Simulation of Thermal and Acoustic Façade Insulation Starting From the Characteristics of the Individual Elements

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Abstract

The thermal and acoustic insulation of individual building elements such as walls, windows and systems for roller shutters significantly affects the thermal and acoustic insulation of a building. This paper considers the acoustic and thermal performance of the individual elements evaluated in laboratory with simulation of both the façade sound reduction index and thermal transmittance of a typical room. The scope of this work is to verify if there are any correlations between acoustic and thermal performance; for this reason, 4 types of opaque wall, 3 window systems for roller shutters and 5 windows for a total of 60 façade configurations have been considered and combined.

1. Introduction

The correct acoustic and thermal design of a building is of fundamental importance for increasing indoor comfort.

Many studies have been carried out regarding acoustic and thermal comfort (Fabbri et al., 2014; Granzotto, 2021; Tronchin et al., 2018; Tronchin et al., 2021), façade acoustic insulation (Hua et al., 2021; Jagniatinskis et al., 2021) and thermal insulation (Theodosiou et al., 2019).

Other studies comparing acoustic and thermal characteristics of walls can be found (Di Bella et al., 2014; Di Bella et al., 2015). Sound insulation is one important factor for façade performance optimization. As an example, Ryu et al. (2010) proved that the sound insulation of a building façade influenced indoor annoyance due to transportation noise and the frequency content of intrusive noise. For façade thermal insulation, Sierra-Peréz et al. (2016) demonstrated how an optimized combination of elements could affect indoor thermal perception.

In this work, the acoustic and thermal insulation of a façade has been considered, varying the performance of single elements. 4 walls, 3 shutter systems and 5 windows.

The acoustic performance was determined in a laboratory while the thermal performance was simulated from the thermal conductivity data, considering, in addition, linear thermal transmittance.

2. Calculation Models

The sound reduction index, R, of a building element is defined as:

$$R = 10\lg\left(\frac{1}{\tau}\right) \quad (1)$$

The transmission coefficient τ is the ratio of the sound power, W_1, which is incident on the test element to the sound power, W_2, radiated by the test element to the other side.

R was measured in laboratory conditions according to the ISO 10140 (2021) series standard:

$$R = L_1 - L_2 + 10\lg\left(\frac{S}{A}\right) \quad (2)$$

The composed sound reduction index, R_{tot}, was calculated as:

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$$R_{\text{tot}} = 10\lg\left(\frac{\sum_{i=1}^{n} S_i}{\sum_{i=1}^{n} 10^{(-R_i/10)} S_i}\right) \tag{3}$$

The weighted sound reduction index, R_w and the spectrum adaptation term for pink noise, C, and for traffic noise, C_{tr}, were calculated according to ISO 717-1 (2020). The thermal conductivity, λ, of materials such as rock wool, EPS and XPS is measured according to EN 12667 standard (2021), while the thermal transmittance, U, and the linear thermal transmittance, Ψ, were simulated by means of a FEM software according to ISO 10077-2 (2017) and ISO 10211 (2017) standards.

The composed thermal transmittance, U_{tot}, of the façade was obtained according to ISO 10077-1 (2017) with the following formula:

$$U_{\text{tot}} = \frac{\sum_{i=1}^{n} U_i S_i + \sum_{k=1}^{m} \Psi_k l_k}{\sum_{i=1}^{n} S_i} \tag{4}$$

3. Building Elements

The building elements considered are reported in Tables 1, 2 and 3.

Table 1 – Building elements - Walls

ID	Description
A	Aerated concrete blocks (350 kg/m^3, 300 mm) lined with rock wool panels (45 mm) and gypsum board (12.5 mm).
B	Hollow brick plastered one side (250 mm) lined with rock wool panels (140 mm) and plaster (5 mm).
C	Hollow brick plastered one side (250 mm) lined with EPS panels (140 mm) and plaster (5 mm).
D	Aerated concrete blocks (300 kg/m^3, 400 mm).

Table 2 – Building elements - Windows systems for roller shutters

ID	Description
a	Integrated windows system for roller shutter for window flush with the internal wall. S=0.75 m^2.
b	Integrated windows system for roller shutter for window in the middle of the wall. S=0.75 m^2.
c	Box for roller shutter suitable for building renovations. S=0.45 m^2.

