CLT Handbook

CROSS-LAMINATED TIMBER

U.S. EDITION

The U.S. Edition of the CLT Handbook: cross-laminated timber can be electronically downloaded without charge from the website www.masstimber.com. Additional information can be obtained by visiting the websites of FPInnovations, USFPL, American Wood Council (AWC), APA and U.S. WoodWorks. Hard copies can be obtained through AWC (www.awc.org).

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CROSS-LAMINATED TIMBER

Edited by
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Pointe-Claire, QC
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PREFACE

Expansion into mid-rise, high-rise and non-residential applications presents one of the most promising avenues for the North American wood industry to diversify its end use markets. This may be achieved by:

- Designing to new building heights with **Light Frame Wood Construction**
- Revival of **Heavy Timber Frame Construction**
- Adoption of **Cross-laminated Timber** (CLT)
- Facilitating **Hybrid Construction**

There are concerted efforts both in Canada and in the United States towards realizing that goal. In fact, the Canadian provinces of British Columbia and Quebec went even further and created specific initiatives to support the use of wood in those applications.

This Handbook is focused on one of these options – adoption of cross-laminated timber (CLT). CLT is an innovative wood product that was introduced in the early 1990s in Austria and Germany and has been gaining popularity in residential and non-residential applications in Europe. The Research and Standards Subcommittee of the industry's CLT Steering Committee identified CLT as a great addition to the "**wood product toolbox**" and expects CLT to enhance the re-introduction of wood-based systems in applications such as 5- to 10-story buildings where heavy timber systems were used a century ago. Several manufacturers have started to produce CLT in North America, and their products have already been used in the construction of a number of buildings.

CLT, like other structural wood-based products, lends itself well to prefabrication, resulting in very rapid construction, and dismantling at the end of its service life. The added benefit of being made from a renewable resource makes all wood-based systems desirable from a sustainability point of view.

In Canada, in order to facilitate the adoption of CLT, FPInnovations published the Canadian edition of the CLT Handbook in 2011 under the Transformative Technologies Program of Natural Resources Canada. The broad acceptance of the Canadian CLT Handbook in Canada encouraged this project, to develop a U.S. Edition of the CLT Handbook. Funding for this project was received from the Binational Softwood Lumber Council, Forestry Innovation Investment in British Columbia, and three CLT manufacturers, and was spearheaded by a Working Group from FPInnovations, the American Wood Council (AWC), the U.S. Forest Products Laboratory, APA-The Engineered Wood Association and U.S. WoodWorks. The U.S. CLT Handbook was developed by a team of over 40 experts from all over the world.

Both CLT handbooks serve two objectives:

- Provide immediate support for the design and construction of CLT systems under the alternative or innovative solutions path in design standards and building codes;
- Provide technical information that can be used for implementation of CLT systems as acceptable solutions in building codes and design standards to achieve broader acceptance.

The implementation of CLT in North America marks a new opportunity for cross-border cooperation, as five organizations worked together with the design and construction community, industry, universities, and regulatory officials in the development of this Handbook. This multi-disciplinary, peer-reviewed CLT Handbook is designed to facilitate the adoption of an innovative wood product to enhance the selection of wood-based solutions in non-residential and multi-storey construction.

Credible design teams in different parts of the world are advocating for larger and taller wood structures, as high as 30 stories. When asked, they identified the technical information compiled in this Handbook as what was needed for those applications.

A Renaissance in wood construction is underway; stay connected.

ACKNOWLEDGEMENTS

The great challenge with this U.S. Edition of the CLT Handbook was to gather experts from the United States, Canada and Europe to bring together their expertise and knowledge into a state-of-the-art reference document. The realization of this Handbook was made possible with the contribution of many people and numerous national and international organizations.

Such a piece of work would not be possible without the support from financing partners and, as such, we would like to express our special thanks to Binational Softwood Lumber Council, Forestry Innovation Investment (FII), Nordic Engineered Wood, Structurlam, and CLT Canada for their financial contribution to this project.

First and most of all, we would like to express our gratitude to AWC, APA, USFPL, FPInnovations, U.S. WoodWorks and their staff for providing the effort and expertise needed to prepare this work. We would also like to express our special thanks to all chapter authors, co-authors, and reviewers who shared their precious time and expertise in improving this manual.

