SOME CONSIDERATIONS ABOUT THE CONTRIBUTION OF ROLLER SHUTTERS POSITIONS TO NOISE INSULATION OF FAÇADES

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Abstract

This paper describes an experimental study on the evaluation of the influence of roller shutters positions on noise insulation of façades. The study is based on the results of a set of tests carried out in laboratory, and *in situ* using the 1st, 2nd, 3rd and 4th floors of a selected new housing building which is typical of Portuguese cooperative construction. For the purpose a specific type of window was considered. The window system (glazing and frame, plus the roller shutter) was firstly characterized in laboratory. *In situ*, the tests were performed in 2 different rooms having different window dimensions. The measurements were done in accordance with what is prescribed by international standards, using a loudspeaker as noise source. The considered shutters positions were: totally opened, half closed, partially closed (shutter extended) and completely closed (shutter fully extended). Additionally, *in situ* measurements with the window open were also done. The results have shown that the façade transmission loss curve related to each shutter position at the same storey and between different floor levels differs with some significance. Other interesting and important conclusions were extracted from the study done, namely: *i*) the important influence of shutter position when the window is open; the discrepancy between laboratory and *in situ* sound insulation performance; the low influence of flanking transmission regarding façades performance, which is due to its weak sound insulation when compared to those of the adjoining elements; and, finally, the evolution of sound insulation in frequency domain for the set of combinations window open and closed *versus* shutter positions.

IF POSSIBLE

1. INTRODUCTION

The noise insulation of building façades integrates the contribution of all façade elements - external walls and windows - and the way these elements are connected with each other and with all adjoining internal partitions – horizontal and vertical. It is of common knowledge that the window element, which includes the glazing and the frame, is the weakest point regarding façades noise insulation.

In Portugal, and likely in the most part of southern European and Mediterranean countries, two additional components currently proposed for building façades by designers and architects are the balconies and the roller shutters, being the first ones constructive building elements and the second lighting controlling devices.

Former studies developed by LNEC [1] have shown that balconies do not significantly influence the noise insulation of all façade system (wall and window), unless the incidence angles of sound waves be so high that causes the ceiling of the subsequent balcony to act as a reflecting plane increasing the global noise that is hitting the façade surface. Regarding the other additional façade component – the shutter – and in what concerns its efficiency for the improvement of global façade noise insulation, it seems that no enough information is currently available.

Generally, either at design stage or either when assessing the accomplishment of national regulations, the contribution of shutters for the insulation of façades against external noise is not taken into account. At design stage and because the dwellers have the right to have their national noise insulation requirements effectively accomplished, without closing the shutters, it is not advisable to include their effects. Secondly, regarding the evaluation of compliance with national regulations, their effects are not considered because the measurements are usually done with the shutters completely opened (worst situation); it should be mentioned that in the text of Portuguese regulations, which were set into forth in 2002, nothing is written about this.

This experimental study follows a work done by the authors and presented in two previous papers [2, 3]. Its goal is the evaluation of contribution of shutters positions to noise insulation of façades, considering them an additional possible measure that - in compromise with the needs of shadowing effects they are intended to do so in relation with thermal insulation and visual comfort - could improve the acoustic performance of façades.

The study was done in laboratory conditions (reverberation rooms) and on site, using a Portuguese typical housing building with current construction elements (walls and window types). In laboratory two standardized reverberation rooms were used. *In situ* the tests were performed in 2 different rooms (one with a balcony and the other without) having different window dimensions – window in room 1 (without balcony): 2.50 m × 1.50 m; window in room 2 (with balcony): 1.10 m × 1.50 m, and on the first 4 floors of the building. The area of façade of room 1 is 10.80 m^2 and that of room 2 is 6.21 m^2. The external wall is homogenous, of masonry and double, having 0.11 m thickness each pane and an air cavity (4 cm thickness) filled with expanded polystyrene. The window frames are made of aluminum and the glazing is double: 5 mm thickness each pane separated by 6 mm of air gap. All the systems were conveniently sealed. The roller shutters are made of plastic have 10 mm thickness, and slide at 5 cm distance from the glazing. A loudspeaker as noise source was used both in laboratory and on site.

For the study and respecting the set of tests performed, the shutters positions considered were:

i) Totally opened *SO*;
ii) Half closed *SHC*;
iii) Partially closed (shutter extended) *SPC*; and
iv) Completely closed *SC* (shutter fully extended).

For the *in situ* case, measurements with windows completely opened (*WO*) were also done.

Among all these shutter positions the ones associated with items *ii*) and *iii*) seems to be the most important ones, for they are strongly related to the accomplishment of the compromise between acoustic insulation and shadowing effects. This compromise is a key issue for licensing authorities (the Municipalities) and designers because the shadowing capabilities provided by shutters has a strong influence on thermal building performance, cumulatively to visual effects and, as a consequence, to building energetic consumption. Having in mind the need to start developing buildings in a sustainable manner and the people's needs of residential comfort, the compromise among all of these is a challenge for all those involved in the market of buildings construction.