Table 3 – Building elements - Windows

ID	Description
1	One sash window with glass: 6 mm + 0.76 mm acoustic PVB + 6 mm / 16 mm Argon / 4 + 0.50 mm acoustic PVB + 4 mm.
2	One sash window with glass: 3 mm + 0.50 mm acoustic PVB + 3 mm / 15 mm Argon / 4 mm / 15 mm Argon / 3 mm + 0.50 mm acoustic PVB + 3 mm.
3	Two sash windows with glass: 4 mm + 0.76 mm acoustic PVB + 4 mm / 15 mm Argon / 4 mm / 15 mm Argon / 4 mm + 0.76 acoustic PVB + 4 mm.
4	One sash window with glass: 6 mm + 0.76 acoustic PVB + 6 mm / 12 mm Argon / 4 mm / 12 mm Argon / 4 mm + 0.76 acoustic PVB + 4 mm.
5	Two sash windows with glass: 3 + 0.38 PVB + 3 mm / 18 Argon / 4 + 0.50 acoustic PVB + 4 mm.

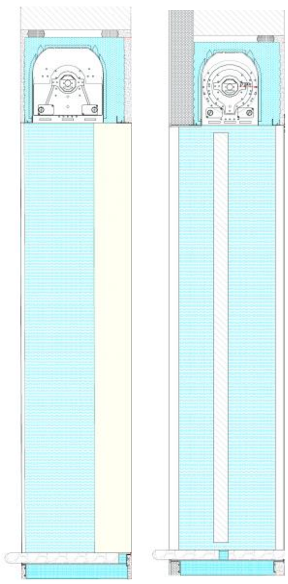

Fig. 1 – Window system for roller shutter “a” and “b”

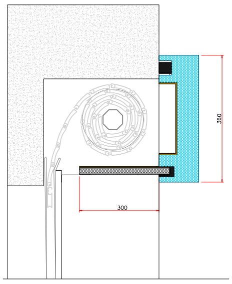

Fig. 2 – Window system for roller shutter “c”

Fig. 1 and 2 show the windows system for roller shutter used in the simulations. Window dimension was 1230 mm x 1480 mm, and wood frame thickness was 80 mm.

4. Acoustic Measurements and Thermal Simulations

The sound reduction index of the building elements was measured in the laboratory according to ISO 10140 (2021) series standard (Figs. 3, 4 and 5). The sound reduction index, *R*, of the building elements in the 1/3 octave frequency band is shown in Fig. 6. The weighted sound reduction and the thermal transmittance are shown in Table 4.
The thermal transmittance of the windows and window systems for roller shutters was simulated with FRAME SIMULATOR software.
From the thermal profiles in Fig. 7, it is possible to consider the “a” box shutter as the one with the best performance followed by “b” and “c”.

Fig. 3 – Window – Laboratory test according to ISO 10140 (2021) series standard

Fig. 4 – Window system for roller shutter “a” – Laboratory test according to ISO 10140 (2021) series standard

Fig. 5 – Wall – Laboratory test according to ISO 10140 (2021) series standard

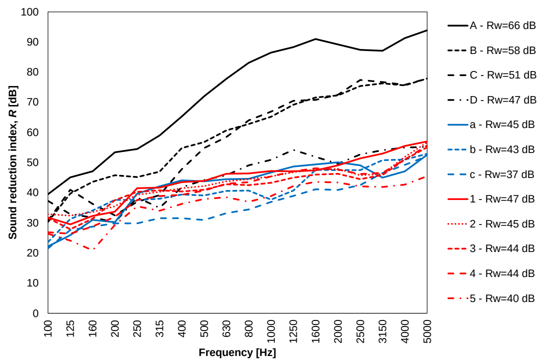

Fig. 6 – Sound reduction index of building elements in 1/3 octave bands

Table 4 – Building elements acoustic and thermal performance

Element	Type	$R_w(C;C_{tr})$	U
A	Wall	66(-2;-9)	0.201
B	Wall	58(-3;-9)	0.219
C	Wall	51(-2;-7)	0.193
D	Wall	47(-2;-6)	0.170
a	Shutter box	45(-2;-8)	0.385
b	Shutter box	44(-2;-5)	0.842
c	Shutter box	37(-1;-3)	1.061
1	Window	47(-2;-5)	1.200
2	Window	45 (-1;-3)	0.890
3	Window	44 (-1;-3)	1.100
4	Window	44(-1;-5)	0.890
5	Window	40(-2;-5)	1.300

