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THE INFLUENCE OF SHUTTERS POSITION ON NOISE INSULATION OF FAÇADES

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ABSTRACT
This paper presents the results of an experimental set of tests carried out on a selected new housing building with a view to study the influence of roller shutters position on noise insulation of façades. These tests were done in 3 different rooms with different window dimensions – on the first floor – and in a similar room and window, for the 3 subsequent upper floors, in accordance to what is prescribed in the international standards EN ISO 20140-5 and 717-1, using a loudspeaker as a noise source. The shutters positions were: totally opened, half closed, partially closed with internal blades exposed, and completely closed. The results have shown that the transmission loss curve for each shutter position differs with some significance whilst the noise insulation index of the façade remains almost constant for all positions, exception made for the position to which the shutter is completely closed.

1 - INTRODUCTION
It is assumed that noise insulation of façades in situ integrates the contribution of all façade elements – external walls and windows – and the way these elements are connected with each other and with all the adjoining internal partitions – horizontal and vertical. It is well known that the window element, which includes the glaze and the frame, is the weakest point as regards noise insulation of façades.
In Portugal, two main additional components currently proposed for building façades, by designers and architects are the balconies, as a constructive building element, and the roller shutters as a protective and decorative one. Former studies developed by LNEC [3] have shown that balconies do not significantly influence the noise insulation of all the façade system; wall and window, unless the noise incidence angle is too high in such a way that in a certain floor the lower surface of the balcony above could act as a reflecting plane causing an increment of global noise incident on the façade. As regards the other façade component – shutters – and their efficiency for improving the global façade noise insulation, it seems that no information is currently available.
Generally, either at project stage or in an evaluation process of compliance with national regulations, the contribution of shutters for noise insulation of façades against external noise is not taken into account. At project 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. In the evaluation of compliance, their effects are not considered because the measurements are usually done with the shutters completely opened. It should be mentioned that in the text of Portuguese regulations nothing is written about this need. They just refer to the fact that the noise insulation index R'_{45} of façades, for housing buildings that have been subjected to a licensing procedure for construction, renovation or rehabilitation, must be greater a certain value (in case: 25 dB for less noisy sites; 30 dB for noisy sites; and 35 dB for high noisy sites).
So, the objective of this study was the evaluation of shutters contribution to noise insulation of façades, considering them as an additional possible measure that could – in compromise with the need of shadowing effects they are intended to accomplish, in a correlation with thermal insulation and visual comfort – improve the sound insulation of façades. In the set of tests performed, the shutters positions were:

i) totally opened *O*; *ii*) half closed *HC*; *iii*) partially closed with internal blades exposed *PC*; and *iv*) completely closed *C*. Among all these positions the ones referred to in *ii*) and *iii*) are very important because they may be more devoted to accomplish the previously mentioned compromise. Figures 1 and 2 illustrate the building façade tested and the shutter position *PC*.

Figure 1: Building façade.

2 - THEORY

According to the international standard EN ISO 140-5, the noise insulation of façades and façade elements measured in situ is given by the following equation.

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

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

This equation is valid when the noise source is a loudspeaker, on the assumption that the sound is incident from an angle of 45° and that the sound field in the receiving room is diffuse. Nevertheless, when performing tests in situ it is not easy to have always an incident angle of 45°. And, cumulative to that, the façades are usually subjected to noise coming from other noise sources, generally the road traffic noise. These noise sources are placed in the same position along the years; the road always stays where it was firstly constructed. So, it seems to be of great importance to convert the values of noise insulation obtained for different angles in situ $-$ R'_θ corresponding to the angle formed by the height of the façade and the distance between the building and the position from which the noise comes from,

Figure 2: Shutter position PC.

normally the middle of the street – to R'_{45} values in order to make a good comparison between what is proposed in commercial leaflets and what is obtained in real situations concerning real dwellers. Thus, having, for homogenous elements [1]:

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

where: θ is the incidence angle; Z_0 is the acoustic impedance of the air; ω the angular frequency; and m is the mass per unit area.
From equation (2) the following conversion equation can be obtained:

$$R'_{45} = R'_\theta + 10\ \ \log\left(\frac{1}{2\cos^2\theta}\right) \tag{3}$$

The equation used to perform calculations of noise insulation of façades, at project stage, from the values of the indices R_w related to each component of the global façade, i. e. the massive part and the window, is the following:

$$R_w = 10\ \log\left(\frac{\sum_i S_i}{\sum_i S_i 10^{-R_{wi}/10}}\right) \tag{4}$$

where: R_{wi} represents the noise insulation index of each type of façade component; and S_i its correspondent surface.
Normally, the laboratory values of R_{wi} do not strictly represent the performance of the insulation system when it is subject to an incidence angle of 45° because they are obtained in reverberation rooms; diffuse fields.