2. THEORY

The sound insulation, R, of façade elements (window itself and the influence of shutter position) is measured under laboratory conditions in accordance with what is set in the international standard EN ISO 20140-3 [4], using Eq. (1).

$$R = L_1 - L_2 + 10\log\left(\frac{S}{A}\right) \qquad \text{dB} \qquad (1)$$

In this equation L_1 is the average sound pressure level in the emission reverberation room, in dB; L_2 is the average sound pressure level in the receiving room, in dB; S is the area of the test specimen (window and shutter), in m^2; and A is the equivalent sound absorption area of receiving room, in m^2.

Regarding *in situ* measurements, and to quantify the parameter R'_{45}, the tests are done in accordance with the international standard EN ISO 140-5 [5]. The noise insulation of façades is given by the following equation.

$$R'_{45} = L_{1,s} - L_2 + 10\log\left(\frac{S}{A}\right) - 1{,}5 \qquad \text{dB} \qquad (2)$$

Similarly, $L_{1,s}$ is the average sound pressure level on the surface of the façade, in dB; L_2 is the average sound pressure level in the receiving room, in dB; S is the area of the façade, in m^2; and A is the equivalent sound absorption area of receiving room, in m^2.

The Eq. (2) is valid when the noise source is a loudspeaker and on the assumption the sound waves are hitting the façade surface with an incidence angle of 45º, relatively to its normal, and that in the receiving room there is a diffuse sound field.

When performing tests *in situ* using loudspeakers, sound incidence angles of 45º for all building floors (or façades) are hard to find, unless the sound source be located in such a way that changing its position on the street one could be able obtain an incidence angle of 45º degrees. However, acting against this requirement is the fact that the façades are usually subjected to noise coming from various different noise sources (cars and trucks) which constitutes the global road traffic, seldom defining an angle of 45º degrees relatively to the normal of façade surface.

Comparing the results obtained with equation (1) - for which the sound in the reverberation emission room is considered diffuse as it is in the receiving room - with those got from Eq. (2) without the influence of reflections on the façade, the results obviously may be different from each other.

Thus, it seems to be of great importance the conversion of the values of noise insulation obtained for different angles *in situ* - R'_θ - to values of R'_{45} in order to make a good comparison between what is proposed in commercial leaflets and what is felt in real situations by real dwellers. So, having for homogenous elements the following formula:

$$R'_{\theta} = 10\ \log\left(\frac{m\omega}{2Z_0}\cos\theta\right)^2 \qquad \text{dB} \qquad (3)$$

In which θ is the incidence angle, in radian; Z_0 is the acoustic impedance of the air, in kg m^{-2} s^{-1}; ω the angular frequency, in rad/s; and m is the mass per unit area, in Kg m^{-2}, the following conversion equation can be obtained:

$$R'_{45} = R'_{\theta} + 20\ \log\left(\frac{\sqrt{2}}{2\ \cos\theta}\right) \qquad \text{dB} \qquad (4)$$

The equation used to perform calculations of noise insulation of façades (massive part and window) at project stage, on the basis of the values of the indices R_w [6] got from laboratory tests or appropriate modeling, is the following [7, 8]:

$$R_w = 10\ \log\left(\frac{\sum_i S_i}{\sum_i S_i 10^{-R_{wi}/10}}\right) \qquad \text{dB} \qquad (5)$$

In this equation, R_{wi} represents the noise insulation index of each type of façade element, and S_i its area.

According to Portuguese Buildings Code [9], which requirements have to be accomplished *in situ* - not only at design stage -, the noise insulation of façades is characterized by the parameter $D_{2m,n,w}$ (normalized level difference between outside noise measured with microphone placed at 2 m distance from the façade and the noise inside the room; EN ISO 717-1 [10]).

At design stage, the noise insulation of façades index is calculated from laboratory values of each façade element (massive part or glazing) or using adequate prediction methods, using the following equation:

$$D_{2m,n,w} = 10\ \log\left(\frac{\sum_i S_i}{\sum_i S_i 10^{-R_{wi}/10}}\right) + 10\ \log\frac{A_0}{S} \qquad \text{dB} \qquad (6)$$

where A_0 is the normalized equivalent absorption area of the reception room (equal to 10 m^2) and S the area of the façade.

Despite the main purpose of this paper be the evaluation of the influence of contribution of shutter positions to the sound insulation of façades, based on the comparison among all of the selected positions previously mentioned, an additional comparison between the values of the indices commonly considered for façades sound insulation characterization, is also done.

