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Article in *Energy Procedia* · December 2015

DOI: 10.1016/j.egypro.2015.11.133

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## Analysis of direct and flanking sound transmission between rooms with curtain wall facades

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### Abstract

Curtain walls have nowadays reached good performance in terms of façade sound insulation, thermal insulation and solar protection.

In this work, flanking and direct structural transmission are analysed with reference to the joints of the mullion of the curtain wall with lightweight plasterboard partitions. Airborne sound insulation and vibrational measurements were made in two adjacent rooms affected by the acoustic problems determined by the curtain wall joint.

Traditional acoustic measurements carried out according to EN ISO 16283-1 highlight problems in sound insulation between rooms, but without any indication on different sound transmission paths through the wall. Vibrational measurements were made for every part of the system (frame columns and beams, windows' glasses, plasterboard wall, plasterboard false ceiling, etc.) to better understand the sound transmission paths in these kinds of structures.

Taking into account previous works and measurements made in this research field, different solutions for curtain wall structures are analysed and technical suggestions are given to improve airborne sound insulation between rooms separated by partitions mounted up to metal frames.

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Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL

*Keywords:* Building acoustics; Curtain wall; Façade; Flanking transmission; Radiation efficiency.

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## 1. Introduction

Since the 90's curtain walls have taken on a role that goes beyond that of a simple curtain closing: they act as a "selective filter" between the internal and external environment; various typologies were developed, such as double skin (double ventilated façade), with or without heat recovery, or front solar photovoltaic, to characterize the architectural design and to obtain energetic advantages as well.

Nowadays curtain walls are used both in new buildings and in renovations, especially in offices or multifunctional buildings, by the replacement or integration of new volumes, thanks to the use of glasses which have various properties (colored and insulating glass, reflective and selective glass, etc.).

Recent studies show that acoustic problems may arise in the joint of the façade with other building structures. As a result, sound insulation between rooms separated by partitions mounted up to the curtain walls is often reduced.

The lack of airborne sound insulation between rooms can influence the fulfillment of the legal requirements and affect privacy, which is fundamental for dwellings and offices.

## 2. Description of the case study

The case study concerns a multipurpose management center, designed for businesses, offices, medical clinics and kindergarten. The main structure is made of reinforced concrete floors with both pillars and supporting partitions of precast concrete, covered with weakly ventilated facing brick. The glazing consists of curtain wall structures, with aluminum frames and double glass windows.

Like many others, this type of curtain wall have good thermal insulation properties [1]. In this case the heat flow control is governed by double glazing with cavity filled with Argon gas (10 mm glass /14 mm Argon gas/66. ldouble layer glass with single layer of PVB, total thickness: 36 mm), having a transmittance value of about 1.1 W/m<sup>2</sup>K. The control of the solar radiation is made exclusively by the use of selective glasses of green colour having a solar factor  $g = 22\%$ , a light transmission  $\tau_l = 48\%$  and a colour rendering index  $IR = 91\%$ .

Despite very good performance in terms of façade sound insulation, curtain wall systems frequently show problems with the acoustic insulation between adjoining rooms: direct and flanking structural transmissions can occur both vertically and horizontally [2, 3, 4] through the mullions of the curtain wall. For this reason, flanking transmission is a characteristic that has to be declared in accordance to the product standard for curtain walls described by prEN 13830 [5].

