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Improvement on nighttime sound insulation of windows by external shutters- Part 1: Measurement results

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1. Motivation

Window elements are often equipped with external shutters for the purpose of shading a room especially during nighttime. Although it is known that a shading device can have an effect on sound insulation of the overall window construction [1], [2], [3], [4] it is usually not taken into account for a prognosis of sound insulation performance. In terms of enhanced sound protection requirements during nighttime it is desirable to incorporate this effect in design and planning procedures.

To investigate this effect a joint research project by ift Rosenheim, TH Rosenheim and HfT Stuttgart was started with support by German „Bundesministerium für Wirtschaft und Klimaschutz“ within the funding program „WIPANO – Normung und Standardisierung“. While the measurements of sound insulation were performed at ift Rosenheim, investigation on calculation models were done at HfT Stuttgart. TH Rosenheim is investigating this subject by means of numerical simulations.

2. Introduction

The project includes experimental, numerical and theoretical methods for assessment of the improvement on sound insulation of window elements by external shutters. Within this paper measurement results are presented. For numerical analysis see a corresponding article by Martin Schneider et. al. presented at forum acusticum 2026 [5]. Measurements of airborne sound insulation of window elements with and without external shutters were done in the acoustic test stand of ift Rosenheim with the specific small-sized test opening acc. to EN ISO 10140-5, section 4.3.4 [6]. As test specimen a single window in standard dimensions was chosen, see description in table 1 and figure 1. Most measurements were done in connection with roller shutters, but some investigations were done also on a blind screen and wing shutters, see table 1.

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Figure 1. Photos of window element with roller shutter mounted in test stand, photos taken from receiving room side, casement open (bottom at left) and closed (at right). Photo of tested roller shutter as example (top at right)

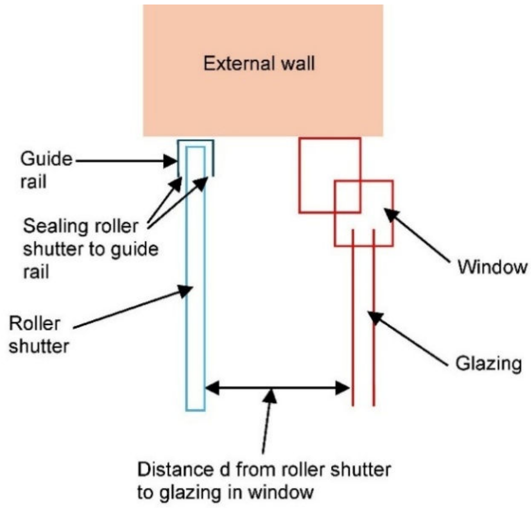

Figure 2. Schematic drawing (horizontal section) of onsite joint configuration for window and roller shutter to external wall in building project

A schematic drawing of the joint configuration of window and roller shutter to an external wall is shown in figure 2. The effects of sound transmission through a roller shutter box were not investigated in this context.

Table 1. Description of test specimen

Test specimen	Configuration
Window Element	Single window in standard dimension, w=1.23m x h=1.48m Material of profile: plastic with steel reinforcement Three rebate seals Three different glazing configurations 4/12/4/12/4 6/12/4/12/8LSG Acoustic 12 LSG Acoustic/12/4/12/8 LSG Acoustic
External Shutter	10 types of roller shutters (material: PVC, Aluminium, timber), mass per area varying between 2.9 kg/m² and 11.8 kg/m² 1 blind screen 2 types of wing shutters (PVC) with mass per area of 17.4 kg/m² resp. 18.1 kg/m², installed in separate frame
Guide rail for roller shutters	2 different guide rails (PVC and aluminium profile) with distance to glazing in window varying from 23 mm up to 366 mm sealing towards roller shutter with brush seal or "Keder"-gasket

3. Testing program

The testing program included the variation of the main parameters to be expected to have an influence on sound insulation:

a) Variation of sound insulation of the window element
   This was achieved by installing different glazing configurations. The sound insulation of the window varied between
   R_w = 35 dB with glazing 4/12/4/12/4
   R_w = 42 dB with glazing 6/12/4/12/8LSG Acoustic
   R_w = 45 dB with glazing 12 LSG Acoustic/12/4/12/8LSG Acoustic
b) Variation of the shutter
   The different types of shutters (roller shutter, wing shutter, screen) are expected to have different influence on sound insulation. Even the investigated roller shutters vary in terms of shape (profile cross section), material and mass per area. The mass per area has (through the Berger mass law of building acoustic) a direct influence on sound insulation, whereas the profile section affects the sealing of the roller shutter to the guide rail.
c) Variation of distance between shutter and glazing
   Most measurements were performed with the roller shutter elements, resulting in a distance varying between 44 mm (guide rail mounted directly to the window frame) and 366 mm.
d) Variation of sealing of roller shutter to guide rail
   Typical sealing configurations with brush seals and "Keder"-gaskets were investigated. For comparison tests without sealing and with an idealized sealing with mastic (in not operable condition) were performed.

