Acoustics: sound insulation in mid-rise wood buildings: report to Research Consortium for Wood and Wood-Hybrid Mid-Rise Buildings

Schoenwald, S.; Zeitler, B.; King, F.; Sabourin, I.

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REPORT TO RESEARCH CONSORTIUM FOR WOOD AND WOOD-HYBRID MID-RISE BUILDINGS

Acoustics –

Sound Insulation in Mid-Rise Wood Buildings

CLIENT REPORT: A1-100035-02.1

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REPORT TO RESEARCH CONSORTIUM FOR WOOD AND WOOD-HYBRID MID-RISE BUILDINGS

ACOUSTICS – SOUND INSULATION IN MID-RISE WOOD BUILDINGS

S. Schoenwald, B. Zeitler, F. King and I. Sabourin

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ACOUSTICS - SOUND INSULATION IN MID-RISE WOOD BUILDINGS

S. Schoenwald, B. Zeitler, F. King and I. Sabourin

1. Introduction

This client report on the acoustics research component regarding sound insulation of elements and systems for mid-rise wood buildings is structured into a main part and four appendices. The main part outlines the background, main research considerations and summarizes conducted research and major outcomes briefly. It is structured like the Acoustics tasks in the Statement of Work of the Mid-rise Wood research project to identify accomplishments. For details on the research, testing and results, the main part references to four appendices that contain more details including test plans, test methods, specimen descriptions and all test data that is vetted so far. The appendices do not have the same structure as the Acoustic tasks in the statement of work and are on the following research components:

- A.1 Direct Sound Insulation of Wood Frame Wall Assemblies for High Axial and Lateral Loads
- A.2 Direct Sound Insulation of CLT-Elements
- A.3 Flanking Sound Transmission in Wood Frame Mid-Rise Buildings
- A.4 Flanking Sound Transmission in CLT Buildings

2. Background

The goal of the acoustics research components was to develop design solutions for mid-rise wood and wood-hybrid buildings that comply both with the current National Building Code of Canada (NBCC) 2010 [1] requirements for direct sound insulation and with the anticipated requirements for flanking sound transmission in the proposed, 2015 version of the NBCC. In addition, the design solutions were to provide better impact sound insulation while still achieving code compliance for all other disciplines (interdependencies) as identified in the final report of the scoping study conducted in FY 2010/2011 [2]. The design process required three steps (benchmarking, development, and demonstration of code compliance) with the exchange of information and coordination between the disciplines that were involved in each step. Demonstration of code compliance of a design solution required the testing of full-scale building elements using methods and facilities that conformed to the ASTM International standards for the testing of sound insulation.

Four acoustic tasks were identified in the statement of work of this project. The first step involved networking, international reporting and monitoring of research carried out by other parties as well as of code developments. The other three tasks were research and development tasks which focused on the following building elements:

- Interior wall assemblies – Direct airborne sound transmission through wood-frame and cross-laminated timber (CLT) wall assemblies for mid-rise buildings that fulfill or exceed the acoustic and other code requirements
- Floor assemblies – Direct airborne and impact sound transmission through CLT floor assemblies for mid-rise buildings that fulfill or exceed the acoustic and other code requirements
- Assessment of the sound insulation performance in mid-rise wood-frame (including exterior walls) and CLT buildings (flanking and apparent).

Detailed research plans were developed and test specimens were selected for the tasks with the project partners (Canadian Wood Council, FPInnovations and the Provinces) and in close consultation with researchers in other disciplines (i.e. fire, structure, heat-and-moisture). During the research tasks, results were shared and discussed with the project partners during workgroup meetings which were held on a regular basis. Research plans were adjusted accordingly when new knowledge became available. In addition, research conducted by other groups in Canada (i.e. FPInnovations, NEWBuildS) as well as abroad (i.e. in Europe) was taken into account. Acoustic researchers participated in work group meetings of other disciplines and advised on the selection of specimens for their research components.

A large amount of data was collected during the testing phase which commenced in November 2011 and was completed by March 2014. The outcome from the testing phase was design solutions for mid-rise wood buildings that fulfill code requirements for all of the relevant disciplines. In the following sections, the main results and outcomes for the different acoustic tasks that were identified in the statement of work are summarized. References are given to the Appendices which document additional details about the designs which were tested.

3. Interior Wall Assemblies

The National Building Code of Canada 2010 requires that the sound transmission class rating (STC rating) for the direct airborne sound insulation of wall assemblies that separate residential spaces from adjacent elevator shafts and refuse chutes must be 55 or higher and the sound insulation of wall assemblies for interior wall assemblies that separate a residential unit from other spaces in the building must be 50 or higher. The STC rating is determined in accordance with the standard, ASTM E413 [3] from data measured in accordance with the standard, ASTM E90 [4].

The wall assemblies for mid-rise wood buildings can be very different from the assemblies that are commonly used for low-rise buildings (buildings up to four stories), as loadbearing wall assemblies on the lower levels of mid-rise buildings must resist higher axial loading due to the weight of the upper storeys and often must do this in combination with higher lateral loads from wind or earthquakes. This requirement can be achieved for wood-frame wall assemblies through the strengthening of the framing (e.g. using larger members or built-up members), the addition shear bracing or by other measures (e.g. tie-downs to prevent overturning due to wind or seismic loads). Some of these measures can have profound effects on the sound insulation performance of the building elements and additional sound insulation treatments may be required to meet the current and proposed acoustic requirements of the NBCC.

Newer wood construction technologies such as wood-framed, Mid-Ply Shear Walls (developed by FPInnovations) or cross-laminated timber walls and floors (CLT, which are mass wood wall and floor elements – a concept developed in Europe and has come to Canada) could also be structural solutions for mid-rise wood buildings. However, standardized sound insulation laboratory test data for these products was limited at the start of this study. Therefore, additional sound insulation solutions for these products were developed in this research project.

The acoustic research on interior wall assemblies was divided into two components, one on wood-frame wall assemblies and the other on solid wood CLT walls.

3.1. Wood Frame Wall Assemblies for High Axial and Lateral Loads

The study of the sound insulation of wood-frame walls focused mainly on the design of the framing and the shear bracing. Walls framed with staggered and double wood stud rows were identified as the most likely useful wall designs for mid-rise wood buildings.

In the case of walls with a single stud row or staggered stud rows, the wood studs are attached to a common header and footer. The staggered stud framing includes either an end stud which is attached to the membrane on one side of the wall or to a 2x6, continuous end stud which spans the width of the cavity (see Figures A.1-2 and A.1-3). The continuous end studs and the common header and footer couple the membranes on each side of the wall and therefore walls with a single stud row or staggered stud rows may provide much less sound insulation than walls with double stud rows where the two stud rows each have decoupled headers and footers. Therefore, the effect of structural changes in walls with a single stud row or staggered stud rows on the sound insulation can be more profound than changes to walls with double studs. It was expected that some walls with single stud row or staggered stud rows might not meet the minimum code requirement for sound insulation.

The test series was structured as a parametric study where changes in the sound insulation could be related to a single structural modification of the specimen. The measured data could then be used to predict the sound insulation performance of similar (but not tested) assemblies. A total of 49 wall assemblies were built and tested. The test results are presented in Table 1 which shows the STC ratings of 67 assemblies. The STC ratings shown in black are measured values and the predicted STC ratings for additional generic wood-frame wall assemblies are shown in blue. Some of the tested results in Table 1 are the averages of several measurements. A complete listing of all of the tested assemblies along with detailed descriptions of the assemblies is given in Appendix A.1.

Table 1: STC ratings for measured (black) and predicted (blue) generic wood-frame wall assemblies for mid-rise buildings.

		2 layers 12.7 mm Type X gypsum board directly attached on both sides						2 layers 12.7 mm Type X gypsum board directly attached on one side and mounted to resilient channels on the other side					
		Without wood shear membrane			With shear membrane			Without wood shear membrane			With wood shear membrane		
		Base Framing[1]	Framing with Continuous end studs[2]	Framing with end Columns[3]	Base Framing[1]	Framing with Continuous end studs[2]	Framing with end Columns[3]	Base Framing[1]	Framing with Continuous end studs[2]	Framing with end Columns[3]	Base Framing[1]	Framing with Continuous end studs[2]	Framing with end Columns[3]
Staggered stud frame	2x4 studs @ 400 mm o.c.[1]	50	48	47	51/52	48	47	59	56	54	60	57	54
	2x4 tripled studs @ 400 mm o.c.[4]	49	47	46	48	47	45	57	55	53	58	55	53
	2x4 studs @ 100 mm o.c.[5]	36	36	36	35	35	35	50	50	49	52	51	50
	2x6 studs @ 400 mm o.c.	50	48	48	51	49	48	59	57	56	61	59	57
	2x6 tripled studs @ 400 mm o.c.	47	47	47	47	47	47	59	57	55	60	58	56
Single stud frame	2x6 studs @ 200 mm o.c.	N/A	N/A	N/A	N/A	N/A	N/A	51	N/A	N/A	51	N/A	N/A
	2x6 tripled studs @ 200 mm o.c.	N/A	N/A	N/A	N/A	N/A	N/A	53	N/A	N/A	53	N/A	N/A

		2 layers 12.7 mm Type X directly attached	2 layers 12.7 mm Type X directly attached and mounted to resilient channels	2 layers 12.7 mm Type X mounted to resilient channels
Mid-ply	2x6 and 2x4 studs @ 600 mm o.c.	48	55	57

Notes:

- Black numbers: Measured ratings
- Blue numbers: Predicted ratings based on measured ratings
- N/A: not tested or predicted
- 1: Refer to Figure A.1-2
- 2: Refer to Figure A.1-3
- 3: Refer to Figure A.1-4
- 4: Refer to Figure A.1-5
- 5: Refer to Figure A.1-6

For the test series, staggered wood stud walls with two stud dimensions (depths) – 2x4 (38 x 89 mm) studs on 2x6 (38 x 140 mm) plates, and 2x6 studs on 2x8 (38 x 184 mm) plates were considered and the sound insulation performance of the following framing options were compared:

1. Common wood framing – single studs spaced 400 mm on centre (o.c.)
2. Built-up column wood studs – tripled studs spaced 400 mm on centre
3. Increased number of wood studs – studs spaced 100 mm on centre
4. Wood end studs – studs with the same dimension (depth) as the plates at each wall end that couple the gypsum board membranes
5. Built-up wood end columns – columns built out of five studs with the same dimension (depth) as the plates at each wall end that couple the gypsum board membranes

Initial benchmarking with 2x4 staggered wood studs showed that sound insulation of walls with the small stud spacing framing variant was much worse than with built-up column studs at the common stud spacing. Walls with built-up column studs performed almost as well as walls with conventional framing (see Figure A.1 - 10). For this reason, framings with very small stud spacing were omitted in the series of tests with 2x6 staggered studs. Additionally, walls with a single row of 2x6 single or tripled wood studs and moderately more tightly spaced studs than found in traditional single row framing (200 mm on centre) were tested as alternative framing variants to staggered studs.

The effects of adding wood shear membranes of different materials (9.5 mm or 15.9 mm oriented strand board (OSB) or plywood) and different configurations (boards oriented vertically or horizontally, and joints blocked or not blocked) were studied for the first staggered stud wall framing variant. The wood shear membrane was attached to one side of the frame under the directly attached gypsum board membrane. It was found that adding a wood shear membrane improved the sound insulation slightly in most cases. The differences between the results for the wood shear membrane variants were very small and in most cases only marginally greater than the uncertainty of the measurement method. It was concluded that all wood shear membranes perform similarly and therefore consecutive test specimens were characterized with a single variant that was identified as the lowest-performing combination (15.9 mm plywood, oriented vertically, joints blocked).

A novel shear wall design, the Mid-Ply Wall, with a centre wood shear membrane sandwiched between two sets of framing (2x4 and 2x6) wood studs spaced 600 mm on centre with 2x4 plates) was also tested (see Figure A.1 - 9). In this design, the wood studs and plates were attached flat-wise on both sides of a 12.7 mm plywood membrane and were connected with nails that penetrated the membrane.

The gypsum board membranes of all of the tested wood-frame walls consisted of 2 layers of 12.7 mm thick Type X gypsum board, following the fire protection strategy of encapsulating the wood structural members as examined in the fire research portion of the project. The gypsum board membrane was either directly attached on both sides to the wall framing, or mounted on resilient channels spaced 600 mm on centre on one side and directly attached on the other side of the wall. For the Mid-Ply Shear Wall, the use of resilient channels on both sides of the walls was examined. For the Mid-Ply Shear Wall, the centre shear membrane prevents the studs from buckling and therefore, it was possible to use resilient channels on both sides of the walls for this framing variant. The cavities between the studs of all walls were filled at least two-thirds full with glass fibre insulation batts.

The values of the sound insulation of the assemblies with gypsum board mounted to resilient channels on one side are shown in Table 1 to exceed the required STC 50 rating. (More details about the improvements due to adding resilient channels on various wood stud configurations can be seen in Figure A.1 - 11). Of the assemblies shown in Table 1 that had both gypsum board membranes directly attached to the framing, only the assemblies with conventional framing with single studs spaced 400 mm on centre meet the STC 50 code requirement. The walls with continuous end studs and columns or with tripled studs (as described in Appendix A.1) perform slightly worse and have STC ratings in the high forties. The wall variant with very narrow stud spacing performs much worse and achieves STC ratings that are over 20 points lower than the walls with the tripled studs.

The tested Mid-Ply Shear Walls perform very well with ratings of STC 55 and STC 57 when the gypsum board membrane is mounted on resilient channels on at least one side of the walls.

Summary: Wood Frame Wall Assemblies for High Axial and Lateral Loads

- Walls with small stud spacing of 100 mm o.c. have much lower sound insulation properties than walls with staggered tripled studs at 400 mm on centre spacing, both of which carry a similar axial load.
- Adding end studs or tripled studs worsens the sound insulation by a few STC points.
- Adding a wood shear membrane slightly improves the direct sound insulation by approximately 1 STC point for walls tested in the lab; a conservative estimate is to neglect their effect.
- All of the wall assemblies (from Table 1 that use resilient channels on one side exceed STC 50, the current minimum NBCC 2010 sound insulation requirement for noise transmitted between dwellings.
- For walls with directly attached gypsum board on both sides, only the assemblies with single, staggered studs spaced at 400 mm on centre meet STC 50, the NBCC 2010 sound insulation requirement.
- Mid-Ply Shear Walls with resilient channels perform well (STC 55-57).

3.2. Cross Laminated Timber (CLT) Walls

In comparison to the many framing and shear bracing variants considered in the wood-frame wall study, the number of different CLT panels that provide the structural strength in a building is fairly limited – typically 3-ply and 5-ply CLT panels. Therefore, specimens were tested based only on the following three CLT wall structures:

- 5-ply CLT wall, thickness: 175 mm; mass-per-area: 92 kg/m^2
- 3-ply CLT wall, thickness: 78 mm; mass-per-area: 42 kg/m^2
- 3-ply CLT double leaf wall (two 3-ply CLT wall panels separated by a 25 mm deep cavity filled with glass fibre insulation), total wall thickness: 181 mm, mass-per-area: 85 kg/m^2

The test series focused mainly on the mounting options for the two layers of 12.7 mm thick Type X gypsum board that were used for the encapsulation of the CLT by the fire research team on the midrise wood building project and for sound insulation. A parametric study was conducted to determine the change of the sound insulation due to adding the following six gypsum board wall membrane configurations to the bare structure:

- Gypsum board directly attached with screws
- Gypsum board mounted with screws on 38 mm thick wood furring which were attached to the CLT and spaced 400 mm on centre
- Gypsum board mounted with screws on 38 mm thick wood furring which were attached to the CLT and spaced 600 mm on centre.
- Gypsum board mounted with screws on resilient channels spaced 600 mm on centre. on 38 mm wood furring spaced 400 mm on centre
- Gypsum board mounted with screws on 64 mm thick wood furring which were attached to the CLT and spaced 600 mm on centre
- Gypsum board mounted with screws on 64 mm thick wood-stud frame with 25 mm air gap between the wood frame and CLT panels.

The cavities between the wood furring or studs were filled to at least two-thirds full with glass fibre insulation. To avoid the repetitive testing of wall membrane configurations on all CLT base walls, a method was applied that is also commonly used for concrete and masonry building elements and is in accordance with the ISO 15712-1 [5] prediction method applied for predicting sound insulation in CLT buildings in Task 3 – System Performance. Following this method, a wall membrane configuration was applied to one CLT element and the measured incremental change of sound insulation was added to the sound transmission loss measured for another bare CLT wall. However, special care was taken as the mass of the CLT walls is much closer to the mass of the gypsum board membrane than for masonry walls and therefore, the degree of change in the sound insulation also depended on the weight of the base wall. The research showed that the improvement due to adding the membrane is about 3 dB greater in some frequency bands for the 3-ply CLT than for the 5-ply CLT. Hence, all wall membrane configurations, with the exception of the directly attached gypsum board, were tested on the 5-ply wall and the results were used to predict the performance when added to 3-ply walls, as a conservative approach.

In total, 25 CLT wall assemblies were built and tested. The STC ratings are presented in Table 2, Table 3 and Table 4. Data in the tables shown in black are measured values and data shown in blue are predicted values. Predicted results that achieve sound insulation values of more than STC 60 are indicated as "> 60". The test results as well as detailed descriptions of the test assemblies are given in Appendix A.2.

Table 2: Measured (black) and predicted (blue) STC-ratings of the 5-ply CLT wall with and without gypsum board linings

CLT Wall, 5-ply (Thickness: 175 mm, Mass/Area: 91.4 kg/m^2)			**Membrane on wall surface 2: 2 Layers 12.7 mm Type X gypsum board**					
		Bare	**Directly attached**	**38 mm wood furring @ 400 mm o.c.**	**38 mm wood furring @ 600 mm o.c.**	**Resilient channels @ 600 mm on 38 mm wood furring @ 400 mm o.c.**	**64 mm wood furring @ 600 mm o.c.**	**64 mm wood frame w. studs @ 600 mm o.c. and 12.7 mm air gap**
Bare		**38**						
Membrane on wall surface 1: 2 Layers 12.7 mm Type X gypsum board	**Directly attached**	**43**	**42**					
	38 mm wood furring @ 400 mm o.c.	**45**	**45/46***	**39**				
	38 mm wood furring @ 600 mm o.c.	**50**	**49**	**46**	**56**			
	Resilient channels @600 mm o.c. on 38 mm wood furring @ 400 mm o.c.	**58**	**60**	**55**	**> 60**	**> 60**		
	64 mm wood furring @ 600 mm o.c.	**49**	**48**	**51**	**55**	**> 60**	**54**	
	64 mm wood frame w. studs @ 600 mm o.c. and 12.7 mm air gap	**59**	**59**	**59**	**> 60**	**> 60**	**> 60**	**> 60**

Notes:

- Black numbers: Measured ratings
- Blue numbers: Predicted ratings based on measured ratings
- Further information about the assemblies can be found in in Appendix A.2.
- *: The rating for this configuration has been both measured (black) and predicted (blue)

Table 3: Measured (black) and predicted (blue) STC-ratings of the 3-ply CLT wall with and without gypsum board linings

CLT Wall, 3-ply (Thickness: 78 mm, Mass/Area: 42.4 kg/m^2)		Bare	Membrane on wall surface 2: 2 Layers 12.7 mm Type X gypsum board					
			Directly attached	38 mm wood furring @ 400 mm o.c.	38 mm wood furring @ 600 mm o.c.	Resilient channels @ 600 mm on 38 mm wood furring @ 400 mm o.c.	64 mm wood furring @ 600 mm o.c.	64 mm wood frame w. studs @ 600 mm o.c. and 12.7 mm air gap
Bare		33						
Membrane on wall surface 1: 2 Layers 12.7 mm Type X gypsum board	Directly attached	38	38					
	38 mm wood furring @ 400 mm o.c.	40	44	39				
	38 mm wood furring @ 600 mm o.c.	45/44*	47/46*	50/49*	51/50*			
	Resilient channels @600 mm o.c. on 38 mm wood furring @ 400 mm o.c.	53	56	53	60	> 60		
	64 mm wood furring @ 600 mm o.c.	43	44	49	52	> 60	50	
	64 mm wood frame w. studs @ 600 mm o.c. and 12.7 mm air gap	53	54	57	> 60	> 60	60	> 60

Notes:

- Black numbers: Measured ratings
- Blue numbers: Predicted ratings based on measured ratings
- Further information about the assemblies can be found in in Appendix A.2.
- *: The rating for this configuration has been both measured (black) and predicted (blue)

Table 4: Measured (black) and predicted (blue) STC-ratings of the 3-ply double CLT wall with and without gypsum board linings

Double Leaf 3-ply CLT Wall: CLT 78 mm, Insulation 25 mm, CLT 78 mm (Thickness: 181 mm, Mass/Area: 89.6 kg/m²)		Bare	Membrane on wall surface 2: 2 Layers 12.7 mm Type X gypsum board: Directly attached	38 mm wood furring @ 400 mm o.c.	38 mm wood furring @ 600 mm o.c.	Resilient channels @ 600 mm on 38 mm wood furring @ 400 mm o.c.	64 mm wood furring @ 600 mm o.c.	64 mm wood frame w. studs @ 600 mm o.c. and 12.7 mm air gap
Bare		47						
Membrane on wall surface 1: 2 Layers 12.7 mm Type X gypsum board	Directly attached	53	55					
	38 mm wood furring @ 400 mm o.c.	49	53	43				
	38 mm wood furring @ 600 mm o.c.	56/57*	59	52	> 60			
	Resilient channels @600 mm o.c. on 38 mm wood furring @ 400 mm o.c.	> 60	> 60	57	> 60	> 60		
	64 mm wood furring @ 600 mm o.c.	56	59	55	> 60	> 60	> 60	
	64 mm wood frame w. studs @ 600 mm o.c. and 12.7 mm air gap	> 60	> 60	> 60	> 60	> 60	> 60	> 60

Notes:
- Black numbers: Measured ratings
- Blue numbers: Predicted ratings based on measured ratings
- Further information about the assemblies can be found in in Appendix A.2.
- *: The rating for this configuration has been both measured (black) and predicted (blue)

Table 2 shows that the 5-ply CLT wall with a well-decoupled gypsum board membrane attached to one side achieves the current minimum code requirement. Even better performance (STC >60) is achieved if a well-decoupled gypsum board membrane is added to both sides of the CLT. In general, membranes offer between 5 and 20 STC points of improvement on sound insulation of the 5-ply CLT wall.

The 3-ply CLT wall is thinner and lighter than the 5-ply CLT wall and therefore, the sound insulation of the bare wall is only STC 33 as shown in Table 3. The improvement in the sound insulation with a membrane applied on one side only is similar to the improvement shown for the 5-ply CLT wall.

An additional 2 to 5 STC points are gained if a membrane is applied to both sides (see Figure A.2 - 6).

Table 4 shows that the best sound insulation performance (STC 47) was achieved for a bare wall using the 3-ply CLT double wall (see Figure A.2 - 5). A 3-ply CLT double wall with gypsum board directly attached to only one side is shown to have a sound insulation that exceeds the code minimum of STC 50. Higher sound insulation performances are achieved for most of the other wall membrane configurations as shown in Table 4.

The bare 3-ply CLT double wall is approximately 9 STC points better than the 5-ply CLT wall, but the improvement due to applying membranes is 2 to 9 STC points lower. The smaller improvement due to apply membranes as compared to the 5-ply CLT was due to the good sound insulation of the base wall. Therefore, additional improvements to the sound insulation of the base wall by adding membranes were not as significant as for the 3-ply CLT.

The test results in the tables show that special care must to be taken in both the design of a wall membrane configuration and in the number of fasteners to be used. For example, in the case of the 38 mm wood furring shown in in Table 2, a 6 point improvement to STC 45 was achieved when it was spaced at 400 mm on centre when applied to one side of the CLT. However, the STC rating decreased to STC 39 when it was also added to the second side (see Figure A.2 - 3). The addition of the wood furring to both sides of the CLT created two mass-spring resonances (CLT-air-gypsum board) with identical frequencies. The resonances caused the reduction in the STC rating. However, the table shows that the same wall membrane mounted on wider spaced 38 mm wood furring (600 mm on centre) gave much better performance for both situations (STC 50 and STC 56) (see Figure A.2 - 4). The resonances still existed for the wide spaced furring, but the resonances were shifted down out of the frequency range of interest and therefore, the STC rating was no longer limited by the resonance.

Summary: Cross Laminated Timber (CLT) Walls

- The 5-ply CLT wall with a well-decoupled gypsum board membrane achieves STC 50 or higher, which is the minimum 2010 NBCC sound insulation requirement for noise between dwellings.
- The double 3-ply CLT wall shows the highest sound insulation performance was 9 STC points higher than the 5-ply CLT wall.
- Membranes are more effective on single CLT element walls than on double 3-ply walls, with improvements from 5 to 20 STC points.
- Membrane configurations should be selected carefully to avoid a reduction in the STC ratings.

4. Floor Assemblies

Floor assemblies which separate a residential unit from others spaces in the building must fulfill the same requirement (STC 55 or greater between dwellings and adjacent elevator shafts and refuse chutes and STC 50 or greater between dwellings and all other spaces in a building) for direct airborne sound insulation as walls. In addition, floor assemblies are also “excited” by people walking on them and noise is transmitted as so-called impact noise into the spaces below. Even though impact noise is a very common source of complaints by building occupants and even though many other Organization for Economic Co-operation and Development (OECD) countries include impact noise requirements in their building codes, there is no requirement for the impact sound insulation (IIC rating) of floors in the current 2010 National Building Code of Canada. However, impact noise data was collected for this research project because an acceptable impact sound insulation is important for market acceptance of buildings. The IIC rating was determined in accordance with ASTM E989 [6] from data measured in accordance with ASTM E492 [7].

The wood-frame floor assemblies used in low-rise and mid-rise wood buildings are similar, since the floors used on different levels of the buildings typically do not have to be designed to resist higher loads, unlike loadbearing wall assemblies which must be designed to support the higher loads at the lower levels. Therefore, sound insulation data was already available for wood-frame floors. Therefore, this research component focused exclusively on CLT floor assemblies since only limited data existed in Canada for this relatively-new building system.

The same methodology described in this document for CLT walls was applied for testing and predicting the direct airborne and the impact sound insulation of CLT floor assemblies. The test series was structured as a parametric study and two base CLT floor structures were considered:

- 5-ply CLT floor, thickness: 175 mm; mass-per-area: 92 kg/m^2
- 7-ply CLT floor, thickness: 245 mm; mass-per-area: 130 kg/m^2

Originally, 3-ply CLT floors (thickness: 105 mm) were also considered for testing, but this plan was modified because the allowable span of 3-ply CLT floors is limited due to vibration serviceability requirements. 7-ply CLT floors were used instead since they have a greater allowable span and since they became more commonly produced during the project.

As with the CLT wall study, the test series focused mainly on ceiling treatments using two layers of 12.7 mm thick Type X gypsum board. The following four gypsum board ceiling configurations were added to the bottom side of the 5-ply CLT floor:

- 2 layers of 12.7 mm thick Type X gypsum board directly attached
- 2 layers of 12.7 mm thick Type X gypsum board attached to 38 mm thick wood furring spaced 600 mm on centre with 38 mm of glass fibre insulation in the cavity
- A ceiling with 2 layers of 12.7 mm thick Type X gypsum board on metal channel grillage suspended 150 mm below the bare CLT surface and with 140 mm of glass fibre insulation in the cavity
- A ceiling with 15.9 mm thick Type X gypsum board on metal channel grillage suspended 150 mm below the CLT element. Two layers of 12.7 mm thick Type X gypsum board were directly attached to the bottom side of the CLT. The ceiling cavity was filled with 140 mm of glass fibre insulation.

The following seven floor topping configurations were installed on top of the 5-ply CLT floor:

- 38 mm thick concrete topping on a closed-cell polyethylene (PE) foam interlayer
- 38 mm thick concrete topping on a wood fiberboard interlayer
- 38 mm thick concrete topping on a recycled fibre felt interlayer
- 38 mm thick concrete topping on three different commercial recycled rubber interlayer products
- 38 mm thick concrete topping directly on CLT (no bond)

For the floor topping series of tests, a prefabricated concrete topping was manufactured that was lifted with a crane to simplify the exchange of the interlayer materials. This allowed for a comparison of the incremental sound insulation performance of the interlayer materials. This study was necessary as the interlayer may behave differently on CLT floors than on much lighter wood-framed floors or much heavier concrete floors for which data is already available.

Twelve assemblies which used the bare CLT floors as a base were built and tested. The STC and IIC ratings of forty generic CLT floor designs based on the CLT floors are shown in Table 5 and Table 6. Ratings in the tables which are shown in black are measured values and values shown in blue are predicted values. The predicted values were estimated based on combinations of improvements which resulted from adding a topping or ceiling treatment to the bare assembly. These improvements were combined to arrive at the predicted values for cases including both a floor topping and a ceiling treatment.

Table 5: Measured (black) and predicted (blue) STC and IIC-ratings (in brackets) of 5-ply CLT floors with and without floor toppings and gypsum board ceilings

CLT Floor 5-ply: (Thickness: 175 mm, Mass/Area: 91.4 kg/m^2) **STC (IIC)**		Bare	Gypsum Board Ceiling: 2 Layers 12.7 mm thick Type X gypsum board – Directly attached	Gypsum Board Ceiling: 38 mm wood furring @ 600 mm o.c.	Gypsum Board Ceiling: As hung ceiling on metal grillage 150 mm below CLT surface	Gypsum Board Ceiling: Directly attached to CLT and additional acoustic hung ceiling with 15.9 mm thick Type X on metal grillage 150 mm underneath
Bare		41 (25)	42 (25)	50 (36)	68 (56)	67 (55)
Floor Toppings:	38 mm concrete topping on 9.5 mm closed-cell foam	53 (36)	53 (40)	59 (50)	76 (66)	74 (64)
	38 mm concrete topping on 12.7 mm wood fiberboard	52 (35)	53 (38)	59 (47)	76 (64)	73 (63)
	38 mm concrete topping on 19 mm recycled fabric felt	59 (42)	59 (46)	63 (45)	77 (61)	75 (60)
	38 mm concrete topping on 12.7 mm rubber nuggets on foil	53 (46)	53 (44)	59 (49)	73 (65)	70 (63)
	38 mm concrete topping on 8 mm shredded rubber mat	52 (38)	52 (38)	58 (48)	76 (66)	74 (64)
	38 mm concrete topping on 17 mm shredded rubber mat	54 (44)	54 (43)	60 (51)	76 (67)	73 (65)
	38 mm concrete topping not bonded to CLT	49 (28)	49 (32)	56 (41)	75 (60)	74 (60)
	2x12 mm cement board on 12.7 mm wood fiberboard	48 (46)	48 (38)	54 (47)	69 (63)	68 (60)
	38 mm gypsum concrete on 9.5 mm closed-cell foam	50 (41)	50 (41)	58 (49)	72 (63)	73 (63)

Notes:

- Black numbers: Measured ratings
- Blue numbers: Predicted ratings based on the measured ratings
- Numbers in brackets are the IIC ratings
- For all gypsum board ceilings with cavities: the cavity between the furring the ceiling was filled with glass fibre batts (thickness 38 mm for furring and 140 mm for hung ceiling).

Table 6: Measured (black) and predicted (blue) STC and IIC-ratings (in brackets) of 7-ply CLT floors with and without floor toppings and gypsum board ceilings

CLT Floor 7-ply: (Thickness: 245 mm, Mass/Area: 130 kg/m²) **STC (IIC)**		Bare	**Gypsum Board Ceiling: 2 Layers 12.7 mm thick Type X gypsum board**			
			Directly attached	38 mm wood furring @ 600 mm o.c.	As hung ceiling on metal grillage 150 mm below CLT surface	Directly attached to CLT and additional acoustic hung ceiling with 15.9 mm thick Type X on metal grillage 150 mm underneath
Bare		**44 (30)**	**45 (29)**	52 (40)	71 (60)	70 (58)
Floor Toppings:	**38 mm concrete topping on 9.5 mm closed-cell foam**	**56 (44)**	**56 (44)**	61 (53)	78 (69)	76 (67)
	38 mm concrete topping on 12.7 mm wood fiberboard	55 (42)	55 (41)	61 (51)	79 (67)	76 (66)
	38 mm concrete topping on 19 mm recycled fabric felt	61 (49)	61 (50)	65 (48)	80 (64)	77 (62)
	38 mm concrete topping on 12.7 mm rubber nuggets on foil	56 (49)	56 (47)	61 (51)	76 (67)	73 (65)
	38 mm concrete topping on 8 mm shredded rubber mat	54 (43)	55 (42)	61 (52)	79 (70)	76 (68)
	38 mm concrete topping on 17 mm shredded rubber mat	56 (48)	56 (46)	62 (53)	78 (69)	75 (67)
	38 mm concrete topping not bonded to CLT	51 (35)	52 (36)	59 (46)	78 (66)	76 (62)
	2x12 mm cement board on 12.7 mm wood fiberboard	51 (44)	51 (41)	57 (50)	73 (66)	70 (64)
	38 mm gypsum concrete on 9.5 mm closed-cell foam	52 (46)	52 (44)	60 (51)	76 (67)	75 (65)

Notes:

- Black numbers: Measured ratings
- Blue numbers: Predicted ratings based on the measured ratings
- Numbers in brackets are the IIC ratings
- For all gypsum board ceilings with cavities: the cavity between the furring the ceiling was filled with glass fibre batts (thickness 38 mm for furring and 140 mm for hung ceiling).

The data in the tables shows that neither the bare 5-ply CLT floor (STC 41, IIC 25) nor the bare 7-ply CLT floor (STC 44, IIC 30) meet the NBCC minimum STC rating requirements.

Applying a topping to the 5-ply CLT floor improves the STC rating to within the range of 48 to 59 and for the 7-ply CLT floor within the range of 51 to 61. Adding only a floor topping, or in combination with directly attached gypsum board, increases the STC ratings above the code minimum. However, the impact sound insulation of these assemblies does not satisfy the typical market demands, with values far less than the IIC 50 that is used in many design guidelines as the minimum requirement (see for example, Reference [3]). Configurations which include decoupled ceiling solutions are the preferable design options to reduce vertical impact noise.

The improvement resulting from the ceiling membrane configurations alone varied between 1 and 27 STC points for the 5-ply and 7-ply CLT floors. The hung gypsum board ceilings offered the best STC and IIC improvements; approximately 26 and 30 points improvement, respectively, as compared to floor toppings (7 - 18 and 3 - 19 points improvement, respectively) (see Figure A.2 - 7).

The hung gypsum board ceilings in combination with the floor toppings were found to be very effective for achieving high levels of sound insulation for both airborne and impact sound insulation.

Summary: Cross-laminated Timber (CLT) Floors

- A floor topping and/or a decoupled ceiling are necessary for 5-ply or 7-ply CLT floors to achieve a rating of STC 50 or higher, which is the 2010 NBCC minimum sound insulation requirement.
- The best floor assemblies of those tested with respect to sound insulation performance are those with both a topping and a hung gypsum board ceiling.
- Only CLT floors with decoupled ceilings achieve the levels of impact insulation expected by market demand (IIC > 50).

5. System Performance

In addition to the measurements of the sound insulation of individual walls and floors, this research project also investigated the airborne and impact sound insulation of combined building systems for which floors and walls are coupled together to form part of a mid-rise wood building. It is important to distinguish between the airborne and impact sound insulation of the individual building elements and the combined building system. The sound insulation performance between rooms separated by a wall or floor in an actual building might be much less than the sound insulation performance of just the separating wall or floor as measured in a direct sound transmission facility. The reason for the difference is the flanking sound transmission between actual rooms which includes the elements adjoining the separating element. To account for flanking transmission and to give a more realistic requirement for airborne sound insulation which better matches with what is perceived by occupants, a code change was proposed to introduce a new requirement for an Apparent Sound Transmission Class (ASTC) rating in the National Building Code of Canada in 2015. As the code change is not yet finalized, the new required performance is not yet set. However, an ASTC rating of 47 is expected to be the new minimum requirement for airborne sound insulation. This performance is usually met by most building elements with a direct sound insulation of STC 50, combined with the appropriate design of the element junctions (e.g. wall-to-wall and wall-to-floor junctions).

In anticipation of the proposed code changes, the system performance of wood-frame and cross-laminated timber (CLT) structures for mid-rise wood buildings was assessed in this research project using two different approaches as outlined in the following sections.

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5.1. System Performance in Wood Frame Mid-Rise Buildings

For lightweight, framed building systems, a special facility must be used to measure the sound transmission through the separating element and through the flanking paths involving the building element junctions. Once the measurements are made in the facility, changes in the sound insulation performance due to adding floor toppings or changing the gypsum board membrane (e.g. mounted to resilient channels instead of directly attached) can be predicted based on the changes measured for similar structures.

For this project, nine full-scale eight room sections (i.e. one base assembly with eight variations) of a mid-rise wood-frame building were characterized in the NRC's Flanking Sound Transmission Facility. Each specimen consisted of eight walls and four floors that were coupled at two wall-to-wall junctions, two loadbearing floor-to-wall junctions where the floor joists were supported and two non-loadbearing floor-to-wall junctions that were parallel to the floor joists.

The base assembly consisted of the following elements (a detailed description is given in Appendix A.3):

- 2 axial and lateral loadbearing walls:
  2x4 tripled wood studs spaced 400 mm on centre in staggered rows with 2x6 single footer and double header, 2 layers of 12.7 mm thick Type X gypsum board directly attached on both sides of the frame, a 15.9 mm thick plywood shear membrane on one side between the gypsum board and the framing members, cavities between one set of studs filled with 90 mm of glass fibre insulation
- 2 axial loadbearing walls:
  Similar to the above assemblies, but without the 15.9 mm thick plywood shear membrane
- 4 lateral loadbearing walls:
  2x4 single wood studs spaced 400 mm on centre in staggered rows with 2x6 single footer and double header, 2 layers 12.7 mm thick Type X gypsum board directly attached on both sides of the frame, a 15.9 mm thick plywood shear membrane on one side between the gypsum board and the framing members, cavities between one set of studs filled with 90 mm of glass fibre insulation
- 4 wood-frame floors:
  302 mm thick wood I-joists spaced 400 mm on centre with a single layer 15.5 mm thick OSB subfloor, 2 layers of 12.7 mm thick Type X gypsum board mounted on resilient channels spaced 400 mm on centre as ceiling, cavities between I-joists filled with 150 mm of glass fibre insulation.

The sound transmission was measured between all of the possible room pairs. The measurements included the direct sound transmission through the separating elements as well as the flanking sound transmission through the elements that were coupled to the separating element at the building junctions. By repeating the tests with some of the wall surfaces successively shielded to suppress specific transmission paths, an extensive set of data was collected that allowed the extraction of sound insulation data for all of the flanking paths of interest.

In addition, the base test specimen was modified to investigate the effect of changes using only a limited set of tests. The modifications included the:

- Removal of the 15.9 mm thick plywood shear membrane in two of the four lateral loadbearing walls
- Addition of a 38 mm thick gypsum concrete floor topping on a 9.5 mm thick polyethylene closed-cell foam interlayer in one room
- Addition of two layers of 12.7 mm thick cement board on 12.7 mm thick wood fiberboard as floor topping in one room
- Replacing the directly attached, two layers of 12.7 mm thick Type X gypsum board on the walls in two of the rooms with two layers of 12.7 mm thick Type X gypsum board attached to resilient channels

- Mounting of one layer of 15.9 mm thick Type X gypsum board to resilient channels which were attached to the studs of the walls in two rooms
- Addition of tie-downs in four rooms
- Detaching the floor in one of the four rooms to simulate exterior walls as a T-junction for axial loadbearing and non-loadbearing cases
- Modifying the framing of the "exterior walls" from 2x4 staggered wood studs to 2x6 wood studs with exterior cladding
- Replacing the glass fibre insulation with spray foam insulation in one wall in one room

In total, the sound transmission was measured between over 550 room pairs for airborne sound and the impact sound was measured between over 400 room pairs. Measured data for the 26 unique wall-to-wall, 20 horizontal wall-to-floor/ceiling and 22 vertical floor-to-wall junctions with junction descriptions is given in Appendix A.3. The sound insulation values for all of the paths predicted from the measured data sets were gained through thorough data vetting and analysis. The same paths were predicted through many measurements and analysis approaches and finally averaged over larger sets to reduce the measurement and prediction uncertainties. Data for similarly designed junctions were also averaged, but axially non-loadbearing and loadbearing junctions were always averaged separately.

In general, it was found that the sound transmission values via flanking paths involving ceilings on resilient channels as well as side walls with directly attached gypsum board or shear membranes, were is in most cases sufficiently suppressed to achieve the proposed future requirement of ASTC 47 or higher.

For the side-by-side room case (horizontal transmission) involving just the bare floor, it was found that the flanking sound insulation was quite low. For a subfloor that was continuous across the junction, the flanking sound insulation of the floor-to-floor path was even less than the direct sound insulation of the staggered wood stud walls with directly attached gypsum board (see Figure A.3- 6). Floor toppings had to be added to the bare base floor to improve the flanking sound insulation (see Figure A.3 - 7). For example, approximately 10 STC points were gained by applying a 38 mm gypsum concrete topping on a 9.5 mm thick closed-cell foam interlayer to the floor on one side of the wall.

For the one-above-another room case (vertical transmission) without a topping, it was found that the direct floor-ceiling path was the lowest for sound insulation. However, by adding a topping to the floor of the upper room, ASTC values in the mid-60s could be achieved.

Configurations which included gypsum board membranes mounted on resilient channels for the separating and flanking walls were necessary to achieve the higher levels of sound insulation which are often demanded by the market. Resilient channels increased the flanking STC by approximately twice as much as the direct STC (4 versus 8 points).

The inclusion of a wood shear membrane is almost insignificant for direct and vertical flanking transmission paths, but the wood shear membrane reduces the flanking STC by approximately 3 points for horizontal paths. However, this reduction only becomes relevant for high sound insulating systems with ASTC greater than 60 as this path is already highly attenuated.

Tie-downs were found to have no significant influence on either the horizontal or vertical flanking sound transmission between rooms (see Figure A.3 - 8).

Using 2x6 wood stud walls instead of 2x4 staggered wood stud walls had no effect on the vertical flanking paths for both the axial loadbearing and non-loadbearing walls. However, for the horizontal flanking paths, the flanking sound insulation decreased by 3 STC points over the loadbearing junction and was increased by 3 STC points over the non-loadbearing junction. Note that these flanking paths have quite high attenuation and only become significant when ASTC values of over 60 are to be achieved.

Replacing the glass fibre insulation with spray foam insulation had no significant effect on either the vertical or horizontal flanking paths. However, the STC ratings of the direct paths were reduced by 4 STC points for non-loadbearing walls (STC 38 to STC 34) and by 6 STC points for loadbearing walls (STC 42 to STC 36). These results are compared to those for interior non-loadbearing and loadbearing walls that achieve STC values in the low 50s in Figure A.3 – 9 and Figure A.3 - 10.

Summary: System Performance in Wood-frame Midrise Buildings

- Of the junctions evaluated, axial loadbearing junctions (tripled studs junctions) improve the sound insulation of side-by-side rooms (horizontal flanking) more than axial non-loadbearing junctions. The opposite is true for vertical one-above-another rooms (vertical flanking).
- The use of resilient channels improved the flanking sound insulation by approximately double that of the direct fixed case (4 versus 8 points).
- The negative effect of wood shear membranes on vertical flanking sound transmission is only relevant for systems with an ASTC greater than 60.
- Tie-downs have no significant effect on direct or flanking transmission for the assemblies tested.
- Floor toppings can improve the direct sound insulation by 15 STC points and the flanking transmission by 10 ASTC points when applied to the floor on one side of a wall (i.e. in one room)
- For rooms side by side, the effect of floor topping on the flanking sound insulation can be doubled when applied to the floors in both rooms.
- In cases where the ASTC values are lower than 60, exterior walls have no effect on the flanking sound transmission for rooms one-above-another (vertical flanking) and a negligible effect for rooms side-by-side (horizontal flanking).
- The tested exterior walls have STC values in the high 30s to low 40s, much lower than interior walls (around STC 50).
- The use of spray foam insulation instead of fiberglass insulation reduces the direct sound insulation by approximately 5 STC points, but does not significantly influence the flanking sound insulation.

5.2. System Performance of Cross Laminated Timber (CLT)

In terms of sound insulation, CLT elements can be approximated as monolithic and as more homogeneous than wood-framed elements and therefore are comparable to masonry and concrete building elements. This approximation allows for a more flexible prediction of the apparent airborne and impact sound insulation utilizing the ISO 15712 framework [5]. The ISO 15712 framework uses as input data the measured sound insulation data of the elements and the measured vibration attenuations at the junctions. The sound insulation data of the elements was collected during the CLT wall and floor study in this research project as described in sections 3.2 and 4.

For the measurement of the vibration attenuation at the junction according to the standard, ISO 10848 [8], an additional test set-up was designed where full scale CLT walls and floors were connected to form isolated building junctions. Floor-to-wall junctions required more effort for testing than wall-to-wall junctions as the floors had to be supported at their free edges. A dead load for simulating the load from the upper building storeys was applied during the testing in order to ensure that the interfaces between the elements were compressed as in a real building, since this could affect the junction coupling.

Vibration transmission was measured for the following wall-to-wall junctions:

- Cross-junction (X-junction) and T-junction, continuous 5-ply wall and 5-ply wall(s) butted against continuous elements
- X-junction and T-junction, continuous 5-ply wall and 3-ply wall(s) butted against the continuous element
- X-junction and T-junction, continuous 3-ply wall and 5-ply wall(s) butted against the continuous elements
- X-junction and T-junction, continuous 3-ply wall and 3-ply wall(s) butted against the continuous elements

For all of the wall-to-wall junctions, the elements were connected with 90 mm angle brackets fastened with screws on both sides of the butted elements and spaced 600 mm on centre.

Additional testing was done for the X-junction with continuous 5-ply wall and 3-ply wall(s) butted against the continuous element to evaluate the effects of using different methods to connect the elements. The junctions were:

- The lower and upper walls were connected with 90 mm angle brackets fastened with screws on both sides of the walls and spaced at 300 mm on centre
- The lower wall was connected with long self-tapping screws spaced 300 mm on centre and driven from the top through the floor into the lower wall. The upper wall was connected with 90 mm angle brackets fastened with screws on both sides of the walls and spaced 300 mm on centre
- As in the previous case, with additional hold-downs connecting the upper and lower walls on both sides at each end

The configuration using angle brackets (method 1 as listed above) was also applied in the case of a T-junction in which the 3-ply walls were discontinuous but the 5-ply floor did not extend beyond the walls on one side.

The X- and T-junctions with continuous 5-ply wall and 5-ply wall(s) butted against continuous elements were also tested using angle brackets to connect the elements. In addition, the X-junction was also tested after hold-downs were added to the brackets.

The coupled CLT elements were excited with a hammer and the difference of the vibration levels between the source element and receiver element were measured. The measured data could be adjusted to the geometry of the coupled CLT elements in real buildings as input data for the ISO 15712 predictions. Detailed junction descriptions and flanking path data for the bare vertical junctions are given in Appendix A.4.

The results show that there is a difference in the attenuation of the wall-to-wall and floor-to-wall junctions built of the same CLT elements (see Figure A.4 - 8). This is probably due to the orientation of the wood in the outer plies of the CLT elements.

The results also show that the vibration attenuation between the upper and lower walls as well as between the floor and the lower wall is higher for the connection with the self-tapping screws than for the connection using angle brackets (see Figure A.4 - 10). Therefore, it is concluded that the angle bracket results give more conservative results and were used for the subsequent tests as a conservative estimate for both situations.

The use of glue increases the sound transmission between the attached elements and lowers the performance in that direction.

The load applied to the wall-floor junction did not have an influence on the junction attenuation (see Figure A.4 - 7).

In general, the results show that vibration transmission from and to the elements that are connected with angle brackets or self-tapping screws is sufficiently attenuated so that the flanking sound insulation is acceptable even without the use of additional treatments of the surfaces. This is the case for flanking paths (without hold-downs) between one above another rooms with the CLT floor elements resting on the walls and upper walls resting on the floor. Hold-downs create a short between the upper and lower wall, decreasing the attenuation across the discontinuous junction (see Figure A.4 - 9).

The incremental improvements of sound insulation due to the addition of gypsum board wall membranes was measured and the data was added to the predicted flanking sound transmission loss of the bare structure to predict the sound insulation performance in CLT buildings with wall membranes.

Vibration transmission in across continuous CLT elements is not well attenuated and dominates the flanking sound transmission for the side-by-side room case. Therefore, additional measures, such as floor toppings, decoupled gypsum board ceilings, decoupled gypsum board wall membrane configurations or treatments such as structural breaks in the CLT elements at the junction, are necessary to improve the flanking sound insulation to achieve the possible new code requirement for the ASTC.

Summary: System Performance of Cross-laminated Timber (CLT)

- The vibration attenuation at the "same" wall-to-wall and floor-to-wall junctions is different, probably due to the orientation of the outer plies in the CLT element.
- The use of self-tapping screws to attach the floor to the lower wall slightly increases the vibration attenuation through the junction as compared to brackets. A higher vibration attenuation is better is better in terms of the flaking sound insulation.
- The amount of load applied on the floor-to-wall CLT junction has negligible effect on the CLT junction attenuation.
- For rooms one above another, the use of hold-downs creates a bridge between the two walls which decreases the vibration attenuation of the vertical wall-to-wall discontinuous path of the floor-to-wall junction. This can result in the discontinuous wall-to-wall flanking path becoming a significant contributor to the transmission of noise between the rooms.
- Floor toppings or ceiling membranes are needed to reduce the transmission of noise along the continuous flanking path for the side-by-side room case.

6. Review Proposed Code Changes for the NBC, Networking, and Other Issues

During the whole research project, the acoustic research team closely monitored the activities of the NBCC standing committees considering changes on sound insulation requirements for the NBCC 2015. The research and research plans described above reflect the results of these activities so far and various anticipated possible developments. However, since the code development is an ongoing process in parallel with this work, and the decisions of the code committees are not yet finalized, the final conclusions on the level of required sound insulation performance cannot be made.

The acoustic research was conducted in collaboration with partners and co-ordinated with other research activities in this field in Canada and abroad including the following initiatives:

- Support and supervision of Ph.D. research of Armin Eslami (NEWBuildS) by NRC researchers
- Meeting of acoustic researchers from FPInnovations and NRC
- Meeting of an NRC researcher with researchers at the German wood construction centre in Rosenheim, Germany. Important information was gathered during this meeting for the CLT junction test series and for the design of the experimental set-up as researchers conducted similar research for the sound insulation design of the tallest wooden building (8-storey) constructed using CLTs in Germany.
- NRC researcher meeting with Swedish researchers to gain information about their experience with midrise wooden buildings, and visiting mid-rise wooden building and research facilities in Sweden.

7. Conclusions

As part of the Mid-rise Wood Buildings project, acoustic performance data was measured for wood building assemblies and systems. Thousands of solutions were found that not only satisfy the requirements in the current 2010 National Building Code of Canada (NBCC) for sound insulation as well as other important disciplines (fire, hygrothermal, structural), but which also satisfy the proposed 2015 NBCC sound insulation requirements.

The sound insulation requirements proposed for the 2015 NBCC represent a change from requirements which only limit the sound transmitted between adjacent dwellings through only the separating partition (direct sound transmission class rating – STC rating) to requirements which limit the sound transmitted through all paths including the direct and the flanking paths (apparent sound transmission class rating – ASTC rating).

Before the start of this project, a wide range of sound insulation performance data already existed for the design details of low-rise wood buildings. However, not all of these design details could be directly adopted for mid-rise wood constructions. The challenge for mid-rise and taller wood buildings is that the higher axial and lateral loads on the walls require design changes that strongly influence the sound transmission between the rooms of the buildings. In this project, systematic studies were performed on walls, floors and complete wall-floor systems, which led to much larger sets of solutions.

Solutions were found specifically for assemblies based on lightweight wood-frame walls and floors as well as cross-laminated timber (CLT) assemblies. The parameters investigated in the wood-frame wall studies included framing variants, sheathing and blocking variants, tie-downs, and insulation types. The wood-frame floor solutions available for low-rise wood buildings could also be used for mid-rise buildings as they have similar design details when used for mid-rise buildings. The CLT studies included parameter variations of furring and cladding for the walls and topping and ceiling for the floors. These solutions will be made available by 2015 through guides and soundPATHS which is a web-based ASTC prediction tool that NRC has been developed with industry partners (http://www.nrc-cnrc.gc.ca/eng/solutions/advisory/soundpaths/index.html).

8. References

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[2] Su, Joseph et al., “Wood and Wood Mid-Rise Buildings – Phase 1: Scoping Study”, NRC-Client Report B4726, 2011

[3] ASTM E413-04 “Classification for Rating Sound Insulation” ASTM International

[4] ASTM E90- 09 “Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements”, ASTM International

[5] ISO 157121:2005; “Building Acoustics – Estimation of acoustic performance of buildings from the performance of elements – Part 1: Airborne sound insulation between rooms”, ISO-Standard, 2005

[6] ASTM E989-06 “Standard Classification for Determination of Impact Insulation Class (IIC)”, ASTM International

[7] ASTM E492-09: “Standard Test Method for Laboratory Measurement of Impact Sound Transmission through Floor-Ceiling Assemblies Using the Tapping Machine”, ASTM International

[8] ISO 10848-1:2010; “Acoustics – Laboratory measurement of the flanking transmission of airborne and impact sound between adjoining rooms – Part 4: Application to junctions with at least one heavy element”, ISO-Standard, 2010

A.1 Direct Sound Insulation of Wood Frame Wall Assemblies for High Axial and Lateral Loads

A.1.1 Background

The National Building Code Canada 2010 has existing requirements of Sound Transmission Class STC 50 or higher for direct airborne sound insulation (STC-rating) for interior wall assemblies that separate a residential unit from other spaces in the building. Wall assemblies for mid-rise wooden buildings are very different from assemblies that are commonly used for low-rise wooden buildings, as load bearing wall assemblies on the lower levels of mid-rise buildings have to resist higher axial loads due to the weight of the upper storeys and higher lateral loads in case of seismic events or wind loads. Wood framed wall assemblies achieve this by strengthening of the framing and shear bracing as well as by other measures (e.g. tie-downs). Some of these may have profound effects on the sound insulation performance and require additional sound insulation treatment as shown in this research project.

An earlier NRC study [1] gives some insight into the sound insulation of framed shear wall assemblies; however, the data is limited to designs that are typically for low rise residential buildings and does not include novel wood construction technologies such as framed mid-ply shear walls (developed by FPInnovations).

The study on direct sound insulation of framed walls of the mid-rise wood research project was structured into two consecutive phases. The first was a preparatory study to identify important parameters for load bearing wall design and the second was a round of testing with a limited number of specimens and additional framing variants to increase design options. Both phases focused mainly on the design of the framing and shear bracing. Walls framed with staggered and double rows of studs were identified as the most suitable wall designs for mid-rise wood buildings. However the limited project timeline allowed only bracketing of the lower bound of allowable sound insulation. For walls with single or staggered rows of studs, all studs were attached to the same header and footer and thus provided much less sound insulation than walls with two stud rows where both have their own decoupled header and footer. The effect of structural changes on sound insulation is more profound with one header and footer and some walls might not meet minimum code requirement for sound insulation anymore. The test series was structured as a parametric study where changes in sound insulation can be related to a single structural modification of the specimen and measured data were used to predict sound insulation performance of similar but not tested assemblies.

A.1.2 Test Method

Testing is conducted according to ASTM E90 test protocol [2] for direct airborne sound transmission testing through walls and floors in NRC's Wall Sound Transmission Test Facility. In this facility that conforms to ASTM E90 full scale wall assemblies are placed in a testing frame with a 3.66 m wide and 2.44 m high test opening between two decoupled rooms of app. 250 m^3 and 140 m^3 room volume. The facility is equipped with an automated sound and measurement system for data acquisition and post processing. Sound transmission loss is measured in both directions – from the large to the small room and vice-versa – and results were averaged to reduce measurement uncertainty due to e.g. calibration errors. The wall specimens with different frames were constructed in two movable frames to make testing even more efficient. To refer sound insulation changes to the right reference case the wall specimens were identified with N (North Frame) and S (South Frame) in the specimen-id number. A drawing of the NRC Wall Sound Transmission Facility is given in Figure A.1 - 1.

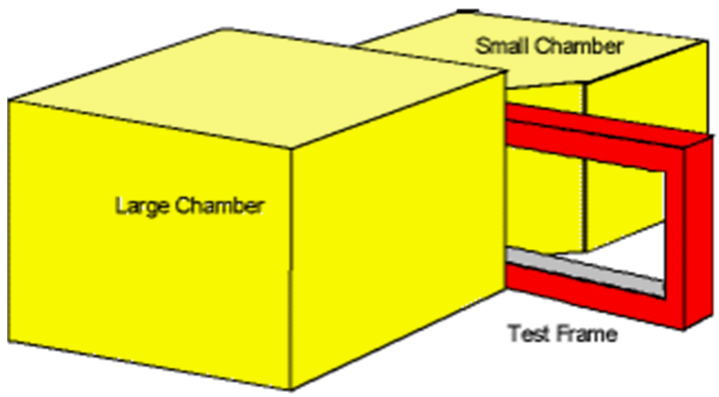


Figure A.1 - 1: NRC's Wall Sound Transmission Facility with the specimen mounted in a movable test frame between two decoupled rooms (room volume: app. 250 m^3 and 140 m^3)

The frequency dependent sound transmission loss is measured for all assemblies in an extended frequency range from 31.5 Hz to 10 kHz, although only a limited range is considered in the Sound Transmission Class (STC) single-number-rating according to ASTM E413 [3].

A.1.3 Preparatory Shear Wall Study on 2x4 Staggered Stud Walls

To expand the knowledge on axial and lateral load bearing walls as well as to get a tie-back to existing data, a preparatory test series was conducted to identify the design parameters that are important for the sound insulation of high capacity shear walls and axially load bearing walls for mid-rise wood frame construction. The knowledge gained in this series was used to plan consecutive measurements on walls designed for mid-rise buildings to demonstrate code compliance with acoustic requirements.

The preparatory study included the following 5 steps, each of which to assess the importance of one design parameter that was changed systematically:

1. Benchmarking
2. Effect of shear membrane material and thickness
3. Effect of blocked and un-blocked shear wall configuration
4. Effect of build-up end columns
5. Effect of doubling/tripling studs
6. Effect of decreasing stud spacing

A.1.3.1 Specimens

The preparatory study was conducted on a 2x4 staggered stud wall assembly, because this wall type is likely to be used in mid-rise buildings as separation with sound insulation requirement of STC 50 or higher. Design modifications considered in this preparatory study were all expected to affect the sound insulation of walls with staggered studs as much or even more than of other wall types, like e.g. double frame walls, that are likely to be used in mid-rise construction, because sound insulation of conventional assemblies with staggered rows of studs for low-rise buildings is much closer to STC 50, i.e. some of these benchmark assemblies are listed in the current code tables with STC 55/60. Thus, the “safety-margin” towards the code requirement is much less for these walls than for instance for double frame wall assemblies that all achieve STC >60, if sound insulation is compromised by design modifications. A full list of all tested specimens can be found in Section A.1.3.2 of this report.

A.1.3.1.1 Framing variants

Base Framing

For benchmarking and tie-back to old data measurements were conducted on a 2x4 staggered stud wall with studs spaced 400 mm on centre as shown in Figure A.1 - 2. The wall was framed with a single 2x6 foot plate and a double 2x6 head plate. For the base wall design a 3.60 m long section was assumed and the gypsum board of one wall membrane was caulked and taped and not attached to a stud to avoid increase of sound insulation due to the additional constraint.

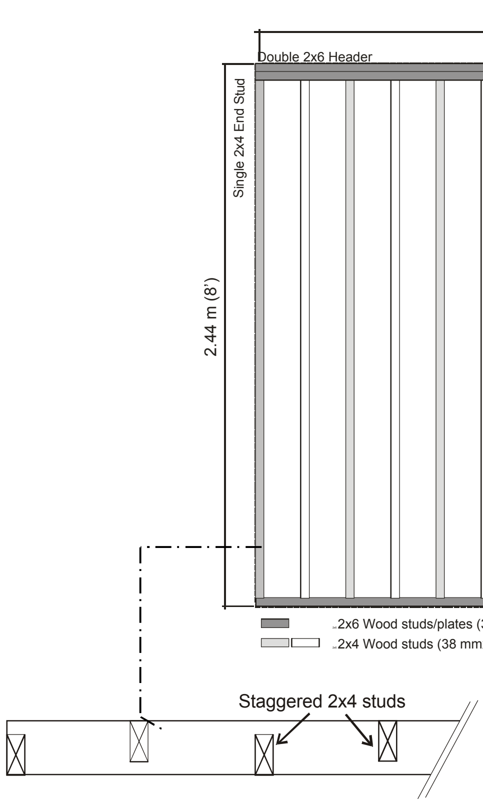


Figure A.1 - 2: Framing details for benchmark 2x4 staggered stud wall with studs spaced 400 mm on centre

End studs and end columns

Further, the effect of 2x6 end studs that couple the gypsum membranes of both wall sides was investigated because this way of framing is often found on construction sites at the wall ends or around openings, e.g. doors, to ensure fastening of the gypsum board membranes of both wall sides as shown in Figure A.1 - 3. Heavy build-up end columns are used to withstand the compression load in mid-rise wooden buildings that are caused by so-called tie-downs. The columns are fabricated from several wall studs that joint together to form an end stud. In this preparatory study the effect of these columns on the sound insulation was investigated and five additional 2x6 wood studs were added to each end stud of the benchmark walls as shown in Figure A.1 - 4.

The end studs and columns were expected to increase the coupling between the gypsum board leaves and thus to compromise the sound insulation of the wall. The change of sound insulation due to the coupling by the end studs was considered as an additional transmission path that could be accounted for depending on the wall geometry and number of end columns or studs in the separating element.

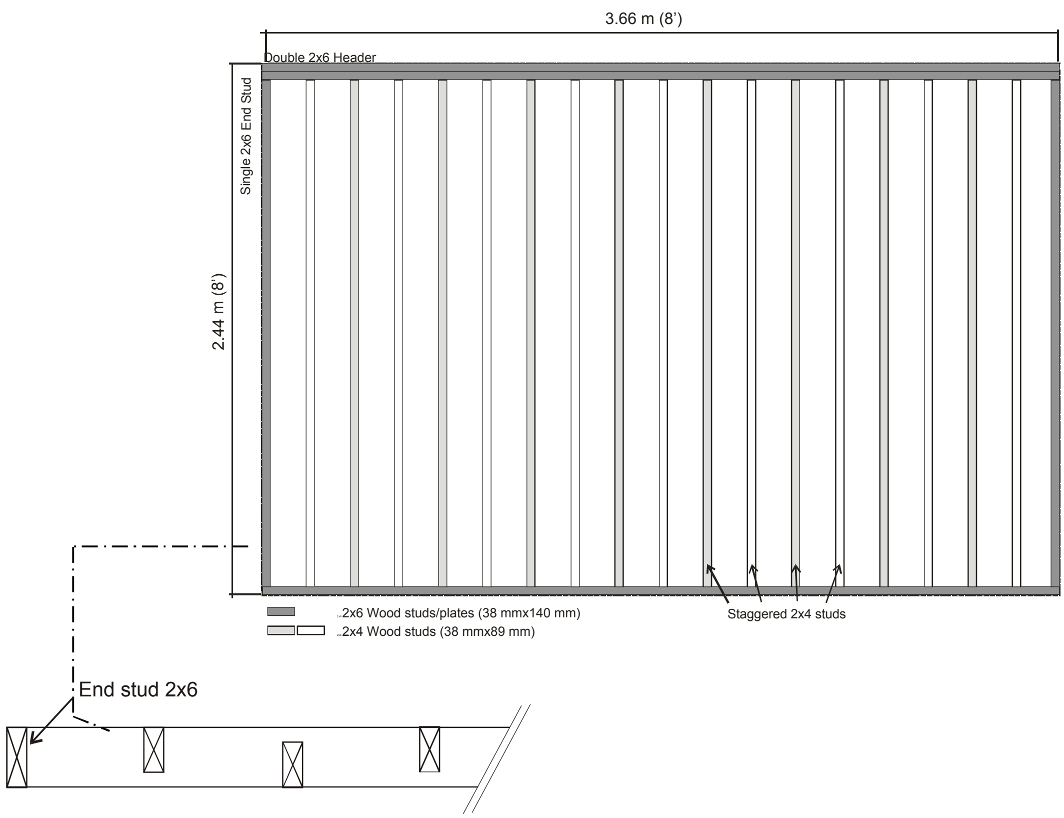


Figure A.1 - 3: Framing details 2x4 staggered stud wall with studs spaced 400 mm on centre with 2x6 end studs

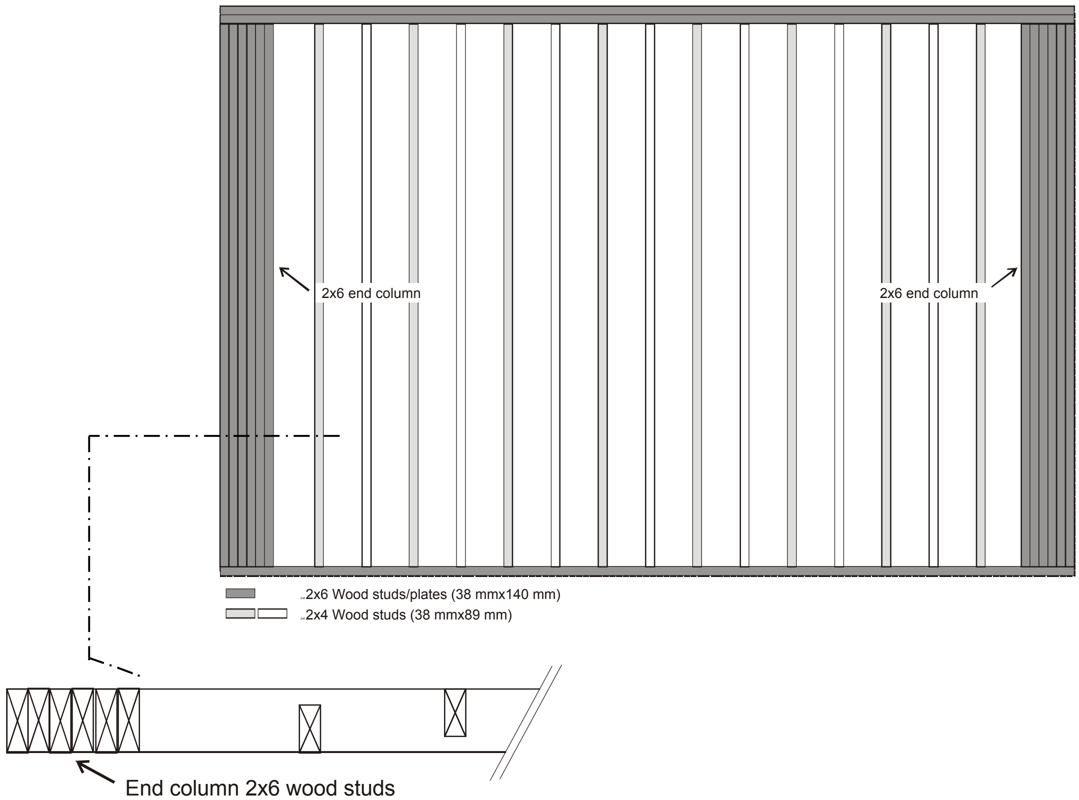


Figure A.1 - 4: Framing details 2x4 staggered stud wall with studs spaced 400 mm on centre with 2x6 end columns

Tripled studs vs. decreased stud spacing

Two strategies – either keeping wide stud-spacing and using columns with doubled/tripled studs, or reducing the stud spacing and using single studs - are possible to increase the axial load bearing capacity of wood frame walls. Two framing variants of the 2x4 staggered stud wall were considered in this study to investigate the effect of both designs on sound insulation:

1. staggered stud wall with tripled studs (columns out of 3 2x4 studs joined together) spaced @ 400 mm (16”) o.c., see Figure A.1 - 5
2. staggered stud wall with 2x4 single studs @ 100 mm (4”) o.c., see Figure A.1 - 6

The change of the framing again was expected to change the structural coupling between the gypsum board membranes as well as the coupling between the wall and the rooms on either side due to the increase of the sound radiation efficiency.

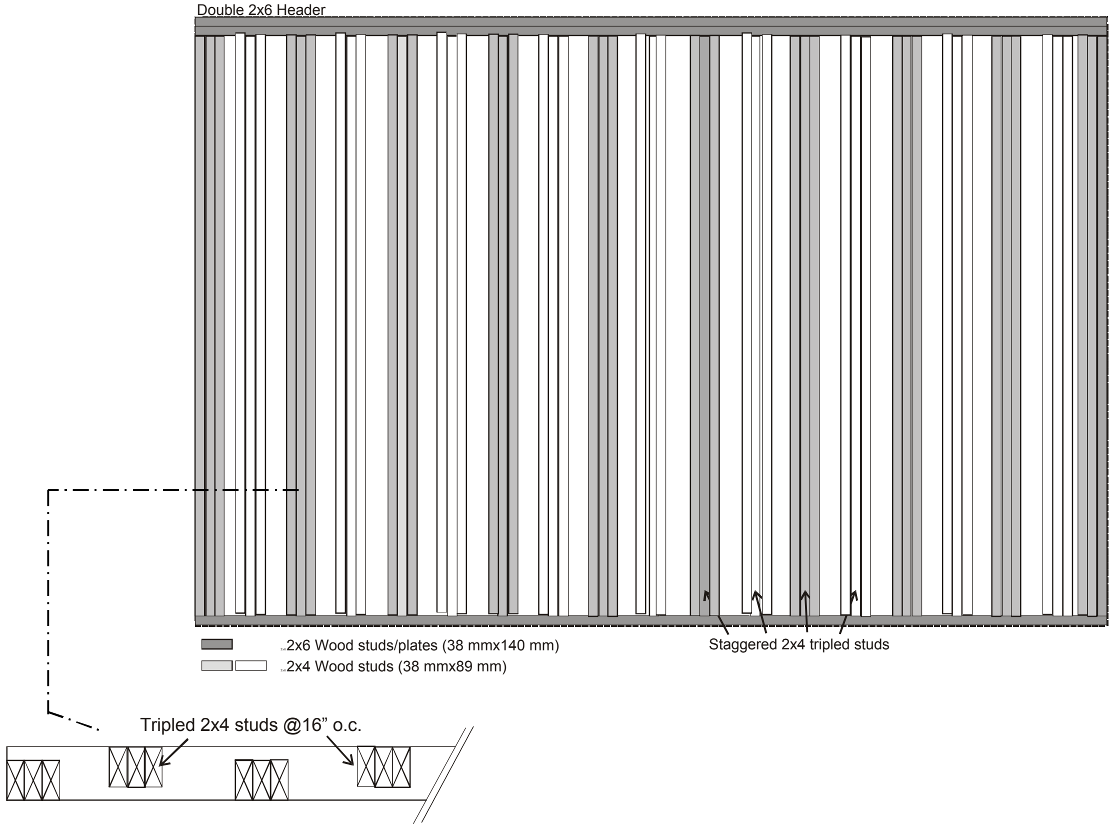


Figure A.1 - 5: Framing details tripled 2x4 staggered stud wall with studs spaced 400 mm

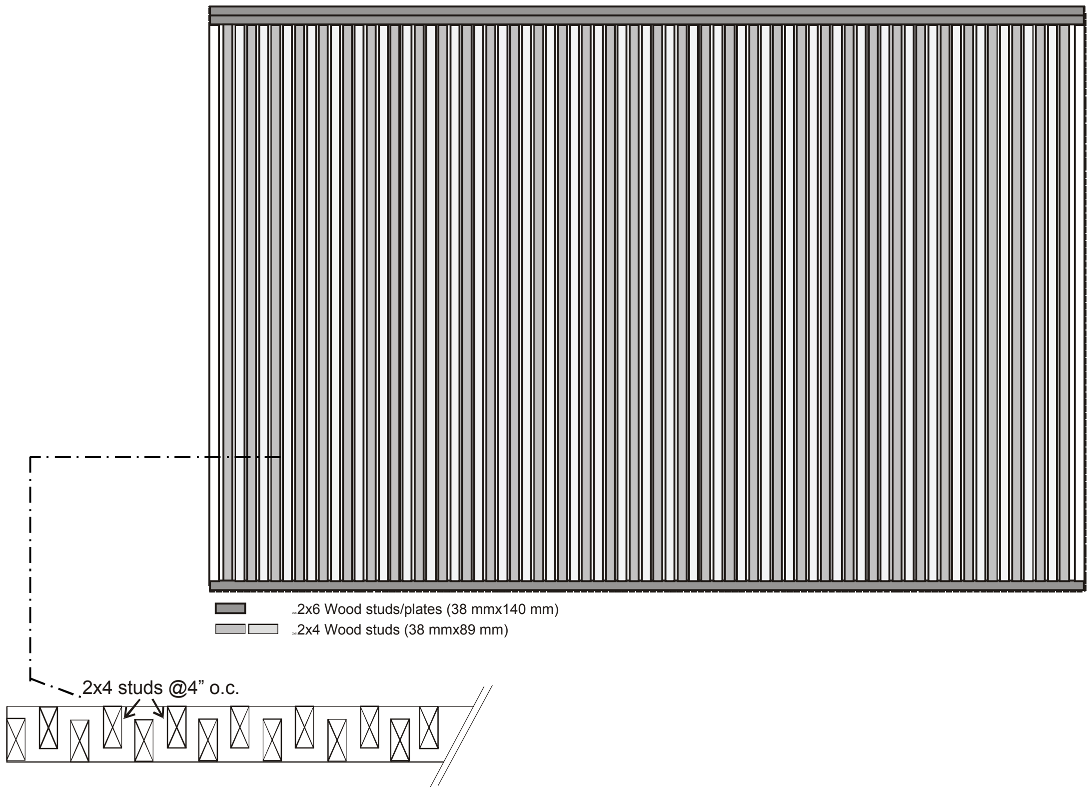


Figure A.1 - 6: Framing – 2x4 staggered stud studs @ 100 mm (4") o.c.

A.1.3.1.2 Gypsum board membrane

Two layers of 12.7 mm thick Type X gypsum board were used on both sides of the framing as gypsum board membrane for almost all specimens for fire protection of the combustible wood frame. The long axis of the boards are oriented parallel to the studs. The joints of the face layer are offset from the base layer joints. Two different mountings of gypsum board are considered in this study:

1. **Directly Attached (DA)** – the gypsum board was directly attached to the wood frame. Screws and screw spacing were used in accordance with CSA A82.31-M1980 "Gypsum board Application".
2. **Resilient Channels (RC)** – the gypsum board was mounted on resilient channels spaced 600 mm o.c.. Screws and screw spacing for gypsum board attachment were used in accordance with CSA A82.31-M1980 "Gypsum board Application".

Screw length and spacing used to fasten the gypsum board are given in the wall data sheets in Section A.1.6.

For one wall specimen 15.9 mm thick Type X gypsum board was used to get a tie-back to sound insulation data from an earlier NRC study [4] as more data was available for this gypsum board membrane.

A.1.3.1.3 Shear membrane

For the staggered stud wall framings the shear membranes are attached to the frame on one side under a directly attached gypsum board membrane.

Material and thickness

The effect of the shear membrane material and thickness was investigated. OSB and plywood boards with thicknesses of 10 mm (3/8"), 12.7 mm (1/2") and 15.9 mm (5/8") are common as shear layers in mid-rise wood framed buildings. In the research report NRC-IR 832 [1] only 10 mm and 12.7 mm shear membranes were used. It was concluded that there was no big difference in the sound insulation for the used materials, but the 12.7 mm layers tend to perform slightly better because of the slightly bigger mass. 15.9 mm thick shear membranes were not included in the previous study. Their increased mass suggests further improvement of sound insulation, however the increased bending stiffness of the 15.9 mm shear membrane compromises the sound insulation. In the course of this study four different shear layers were added to one side of the staggered stud wall to assess the performance of the shear membrane materials and thicknesses:

1. 10 mm plywood
2. 10 mm OSB
3. 15.9 mm plywood
4. 15.9 mm OSB

In this study the shear membrane was first sheathed vertically with the long axis of the boards parallel to the studs and the boards fastened every 75 mm (3") along the board perimeter of the boards and at intermediate studs. In real construction 8d or 10d nails are used to fasten the shear membrane, however, screws were instead used in this study for the matter of simplifying specimen changes without damaging the wood framing that could increase measurement uncertainty. It was demonstrated in previous studies that the attachment method of the shear membrane has little effect on the sound insulation ([1], Figure 11). As substitute for 10d nails a #10 wood screw (d = 3.78 mm (0.149")) with 3" length was chosen that had a slightly bigger diameter for all panels.

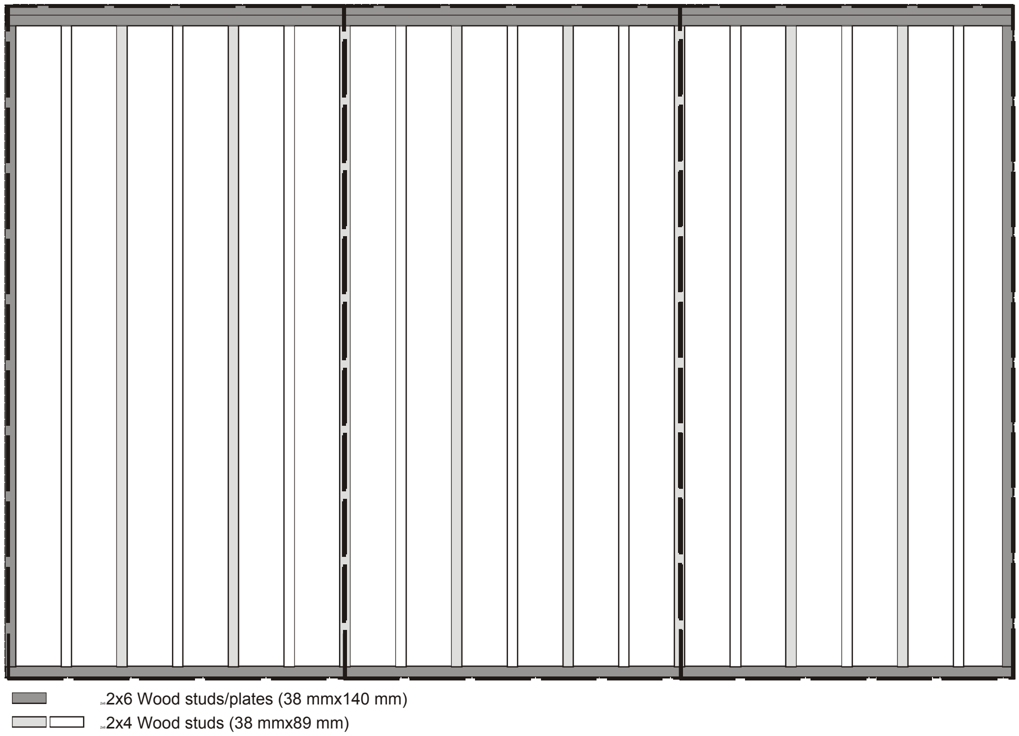


Figure A.1 - 7: Shear membrane configuration – shear membrane material and thickness study

Blocked and un-blocked shear membrane configuration

The performance of blocked and un-blocked shear walls was investigated for the 15.9 mm plywood shear membrane. Blocking is usually used to strengthen shear membranes with horizontal board joints. For this study the walls were sheathed horizontally with a horizontal gap along the center of the shear membrane. Two cases were compared:

1. With blocking (pieces of 2x6 attached flat wise along the gap to the shear membrane)
2. Without blocking (joint between the boards not strengthened)

The fastener spacing was 75 mm (3”) on centre along the edges backed by the framing, the intermediate studs and also along the horizontal blocking for the blocked shear membrane – again #10 wood screws were used as substitutes for the 10d nails.

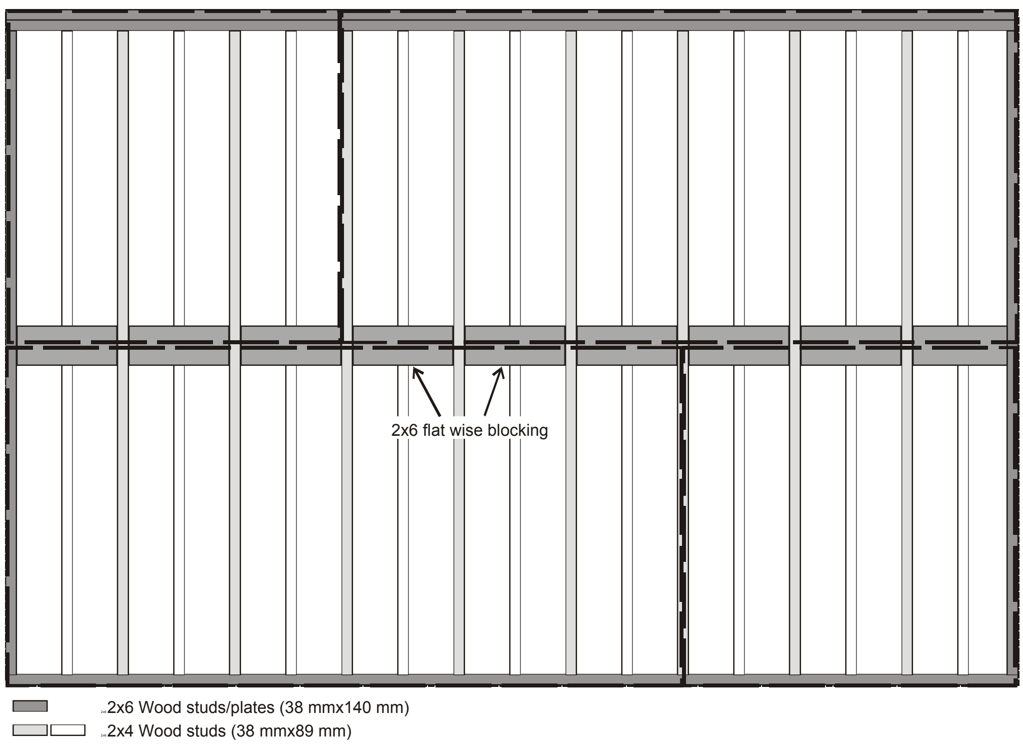


Figure A.1 - 8: Shear membrane configuration – blocked case

A.1.3.1.4 Cavity Absorption/Insulation

One layer of glass fiber batts (thickness 89 mm) was put on one wall side between the studs as cavity insulation.

A.1.3.2 Summary of Measurement Results of Preparatory Study

A.1.3.2.1 Benchmark Walls

The following wall designs were tested to benchmark sound transmission loss of conventional staggered stud walls for low-rise construction.

Table A.1 - 1: STC-ratings of 2x4 staggered stud benchmark walls

Id	Note	Gypsum Board Membrane 1			Frame	Insulation	Shear Layer	Gypsum Board Membrane 2			STC
		Face Layer	Base Layer	)*				Face Layer	Base Layer	)*	Test-id
1WS	Reference wall, wood frame 1	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	DA	2x4 staggered stud: - studs @ 400 mm o.c. - 2x6 double header - 2x6 single footer	Glass fiber 90 mm (R-12)	N/A	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	DA	**STC 51** (55) Average of 4 Tests
1WN	Reference wall, wood frame 2	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	DA	2x4 staggered stud: - studs @ 400 mm o.c. - 2x6 double header - 2x6 single footer	Glass fiber 90 mm (R-12)	N/A	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	DA	**STC 49** (55) TLA-11-052
3WS	Reference wall with resilient channels, wood frame 1	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	DA	2x4 staggered stud: - studs @ 400 mm o.c. - 2x6 double header - 2x6 single footer	Glass fiber 90 mm (R-12)	N/A	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	RC (610)	**STC 59** (60) TLA-11-059

*Attachment method: DA, cladding directly attached to wood frame; RC(610), cladding mounted on RC spaced 610 mm o.c. with lowermost channel inverted
**In parenthesis: STC rating as tested in [3] and according to NBCC, tables

A.1.3.2.2 Tieback to earlier study from 1993 [4]

STC-rating of the benchmarking assemblies was less (up to 5 STC-points) than what was achieved for nominally the same specimens in an earlier study in 1993 [4]. Therefore additional measurements were conducted as tie-back to the previous series to identify the cause.

