Acoustical performance of connections between windows and timber frame façade elements

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Summary

The sound insulation performance of a composed façade is usually dominated by the performance of its weakest element(s). These may for instance be windows or ventilation grids. However, when no ventilation grids are present in façades with highly insulating windows and wall elements, the connection between these may start playing a significant role in the total sound transmission. Unfortunately, very little data exists on the performance of these connections, in particular for timber frame façades. Therefore, some laboratory measurements were conducted on a real-scale highly-insulating timber frame base wall. By installing a heavy wooden dummy window in this wall, the influence of several connection details was studied: connection system, gap width, nature of the insulating material, gap shielding, sealing and airtightness, moisture barrier … It was found that airtightness was a primordial parameter and that mounting method and the kind of sound insulating material in the gap was of minor importance.

1. Introduction

In noisy outdoor environments the façade sound insulation requirements may become hard to fulfill, especially when using lightweight building elements. Since highly insulating solutions do exist for timber frame façade elements and windows, it is more and more important to know whether the connections between these elements may eventually deteriorate the overall performance of composed façades. The following questions may arise: what materials are to be used to fill the gaps between windows and façade elements? What is the importance of airtightness? What is the influence of the mounting system and possible structural coupling? How are the gaps to be sealed?

This paper tries to give an answer on some of these questions for typical connections between a timber frame façade wall and windows.

2. Measurement method

In ISO 10140-1, Annex J [1] proposes a method to evaluate the sound insulating properties of connections between building elements (gaps, slits or joints). The method may be used on connections built up in the specific small test opening for windows and glazings, but may also be applied on larger building elements. Since in this paper we want to focus on timber frame façades and are particularly interested in the low frequency behavior, we chose to perform the measurements on a real-scale 10 m² test setup.

The ISO method defines the sound reduction index of a joint R_s as the sound reduction index of a 1 m² panel with 1 m of this joint, where it is assured that all the sound is only transmitted by the joint. Using this definition, the sound reduction index R_{tot} of a composed façade wall with an integrated window may be written as:

$$R_{tot} = -10 \lg \left(\frac{S_f \cdot 10^{(-R_f/10)} + S_w \cdot 10^{(-R_w/10)} + 1 \cdot l_s \cdot 10^{(-R_s/10)}}{S_f + S_w} \right)$$

(1)

where S_f and R_f are the area and sound reduction index of the base façade element, S_w and R_w are the area and sound reduction index of the window and l_s is the total length of the joint between the window and the façade panel. Inversely, when R_f and R_w have been measured on beforehand, R_s may be calculated by measuring R_{tot} of the composed façade.

2.1. Façade composition

The base façade element consists of 190x45 mm² timber studs spaced 600 mm on center. The air space between the studs is completely filled with mineral wool.

The "exterior" side consists of a 24 kg/m² structural wood fibre cement board. In front of that is a 15 kg/m² fibre cement board composing a ventilated lining screwed on 30 mm timber studs. The water tightness is assured using squeezed profiled EPDM strips.

The "interior" lining consist of a 16 kg/m² fibre reinforced gypsum board, connected via horizontal steel resilient channels to the structural timber frame. In between the channels and the frame, an airtightness foil is applied.

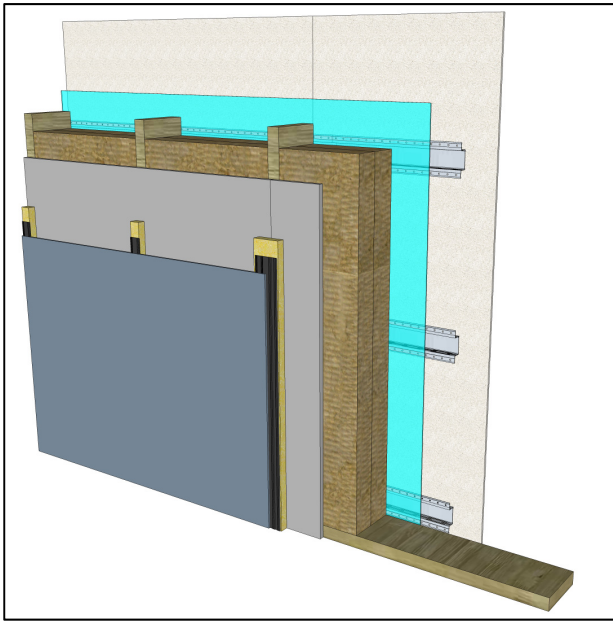The base façade wall has a measured weighted R_{Atr} (= R_w+C_{tr}) value of 50.2 dB.