In total 414 measurements on different combinations of test configurations a), b), c) and d) were performed.

Testing was done according to EN ISO 10140-2 in the specific small-sized opening according to EN ISO 10140-5, section 4.3.4. The window element was mounted to the wall element on the sending room side. To adapt for various distances between roller shutter and window a heavy reveal element to accommodate the guide rails were mounted on the sending room side of the test stand.

Sound insulation was measured in terms of sound reduction index R and evaluated in terms of weighted sound reduction index and spectrum adaptation terms $R_w(C;C_{tr})$. To analyze the acoustic performance of the external shutter the sound reduction improvement index ΔR was calculated as $\Delta R = R_{\text{window element with shutter}} - R_{\text{window element}}$.

4. Test results

In the following sections a selection of measurement results is presented.

4.1 Effect on windows with different sound insulation performance

External shutters were tested together with a window element featuring different glazing infill resulting in different sound reduction indices. In Figure 3 and 4 the effect on sound insulation when combining the identical external shutter configuration (here PVC roller shutter m'=3.5 kg/m², sealed with brush seal in guide rail, in distance of 143 mm to the glazing) with the 3 different window configurations is shown. By installation of the roller shutter in front of the window an improvement of sound insulation at high frequencies can be seen. At low frequencies the improvement is much less and can be depending on the configuration (mass of shutter, distance) also be negative. Comparing the effect of the same roller shutter system combined with different window configurations the improvement within the single number rating $R_w(C;C_{tr})$ is highest for the window with the lower sound insulating glass configuration 4/12/4/12/4. However in terms of the frequency dependent sound reduction improvement the curves for all three windows appear to be mostly comparable. To explain this behavior the acoustic performance of the additional shutter element was described in terms of a mass/spring/mass model, details and analysis see [5].

4.2 Varying sealing of roller shutter to guide rail

The cavity between the window element and the roller shutter (in lowered position) is ventilated to the outside for pressure compensation. In order to achieve a minimum degree of sealing and as protection against water penetration usually a sealing profile (typically as "Keder"-gasket or brush seal) is fitted into the guide rail thus closing the gap to the roller shutter.

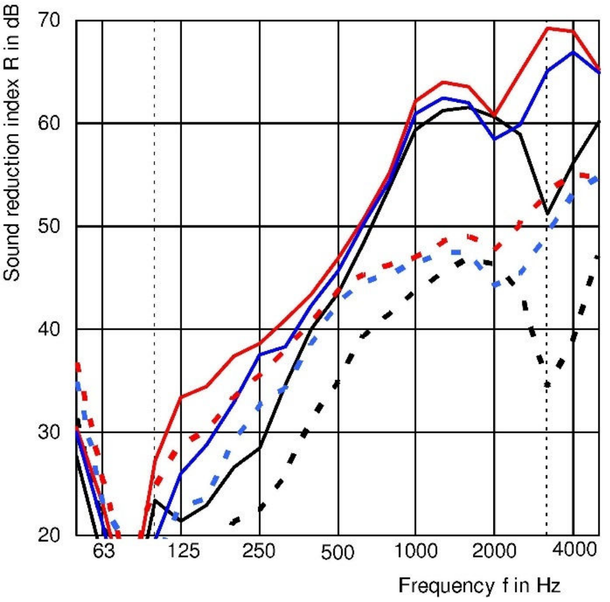

Figure 3. Sound reduction index R of window with and without roller shutter (PVC profile „maxi", 3.5 kg/m², sealing with brush seal towards guide rail, distance of 143 mm to glazing)
Window with glazing 4/12/4/12/4 without shutter (dotted black line) and with shutter ($R_w(C;C_{tr})$=42(-2;-7)dB, solid black line,)
Window with glazing 6/12/4/12/8 LSG Acoustic without shutter (dotted blue line) and with shutter ($R_w(C;C_{tr})$= 46(-2;-9)dB, solid blue line)
Window with glazing 12 LSG Acoustic/12/4/12/8 LSG Acoustic without shutter (dotted red line) and with shutter ($R_w(C;C_{tr})$=50(-1;-7)dB, solid red line)