Table A.1 - 2: STC-ratings of 2x4 staggered stud walls tested as tie-back to existing data

Id	Note	Gypsum Board Membrane 1			Frame	Insulation	Shear Layer	Gypsum Board Membrane 2			STC
		Face Layer	Base Layer	)*				Face Layer	Base Layer	)*	Test-id
2WS	Tieback frame 1, 15.9 mm Type X	15.9 mm thick Type X, screws @ 300 mm		DA	2x4 staggered stud: - tripled studs @ 400 mm o.c. - 2x6 double header - 2x6 single footer	Glass fiber 90 mm (R-12)	N/A	15.9 mm thick Type X, screws @ 300 mm		DA	STC 43 (47) TLA-11-053
15WN	Tieback frame 1, screws @ 300 mm	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	DA	2x4 staggered stud: - studs @ 400 mm o.c. - 2x6 single header - 2x6 single footer	Glass fiber 90 mm (R-12)	N/A	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	DA	STC 50 (55) Average of 2 Tests
15WN-a	Tieback frame 1, screws @ 400 mm	12.7 mm thick Type X, screws @ 400 mm	12.7 mm thick Type X, screws @ 600 mm	DA	2x4 staggered stud: - studs @ 400 mm o.c. - 2x6 single header - 2x6 single footer	Glass fiber 90 mm (R-12)	N/A	12.7 mm thick Type X, screws @ 400 mm	12.7 mm thick Type X, screws @ 600 mm	DA	STC 52 (55) Average of 2 Tests
16WN	Tieback frame 1, 15.9 mm Type X, screws @ 400 mm	15.9 mm Type X, screws @ 400 mm		DA	2x4 staggered stud: - studs @ 400 mm o.c. - 2x6 single header - 2x6 single footer	Glass fiber 90 mm (R-12)	N/A	15.9 mm Type X, screws @ 400 mm		DA	STC 45 (47) TLA-12-004

*Attachment method: DA, cladding directly attached to wood frame; RC(610), cladding mounted on RC spaced 610 mm o.c. with lowermost channel inverted
**In parenthesis: STC rating as tested during Walls I study and according to NBCC, tables

The change of STC rating for the nominally same specimen between 1993 and present has several reasons. The greatest change is caused by a wider screw spacing of 400 mm instead of 300 mm that was used to attach the face-layer of the gypsum board membrane in [4]. Second also the material properties especially of the 12.7 mm thick Type X gypsum board changed over the years. To a lesser extent changes in the test results are due to the renovation of the NRC Wall Sound Transmission Test Facility in 2000 when amongst other things the room volume of the small chamber as well as the opening size was increased [5]. Both facilities – before and after renovation – conform to ASTM E90 [3].

A.1.3.2.3 Shear Walls

Table A.1 - 3: STC-ratings of 2x4 staggered stud walls with different shear membranes and configurations

Id	Note	Gypsum Board Membrane 1			Frame	Insulation	Shear Layer	Gypsum Board Membrane 2			STC
		Face Layer	Base Layer	)*				Face Layer	Base Layer	)*	Test-id
3WN	OSB 10mm vertical, wood frame 2	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X screws @ 600 mm	DA	2x4 staggered stud: - studs @ 400 mm o.c. - 2x6 double header - 2x6 single footer	Glass fiber 90 mm (R-12)	10 mm OSB vertically, fastened @ 75 mm	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	DA	STC 51 TLA-11-060
5WN	OSB 16mm vertical, wood frame 2	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X screws @ 600 mm	DA	2x4 staggered stud: - studs @ 400 mm o.c. - 2x6 double header - 2x6 single footer	Glass fiber 90 mm (R-12)	15.9 mm OSB vertically, fastened @ 75 mm	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	DA	STC 52 TLA-11-062
4WS	PLY 10mm vertical, wood frame 1	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X screws @ 600 mm	DA	2x4 staggered stud: - studs @ 400 mm o.c. - 2x6 double header - 2x6 single footer	Glass fiber 90 mm (R-12)	10 mm Plywood vertically, fastened @ 75 mm	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	DA	STC 52 TLA-11-061
6WS	PLY 16mm vertical, wood frame 1	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X screws @ 600 mm	DA	2x4 staggered stud: - studs @ 400 mm o.c. - 2x6 double header - 2x6 single footer	Glass fiber 90 mm (R-12)	15.9 mm plywood vertically, fastened @ 75 mm	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	DA	STC 51 Average of 2 Tests
7WS	PLY 16mm horiz. blocked, wood frame 1	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X screws @ 600 mm	DA	2x4 staggered stud: - studs @ 400 mm o.c. - 2x6 double header - 2x6 single footer	Glass fiber 90 mm (R-12)	15.9 mm plywood horizontally 2x6 flat-wise blocking fastened @ 75 mm	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	DA	STC 52 TLA-11-070
8WS	PLY 16mm horiz. unblocked, wood frame 1	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X screws @ 600 mm	DA	2x4 staggered stud: - studs @ 400 mm o.c. - 2x6 double header - 2x6 single footer	Glass fiber 90 mm (R-12)	15.9 mm plywood horizontally no blocking fastened @ 75 mm	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	DA	STC 51 TLA-11-070

*Attachment method: DA, cladding directly attached to wood frame; RC(610), cladding mounted on RC spaced 610 mm o.c. with lowermost channel inverted

Adding a shear membrane of the tested materials and in the tested thickness range slightly improves sound transmission loss in comparison to the benchmark wall. The difference in improvement for the different materials and thickness is marginally greater than the re-build uncertainty of the test method itself. With the 15.9 mm plywood membrane the least improvement was achieved due to the stiffness increase of the wall membrane. Hence this material was used as shear membrane for further studies as the measured improvement can be used as conservative estimate for the other materials and thicknesses. The configuration of the membrane – blocked and un-blocked – did not change the sound insulation performance significantly.

A.1.3.2.4 Framing Variants – End Studs and Columns

Table A.1 - 4: STC-ratings of 2x4 staggered stud walls with 2x6 end studs and end columns that connect both gypsum board membranes

Id	Note	Gypsum Board Membrane 1			Frame	Insulation	Shear Layer	Gypsum Board Membrane 2			STC
		Face Layer	Base Layer	)*				Face Layer	Base Layer	)*	Test-id
1WS-a	2x6 end studs, wood frame 1	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X screws @ 600 mm	DA	2x4 staggered stud: - studs @ 400 mm o.c. - 2x6 double header - 2x6 single footer - 2x6 single end studs	Glass fiber 90 mm (R-12)	N/A	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	DA	STC 49 TLA-11-044
9WS	2x6 end columns, wood frame 1	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X screws @ 600 mm	DA	2x4 staggered stud: - studs @ 400 mm o.c. - 2x6 double header - 2x6 single footer - six 2x6 studs build-up as end columns at each end	Glass fiber 90 mm (R-12)	N/A	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	DA	STC 47 TLA-11-076
10WS	2x6 end columns with resilient channels, wood frame 1	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X screws @ 600 mm	DA	2x4 staggered stud: - studs @ 400 mm o.c. - 2x6 double header - 2x6 single footer - six 2x6 studs build-up as end columns at each end	Glass fiber 90 mm (R-12)	N/A	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	RC(610)	STC 54 TLA-11-078

*Attachment method: DA, cladding directly attached to wood frame; RC(610), cladding mounted on RC spaced 610 mm o.c. with lowermost channel inverted

As expected decreased sound insulation performance of the walls results with staggered rows of studs if end studs or columns are used that couple the gypsum board membranes on both sides of the framing. With a single end stud on both wall ends the STC-rating decreases only by 2 points vs. 4 points with build-up columns. The effect on the STC is the same (i.e. 4 to 5 points decrease) for directly attached gypsum board and when it is mounted on one side of the framing on resilient channels.

A.1.3.2.5 Framing Variants – Studs

Table 7: STC-ratings of 2x4 staggered stud walls with different stud configurations to increase axial load bearing capacity

Id	Note	Gypsum Board Membrane 1			Frame	Insulation	Shear Layer	Gypsum Board Membrane 2			STC
		Face Layer	Base Layer	)*				Face Layer	Base Layer	)*	Test-id
11WS	Tripled studs @ 400 mm	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X screws @ 600 mm attached to studs along single line	DA	2x4 staggered stud: - tripled studs @ 400 mm o.c. - 2x6 double header - 2x6 single footer	Glass fiber 90 mm (R-12)	N/A	12.7 mm thick Type X, screws @ 300 mm attached to studs along single line	12.7 mm thick Type X, screws @ 600 mm	DA	STC 49 TLA-11-083
12WS	Tripled studs @ 400 mm w. RC, Variant 1	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X screws @ 600 mm	DA	2x4 staggered stud: - tripled studs @ 400 mm o.c. - 2x6 double header - 2x6 single footer	Glass fiber 90 mm (R-12)	N/A	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	RC^3(610)	STC 56 TLA-11-084
12WS-a	Tripled studs @ 400 mm w. RC, Variant 2	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X screws @ 600 mm	DA^3	2x4 staggered stud: - tripled studs @ 400 mm o.c. - 2x6 double header - 2x6 single footer	Glass fiber 90 mm (R-12)	N/A	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	RC^3(610)	STC 55 TLA-11-085
12WS-b	Tripled studs @ 400 mm w. RC, Variant 3	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X screws @ 600 mm	DA	2x4 staggered stud: - tripled studs @ 400 mm o.c. - 2x6 double header - 2x6 single footer	Glass fiber 90 mm (R-12)	N/A	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	RC(610)	STC 55 TLA-11-087
13WS	Studs @ 100 mm	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X screws @ 600 mm	DA	2x4 staggered stud: - studs @ 100 mm o.c. - 2x6 double header - 2x6 single footer	Glass fiber 90 mm (R-12)	N/A	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	DA	STC 36 TLA-11-090
14WS	Studs @ 100 mm	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X screws @ 600 mm	DA	2x4 staggered stud: - studs @ 100 mm o.c. - 2x6 double header - 2x6 single footer	Glass fiber 90 mm (R-12)	N/A	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	RC(610)	STC 50 TLA-11-091

*Attachment method: DA, cladding directly attached to wood studs along single line; DA^3, cladding directly attached to tripled wood studs along 3 lines; RC(610), cladding mounted on RC spaced 610 mm o.c. with lowermost channel inverted, channels fastened to each wood studs at single points; RC^3(610), cladding mounted on RC spaced 610 mm o.c. with lowermost channel inverted, channels fastened to each tripled wood studs at 3 points

The tripled stud walls achieve much higher STC-ratings (STC 49 to STC 56) than the assemblies with the small stud spacing (STC 36 to STC 50) and therefore are the preferred design option. The attachment of the gypsum board and resilient channels along the tripled studs (single in the middle row vs. three rows) has a negligible effect on the sound insulation performance. The worse sound insulation performance of the walls with the small stud spacing is caused by the additional structural coupling of the gypsum board membranes as well as by the global stiffening of the panels which increases the sound radiation efficiency and hence the coupling of sound field in the rooms and the walls.

A.1.4 2nd Round of Wall Testing

In Section A.1.3 the change of the sound insulation due to design modifications required for mid-rise construction was investigated at single wall type. Based on these findings the list of walls that were initially identified as relevant for mid-rise buildings was revisited and a limited number of further specimens selected. As for the preparatory study the selection was made to bracket the lower bound of the direct sound insulation (STC 50) that is required by the National Building Code Canada (NBCC).

A.1.4.1 Specimens with common framing

A detailed description of all tested specimens is given in the data sheets in Section A.1.6. In the following the major test considerations are described.

A.1.4.1.1 Framing variants

In the 2nd round of wall testing two conceptually different common wall framings were considered – 2x6 staggered studs and 2x6 single studs with smaller spacing.

2x6 Staggered Stud Walls – Studs @ 400 mm

The sound insulation of 2x6 staggered studs on 2x8 plates with studs spaced 400 mm o.c. was investigated. Wall framing variants with single studs, with columns made out of three studs that were joined together and with build-up end columns made out of 2x8s that couple both wall claddings were investigated. Because of its poor performance walls with very tight stud spacing (i.e. 100 mm) were omitted for these stud configurations.

2x6 Single Stud Walls – Studs @ 200 mm o.c.

The second framing variant 2x6 single stud wall is structurally equivalent to a 2x6 staggered stud wall and is expected to exceed code minimum of STC 50 or higher with the gypsum board membrane directly attached on one side and mounted on resilient channels on the other. Thus, it is a more slender alternative to the 2x6 staggered stud walls. The wall framing variants are with single studs and with columns made out of three studs that were joined together.

A.1.4.1.2 Gypsum board membrane

In the second testing round, the same gypsum board membrane variants were considered as in the preparatory study - namely two layers of 12.7 mm thick Type X gypsum board - as well as the same two mounting options – directly attached and on resilient channels. Screw length and spacing used to fasten the gypsum board are given in the data sheets in Section A.1.6.

A.1.4.1.3 Shear membrane

Based on the results of the preparatory study only 15.9 mm plywood mounted with the long edges parallel to the studs (vertically) was considered in the second testing round. This configuration gave the least sound insulation improvement and thus can be used as a conservative estimate for the other materials and thicknesses. The boards were fastened with screws spaced 75 mm (3”) along the perimeter of the boards and at intermediate studs with #10 wood screws (d = 3.78 mm (0.149”)) of 75 mm (3”) length were chosen as substitute for 10d nails.

A.1.4.1.4 Cavity Absorption/Insulation

As cavity absorption glass fiber batts were used with a thickness depending on the framing. For the 2x6 staggered stud walls only the space between the studs of one stud row was filled 150 mm thick glass fiber batts. In case of the single 2x6 wall framing the cavities between the studs were filled with 140 mm thick glass fiber batts.

A.1.4.2 Novel Specimens - Mid-Ply Shear Wall

The mid-ply shear wall is a novel innovative shear wall design where the shear membrane is located in the centre plane of the wall instead of attached to one side of the frame like at conventional shear walls. So far this wall design was thoroughly tested for structural and seismic loads; however, no data for the sound insulation rating was available yet. To accommodate the shear membrane in the centre plane of the wall a special framing was necessary.

A.1.4.2.1 Framing and Shear Membrane

The framing details of the mid-ply shear walls with studs spaced 610 mm are given below and shown in Figure A.1 - 9:

- Footer, header, end studs and intermediate studs:
  two 2x4 lumber (No.2 & Btr SPF) flat wise were fastened together sandwiching the shear membrane
- Studs at joint of shear-membrane:
  two 2x6 lumber flat wise were fastened together sandwiching the shear membrane
- Nailing pattern:
  - along end studs, footer and header:
    two studs and plates were fastened together with 3 mm thick and 83 mm (3.25”) long nails @ 100 mm along two lines
  - along 2x6 studs:
    two studs and plates were fastened together with 3 mm thick and 83 mm (3.25”) long nails @ 100 mm. The nails were located along three lines. Two lines were off-set from the centre and the nails were penetrating the studs and the shear membrane on the right and on the left, the third line was along the centre where a 12 mm gap was between the boards of the shear membrane, the nails just penetrated the two studs.
  - along intermediate 2x4 studs:
    two studs and plates were fastened together with 3 mm thick and 83 mm (3.25”) long nails @ 100 mm along single line
- End studs with buckling studs:
  At the end studs a third 2x4 (buckling stud) was attached to the sides of the two 2x4 that were sandwiching the shear membrane with 83 mm (3.25”) long nails @ 100 mm o.c. along two lines. The nails were fastened to the buckling stud to both 2x4 end studs. They had the same length as the other studs and were placed between the header and footer.
- Shear membrane:
  12 mm plywood was sandwiched between framing, at both sides, top and bottom 12 mm shorter than lower end studs, edge of footer and upper edge of header and with a 12 mm gap between joint of boards along 2x6 studs

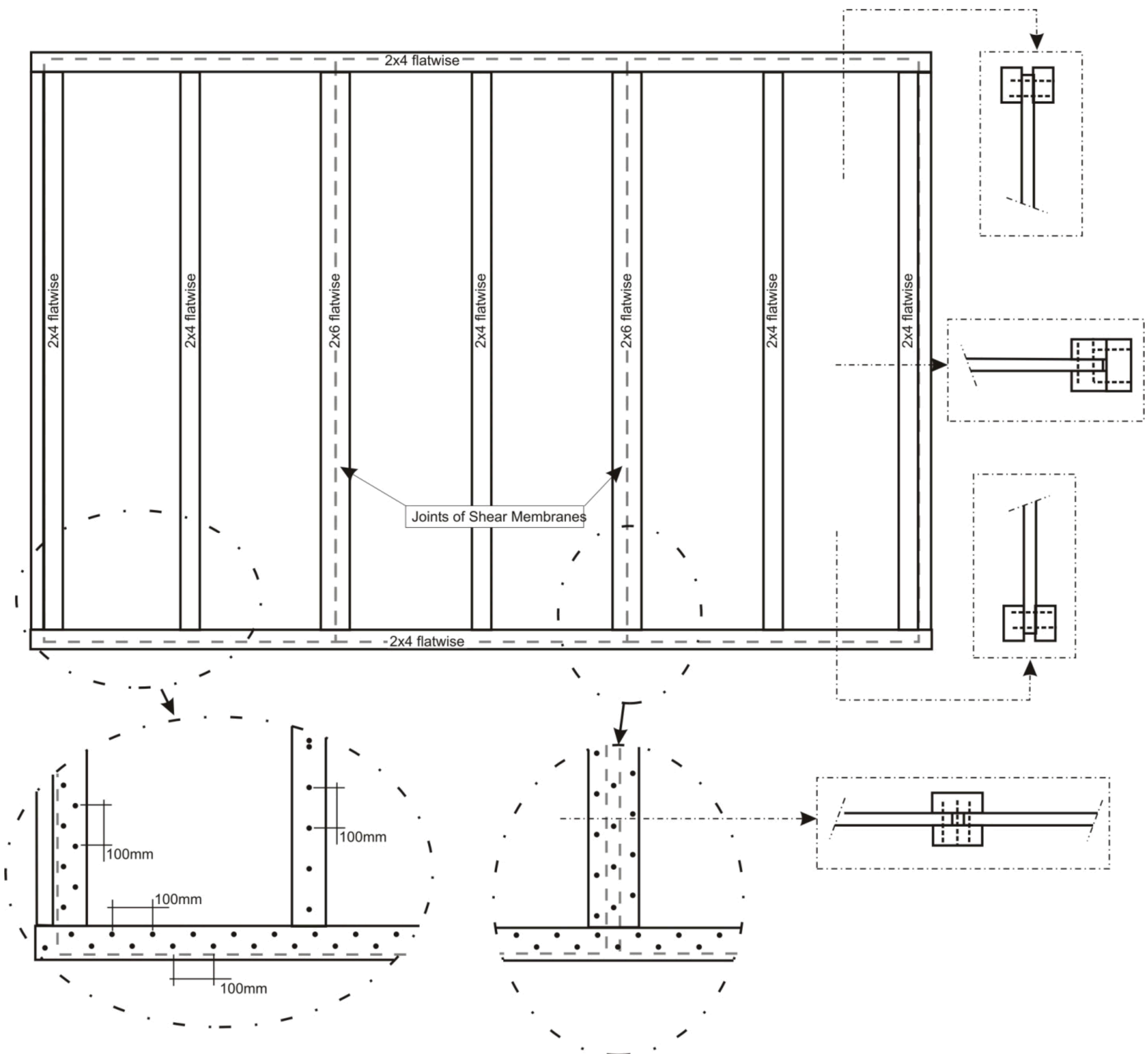


Figure A.1 - 9: Framing details of mid-ply shear wall

A.1.4.2.2 Gypsum board membrane

For the mid-ply wall the same gypsum board membrane variants were considered as for the conventional framings - namely two layers of 12.7 mm thick Type X gypsum board. There were 3 different attachment methods used, namely the gypsum board membrane was

- directly attached on both sides,
- mounted on resilient channels on one side and directly attached on the other, or
- mounted on resilient channels on both sides (only possible for the mid-ply shear wall due to the centre shear membrane).

Screw length and spacing used to fasten the gypsum board are given in the datasheets in Section A.1.6.

A.1.4.2.3 Cavity Absorption/Insulation

As cavity absorption, 38 mm thick glass fiber batts were installed in the cavities between the studs on both sides of the centre shear membrane. To demonstrate the negative effect of those shallow cavities, that have their fundamental mass-spring-mass resonance frequency right in the middle of the building acoustics range, an additional specimen without cavity insulation was tested.

A.1.4.3 Summary of Measurement Results of 2nd Round of Wall Testing

A.1.4.3.1 Summary STC-ratings and descriptions of 2x6 staggered stud wall assemblies

Table A.1 - 5: 2x6 staggered stud wall assemblies

Id	Note	Gypsum Board Membrane 1			Frame	Insulation	Shear Layer	Gypsum Board Membrane 2			Test-Id
		Face Layer	Base Layer	)*				Face Layer	Base Layer	)*	STC
18W	2x6 staggered studs on 2x8 plate, Benchmark	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X screws @ 600 mm	DA	2x6 staggered stud: - studs @ 400 mm o.c. - 2x8 double header - 2x8 single footer - 2x6 end studs	Glass fiber 152mm (R-20)	N/A	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	DA	TLA-12-060 STC 50
19W	2x6 staggered studs on 2x8 plate, Benchmark RC	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X screws @ 600 mm	RC(610)	2x6 staggered stud: - studs @ 400 mm o.c. - 2x8 double header - 2x8 single footer - 2x6 end studs	Glass fiber 152mm (R-20)	N/A	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	DA	TLA-12-061 STC 59
20W	2x6 staggered studs on 2x8 plate, End Columns, DA	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X screws @ 600 mm	DA	2x6 staggered stud: - studs @ 400 mm o.c. - 2x8 double header - 2x8 single footer - six 2x8 studs build-up as end columns at each end	Glass fiber 152mm (R-20)	N/A	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	DA	TLA-12-062 STC 48
21W	2x6 staggered studs on 2x8 plate, End Columns, RC	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X screws @ 600 mm	RC(610)	2x6 staggered stud: - studs @ 400 mm o.c. - 2x8 double header - 2x8 single footer - six 2x8 studs build-up as end columns at each end	Glass fiber 152mm (R-20)	N/A	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	DA	TLA-12-063 STC 56
22W	2x6 staggered studs on 2x8 plate, Shear Wall DA	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X screws @ 600 mm	DA	2x6 staggered stud: - studs @ 400 mm o.c. - 2x8 double header - 2x8 single footer - 2x6 end studs	Glass fiber 152mm (R-20)	15.9 mm plywood vertically, fastened @ 75 mm	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	DA	TLA-12-081 STC 51
23W	2x6 staggered studs on 2x8 plate, Shear Wall RC	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X screws @ 600 mm	RC(610)	2x6 staggered stud: - studs @ 400 mm o.c. - 2x8 double header - 2x8 single footer - 2x6 end studs	Glass fiber 152mm (R-20)	15.9 mm plywood vertically, fastened @ 75 mm	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	DA	TLA-12-082 STC 61

Table A.1 - 5– continued: 2x6 staggered stud wall assemblies

Id	Note	Gypsum Board Membrane 1			Frame	Insulation	Shear Layer	Gypsum Board Membrane 2			Test-Id
		Face Layer	Base Layer	)*				Face Layer	Base Layer	)*	STC
24W	2x6 tripled staggered studs on 2x8 plate, Shear Wall DA	12.7 mm thick Type X, screws @ 300 mm in single line along tripled studs	12.7 mm thick Type X screws @ 600 mm in single line along tripled studs	DA	2x6 tripled staggered stud: - studs @ 400 mm o.c. - 2x8 double header - 2x8 single footer - 2x6 tripled end studs	Glass fiber 152mm (R-20)	15.9 mm plywood vertically, fastened @ 75 mm	12.7 mm thick Type X, screws @ 300 mm in single line along tripled studs	12.7 mm thick Type X, screws @ 600 mm in single line along tripled studs	DA	TLA-12-083 STC 47
25W	2x6 tripled staggered studs on 2x8 plate, Shear Wall, RC	12.7 mm thick Type X, screws @ 300 mm in single line along tripled studs	12.7 mm thick Type X screws @ 600 mm in single line along tripled studs	RC(610)	2x6 tripled staggered stud: - studs @ 400 mm o.c. - 2x8 double header - 2x8 single footer - 2x6 tripled end studs	Glass fiber 152mm (R-20)	15.9 mm plywood vertically, fastened @ 75 mm in single line along tripled studs	12.7 mm thick Type X, screws @ 300 mm in single line along tripled studs	12.7 mm thick Type X, screws @ 600 mm in single line along tripled studs	DA	TLA-12-084 STC 60
26W	2x6 tripled staggered studs on 2x8 plate, RC	12.7 mm thick Type X, screws @ 300 mm in single line along tripled studs	12.7 mm thick Type X screws @ 600 mm in single line along tripled studs	RC(610)	2x6 tripled staggered stud: - studs @ 400 mm o.c. - 2x8 double header - 2x8 single footer - 2x6 tripled end studs	Glass fiber 152mm (R-20)	N/A	12.7 mm thick Type X, screws @ 300 mm in single line along tripled studs	12.7 mm thick Type X, screws @ 600 mm in single line along tripled studs	DA	TLA-12-089 STC 59
27W	2x6 tripled staggered studs on 2x8 plate,	12.7 mm thick Type X, screws @ 300 mm in single line along tripled studs	12.7 mm thick Type X screws @ 600 mm in single line along tripled studs	DA	2x6 tripled staggered stud: - studs @ 400 mm o.c. - 2x8 double header - 2x8 single footer - 2x6 tripled end studs	Glass fiber 152mm (R-20)	N/A	12.7 mm thick Type X, screws @ 300 mm in single line along tripled studs	12.7 mm thick Type X, screws @ 600 mm in single line along tripled studs	DA	TLA-12-090 STC 47

*Attachment method: DA, cladding directly attached to wood frame; RC(610), cladding mounted on RC spaced 610 mm o.c. with lowermost channel inverted

The performance of the 2x6 staggered stud wall assemblies is similar to the corresponding specimens with 2x4 studs that were considered in the preparatory study. When the framing of the walls is strengthened to account for increased axial loads mounting of the gypsum board membrane on one side on resilient channels is required to achieve current NBCC 2015 code minimum.

A.1.4.3.2 Summary STC-ratings and descriptions of 2x6 single wall assemblies

At all 2x6 single stud row wall assemblies the gypsum board membrane on one wall side was mounted on resilient channels spaced 600 mm to achieve current code minimum requirement of STC 50 or greater.

Table A.1 - 6: 2x6 single stud row wall assemblies

Id	Note	Gypsum Board Membrane 1			Frame	Insulation	Shear Layer	Gypsum Board Membrane 2			Test-Id
		Face Layer	Base Layer	)*				Face Layer	Base Layer	)*	STC
28W	2x6 studs on 2x6 plate, benchmark	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X screws @ 600 mm	RC(610)	2x6 single stud frame: - studs @ 200 mm o.c. - 2x6 double header - 2x6 single footer - 2x6 end single stud	Glass fiber 140 mm (R-20)	N/A	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	DA	TLA-12-169 STC 51
29W	2x6 studs on 2x6 plate, Shear wall	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X screws @ 600 mm	RC(610)	2x6 single stud frame: - studs @ 200 mm o.c. - 2x6 double header - 2x6 single footer - 2x6 end single stud	Glass fiber 140 mm (R-20)	15.9 mm plywood vertically, fastened @ 75 mm in single line along tripled studs	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	DA	TLA-12-161 STC 51
30W	2x6 tripled studs on 2x6 plate, shear wall	12.7 mm thick Type X, screws @ 300 mm in single line along tripled studs	12.7 mm thick Type X screws @ 600 mm in single line along tripled studs	RC(610)	2x6 tripled single stud frame: - tripled studs @ 200 mm - 2x6 double header - 2x6 single footer - 2x6 double end stud	Glass fiber 140 mm (R-20)	15.9 mm plywood vertically, fastened @ 75 mm in single line along tripled studs	12.7 mm thick Type X, screws @ 300 mm in single line along tripled studs	12.7 mm thick Type X, screws @ 600 mm in single line along tripled studs	DA	TLA-12-167 STC 53
31W	2x6 tripled studs on 2x6 plate	12.7 mm thick Type X, screws @ 300 mm in single line along tripled studs	12.7 mm thick Type X screws @ 600 mm in single line along tripled studs	RC(610)	2x6 tripled single stud frame: - studs @ 200 mm - 2x6 double header - 2x6 single footer - 2x6 double end stud	Glass fiber 140 mm (R-20)	N/A	12.7 mm thick Type X, screws @ 300 mm in single line along tripled studs	12.7 mm thick Type X, screws @ 600 mm in single line along tripled studs	DA	TLA-12-168 STC 53

*Attachment method: DA, cladding directly attached to wood frame; RC(610), cladding mounted on RC spaced 610 mm o.c. with lowermost channel inverted

The results demonstrate that wall assemblies with a single 2x6 stud row and studs spaced 200 mm achieve code compliance with the sound insulation requirement. This structurally enhanced wall system could be used as more slender alternative to a 2x6 staggered stud row wall that has equivalent axial load bearing capacity.

A.1.4.3.3 Summary STC-ratings and descriptions of mid-ply shear wall assemblies

Four mid-ply shear wall assemblies were considered in the test matrix, three with cavity insulation and one with cavity insulation removed to investigate the effect of the narrow cavities that have their fundamental resonance right in the middle of the building acoustics frequency range.

Table A.1 - 7: Mid-ply shear wall assemblies

Id	Note	Gypsum Board Membrane 1			Frame	Insulation	Shear Layer	Gypsum Board Membrane 2			Test-Id
		Face Layer	Base Layer	)*				Face Layer	Base Layer	)*	STC
32W	Mid-Ply Shear, Baseline	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X screws @ 600 mm	DA	Mid-ply shear wall framing studs @ 610 mm o.c. as specified above	38 mm glass fiber on both sides of shear membrane	12 mm plywood	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	DA	TLA-12-142 STC 48
33W	Mid-Ply Shear, RC-DA	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X screws @ 600 mm	RC(610)	Mid-ply shear wall framing studs @ 610 mm o.c. as specified above	38 mm glass fiber sides of shear membrane	12 mm plywood	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	DA	TLA-12-144 STC 55
34W	Mid-Ply Shear, RC-RC	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X screws @ 600 mm	RC(610)	Mid-ply shear wall framing studs @ 610 mm o.c. as specified above	38 mm glass fiber sides of shear membrane	12 mm plywood	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	RC(610)	TLA-12-146 STC 57
35W	Mid-Ply Shear, RC-RC	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X screws @ 600 mm	RC(610)	Mid-ply shear wall framing studs @ 610 mm o.c. as specified above	No insulation	12 mm plywood	12.7 mm thick Type X, screws @ 300 mm	12.7 mm thick Type X, screws @ 600 mm	RC(610)	TLA-12-147 STC 46

*Attachment method: -DA, cladding directly attached to wood frame; RC(610), cladding mounted on RC spaced 610 mm o.c. with lowermost channel inverted

The sound insulation performance of the tested mid-ply shear wall assemblies is acceptable when the gypsum board membrane of at least one wall side is mounted on resilient channels and the cavities are filled with glass fiber insulation. When the insulation was removed, the sound insulation performance of the specimen with both gypsum board membranes on resilient channels decreased from STC 57 to STC 46. Thus, assemblies with the shallow cavities require sufficient damping of the cavities.

A.1.5 Summary Table – Measured and predicted STC ratings

Because the measurement series were structured as parametric studies to relate the incremental change of sound insulation to a single modification at the wall assemblies, it was possible to predict the sound insulation performance of wall assemblies that were sufficiently similar yet not tested.

The predictions were done in two different ways. For adding a shear membrane the incremental change of frequency dependent sound transmission loss was added to the test results for assemblies without shear membrane. For other changes, i.e. due to adding the end studs and end columns that introduce additional structural coupling between the gypsum board membranes, another approach was utilized and from the measured results an equivalent sound transmission loss for the additional coupling by the end studs and columns was calculated like for composed elements. Using this sound transmission loss estimate the effect for other wall assemblies was predicted.

The tested and predicted STC ratings of 67 wood frame wall designs for mid-rise buildings are presented in Table A.1 - 8. Measured STC results are in blue font and predicted in green font. All assemblies in Table A.1 - 8 with gypsum board mounted to resilient channels on one side exceed the required STC 50 rating. The improvement of adding resilient channels is between 8-9 and 14 STC points with studs 400 mm on centre and 100 mm on centre respectively (see Figure A.1 - 11).

In the left side of the table assemblies are listed with both gypsum board membranes directly attached. Here only assemblies with conventional framing with single studs spaced 400 mm meet the STC 50 code requirement. The walls with continuous end studs and columns or with tripled studs are slightly worse and have STC-ratings in the high forties. The wall variant with the very narrow stud spacing is much worse and achieves STC-ratings that are over 20 points less than the walls with the tripled studs (see Figure A.1 - 10).

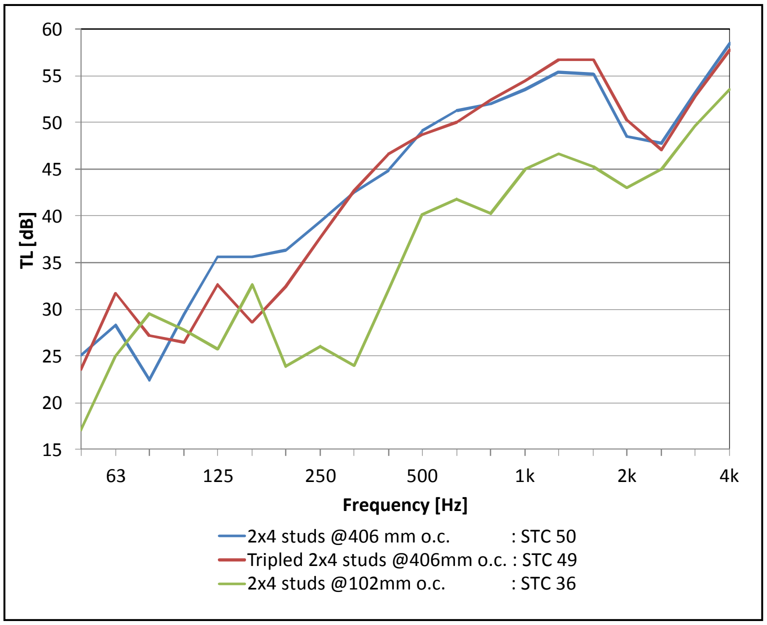


Figure A.1 - 10: TL of Walls with Various Stud Spacing with DA Gypsum Board

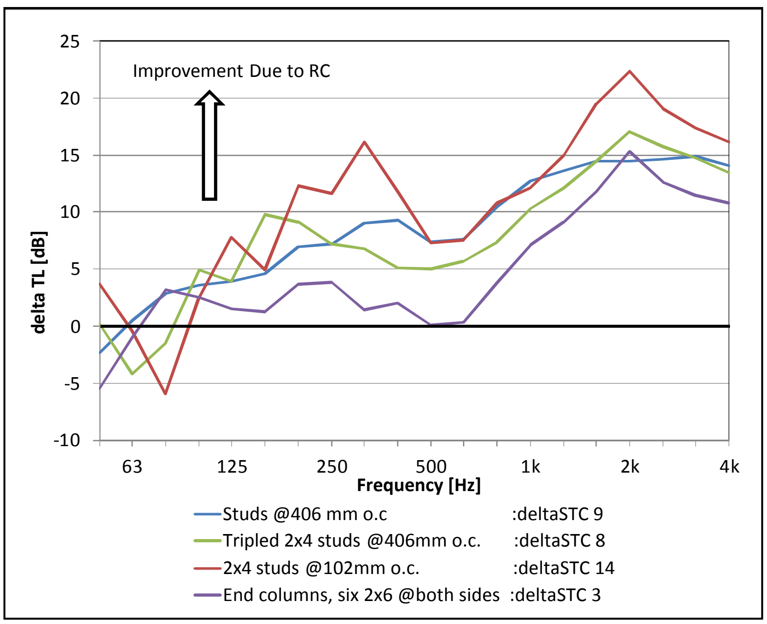


Figure A.1 - 11: TL Improvement of Adding RC to Various Stud Spacing

Table A.1 - 8: Summary table with measured (blue) and predicted (green) STC-ratings of 67 generic wood frame wall designs for mid-rise wooden buildings

		2 layers 12.7 mm Type X gypsum board directly attached[1)]						2 layers 12.7 mm Type X gypsum board directly attached and mounted to resilient channels[1)]					
		Without shear membrane[2)]			With shear membrane[2)]			Without shear membrane[2)]			With shear membrane[2)]		
		Base Framing[3)]	Framing with end studs[4)]	Framing with end Columns[5)]	Base Framing[3)]	Framing with end studs[4)]	Framing with end Columns[5)]	Base Framing[3)]	Framing with end studs[4)]	Framing with end Columns[5)]	Base Framing[3)]	Framing with end studs[4)]	Framing with end Columns[5)]
Staggered stud frame	2x4 studs @ 400 mm[3)]	50	48	47	51/52	48	47	59	56	54	60	57	54
	2x4 tripled studs @ 400 mm[6)]	49	47	46	48	47	45	57	55	53	58	55	53
	2x4 studs @ 100 mm[7)]	36	36	36	35	35	35	50	50	49	52	51	50
	2x6 studs @ 400 mm	50	48	48	51	49	48	59	57	56	61	59	57
	2x6 tripled studs @ 400 mm	47	47	47	47	47	47	59	57	55	60	58	56
Single stud frame	2x6 studs @ 200 mm	N/A	N/A	N/A	N/A	N/A	N/A	51	N/A	N/A	51	N/A	N/A
	2x6 tripled studs @ 200 mm	N/A	N/A	N/A	N/A	N/A	N/A	53	N/A	N/A	53	N/A	N/A

		2 layers 12.7 mm Type X directly attached	2 layers 12.7 mm Type X directly attached and mounted to resilient channels	2 layers 12.7 mm Type X mounted to resilient channels
Mid -ply	2x6 and 2x4 studs @ 600 mm	48	55	57

Notes:

1) Refer to A.1.3.1.2
2) Refer to A.1.3.1.3
3) Refer to Figure A.1-2
4) Refer to Figure A.1-3
5) Refer to Figure A.1-4
6) Refer to Figure A.1-5
7) Refer to Figure A.1-6

A.1.6 References

[1] T.R.T. Nightingale, et al. “Sound Insulation of Load Bearing Shear-Resistant Wood and Steel Stud Walls”, National Research Council Canada, Institute for Research in Construction, Internal Report IRC-IR 832, January 2002

[2] ASTM E90 - 09 “Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements”, ASTM International

[3] ASTM E413 – 04 “Classification for Rating Sound Insulation” ASTM International

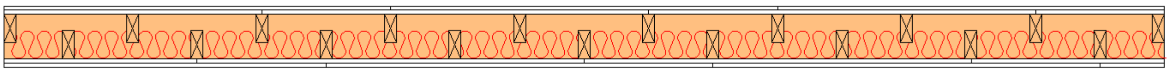
[4] R.E. Halliwell, et al., “Gypsum Board Walls: Transmission Loss Data”, National Research Council Canada, Institute for Research in Construction, Internal Report IR-761, March 1998

[5] R.E. Halliwell, “Renovations of the IRC/NRC Acoustical Transmission Loss Facility for Walls and their Effects”, National Research Council Canada, Institute for Research in Construction, Internal Report IR-826, September 2001

A.1.7 Wall Data Sheets

The following wall data sheets list the construction details and test results of all tested specimens. All sheets are two pagers. The specimen-id is given on top of the first page, followed by a drawing, a short description code and a detailed description of the construction. The drawing at top is schematic, not to scale and just for illustration purposes. In the first table on the second page all conducted sound insulation tests are listed with the test-id number and the determined single number STC rating. Further in the top bar of the results table an average STC is listed which is determined from the arithmetic average of the frequency dependent Transmission Loss (TL) data of all listed tests. The second table on the second page contains the actuals (i.e. dimensions and mass) of the materials used to assemble the walls. The order of the listed materials may not reflect the order in which the materials were installed in the wall.

Midrise-1WN



G13_G13_SWS140(406)_GFB90_G13_G13

Description	Two layers of 12.7 mm thick Type X gypsum board directly attached on each side installed on 2x4 staggered wood studs (wood frame 2)
Cladding 1	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
Framing & Cavity Insulation	• Staggered 2x4 wood studs spaced 406 mm oc and toe-screwed using 4 screws at the top and bottom. • 2x4 end studs installed on one side of the assembly. • Double 2x6 headers attached to the test frame using four 50 mm long screws. • Single 2x6 footer attached to the test frame using four 50 mm long screws. • Cavities between studs on one side filled with 90 mm glass fibre insulation (R-12)
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-1WN

ASTM E90 Sound Transmission Class - Single Number Rating

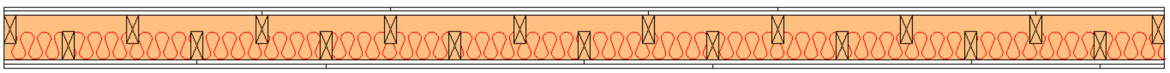
Test ID(s)	Average STC 49
TLA-11-052	**49**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum (Cladding 1)	180.7	26
2x4 (38 x 89 mm) Staggered Wood Studs	61.6	140
2x4 (38 x 89 mm) End Stud	7.2	
2x6 (38 x 140 mm) Double Header	17.9	
2x6 (38 x 140 mm) Single Footer	8.9	
90 mm Glass Fibre Insulation	7.2	90*
2*12.7 mm Gypsum (Cladding 2)	181.6	26
	465.1	**192**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-1WS



G13_G13_SWS140(406)_GFB90_G13_G13

Description	Two layers of 12.7 mm thick Type X gypsum board directly attached on each side installed on 2x4 staggered wood studs (wood frame 1)
Cladding 1	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
Framing & Cavity Insulation	• Staggered 2x4 wood studs spaced 406 mm oc and toe-screwed using 4 screws at the top and bottom. • 2x4 end studs installed on one side of the assembly. • Double 2x6 headers attached to the test frame using four 50 mm long screws. • Single 2x6 footer attached to the test frame using four 50 mm long screws. • Cavities between studs on one side filled with 90 mm glass fibre insulation (R-12)
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-1WS

ASTM E90 Sound Transmission Class - Single Number Rating

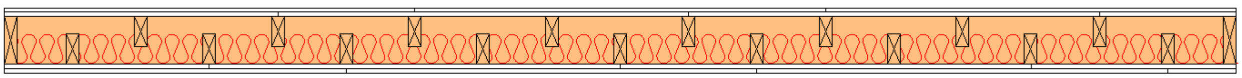
Test ID(s)	Average STC 51
TLA-11-046	**51**
TLA-11-048	**50**
TLA-11-049	**50**
TLA-11-050	**51**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum (Cladding 1)	183.6	26
2x4 (38 x 89 mm) Staggered Wood Studs	65	140
2x4 (38 x 89 mm) End Stud	7.6	
2x6 (38 x 140 mm) Double Header	17.1	
2x6 (38 x 140 mm) Single Footer	8.5	
90 mm Glass Fibre Insulation	7.2	90*
2*12.7 mm Gypsum (Cladding 2)	182.3	26
	471.3	**192**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-1WS-a



G13_G13_SWS140(406)_GFB90_G13_G13

Description	Two layers of 12.7 mm thick Type X gypsum board directly attached on each side of 2x4 staggered wood studs with 2x6 end studs (wood frame 1)
Cladding 1	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
Framing & Cavity Insulation	• Staggered 2x4 wood studs spaced 406 mm oc and toe-screwed using 4 screws at the top and bottom. • 2x6 end studs installed on assembly. • Double 2x6 headers attached to the test frame using four 50 mm long screws. • Single 2x6 footer attached to the test frame using four 50 mm long screws. • Cavities between studs on one side filled with 90 mm glass fibre insulation (R-12)
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-1WS-a

ASTM E90 Sound Transmission Class - Single Number Rating

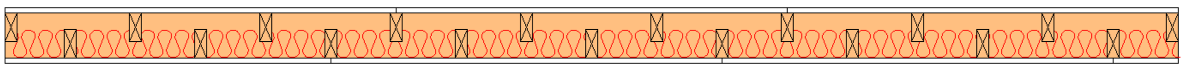
Test ID(s)	Average STC 49
TLA-11-043	**49**
TLA-11-044	**49**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum (Cladding 1)	183.6	26
2x4 (38 x 89 mm) Staggered Wood Studs	65	140
2x6 (38 x 140 mm) End Stud	11.2	
2x6 (38 x 140 mm) Double Header	17.1	
2x6 (38 x 140 mm) Single Footer	8.5	
90 mm Glass Fibre Insulation	7.2	90*
2*12.7 mm Gypsum (Cladding 2)	182.3	26
	474.9	**192**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-2WS



G16_3SWS140(406)_GFB90_G16

Description	One layer of 15.9 mm Type X gypsum board directly attached on each side of 2x4 staggered wood studs (wood frame 1)
Cladding 1	• One layer of 15.9 mm Type X gypsum board installed vertically. • Gypsum board directly attached using Type S screws 32 mm long spaced 300 mm along the edge and in the field. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
Framing & Cavity Insulation	• Staggered 2x4 wood studs spaced 406 mm oc and toe-screwed using 4 screws at the top and bottom. • 2x4 end studs installed on one side of the assembly. • Double 2x6 headers attached to the test frame using four 50 mm long screws. • Single 2x6 footer attached to the test frame using four 50 mm long screws. • Cavities between studs on one side filled with 90 mm glass fibre insulation (R-12)
Cladding 2	• One layer of 15.9 mm Type X gypsum board installed vertically. • Gypsum board directly attached using Type S screws 32 mm long spaced 300 mm along the edge and in the field. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-2WS

ASTM E90 Sound Transmission Class - Single Number Rating

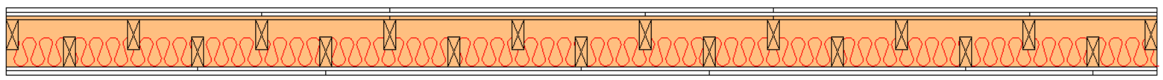
Test ID(s)	Average STC 43
TLA-11-053	**43**

Element Details

Element	Mass (kg)	Depth (mm)
15.9 mm Gypsum (Cladding 1)	98.5	16
2x4 (38 x 89 mm) Staggered Wood Studs	65	140
2x4 (38 x 89 mm) End Stud	7.6	
2x6 (38 x 140 mm) Double Header	17.9	
2x6 (38 x 140 mm) Single Footer	8.9	
90 mm Glass Fibre Insulation	7.2	90*
15.9 mm Gypsum (Cladding 2)	98.9	16
	304	**172**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-3WN



G13_G13_SWS140(406)_GFB90_OSB10_G13_G13

Description

Two layers of 12.7 mm thick Type X gypsum board directly attached on one side with 10 mm OSB shear membrane and two layers of 12.7 mm thick Type X gypsum board directly attached on the other side of 2x4 staggered wood studs (wood frame 2)

Cladding 1

- Two layers of 12.7 mm thick Type X gypsum board installed vertically.
- Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field.
- Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field.
- Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Framing & Cavity Insulation

- Staggered 2x4 wood studs spaced 406 mm oc and toe-screwed using 4 screws at the top and bottom.
- 2x4 end studs installed on one side of the assembly.
- Double 2x6 headers attached to the test frame using four 50 mm long screws.
- Single 2x6 footer attached to the test frame using four 50 mm long screws.
- Cavities between studs on one side filled with 90 mm glass fibre insulation (R-12)

Shear Membrane

- One layer of 10 mm OSB installed vertically.
- OSB shear membrane attached using #10, 75 mm long screws spaced at 75 mm in the field and along the edge.

Cladding 2

- Two layers of 12.7 mm thick Type X gypsum board installed vertically.
- Base layer gypsum board directly attached using Type S screws 50 mm long spaced 600 mm along the edge and in the field.
- Face layer gypsum board directly attached using Type S screws 56 mm long spaced 300 mm along the edge and in the field.
- Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-3WN

ASTM E90 Sound Transmission Class - Single Number Rating

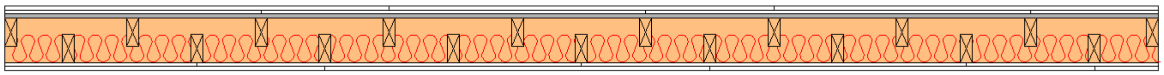
Test ID(s)	Average STC 51
TLA-11-060	**51**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum (Cladding 1)	180.7	26
2x4 (38 x 89 mm) Staggered Wood Studs	61.6	140
2x4 (38 x 89 mm) End Stud	7.2	
2x6 (38 x 140 mm) Double Header	17.9	
2x6 (38 x 140 mm) Single Footer	8.9	
90 mm Glass Fibre Insulation	7.2	90*
10 mm Oriented Strand Board	63	10
2*12.7 mm Gypsum (Cladding 2)	181.6	26
	528.1	**202**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-3WS



G13_G13_SWS140(406)_GFB90_RC13(610)_G13_G13

Description	Two layers of 12.7 mm thick Type X gypsum board directly attached on one side and two layers of 12.7 mm thick Type X gypsum board on resilient channels on the other side of 2x4 staggered wood studs (wood frame 1)
Cladding 1	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
Framing & Cavity Insulation	• Staggered 2x4 wood studs spaced 406 mm oc and toe-screwed using 4 screws at the top and bottom. • 2x4 end studs installed on one side of the assembly. • Double 2x6 headers attached to the test frame using four 50 mm long screws. • Single 2x6 footer attached to the test frame using four 50 mm long screws. • Cavities between studs on one side filled with 90 mm glass fibre insulation (R-12)
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board attached to RC using Type S screws 31 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board attached to RC using Type S screws 41 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape. • Resilient channels installed horizontally with spacing of 610 mm oc with lowermost channel inverted.

Midrise-3WS

ASTM E90 Sound Transmission Class - Single Number Rating

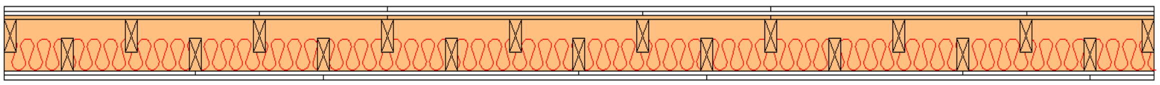
Test ID(s)	Average STC 59
TLA-11-059	**59**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum (Cladding 1)	183.6	26
2x4 (38 x 89 mm) Staggered Wood Studs	65	140
2x4 (38 x 89 mm) End Stud	7.6	
2x6 (38 x 140 mm) Double Header	17.9	
2x6 (38 x 140 mm) Single Footer	8.9	
90 mm Glass Fibre Insulation	7.2	90*
12.7 mm Resilient channels	4.0	13
2*12.7 mm Gypsum (Cladding 2)	182.3	26
	476.5	**205**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-4WS



G13_G13_SWS140(406)_GFB90_PLY10_G13_G13

Description	Two layers of 12.7 mm thick Type X gypsum board directly attached on one side with 10 mm plywood shear membrane and two layers of 12.7 mm thick Type X gypsum board directly attached on the other side of 2x4 staggered wood studs (wood frame 1)
Cladding 1	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
Framing & Cavity Insulation	• Staggered 2x4 wood studs spaced 406 mm oc and toe-screwed using 4 screws at the top and bottom. • 2x4 end studs installed on one side of the assembly. • Double 2x6 headers attached to the test frame using four 50 mm long screws. • Single 2x6 footer attached to the test frame using four 50 mm long screws. • Cavities between studs on one side filled with 90 mm glass fibre insulation (R-12)
Shear Membrane	• One layer of 10 mm plywood installed vertically. • Plywood shear membrane attached using #10, 75 mm long screws spaced at 75 mm in the field and along the edge.
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 50 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 56 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-4WS

ASTM E90 Sound Transmission Class - Single Number Rating

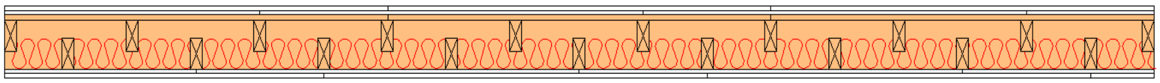
Test ID(s)	Average STC 52
TLA-11-061	**52**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum (Cladding 1)	183.6	26
2x4 (38 x 89 mm) Staggered Wood Studs	65	140
2x4 (38 x 89 mm) End Stud	7.6	
2x6 (38 x 140 mm) Double Header	17.9	
2x6 (38 x 140 mm) Single Footer	8.9	
90 mm Glass Fibre Insulation	7.2	90*
10 mm Plywood	36	10
2*12.7 mm Gypsum (Cladding 2)	182.3	26
	508.5	**202**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-5WN



G13_G13_SWS140(406)_GFB90_OSB16_G13_G13

Description	Two layers of 12.7 mm thick Type X gypsum board directly attached on one side with 15.9 mm OSB shear membrane and two layers of 12.7 mm thick Type X gypsum board directly attached on the other side of 2x4 staggered wood studs (wood frame 2)
Cladding 1	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
Framing & Cavity Insulation	• Staggered 2x4 wood studs spaced 406 mm oc and toe-screwed using 4 screws at the top and bottom. • 2x4 end studs installed on one side of the assembly. • Double 2x6 headers attached to the test frame using four 50 mm long screws. • Single 2x6 footer attached to the test frame using four 50 mm long screws. • Cavities between studs on one side filled with 90 mm glass fibre insulation (R-12)
Shear Membrane	• One layer of 15.9 mm OSB installed vertically. • OSB shear membrane attached using #10, 75 mm long screws spaced at 75 mm in the field and along the edge.
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 50 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 62 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-5WN

ASTM E90 Sound Transmission Class - Single Number Rating

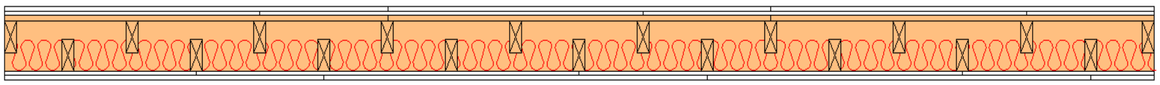
Test ID(s)	Average STC 52
TLA-11-062	**52**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum (Cladding 1)	180.7	26
2x4 (38 x 89 mm) Staggered Wood Studs	61.6	140
2x4 (38 x 89 mm) End Stud	7.2	
2x6 (38 x 140 mm) Double Header	17.9	
2x6 (38 x 140 mm) Single Footer	8.9	
90 mm Glass Fibre Insulation	7.2	90*
15.9 mm Oriented Strand Board	90.7	16
2*12.7 mm Gypsum (Cladding 2)	181.6	26
	555.8	**208**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-6WS



G13_G13_SWS140(406)_GFB90_PLY16_G13_G13

Description	Two layers of 12.7 mm thick Type X gypsum board directly attached on one side with 15.9 mm plywood shear membrane and two layers of 12.7 mm thick Type X gypsum board directly attached on the other side of 2x4 staggered wood studs (wood frame 1)
Cladding 1	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
Framing & Cavity Insulation	• Staggered 2x4 wood studs spaced 406 mm oc and toe-screwed using 4 screws at the top and bottom. • 2x4 end studs installed on one side of the assembly. • Double 2x6 headers attached to the test frame using four 50 mm long screws. • Single 2x6 footer attached to the test frame using four 50 mm long screws. • Cavities between studs on one side filled with 90 mm glass fibre insulation (R-12)
Shear Membrane	• One layer of 15.9 mm plywood installed vertically. • Plywood shear membrane attached using #10, 75 mm long screws spaced at 75 mm in the field and along the edge.
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 50 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 62 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-6WS

ASTM E90 Sound Transmission Class - Single Number Rating

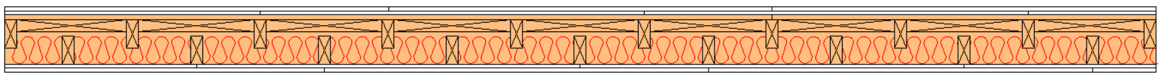
Test ID(s)	Average STC 51
TLA-11-063	**50**
TLA-11-064	**51**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum (Cladding 1)	183.6	26
2x4 (38 x 89 mm) Staggered Wood Studs	65	140
2x4 (38 x 89 mm) End Stud	7.6	
2x6 (38 x 140 mm) Double Header	17.9	
2x6 (38 x 140 mm) Single Footer	8.9	
90 mm Glass Fibre Insulation	7.2	90*
15.9 mm Plywood	67.9	16
2*12.7 mm Gypsum (Cladding 2)	182.3	26
	540.4	**208**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-7WS



G13_G13_SWS140(406)_GFB90_PLY16_BLK_G13_G13

Description	Two layers of 12.7 mm thick Type X gypsum board directly attached on one side with 15.9 mm plywood shear membrane installed horizontally with blocking and two layers of 12.7 mm thick Type X gypsum board directly attached on the other side of 2x4 staggered wood studs (wood frame 1)
Cladding 1	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
Framing & Cavity Insulation	• Staggered 2x4 wood studs spaced 406 mm oc and toe-screwed using 4 screws at the top and bottom. • 2x4 end studs installed on one side of the assembly. • Double 2x6 headers attached to the test frame using four 50 mm long screws. • Single 2x6 footer attached to the test frame using four 50 mm long screws. • Cavities between studs on one side filled with 90 mm glass fibre insulation (R-12)
Shear Membrane	• One layer of 15.9 mm plywood installed horizontally with horizontal gap with pieces of 2x6 studs attached flat-wise mid-height of the wall as blocking. • Plywood shear membrane attached using #10, 75 mm long screws spaced at 75 mm in the field and along the edge.
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 50 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 62 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-7WS

ASTM E90 Sound Transmission Class - Single Number Rating

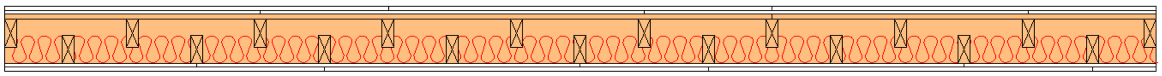
Test ID(s)	Average STC 52
TLA-11-070	**52**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum (Cladding 1)	183.6	26
2x4 (38 x 89 mm) Staggered Wood Studs	65	140
2x4 (38 x 89 mm) End Stud	7.6	
2x6 (38 x 140 mm) Double Header	17.9	
2x6 (38 x 140 mm) Single Footer	8.9	
90mm Glass Fibre Insulation	7.2	90*
2x6 (38 x 140 mm) Blocking	7.2	
15.9 mm Plywood	67.9	16
2*12.7 mm Gypsum (Cladding 2)	182.3	26
	547.6	**208**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-8WS



G13_G13_SWS140(406)_GFB90_PLY16_G13_G13

Description	Two layers of 12.7 mm thick Type X gypsum board directly attached on one side with 15.9 mm plywood shear membrane installed horizontally and two layers of 12.7 mm thick Type X gypsum board directly attached on the other side of 2x4 staggered wood studs (wood frame 1)
Cladding 1	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
Framing & Cavity Insulation	• Staggered 2x4 wood studs spaced 406 mm oc and toe-screwed using 4 screws at the top and bottom. • 2x4 end studs installed on one side of the assembly. • Double 2x6 headers attached to the test frame using four 50 mm long screws. • Single 2x6 footer attached to the test frame using four 50 mm long screws. • Cavities between studs on one side filled with 90 mm glass fibre insulation (R-12)
Shear Membrane	• One layer of 15.9 mm plywood installed horizontally with horizontal gap mid-height of the wall. • Plywood shear membrane attached using #10, 75 mm long screws spaced at 75 mm in the field and along the edge.
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 50 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 62 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-8WS

ASTM E90 Sound Transmission Class - Single Number Rating

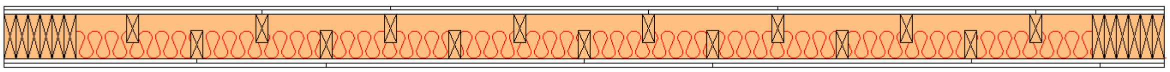
Test ID(s)	Average STC 51
TLA-11-071	**51**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum (Cladding 1)	183.6	26
2x4 (38 x 89 mm) Staggered Wood Studs	65	140
2x4 (38 x 89 mm) End Stud	7.6	
2x6 (38 x 140 mm) Double Header	17.9	
2x6 (38 x 140 mm) Single Footer	8.9	
90 mm Glass Fibre Insulation	7.2	90*
15.9 mm Plywood	67.9	16
2*12.7 mm Gypsum (Cladding 2)	182.3	26
	540.4	**208**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-9WS



G13_G13_SWS140(406)_GFB90_G13_G13

Description	Two layers of 12.7 mm thick Type X gypsum board directly attached on each side of 2x4 staggered wood studs with six 2x6 studs build-up as end columns (wood frame 1)
Cladding 1	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
Framing & Cavity Insulation	• Staggered 2x4 wood studs spaced 406 mm oc and toe-screwed using 4 screws at the top and bottom. • End-columns made out of six 2x6 studs toe screwed from one side only and screwed to adjacent stud with #10, 75 mm long screws spaced 750 mm oc. • Double 2x6 headers attached to the test frame using four 50 mm long screws. • Single 2x6 footer attached to the test frame using four 50 mm long screws. • Cavities between studs on one side filled with 90 mm glass fibre insulation (R-12)
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-9WS

ASTM E90 Sound Transmission Class - Single Number Rating

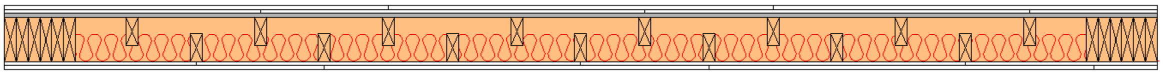
Test ID(s)	Average STC 47
TLA-11-076	**47**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum (Cladding 1)	182.8	26
2x4 (38 x 89 mm) Staggered Wood Studs	56	140
6*2x6 (38 x 140 mm) Studs as End Columns	60.6	
2x6 (38 x 140 mm) Double Header	17.9	
2x6 (38 x 140 mm) Single Footer	8.9	
90 mm Glass Fibre Insulation	7.2	90*
2*12.7 mm Gypsum (Cladding 2)	183.2	26
	516.6	**192**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-10WS



G13_G13_SWS140(406)_GFB90_RC13(610)_G13_G13

Description	Two layers of 12.7 mm thick Type X gypsum board directly attached on one side and two layers of 12.7 mm thick Type X gypsum board on resilient channels on the other side of 2x4 staggered wood studs with six 2x6 studs build-up as end columns (wood frame 1)
Cladding 1	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
Framing & Cavity Insulation	• Staggered 2x4 wood studs spaced 406 mm oc and toe-screwed using 4 screws at the top and bottom. • End-columns made out of six 2x6 studs toe screwed from one side only and screwed to adjacent stud with #10, 75 mm long screws spaced 750 mm oc. • Double 2x6 headers attached to the test frame using four 50 mm long screws. • Single 2x6 footer attached to the test frame using four 50 mm long screws. • Cavities between studs on one side filled with 90 mm glass fibre insulation (R-12)
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board attached to RC using Type S screws 31 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board attached to RC using Type S screws 41 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape. • Resilient channels installed horizontally with spacing of 610 mm oc with lowermost channel inverted.

Midrise-10WS

ASTM E90 Sound Transmission Class - Single Number Rating

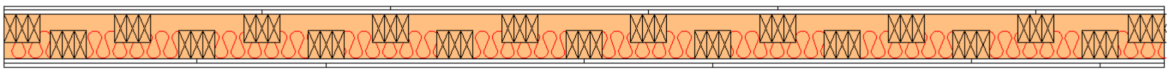
Test ID(s)	Average STC 54
TLA-11-078	**54**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum (Cladding 1)	182.8	26
2x4 (38 x 89 mm) Staggered Wood Studs	56	140
6*2x6 (38 x 140 mm) Studs as End Columns	60.6	
2x6 (38 x 140 mm) Double Header	17.9	
2x6 (38 x 140 mm) Single Footer	8.9	
90 mm Glass Fibre Insulation	7.2	90*
12.7 mm Resilient channels	4.0	13
2*12.7 mm Gypsum (Cladding 2)	183.2	26
	520.6	**205**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-11WS



G13_G13_3SWS140(406)_GFB90_G13_G13

Description	Two layers of 12.7 mm thick Type X gypsum board directly attached on each side of tripled 2x4 staggered wood studs (wood frame 1)
Cladding 1	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Cladding directly attached to tripled wood studs along single line. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
Framing & Cavity Insulation	• Tripled staggered 2x4 wood studs spaced 406 mm oc. • Middle stud was toe-screwed using 4 screws at the top and bottom. • Two added 2x4 studs were attached with 2 toe screws and with screws at 600 mm o.c. with #10, 75 mm long screws from one side only. • Three 2x4 end studs toe screwed from one side and screwed to adjacent stud with #10, 75 mm long screws spaced 750 mm oc. The end studs were installed on one side of the assembly. • Double 2x6 headers attached to the test frame using four 50 mm long screws. • Single 2x6 footer attached to the test frame using four 50 mm long screws. • Cavities between studs on one side filled with 90 mm glass fibre insulation (R-12)
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Cladding directly attached to wood studs along single line. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-11WS

ASTM E90 Sound Transmission Class - Single Number Rating

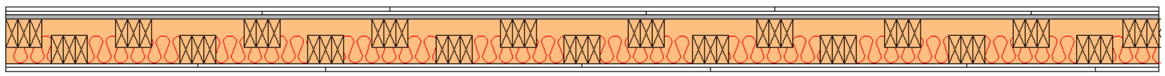
Test ID(s)	Average STC 49
TLA-11-083	**49**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum (Cladding 1)	182.8	26
3*2x4 (38 x 89 mm) Staggered Wood Studs	190.4	140
3*2x4 (38 x 89 mm) End Studs	22.4	
2x6 (38 x 140 mm) Double Header	17.9	
2x6 (38 x 140 mm) Single Footer	8.9	
90 mm Glass Fibre Insulation	7.2	90*
2*12.7 mm Gypsum (Cladding 2)	183.2	26
	612.8	**192**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-12WS



G13_G13_3SWS140(406)_GFB90_RC13(610)_G13_G13

Description	Two layers of 12.7 mm thick Type X gypsum board directly attached on one side (only along middle stud) and two layers of 12.7 mm thick Type X gypsum board on resilient channels installed (RC fastened to all 3 studs) on the other side of tripled 2x4 staggered wood studs (wood frame 1)

Cladding 1

- Two layers of 12.7 mm thick Type X gypsum board installed vertically.
- Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field.
- Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field.
- Cladding directly attached to tripled wood studs along single line.
- Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Framing & Cavity Insulation

- Tripled staggered 2x4 wood studs spaced 406 mm oc.
- Middle stud was toe-screwed using 4 screws at the top and bottom.
- Two added 2x4 studs were attached with 2 toe screws and with screws at 600 mm o.c. with #10, 75 mm long screws from one side only.
- Three 2x4 end studs toe screwed from one side and screwed to adjacent stud with #10, 75 mm long screws spaced 750 mm oc. The end studs were installed on one side of the assembly.
- Double 2x6 headers attached to the test frame using four 50 mm long screws.
- Single 2x6 footer attached to the test frame using four 50 mm long screws.
- Cavities between studs on one side filled with 90 mm glass fibre insulation (R-12)

Cladding 2

- Two layers of 12.7 mm thick Type X gypsum board installed vertically.
- Base layer gypsum board attached to RC using Type S screws 31 mm long spaced 600 mm along the edge and in the field.
- Face layer gypsum board attached to RC using Type S screws 41 mm long spaced 300 mm along the edge and in the field.
- Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
- Resilient channels installed horizontally with spacing of 610 mm oc with lowermost channel inverted.
- The resilient channels were fastened to each one of the tripled wood studs.

Midrise-12WS

ASTM E90 Sound Transmission Class - Single Number Rating

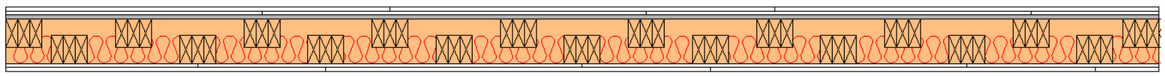
Test ID(s)	Average STC 56
TLA-11-084	**56**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum (Cladding 1)	182.8	26
3*2x4 (38 x 89 mm) Staggered Wood Studs	190.4	140
3*2x4 (38 x 89 mm) End Studs	22.4	
2x6 (38 x 140 mm) Double Header	17.9	
2x6 (38 x 140 mm) Single Footer	8.9	
90 mm Glass Fibre Insulation	7.2	90*
12.7 mm Resilient channels	4.0	13
2*12.7 mm Gypsum (Cladding 2)	183.2	26
	616.8	**205**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-12WS-a



G13_G13_3SWS140(406)_GFB90_RC13(610)_G13_G13

Description

Two layers of 12.7 mm thick Type X gypsum board directly attached on one side along all 3 studs of each column and two layers of 12.7 mm thick Type X gypsum board on resilient channels installed (RC fastened to all 3 studs) on the other side of tripled 2x4 staggered wood studs (wood frame 1)

Cladding 1

- Two layers of 12.7 mm thick Type X gypsum board installed vertically.
- Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field.
- Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field.
- Cladding directly attached to tripled wood studs along 3 lines.
- Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Framing & Cavity Insulation

- Tripled staggered 2x4 wood studs spaced 406 mm oc.
- Middle stud was toe-screwed using 4 screws at the top and bottom.
- Two added 2x4 studs were attached with 2 toe screws and with screws at 600 mm o.c. with #10, 75 mm long screws from one side only.
- Three 2x4 end studs toe screwed from one side and screwed to adjacent stud with #10, 75 mm long screws spaced 750 mm oc. The end studs were installed on one side of the assembly.
- Double 2x6 headers attached to the test frame using four 50 mm long screws.
- Single 2x6 footer attached to the test frame using four 50 mm long screws.
- Cavities between studs on one side filled with 90 mm glass fibre insulation (R-12)

Cladding 2

- Two layers of 12.7 mm thick Type X gypsum board installed vertically.
- Base layer gypsum board attached to RC using Type S screws 31 mm long spaced 600 mm along the edge and in the field.
- Face layer gypsum board attached to RC using Type S screws 41 mm long spaced 300 mm along the edge and in the field.
- Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
- Resilient channels installed horizontally with spacing of 610 mm oc with lowermost channel inverted.
- The resilient channels were fastened to each one of the tripled wood studs.

Midrise-12WS-a

ASTM E90 Sound Transmission Class - Single Number Rating

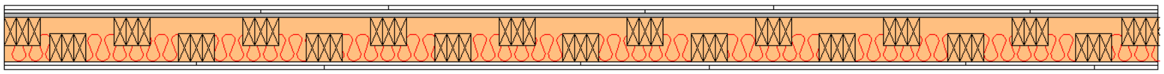
Test ID(s)	Average STC 55
TLA-11-085	**55**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum (Cladding 1)	182.8	26
3*2x4 (38 x 89 mm) Staggered Wood Studs	190.4	140
3*2x4 (38 x 89 mm) End Studs	22.4	
2x6 (38 x 140 mm) Double Header	17.9	
2x6 (38 x 140 mm) Single Footer	8.9	
90 mm Glass Fibre Insulation	7.2	90*
12.7 mm Resilient channels	4.0	13
2*12.7 mm Gypsum (Cladding 2)	183.2	26
	616.8	**205**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-12WS-b



G13_G13_3SWS140(406)_GFB90_RC(610)_G13_G13

Description

Two layers of 12.7 mm thick Type X gypsum board directly attached on one side along middle stud and two layers of 12.7 mm thick Type X gypsum board on resilient channels installed (RC fastened to middle stud only) on the other side of tripled 2x4 staggered wood studs (wood frame 1)

Cladding 1

- Two layers of 12.7 mm thick Type X gypsum board installed vertically.
- Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field.
- Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field.
- Cladding directly attached to tripled wood studs along single line.
- Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Framing & Cavity Insulation

- Tripled staggered 2x4 wood studs spaced 406 mm oc.
- Middle stud was toe-screwed using 4 screws at the top and bottom.
- Two added 2x4 studs were attached with 2 toe screws and with screws at 600 mm o.c. with #10, 75 mm long screws from one side only.
- Three 2x4 end studs toe screwed from one side and screwed to adjacent stud with #10, 75 mm long screws spaced 750 mm oc. The end studs were installed on one side of the assembly.
- Double 2x6 headers attached to the test frame using four 50 mm long screws.
- Single 2x6 footer attached to the test frame using four 50 mm long screws.
- Cavities between studs on one side filled with 90 mm glass fibre insulation (R-12)

Cladding 2

- Two layers of 12.7 mm thick Type X gypsum board installed vertically.
- Base layer gypsum board attached to RC using Type S screws 31 mm long spaced 600 mm along the edge and in the field.
- Face layer gypsum board attached to RC using Type S screws 41 mm long spaced 300 mm along the edge and in the field.
- Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
- Resilient channels installed horizontally with spacing of 610 mm oc with lowermost channel inverted.
- The resilient channels were only fastened to the middle stud of the tripled stud.

Midrise-12WS-b

ASTM E90 Sound Transmission Class - Single Number Rating

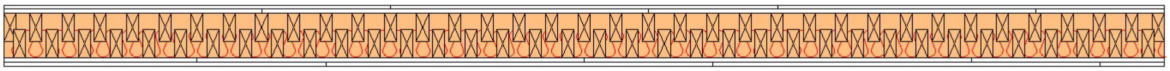
Test ID(s)	Average STC 56
TLA-11-087	**56**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum (Cladding 1)	182.8	26
3*2x4 (38 x 89 mm) Staggered Wood Studs	190.4	140
3*2x4 (38 x 89 mm) End Studs	22.4	
2x6 (38 x 140 mm) Double Header	17.9	
2x6 (38 x 140 mm) Single Footer	8.9	
90 mm Glass Fibre Insulation	7.2	90*
12.7 mm Resilient channels	4.0	13
2*12.7 mm Gypsum (Cladding 2)	183.2	26
	616.8	**205**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-13WS



G13_G13_SWS140(100)_GFB90_G13_G13

Description	Two layers of 12.7 mm thick Type X gypsum board directly attached on each side of 2x4 staggered wood studs with 100 mm spacing (wood frame 3)
Cladding 1	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
Framing & Cavity Insulation	• Staggered 2x4 wood studs spaced 100 mm oc and end nailed using 2 nails at the top and bottom. • 2x4 end studs installed on one side of the assembly. • Double 2x6 headers attached to the test frame using four 50 mm long screws. • Single 2x6 footer attached to the test frame using four 50 mm long screws. • Cavities between studs on one side filled with 90 mm glass fibre insulation (R-12)
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-13WS

ASTM E90 Sound Transmission Class - Single Number Rating

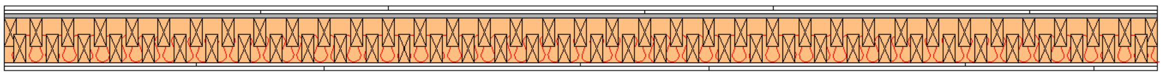
Test ID(s)	Average STC 36
TLA-11-090	**36**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum (Cladding 1)	182.6	26
2x4 (38 x 89 mm) Staggered Wood Studs	262.6	140
2x4 (38 x 89 mm) End Stud	7.4	
2x6 (38 x 140 mm) Double Header	19.5	
2x6 (38 x 140 mm) Single Footer	9.8	
90 mm Glass Fibre Insulation	4.1	90*
2*12.7 mm Gypsum (Cladding 2)	179.6	26
	665.6	**192**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-14WS



G13_G13_SWS140(100)_GFB90_RC13(610)_G13_G13

Description	Two layers of 12.7 mm thick Type X gypsum board directly attached on one side and two layers of 12.7 mm thick Type X gypsum board on resilient channels on the other side of 2x4 staggered wood studs with 100 mm spacing (wood frame 3)
Cladding 1	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
Framing & Cavity Insulation	• Staggered 2x4 wood studs spaced 100 mm oc and end nailed using 2 nails at the top and bottom. • 2x4 end studs installed on one side of the assembly. • Double 2x6 headers attached to the test frame using four 50 mm long screws. • Single 2x6 footer attached to the test frame using four 50 mm long screws. • Cavities between studs on one side filled with 90 mm glass fibre insulation (R-12)
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board attached to RC using Type S screws 31 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board attached to RC using Type S screws 41 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape. • Resilient channels installed horizontally with spacing of 610 mm oc with lowermost channel inverted.