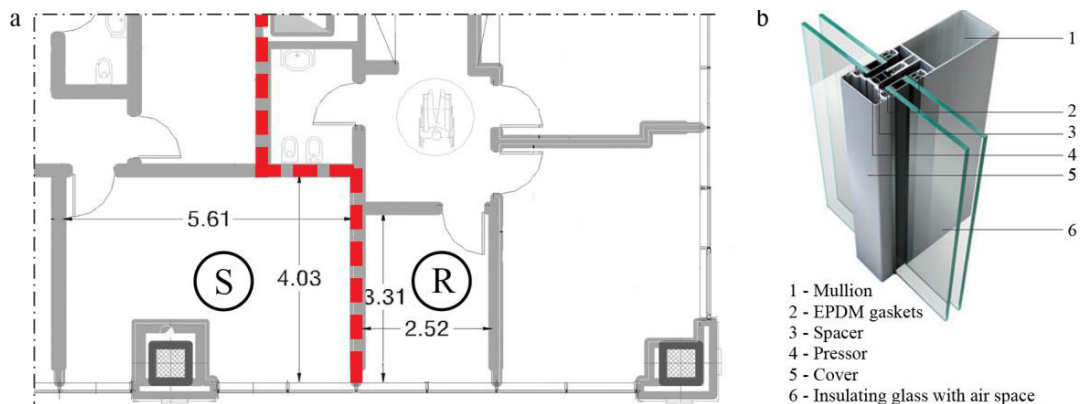


Fig. 1. (a) Plan portion of the building under test where: S = source room, R = receiving room, dashed line is the limit of two distinct properties; (b) detail of the curtain wall structure.

To better characterize the sound transmission through a curtain wall, the Apparent Sound Reduction Index of the partition between the adjoining rooms shown in Fig. 1.a was measured according to the procedure described by EN ISO 16283-1 [6], while velocity vibration measurements were carried out according to EN ISO 10848 [7].

Airborne sound insulation measurements showed the value of 41.2 dB for  $R'_w$ , which is far from the Italian legal requirement [8] of 50 dB (for offices) and also from the value of  $R_w$  certified in laboratory for this kind of partition.

$R'$  curve (Fig. 3.b) shows an irregular behavior around 1000 Hz: this kind of performance drop is usual to be expected around 2500-3150 Hz, which is the average coincidence frequency for plasterboard wall [9].

Airborne sound insulation measurements do not give us any hint to solve this problem, so vibratory measurements were carried out on the three different components forming the wall, and on the flanking components as well. The same sound source was used both for acoustic insulation and for vibration velocity measurements.

Velocity level measurements were carried out using 2 grams mono axial accelerometers, randomly placed over the surfaces. Plasterboard main wall, plasterboard joint and metal curtain wall mullion, illustrated in Fig. 4.a, were first analyzed. Other flanking noise paths (floor, glazing, ceiling) were investigated too, but they had much lower velocity levels, compared to those measured over the main wall. In consideration of this fact, velocity levels for flanking components are omitted for brevity.

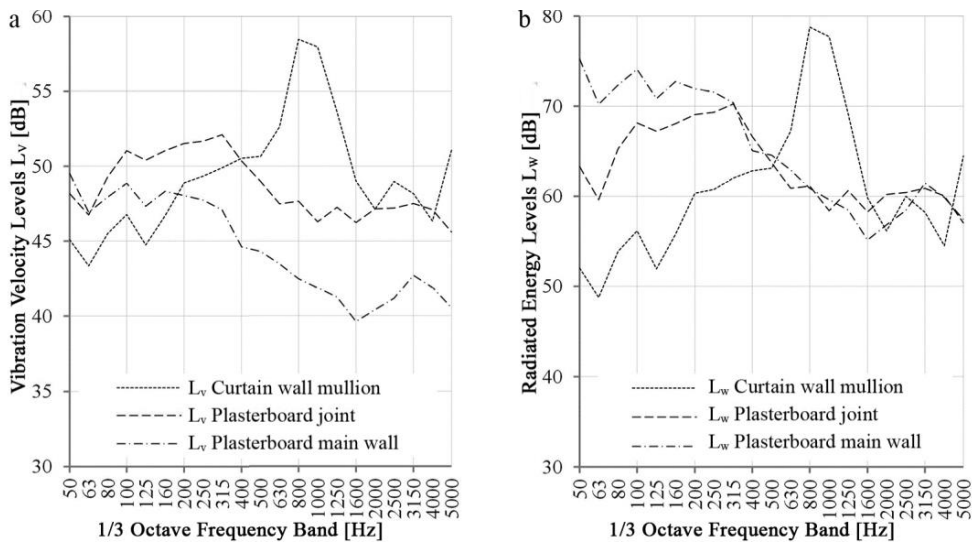


Fig. 2. (a) Measured velocity levels  $L_v$  in dB; (b) Estimated radiated energy levels  $L_w$  in dB.

