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Effects of construction details on measured sound insulation of timber frame partition walls

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Abstract
In this paper we discuss the airborne sound insulation of timber frame partition walls with different construction details measured in the laboratory according to EN ISO 10140-2. The following construction details were varied, and their acoustical effects investigated:
- wall type (single/double wall, symmetrical/asymmetrical structure)
- studs (monolithic/separated studs, distances between studs, stud width)
- gap width at double wall
- sheathing material (OSB, one/two layers of gypsum board and sand board)
All analyses are done including the lower frequency range, i.e. 50 Hz – 5000 Hz. Beside the frequency dependent sound reduction indexes, we discuss the single number quantity R_w, including the spectral adaption terms $C_{50\text{-}5000}$ and $C_{tr,\,50\text{-}5000}$ of all investigated walls.

Keywords: parametric study, planning data, multi-story building, double wall, separated studs

1 Introduction

To plan the sound insulation in buildings, reliable acoustical data of building elements are necessary. Holzforschung Austria therefore initiated the research project "Sound.Wood.Austria" in cooperation with Technical University of Graz and started the project in fall 2018. Aim of the project is to provide detailed data about the sound insulation of walls and floors in timber frame and CLT construction methods. For this purpose, extensive parametric studies are part of the project. Already published data from external timber frame and CLT walls with different facades can be found in [1–4].

Numerous parametric studies on lightweight walls are available in the literature [5–11]. Often, the distance between the screws was detected as an important factor to control the sound insulation of the wall [8–11].
Figure 1 and Figure 2 show the typical influence of the screw distance on the sound reduction index R for lightweight constructions with timber studs. Remarkable are the significant dips between 160 Hz and 800 Hz due to the reduced screw distance.
From the statics point of view, small screw distances can be necessary, especially at the OSB sheathing of stiffening elements. This should be considered when acoustical data of timber building elements are used for planning.

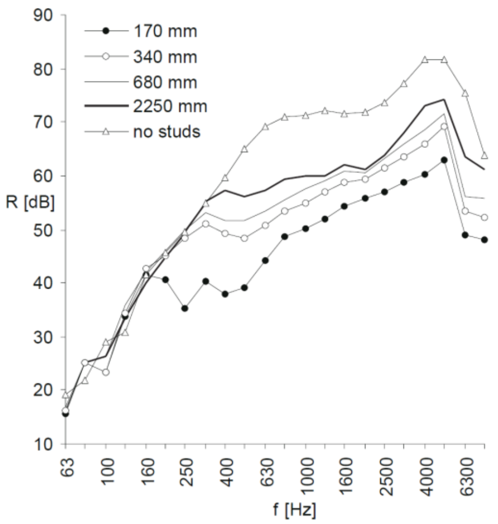

Figure 1: Influence of screw distance for lightweight, insulated test elements with metal sheathing and wooden studs [8]

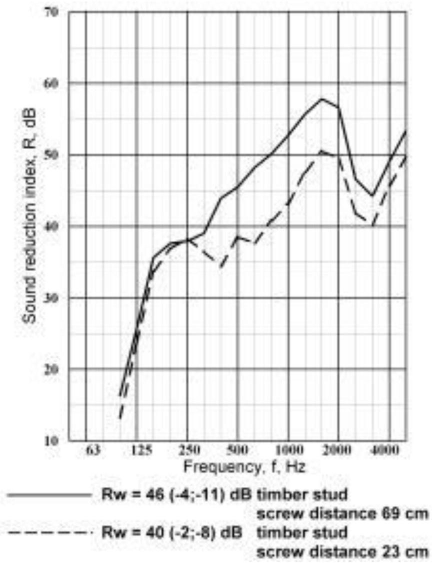

Figure 2: Influence of screw distance for insulated timber frame test element with gypsum board sheathing [9]

2 Materials and Methods

Figure 3 gives the construction details of an investigated double wall and single wall with separated studs. Note that a screw distance at the OSB sheathing of 5 cm was realized for all elements, according to the static requirements of the industrial partners for multi-story buildings. Due to construction reasons, the studs of the double wall were displaced to each other. The displacement was around 25 cm for a center distance e = 62,5 cm. At smaller e, the displacements of the studs were smaller. The size of all test walls was 3,97 m x 2,67 m (10,6 m²).