3. DESCRIPTION OF TESTS

3.1 Laboratory characterizations

A test specimen (window and shutter) was constructed in the LNEC standard test opening (S = 10 m^2). The shutter box was conveniently treated with mineral wool, by placing a layer of this material fixed on the upper internal surface of the box, in order to increase the sound absorption area inside this ”weakest” point of the façade. In Figures 1 and 2 a view of the window system is presented, in position totally open and half close, as well as a cross view of the system in Figure 3.

Figure 1 – Window tested: shutter *SO*

Figure 2 – Window tested: shutter *SHC*

Figure 3 – Cross view of the window tested: shutter *SHC*

3.2. *In situ* measurements

Two types of façades were chosen for the purpose: one with a balcony and other without. *In situ*, as this situation represents current buildings constructions, no acoustic treatment was applied inside the shutter box. Figures 4 and 5 illustrate the two building façades tested.

Figure 4 – Building façade (balcony)

Figure 5 – Building façade (simple)

Figures 6 and 7 illustrate the shutters position *SHC* (Half Closed) and *SPC* (Partially Closed), for the tests performed *in situ*.

Figure 5 – Shutter position *SHC*

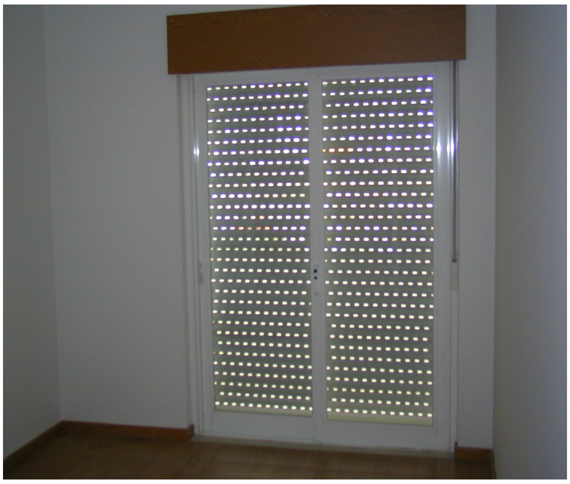


Figure 7 – Shutter position *SPC*

4. RESULTS

In Figure 8, the normalized sound insulation – D_n - for the window tested under laboratory conditions with all the positions considered for the roller shutter is shown.

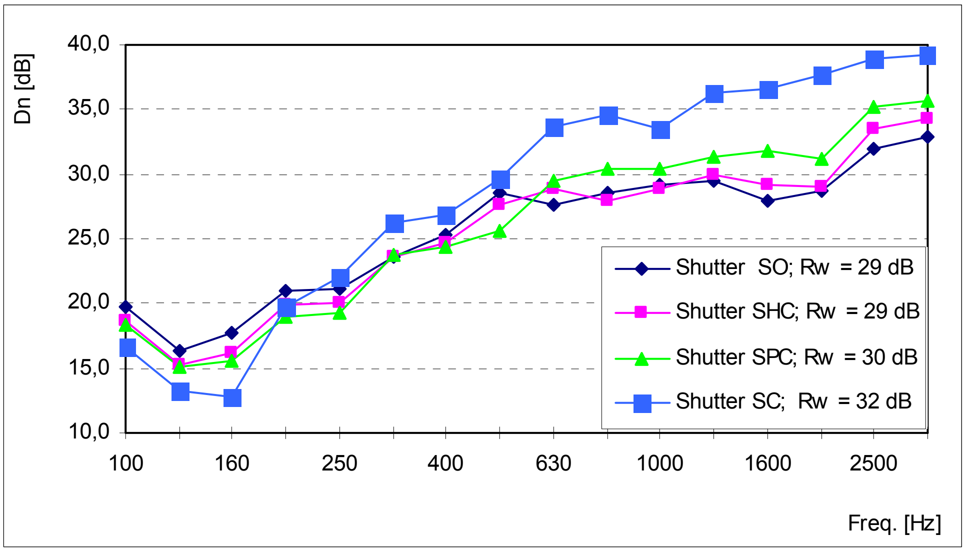


Figure 8 – Sound insulation curves obtained in laboratory for all shutter positions

As it was mentioned, the parameter that is only possible to measure in laboratory conditions is the R_w. The value so obtained does not adequately represent the performance of the façade element *in situ* whenever it is subjected to sound incidence angles different from 45º; for laboratory reverberation rooms only permit the creation of *quasi* diffuse sound fields. This situation is more accentuated in the cases of double glazing windows, or even of double windows.