Figure 1. Base façade wall composition with the exterior side in front.

2.2. Window composition

In this base façade element, a highly insulating dummy window is inserted. It consists of a 110 mm thick heavy wooden frame on which two 2 mm steel sheets are screwed on both sides with a 3 mm dampening roofing layer between the steel plates. The cavity in the wooden frame is completely filled with mineral wool. This dummy window with outer dimensions of 1480 x 1230 x 124 mm³ has a measured R_{Atr} value of 53.9 dB.

Figure 2. Construction of the dummy window

2.3. Tested connections

The dummy window has been mounted in the base façade wall using two methods that are common practice in Belgium. The first method uses steel anchors that connect the window frame with the structural timber frame (see Figure 3). The second method uses a wooden frame that is pre-attached in an airtight way to the window (see Figure 4). Long screws connect this frame through intermediate wooden mounting blocks to the structural frame.

Figure 3. Steel anchor connecting dummy window to timber frame.

Figure 4. Pre-attached frame with a strip of mineral wool in front of it to avoid cold bridges.

For the connections with anchors (method 1), the gap between window and façade element was alternated between 20 mm and 40 mm, while it was kept 20 mm between the pre-attached frame and façade element for the connections according to method 2. The gap below the window or the pre-attached frame was 20 mm in any case. The gaps are tested empty, filled with mineral wool and filled with acoustic (resilient) PUR foam. In some cases, also rigid PUR foam was used. On the interior side, the gaps are sealed with an airtightness foil. On the exterior side, the gaps are either covered with wooden laths that support the reveals or either sealed with tape. In the latter case, the exterior reveals are screwed into mounting blocks that are screwed into the structural timber frame of the base wall (see Figure 6).

Since the interior lining of the wall is connected resiliently to the structural studs to obtain a high sound reduction index for the base wall, care has been taken not to make structural bridges between this interior lining and the timber frame through the reveal boards. This has been realized using wooden channels with resilient pads. (see Figure 5)

Figure 5. Vibrational decoupling of the reveals of the interior lining using resilient pads between timber laths.

To make it possible to calculate R_s values for a particular connection detail, it was chosen to finish the exterior top joint in an equal way compared to the vertical joints. This is however not recommended, since eventual rain or condense water behind the lining above the window should have the possibility to be evacuated through a ventilating grille.

All joints between the dummy window and all reveal boards are finally sealed with an elastic sealant.

3. Measurement results

3.1. Ideal sound reduction index

Based on the measured sound reduction indices of the base façade wall and the dummy window, the ideal sound reduction index may be calculated using equation (1), by assuming no sound is transmitted through the connections ($R_s = \infty$) (see Figure 7).
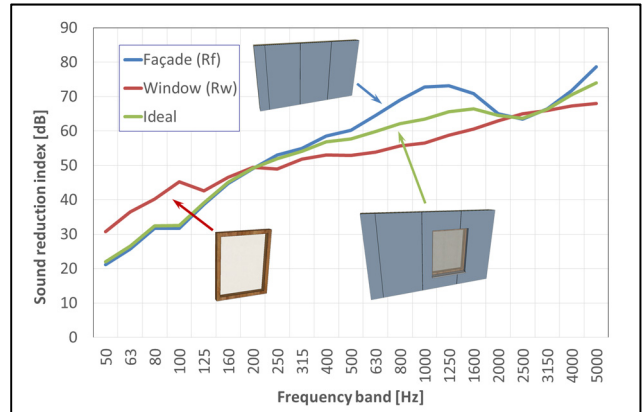

Figure 7. Sound reduction index spectra of façade ($R_{f,Atr}$ = 50.2 dB), window ($R_{w,Atr}$ = 53.9 dB) and ideal composed wall ($R_{tot,ideal,Atr}$ = 50.7 dB).