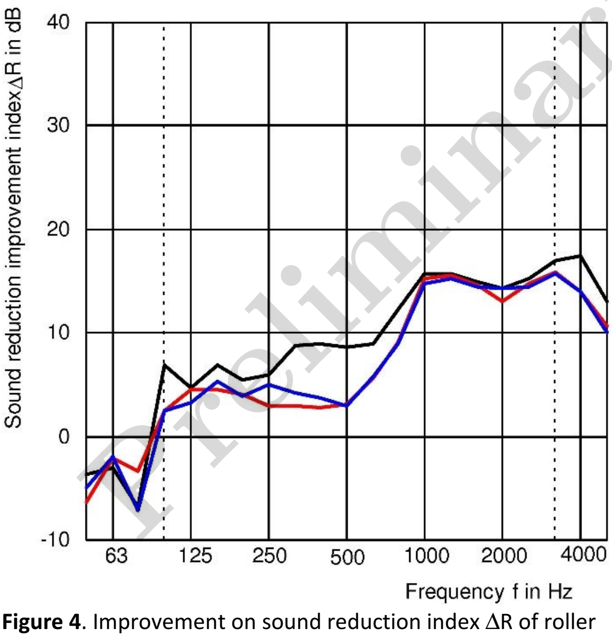

Figure 4. Improvement on sound reduction index ΔR of roller shutter (PVC profile „maxi", 3.5 kg/m², sealing with brush seal towards guide rail, distance of 143 mm to glazing) on a window element
In connection with window with glazing 4/12/4/12/4 (solid black line)
In connection with window with glazing 6/12/4/12/8 LSG Acoustic (solid blue line)
In connection with window with glazing 12 LSG Acoustic/12/4/12/8 LSG Acoustic (solid red line)

The different sealing configurations have been analyzed and typical results are presented in Figures 5 and 6. Here it can be seen that the improvement of sound insulation for the different practical types of sealing profiles ("Keder"-gasket or brush seal) is largely the same. However compared with an ideally sealed joint (here additional sealing with mastic, possibly causing also a damping of the shutter profile) a loss in sound insulation over the complete frequency range can be seen. By averaging all measurements the sound transmission loss via this joint was evaluated to be for the single number ratings ΔR_w, $\Delta(R_w+C)$, $\Delta(R_w+C_{tr})$ approximately 2.2 dB +/- 1.3 dB. Thus within this error the results can be applied to either of the tested sealing systems (brush seal or "Keder"-gasket).

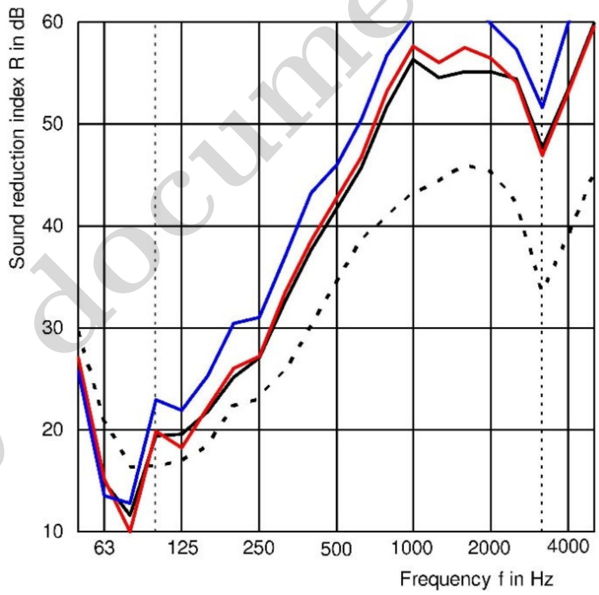

Figure 5. Sound reduction index R of window with and without roller shutter, sealing of roller shutter to guide rail with brush seal (red solid line), gasket (black solid line), and with mastic (not operable condition, blue solid line)
dotted black line: Window with glazing 4/12/4/12/4 without external shutter

4.3 Variation of distance between shutter of window

The distance between the shutter and the window element was expected to be one of the crucial parameters determining the acoustic performance of the external shutter, because the distance has a strong influence on the resonance frequency of the double-leaf resonance system between shutter and window. It also determines the volume of the cavity with effects on sound absorption. Results for one measurement series are depicted in Figure 7. The figure shows the strong dependence between the distance from the roller shutter to the glazing of the window elements. This dependency has also been analyzed for the single number ratings. Here the following quantities have been calculated as follows:

