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The effect of the rolling shutter in the perception of the sound insulation

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ABSTRACT

Rolling shutters or blinds are elements placed outside the window. They aim to protect the interior of dwellings from the direct exposure to sunlight. Even though they are not usual in some countries, they are commonly used in Mediterranean countries due to longer exposure to daylight. Acoustic insulation of window elements might be modified due to the shutter position. This research studies the subjective perception of the acoustic insulation of different window elements according to the position of the rolling shutter, by analyzing the correlation between the subjective perception and the usual SRI (Sound Reduction Index). For this purpose, a paired-comparison listening test is carried out for a normal-hearing heterogeneous panel of 120 people in which several window and shutter configurations are considered. The spectral features of each configuration are obtained by averaging several laboratory measurements for each configuration. Sound samples for the test are obtained by filtering the average spectral features of each configuration with typical urban sources of noise. Then, the responses of the participants are compared to the SRI by means of statistical methods.

Keywords: Window, shutter, insulation, perception
I-INCE Classification of Subject Number: 33

1. INTRODUCTION

Noise is one of the most harmful pollutants in urban environments and it does not only affect citizens when they are outside their homes but it can also affect them while inside dwellings. Outside noise can be transmitted to indoor environments through several propagation paths, the most common being the element that separates these indoor environments from the outside, that is, the façade.

The impact of noise on the population have been highly studied and there are numerous guidelines and regulations aimed at reducing environmental noise [1–3]. A good protection of the façade, in addition to the application of guidelines for the reduction of environmental noise, can improve the quality of life and the rest of the citizens.

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Facades are usually made up of a blind part, which generally provides a high protection against noise, and a hollow area. A window or a similar element, which commonly provides a weaker protection against noise, forms this hollow area.

It is important, therefore, to characterize accurately the protection against noise of these weaker façade elements.

In Mediterranean countries, such as Spain, Italy or Greece, the long and powerful exposure to sunlight requires the installation of rolling shutters on the outside of the windows. The position (fully extended or retracted) of these blinds, can affect the sound insulation of the window elements, as it has already been pointed out in [4,5]. It is, therefore, important to assess precisely the effect that the position of the blind has on the subjective perception of the sound insulation of window elements. It can also be interesting to evaluate the need of having into account the effect of the blind in the building design stage, in those cases where the window element is to be installed with integrated rolling shutter.

The aim of this work is to present the results of a subjective and objective evaluation of the effect of the rolling shutter in the sound insulation of window elements. For this purpose, a listening test comprising three different window elements and two shutter positions, as well as different sources of urban noise was performed by 120 participants.

First, the design and performance of the listening test are explained, focusing on the selection of the window-shutter configurations, the selection of the urban noise stimuli, the type of listening test and the steps of the experimental procedure followed by the participants. Then, the differences between the same window elements for both shutter positions are objectively assessed by comparing the 1/3 octave SRI of the fully retracted and fully extended shutter configurations. Finally, the results of the listening test are statistically analysed to determine whether the position of the shutter has some effect on the subjective perception of the window elements and how they relate with the objective results found.

2. METHODOLOGY

2.1 Design of the listening test

The design of the listening test is one of the most important stages of the subjective evaluation process, since different results and conclusions might be draw depending on its design.

In the design of a listening test several aspects must be addressed:

1. The quantity and type of the elements to be compared must be determined. In this case, the window elements with extended and retracted blinds must be selected.

2. The quantity and type of stimuli by which the elements to be compared are filtered. In this case, the different urban noise stimuli as well as pink noise.

3. The type of listening test to be used to achieve the proposed purpose. In this case, the listening test follows a pairwise comparison procedure.

In this section, each of these aspects is explained independently.

Selection of the window-shutter configurations

Given that the purpose of the study is the evaluation of the effect of the shutter's position on the sound insulation of window elements, it is necessary to select different window elements, with integrated shutter, and to consider their SRI both for extended and retracted shutter positions.

Based on a large database of laboratory window measurements generated over several years by our research group, which are described in greater depth in [5,6], the SRI has been obtained for the elements the participants had to evaluate. To do this, three usual window types have been selected. Next, the average SRI for each of the types has been obtained, from all available measurements in database for windows of the same type, both for their extended and retracted blind configurations.

For the selection of elements, it was sought to obtain the maximum difference between the SRI, keeping, in turn, a relatively narrow SNQ (single number quantity) range. In particular, the selected windows are, in terms of Rw, in a range of 7 dB, between 32 and 39 dB.