3.2. Comparison of gap filling material

For mounting method 1, the influence of the kind of gap filling material is displayed in Figure 8 for the case of 40 mm gap width. Where no marker point is visible, it means that no value could be determined because the measured R_{tot} value was higher than the ideal R_{tot} value – 0.1 dB due to usual measurement uncertainties. When mounting laths are used for the exterior reveal boards, a large increase in joint sound reduction is observed in mid- and high frequencies when filling the gaps. The flexible PUR foam is performing less good at mid and high frequencies causing a 1 dB lower single number value. When mounting blocks are used, there is no substantial difference between the flexible PUR foam and the mineral wool at mid- and high frequencies, due to the presence of a moisture barrier tape closing the gap between window and façade element at the exterior side. In this case, the flexible PUR has a slightly higher single number value due to its better performance at the lowest frequency bands (100-160 Hz). Further tests comparing flexible PUR foam with rigid PUR foam, showed no substantial difference.
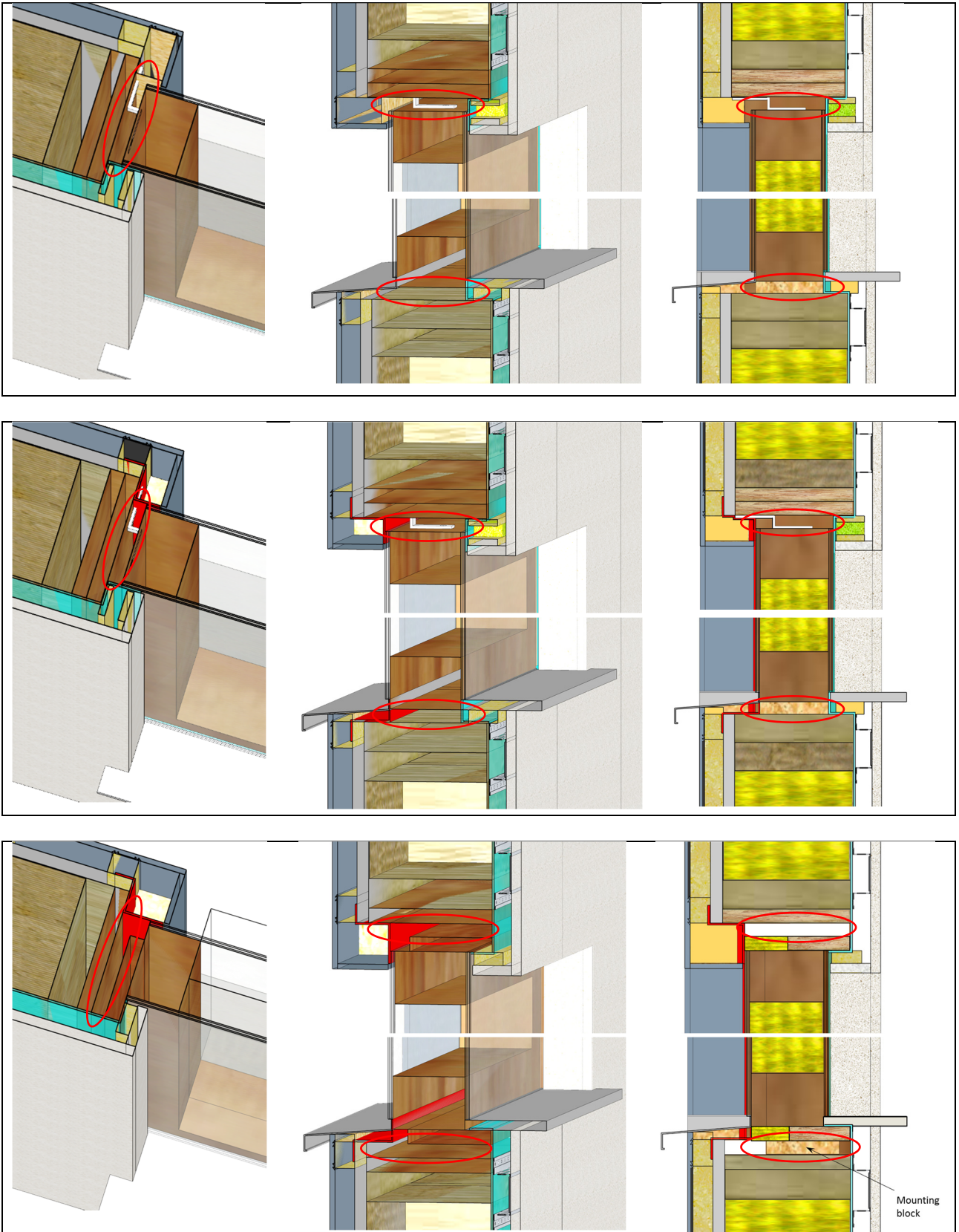
Figure 6. *Top:* mounting method 1 (anchors) with 20 mm air gap using laths to cover the air gap at the exterior side. *Middle:* mounting method 1 (anchors) with 20 mm air gap using mounting blocks and tape to close the air gap. *Bottom:* mounting method 2 (pre-attached frame) with 20 mm air gap. Red strips are moisture barriers (tape). Blue strips are airtightness foils. All gaps that can be filled with mineral wool or PUR foam are indicated using a red oval.