For the parametric study we varied the following details:

Single wall with continuous studs (one half of the double wall)

- Cavity thickness t (10 cm, 18 cm)
- Sheathing at one side (OSB, 1x/2x gypsum board (GB))
- Distance between the stud centers e (stud spacing; 62,5 cm, 31,3 cm, 20,0 cm)

Double wall:

- "Exterior" sheathing (sheathing at the sending- or receiving room; OSB, 1x/2x GB)
- "Interior" sheathing (sheathing at the gap of the double wall; with/without OSB)
- Cavity thicknesses of wall 1 and 2 $t_{1/2}$ (10 cm, 18 cm)
- Distance between the stud centers in wall 1 and 2 $e_{1/2}$ (stud spacing; 62,5 cm, 31,3 cm, 20,0 cm)
- Width of the gap in the double wall g (2 cm, 8 cm)

Single wall with separated studs

- Sheathing (OSB, 1x/2x GB, 1x/2x sand board)

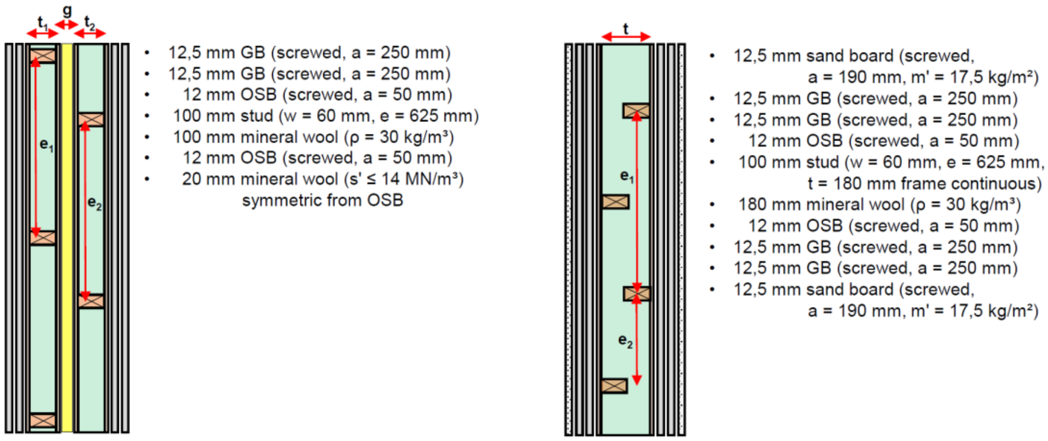

Figure 3: Left: Construction details of an investigated symmetrical double wall, made of two single walls with insulated gap between walls. Right: Construction details of an investigated symmetrical wall with separated studs. Note that the studs are separated from one side, but the framing (top/bottom/left/right beam) is continuous from one side to the other. GB: gypsum board (fire resistant); t: thickness of the cavity; g: gap width between the single walls; e: distance between the stud centers; a: distance between the screws; w: width of the stud; s': dynamical stiffness; ρ: bulk density

Figure 4 left shows the profile of a sand board. The right picture gives the mounting situation of the sand boards on the wall with separated studs. Due to the order of variations, we located the sand boards at the external side on top of the GB and screwed it into the studs. Usually the sandboards should be below the exterior GB and, following the specifications of the manufacturer, the exterior GB should only be screwed into the sand boards (no direct connection of exterior GB with studs).

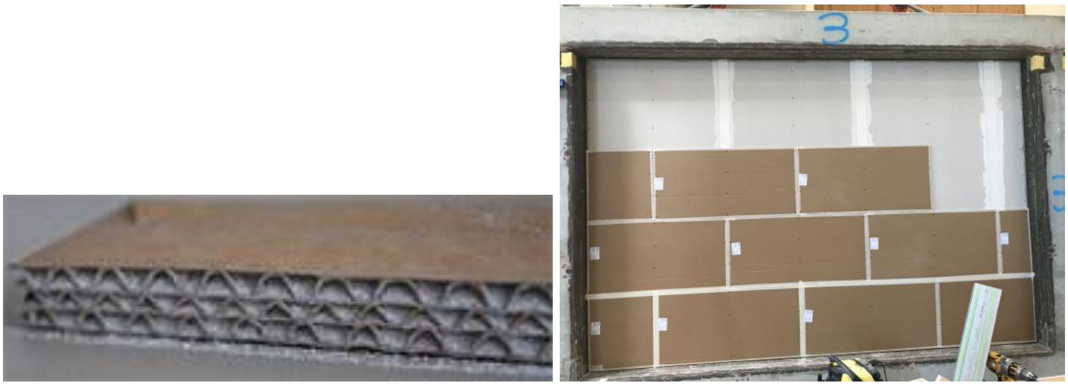

Figure 4: Left: sand board (corrugated cardboard filled with quartz sand, www.wolf-bavaria.com, 07/27/2021). Right: Application of sand boards on top of the gypsum boards. The sand boards were screwed into the studs.