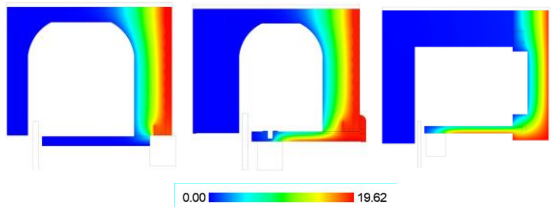

Fig. 7 – Temperature for windows system for roller shutter (left: “a”, center: “b”, right: “c”)

The linear thermal transmittances, Ψ, of the shutter-wall interface, wall-window interface and shutter-window interface were calculated with Finite Element Method software MOLD SIMULATOR, according to ISO 10211 (2017). Ψ_1 is the linear thermal transmittance for wall-shutter box, Ψ_2 is the linear thermal transmittance for wall-shutter-window, Ψ_3 is the linear thermal transmittance for shutter-window (Fig. 8 and Table 5).

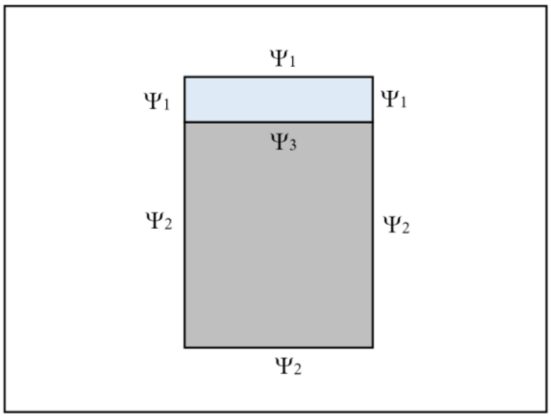

Fig. 8 – Linear thermal transmittance scheme

Table 5 – Building elements – Linear thermal transmittance

Configuration	Ψ_1	Ψ_2	Ψ_3
Aa	0.33	0.08	0.23
Ab	0.33	0.08	0.38
Ac	0.10	0.10	0.55
Ba	0.40	0.11	0.23
Bb	0.40	0.08	0.38
Bc	0.45	0.11	0.55
Ca	0.40	0.12	0.23
Cb	0.40	0.09	0.38
Cc	0.45	0.11	0.55
Da	0.33	0.08	0.23
Db	0.33	0.08	0.38
Dc	0.10	0.09	0.55

Figs. 9, 10 and 11 show some temperature examples of linear thermal transmittance simulations.

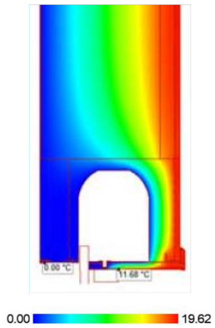

Fig. 9 – Example of Ψ_1 simulation with MOLD software for "b" shutter box and wall "D"

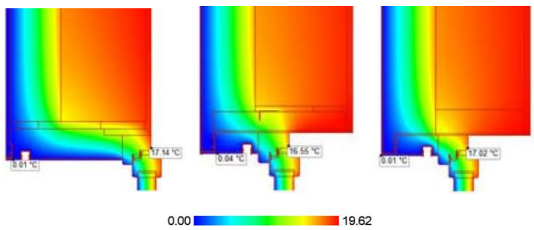

Fig. 10 – Example of Ψ_2 simulation with MOLD software for "a", "b" and "c" shutter box (with Wall "B")

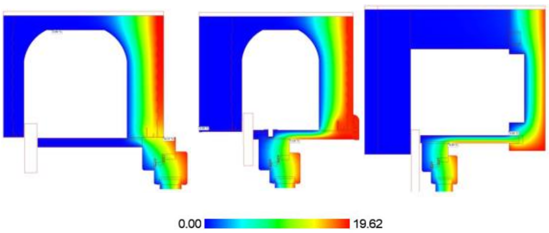

Fig. 11 – Ψ_3 simulation with MOLD software for "a", "b" and "c" shutter box

5. Results

The acoustic and thermal insulation of a 2.7-m-high and 4-m-wide façade has been considered.

The composed weighted sound reduction index, R_w, vs composed thermal transmittance, U, is shown in Fig. 12.

The composed weighted sound reduction index, R_w+C_{tr}, vs composed thermal transmittance, U, is shown in Fig. 13. R_w+C_{tr} considers weighted sound reduction index in dB(A) for traffic noise.

The best configurations are located in the upper left quadrant.