From Figure 8 it is possible to conclude that the best value of window sound insulation corresponds to the position of shutter closed, as it was expected. However, regarding this shutter position, it is interesting to notice the worst window sound insulation at the low frequencies than for other shutter positions. And it is even better than that corresponding to shutter open. The reason for this seems to lie in the fact that the acoustic enclosed space, defined by the shutter and the window glazing, forms a sort of resonant acoustic system (panel) which redistributes the sound energy inside the system and increases it at certain eigen modes of vibration. Knowing that the shutter slides at 5 cm distance from the glazing, this system could act as a resonant "panel" whose value of its fundamental frequency is $\approx$ 120 Hz [$f_r = 600/(m\ d)^{0,5}$ with m in kgm^{-2} and *d* in cm; the considered mass per unit area of the shutter is 6,2 kg m^{-2} and the calculations were done on the assumption that the PVC lumped mass is 1,6 kg m^{-2}]. This also leads to the occurrence of several harmonics that will contribute for the redistribution of sound energy inside the "virtual" box defined by the glazing and the shutter.

Regarding *in situ* measurements, Table 1 shows the values of several noise insulation indices related to room 1 (the one without balcony) for the 2nd, 3rd and 4th floors, respectively: R_θ, $D_{2m,n,w}$ and R in dB(A) (measured); and R'_{45}, which is calculated with Eq. (4). It must be mentioned, for conversion of R'_θ into R'_{45}, that the noise source was located 3 m from the façade and the height of each storey is 2.7 m. This physical set up (relative location of building and sound source) yield angles of 61º for 2nd floor, 70º and 75º for the subsequent upper floors, 3rd and 4th.

In this table WC means "window closed" and WO "window open". As mentioned, SO means "shutter open" and SHC "shutter half closed", and so on.

Table 1 – *Results of room 1: values of several noise insulation indices*

	R´$_{\theta}$ [dB]							
	WC-SO	WC-SHC	WC-SPC	WC-SC	WO-SO	WO-SHC	WO-SPC	WO-SC
2nd Floor	32	31	33	36	15	16	20	28
3rd Floor	33	32	33	38	16	17	20	30
4th Floor	33	33	32	35	17	18	21	27
	$D_{2m,n,w}$ [dB]							
	WC-SO	WC-SHC	WC-SPC	WC-SC	WO-SO	WO-SHC	WO-SPC	WO-SC
2nd Floor	31	30	32	36	14	15	19	27
3rd Floor	32	30	31	37	15	16	19	28
4th Floor	32	31	30	34	16	17	19	25
	R [dB (A)]							
	WC-SO	WC-SHC	WC-SPC	WC-SC	WO-SO	WO-SHC	WO-SPC	WO-SC
2nd Floor	37	29	30	35	14	15	18	25
3rd Floor	33	31	30	35	16	16	18	27
4th Floor	33	32	30	33	17	18	19	25
	R´$_{45}$ [dB]							
	WC-SO	WC-SHC	WC-SPC	WC-SC	WO-SO	WO-SHC	WO-SPC	WO-SC
2nd Floor	33	32	34	37	16	17	21	29
3rd Floor	37	36	37	42	20	21	24	34
4th Floor	40	40	39	42	24	25	28	34

Table 2 shows the values of sound insulation index the window (glazing and frame) should exhibit in order to comply with measured values of R´$_{\theta}$ [calculated with Eq. (6)].

Table 2 – *Calculated values of sound insulation index for the window itself*

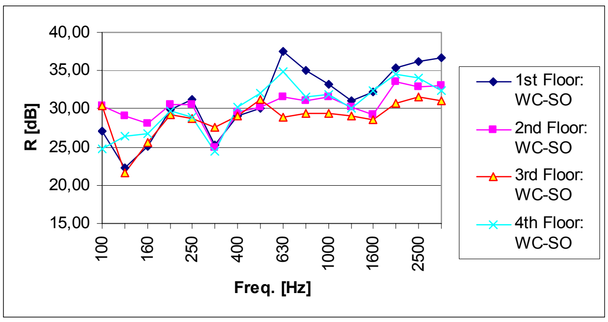
	R_w [dB] – Window and shutter only							
	WC-SO	WC-SHC	WC-SPC	WC-SC	WO-SO	WO-SHC	WO-SPC	WO-SC
2nd Floor	27	25	27	30	-	-	14	22
3rd Floor	28	26	27	32	-	-	14	24
4th Floor	28	27	26	29	-	-	15	21

Table 3 shows the values of the same parameters of Table 1; in this case for room 2 (the one with balcony). In these tests, the relative location of building and sound source yields incidence angles of 42º for the first floor, and 61º, 70º and 75º for the subsequent upper floors (2nd, 3rd and 4th).