Improvement of weighted sound reduction index $\Delta R_w = R_{w,\text{window element with shutter}} - R_{w,\text{window element}}$
Improvement of weighted sound reduction index including spectrum adaptation term C: $\Delta(R_w+C) = (R_w+C)_{\text{window element with shutter}} - (R_w+C)_{\text{window element}}$
Improvement of weighted sound reduction index including spectrum adaptation term C_{tr}: $\Delta(R_w+C_{tr}) = (R_w+C_{tr})_{\text{window element with shutter}} - (R_w+C_{tr})_{\text{window element}}$

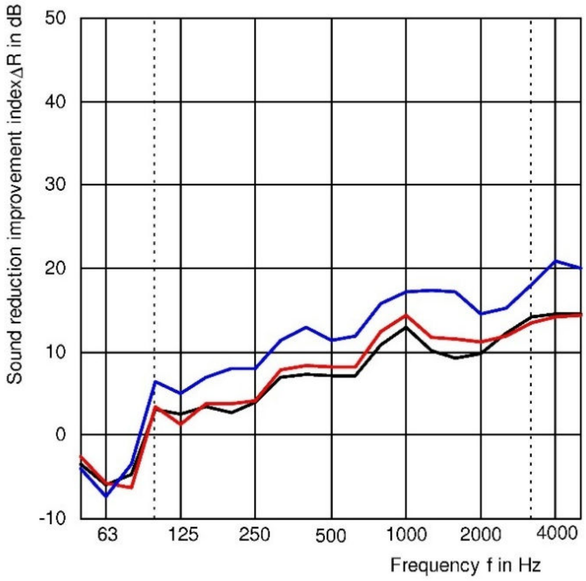

Figure 6. Improvement on sound reduction index ΔR of window with roller shutter
Window with glazing 4/12/4/12/4
Plastic roller shutter with m'= 3.5 kg/m² in distance of 166 mm, sealing of roller shutter to guide rail with brush seal (red solid line), gasket (black solid line), and with mastic (not operable condition, blue solid line)

Results of this analysis are shown in Figure 8. The same effects have been achieved on other testing series with different configurations of window and roller shutter.
The analysis is in accordance with the expected behavior for a double-leaf system with a resonance frequency. Shifting the resonance to lower frequencies enhances the improvement on sound insulation. This can be seen in Figure 8, depending on the distance of the shutter to the glazing the resonance frequency is lowered from 125 Hz (distance of 66 mm) down to 53 Hz at a distance of 366 mm. At smaller distances there can be also a reduction of sound insulation in terms of the single number ratings $R_w(C;C_{tr})$. The general behavior can be seen as basis for a prediction model, see also discussion in [5].

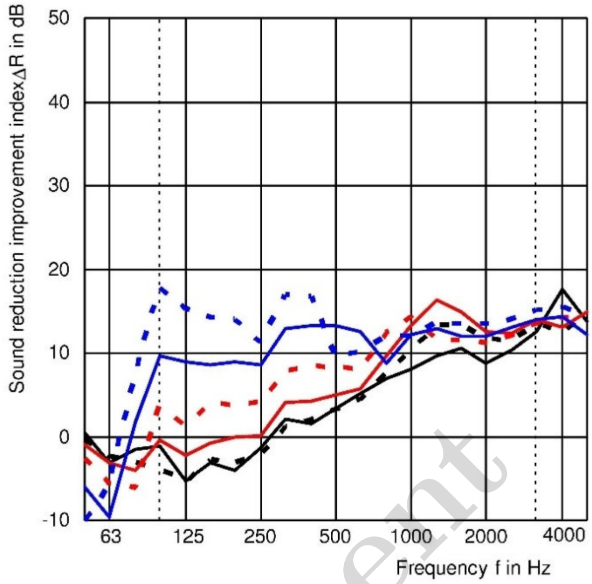

Figure 7. Improvement on sound reduction index ΔR of window with roller shutter
Window with glazing 4/12/4/12/4
PVC roller shutter with m'=3.5 kg/m² and distance to glazing of 66 mm solid black line, 96 mm dotted black line, 116 mm solid red line, 166 mm dotted red line, 266 mm solid blue line, 366 mm dotted blue line