All tests were carried out at the Akustik Center Austria [12,13] according to ISO 10140-2:2010 [14]. The ratings of the measured sound reduction index were done according to ISO 717-1:2013 [15].
The shown mass-spring-mass resonances (msm-resonances) of the walls and first natural frequencies of the sheathings were calculated according to [16].

3 Results and Discussion

In the following we discuss the sound reduction index (SRI) and the single number quantities (SNQ) R_w, R_w+$C_{50\text{-}5000}$ and R_w+$C_{tr,50\text{-}5000}$ of the investigated walls. The paragraph is split into three parts:

- Single wall with continuous studs
- Double wall
- Single wall with separated studs

3.1 Single wall with continuous studs

For the single wall with continuous studs the following parameters were varied and will be discussed hereinafter:

- Cavity thickness and sheathing
- Stud spacing

3.1.1 Influence of cavity thickness and sheathing

Figure 5 shows the influence of the cavity thickness on the SRI of the single wall with varied sheathing at one side of the wall. The graphs point out, that an increased cavity thickness leads to higher SNQ almost over the entire frequency range. At the frequencies below 100 Hz a shift of the dip into lower frequencies due to the lower msm-resonance is visible. However, the first natural frequency of the sheathings is also in that frequency range, which overlaps the positive effect of the wider cavity [3].
Comparing the improvements due to the additional sheathing clarifies, that the gains due to additional GB are very similar for both cavity thicknesses. However, at t = 10 cm slightly larger gains with the second GB can be detected between 125 Hz and 800 Hz, also the distinct dip at 160 Hz was reduced by the second GB. It is also shown in the graphs, that applying a second GB leads to an increase in the SRI below 125 Hz, independent of the cavity thickness.
As shown in the literature (see Figure 1 and Figure 2), there is a dip at 160 Hz and above due to the small screw distances. This dip appears in all versions, independent of the added GB.
Looking at the SNQ in the graphs makes clear, that an increased cavity thickness increases all shown SNQ. It is also visible, that a second GB changes the $R_w + C_{50\text{-}5000}$- and the $R_w + C_{tr,50\text{-}5000}$-value more than just one GB.

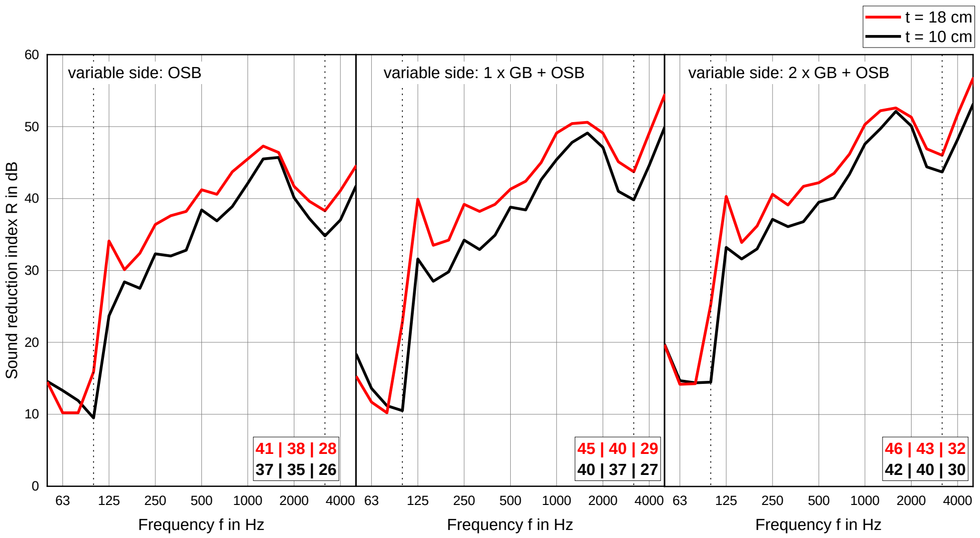

Figure 5: Influence of cavity thickness t = 10 cm and t = 18 cm, respectively at varied sheathing on one side of the single walls. The other side was always planked with 12 mm OSB. GB: gypsum board; SNQ R_w | $R_w + C_{50\text{-}5000}$ | $R_w + C_{tr,50\text{-}5000}$ in dB in the lower right corner of the graphs

