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Flanking transmission across timber frame façade elements

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ABSTRACT

A big advantage of lightweight timber frame constructions compared to heavyweight constructions is the prefabrication and speed of assembly. To optimize the assembly process, the use of multi-storey façade elements is considered by construction companies. This will however have large implications on the flanking transmission across the façade. To investigate the possibilities and limitations of this assembly method, a large experimental study was set up in the laboratory. The airborne flanking transmission $D_{n,f}$ across two heavyweight floor - timber frame façade junctions was measured, focusing on the Ff flanking path (façade wall - façade wall). In the first set-up, the façade was composed of two decoupled elements. Secondly, one continuous façade element was used. In both cases, the influence of several parameters was investigated, like the number and type of finishing boards, the presence of technical or acoustical linings, and the type of firestop used. The additional structural flanking transmission via the continuous studs in the second set-up proves very important. To eliminate the flanking transmission across the multi-storey façade elements, additional measures will be necessary, e.g. the installation of acoustical (technical) linings.

Keywords: Sound insulation, Lightweight constructions
I-INCE Classification of Subject Number: 33,43

1. INTRODUCTION

For heavyweight floor constructions with high direct sound insulation, the overall sound insulation *in situ* is generally influenced by flanking transmission via the walls and façade. The flanking transmission will be especially important for lightweight walls

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or façade elements. Notwithstanding these acoustical issues, the use of lightweight timber frame constructions has a lot of advantages, like the possibility to apply large thicknesses of thermal insulation in the elements, the prefabrication and speed of assembly. To further profit from these advantages, timber frame construction companies are considering the use of multi-storey façade elements that can be fixed to a heavyweight, load-bearing construction. Because the lightweight façade elements are not interrupted by the floor structure in this construction method, the Ff flanking path (façade wall - façade wall) can prove problematic.

The flanking transmission through timber frame constructions is very complicated and difficult to predict because a lot of different flanking paths - both structure-borne and airborne - are present in multilayered structures [1]. The prediction standard EN 12354-1 [2] gives empirical estimates for the normalized flanking level difference of junctions composed of timber frame building elements. The standard also gives empirical formulae for the vibration reduction index of junctions composed of lightweight double leaf walls and homogeneous elements. However, no estimates are given for the normalized flanking level difference across lightweight timber frame building elements fixed to a homogeneous element. Within the frame of the national research project A-light II, the flanking sound transmission via lightweight timber frame façade elements has therefore been investigated experimentally in collaboration with Machiels Building Solutions. The normalized flanking level difference was measured for 19 different test set-ups. This paper focuses on the influence of the use of one continuous façade element. Furthermore, the influence of secondary parameters like the interior finishing, the exterior finishing and the firestop is investigated.

2. MEASUREMENT SET-UP AND RESULTS

2.2.1. Test junction

To study the flanking transmission across different types of lightweight timber frame façade elements fixed to a heavyweight floor, a T-junction was constructed in between two transmission rooms of the laboratory of Acoustics of the Belgian Building Research Institute (Figure 1). For practical reasons, the test set-ups were built using a vertical junction with height 2.42 m instead of a horizontal junction. In the case of two decoupled façade elements (Figures 2 and 3), the façade elements at the source side and receiving

(a) (b)

Figure 1: (a) façade test element without interior finishing in the sending room and (b) façade test element with interior finishing in the receiving room.

side had a length of approximately 3.2 m. In the case of one continuous façade element (Figures 4 and 5), the total length was approximately 6.4 m.

The façade elements were built at a distance of approximately 180 mm from the side wall of the transmission rooms. To better represent the real situation where an acoustic halfspace is present at the outer side of the façade elements, a timber frame was built in the cavity between the façade elements and the laboratory walls and filled with mineral wool. In this way, standing waves in the cavity are damped. To suppress any possible flanking transmission via the cavity between the façade elements and the laboratory side walls, two concrete block columns were built in the outer cavity at the junction and mineral wool was placed in between the columns. The wooden frames and the concrete blocks didn't make any contact with the façade elements.