Our very special thanks go to Loren Ross at AWC and Sylvain Gagnon at FPInnovations for their work as project leaders and for their special efforts in gathering the expertise of everyone into a unique document. Special thanks also go to the Working Group, Dr. Borjen Yeh from APA, Dave Kretschmann from the U.S. Forest Products Laboratory, and Lisa Podesto from U.S. WoodWorks. Thanks also to Madeline Leroux for her work on the drawings, Odile Fleury for her help with bibliographic references, and Marie-Claude Thibault for her support in editing and coordination work.

Erol Karacabeyli, P.Eng. and **Brad Douglas**, P.E.
Co-editors
CLT Handbook, U.S. Edition

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Sound

Sound insulation of cross-laminated timber assemblies

CHAPTER 9

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The U.S. Edition of the CLT Handbook: *cross-laminated timber* combines the work and knowledge of American, Canadian and European specialists. The handbook is based on the original Canadian Edition of the CLT Handbook: *cross-laminated timber*, that was developed using a series of reports initially prepared by FPInnovations and collaborators to support the introduction of CLT in the North American market. A multi-disciplinary team revised, updated and implemented their know-how and technologies to adapt this document to U.S. standards.

The publication of this handbook was made possible with the special collaboration of the following partners:

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ABSTRACT

The intent of this Chapter is to answer simple questions related to the definition of sound, its sources, quantification and methods of measurement, acceptable levels of sound, differences between sound and noise, etc. Of course, when verbalizing such questions, the solutions for sound control will be naturally unfolded to readers.

This Chapter is intended to thoroughly separate myth from reality. The Chapter also introduces the International Building Code (IBC) requirements for sound insulation in buildings. State of the art construction details for CLT walls and floor/ceiling assemblies generally meeting IBC requirements are provided herein and are based on results of tests performed in various laboratories in the world and in the field by FPInnovations. A step by step construction practices guide then leads the reader towards the final goal, which is the occupants' satisfaction. We expect that after reading this Chapter, the reader will be in a position to acknowledge that CLT buildings can achieve satisfactory sound insulation levels if proper design and installation are followed. Note that, considering the short history of CLT construction, the journey is only beginning.

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1 INTRODUCTION

This Chapter addresses sound insulation for demising walls, partitions and floor/ceiling assemblies between adjacent spaces, such as dwelling units; and between dwelling units and adjacent public areas, such as halls, corridors, stairs or service areas in buildings employing CLT construction.

2 FUNDAMENTALS

Because it is too vast to cover, a complete knowledge of the fundamentals of acoustics will not be presented here. This section intends to provide basic information about what lies behind the building code requirements concerning sound insulation and specific solutions provided by CLT buildings.

2.1 Sound and its Source

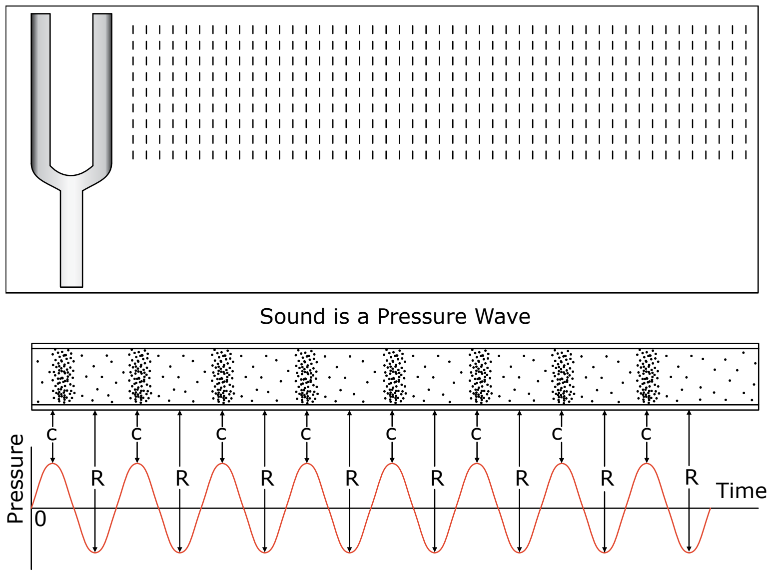
Acoustics is typically defined as the science of sound. Acoustics is the interdisciplinary science that deals with the study of all mechanical waves in gases, liquids, and solids including vibration, sound, ultrasound and infrasound. A scientist who works in the field of acoustics is an acoustician while someone working in the field of acoustics technology may be called an acoustical engineer, although these terms are often used interchangeably. The application of acoustics can be seen in almost all aspects of modern society, with the most obvious being the audio and noise control industries.