3.1.2 Influence of stud spacing

Figure 6 illustrates that the stud spacing effects the SRI considerably, caused by the shifted first natural frequency of the sheathing. Especially if there is only OSB sheathing on the wall, as shown in the left graph [3].
Adding a GB at the side of the receiving room changes the first natural frequency of the sound radiating sheathing. Considering only the GB as relevant sheathing gives a first natural frequency between 32 Hz and 71 Hz (distance between the vertical screw axis at the GB was in all cases e_s = 62,5 cm). However, a dip which indicates this is not visible in the middle and right-hand graph. Nevertheless, the dips due to the first natural frequency of the OSB in the left graph nearly disappeared for the versions with GB sheathing and e = 31,3 cm and e = 20 cm. For the versions with e = 62,5 cm, a wider dip below 100 Hz due to the additional GB is visible. This correlates with the reduced msm-resonance. Besides that, it becomes also clear that adding a GB at one side of the wall generally reduces the differences between the versions with different e.
Looking at the SNQ in the graphs makes clear that a reduced stud spacing results generally in a reduced R_w-value. In contrary to that, the $R_w + C_{tr,50\text{-}5000}$-value improved for the versions with GB by changing e from 62,5 cm to 31,5 cm or less.
Adding an additional GB to one side of the wall always leads to an increase of all shown SNQ.

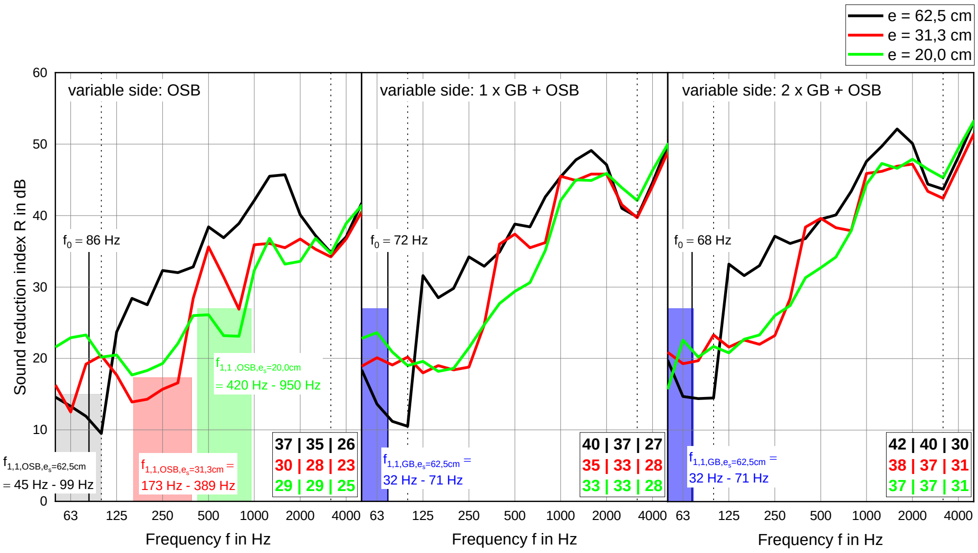

Figure 6: Influence of stud spacing and varied sheathing at one side of a single wall on SRI, first natural frequency ranges of the sheathing and the mass-spring-mass-resonance of the wall. The other side of the wall was planked with 12 mm OSB. GB: gypsum board; e: distance between the stud centers; e_s: distance between the vertical screw axis; $f_{1,1}$: first natural frequency range for simply supported and clamped exterior sheathing; f_0: mass-spring-mass-resonance; SNQ R_w | $R_w + C_{50\text{-}5000}$ | $R_w + C_{tr,50\text{-}5000}$ in dB in the lower right corner of the graphs

3.2 Double wall

For the double wall the following parameters were varied and will be discussed hereinafter:

- Exterior sheathing and stud spacing
- Cavity thickness and interior sheathing
- Gap width

