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# An experimental study on the effect of rolling shutters and shutter boxes on the airborne sound insulation of windows

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ABSTRACT

The façade of a room is usually composed of different construction elements, one of which is the window. This fulfils both an aesthetic function and closes the wall opening. In order to improve thermal behaviour and control solar radiation, the window is fitted with different protection features, such as the shutter. In climate zones with many hours of sunlight, windows in residential buildings commonly incorporate a rolling shutter. Traffic noise and higher standards of energy saving, comfort, durability and sustainability in buildings means that windows now have to comply with stricter requirements, including their sound insulation from airborne noise. This work contains a summary of studies carried out on the sound insulation from airborne noise in several types of windows (double side-hung casement and double horizontal sliding sash) with built-on shutter and prefabricated box. For each type of window, an analysis was made of the effects of the interior finishings in the shutter box, the shutter position (whether fully retracted or extended) and the weighted sound reduction index of windows for traffic noise in accordance with EN ISO 717-1.



## 1. Introduction

Buildings in southern Europe are subject to a considerable number of hours of exposure to sunlight every year. To reduce solar radiation in the rooms of residential buildings, the opening in the façades is usually closed by means of a window with a rolling shutter.

The study of the effect of the rolling shutter and its box on the sound reduction index of the window is relevant for rooms in residential buildings whose façades are facing streets with high levels of traffic noise, or which are close to a motorway.

In general, building codes specify the minimum values required to comply with the standardised sound level difference of the façade with traffic noise, and this figure depends significantly on the apparent sound reduction index of the façade [1] as determined by the equation

$$D_{2m,nT} = R' + \Delta L_{fs} + 10\lg 0.32\frac{V}{S} \quad (1)$$

where $V$ is the volume of the receiving room, in $m^3$; $S$ the total area of the façade, in $m^2$, $\Delta L_{fs}$ is the level difference due to the façade shape, in dB; and $R'$ the apparent sound reduction index of the façade, in dB.

The overall sound transmission through the façade is due to the sound transmission by the different elements it comprises. There is little information available on the sound reduction index of windows with shutters and shutter boxes.

A window is a construction element which is designed to close the wall opening in a functional and aesthetic manner. It is the transparent part of the façade which permits interaction between the interior and exterior, as well as allowing entry of air, natural light, solar radiation and two-way vision. Usually, about 70–80% of the window is glass, which is supported on frames made of a range of materials, including wood, aluminium, PVC, polyurethane and mixed materials.

Regardless of the primary material of their frames and opening system, windows all share fundamental characteristics which affect their compliance with basic building requirements. The following general technical features are defined in the product standard and performance characteristics [2]: resistance to wind load, snow and permanent load; reaction to fire and external fire performance; watertightness, dangerous substances; impact resistance; load-bearing capacity of safety devices; acoustic performance; thermal transmittance; radiation properties; air permeability; durability, and so on.

In order to improve thermal behaviour and reduce solar radiation, the window is equipped with different protection features, such as shutters. The rolling blind with box and tape came into use at the beginning of the 20th century. When the blind is extended it saves energy and preserves the privacy of the room.

In the sound reduction index of windows $R$, the following factors must be taken into consideration: type of glass, dimensions of glass, type of joinery, joints and seals in the window-opening

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system and the presence of shutters and shutter boxes. Laboratory measurements of the sound reduction index of windows are generally only carried out on the glass and frame. This work contains a summary of studies on the sound insulation from airborne noise in several types of windows (double side-hung casement and double horizontal sliding sash) with built-on shutter and prefabricated box. We provide the experimental results of the sound reduction index for the different types of windows. We also analyse the effects of the thickness of the glass, the shutter box and its interior finish and the shutter position (whether fully retracted or extended).

## 2. Sound transmission through windows with double glazing and extended shutter

The roller shutter on the window exterior adds a supplementary thermal resistance as a result of the air chamber enclosed between both panes and the shutter itself. Roller shutters with wood, plastic or metal slats are generally considered to have average air permeability. If the slats are placed on guide rails and on the final lath, the side and lower interstices are considered to be nil [3].

The sound reduction index for double and triple glazing with various thicknesses and distances between the glasses has been studied in depth in different laboratories [4–10]. Other more recent works [11,12] have studied the sound insulation from airborne noise in windows in an overall manner, including the shutter and the shutter box. However, the first reference contains few tests of sliding windows and the second deals with windows with aerators and shutter retracted.

It is well established that the sound reduction index $R$ of a thin panel may be divided into five regions based on frequency [13,14]. From low to high frequencies, $R$ is controlled by stiffness, resonance, mass, damping and shear.