3 - TESTS CARRIED OUT

For this study, a set of tests was performed in a selected new building in 3 different rooms with different window dimensions – window in room 1: 1,58 m × 1,87 m; window in room 2: 0,78 m × 1,87 m; and window in room 3: 1,58 m × 1,58 m – on the first floor, and in a similar room and window – window: 1,58 m × 1,87 m – for the 3 subsequent floors, using a loudspeaker as a noise source. The façades in each room are equal with 3,2 m × 2,8 m. The building specifications were accomplished in accordance to what was prescribed in the project. The external wall is homogenous, and double, with 0,11 m thickness each pane, and the air cavity (4 cm thickness) is filled with expanded polystyrene. The window frame is made of aluminum and the glaze is double: 5 mm thickness each pane separated by 6 mm of air cavity. All the system was conveniently sealed. The roller shutters are made of plastic.

4 - RESULTS

The results of noise insulation index R'_θ, in dB, obtained for all the tests performed in the building are presented in table 1. The values of θ are: 1st floor – 45°; 2nd floor – 59°; 3rd floor – 66ª; 4th floor – 72°.

Same Room / Different floors					Same floor / Different room				
Floor	O	HC	PC	C	Room	O	HC	PC	C
1st floor	27	27	27	33	1	27	27	27	33
2nd floor	24	23	24	30	2	41	41	41	41
3rd floor	26	27	27	32	3	34	34	33	36
4th floor	28	26	26	30					

Table 1: Noise insulation indexes R'_θ.

Table 2 presents the results of noise insulation index R'_θ, in dB, by making the calculations without adjusting the reference curve with steps of 1 dB. The rounding standardized procedure may yield differences of almost 1 dB between the values of the indices.

Same Room / Different floors					Same floor / Different room				
Floor	O	HC	PC	C	Room	O	HC	PC	C
1st floor:	27,6 (+0.6)	27,8 (+0.8)	27,6 (+0.6)	33,1 (+0.1)	R1:	27,6 (+0.6)	27,8 (+0.8)	27,6 (+0.6)	33,1 (+0.1)
2st floor:	24,2 (+0.2)	23,9 (+0.9)	24,9 (+0.9)	30,2 (+0.2)	R2:	41,6 (+0.6)	41,5 (+0.5)	41,3 (+0.3)	41,3 (+0.3)
3st floor:	26,1 (+0.1)	27,0 (+0.0)	27,0 (+0.0)	32,2 (+0.2)	R3:	34,9 (+0.9)	34,6 (+0.6)	33,9 (+0.9)	36,8 (+0.6)
4st floor:	28,0 (+0.0)	26,1 (+0.1)	26,5 (+0.5)	30,6 (+0.6)					

Table 2: Noise insulation indexes not rounded.

By considering the correction yielded by equation 3, the values of R'_{45} for the 2nd, 3rd and 4th floors must be, respectively, those presented in Table 3: the calculated index added with the value in parenthesis.

Floor	O	HC	PC	C
2nd floor	24 (+3)	23 (+3)	24 (+3)	30 (+3)
3rd floor	26 (+5)	27 (+5)	27 (+5)	32 (+5)
4th floor	28 (+7)	26 (+7)	26 (+7)	30 (+7)

Table 3: Noise insulation indices R'_{45}.

The next two figures illustrate the influence on noise insulation, R, of shutters position, in frequency domain, for different floors.
Similarly, the influence on noise insulation, R, of shutters position in the same floor but with different window dimensions (figures 5 and 6), and the differences between the shutter totally opened positions and the other situations (figure 7), as well as each window glaze pane noise reduction – sectors A, B, C, D – and the roller shutter case – sector E – (figure 8) are illustrated below.
From the results presented in the previous figures it can be seen that, apart from the fact that the values of noise insulation indices remain almost constant for all shutters position, exception made to the closed one, there are significant differences of that insulation in the frequency domain. Table 4 presents the differences of noise insulation index expressed in dB(A) by taking the opened position as the basic one.