3.2.1 Influence of exterior sheathing and stud spacing

Figure 7 left shows the effect of a double wall compared to a single wall and the influence of varied sheathing at one side of the double wall. The SRI of the double wall with OSB is higher over the whole frequency range (except at 50 Hz) compared to the single wall. Also visible is the reduced dip at the double wall compared to the single wall in the range of the first natural frequency.
Additionally, it is observable that the second GB at the double wall lowers the dip between 125 Hz and 315 Hz due to the small screw distances. Apart from that the benefit of the second GB is smaller compared to the first GB.
Figure 7 middle indicates the effect of different stud spacings at the double wall with a gap width of 2 cm. The graph points out that a reduced stud spacing at just one wall reduces the SRI between 100 Hz and 500 Hz significantly due to the shifted first natural frequency of the sheathing (see Figure 6). However, the SRI in the lower frequency range stays rather low due to the unchanged first natural frequency (45 Hz – 99 Hz) of the wall with e = 62,5 cm. In contrast to that, additionally reducing the stud spacing in the second wall results in a significant increase of the SRI in the lower frequency range.
Looking at the SNQ clarifies, that the R_w-value of the symmetrical wall with e = 62,5 cm is higher compared to the versions with smaller stud spacing. Contrary to that, reducing the stud spacing at both walls gives considerable higher $R_w + C_{50\text{-}5000}$ and $R_w + C_{tr,50\text{-}5000}$-values.

Figure 7 right clarifies that for double walls with g = 8 cm and constant large stud spacing in one of the walls, the influence of stud spacing in the other wall is clearly reduced compared to the versions with g = 2 cm. This holds especially for the lower frequency range.

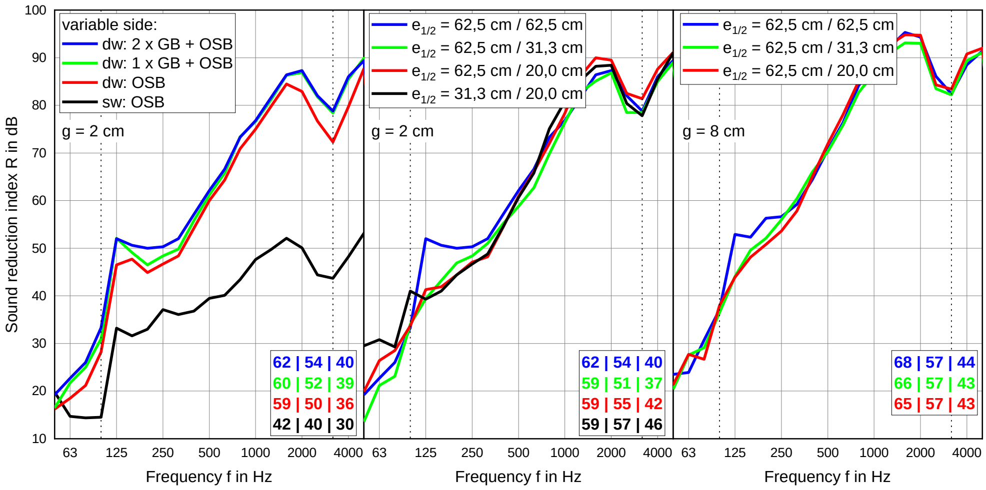

Figure 7: Left: Influence of a second wall (two single walls (sw) combined to a double wall (dw)) and varied sheathing at one exterior side of the double wall. The other exterior side was always planked with 2 x 12,5 mm gypsum board (GB) and 12 mm OSB. Middle and right: Influence of changed stud spacing at the double walls with 2 x 12,5 mm GB and 12 mm OSB sheathing at varied gap width (g). $e_{1/2}$: distance between the stud centers at wall 1 and 2; SNQ R_w | $R_w + C_{50\text{-}5000}$ | $R_w + C_{tr,50\text{-}5000}$ in dB in the lower right corner of the graphs

3.2.2 Influence of cavity thickness and interior sheathing

Figure 8 demonstrates the influence of the cavity thicknesses for the double wall as well as the influence of the interior OSB. The graph points out, that an increased cavity thickness from 10 cm to 18 cm results in a distinctive increase of the SRI in the lower frequency range. That improvement can partly be explained by the shifted msm-resonance due to of the wider cavity. Why the influence of to the first natural frequency is not visible at the version with 18 cm wide cavity is unclear. It is also visible, that the dip between 125 Hz and 315 Hz is clearly lower at the version with the wider cavity at one side.