For mounting method 2 (pre-attached frame), no significant difference was observed between empty cavity, mineral wool or PUR foam, since the single number values of $R_{s,Atr}$ are solely determined by their (uncertain) values at 100-160 Hz.
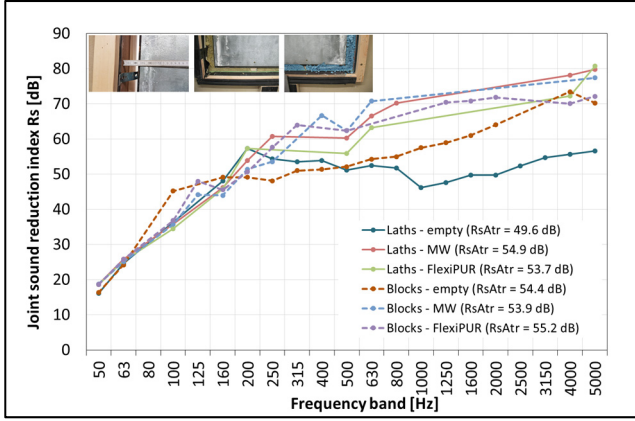

Figure 8. Joint sound reduction indices R_s for measurement setups according to mounting method 1 (anchors) with a gap width of 40 mm using mounting laths (full lines) and mounting blocks in combination with a moisture barrier tape (broken lines).

3.3. Comparison of mounting method and gap width

In Figure 9, all mounting variants using mineral wool as gap filler are compared against the ideal total sound reduction index. It can be seen that for method 1 (anchors) with 2 cm gap widths, lower values are obtained in the frequency region 200-1000 Hz. Afterwards, it was found that this drop is caused by a leak in the sealing between the interior lining and the interior windowsill (see picture insert in Figure 9). Hence, it may be concluded that all mounting methods should give comparable results, regardless of the gap width. The single number value of the total sound reduction index should in all cases be about 1 dB lower compared to the calculated ideal value.

In Figure 10, all mounting variants using flexible PUR foam as gap filler are compared against the ideal total sound reduction index. It may be observed that the sealant leak related differences between the 2 cm gap width and 4 cm gap width variants in mounting method 1, are much smaller due to the higher airtightness of PUR foam compared to mineral wool. Also, for all mounting variants using flexible PUR gap filling, the single number value of the total sound reduction index

should in all cases be about 1 dB lower compared to the calculated ideal value.
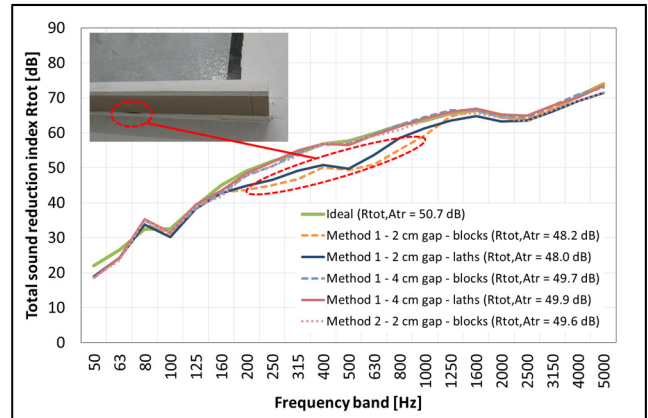

Figure 9. Total sound reduction index R_{tot} for all setups using mineral wool as gap filler.
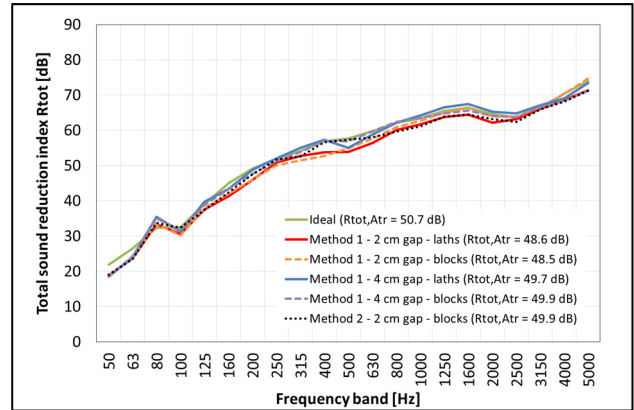

Figure 10. Total sound reduction index R_{tot} for all setups using flexible PUR foam as gap filler.