Now, we might ask, what is sound and where does it come from? Sound has been defined as a physical disturbance in an elastic medium (i.e., in a gas, liquid, or solid) that is capable of being detected by the human ear. The medium in which the sound or pressure waves travel must have mass and elasticity. Thus, sound waves will not travel through a vacuum (Harris, 1991).

Sound waves in air are caused by variations in pressure above and below the static value of atmospheric pressure (Harris, 1991). These pressure variations originate in many ways, for example: 1) by a pulsating airstream, e.g., that produced by fan blades as they rotate, by a loudspeaker, etc.; 2) by supersonic flight of an aircraft, which creates shock waves; 3) by the vibration of a surface, such as wall or partition; and 4) by talking or by a musical instrument.

A pressure wave propagating through air is referred to as airborne sound while the pressure wave propagating through a solid structure is referred to as structure-borne sound. Figure 1 illustrates the propagation of pressure wave through both air and a solid structure (Kappagantu, 2010). It must be pointed out that, for the sake of simplicity, Figure 1 only illustrates a simple harmonic sound wave, which can be generated by most musical instruments that produce several simple harmonics simultaneously. On the other hand, sound produced by machines or structures do not behave as simple harmonic sound waves, they rather are random in time and are commonly known as noise (Crocker, 2007).

More basically, noise is commonly defined as “unwanted sound”; however, what might be noise to one person could be a valuable source of aural information to another. For example, consider the sound produced by a machine in a factory. To the office worker trying to concentrate on some mental task in an adjacent office, it is noise; whereas, to the operator of the machine, the sound provides him or her with audible clues as to whether the machine is operating properly or not.



Note: In this figure, C signifies regions of compression and R signifies regions of rarefaction of the air molecules. Furthermore, the “0” pressure line in the graph represents the atmospheric pressure level.

Figure 1
Simplified illustration of sound (pressure wave) propagation through air/solid structure (Kappagantu, 2010)

2.2 Quantification of Sound and Measurement

2.2.1 Sound Pressure

Sound has numerous attributes and can be described by various quantities. Sound has level or magnitude. Sound has frequency content. And sound can vary in level and frequency as a function of time. With respect to the level or magnitude of sound, the most commonly used metric that can be directly measured is sound pressure. Other quantities can also be derived from sound pressure. Sound pressure is the pressure variation above and below the atmospheric pressure (Crocker, 2007). Sound pressure is a fluctuating quantity measured in Pascal units (Pa). Sound pressure is influenced by the energy produced by the sound source, the environment, and the distance between the source and the receiver (Pope, 2003). It is usually characterized by its Root Mean Square (RMS) or Peak values, with mean pressure disregarded (Pope, 2003).

To convey an understanding of sound pressure, Pope (2003) gave some examples of the sound produced by various sources and their pressure (Table 1).

Table 1
Sound generated by various sources and their pressure (Pope, 2003)

Source of Sound	RMS Pressure (Pa)
Music club (loud)	~ 10
Heavy traffic at 32.81 ft. (10 m)	~ 1
Busy office	~ 10^{-1}
Normal speech at 3.28 ft. (1 m)	~ 10^{-2}

2.2.2 Sound Pressure Level (SPL)

Sound pressure is related to atmospheric pressure at the point where the sound pressure is measured. In contrast, sound is better quantified using absolute values independent of the atmospheric pressure for comparison of sound performance in various atmospheres. Therefore, sound pressure level is used. Sound pressure level (SPL) is the power ratio of sound pressure to a reference sound pressure. The unit of SPL is the decibel (dB), which unit is read on a logarithmic scale. Figure 2 demonstrates the relationship between the power ratio and dB.

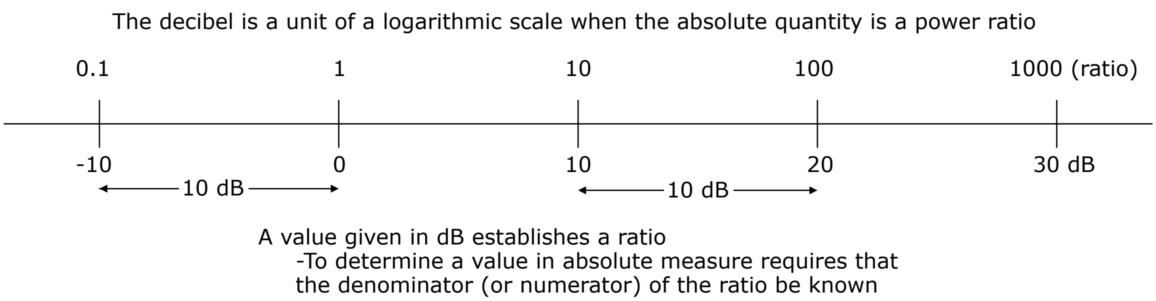


Figure 2
Relationship between a power ratio and the decibel (dB)(Pope, 2003)