Figure 8 also points out that the increase in the lower frequency range can also be accomplished by removing the interior OSB. This lowers the msm-resonance frequency of the larger cavity. However, the calculated msm-resonance of the version without interior OSB is at 30 Hz, not at 63 Hz where the sharp dip occurs. As in the version with 10 cm / 18 cm cavity, the wide dip due to the first natural frequency of the sheathing is not visible anymore. In this case it might be because of a reduced torsional rigidity of the studs (sheathing only at one side) and thus a reduced restraint of the sheathing. Assuming a simple supported situation for the sheathings, the first natural frequency would decrease down to 45 Hz for the OSB and 32 Hz for the GB. In real terms there is no ideal supported situation. Thus, the first natural frequency of the sheathing is higher. It might be in the area of 63 Hz were the sharp dip appears.
Additionally, the influence of to the small screw distances between 125 Hz and 315 Hz becomes slightly stronger due to the missing OSB.

The mentioned effects are also visible in the SNQ. While the version with a cavity thickness of 18 cm shows the highest R_w-value, the version without interior OSB has the highest R_w-$C_{50\text{-}5000}$ and R_w+$C_{tr,50\text{-}5000}$-values.

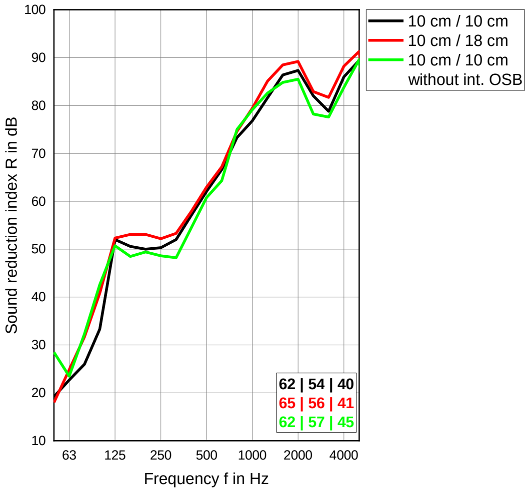

Figure 8: Influence of cavity thickness t_1 / t_2 at the double walls and of an interior OSB (OSB at the gap); Sheathing on exterior sides 2 x 12,5 mm GB and 12 mm OSB and at interior side usually 12 mm OSB; SNQ R_w | R_w + $C_{50\text{-}5000}$ | R_w + $C_{tr,50\text{-}5000}$ in dB in the lower right corner of the graph

3.2.3 Influence of gap width

Figure 9 shows the influence of the gap width on the double walls with different stud spacings and cavity thicknesses. A wider gap results in a clear increase of the SRI above 125 Hz at all versions.
The benefit below 125 Hz remains rather low, which relates most likely to the unchanged first natural frequency of the exterior sheathing and the little impact of a changed gap width on the msm-resonance of the larger cavities. This does not hold for the version with $e_{1/2}$ = 62,5 cm / 31,3 cm. The reason for that is unclear.
The SNQ correspond with the stated findings, the R_W-values changed stronger compared to the R_w + $C_{50\text{-}500}$- and R_w + $C_{tr,50\text{-}5000}$-values.