Midrise-14WS

ASTM E90 Sound Transmission Class - Single Number Rating

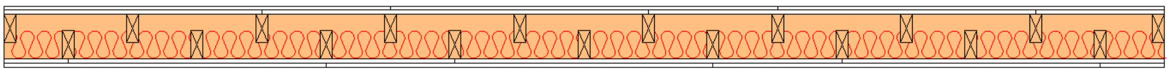
Test ID(s)	Average STC 50
TLA-11-091	**50**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum (Cladding 1)	182.6	26
2x4 (38 x 89 mm) Staggered Wood Studs	262.6	140
2x4 (38 x 89 mm) End Stud	7.4	
2x6 (38 x 140 mm) Double Header	19.5	
2x6 (38 x 140 mm) Single Footer	9.8	
90 mm Glass Fibre Insulation	4.1	90*
12.7 mm Resilient channels	4.0	13
2*12.7 mm Gypsum (Cladding 2)	179.6	26
	669.6	**205**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-15WN



G13_G13_SWS140(406)_GFB90_G13_G13

Description	Two layers of 12.7 mm thick Type X gypsum board directly attached on each side of 2x4 staggered wood studs (tieback frame)
Cladding 1	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
Framing & Cavity Insulation	• Staggered 2x4 wood studs spaced 406 mm oc and end-nailed with two nails at the top and bottom. • 2x4 end studs installed on one side of the assembly. • Single 2x6 header attached to the test frame using two 50 mm long screws. • Single 2x6 footer attached to the test frame using two 50 mm long screws. • Cavities between studs on one side filled with 90 mm glass fibre insulation (R-12)
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-15WN

ASTM E90 Sound Transmission Class - Single Number Rating

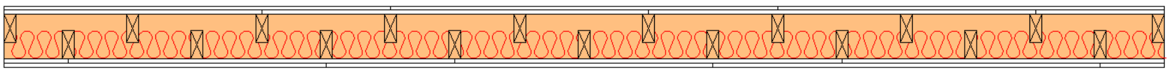
Test ID(s)	Average STC 50
TLA-11-092	**50**
TLA-12-001	**50**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum (Cladding 1)	180.7	26
2x4 (38 x 89 mm) Staggered Wood Studs	60.1	140
2x4 (38 x 89 mm) End Stud	7.1	
2x6 (38 x 140 mm) Single Header	9.2	
2x6 (38 x 140 mm) Single Footer	9.2	
90 mm Glass Fibre Insulation	7.2	90*
2*12.7 mm Gypsum (Cladding 2)	181.6	26
	455.1	**192**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-15WN-a



G13_G13_SWS140(406)_GFB90_G13_G13

Description	Two layers of 12.7 mm thick Type X gypsum board directly attached on each side of 2x4 staggered wood studs (tieback frame)
Cladding 1	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 400 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
Framing & Cavity Insulation	• Staggered 2x4 wood studs spaced 406 mm oc and end-nailed with two nails at the top and bottom. • 2x4 end studs installed on one side of the assembly. • Single 2x6 header attached to the test frame using two 50 mm long screws. • Single 2x6 footer attached to the test frame using two 50 mm long screws. • Cavities between studs on one side filled with 90 mm glass fibre insulation (R-12)
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 400 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-15WN-a

ASTM E90 Sound Transmission Class - Single Number Rating

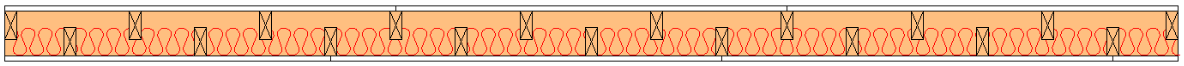
Test ID(s)	Average STC 52
TLA-12-002	**52**
TLA-12-003	**52**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum (Cladding 1)	179.5	26
2x4 (38 x 89 mm) Staggered Wood Studs	60.1	140
2x4 (38 x 89 mm) End Stud	7.1	
2x6 (38 x 140 mm) Single Header	9.2	
2x6 (38 x 140 mm) Single Footer	9.2	
90 mm Glass Fibre Insulation	7.2	90*
2*12.7 mm Gypsum (Cladding 2)	179.2	26
	451.5	**192**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-16WN



G16_SWS140(406)_GFB90_G16

Description	One layer of 15.9 mm Type X gypsum board directly attached on each side installed on 2x4 staggered wood studs (tieback frame)
Cladding 1	• One layer of 15.9 mm Type X gypsum board installed vertically. • Gypsum board directly attached using Type S screws 32 mm long spaced 400 mm along the edge and in the field. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
Framing & Cavity Insulation	• Staggered 2x4 wood studs spaced 406 mm oc and end-nailed with two nails at the top and bottom. • 2x4 end studs installed on one side of the assembly. • Single 2x6 header attached to the test frame using two 50 mm long screws. • Single 2x6 footer attached to the test frame using two 50 mm long screws. • Cavities between studs on one side filled with 90 mm glass fibre insulation (R-12)
Cladding 2	• One layer of 15.9 mm Type X gypsum board installed vertically. • Gypsum board directly attached using Type S screws 32 mm long spaced 400 mm along the edge and in the field. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-16WN

ASTM E90 Sound Transmission Class - Single Number Rating

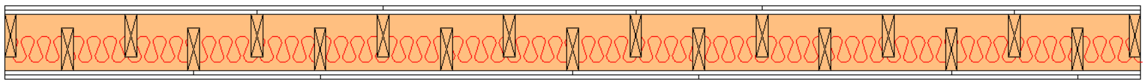
Test ID(s)	Average STC 45
TLA-12-004	**45**

Element Details

Element	Mass (kg)	Depth (mm)
15.9 mm Gypsum (Cladding 1)	98.4	16
2x4 (38 x 89 mm) Staggered Wood Studs	60.1	140
2x4 (38 x 89 mm) End Stud	7.1	
2x6 (38 x 140 mm) Single Header	9.2	
2x6 (38 x 140 mm) Single Footer	9.2	
90 mm Glass Fibre Insulation	7.2	90*
15.9 mm Gypsum (Cladding 2)	98.7	16
	289.9	**172**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-18WN



G13_G13_GFB152_SWS184(406)_G13_G13

Description	Two layers of 12.7 mm thick Type X gypsum board directly attached on each side installed on 2x6 staggered wood studs (wood frame 4)
Cladding 1	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
Framing & Cavity Insulation	• Staggered 2x6 wood studs spaced 406 mm oc and toe-screwed using two 57 mm long (#10, w) screws at the top and two at the bottom. • 2x6 end studs installed on one side of the assembly not fastened to the liner with sill gasket in between. • Double 2x8 headers attached to the test frame using four 50 mm long screws. • Single 2x8 footer attached to the test frame using four 50 mm long screws. • Cavities between studs on one side filled with 152 mm glass fibre insulation (R-20)
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-18WN

ASTM E90 Sound Transmission Class - Single Number Rating

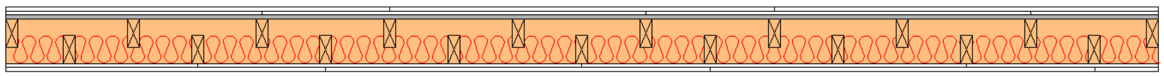
Test ID(s)	Average STC 50
TLA-12-059	**50**
TLA-12-060	**50**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum (Cladding 1)	175.8	26
2x6 (38 x 140 mm) Staggered Wood Studs	105.4	184
2x6 (38 x 140 mm) End Stud	12.4	
2x8 (38 x 184 mm) Double Header	25.2	
2x8 (38 x 184 mm) Single Footer	12.6	
152 mm Glass Fibre Insulation	11.5	152*
2*12.7 mm Gypsum (Cladding 2)	175.9	26
	518.8	**236**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-19WN



G13_G13_RC13(610)_GFB152_SWS184(406)_G13_G13

Description	Two layers of 12.7 mm thick Type X gypsum board directly attached on one side and two layers of 12.7 mm thick Type X gypsum board on resilient channels on the other side of 2x6 staggered wood studs
Cladding 1	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board attached to RC using Type S screws 31 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board attached to RC using Type S screws 41 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape. • Resilient channels installed horizontally with spacing of 610 mm oc with lowermost channel inverted.
Framing & Cavity Insulation	• Staggered 2x6 wood studs spaced 406 mm oc and toe-screwed using two 57 mm long (#10, w) screws at the top and two at the bottom. • 2x6 end studs installed on one side of the assembly not fastened to the liner with sill gasket in between. • Double 2x8 headers attached to the test frame using four 50 mm long screws. • Second head plate is attached to first with 76 mm long screws (#10) at 600 mm o.c. • Single 2x8 footer attached to the test frame using four 50 mm long screws. • Cavities between studs on one side filled with 152 mm glass fibre insulation (R-20)
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-19WN

ASTM E90 Sound Transmission Class - Single Number Rating

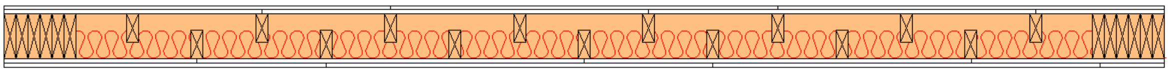
Test ID(s)	Average STC 59
TLA-12-061	**59**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum (Cladding 1)	175.8	26
12.7 mm Resilient Channel	4.0	13
152 mm Glass Fibre Insulation	11.5	152*
2x6 (38 x 140 mm) Staggered Wood Studs	105.4	
2x6 (38 x 140 mm) End Stud	12.4	
2x8 (38 x 184 mm) Double Header	25.2	
2x8 (38 x 184 mm) Single Footer	12.6	184
2*12.7 mm Gypsum (Cladding 2)	175.9	26
	522.8	**249**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-20WN



G13_G13_GFB152_SWS184(406)_G13_G13

Description	Two layers of 12.7 mm thick Type X gypsum board directly attached on each side of 2x6 staggered wood studs with six 2x8 studs build-up as end columns (wood frame 4)
Cladding 1	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
Framing & Cavity Insulation	• Staggered 2x6 wood studs spaced 406 mm oc and toe-screwed using two 57 mm long (#10, w) screws at the top and two at the bottom. • Six 2x8 end studs at each end with sill gasket between the first stud and the liner and the other studs toe screwed from one side only and screwed to adjacent stud with #10, 75 mm long screws spaced 750 mm oc. • Double 2x8 headers attached to the test frame using four 50 mm long screws. • Second head plate is attached to first with 76 mm long screws (#10) at 600 mm o.c. • Single 2x8 footer attached to the test frame using four 50 mm long screws. • Cavities between studs on one side filled with 152 mm glass fibre insulation (R-20)
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-20WN

ASTM E90 Sound Transmission Class - Single Number Rating

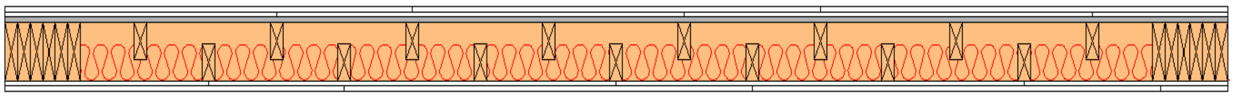
Test ID(s)	Average STC 48
TLA-12-062	**48**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum (Cladding 1)	175.8	26
2x6 (38 x 140 mm) Staggered Wood Studs	93	
6*2x8 (38 x 184 mm) End Stud	78	
2x8 (38 x 184 mm) Double Header	25.2	
2x8 (38 x 184 mm) Single Footer	12.6	184
152 mm Glass Fibre Insulation	11.5	152*
2*12.7 mm Gypsum (Cladding 2)	175.9	26
	572	**236**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-21WN



G13_G13_ RC13(610)_GFB152_SWS184(406)_G13_G13

Description	Two layers of 12.7 mm thick Type X gypsum board directly attached on one side and two layers of 12.7 mm thick Type X gypsum board on resilient channels on the other side of 2x6 staggered wood studs with six 2x8 studs build-up as end columns (wood frame 4)
Cladding 1	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board attached to RC using Type S screws 25 mm long near the end columns and 31 mm long spaced 600 mm along the remainder of RC. • Face layer gypsum board attached to RC using Type S screws 41 mm long spaced 300 mm along the RC. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape. • Resilient channels installed horizontally with spacing of 610 mm oc with lowermost channel inverted.
Framing & Cavity Insulation	• Staggered 2x6 wood studs spaced 406 mm oc and toe-screwed using two 57 mm long (#10, w) screws at the top and two at the bottom. • Six 2x8 end studs at each end with sill gasket between the first stud and the liner and the other studs toe screwed from one side only and screwed to adjacent stud with #10, 75 mm long screws spaced 750 mm oc. • Double 2x8 headers attached to the test frame using four 50 mm long screws. • Second head plate is attached to first with 76 mm long screws (#10) at 600 mm o.c. • Single 2x8 footer attached to the test frame using four 50 mm long screws. • Cavities between studs on one side filled with 152 mm glass fibre insulation (R-20)
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-21WN

ASTM E90 Sound Transmission Class - Single Number Rating

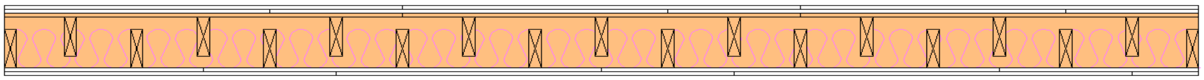
Test ID(s)	Average STC 56
TLA-12-063	**56**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum (Cladding 1)	175.8	26
2x6 (38 x 140 mm) Staggered Wood Studs	93	184
2x6 (38 x 140 mm) End Stud	78	
2x8 (38 x 184 mm) Double Header	25.2	
2x8 (38 x 184 mm) Single Footer	12.6	
152 mm Glass Fibre Insulation	11.5	152*
12.7 mm Resilient channels	4.0	13
2*12.7 mm Gypsum (Cladding 2)	175.9	26
	576	**249**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-22WN



G13_G13_GFB152_SWS184(406)_PLY16_G13_G13

Description

Two layers of 12.7 mm thick Type X gypsum board directly attached on one side with 15.9 mm plywood shear membrane and two layers of 12.7 mm thick Type X gypsum board directly attached on the other side of 2x6 staggered wood studs (wood frame 4)

Cladding 1

- Two layers of 12.7 mm thick Type X gypsum board installed vertically.
- Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field.
- Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field.
- Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Framing & Cavity Insulation

- Staggered 2x6 wood studs spaced 406 mm oc and toe-screwed using two 57 mm long (#10, w) screws at the top and two at the bottom.
- 2x6 end studs installed on one side of the assembly not fastened to the liner with sill gasket in between.
- Double 2x8 headers attached to the test frame using four 50 mm long screws.
- Second head plate is attached to first with 76 mm long screws (#10) at 600 mm o.c.
- Single 2x8 footer attached to the test frame using four 50 mm long screws.
- Cavities between studs on one side filled with 152 mm glass fibre insulation (R-20)

Shear Membrane

- One layer of 15.9 mm plywood installed vertically.
- Plywood shear membrane attached using #10, 75 mm long screws spaced at 75 mm in the field and along the edge.

Cladding 2

- Two layers of 12.7 mm thick Type X gypsum board installed vertically.
- Base layer gypsum board directly attached using Type S screws 50 mm long spaced 600 mm along the edge and in the field.
- Face layer gypsum board directly attached using Type S screws 62 mm long spaced 300 mm along the edge and in the field.
- Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-22WN

ASTM E90 Sound Transmission Class - Single Number Rating

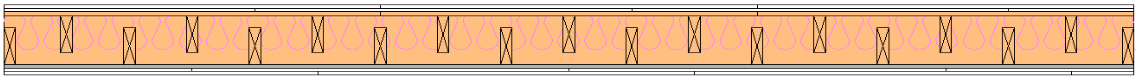
Test ID(s)	Average STC 51
TLA-12-081	**51**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum (Cladding 1)	175.5	26
2x6 (38 x 140 mm) Staggered Wood Studs	105.4	184
2x6 (38 x 140 mm) End Stud	12.4	
2x8 (38 x 184 mm) Double Header	25.2	
2x8 (38 x 184 mm) Single Footer	12.6	
152 mm Glass Fibre Insulation	11.5	152*
1*15.9 mm plywood	65.9	16
2*12.7 mm Gypsum (Cladding 2)	175.9	26
	584.4	**252**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-23WN



G13_G13_ RC(610)_GFB152_SWS184(406)_PLY16_G13_G13

Description	Two layers of 12.7 mm thick Type X gypsum board directly attached on one side with 15.9 mm plywood shear membrane and two layers of 12.7 mm thick Type X gypsum board on resilient channels on the other side of 2x6 staggered wood studs (wood frame 4)
Cladding 1	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board attached to RC using Type S screws 31 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board attached to RC using Type S screws 41 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape. • Resilient channels installed horizontally with spacing of 610 mm oc with lowermost channel inverted
Framing & Cavity Insulation	• Staggered 2x6 wood studs spaced 406 mm o.c. and toe-screwed using two 57 mm long (#10, w) screws at the top and two at the bottom. • 2x6 end studs installed on one side of the assembly not fastened to the liner with sill gasket in between. • Double 2x8 headers attached to the test frame using four 50 mm long screws. • Second head plate is attached to first with 76 mm long screws (#10) at 600 mm o.c. • Single 2x8 footer attached to the test frame using four 50 mm long screws. • Cavities between studs on one side filled with 152 mm glass fibre insulation (R-20)
Shear Membrane	• One layer of 15.9 mm plywood installed vertically. • Plywood shear membrane attached using #10, 75 mm long screws spaced at 75 mm in the field and along the edge.
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 50 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 62 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-23WN

ASTM E90 Sound Transmission Class - Single Number Rating

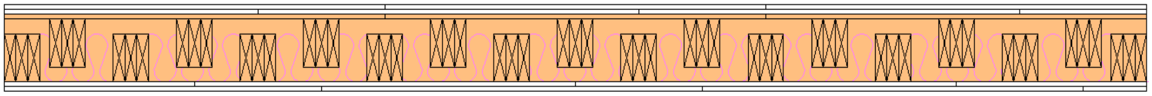
Test ID(s)	Average STC 61
TLA-12-082	**61**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum(Cladding 1)	175.5	26
12.7 mm Resilient channels	4.5	13
152 mm Glass Fibre Insulation	11.5	152*
2x6 (38 x 140 mm) Staggered Wood Studs	105.4	
2x6 (38 x 140 mm) End Stud	12.4	
2x8 (38 x 184 mm) Double Header	25.2	
2x8 (38 x 184 mm) Single Footer	12.6	184
15.9 mm plywood (Cladding 2)	65.9	16
2*12.7 mm Gypsum(Cladding 2)	175.9	26
	588.9	**265**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-24WN



G13_G13_GFB152_3SWS184(406)_PLY16_G13_G13

Description

Two layers of 12.7 mm thick Type X gypsum board directly attached on one side with 15.9 mm plywood shear membrane and two layers of 12.7 mm thick Type X gypsum board directly attached on the other side of 2x6 staggered wood studs (wood frame 4)

Cladding 1

- Two layers of 12.7 mm thick Type X gypsum board installed vertically.
- Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field.
- Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field.
- Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Framing & Cavity Insulation

- Tripled staggered 2x6 wood studs spaced 406 mm o.c.
- Middle stud was toe-screwed using 2 screws each at the top and bottom.
- Two added 2x6 studs were toe screwed using 2 screws each at the top and bottom and screwed to adjacent stud from one side only with #10, 75 mm long screws at 600 mm o.c.
- Three 2x6 end studs toe screwed using 2 screws each at the top and bottom from one side and screwed to adjacent stud with #10, 75 mm long screws spaced 750 mm oc.
- 2x6 end studs installed on one side of the assembly not fastened to the liner with sill gasket in between.
- Double 2x8 headers attached to the test frame using four 50 mm long screws.
- Second head plate is attached to first with 76 mm long screws (#10) at 600 mm o.c.
- Single 2x8 footer attached to the test frame using four 50 mm long screws.
- Cavities between studs on one side filled with 152 mm glass fiber insulation (R-20)

Shear Membrane

- One layer of 15.9 mm plywood installed vertically.
- Plywood shear membrane attached using #10, 75 mm long screws spaced at 75 mm in the field and along the edge.

Cladding 2

- Two layers of 12.7 mm thick Type X gypsum board installed vertically.
- Base layer gypsum board directly attached using Type S screws 50 mm long spaced 600 mm along the edge and in the field.
- Face layer gypsum board directly attached using Type S screws 62 mm long spaced 300 mm along the edge and in the field.
- Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and

taped with aluminum tape.

Midrise-24WN

ASTM E90 Sound Transmission Class - Single Number Rating

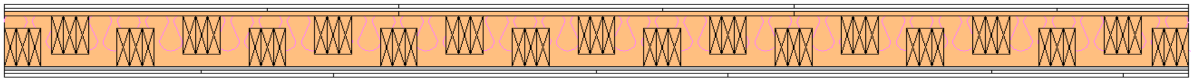
Test ID(s)	Average STC 47
TLA-12-083	**47**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum(Cladding 1)	176.3	26
152 mm Glass Fibre Insulation	9.8	152*
3*2x6 (38 x 140 mm) Staggered Wood Studs	309.3	
3*2x6 (38 x 140 mm) End Stud	36.4	
2x8 (38 x 184 mm) Double Header	24.7	
2x8 (38 x 184 mm) Single Footer	12.3	184
15.9 mm plywood (Cladding 2)	65.9	16
2*12.7 mm Gypsum(Cladding 2)	175.9	26
	811.4	**252**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-25WN



G13_G13_ RC13(610)_GFB152_3SWS184(406)_PLY16_G13_G13

Description

Two layers of 12.7 mm thick Type X gypsum board directly attached on one side with 15.9 mm plywood shear membrane and two layers of 12.7 mm thick Type X gypsum board on resilient channels on the other side of 2x6 staggered wood studs (wood frame 4)

Cladding 1

- Two layers of 12.7 mm thick Type X gypsum board installed vertically.
- Base layer gypsum board attached to RC using Type S screws 31 mm long spaced 600 mm along the edge and in the field.
- Face layer gypsum board attached to RC using Type S screws 41 mm long spaced 300 mm along the edge and in the field.
- Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
- Resilient channels installed horizontally with spacing of 610 mm oc with lowermost channel inverted

Framing & Cavity Insulation

- Tripled staggered 2x6 wood studs spaced 406 mm o.c.
- Middle stud was toe-screwed using 2 screws each at the top and bottom.
- Two added 2x6 studs were toe screwed using 2 screws each at the top and bottom and screwed to adjacent stud from one side only with #10, 75 mm long screws at 600 mm o.c.
- Three 2x6 end studs toe screwed using 2 screws each at the top and bottom from one side and screwed to adjacent stud with #10, 75 mm long screws spaced 750 mm oc.
- 2x6 end studs installed on one side of the assembly not fastened to the liner with sill gasket in between.
- Double 2x8 headers attached to the test frame using four 50 mm long screws.
- Second head plate attached to first with 76 mm long screws (#10) at 600 mm o.c.
- Single 2x8 footer attached to the test frame using four 50 mm long screws.
- Cavities between studs on one side filled with 152 mm glass fiber insulation (R-20)

Shear Membrane

- One layer of 15.9 mm plywood installed vertically.
- Plywood shear membrane attached using #10, 75 mm long screws spaced at 75 mm in the field and along the edge.

Cladding 2

- Two layers of 12.7 mm thick Type X gypsum board installed vertically.
- Base layer gypsum board directly attached using Type S screws 50 mm long spaced 600 mm along the edge and in the field.
- Face layer gypsum board directly attached using Type S screws 62 mm long spaced 300 mm along the edge and in the field.
- Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-25WN

ASTM E90 Sound Transmission Class - Single Number Rating

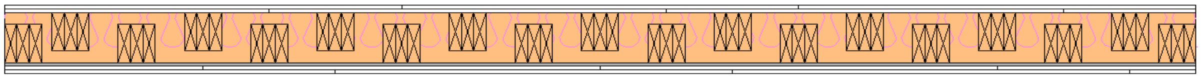
Test ID(s)	Average STC 60
TLA-12-084	**60**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum(Cladding 1)	176.3	26
12.7 mm Resilient channels	4.5	13
152 mm Glass Fibre Insulation	9.8	152*
3*2x6 (38 x 140 mm) Staggered Wood Studs	309.3	
3*2x6 (38 x 140 mm) End Stud	36.4	
2x8 (38 x 184 mm) Double Header	24.7	
2x8 (38 x 184 mm) Single Footer	12.3	184
15.9 mm plywood	65.9	16
2*12.7 mm Gypsum(Cladding 2)	175.9	26
	815.9	**236**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-26WN



G13_G13_ RC13(610)_GFB152_3SWS184(406)_G13_G13

Description	Two layers of 12.7 mm thick Type X gypsum board directly attached on one side and two layers of 12.7 mm thick Type X gypsum board on resilient channels on the other side of 2x6 staggered wood studs (wood frame 4)
Cladding 1	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board attached to RC using Type S screws 31 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board attached to RC using Type S screws 41 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape. • Resilient channels installed horizontally with spacing of 610 mm oc with lowermost channel inverted
Framing & Cavity Insulation	• Tripled staggered 2x6 wood studs spaced 406 mm oc • Middle stud was toe-screwed using 2 screws each at the top and bottom. • Two added 2x6 studs were toe screwed using 2 screws each at the top and bottom and screwed to adjacent stud from one side only with #10, 75 mm long screws at 600 mm o.c. • Three 2x6 end studs toe screwed using 2 screws each at the top and bottom from one side and screwed to adjacent stud with #10, 75 mm long screws spaced 750 mm oc. • 2x6 end studs installed on one side of the assembly not fastened to the liner with sill gasket in between. • Double 2x8 headers attached to the test frame using four 50 mm long screws. • Second head plate is attached to first with 76 mm long screws (#10) at 600 mm o.c. • Single 2x8 footer attached to the test frame using four 50 mm long screws. • Cavities between studs on one side filled with 152 mm glass fiber insulation (R-20)
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-26WN

ASTM E90 Sound Transmission Class - Single Number Rating

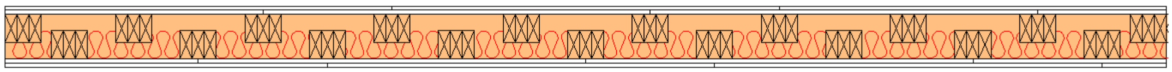
Test ID(s)	Average STC 59
TLA-12-089	**59**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum(Cladding 1)	176.3	26
12.7 mm Resilient channels	4.5	13
152 mm Glass Fibre Insulation	9.8	152*
3*2x6 (38 x 140 mm) Staggered Wood Studs	309.3	
3*2x6 (38 x 140 mm) End Stud	36.4	
2x8 (38 x 184 mm) Double Header	24.7	
2x8 (38 x 184 mm) Single Footer	12.3	184
2*12.7 mm Gypsum(Cladding 2)	175.9	26
	749.2	**249**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-27WN



G13_G13_GFB152_3SWS184(406)_G13_G13

Description	Two layers of 12.7 mm thick Type X gypsum board directly attached on one side and two layers of 12.7 mm thick Type X gypsum board directly attached on the other side of 2x6 staggered wood studs (wood frame 4)
Cladding 1	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
Framing & Cavity Insulation	• Tripled staggered 2x6 wood studs spaced 406 mm oc • Middle stud was toe-screwed using 2 screws each at the top and bottom. • Two added 2x6 studs were toe screwed using 2 screws each at the top and bottom and screwed to adjacent stud from one side only with #10, 75 mm long screws at 600 mm o.c. • Three 2x6 end studs toe screwed using 2 screws each at the top and bottom from one side and screwed to adjacent stud with #10, 75 mm long screws spaced 750 mm oc. • 2x6 end studs installed on one side of the assembly not fastened to the liner with sill gasket in between. • Double 2x8 headers attached to the test frame using four 50 mm long screws. • Second head plate is attached to first with 76 mm long screws (#10) at 600 mm o.c. • Single 2x8 footer attached to the test frame using four 50 mm long screws. • Cavities between studs on one side filled with 152 mm glass fibre insulation (R-20)
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-27W

ASTM E90 Sound Transmission Class - Single Number Rating

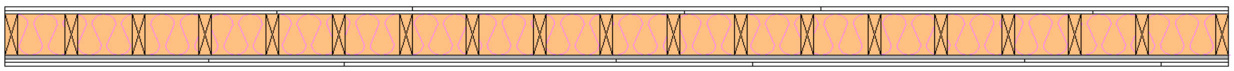
Test ID(s)	Average STC 47
TLA-12-090	**47**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum(Cladding 1)	176.3	26
152 mm Glass Fibre Insulation	9.8	152*
3*2x6 (38 x 140 mm) Staggered Wood Studs	309.3	
3*2x6 (38 x 140 mm) End Stud	36.4	
2x8 (38 x 184 mm) Double Header	24.7	
2x8 (38 x 184 mm) Single Footer	12.3	184
2*12.7 mm Gypsum(Cladding 2)	175.9	26
	744.7	**236**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise- 28WN



G13_G13_RC13(610)_GFB152_WS140(203)_G13_G13

Description	Two layers of 12.7 mm thick Type X gypsum board on resilient channels on one side and two layers of 12.7 mm thick Type X gypsum board directly attached on the other side of 2x6 single wood studs.
Cladding 1	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board attached to RC using Type S screws 31 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board attached to RC using Type S screws 41 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape. • Resilient channels installed horizontally with spacing of 610 mm oc with lowermost channel inverted
Framing & Cavity Insulation	• Single 2x6 wood studs spaced 203 mm oc and toe-screwed using two 57 mm long (#10, w) screws at the top and two at the bottom. • 2x6 single end studs not fastened to the liner with sill gasket in between. • Sill gasket placed between the liner and the footer and the first header plate. • Double 2x6 headers attached to the test frame using four 50 mm long screws. • Second head plate is attached to first with 76 mm long screws (#10) at 600 mm o.c. • Single 2x6 footer attached to the test frame using four 50 mm long screws. • Cavities between studs filled with 152 mm glass fibre insulation (R-20)
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field on every stud. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field on every stud. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-28WN

ASTM E90 Sound Transmission Class - Single Number Rating

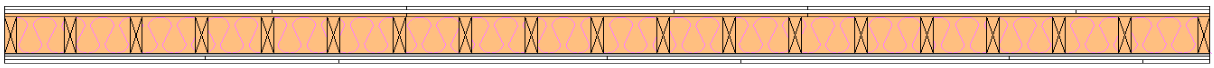
Test ID(s)	Average STC 51
TLA-12-169	**51**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum(Cladding 1)	176.0	26
12.7 mm Resilient channels	4.5	13
2x6 (38 x 140 mm) Single Wood Studs	106.5	
2x6 (38 x 140 mm) End Stud	12.5	
2x6 (38 x 184 mm) Double Header	17	
2x6 (38 x 184 mm) Single Footer	8.5	140
152 mm Glass Fibre Insulation	6.4	152*
2*12.7 mm Gypsum(Cladding 2)	176.2	26
	507.6	**205**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise- 29WN



G13_G13_RC13(610)_GFB152_WS140(203)_PLY16_G13_G13

Description

Two layers of 12.7 mm thick Type X gypsum board on resilient channels on one side and two layers of 12.7 mm thick Type X gypsum board directly attached on the other side of 2x6 single wood studs with15.9 mm plywood shear membrane.

Cladding 1

- Two layers of 12.7 mm thick Type X gypsum board installed vertically.
- Base layer gypsum board attached to RC using Type S screws 31 mm long spaced 600 mm along the edge and in the field.
- Face layer gypsum board attached to RC using Type S screws 41 mm long spaced 300 mm along the edge and in the field.
- Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
- Resilient channels installed horizontally with spacing of 610 mm oc with lowermost channel inverted

Framing & Cavity Insulation

- Single 2x6 wood studs spaced 203 mm oc and toe-screwed using two 57 mm long (#10, w) screws at the top and two at the bottom.
- 2x6 single end studs not fastened to the liner with sill gasket in between.
- Sill gasket placed between the liner and the footer and the first header plate.
- Double 2x6 headers attached to the test frame using four 50 mm long screws.
- Second head plate is attached to first with 76 mm long screws (#10) at 600 mm o.c.
- Single 2x6 footer attached to the test frame using four 50 mm long screws.
- Cavities between studs filled with 152 mm glass fibre insulation (R-20)

Shear Membrane

- One layer of 15.9 mm plywood installed vertically.
- Plywood shear membrane attached using #10, 75 mm long screws spaced at 75 mm in the field and along the edge.

Cladding 2

- Two layers of 12.7 mm thick Type X gypsum board installed vertically.
- Base layer gypsum board directly attached using Type S screws 50 mm long spaced 600 mm along the edge and in the field on every stud.
- Face layer gypsum board directly attached using Type S screws 62 mm long spaced 300 mm along the edge and in the field on every stud.
- Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-29WN

ASTM E90 Sound Transmission Class - Single Number Rating

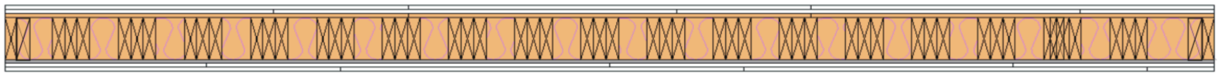
Test ID(s)	Average STC 51
TLA-12-161	**51**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum(Cladding 1)	176.0	26
12.7 mm Resilient channels	4.5	13
2x6 (38 x 140 mm) Single Wood Studs	106.5	
2x6 (38 x 140 mm) End Stud	12.5	
2x6 (38 x 184 mm) Double Header	17	
2x6 (38 x 184 mm) Single Footer	8.5	140
152 mm Glass Fibre Insulation	6.4	152*
15.9 mm plywood	76.2	16
2*12.7 mm Gypsum(Cladding 2)	176.2	26
	583.8	**221**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise- 30WN



G13_G13_RC13(610)_GFB152_3WS140(203)_PLY16_G13_G13

Description	Two layers of 12.7 mm thick Type X gypsum board on resilient channels on one side of 2x6 tripled wood studs and two layers of 12.7 mm thick Type X gypsum board directly attached on the other side of 2x6 tripled wood studs with15.9 mm plywood shear membrane.
Cladding 1	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board attached to RC using Type S screws 31 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board attached to RC using Type S screws 41 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape. • Resilient channels installed horizontally with spacing of 610 mm oc with lowermost channel inverted
Framing & Cavity Insulation	• Double end studs not fastened to the liner with sill gasket in between. • Sill gasket placed between the liner and the footer and the first header plate. • Tripled 2x6 wood studs spaced 203 mm oc • Middle stud was toe-screwed using 2 screws each at the top and bottom. • Two added 2X6 studs were toe screwed using 2 screws each at the top and bottom and screwed to adjacent stud from one side only with #10, 75 mm long screws at 600 mm o.c. • Double 2x6 headers attached to the test frame using four 50 mm long screws. • Second head plate is attached to first with 76 mm long screws (#10) at 600 mm o.c. • Single 2x6 footer attached to the test frame using four 50 mm long screws. • Cavities between studs filled with 152 mm glass fibre insulation (R-20)
Shear Membrane	• One layer of 15.9 mm plywood installed vertically. • Plywood shear membrane attached using #10, 75 mm long screws spaced at 75 mm in the field and along the edge.
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 50 mm long spaced 600 mm along the edge and in the field on every middle stud. • Face layer gypsum board directly attached using Type S screws 62 mm long spaced 300 mm along the edge and in the field on every middle stud. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-30WN

ASTM E90 Sound Transmission Class - Single Number Rating

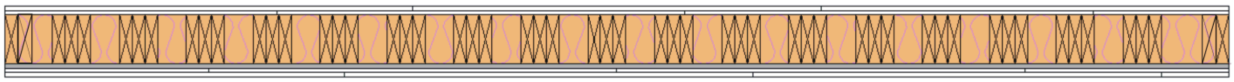
Test ID(s)	Average STC 53
TLA-12-167	**53**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum(Cladding 1)	176.0	26
12.7 mm Resilient channels	4.5	13
3*2x6 (38 x 140 mm) Single Wood Studs	306.4	
2*2x6 (38 x 140 mm) End Stud	24	
2x6 (38 x 184 mm) Double Header	17	
2x6 (38 x 184 mm) Single Footer	8.5	140
152 mm Glass Fibre Insulation	6.4	152*
15.9 mm plywood	76.2	16
2*12.7 mm Gypsum(Cladding 2)	176.2	26
	795.2	**221**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise- 31WN



G13_G13_RC13(610)_GFB152_3WS140(203)_G13_G13

Description	Two layers of 12.7 mm thick Type X gypsum board on resilient channels on one side and two layers of 12.7 mm thick Type X gypsum board directly attached on the other side of 2x6 tripled wood studs.
Cladding 1	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board attached to RC using Type S screws 31 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board attached to RC using Type S screws 41 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape. • Resilient channels installed horizontally with spacing of 610 mm oc with lowermost channel inverted
Framing & Cavity Insulation	• Double end studs not fastened to the liner with sill gasket in between. • Sill gasket placed between the liner and the footer and the first header plate. • Tripled 2x6 wood studs spaced 203 mm oc • Middle stud was toe-screwed using 2 screws each at the top and bottom. • Two added 2X6 studs were toe screwed using 2 screws each at the top and bottom and screwed to adjacent stud from one side only with #10, 75 mm long screws at 600 mm o.c. • Double 2x6 headers attached to the test frame using four 50 mm long screws. • Second head plate is attached to first with 76 mm long screws (#10) at 600 mm o.c. • Single 2x6 footer attached to the test frame using four 50 mm long screws. • Cavities between studs filled with 152 mm glass fibre insulation (R-20)
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field on every middle stud. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field on every middle stud. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Midrise-31WN

ASTM E90 Sound Transmission Class - Single Number Rating

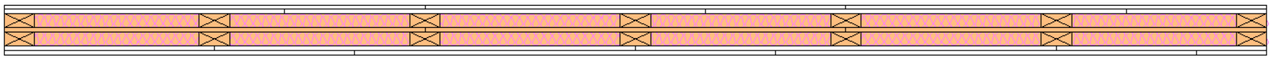
Test ID(s)	Average STC 53
TLA-12-168	**53**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum(Cladding 1)	176.0	26
12.7 mm Resilient channels	4.5	13
3*2x6 (38 x 140 mm) Single Wood Studs	306.4	
2*2x6 (38 x 140 mm) End Stud	24	
2x6 (38 x 184 mm) Double Header	17	
2x6 (38 x 184 mm) Single Footer	8.5	140
152 mm Glass Fibre Insulation	6.4	152*
2*12.7 mm Gypsum(Cladding 2)	176.2	26
	719	**205**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-32WN



G13_G13_GFB38_SHWS89(610)_MPLY13_GFB38_G13_G13

Description

Two layers of 12.7 mm thick Type X gypsum board directly attached on each side with one 12.7 mm plywood shear membrane sandwiched in the middle of flat-wise 2x4 and 2x6 studs spaced 610 mm (wood frame 5)

Cladding 1

- Two layers of 12.7 mm thick Type X gypsum board installed vertically.
- Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field.
- Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field.
- Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Framing & Cavity Insulation

- Two 2x4 flat wise studs fastened together sandwiching the shear membrane.
- Studs fastened together with 3 mm thick and 83 mm (3.25”) long nails @ 100 mm o.c. along one line.
- Two 2x6 flat wise studs fastened together sandwiching the shear membrane at the middle joints.
- Studs fastened together with 3 mm thick and 83 mm (3.25”) long nails @ 100 mm o.c. along three lines.
- Two lines are off-set from the centre and the nails are penetrating the studs and the shear membrane on the right and on the left, the third line is along the centre where the 12 mm gap is between the shear membranes.
- At the end studs a third 2x4 (buckling stud) is attached to the sides of the two 2x4 that are sandwiching the shear membrane with 83 mm (3.25”) long nails @ 100 mm o.c. along two lines. The nails fasten the buckling stud to both 2x4 end studs. They have the same length as the other studs and are placed between the header and footer.
- Studs fastened together with 3 mm thick and 83 mm (3.25”) long nails @ 100 mm o.c. along two lines.
- Two 2x4 flat wise headers fastened together sandwiching the shear membrane.
- Headers fastened together with 3 mm thick and 83 mm (3.25”) long nails @ 100 mm o.c. along two lines.
- Two 2x4 flat wise footers fastened together sandwiching the shear membrane.
- Footers fastened together with 3 mm thick and 83 mm (3.25”) long nails @ 100 mm o.c. along two lines.
- Cavities between studs on both sides filled with 38 mm glass fibre insulation

Shear Membrane	• 12 mm plywood sandwiched between framing, at both sides, top and bottom 12 mm shorter than lower end studs, edge of footer and upper edge of header and 12 mm gap between joint of boards along 2x6 studs
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

ASTM E90 Sound Transmission Class - Single Number Rating

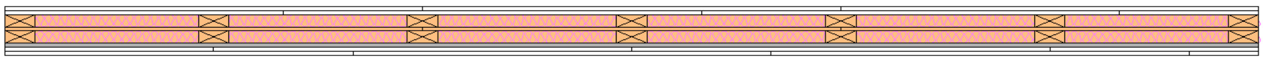
Test ID(s)	Average STC 48
TLA-12-142	**48**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum(Cladding 1)	176.2	26
2*2x4 (38 x 89 mm) Flat-wise Studs	29	76
2*2x6 (38 x 140 mm) Flat-wise Studs	19.6	
2x4 (38 x 89 mm) End and Buckling Studs	7.2	
2*2x4 (38 x 89 mm) Flat-wise Header	12.2	
2*2x4 (38 x 89 mm) Flat-wise Footer	12.2	
2*38 mm Glass Fibre Insulation	9.6	76*
12 mm Plywood (mid-ply)	66.4	13
2*12.7 mm Gypsum(Cladding 2)	176.2	26
	508.6	**141**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-33WN



G13_G13_GFB38_SHWS89(610)_MPLY13_GFB38_RC13(610)_G13_G13

Description

Two layers of 12.7 mm thick Type X gypsum board directly attached on one side, two layers of 12.7 mm thick Type X gypsum board installled on resilient channels on the other side, with one 12 mm plywood shear membrane sandwiched in the middle of flat-wise 2x4 and 2x6 studs spaced 610 mm (wood frame 5)

Cladding 1

- Two layers of 12.7 mm thick Type X gypsum board installed vertically.
- Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field.
- Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field.
- Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Framing & Cavity Insulation

- Two 2x4 flat wise studs fastened together sandwiching the shear membrane.
- Studs fastened together with 3 mm thick and 83 mm (3.25”) long nails @ 100 mm o.c. along one line.
- Two 2x6 flat wise studs fastened together sandwiching the shear membrane at the middle joints.
- Studs fastened together with 3 mm thick and 83 mm (3.25”) long nails @ 100 mm o.c. along three lines.
- Two lines are off-set from the centre and the nails are penetrating the studs and the shear membrane on the right and on the left, the third line is along the centre where the 12 mm gap is between the shear membranes.
- At the end studs a third 2x4 (buckling stud) is attached to the sides of the two 2x4 that are sandwiching the shear membrane with 83 mm (3.25”) long nails @ 100 mm o.c. along two lines. The nails fasten the buckling stud to both 2x4 end studs. They have the same length as the other studs and are placed between the header and footer.
- Studs fastened together with 3 mm thick and 83 mm (3.25”) long nails @ 100 mm o.c. along two lines.
- Two 2x4 flat wise headers fastened together sandwiching the shear membrane.
- Headers fastened together with 3 mm thick and 83 mm (3.25”) long nails @ 100 mm o.c. along two lines.
- Two 2x4 flat wise footers fastened together sandwiching the shear membrane.
- Footers fastened together with 3 mm thick and 83 mm (3.25”) long nails @ 100 mm o.c. along two lines.
- Cavities between studs on both sides filled with 38 mm glass fibre insulation

Shear Membrane

- 12 mm plywood sandwiched between framing, at both sides, top and bottom 12 mm shorter than lower end studs, edge of footer and upper edge of header and 12 mm gap between joint of boards along 2x6 studs

Cladding 2	
	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board attached to RC using Type S screws 31 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board attached to RC using Type S screws 41 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape. • Resilient channels installed horizontally with spacing of 610 mm oc with lowermost channel inverted.

ASTM E90 Sound Transmission Class - Single Number Rating

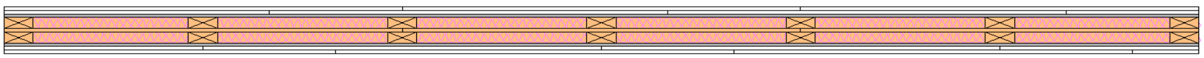
Test ID(s)	Average STC 55
TLA-12-144	**55**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum(Cladding 1)	176.2	26
2*2x4 (38 x 89 mm) Flat-wise Studs	29	76
2*2x6 (38 x 140 mm) Flat-wise Studs	19.6	
2x4 (38 x 89 mm) End and Buckling Studs	7.2	
2*2x4 (38 x 89 mm) Flat-wise Header	12.2	
2*2x4 (38 x 89 mm) Flat-wise Footer	12.2	
2*38 mm Glass Fibre Insulation	9.6	76*
12 mm Plywood (mid-ply)	66.4	13
12.7 mm Resilient channels	4.0	13
2*12.7 mm Gypsum(Cladding 2)	176.2	26
	512.6	**154**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-34WN



G13_G13_RC13(610)_GFB38_SHWS89(610)_MPLY13_GFB38_RC13(610)_G13_G13

Description

Two layers of 12.7 mm thick Type X gypsum board directly attached on one side, two layers of Type X gypsum board installed on resilient channels on the other side, with one 12 mm plywood shear membrane sandwiched in the middle of flat-wise 2x4 and 2x6 studs spaced 610 mm (wood frame 5)

Cladding 1

- Two layers of 12.7 mm thick Type X gypsum board installed vertically.
- Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field.
- Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field.
- Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
- Resilient channels installed horizontally with spacing of 610 mm oc with lowermost channel inverted.

Framing & Cavity Insulation

- Two 2x4 flat wise studs fastened together sandwiching the shear membrane.
- Studs fastened together with 3 mm thick and 83 mm (3.25”) long nails @ 100 mm o.c. along one line.
- Two 2x6 flat wise studs fastened together sandwiching the shear membrane at the middle joints.
- Studs fastened together with 3 mm thick and 83 mm (3.25”) long nails @ 100 mm o.c. along three lines.
- Two lines are off-set from the centre and the nails are penetrating the studs and the shear membrane on the right and on the left, the third line is along the centre where the 12 mm gap is between the shear membranes.
- At the end studs a third 2x4 (buckling stud) is attached to the sides of the two 2x4 that are sandwiching the shear membrane with 83 mm (3.25”) long nails @ 100 mm o.c. along two lines. The nails fasten the buckling stud to both 2x4 end studs. They have the same length as the other studs and are placed between the header and footer.
- Studs fastened together with 3 mm thick and 83 mm (3.25”) long nails @ 100 mm o.c. along two lines.
- Two 2x4 flat wise headers fastened together sandwiching the shear membrane.
- Headers fastened together with 3 mm thick and 83 mm (3.25”) long nails @ 100 mm o.c. along two lines.
- Two 2x4 flat wise footers fastened together sandwiching the shear membrane.
- Footers fastened together with 3 mm thick and 83 mm (3.25”) long nails @ 100 mm o.c. along two lines.
- Cavities between studs on both sides filled with 38 mm glass fibre insulation

Shear

- 12 mm plywood sandwiched between framing, at both sides, top and bottom 12 mm shorter than lower end studs, edge of footer and upper edge of header and

Membrane	12 mm gap between joint of boards along 2x6 studs
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board attached to RC using Type S screws 31 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board attached to RC using Type S screws 41 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape. • Resilient channels installed horizontally with spacing of 610 mm oc with lowermost channel inverted.

ASTM E90 Sound Transmission Class - Single Number Rating

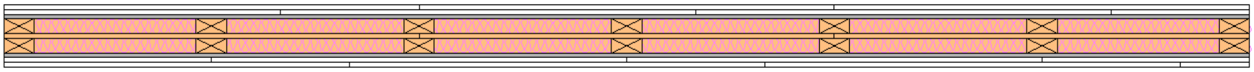
Test ID(s)	Average STC 57
TLA-12-146	**57**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum(Cladding 1)	176.2	26
2*2x4 (38 x 89 mm) Flat-wise Studs	29	76
2*2x6 (38 x 140 mm) Flat-wise Studs	19.6	
2x4 (38 x 89 mm) End and Buckling Studs	7.2	
2*2x4 (38 x 89 mm) Flat-wise Header	12.2	
2*2x4 (38 x 89 mm) Flat-wise Footer	12.2	
2*38 mm Glass Fibre Insulation	9.6	76*
12 mm Plywood (mid-ply)	66.4	13
2*12.7 mm Resilient channels	8.0	26
2*12.7 mm Gypsum(Cladding 2)	176.2	26
	516.6	**167**

*Installed in cavity and does not contribute to total thickness of specimen

Midrise-35WN



G13_G13_RC13(610)_SHWS89(610)_MPLY13_RC13(610)_G13_G13

Description	Two layers of 12.7 mm thick Type X gypsum board directly attached on one side, two layers of Type X gypsum board installed on resilient channels on the other side, with one 12 mm plywood shear membrane sandwiched in the middle of flat-wise 2x4 and 2x6 studs spaced 610 mm (wood frame 5) – no cavity insulation

Cladding 1

- Two layers of 12.7 mm thick Type X gypsum board installed vertically.
- Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field.
- Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field.
- Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
- Resilient channels installed horizontally with spacing of 610 mm oc with lowermost channel inverted.

Framing & Cavity Insulation

- Two 2x4 flat wise studs fastened together sandwiching the shear membrane.
- Studs fastened together with 3 mm thick and 83 mm (3.25") long nails @ 100 mm o.c. along one line.
- Two 2x6 flat wise studs fastened together sandwiching the shear membrane at the middle joints.
- Studs fastened together with 3 mm thick and 83 mm (3.25") long nails @ 100 mm o.c. along three lines.
- Two lines are off-set from the centre and the nails are penetrating the studs and the shear membrane on the right and on the left, the third line is along the centre where the 12 mm gap is between the shear membranes.
- At the end studs a third 2x4 (buckling stud) is attached to the sides of the two 2x4 that are sandwiching the shear membrane with 83 mm (3.25") long nails @ 100 mm o.c. along two lines. The nails fasten the buckling stud to both 2x4 end studs. They have the same length as the other studs and are placed between the header and footer.
- Studs fastened together with 3 mm thick and 83 mm (3.25") long nails @ 100 mm o.c. along two lines.
- Two 2x4 flat wise headers fastened together sandwiching the shear membrane.
- Headers fastened together with 3 mm thick and 83 mm (3.25") long nails @ 100 mm o.c. along two lines.
- Two 2x4 flat wise footers fastened together sandwiching the shear membrane.
- Footers fastened together with 3 mm thick and 83 mm (3.25") long nails @ 100 mm o.c. along two lines.

Shear Membrane	• 12 mm plywood sandwiched between framing, at both sides, top and bottom 12 mm shorter than lower end studs, edge of footer and upper edge of header and 12 mm gap between joint of boards along 2x6 studs
Cladding 2	• Two layers of 12.7 mm thick Type X gypsum board installed vertically. • Base layer gypsum board attached to RC using Type S screws 31 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board attached to RC using Type S screws 41 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape. • Resilient channels installed horizontally with spacing of 610 mm oc with lowermost channel inverted.

ASTM E90 Sound Transmission Class - Single Number Rating

Test ID(s)	Average STC 45
TLA-12-147	**45**

Element Details

Element	Mass (kg)	Depth (mm)
2*12.7 mm Gypsum(Cladding 1)	176.2	26
2*2x4 (38 x 89 mm) Flat-wise Studs	29	76
2*2x6 (38 x 140 mm) Flat-wise Studs	19.6	
2x4 (38 x 89 mm) End and Buckling Studs	7.2	
2*2x4 (38 x 89 mm) Flat-wise Header	12.2	
2*2x4 (38 x 89 mm) Flat-wise Footer	12.2	
12 mm Plywood (mid-ply)	66.4	13
2*12.7 mm Resilient channels	8.0	26
2*12.7 mm Gypsum(Cladding 2)	176.2	26
	507	**167**

*Installed in cavity and does not contribute to total thickness of specimen

A.2 Direct Sound Insulation of CLT-Elements

A.2.1 Background

The National Building Code Canada (NBCC) 2010 has existing requirements for Sound Transmission Class STC 50 or higher for direct airborne sound insulation (STC-rating) for interior wall and floor assemblies that separate a residential unit from other spaces in the building. Besides airborne sound, floor assemblies are also excited by people walking on them and noise is transmitted as so-called impact sound. Even though impact noise is a very common source of complaint by building occupants, there is currently no requirement for impact sound insulation (IIC-rating) of floors in the current National Building Code of Canada, as found in most other OECD countries. However, impact noise was taken into account in this research project because an acceptable impact sound insulation is important for market acceptance of buildings and the incremental effort to collect impact data is relatively small, once a specimen is in place.

Novel wood construction technologies, i.e. Cross Laminated Timber (CLT) (solid wood elements that are emerging from Europe into Canada), are structural solutions for mid-rise wooden buildings. Unfortunately, in Canada only limited standardized sound insulation lab test data were available for CLT [1] and therefore they were investigated in this research project. The number of structural base CLT elements that could be used as separating floors or walls is very limited, i.e. 3-ply, 5-ply and 7-ply panels; however, to protect the combustible structure from fire and to achieve acceptable sound insulation, additional measures are necessary, like with gypsum board wall linings and ceilings, as well as floor toppings. Therefore the main focus of this research is on achievable improvement of sound insulation due to these treatments. The sound insulation data of the elements that is necessary to demonstrate code compliance is also used in a further acoustic research component as input data for the prediction of sound insulation in CLT buildings that is likely required in NBCC 2015.

The acoustics research on CLT walls and floors was developed and conducted at NRC Construction in close coordination with the project partners (Canadian Wood Council, FPInnovations and the Provinces) and in close consultation with other disciplines (i.e. structure, fire, heat and moisture). The applied methodology, selection of test specimens, and test results were discussed with these groups at workgroup meetings held on a regular basis. Further, research conducted by other groups in Canada (i.e. FPInnovations, NEWBuildS) as well as abroad (i.e. in Europe) was taken into account in this project. When new knowledge, e.g. from this research component or other disciplines, became available during the research project, research plans were changed accordingly to account for these new developments.

A.2.2 Sound Insulation Testing of CLT Elements

The test series on CLT walls and floors are structured as parametric studies to relate a change in sound insulation to a single change of the specimen. CLT elements are very similar to homogeneous monolithic building elements, like masonry walls and concrete floors, however the weight of CLT panels is less and internal damping is much higher. Therefore, a predictive method that was already applied in earlier research projects to generate STC data, for e.g. masonry walls [2], is utilized to obtain sound insulation data of many CLT design variants with a minimum effort for testing. It is assumed that the wall liner or floor topping is sufficiently decoupled from a much heavier base element, which might not always be the case for thin CLT elements. Then the sound insulation performance of the bare element is measured and further after the gypsum board lining or floor topping is added. Within limits, the measured incremental change of sound insulation then can be added to the measured sound insulation results of other bare CLT elements. This method is also described in ISO 10140-5 [3] and ISO 15712-1 [4].

A.2.2.1 Airborne Sound insulation Testing –ASTM E90

Airborne sound insulation testing is conducted according to ASTM E90 test protocol [5] for direct airborne sound transmission testing through walls and floors in NRC Construction's Wall Sound Transmission Test Facility and Floor Sound Transmission Facility. Both facilities conform to ASTM E90 for full scale testing of building elements and consist of two decoupled chambers with a test opening in between that accommodates movable frames containing the floor and wall test specimens. The facilities are both equipped with automated sound and measurement system for data acquisition and post-processing. Sound transmission loss is measured in both directions – from the large to the small room or upper and lower respectively and vice-versa – and results were averaged to reduce measurement uncertainty due to e.g. calibration errors. The wall facility shown in Figure A.2 - 1 has a 3.66 m wide and 2.44 m high test opening between two decoupled rooms of app. 250 m^3 and 140 m^3 room volume.

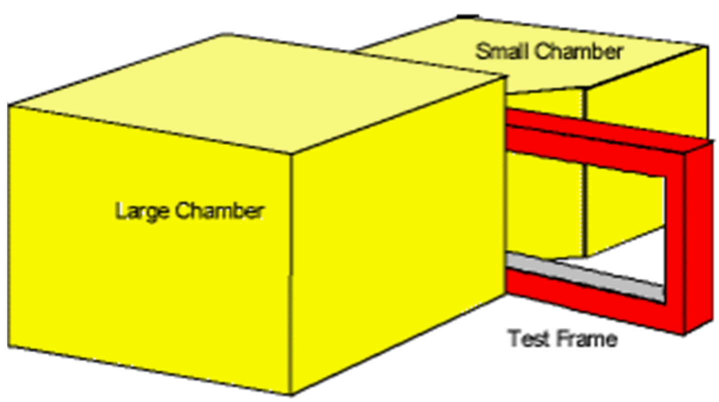


Figure A.2 - 1: NRC Construction's Wall Sound Transmission Facility with the specimen mounted in a movable test frame between two decoupled rooms (room volume: large chamber app. 250 m^3 and small chamber 140 m^3)

The floor facility shown in Figure A.2 - 2 and has a 4.70 m by 3.78 m wide test opening to accommodate the floors between two chambers of app. 175 m^2 room volume that are located one above the other.

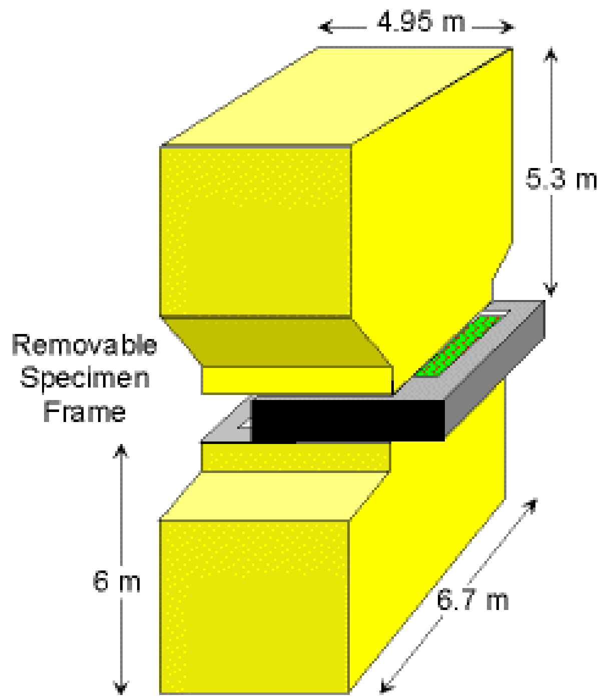


Figure A.2 - 2: NRC Construction's Floor Sound Transmission Facility with the specimen mounted in a movable test frame between two decoupled rooms (room volumes: app. 175 m^3)

The frequency dependent sound transmission loss is measured for all assemblies in an extended frequency range from 31.5 Hz to 10 kHz, although only a limited range is considered in the Sound Transmission Class (STC) single-number-rating according to ASTM E413 [6].

A.2.2.2 Impact Sound insulation Testing –ASTM E492

Impact sound insulation testing is conducted according to ASTM E492 test protocol [7] for direct impact sound transmission testing through floors using a standardized tapping machine. Impact testing was conducted in the same facility using the same measurement system as described above in Section A.2.2.1 with a tapping machine instead of the sound system exciting the floor. The tapping machine consists of five steel hammers that are lifted and each dropped on the floor twice a second. The Normalized Impact Sound Pressure Level was also measured in the extended frequency range from 31.5 Hz to 10 kHz, although only a limited range is considered in the Impact Insulation Class (STC) single-number-rating according to ASTM E989 [8].

A.2.2.3 Additional Testing

Even though not required by the ASTM-test protocols additional measurements to characterize the structural reverberation time of the test specimens without surface treatments were carried out when installed in the direct sound transmission facility. For some other types of construction this data is required as input data (transfer of lab data to field situation) of ISO 15712 prediction method for CLT system performance described in Appendix A.4.

Further, the sound radiation efficiencies of the CLT elements were measured when installed in the transmission suite for two excitation cases – airborne sound and structural excitation with the tapping machine for floors and with an electro dynamic shaker for walls. This data was measured in anticipation of a revision of the ISO 15712 prediction method which likely introduces a new method to correct the measured sound transmission loss input data to obtain less conservative prediction results for sound insulation in buildings constructed out of building elements with a high coincidence frequency as it is the case for thin CLT-elements.

A.2.3 CLT Wall Testing

A.2.3.1 CLT Wall Specimens

Additional layers and wall linings have to be added to the base CLT wall assemblies in order to achieve the current minimum code requirement of STC 50 for direct sound transmission and to provide fire resistance and encapsulation of the combustible structure. The simplest lining would be two layers of Type X gypsum board directly attached to the surface of the CLT. However with this treatment, STC ratings published in FPInnovations' CLT-Handbook [1] (based on test data from Europe on European CLT elements) already indicated that the acoustic code requirement can be achieved only with CLTs in a double leaf wall configuration. Therefore, wall linings that are more decoupled from the CLT base wall and provide greater improvement of sound insulation were considered. Such kind of wall linings are gypsum board layers mounted to framing members, like wooden battens or wood studs.

A.2.3.1.1 Base CLT Walls:

Assemblies based on the following three base CLT wall assemblies listed in Table A.2 - 1 were tested. All CLT base walls were delivered as two smaller CLT panels of approximately 2.40 m x 2.40 m and 1.20 m x 2.40 m size that had lap joints at one side and were assembled in the wall test frame. The lap-joints were connected with self-tapping screws spaced 300 mm (screw length, 3-ply: 70 mm, 5-ply: 160 mm) and additionally caulked and taped to eliminate sound leaks.

Table A.2 - 1: Base CLT walls for wall assemblies

Element	Configuration
5-ply CLT	single leaf, thickness: 175 mm, mass-per-area: 92 kg/m2
3-ply CLT	single leaf, thickness: 78 mm; mass-per-area: 42 kg/m^2
3-ply CLT	double leaf wall (two 3-ply CLT wall panels separated by a 25 mm cavity filled with glass fiber insulation), thickness: 181 mm, mass-per-area: 50 kg/m^2

A.2.3.1.2 Tested Wall Linings:

Six wall linings listed in Table A.2 - 2 are relevant for mid-rise construction and were selected as candidate wall linings for testing. For all wall linings two layers of 12.7 mm thick Type X gypsum board were used as gypsum board membrane following the strategy of fire protection of the combustible CLT elements.

Table A.2 - 2: Gypsum board linings for CLT walls considered in this research project

Gypsum Board Membrane	Attachment Method
2 layers of 12.7 mm (1/2") Type X	Directly attached (DA) with screws
2 layers of 12.7 mm (1/2") Type X	wood furring 38 mm (2x2) spaced 400 mm o.c. cavity filled with 38 mm glass fiber insulation
2 layers of 12.7 mm (1/2") Type X	wood furring 38 mm (2x2) spaced 600 mm o.c. cavity filled with 38 mm glass fiber insulation
2 layers of 12.7 mm (1/2") Type X	resilient metal channels 12.7 mm spaced 600 mm o.c. on perpendicular 38 mm wood furring (2x2) spaced 400 mm o.c,. cavity filled with 38 mm glass fiber insulation
2 layers of 12.7 mm (1/2") Type X	wood furring 64 mm (2x3) spaced 600 mm o.c. cavity filled with 64 mm glass fiber insulation
2 layers of 12.7 mm (1/2") Type X	wood frame made out of 64 mm (2x3) wood studs spaced 600 mm o.c. and 64 mm plates placed in front of CLT with 12.7 mm air gap cavity filled with 64 mm glass fiber insulation

A.2.3.2 Summary – Tested CLT Walls and STC-Ratings

To avoid repetitive testing the wall linings were attached only to a minimum number of base CLT walls to allow extraction of the sound insulation improvement. The improvement of sound insulation is usually greater if wall linings are applied to a base assembly with mass-per-unit area close to the one of the wall liner than when applied to a much heavier base assembly. Thus, all wall liners listed in Table A.2 - 2 were applied to the 5-ply CLT wall in various configurations. The improvement of sound insulation then can be applied for a conservative prediction of the 3-ply wall assemblies. However, some wall linings were also tested when applied to the 3-ply wall assemblies. First, the directly attached gypsum board, as this wall liner is well coupled to the base assembly and the improvement of sound insulation depends mainly on the relative added mass. Second, the wall liner with gypsum board mounted on 38 mm wood strapping spaced 600 mm for validation of the prediction approach. As expected, for the latter it was found that the frequency dependent sound transmission loss improvement is about 3 dB greater in the high frequency range when the liner was applied to the 3-ply CLT wall. Detailed descriptions for the 5-ply CLT test specimens and test results are listed in Table A.2 - 3. Here also variants with different wall liners on both sides of the wall are presented, since new wall liners were added to the other wall side before the already tested wall liner was removed. By doing this the amount of test data was increased without additional construction efforts. Descriptions and results for the 3-ply single wall are given in Table A.2 - 4 and for the 3-ply double wall in Table A.2 - 5.

Table A.2 - 3: Tested CLT 5-ply (thickness: 175 mm) wall specimens

	Id	Description	Gypsum Board Wall Liner, Side #1			Gypsum Board Wall Liner, Side #2			Test-#, STC
			Face Layer	Base Layer	Fastening Method	Face Layer	Base Layer	Fastening Method	
Benchmark – Bare 175 mm thick 5-ply CLT element									
1	CLT5-01W	CLT 5-ply, 175 mm thick, bare, benchmark	N/A	N/A	N/A	N/A	N/A	N/A	TLA-12-170 **STC 38**
Wall liner applied to one side only - 175 mm thick 5-ply CLT element									
2	CLT5-02W	CLT 5-ply, drywall directly attached one side	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 300 mm	N/A	N/A	N/A	N/A	TLA-12-172 **STC 43**
3	CLT5-02Wa	CLT 5-ply, drywall directly attached one side	N/A	N/A	N/A	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 300 mm	N/A	TLA-12-174 **STC 42**
4	CLT5-05W	CLT 5-ply, drywall directly attached on 38 mm (2x2) furring @ 400 mm on one side	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 600 mm	38 mm (2x2) furring @ 400 mm: – 38 mm furring @ 400 mm o.c. – attached with 76 mm screws @ 600 mm – 38 mm glass fiber insulation in cavities	N/A	N/A	N/A	TLA-12-177 **STC 45**
5	CLT5-11W	CLT 5-ply, drywall directly attached on 38mm (2x2) furring @ 600 mm on one side	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 600 mm	38 mm (2x2) furring @ 600 mm: – 38 mm furring @ 600 mm o.c. – attached with 76 mm screws @ 600 mm – 65 mm glass fiber insulation in cavities	N/A	N/A	N/A	TLA-12-181 **STC 50**
6	CLT5-10W	CLT 5-ply, drywall directly attached on 64mm (2x3) wood studs @ 600 mm on one side	N/A	N/A	N/A	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 600 mm	64 mm (2x3) wood studs @ 600 mm: – 64 mm furring @ 600 mm o.c. – attached with 96 mm screws @ 600 mm – 38 mm glass fiber insulation in cavities	TLA-12-183 **STC 49**

Table A.2 - 3: Tested CLT 5-ply (thickness: 175 mm) wall specimens - continued

7	CLT5-08W	CLT 5-ply, drywall on 38 mm (2x2) furring @ 400 mm, on RC @ 600 mm on one side	12.7 mm thick Type X, 42 mm screws @ 300 mm	12.7 mm thick Type X 32 mm screws @ 600 mm	38 mm (2x2) furring @ 400 mm and resilient channels @ 600 mm: – 38 mm furring @ 400 mm o.c., attached with 76 mm screws @ 600 mm – resilient channels @ 600 mm oc. attached with 32 mm screws – 38 mm glass fiber insulation in cavities	N/A	N/A	N/A	TLA-12-180 **STC 58**
8	CLT5-13W	CLT 5-ply, drywall on 64 mm (2x3) wood frame with studs @ 600 mm with 12.7 mm air gap on one side	12.7 mm thick Type X, 42 mm screws @ 300 mm	12.7 mm thick Type X 32 mm screws @ 600 mm	64 mm (2x3) wood frame with studs @ 600 mm: – 64mm frame with studs @ 600 mm o.c. on 64 mm sole and top plate, – 64 mm glass fiber insulation in cavities – 12.7 mm air gap between frame and CLT	N/A	N/A	N/A	TLA-12-185 **STC 59**
Same wall liner applied to both sides - 175 mm thick 5-ply CLT element									
9	CLT5-03W	CLT 5-ply, drywall directly attached both sides	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 300 mm	N/A	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 300 mm	N/A	TLA-12-173 **STC 42**
10	CLT5-06W	CLT 5-ply, drywall directly attached to 38 mm (2x2) furring @ 400 mm on both sides	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 600 mm	38 mm (2x2) furring @ 400 mm: – 38 mm furring @ 400 mm o.c. – attached with 76 mm screws @ 600 mm – 38 mm glass fiber insulation in cavities	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 600 mm	38 mm (2x2) furring @ 400 mm: – 38 mm furring @ 400 mm o.c. – attached with 76 mm screws @ 600 mm – 38 mm glass fiber insulation in cavities	TLA-12-178 **STC 39**
11	CLT5-12W	CLT 5-ply, drywall directly attached to 38 mm (2x2) furring @ 600 mm on both sides	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 600 mm	38 mm (2x2) furring @ 600 mm: – 38 mm furring @ 600 mm o.c. – attached with 76 mm screws @ 600 mm – 38 mm glass fiber insulation in cavities	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 600 mm	38 mm (2x2) furring @ 600 mm: – 38 mm furring @ 600 mm o.c. – attached with 76 mm screws @ 600 mm – 38 mm glass fiber insulation in cavities	TLA-12-182 **STC 56**

Table A.2 - 3: Tested CLT 5-ply (thickness: 175 mm) wall specimens **- continued**

Different wall liner applied to both sides - 175 mm thick 5-ply CLT element									
12	CLT5-04W	CLT 5-ply, drywall directly attached one side, on 38 mm (2x2) furring @ 400 mm on other	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 600 mm	38 mm (2x2) furring @ 400 mm: – 38 mm furring @ 400 mm o.c. – attached with 76 mm screws @ 600 mm – 38 mm glass fiber insulation in cavities	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 600 mm	N/A	TLA-12-176 **STC 45**
13	CLT5-07W	CLT 5-ply, drywall on 38 mm (2x2) furring @ 400 mm, directly attached on one side and on RC @ 600 mm on the other	12.7 mm thick Type X, 42 mm screws @ 300 mm	12.7 mm thick Type X 32 mm screws @ 600 mm	38 mm (2x2) furring @ 400 mm and resilient channels @ 600 mm: – 38 mm furring @ 400 mm o.c., attached with 76 mm screws @ 600 mm – resilient channels @ 600 mm oc. attached with 32 mm screrws – 38 mm glass fiber insulation in cavities	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 600 mm	38 mm (2x2) furring @ 400 mm: – 38 mm furring @ 400 mm o.c. – attached with 76 mm screws @ 600 mm – 38 mm glass fiber insulation in cavities	TLA-12-179 **STC 55**
14	CLT5-09W	CLT 5-ply, drywall directly attached on 38 mm (2x2) furring @ 600 mm on one and on 64mm (2x3) wood studs on other	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 600 mm	38 mm (2x2) furring @ 600 mm: – 38 mm furring @ 600 mm o.c. – attached with 76 mm screws @ 600 mm – 38 mm glass fiber insulation in cavities	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 600 mm	64 mm (2x3) wood studs @ 600 mm: – 64 mm furring @ 600 mm o.c. – attached with 96 mm screws @ 600 mm – 64 mm glass fiber insulation in cavities	TLA-12-182 **STC 55**

Table A.2 - 4: Tested single CLT 3-ply (thickness: 78 mm) wall specimens

	Id	Description	Gypsum Board Wall Liner, Side #1			Gypsum Board Wall Liner, Side #2			Test-#, STC
			Face Layer	Base Layer	Fastening Method	Face Layer	Base Layer	Fastening Method	
Benchmark – Bare 78 mm thick 3-ply CLT element									
1	CLT3-01W	CLT 3-ply, 78 mm thick, bare, benchmark	N/A	N/A	N/A	N/A	N/A	N/A	TLA-12-197 **STC 33**
Directly attached gypsum board - 78 mm thick 3-ply CLT element									
2	CLT3-02W	CLT 3-ply, drywall directly attached one side	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 300 mm	N/A	N/A	N/A	N/A	TLA-12-198 **STC 38**
3	CLT3-03W	CLT 3-ply, drywall directly attached both sides	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 300 mm	N/A	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 300 mm	N/A	TLA-12-199 **STC 38**
Gypsum board on 2x2 strapping - 78 mm thick 3-ply CLT element									
4	CLT3-05W	CLT 3-ply, drywall directly attached to wood strapping @ 600 mm one side	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 600 mm	38 mm (2x2) furring @ 600 mm: – 38 mm furring @ 600 mm o.c. – attached with 76 mm screws @ 600 mm – 38 mm glass fiber insulation in cavities	N/A	N/A	N/A	TLA-12-201 **STC 45**
5	CLT3-06W	CLT 3-ply, drywall directly attached to wood strapping @ 600 mm both sides side	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 600 mm	38 mm (2x2) furring @ 600 mm: – 38 mm furring @ 600 mm o.c. – attached with 76 mm screws @ 600 mm – 38 mm glass fiber insulation in cavities	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 600 mm	38 mm (2x2) furring @ 600 mm: – 38 mm furring @ 600 mm o.c. – attached with 76 mm screws @ 600 mm – 38 mm glass fiber insulation in cavities	TLA-12-203 **STC 51**
Different wall liners applied to both sides - 78 mm thick 3-ply CLT element									
6	CLT3-04W	CLT 3-ply, drywall directly attached one side, 2x2 wood strapping @ 600 mm other	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 600 mm	38 mm (2x2) furring @ 600 mm: – 38 mm furring @ 600 mm o.c. – attached with 76 mm screws @ 600 mm – 38 mm glass fiber insulation in cavities	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 300 mm	N/A	TLA-12-200 **STC 47**

Table A.2 - 5: Tested double CLT 3-ply (CLT3 78 mm – Insulation 25 mm - CLT3 78 mm) wall specimens

	Id	Description	Gypsum Board Wall Liner, Side #1			Gypsum Board Wall Liner, Side #2			Test-#, STC
			Face Layer	Base Layer	Fastening Method	Face Layer	Base Layer	Fastening Method	
Benchmark – Bare double leaf 3-ply CLT element (CLT3 78 mm – Insulation 25 mm - CLT3 78 mm)									
1	CLT3-09W	Double CLT 3-ply, 2*78 mm thick CLT leaves with 25 mm insulation in-between, no liners	N/A	N/A	N/A	N/A	N/A	N/A	TLA-12-219 **STC 47**
Gypsum board on 2x2 strapping - Double leaf 3-ply CLT element (CLT3 78 mm – Insulation 25 mm - CLT3 78 mm)									
2	CLT3-08W	Double CLT 3-ply, gypsum board directly attached to 2x2 wood strapping @ 600 mm on one side	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 600 mm	38 mm (2x2) furring @ 600 mm: – 38 mm furring @ 600 mm o.c. – attached with 76 mm screws @ 600 mm – 38 mm glass fiber insulation in cavities	N/A	N/A	N/A	TLA-12-218 **STC 56**
Directly attached gypsum board - 78 mm thick 3-ply CLT element									
3	CLT3-10W	Double CLT 3-ply, gypsum board directly attached one side	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 300 mm	N/A	N/A	N/A	N/A	TLA-12-220 **STC 53**
4	CLT3-11W	Double CLT 3-ply, gypsum board directly attached both sides	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 300 mm	N/A	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 300 mm	N/A	TLA-12-221 **STC 55**

A.2.3.3 Summary of Single Number Ratings

In Table A.2 - 6 (5-ply CLT), Table A.2 - 7 (3-ply CLT), and Table A.2 – 8 (3-ply double CLT) tested and predicted STC-ratings are summarized. Test data is in black and predicted data is in blue, with predicted results with greater STC 60 indicated with STC >60.

Table A.2 - 6: CLT 5-ply wall with gypsum board liners

CLT Wall, 5-ply (Thickness: 175 mm, Mass/Area: 91.4 kg/m²)		**Bare**	**Liner on wall surface 2: 2 Layers 12.7 mm thick Type X gypsum board**					
			Directly attached	**38 mm wood furring @ 400 mm**	**38 mm wood furring @ 600 mm**	**Resilient channels @ 600 mm on 38 mm wood furring @ 400 mm**	**64 mm wood furring @ 600 mm**	**64 mm wood frame w. studs @ 600 mm and 12.7 mm air gap**
Bare		**38**						
Liner on wall surface 1: 2 Layers 12.7 mm thick Type X gypsum board	**Directly attached**	**43**	**42**					
	38 mm wood furring @ 400 mm	**45**	**45/46***	**39**				
	38 mm wood furring @ 600 mm	**50**	**49**	**46**	**56**			
	Resilient channels @ 600 mm on 38 mm wood furring @ 400 mm	**58**	**60**	**55**	**>60**	**>60**		
	64 mm wood furring @ 600 mm	**49**	**48**	**51**	**55**	**>60**	**54**	
	64 mm wood frame w. studs @ 600 mm and 12.7 mm air gap	**59**	**59**	**59**	**>60**	**>60**	**>60**	**>60**

For all wall liners: Cavity between strapping, furring and studs filled with glass fiber batts (thickness 38 mm for strapping and 64 mm for studs)

Black numbers: Measured STC ratings

Blue numbers: Predicted STC ratings from measured TL of bare element and measured TL improvement due to adding extra layers

*) STC of wall configuration predicted from measured TL of bare element and measured TL improvement due to adding extra layers of other configurations at 5-ply CLT wall.

For the 5-ply wall a well decoupled gypsum board wall lining, like the 38 mm (2x2) wood furring spaced 600 mm, or the 64 mm (2x3) wood frame, is necessary on at least at one side of the wall to exceed current code minimum requirement of STC 50 or higher. An excellent example that shows important design parameters is the 38 mm furring. When spaced 400 mm the sound insulation improvement is much less (single side STC 45 and both sides STC 39) (Figure A.2 - 3) than for the case with the more decoupled gypsum board membrane when the furring is spaced 600 mm on centre (single side STC 50 and both sides STC 56) (Figure A.2 - 4). The 400 mm spaced furring has a resonance at 125 Hz that causes a deep dip in sound transmission loss when the wall lining is applied to both sides. When the furring is spaced 600 mm this resonance is shifted to the 100 Hz one third octave band that is not considered in the STC rating.

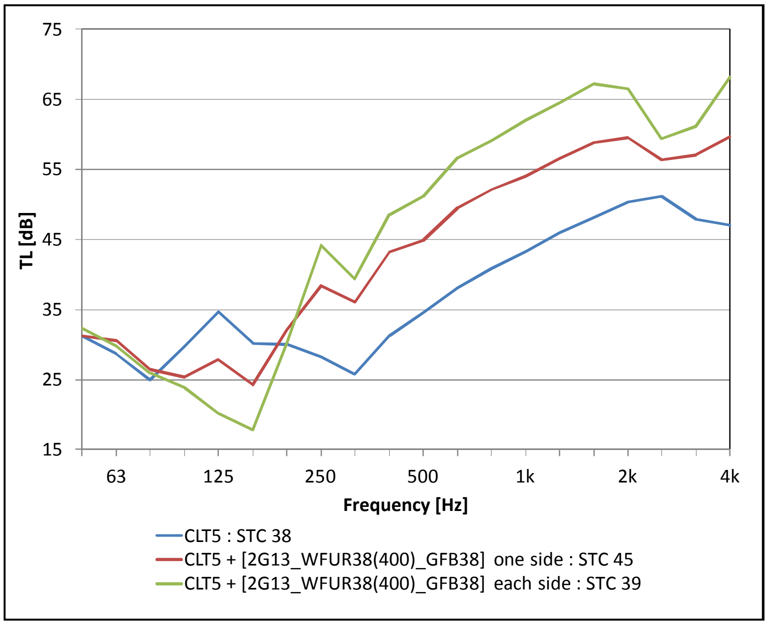


Figure A.2 - 3: TL Improvement - Liner Improvements (400 mm Spacing) on CLT5 Wall

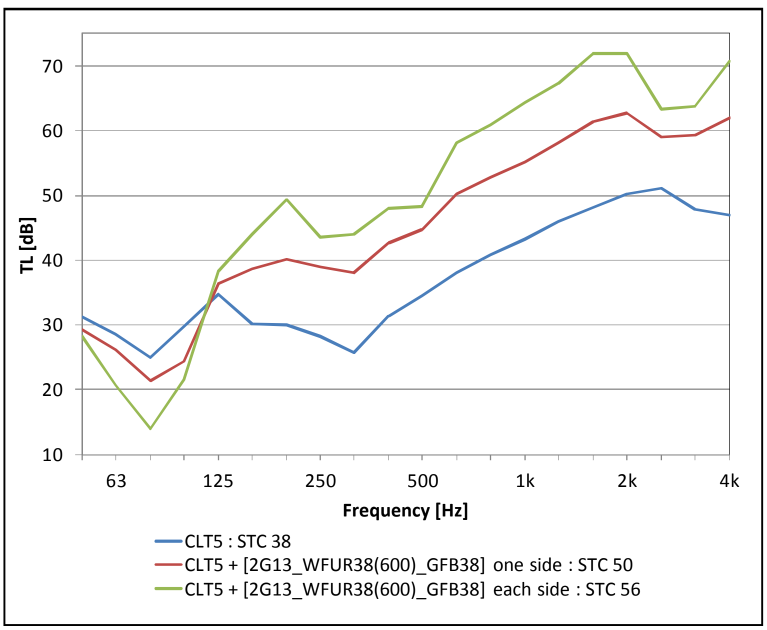


Figure A.2 - 4: TL Improvement - Liner Improvements (600 mm Spacing) on CLT5 Wall

Table A.2 - 7: CLT 3-ply wall with gypsum board liners

CLT Wall, 3-ply (Thickness: 78 mm, Mass/Area: 42.4 kg/m^2)		**Bare**	**Liner on wall surface 2: 2 Layers 12.7 mm thick Type X gypsum board**					
			Directly attached	**38 mm wood furring @ 400 mm**	**38 mm wood furring @ 600 mm**	**Resilient channels @ 600 mm on 38 mm wood furring @ 400 mm**	**64 mm wood furring @ 600 mm**	**64 mm wood frame w. studs @ 600 mm and 12.7 mm air gap**
Bare		**33**						
Liner on wall surface 1: 2 Layers 12.7 mm thick Type X gypsum board	**Directly attached**	**38**	**38**					
	38 mm wood furring @ 400 mm	40	44	39				
	38 mm wood furring @ 600 mm	**45**/44*	**47**/46*	**50**/49*	**51**/50*			
	Resilient channels @ 600 mm on 38 mm wood furring @ 400 mm	53	56	53	60	>60		
	64 mm wood furring @ 600 mm	43	44	49	52	>60	50	
	64 mm wood frame w. studs @ 600 mm and 12.7 mm air gap	53	54	57	>60	>60	60	>60

For all wall liners: Cavity between strapping, furring and studs filled with glass fiber batts (thickness 38 mm for strapping and 64 mm for studs)

Black numbers: Measured STC ratings

Blue numbers: Predicted STC ratings from measured TL of bare element and measured TL improvement due to adding extra layers

*) STC of wall configuration predicted from measured TL of bare element and measured TL improvement due to adding extra layers at CLT5 wall.

The sound insulation performance of the 3-ply base CLT in Table A.2 - 7 is 5 points less than the one of 5-ply CLT because of its smaller mass-per-unit area. Thus, the STC is also less when wall liners are applied and enhanced surface treatments are necessary to achieve the same grade of performance as for the 5-ply CLT wall. In the 4th data row of Table A.2 - 7 measured and predicted STC data is compared. Measured incremental improvement of the decoupled wall linings from 5-ply CLT assemblies were used for the predictions. The agreement of tested and predicted STC data is very good, and as expected predicted results are slightly more conservative (about one point) than measured.

Table A.2 - 8: Double 3-ply CLT wall with gypsum board liners

Double Leaf 3-ply CLT Wall: CLT 78 mm, Insulation 25 mm, CLT 78 mm (Thickness: 181 mm, Mass/Area: 89.6 kg/m^2)		**Bare**	**Liner on wall surface 2: 2 Layers 12.7 mm thick Type X gypsum board**					
			Directly attached	**38 mm wood furring @ 400 mm**	**38 mm wood furring @ 600 mm**	**Resilient channels @ 600 mm on 38 mm wood furring @ 400 mm**	**64 mm wood furring @ 600 mm**	**64 mm wood frame w. studs @ 600 mm and 12.7 mm air gap**
Bare		**47**						
Liner on wall surface 1: 2 Layers 12.7 mm thick Type X gypsum board	**Directly attached**	**53**	**55**					
	38 mm wood furring @ 400 mm	49	53	43				
	38 mm wood furring @ 600 mm	**56**/57*	59	52	>60			
	Resilient channels @ 600 mm on 38 mm wood furring @ 400 mm	>60	>60	57	>60	>60		
	64 mm wood furring @ 600 mm	56	59	55	>60	>60	>60	
	64 mm wood frame w. studs @ 600 mm and 12.7 mm air gap	>60	>60	>60	>60	>60	>60	>60

For all wall liners: Cavity between strapping, furring and studs filled with glass fiber batts (thickness 38 mm for strapping and 64 mm for studs)

Black numbers: Measured STC ratings

Blue numbers: Predicted STC ratings from measured TL of bare element and measured TL improvement due to adding extra layers

*) STC of wall configuration predicted from measured TL of bare element and measured TL improvement due to adding extra layers at CLT5 wall.

Because of the double structure the performance of the bare CLT assembly is much greater than for the single walls (STC 47) (Figure A.2 - 5) and code minimum requirement is already met when the gypsum board membrane is directly attached to a single side only. The improvement due to directly attaching the gypsum board membrane to one or both sides (6 and 8 points) is greater than for the single elements, as the added mass causes a shift of the mass-spring-mass resonance of the double leaf structure to lower frequencies. For one case again the prediction approach is validated for one example. As for the 3-ply wall the agreement between measurement and prediction is good, however, prediction slightly overestimates STC by one point. However, this is within the measurement uncertainty of STC and most assemblies exceed code minimum requirement of STC 50 by far.

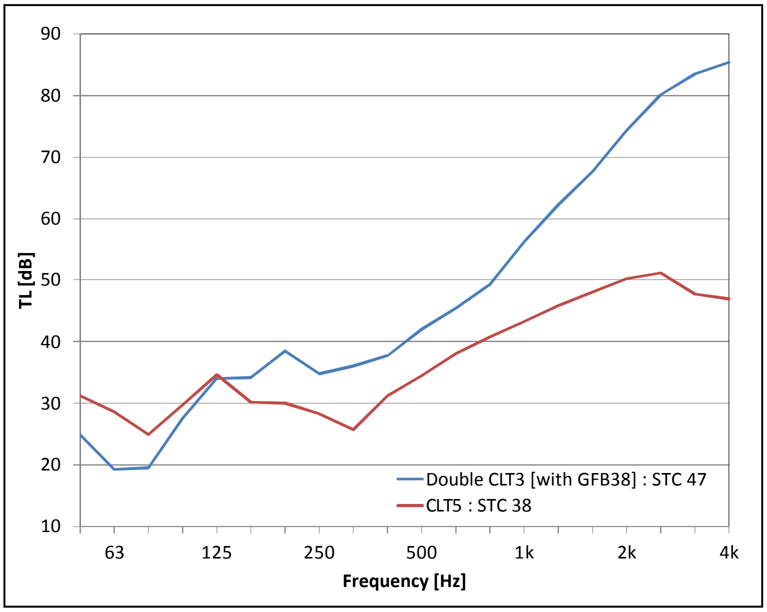


Figure A.2 - 5: Direct TL - Double CLT3 vs CLT5

The improvement of adding the same liner on CLT3 and CLT5 walls is very similar as can be observed in Figure A.2 - 6. For most liners, the TL improvement on various single element CLT walls is the same.

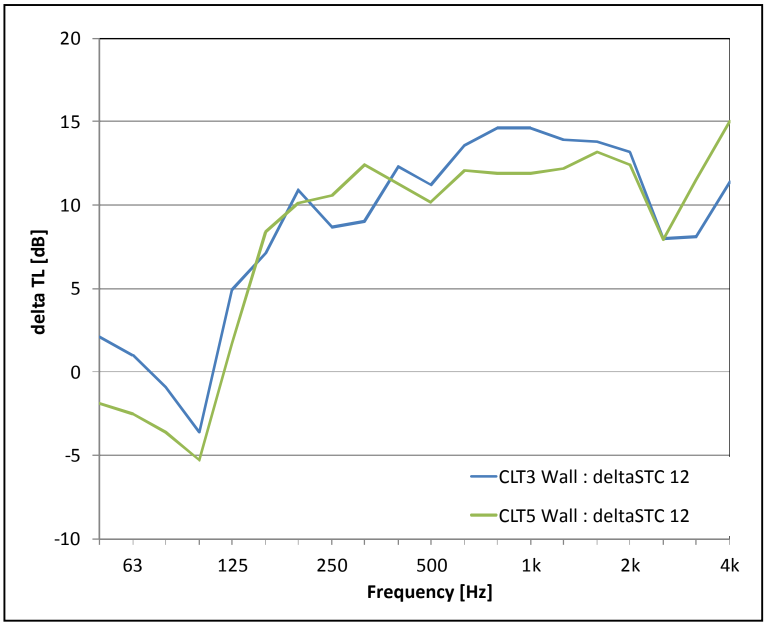


Figure A.2 - 6: TL Improvement - Effect of Same Liner [2G13_WFUR38(600)_GFB38] on Various CLT

A.2.4 CLT Floor Study

As for the CLT wall elements additional floor toppings and gypsum board ceilings (providing a non-combustible surface) have to be added to bare CLT floors for fire resistance, encapsulation of the combustible structure as well as to achieve STC 50 for direct sound transmission and an acceptable impact sound insulation. For the ceiling the simplest lining is directly attached layers of Type X gypsum board. However with this treatment, STC ratings published in FPInnovations' CLT-Handbook [1] (based on test data from Europe on European CLT elements) indicated that the acoustic code requirement and the acceptable impact sound insulation were only achievable with a very good floor topping. Therefore solutions with a well decoupled gypsum board ceiling are necessary and were also considered in this study.

The incremental improvement of sound insulation due to adding weakly coupled ceilings and toppings to a much heavier homogenous monolithic wall or floor can also be added within limits to the measured sound insulation of other base floors to predict their performance. In this study 5-ply floors were considered as base assembly as they are most commonly used. Further, the mass-per-unit area of both 5-ply floors as well as less common 7-ply CLT floors are much greater than of the added floor toppings or ceilings. Therefore the decoupled ceilings and toppings were tested only installed on the 5-ply CLT floor and the measured incremental improvement for airborne and impact sound insulation was applied to the 7-ply floor. Note that at issue date of this report not all data was fully analyzed and therefore only data for 5-ply CLT are included. The incremental improvement of sound insulation further was also necessary as input data for predicting the acoustic system performance of CLT-buildings using ISO 15712 methods.