As an explanation of why we use the logarithmic decibel scale rather than a linear scale, White (1975) stated the following: *"Because both the human ear and our acoustical instruments respond to changes in pressure, it is desirable to have a scale that will measure these changes in convenient notation. Since the ear can detect changes in pressure amplitude of 1,000,000 to 1, the scale should encompass a large dynamic range. Furthermore, it would be desirable if the physically measureable scale of pressure increments corresponded to our auditory perception of increasing "loudness." The decibel scale satisfies both of these requirements, being formulated from observations and experiments in both physiology and electrical engineering."*

Figure 3 illustrates the range of sound pressure in linear and dB scales corresponding to the range given in Table 1.

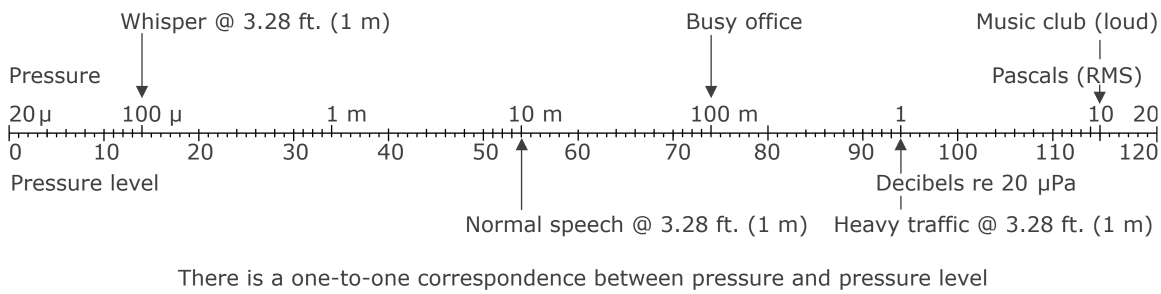


Figure 3
Sound pressure in linear and sound pressure level in dB (Pope, 2003)

2.2.3 Measurement and Spectrum Analysis

Sound pressure level can be measured with a Sound Level Meter (SLM). Another useful measuring instrument is the spectrum analyzer, which measures and presents sound pressure level as a function of frequency. With this instrument, sound level versus time signal is transformed into the frequency domain for spectrum analysis. It produces the frequency distribution of the sound pressure level of the signal. Spectrum analysis is important for understanding the behavior of sound and for developing noise control measures. Figure 4 shows a spectrum of a sound pressure level measured in a condominium located below another condominium in a wood-framed floor/ceiling assembly with a running ISO tapping machine on the floor. The graph shows how the measured sound pressure level varied with frequency.