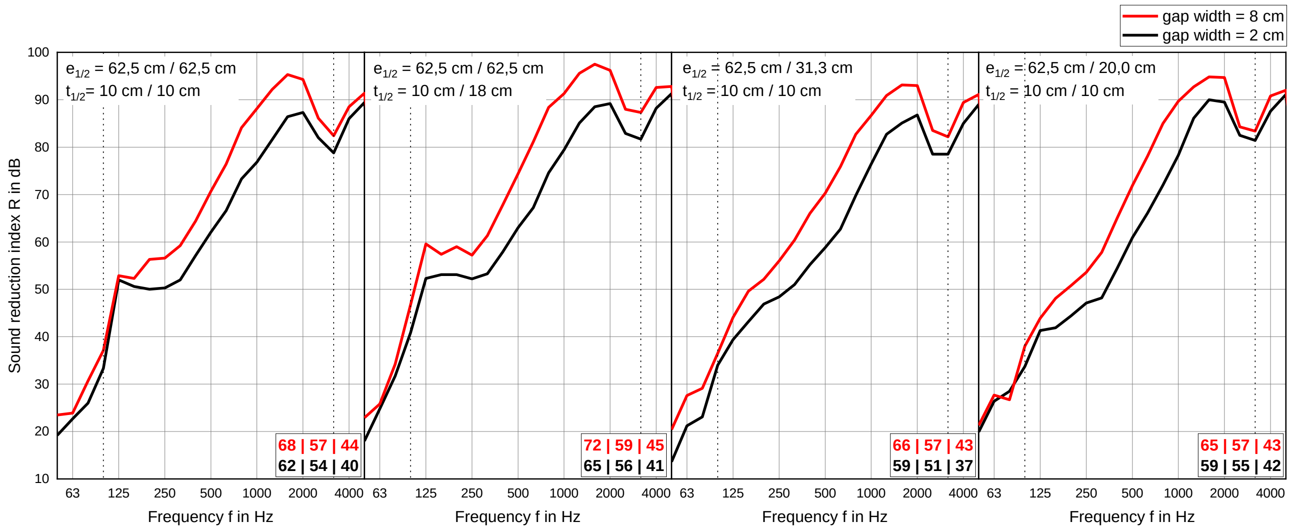

Figure 9: Influence of the gap width at the double wall and the interior OSB. Sheathings on exterior sides 2 x 12,5 mm GB and 12 mm OSB and on interior sides 12 mm OSB; $e_{1/2}$: distance between the stud centers at wall 1 and 2; $t_{1/2}$: cavity thickness at wall 1 and 2; SNQ R_w | $R_w + C_{50\text{-}5000}$ | $R_w + C_{tr,50\text{-}5000}$ in dB in the lower right corner of the graph

3.3 Single wall with separated studs

For the single wall with separated studs the following parameters were varied and will be discussed hereinafter:

- Stud type
- Sheathing

3.3.1 Influence of stud type

Figure 10 demonstrates the effect of separated studs (with continuous frame) instead of monolithic studs with varied sheathing at one side of the wall. Due to the separated studs the SRI increases significantly below 125 Hz and above 400 Hz. In the Frequency range between, the SRI stays rather low due to the small screw distances. However, the sharp dips at 160 Hz at the version with monolithic studs were reduced by the separated studs. Nevertheless, the still existing “screw effect” from the OSB diminished the increase of the R_w-value due to the decoupling made by the separated studs. The $R_w + C_{50\text{-}5000}$- and $R_w + C_{tr,50\text{-}5000}$-value nevertheless increases significantly at the versions with GB.
Looking at the Frequency range below 125 Hz shows that a shift of the msm-resonance dip due to the added sheathing (see calculated f_0 in the graph) is visible only at the walls with separated studs. Like at the double wall without interior OSB in Figure 8, there is a sharp dip at 63 Hz at the version with separated studs in the left graph of Figure 10. Additionally, the wide dip due to the first natural frequency at the versions with monolithic studs is generally not visible at the versions with separated studs. Again, this might be because of a reduced torsional rigidity of the studs (sheathing only at one side) and thus a reduced restraint of the sheathing.

