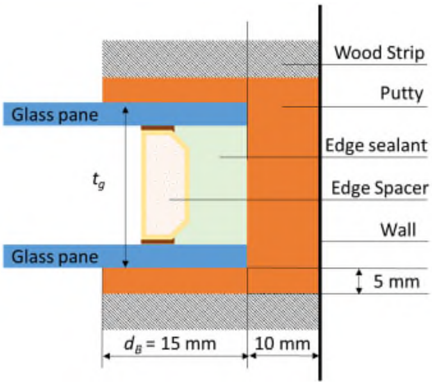

Figure 6: A double-layer glass pane aligned in the opening according to IS0 10140

As the putty-covered area increases, more incoming sound power can be dissipated along the boundary, while the incoming sound power is proportional to the surface area. Therefore, the effect of the boundary dissipation must be evaluated in terms of the ratio of the putty-covered area to the surface area, as given below:

$$r_P = \frac{L_p(2d_B + t_g)}{S_w} \qquad (1)$$

where d_B and t_g are respectively the thickness of the area covered by the putty and the total thickness of the glazing. According to DIN EN ISO 10140, $d_B = 15$ mm. The thickness of the single glazing is equal to the thickness of the glass panel, while the thickness of the multi-glazing is the total thickness of the glass plates and the cavity thickness. S_w and L_p are the surface area and the perimeter of the glazing with the height H and the width W.

$$S_w = H\,W \quad [\mathrm{m}^2] \qquad (2)$$
$$L_p = 2(H + W) \quad [\mathrm{m}]$$

In Figure 3, the derivation of r_P (black dotted line) from the reference panel with the dimensions of 1230 x 1480 x 4 mm is also plotted by the dotted line on the right-hand side y-axis. In both plots, only one dotted curve is included, because the change of the aspect ratio (left) or the change of the surface area (right) has a negligible effect on the deviation curve of r_P.

Figure 3 clearly confirms that the change of the R_w due to the dimensions of the glazing is closely related to the area ratio r_P. Therefore, the sound transmission loss of a single glazing with various dimensions can be analytically derived using R_w of the standardized glazing and the correction factor as follows:

$$R_w(H,W) = R_{w,S0} + C_1(r_p - r_{p,S0}) \quad [\mathrm{dB}] \qquad (3)$$

where $R_{w,S0}$ and $r_{p,S0}$ respectively denote the sound reduction index and the area ratio of the 4mm glass with the standard dimensions of 1230 mm x 1480 mm. C_1 denotes the constant for the single glazing, which is estimated to be around $C_1 = 8$ in this study.

The same tendency can be confirmed by the measured sound transmission loss of the triple glazing in Figure 4. The deviation of the area ratio r_p (dotted line) from the refence value is additionally plotted by a dotted line. The average thickness of $t_g = 37$ mm was used, which corresponds to the thickness of 3-3-3 mm glass windows. Finally, the correction factor for the triple glazing can be estimated as:

$$R_w(H,W) = R_{w,S0} + C_3(r_p - r_{p,S0}) \quad [\mathrm{dB}] \qquad (4)$$

where $C_{exp,3} = 14$, which is much higher than the constant for the single glazing, $C_1 = 8$. It indicates that the multiple glazing requires higher a correction factor than the single glazing.

Conclusions

Through the systematic investigation on triple glazing, the influence of the glass thickness of the three layers on the acoustic properties also became evident. The experiments clearly indicated that a difference of 1 mm in middle layer has a negligible effect on the sound transmission loss, while increasing the outer layer thickness by 1 mm brings an improvement of more than 3 dB in R_w.

Both the analytical and experimental results indicate that the surface area affects the sound transmission loss. The aspect ratio has smaller influences on the STL according to the analytical results. The influence of the dimensions of the glazing on R_w is closely related to the ratio of the putty-covered boundary area to the free surface area, r_P. The correction factor was derived for both the single glazing and the triple glazing to determine the sound reduction index of glazing with any dimensions by using the index of the glazing with the standard dimensions of 1230 mm x 1480 mm. The quality of the correction factor should be further improved by additional measurements.

Literature

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