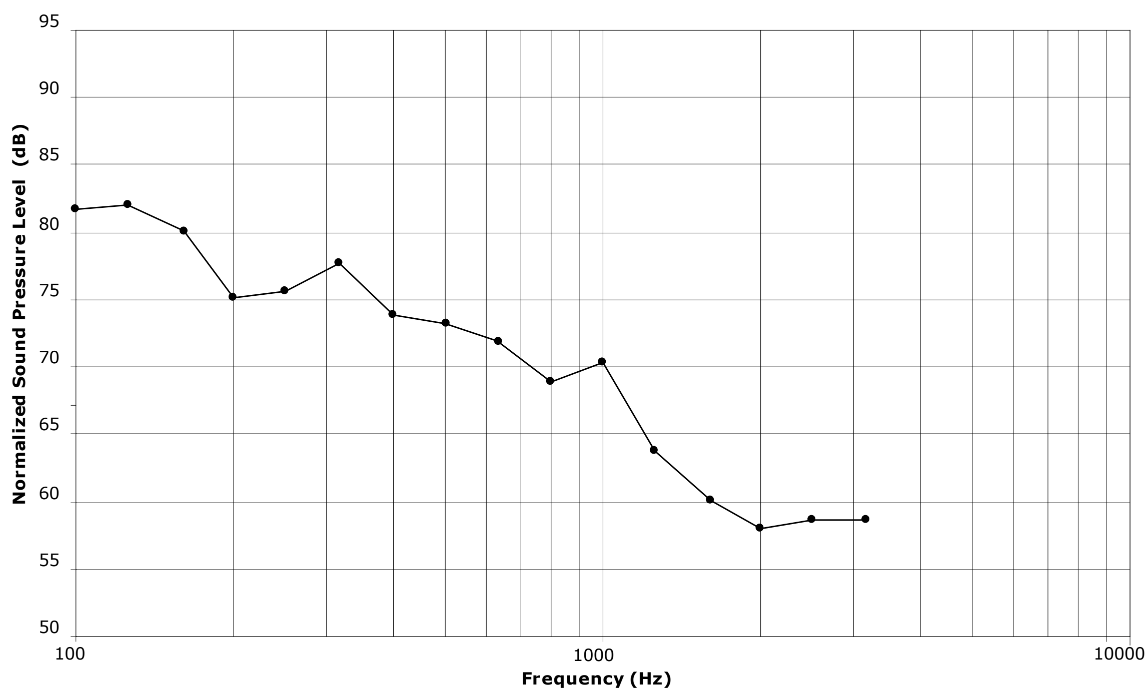


Figure 4
Typical spectrum of sound pressure level measured below a wood-framed floor/ceiling assembly using a tapping machine and a sound level meter

2.3 Human Hearing and Perception

2.3.1 Audible Frequency Range and Auditory Area of Sound

According to Crocker (2007), humans can hear sound in the frequency range between 15-16 Hz and 15-16 kHz. However, humans do not hear all sounds equally, meaning their hearing sensitivity is nonlinear. The sensitivity of human hearing is frequency- and sound pressure level-dependent. Humans are most sensitive to sounds at about 4000 Hz, and less sensitive to sounds below 200 Hz. Below that level, humans cannot hear sound well, unless the sound pressure level is high enough (Crocker, 2007). Figure 5 from White (1975) shows the average threshold curve for young adults with "normal" hearing. Note that the threshold of hearing is markedly dependent on frequency.

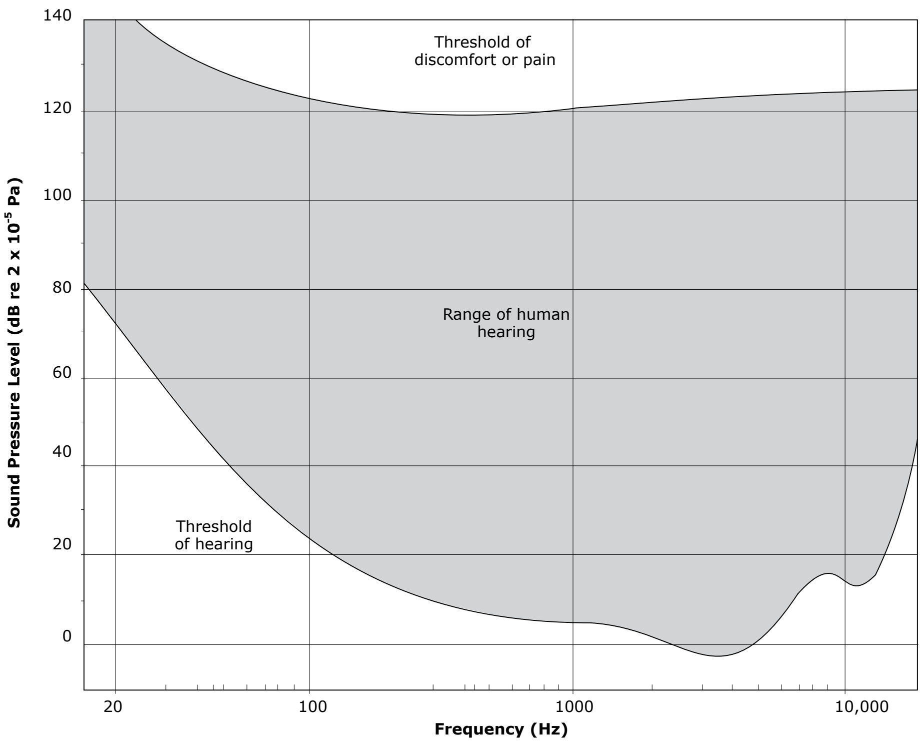


Figure 5
Range of human hearing (White, 1975)

2.3.2 Human Perception of Sound

Human perception of sound is both objective and subjective and several factors affect it:

- Level and frequency spectrum, sharpness, masking effects;
- Variations such as fluctuation, roughness, modulations, transients;
- Context such as day vs. night, music vs. machine, etc.;
- Individual preferences.