A.2.4.1 Base Floor Assemblies:

Two base CLT floor assemblies listed in Table A.2 - 9 were tested in this study. Initially, also 3-ply floors (thickness: 105 mm) were considered, but then later removed from the test plans, since they are not very common as the maximum allowable floor span for vibration serviceability is only 3.00 m for this assembly.

Table A.2 - 9: Base CLT floors considered in test series

Element	Configuration
5-ply CLT	single leaf, thickness: 175 mm, mass-per-area: 92 kg/m2
7-ply CLT	single leaf, thickness: 245 mm, mass-per-area: 130 kg/m2

The CLT floors were delivered in two sections that had lap joints at one side. They were connected in the floor test frame with self-tapping screws spaced 300 mm (screw length, 5-ply: 160 mm, 7-ply: 240 mm) and additionally caulked and taped to eliminate sound leaks

A.2.4.2 Floor Toppings for CLT Assemblies

The following floor toppings were identified to be relevant for mid-rise construction as they provide sufficient improvement for airborne and impact sound insulation, are non-combustible and encapsulate the combustible structure for fire protection. The designs were finalized in consultation with the other disciplines (i.e. fire, structural) and the project collaborators.

Table A.2 - 10: Floor toppings considered in CLT Floor Study

Toppings	Interlayer
38 mm concrete topping (at least 70 kg/m2)	All interlayer listed in Table A.2 - 11
38 mm gypsum-concrete (at least 44 kg/m2)	9 mm closed cell foam
2 layers of 12.7 mm (1/2”) cement board with long sides perpendicular and joints staggered by at least 405 mm. Layers fastened together with glue and staples having a length not more than 25 mm, spaced at 203 mm along edge and in the field.	12.7 mm wood fibre board

Suitable floor topping materials that fulfill fire protection requirements are listed in Table A.2 - 10. If those topping materials are directly applied or bonded on top of the CLT floor this solution would provide increased fire resistance. However, for sound insulation these solutions would not be very effective. For a bonded topping, the improvement of sound insulation is mainly due to the added mass which is relatively small as the mass of the base CLT elements is already great. The improvement due to a thin bonded topping would be very small. Thus, a topping must be applied on a resilient interlayer that effectively decouples it from the base assembly to achieve a great improvement of sound insulation.

Table A.2 - 11: Selected elastic floor interlayer materials for floor toppings

Thickness [mm]	Description
9 mm	PE closed cell foam
12.7 mm	Wood fibre board, natural panels
19 mm	Recycled fabric felt
12.7 mm	Rubber nuggets on plastic foil
8 mm	Shredded rubber mat with 4 mm dimples
17 mm	Shredded rubber mat with 8 mm dimples

Suitable floor interlayer materials that were considered in this study are listed in Table A.2 - 11. The products range from commercially available products (e.g. closed cell foam, rubber) to other building materials that were identified to have appropriate elastic properties (e.g. wood fiber board, recycled fabric felt). To gain a better insight in their performance on CLT floors - a lot of data is already available when applied to much heavier concrete floors or much more lightweight wood framed floors – all interlayer materials were tested when installed under the 38 mm concrete topping. Hereby, the 38 mm floor topping was a pre-fabricated slab. It was possible to easily lift it with a crane and thus allowed for a relative quick change of the interlayer materials without delays for curing. Besides the sound insulation the elastic material properties of the interlayers were also determined in parallel. In further analysis the incremental sound insulation improvement will be related to the material properties and to identify the parameters that are most relevant for a generic description of the materials.

A.2.4.3 Gypsum Board Ceilings for CLT Assemblies

Four gypsum board ceilings were identified as relevant for mid-rise construction as they are non-combustible and the hung ceilings were expected to provide sufficient improvement for airborne and impact sound insulation. The designs were finalized in consultation with the other disciplines (i.e. fire, structural) and the project collaborators.

Table A.2 - 12: Gypsum board ceiling solutions for CLT floor assemblies

Gypsum Board Membrane	Mounting
2 layers of 12.7 mm (1/2”) Type X gypsum board	Directly attached (DA) with screws
2 layers of 13 m (1/2”) Type X gypsum board	Attached to: - 38.1 mm (2x2) wood furring strips @ 600 o.c. nailed to the CLT - ceiling cavity filled with 38 mm glass fiber insulation
2 layers of 12.7 mm (1/2”) Type X gypsum board	Attached 150 mm below ceiling to metal ceiling grillage according to ASTM C754-11: - 38.1 mm (1-1/2”) carrying channels spaced @ 1200 mm hung with 4.1 mm (8-ga.) hanger wires spaced @ 1200 mm - DWC-25-ga. rigid metal furring channels spaced @ 600 mm saddle tied to carrying channels with double-strand 1.2 mm (18-ga.) tie wire to carrying channels - ceiling cavity filled with 140 mm glass fiber insulation (R20)
1 layer of 15.9 mm (5/8”) Type X gypsum board	Attached 150 mm below directly attached gypsum board ceiling (2- layers of 12.7 mm thick Type X as described in line 1) to metal ceiling grillage according to ASTM C754-11: - 38.1 mm (1-1/2”) carrying channels spaced @ 1200 mm hung with 4.1 mm (8-ga.) hanger wires spaced @ 1200 mm - DWC-25-ga. rigid metal furring channels spaced @ 600 mm saddle tied to carrying channels with double-strand 1.2 mm (18-ga.) tie wire to carrying channels - ceiling cavity filled with 140 mm glass fiber insulation (R20)

The simplest considered gypsum board ceiling was two layers of 12.7 mm Type X gypsum board directly attached. As a second more enhanced ceiling the 2 layers of Type X gypsum board were mounted on 38 mm wood furring spaced 600 mm with cavities in-between filled with 38 mm glass fiber insulation. This assembly is used as cross-check to the wall study. Further, two well decoupled hung gypsum board ceiling variants were considered that are generic designs according to ASTM C754-11. The hung gypsum board is 150 mm below the base floor element mounted to a metal grillage. The grillage is constructed from 38 mm metal C- and furring channels and hung from ceiling with wire hangers. The cavity was filled with 140 mm glass fiber insulation. The two hung ceiling variants only differ in the gypsum board membrane configuration. For the first variant the CLT surface was exposed in the ceiling cavity and two layers of 12.7 mm thick Type X gypsum board were attached to the metal grillage. For the second variant 2 layers of 12.7 mm thick Type X gypsum board were directly attached to the bottom side of the CLT for fire-protection and the hung gypsum board ceiling has a single layer of 15.9 mm Gypsum board. The purpose of this dropped ceiling for the second variant is to achieve acceptable airborne sound insulation as well as to provide necessary space for installation of building equipment like electric-conduits and ductwork.

All hung ceiling variants were tested on the 5-ply CLT floor and only a limited set was tested for validation of the prediction approach on the 7-ply CLT floor.

A.2.4.4 Summary Tested CLT Floors with STC-Ratings

A brief description of the CLT floor assemblies that were tested are summarized in Table A.2 - 13 and Table A.2 - 14.

Table A.2 - 13: Tested 5-ply CLT floor specimens with descriptions and STC and IIC-ratings

	Id	Description	Floor Topping		Gypsum Board Ceiling			Test-#, STC	Test-#, IIC
			Topping	Interlayer	Face Layer	Base Layer	Fastening Method		
Benchmark – Bare 5-ply CLT floor, Thickness: 175 mm									
1	B7000-01F	Bare 5-ply CLT Floor	N/A	N/A	N/A	N/A	N/A	TLF-12-039 STC 41	IIF-12-026 IIC 25
5-ply CLT Floor - Gypsum Board Ceiling Study									
2	B7000-09F	5-ply CLT floor with directly attached gypsum board ceiling	N/A	N/A	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 300 mm	Directly attached	TLF-13-011 STC 42	IIF-13-010 IIC 25
3	B7000-11F	5-ply CLT floor with gypsum board directly attached to 38 mm (2x2) wood furring @ 600 mm	N/A	N/A	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 600 mm	38 mm (2x2) furring @ 600 mm: – 38 mm furring @ 600 mm o.c. – attached with 76 mm screws @ 600 mm – 38 mm glass fiber insulation in cavities	TLF-13-014 STC 50	IIF-13-013 IIC 36
4	B7000-12F	5-ply CLT floor with 2 layers 12.7 mm Type X gypsum board as hung ceiling	N/A	N/A	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 600 mm	Attached 150 mm below ceiling to metal ceiling grillage according to ASTM C754-11: – 38 mm (1-1/2") carrying channels spaced @ 1200 mm hung with 4.1 mm (8-ga.) hanger wires spaced @ 1200 mm – DWC-25-ga. rigid metal furring channels spaced @ 600 mm tied to carrying channels – ceiling cavity filled with 140 mm glass fiber insulation (R20)	TLF-13-016 STC 68	IIF-13-014 IIC 54

Table A.2 - 13: **Tested 5-ply CLT floor specimens with descriptions and STC and IIC-ratings** - continued

5	B7000-10F	5-ply CLT floor with 2 layers 12.7 mm Gypsum board directly attached and hung ceiling for sound insulation	N/A	N/A	16mm gypsum board, 50 mm screws @ 300 mm		Attached 150 mm below ceiling to metal ceiling grillage according to ASTM C754-11: – 38 mm (1-1/2") carrying channels spaced @ 1200 mm hung with 4.1 mm (8-ga.) hanger wires spaced @ 1200 mm – DWC-25-ga. rigid metal furring channels spaced @ 600 mm tied to carrying channels – ceiling cavity filled with 140 mm glass fiber insulation (R20) – 2 layers 12.7 mm thick Type X gypsum board directly attached, face layer: 50 mm screws @ 300 mm base layer: 41 mm screws @ 300 mm	TLF-13-012 STC 67	IIF-13-011 IIC 55
5-ply CLT Floor – Interlayer study									
6	B7000-02F	5-ply CLT floor with 38 mm concrete topping on 9.5 mm foam	38 mm concrete topping	9.5 mm closed cell foam interlayer	N/A	N/A	N/A	TLF-12-048 STC 53	IIF-12-037 IIC 36
7	B7000-03F	5-ply CLT floor with 38 mm concrete topping on 12.7 mm fiber board	38 mm concrete topping	12.7 mm soft wood fiber board	N/A	N/A	N/A	TLF-12-049 STC 52	IIF-12-039 IIC 35
8	B7000-04F	5-ply CLT floor with 38 mm concrete topping on 19 mm felt	38 mm concrete topping	19 mm recycled fabric felt	N/A	N/A	N/A	TLF-12-044 STC 59	IIF-12-034 IIC 42
9	B7000-05F	5-ply CLT floor with 38 mm concrete topping on 12.7 mm rubber nuggets	38 mm concrete topping	12.7 mm rubber nuggets on plastic foil	N/A	N/A	N/A	TLF-13-009 STC 53	IIF-13-008 IIC 46
10	B7000-06F	5-ply CLT floor with 38 mm concrete topping on 9.5 mm rubber matt	38 mm concrete topping	9.5 mm shredded rubber matt with 4 mm dimples	N/A	N/A	N/A	TLF-12-052 STC 52	IIF-13-001 IIC 38
11	B7000-07F	5-ply CLT floor with 38 mm concrete topping on 17 mm rubber matt	38 mm concrete topping	17 mm shredded rubber matt with 8 mm dimples	N/A	N/A	N/A	TLF-13-004 STC 54	IIF-13-004 IIC 44
12	B7000-08F	5-ply CLT floor with 38 mm concrete topping without interlayer	38 mm concrete topping	No interlayer/no bond	N/A	N/A	N/A	TLF-13-010 STC 49	IIF-13-004 IIC 28

Table A.2 - 13: Tested 5-ply CLT floor specimens with descriptions and STC and IIC-ratings - continued

13	B7000-14F	5-ply CLT floor with 2 layers of 12 mm cement board	2 layers of 12 mm cement board glued using thinset and stapled every 150 mm	12.7 mm soft wood fiber board	N/A	N/A	N/A	TLF-13-018 STC 48	IIF-13-016 IIC 40
14	B7000-16F	5-ply CLT floor with 38 mm gypsum concrete on 9.5 mm foam	38 mm gypsum concrete	9.5 mm closed cell foam interlayer	N/A	N/A	N/A	TLF-13-021 STC 50	IIF-13-019 IIC 41
5-ply CLT Floor – Interlayer and Gypsum Board Ceiling Study									
15	B7000-13F	5-ply CLT floor with 2 layers of 12 mm cement board 13mm wood board with 2 layers of 12.7 mm Type X gypsum board as hung ceiling	2 layers of 12 mm cement board glued using thinset and stapled every 150 mm	12.7 mm soft wood fiber board	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 600 mm	Attached 150 mm below ceiling to metal ceiling grillage according to ASTM C754-11: – 38 mm (1-1/2”) carrying channels spaced @ 1200 mm hung with 4.1 mm (8-ga.) hanger wires spaced @ 1200 mm – DWC-25-ga. rigid metal furring channels spaced @ 600 mm tied to carrying channels – ceiling cavity filled with 140 mm glass fiber insulation (R20)	TLF-13-017 STC 69	IIF-13-015 IIC 63
16	B7000-15F	5-ply CLT floor with 38 mm gypsum concrete on 9.5 mm foam with 2 layers of 12.7 mm Type X gypsum board as hung ceiling	38 mm gypsum concrete	9.5 mm closed cell foam interlayer	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 600 mm	Attached 150 mm below ceiling to metal ceiling grillage according to ASTM C754-11: – 38 mm (1-1/2”) carrying channels spaced @ 1200 mm hung with 4.1 mm (8-ga.) hanger wires spaced @ 1200 mm – DWC-25-ga. rigid metal furring channels spaced @ 600 mm tied to carrying channels – ceiling cavity filled with 140 mm glass fiber insulation (R20)	TLF-13-020 STC 72	IIF-13-018 IIC 63

Table A.2 - 14: Tested 7-ply CLT floor specimens with descriptions and STC and IIC-ratings

Benchmark – Bare 7-ply CLT floor, Thickness: 245 mm										
17	B7000-20F	Bare 7-ply CLT floor	N/A	N/A	N/A	N/A	N/A	TLF-13-025 STC 44	IIF-13-024 IIC 30
7-ply CLT Floor – Interlayer study										
18	B7000-17F	7-ply CLT floor with 38 mm gypsum concrete on 9.5 mm foam	38 mm concrete topping	9.5 mm closed cell foam interlayer	N/A	N/A	N/A	TLF-13-022 STC 57	IIF-13-020 IIC 41
7-ply CLT Floor - Gypsum Board Ceiling Study										
19	B7000-19F	7-ply CLT floor with directly attached gypsum board ceiling	N/A	N/A	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 300 mm	Directly attached	TLF-13-024 STC 45	IIF-13-022 IIC 32
7-ply CLT Floor – Interlayer and Gypsum Board Ceiling Study										
20	B7000-18F	7-ply CLT floor with 38 mm gypsum concrete on 9.5 mm foam with directly attached gypsum board ceiling	38 mm concrete topping	9.5 mm closed cell foam interlayer	12.7 mm thick Type X, 50 mm screws @ 300 mm	12.7 mm thick Type X 41 mm screws @ 300 mm	Directly attached	TLF-13-023 STC 56	IIF-13-021 IIC 45

A.2.4.5 Summary of Single Number Ratings

Table A.2 - 15: Airborne (STC-rating) and impact (IIC-rating, in brackets) sound insulation of 5-ply CLT floor designs:

CLT Floor 5-ply: (Thickness: 175 mm, Mass/Area: 91.4 kg/m²) **STC (IIC)**		Bare	Gypsum board Ceiling: 2 Layers 12.7 mm thick Type X gypsum board – Directly attached	Gypsum board Ceiling: 2 Layers 12.7 mm thick Type X gypsum board – 38 mm wood furring @ 600 mm	Gypsum board Ceiling: 2 Layers 12.7 mm thick Type X gypsum board – As hung ceiling on metal grillage 150 mm below CLT surface	Gypsum board Ceiling: 2 Layers 12.7 mm thick Type X gypsum board – Directly attached to CLT and additional acoustic hung ceiling with 15.9 mm thick Type X on metal grillage 150 mm underneath
	Bare	41 (25)	42 (25)	50 (36)	68 (56)	67 (55)
Floor Toppings:	38 mm concrete topping on 9.5 mm closed cell foam	53 (36)	53 (40)	59 (50)	76 (66)	74 (64)
	38 mm concrete topping on 12.7 mm wood fiber board	52 (35)	53 (38)	59 (47)	76 (64)	73 (63)
	38 mm concrete topping on 19 mm recycled fiber felt	59 (42)	59 (46)	63 (45)	77 (61)	75 (60)
	38 mm concrete topping on 12.7 mm rubber nuggets on foil	53 (46)	53 (44)	59 (49)	73 (65)	70 (63)
	38 mm concrete topping on 8 mm shredded rubber mat	52 (38)	52 (38)	58 (48)	76 (66)	74 (64)
	38 mm concrete topping on 17 mm shredded rubber mat	54 (44)	54 (43)	60 (51)	76 (67)	73 (65)
	38 mm concrete topping not bonded to CLT	49 (28)	49 (32)	56 (41)	75 (60)	74 (60)
	2x12 mm cement board on 12.7 mm wood fiber board	48 (46)	48 (38)	54 (47)	69 (63)	68 (60)
	38 mm gypsum concrete on 9.5 mm closed cell foam	50 (41)	50 (41)	58 (49)	72 (63)	73 (63)

For all hung gypsum board ceilings: Cavity between furring and above hung ceiling filled with glass fiber batts (thickness 38 mm for furring and 140 mm for hung ceiling)

Black numbers: Measured STC ratings

Blue numbers: Predicted STC ratings from measured TL of bare element and measured TL improvement due to adding extra layers

Table A.2 - 16: Airborne (STC-rating) and impact (IIC-rating, in brackets) sound insulation of 7-ply CLT floor designs:

CLT Floor 7-ply: (Thickness: 245 mm, Mass/Area: 130 kg/m^2) **STC (IIC)**		**Bare**	**Gypsum board Ceiling: 2 Layers 12.7 mm thick Type X gypsum board** — Directly attached	38 mm wood furring @ 600 mm	As hung ceiling on metal grillage 150 mm below CLT surface	Directly attached to CLT and additional acoustic hung ceiling with 15.9 mm thick Type X on metal grillage 150 mm underneath
	Bare	**44 (30)**	**45 (29)**	52 (40)	71 (60)	70 (58)
Floor Toppings:	**38 mm concrete topping on 9.5 mm closed cell foam**	**56 (44)**	**56 (44)**	61 (53)	78 (69)	76 (67)
	38 mm concrete topping on 12.7 mm wood fiber board	55 (42)	55 (41)	61 (51)	79 (67)	76 (66)
	38 mm concrete topping on 19 mm recycled fiber felt	61 (49)	61 (50)	65 (48)	80 (64)	77 (62)
	38 mm concrete topping on 12.7 mm rubber nuggets on foil	56 (49)	56 (47)	61 (51)	76 (67)	73 (65)
	38 mm concrete topping on 8 mm shredded rubber mat	54 (43)	55 (42)	61 (52)	79 (70)	76 (68)
	38 mm concrete topping on 17 mm shredded rubber mat	56 (48)	56 (46)	62 (53)	78 (69)	75 (67)
	38 mm concrete topping not bonded to CLT	51 (35)	52 (36)	59 (46)	78 (66)	76 (62)
	2x12 mm cement board on 12.7 mm wood fiber board	51 (44)	51 (41)	57 (50)	73 (66)	70 (64)
	38 mm gypsum concrete on 9.5 mm closed cell foam	52 (46)	52 (44)	60 (51)	76 (67)	75 (65)

For all hung gypsum board ceilings: Cavity between furring and above hung ceiling filled with glass fiber batts (thickness 38 mm for furring and 140 mm for hung ceiling)

Black numbers: Measured STC ratings

Blue numbers: Predicted STC ratings from measured TL of bare element and measured TL improvement due to adding extra layers

In Table A.2 - 15 and Table A.2 - 16, there are the tested or predicted STC and IIC ratings of CLT 40 - 5-ply CLT floor assemblies and 40 - 7-ply CLT floor assemblies. Tested results are in black and predicted in blue. The numbers in the brackets are IIC ratings.

The 5-ply CLT floor achieves 3 points better sound insulation with STC 41 in comparison to the 5-ply CLT wall with nominally identical thickness of 175 mm. However, this is caused by a dip in the sound transmission loss in a single frequency band that governs the rating. The difference vanishes as soon as the gypsum board ceiling is added and identical STC ratings (Table A.2 - 13, line 2 and line 3) are achieved for the 5-ply CLT floor and wall.

The elastic interlayer study with the 38 mm topping on the 5-ply CLT revealed that most tested interlayer materials achieve airborne sound insulation improvement in the range of 11 to 13 STC points with exception of the felt that performed much better and achieved 18 STC-points improvement. On the other hand the spread of impact sound insulation improvement is much greater and ranges between 10 IIC-points for the wood fiber board and 21 IIC-points for the rubber nuggets on plastic foil. As expected the thin and relative stiff interlayer materials closed cell foam, wood fiber board, and 8 mm shredded rubber mat perform worse than the thicker more elastic ones.

The improvement of ceiling liners varied between 1 and 27 STC points for the 5-ply CLT floor and 7-ply CLT floors. The hung gypsum board ceilings offer the best STC and IIC improvement; ~26 and ~30 points improvement respectively when compared to toppings (see Figure A.2 - 7).

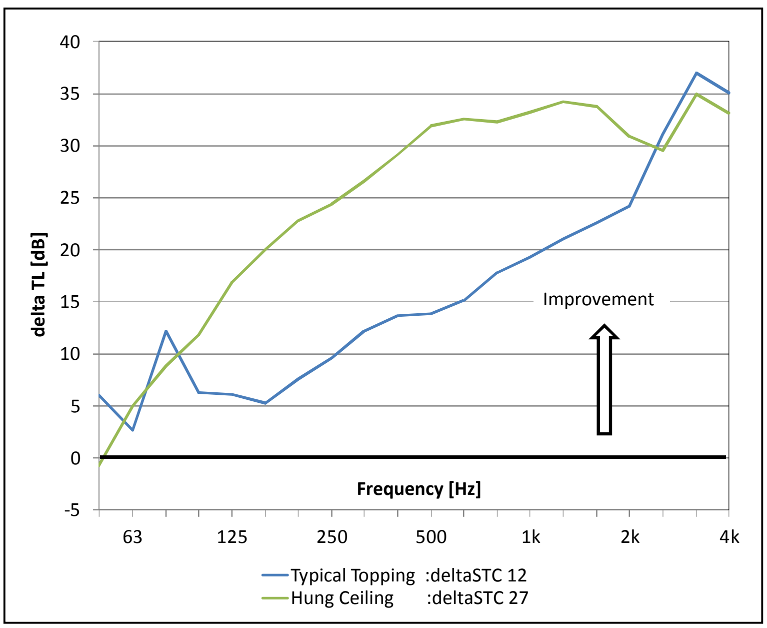


Figure A.2 - 7: TL Improvement –Hung Ceiling vs. Typical Topping on 5-ply CLT Floor

The hung gypsum board ceilings in combination with the floor toppings were found to be very effective for achieving high grades of sound insulation for both airborne and impact sound insulation. Adding only a floor topping, or in combination with directly attached gypsum board, increases the STC ratings above code minimum. However, impact sound insulation of these assemblies does not satisfy market demands with values far less than IIC 50 which is used in many design guidelines as the minimum requirement. Thus, variants with decoupled ceiling solutions are preferable design options.

A.2.5 Summary and Conclusions

In this study direct sound insulation of CLT wall and floor assemblies was tested. The test series were structured as parametric studies to minimize extensive testing by predicting the sound insulation performance of un-tested CLT assemblies with added gypsum board wall linings, floor toppings and gypsum board ceilings. The outcomes of the study give a great number of design options for CLT wall and floor assemblies that were demonstrated to meet and exceed minimum airborne sound insulation requirement STC 50 in the National Building Code of Canada 2010 as well as floors that also provide acceptable impact sound insulation as is demanded by the market.

A.2.6 References

[1] Sylvain Gagnon et al. "CLT Handbook – Canadian Edition", FPInnovations, Special Publication SP-528E, 2011

[2] A.C.C. Warnock, "Sound Transmission Loss Measurements through 190 mm and 140 mm Blocks with Added Drywall and Through Cavity Block Walls", National Research Council Canada, Institute for Research in Construction, Internal Report IR-586, January 1990

[3] ISO 10140-5:2010 "Acoustics – Laboratory measurement of sound insulation of building elements – Part 5: Requirements for test facility and equipment", ISO-Standard

[4] ISO 15712-1:2005 "Building Acoustics – Estimation of acoustic performance of buildings from the performance of elements – Part 1: Airborne sound insulation between rooms", ISO-Standard

[5] ASTM E90 - 09 "Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements", ASTM International

[6] ASTM E413 – 04 "Classification for Rating Sound Insulation" ASTM International

[7] ASTM E492 – 09: "Standard Test Method for Laboratory Measurement of Impact Sound Transmission through Floor-Ceiling Assemblies Using the Tapping Machine", ASTM International

[8] ASTM E989 – 06 "Standard Classification for Determination of Impact Insulation Class (IIC)", ASTM International

A.3 Flanking Sound Transmission in Wood Frame Mid-Rise Buildings

A.3.1 Background

The acoustic system performance of wood framed structures for mid-rise buildings was assessed in this research project in anticipation of a possible code change as early as in the National Building Code of Canada (NBCC) 2015. The system performance is the airborne and impact sound insulation, when floors and walls are coupled and form part of a building. Much data already exists for the system performance of low-rise wood framed construction, however, this cannot be used for mid-rise construction, because the wall designs are quite different due to the higher axial and lateral loads, leading to a different sound insulation performance.

Currently, there is only a minimum requirement for direct airborne sound insulation of Sound Transmission Class STC 50 for the building element separating a residential unit form other spaces in a building in National Building Code of Canada 2010. The direct sound insulation performance of framed walls and floors with various claddings were assessed in a research component conducted in parallel. The sound insulation performance between two rooms separated by a wall or floor might be much less than the sound transmission of the separating element when installed in a direct sound transmission facility. The reason is the so-called flanking sound transmission involving the elements adjoining the separating element at its edges. To account for this effect and to give a more realistic requirement for airborne sound insulation that better matches with what is perceived by occupants, a code change was proposed and a new requirement for the Apparent Sound Transmission Class (ASTC) may be introduced in the National Building Code Canada in 2015. As the code change is not yet finalized, the new required performance is not set, but ASTC 47 is expected to be the likely new minimum requirement for airborne sound insulation.

The acoustics research on wood framed systems was developed and conducted at NRC Construction in close coordination with the project partners (Canadian Wood Council, FPInnovations and the Provinces) and in close consultation with other disciplines (i.e. structure, fire, heat and moisture). The applied methodology, selection of test specimens, and test results were discussed with these groups at workgroup meetings held on a regular basis. Further, research conducted by other groups in Canada (i.e. FPInnovations, NEWBuildS) was taken into account in this project. When new knowledge, e.g. from this research component or other disciplines, became available during the research project, research plans were changed accordingly to account for these new developments.

A.3.2 Introduction

This Appendix briefly describes how to measure, and the facility used to measure airborne and impact flanking sound transmission in mid-rise wood framed construction, before listing measurement results for thirty-nine junctions tested. Note that the sound transmission results presented here are first estimates obtained directly from measurements, or from minimal analysis of those measurements. At the current stage of analysis not all of the path data exists, however the measurement data is available to, with more thorough analysis, extract the missing path data, and to calculate more exact results. The data was measured in the NRC Flanking facility on five specimens, each having eight rooms over two storeys, four on the upper and four on the lower storey. The reference specimen B7000-01 was built, characterized, and modified to create the other five.

For lightweight framed building systems, sound transmission through the separating element and all flanking paths at a building junction must be measured in a special test facility. Only the changes of sound insulation performance due to adding floor toppings or changes at the gypsum board membrane (e.g. mounted to resilient channels instead of directly attached) can be predicted based on the changes measured for similar structures.

In this project 6 full-scale 8-room sections (i.e. 1 base assembly with 5 changes) of a mid-rise wood frame building were characterized in NRC Construction's Flanking Sound Transmission Facility. Each specimen consists of 8 walls and 4 floors that were coupled at 2 wall-wall junctions, 2 load bearing floor-wall junctions where the floor joists are supported and 2 non-load bearing junctions that are parallel to the floor joists.

A.3.3 NRC Flanking Transmission Facility

Figure A.3 - 1 shows a sketch of the NRC/IRC Flanking Transmission Facility in which the floor specimens were evaluated for airborne sound insulation using ASTM E336 and impact sound insulation using the light impact source in ASTM E1007.

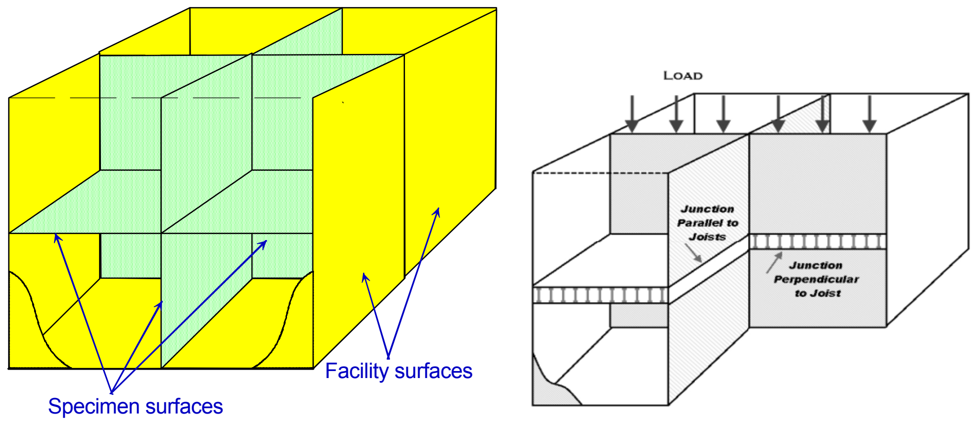


Figure A.3 - 1: Specimen walls divide the NRC\IRC Flanking Transmission Facility into four rooms above and below the floor assembly

The permanent part of the facility (upper ceiling/roof, perimeter walls, and foundation floor) is constructed of high sound insulating elements that are resiliently isolated from each other and from structural support members, with vibration breaks in the permanent surfaces where the specimens are installed.

Upper rooms have a ceiling height of 2.7 m while the lower rooms have a height of 2.4 m. The volume of the rooms used to assess flanking transmission in this study ranged from 35 to 45 m^3.

Figure A.3 - 2 shows the loading beam that spans the top of the chambers that enables a static load to be applied to the bearing walls to simulate the load that would occur in a real building. In a previous study [1] it was shown that applying a load to the load bearing walls has an effect on the sound transmission of several paths. However, the effect of the load stagnates after increasing it to simulate a load of half a storey. In other words, the effect of axially load on flanking sound transmission is the same for any load simulating more than one storey. For this study, although interested in construction from four to six storeys, the load of approximately one storey was applied.

Figure A.3 - 2: Photograph of the NRC\IRC Flanking Transmission Facility showing the loading beam (in red) used to apply the static load to specimen bearing walls.

In such a facility, specific construction changes can be systematically introduced such that resulting changes in the sound insulation performance of the experimental surfaces can be accurately determined. Using custom hardware and software developed at NRC, the measurements are performed completely under computer control, from calibration and microphone probe positioning to report generation. This provides a high degree of precision and repeatability. For all airborne tests, the sound pressure levels are sampled at a minimum of 9 positions in each room (which exceeds the minimum of 5 required by the airborne standard). The robot systems in each room (Figure A.3 - 3) position the microphones (12.5 mm precision condenser microphones with random incidence response), and signals are simultaneously measured in all 8 rooms using a National Instruments analogue to digital converter. Proprietary software developed at NRC-IRC performs the time weighting, filtering, and all computations necessary to obtain estimates of the sound insulation.

Figure A.3 - 3: Photograph of the NRC Flanking Transmission Facility showing the robots used to position microphones in the upper four rooms. Photo taken before walls of the specimen were installed.

The light impact tests were conducted following the ASTM E1007 standard using the required tapping machine positions as shown below in Figure A.3 - 4.

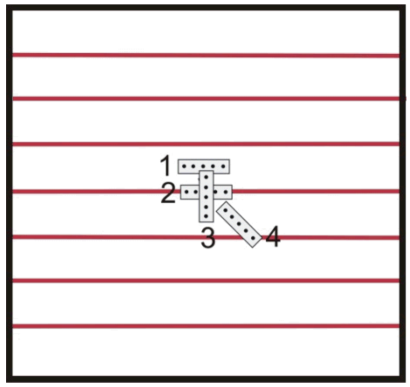


Figure A.3 - 4: Location of the excitation positions used for the light impact source (tapping machine) relative to the joists (not to scale).

A.3.4 Measurement method and results

The following sections contain sound insulation results for airborne and light impact sources measured in the NRC flanking facility (TH7). The results are grouped in three junction types (wall-wall junction, horizontal floor-wall junction, vertical floor-wall junction), with each junction being a combination of three elements. Those three types of junctions are again distinguished by load-bearing and non-load-bearing walls. An axial load is applied to the walls in the load-bearing cases, in which the joists run perpendicular to the junction, whereas, no load is applied to the non-load bearing cases, in which the joists run parallel to the junction. For the example given in below in Figure A.3 - 5, the horizontal floor-wall junction consists of two floor elements and one wall element.

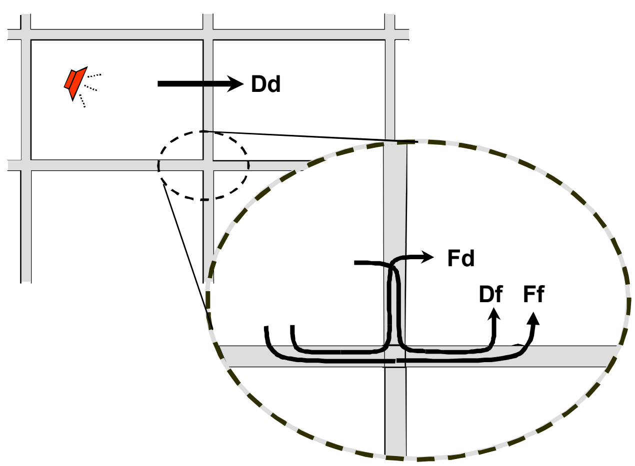


Figure A.3 - 5: Junction and labeling convention for transmission paths (according to ISO 15712 [2]).

Consider transmission from a source room at the left to the receiving room beside it. Each transmission path involves one surface in the source room (denoted by a capital letter) and one in the receive room (lower case). Direct transmission through the separating wall is path Dd. For each edge of the separating assembly there are three flanking paths, each involving a surface in the source room and one in the receiving room, that connect at this edge: Ff from flanking surface F to flanking surface f, Df from direct surface D to flanking surface f, and Fd from flanking surface F to direct surface d in the receiving room.

Note that the letter "F" or "f" denotes **f**lanking surface, and "D" or "d" denotes the surface for **d**irect transmission, i.e. - the surface of the separating assembly. These surfaces may be either wall or floor/ceiling assemblies, which are for the below junction described in the following section.

In order to measure, for example, the Dd path, sound transmission through the F and f elements needs to be suppressed sufficiently. This suppression/insulation is achieved by shielding that element by placing, without structural coupling, 90 mm glass fiber insulation batts and two layers of 15.9 mm Gypsum board in front of those elements. More details on shielding methods can be found in NRC RR-218 [3], [4], [5], [6] and [7].

Each page below represents one tested junction, and has a junction descriptor (explained below), a junction diagram, a table describing the elements, and a table containing the single number ratings.

As there are two element faces on each side of the junction there are a total of four possible paths (denoted by Dd, Df, Fd, FF) through the junction as already illustrated in Figure A.3 - 5. The Dd path is the direct path and the others are the flanking paths. In order to estimate the apparent sound transmission between two rooms, the flanking STC (three flanking paths per junction) of all four junctions defining a room and the direct path have to be considered (total of 13 paths, or four flanking junction and one direct). When doing these types of calculations, note that the STC values represent logarithmic inverse power losses.

As only the exposed cladding of an element is relevant for flanking sound transmission, the unexposed cladding is not depicted in the junction diagrams below. Any type of cladding can be chosen on the unexposed side of the flanking element.

Table A.3 - 1: Junction Descriptor

WW	Wall-Wall Junction
WF	Horizontal Bottom junction involving the floor on both sides of a separating wall
WC	Horizontal Top junction involving the ceiling on both sides of a separating wall
FW	Vertical junction involving side walls above and below a floor ceiling assembly
NLB	Non-load bearing junction (floor joists perpendicular to junction support wall)
LB	Load bearing junction (floor joists parallel junction)

Table A.3 - 2: Single number table example for horizontal floor-wall junction:

Path	Fl-STC	Fl-IIC->	Fl-IIC<-
Dd	50		
Df	50		
Fd	50	50	50
Ff	50	50	50
Flanking	45	47	47
Total	44	47	47

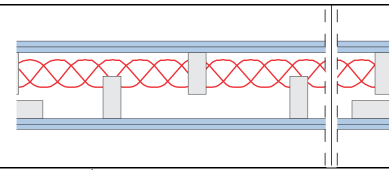
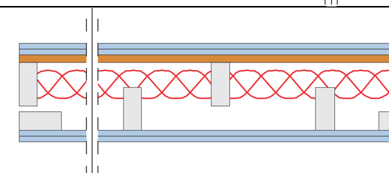
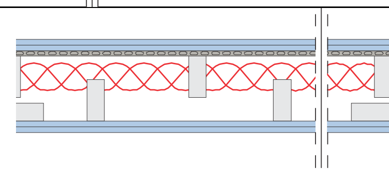
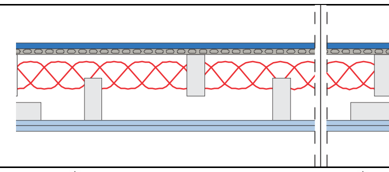
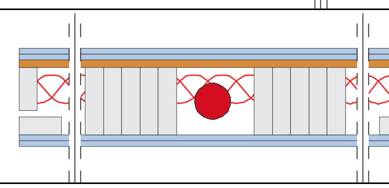
The first column lists the name of the path (explained in Figure A.3 - 5) or sum of paths, where Flanking meaning the “sum” of the three flanking paths Df, Fd, and Ff; and Total is the “sum” of all four paths in this junction (Dd, Df, Fd, and Ff). The values in column two to four are the direction independent airborne Flanking-STC (Fl-STC), the impact Flanking-IIC from left to right (Fl-IIC->), and impact Flanking-IIC from right to left (Fl-IIC<-) respectively. As, in the horizontal example case, the floor is a flanking path, meaning no direct path exists, the single number ratings for Flanking and Total are the same.

In order to calculate the apparent sound transmission class (ASTC) for a room pair, the single number ratings the direct path (Dd) and Flanking single number rating for all four junction connecting the rooms have to be “summed” up.

A.3.4.1 Wall-Wall Non-load Bearing Junctions

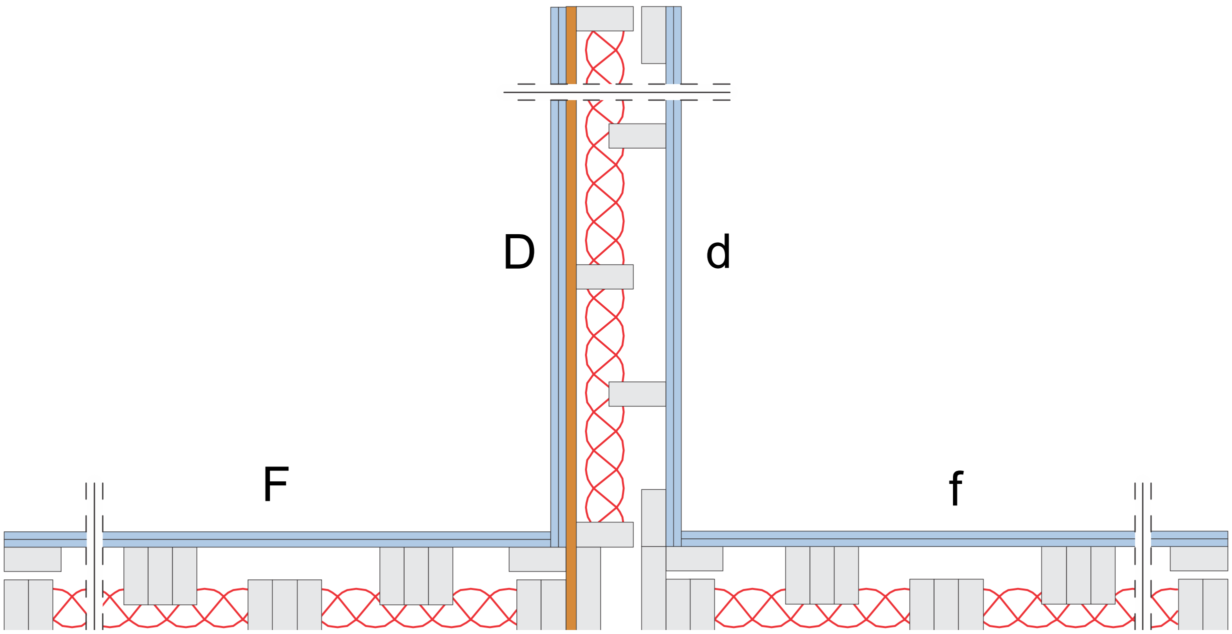
In this section, there are 13 distinct wall-wall non-load bearing junctions with results of their flanking paths.

Junction Name	F	Direct (Dd)	f
FTL-13-SWS140-WW-NLB-001	2G13	NLB-W2 (Shear)	2G13
FTL-13-SWS140-WW-NLB-002	2G13_PLY16	NLB-W2 (Shear)	2G13
FTL-13-SWS140-WW-NLB-003	2G13	NLB-W1	2G13
FTL-13-SWS140-WW-NLB-004	2G13	NLB-W3 (2G13_RC)	2G13
FTL-13-SWS140-WW-NLB-005	2G13_RC	NLB-W2 (Shear)	2G13_PLY16
FTL-13-SWS140-WW-NLB-006	2G13	NLB-W4 (G16_RC)	2G13
FTL-13-SWS140-WW-NLB-007	G16_RC	NLB-W2 (Shear)	2G13_PLY16
FTL-13-SWS140-WW-NLB-008	2G13 (Tie-down)	NLB-W2 (Shear)	2G13
FTL-13-SWS140-WW-NLB-009	2G13_PLY16	NLB-W5 (Tie-down)	2G13
FTL-13-SWS140-WW-NLB-010	2G13 (Tie-down)	NLB-W4 (G16_RC)	2G13
FTL-13-SWS140-WW-NLB-011	G16_RC	NLB-W5 (Tie-down)	2G13_PLY16
FTL-13-SWS140-WW-NLB-014	2G13	NLB-W4 (G16_RC)	2G13
FTL-13-SWS140-WW-NLB-015	2G13	NLB-W4 (G16_RC)	2G13

Separating Wall	Short Description	Top View
NLB-W1	G13_G13_SWS140(406)_GFB90_G13_G13	
NLB-W2 (Shear)	G13_G13_PLY16_SWS140(406)_GFB90_G13_G13	
NLB-W3 (2G13_RC)	G13_G13_RC_SWS140(406)_GFB90_G13_G13	
NLB-W4 (G16_RC)	G16_RC_SWS140(406)_GFB90_G13_G13	
NLB-W5 (Tie-down)	G13_G13_PLY16_SWS140(406)_GFB90_G13_G13	

The wall elements found in this section are described in detail in Appendix A.3.5 below.

FTL-13-SWS140-WW-NLB-001

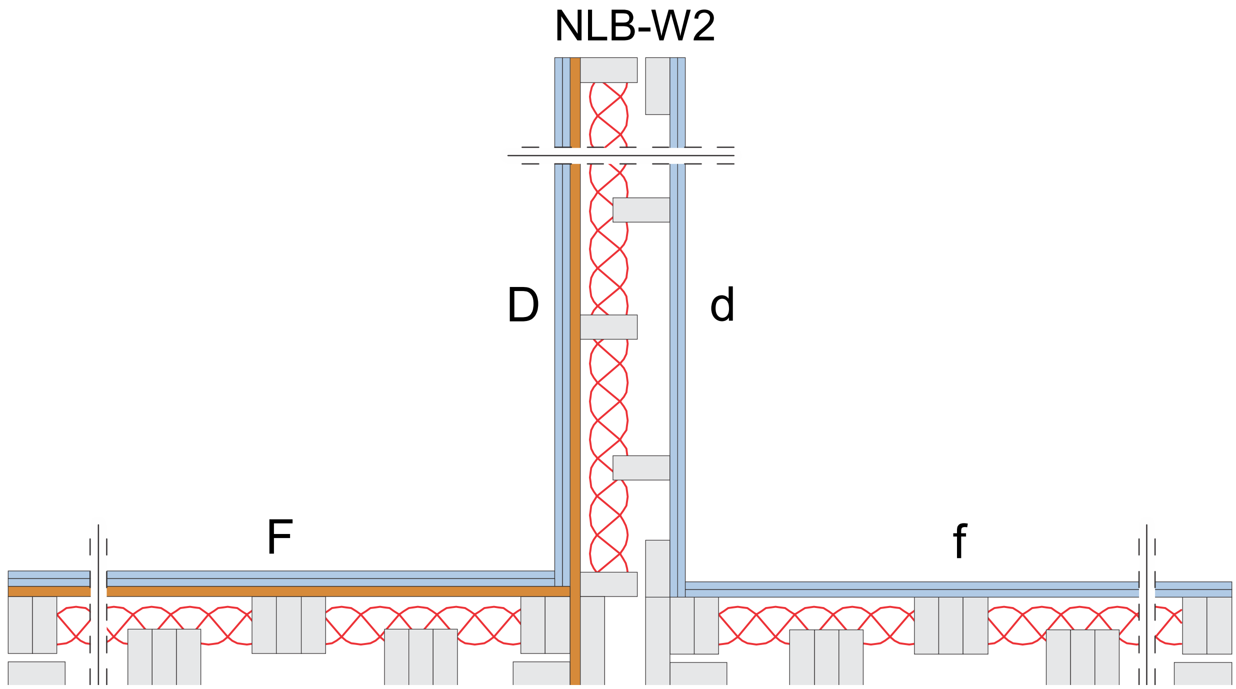


Element	Reference
D	NLB-W2 (Cladding 1)
d	NLB-W2 (Cladding 2)
F	LB-W2 (Cladding 2)
f	LB-W1 (Cladding 1 or 2)

Paths	FI-STC
Dd	51
Df	67
Fd	68
Ff	77
Flanking	**64**
Total	**51**

Specimen	Room Pairs	Junction name
B7000-01	LNW->LNE	FTL-13-SWS140-WW-NLB-001ar
B7000-01	UNW->UNE	FTL-13-SWS140-WW-NLB-001b

FTL-13-SWS140-WW-NLB-002

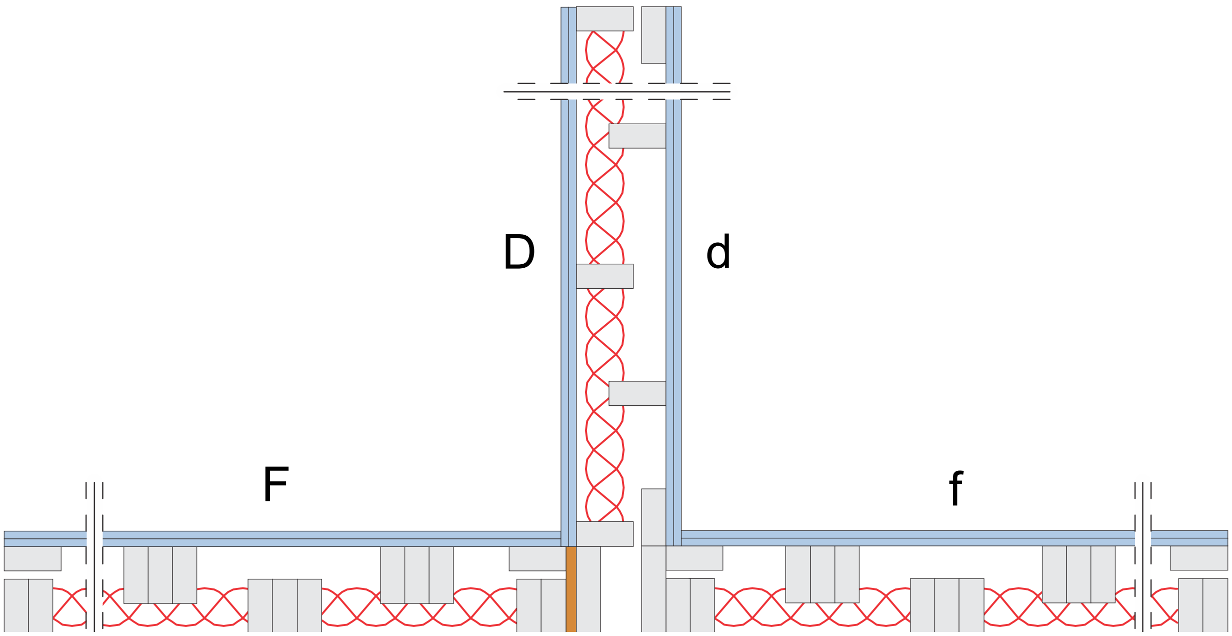


Element	Reference
D	NLB-W2 (Cladding 1)
d	NLB-W2 (Cladding 2)
F	LB-W2 (Cladding 1)
f	LB-W1 (Cladding 1 or 2)

Paths	FI-STC
Dd	51
Df	67
Fd	67
Ff	77
Flanking	**64**
Total	**51**

Specimen	Room Pairs	Junction name
B7000-01	LSW->LSE	FTL-13-SWS140-WW-NLB-002ar
B7000-02	LSW->LSE	FTL-13-SWS140-WW-NLB-002ar
B7000-03	LSW->LSE	FTL-13-SWS140-WW-NLB-002ar
B7000-04	LSW->LSE	FTL-13-SWS140-WW-NLB-002ar
B7000-01	USW->USE	FTL-13-SWS140-WW-NLB-002b
B7000-02	USW->USE	FTL-13-SWS140-WW-NLB-002b
B7000-03	USW->USE	FTL-13-SWS140-WW-NLB-002b
B7000-04	USW->USE	FTL-13-SWS140-WW-NLB-002b
B7000-05	USW->USE	FTL-13-SWS140-WW-NLB-002b
B7000-06	USW->USE	FTL-13-SWS140-WW-NLB-002b

FTL-13-SWS140-WW-NLB-003

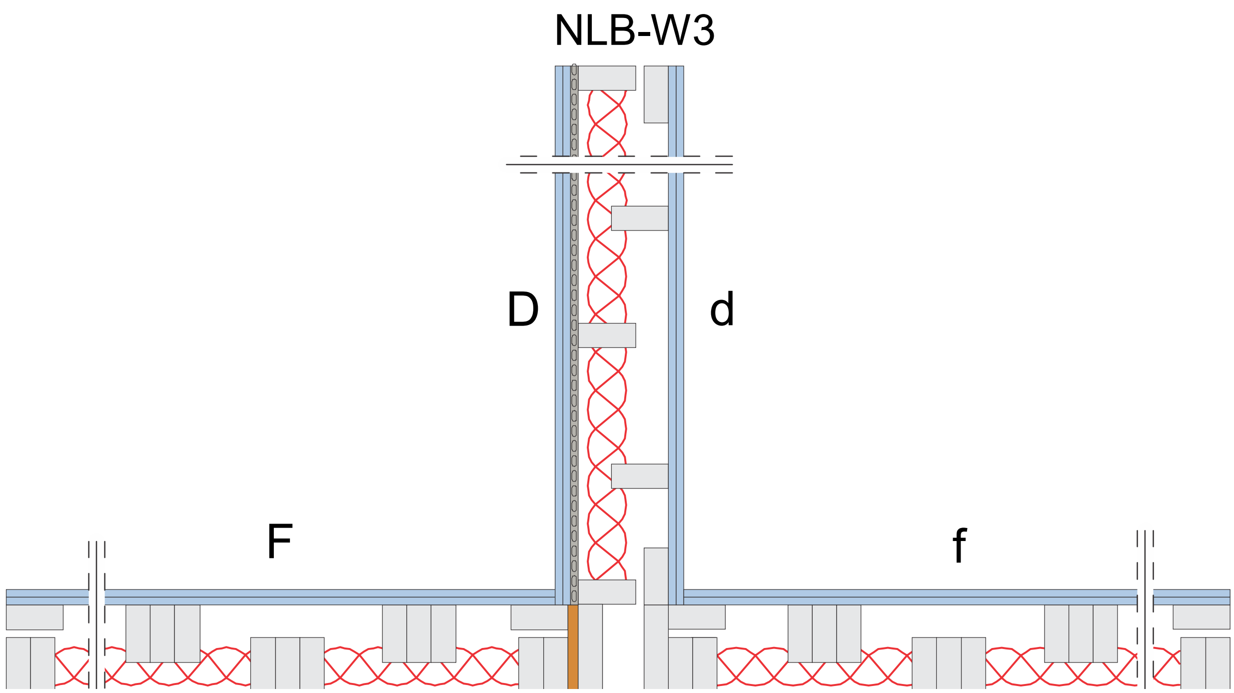


Element	Reference
D	NLB-W1 (Cladding 1)
d	NLB-W1 (Cladding 2)
F	LB-W2 (Cladding 1)
f	LB-W1 (Cladding 1 or 2)

Paths	FI-STC
Dd	48
Df	68
Fd	68
Ff	77
Flanking	**65**
Total	**48**

Specimen	Room Pairs	Junction name
B7000-02	LNW->LNE	FTL-13-SWS140-WW-NLB-003ar
B7000-03	LNW->LNE	FTL-13-SWS140-WW-NLB-003ar
B7000-04	LNW->LNE	FTL-13-SWS140-WW-NLB-003ar
B7000-02	UNW->UNE	FTL-13-SWS140-WW-NLB-003b
B7000-03	UNW->UNE	FTL-13-SWS140-WW-NLB-003b
B7000-04	UNW->UNE	FTL-13-SWS140-WW-NLB-003b
B7000-05	UNW->UNE	FTL-13-SWS140-WW-NLB-003b
B7000-06	UNW->UNE	FTL-13-SWS140-WW-NLB-003b

FTL-13-SWS140-WW-NLB-004

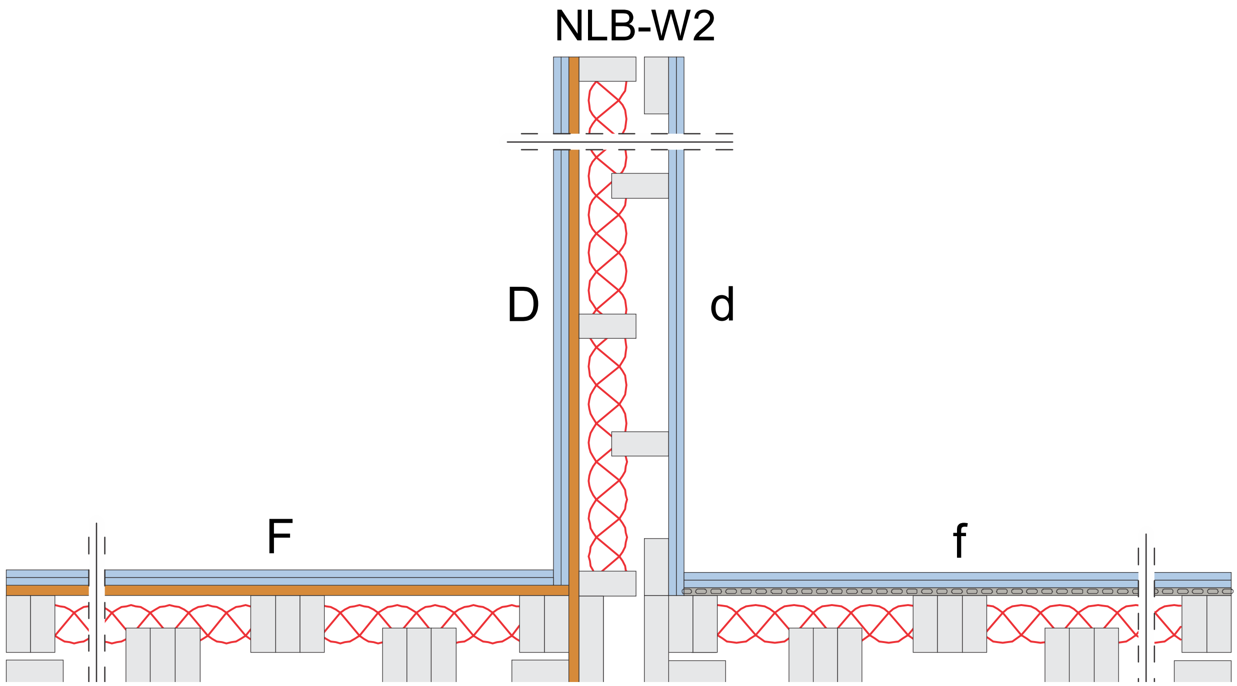


Element	Reference
D	NLB-W3 (Cladding 1)
d	NLB-W3 (Cladding 2)
F	LB-W2 (Cladding 2)
f	LB-W3 (Cladding 2)

Paths	FI-STC
Dd	58
Df	69
Fd	68
Ff	77
Flanking	**65**
Total	**57**

Specimen	Room Pairs	Junction name
B7000-05	LNW->LNE	FTL-13-SWS140-WW-NLB-004r

FTL-13-SWS140-WW-NLB-005

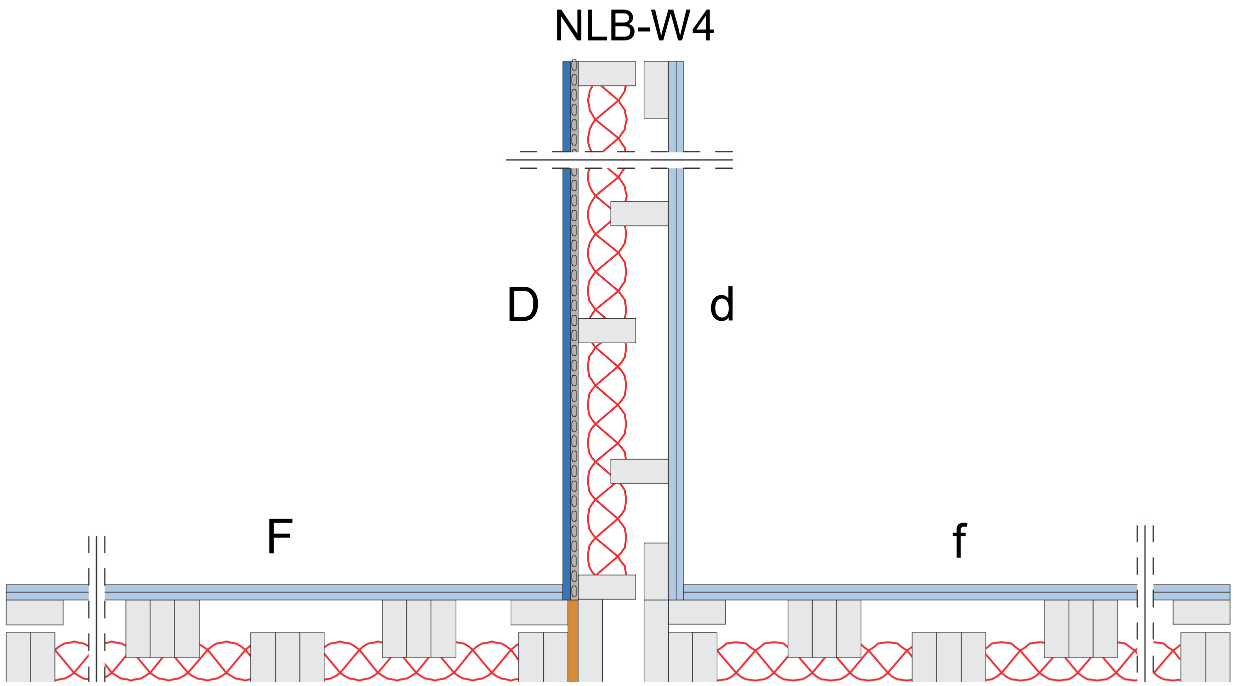


Element	Reference
D	NLB-W3 (Cladding 1)
d	NLB-W3 (Cladding 2)
F	LB-W3 (Cladding 1)
f	LB-W2 (Cladding 1)

Paths	FI-STC
Dd	51
Df	70
Fd	67
Ff	76
Flanking	**65**
Total	**51**

Specimen	Room Pairs	Junction name
B7000-05	LSE->LSW	FTL-13-SWS140-WW-NLB-005r

FTL-13-SWS140-WW-NLB-006

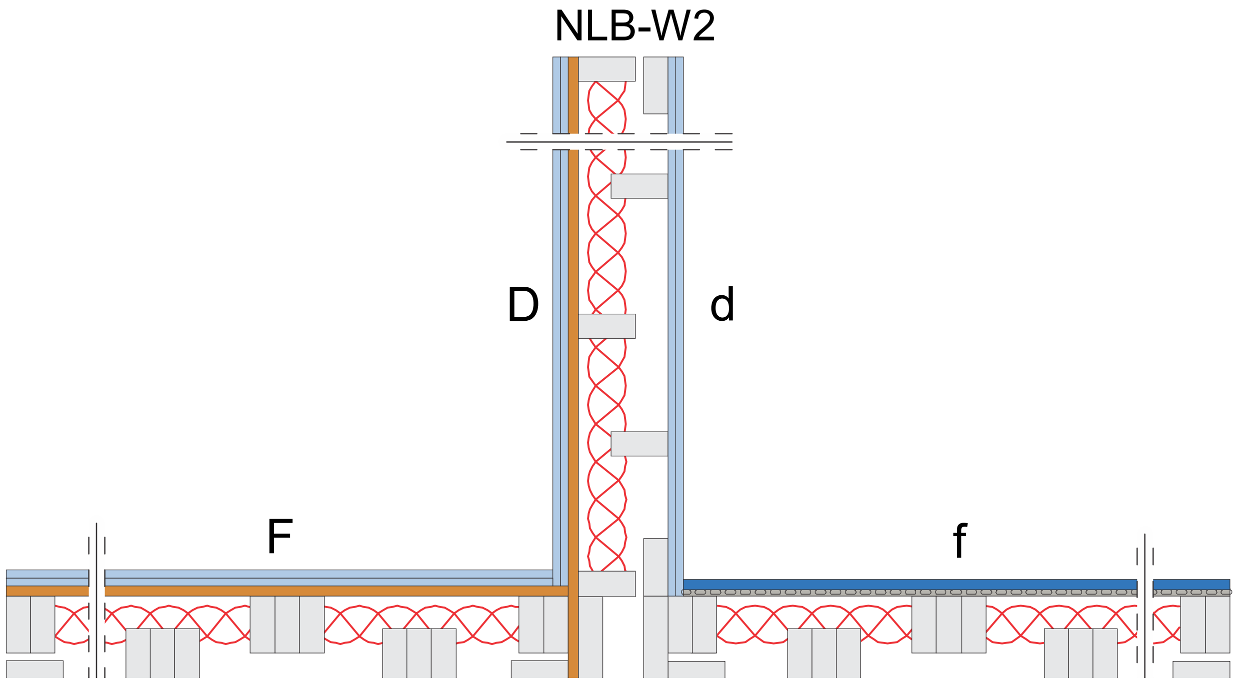


Element	Reference
D	NLB-W4 (Cladding 1)
d	NLB-W4 (Cladding 2)
F	LB-W2 (Cladding 2)
f	LB-W4 (Cladding 2)

Paths	FI-STC
Dd	55
Df	70
Fd	68
Ff	77
Flanking	**66**
Total	**55**

Specimen	Room Pairs	Junction name
B7000-06	LNW->LNE	FTL-13-SWS140-WW-NLB-006r

FTL-13-SWS140-WW-NLB-007

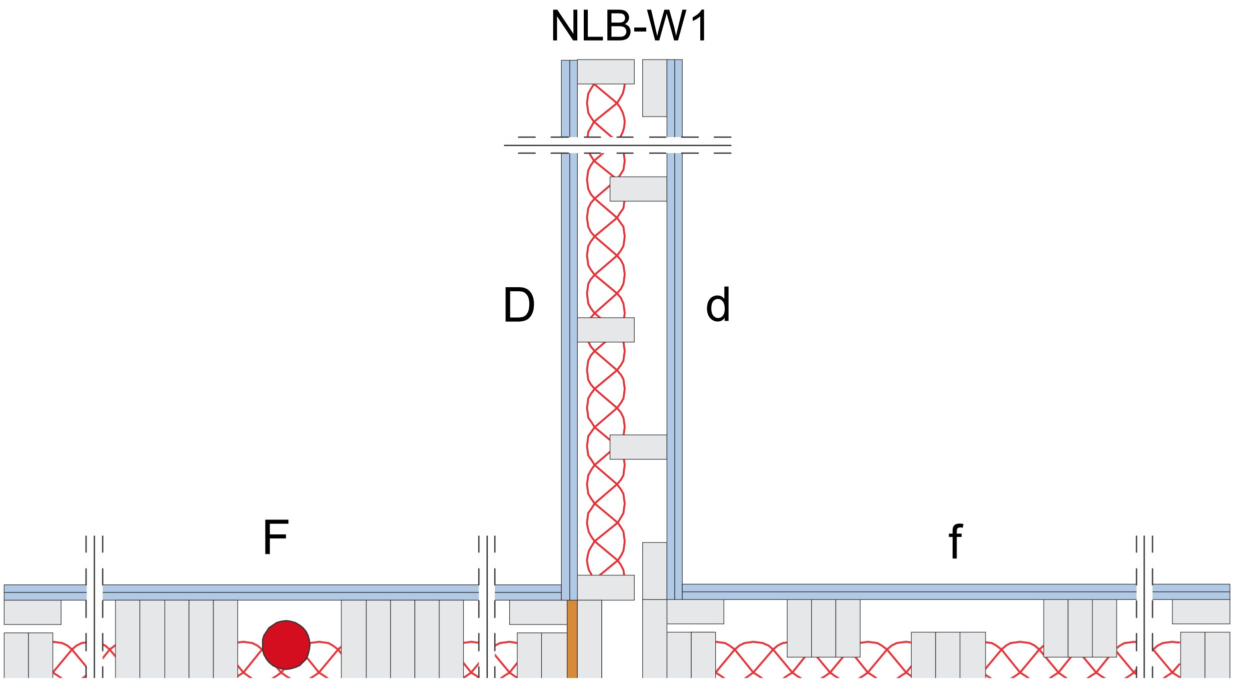


Element	Reference
D	NLB-W2 (Cladding 1)
d	NLB-W2 (Cladding 2)
F	LB-W4 (Cladding 1)
f	LB-W2 (Cladding 1)

Paths	FI-STC
Dd	51
Df	69
Fd	67
Ff	77
Flanking	**65**
Total	**51**

Specimen	Room Pairs	Junction name
B7000-06	LSE->LSW	FTL-13-SWS140-WW-NLB-007r

FTL-13-SWS140-WW-NLB-008

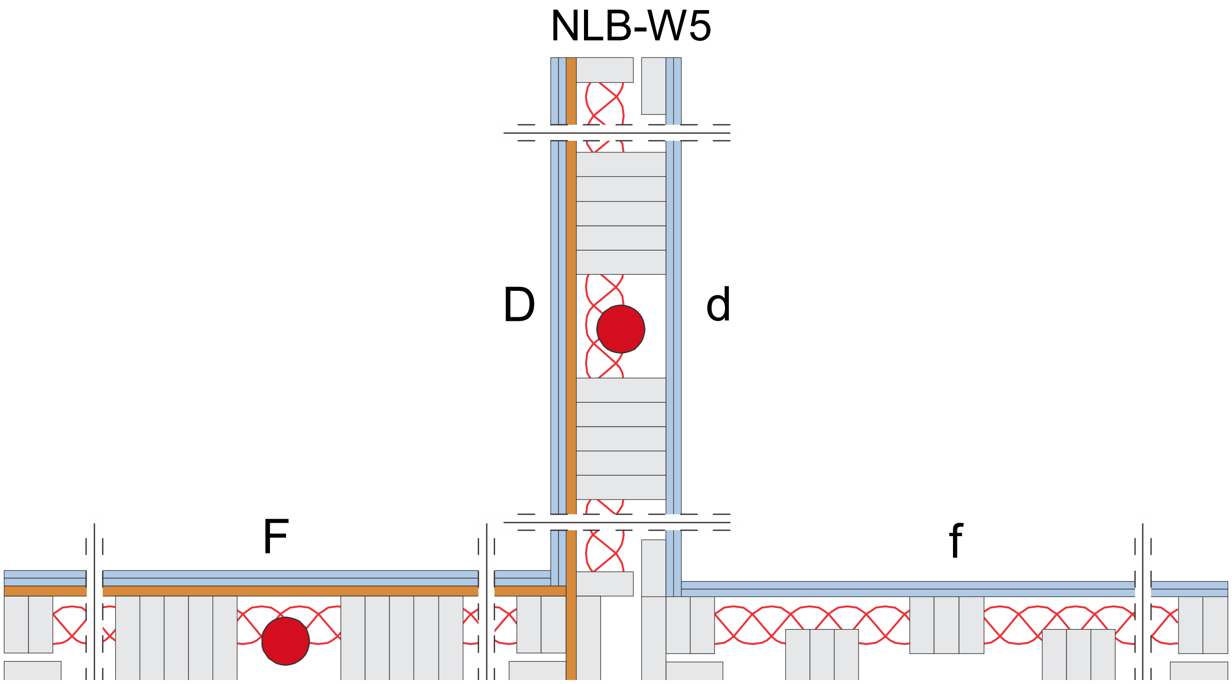


Element	Reference
D	NLB-W1 (Cladding 1)
d	NLB-W1 (Cladding 2)
F	LB-W5 (Cladding 2)
f	LB-W1 (Cladding 2)

Paths	FI-STC
Dd	48
Df	68
Fd	68
Ff	77
Flanking	**65**
Total	**48**

Specimen	Room Pairs	Junction name
B7000-07	UNW->UNE	FTL-13-SWS140-WW-NLB-008

FTL-13-SWS140-WW-NLB-009

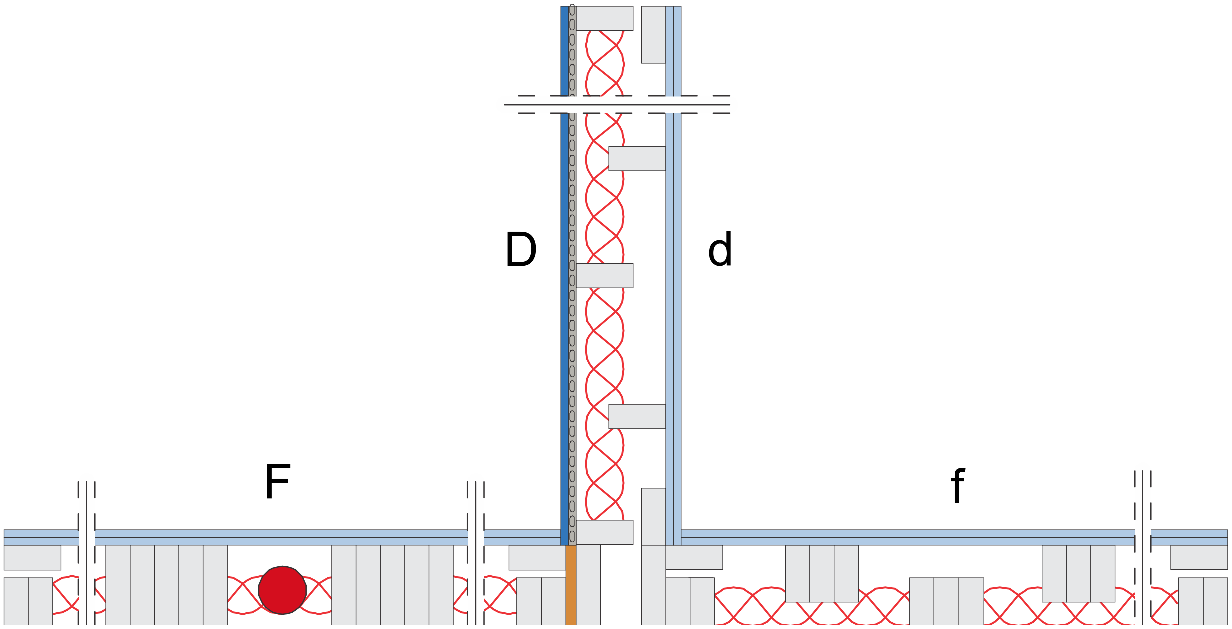


Element	Reference
D	NLB-W5 (Cladding 1)
d	NLB-W5 (Cladding 2)
F	LB-W5 (Cladding 1)
f	LB-W1 (Cladding 1)

Paths	FI-STC
Dd	51
Df	67
Fd	67
Ff	77
Flanking	**64**
Total	**51**

Specimen	Room Pairs	Junction name
B7000-07	USW->USE	FTL-13-SWS140-WW-NLB-009

FTL-13-SWS140-WW-NLB-010

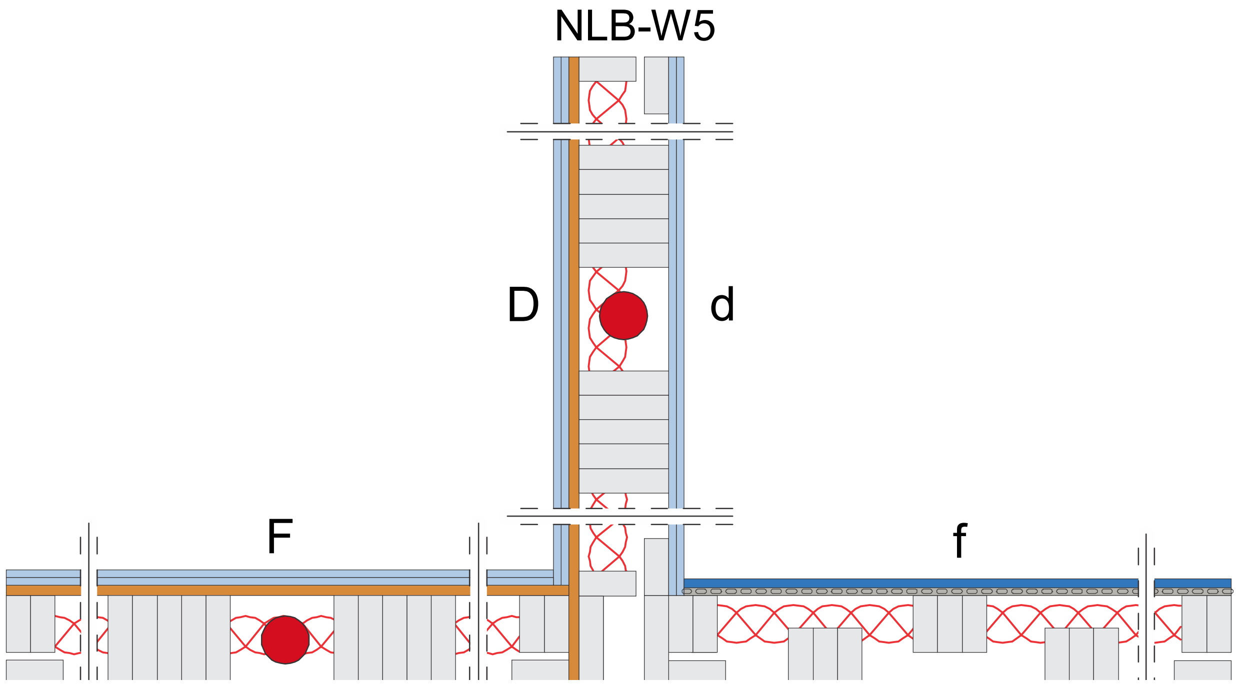


Element	Reference
D	NLB-W4 (Cladding 1)
d	NLB-W4 (Cladding 2)
F	LB-W5 (Cladding 2)
f	LB-W4 (Cladding 2)

Paths	FI-STC
Dd	55
Df	70
Fd	68
Ff	77
Flanking	**66**
Total	**55**

Specimen	Room Pairs	Junction name
B7000-07	LNW->LNE	FTL-13-SWS140-WW-NLB-010r

FTL-13-SWS140-WW-NLB-011



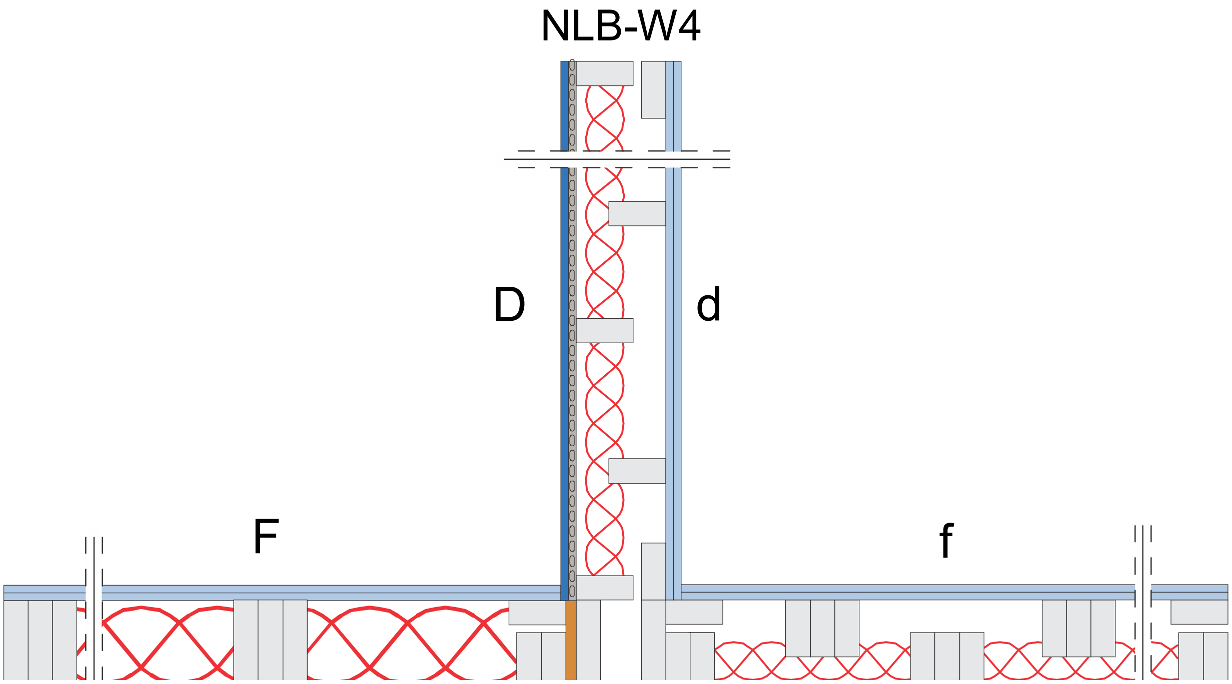
Element	Reference
D	NLB-W5 (Cladding 1)
d	NLB-W5 (Cladding 2)
F	LB-W4 (Cladding 1)
f	LB-W5 (Cladding 1)

Paths	FI-STC
Dd	51
Df	69
Fd	67
Ff	77
Flanking	**65**
Total	**51**

Specimen	Room Pairs	Junction name
B7000-07	LSE->LSW	FTL-13-SWS140-WW-NLB-011r

NRC·CNRC

FTL-13-SWS140-WW-NLB-014

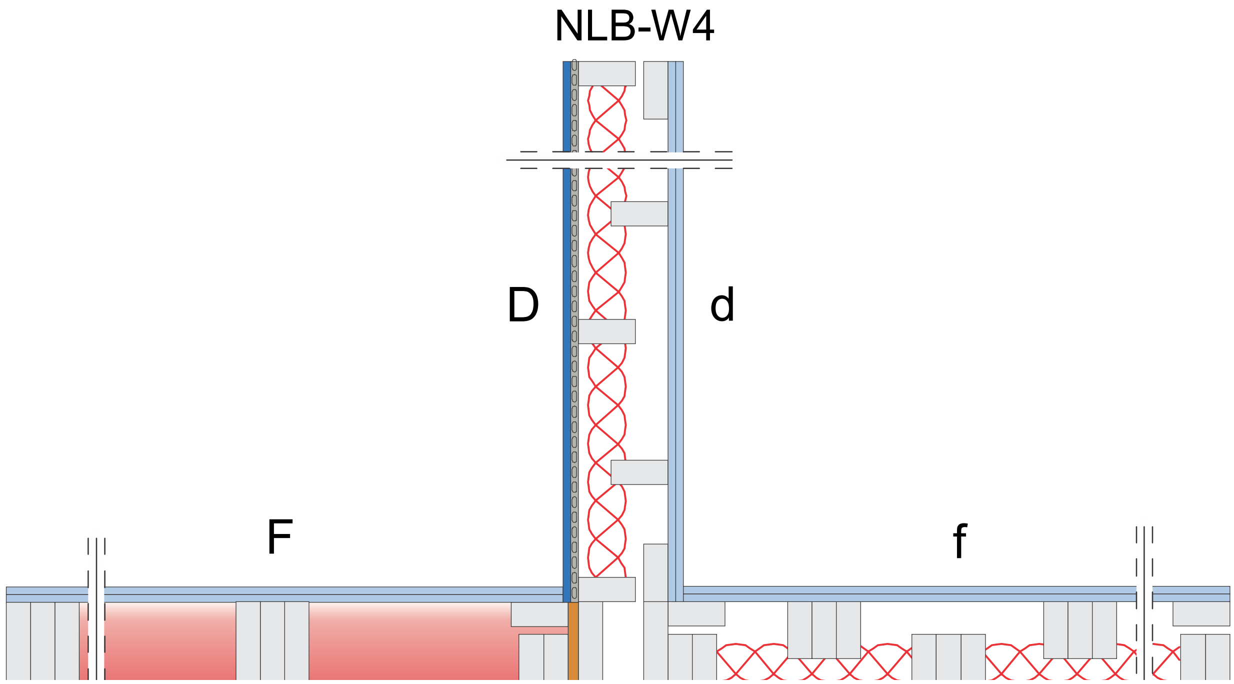


Element	Reference
D	NLB-W4 (Cladding 1)
d	NLB-W4 (Cladding 2)
F	LB-W6 (Cladding 1)
f	LB-W4 (Cladding 1)

Paths	FI-STC
Dd	55
Df	70
Fd	65
Ff	74
Flanking	**63**
Total	**54**

Specimen	Room Pairs	Junction name
B7000-08	LNE->LNW	FTL-13-SWS140-WW-NLB-014r
B7000-09	LNE->LNW	FTL-13-SWS140-WW-NLB-014r

FTL-13-SWS140-WW-NLB-015



Element	Reference
D	NLB-W4 (Cladding 1)
d	NLB-W4 (Cladding 2)
F	LB-W7 (Cladding 1)
f	LB-W4 (Cladding 2)

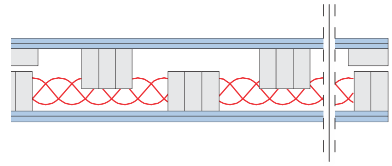
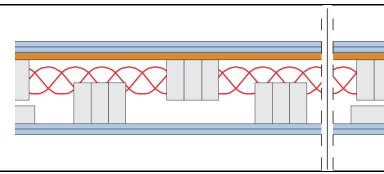
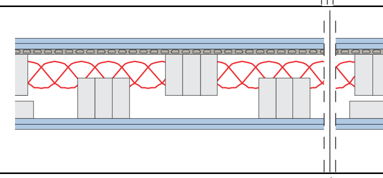
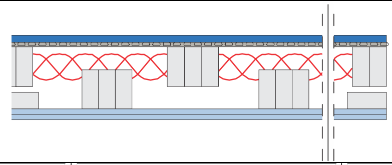
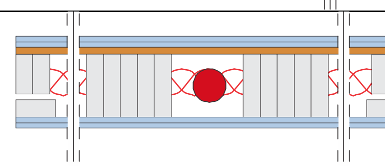
Paths	FI-STC
Dd	55
Df	70
Fd	65
Ff	74
Flanking	**63**
Total	**54**

Specimen	Room Pairs	Junction name
B7000-10	LSE->LSW	FTL-13-SWS140-WW-NLB-015r

A.3.4.2 Wall-Wall Load Bearing Junctions

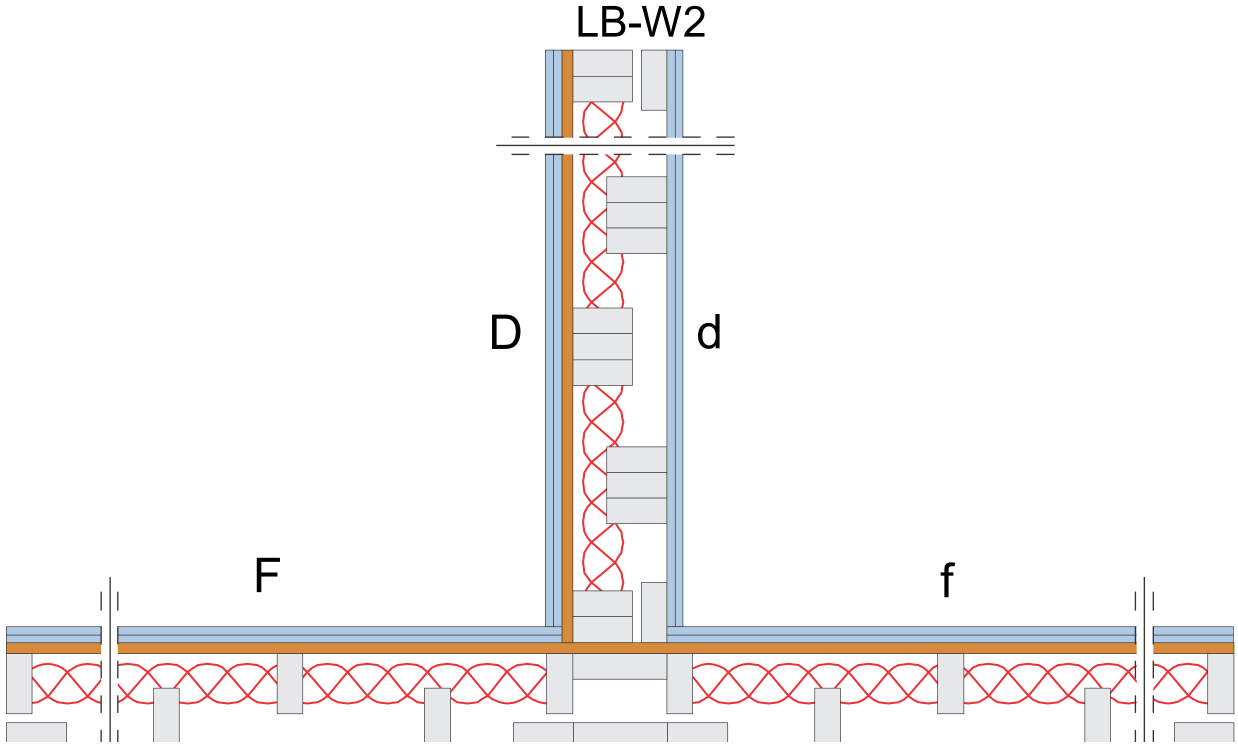
In this section, there are 13 distinct wall-wall load bearing junctions with results of their flanking paths.

