Parametric study of direct airborne insulation of wood stud walls in midrise construction

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ABSTRACT

There has been a proposal in Canada to increase the maximum allowable height of wood framed construction in the National Building Code of Canada (NBCC) from 4 stories to 6 stories. Design of taller buildings will lead to a change in the details of the walls that have to withstand the higher axial and lateral loads. However, also requirements of other building physics disciplines, one of those being the sound insulation, still have to be met. In the study presented here various assemblies that meet the higher load requirements are compared for direct airborne sound insulation. Parameters that were modified include: sheathing membranes, stud arrangement, stud depth, and resilient channels. Some of the wall design variants that work well structurally have very poor sound insulation properties and most of them require the use of resilient channels to obtain somewhat acceptable sound insulation properties. These and more results will be presented here.

Keywords: Sound, Insulation, Transmission I-INCE Classification of Subjects: 51.3, 51.4

1. INTRODUCTION

The change of the sound insulation of wood frame walls due to different structural measures needed to ensure that midrise buildings are structurally sound will be presented below. Measurements are carried out according to ASTM protocols and ASTM metrics are used to quantify airborne sound insulation quality throughout the paper in order to be consistent with the sound insulation requirements of the National Building Code of Canada (NBCC). Currently, the only requirement is a Sound Transmission Class (STC) of 50 for direct sound transmission through an element separating adjacent rooms of different dwellings. This paper starts of by describing the measurement procedures, and the specimen details, and ends with results and conclusions.

2. Measurement procedure

The airborne sound transmission loss (very similar to ISO 10140’s sound reduction index, R [1]) was measured according to the test protocol in ASTM E90 [2] in the NRC-Construction wall sound transmission facility. The facility consists of two adjoining, structurally isolated rooms with a test opening in the partition that can accommodate a test frame with a 3.65 m wide and 2.40 m high wall specimen. The small and large room volumes are 140 m^3 and 250 m^3 respectively.

Tests were conducted in forward and reverse direction, i.e. for the first measurement, the small room was source room and the large room receiving room and for the second, vice-versa. The sound transmission loss (TL) presented in this paper is the average of both directions. The higher the TL value, the higher the sound insulation properties of the wall. From these one-third octave band sound transmission loss values, the sound transmission class, STC, a single number rating, was calculated according to ASTM E413.

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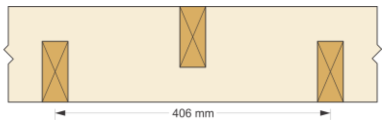
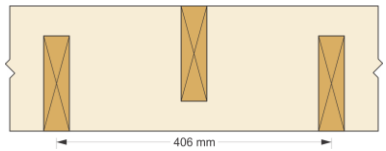
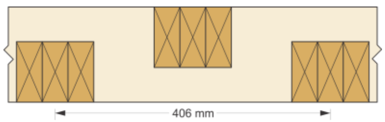
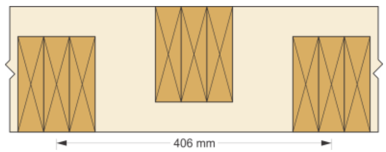
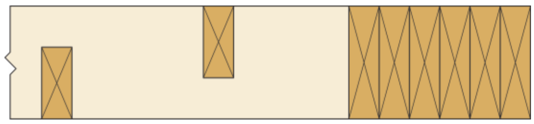
3. Specimen Description

Several parameters were varied among the wood stud walls investigated in this study. Yet, common to all specimen, are the use of staggered studs (see section 3.1 Framing), with a double header and single footer, fibrous insulation, and two layers of 13 mm gypsum board applied to both sides of the wall of approximately 10kg/m^2 per layer.

3.1 Framing

The three framing parameters varied, depicted in Table 1, are the depth of the studs, the width of the studs (increased by screwing three studs together here called tripled studs), and the use of end columns. End columns are often needed in midrise construction to support the load of tie-downs that prevent toppling of the building. To carry the high axial load caused by the loads of the upper floors of mid-rise buildings, wall framing is strengthened by using tripled staggered wood studs (3SWS as in the bottom row of Table 1). Comparisons are made with the more traditional staggered wood studs (1SWS as in top row of Table 1). The depth of the wall cavity was varied from 140mm (left column) to 184mm (right column) using staggered 2x4's and 2x6's respectively.