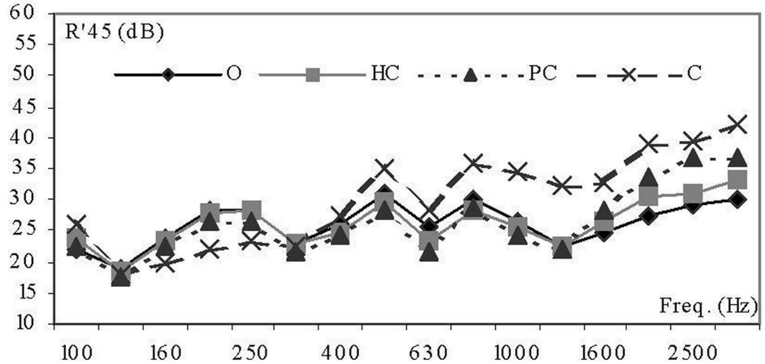

Figure 3: Noise insulation – 1st floor, room 1.

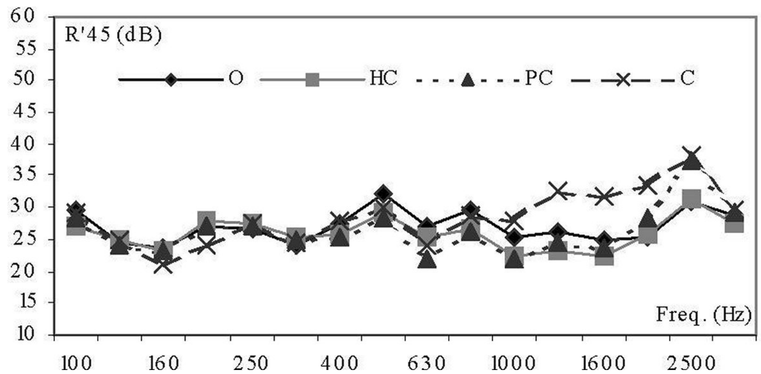

Figure 4: Noise insulation – 4th floor, room 1.

Same Room / Different floors				Same floor / Different room			
Floor	HC	PC	C	Room	HC	PC	C
1st floor:	-0,7	-1,5	+1,3	R1:	-0,7	-1,5	+1,3
2st floor:	-1,3	-0,7	+2,8	R2:	-0,3	-0,6	-1,0
3st floor:	-2,1	-2,6	-0,1	R3:	0,2	+0,1	-0,9
4st floor:	-1,6	-2,7	-0,8				

Table 4: Noise insulation differences in dB(A) – base: shutter open.

5 - CONCLUSIONS

From the results obtained it is possible to formulate several important and practical conclusions.
The variations of noise insulation of the façade with the shutters positions in frequency domain become lower as, and when, the level of the floor increases (see figures 3 and 4). The position of the shutter in windows of small dimensions – Room 2/floor 1 – does not interfere with the global performance of the façade (see figures 3, 5 and 6). Concerning the values of noise insulation indices, the position *C* is the one that leads to a major difference (see table 1).
Regarding the values obtained for 2nd floor, it seems that the difference (3 dB) between these values and the ones of all other floors may be due to a loss of sound insulation of the window originated by resonance effects inside its air cavity defined by the double glaze panes.
The values of R'_θ and R'_{45}, for shutter positions *O*, *HC* and *PC*, are almost equal (see the values of 1 st, 3rd and 4th floors indices – table 1), exception made to the position *C*. For this position, would it be advisable to consider that, when it is considered in height, it partially decreases the insulation by the rate they should be increased (see table 3)?
The values in dB(A) presented in table 4 show that the noise insulation effects from a subjective perspective inside the rooms are higher for the shutter positions *HC* and *PC*. This may be due to a redistribution of sound energy in frequency domain inside the virtual absorvative box defined by the window and the shutter. Finally, it must be stressed that the shutter case does not influence significantly the performance of the global window system in the most unfavourable shutter position – *C* – (see figure 8).