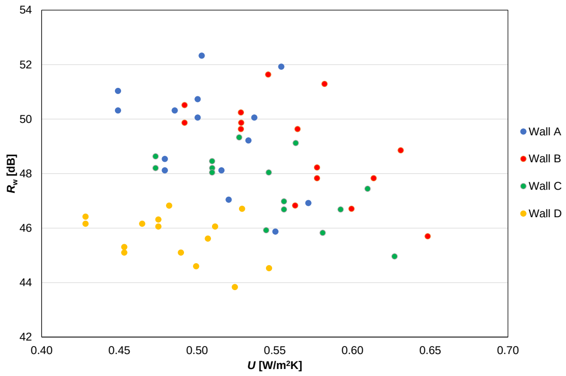

Fig. 12 – R_w vs U

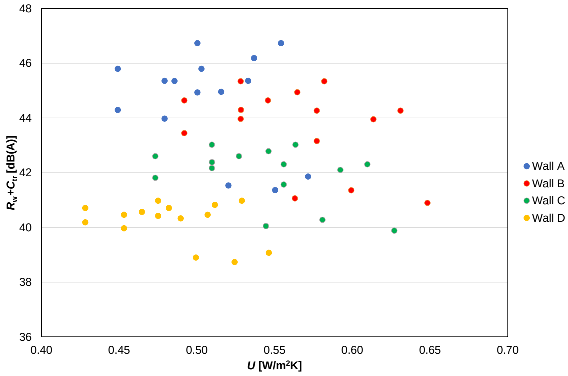

Fig. 13 – R_w+C_{tr} vs U

It can be noted that there are no correlations between acoustic and thermal performance at all. Indeed, poor correlations are obtained even considering single wall results.

For R_w:

- R^2_wallA is 0.13;
- R^2_wall B is 0.41;
- R^2_wall C is 0.42;
- R^2_wall D is 0.15.

For R_w+C_{tr}:

- R^2_wall A is 0.09;
- R^2_wall B is 0.16;
- R^2_wall C is 0.18;
- R^2_wall D is 0.14.

Fig. 14 shows the configurations examined as the thermal transmittance, U, decreases. In the same graph, the indices R_w and R_w+C_{tr} are indicated (dotted line indicates the calculated transmittance without considering the linear thermal transmittance).

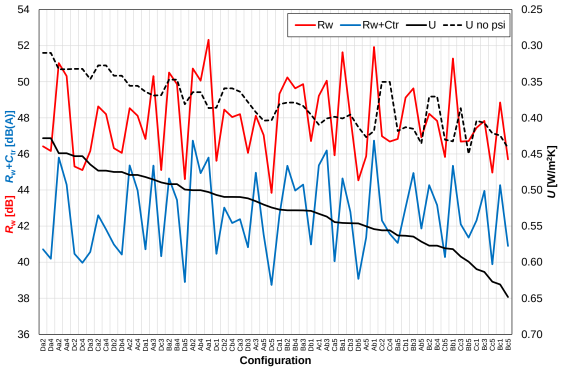

Fig. 14 – U vs R_w and U vs R_w+C_{tr}

Considering the variation in the performance of a single element (wall, window systems for roller shutters and window), it can be noted how the variations in the overall performance of the façade are different from an acoustic and thermal point of view (Fabbri et al., 2021; Tronchin, 2005). Interestingly, it can be noted that, if linear thermal transmittances are not considered, considerable errors are made (ΔU = 0.12-0.21 W/(m²K)).

Furthermore, it can be noted that the configurations with "D" wall are the best in terms of thermal insulation because of low U and reduced thermal bridges, while in terms of sound insulation they are not as effective as the other walls.

The configurations with shutter box type "c" provide good results even if the performances of this element are not optimal. This is due to the small surface of the element, which leads to a small overall influence.

It can be noted that the combination providing better acoustic and thermal performance is represented by the "Aa2" configuration.

In Figs. 15-23, the values of U, R_w, R_w+C_{tr} of the whole façade are reported and parametrically compared with the values of the walls (A, B, C and D), of the shutter boxes (a, b, and c) and of the windows (1, 2, 3, 4 and 5).

Configurations with the lowest value are indicated with a grey dashed line. In Fig. 15, it can be seen how wall A implies a lower value of U for the façade. This is due to the fact that wall A has a lower Ψ_2 value because of its composition (thermal insulating blocks). As regards the acoustic insulation, it can be noted that as the performance of the single element increases, the range of R_w and R_w+C_{tr} increases.