Table 1 summarizes the main features of the selected elements:

Element	Frame Material	Opening	Drum material	Shutter position	Glazing	Rw
W1	PVC	Sliding	Empty	Retracted	4 / 12 / 8	32
W2	PVC	Sliding	Empty	Extended	4 / 12 / 8	36
W3	PVC	Openable	Polystyrene	Retracted	4 / 12 / 4	34
W4	PVC	Openable	Polystyrene	Extended	4 / 12 / 4	37
W5	PVC	Sliding	Polystyrene	Retracted	4 / 12 / 8	35
W6	PVC	Sliding	Polystyrene	Extended	4 / 12 / 8	39

Table 1: Main features of the window-shutter configurations selected for the listening test

As it can be seen, participants finally had to evaluate the differences between six different elements, although in this communication only the differences between the same window configuration and its fully extended and retracted shutter configurations are to be presented.

Selection of the stimuli: Noise fragments

An online survey was conducted to determine which types of urban noise affect the population the most when they are at home. The sample of participants in the online survey described the noise associated with vehicles (motorcycles, cars, buses, horns, sirens ...) as the most annoying type of noise in urban environments with 39% of the responses, followed by the noise caused by pedestrians (people talking, children during school hours ...) with 12%. A lower percentage describes the noise caused by other infrastructures such as aircraft and rail traffic and leisure activities.

Finally, five stimuli were selected. Two of them related to traffic noise in the urban environment, one related to aircraft, another comprising pedestrian noise and a siren and, finally, pink noise.

The duration were set at 15 seconds for urban types of noise. A shorter duration of 5 seconds was set for pink noise, given the constant spectral and temporal features of this stimulus.

All the stimuli used, except for the pink noise, were recorded binaurally, by means of a Dummy Head B & K Type 4100, connected to a portable Pulse recording platform, operated through an iPad with the B & K Sonoscout application (figure 1). The sampling rate was 96 kHz and the bit rate was 32 bits.

Figure 1: Dummy Head during the recording of the urban sources of noise. Left, urban traffic. Middle, flyover of aircrafts. Right, pedestrian noise.

The urban stimuli selected were those that were determined to be more representative of each of the noise sources described. In particular, for traffic noise, a side investigation was carried out [7] to characterize the noise in the centre of Madrid, which allowed the selection of two representative excerpts of different traffic configurations.

For the stimulus of aircraft noise, as well as for the stimulus of pedestrian noise, the selected 15 seconds excerpts were those that were more representative of the average of the psychoacoustic indicators of all the recorded events of each type.

Type of listening test

In the subjective characterization of sound insulation, listening tests are generally based on methods of scale [8,9] and to a much lesser extent on methods based on forced choice procedures such as pairwise comparison [10,11]. Scaling methods allow to place the evaluated elements orderly according to certain attribute on which the participants are consulted. However, they do not allow direct comparison between pairs of elements. Therefore, in this case, where the purpose of the study is to assess the perceptual differences between the retracted and extended shutter positions for the same window elements, the use of the pairwise comparison procedure was found to be appropriate.

A pairwise comparison approach was therefore selected, in which, the participants were presented, for each stimulus, with the six different elements in pairs, and they were asked to choose the one that was the most annoying of the two. In addition, participants could cast a blank vote, in case they did not perceive differences, although they were urged to give an answer as much as possible.

The minimum number of comparisons to be performed by participants, for a pairwise comparison procedure without repetitions, follows equation 1:

$$\# \, comparisons = N * (N - 1)/2 \quad (1)$$

N determines the number of comparisons, which is the number of different elements to be assessed by each participant. Since six different window elements (W1-W6) were selected, N can be set to 6. Then, considering equation 1, the number of comparisons to be performed by each participant for each stimulus is of 15 comparisons. Given that the listening test had to be performed for five different stimuli, the total amount of comparisons to be performed by each participant was of 75. Therefore, considering that the average duration of the stimuli was of 13 seconds, it would require around 37 minutes for each participant to finish the experiment.

In order to ensure the independence of the results, which is one of the necessary statistical conditions in this type of study, the comparisons were presented in random order for each participant, to avoid, as much as possible, the bias due to learning and fatigue of the participant.

2.2 Performance of the listening test

This section describes the environment and equipment used for the performance of the listening test, as well as the different stages of the process.

Test Environment

The tests were carried out in the Laboratory for Acoustics and Vibrations of the Technical School of Architecture (Technical University of Madrid). A DEMVOX ECO100 insulated booth was used to ensure low background noise and comfort. Only a screen, a mouse, a push button and headphones were installed inside the booth. The rest of the equipment was installed outside to avoid undesired sources of noise.

The playback chain consisted of a laptop connected to an RME Fireface UFX audio interface, a RANE HC6S headphone amplifier and Sennheiser HD650 headphones. The reproduction chain was calibrated to present the sound samples at the same level at which they were recorded. In addition, the frequency response of the headphones was taken into account to counteract its effect, as much as possible.