Table 1 – Plan view of framing variants. Table columns identify different cavity depths, and table rows identify single or tippled staggered studs. Bottom row shows end columns that were used for all four framing variant above.

	140 mm cavity	184 mm cavity
1SWS	 1SWS140(406)	 1SWS184(406)
3SWS	 3SWS140(406)	 3SWS184(406)
End column	 End column	

3.2 Shear Layer

Shear layers are necessary to withstand lateral (horizontal) loads caused by wind or seismic activities. In this study the shear layers were of either plywood (PLY) or oriented strand board (OSB) of two different thicknesses (10mm and 16mm). The boards were always applied to the framing directly under the gypsum board with a fastener spacing of 75mm, to ensure structural integrity. The mass per area is 7.6kg/m^2 for PLY16, 4.0 kg/m^2 for PLY10 , 10.2 kg/m^2 for OSB16, and 7.1 kg/m^2 for OSB10.

3.3 Resilient Channels

The resilient channels applied in this study were always located between the studs and the gypsum board spaced at 600mm on centre on only one side of the framing, whereas the gypsum board was directly attached on the other side of the framing.

3.4 Specimen names

To reduce the length of the legends in the following diagrams, specimen names, as listed in the tables below, are used. Note not all permutations of parameters described above were tested, resulting in only 21 specimens instead of 64 = 2 (stud depth) x 2 (stud width) x 2 (end column) x 4 (shear layer) x 2 (RCs). The specimens are listed in Table 2, Table 3, and Table 4, to better highlight logical parametric comparisons that can be made. The prefix MR is short for Mid-rise wood.

In Table 2, specimens with variations of cavity depth, stud width, RCs, and end column can easily be identified. Whereas Table 3 shows specimens with different type and thickness of shear membranes. Finally, Table 4 shows which walls to compare in order to compare the effect of one shear membrane PLY16, under different boundary conditions, such as cavity depth, stud width, for single or tripled staggered studs, with or without RC's.

Table 2 - Specimen names for specimen with and without end columns (rows1 1&2 and 3&4), with directly (DA) and resiliently (RC) attached gypsum board (rows 1&3 and 2&4), for cavities of 140mm and 184mm depth (columns 1&2 and 3&4), and with single (1SWS) and tripled staggered studs (3SWS) (columns 1&3 and 2&4)

		140 mm cavity		184 mm cavity	
		1SWS	3SWS	1SWS	3SWS
w/o end col.	DA	MR01	MR11	MR18	MR27
	RC	MR03	MR12	MR19	MR26
with end col.	DA	MR09		MR20	
	RC	MR10		MR21	

Table 3 - Specimen names for specimen with 10mm and 16mm shear membranes (rows 1 and 2), using plywood (PLY) or OSB (columns 1&2 and 3&4), installed horizontally (H) or vertically (V) (columns 1&3 and 2&4)

	PLY		OSB	
	H	V	H	V
10		MR04		MR03
16	MR08	MR06		MR05

Table 4 - Specimen names for specimen with directly (DA) and resiliently (RC) attached gypsum board (rows1 1&2 and 3&4), with and without 16mm plywood shear membrane (rows 1&3 and 2&4), for cavities of 140mm and 184mm depth (columns 1&2 and 3&4), and with single (1SWS) and tripled (3SWS) staggered studs (columns 1&3 and 2&4)

		140 mm cavity		184 mm cavity	
		1SWS	3SWS	1SWS	3SWS
DA	w/o PLY16	MR01		MR18	MR27
	with PLY16	MR06		MR22	MR24
RC	w/o PLY16			MR19	MR26
	with PLY16			MR23	MR25

4. Results

The results are organized in the same manner as section 3.4, namely, ordered by framing, shear layer, and RCs. Only in Figure 1 are absolute sound transmission loss values shown and compared. Thereafter, the improvements in TL are presented by taking the difference between the TL of interest and a reference case.