Table 3 – *Results of room 2: values of several noise insulation indices*

	R´$_{\theta}$ [dB]			**$D_{2m,n,w}$ [dB]**		
	WC-SO	WC-SC	WO-SO	WC-SO	WC-SC	WO-SO
1st Floor	33	34	17	36	35	17
2nd Floor	31	32	14	32	33	15
3rd Floor	30	31	13	32	32	14
4th Floor	32	34	16	33	35	16
	R [dB (A)]			**R´$_{45}$ [dB]**		
	WC-SO	WC-SC	WO-SO	WC-SO	WC-SC	WO-SO
1st Floor	37	37	20	31	32	15
2nd Floor	34	34	17	32	33	15
3rd Floor	32	31	16	34	35	17
4th Floor	35	36	19	39	40	22

The next set of figures illustrates some of the results obtained in frequency domain, for various situations and parameters.



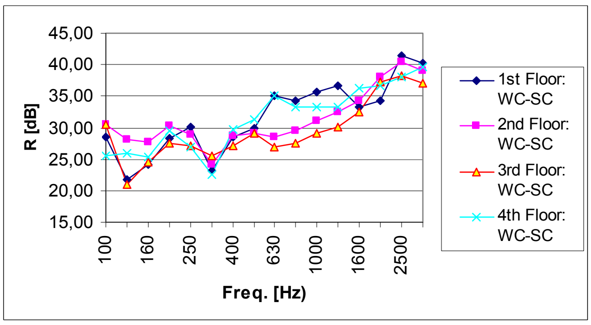


Figure 9 – *Evolution with floor level of sound insulation R_{θ} of Room 2, for window closed, and shutter open and closed*

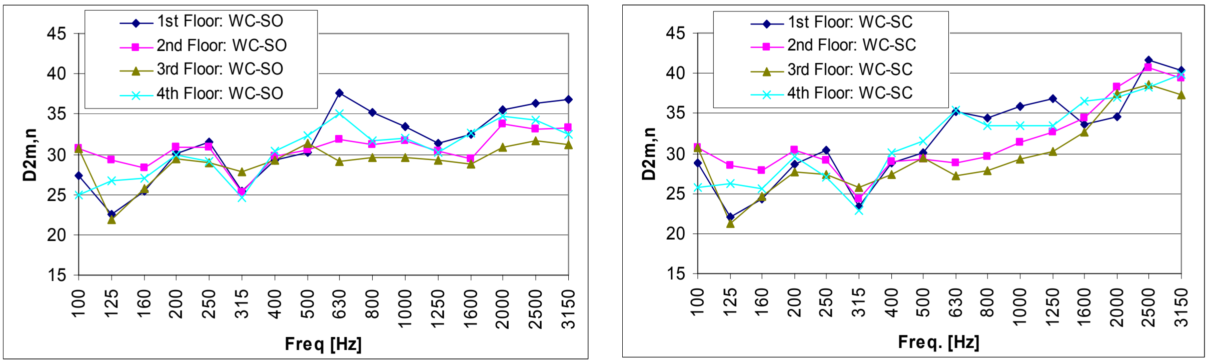


Figure 10 – *Sound insulation $D_{2m,n}$ of Room 2 for window closed and open, and shutter in positions SO and SC (all floors)*

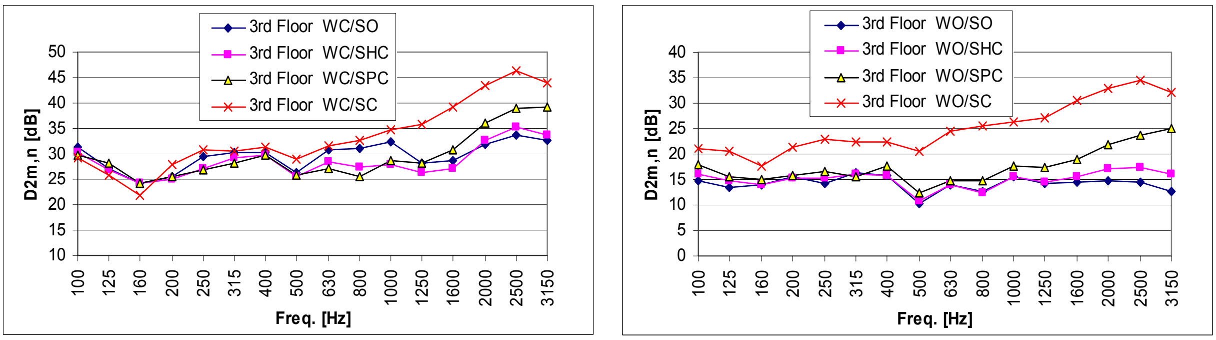


Figure 11 – *Sound insulation $D_{2m,n}$ of 3rd floor (Room 1) for window closed and open, and shutter in all positions*