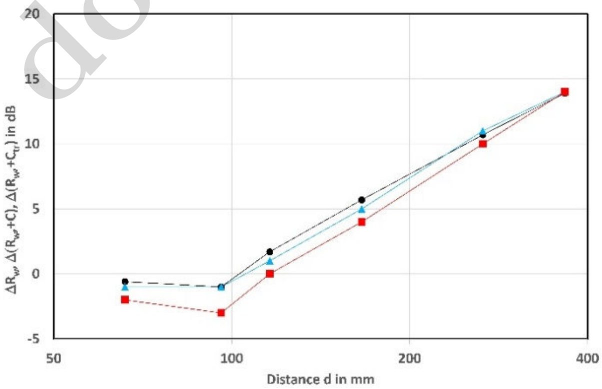

Figure 8. Improvement on sound insulation in terms of single number rating ΔR_w (black curve and symbols), $\Delta(R_w+C)$ (blue curve and symbols), $\Delta(R_w+C_{tr})$ (red curve and symbols) as a function of distance between roller shutter and glazing constructional parameters are identical to the description in Figure 7

4.4 Sound insulation of the shutter

In order to investigate and characterize the different shutters their sound insulation was measured separately (i.e. without window element). Tests on roller shutters were done in guide rails with brush seals or "Keder"-gaskets. The different roller shutters showed a very similar behavior on frequency dependent sound reduction index. Sound insulation generally follows Bergers mass law featuring a slope of roughly 6dB/octave, see Figure 9 and analysis in [5]. The sound insulation of the other tested shutters was different. The blind screen (mounted in a separate guide rail) displayed a much lower sound insulation than the other shutter systems, what can be explained by the construction, especially the lower mass per area. Due to their construction principle (sandwich panel with rigid foam thermal insulation or construction with openable slats) the sound insulation of the wing shutters was also different to the other shutter systems. Here the sound insulation of the wing shutters is influenced by its construction and the sound transmission via the openable joints of the wing to each other and the frame.

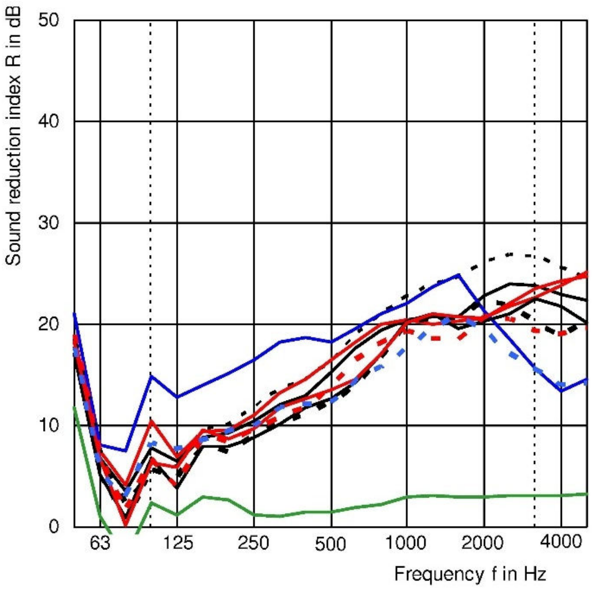

Figure 9. Sound reduction index R of different external shutters
Plastic roller shutter (type “maxi” and “mini”) with m’ = 3.2 kg/m² to 3.5 kg/m² (black dotted and solid lines)
Aluminium roller shutter (type “maxi” and “mini”) with m’ = 2.9 kg/m² to 3.4 kg/m² (red dotted and solid lines)
Blind screen (green solid line)
Wing shutter m’ = 17.4 kg/m² resp. 18.1 kg/m² (blue dotted and solid lines)

5. Summary, Discussions, Outlook

Tests on sound insulation of window elements with and without external shutters have been performed to investigate the acoustic performance of those constructive elements. The main focus was on roller shutters, which were tested in various combinations with a single window featuring different glazing with varying sound insulation. First analysis showed that the acoustic performance can be described in terms of a mass/spring/mass model. The distance between roller shutter and glazing of the window turns out to be the most crucial parameter through its strong influence on the resonance frequency of the double leaf system (window / spacing / shutter). This behavior can be the basis of a prediction model for the improvement of sound insulation by external shutters. With a larger distance between shutter and window an improvement in sound insulation of up to ΔR_w = 14 dB was achieved.

Thus by choosing the right shutter system a significant improvement of sound insulation of windows during night time can be achieved without adding further constructions or improving and changing the window system. Thus it can contribute to a reduction of cost in residential areas with high exposure to sound pressure levels.

However mounting guide rails and shutter very close to the window might result in a reduction of sound insulation in terms of ΔR_w, $\Delta(R_w+C)$ and $\Delta(R_w+C_{tr})$. Thus employing the effects of external shutters for an improvement on sound insulation requires a thorough planning and possible changes in existing constructions.

As next step the existing results including further measurements on the acoustic performance of other shutter systems will be compared to the results of prognosis and calculation models as well as numerical simulations of the system in order to check the accuracy of those models and their application in praxis.

6. Acknowledgments

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