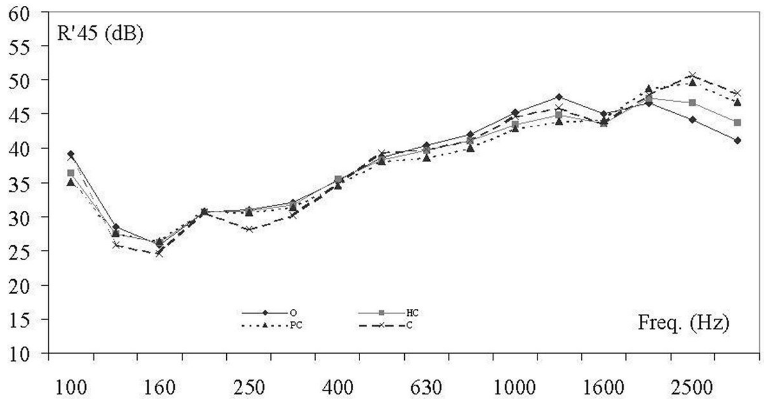

Figure 5: Noise insulation – 1st floor, room 2.

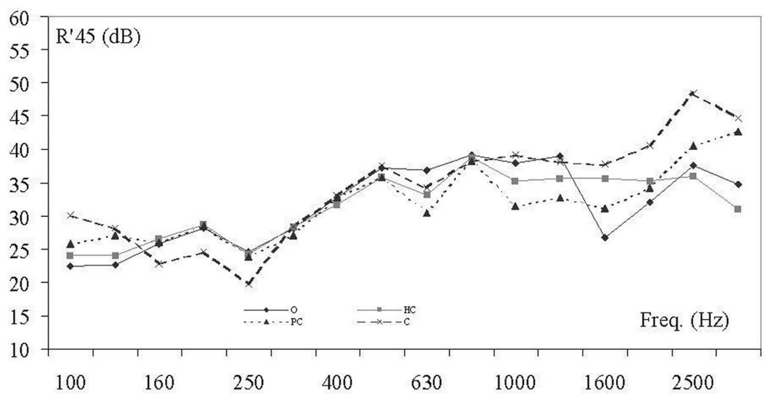

Figure 6: Noise insulation – 1st floor, room 3.

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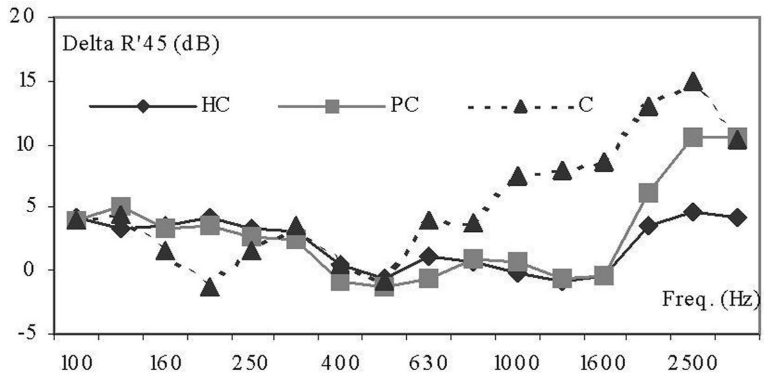

Figure 7: Noise insulation – 3rd floor, room 1.

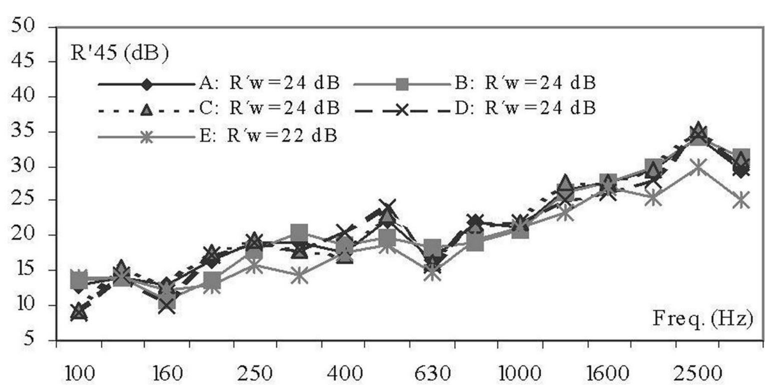

Figure 8: Sectors noise reduction.