The heavyweight floor system was represented by a double concrete block wall with dimensions 3.56 m × 2.42 m. Concrete blocks with thickness 140 mm, plastered (15 mm) at one side, were used to represent the base floor and concrete blocks with thickness 90 mm for the floating floor. The 40 mm cavity in between was filled with glass wool. There was an opening of 100 mm between the 140 mm wall and the façade element to place the firestop. In the tests with a firestop smaller than 100 mm, the wall was extended as needed by aluminium plates fixed with an aluminium L-frame. The 90 mm concrete block wall was not constructed up to the façade element to facilitate the access to the façade elements at the junction. In each test, the opening of approximately 30 cm between the wall and the façade element was closed by five heavy gypsum boards and a steel cover plate.

2.2.2. Measurement method

The normalized flanking level difference $D_{n,f}$ is defined according ISO 10848-1 [3] as the sound pressure level difference between the two rooms, normalized to an equivalent sound absorption area, when the transmission only occurs through a specified flanking path:

$$D_{n,f} = L_1 - L_2 - 10\lg\frac{A}{A_0} \tag{1}$$

where L_1 and L_2 are the average sound pressure levels in the source and receiving room respectively, A is the equivalent sound absorption area in the receiving room and A_0 = 10 m^2.

Because the T-junction consists of relatively lightweight façade elements coupled to a heavyweight wall, it is assumed that the sound transmission via the flanking paths Fd and Df are negligible compared to the sound transmission via the flanking path Ff.

The maximum flanking level difference $D_{nf,max}$ that can be measured is primarily determined by the direct sound transmission through the separating wall. The sound reduction index R_s of the same type of double wall, built in the same test opening, has been measured previously. These measurement results were used to estimate the maximum flanking level difference:

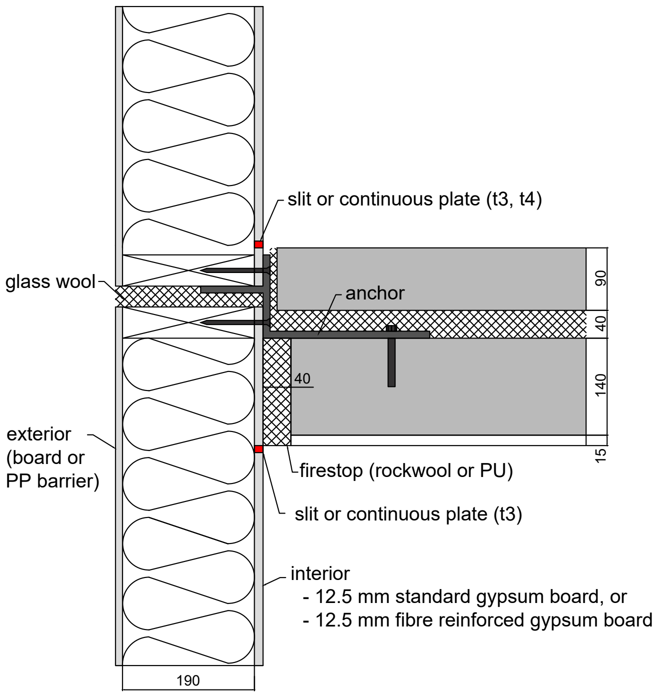
$$D_{nf,max} \simeq R_s + 10\lg\frac{A_0}{S_s} \tag{2}$$

with S_s = 8.6 m^2 the surface area of the separating wall. The maximum flanking level difference is indicated in Figures 6 to 9 by the grey triangles. The flanking transmission measurements were corrected for the contribution of the direct sound transmission. For most cases, the measured normalized level difference was more than 10 dB lower than the normalized level difference of the double wall ($D_{\mathrm{nf,w,max}} = 85.0$ dB), meaning that the overall level difference is determined by the flanking transmission. Only for test 8, the normalized level difference at higher frequencies was limited by the direct sound transmission.

2.2.3. Two decoupled façade elements

Figure 2 and 3 show the test set-ups with two decoupled façade elements without and with technical lining, respectively. For both cases, 5 variants were measured. The timber frame façade elements consisted of a frame of 190 mm × 40 mm studs with a spacing of 400 mm. The studs were perpendicular to the junction and the cavity was entirely filled with glass wool. The façade elements were fixed to the base floor by use of steel z-shaped anchors. In the tests, three anchors were used over the height of the junction (2.42 m). In reality, the spacing between the anchors will usually be significantly larger. The 30 mm gap between the two façade elements was filled with glass wool.