Fig. 2.a shows the velocity vibration levels (dB ref.  $10^{-6}$  m/s) of the three structures. Values are shown both as velocity levels ( $L_v$  in dB) in Fig. 2.a and as radiated power level ( $L_w$  in dB) in Fig. 2.b ( $L_w = 10 \log_{10}(W/W_0)$ , with  $W_0 = 10^{-12}$  W), normalized to respective surfaces; in this comparison we have considered radiation efficiency  $\sigma = 1$  at each 1/3 octave band and for all materials. Radiated power is calculated as follows:

$$W = S_i \rho_0 c_0 \sigma_i \langle v^2 \rangle_{S_i} \quad [W] \quad (1)$$

where:  $S_i = i^{\text{th}}$  element surface [ $\text{m}^2$ ];  $\rho_0 c_0 =$  air impedance [ $\text{kg}/\text{m}^2\text{s}$ ];  $\sigma_i =$  radiation efficiency of  $i^{\text{th}}$  element [-];  $\langle v^2 \rangle =$  average velocity measured over  $i^{\text{th}}$  element surface and averaged over time.

Fig. 2 shows two main paths of sound transmission: transmission through the aluminum mullion of the curtain wall, and transmission through the reduced thickness plasterboard joint (three plasterboard layers directly connected to each other, see Fig. 4.a). It is clear that the sound insulation gap at 1000 Hz is due to the mullion of the curtain wall, although it has the smaller surface, compared to other components.

### 3. Radiation efficiency estimated from EN 12354-1, appendix B.1

In order to estimate the behavior of different elements in terms of Apparent Sound Reduction Indexes, useful for the comparison with the airborne sound insulation method (ISO 16283-1 [6]), the method used for the calculation of the radiation efficiency  $\sigma$ , was the one provided by EN 12354-1, appendix B.1 [10].

The standard gives a general method to estimate the radiation efficiency  $\sigma$  which is only validated for monolithic materials. We are well aware that the application of this method for a case study of multilayer lightweight structures [11, 12] with relatively small dimensions and various edge conditions, could give only approximate results. However many studies on the  $\sigma$  prediction of multilayer elements are being carried out, this problem still requires much work to find reliable solutions for the various possible conditions.

Lightweight structures have a higher radiation efficiency than an infinite unbounded plate, due to the stiffening of the metal frame, or due to the boundary conditions. This fact can be considered both for the aluminum mullion and for the plasterboard joint.

According to some authors [13, 14] a plasterboard wall is comparable to a series of sub-panels, rigidly connected to the mullion: they can act as individual vibrating panels, with increased radiation efficiency, compared to a forced vibration field.

In the reported case study the critical frequency [13] of the different composing elements of the partition, is relatively high (see Tab. 1) and for this reason  $\sigma$  estimation is very difficult and unreliable. Despite these limitations, radiation efficiency was calculated using Formulae B.3.a and B.3.b of EN 12354-1: this was done to try to consider the major emissivity of bounded panels instead of an infinite one, considering the exterior layers, where velocity measurements were carried out. In this case  $\sigma$  was utilized to calculate  $R'$  from measured values as follow:

$$R_{ij} = 10 \log \frac{\langle p_s^2 \rangle}{4 \rho_0^2 c_0^2 \langle v_j^2 \rangle \sigma_j} \quad [\text{dB}] \tag{2}$$

$$R' = -10 \log \sum_{j=1}^n \frac{S_j}{S_i} 10^{-0.1 R_{ij}} \quad [\text{dB}] \tag{3}$$

where:  $\langle p_s^2 \rangle$  is the squared average pressure measured in the Source room;  $S_i$ =total partition surface [ $\text{m}^2$ ];  $S_j$ =surface of the  $j$  element [ $\text{m}^2$ ];  $\rho_0$  is the air density [ $\text{kg}/\text{m}^3$ ];  $c_0$  is the sound speed in air [ $\text{m}/\text{s}$ ];  $\langle v_j^2 \rangle$  is the squared average velocity measured over the  $j$  element;  $\sigma_j$  is the radiation efficiency of the  $j$  element.;  $R_{ij}$  is the calculated flanking sound reduction index for the  $j$ - $i$  path.