A finite-sized panel has numerous normal modes of vibration corresponding to the resonance frequencies. These depend on the dimensions, the rigidity and the mass per unit of surface area of the partition. The resonance frequencies of a simple partition with dimensions $L_x$ and $L_y$ due to transversal vibration of the panel in pure flexion can be calculated by means of the following equation:

$$f_{p,q} = khc_{\mathrm{L}}\left[\left(\frac{p}{L_x}\right)^2 + \left(\frac{q}{L_y}\right)^2\right] \quad \mathrm{Hz} \tag{2}$$

where $c_{\mathrm{L}}$ is the phase speed of quasi-longitudinal waves in the panel; $h$ is the panel thickness; $p, q = 1,2,3,\ldots$; $L_x$, $L_y$ are the dimensions of the partition; $k$ is a numeric coefficient which depends on the way the edges of the partition are placed; its value is $k = 0.45$ for supported edges; $k = 0.86$ for clamped edges. Generally, most windows have edge constraints which range between simply supported and rigidly clamped [15]. The resonance frequency $f_{11}$ predominates, and high values of $L_x$ and $L_y$ reduce $f_{11}$. For example, for a pane of glass with clamped edges with dimensions of $L_x = 1.24$ m, $L_y = 1.49$ m. and a thickness of 4 mm, $f_{11} = 16$ Hz. In the windows tested, which are similar to those installed in buildings, the dimensions of the glass panes are smaller and the frequency $f_{11}$ varies between 40 and 200 Hz, which affects the sound insulation of the system at low frequencies.

Above $f_{11}$, and approximately an octave below the critical frequency $f_{\mathrm{c}}$, Eq. (3), the sound reduction index can be expressed by the field incidence mass law, Eq. (4):

$$f_{\mathrm{c}} = \frac{c^2}{1.8c_{\mathrm{L}}h} \quad \mathrm{Hz} \tag{3}$$

$$R_{\mathrm{f}} \approx 20\lg(mf) - 47 \quad \mathrm{dB} \tag{4}$$

The airborne sound insulation of a simple partition can be increased if the element is divided into two panes separated by an air chamber. However, a double partition has diminished insulation due to the standing waves occurring in the air chamber. The sound reduction index of a double glazing 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. If acoustic and mechanical damping and stiffness are excluded, the sound transmission coefficient is greatest at what is known as the mass–air–mass resonance frequency. For diffuse field sound incidence and a temperature of 20 °C, the resonance frequency can be obtained by means of equation [16]

$$f_{\mathrm{m-a-m}} = \frac{1.34}{2\pi}\sqrt{\frac{\rho_0 c_0^2}{d}\left(\frac{1}{m_1} + \frac{1}{m_2}\right)} \quad \mathrm{Hz} \tag{5}$$

where $m_1$ and $m_2$ are mass per unit area of the panes (kg/m$^2$), and $d$ is the distance between panes (m). This frequency decreases as the distance between panes increases.

The sound reduction index provided by doubling glazing depends quite strongly on the separation between the two panes of glass. When the shutter is retracted, the mass–air–mass frequency of the double systems in the study with an air space of 12 mm is located at around 300 Hz, regardless of the order in which the panes of glass are placed, and in this region the sound reduction index decreases sharply.

The sound insulation from airborne noise of a triple glazing system is usually higher than that of a double element with the same total mass. In this case it is not easy to define a simplified mathematical system which determines the sound index. A decrease in insulation can be expected at frequencies related with normal vibration modes.

For a system of free triple panes, the resonance frequencies of the mass–air–mass–air–mass system are obtained by the expression [7,8,17]

$$f_{1,2} = \frac{1}{2\pi}\sqrt{3.6\rho_0 c_0^2}\sqrt{A \mp \sqrt{A^2 - B}} \quad \mathrm{Hz}; \qquad f_1 < f_2 \tag{6}$$

where

$$A = \frac{1}{2m_2}\left(\frac{m_1 + m_2}{m_1 d_1} + \frac{m_2 + m_3}{m_3 d_2}\right); \quad B = \frac{m_1 + m_2 + m_3}{m_1 m_2 m_3 d_1 d_2}$$

Below $f_1$, the triple glazing element as a whole works as one single pane.

When the shutter is extended, this may be considered a three-pane system. For the openable windows with glass, shutters and air chambers in the study, the resonance frequencies $f_1$ and $f_2$ are located between 250 and 500 Hz. If the order of placement of the glass is changed, the resonance frequencies vary slightly. For sliding windows, the width of the air chamber between the shutter and the glass panes is not constant, and the lowest resonance frequency is located at around 200 Hz. Table 1 shows the theoretical frequencies for each of the situations studied. The experimental results obtained are somewhat lower and nearer those which would be obtained assuming the normal sound incident, as the panes are

**Table 1**
Significant mass–air–mass frequencies and systems with double and triple elements

| Glass | Shutter retracted | Shutter extended | |
|---|---|---|---|
| | | Openable window | Sliding window |
| | $f_{\mathrm{m-a-m}}$ (Hz) | $f_1$; $f_2$ (Hz) | $f_1$; $f_2$ (Hz) |
| 4(12) 4 | 326 | 260; 481 | 205; 473 |
| 4(12)6 | 298 | 252; 447 | 200; 436 |
| 6(12)4 | | 259; 435 | 203; 430 |
| 4(12)8 | 283 | 245; 430 | 197; 416 |
| 8(12)4 | | 257; 410 | 201; 406 |