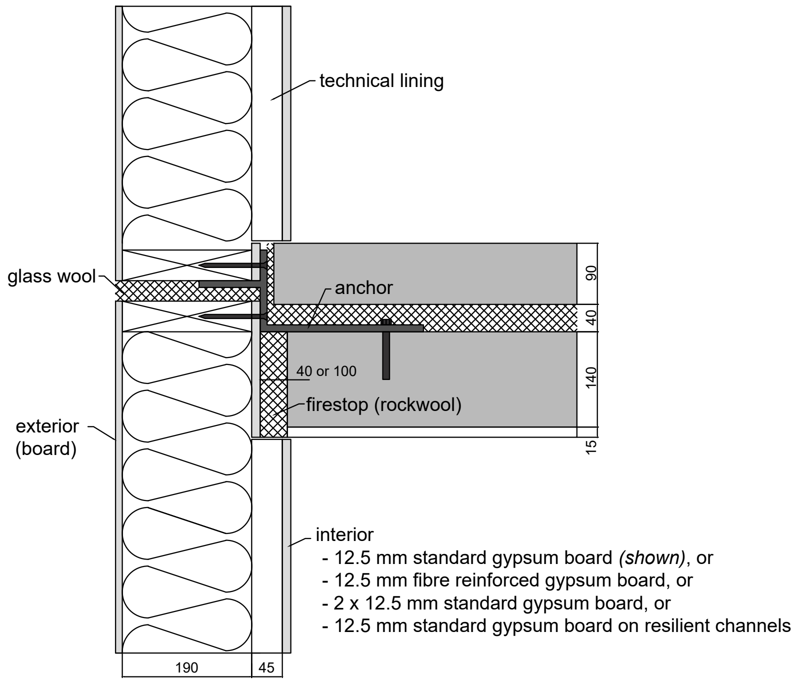
At the exterior side, either a 10 mm wood fibre cement board or a polypropylene rain barrier was attached to the frame. At the interior side, different types of finishing were



Test	Exterior	Interior	Slits	Firestop	$D_{n,f,w}(C; C_{tr})$ [dB]
t1	10 mm wood fibre cement board	12.5 mm standard gypsum board	2	40 mm rockwool	65.7 (−2.0; −7.0)
t2				40 mm PU	67.8 (−2.8; −8.8)
t3	polypropylene rain barrier	12.5 mm fibre reinforced gypsum board	no	40 mm rockwool	62.9 (−2.4; −5.8)
t4			1 (bottom)		64.4 (−1.8; −5.9)
t5			2		66.2 (−2.2; −6.2)

Figure 2: Set-up and results for tests 1-5 with two decoupled façade elements

used: 1 or 2 plates of 12.5 mm standard gypsum board (approximately 9 kg/m^2) or 1 plate of 12.5 mm fibre reinforced gypsum board (approximately 15 kg/m^2). The plates were either fixed directly to the timber frame (Figure 2) or fixed on the battens of a technical lining (Figure 3). The influence of decoupling the interior boards by resilient channels, fixed perpendicular to the battens with a spacing of 400 mm, was also investigated (test 8). The width of the firestop (40 mm or 100 mm) and the firestop material (rockwool or polyurethane foam) were also altered. In tests 6-8 with technical lining and a firestop width of 40 mm, the technical lining covered the firestop entirely. For the other tests without technical lining or with a firestop width of 100 mm, the firestop was partially or fully visible. For tests 1, 2, 4, and 5, the interior plates were slit just below and/or above the junction.