Junction Name	F	Direct (Dd)	f
FTL-13-3SWS140-WW-LB-001	2G13_PLY16	LB-W2 (Shear)	2G13_PLY16
FTL-13-3SWS140-WW-LB-002	2G13	LB-W1	2G13
FTL-13-3SWS140-WW-LB-003	2G13_PLY16	LB-W2 (Shear)	2G13
FTL-13-3SWS140-WW-LB-004	2G13_RC	LB-W2 (Shear)	2G13_PLY16
FTL-13-3SWS140-WW-LB-005	2G13	LB-W3 (2G13_RC)	2G13
FTL-13-3SWS140-WW-LB-006	G16_RC	LB-W2 (Shear)	2G13_PLY16
FTL-13-3SWS140-WW-LB-007	2G13	LB-W4 (G16_RC)	2G13
FTL-13-3SWS140-WW-LB-008	2G13	LB-W1	2G13
FTL-13-3SWS140-WW-LB-009	2G13_PLY16	LB-W5 (Tie-down)	2G13
FTL-13-3SWS140-WW-LB-010	G16_RC	LB-W5 (Tie-down)	2G13_PLY16
FTL-13-3SWS140-WW-LB-011	2G13	LB-W4 (G16_RC)	2G13
FTL-13-3SWS140-WW-LB-014	2G13	LB-W4 (G16_RC)	2G13
FTL-13-3SWS140-WW-LB-015	2G13	LB-W4 (G16_RC)	2G13

Separating Wall	Short Description	Top View
LB-W1	G13_G13_3SWS140(406)_GFB90_G13_G13	
LB-W2 (Shear)	G13_G13_PLY16_3SWS140(406)_GFB90_G13_G13	
LB-W3 (2G13_RC)	G13_G13_RC_3SWS140(406)_GFB90_G13_G13	
LB-W4 (G16_RC)	G16_RC_3SWS140(406)_GFB90_G13_G13	
LB-W5 (Tie-down)	G13_G13_PLY16_3SWS140(406)_GFB90_G13_G13	

The wall elements found in this section are described in detail in Appendix A.3.5 below.

FTL-13-3SWS140-WW-LB-001

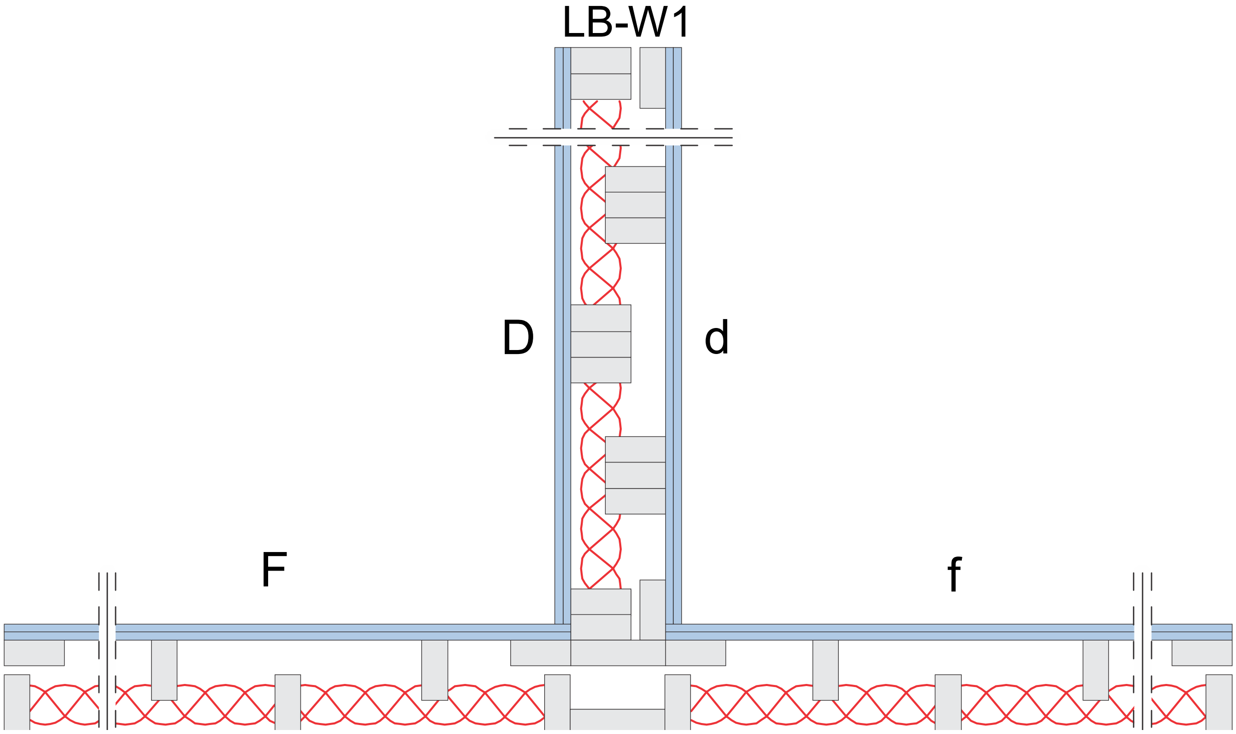


Element	Reference
D	LB-W2 (Cladding 1)
d	LB-W2 (Cladding 2)
F	NLB-W2 (Cladding 1)
f	NLB-W2 (Cladding 1)

Paths	FI-STC
Dd	51
Df	67
Fd	65
Ff	67
Flanking	**61**
Total	**51**

Specimen	Room Pairs	Junction name
B7000-01	USW->UNW	FTL-13-3SWS140-WW-LB-001b
B7000-01	LSW->LNW	FTL-13-3SWS140-WW-LB-001a

FTL-13-3SWS140-WW-LB-002

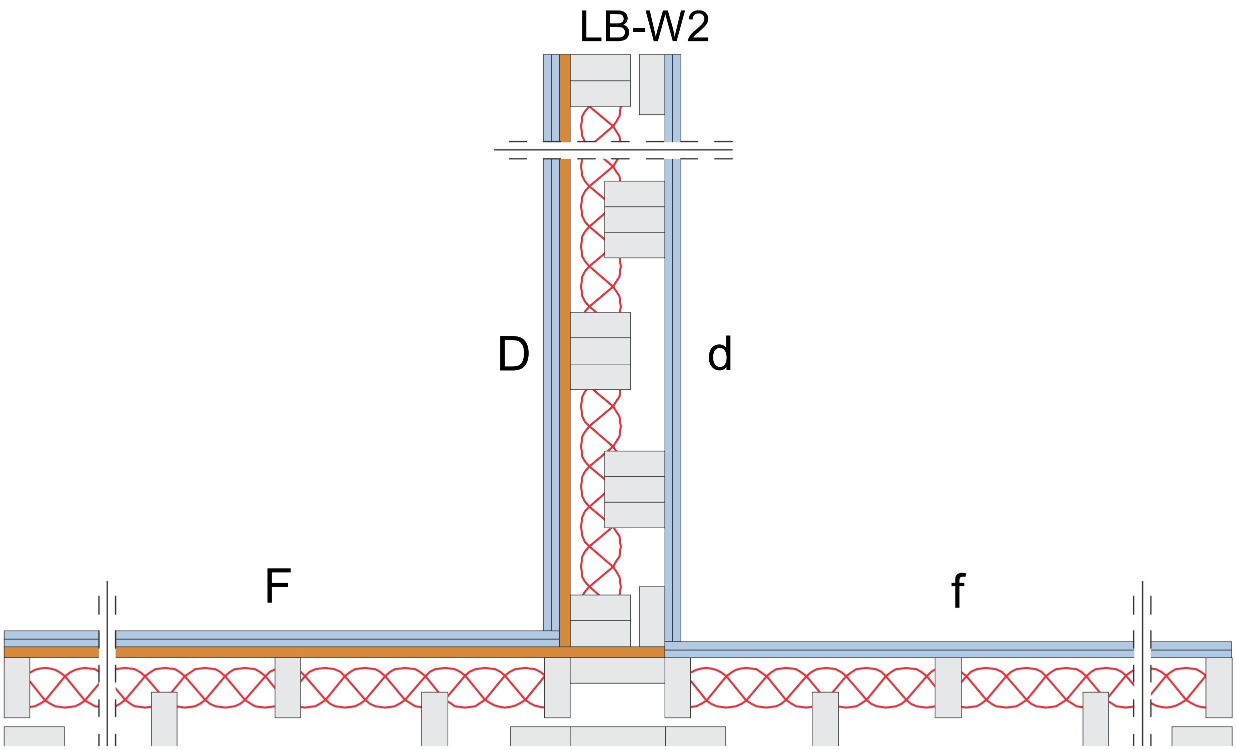


Element	Reference
D	LB-W1 (Cladding 2)
d	LB-W1 (Cladding 1)
F	NLB-W2 (Cladding 2)
f	NLB-W2 (Cladding 2)

Paths	FI-STC
Dd	48
Df	65
Fd	65
Ff	70
Flanking	**61**
Total	**48**

Specimen	Room Pairs	Junction name
B7000-01	USE->UNE	FTL-13-3SWS140-WW-LB-002b
B7000-01	LSE->LNE	FTL-13-3SWS140-WW-LB-002a
B7000-02	USE->UNE	FTL-13-3SWS140-WW-LB-002b
B7000-02	LSE->LNE	FTL-13-3SWS140-WW-LB-002a
B7000-03	USE->UNE	FTL-13-3SWS140-WW-LB-002b
B7000-03	LSE->LNE	FTL-13-3SWS140-WW-LB-002a
B7000-04	USE->UNE	FTL-13-3SWS140-WW-LB-002b
B7000-04	LSE->LNE	FTL-13-3SWS140-WW-LB-002a
B7000-05	USE->UNE	FTL-13-3SWS140-WW-LB-002b
B7000-06	USE->UNE	FTL-13-3SWS140-WW-LB-002b

FTL-13-3SWS140-WW-LB-003

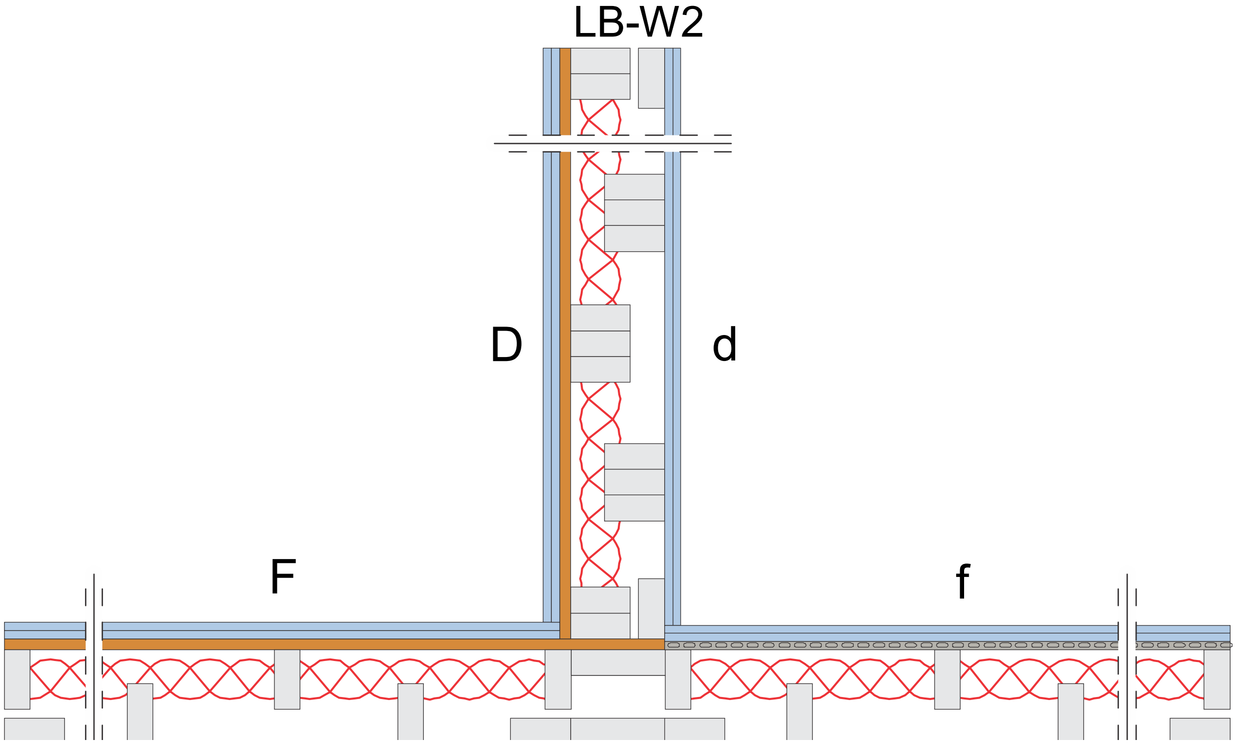


Element	Reference
D	LB-W2 (Cladding 1)
d	LB-W2 (Cladding 2)
F	NLB-W2 (Cladding 1)
f	NLB-W1 (Cladding 1)

Paths	FI-STC
Dd	51
Df	65
Fd	65
Ff	72
Flanking	**62**
Total	**51**

Specimen	Room Pairs	Junction name
B7000-02	LSW->LNW	FTL-13-3SWS140-WW-LB-003a
B7000-02	USW->UNW	FTL-13-3SWS140-WW-LB-003b
B7000-03	LSW->LNW	FTL-13-3SWS140-WW-LB-003a
B7000-03	USW->UNW	FTL-13-3SWS140-WW-LB-003b
B7000-04	LSW->LNW	FTL-13-3SWS140-WW-LB-003a
B7000-04	USW->UNW	FTL-13-3SWS140-WW-LB-003b
B7000-05	USW->UNW	FTL-13-3SWS140-WW-LB-003b
B7000-06	USW->UNW	FTL-13-3SWS140-WW-LB-003b

FTL-13-3SWS140-WW-LB-004

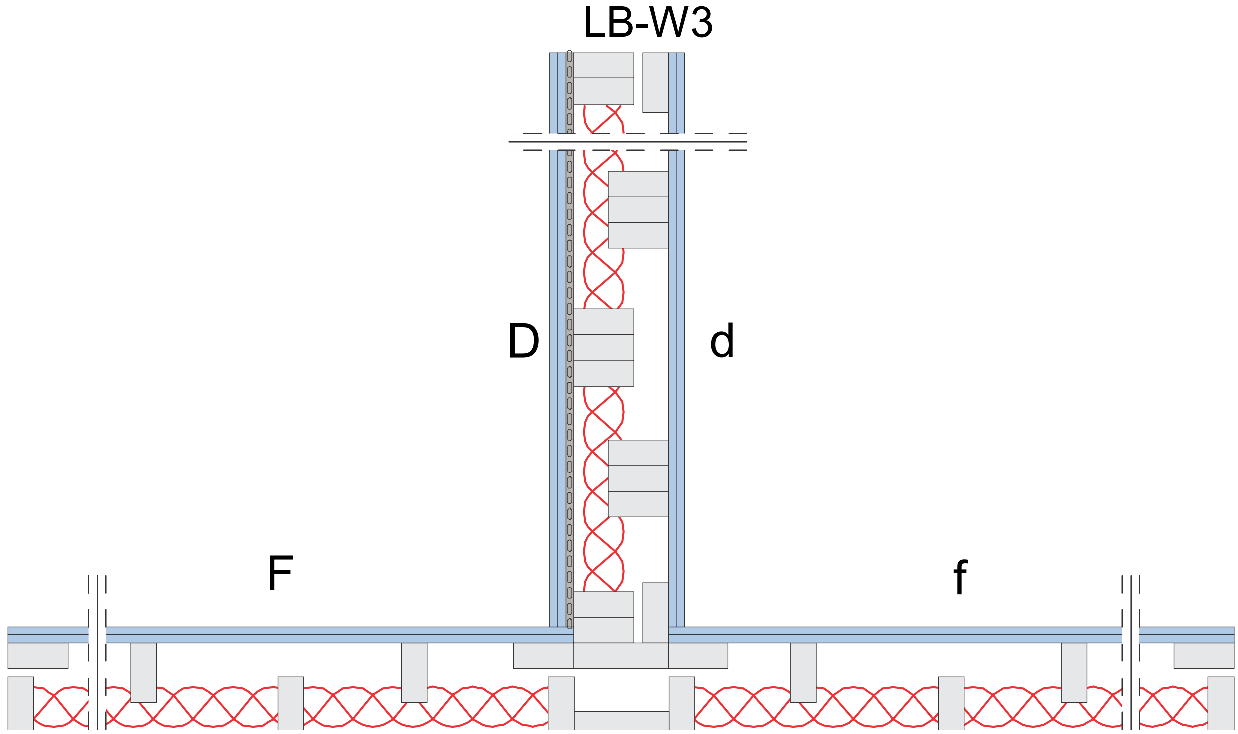


Element	Reference
D	LB-W2 (Cladding 1)
d	LB-W2 (Cladding 2)
F	NLB-W2 (Cladding 1)
f	NLB-W3 (Cladding 1)

Paths	FI-STC
Dd	51
Df	71
Fd	65
Ff	77
Flanking	**64**
Total	**51**

Specimen	Room Pairs	Junction name
B7000-05	LSW->LNW	FTL-13-3SWS140-WW-LB-004

FTL-13-3SWS140-WW-LB-005

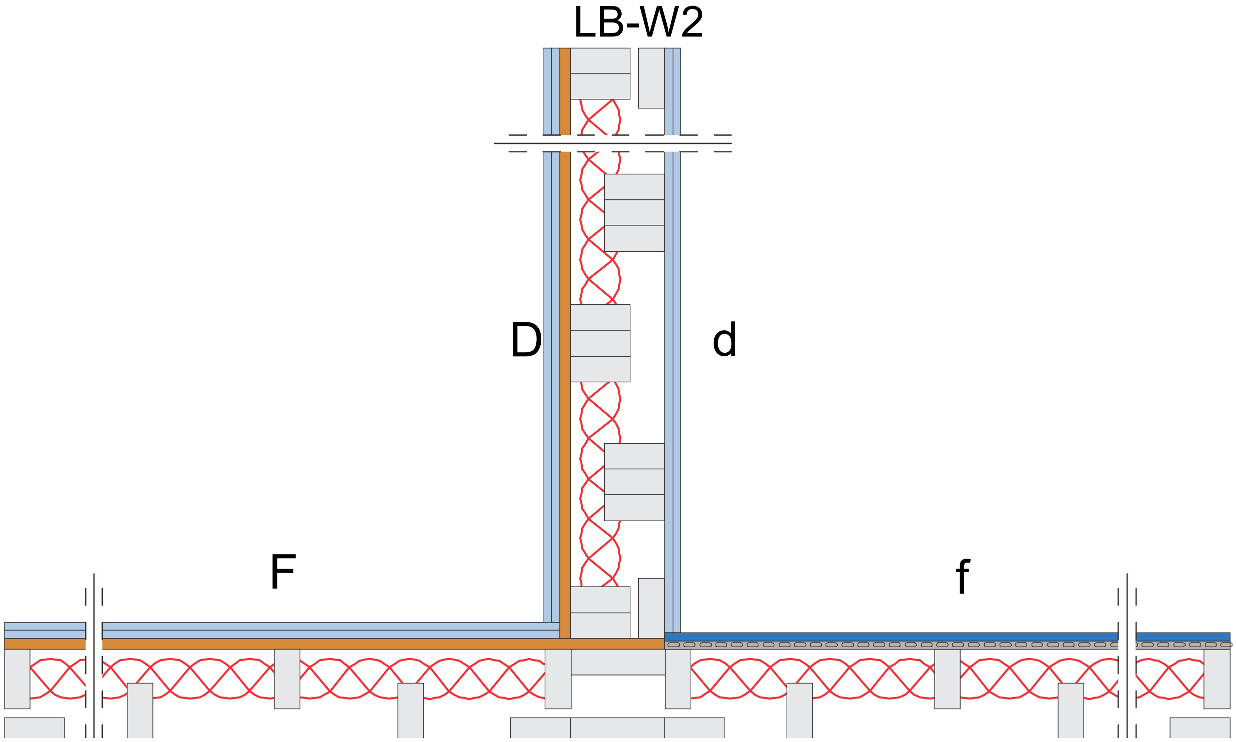


Element	Reference
D	LB-W3 (Cladding 1)
d	LB-W3 (Cladding 2)
F	NLB-W2 (Cladding 2)
f	NLB-W3 (Cladding 2)

Paths	FI-STC
Dd	58
Df	70
Fd	65
Ff	70
Flanking	**63**
Total	**57**

Specimen	Room Pairs	Junction name
B7000-05	LSE->LNE	FTL-13-3SWS140-WW-LB-005

FTL-13-3SWS140-WW-LB-006

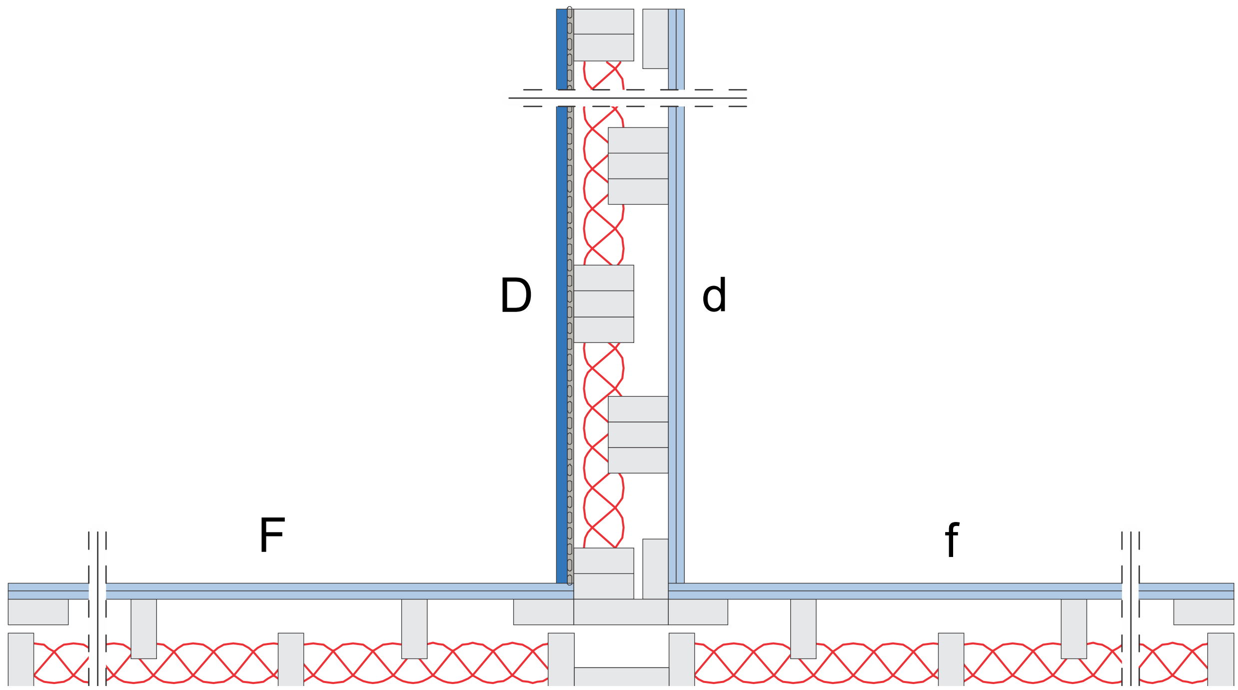


Element	Reference
D	LB-W2 (Cladding 1)
d	LB-W2 (Cladding 2)
F	NLB-W2 (Cladding 1)
f	NLB-W4 (Cladding 1)

Paths	FI-STC
Dd	51
Df	70
Fd	65
Ff	77
Flanking	**64**
Total	**51**

Specimen	Room Pairs	Junction name
B7000-06	LSW->LNW	FTL-13-3SWS140-WW-LB-006

FTL-13-3SWS140-WW-LB-007

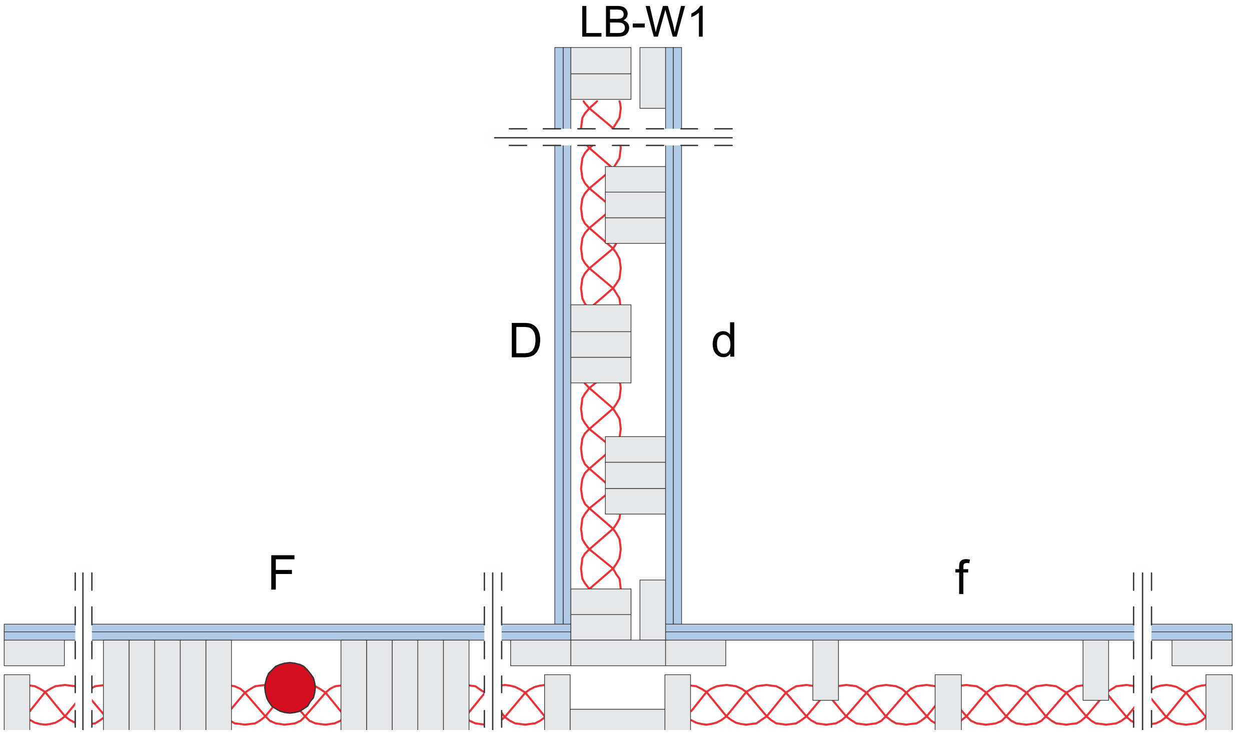


Element	Reference
D	LB-W4 (Cladding 1)
d	LB-W4 (Cladding 2)
F	NLB-W2 (Cladding 2)
f	NLB-W4 (Cladding 2)

Paths	FI-STC
Dd	52
Df	70
Fd	65
Ff	70
Flanking	**63**
Total	**52**

Specimen	Room Pairs	Junction name
B7000-06	LSE->LNE	FTL-13-3SWS140-WW-LB-007

FTL-13-3SWS140-WW-LB-008

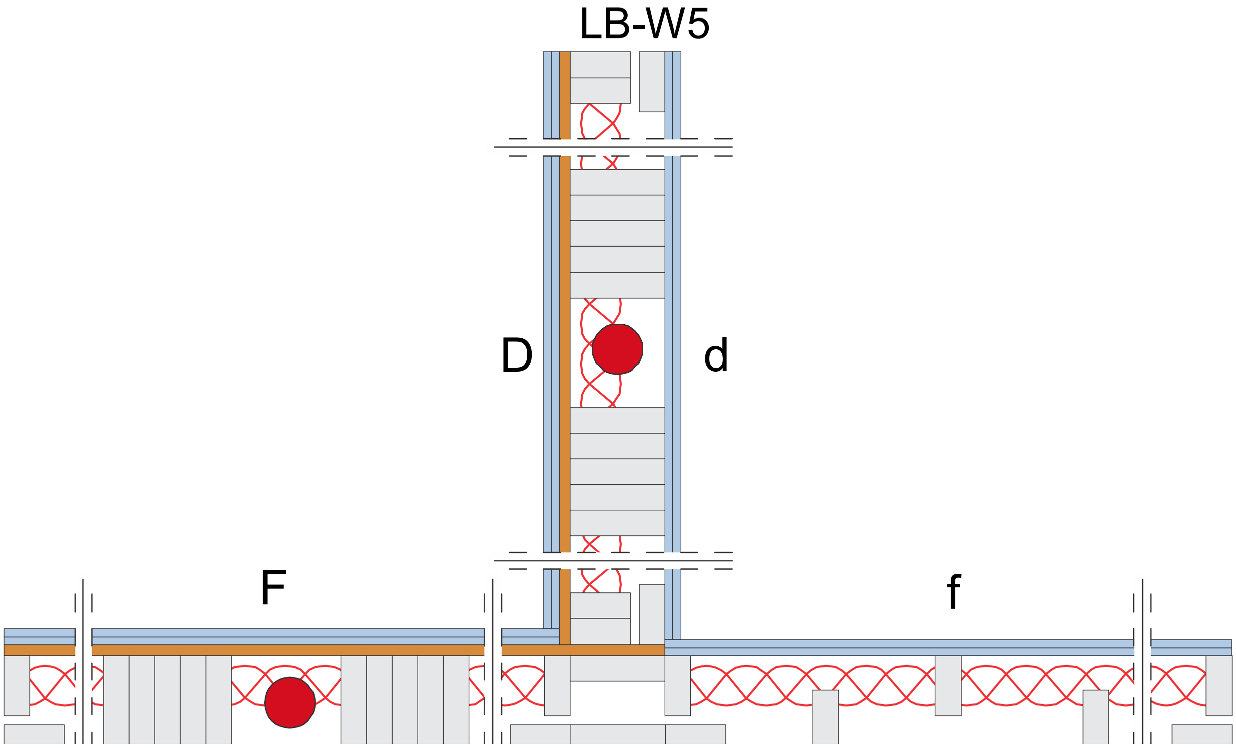


Element	Reference
D	LB-W1 (Cladding 1)
d	LB-W1 (Cladding 2)
F	NLB-W5 (Cladding 2)
f	NLB-W1 (Cladding 2)

Paths	FI-STC
Dd	48
Df	65
Fd	65
Ff	70
Flanking	**61**
Total	**48**

Specimen	Room Pairs	Junction name
B7000-07	USE->UNE	FTL-13-3SWS140-WW-LB-008

FTL-13-3SWS140-WW-LB-009

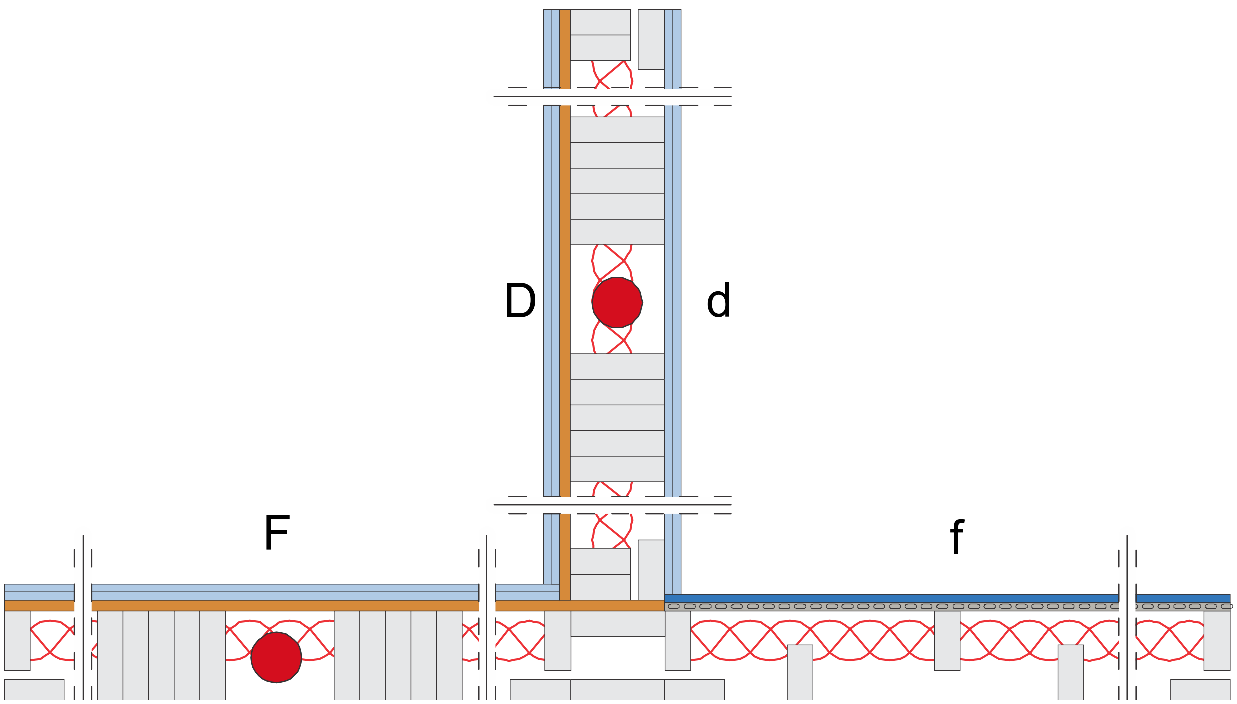


Element	Reference
D	LB-W5 (Cladding 1)
d	LB-W5 (Cladding 2)
F	NLB-W5 (Cladding 1)
f	NLB-W1 (Cladding 1)

Paths	FI-STC
Dd	51
Df	65
Fd	65
Ff	72
Flanking	**62**
Total	**51**

Specimen	Room Pairs	Junction name
B7000-07	USW->UNW	FTL-13-3SWS140-WW-LB-009

FTL-13-3SWS140-WW-LB-010

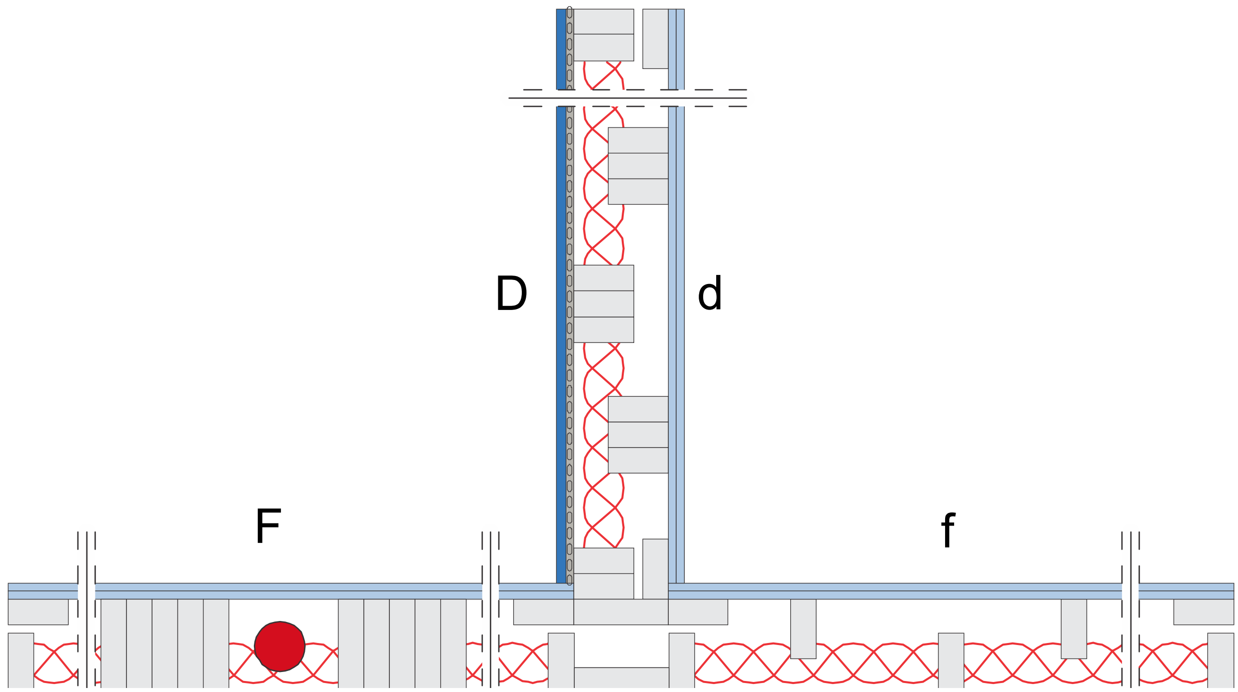


Element	Reference
D	LB-W5 (Cladding 1)
d	LB-W5 (Cladding 2)
F	NLB-W5 (Cladding 1)
f	NLB-W4 (Cladding 1)

Paths	FI-STC
Dd	51
Df	70
Fd	65
Ff	77
Flanking	**64**
Total	**51**

Specimen	Room Pairs	Junction name
B7000-07	LSW->LNW	FTL-13-3SWS140-WW-LB-010

FTL-13-3SWS140-WW-LB-011

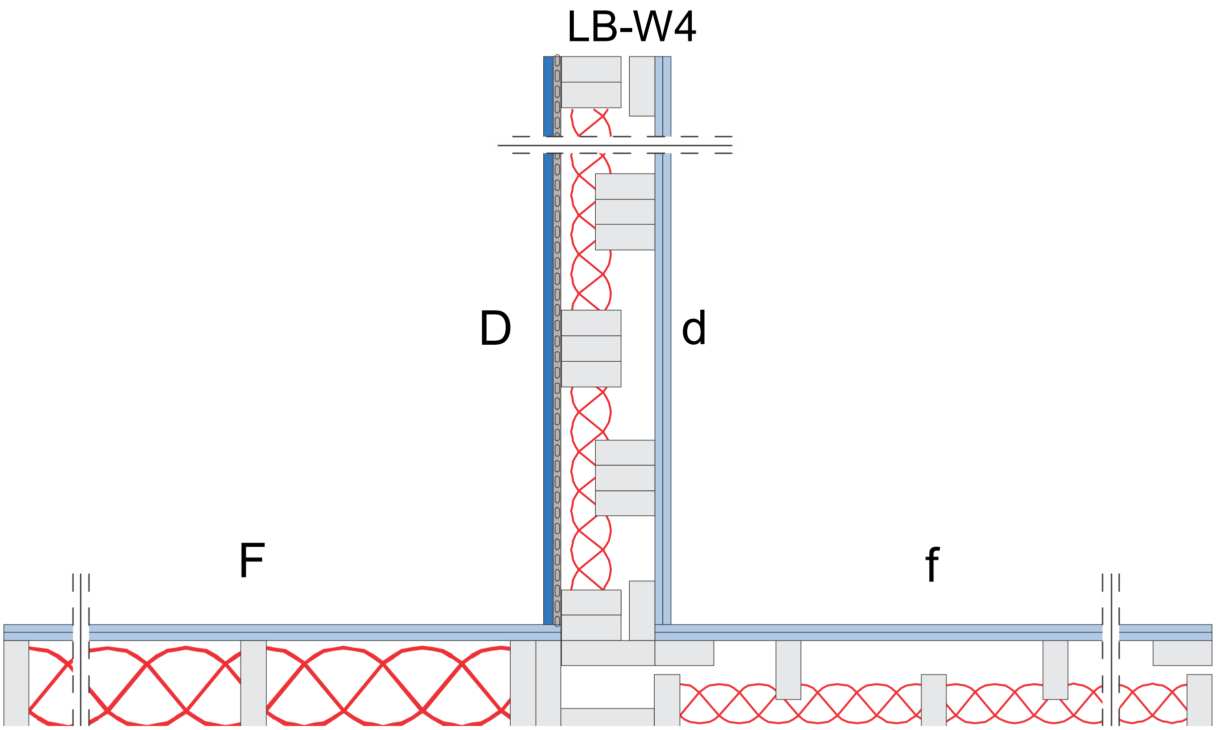


Element	Reference
D	LB-W4 (Cladding 1)
d	LB-W4 (Cladding 2)
F	NLB-W5 (Cladding 2)
f	NLB-W4 (Cladding 2)

Paths	FI-STC
Dd	52
Df	71
Fd	65
Ff	70
Flanking	**63**
Total	**52**

Specimen	Room Pairs	Junction name
B7000-07	LSE->LNE	FTL-13-3SWS140-WW-LB-011

FTL-13-3SWS140-WW-LB-014

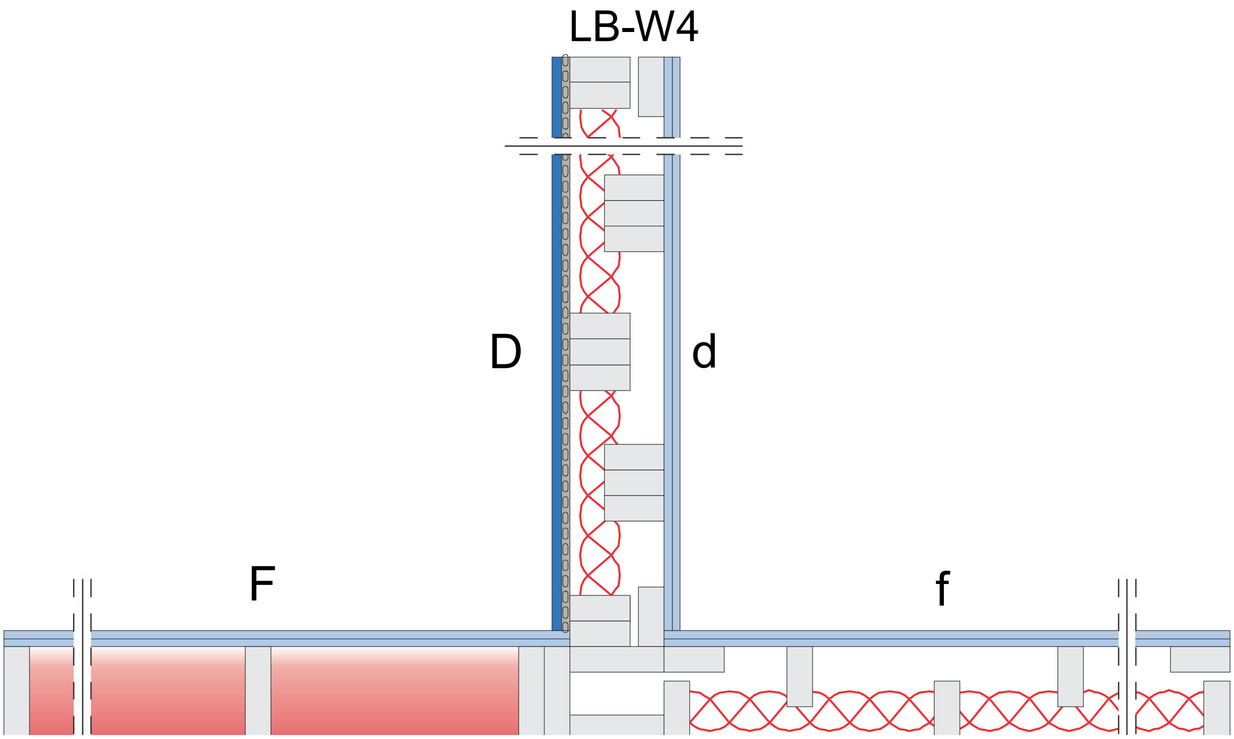


Element	Reference
D	LB-W4 (Cladding 1)
d	LB-W4 (Cladding 2)
F	NLB-W6 (Cladding 1)
f	NLB-W4 (Cladding 1)

Paths	FI-STC
Dd	52
Df	71
Fd	68
Ff	73
Flanking	**65**
Total	**52**

Specimen	Room Pairs	Junction name
B7000-08	LSE->LNE	FTL-13-3SWS140-WW-LB-014
B7000-09	LSE->LNE	FTL-13-3SWS140-WW-LB-014

FTL-13-3SWS140-WW-LB-015



Element	Reference
D	LB-W7 (Cladding 2)
d	LB-W7 (Cladding 1)
F	NLB-W7 (Cladding 2)
f	NLB-W4 (Cladding 1)

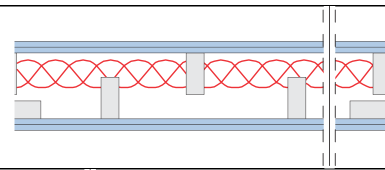
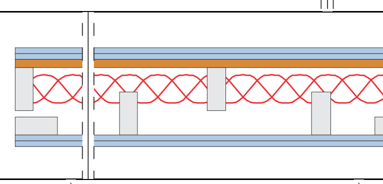
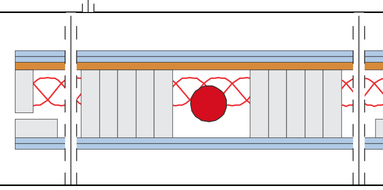
Paths	FI-STC
Dd	52
Df	71
Fd	68
Ff	73
Flanking	**65**
Total	**52**

Specimen	Room Pairs	Junction name
B7000-10	LSE->LNE	FTL-13-3SWS140-WW-LB-015

A.3.4.3 Wall-Floor Non-Load Bearing Junctions

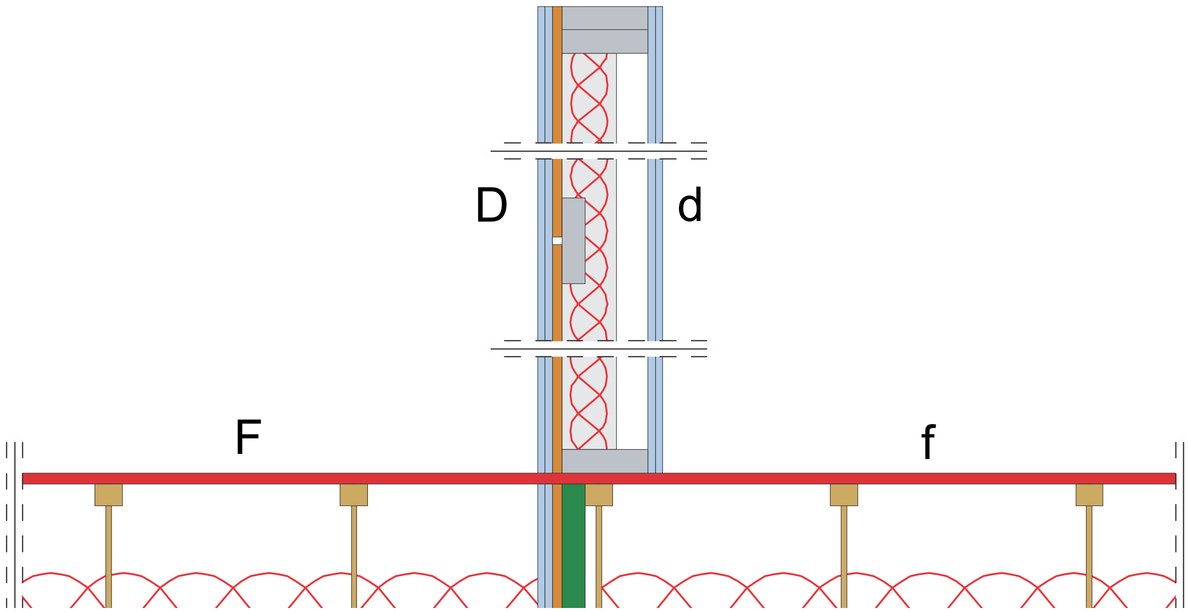
In this section, there are 6 distinct wall-floor non-load bearing junctions with results of their flanking paths.

Junction Name	F	Direct (Dd)	f
FTL-13-SWS140-WF-NLB-001	OSB16	NLB-W2 (Shear)	OSB16
FTL-13-SWS140-WF-NLB-002	OSB16	NLB-W1	OSB16
FTL-13-SWS140-WF-NLB-004	GCON38_RESL9	NLB-W2 (Shear)	OSB16
FTL-13-SWS140-WF-NLB-005	2CEMBRD13(Screws)	NLB-W1	OSB16
FTL-13-SWS140-WF-NLB-006	OSB16	NLB-W5 (Tie-down)	OSB16

Separating Wall	Short Description	Top View
NLB-W1	G13_G13_SWS140(406)_GFB90_G13_G13	
NLB-W2 (Shear)	G13_G13_PLY16_SWS140(406)_GFB90_G13_G13	
NLB-W5 (Tie-down)	G13_G13_PLY16_SWS140(406)_GFB90_G13_G13	

The floor and wall elements found in this section are described in detail in Appendix A.3.5 below.

FTL-13-SWS140-WF-NLB-001

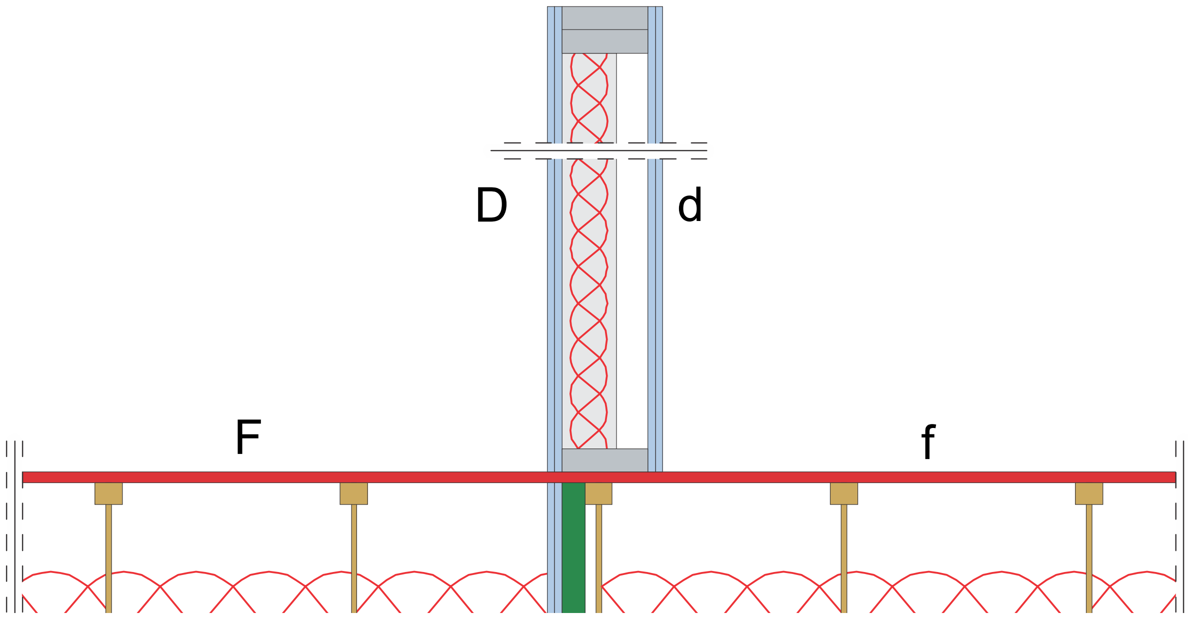


Element	Reference
D	NLB-W2 (Cladding 1)
d	NLB-W2 (Cladding 2)
F	FC-1 (Subfloor)
f	FC-1 (Subfloor)

Paths	FI-STC
Dd	51
Df	52
Fd	58
Ff	48
Flanking	**46**
Total	**45**

Specimen	Room Pairs	Junction name
B7000-01	UNW->UNE	FTL-13-SWS140-WF-NLB-001ar
B7000-01	USW->USE	FTL-13-SWS140-WF-NLB-001b
B7000-02	USW->USE	FTL-13-SWS140-WF-NLB-001b

FTL-13-SWS140-WF-NLB-002

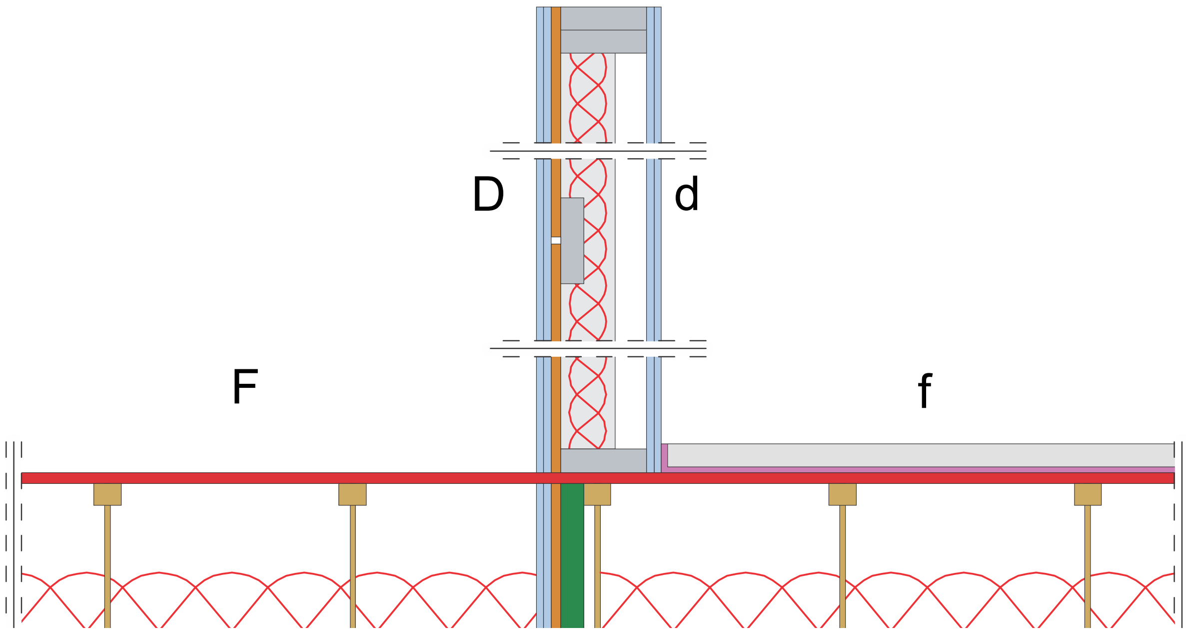


Element	Reference
D	NLB-W1 (Cladding 1)
d	NLB-W1 (Cladding 2)
F	FC-1 (Subfloor)
f	FC-1 (Subfloor)

Paths	FI-STC
Dd	48
Df	58
Fd	58
Ff	48
Flanking	**47**
Total	**45**

Specimen	Room Pairs	Junction name
B7000-02	UNW->UNE	FTL-13-SWS140-WF-NLB-002r

FTL-13-SWS140-WF-NLB-004

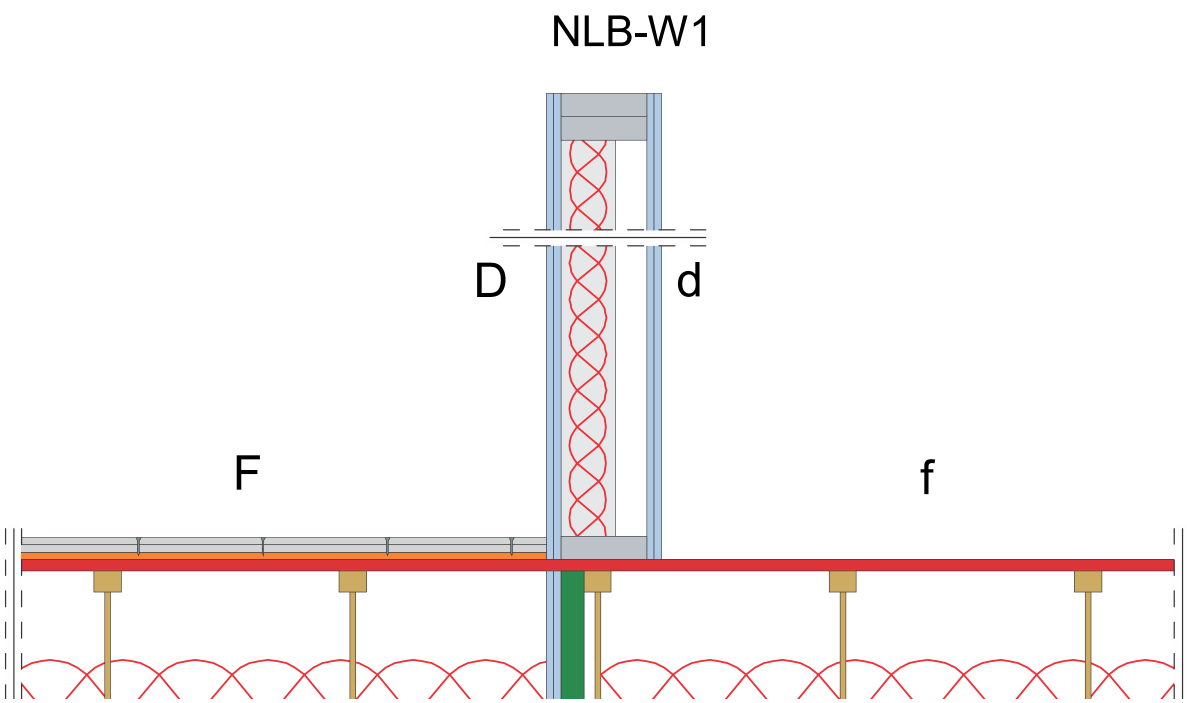


Element	Reference
D	NLB-W2 (Cladding 1)
d	NLB-W2 (Cladding 2)
F	FC-1 (Subfloor)
f	FC-2 (Topping,Subfloor)

Paths	FI-STC
Dd	51
Df	67
Fd	58
Ff	61
Flanking	**56**
Total	**50**

Specimen	Room Pairs	Junction name
B7000-03	USW->USE	FTL-13-SWS140-WF-NLB-004
B7000-04	USW->USE	FTL-13-SWS140-WF-NLB-004v (Vinyl)
B7000-05	USW->USE	FTL-13-SWS140-WF-NLB-004
B7000-06	USW->USE	FTL-13-SWS140-WF-NLB-004

FTL-13-SWS140-WF-NLB-005

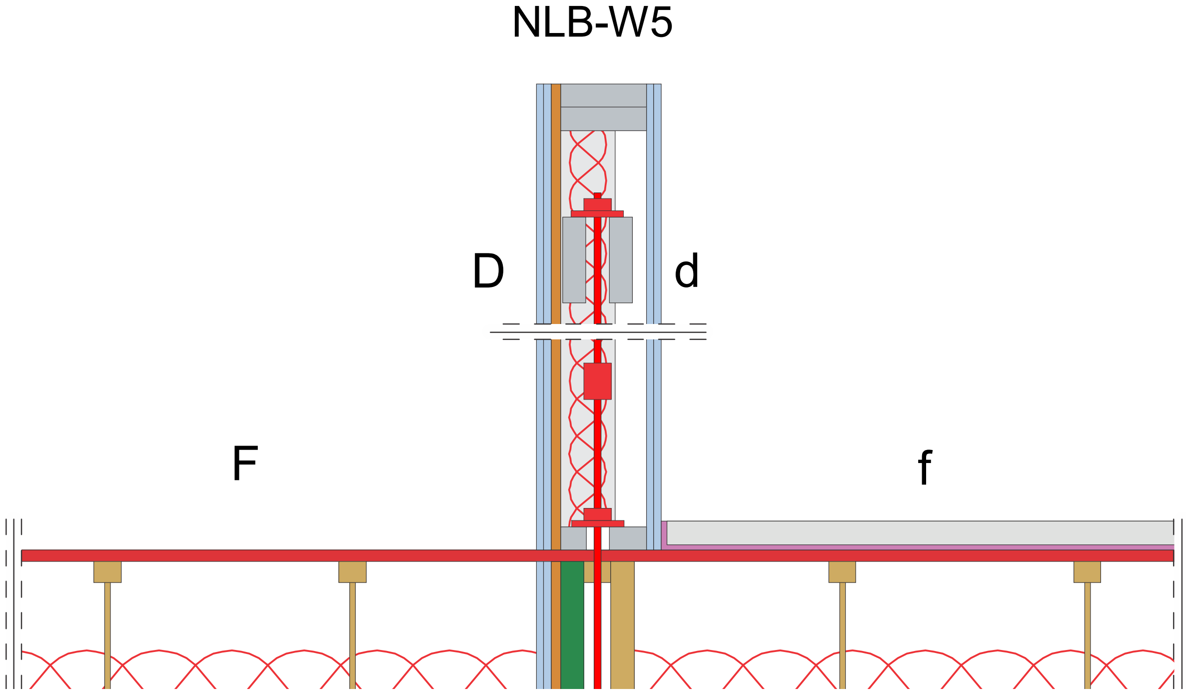


Element	Reference
D	NLB-W1 (Cladding 1)
d	NLB-W1 (Cladding 2)
F	FC-4 (Topping,Subfloor)
f	FC-1 (Subfloor)

Paths	FI-STC
Dd	48
Df	58
Fd	60
Ff	58
Flanking	**54**
Total	**47**

Specimen	Room Pairs	Junction name
B7000-04	UNW->UNE	FTL-13-SWS140-WF-NLB-005r
B7000-05	UNW->UNE	FTL-13-SWS140-WF-NLB-005r
B7000-06	UNW->UNE	FTL-13-SWS140-WF-NLB-005r
B7000-07	UNW->UNE	FTL-13-SWS140-WF-NLB-005r

FTL-13-SWS140-WF-NLB-006



Element	Reference
D	NLB-W5 (Cladding 1)
d	NLB-W5 (Cladding 2)
F	FC-1 (Subfloor)
f	FC-2 (Topping,Subfloor)

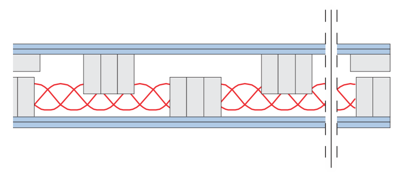
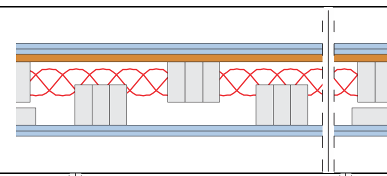
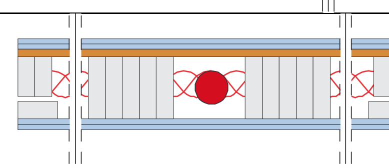
Paths	FI-STC
Dd	51
Df	67
Fd	58
Ff	61
Flanking	**56**
Total	**50**

Specimen	Room Pairs	Junction name
B7000-07	USW->USE	FTL-13-SWS140-WF-NLB-006

A.3.4.4 Wall-Floor Load Bearing Junctions

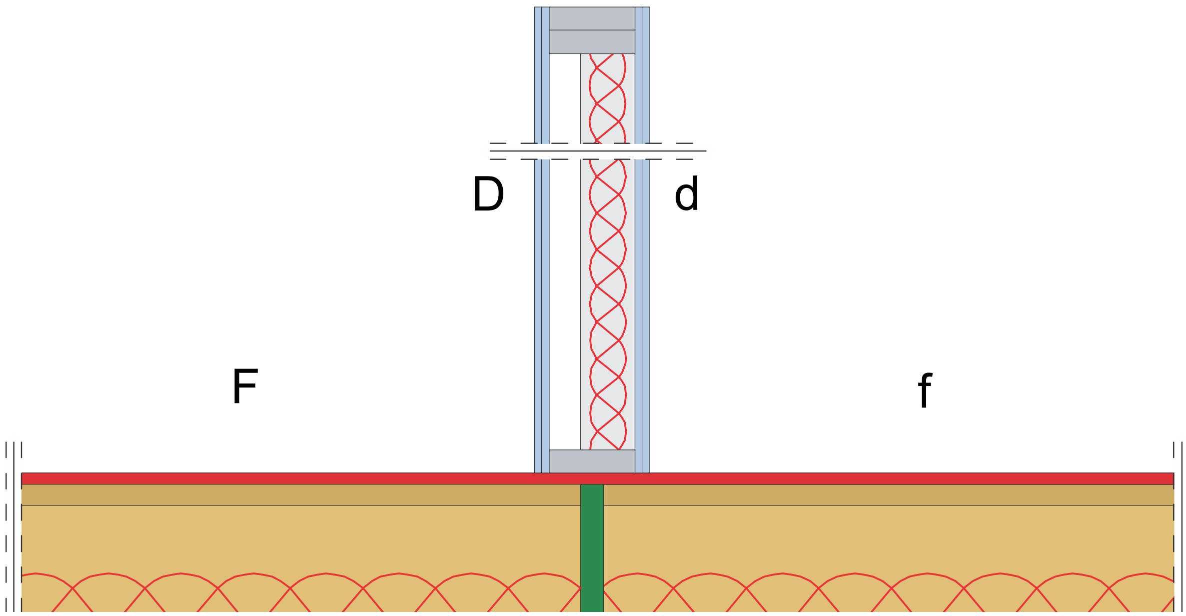
In this section, there are 6 distinct wall-floor load bearing junctions with results of their flanking paths.

Junction Name	F	Direct (Dd)	f
FTL-13-3SWS140-WF-LB-001	OSB16	LB-W1	OSB16
FTL-13-3SWS140-WF-LB-002	OSB16	LB-W2 (Shear)	OSB16
FTL-13-3SWS140-WF-LB-003	GCON38_RESL9	LB-W1	OSB16
FTL-13-3SWS140-WF-LB-005	2CEMBRD13(Screws)	LB-W2 (Shear)	OSB16
FTL-13-3SWS140-WF-LB-006	2CEMBRD13(Screws)	LB-W5 (Tie-down)	OSB16

Separating Wall	Short Description	Top View
LB-W1	G13_G13_3SWS140(406)_GFB90_G13_G13	
LB-W2 (Shear)	G13_G13_PLY16_3SWS140(406)_GFB90_G13_G13	
LB-W5 (Tie-down)	G13_G13_PLY16_3SWS140(406)_GFB90_G13_G13	

The wall elements found in this section are described in detail in Appendix A.3.5 below.

FTL-13-3SWS140-WF-LB-001

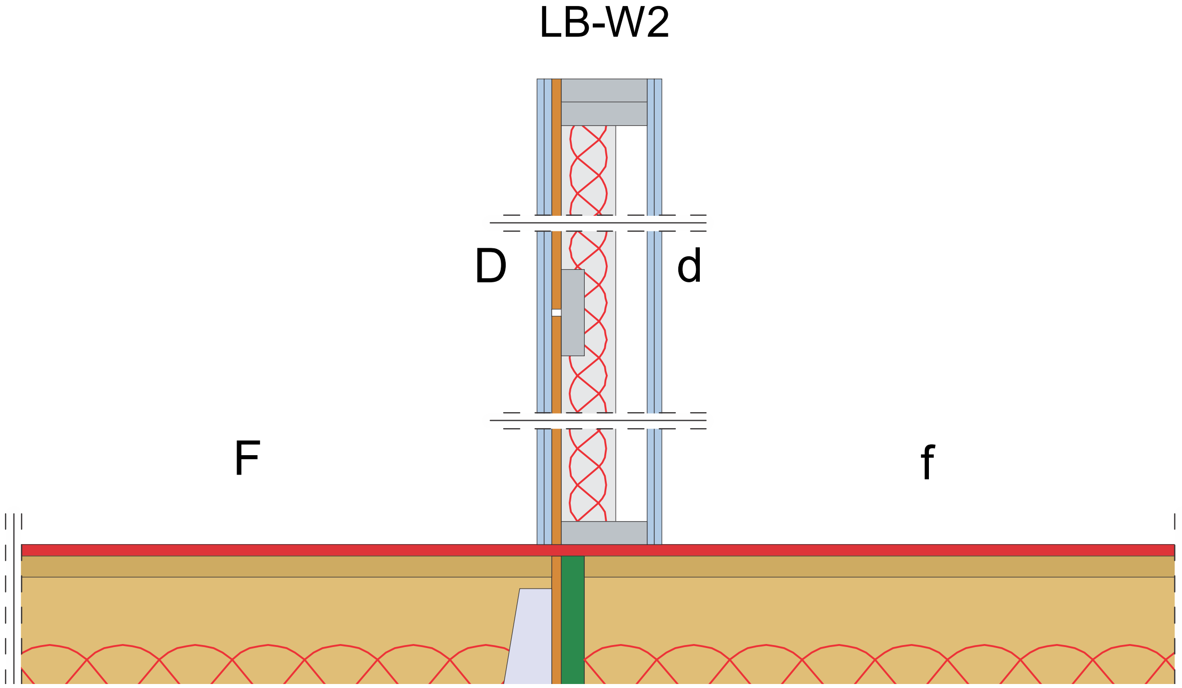


Element	Reference
D	LB-W1 (Cladding 1)
d	LB-W1 (Cladding 2)
F	FC-1 (Subfloor)
f	FC-1 (Subfloor)

Paths	FI-STC
Dd	48
Df	58
Fd	58
Ff	52
Flanking	**50**
Total	**46**

Specimen	Room Pairs	Junction name
B7000-01	USE->UNE	FTL-13-3SWS140-WF-LB-001
B7000-02	USE->UNE	FTL-13-3SWS140-WF-LB-001

FTL-13-3SWS140-WF-LB-002

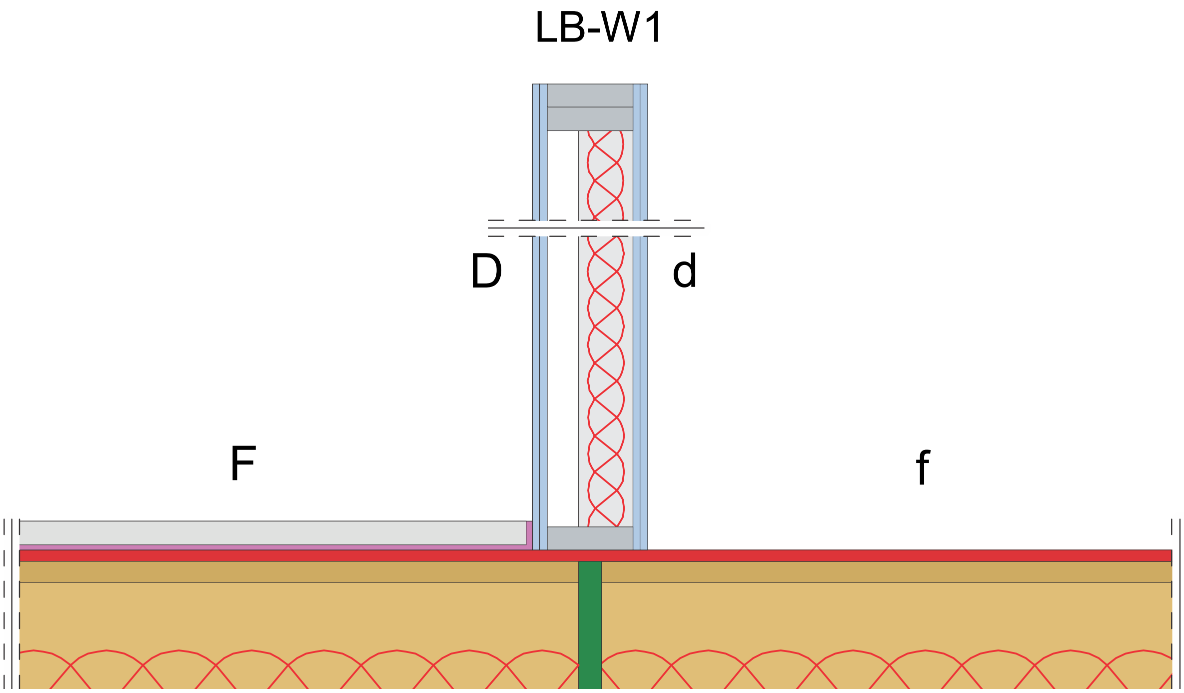


Element	Reference
D	LB-W2 (Cladding 1)
d	LB-W2 (Cladding 2)
F	FC-1 (Subfloor)
f	FC-1 (Subfloor)

Paths	FI-STC
Dd	51
Df	54
Fd	58
Ff	52
Flanking	**49**
Total	**47**

Specimen	Room Pairs	Junction name
B7000-01	UNW->USW	FTL-13-3SWS140-WF-LB-002r
B7000-02	UNW->USW	FTL-13-3SWS140-WF-LB-002r

FTL-13-3SWS140-WF-LB-003

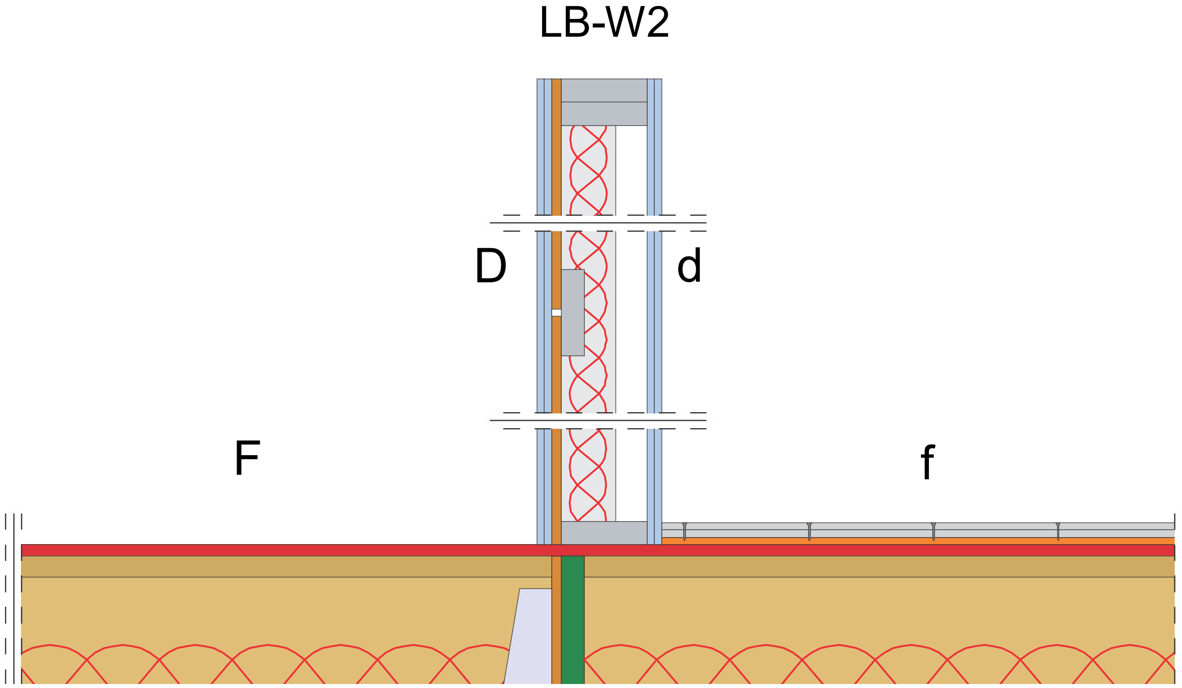


Element	Reference
D	LB-W1 (Cladding 1)
d	LB-W1 (Cladding 2)
F	FC-2 (Topping,Subfloor)
f	FC-1 (Subfloor)

Paths	FI-STC
Dd	48
Df	58
Fd	68
Ff	65
Flanking	**57**
Total	**47**

Specimen	Room Pairs	Junction name
B7000-03	USE->UNE	FTL-13-3SWS140-WF-LB-003
B7000-04	USE->UNE	FTL-13-3SWS140-WF-LB-003v
B7000-05	USE->UNE	FTL-13-3SWS140-WF-LB-003
B7000-06	USE->UNE	FTL-13-3SWS140-WF-LB-003
B7000-07	USE->UNE	FTL-13-3SWS140-WF-LB-003

FTL-13-3SWS140-WF-LB-005

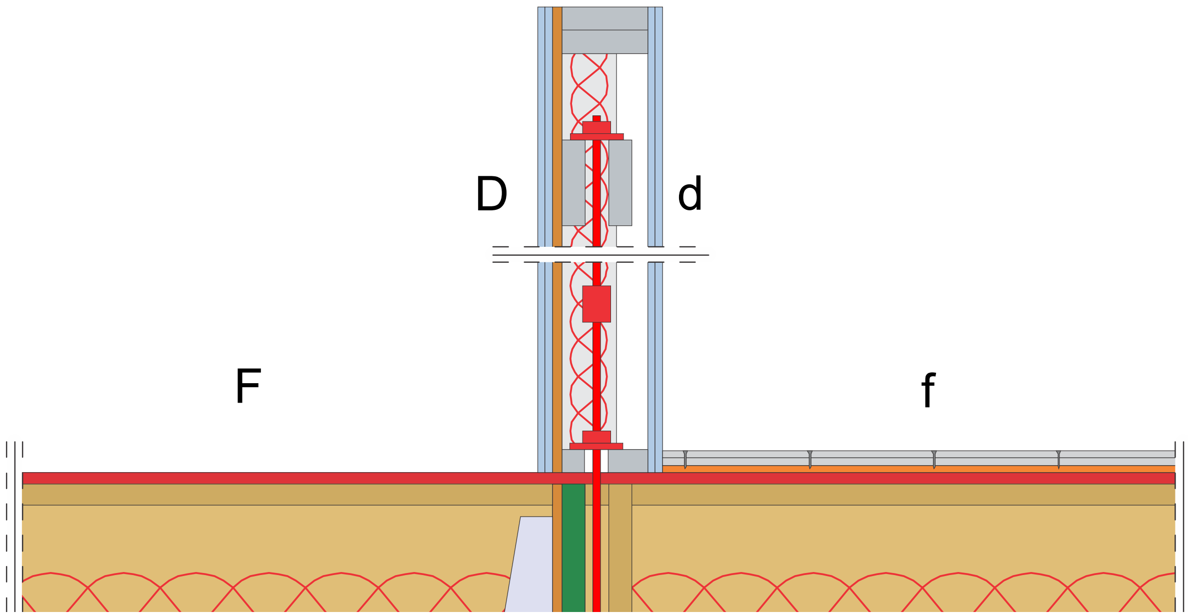


Element	Reference
D	LB-W2 (Cladding 1)
d	LB-W2 (Cladding 2)
F	FC-1 (Subfloor)
f	FC-4 (Topping,Subfloor)

Paths	FI-STC
Dd	51
Df	65
Fd	58
Ff	63
Flanking	**56**
Total	**50**

Specimen	Room Pairs	Junction name
B7000-04	USW->UNW	FTL-13-3SWS140-WF-LB-005r
B7000-05	USW->UNW	FTL-13-3SWS140-WF-LB-005r
B7000-06	USW->UNW	FTL-13-3SWS140-WF-LB-005r

FTL-13-3SWS140-WF-LB-006



Element	Reference
D	LB-W5 (Cladding 1)
d	LB-W5 (Cladding 2)
F	FC-1 (Subfloor)
f	FC-4 (Topping,Subfloor)

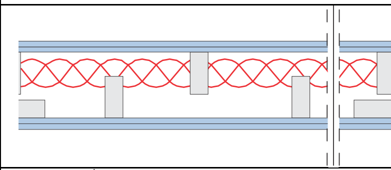
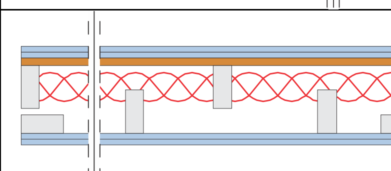
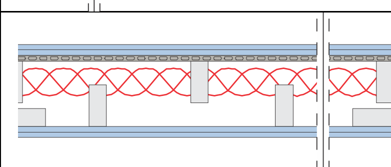
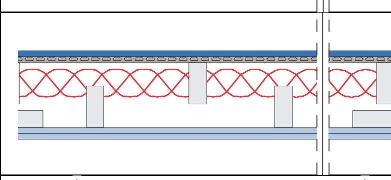
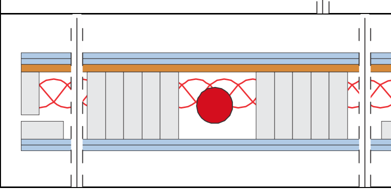
Paths	FI-STC
Dd	51
Df	65
Fd	58
Ff	63
Flanking	**56**
Total	**50**

Specimen	Room Pairs	Junction name
B7000-07	USW->UNW	FTL-13-3SWS140-WF-LB-006r

A.3.4.5 Wall-Ceiling Non-Load Bearing Junctions

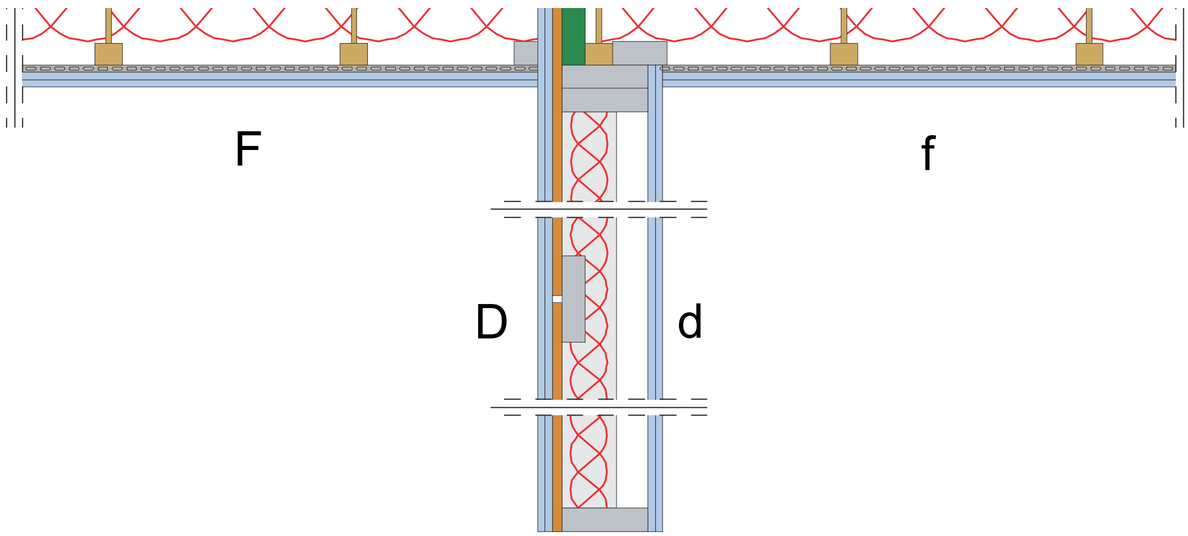
In this section, there are 5 distinct wall-ceiling non-load bearing junctions with results of their flanking paths.