4.1 Framing

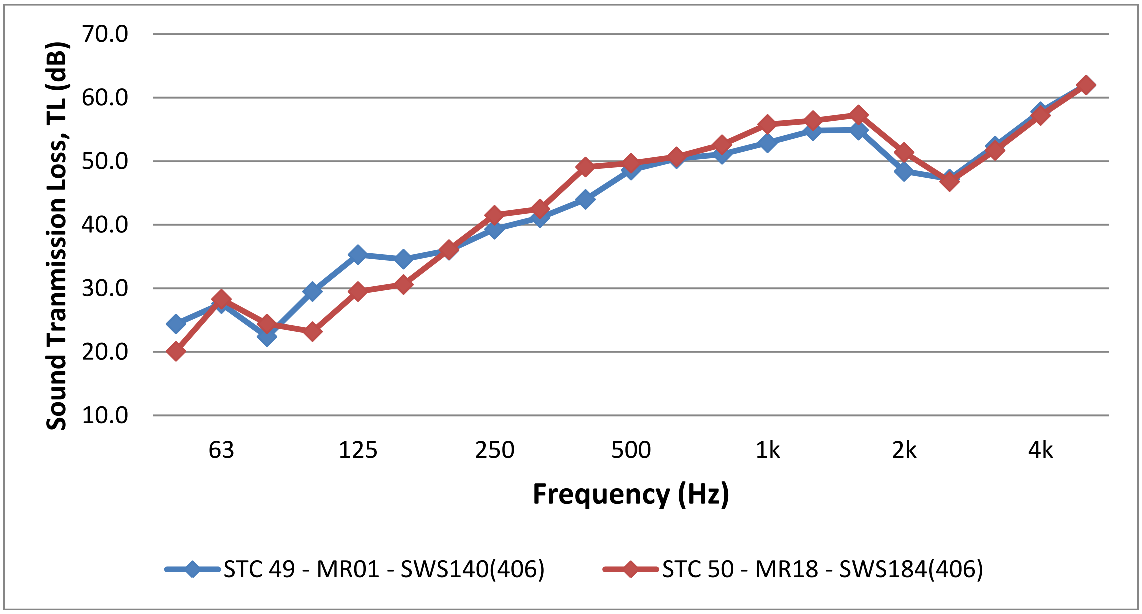


Figure 1 – Effect of stud depth on sound transmission loss. Nominally the same walls except with different stud and cavity depths (140mm and 184mm).

In this first comparison on the effect of stud and cavity depth (140 mm vs 184 mm), both TL curves rise towards higher frequencies and have a dip around 2.5k Hz, the coincidence dip of the gypsum board sheeting which is the same for both walls. The deeper wall MR18 performs better in the mid to high frequency range, whereas the less deep wall MR01 performs better around 125 Hz. Although one would expect the deeper cavity to perform better except around its mass-spring-mass resonance (theoretically below 40 Hz) the stiffness of the deeper studs increases the radiation efficiency of the wall at the low frequencies [3]. The difference of these two curves (SWS184-SWS140) as well as others taken from columns 3-1 and 4-2 (with different framing variants) of Table 2 – that show the change of sound insulation due to the change of the increased stud depth and cavity depth - are plotted below in Figure 2.

This Figure shows that the effect of stud depth for the two cases with directly attached gypsum board (DA) have similar signatures, and the two cases with the gypsum board attached to resilient channels (RC) have similar signatures. All cases show a slight worsening due to increasing the stud depth in the low frequency range, especially at 125Hz for the DA cases. Again, this is caused by the radiation efficiency of the gypsum board increasing due to being coupled to the now stiffer studs. This effect is not so apparent for the resilient channel cases as the gypsum board sheeting on one side is decoupled from the frame and its radiation efficiency is not effected by the stiffening due to the studs. Above 250Hz an improvement in performance can be seen by increasing the stud and cavity depth. The single number rating, STC varies with improvements from -2 to 2.

A similar worsening in performance around 125Hz can be seen in Figure 3, when going from single staggered stud (SWS) to tripled staggered studs (3SWS) moving along rows 1 and 2 in Table 2, or more specifically now subtracting columns 2-1 and 4-3. The curve shapes are similar for directly and resiliently mounted gypsum board. These reductions of TL at 125Hz causes the STC to drop by 0 to 3 points, the highest being for the deep wall (184mm) with directly attached (DA) gypsum board.