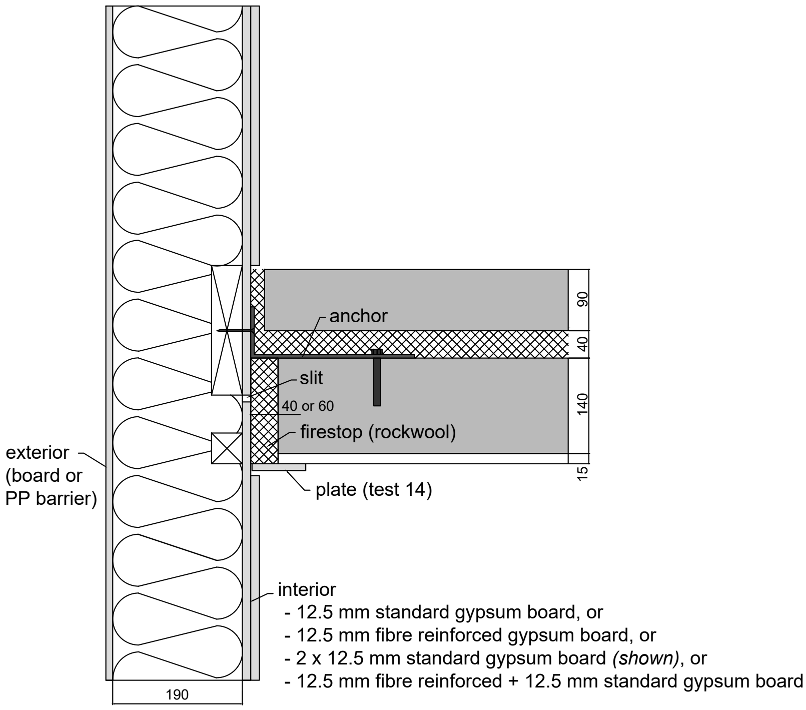


Test	Exterior	Interior	Firestop	$D_{n,f,w}(C; C_{tr})$ [dB]
t6	10 mm wood fibre cement board	12.5 mm standard gypsum board	40 mm rockwool	66.5 (−2.4; −8.0)
t7		2 × 12.5 mm standard gypsum board		69.1 (−2.1; −7.5)
t8		12.5 mm standard gypsum board on resilient channels		73.8 (−5.7; −13.9)
t9		12.5 mm standard gypsum board	100 mm rockwool	65.5 (−2.6; −8.7)
t10		12.5 mm fibre reinforced gypsum board		67.5 (−2.1; −7.4)

Figure 3: Set-up and results for tests 6-10 with two decoupled façade elements and technical linings

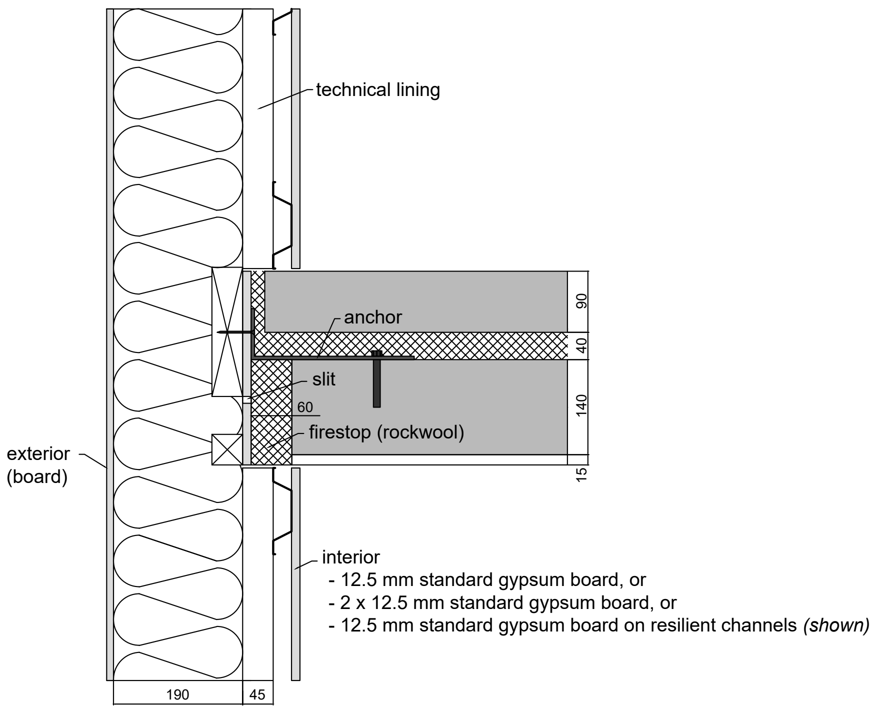
2.2.4. One continuous façade elements

Figure 4 and 5 show the test set-ups with one continuous façade element without and with technical lining, respectively. The structure of the continuous façade element was the same as in the tests with two decoupled façade elements. The studs and exterior finishing (10 mm wood fibre cement board or polypropylene rain barrier) now crossed the junction. The interior gypsum boards were discontinuous in all cases. The width of the rockwool firestop was changed between 40 and 60 mm. In test 14, the firestop was covered with a standard gypsum board plate. Again, different types of finishing were used at the interior side.