Junction Name	F	Direct (Dd)	f
FTL-13-SWS140-WC-NLB-001	2G13_RC	NLB-W2 (Shear)	2G13_RC
FTL-13-SWS140-WC-NLB-002	2G13_RC	NLB-W1	2G13_RC
FTL-13-SWS140-WC-NLB-003	2G13_RC	NLB-W3 (2G13_RC)	2G13_RC
FTL-13-SWS140-WC-NLB-004	2G13_RC	NLB-W4 (G16_RC)	2G13_RC
FTL-13-SWS140-WC-NLB-005	2G13_RC	NLB-W5 (Tie-down)	2G13_RC

Separating Wall	Short Description	Top View
NLB-W1	G13_G13_SWS140(406)_GFB90_G13_G13	
NLB-W2 (Shear)	G13_G13_PLY16_SWS140(406)_GFB90_G13_G13	
NLB-W3 (2G13_RC)	G13_G13_RC_SWS140(406)_GFB90_G13_G13	
NLB-W4 (G16_RC)	G16_RC_SWS140(406)_GFB90_G13_G13	
NLB-W5 (Tie-down)	G13_G13_PLY16_SWS140(406)_GFB90_G13_G13	

The floor and wall elements found in this section are described in detail in Appendix A.3.5 below.

FTL-13-SWS140-WC-NLB-001



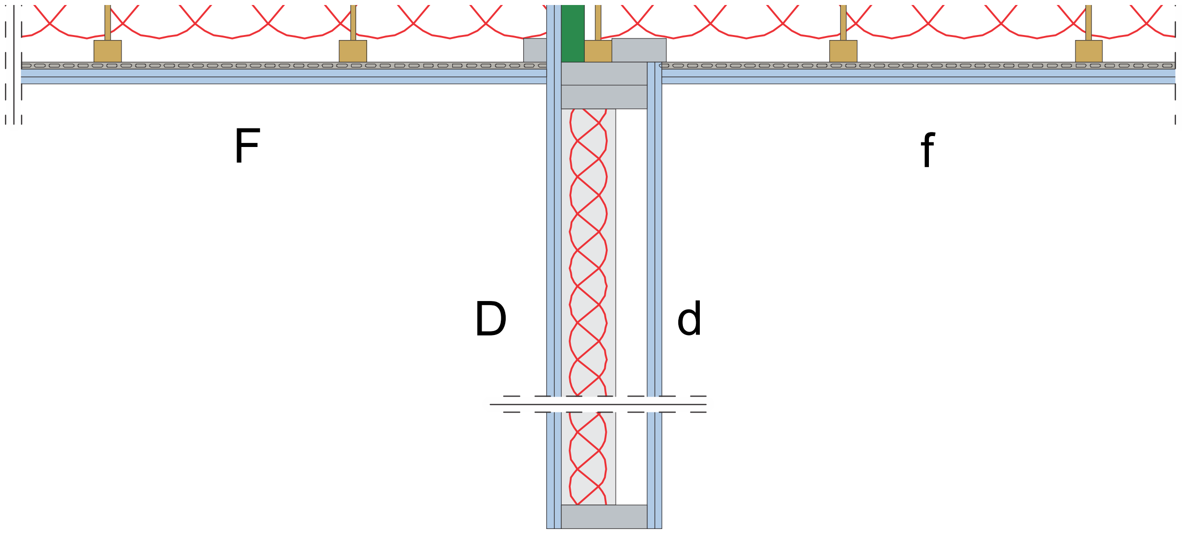
NLB-W2

Element	Reference
D	NLB-W2 (Cladding 1)
d	NLB-W2 (Cladding 2)
F	FC-1 (Ceiling)
f	FC-1 (Ceiling)

Paths	FI-STC
Dd	51
Df	68
Fd	71
Ff	78
Flanking	**66**
Total	**51**

Specimen	Room Pairs	Junction name
B7000-01	LNW->LNE	FTL-13-SWS140-WC-NLB-001ar
B7000-01	LSW->LSE	FTL-13-SWS140-WC-NLB-001b
B7000-02	LSW->LSE	FTL-13-SWS140-WC-NLB-001b
B7000-03	LSW->LSE	FTL-13-SWS140-WC-NLB-001b
B7000-04	LSW->LSE	FTL-13-SWS140-WC-NLB-001b
B7000-05	LSW->LSE	FTL-13-SWS140-WC-NLB-001b
B7000-06	LSW->LSE	FTL-13-SWS140-WC-NLB-001b

FTL-13-SWS140-WC-NLB-002



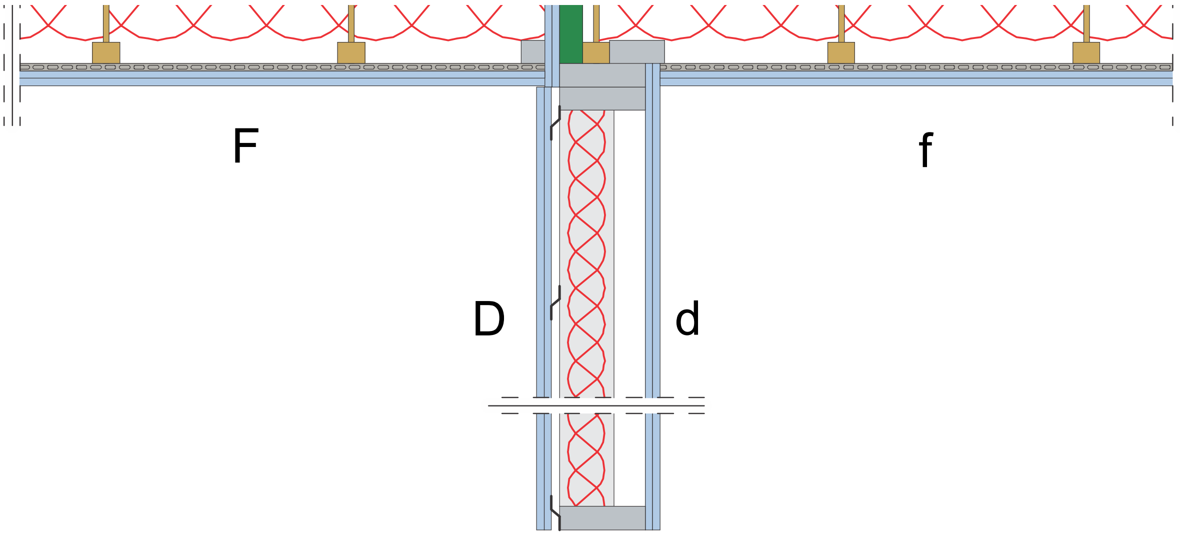
NLB-W1

Element	Reference
D	NLB-W1 (Cladding 1)
d	NLB-W1 (Cladding 2)
F	FC-1 (Ceiling)
f	FC-1 (Ceiling)

Paths	FI-STC
Dd	48
Df	71
Fd	71
Ff	78
Flanking	**68**
Total	**48**

Specimen	Room Pairs	Junction name
B7000-02	LNW->LNE	FTL-13-SWS140-WC-NLB-002r
B7000-03	LNW->LNE	FTL-13-SWS140-WC-NLB-002r
B7000-04	LNW->LNE	FTL-13-SWS140-WC-NLB-002r

FTL-13-SWS140-WC-NLB-003



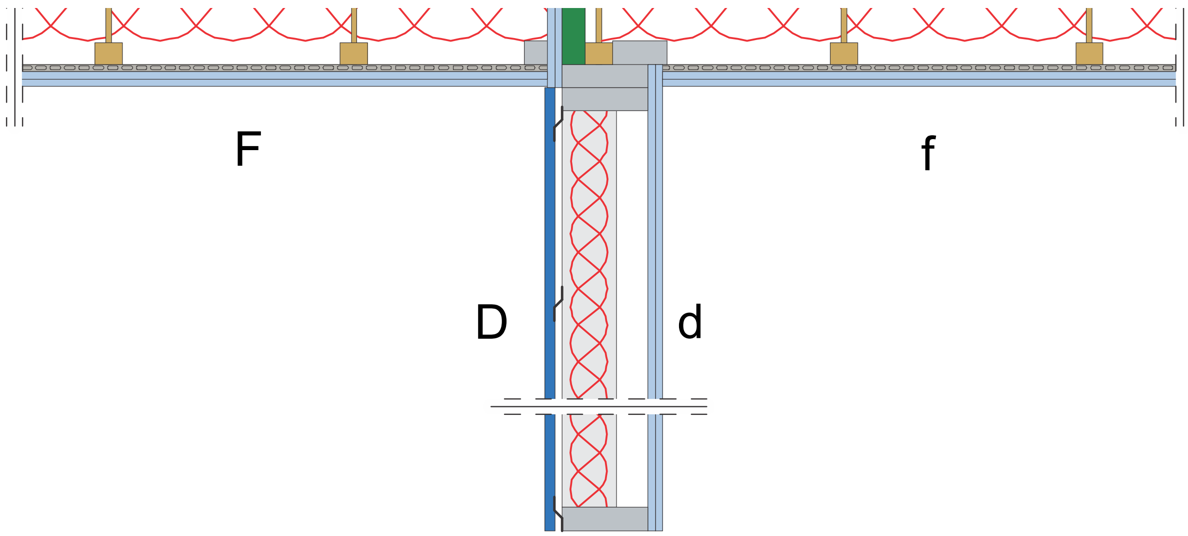
NLB-W3

Element	Reference
D	NLB-W3 (Cladding 1)
d	NLB-W3 (Cladding 2)
F	FC-1 (Ceiling)
f	FC-1 (Ceiling)

Paths	FI-STC
Dd	58
Df	69
Fd	71
Ff	78
Flanking	**67**
Total	**57**

Specimen	Room Pairs	Junction name
B7000-05	LNW->LNE	FTL-13-SWS140-WC-NLB-003r

FTL-13-SWS140-WC-NLB-004



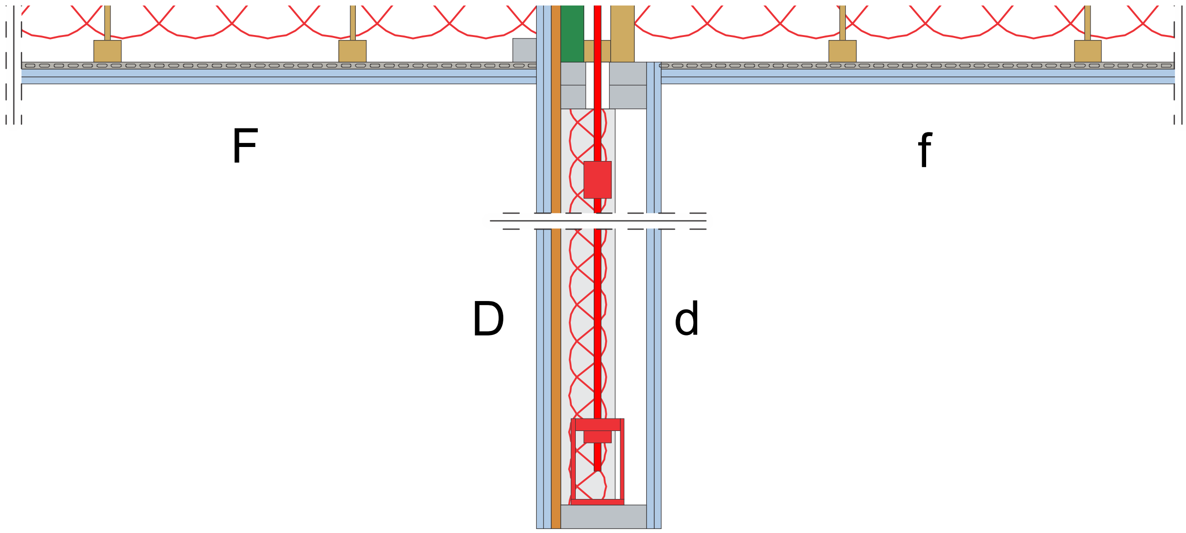
NLB-W4

Element	Reference
D	NLB-W4 (Cladding 1)
d	NLB-W4 (Cladding 2)
F	FC-1 (Ceiling)
f	FC-1 (Ceiling)

Paths	FI-STC
Dd	55
Df	69
Fd	71
Ff	78
Flanking	**67**
Total	**55**

Specimen	Room Pairs	Junction name
B7000-06	LNW->LNE	FTL-13-SWS140-WC-NLB-004r
B7000-07	LNW->LNE	FTL-13-SWS140-WC-NLB-004r

FTL-13-SWS140-WC-NLB-005



NLB-W5

Element	Reference
D	NLB-W5 (Cladding 1)
d	NLB-W5 (Cladding 2)
F	FC-1 (Ceiling)
f	FC-1 (Ceiling)

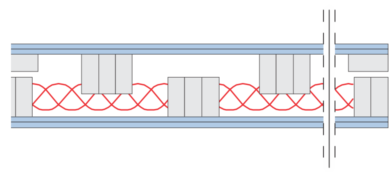
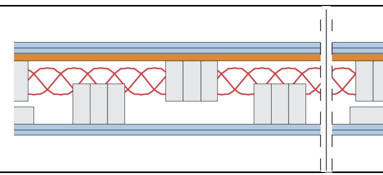
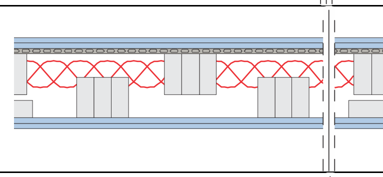
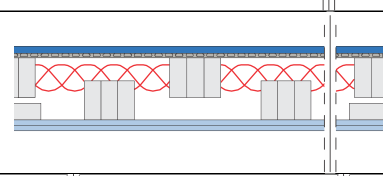
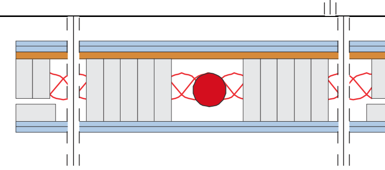
Paths	FI-STC
Dd	51
Df	68
Fd	71
Ff	78
Flanking	**66**
Total	**51**

Specimen	Room Pairs	Junction name
B7000-07	LSW->LSE	FTL-13-SWS140-WC-NLB-005

A.3.4.6 Wall-Ceiling Load Bearing Junctions

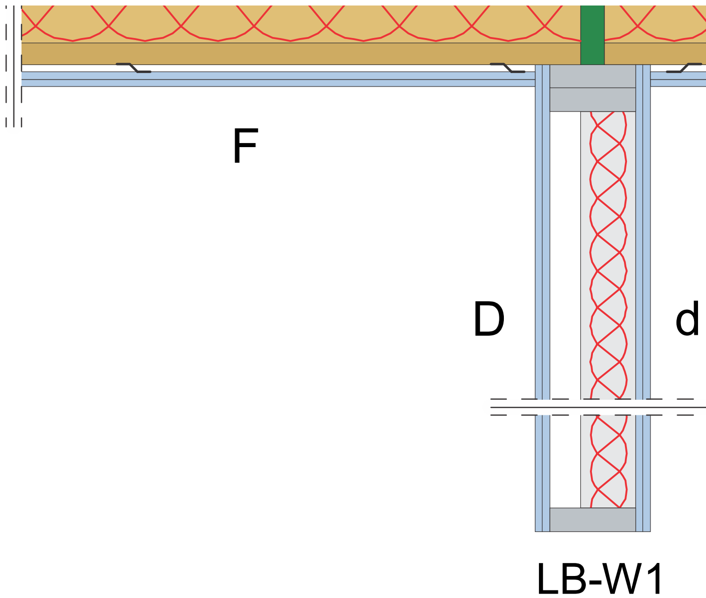
In this section, there are 5 distinct wall-ceiling load bearing junctions with results of their flanking paths.

Junction Name	F	Direct (Dd)	f
FTL-13-3SWS140-WC-LB-001	2G13_RC	LB-W1	2G13_RC
FTL-13-3SWS140-WC-LB-002	2G13_RC	LB-W2 (Shear)	2G13_RC
FTL-13-3SWS140-WC-LB-003	2G13_RC	LB-W3 (2G13_RC)	2G13_RC
FTL-13-3SWS140-WC-LB-004	2G13_RC	LB-W4 (G16_RC)	2G13_RC
FTL-13-3SWS140-WC-LB-005	2G13_RC	LB-W5 (Tie-down)	2G13_RC

Separating Wall	Short Description	Top View
LB-W1	G13_G13_3SWS140(406)_GFB90_G13_G13	
LB-W2 (Shear)	G13_G13_PLY16_3SWS140(406)_GFB90_G13_G13	
LB-W3 (2G13_RC)	G13_G13_RC_3SWS140(406)_GFB90_G13_G13	
LB-W4 (G16_RC)	G16_RC_3SWS140(406)_GFB90_G13_G13	
LB-W5 (Tie-down)	G13_G13_PLY16_3SWS140(406)_GFB90_G13_G13	

The floor and wall elements found in this section are described in detail in Appendix A.3.5 below.

FTL-13-3SWS140-WC-LB-001

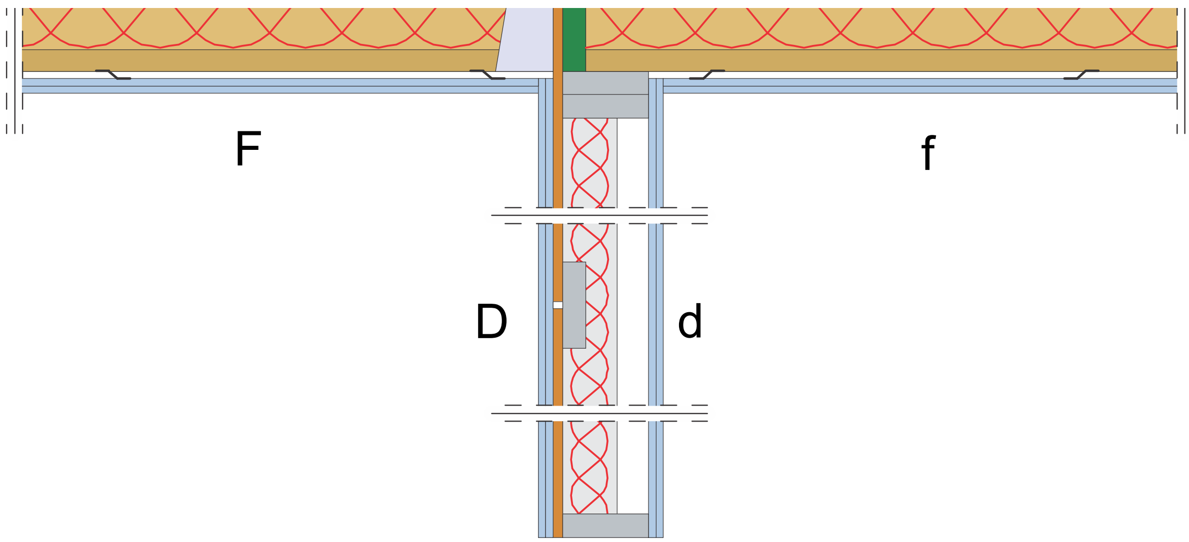


Element	Reference
D	LB-W1 (Cladding 1)
d	LB-W1 (Cladding 2)
F	FC-1 (Ceiling)
f	FC-1 (Ceiling)

Paths	FI-STC
Dd	48
Df	67
Fd	67
Ff	80
Flanking	**64**
Total	**48**

Specimen	Room Pairs	Junction name
B7000-01	LSE->LNE	FTL-13-3SWS140-WC-LB-001
B7000-02	LSE->LNE	FTL-13-3SWS140-WC-LB-001
B7000-03	LSE->LNE	FTL-13-3SWS140-WC-LB-001
B7000-04	LSE->LNE	FTL-13-3SWS140-WC-LB-001

FTL-13-3SWS140-WC-LB-002



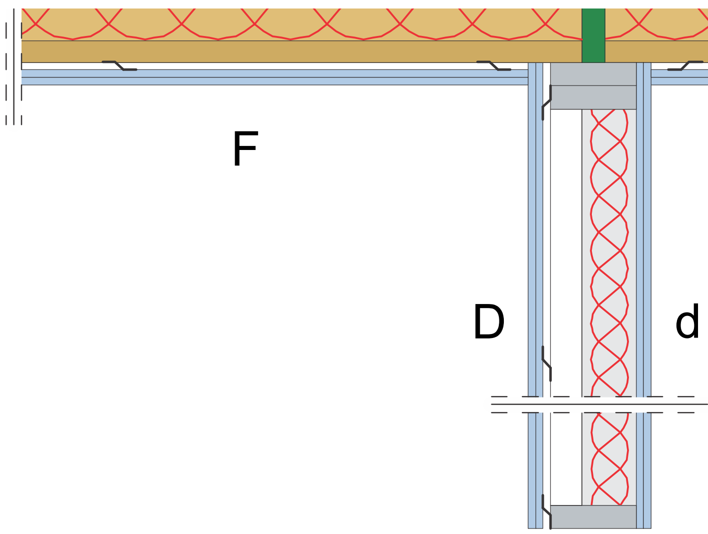
LB-W2

Element	Reference
D	LB-W2 (Cladding 1)
d	LB-W2 (Cladding 2)
F	FC-1 (Ceiling)
f	FC-1 (Ceiling)

Paths	FI-STC
Dd	51
Df	69
Fd	67
Ff	80
Flanking	**65**
Total	**51**

Specimen	Room Pairs	Junction name
B7000-01	LSW->LNW	FTL-13-3SWS140-WC-LB-002r
B7000-02	LSW->LNW	FTL-13-3SWS140-WC-LB-002r
B7000-03	LSW->LNW	FTL-13-3SWS140-WC-LB-002r
B7000-04	LSW->LNW	FTL-13-3SWS140-WC-LB-002r
B7000-05	LSW->LNW	FTL-13-3SWS140-WC-LB-002r
B7000-06	LSW->LNW	FTL-13-3SWS140-WC-LB-002r

FTL-13-3SWS140-WC-LB-003

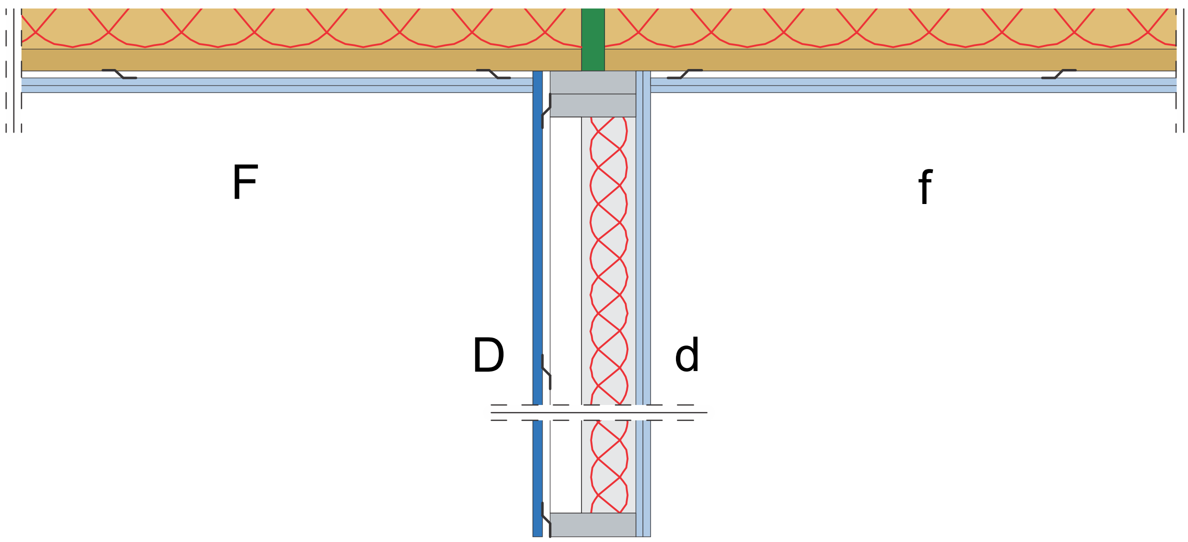


Element	Reference
D	LB-W3 (Cladding 1)
d	LB-W3 (Cladding 2)
F	FC-1 (Ceiling)
f	FC-1 (Ceiling)

Paths	FI-STC
Dd	58
Df	77
Fd	67
Ff	80
Flanking	**66**
Total	**57**

Specimen	Room Pairs	Junction name
B7000-05	LSE->LNE	FTL-13-3SWS140-WC-LB-003

FTL-13-3SWS140-WC-LB-004

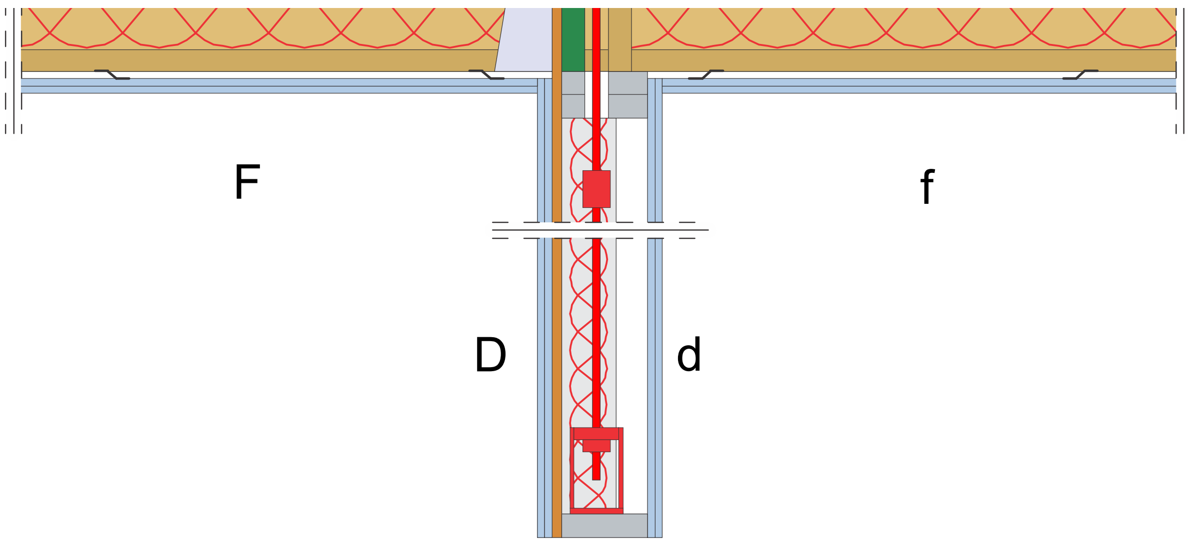


Element	Reference
D	LB-W4 (Cladding 1)
d	LB-W4 (Cladding 2)
F	FC-1 (Ceiling)
f	FC-1 (Ceiling)

Paths	FI-STC
Dd	52
Df	71
Fd	67
Ff	80
Flanking	**65**
Total	**52**

Specimen	Room Pairs	Junction name
B7000-06	LSE->LNE	FTL-13-3SWS140-WC-LB-004
B7000-07	LSE->LNE	FTL-13-3SWS140-WC-LB-004

FTL-13-3SWS140-WC-LB-005



LB-W5

Element	Reference
D	LB-W5 (Cladding 1)
d	LB-W5 (Cladding 2)
F	FC-1 (Ceiling)
f	FC-1 (Ceiling)

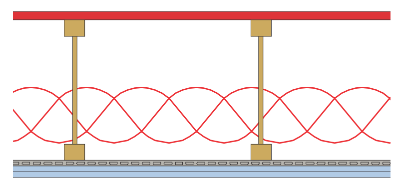
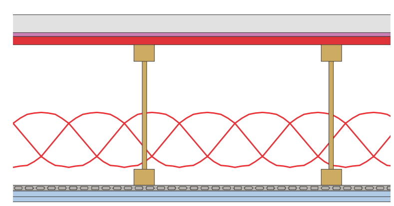
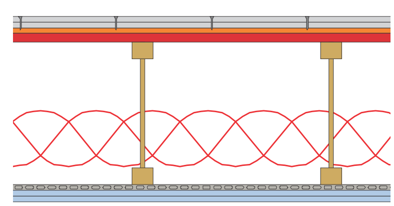
Paths	FI-STC
Dd	51
Df	69
Fd	67
Ff	80
Flanking	**65**
Total	**51**

Specimen	Room Pairs	Junction name
B7000-07	LSW->LNW	FTL-13-3SWS140-WC-LB-005r

A.3.4.7 Floor-Wall Non-Load Bearing junctions

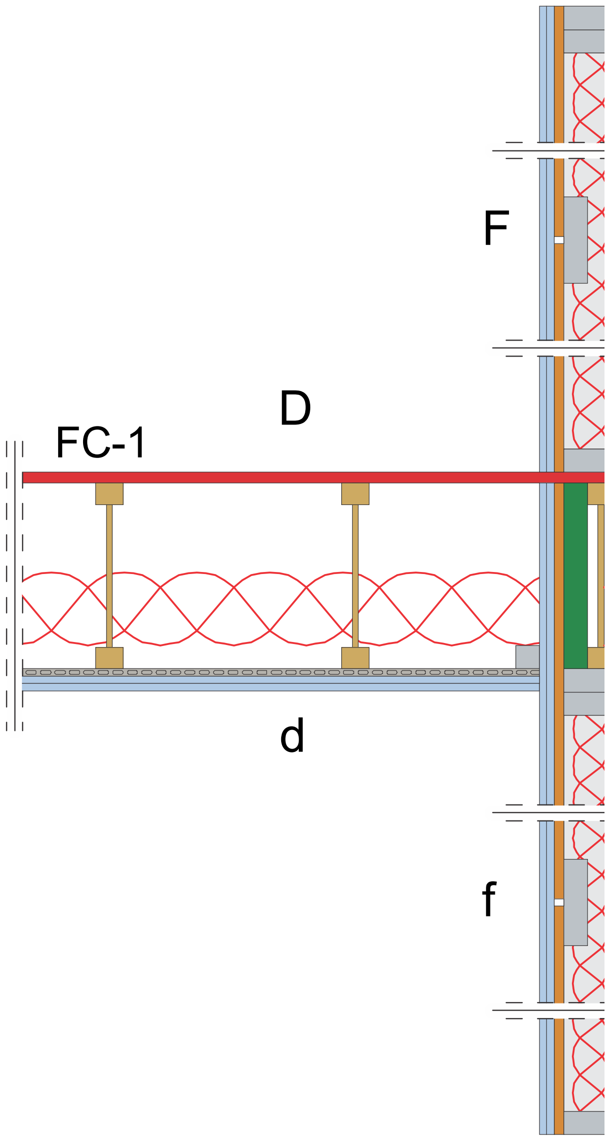
In this section, there are 12 distinct vertical floor-wall non-load bearing junctions with results of their flanking paths.

Junction Name	F	Direct (Dd)	f
FTL-13-WJ235-FW-NLB-001	2G13_PLY16	FC-1	2G13_PLY16
FTL-13-WJ235-FW-NLB-002	2G13	FC-1	2G13
FTL-13-WJ235-FW-NLB-003	2G13	FC-1	2G13
FTL-13-WJ235-FW-NLB-005	2G13	FC-2	2G13
FTL-13-WJ235-FW-NLB-006	2G13	FC-4	2G13
FTL-13-WJ235-FW-NLB-007	2G13	FC-4	2G13_RC
FTL-13-WJ235-FW-NLB-008	2G13	FC-4	G16_RC
FTL-13-WJ235-FW-NLB-009	2G13	FC-2	2G13
FTL-13-WJ235-FW-NLB-010	2G13_PLY16	FC-1	2G13_PLY16
FTL-13-WJ235-FW-NLB-011	2G13	FC-2	2G13
FTL-13-WJ235-FW-NLB-014	2G13	FC-2	2G13

Separating Floor	Short Description	Side View
FC-1(Bare)	OSB16_WJ235(406)_GFB150_RC13(406)_G13_G13	
FC-2 (Gypsum concrete)	GCON38_RESL9_OSB16_WJ235(406)_GFB150 _RC13(406)_G13_G13	
FC-4 (Fastened cement board)	2CEMBRD13(screws)_OSB16_WJ235(406)_GFB150 _RC13(406)_G13_G13	

The floor and wall elements found in this section are described in detail in Appendix A.3.5 below.

FTL-13-WJ235-FW-NLB-001

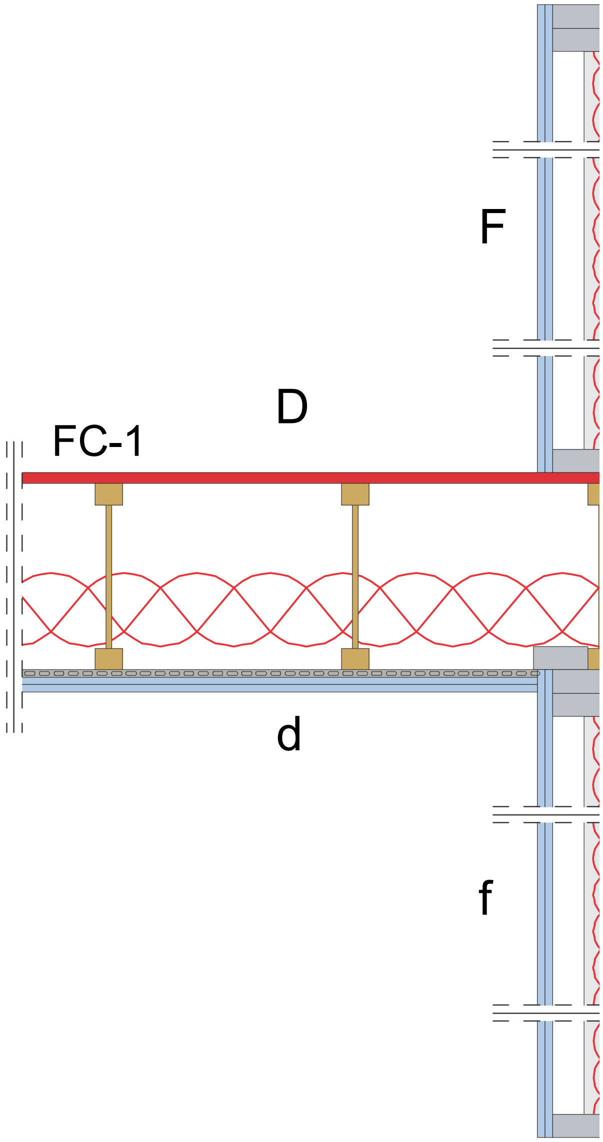


Element	Reference
D	FC-1 (Subfloor)
d	FC-1 (Ceiling)
F	NLB-W2 (Cladding 1)
f	NLB-W2 (Cladding 1)

Paths	FI-STC	FI-IIC
Dd	53	47
Df	> 60	
Fd	> 70	
Ff	> 75	
Flanking	**> 59**	
Total	**> 52**	

Specimen	Room Pairs	Junction name
B7000-01	UNW->LNW	FTL-13-WJ235-FW-NLB-001b
B7000-01	USW->LSW	FTL-13-WJ235-FW-NLB-001a
B7000-02	USW->LSW	FTL-13-WJ235-FW-NLB-001a
B7000-03	USW->LSW	FTL-13-WJ235-FW-NLB-001a
B7000-04	USW->LSW	FTL-13-WJ235-FW-NLB-001a
B7000-05	USW->LSW	FTL-13-WJ235-FW-NLB-001a
B7000-06	USW->LSW	FTL-13-WJ235-FW-NLB-001a

FTL-13-WJ235-FW-NLB-002

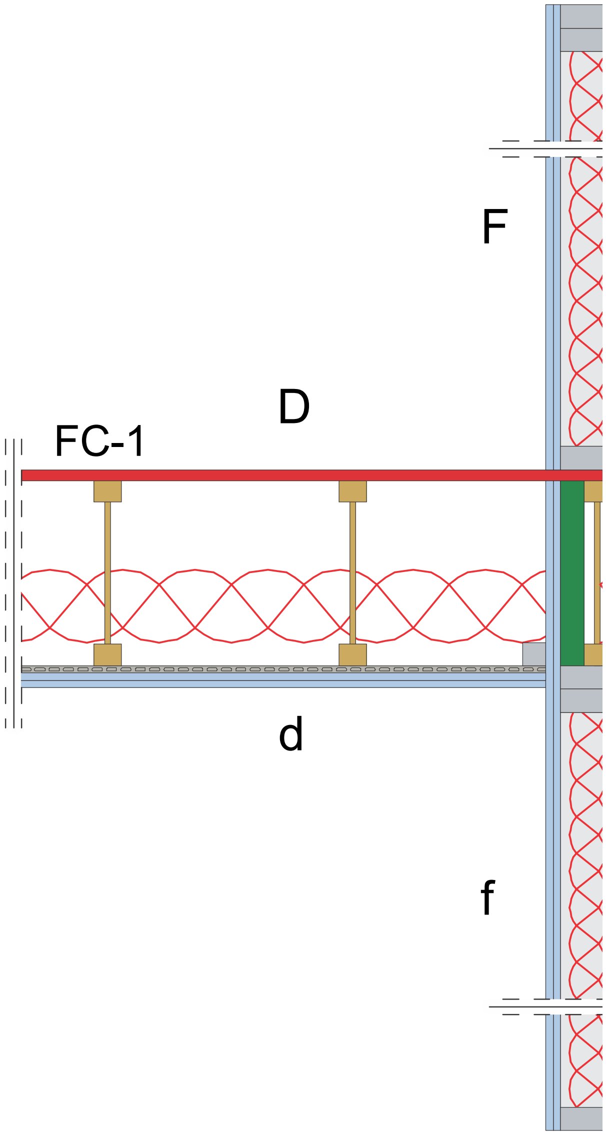


Element	Reference
D	FC-1 (Subfloor)
d	FC-1 (Ceiling)
F	NLB-W2 (Cladding 2)
f	NLB-W2 (Cladding 2)

Paths	FI-STC	FI-IIC
Dd	53	47
Df	> 60	
Fd	> 70	
Ff	> 75	
Flanking	**> 59**	
Total	**> 52**	

Specimen	Room Pairs	Junction name
B7000-01	UNE->LNE	FTL-13-WJ235-FW-NLB-002a
B7000-01	USE->LSE	FTL-13-WJ235-FW-NLB-002b
B7000-02	UNE->LNE	FTL-13-WJ235-FW-NLB-002a
B7000-02	USE->LSE	FTL-13-WJ235-FW-NLB-002b
B7000-03	UNE->LNE	FTL-13-WJ235-FW-NLB-002a
B7000-04	UNE->LNE	FTL-13-WJ235-FW-NLB-002a
B7000-05	UNE->LNE	FTL-13-WJ235-FW-NLB-002a
B7000-06	UNE->LNE	FTL-13-WJ235-FW-NLB-002a
B7000-07	UNE->LNE	FTL-13-WJ235-FW-NLB-002a

FTL-13-WJ235-FW-NLB-003

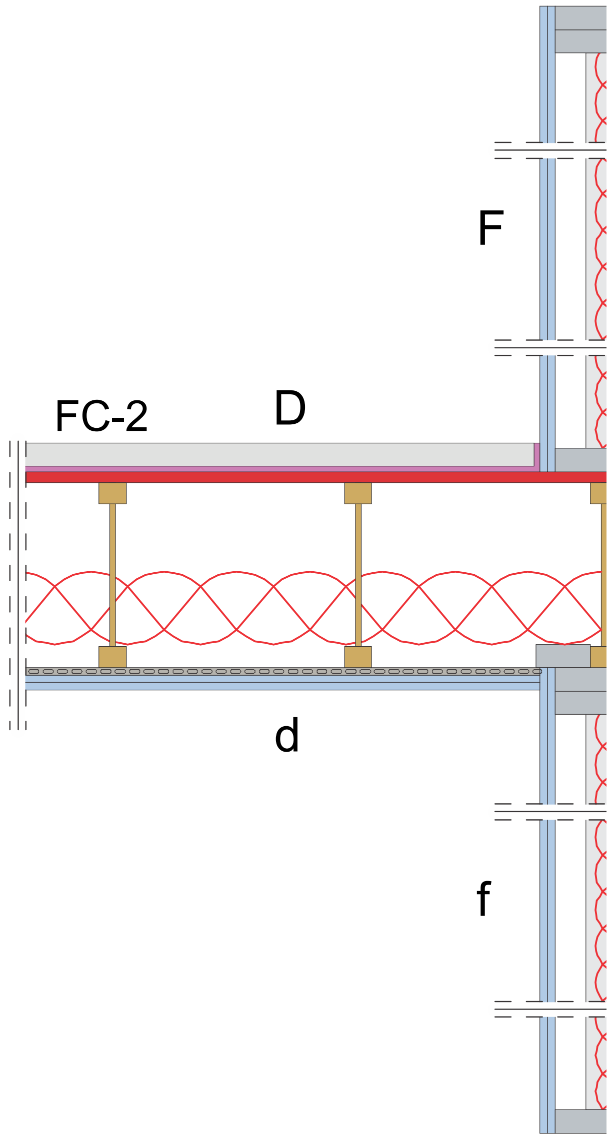


Element	Reference
D	FC-1 (Subfloor)
d	FC-1 (Ceiling)
F	NLB-W1 (Cladding 1)
f	NLB-W1 (Cladding 1)

Paths	FI-STC	FI-IIC
Dd	53	47
Df	> 60	
Fd	> 70	
Ff	> 75	
Flanking	**> 59**	
Total	**> 52**	

Specimen	Room Pairs	Junction name
B7000-02	UNW->LNW	FTL-13-WJ235-FW-NLB-003

FTL-13-WJ235-FW-NLB-005

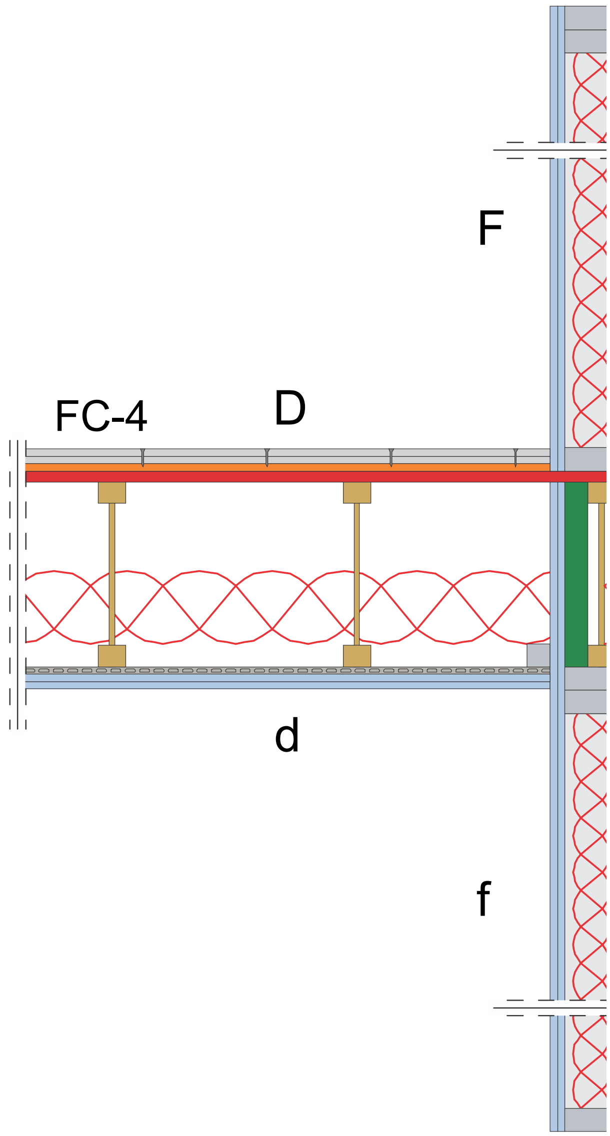


Element	Reference
D	FC-2 (Topping, Subfloor)
d	FC-2 (Ceiling)
F	NLB-W2 (Cladding 2)
f	NLB-W2 (Cladding 2)

Paths	FI-STC	FI-IIC
Dd	68	52
Df	> 70	
Fd	> 70	
Ff	> 75	
Flanking	**> 66**	
Total	**> 64**	

Specimen	Room Pairs	Junction name
B7000-03	USE->LSE	FTL-13-WJ235-FW-NLB-005
B7000-04	USE->LSE	FTL-13-WJ235-FW-NLB-005v (Vinyl)
B7000-05	USE->LSE	FTL-13-WJ235-FW-NLB-005
B7000-06	USE->LSE	FTL-13-WJ235-FW-NLB-005

FTL-13-WJ235-FW-NLB-006

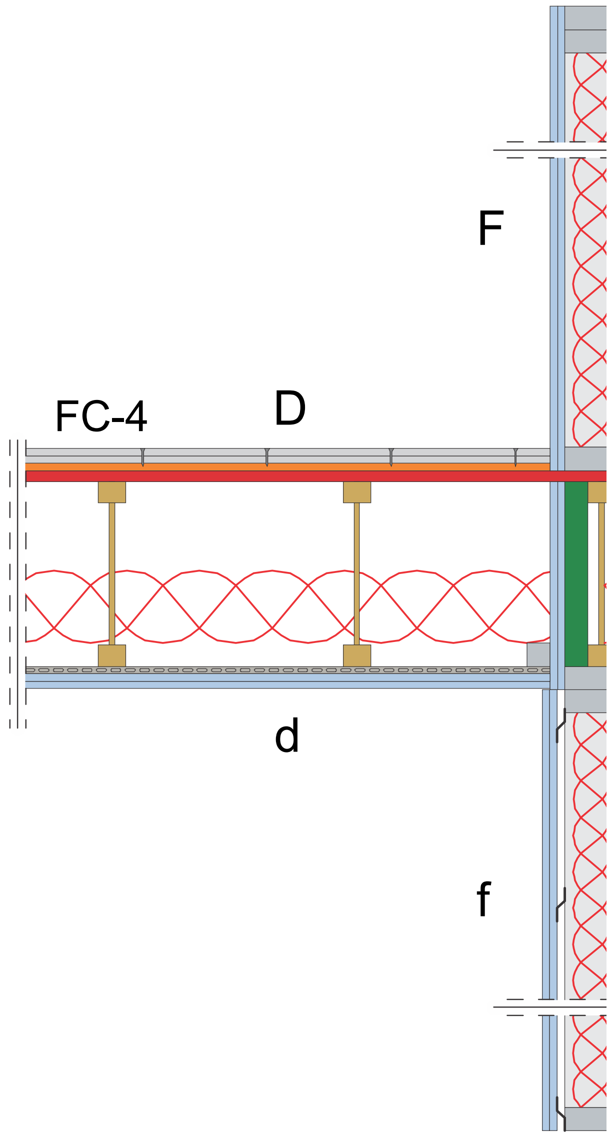


Element	Reference
D	FC-4 (Topping, Subfloor)
d	FC-4 (Ceiling)
F	NLB-W1 (Cladding 2)
f	NLB-W1 (Cladding 2)

Paths	FI-STC	FI-IIC
Dd	57	50
Df	> 65	
Fd	> 70	
Ff	> 75	
Flanking	**> 66**	
Total	**> 52**	

Specimen	Room Pairs	Junction name
B7000-04	UNW->LNW	FTL-13-WJ235-FW-NLB-006

FTL-13-WJ235-FW-NLB-007

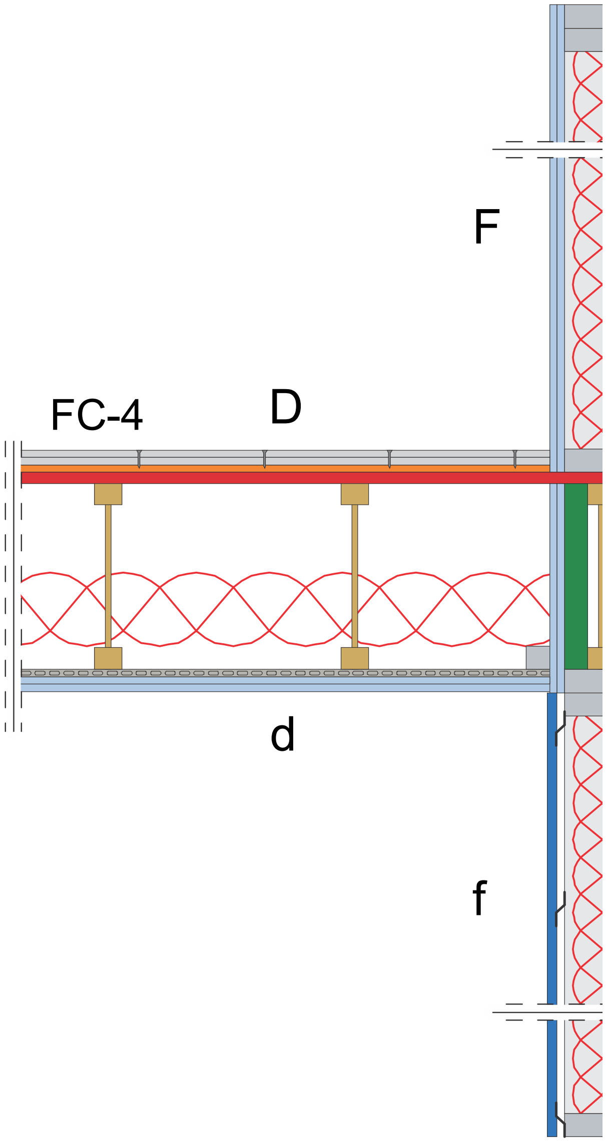


Element	Reference
D	FC-4 (Topping, Subfloor)
d	FC-4 (Ceiling)
F	NLB-W1 (Cladding 1)
f	NLB-W3 (Cladding 1)

Paths	FI-STC	FI-IIC
Dd	57	50
Df	> 70	
Fd	> 70	
Ff	> 80	
Flanking	**> 67**	
Total	**> 57**	

Specimen	Room Pairs	Junction name
B7000-05	UNW->LNW	FTL-13-WJ235-FW-NLB-007

FTL-13-WJ235-FW-NLB-008

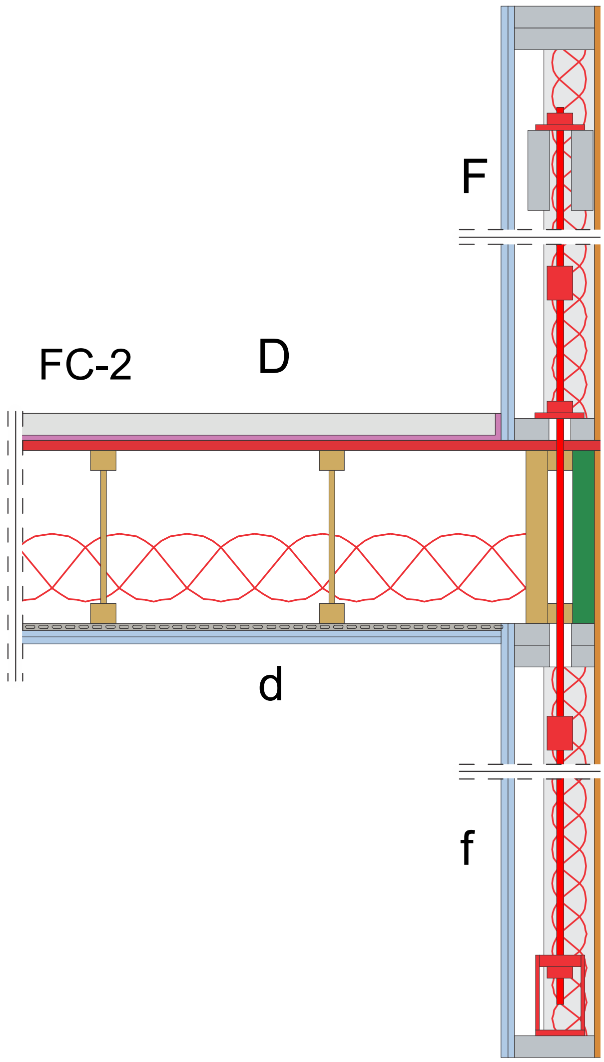


Element	Reference
D	FC-4 (Topping, Subfloor)
d	FC-4 (Ceiling)
F	NLB-W1 (Cladding 1)
f	NLB-W4 (Cladding 1)

Paths	FI-STC	FI-IIC
Dd	57	50
Df	> 70	
Fd	> 70	
Ff	> 80	
Flanking	**> 67**	
Total	**> 57**	

Specimen	Room Pairs	Junction name
B7000-06	UNW->LNW	FTL-13-WJ235-FW-NLB-008
B7000-07	UNW->LNW	FTL-13-WJ235-FW-NLB-008

FTL-13-WJ235-FW-NLB-009

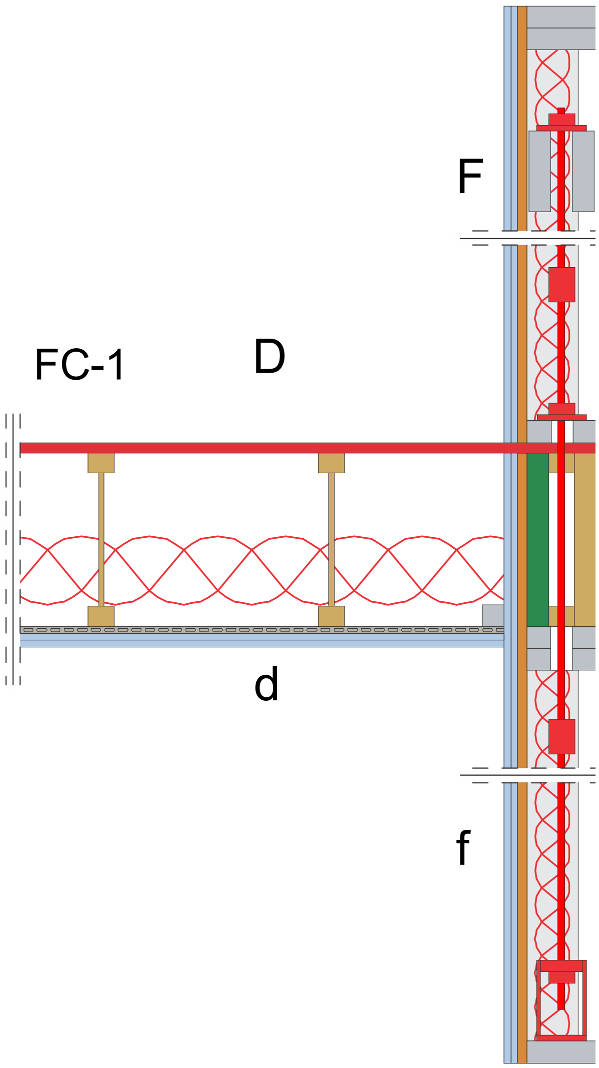


Element	Reference
D	FC-2 (Topping, Subfloor)
d	FC-2 (Ceiling)
F	NLB-W5 (Cladding 2)
f	NLB-W5 (Cladding 2)

Paths	FI-STC	FI-IIC
Dd	68	52
Df	> 70	
Fd	> 70	
Ff	> 75	
Flanking	**> 66**	
Total	**> 64**	

Specimen	Room Pairs	Junction name
B7000-07	USE->LSE	FTL-13-WJ235-FW-NLB-009

FTL-13-WJ235-FW-NLB-010

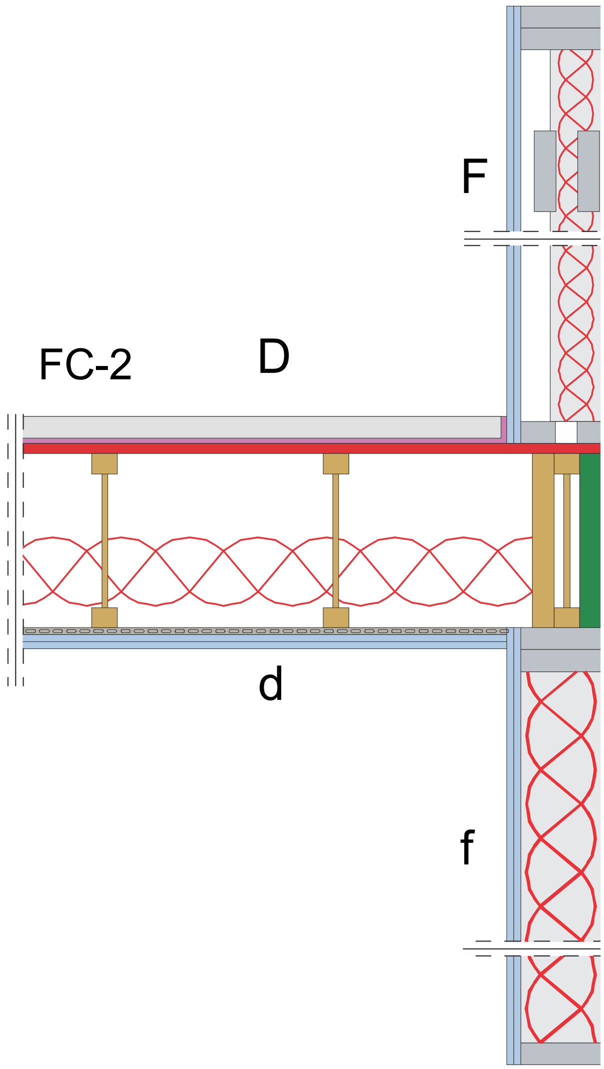


Element	Reference
D	FC-1 (Subfloor)
d	FC-1 (Ceiling)
F	NLB-W5 (Cladding 1)
f	NLB-W5 (Cladding 1)

Paths	FI-STC	FI-IIC
Dd	53	47
Df	> 60	
Fd	> 70	
Ff	> 75	
Flanking	**> 59**	
Total	**> 52**	

Specimen	Room Pairs	Junction name
B7000-07	USW->LSW	FTL-13-WJ235-FW-NLB-010

FTL-13-WJ235-FW-NLB-011

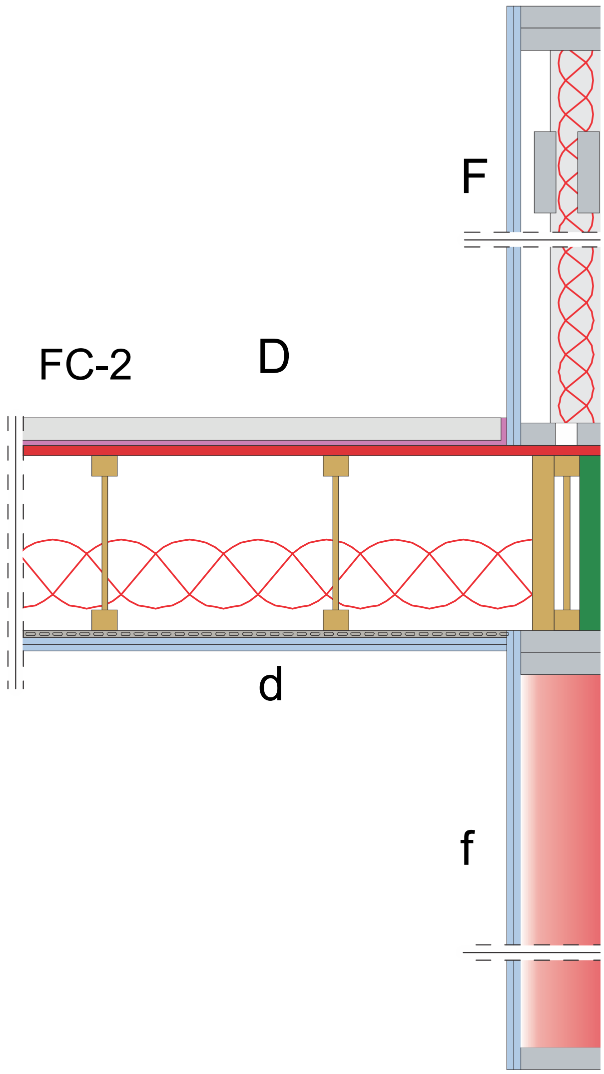


Element	Reference
D	FC-2 (Topping, Subfloor)
d	FC-2 (Ceiling)
F	NLB-W5/8 (Cladding 1)
f	NLB-W6 (Cladding 1)

Paths	FI-STC	FI-IIC
Dd	68	52
Df	> 70	
Fd	> 70	
Ff	> 75	
Flanking	**> 66**	
Total	**> 64**	

Specimen	Room Pairs	Junction name
B7000-08	USE->LSE	FTL-13-WJ235-FW-NLB-011a
B7000-09	USE->LSE	FTL-13-WJ235-FW-NLB-011b

FTL-13-WJ235-FW-NLB-014



Element	Reference
D	FC-2 (Topping, Subfloor)
d	FC-2 (Ceiling)
F	NLB-W5/8 (Cladding 1)
f	NLB-W7 (Cladding 1)

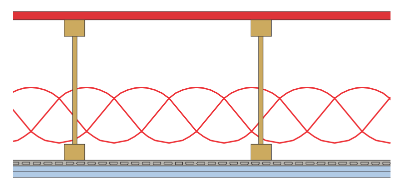
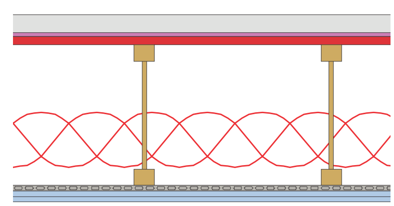
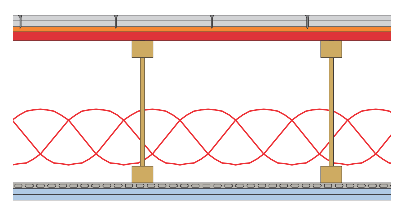
Paths	FI-STC	FI-IIC
Dd	68	52
Df	> 70	
Fd	> 70	
Ff	> 75	
Flanking	**> 66**	
Total	**> 64**	

Specimen	Room Pairs	Junction name
B7000-10	USE->LSE	FTL-13-WJ235-FW-NLB-014

A.3.4.8 Floor-Wall Load Bearing Junctions

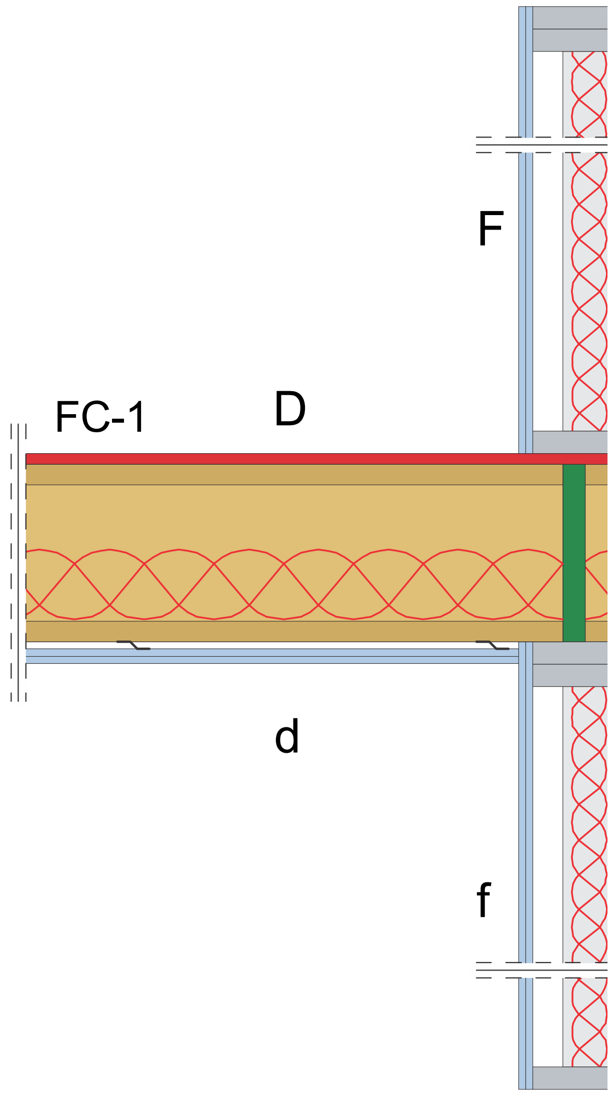
In this section, there are 12 distinct vertical floor-wall load bearing junctions with results of their flanking paths.

Junction Name	F	Direct (Dd)	f
FTL-13-WJ235-FW-LB-001	2G13	FC-1	2G13
FTL-13-WJ235-FW-LB-002	2G13_PLY16	FC-1	2G13_PLY16
FTL-13-WJ235-FW-LB-003	2G13	FC-1	2G13
FTL-13-WJ235-FW-LB-004	2G13	FC-2	2G13
FTL-13-WJ235-FW-LB-006	2G13	FC-4	2G13
FTL-13-WJ235-FW-LB-007	2G13	FC-2	2G13_RC
FTL-13-WJ235-FW-LB-008	2G13	FC-2	G16_RC
FTL-13-WJ235-FW-LB-009	2G13_PLY16	FC-1	2G13_PLY16
FTL-13-WJ235-FW-LB-010	2G13	FC-4	2G13
FTL-13-WJ235-FW-LB-012	2G13	FC-4	2G13
FTL-13-WJ235-FW-LB-015	2G13	FC-4	2G13

Separating Floor	Short Description	Side View
FC-1(Bare)	OSB16_WJ235(406)_GFB150_RC13(406)_G13_G13	
FC-2 (Gypsum concrete)	GCON38_RESL9_OSB16_WJ235(406)_GFB150 _RC13(406)_G13_G13	
FC-4 (Fastened cement board)	2CEMBRD13(screws)_OSB16_WJ235(406)_GFB150 _RC13(406)_G13_G13	

The floor and wall elements found in this section are described in detail in Appendix A.3.5 below.

FTL-13-WJ235-FW-LB-001

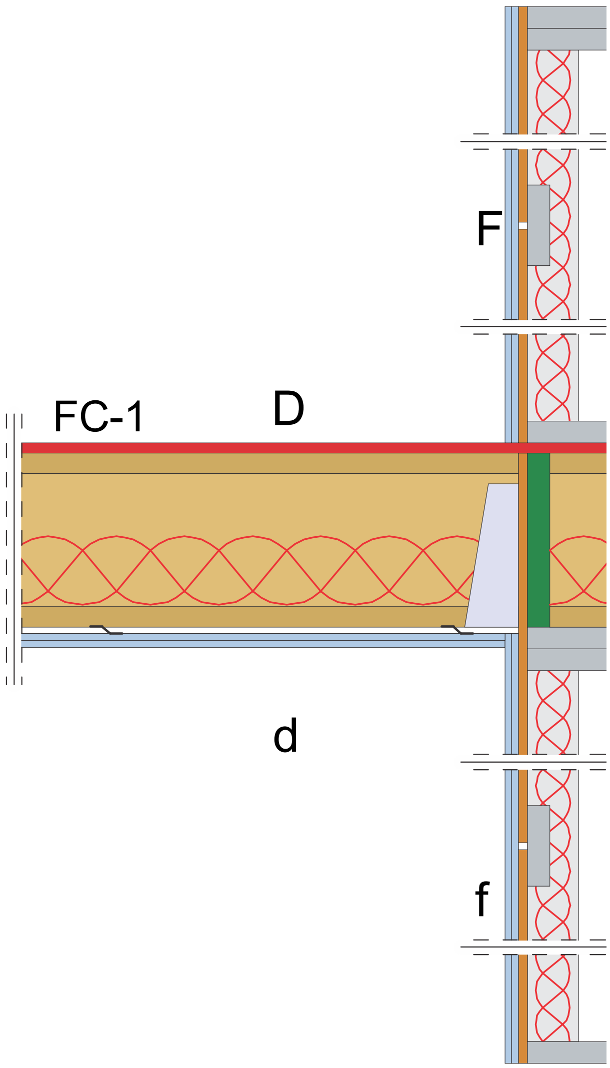


Element	Reference
D	FC-1 (Subfloor)
d	FC-1 (Ceiling)
F	LB-W1 (Cladding 1)
f	LB-W1 (Cladding 1)

Paths	FI-STC	FI-IIC
Dd	53	47
Df	> 60	
Fd	> 70	
Ff	> 75	
Flanking	**> 59**	
Total	**> 52**	

Specimen	Room Pairs	Junction name
B7000-01	UNE->LNE	FTL-13-WJ235-FW-LB-001a
B7000-01	USE->LSE	FTL-13-WJ235-FW-LB-001b
B7000-02	UNE->LNE	FTL-13-WJ235-FW-LB-001a
B7000-02	USE->LSE	FTL-13-WJ235-FW-LB-001b
B7000-03	UNE->LNE	FTL-13-WJ235-FW-LB-001a
B7000-04	UNE->LNE	FTL-13-WJ235-FW-LB-001a
B7000-05	UNE->LNE	FTL-13-WJ235-FW-LB-001a
B7000-06	UNE->LNE	FTL-13-WJ235-FW-LB-001a
B7000-07	UNE->LNE	FTL-13-WJ235-FW-LB-001a

FTL-13-WJ235-FW-LB-002

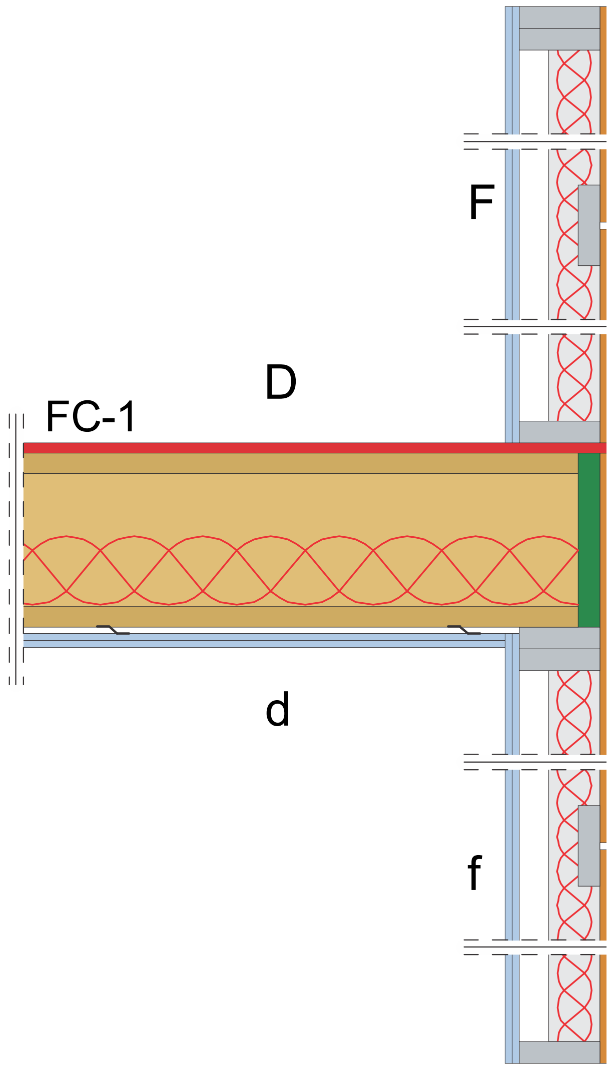


Element	Reference
D	FC-1 (Subfloor)
d	FC-1 (Ceiling)
F	LB-W2 (Cladding 1)
f	LB-W2 (Cladding 1)

Paths	FI-STC	FI-IIC
Dd	53	47
Df	> 60	
Fd	> 70	
Ff	> 75	
Flanking	**> 59**	
Total	**> 52**	

Specimen	Room Pairs	Junction name
B7000-01	USW->LSW	FTL-13-WJ235-FW-LB-002
B7000-02	USW->LSW	FTL-13-WJ235-FW-LB-002
B7000-03	USW->LSW	FTL-13-WJ235-FW-LB-002
B7000-04	USW->LSW	FTL-13-WJ235-FW-LB-002
B7000-05	USW->LSW	FTL-13-WJ235-FW-LB-002
B7000-06	USW->LSW	FTL-13-WJ235-FW-LB-002

FTL-13-WJ235-FW-LB-003

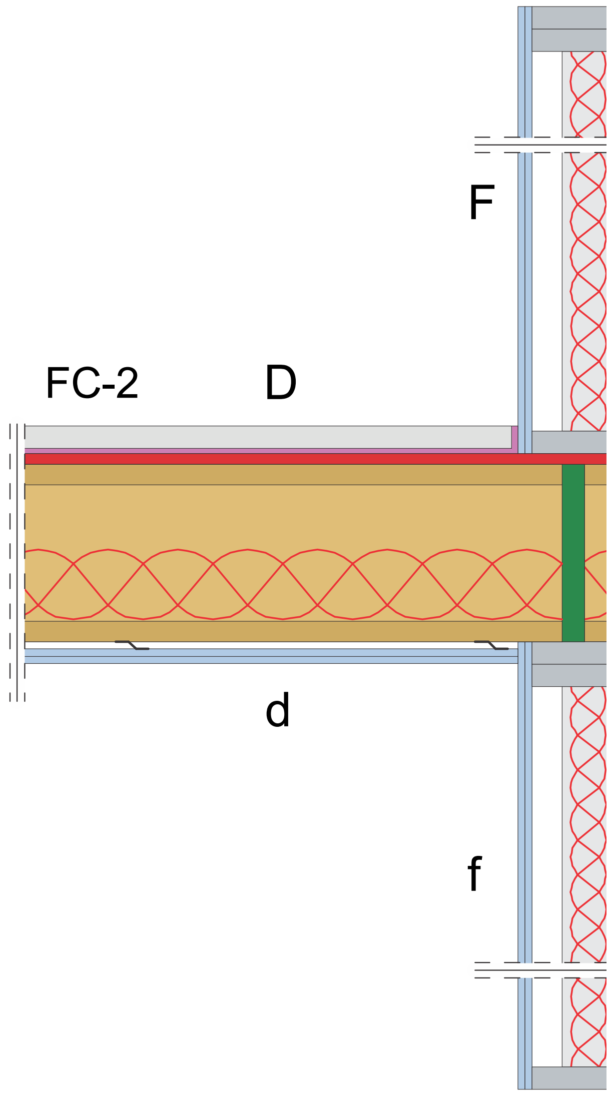


Element	Reference
D	FC-1 (Subfloor)
d	FC-1 (Ceiling)
F	LB-W2 (Cladding 1)
f	LB-W2 (Cladding 1)

Paths	FI-STC	FI-IIC
Dd	53	47
Df	> 60	
Fd	> 70	
Ff	> 75	
Flanking	**> 59**	
Total	**> 52**	

Specimen	Room Pairs	Junction name
B7000-01	UNW->LNW	FTL-13-WJ235-FW-LB-003
B7000-02	UNW->LNW	FTL-13-WJ235-FW-LB-003

FTL-13-WJ235-FW-LB-004

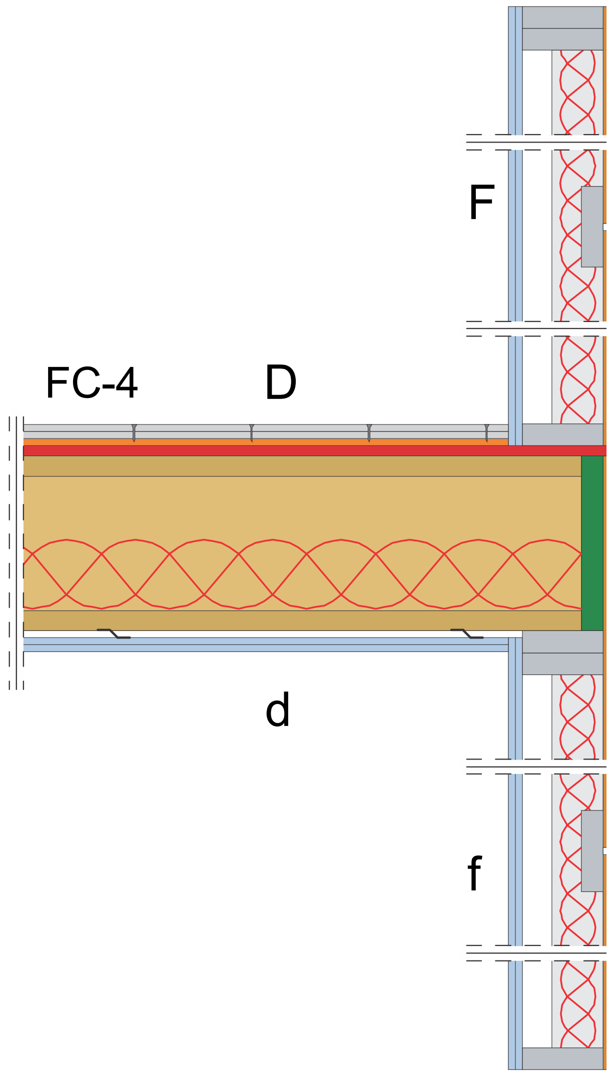


Element	Reference
D	FC-2 (Topping, Subfloor)
d	FC-2 (Ceiling)
F	LB-W1 (Cladding 1)
f	LB-W1 (Cladding 1)

Paths	FI-STC	FI-IIC
Dd	68	52
Df	> 70	
Fd	> 70	
Ff	> 75	
Flanking	**> 66**	
Total	**> 64**	

Specimen	Room Pairs	Junction name
B7000-03	USE->LSE	FTL-13-WJ235-FW-LB-004
B7000-04	USE->LSE	FTL-13-WJ235-FW-LB-004v

FTL-13-WJ235-FW-LB-006

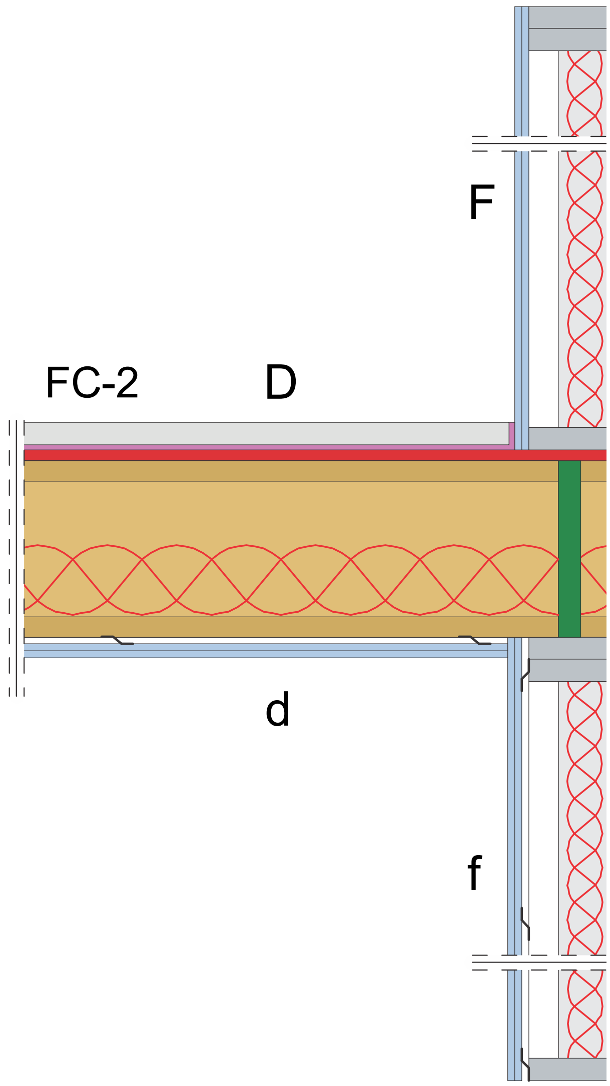


Element	Reference
D	FC-4 (Topping, Subfloor)
d	FC-4 (Ceiling)
F	LB-W2 (Cladding 2)
f	LB-W2 (Cladding 2)

Paths	FI-STC	FI-IIC
Dd	57	50
Df	> 65	
Fd	> 70	
Ff	> 75	
Flanking	**> 63**	
Total	**> 56**	

Specimen	Room Pairs	Junction name
B7000-04	UNW->LNW	FTL-13-WJ235-FW-LB-006
B7000-05	UNW->LNW	FTL-13-WJ235-FW-LB-006
B7000-06	UNW->LNW	FTL-13-WJ235-FW-LB-006

FTL-13-WJ235-FW-LB-007

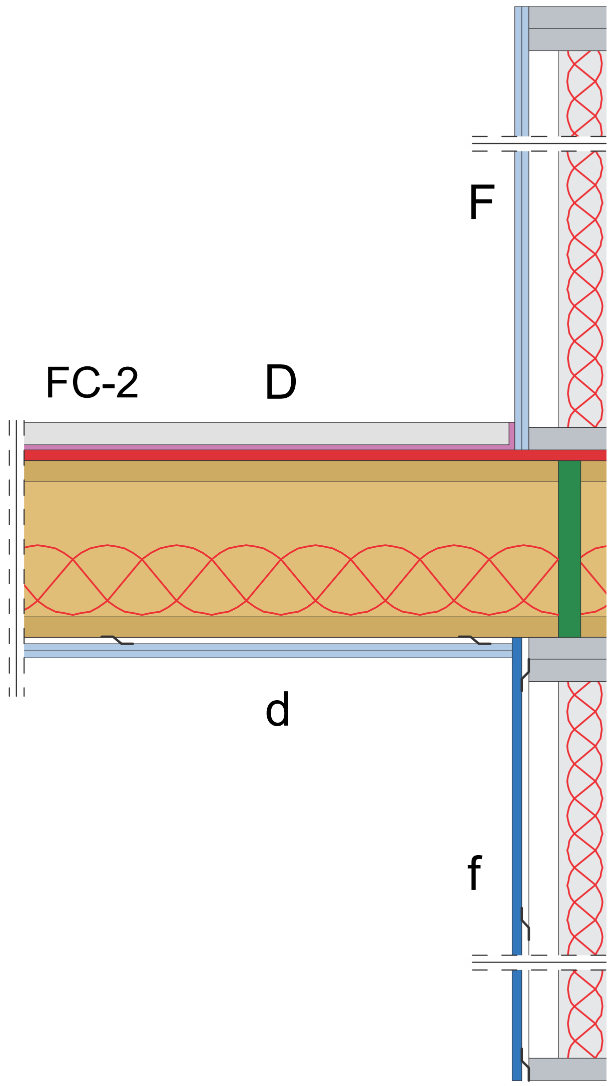


Element	Reference
D	FC-2 (Topping, Subfloor)
d	FC-2 (Ceiling)
F	LB-W1 (Cladding 1)
f	LB-W3 (Cladding 1)

Paths	FI-STC	FI-IIC
Dd	68	52
Df	> 75	
Fd	> 70	
Ff	> 80	
Flanking	**> 68**	
Total	**> 65**	

Specimen	Room Pairs	Junction name
B7000-05	USE->LSE	FTL-13-WJ235-FW-LB-007

FTL-13-WJ235-FW-LB-008

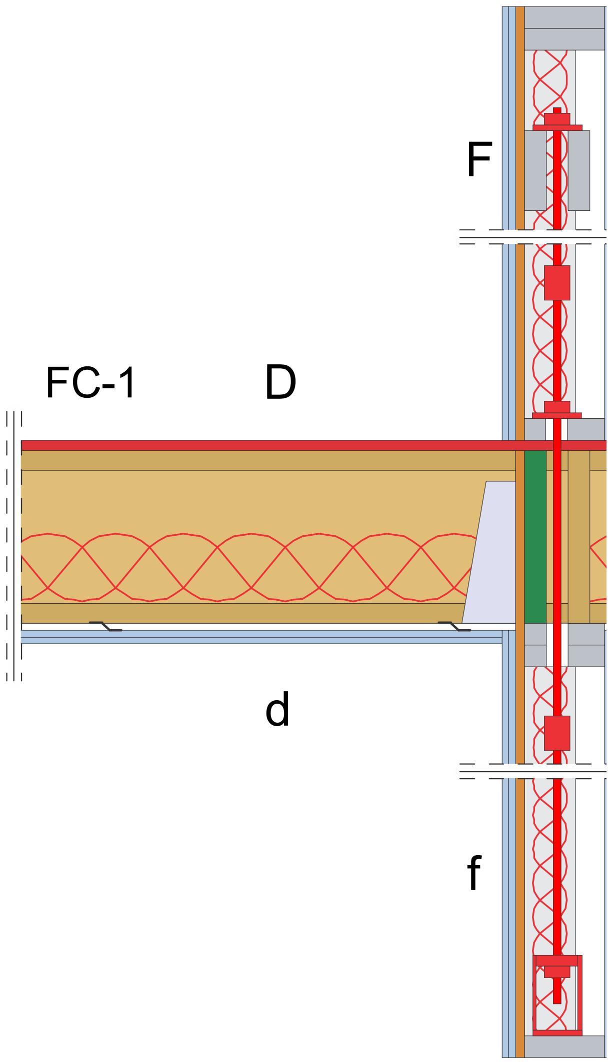


Element	Reference
D	FC-2 (Topping, Subfloor)
d	FC-2 (Ceiling)
F	LB-W1 (Cladding 1)
f	LB-W4 (Cladding 1)

Paths	FI-STC	FI-IIC
Dd	68	52
Df	> 70	
Fd	> 70	
Ff	> 75	
Flanking	**> 66**	
Total	**> 64**	

Specimen	Room Pairs	Junction name
B7000-06	USE->LSE	FTL-13-WJ235-FW-LB-008
B7000-07	USE->LSE	FTL-13-WJ235-FW-LB-008

FTL-13-WJ235-FW-LB-009

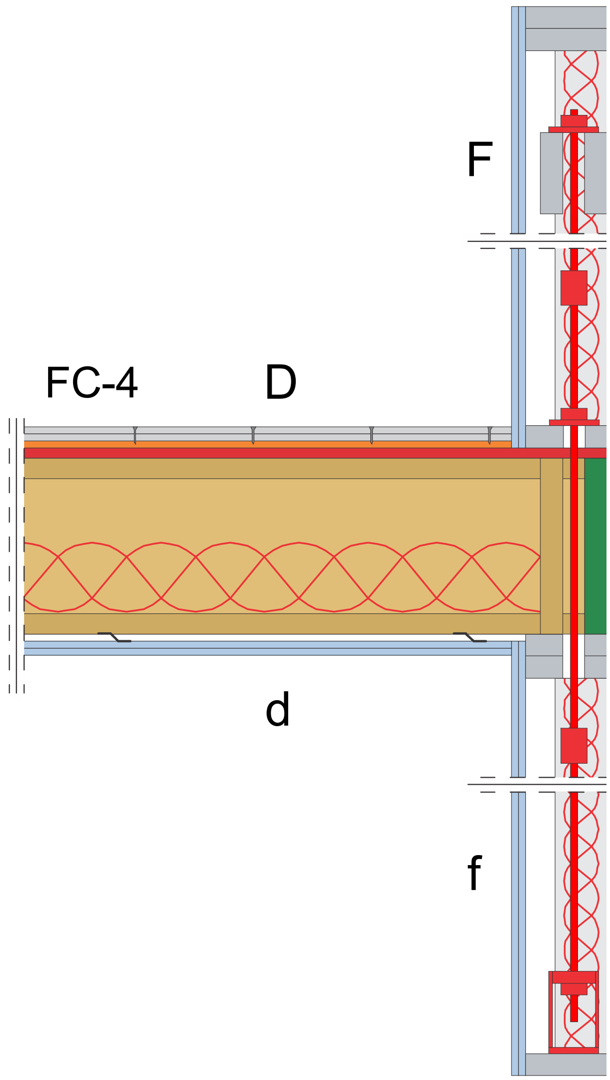


Element	Reference
D	FC-1 (Subfloor)
d	FC-1 (Ceiling)
F	LB-W5 (Cladding 1)
f	LB-W5 (Cladding 1)

Paths	FI-STC	FI-IIC
Dd	53	47
Df	> 60	
Fd	> 70	
Ff	> 75	
Flanking	**> 59**	
Total	**> 52**	

Specimen	Room Pairs	Junction name
B7000-07	USW->LSW	FTL-13-WJ235-FW-LB-009

FTL-13-WJ235-FW-LB-010

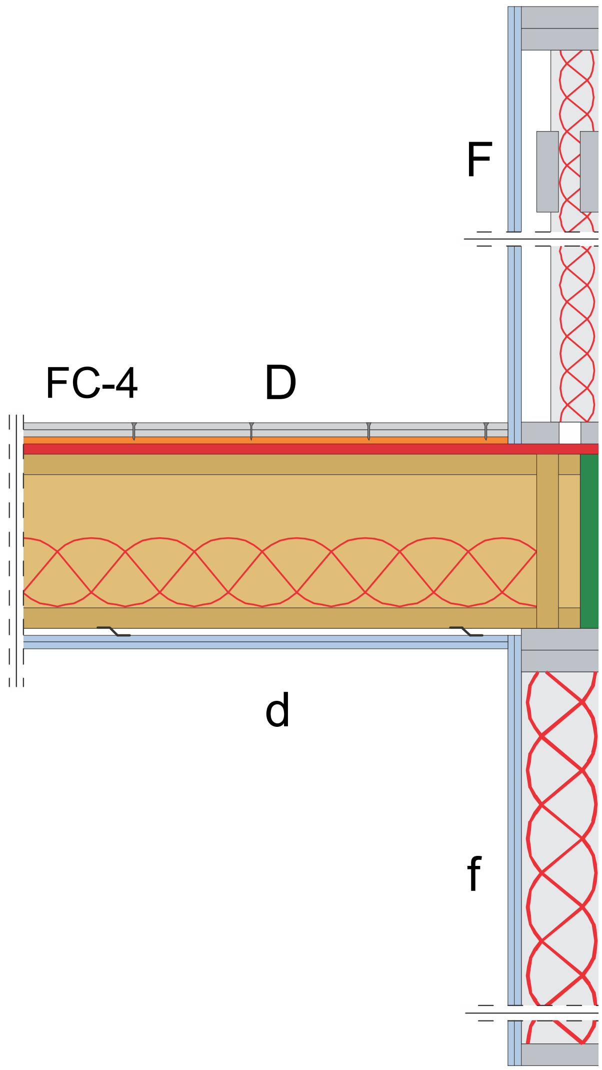


Element	Reference
D	FC-4 (Topping, Subfloor)
d	FC-4 (Ceiling)
F	LB-W5 (Cladding 2)
f	LB-W5 (Cladding 2)

Paths	FI-STC	FI-IIC
Dd	57	50
Df	> 65	
Fd	> 70	
Ff	> 75	
Flanking	**> 63**	
Total	**> 56**	

Specimen	Room Pairs	Junction name
B7000-07	UNW->LNW	FTL-13-WJ235-FW-LB-010

FTL-13-WJ235-FW-LB-012

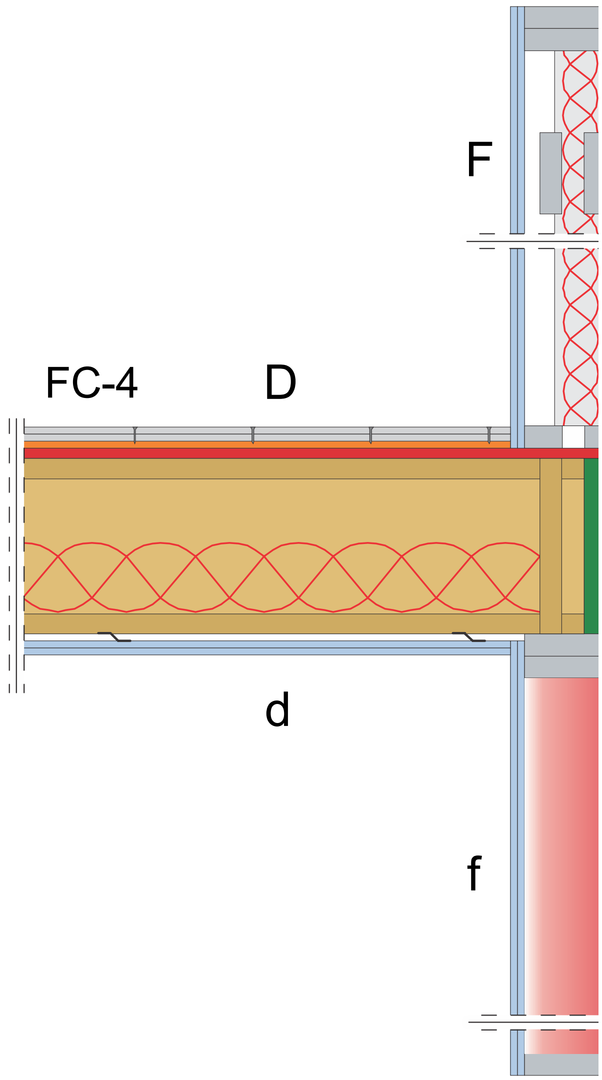


Element	Reference
D	FC-4 (Topping, Subfloor)
d	FC-4 (Ceiling)
F	LB-W5/8 (Cladding 2)
f	LB-W6 (Cladding 1)

Paths	FI-STC	FI-IIC
Dd	57	50
Df	> 65	
Fd	> 70	
Ff	> 75	
Flanking	**> 63**	
Total	**> 56**	

Specimen	Room Pairs	Junction name
B7000-08	UNW->LNW	FTL-13-WJ235-FW-LB-012a
B7000-09	UNW->LNW	FTL-13-WJ235-FW-LB-012b

FTL-13-WJ235-FW-LB-015



Element	Reference
D	FC-4 (Topping, Subfloor)
d	FC-4 (Ceiling)
F	LB-W5/8 (Cladding 2)
f	LB-W7 (Cladding 1)

Paths	FI-STC	FI-IIC
Dd	57	50
Df	> 65	
Fd	> 70	
Ff	> 75	
Flanking	**> 63**	
Total	**> 56**	

Specimen	Room Pairs	Junction name
B7000-10	UNW->LNW	FTL-13-WJ235-FW-LB-015

A.3.5 Partition details

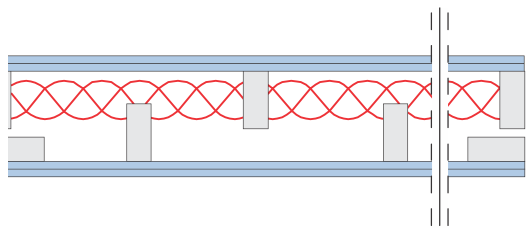
A.3.5.1 Non-Load Bearing Walls

The framing of the walls that do not support the floor ("non-load bearing walls") in mid-rise buildings is similar to the wall framing of low-rise buildings since no significant additional axial dead loads from upper storeys must be supported. However, these walls are often braced and used as shear walls with a lateral load bearing capacity.