2.3.3 Human Perception of Sound Level Change

Pope (2003) described how humans perceive change in sound levels (Table 2). This knowledge is very useful to guide us to develop cost effective sound insulation solutions or to improve existing sound insulation strategies. Table 2 shows that a change (reduction or increase) in sound level of less than 3 dB will most likely not be perceived by a listener, while a change of 3 dB or greater will most likely be perceived by most people.

Table 2
Perceptible change due to the change in sound level (dB) (Pope, 2003)

Change in Sound Level (dB)	Change in Perceived Loudness
3	Just perceptible
6	Noticeable difference
10	Twice as loud, or reduced to half of the loudness
15	Three times as loud, or reduced to one third of the loudness
20	Four times as loud, or reduced to one quarter of the loudness

2.4 Building Sound Insulation

2.4.1 Human Activity Induced Sound

Building acoustics is a vast research area. This section focuses on the sound induced by human activities inside buildings such as talking, playing music, listening to the TV and radio, using various devices, and walking. The building sound insulation discussed below is limited to the interior building components such as common interior or demising walls, partitions and floor/ceiling assemblies between adjacent dwelling units or between dwelling units and adjacent public areas such as halls, corridors, stairs or service areas. Before further discussing sound insulation, it is important to first raise awareness on the unavoidable presence of flanking transmission in buildings.

2.4.2 Flanking Transmission

Flanking transmission is the sound transmission along paths other than the direct path through the common wall or floor/ceiling assembly (Institute for Research in Construction (IRC) of Canada, 2002).

Typical flanking sound transmission paths can include:

- Above and through the ceiling (plenum) spaces;
- Through floor deck and floor joist space;
- Through windows and doors;
- Through fixtures and electrical outlets, light switches, telephone outlets, and recessed lighting fixtures;
- Shared structural building components, such as floor boards, floor joists, continuous drywall partitions, continuous concrete floors, and cement block walls;
- Perimeter joints at wall and floor, through wall and ceiling junctions;
- Through plumbing chases and joints between the walls and floor slab above or at the exterior wall juncture;
- Around the edges of partitions through the adjacent wall.

Some examples of flanking paths are given hereafter. The IRC (2002) found that sound leaks may allow sound to bypass a wall or floor/ceiling assembly. The common problematic zones are cracks at wall/floor junctions, electrical outlets, tubs, medicine cabinets, etc. Figures 6 and 7 illustrate such problems and treatments (IRC, 2002). Figure 8 gives an example of how the floor surface can be a flanking path.

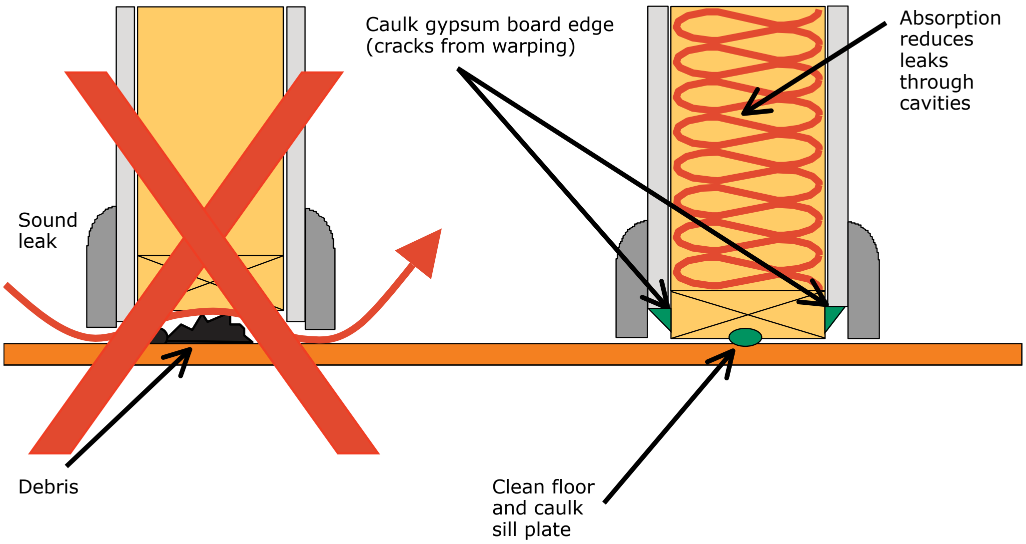


Figure 6
Example of sound leak due to the cracks at the floor and wall junction and treatment (IRC, 2002)