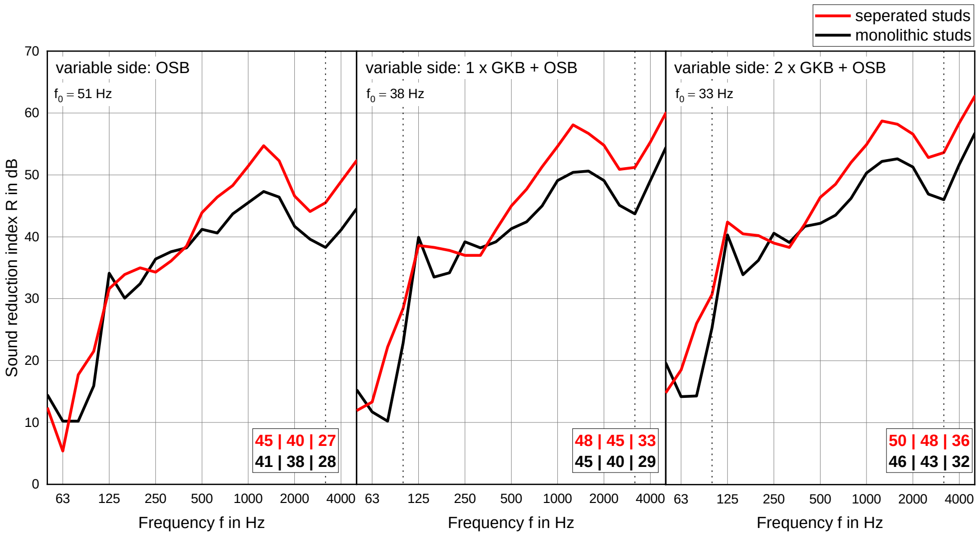

Figure 10: Influence of stud type in a single wall with variable sheathings at one side. Note that the frame is still continuous at the version with separated studs. Sheathing at the constant side 12 mm OSB; Cavity thickness = 18 cm; f_0: msm-resonance; SNQ R_w | $R_w + C_{50\text{-}5000}$ | $R_w + C_{tr,50\text{-}5000}$ in dB in the lower right corner of the graph

3.3.2 Influence of sheathing

Figure 11 presents the effect of different sheathings on the wall with separated studs. Applying additional GB on both sides of the wall increases the SRI and the SNQ clearly (compare with Figure 10). Adding sand boards to one or both sides of the wall results also in a strong increase of the SRI nearly over the whole frequency range. Especially in the frequency range above 1000 Hz the gains are very high. In the frequency range from 160 Hz to 260 Hz the improvements are not that distinct due to the small screw distances. Looking at the frequency range below 125 Hz clarifies that the increase of the SRI due to the sand boards is remarkable, particularly if the sand boards are applied to both sides of the wall.
With sand boards on both sides the second GB brings no additional improvements.
The significant gains due to the sand boards, especially in the lower frequency range can also be seen at the SNQ in the graph.

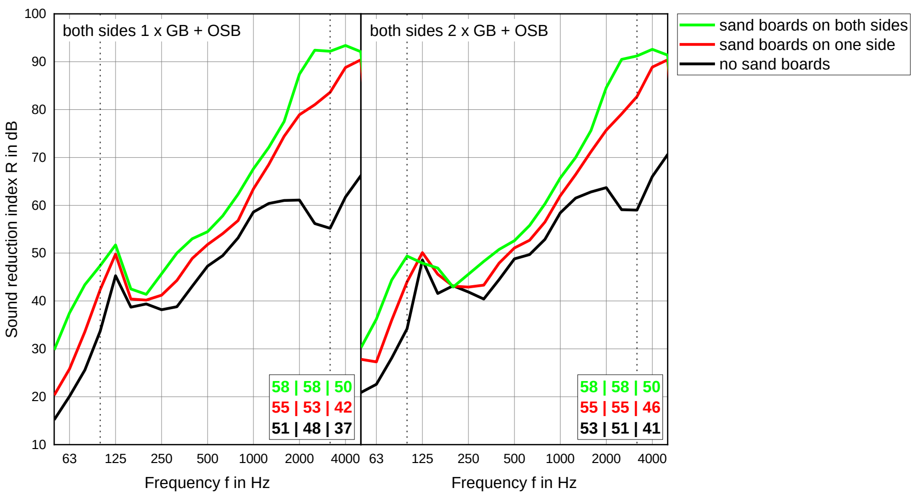

Figure 11: Influence of added GB and sand boards on a single wall with separated studs. SNQ R_w | $R_w + C_{50\text{-}5000}$ | $R_w + C_{tr,50\text{-}5000}$ in dB in the lower right corner of the graph

4 Conclusions

In this paper the sound reduction index and single number quantities of single walls with continuous studs, double walls and single walls with separated studs were discussed. The effects of different sheathings, cavity and gap dimensions and stud types were analysed by a parametrical study.
The data points out, that the strongest increase of the SRI of the partition walls can be achieved by creating a double wall with separated studs and frame, realizing small stud spaces for both walls of the double wall, increasing the cavity depth by removing the interior sheathing and applying sand boards on both exterior sides.
The data also shows that a distinct dip due to reduced screw distances at the sheathings is visible at all investigated versions. This effect should be considered by using measured data as planning data.
The mass-spring-mass-resonances of the walls are often masked by the first natural eigenfrequency of the sheathing, but not that clear at the walls without interior OSB or with separated studs. This might be because of a reduced torsional rigidity of the studs and thus a reduced restraint of the sheathing. More research on this and generally on the acoustical effects of natural frequencies of timber frame walls is necessary.

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