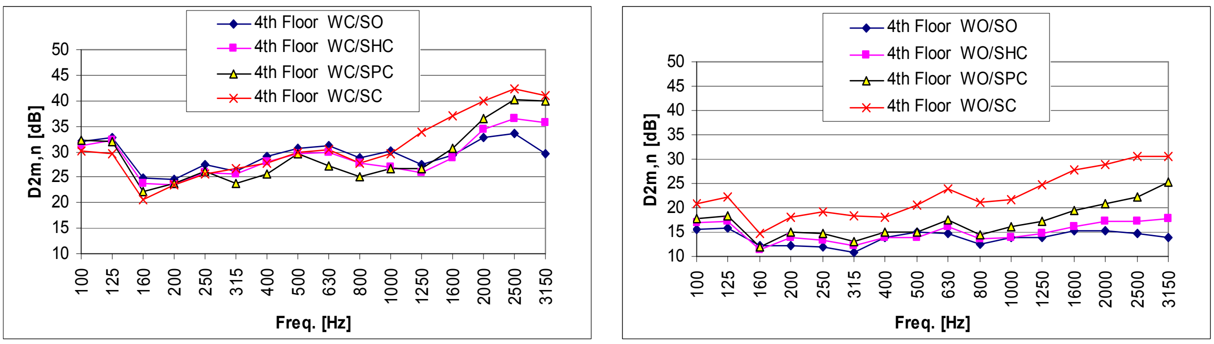


Figure 12 – *Sound insulation $D_{2m,n}$ of 4th floor (Room 1) for window closed and open, and shutter in all positions*

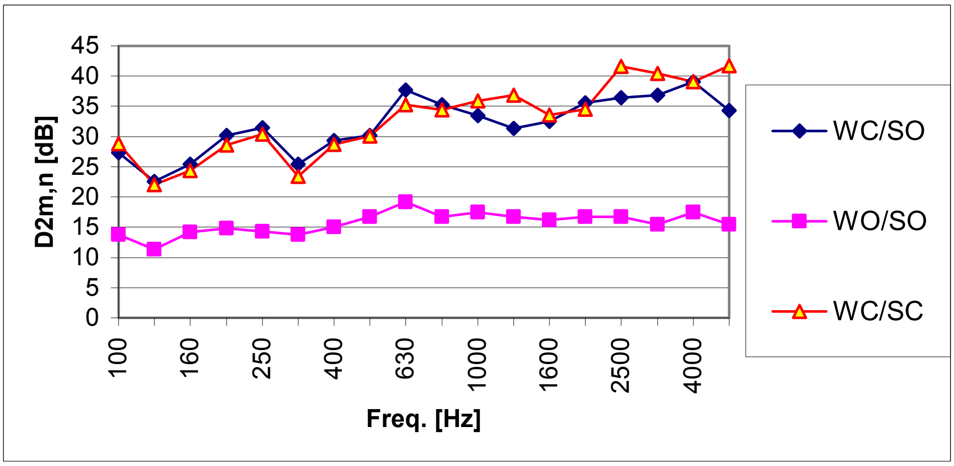


Figure 13 – *Sound insulation $D_{2m,n}$ of 1st floor (Room 2) for three combinations of window situations and shutter positions*

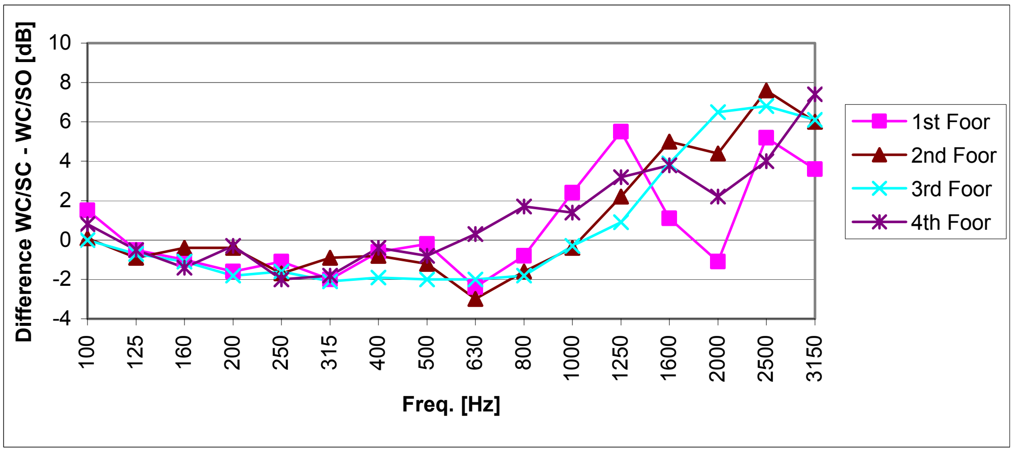


Figure 14 – *Evolution of differences of sound insulation $D_{2m,n}$ (Room 2) for the situation of window closed and shutter in positions closed and opened*

In Table 4, a statistical analysis regarding the values of the various types of indices considered in this study is also presented.