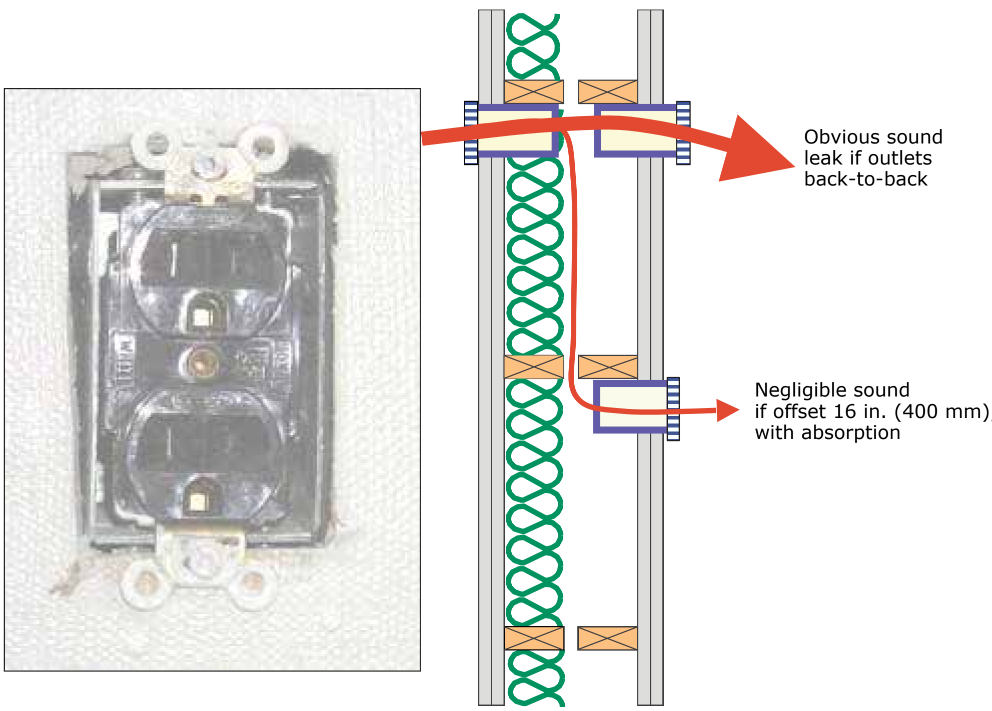
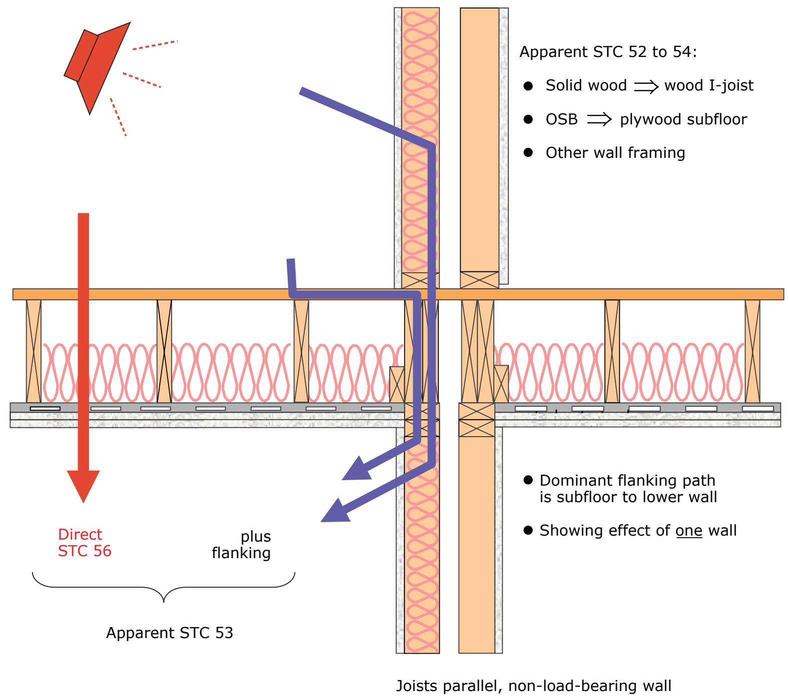


Figure 7
Sound leak at the electrical outlets (IRC, 2002)



Note: the red arrow indicates the direct path, and blue arrows indicate the flanking path

Figure 8
Floor surface as flanking path (IRC, 2002)

Many studies have been conducted on flanking and methods to control this phenomenon. Section 7 of this Chapter summarizes the findings so far, including significant flanking paths and their treatments.