Experimental procedure

The participants were first welcome on their arrival and invited to enter the booth. Then, they were asked to answer an anonymous demographic survey regarding age, gender, nationality and level of education. This survey allowed to gather information that might be helpful during the analysis stage but also to help the participants to become familiar with the test environment.

Once they were finished with the survey and they were familiar with the test environment, a document was provided where a detailed explanation of the process could be found. Then, the participants were asked regarding any doubts the might have with the experimental procedure.

Following, the participants were presented, on the computer screen, with the formulary that must be answered and a short training of two comparisons was carried out, in order to assess the real understating of the test they were going to perform. After this familiarization phase were finished, the actual test began.

The listening test was performed as five individual tests, one for each stimulus, with a short break between each of them. During the break, avoiding it to look as part of the evaluation, the participant was interviewed about the previous finished test. Interesting answers to the interview were noted for further consultation, in case they were necessary.

Once the five tests were completed, all participants were given a screening audiometry to know their hearing status. Each participant received the result of the audiometry which was then explained in detail.

2.3 Analysis of the results

The results of the listening test were analysed according to the method described in ISO 5495: 2005[12]. This method, though, does not consider that the participants might not make a judgment. Therefore, those cases were removed from the dataset prior to analysis.

For each pair of comparisons there were two results, describing the number of times each of the elements in the pair was considered as more annoying as the other. As explained in ISO 5495: 2005[12] any of them should rise a threshold, which is also given in the standard, so it can be stated that any of them was significantly more annoying than the other.

Depending on the total number of comparisons that were performed for a pair of elements, which can differ from case to case because of what it has been stated in the first paragraph of this section, a different threshold was established. This threshold also depend on the required significance at a certain α-level of confidence. Then, the number of comparisons was accounted, in which each of the elements of the pair was selected as more annoying. If either of the two elements exceeded the threshold, it could be determined that, for a certain level of significance a perceptible difference existed between the elements of the pair, regarding perceived annoyance.

For this research, the α-level was selected to be of 0.05.

3. RESULTS

This section shows the results of both the objective and subjective analysis, of the difference between the extended and retracted blind positions, for the same window element.

First, the results of the objective analysis are shown. Then, the subjective results are presented.

3.1 Objective comparison

For each of the three window elements, two different window configurations, regarding the position of the blind are presented. Figures 2 shows the overlapping between the 1/3 octave SRI for elements W1 and W2, W3 and W4 and W5 and W6 from left to right respectively. Below each comparison, an additional graph shows the difference between the first and the second element of each pair. For each band, positive values mean that the first element of the pair has a higher SRI. Therefore, negative values show that the second element of the pair has a higher SRI.

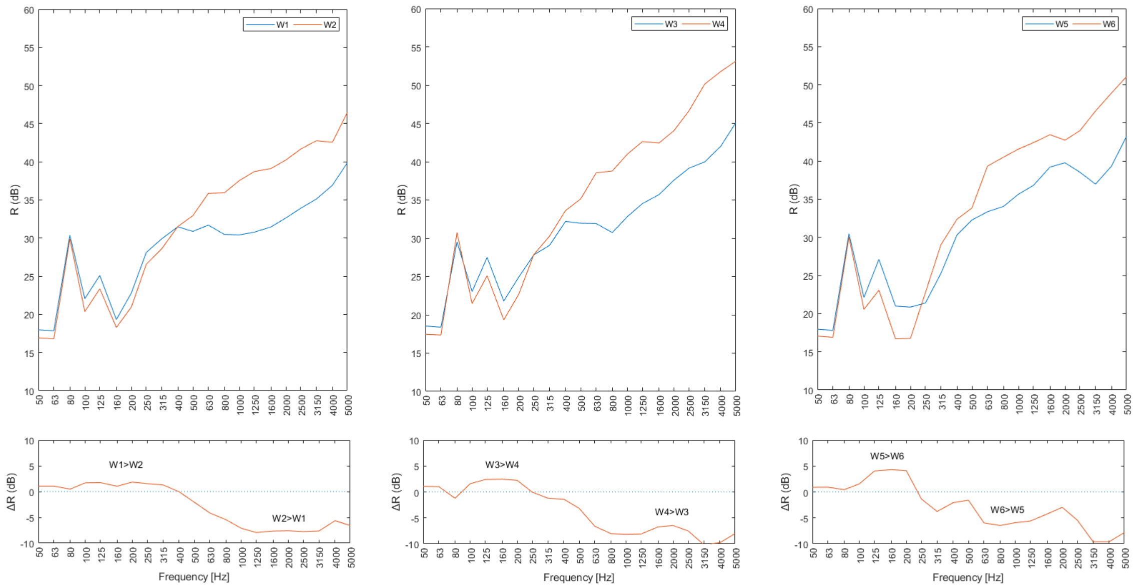

Figure 2: Overlapping of each pair of elements. Left: W1-W2, Middle: W3-W4, Right: W5-W6. Below: Difference between the first and the second element of each pair.