In Figs. 16 and 17, the overall acoustic performance is studied parametrically and compared to the wall ones. Interestingly, an important influence is assessed below 55 dB, while over this threshold no significant difference is found.

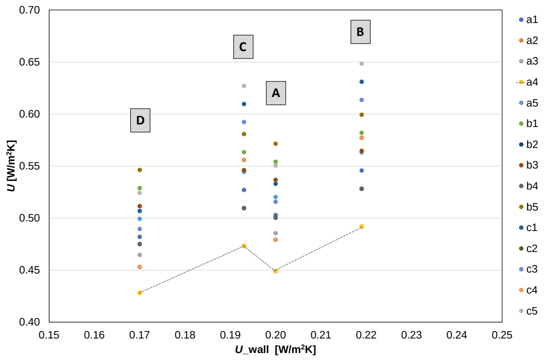

Fig. 15 – Overall U compared to the thermal transmittance of the wall (A, B, C and D), U_wall

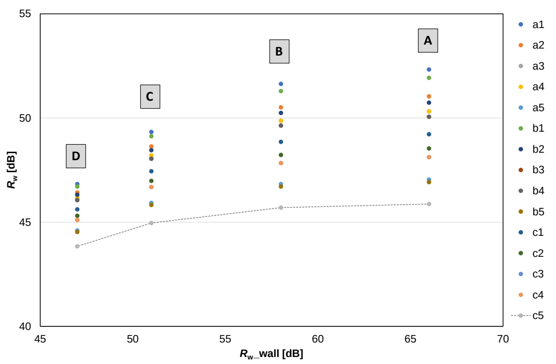

Fig. 16 – Overall R_w compared to the weighted sound reduction index of the wall (A, B, C and D), R_w_wall

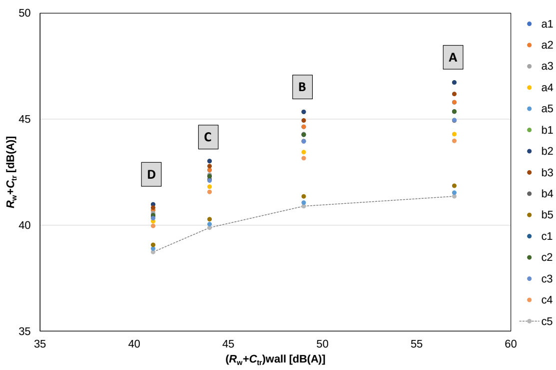

Fig. 17 – Overall R_w+C_{tr} compared to the weighted sound reduction index of the wall (A, B, C and D), (R_w+C_{tr}) wall

The influence of the shutter box transmittance is reported in Fig. 18. It is clear that shutters affect the final performance, but do not drive the overall final result because of their reduced area.

Moving on to the shutter box acoustic performances (Figs. 19-20), it can be seen that their influence affects overall results more when the wall provides high acoustic insulation.
The window parametric influence on overall results is depicted in Fig. 21.

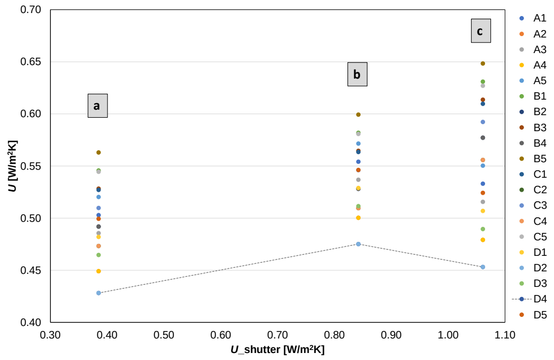

Fig. 18 – Overall *U* compared to the thermal transmittance of the shutter box, (a, b and c) *U*_shutter

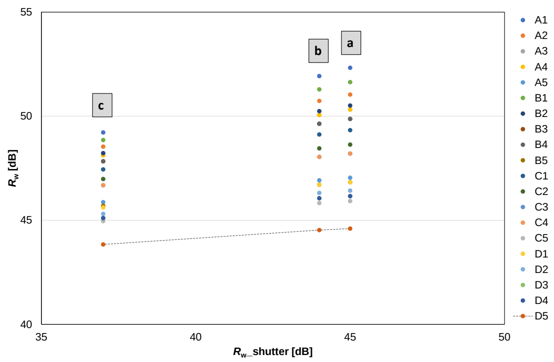

Fig. 19 – Overall R_w compared to the weighted sound reduction index of the shutter box (a, b and c), R_w_shutter