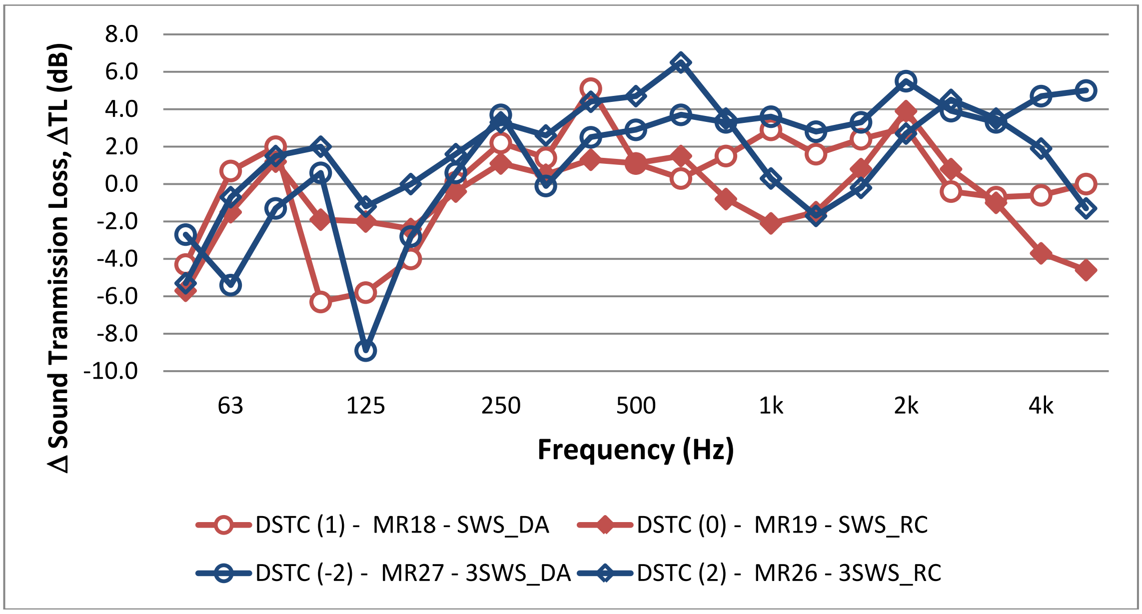


Figure 2 - Effect of stud depth on sound transmission loss for different design variants: single and tripled studs, and directly and resiliently mounted gypsum board.

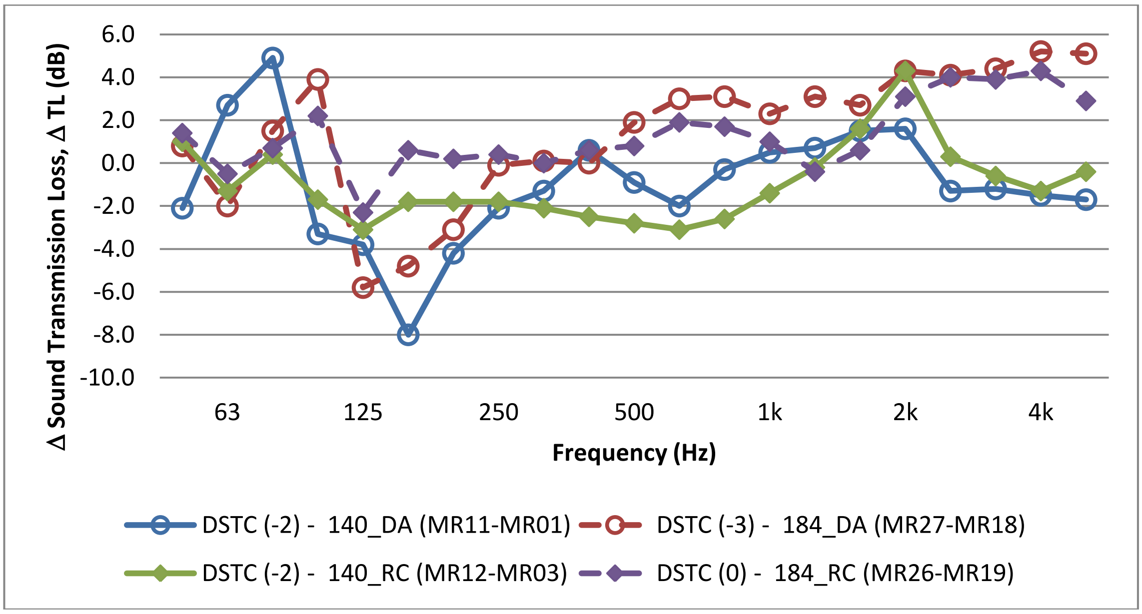


Figure 3 - Effect of stud width (single or tripled) on sound transmission loss for different design variants: 140mm and 184mm deep cavity, and direct and resiliently mounted gypsum board.