Test	Exterior	Interior	Firestop	$D_{n,f,w}(C; C_{tr})$ [dB]
t11	10 mm wood fibre cement board	12.5 mm standard gypsum board	60 mm rockwool	56.3 (−1.7; −5.7)
t12		2×12.5 mm standard gypsum board		59.0 (−2.4; −8.0)
t13	polypropylene rain barrier	12.5 mm fibre reinforced gypsum board	40 mm rockwool	53.9 (−2.5; −8.5)
t14			40 mm rockwool + plate	54.6 (−2.5; −8.3)
t15		12.5 mm fibre reinforced gypsum board + 12.5 mm standard gypsum board	40 mm rockwool	59.1 (−2.9; −8.9)
t16			60 mm rockwool	59.6 (−3.2; −9.6)

Figure 4: Set-up and results for tests 11-16 with one continuous façade element



Test	**Exterior**	**Interior**	**Firestop**	**$D_{n,f,w}(C; C_{tr})$ [dB]**
t17	10 mm wood fibre cement board	12.5 mm standard gypsum board	60 mm rockwool	60.6 (−4.2; −11.2)
t18		2×12.5 mm standard gypsum board		63.7 (−4.2; −10.9)
t19		12.5 mm standard gypsum board on resilient channels		65.7 (−3.8; −10.7)

Figure 5: Set-up and results for tests 17-19 with one continuous façade element and technical linings

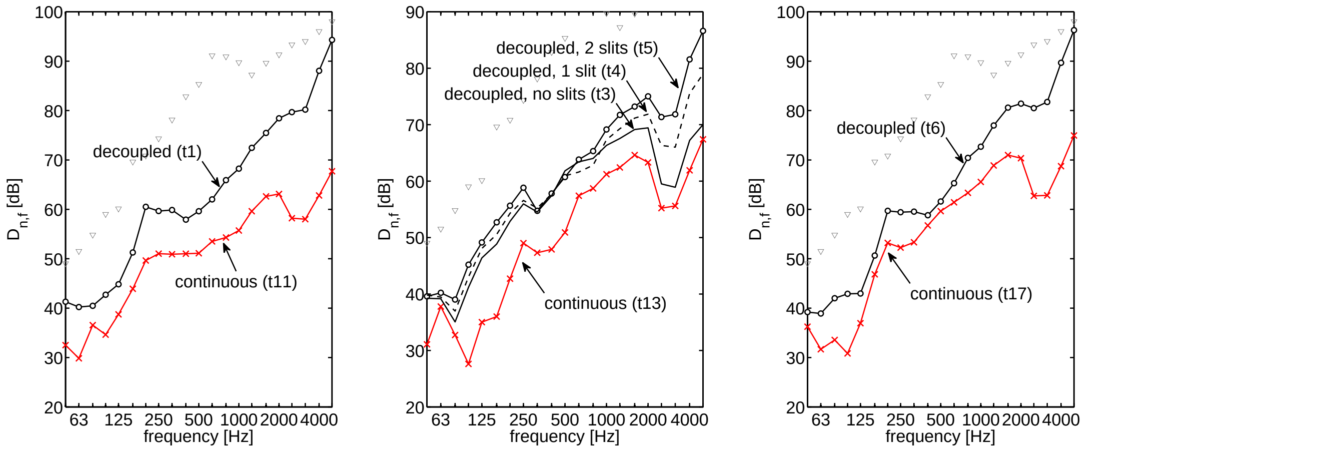
3. DISCUSSION OF RESULTS

The tables in Figures 2 to 5 give the single number quantities $D_{n,f,w}(C; C_{tr})$ for the 19 tests of the measurement campaign. The spectra of the normalized flanking level differences all show the same general trends (Figures 6 to 10). At low frequencies, a dip is visible which may be related to different mass-spring-mass resonance phenomena. Apart from the classical mass-spring-mass resonance between the interior and exterior boards of the façade elements, there are additional resonance phenomena due to the presence of the laboratory back wall. On the one hand, the presence of the back wall may increase the sound transmission compared to the *in situ* case without back wall. On the other hand, the low-frequent sound transmission will also be influenced by the presence of an exterior cladding *in situ*. Above the mass-spring-mass resonance dip(s), the sound insulation increases strongly with frequency up till approximately 200 Hz. Above this frequency, the structure-borne sound transmission becomes dominant [4]. As a result, the increase in sound insulation with frequency is much smaller. In a lot of tests, a plateau in sound insulation is visible between approximately 500 Hz and 1000 Hz. Around 2500 − 3150 Hz, the coincidence dip of the gypsum boards is observed.