The specimens used in the light framed flanking study include common 2x4 staggered stud walls without (NLB-W1) and with (NLB-W2) shear bracing (Walls 1WS/WN and 7WS of "Preparatory Wall Study"), walls with resilient channels (NLB-W3 and NLB-W4), walls with tie-down rods (NLB-W5) and two exterior walls (NLB-W6 and NLB-W7).

NLB-W1 (no shear membrane/bracing)

Top View



G13_G13_SWS140(406)_GFB90_G13_G13

Description

Two layers of gypsum board directly attached on each side of 2x4 staggered wood studs

Cladding 1

- Two layers of 12.7 mm Type X gypsum board installed vertically.
- Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field.
- Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field.
- Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Framing & Cavity Insulation

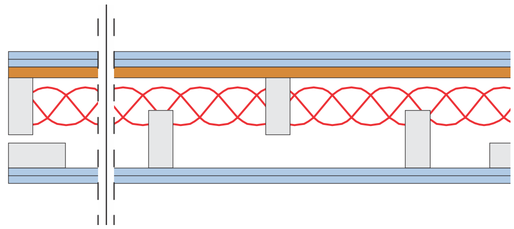
- Staggered 2x4 wood studs spaced 406 mm o.c.
- Studs were toe-screwed using 4 screws at the top and bottom.
- Two 2x4 end studs toe screwed from one side and screwed to adjacent stud with #10 - 75 mm long screws spaced 750 mm o.c. The end studs were installed on one side of the assembly with another 2x4 installed flat-wise on the other side.
- Double 2x6 headers and single 2x6 footer
- Cavities between studs on one side filled with 90 mm glass fibre insulation (R-12)

Cladding 2

- Same as cladding 1.

NLB-W2 (shear membrane/bracing)

Top View

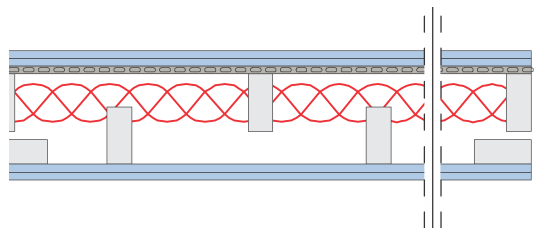


G13_G13_PLY16_SWS140(406)_GFB90_G13_G13

Description	Two layers of gypsum board directly attached on each side of 2x4 staggered wood studs with one layer of shear membrane
Cladding 1	• Two layers of 12.7 mm Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
Shear Membrane	• One layer of 15.9 mm plywood installed horizontally with horizontal gap with pieces of 2x6 studs attached flat-wise mid-height of the wall. • Plywood shear membrane continuous to subfloor and attached using #10, 75 mm long screws spaced at 75 mm in the field and along the edge.
Framing & Cavity Insulation	• Staggered 2x4 wood studs spaced 406 mm o.c. • Studs were toe-screwed using 4 screws at the top and bottom. • The end studs were installed on one side of the assembly with another 2x4 installed flat-wise on the other side. • Double 2x6 headers and single 2x6 footer • Cavities between studs on one side filled with 90 mm glass fibre insulation (R12)
Cladding 2	• Same as cladding 1 without the shear membrane.

NLB-W3 (RC – 2 gypsum board layers)

Top View

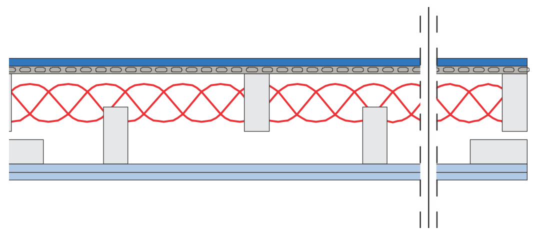


G13_G13_RC(610)_SWS140(406)_GFB90_G13_G13

Description	Two layers of gypsum board on resilient channels on one side and two layers of gypsum board directly attached on one side of 2x4 staggered wood studs
Cladding 1	• Two layers of 12.7 mm Type X gypsum board installed vertically. • Base layer gypsum board attached to RC using Type S screws 31 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board attached to RC using Type S screws 41 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape. • Resilient channels installed horizontally with spacing of 610 mm oc with lowermost channel inverted.
Framing & Cavity Insulation	• Staggered 2x4 wood studs spaced 406 mm o.c. • Studs were toe-screwed using 4 screws at the top and bottom. • The end studs were installed on one side of the assembly with another 2x4 installed flat-wise on the other side. • Double 2x6 headers and single 2x6 footer • Cavities between studs on one side filled with 90 mm glass fibre insulation (R12)
Cladding 2	• Two layers of 12.7 mm Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

NLB-W4 (RC – 1 gypsum board layer)

Top View



G13_G13_SWS140(406)_GFB90_G13_G13

Description

One layer of gypsum board on resilient channels on one side and two layers of gypsum board directly attached on one side of 2x4 staggered wood studs

Cladding 1

- One layers of 15.9 mm Type X gypsum board installed vertically to RC using Type S screws 31 mm long spaced 300 mm along the edge and in the field.
- The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
- Resilient channels installed horizontally with spacing of 610 mm oc with lowermost channel inverted.

Framing & Cavity Insulation

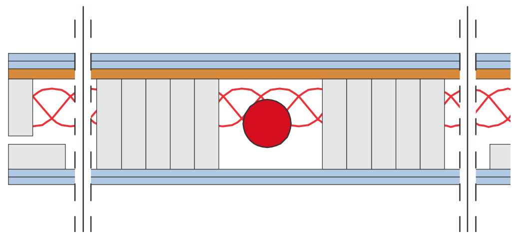
- Staggered 2x4 wood studs spaced 406 mm o.c.
- Studs were toe-screwed using 4 screws at the top and bottom.
- The end studs were installed on one side of the assembly with another 2x4 installed flat-wise on the other side.
- Double 2x6 headers and single 2x6 footer
- Cavities between studs on one side filled with 90 mm glass fibre insulation (R12)

Cladding 2

- Two layers of 12.7 mm Type X gypsum board installed vertically.
- Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field.
- Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field.
- Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

NLB-W5 (Tie-down)

Top View

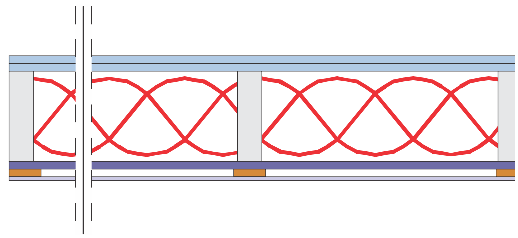


G13_G13_SWS140(406)_GFB90_G13_G13

Description	Two layers of gypsum board directly attached on each side of 2x4 staggered wood studs with one layer of shear membrane and tiedown system including loading columns
Cladding 1	• Two layers of 12.7 mm Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
Shear Membrane	• One layer of 15.9 mm plywood installed horizontally with horizontal gap with pieces of 2x6 studs attached flat-wise mid-height of the wall. • Plywood shear membrane continuous to subfloor and attached using #10, 75 mm long screws spaced at 75 mm in the field and along the edge.
Framing & Cavity Insulation	• Staggered 2x4 wood studs spaced 406 mm o.c. • Studs were toe-screwed using 4 screws at the top and bottom. • The end studs were installed on one side of the assembly with another 2x4 installed flat-wise on the other side. • Double 2x6 headers and single 2x6 footer • Cavities between studs on one side filled with 90 mm glass fibre insulation (R12) • Simpson Strong-Tie Anchor Tiedown System (ATS) installed in the middle of the wall with five 2x6 studs on each side as loading columns.
Cladding 2	• Same as cladding 1 without the shear membrane

NLB-W6 (exterior wall – glass fibre batts)

Top View

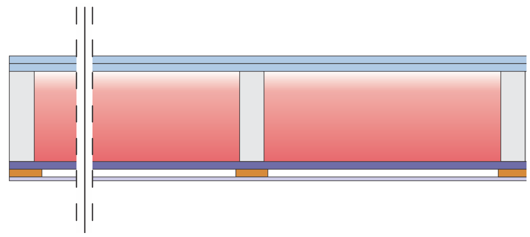


G13_G13_WS140(406)_GFB140_EXTG13_WFUR13(406)_CEMBRD7

Description	Two layers of gypsum board directly attached (inside) on one side of 2x6 wood studs with glass fibre batts and one layer of exterior grade gypsum board with vertical wood strapping and cement panels.
Interior Cladding	• Two layers of 12.7 mm Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
Framing & Cavity Insulation	• 2x6 wood studs spaced 406 mm o.c. • Double 2x6 headers and single 2x6 footer • Cavities between studs filled with 140 mm glass fibre insulation (R20)
Outside Cladding	• One layer of 12.7 mm exterior grade gypsum board (1220 x 2440 mm^2) installed vertically with 41 mm Type S screws spaced 100 mm along the edge and 203 mm in the field. The gaps along the joints and the perimeter were caulked and taped with aluminum tape. Acoustic caulk was applied around the edge of the wall and the facility. • 12.7 mm thick x 50 mm wide wood furring installed vertically and spaced 406 mm o.c. and attached to each stud using 38 mm Type G screws spaced 610 mm along the studs. • One layer of 7 mm (5/16”) cement panels (cut to 813 x 1524 mm^2) installed vertically and attached to wood furring using 38 mm Type G screws spaced 100 mm o.c. along the edge and in the field. One horizontal gap of 12.7 mm left between cement panels.

NLB-W7 (exterior wall – spray foam insulation)

Top View



G13_G13_WS140(406)_SPFOAM140_EXTG13_WFUR13(406)_CEMBRD7

Description

Two layers of gypsum board directly attached (inside) on one side of 2x6 wood studs with spray foam insulation and one layer of exterior grade gypsum board with vertical wood strapping and cement panels.

Interior Cladding

- Two layers of 12.7 mm Type X gypsum board installed vertically.
- Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field.
- Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field.
- Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Framing & Cavity Insulation

- 2x6 wood studs spaced 406 mm o.c.
- Double 2x6 headers and single 2x6 footer
- Cavities between studs filled with spray foam insulation from the interior side. Small cavity left on the inside to attach interior drywall.

Outside Cladding

- One layer of 12.7 mm exterior grade gypsum board (1220 x 2440 mm^2) installed vertically with 41 mm Type S screws spaced 100 mm along the edge and 203 mm in the field. The gaps along the joints and the perimeter were caulked and taped with aluminum tape. Acoustic caulk was applied around the edge of the wall and the facility.
- 12.7 mm thick x 50 mm wide wood furring installed vertically and spaced 406 mm o.c. and attached to each stud using 38 mm Type G screws spaced 610 mm along the studs.
- One layer of 7 mm (5/16") cement panels (cut to 813 x 1524 mm^2) installed vertically and attached to wood furring using 38 mm Type G screws spaced 100 mm o.c. along the edge and in the field. One horizontal gap of 12.7 mm left between cement panels.

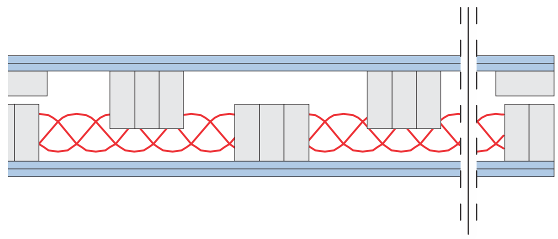
A.3.5.2 Load Bearing Walls

The framing of the walls that support the floor ("load bearing walls") in mid-rise buildings is very different from the wall framing in low-rise buildings since significant additional axial dead loads from upper storeys must be supported. Further, these walls are sometimes shear braced to increase the lateral load bearing capacity of these walls.

The specimens include axial load bearing 2x4 triple staggered stud walls without (LB-W1) and with (LB-W2) shear bracing (Wall 11WS and 12WS-b of "Preparatory Wall Study"), walls with resilient channels (LB-W3 and LB-W4), walls with tie-down rods (LB-W5) and two exterior walls (LB-W6 and LB-W7).

LB-W1 (no shear membrane/bracing)

Top View

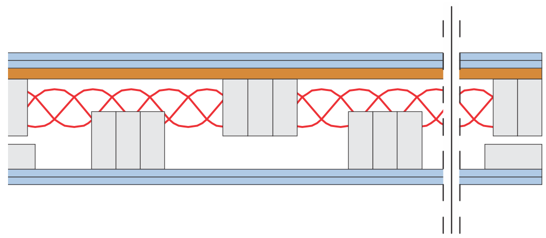


G13_G13_3SWS140(406)_GFB90_G13_G13

Description	Two layers of gypsum board directly attached on each side of tripled 2x4 staggered wood studs
Cladding 1	• Two layers of 12.7 mm Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Cladding directly attached to tripled wood studs along single line. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
Framing & Cavity Insulation	• Tripled staggered 2x4 wood studs spaced 406 mm o.c. • Middle stud was toe-screwed using 4 screws at the top and bottom. • Two added 2x4 studs were attached with 2 toe screws and with screws at 600 mm o.c. with #10, 75 mm long screws from one side only. • Two 2x4 end studs toe screwed from one side and screwed to adjacent stud with #10, 75 mm long screws spaced 750 mm o.c. • The end studs were installed on one side of the assembly with another 2x4 installed flat-wise on the other side. • Double 2x6 headers and single 2x6 footer • Cavities between studs on one side filled with 90 mm glass fibre insulation (R12)
Cladding 2	• Same as cladding 1

LB-W2 (shear membrane/bracing)

Top View

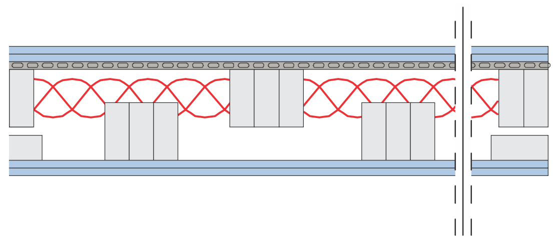


G13_G13_PLY16_3SWS140(406)_GFB90_G13_G13

Description	Two layers of Type X gypsum board directly attached on one side with 15.9 mm plywood shear membrane installed horizontally with blocking and two layers of gypsum board Type X directly attached on the other side of tripled 2x4 staggered wood studs
Cladding 1	• Two layers of 12.7 mm Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Cladding directly attached to tripled wood studs along single line. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
Shear Membrane	• One layer of 15.9 mm plywood installed horizontally with horizontal gap with pieces of 2x6 studs attached flat-wise mid-height of the wall. • Plywood shear membrane continuous to subfloor and attached using #10, 75 mm long screws spaced at 75 mm in the field and along the edge.
Framing & Cavity Insulation	• Tripled staggered 2x4 wood studs spaced 406 mm o.c. • Middle stud was toe-screwed using 4 screws at the top and bottom. • Two added 2x4 studs were attached with 2 toe screws and with screws at 600 mm o.c. with #10, 75 mm long screws from one side only. • Two 2x4 end studs toe screwed from one side and screwed to adjacent stud with #10, 75 mm long screws spaced 750 mm o.c. The end studs were installed on one side of the assembly with another 2x4 installed flat-wise on the other side. • Double 2x6 headers and single 2x6 footer • Cavities between studs on one side filled with 90 mm glass fibre insulation (R12)
Cladding 2	• Same as cladding 1 without the shear membrane

LB-W3 (RC – 2 gypsum board layers)

Top View

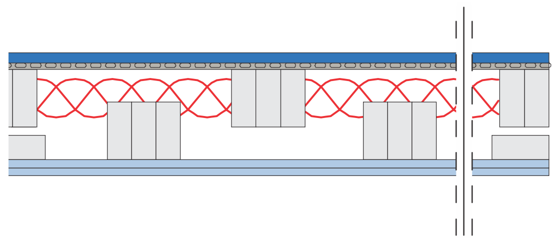


G13_G13_PLY16_3SWS140(406)_GFB90_G13_G13

Description	Two layers of Type X gypsum board directly attached on one side with 15.9 mm plywood shear membrane installed horizontally with blocking and two layers of gypsum board Type X directly attached on the other side of tripled 2x4 staggered wood studs
Cladding 1	• Two layers of 12.7 mm Type X gypsum board installed vertically. • Base layer gypsum board attached to RC using Type S screws 32 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board attached to RC using Type S screws 41 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape. • Resilient channels installed horizontally with spacing of 610 mm oc with lowermost channel inverted and were attached to middle stud only.
Framing & Cavity Insulation	• Tripled staggered 2x4 wood studs spaced 406 mm o.c. • Middle stud was toe-screwed using 4 screws at the top and bottom. • Two added 2x4 studs were attached with 2 toe screws and with screws at 600 mm o.c. with #10, 75 mm long screws from one side only. • Two 2x4 end studs toe screwed from one side and screwed to adjacent stud with #10, 75 mm long screws spaced 750 mm o.c. The end studs were installed on one side of the assembly with another 2x4 installed flat-wise on the other side. • Double 2x6 headers and single 2x6 footer • Cavities between studs on one side filled with 90 mm glass fibre insulation (R12)
Cladding 2	• Two layers of 12.7 mm Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 50 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 62 mm long spaced 300 mm along the edge and in the field. • Cladding directly attached to tripled wood studs along single line. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

LB-W4 (RC – 1 gypsum board layer)

Top View



G13_G13_PLY16_3SWS140(406)_GFB90_G13_G13

Description

Two layers of Type X gypsum board directly attached on one side with 15.9 mm plywood shear membrane installed horizontally with blocking and two layers of gypsum board Type X directly attached on the other side of tripled 2x4 staggered wood studs

Cladding 1

- One layers of 15.9 mm Type X gypsum board installed vertically to RC using Type S screws 32 mm long spaced 300 mm along the edge and in the field.
- The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
- Resilient channels installed horizontally with spacing of 610 mm oc with lowermost channel inverted and were attached to middle stud only.

Framing & Cavity Insulation

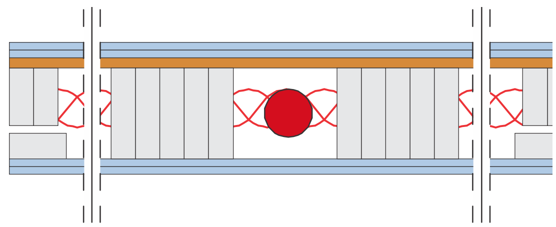
- Tripled staggered 2x4 wood studs spaced 406 mm o.c.
- Middle stud was toe-screwed using 4 screws at the top and bottom.
- Two added 2x4 studs were attached with 2 toe screws and with screws at 600 mm o.c. with #10, 75 mm long screws from one side only.
- Two 2x4 end studs toe screwed from one side and screwed to adjacent stud with #10, 75 mm long screws spaced 750 mm o.c. The end studs were installed on one side of the assembly with another 2x4 installed flat-wise on the other side.
- Double 2x6 headers and single 2x6 footer
- Cavities between studs on one side filled with 90 mm glass fibre insulation (R12)

Cladding 2

- Two layers of 12.7 mm Type X gypsum board installed vertically.
- Base layer gypsum board directly attached using Type S screws 50 mm long spaced 600 mm along the edge and in the field.
- Face layer gypsum board directly attached using Type S screws 62 mm long spaced 300 mm along the edge and in the field.
- Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

LB-W5 (Tie-down)

Top View

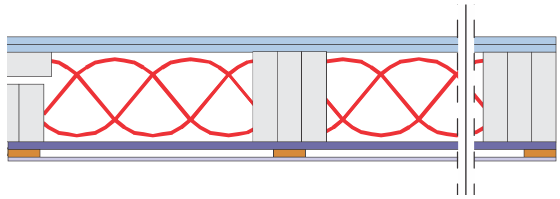


G13_G13_PLY16_3SWS140(406)_GFB90_G13_G13

Description	Two layers of gypsum board directly attached on each side of tippled 2x4 staggered wood studs with one layer of shear membrane and tiedown system including loading columns
Cladding 1	• Two layers of 12.7 mm Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
Shear Membrane	• One layer of 15.9 mm plywood installed horizontally with horizontal gap with pieces of 2x6 studs attached flat-wise mid-height of the wall. • Plywood shear membrane continuous to subfloor and attached using #10, 75 mm long screws spaced at 75 mm in the field and along the edge.
Framing & Cavity Insulation	• Tripled staggered 2x4 wood studs spaced 406 mm o.c. • Middle stud was toe-screwed using 4 screws at the top and bottom. • Two added 2x4 studs were attached with 2 toe screws and with screws at 600 mm o.c. with #10, 75 mm long screws from one side only. • Two 2x4 end studs toe screwed from one side and screwed to adjacent stud with #10, 75 mm long screws spaced 750 mm o.c. The end studs were installed on one side of the assembly with another 2x4 installed flat-wise on the other side. • Double 2x6 headers and single 2x6 footer • Cavities between studs on one side filled with 90 mm glass fibre insulation (R12) • Simpson Strong-Tie Anchor Tiedown System (ATS) installed in the middle of the wall with five 2x6 studs on each side as loading columns.
Cladding 2	• Same as cladding 1 without the shear membrane

LB-W6 (exterior wall – glass fibre batts)

Top View

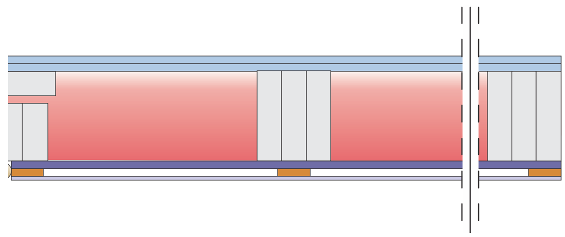


G13_G13_3WS140(406)_GFB140_EXTG13_WFUR13(406)_CEMBRD7

Description	Two layers of gypsum board directly attached (inside) on one side of tippled 2x6 wood studs with glass fibre batts and one layer of exterior grade gypsum board with vertical wood strapping and cement panels.
Interior Cladding	• Two layers of 12.7 mm Type X gypsum board installed vertically. • Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.
Framing & Cavity Insulation	• Tripled 2x6 wood studs spaced 406 mm o.c. • Middle stud was toe-screwed using 4 screws at the top and bottom. • Two added 2x6 studs were attached with 2 toe screws and with screws at 600 mm o.c. with #10, 75 mm long screws from one side only. • Two 2x4 end studs toe screwed from one side and screwed to adjacent stud with #10, 75 mm long screws spaced 750 mm o.c. The end studs were installed on one side of the assembly with another 2x4 installed flat-wise on the other side. • Double 2x6 headers and single 2x6 footer • Cavities between studs filled with 140 mm glass fibre insulation (R20)
Outside Cladding	• One layer of 12.7 mm exterior grade gypsum board (1220 x 2440 mm^2) installed vertically with 41 mm Type S screws spaced 100 mm along the edge and 203 mm in the field. The gaps along the joints and the perimeter were caulked and taped with aluminum tape. Acoustic caulk was applied around the edge of the wall and the facility. • 12.7 mm thick x 50 mm wide wood furring installed vertically and spaced 406 mm o.c. and attached to each stud using 38 mm Type G screws spaced 610 mm along the studs. • One layer of 7 mm (5/16”) cement panels (cut to 813 x 1524 mm^2) installed vertically and attached to wood furring using 38 mm Type G screws spaced 100 mm o.c. along the edge and in the field. One horizontal gap of 12.7 mm left between cement panels.

LB-W7 (exterior wall – spray foam insulation)

Top View



G13_G13_3WS140(406)_SPFOAM140_EXTG13_WFUR13(406)_CEMBRD7

Description

Two layers of gypsum board directly attached (inside) on one side of tippled 2x6 wood studs with spray foam insulation and one layer of exterior grade gypsum board with vertical wood strapping and cement panels.

Interior Cladding

- Two layers of 12.7 mm Type X gypsum board installed vertically.
- Base layer gypsum board directly attached using Type S screws 41 mm long spaced 600 mm along the edge and in the field.
- Face layer gypsum board directly attached using Type S screws 50 mm long spaced 300 mm along the edge and in the field.
- Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

Framing & Cavity Insulation

- Tripled 2x6 wood studs spaced 406 mm o.c.
- Middle stud was toe-screwed using 4 screws at the top and bottom.
- Two added 2x6 studs were attached with 2 toe screws and with screws at 600 mm o.c. with #10, 75 mm long screws from one side only.
- Two 2x4 end studs toe screwed from one side and screwed to adjacent stud with #10, 75 mm long screws spaced 750 mm o.c. The end studs were installed on one side of the assembly with another 2x4 installed flat-wise on the other side.
- Double 2x6 headers and single 2x6 footer
- Cavities between studs filled with spray foam insulation from the interior side. Small cavity left on the inside to attach interior drywall.

Outside Cladding

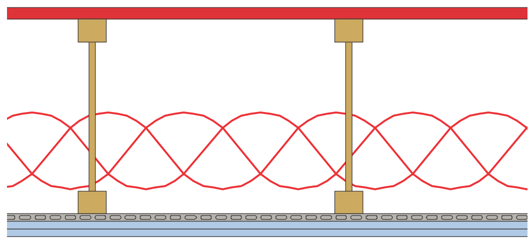
- One layer of 12.7 mm exterior grade gypsum board (1220 x 2440 mm^2) installed vertically with 41 mm Type S screws spaced 100 mm along the edge and 203 mm in the field. The gaps along the joints and the perimeter were caulked and taped with aluminum tape. Acoustic caulk was applied around the edge of the wall and the facility.
- 12.7 mm thick x 50 mm wide wood furring installed vertically and spaced 406 mm o.c. and attached to each stud using 38 mm Type G screws spaced 610 mm along the studs.
- One layer of 7 mm (5/16”) cement panels (cut to 813 x 1524 mm^2) installed vertically and attached to wood furring using 38 mm Type G screws spaced 100 mm o.c. along the edge and in the field. One horizontal gap of 12.7 mm left between cement panels.

A.3.5.3 Floors

The specimens include a total of four floor types: a base floor (FC-1), a base floor with a concrete gypsum topping (FC-2), and a base floor with a screwed down concrete board topping (FC-4).

FC-1 (Bare)

Side View

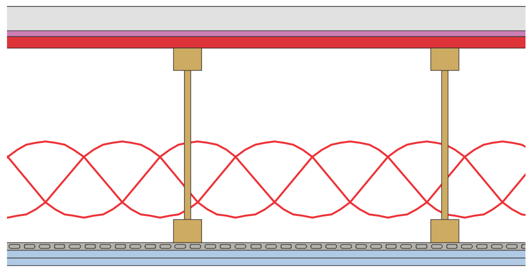


OSB16_WI302(406)_GFB150_RC13(406)_G13_G13

Description	**Base floor assembly, F9g from the NBCC 2010** (STC 51, 1 h fire resistance rating) One layer of OSB installed on wood I-joists with two layers of gypsum board Type X on resilient channels.
Subfloor	• One layer of 15.9 mm OSB installed with long axis perpendicular to the joists. • Subfloor directly attached to wood I-joists using #8 screws 50 mm long spaced 150 mm along the edge and 300 mm in the field.
Framing & Cavity Insulation	• Wood I-joists (type TJI 110) 302 mm deep spaced 406 mm o.c. and toe-screwed using 4 screws on each side (2 on wall header and 2 on rim board). Joists hangers were only used on the load bearing wall of the LSW room. • Rim boards (45 mm thick and 302 mm deep) installed at each ends of the wood I-joists. • Cavities between I-joists filled with 150 mm glass fibre insulation (R-20)
Ceiling	• Resilient channels installed perpendicular to wood I-joists and spaced 406 mm o.c. using 32 mm type W screws. • Two layers of 12.7 mm Type X gypsum board installed with long axis perpendicular to resilient channels. • Base layer gypsum board attached to RC using Type S screws 32 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board attached to RC using Type S screws 41 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

FC-2 (Gypsum concrete topping)

Side View

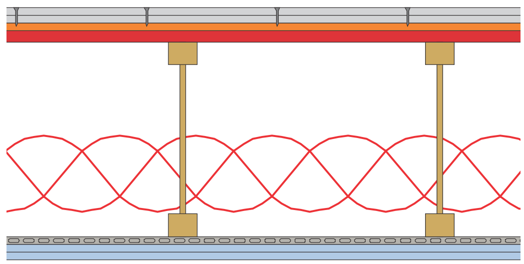


OSB16_WI302(406)_GFB150_RC13(406)_G13_G13

Description	**Base floor assembly with gypsum concrete topping** One layer of OSB installed on wood I-joists with two layers of gypsum board Type X on resilient channels.
Topping	• 38 mm nominal thickness gypsum concrete poured on 9.5 mm closed cell foam interlayer with all seams taped
Subfloor	• One layer of 15.9 mm OSB installed with long axis perpendicular to the joists. • Subfloor directly attached to wood I-joists using #8 screws 50 mm long spaced 150 mm along the edge and 300 mm in the field.
Framing & Cavity Insulation	• Wood I-joists (type TJI 110) 302 mm deep spaced 406 mm o.c. and toe-screwed using 4 screws on each side (2 on wall header and 2 on rim board). Joists hangers were only used on the load bearing wall of the LSW room. • Rim boards (45 mm thick and 302 mm deep) installed at each ends of the wood I-joists. • Cavities between I-joists filled with 150 mm glass fibre insulation (R-20)
Ceiling	• Resilient channels installed perpendicular to wood I-joists and spaced 406 mm o.c. using 32 mm type W screws. • Two layers of 12.7 mm Type X gypsum board installed with long axis perpendicular to resilient channels. • Base layer gypsum board attached to RC using Type S screws 32 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board attached to RC using Type S screws 42 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

FC-4 (fastened cementitious board topping)

Side View



OSB16_WI302(406)_GFB150_RC13(406)_G13_G13

Description	**Base floor assembly with fastened cementitious board topping** One layer of OSB installed on wood I-joists with two layers of gypsum board Type X on RC.
Topping	• Two layers of 12 mm cementitious flooring underlayment with their long sides perpendicular and joints staggered by at least 405 mm (16"). Layers fastened together with glue and staples having a length not more than 25 mm (1"), spaced at 203 mm (8") o.c. along edge and in the field and installed on top of 12 mm wood fibre board underlayment.
Subfloor	• One layer of 15.9 mm OSB installed with long axis perpendicular to the joists. • Subfloor directly attached to wood I-joists using #8 screws 50 mm long spaced 150 mm along the edge and 300 mm in the field.
Framing & Cavity Insulation	• Wood I-joists (type TJI 110) 302 mm deep spaced 406 mm o.c. and toe-screwed using 4 screws on each side (2 on wall header and 2 on rim board). Joists hangers were only used on the load bearing wall of the LSW room. • Rim boards (45 mm thick and 302 mm deep) installed at each ends of the wood I-joists. • Cavities between I-joists filled with 150 mm glass fibre insulation (R-20)
Ceiling	• Resilient channels installed perpendicular to wood I-joists and spaced 406 mm o.c. using 32 mm type W screws. • Two layers of 12.7 mm Type X gypsum board installed with long axis perpendicular to resilient channels. • Base layer gypsum board attached to RC using Type S screws 32 mm long spaced 600 mm along the edge and in the field. • Face layer gypsum board attached to RC using Type S screws 42 mm long spaced 300 mm along the edge and in the field. • Joints of face and base layers of gypsum boards were staggered by at least one stud spacing. The gaps along the joints and the perimeter were caulked and taped with aluminum tape.

A.3.6 Summary and Conclusions

Sound transmission was measured between over 550 room pairs for airborne sound and over 400 room pairs for impact sound. Measured data for the 26 unique wall-wall, 20 horizontal wall-floor/ceiling and 22 vertical floor-wall junctions with junction descriptions are given in Appendix A.3. The sound insulation for all paths from the measured data sets was gained through thorough data vetting and analysis. The same paths were predicted through many measurements and analysis approaches and finally averaged over larger sets to reduce the measurement and prediction uncertainties. Data for similarly designed junctions were also averaged, however axially NLB and LB junctions were always distinguished.

Generally, it was found that the sound transmission via flanking paths involving ceilings on resilient channels, as well as sidewalls with directly attached gypsum board or shear membranes, is in most cases sufficiently suppressed to achieve the proposed future requirement of ASTC 47 or higher.

However, sound insulation of flanking paths involving the bare floor assemblies, for side-by-side room cases is quite low. For a subfloor that was continuous across the junction, flanking sound insulation of the floor-floor path is even less than the direct sound insulation of the staggered stud walls with directly attached gypsum board (see Figure A.3 - 6). As a solution, floor toppings had to be added to the base floor to improve the flanking sound insulation (see Figure A.3 - 7) by about 10 STC points for a 38 mm gypsum concrete topping on a 9 closed cell foam interlayer applied to one side.

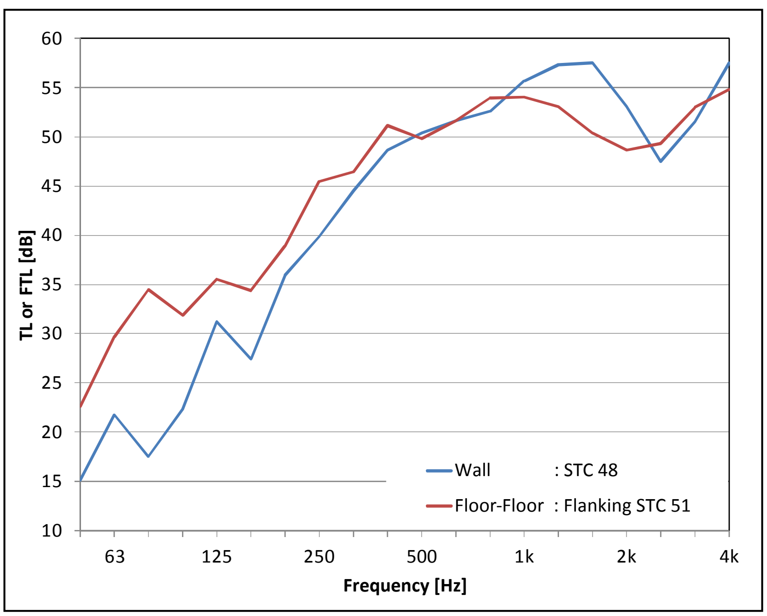


Figure A.3 - 6: Sound transmission directly through wall (LB-W1) versus through bare floor-floor path

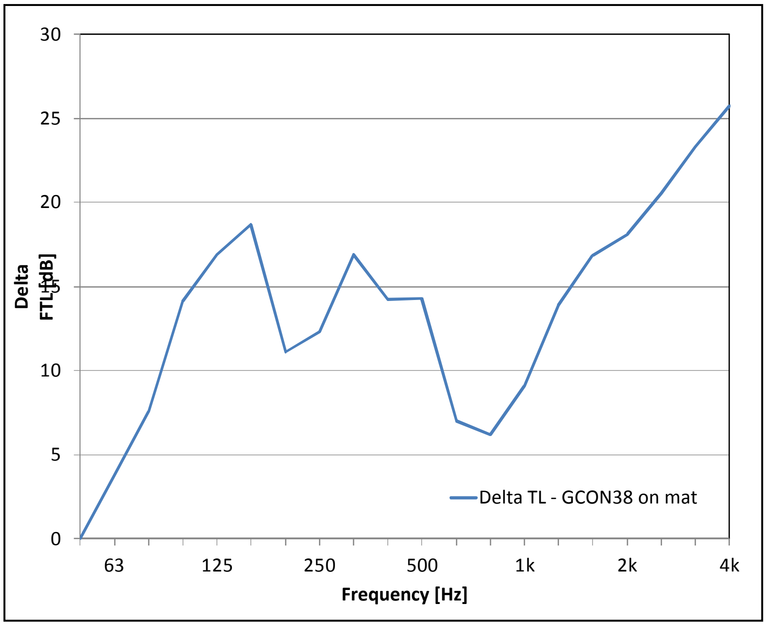


Figure A.3 - 7: Flanking TL Improvement due to Adding a 38 mm Gypsum Concrete Topping

For the room one-above-another case without a topping, it was found that if the direct floor-ceiling path was the weakest. By adding a topping, ASTC values in the mid 60s can be achieved.

Tested options with the gypsum board membranes at the separating and flanking walls mounted on resilient channels are necessary to design for higher grades of sound insulation as demanded by the market. Resilient channels reduce the Flanking STC by approximately half as much as the direct STC (4 vs. 8 points).

The inclusion of a shear membrane is almost insignificant for direct and vertical flanking transmission paths, but it reduces the Flanking STC by approximately 3 points for horizontal paths. However, this reduction only becomes relevant for high sound insulating systems with ASTC > 60, as this path is already highly attenuated.

Tie-downs have no significant influence the flanking sound transmission between rooms one above the other nor side-by side (see Figure A.3 – 8).

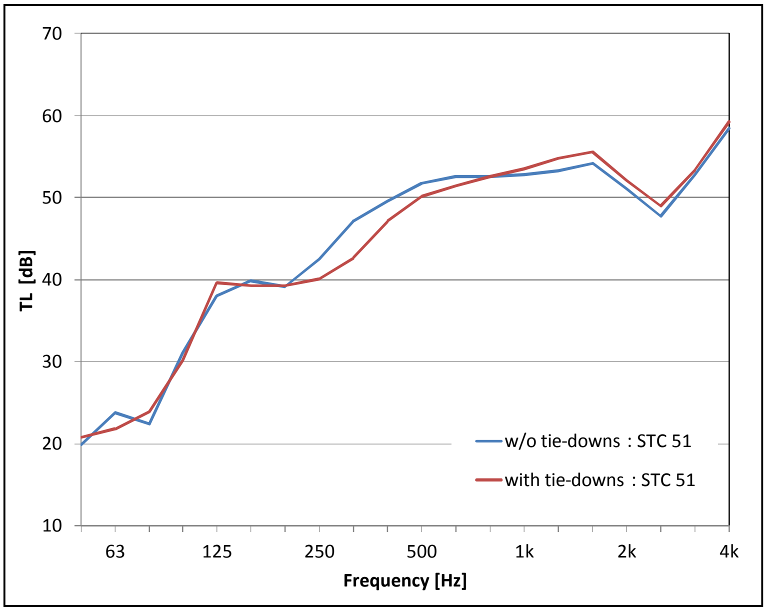


Figure A.3 - 8: Direct TL through NLB wall with (NLB-W5) and without (NLB-W2) tie-downs

Switching from 2x4 staggered stud walls to 2x6 stud walls has no effect on the vertical flanking paths (rooms one-above-another), for both the axial load bearing and non-load bearing walls. However, for the horizontal wall-wall flanking paths (rooms side-by-side), the flanking sound transmission increases by 3 points over the load bearing junction and reduces by 3 points over the non-load bearing junction. Note that these flanking paths are quite high and only become significant when ASTC values of over 60 are to be achieved.

Replacing the glass fibre insulation by spray foam insulation has no effect on both vertical and horizontal flanking paths. The direct paths however are reduced quite sufficiently for NLB from STC 38 to STC 34 and for LB walls from STC 42 to STC 36. These are further compared to interior walls in Figures A.3 – 9 and 10 for NLB and LB walls respectively that reach STC values in the low 50s.

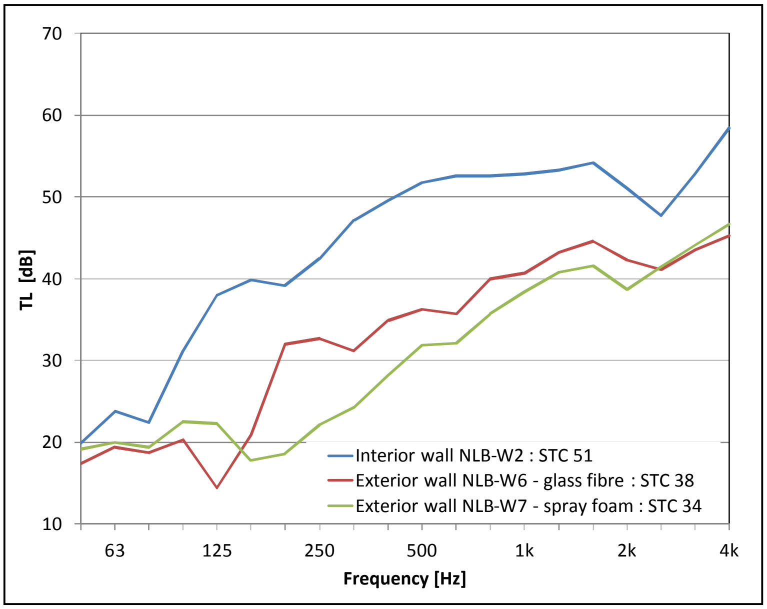


Figure A.3 - 9: Direct TL through interior (NLB-W2) and exterior NLB walls; exterior with glass fiber (NLB-W6) and spray foam (NLB-W7) insulation

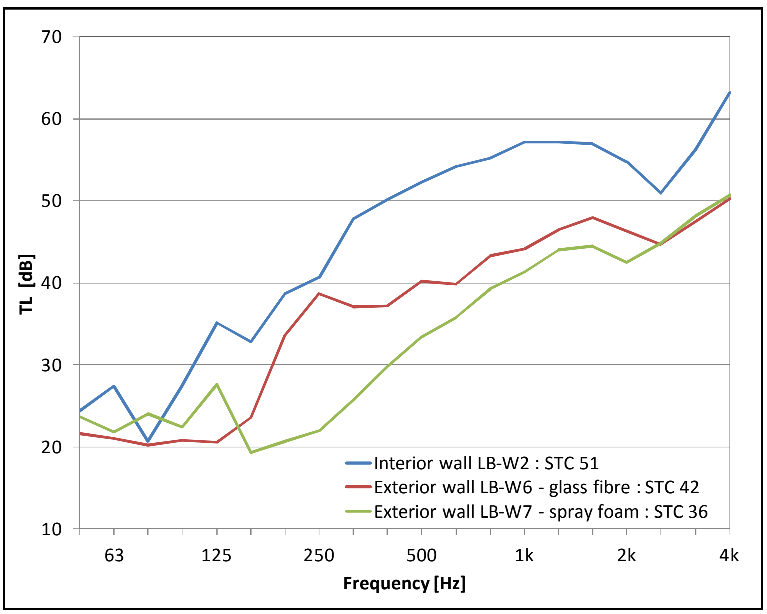


Figure A.3 - 10: Direct TL through interior (LB-W2) and exterior LB walls; exterior with glass fiber (LB-W6) and spray foam (LB-W7) insulation

A.3.7 References

[1] I. Sabourin et. al., "Effect of structural load and joist type on flanking sound transmission," Acoustics Week in Canada 2009 (Annual Conference of the Canadian Acoustical Association), Niagara-on-the-lake, Ontario, Canada, 2009.

[2] ISO 15712-1:2005; "Building Acoustics – Estimation of acoustic performance of buildings from the performance of elements – Part 1: Airborne sound insulation between rooms", ISO-Standard, 2005

[3] Nightingale, Quirt and King, "Flanking Transmission in Multi-Family Dwellings: Phase IV," NRC, Ottawa, 2006.

[4] King, Schoenwald and Sabourin, "Characterizing flanking transmission paths in the NRC-IRC Flanking Facility," Acoustics Week in Canada 2009 (Annual Conference of the Canadian Acoustical Association):, Niagara on the Lake, Ontario, Canada, 2009.

[5] ASTME336, "Standard Test Method for Measurement of Airborne Sound Attenuation between Rooms in Buildings," ASTM International, West Conshohocken, PA, 2011.

[6] ISO10848, "Laboratory measurement of the flanking transmission of airborne and impact sound between adjoining rooms," International Organization for Standardization, Geneva, 2006.

[7] T. Estabrooks et. al., "NRC-IRC Flanking Facility," Acoustics Week in Canada 2009 (Annual Conference of the Canadian Acoustical Association), Niagara-on-the-Lake, Ontario, Canada, 2009.

A.4 Flanking Sound Transmission in CLT Buildings

A.4.1 Background

The acoustic system performance of Cross-Laminated Timber (CLT) structures for mid-rise wooden buildings was assessed in this research project in anticipation of a possible code change as early as in the National Building Code of Canada (NBCC) 2015 from element to system requirement for airborne sound insulation. The system performance is the airborne and impact sound insulation, when floors and walls are coupled and part of a building.

Currently, there is only a minimum requirement in the NBCC 2015 for direct airborne sound insulation of Sound Transmission Class STC 50 for the building element separating a residential unit from other spaces. The direct sound insulation performance of CLT walls and floors with various surface treatments was assessed in a research component conducted in parallel. The sound insulation between two rooms in a building separated by a wall or a floor might be much less than when the separating element is tested in a direct sound transmission facility. The reason is the so-called flanking sound transmission involving the elements adjoining the separating element at its edges. To account for this effect and to give a more realistic requirement for airborne sound insulation, that better matches with what is perceived by occupants, a code change was proposed and a new requirement for the Apparent Sound Transmission Class (ASTC) may be introduced in the NBCC 2015. Since the code change is not yet finalized, the new required performance is not set, but ASTC 47 is expected to be the likely new minimum requirement for airborne sound insulation. Since CLT is a novel wood construction technology emerging from Europe, no data was available in Canada for the apparent sound transmission so far.

The acoustic research on CLT systems was developed and conducted at NRC Construction in close coordination with the project partners (Canadian Wood Council, FPInnovations and the Provinces) and in close consultation with other disciplines (i.e. structure, fire, heat and moisture). The applied methodology, selection of test specimens, and test results were discussed with these groups at workgroup meetings held on regular basis. Furthermore, research conducted by other groups in Canada (i.e. FPInnovations, NEWBuildS) as well as abroad (i.e. in Europe) was taken into account in this project. When new knowledge, e.g. from this research component or other disciplines, became available during the research project, research plans were changed accordingly to account for these new developments.

A.4.2 Apparent Sound Insulation in Buildings

A.4.2.1 In General

Sound transmission between two spaces in a building occurs not only through the separating floor or wall assembly (direct transmission, data for CLT in Appendix A.2), but also involves the flanking building elements adjoining the separating element at its edges (flanking transmission). Hereby, the separating assembly and flanking elements are excited in the source room by incident sound. Structure-borne sound then is transmitted at the building junctions from the exposed building structure on the source side to coupled building elements on the receiving side where it is radiated again as airborne sound into the receiving room. This principle is depicted in Figure A.4 - 1 for two rooms side-by-side separated by a wall. The direct Dd-Path through the separating wall and three possible flanking paths at the floor-wall junctions are shown, too. For all four junctions at the element edges, the 3 paths (Ff, Fd, and Df) exist, thus a total of 12 flanking paths and one direct path have to be taken into account for estimating the apparent airborne sound insulation that is perceived by the building occupants in real buildings. Impact flanking sound transmission due to people walking also occurs; however, the number of possible transmission paths is limited as only the floor is excited in this case.

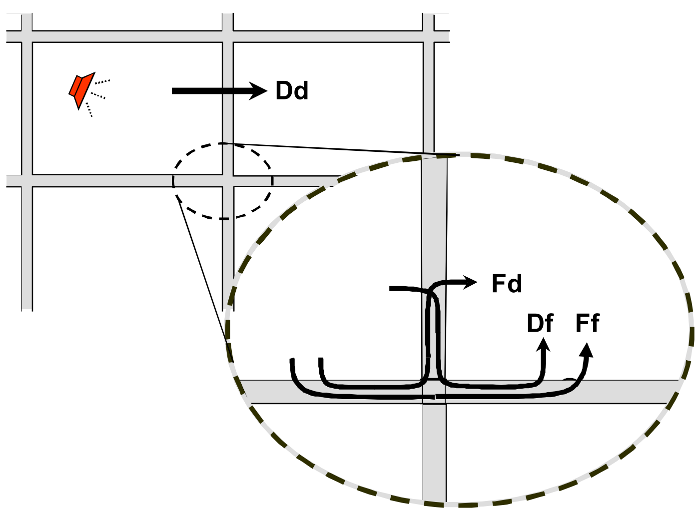


Figure A.4 - 1: Direct and flanking sound transmission for the floor-wall junction between two side-by-side rooms (Path naming convention according to ISO 15712 [1]: "D", "d": direct element; "F", "f": flanking element; Source room: Capital letter; Receiving room: lowercase)

The letters that reference the flanking paths are in accordance with the naming convention in ISO 15712-1 [1] prediction method for sound insulation in buildings that was utilized in this research component. Letter "D" or "d" references the separating element ("direct") and letter "F" or "f" the flanking elements at one junction. Capital letters "F" and "D" denote elements that are excited by sound in the source room (e.g. on the left in Figure A.4 - 1) and lower case letters "d" and "f" radiating elements in the receiving room (e.g. on the left in Figure A.4 - 1). So for the direct path “Dd” the separating element “D” is excited and “d” is also radiating sound, for path “Fd” the flanking element “F” is excited and separating element “d” is radiating and so on. Furthermore, it is important that for every separate transmission path the so-called reciprocity principle holds, thus, for example, the Flanking Sound Transmission Class (Fl-STC) of path “Ff” from the left to the right in Figure A.4 - 1 would be the same in opposite direction from the right to the left.

A.4.2.2 In CLT Buildings

In CLT buildings the same transmission paths exist as in every other building with the same geometry. In this section the methodology is outlined that was applied to estimate sound transmission along all possible flanking paths. The following report refers to airborne sound only. The described methods can also be applied for impact sound and the necessary input data was collected in this research project, however, analysis is not fully completed for impact yet.

A.4.2.2.1 ISO 15712-1 - Prediction Method

CLT elements are monolithic and more homogeneous than e.g. wood framed elements and thus comparable to masonry and concrete building elements. This allows for a more flexible prediction of the apparent airborne and impact sound insulation in CLT buildings utilizing the methods of the ISO 15712 framework [1], with measured direct sound insulation data for the elements and measured vibration attenuation at the junction as input data. Unfortunately, the ISO 15712 is written, and prediction results are expressed, in terms of ISO-quantities.

In Canada building elements are tested according to the ASTM E90 [2] test protocol and code requirements are given in terms of Sound Transmission Class (STC) and possibly Apparent Sound Transmission Class (ASTC) determined according to ASTM E413 [3]. Nevertheless, ISO 15712 can be used to obtain ASTM sound insulation ratings, since the engineering method is based on a physical foundation. To do so, data tested according to ASTM-protocols has to be used as input where equivalent quantity exists in ASTM standards (i.e. Sound Transmission Loss (TL)) and the results have to be rated according to the ASTM E413 protocol to obtain ASTC-ratings. Where no equivalent exists in ASTM standards (i.e. junction coupling), data obtained according to ISO-protocols was used as input data. In the following, the most important steps in the prediction method are outlined. Presented equations of ISO 15712 are re-written in ASTM terminology where applicable and calculations have to be conducted in a minimum frequency range from 125 Hz to 4000 Hz in order to obtain ASTC-ratings.

The Apparent Sound Transmission Loss (ATL) between two rooms (neglecting sound that is by-passing the building structure, e.g. leaks, ducts,…) is the resultant of the Sound Transmission Loss (TL_{Dd}) of the separating element and the Flanking Sound Transmission Loss (TL_{ij}) of up to three paths for every junction at the four edges.

$$ATL = -10 \cdot \lg\left(10^{-0.1 \cdot TL_{Dd}} + \sum_{edge=1}^{4}\left(10^{-0.1 \cdot TL_{Ff}} + 10^{-0.1 \cdot TL_{Fd}} + 10^{-0.1 \cdot TL_{Df}}\right)\right) \qquad \text{Eq. 1}$$

Eq. 1 is universally valid for all building systems and the major challenge is to find the right input data for the transmission paths for the considered building system and situation.

Direct Sound Transmission Loss

For the direct path TL_{Dd} is obtained according to Eq. 2 from the direct sound insulation of the bare element TL_{situ} and from the incremental change of Sound Transmission Loss ∆TL due to additional layers, like wall linings, ceilings, and floor toppings at the source "D" and receiving side "d" of the separation.

$$TL_{Dd} = TL_{situ} + \Delta TL_{D,situ} + \Delta TL_{d,situ} \qquad \text{Eq. 2}$$

"situ" indicates that the input data is transferred from the lab situation to the considered building situation. Above coincidence frequency the TL of a building element depends on the damping that is governed by the internal losses in the building element itself and by the losses at its edges due to structure-borne sound that is transmitted to other elements of the building. For elements with small internal losses, like concrete and masonry, edge losses are dominating; the total loss factor can be different in the lab and in the building situation. Thus, a correction is necessary to adjust the TL data in the prediction. For building elements with high internal losses (i.e. according to ISO 15712 internal loss factor greater than 0.03) the total loss factor is dominated by these and edge losses are negligible. The total loss factor of the element is similar when installed in the lab and in buildings. Therefore, TL from the lab can be used directly without adjustments in the predictions. This is the case for the CLT elements used in this research project that had a measured internal loss factor of around 0.06 in the relevant frequency range. Thus, no corrections were made in this report to transfer lab data to the predicted building situation.

Flanking Sound Transmission Loss

The Sound Transmission Loss is calculated using Eq. 3 for every flanking path where index i and j refer to the coupled elements; thus, "i" can either be "D" or "F" and "j" can be "f" or "d".

$$TL_{ij} = \frac{TL_i}{2} + \frac{TL_j}{2} + K_{ij} + \Delta TL_i + \Delta TL_j + 10 \cdot lg\, \frac{s_S}{l_0 \cdot l_{ij}} \qquad \text{Eq. 3}$$

The equation presented for CLT in this report is simplified for the special case when the coupled elements have an internal loss factor greater than 0.03, because some corrections to transfer lab data to building situation data are not necessary like for the prediction of direct sound insulation as already explained in the previous section.

TL_i and TL_j are Sound Transmission Loss of the two coupled bare CLT elements i and j respectively. This data should strictly refer to only resonant sound transmission. However, below coincidence frequency forced transmission also occurs. This is especially an issue for thin CLT elements where the coincidence frequency is right in the middle of the considered standard frequency range (e.g. for a 78 mm thick 3-ply panel around 800 Hz) whereas for thick elements it is much lower (e.g. 5-ply 175 mm thick CLT wall at around 250 Hz). Thus, the TL for only resonant transmission would be greater below the coincidence frequency than the one measured in the direct sound transmission facility. However, the current ISO 15712-standard does not give a reliable correction to account for this effect and it is suggested to use lab TL data directly as input which leads to a conservative estimate for the flanking sound insulation. More recent research projects suggest correction methods [4, 5] which were validated, e.g. [6], and that likely will be introduced in future revisions of the ISO 15712 standard. All necessary data to apply these corrections to obtain less conservative and more accurate prediction results were already collected in this research project, but are not fully analyzed yet. Thus, the presented data in this report use lab TL data directly as input data. ΔTL is the incremental change of sound insulation due to additional layers, like wall linings, floor toppings or ceilings added to element "i" and "j".

The Vibration Reduction Index K_{ij} describes the coupling of the elements and the structure-borne sound transmission across the junction. It is a normalized velocity level difference that is measured according to ISO 10848-1 [7] and ISO 10848-4 [8]. Some values from empirical studies are also given in ISO 15712 for junctions of building elements that are rigidly coupled along a line (e.g. concrete, masonry) or for situations where some elements are weakly coupled and do not affect transmission. However, for CLT elements with point connections K_{ij} data is not readily available and was therefore measured in this research project as described in Section A.4.2.2.2.

Further in Eq. 3, S_s is the area of the separating element, l_{ij} is the length of the junction between the two coupled elements, and l_0 is a reference length equal to 1 m.

To reduce the amount of data that is presented in this summary report, a new quantity, $TL_{ij,n}$ is introduced as Normalized Flanking Transmission Loss. It is the sum of the first 3 terms.

$$TL_{ij,n} = \frac{TL_i}{2} + \frac{TL_j}{2} + K_{ij} \qquad \text{Eq. 4}$$

$$TL_{ij} = TL_{ij,n} + \Delta TL_i + \Delta TL_j + 10 \cdot lg \frac{S_S}{l_0 \cdot l_{ij}} \qquad \text{Eq. 5}$$

In this way, $TL_{ij,n}$ for the junctions has only to be adjusted for geometry in the building and for the improvement of additional layers and can directly be used for predictions.

A.4.2.2.2 Input Data for ISO 15712

For the predictions according to ISO 15712 all necessary input data was measured as outlined in the following.

Direct Sound Insulation of CLT elements

Test data from the CLT wall and floor study was used as input for the direct Sound Transmission Loss (TL) for the bare CLT elements. This data was measured according to ASTM E90 in NRC Construction's Direct Sound Transmission Facilities and is also necessary to demonstrate code compliance with current code requirement of STC 50 or higher for separations between residential units and other spaces in the building. The incremental change in sound insulation due to added gypsum board wall liners, gypsum board ceilings, and floor toppings on bare CLT walls and floors was also measured in this study. This data can be used for the prediction of direct and flanking sound transmission and added in many combinations to the presented bare CLT flanking data to already predict the building performance in the design stage.

Junction Coupling According to ISO 10848

The Vibration Reduction Index K_{ij} for the prediction method was measured using the direct method of ISO 10848-1 for a set of relevant wall-wall and floor-wall junctions. The measurements were conducted on full-size junction mock-ups that are shown in Figure A.4 - 2 and Figure A.4 - 3. Cross (X-) as well as T-Junctions were considered for the vertical (wall-wall) and for the horizontal (floor-wall) junctions.

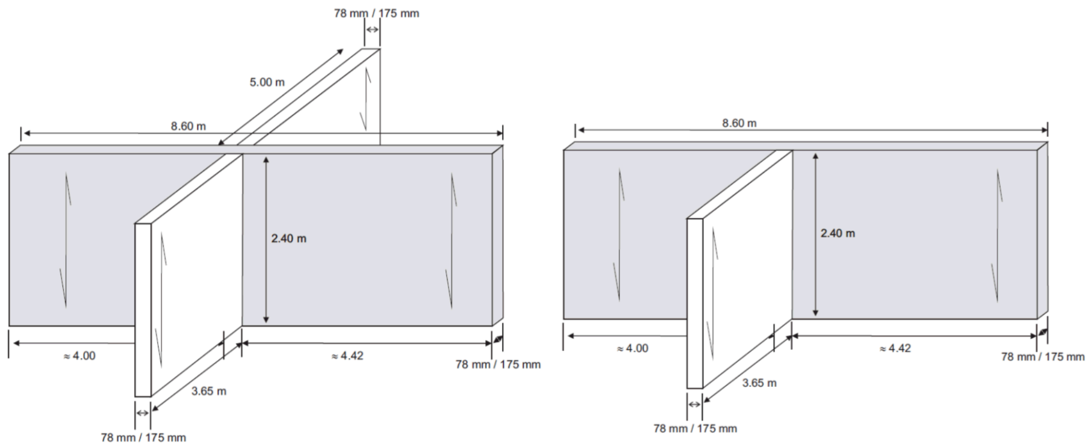


Figure A.4 - 2: Dimension of vertical (wall-wall) junction mock-ups for measurement of Vibration Reduction Index according to ISO 10848; left: wall-wall cross (X-) junction, right: wall-wall T-Junction

The dimension of the junction specimens were in accordance with the test standard. For the vertical junctions the length of all coupled wall elements differed by at least 10% to avoid coupling of resonant modes of the elements with similar resonance frequency. For the horizontal junctions the length of the floors differed also by 10%, however, the two walls had the same height, like it is typically found in real buildings.

The construction of the vertical junctions was comparably easy, as the walls were erected free standing on a rigid concrete floor. To further suppress structure-borne sound transmission from the walls into the rigid floor and back into the other wall, rubber pads were placed between the CLT walls and the floor. For the floor-wall junctions, the lower wall again was placed on rubber pads on the rigid concrete floor, the CLT floor was placed on top and supported by adjustable scaffolding at the free edges with rubber pads in-between as vibration isolators. The upper wall was free standing on the CLT floor. To simulate compression forces that act on the junction due to the dead load of upper stories in real buildings, a steel loading beam spanned over the top wall on which a static force of 8000 lbs was applied by four hydraulic cylinders. This load is sufficient to compress voids at the junction that change their mechanics. Initial tests showed that the coupling at the junction did not change significantly anymore when 4000 lbs or 8000 lbs were applied.

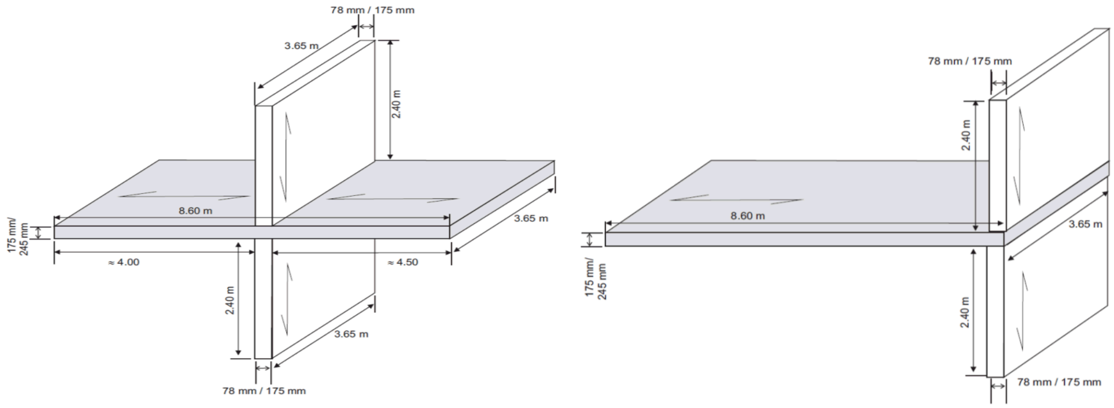


Figure A.4 - 3: Dimension of floor-wall junction mock-ups for measurement of Vibration Reduction Index according to ISO 10848; left: floor-wall cross (X-) junction, right: floor-wall T-Junction

Figure A.4 - 4 shows one of the tested floor-wall junctions with the upper wall loaded with static load applied by the hydraulic cylinders.

Figure A.4 - 4: CLT floor-wall junction mock-up with loading frame and measurement system

The Vibration Reduction Index K_{ij} for elements with internal loss factors greater than 0.03 is defined in Eq. 6 as a function of the direction averaged velocity level difference $\overline{D_{v,ij}}$ between the elements "i" and "j", with the junction length l_{ij}, the reference length l_0, and the areas S_i and S_j of both coupled elements.

$$K_{ij} = \overline{D_{v,ij}} + 10 \cdot lg \frac{l_{ij} \cdot l_0}{\sqrt{S_i S_j}} , \quad with \ \overline{D_{v,ij}} = \frac{D_{v,ij} + D_{v,ji}}{2} \qquad \text{Eq. 6}$$

$\overline{D_{v,ij}}$ is the average of the velocity level differences of $D_{v,ij}$ and $D_{v,ji}$ that are measured in opposite direction; namely for $D_{v,ij}$ element "i", is excited and the difference of the velocity levels on both coupled elements "i" and "j' are measured, while for $D_{v,ji}$ element "j" is excited.

In this research project the velocity levels were measured with 16 accelerometers connected to a 16-channel data acquisition system at the X-junctions and with 12 accelerometers at the T-junctions. Hereby, 4 accelerometers were distributed randomly on each element in the area defined by ISO 10848-1. During the measurement, the velocity levels were measured simultaneously with all channels while one element of the junction was excited with a hammer. For excitation the so-called rain-on-the-roof method was applied where the source element was hit with repeated hammer blows in an area of approximately 1 m x 1 m during a 30 s long measurement interval. Each of the coupled elements was excited in four different areas and for each excitation point 4 different accelerometer positions were used on all elements. In total the velocity levels were measured on 16 positions on each element for every source element. Processing of the measurement data, i.e. background noise correction and averaging, was done in compliance with ISO 10848-1.

A.4.3 Summary of Measurement Data

The input data necessary to predict the Apparent Sound Transmission Loss (ATL) and the Apparent Sound Transmission Class (ASTC) using Eq. 1, Eq. 2 and Eq. 5 are presented in the following order. In the first part, the data for the junction coupling that was measured in this study is presented in more detail with descriptions of the junction properties and connectors used. Then, in the second part the data for direct sound insulation of the bare CLT elements and in the third the incremental improvement due to additional layers are listed more briefly. Both data are taken from the CLT wall and floor sound insulation study of this research project and details are available in Appendix A.2.

A.4.3.1 Junction Description and Data

In this report, only data for the vertical wall-wall junctions will be presented as the data analysis for the horizontal floor-wall junctions is not finalized. Moreover, the presented data is also preliminary as further analysis in combination with the data for vertical junctions may lead to a better understanding of the collected data and may justify changes. The presented junctions have bare CLT elements, i.e. if wall liners, floor toppings and ceilings are applied their incremental sound insulation change has to be added.

The following data sheets contain all tested wall-wall junctions. The data sheets have a junction-identification and a drawing of the elements at the top. The name identifies the junction type (Wall or Floor) and the junction geometry (T-or X), e.g. “Wall-01-X” is a vertical X-Junction. Then the properties of the three (T-junction) or four (X-junction) coupled elements are outlined, followed by a description of the junction and connection methods. Underneath, there are two tables are shown, in the first, the Normalized Flanking Sound Transmission Loss $TL_{ij,n}$ from Eq. 4 is presented that is independent of the junction geometry and must be adjusted with Eq. 5 to the building situation of interest. The second table lists values with Flanking Sound Transmission Loss TL_{ij} with the data from the first table adjusted to the geometry of a representative building situation. The considered area of the separating element as well as the junction length is given in the table as they may change depending on junction type and path. The TL data is presented in octave bands from 63 Hz to 4000 Hz derived from one-third octave band data in accordance with ISO 10848-4. Furthermore, a single number STC-rating was determined from the one-third octave band data according to ASTM E413 that is presented in the first data column and allows for a quick comparison of the data.

The number of flanking transmission loss data sets may vary for junctions as it depends on the junction geometry as well as on the coupled elements and connection details. The possible transmission paths between two rooms “A” and “B” separated by a T-junction are shown in Figure A.4 - 5. There is only one of each transmission path possible, i.e. one Ff-path via elements 1 and 3, one Fd-path via elements 1 and 2, and one Df-path via elements 2 and 3. As already mentioned earlier, the sound transmission of each path in opposite direction from room “B” to room “A”, is equal, however, the naming convention would change, e.g. path 1-2 is equal to path 2-1, but would be Df-path instead of Fd-path. Furthermore, if e.g. elements 1 and 3 are nominally the same elements then also the sound insulation of path 1-2 is equal to path 2-3 and thus only one data set is presented in the tables for both paths.

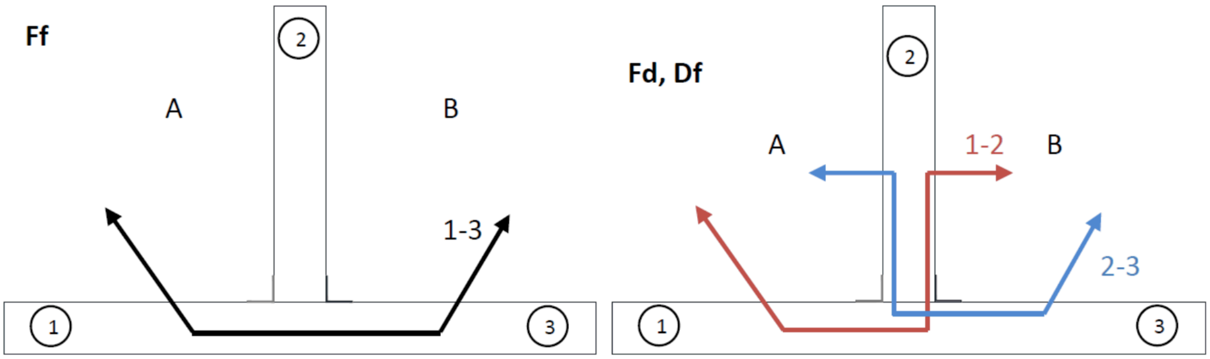


Figure A.4 - 5: Possible sound transmission paths for T-junctions; left: Ff-paths; right: Fd- and Df-paths

For X-junctions there are many more paths than as it seems on the first glance in Figure A.4 - 6 because there are more rooms and elements involved. However, a detailed inspection of the paths reveals that there are only a maximum of 2 unique Ff-paths (coupling of elements 1 and 3, and of elements 2 and 4) and 4 unique Df- or Fd-paths (path 1-2, path 2-3, path 3-4, and path 1-4) possible. For example, path 1-2 is the Fd-path between room "A" and "B", but it is also the Fd-path between room "A" and room "C". The number of unique data sets reduces further if e.g. element 1 and 3 as well as 2 and 4 are the same, including the connection details. In this case there is only one unique data set for all Df- and Fd- paths. On the other hand, if for instance different connection methods are applied to connect element 2 and element 4 (e.g. element 2 connected with angle brackets and element 4 with screws) then two data sets are presented, one for path 1-2 and path 2-3 and another for path 1-4 and path 3-4.

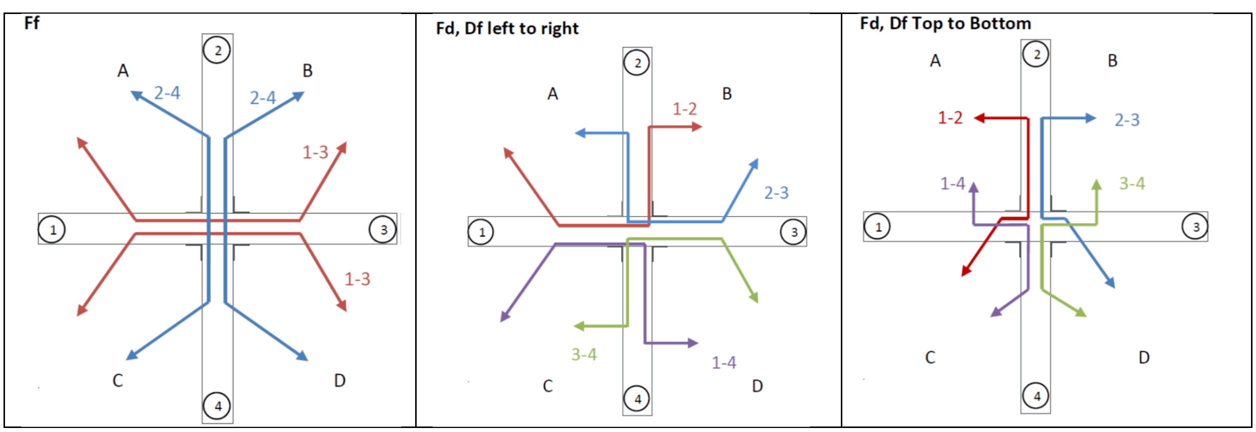
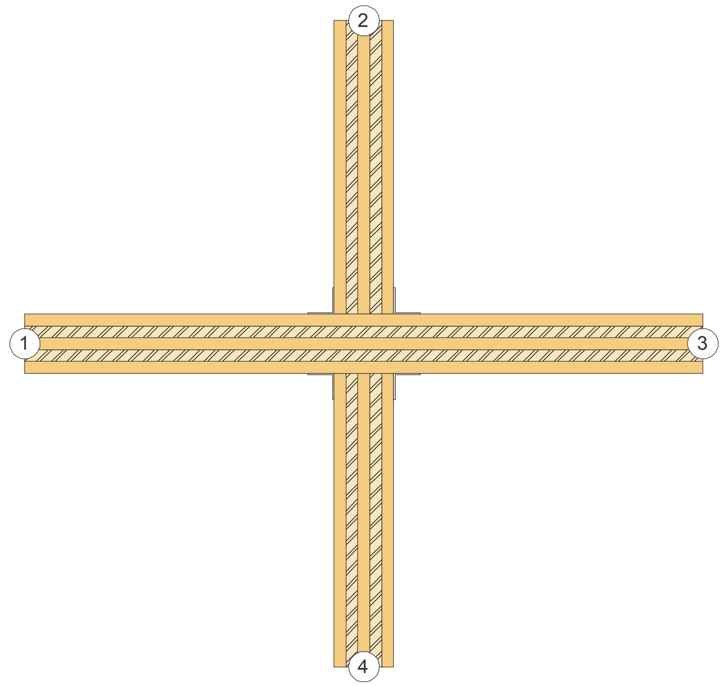


Figure A.4 - 6: Possible sound transmission paths for X-junctions; left: Ff-paths; middle: Fd- and Df-paths between left and right; right: Fd- and Df-paths between top and bottom

A.4.3.1.1 CLT Wall-Wall Junctions

Wall_01_X



Element	Description	Thickness (mm)	Mass-per-Area (kg/m²)
1	CLT 5-ply wall	175	91.4
2	CLT 5-ply wall	175	91.4
3	CLT 5-ply wall	175	91.4
4	CLT 5-ply wall	175	91.4

Junction Details

Wall 1 and 3 are continuous. Wall 2 and 4 are connected to the continuous wall with 90 mm angle brackets 600 mm o.c.