Table 1. Data of the external layers of the subsystems assembling the wall under test (see also Fig. 4).

Subsystem	B × H [ $\text{cm}^2$ ]	Thicknes [cm]	$\rho$ [ $\text{kg}/\text{m}^3$ ]	$\rho_s$ [ $\text{kg}/\text{m}^2$ ]	E [ $\text{N}/\text{m}^2$ ]	$\nu$ [%]	$f_c$ [Hz]
Plasterboard Wall	300 × 320	2 × 1,25	900	22,5	5,50 × 10 <sup>9</sup>	0,34	≈ 900
Plasterboard Joint	30 × 320	2 × 1,25	900	22,5	5,50 × 10 <sup>9</sup>	0,34	≈ 900
Aluminium Mullion	12 × 320	0,25	2700	6,75	7,16 × 10 <sup>10</sup>	0,23	≈ 5000

Using the approximations above explained,  $R'$  was calculated from the measured vibration velocity and compared to  $R'$  measured with EN ISO 16283-1 method. Only velocities measured over the main wall components were considered, due to the fact that flanking components have an average of 5÷10 dB lower  $L_v$ . Despite the approximations in the calculation of the radiation efficiency, a good agreement between the two  $R'$  curves is shown in Fig. 3.a. The continuous curve is  $R'$  estimated using the EN 12354-1 hypothesis; empty dots are the ISO 16283-1 measurement's values.

Errors between prevision and measurement are mainly included in a ± 3 dB range. Greater errors are presents at 250 Hz, probably due to the overestimation of the critical frequency  $f_c$  for the plasterboard joint. The used model

obviously does not take into account of airborne transmission paths existing due to construction errors, such as holes for the air plant in the wall (behind a false ceiling), or the wall sockets, coupled on both sides of the wall.

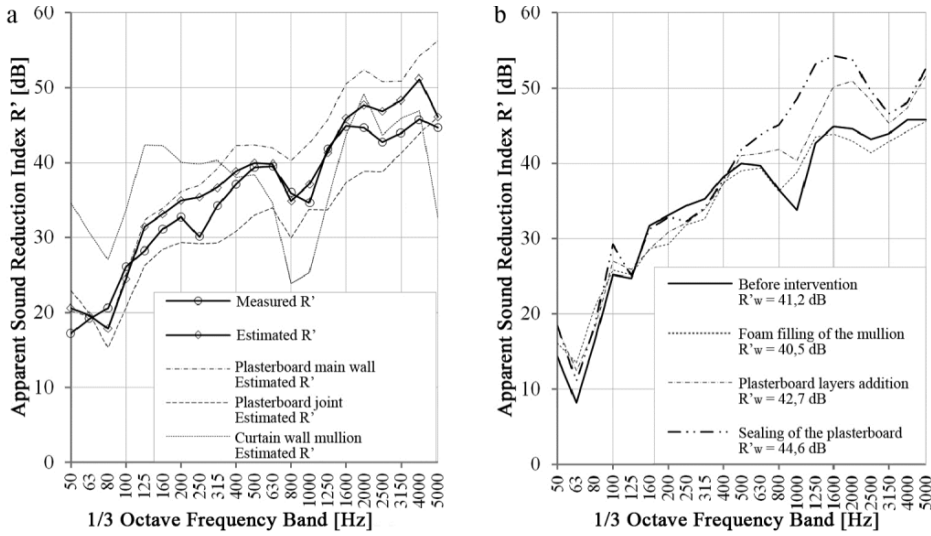


Fig. 3. (a) Graph of the Apparent Sound Reduction Index,  $R'$ , measured (EN ISO 16283-1:2014) and estimated with EN 12354-1, Appendix B.1 method.  $R'$  estimations for each element composing the wall are reported as well. (b) Graph of the Apparent Sound Reduction Index  $R'$  before (continuous curve) and after the interventions.