Table 4 – *Standard deviations for the most important indices considered in relation with the shutter positions WC-SO, WC-SC and WO-SO*

R_θ [dB]			$D_{2m,n,w}$ [dB]			R_w [dB(A)]		
WC-SO	WC-SC	WO-SO	WC-SO	WC-SC	WO-SO	WC-SO	WC-SC	WO-SO
1,07	2,19	1,40	1,50	1,59	1,03	1,84	1,84	1,85

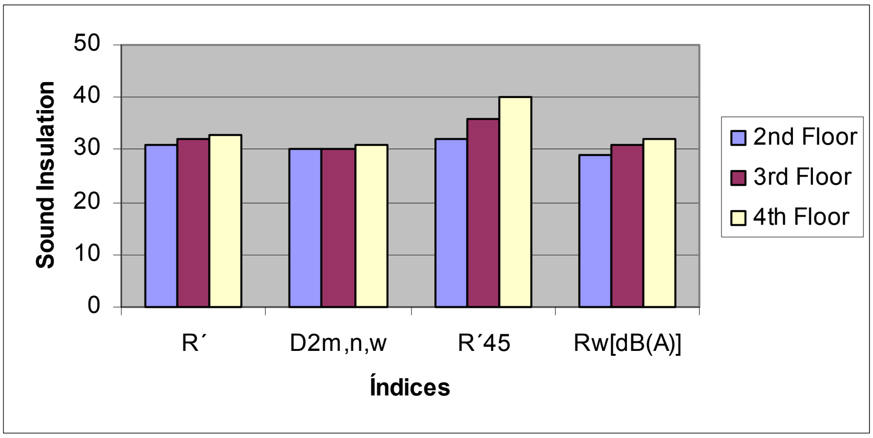


Figure 15 – *Comparison among all indices considered for the characterization in room 1*

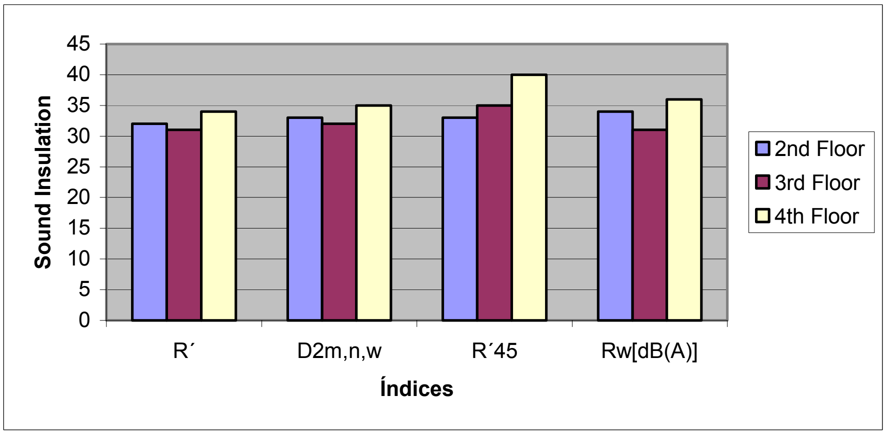
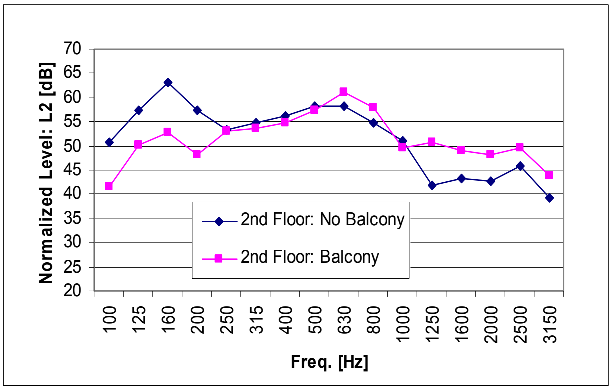


Figure 16 – *Comparison among all indices considered for the characterization in room 2*

Finally, in Figure 17 a comparison of sound levels inside rooms, with and without balcony, for the same level of sound emission outside (measured in front of façade at 2 m distance), is shown for the 2nd and 3rd floors.



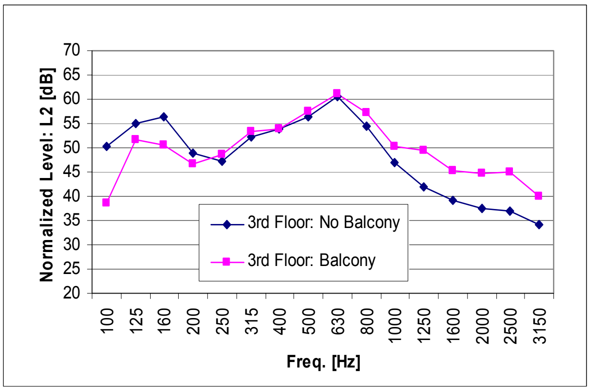


Figure 17 – *Comparison of sound levels inside rooms with and without balcony, for the same emission level*