In the following sections, the influence of different parameters are discussed in detail.

3.3.1. Influence of continuous façade element

As expected, the additional structural transmission via the continuous façade element is very important (Figure 6). Because the interior gypsum boards are discontinuous, the most important additional flanking path is the structural transmission via the studs that cross the junction. The flanking sound transmission is increased in the entire frequency range, but the increase is the largest at high frequencies. The coincidence dip around the critical frequency of the gypsum boards is generally more pronounced for the cases with a continuous façade element. This may be expected as the radiation of sound by free bending waves on the gypsum boards, excited by the studs, is very efficient around the critical frequency. The overall increase in single-number rating $D_{n,f,w}$ lies between 9 and 12 dB for the cases without technical lining and between 5 and 8 dB for the cases with technical lining.



(a) 1 standard gypsum board (interior), board (exterior)

(b) 1 fibre reinforced gypsum board (interior), PP barrier (exterior)

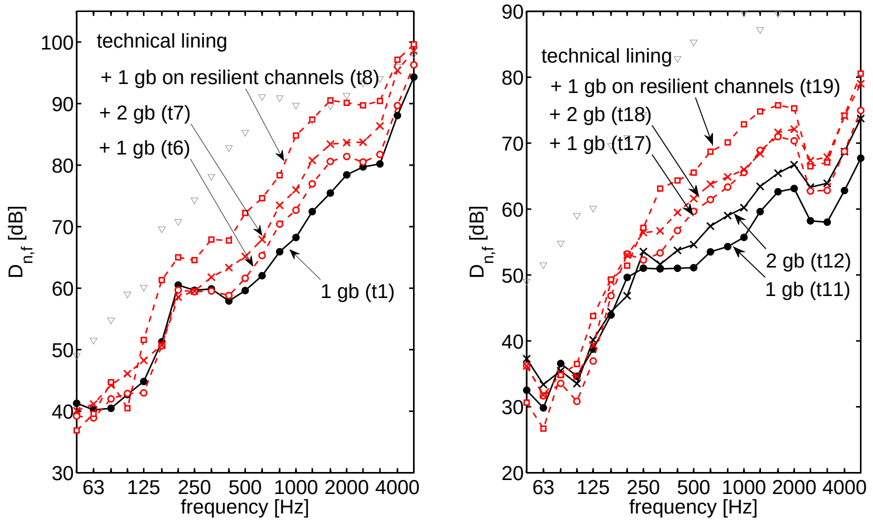
(c) 1 standard gypsum board on technical lining (interior), board (exterior)

Figure 6: Influence of continuity of façade element

Even when two decoupled façade elements are used, structure-borne sound transmission between the façade elements is possible via the anchors used to fix the elements to the floor. The importance of this structural flanking path is observed when looking at the influence of the slits in the interior gypsum boards just below and above the floor junction (Figure 6(b)). The effect of the structure-borne sound transmission via the interior gypsum board is most pronounced around the critical frequency of the gypsum boards. One slit below the floor increases the $D_{n,f,w}$-value by 1.5 dB, while two slits give a gain of more than 3 dB. When a technical lining is present, there are always discontinuities in the interior gypsum boards and this structure-borne transmission will pose less problems.

3.3.2. Influence of interior finishing

The interior finishing has an important influence on the flanking sound insulation, both for the set-up with two decoupled façade elements and the set-up with one continuous



(a) Two decoupled façade elements (b) One continuous façade element

Figure 7: Influence of interior finishing (gb = standard gypsum board)

façade element (Figure 7). The influence is most important at mid and high frequencies, i.e. the frequency region where the structure-borne sound transmission is dominant. The low-frequent sound insulation is only improved when resilient channels are used to acoustically decouple the gypsum boards from the battens and studs.

The technical lining decreases the structure-borne sound transmission between the studs and the gypsum boards. As the influence of the structure-borne sound transmission via the studs is more important for the set-up with one continuous façade element, a larger influence of the technical lining can be expected. Indeed, the presence of a technical lining improves the overall flanking sound insulation $D_{\mathrm{n,f,w}}$ with 4 to 5 dB in the case of one continuous façade element, while for the set-up with two decoupled façade elements, the influence of the technical lining is smaller, with only an increase of 1 dB in $D_{\mathrm{n,f,w}}$.