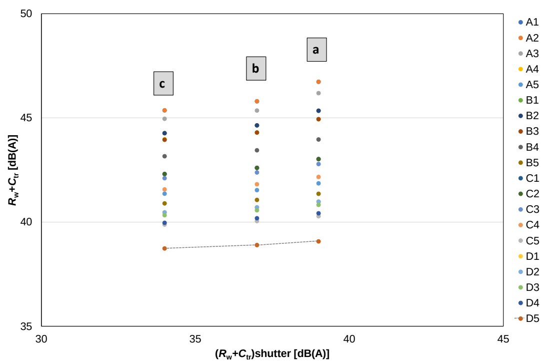

Fig. 20 – Overall R_w+C_{tr} compared to the weighted sound reduction index of the shutter box (a, b and c), (R_w+C_{tr}) shutter

Here, it can be seen how, almost linearly, window thermal transmittances increase the overall final performances as expected because of their significant area.

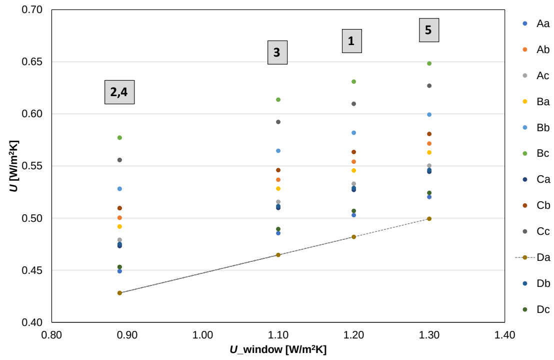

Fig. 21 – Overall *U* compared to the thermal transmittance of the window, (1, 2, 3, 4 and 5) *U*_window

When moving on to window acoustic parametric influence (Figs. 22-23), it can be highlighted that, when the sound insulation increases, the overall acoustic performance increases too. Again, this is due to window area, which is significant in the façades considered.

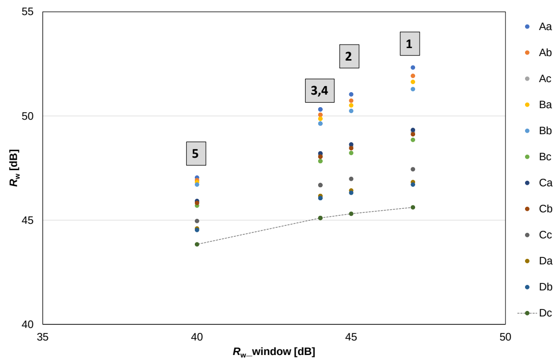

Fig. 22 – Overall R_w compared to the weighted sound reduction index of the window (1, 2, 3, 4 and 5), R_w_window

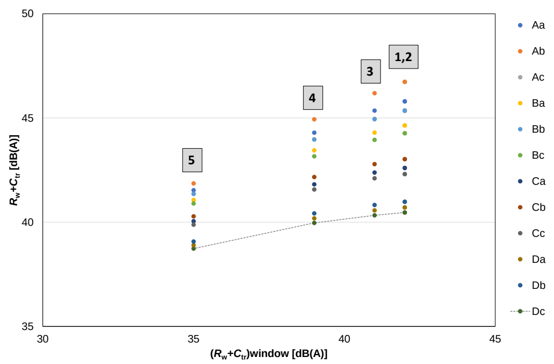

Fig. 23 – Overall R_w+C_{tr} compared to the weighted sound reduction index of the window (1, 2, 3, 4 and 5), (R_w+C_{tr}) window

6. Conclusion

In this work, the acoustic and thermal insulation of 60 different combinations of façade elements was studied. 4 walls, 3 shutter systems and 5 windows were considered. It was possible to verify that there is no correlation between the overall final acoustic and thermal performances.

Some further considerations can be made:

- the best solutions from the thermal point of view are not the best ones from the acoustic point of view;
- the best combined thermal and acoustic performances are obtained using thermally insulating blocks (aerated concrete block) with internal lining and use of integrated window systems for roller shutters
- if linear thermal transmittance is not considered, considerable errors can be made (ΔU=0.12-0.21 W/(m^{2}K)).
- it can finally be pointed out how, from a thermal point of view, all three elements equally contribute to the final performance, while, regarding acoustic insulation, the wall and the windows play a more important role due to their more extended area.

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