For all the cases it can be seen that the insulation is higher in the range of medium and high frequencies for the element in which the shutter is fully extended (W2, W4 and W6), while in the low frequencies the insulation decreases regarding to the fully retracted shutter configuration.

In particular, in the case W1-W2 (Figure 1, left), the inversion occurs at the frequency band centered at 400 Hz. The element W1 (fully retracted blind) has higher sound insulation below that band, with an average difference against W2 of 1.3 dB and a maximum difference of 1.8 dB in the band centered at 200 Hz band. Above the inversion frequency, the element W2 (fully extended blind) has higher sound insulation than W1, with an average difference against W1 of 5.8 dB and a maximum difference of 7.9 dB in the band centered at 1250 Hz.

Similarly, in the case W3-W4 (Figure 1, middle), the frequency band at which the inversion occurs is centered at 250 Hz. The element W3 (fully retracted blind) has a higher sound insulation below that band, with an average difference versus W4 of 1.8 dB and a maximum difference of 2.5 dB in the 160 Hz band. Above the inversion frequency, the element W4 (fully extended blind) has a greater sound insulation than W3, with an average difference versus W3 of 6.1 dB and a maximum difference of 10.2 dB in the 3150 Hz band.

Finally, in the case W5-W6 (Figure 1, right), the frequency band at which the inversion occurs is centered at 200 Hz. The element W5 (fully retracted blind) has a higher sound insulation below that band, with an average difference aginst W6 of 2.3 dB and a maximum difference of 4.3 dB in the 160 Hz band. Above the inversion frequency band, the element W6 (fully extended blind) has a higher sound insulation than W5, with an average difference against W5 of 5.2 dB and a maximum difference of 9.6 dB in the 3150 Hz band.

3.2 Listening test results

Tables 2, 3 and 4 present the decision results reported by the participants, for the cases W1-W2, W3-W4 and W5-W6 and each of the used stimuli. The participants also compared the rest of possible combinations of elements and their results will be presented in the future.

	Traffic 1	**Traffic 2**	**Aircraft**	**Pedestrian**	**Pink**
#W1	61	30	36	102	77
#W2	38	78	73	8	32
#total	99	108	109	110	109
Threshold	60	65	66	66	66
Most Annoying	W1	W2	W2	W1	W1

Table 2: Number of times W1 and W2 were chosen as more annoying. Total number of judgments. Threshold for alpha-level of 0.05. Most annoying element for that level of significance.

	Traffic 1	**Traffic 2**	**Aircraft**	**Pedestrian**	**Pink**
#W3	89	69	76	106	71
#W4	17	31	29	7	36
#total	106	100	105	113	107
Threshold	64	61	64	68	65
Most Annoying	W3	W3	W3	W3	W3

Table 3: Number of times W3 and W4 were chosen as more annoying. Total number of judgments. Threshold for alpha-level of 0.05. Most annoying element for that level of significance.

	Traffic 1	**Traffic 2**	**Aircraft**	**Pedestrian**	**Pink**
#W5	79	47	61	89	60
#W6	29	50	49	20	48
#total	108	97	110	109	108
Threshold	65	59	66	66	65
Most Annoying	W5	-	-	W5	-

Table 4: Number of times W5 and W6 were chosen as more annoying. Total number of judgments. Threshold for alpha-level of 0.05. Most annoying element for that level of significance.

It can be seen that for the case W1-W2 (table 2), depending on the type of stimulus, one element of the pair or the other was selected significantly as more annoying by the participants.

In the case W3-W4 (table 3), regardless of the stimulus that was selected, the participants perceive the element W3 (fully retracted blind) as more annoying.

Finally, for the case W5-W6 (table 4), only for two of the stimuli the participants were able to make a significant judgment. In those cases, the element W5 (fully retracted blind) was selected as more annoying. For the other cases, neither of the two elements exceeded the threshold, although in two of these cases the tendency was to select the element W5 as more annoying.

4. CONCLUSIONS

The fact of placing the shutter in different positions considerably affects the acoustic insulation of windows. Therefore, between the two extreme shutter situations (fully retracted and extended), the acoustic behavior of the element can vary drastically. A frequency can be found, in all the cases, where the difference between the elements of the pair shifts its behavior and the element with higher sound insulation becomes the element with lower sound insulation and vice versa.

Regarding the subjective perception of these objective differences, it can be stated that the participants perceived the position of the blind as changes in the sound insulation. In general, the position for which the shutter was fully extended was perceived as less annoying.

However, depending on the particular window element, the differences between the retracted and extended shutter configurations and the type of stimulus, variations in this behavior may occur.

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