The effect of the last framing modification, namely adding columns at both wall ends, that now directly couple gypsum board sheathings on both sides of the framing, is shown in Figure 4. All cases, with DA or RC gypsum board, and 140 mm or 184 mm cavity depth, show very similar trends; especially when the cavity depth is the same. Throughout most of the frequency range, adding the end columns worsens the performance of the wall. The strongest degradation is around 500 Hz with a worsening of 4 to 7 dB. This is the range where for wood stud walls with cavity absorption structural coupling is the most predominant path of transmission. The single number ratings decrease by 2 to 5 points.

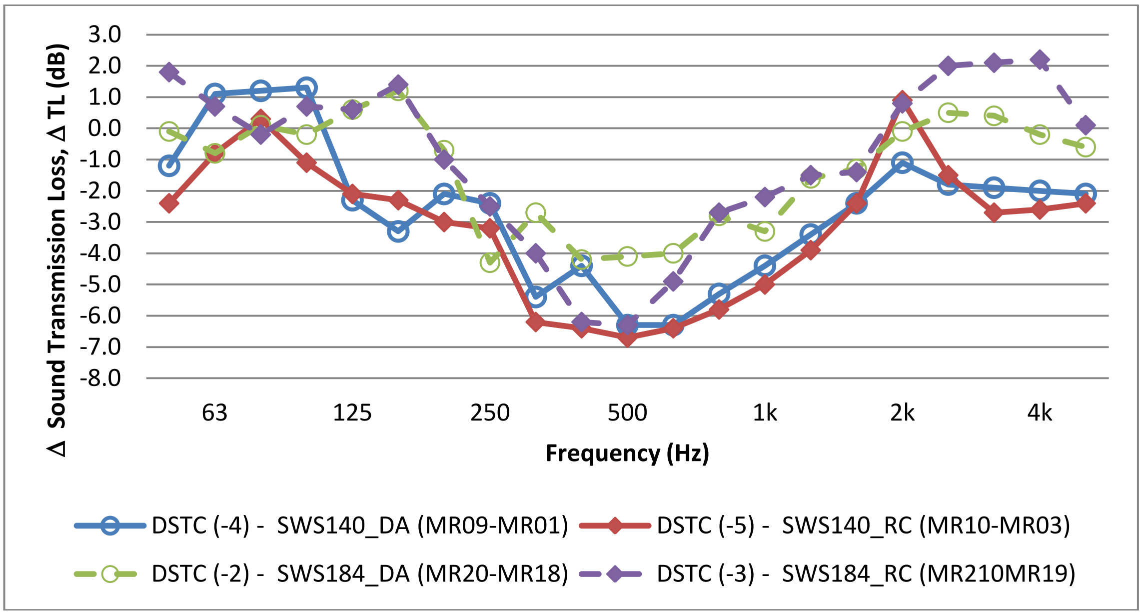


Figure 4 - Effect of end columns on sound transmission loss for different design variants: 140mm and 184mm deep cavity, and direct (DA) and resiliently (RC) mounted gypsum board.

4.2 Shear Layer

A slight improvement of performance can be seen in Figure 5 by adding different types of shear layers to the 140 mm deep staggered wood studs (SWS140) under the two layers of 13 mm gypsum board. Note, that the improvements are not much higher than repeatability uncertainties. The improvement is expected to be higher if the gypsum board would not have such a high surface density of 20 kg/m^2 per side already. The OSB16 with the highest mass shows the highest improvement. The plywood shows less improvement than the OSB. Not much difference can be seen between applying the plywood sheets with the long axis vertically (V) or horizontally (H). The improvement from 10 mm to 16 mm is also not significant.