Increasing the mass of the interior finishing will improve the normalized flanking level difference. The use of an additional standard gypsum board improves the $D_{\mathrm{n,f,w}}$-value by approximately 3 dB, both for the case with and without technical lining. Similarly, the use of heavier fibre reinforced gypsum boards (15 kg/m^2 versus 9 kg/m^2 for the standard gypsum boards) improves the normalized flanking level difference (Figure 8). In the case of two decoupled façade elements with technical lining, the improvement in single-number rating $D_{\mathrm{n,f,w}}$ is 2 dB.

Finally, an increase of 5 to 6 dB can be attained by fixing the standard gypsum board on the battens of the technical lining with resilient channels.

3.3.3. Influence of firestop

The airborne flanking transmission via the rockwool firestop is negligible in most frequency bands. The flanking transmission is only affected in the frequency range 250 – 500 Hz when the width of the firestop is changed (Figure 9(a)) or the visible part of the firerstop is covered with a gypsum plate (Figure 9(b)). The high frequent sound that might propagate through the gap is effectively damped by the absorptive material. The change in single number rating $D_{\mathrm{n,f,w}}$ is limited to 1 dB in both cases.

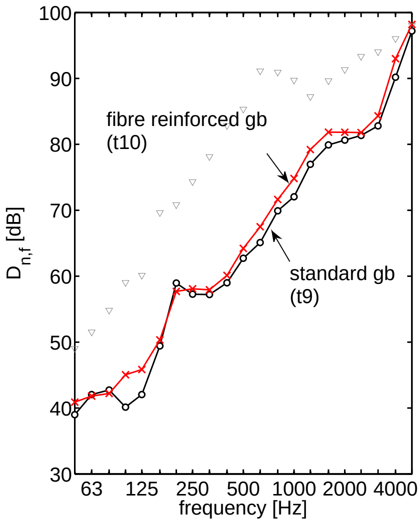
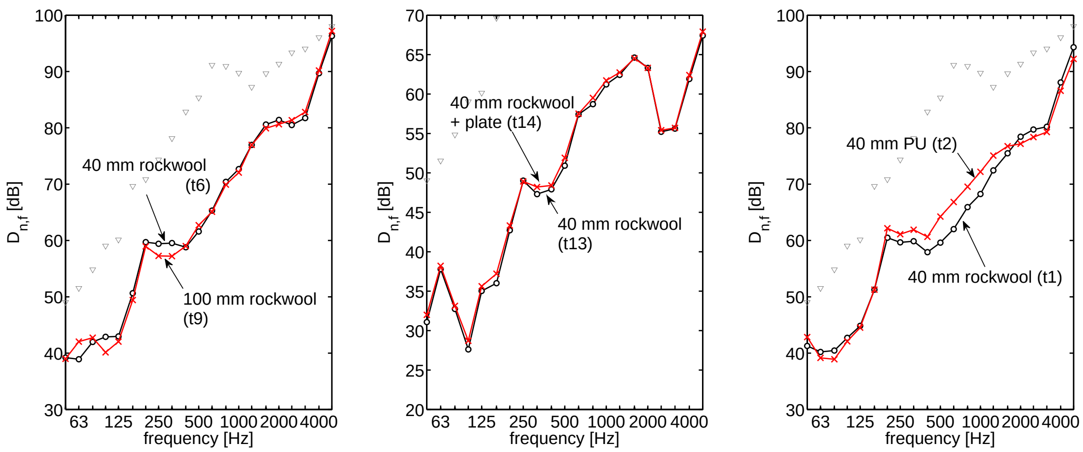


Figure 8: Influence of type of gypsum board (gb). Two decoupled façade elements with technical lining and 1 gypsum board.



