Acoustics summary: sound insulation in mid-rise wood building (Report to Research Consortium for wood and wood-hybrid mid-rise buildings)

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

Acoustics Summary –

Sound Insulation in Mid-rise Wood Buildings

CLIENT REPORT: A1-004377.2

December 31, 2014

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

ACOUSTICS SUMMARY– SOUND INSULATION IN MID-RISE WOOD BUILDINGS

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

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The following staff members of project partner/collaborator organizations have contributed to the working groups and this progress report:

CWC: Peggy Lepper; Ineke Van Zeeland,

FPI: Lin Hu; Julie Frappier (Nordic);

NRC: Frances King; Gabriel Latour; Don MacMillan; Ivan Sabourin; Stefan Schoenwald; Berndt Zeitler; Jeffrey Mahn

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ACOUSTICS SUMMARY- SOUND INSULATION IN MID-RISE WOOD BUILDINGS

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

1. Introduction

This report summarizes the acoustics research component regarding sound insulation of elements and systems for the research project on mid-rise and larger wood buildings. The summary outlines the background, main research considerations, research conducted and major outcomes. Further details of the design and the results can found in the appendix of Client Report A1-100035-02.1 [1].

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 [2] 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 [3]. 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 of Report A1-100035-02.1 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 [4] from data measured in accordance with the standard, ASTM E90 [5].

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 of report A1-100035-02.1). 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 Client Report A1-100035-02.1, 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*	Framing with Continuous* end studs	Framing with end Columns*	Base Framing*	Framing with Continuous* end studs	Framing with end Columns*	Base Framing*	Framing with Continuous* end studs	Framing with end Columns*	Base Framing*	Framing with Continuous* end studs	Framing with end Columns*
Staggered stud frame	2x4 studs @ 400 mm o.c.*	50	48	47	51/52	48	47	59	56	54	60	57	54
	2x4 tripled studs @ 400 mm o.c.*	49	47	46	48	47	45	57	55	53	58	55	53
	2x4 studs @ 100 mm o.c.*	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
- *: Detailed drawings of the framing can be found in section A.1.3.1.1 of Report A1-100035-02.1

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:

- Common wood framing – single studs spaced 400 mm on centre (o.c.)
- Built-up column wood studs – tripled studs spaced 400 mm on centre
- Increased number of wood studs – studs spaced 100 mm on centre
- Wood end studs – studs with the same dimension (depth) as the plates at each wall end that couple the gypsum board membranes
- 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 Client Report A1-100035-02.1, 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 of Report A1-100035-02.1). 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 Client Report A1-100035-02.1, 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 Client Report A1-100035-02.1, 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 [6] 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 Client Report A1-100035-02.1, Appendix A.2.

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

CLT Wall, 5-ply (Thickness: 175 mm, Mass/Area: 91.4 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		**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**	**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 the appendix of Client Report A1-100035-02.1

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

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**	**47**	**50**	**51**			
	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 of Client Report A1-100035-02.1

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

<table>
<tr><td colspan="2" rowspan="2">Double Leaf 3-ply CLT Wall:
CLT 78 mm,
Insulation 25 mm,
CLT 78 mm
(Thickness: 181 mm,
Mass/Area: 89.6 kg/m²)</td><td rowspan="2">Bare</td><td colspan="7">Membrane on wall surface 2:
2 Layers 12.7 mm Type X gypsum board</td></tr>
<tr><td>Directly attached</td><td>38 mm wood furring @ 400 mm o.c.</td><td>38 mm wood furring @ 600 mm o.c.</td><td>Resilient channels @ 600 mm on 38 mm wood furring @ 400 mm o.c.</td><td>64 mm wood furring @ 600 mm o.c.</td><td>64 mm wood frame w. studs @ 600 mm o.c. and 12.7 mm air gap</td></tr>
<tr><td colspan="2">Bare</td><td>47</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="6">Membrane on wall surface 1:
2 Layers 12.7 mm Type X gypsum board</td><td>Directly attached</td><td>53</td><td>55</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>38 mm wood furring @ 400 mm o.c.</td><td>49</td><td>53</td><td>43</td><td></td><td></td><td></td><td></td></tr>
<tr><td>38 mm wood furring @ 600 mm o.c.</td><td>56</td><td>59</td><td>52</td><td>> 60</td><td></td><td></td><td></td></tr>
<tr><td>Resilient channels @ 600 mm o.c. on 38 mm wood furring @ 400 mm o.c.</td><td>> 60</td><td>> 60</td><td>57</td><td>> 60</td><td>> 60</td><td></td><td></td></tr>
<tr><td>64 mm wood furring @ 600 mm o.c.</td><td>56</td><td>59</td><td>55</td><td>> 60</td><td>> 60</td><td>> 60</td><td></td></tr>
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</table>

Notes:
- Black numbers: Measured ratings
- Blue numbers: Predicted ratings based on measured ratings
- Further information about the assemblies can be found in in Appendix of Client Report A1-100035-02.1

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 Client Report A1-100035-02.1, 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 Client Report A1-100035-02.1, 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 Client Report A1-100035-02.1, 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 Client Report A1-100035-02.1, 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 [7] from data measured in accordance with ASTM E492 [8].

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	**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		41 (25)	42 (25)	50 (36)	68 (56)	67 (55)
Floor Toppings:	38 mm concrete topping on 9 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 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 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 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 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 [4]). 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 Client Report A1-100035-02.1, 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.

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 Client Report A1-100035-02.1, 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 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 Client Report A1-100035-02.1, 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 Client Report A1-100035-02.1, Figure A.3- 6). Floor toppings had to be added to the bare base floor to improve the flanking sound insulation (see Client Report A1-100035-02.1, Figure A.3 - 7). For example, approximately 10 STC points were gained by applying a 38 mm gypsum concrete topping on a 9 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 Client Report A1-100035-02.1, 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 of Client Report A1-100035-02.1.

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 [6]. 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 [9], 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:

1. 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
2. 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
3. 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 Client Report A1-100035-02.1, 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 Client Report A1-100035-02.1, 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 Client Report A1-100035-02.1, 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 Client Report A1-100035-02.1, 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 Client Report A1-100035-02.1, 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. 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).

7. References

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