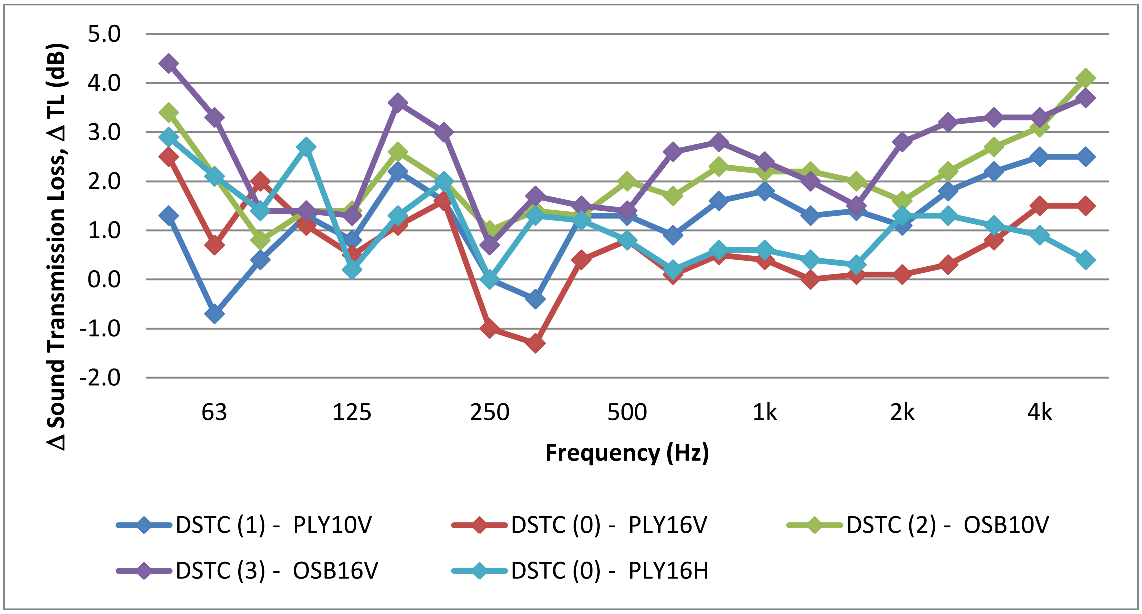


Figure 5 - Effect of shear layers on sound transmission loss for on wall MR01 with 140mm cavity depth and directly attached gypsum board.

The PLY16V case was chosen as the worst case scenario of these tested assemblies and so it was mounted on different framing variants in subsequent tests to obtain conservative test results valid for all common shear membranes. Figure 6 shows the average improvement due to adding PLY16 on all framing variants in Table 4 for the DA and RC cases. The addition of the plywood results in a higher improvement for the RC cases than the DA cases.

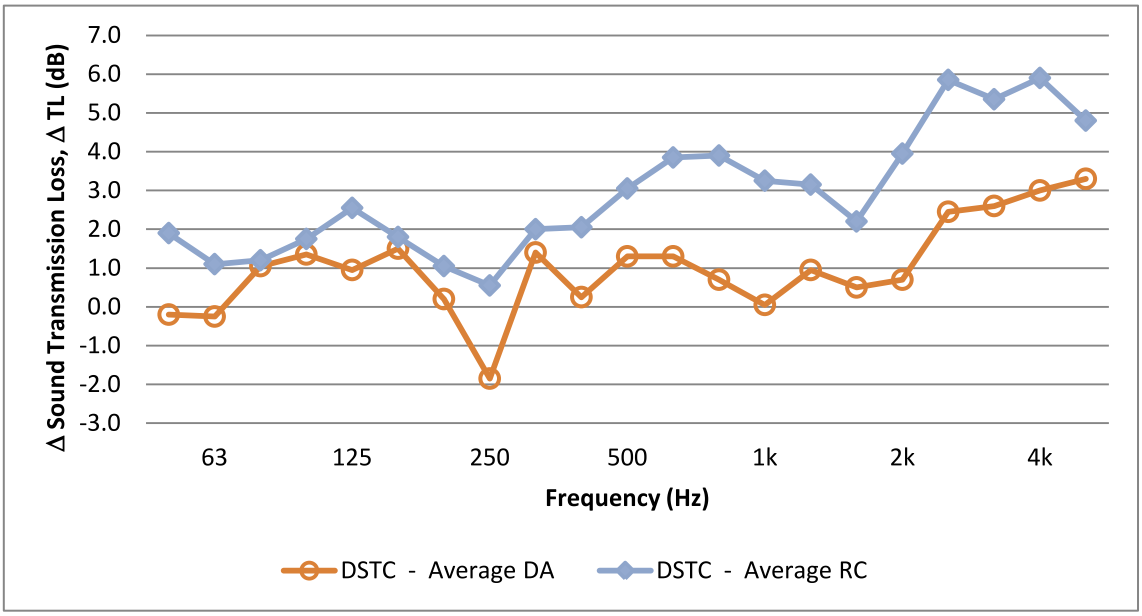


Figure 6 – Average effect of PLY16V shear membrane on sound transmission loss for direct and resiliently mounted gypsum board.