A very interesting conclusion can be extracted from these tests. In both situations, the existence of balconies turns the sound field inside the room worst at medium and high frequencies than at the low frequencies. In the range of low frequencies the opposite behavior is met. The noise comfort (sound level inside the rooms) for the same level of emission outside is better. Obviously, this aspect influences the sound insulation of the global façade when expressed in terms of its index (unique value) because its calculation is due to the difference between inside and outside sound levels. The changes of façade performance along frequency, when there is a balcony and when there is not, can be due to the "virtual barrier effect" created by the floor of the balcony, which attenuates more the high frequencies (small wavelengths) than the low frequencies (large wavelengths).

5. CONCLUSIONS

Regarding the laboratory tests where a *quasi* diffuse sound field is established, from Figure 8 is possible to note that the best value of window sound insulation corresponds to the position of shutter closed. Nevertheless, it can be noticed that for this position its sound insulation is worst at the low frequencies range than at other shutter positions. And it is even worse than the one corresponding to shutter open. The reason for that seems to lie in the fact that the acoustic enclosed space, defined by the shutter and the window glazing, forms a sort of resonant acoustic system (panel) increasing the sound energy at certain modes of vibration, which leads to the excitation of several harmonics that will contribute for the redistribution of sound energy inside the virtual box defined by the glazing and the shutter.

In situ, it is strongly evident that the best sound insulation index of the façade is obtained when both the window and shutter are closed. Also, when the shutter is half closed (HC) the sound insulation index is worst than in the case of shutter open WC-SO (see Tables 1 and 2).

The influence of shutter is strongly important when the window is open and the shutter is closed (WO-SC), as can been seen in Figures 11 and 12. Additionally, it is important when the position is partially closed for it corresponds to the strong needs of ventilation in Mediterranean countries.

A lack of insulation is noticed in low frequency bands, both for the window only and for the complete façade, at floors of low level (1^{st} and 2^{nd}). This lack is less evident when the floor level increases. Probably it would be due to the incidence angle of sound waves on the façade. (see Figures 9, 10, 11 and 12).

In terms of comparison between window closed and shutter opened, one may state: the case WO-SO and WO-SHC decreases the insulation in 15-17 dB; the case WO-SPC decreases the insulation in 11-13 dB; and the case WO-SC decreases the insulation in 7-10 dB.

It is also important to notice that the values obtained by calculations regarding the efficiency of the window system itself differs around 2 dB from the ones obtained in laboratory tests (see Figure 8 and Table 2). This proves the need of a suitable sealing of the window and that the influence of shutter box is relevant (in laboratory tests absorption material was placed inside this box whilst *in situ* the shutter box is not covered with absorption material).

An additional interesting information is the evolution of differences of sound insulation $D_{2m,n}$ (analyzed in Room 2 – Figure 10) for the situation of window closed and shutter closed and open. As can be noticed all of these differences do not follow a specific pattern, appearing to follow some sort of randomness for the medium and high frequencies, when considered in accordance with the floor level from the ground. A specific pattern is only obtained for the first and second floors, the ones that are in a range of incidence angles near 45º degrees. This can lead to state that these floors can be the reference ones for the determination of façade sound insulation? More studies are needed to conclude something substantial.

Regarding the effects of flanking transmission [9], in the global insulation of façade, it seems its influence is negligible because the buildings partitions are normally made of homogenous and heavy construction elements which provokes the sound energy to flow almost completely through the window (and so through the façade itself) with no relevant contribution from the adjoining partitions (floors, ceilings and internal walls). In practice the sound insulation of façades is very poor when compared to sound insulation provided by blind partition elements. Having this in attention, the requirements set forth for façades are also very low; for instance, in the Portuguese Building Code [9], the requirements for the airborne sound insulation index of façades must be greater than 28 dB for sensitive zones - defined as those that are exposed to $L_{Aeq} \leq 55$ dB(A) between 7 h and 22 h and $L_{Aeq} \leq 45$ dB(A) between 22 h and 7 h -, and greater than 33 dB for other zones (normally, named mixed zones).

Regarding the information set in Table 4, as well as in Figures 15 and 16, one may state that the best index to describe the performance of façades is the parameter $D_{2m,n,w}$, for the values of standard deviation calculated from the amount of indices obtained for all floors and for each group of shutter positions are the less ones.

Finally, in Figure 17 a very important conclusion can be extracted. The existence of balcony turns the sound field inside the room worst at medium and high frequencies than at low frequencies. In the range of low frequencies the opposite performance is met. Obviously, this aspect influences the sound insulation of the global façade when expressed in terms of its index (unique value) because its calculation is due to the difference between inside and outside sound levels. This variation is of 2-3 dB magnitude (see Tables 1 and 2).

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