3.4. Importance of airtightness

To illustrate the importance of airtightness, an elastic sealing strip between the dummy window and the upper interior reveal board was removed in the setup with mounting method 1 with laths covering the 4 cm empty air gaps between window and façade at the exterior side. The effect on the total sound reduction index can be observed in Figure 11. A comparable drop of the sound reduction index between 200 and 1000 Hz as in Figure 9 can be observed. Because no porous material is present in the gap between window and façade wall, a further decrease can also be observed at higher frequencies.
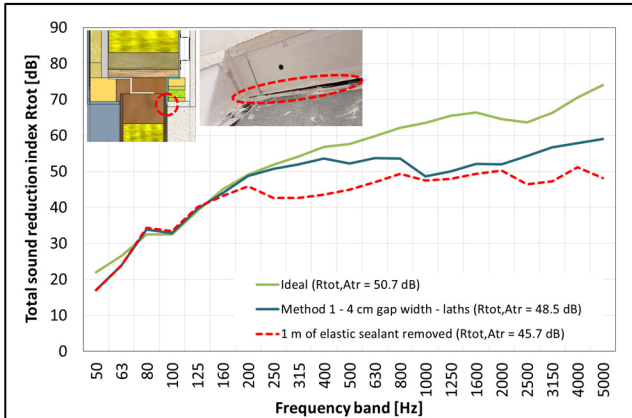
Figure 11. The effect of the removal of about 1 m of elastic sealant, creating a 5 mm thick air gap.

3.5. Effect of structural coupling by the interior reveal boards

As explained in section 2.3, the interior reveal boards are structurally decoupled from the structural timber frame by using resilient pads (see Figure 5) in order not to short-circuit the resilient steel channels used to fix the interior lining to the structural timber frame. However, it was not clear at the beginning if this was really necessary. Therefore, the measurement for mounting method 1 with 4 cm gaps filled with flexible PUR foam and covered with blocks was repeated after replacing the resilient wooden channels with wooden laths. It can be seen that the decrease in joint sound reduction index was small (see Figure 12). Moreover, it had no influence on the single number value of $R_{s,Atr}$ because this value is determined by the spectral values at 100-160 Hz.
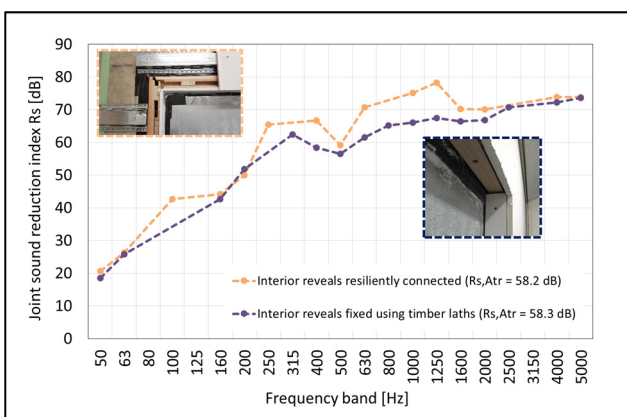

Figure 12: effect of rigid coupling of interior reveal boards on the joint sound reduction index.

4. Conclusions

All investigated mounting methods are acoustically good solutions that can be used for dwellings in very noisy environments ($L_{A,2m}$ up to 77 dB) according to the Belgian building requirements.

No substantial difference between the use of mineral wool, flexible PUR foam or rigid PUR foam as gap filling material was observed, as long as a good airtightness is ensured.

Airtightness was found to be an important prerequisite, especially for gaps filled with mineral wool.

The traffic noise related single number joint sound reduction index $R_{s,Atr}$ ($= R_{s,w}+C_{tr}$) of the studied connections was found to be determined by its spectral values between 100-160 Hz.

References

[1] ISO 10140-1 Acoustics — Laboratory measurement of sound insulation of building elements — Part 1: Application rules for specific products (ISO, 2016).