4.3 Resilient Channels

Resilient channels are needed to counter act the degradations caused by the stiffening measures, that were up to 3 STC points due to tripling the studs and caused by the sound bridging of the two gypsum board sheathings with the end columns that were up to 4 STC points (without RCs). However, they do result in a worsening at the low frequencies due to shifting the mass-spring-mass resonance to 63 Hz. However, above the resonance, improvements can be seen across the whole frequency range reaching up to 15 dB around 2k Hz. The effect of RC's on different framing variants shows a similar trend with the largest difference between cases around 125 Hz. There the 3SWS184 case shows the highest improvement, probably because for that DA case tripled studs caused a lot of structural coupling as well had the highest radiation efficiency as mentioned earlier. The average improvement due to adding the RC was around 8 dB both for the sound transmission loss as well as in its single number rating. STC in the high 50's can be achieved by using RCs.

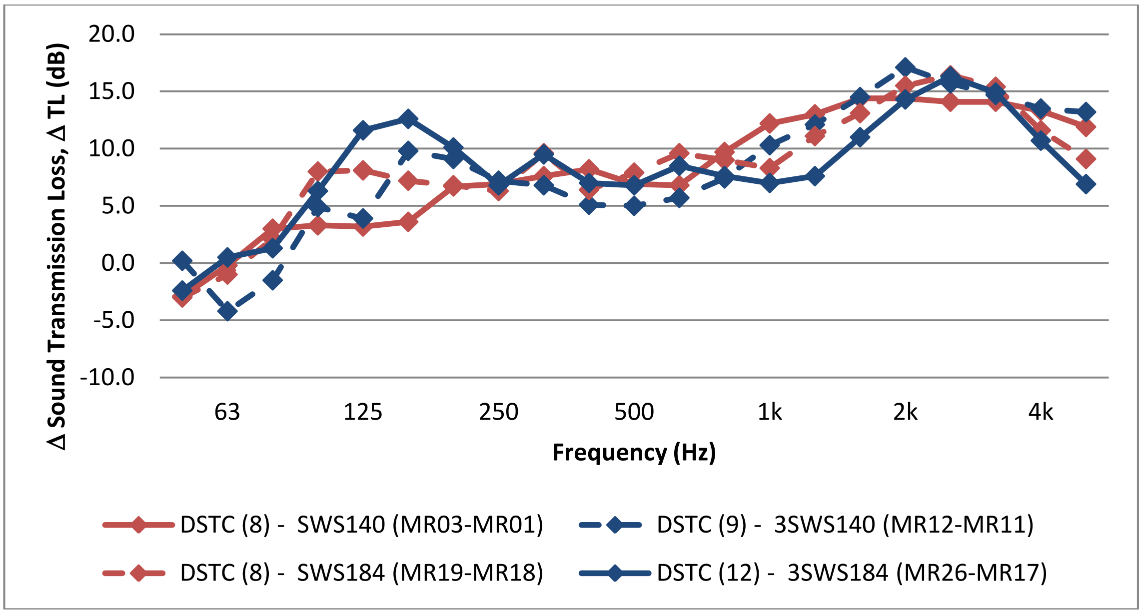


Figure 7 - Effect of resilient channels on sound transmission loss for different design variants: 140 mm and 184 mm deep studs, and single and tripled studs.

5. SUMMARY AND CONCLUSIONS

Construction details necessary to ensure a stable midrise building tend to affect the direct sound insulation properties of load bearing walls differently. Where the inclusion of a shear membrane (for horizontal loads), slightly increases the performance of the wall by up to only a few points, the addition of tripled studs (for vertical loads) decreases the sound insulation performance by up to three points. End columns, often required in midrise wood buildings also degrade the performance by up to 5 points. With these structural measures STC only in the mid to high 40’s range can be met. Only with resilient channels can sufficient sound insulation performance in the mid to high 50’s be achieved through structural decoupling and modification of the overall radiation efficiency.

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