**4. Measurement results after intervention**

The improvement intervention were realized in the junction between the separating wall and the curtain wall, where the wall thickness was reduced by the architects to allow the opening of the windows of the facade. Moreover, the curtain wall mullion was realized with a single aluminum section (Fig. 1.b).

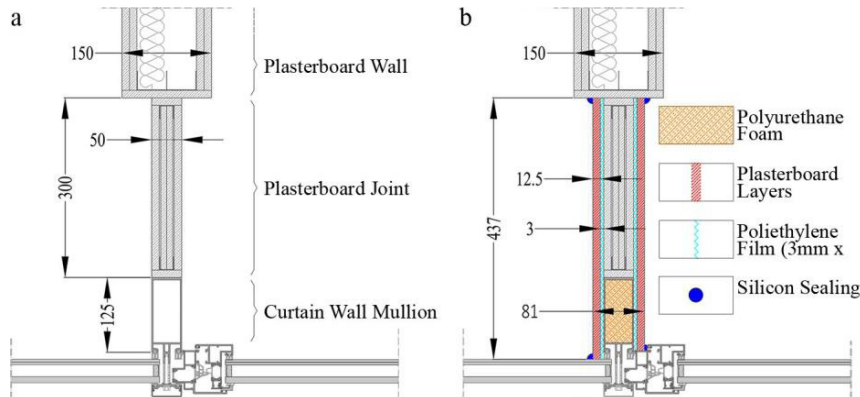


Fig. 4. The junction between the separating wall and the curtain wall before (a) and after (b) the improvement intervention. Dimensions are in mm. The main wall has a 5 cm mineral wool layer and an air gap of 5 cm.

The intervention was limited by the need not to increase the wall thickness more than 2 cm per side, to allow the opening of the windows. Two layers of closed-cell polyethylene film 3 mm thick and a layer of plasterboard on each side of the separating wall were applied (Fig. 4.b). Furthermore, the vertical mullion of the curtain wall was filled with polyurethane foam.

In spite of this, the apparent sound reduction index only increases at mid and high frequencies, as the graph in Fig. 3.b shows. This fact is due to different problems of the separating wall but mainly to the structural sound transmission through the metal mullion of the curtain wall. Moreover an increasing in the coupling between receiver and source side of the vertical aluminum mullion could be caused by the polyurethane foam filling: despite a lower dip at 800 and 1000 Hz, a wider frequency range, between 160 and 400 Hz, is affected by a significant worsening of the performance. This problem is only partially solved when a new plasterboard layer was added and sealed (dash-dot-dot line in Fig. 3.b).

Fig. 3.b shows that the lining of the vertical mullion of the curtain wall at the junction with the separating wall causes an average  $3\pm 15$  dB increasing of the apparent sound reduction index  $R'$ , at mid and high frequencies. The difference is instead not significant at lower frequencies where the resonance of the lining system described in Fig. 3.b reduces the acoustic performance of the partition. In particular it is interesting to note that the lining of the frame eliminates the insulation drop at 1000 Hz, which is probably due to a resonance of the mullion of the curtain wall. A similar problem was shown also in a previous study on this kind of junction [2].

## 5. Conclusions

In the paper direct and flanking transmission in partitions mounted up to curtains walls was investigated. It was shown that, following a bad joint design, intervention is difficult and not entirely effective. The vibration velocity measurements show that flanking transmission through opaque elements (lateral walls, floor, ceiling) in this kind of structures can be insignificant, compared to the ones observed over the main partition, when excited by a sound source. The main sound insulation gap is due to the mullion of the curtain wall, which has very high  $L_v$ .

A good practice on curtain wall building design could be a better spatial distribution of rooms, to reduce flanking sound transmissions: walls separating independent units should be placed, when possible, in correspondence of concrete pillars, avoiding connection with the façade mullion.

Part of this work attempts to calculate  $R'$  from vibration velocity measurements, modifying the EN 12354-1 model on  $\sigma$  estimation. The higher emissivity of stiffened elements is considered and  $\sigma$  is evaluated for a free vibration field instead of a forced one. A good agreement between  $R'$  calculated from velocity and  $R'$  measured in respect of the EN ISO 16283-1:2014 was found.

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