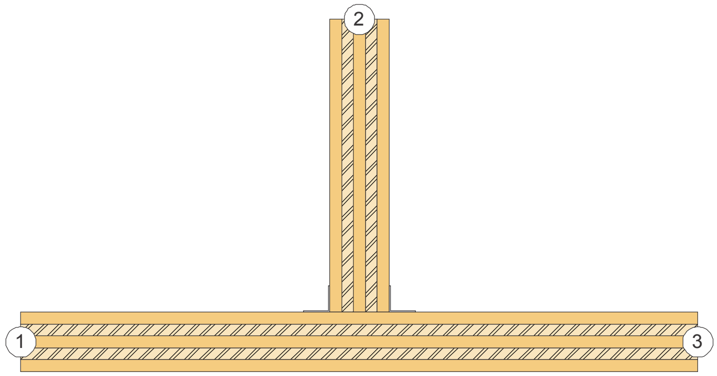
Flanking Sound Transmission Loss $TL_{ij,n}$ – Normalized

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	41	26.9	32.6	32.3	34.7	42.1	52.2	60.8
Ff (2-4)	48	36.0	45.8	38.7	45.5	65.6	78.3	79.4
Fd, Df (1-2,3-2,1-4,3-4)	45	32.8	37.6	33.9	41.7	57.3	66.6	72.3

Flanking Sound Transmission Loss TL_{ij} – Adjusted to S_s = 10 m² and L_{ij} = 2.5 m

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	47	32.9	38.6	38.3	40.7	48.1	58.2	66.8
Ff (2-4)	55	42.1	51.9	44.7	51.6	71.7	84.3	85.4
Fd, Df (1-2,3-2,1-4,3-4)	51	38.8	43.6	39.9	47.7	63.3	72.6	78.3

Wall_01_T



Element	Description	Thickness (mm)	Mass-per-Area (kg/m^2)
1	CLT 5-ply wall	175	91.4
2	CLT 5-ply wall	175	91.4
3	CLT 5-ply wall	175	91.4

Junction Details

Wall 1 and 3 are continuous. Wall 2 is connected to the continuous wall with 90 mm angle brackets 600 mm o.c.

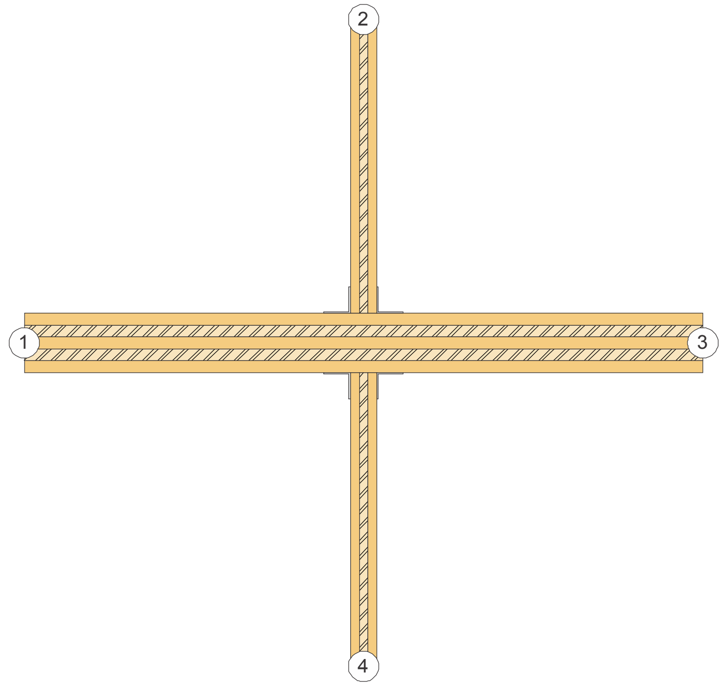
Flanking Sound Transmission Loss $TL_{ij,n}$ – Normalized

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	38	27.3	34.6	28.2	32.4	41.5	51.9	61.3
Fd, Df (1-2,3-2)	45	29.9	34.8	35.0	39.1	49.9	64.6	65.3

Flanking Sound Transmission Loss TL_{ij}– Adjusted to S_s = 10 m^2 and L_{ij} = 2.5 m

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	44	33.3	40.6	34.2	38.5	47.5	57.9	67.4
Fd, Df (1-2,3-2)	51	35.9	40.8	41.0	45.2	56.0	70.7	71.3

Wall_02_X



Element	Description	Thickness (mm)	Mass-per-Area (kg/m^2)
1	CLT 5-ply wall	175	91.4
2	CLT 3-ply wall	78	42.4
3	CLT 5-ply wall	175	91.4
4	CLT 3-ply wall	78	42.4

Junction Details

Wall 1 and 3 are continuous. Wall 2 and 4 are connected to the continuous wall with 90 mm angle brackets 600 mm o.c.

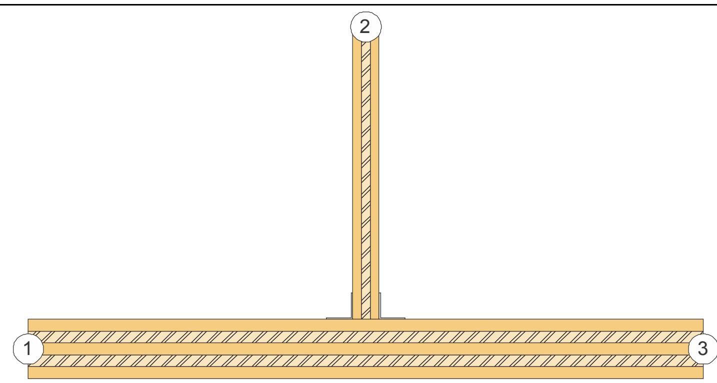
Flanking Sound Transmission Loss $TL_{ij,n}$ – Normalized

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	41	26.8	33.3	32.3	35.2	43.2	52.3	59.8
Ff (2-4)	49	39.2	44.5	41.1	42.4	51.4	68.8	76.8
Fd, Df (1-2,3-2,1-4,3-4)	45	34.4	37.3	34.6	39.0	48.1	62.9	70.8

Flanking Sound Transmission Loss TL_{ij} – Adjusted to S_s = 10 m^2 and L_{ij} = 2.5 m

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	47	32.8	39.3	38.3	41.2	49.2	58.3	65.8
Ff (2-4)	55	45.2	50.6	47.2	48.4	57.5	74.8	82.8
Fd, Df (1-2,3-2,1-4,3-4)	51	40.4	43.4	40.6	45.0	54.1	68.9	76.8

Wall_02_T



Element	Description	Thickness (mm)	Mass-per-Area (kg/m^2)
1	CLT 5-ply wall	175	91.4
2	CLT 3-ply wall	78	42.4
3	CLT 5-ply wall	175	91.4

Junction Details

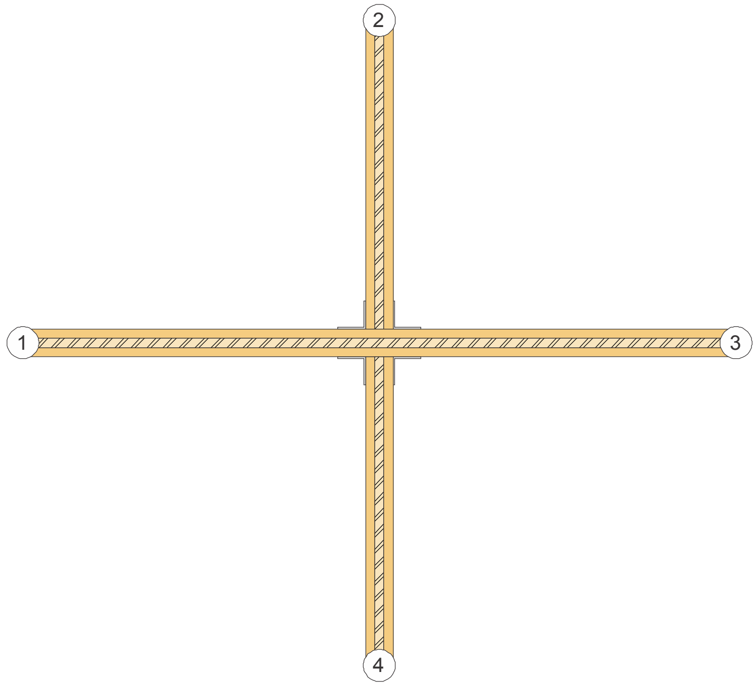
Wall 1 and 3 are continuous. Wall 2 is connected to the continuous wall with 90 mm angle brackets 600 mm o.c.

Flanking Sound Transmission Loss $TL_{ij,n}$ – Normalized

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	41	26.8	33.3	32.3	35.2	43.2	52.3	59.8
Fd, Df (1-2,3-2)	45	34.6	36.8	35.2	39.3	48.3	63.7	71.1

Flanking Sound Transmission Loss TL_{ij} – Adjusted to S_s = 10 m^2 and L_{ij} = 2.5 m

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	47	32.8	39.3	38.3	41.2	49.2	58.3	65.8
Fd, Df (1-2,3-2)	51	40.6	42.9	41.2	45.4	54.3	69.8	77.1

Wall_03_X			
			
Element	**Description**	**Thickness (mm)**	**Mass-per-Area (kg/m²)**
1	CLT 3-ply wall	78	42.4
2	CLT 3-ply wall	78	42.4
3	CLT 3-ply wall	78	42.4
4	CLT 3-ply wall	78	42.4
Junction Details			
Wall 1 and 3 are continuous. Wall 2 and 4 are connected to the continuous wall with 90 mm angle brackets 600 mm o.c.			

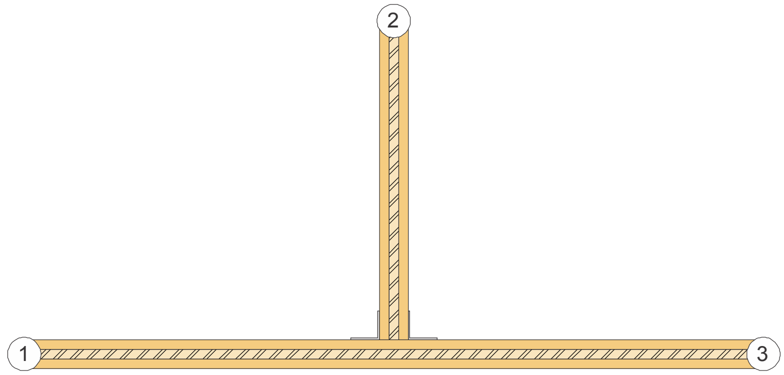
Flanking Sound Transmission Loss $TL_{ij,n}$ – Normalized

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	38	23.9	23.6	27.6	33.7	38.2	47.2	62.6
Ff (2-4)	43	26.0	29.4	33.2	36.5	45.4	63.3	75.5
Fd, Df (1-2,3-2,1-4,3-4)	39	26.9	27.3	28.8	32.5	40.5	55.9	71.1

Flanking Sound Transmission Loss TL_{ij} – Adjusted to S_s = 10 m^2 and L_{ij} = 2.5 m

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	44	30.0	29.6	33.6	39.8	44.2	53.2	68.6
Ff (2-4)	49	32.0	35.4	39.3	42.6	51.4	69.4	81.5
Fd, Df (1-2,3-2,1-4,3-4)	45	32.9	33.4	34.8	38.6	46.5	61.9	77.2

Wall_03_T



Element	Description	Thickness (mm)	Mass-per-Area (kg/m^2)
1	CLT 3-ply wall	78	42.4
2	CLT 3-ply wall	78	42.4
3	CLT 3-ply wall	78	42.4

Junction Details

Wall 1 and 3 are continuous. Wall 2 is connected to the continuous wall with 90 mm angle brackets 600 mm o.c.

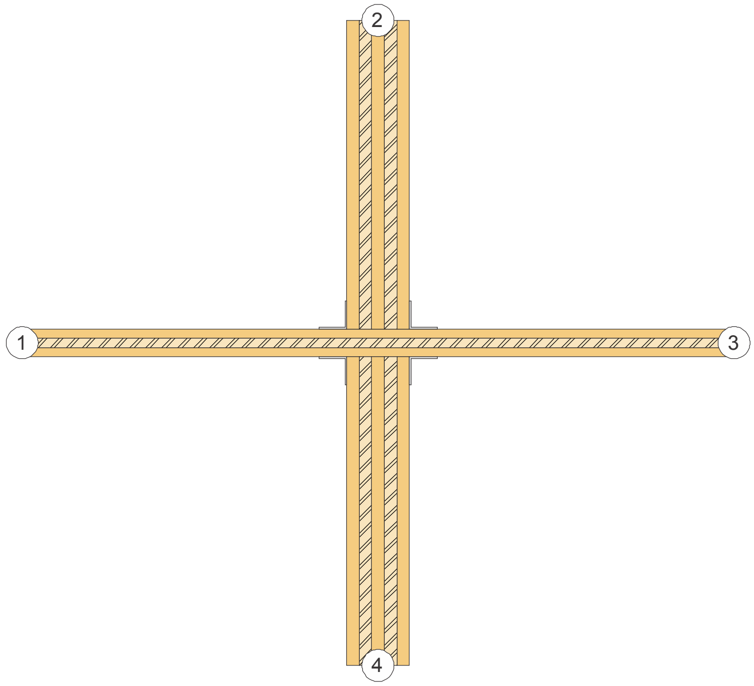
Flanking Sound Transmission Loss $TL_{ij,n}$ – Normalized

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	37	23.0	23.2	28.6	31.4	34.8	46.2	60.4
Fd, Df (1-2,3-2)	38	24.8	25.2	28.1	31.3	40.9	55.7	70.4

Flanking Sound Transmission Loss TL_{ij} – Adjusted to S_s = 10 m^2 and L_{ij} = 2.5 m

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	43	29.1	29.2	34.6	37.4	40.8	52.2	66.4
Fd, Df (1-2,3-2)	44	30.8	31.3	34.1	37.4	46.9	61.7	76.4

Wall_04_X



Element	Description	Thickness (mm)	Mass-per-Area (kg/m^2)
1	CLT 3-ply wall	78	42.4
2	CLT 5-ply wall	175	91.4
3	CLT 3-ply wall	78	42.4
4	CLT 5-ply wall	175	91.4

Junction Details

Wall 1 and 3 are continuous. Wall 2 and 4 are connected to the continuous wall with 90 mm angle brackets 600 mm o.c.

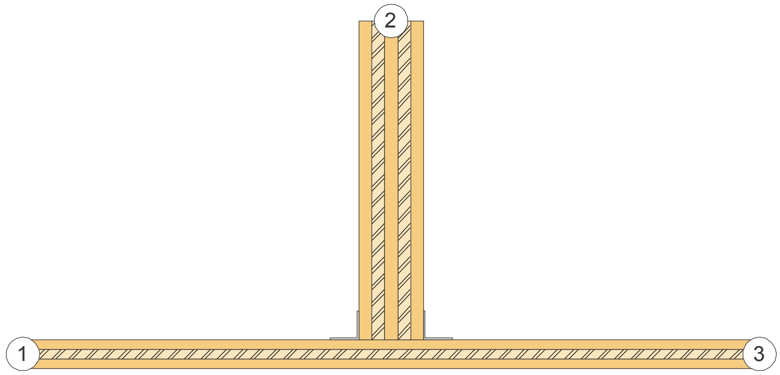
Flanking Sound Transmission Loss $TL_{ij,n}$ – Normalized

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	38	30.9	28.0	31.5	34.5	35.0	47.0	62.5
Ff (2-4)	44	28.0	33.3	33.1	42.4	60.3	73.5	74.2
Fd, Df (1-2,3-2,1-4,3-4)	43	31.4	30.6	31.5	37.2	50.6	60.7	72.1

Flanking Sound Transmission Loss TL_{ij} – Adjusted to S_s = 10 m^2 and L_{ij} = 2.5 m

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	44	36.9	34.0	37.5	40.6	41.1	53.0	68.5
Ff (2-4)	50	34.0	39.3	39.1	48.4	66.3	79.6	80.3
Fd, Df (1-2,3-2,1-4,3-4)	49	37.4	36.6	37.5	43.2	56.6	66.7	78.2

Wall_04_T(a)



Element	Description	Thickness (mm)	Mass-per-Area (kg/m²)
1	CLT 3-ply wall	78	42.4
2	CLT 5-ply wall	175	91.4
3	CLT 3-ply wall	78	42.4

Junction Details

Wall 1 and 3 are continuous. Wall 2 is connected to the continuous wall with 90 mm angle brackets 600 mm o.c.

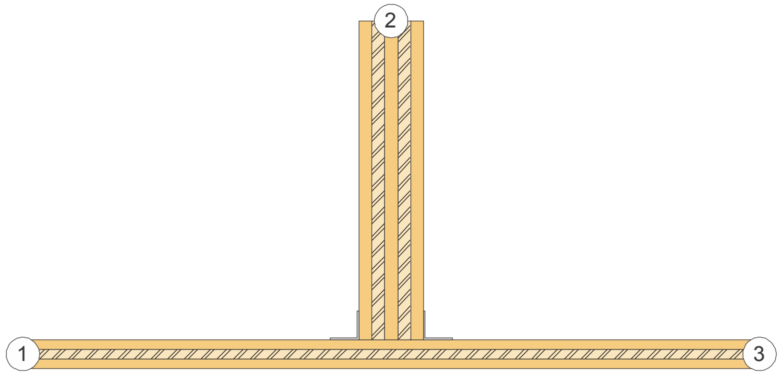
Flanking Sound Transmission Loss $TL_{ij,n}$ – Normalized

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	34	27.2	25.7	25.9	27.5	33.7	46.0	61.0
Fd, Df (1-2,3-2)	42	29.1	29.2	29.4	36.5	49.6	59.7	73.0

Flanking Sound Transmission Loss TL_{ij} – Adjusted to S_s = 10 m² and L_{ij} = 2.5 m

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	40	33.2	31.7	31.9	33.5	39.7	52.0	67.0
Fd, Df (1-2,3-2)	48	35.1	35.2	35.4	42.5	55.6	65.8	79.0

Wall_04_T(b)			



Element	Description	Thickness (mm)	Mass-per-Area (kg/m^2)
1	CLT 3-ply wall	78	42.4
2	CLT 5-ply wall	175	91.4
3	CLT 3-ply wall	78	42.4

Junction Details

Wall 1 and 3 are continuous. Wall 2 is connected to the continuous wall with 90 mm angle brackets 600 mm o.c. and glued using construction grade acrylic adhesive.

Flanking Sound Transmission Loss $TL_{ij,n}$ – Normalized

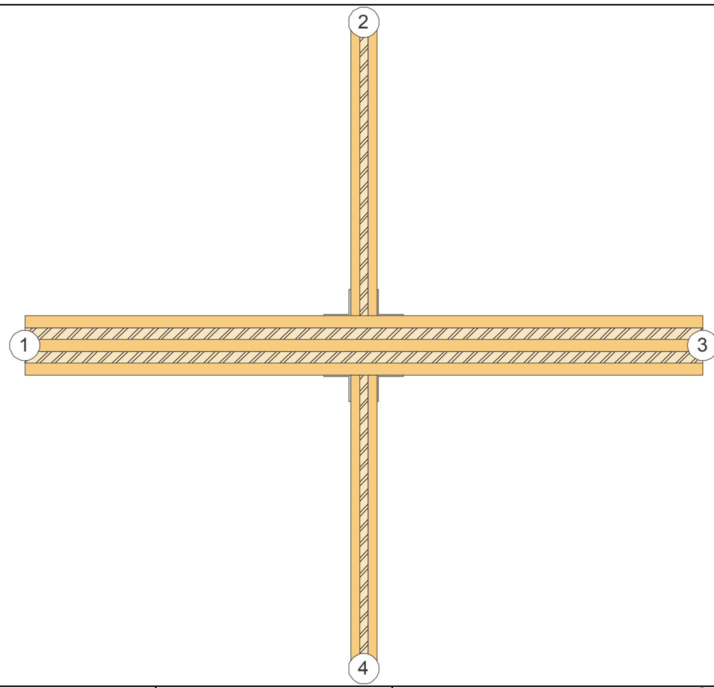
	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	42	33.4	31.7	31.6	36.0	42.9	51.4	62.5
Fd, Df (1-2,3-2)	40	30.7	32.7	30.0	34.6	44.5	53.4	66.7

Flanking Sound Transmission Loss TL_{ij} – Adjusted to S_s = 10 m^2 and L_{ij} = 2.5 m

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	48	39.5	37.7	37.6	42.0	48.9	57.5	68.5
Fd, Df (1-2,3-2)	46	36.7	38.8	36.0	40.6	50.5	59.4	72.8

A.4.3.1.2 CLT Floor-Wall Junctions

Floor_01_X(a)



Element	Description	Thickness (mm)	Mass-per-Area (kg/m^2)
1	CLT 5-ply floor	175	91.4
2	CLT 3-ply wall	78	42.4
3	CLT 5-ply floor	175	91.4
4	CLT 3-ply wall	78	42.4

Junction Details

Floor 1 and 3 are continuous. Wall 2 and 4 are connected to the continuous floor with 90 mm angle brackets 300 mm o.c.

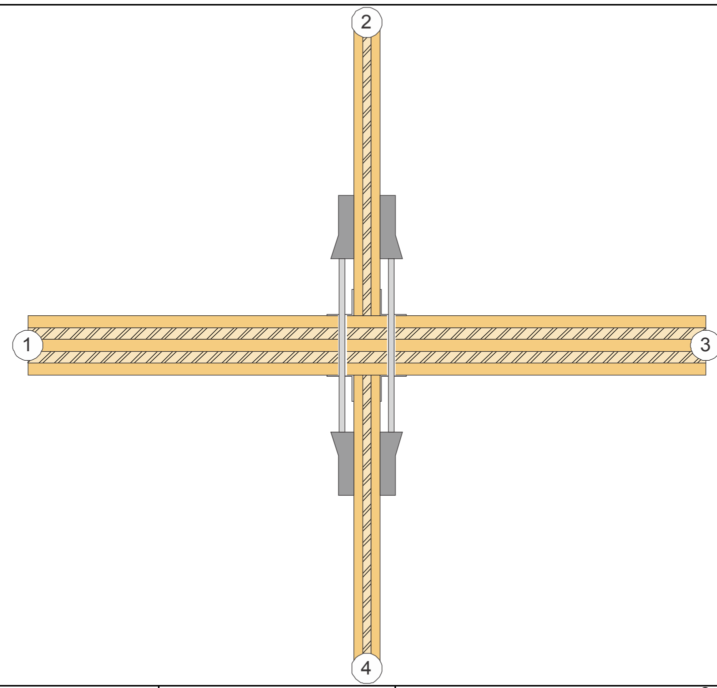
Flanking Sound Transmission Loss $TL_{ij,n}$ – Normalized

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	42	25.8	34.8	32.8	38.6	41.9	46.6	43.2
Ff (2-4)	55	48.7	50.3	51.1	48.6	53.4	60.9	67.9
Fd, Df (1-2,3-2,1-4,3-4)	49	38.0	41.5	41.9	44.3	48.5	55.8	55.0

Flanking Sound Transmission Loss TL_{ij} – Adjusted to S_s = 20m^2 and L_{ij} = 6 m

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	47	31.1	40.0	38.0	43.9	47.1	51.8	48.4
Ff (2-4)	60	54.0	55.5	56.4	53.9	58.7	66.1	73.1
Fd, Df (1-2,3-2,1-4,3-4)	54	43.2	46.7	47.1	49.6	53.8	61.0	60.2

Floor_01_X(b)



Element	Description	Thickness (mm)	Mass-per-Area (kg/m²)
1	CLT 5-ply floor	175	91.4
2	CLT 3-ply wall	78	42.4
3	CLT 5-ply floor	175	91.4
4	CLT 3-ply wall	78	42.4

Junction Details

Floor 1 and 3 are continuous. Wall 2 and 4 are connected to the continuous floor with 90 mm angle brackets 300 mm o.c. and 2 hold-down brackets on each sides.

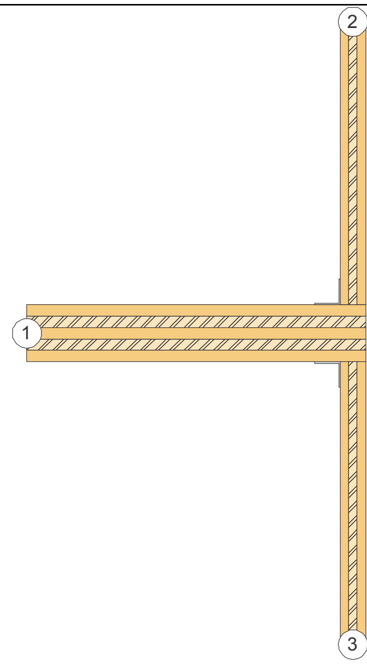
Flanking Sound Transmission Loss $TL_{ij,n}$ – Normalized

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	41	25.4	33.4	32.7	38.1	42.2	49.2	40.8
Ff (2-4)	47	33.1	44.3	40.3	45.1	44.4	57.0	64.5
Fd, Df (1-2, 3-2)	48	38.0	39.8	40.3	43.0	47.8	54.7	54.9
Fd, Df (1-4, 3-4)	51	38.4	42.0	43.2	47.5	51.4	54.3	53.9

Flanking Sound Transmission Loss TL_{ij} – Adjusted to S_s = 20m² and L_{ij} = 6 m

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	47	30.6	38.6	37.9	43.3	47.4	54.4	46.1
Ff (2-4)	52	38.3	49.5	45.6	50.3	49.7	62.3	69.7
Fd, Df (1-2, 3-2)	54	43.2	45.0	45.6	48.2	53.0	59.9	60.2
Fd, Df (1-4, 3-4)	56	43.6	47.3	48.4	52.8	56.6	59.5	59.1

Floor_01_T



Element	Description	Thickness (mm)	Mass-per-Area (kg/m^2)
1	CLT 5-ply floor	175	91.4
2	CLT 3-ply wall	78	42.4
3	CLT 3-ply wall	78	42.4

Junction Details

Wall 2 and 3 are separated by floor 1 and are connected to the floor with 90 mm angle brackets at 300 mm o.c.

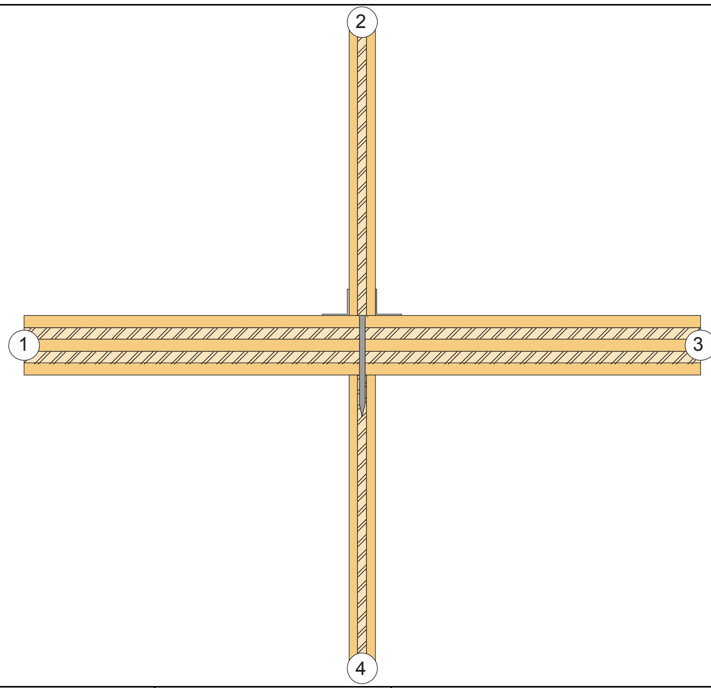
Flanking Sound Transmission Loss $TL_{ij,n}$ – Normalized

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (2-3)	51	43.5	44.6	48.7	45.3	47.9	57.3	63.7
Fd, Df (1-2, 1-3)	47	35.1	36.9	38.1	42.2	45.8	52.7	50.4

Flanking Sound Transmission Loss TL_{ij} – Adjusted to S_s = 20m^2 and L_{ij} = 6 m

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (2-3)	55	42.1	48.1	42.4	50.1	63.5	73.7	72.4
Fd, Df (1-2, 1-3)	50	37.9	40.4	37.4	49.1	56.9	62.4	55.2

Floor_01_X(c)



Element	Description	Thickness (mm)	Mass-per-Area (kg/m²)
1	CLT 5-ply floor	175	91.4
2	CLT 3-ply wall	78	42.4
3	CLT 5-ply floor	175	91.4
4	CLT 3-ply wall	78	42.4

Junction Details

Floor 1 and 3 are continuous. Wall 2 is connected to the continuous floor with 90 mm angle brackets 300 mm o.c. and wall 4 is connected using 280 mm self-tapping screws at 300 mm o.c.

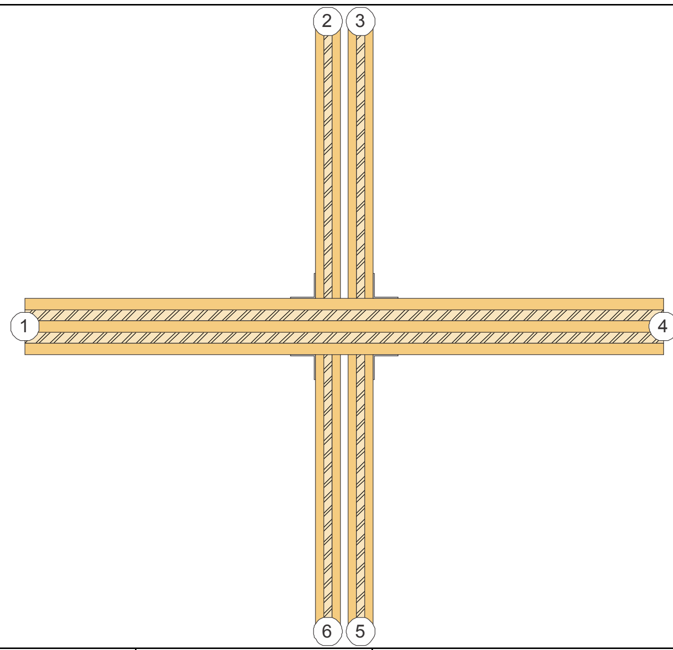
Flanking Sound Transmission Loss $TL_{ij,n}$ – Normalized

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	42	25.3	33.6	32.8	37.7	41.6	49.6	45.3
Ff (2-4)	56	52.0	51.5	53.2	49.9	53.8	63.6	70.3
Fd, Df (1-2, 3-2)	48	37.8	40.6	40.4	43.0	47.6	54.8	55.0
Fd, Df (1-4, 3-4)	52	39.6	42.6	44.2	48.0	52.3	55.4	54.5

Flanking Sound Transmission Loss TL_{ij} – Adjusted to S_s = 20m² and L_{ij} = 6 m

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	47	30.5	38.8	38.0	43.0	46.9	54.8	50.5
Ff (2-4)	62	57.2	56.7	58.4	55.1	59.1	68.8	75.5
Fd, Df (1-2, 3-2)	53	43.0	45.8	45.6	48.3	52.8	60.1	60.2
Fd, Df (1-4, 3-4)	57	44.8	47.8	49.4	53.2	57.5	60.6	59.7

Floor_02_X



Element	Description	Thickness (mm)	Mass-per-Area (kg/m²)
1	CLT 5-ply floor	175	91.4
2	CLT 3-ply wall	78	42.4
3	CLT 3-ply wall	78	42.4
4	CLT 5-ply floor	175	91.4
5	CLT 3-ply wall	78	42.4
6	CLT 3-ply wall	78	42.4

Junction Details

Floor 1 and 4 are continuous. Walls 2,3,5, and 6 are connected to the continuous floor with 90 mm angle brackets 300 mm o.c. on one side of each wall. There is a 25 mm gap filled with glass fibre insulation between both parallel walls.

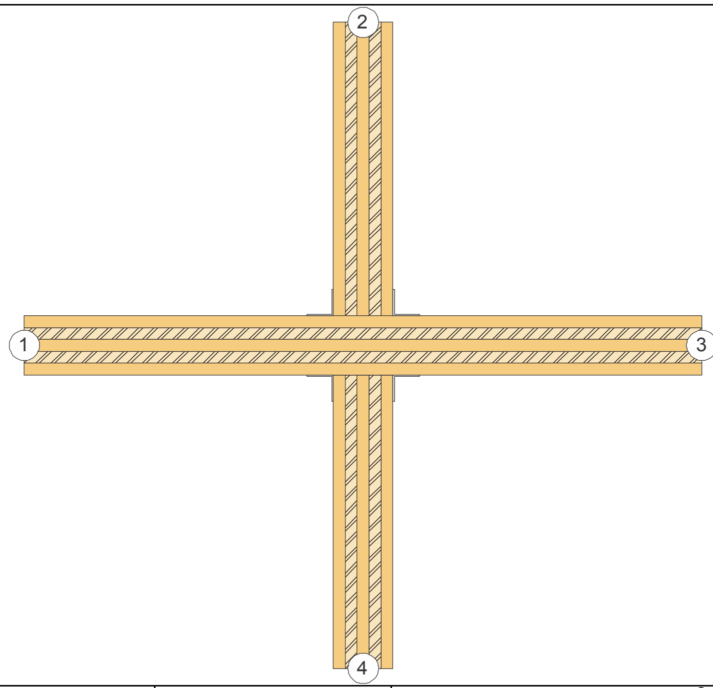
Flanking Sound Transmission Loss $TL_{ij,n}$ – Normalized

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	40	24.6	33.7	37.1	38.3	41.4	46.6	39.4
Ff_dbl_vert (2-4)	54	43.7	45.0	45.2	47.4	55.4	69.4	81.1
Ff_dbl_diag (2-4)	54	43.8	45.7	46.8	47.3	56.9	71.0	82.7
Fd, Df_dbl_hor (1-2, 3-2, 1-4, 3-4)	52	35.9	41.3	43.5	46.2	51.8	60.3	64.5
Fd, Df_dbl_vert (1-2, 3-2, 1-4, 3-4)	46	35.4	38.6	37.1	40.4	48.1	58.5	62.7

Flanking Sound Transmission Loss TL_{ij} – Adjusted to S_s = 20m² and L_{ij} = 6 m

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	45	29.9	38.9	42.4	43.6	46.6	51.8	44.7
Ff_dbl_vert (2-4)	59	48.9	50.2	50.5	52.6	60.7	74.6	86.3
Ff_dbl_diag (2-4)	59	49.0	51.0	52.0	52.5	62.2	76.2	87.9
Fd, Df_dbl_hor (1-2, 3-2, 1-4, 3-4)	57	41.1	46.5	48.7	51.5	57.0	65.6	69.7
Fd, Df_dbl_vert (1-2, 3-2, 1-4, 3-4)	52	40.6	43.8	42.3	45.7	53.3	63.8	67.9

Floor_03_X(a)



Element	Description	Thickness (mm)	Mass-per-Area (kg/m²)
1	CLT 5-ply floor	175	91.4
2	CLT 5-ply wall	175	91.4
3	CLT 5-ply floor	175	91.4
4	CLT 5-ply wall	175	91.4

Junction Details

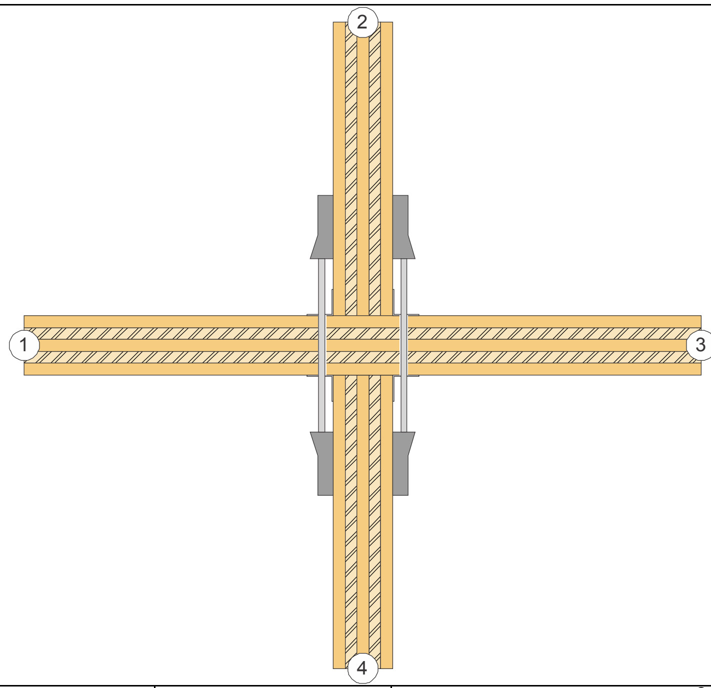
Floor 1 and 3 are continuous. Wall 2 and 4 are connected to the continuous wall with 90 mm angle brackets 300 mm o.c.

Flanking Sound Transmission Loss $TL_{ij,n}$ – Normalized

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	41	26.2	35.6	35.7	36.2	41.6	48.6	41.0
Ff (2-4)	53	39.4	47.3	41.6	47.9	66.1	70.6	68.3
Fd, Df (1-2,3-2,1-4,3-4)	49	32.7	39.5	36.2	45.4	56.5	57.8	52.4

Flanking Sound Transmission Loss TL_{ij} – Adjusted to S_s = 20m² and L_{ij} = 6 m

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	46	31.4	40.8	40.9	41.4	46.8	53.8	46.3
Ff (2-4)	58	44.6	52.5	46.9	53.1	71.3	75.8	73.5
Fd, Df (1-2,3-2,1-4,3-4)	54	37.9	44.7	41.4	50.6	61.7	63.1	57.6

Floor_03_X(b)			
			
Element	**Description**	**Thickness (mm)**	**Mass-per-Area (kg/m²)**
1	CLT 5-ply floor	175	91.4
2	CLT 5-ply wall	175	91.4
3	CLT 5-ply floor	175	91.4
4	CLT 5-ply wall	175	91.4

Junction Details

Floor 1 and 3 are continuous. Wall 2 and 4 are connected to the continuous floor with 90 mm angle brackets 300 mm o.c. and 2 hold-down brackets on each sides.

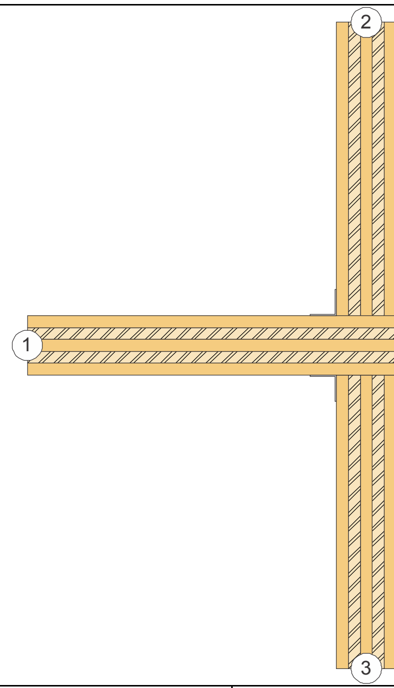
Flanking Sound Transmission Loss $TL_{ij,n}$ – Normalized

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	43	25.5	35.1	35.9	36.9	41.3	49.3	-
Ff (2-4)	50	37.9	46.2	39.6	46.6	54.7	64.0	65.1
Fd, Df (1-2,3-2,1-4,3-4)	49	31.7	38.4	36.1	45.4	55.6	56.4	51.9

Flanking Sound Transmission Loss TL_{ij} – Adjusted to S_s = 20m² and L_{ij} = 6 m

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (1-3)	48	30.8	40.3	41.2	42.1	46.6	54.5	-
Ff (2-4)	55	43.1	51.4	44.8	51.8	60.0	69.3	70.3
Fd, Df (1-2,3-2,1-4,3-4)	54	36.9	43.6	41.3	50.7	60.8	61.6	57.2

Floor_03_T



Element	Description	Thickness (mm)	Mass-per-Area (kg/m²)
1	CLT 5-ply floor	175	91.4
2	CLT 5-ply wall	175	91.4
3	CLT 5-ply wall	175	91.4

Junction Details

Wall 2 and 3 are separated by floor 1 and are connected to the floor with 90 mm angle brackets at 300 mm o.c.

Flanking Sound Transmission Loss $TL_{ij,n}$ – Normalized

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (2-3)	50	36.9	42.8	37.2	44.8	58.3	68.5	67.1
Fd, Df (1-2, 1-3)	45	32.6	35.2	32.2	43.9	51.7	57.1	50.0

Flanking Sound Transmission Loss TL_{ij} – Adjusted to S_s = 20m² and L_{ij} = 6 m

	STC	63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz
Ff (2-3)	56	48.7	49.9	54.0	50.5	53.1	62.6	69.0
Fd, Df (1-2, 1-3)	52	40.3	42.1	43.3	47.4	51.0	57.9	55.6

A.4.3.2 Comparison of CLT flanking data

Below comparisons are presented of the normalized flanking data of different wall-wall and floor-wall CLT assemblies.

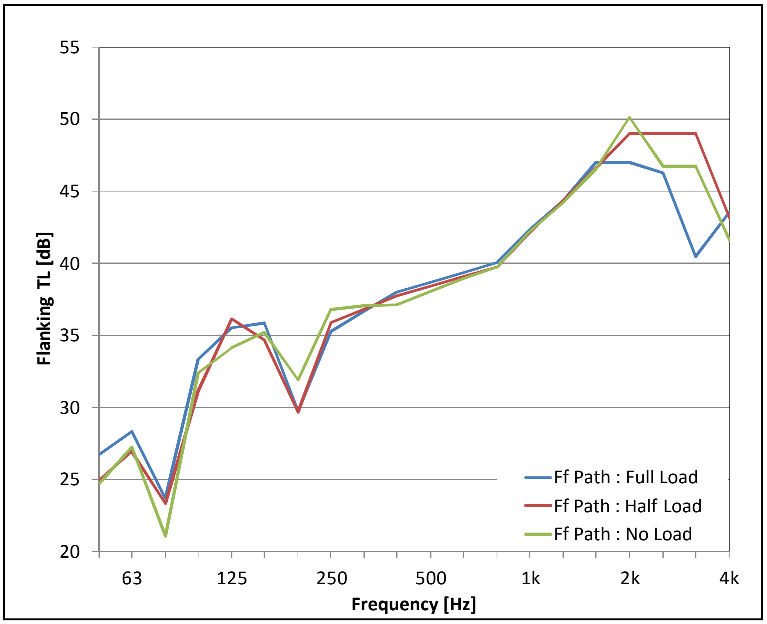


Figure A.4 - 7: CLT Junction Attenuation - Effect of Loading on Ff Path [Floor_01_X]

Figure A.4 - 7 shows that loading the floor-wall junction has an insignificant effect on the flanking sound transmission in the frequency range of interest. However there is a slight difference in the high frequency range.

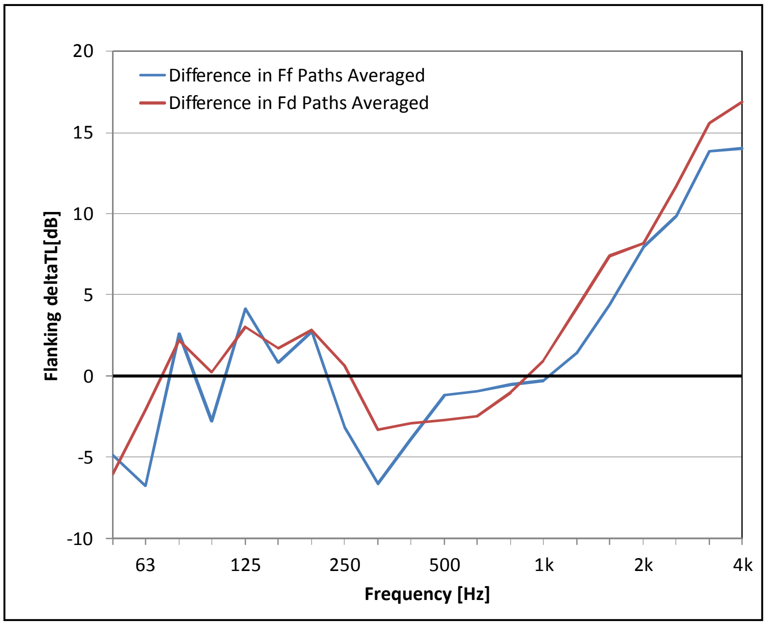


Figure A.4 - 8: Comparison of Similar CLT Floor-Wall and Wall-Wall Junctions Attenuation

Figure A.4 - 8 shows that the there is a similar difference between wall-wall and wall-floor junctions, for both the CLT5/CLT5 and CLT3/CLT5 junctions, build of the same CLT elements. The observed difference is probably due to the CLT orientation.

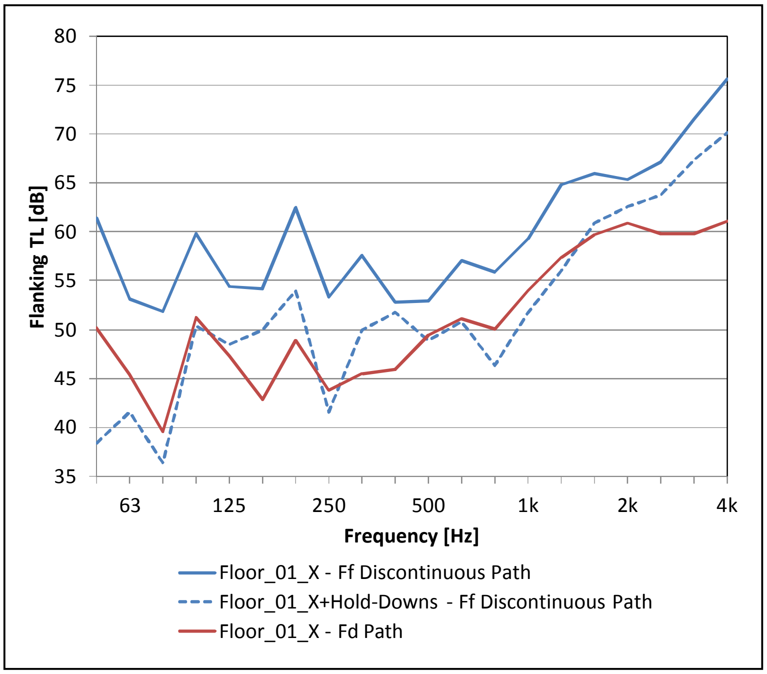


Figure A.4 - 9: CLT Flanking TL - Change in Ff Path [Floor_01_X] Due to Hold-downs

When hold-downs are used on CLT walls, they create a good connection between the upper wall and the lower wall, thus reducing the attenuation across that path. As seen in Figure A.4 - 9, the Ff flanking path of the CL5/CLT3 (Floor_01_X) floor/wall junction becomes as significant as the Fd/Df flanking path when hold-downs are installed. A similar but less pronounced effect is observed for the CLT5/CLT5 (Floor_03_X) floor/wall junction.

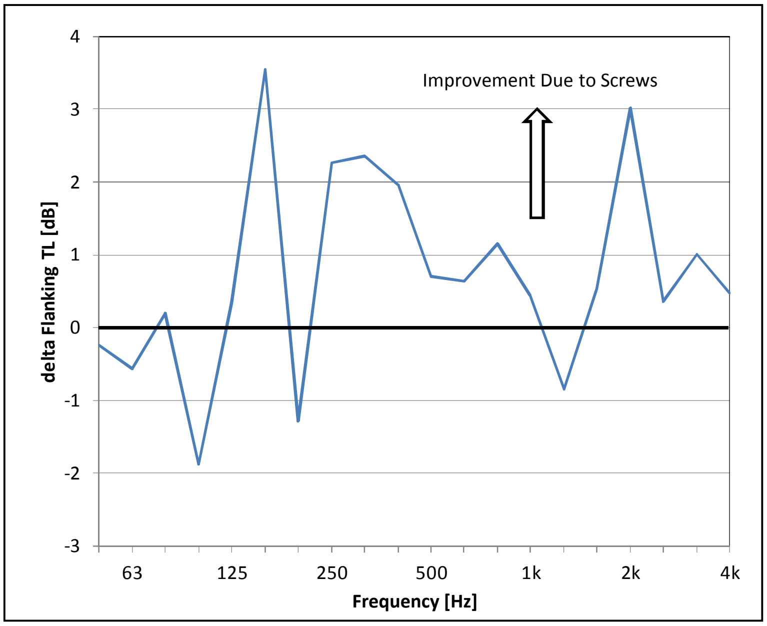


Figure A.4 - 10: CLT Flanking TL - CLT Junction Attenuation - Screws vs Brackets

Figure A.4 - 10 shows that using self-tapping screws to fasten the floor to the lower wall is slightly better than using brackets for the Df/Fd floor to lower wall path.

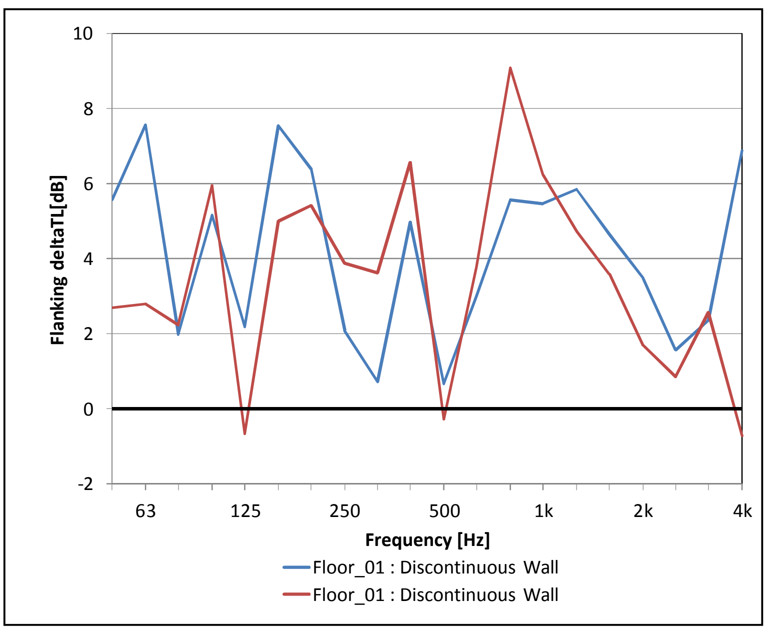


Figure A.4 - 11: Difference between X and T Junction for flanking sound transmission path Ff in floor-wall assembly

Figure A.4 - 11 shows that for the difference between X and T Junction is the same for both 5-ply/3-ply and 5-ply/5-ply floor wall assemblies. In other words going from Floor_01_X to Floor_01_T is the same as going from Floor_03_X to Floor_03_T. The Ff path shows an average improvement of ~4dB for the X junction throughout the frequency range of interests which indicates that the X junction energy is dissipated through the

A.4.3.3 Direct Sound Insulation Data

The Sound Transmission Loss of the bare CLT elements listed in Table A.4 - 1 is taken from the CLT wall and floor study of the mid-rise wood research project. Only octave band TL-data as well as STC ratings are listed to reduce the data. Details on testing and specimens are given in Appendix A.2.

Table A.4 - 1: Direct Sound Transmission Loss of bare CLT wall elements

CLT Element	STC	63Hz	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz
3-ply wall, 42.4 kg/m^2	33	23.0	24.5	25.1	27.6	32.3	42.0	48.2
5-ply wall, 91.4 kg/m^2	38	27.5	31.0	27.6	33.8	42.8	49.6	47.8

Table A.4 - 2: Direct Sound Transmission Loss of bare CLT floor elements

CLT Element	STC	63Hz	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz
5-ply floor, 91.4 kg/m^2	41	25.8	29.4	30.6	36.8	44.0	50.0	43.9
7-ply floor, 130.0 kg/m^2	44	29.7	31.3	32.8	39.7	46.3	51.8	52.5

The STC ratings presented in the first data column were determined from one-third octave band data and the octave band data was averaged according to ISO 10848.

A.4.3.4 Incremental Change of TL due to Added Layers

The incremental change of Sound Transmission Loss ∆TL is also taken from the CLT wall and floor study and was used there to estimate the direct sound insulation performance of CLT walls and floors with added layers, like wall linings, floor toppings and gypsum board ceilings. As the floor data is not fully analyzed, only data for the wall linings are listed. For detailed descriptions it is again referred to Appendix A.2.

Table A.4 - 3: Incremental change of Sound Transmission Loss ∆TL for direct sound transmission when a wall liner is only applied to one side of the CLT wall and for flanking paths

Gypsum board wall liners 2 layers 12.7 mm thick Type X	63Hz	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz
Directly attached to 5-ply wall, 91.4 kg/m2	1.8	0.1	2.4	3.7	5.9	4.9	7.8
Directly attached to 3-ply wall, 42.4 kg/m2	2.9	3.6	3.6	3.5	7.2	4.7	4.0
Directly attached to double 3-ply wall, 89.6 kg/m2	1.6	4.4	4.8	7.6	8.7	6.2	2.5
38 mm wood furring @ 400 mm	1.1	-5.8	7.5	11.2	10.9	8.4	12.2
38 mm wood furring @ 600 mm	-2.7	1.6	11.0	11.2	12.0	11.2	14.6
Resilient channels @ 600 mm on 38 mm wood furring @ 400 mm	-4.0	4.7	17.1	23.2	25.1	21.2	24.0
64 mm wood furring @ 600 mm	-3.6	4.1	10.5	9.7	9.3	9.6	14.5
64 mm wood frame w. studs @ 600 mm and 12.7 mm air gap	1.8	11.4	17.9	21.2	21.6	23.7	29.6

It was found that in the mid- and high frequency range, the improvement was higher for all liners when it was added to only one side of the CLT compared when a second wall lining was added to the second side. This was expected for directly attached gypsum board, as the improvement depends on the relative increase of mass which is greater for the first layer. However, a similar effect was found for the well decoupled wall liners too, even when the gypsum board was mounted on a separate wood frame. To account for this effect, two sets of ∆TL data are presented. In Table A.4 - 3, data are listed that should be applied when a wall liner is added to a flanking path and for the direct path if there is a wall liner only on one side of the element. The well decoupled wall linings, e.g. on strapping and wood framing, are valid for all tested CLT base elements. The directly attached gypsum board data is only valid for the element that are listed as the improvement is mainly due to the relative increase of the mass-per-unit area that differs for all base CLT elements. In Table A.4 - 4, the data is listed that has to be used if the direct sound insulation of a wall is predicted that has wall liners attached to both sides. Hereby, the data listed in Table A.4 - 4 has to be applied as improvement for the wall liners on both sides. Application of data from Table A.4 - 3 for one or both of the wall liners would lead to a slight overestimation of direct sound transmission loss for a wall with liners one both sides.

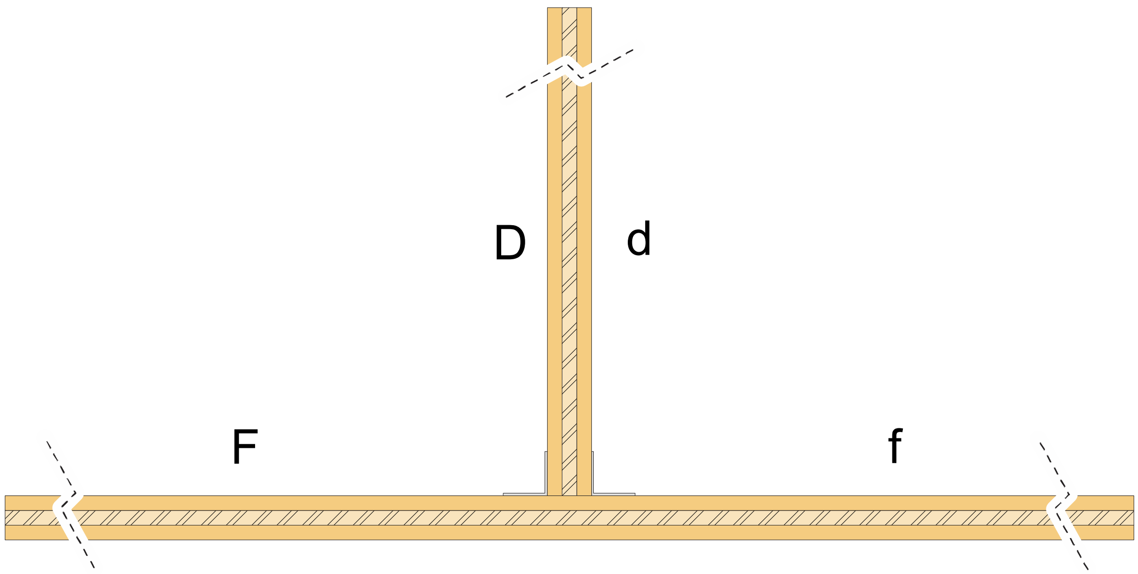
Table A.4 - 4: Incremental change of Sound Transmission Loss ΔTL for direct sound transmission when wall liners are applied on both sides of the CLT wall

Gypsum board wall liners **2 layers 12.7 mm thick Type X**	**63Hz**	**125Hz**	**250Hz**	**500Hz**	**1kHz**	**2kHz**	**4kHz**
Directly attached to 5-ply wall, 91.4 kg/m2	1.3	0.5	1.2	1.2	4.6	4.1	6.4
Directly attached to 5-ply wall, 42.4 kg/m2	2.8	2.8	2.5	1.4	4.1	3.1	3.4
Directly attached to double 3-ply wall, 89.6 kg/m2	1.5	3.6	3.6	5.7	7.5	5.7	2.2
38 mm wood furring @ 400 mm	0.5	-5.5	4.9	8.7	9.3	7.3	10.1
38 mm wood furring @ 600 mm	-3.7	1.6	8.8	8.4	10.4	9.6	11.4
Resilient channels @ 600 mm on 38 mm wood furring @ 400 mm	-5.1	6.0	18.8	22.8	23.3	20.6	22.4
64 mm wood furring @ 600 mm	-4.1	3.6	8.8	8.6	9.2	8.4	13.1
64 mm wood frame w. studs @ 600 mm and 12.7 mm air gap	1.0	11.7	16.7	19.3	20.3	22.7	27.7

A.4.3.5 CLT Junction Examples

Below are examples of CLT junctions with added liners and toppings for rooms side-by-side and one-above-the-other.

CLT3-WF-NLB-001



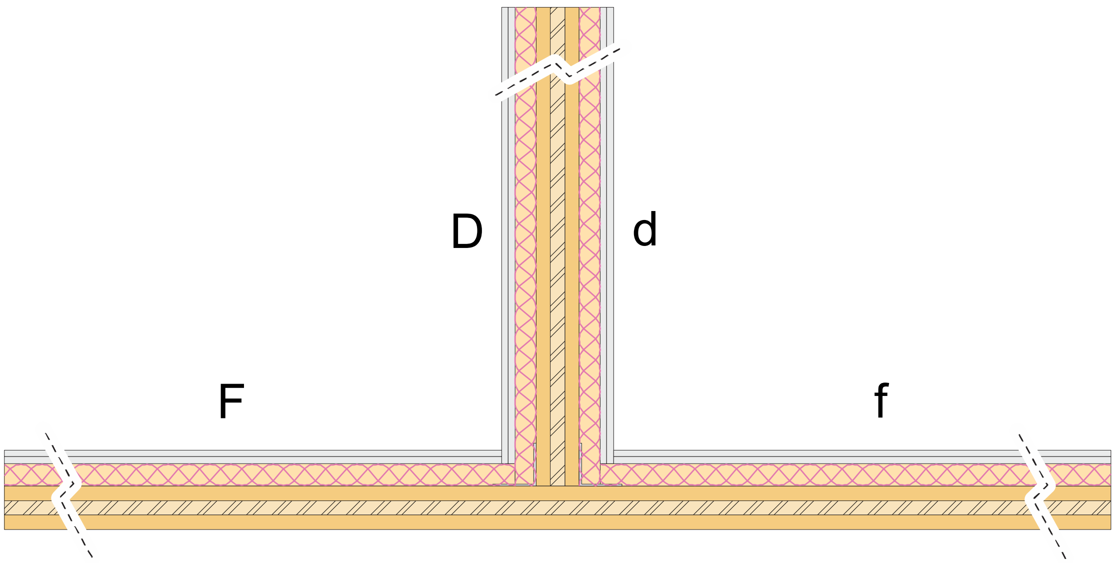
Element	Reference
D	CLT3(wall)
d	CLT3(wall)
F	CLT3(wall)
f	CLT3(wall)

Paths	FI-STC
Dd	33
Df	52
Fd	52
Ff	46
Flanking	**44**
Total	**31**

Non-load bearing T-junction of separating wall/abutting side wall

- 3-ply 78 mm thick CLT wall panels with mass ~42.4 kg/m^2
- CLT wall panels are oriented so face ply strands are vertical
- Connected with 90 mm equal leg angle brackets either nailed or screwed to both sides of the separating element and spaced 600 mm o.c.
- No added linings on either sides

CLT3-WF-NLB-002



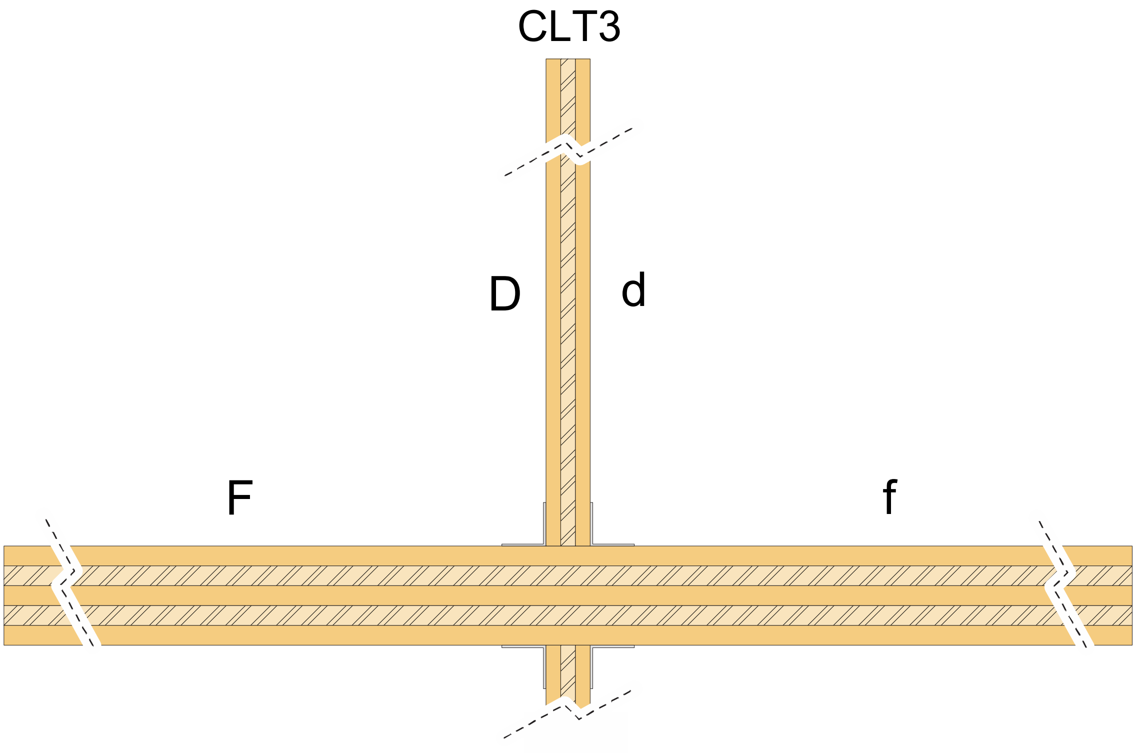
Element	Reference
D	CLT3(wall)+WFUR38(600)+GFB38+2G13
d	CLT3(wall)+WFUR38(600)+GFB38+2G13
F	CLT3(wall)+WFUR38(600)+GFB38+2G13
f	CLT3(wall)+WFUR38(600)+GFB38+2G13

Paths	FI-STC
Dd	51
Df	62
Fd	62
Ff	62
Flanking	**57**
Total	**50**

Non-load bearing T-junction of separating wall/abutting side wall

- 3-ply 78 mm thick CLT wall panels with mass ~42.4 kg/m^2
- CLT wall panels are oriented so face ply strands are vertical
- Connected with 90 mm equal leg angle brackets either nailed or screwed to both sides of the separating element and spaced 600 mm o.c.
- Lining on each side of separating wall (D and d) and each side of abutting wall (F and f) of 2 layers of 12.7 mm Gypsumboard supported on 38 mm wood furring spaced 600 mm o.c. with absorptive material in the cavities

CLT3-FW-LB-001



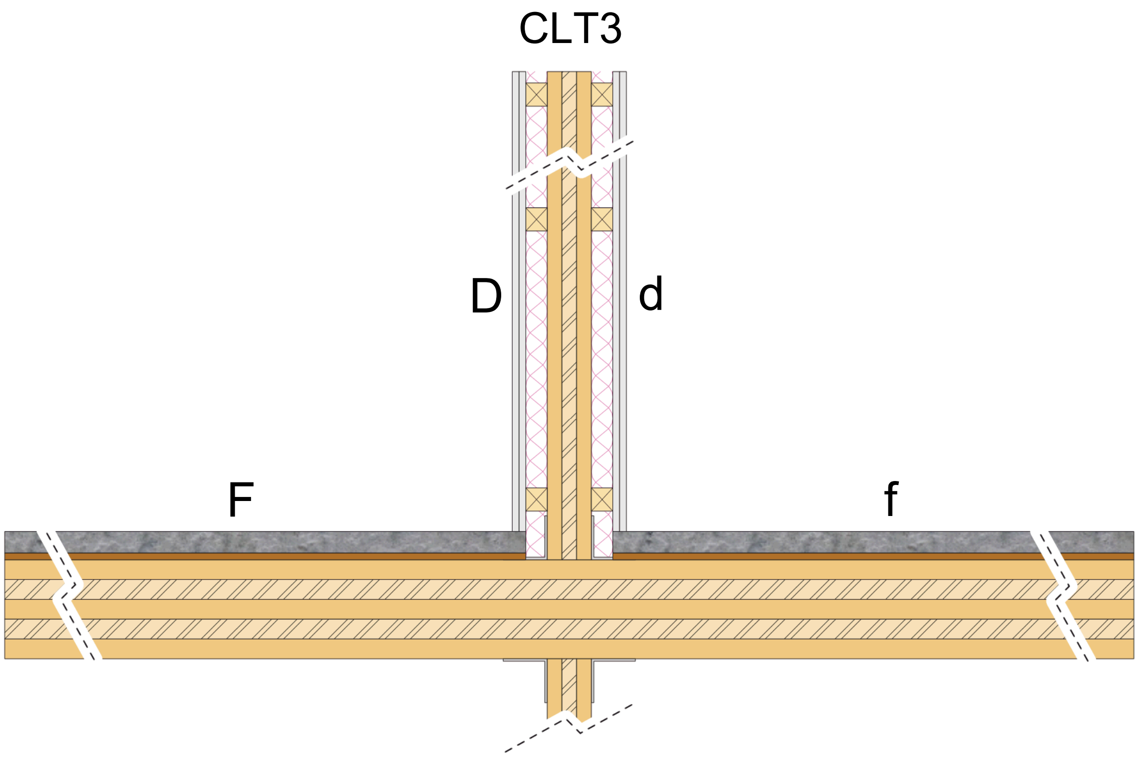
Element	Reference
D	CLT3(wall)
d	CLT3(wall)
F	CLT5(floor)
f	CLT5(floor)

Paths	FI-STC
Dd	33
Df	52
Fd	52
Ff	46
Flanking	**44**
Total	**33**

Load bearing X-junction of separating wall/floor

- 3-ply 78 mm thick CLT wall panels with mass ~42.4 kg/m^2
- 5-ply 175 mm thick CLT floor panels with mass ~92.1 kg/m^2 and continuous through cross junction with separating wall.
- CLT floor/ceiling panels are oriented so face ply strands are perpendicular to load bearing junction.
- Connected with 90 mm equal leg angle brackets either nailed or screwed to both sides of the separating element and spaced 300 mm o.c.
- No added linings on either sides.

CLT3-FW-LB-002



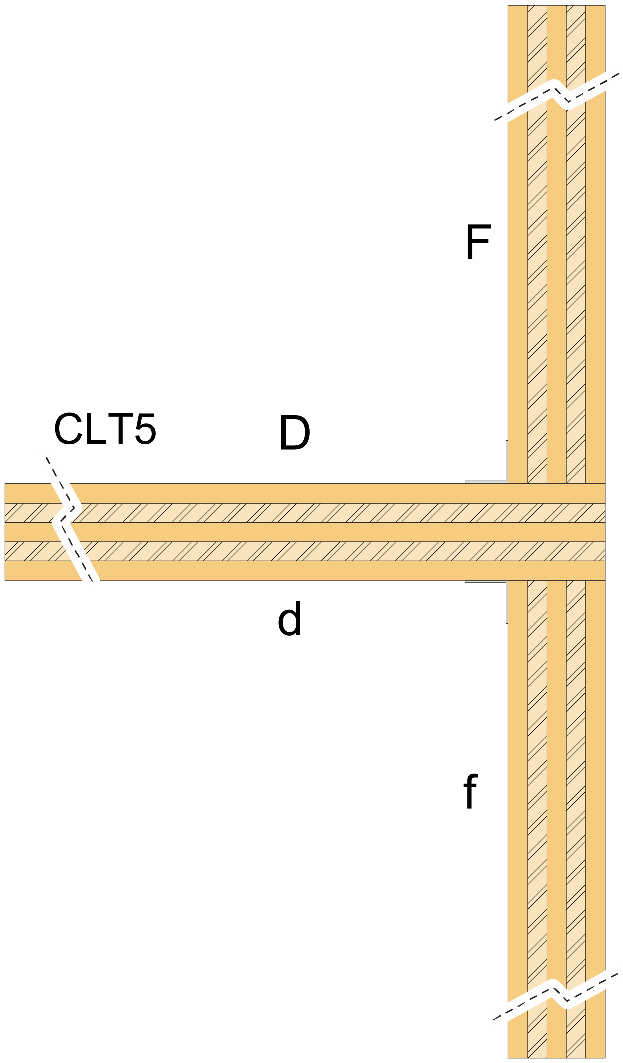
Element	Reference
D	CLT3(wall)+WFUR38(600)+GFB38+2G13
d	CLT3(wall)+WFUR38(600)+GFB38+2G13
F	CLT5(floor)+WFIBER12+CON38
f	CLT5(floor)+WFIBER12+CON38

Paths	FI-STC
Dd	51
Df	72
Fd	72
Ff	69
Flanking	**66**
Total	**51**

Load bearing X-junction of separating wall/floor

- 3-ply 78 mm thick CLT wall panels with mass ~42.4 kg/m^2
- 5-ply 175 mm thick CLT floor panels with mass ~92.1 kg/m^2 and continuous through cross junction with separating wall.
- CLT floor/ceiling panels are oriented so face ply strands are perpendicular to load bearing junction.
- Connected with 90 mm equal leg angle brackets either nailed or screwed to both sides of the separating element and spaced 300 mm o.c.
- Floor topping of 38 mm concrete over 12.7 mm wood fiber board installed on both sides (F and f)
- Lining on each side of separating wall (D and d) of 2 layers of 12.7 mm Gypsumboard supported on 38 mm wood furring spaced 600 mm o.c. with absorptive material in the cavities

CLT5-WF-NLB-001



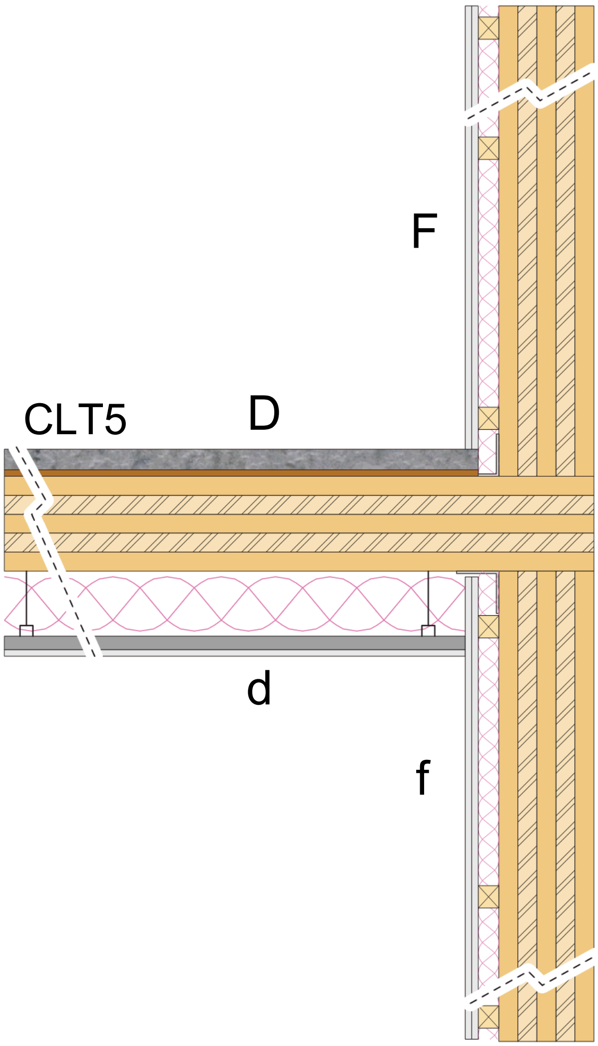
Element	Reference
D	CLT5(floor)
d	CLT5(ceiling)
F	CLT5(wall)
f	CLT5(wall)

Paths	FI-STC
Dd	41
Df	52
Fd	52
Ff	57
Flanking	**48**
Total	**40**

Non-load bearing T-junction of separating floor/flanking walls

- 5-ply 175 mm thick CLT floor panels with mass ~92.1 kg/m^2.
- 5-ply 175 mm thick CLT wall panels with mass ~94.1 kg/m^2 and abutting on floor.
- CLT floor/ceiling panels are oriented so face ply strands are perpendicular to load bearing junction.
- Connected with 90 mm equal leg angle brackets either nailed or screwed to both sides of the separating element and spaced 300 mm o.c.
- No added linings on either sides.

CLT5-WF-NLB-002



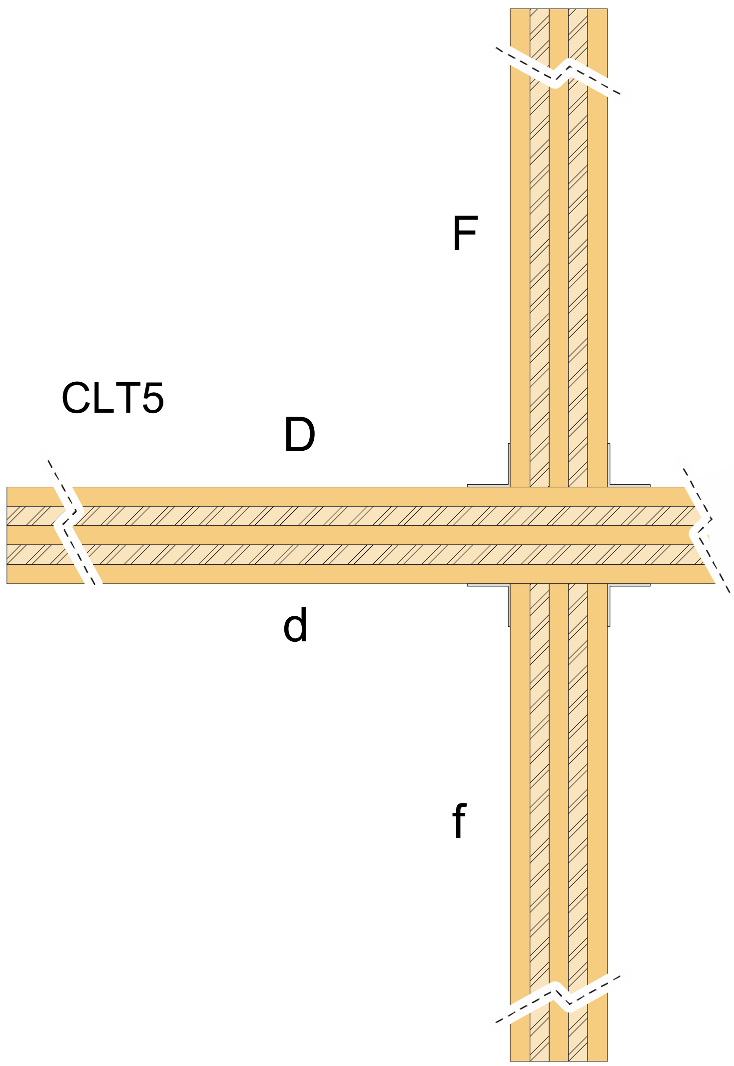
Element	Reference
D	CLT5(floor)+WFIBER12 +CON38
d	CLT5(ceiling)+GFB140 +HAT150+G16
F	CLT5(wall) +WFUR38(600)+GFB38+2G13
f	CLT5(wall) +WFUR38(600)+GFB38+2G13

Paths	FI-STC
Dd	72
Df	71
Fd	83
Ff	74
Flanking	**69**
Total	**67**

Non-load bearing T-junction of separating floor/flanking walls

- 5-ply 175 mm thick CLT floor panels with mass ~92.1 kg/m^2.
- 5-ply 175 mm thick CLT wall panels with mass ~94.1 kg/m^2 and abutting on floor.
- CLT floor/ceiling panels are oriented so face ply strands are perpendicular to load bearing junction.
- Connected with 90 mm equal leg angle brackets either nailed or screwed to both sides of the separating element and spaced 300 mm o.c.
- Floor topping (D) of 38 mm concrete over 12.7 mm wood fiber board.
- Lining on each flankking walls (F and f) of 2 layers of 12.7 mm Gypsumboard supported on 38 mm wood furring spaced 600 mm o.c. with absorptive material in the cavities
- Ceiling lining (d) of 15.9 mm Gypsum board fastened to hat-channels supported on cross-channels hung on wires, a ceiling caviity of 150 mm filled with 140 mm absorptive material.

CLT5-WF-LB-001



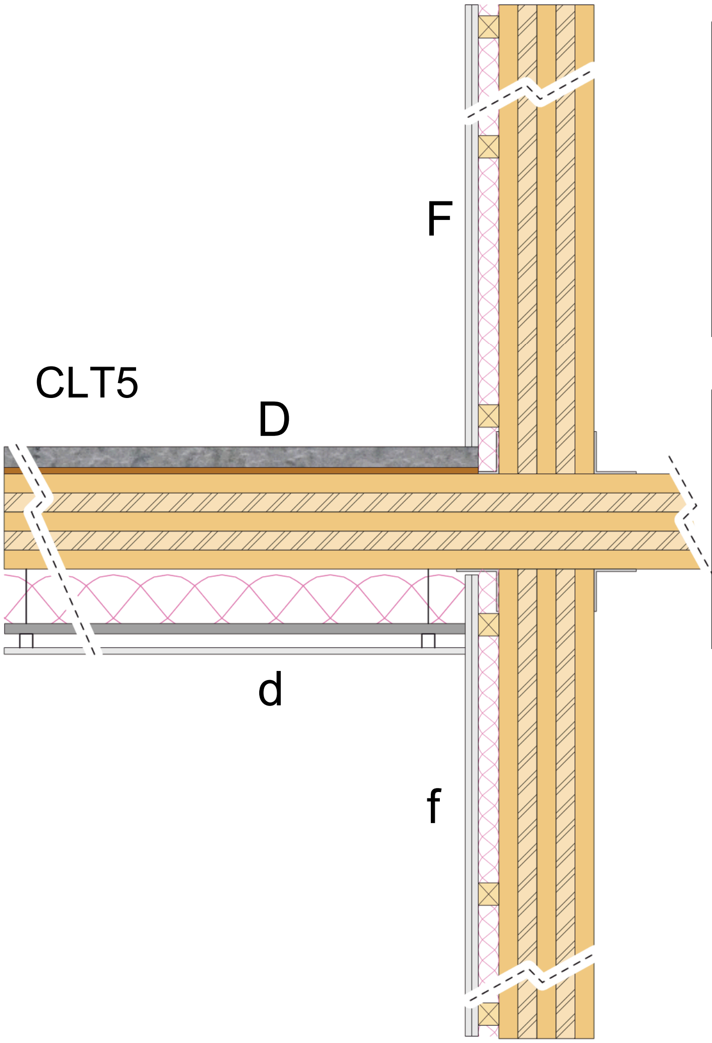
Element	Reference
D	CLT5(floor)
d	CLT5(ceiling)
F	CLT5(wall)
f	CLT5(wall)

Paths	FI-STC
Dd	41
Df	55
Fd	59
Ff	59
Flanking	**52**
Total	**41**

Load bearing X-junction of separating floor/flanking walls

- 5-ply 175 mm thick CLT floor panels with mass ~92.1 kg/m^2 and continuous through cross junction with separating wall.
- 5-ply 175 mm thick CLT wall panels with mass ~94.1 kg/m^2 and abutting on continuous floor.
- CLT floor/ceiling panels are oriented so face ply strands are perpendicular to load bearing junction.
- Connected with 90 mm equal leg angle brackets either nailed or screwed to both sides of the separating element and spaced 300 mm o.c.
- No added linings on either sides.

CLT5-WF-LB-002



Element	Reference
D	CLT5(floor)+WFIBER12 +CON38
d	CLT5(ceiling)+GFB140 +HAT150+G16
F	CLT5(wall)+WFUR38(600) +GFB38+2G13
f	CLT5(wall)+WFUR38(600) +GFB38+2G13

Paths	FI-STC
Dd	72
Df	73
Fd	84
Ff	73
Flanking	**70**
Total	**68**

Load bearing X-junction of separating floor/flanking walls

- 5-ply 175 mm thick CLT floor panels with mass ~92.1 kg/m^2 and continuous through cross junction with separating wall.
- 5-ply 175 mm thick CLT wall panels with mass ~94.1 kg/m^2 and abutting on continuous floor.
- CLT floor/ceiling panels are oriented so face ply strands are perpendicular to load bearing junction.
- Connected with 90 mm equal leg angle brackets either nailed or screwed to both sides of the separating element and spaced 300 mm o.c.
- Floor topping (D) of 38 mm concrete over 12.7 mm wood fiber board.
- Lining on each flankking walls (F and f) of 2 layers of 12.7 mm Gypsumboard supported on 38 mm wood furring spaced 600 mm o.c. with absorptive material in the cavities
- Ceiling lining (d) of 15.9 mm Gypsum board fastened to hat-channels supported on cross-channels hung on wires, a ceiling caviity of 150 mm filled with 140 mm absorptive material.

A.4.4 Summary and Conclusions

The methodology for the prediction of the apparent sound insulation in CLT buildings has been outlined and input data that is necessary to predict the flanking sound insulation is listed. The results indicate that flanking sound transmission is a smaller problem when flanking elements are not continuous for example when connected with angle brackets due to the structural break. When the elements are continuous, like for the Ff-paths with coupling of elements 1 and 3 in the data sheets, additional measures like decoupled wall linings, e.g. gypsum board on wood strapping spaced 600 mm, are necessary to achieve possible future code minimum. A second alternative would be a structural break in the element along the junction which certainly has structural implications.

A.4.5 References

[1] ISO 15712-1:2005; "Building Acoustics – Estimation of acoustic performance of buildings from the performance of elements – Part 1: Airborne sound insulation between rooms", ISO-Standard

[2] ASTM E90 – 09; "Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements", ASTM International

[3] ASTM E413 – 04; "Classification for Rating Sound Insulation" ASTM International

[4] C. Guigou-Carter et al.; "Prediction Method Adapted to Wood Frame Lightweight Construction"; Building Acoustics, Volume 13(3) (2006) 173-188

[5] M. Villot et al.; "Measurement Methods Adapted to Wood Frame Lightweight Construction"; Building Acoustics, Volume **13(3)** (2006) 189-198.

[6] S. Schoenwald; "Measurement Methods Adapted to Wood Frame Lightweight Construction", Proceedings of EURONOISE 2012, Prague, Czech Republic, 2012.

[7] ISO 10848-1:2006; "Acoustics – Laboratory measurement of the flanking transmission of airborne and impact sound between adjoining rooms – Part 1: Frame document", ISO-Standard, 2006

[8] ISO 10848-1:2010; "Acoustics – Laboratory measurement of the flanking transmission of airborne and impact sound between adjoining rooms – Part 4: Application to junctions with at least one heavy element", ISO-Standard, 2010