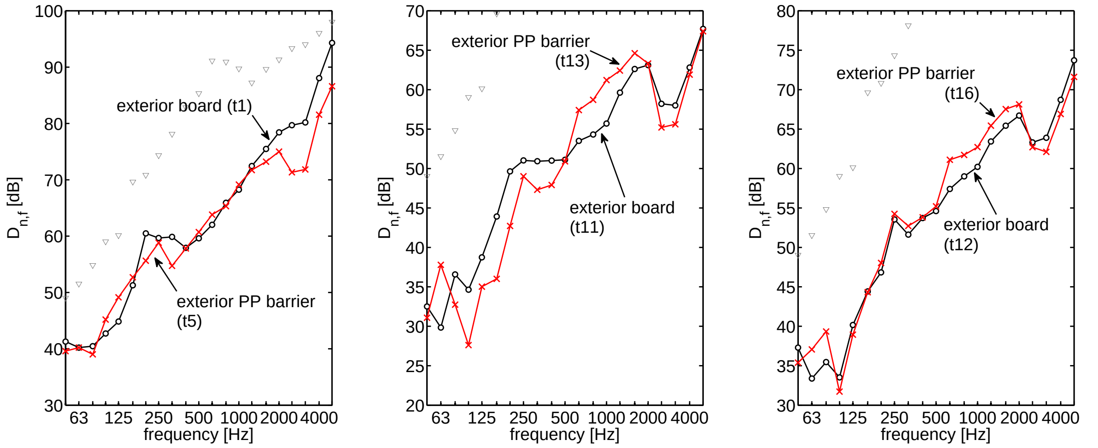
(a) Thickness of rockwool (b) Additional plate (c) Rockwool versus PU

Figure 9: Influence of firestop

The use of polyurethane (PU) foam instead of rockwool as fireresistant material in the gap has a larger influence on the flanking transmission at mid frequencies, i.e. the frequency range where the structure-borne sound transmission is dominant (Figure 9(c)). The PU foam gives an increase in $D_{\mathrm{n,f,w}}$-value of 2 dB. The effect might be explained by the additional structural damping provided by the foam and an increased air tightness.

3.3.4. Influence of exterior finishing

The influence of the exterior finishing has not been investigated exclusively, because the use of a polypropylene rain barrier instead of a fibre cement board always requires the use of a fibre reinforced gypsum board at the interior side. The differences in Figure 10 are thus related both to the different exterior finishing and the different type of interior gypsum board (i.e. exterior board and standard gypsum board versus exterior PP barrier



(a) Two decoupled façade elements with 1 gypsum board (interior)

(b) One continuous façade elements with 1 gypsum board (interior)

(c) One continuous façade elements with 2 gypsum boards (interior)

Figure 10: Influence of exterior finishing

and fibre reinforced gypsum board).

For the case of two decoupled façade elements (Figure 10(a)), the type of exterior finishing has only a minor influence, with an overall difference in $D_{n,f,w}$ of approximately 0.5 dB. The largest differences are observed near the coincidence dip of the gypsum boards around 2500−3150 Hz, which might be related to differences in structural damping in the two set-ups. Also for the case of one continuous façade element and two gypsum boards at the interior side (Figure 10(c)), the influence is very small (difference in $D_{n,f,w}$ of 0.6 dB). The improvement between 800 and 1600 Hz is probably related to the different type of gypsum board used at the interior side (see section 3.2).

For the case of one continuous façade element with only one gypsum board at the interior side (Figure 10(b)), the type of exterior finishing has a larger influence. The lower mass of the façade element as a whole may explain the decrease below 500 Hz when the exterior board is replaced by the rain barrier. Again, the improvement between 800 and 1600 Hz is probably related to the different type of gypsum board.

4. CONCLUSIONS

The normalized flanking level difference $D_{n,f}$ across 19 different T-junctions composed of timber frame façade elements fixed to a heavyweight floor was measured in the laboratory to investigate the effect of the continuity of the façade element, the interior and exterior finishing and the firestop.

Generally, the flanking transmission through a standard continuous façade element across the separating floor will be too high ($D_{n,f,w}$ = 54 dB) to achieve acoustical comfort between dwellings. By use of a technical lining, this value can be increased up to 63 dB (two standard gypsum boards) or 65 dB (one standard gypsum board on resilient channels). These are maximum values that can be obtained *in situ*, because the total sound transmission is also affected by the direct sound transmission through the floor structure and additional flanking paths across the other façades or interior walls.

When the façade elements are interrupted at the floor junction, the normalized flanking level difference $D_{n,f,w}$ is 5 to 12 dB higher. A maximum value of 73 dB has been obtained for the case with a technical lining and gypsum board fixed on resilient channels.

Apart from the continuity of the façade elements, the interior finishing proves important, while the influence of the exterior finishing and firestop on the overall flanking transmission is very limited. The use of an additional standard gypsum board at the interior side improves the $D_{n,f,w}$-value by approximately 3 dB, while the use of heavier fibre reinforced gypsum boards will increase $D_{n,f,w}$ by approximately 2 dB. Decoupling the interior gypsum boards with resilient channels gives improvements of 5 to 6 dB.

5. ACKNOWLEDGEMENTS

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