Flanking always exists to some degree in buildings (IRC, 2002). As demonstrated in Figure 8, flanking reduces the sound insulation performance of a separation in a building. Therefore, a high performance floor/ceiling assembly or wall does not guarantee good sound isolation unless proper attention has been given to eliminating or minimizing flanking paths.

2.4.3 Sound Insulating Performance of Walls and Floor/Ceiling Assemblies Using a Single Number Rating

The airborne sound insulating performance of a wall or a floor/ceiling assembly is measured by sound transmission loss through the wall or floor/ceiling assembly. Transmission Loss (TL) is the ratio of transmitted power over incident power, measured in dB. TL is the measure of sound attenuation through the wall or floor/ceiling assembly. The greater the TL value, the less sound is transmitted through the wall or floor/ceiling assembly, and the better the sound insulation of the wall or floor/ceiling assembly will be. Like sound pressure level, TL varies with frequency.

The single number rating of the airborne sound insulation of a building element, e.g., a wall or a floor/ceiling assembly is called Sound Transmission Class (STC). The greater the STC, the better the airborne sound insulation of the wall or the floor/ceiling assembly.

Similarly, the single number rating for the impact sound insulating performance of a floor/ceiling assembly is called Impact Insulation Class (IIC). As stated in ASTM E989, the greater the IIC value, the greater the impact sound insulation will be.

One should note that both STC and IIC ratings are just that—ratings. These ratings allow us to say one construction is better than another in terms of airborne or impact sound insulation and to judge which might be better in a certain situation. To fully understand the sound insulating performance of walls and floor/ceiling assemblies, please refer to the actual laboratory or field TL or SPL spectrum of the test. It also should be known that for floor/ceiling assemblies, there is no correlation between STC and IIC; a good STC does not guarantee good IIC, and vice versa (IRC, 2002). One such example is the case of a lightweight wood-framed floor/ceiling assembly with a carpet. This type of assembly can have a good IIC, but the STC can be very low due to lack of mass. On the other hand, a lightweight wood-framed floor/ceiling assembly layered with a 1.5 in. (38 mm) thick concrete topping directly poured on the subfloor, but without a carpet or floating flooring, can have a good STC, but very poor IIC due to the hard surface.

2.4.3.1 Determination of STC and IIC in the Laboratory

ASTM E90 standard specifies the test method for laboratory measurement of airborne sound transmission loss of building partitions and elements. This method requires conducting the test under ideal conditions, which means no flanking. Figure 9 (Harris, 1957) illustrates such a test for a wall between two adjacent reverberant chambers. The chambers for testing floor/ceiling assemblies are similar, but the two reverberant rooms are vertically stacked.

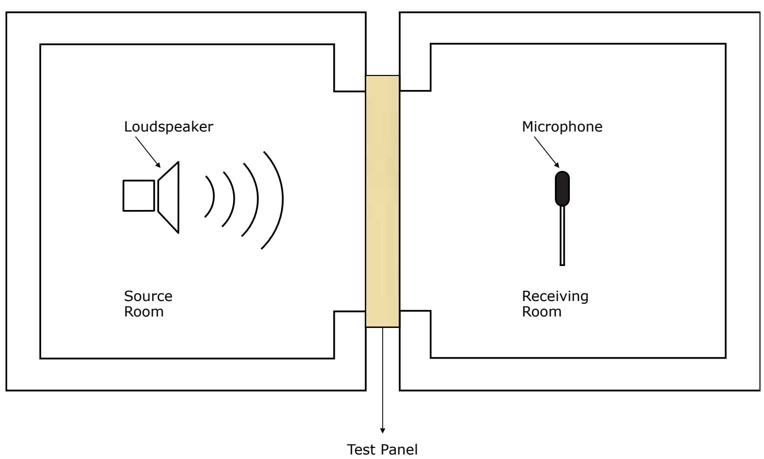
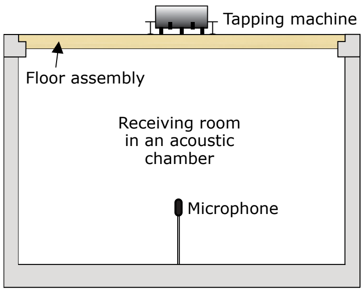


Figure 9
Simple illustration of laboratory acoustic chambers for testing walls (Harris, 1957)

While the test is conducted using the procedures of ASTM E90 standard, ASTM E413 standard provides the numerical procedure for determining the STC from the measured sound transmission loss data. According to E413 standard, STC ratings correlate in a general way with subjective impressions of sound transmission for speech, radio, television, and similar sources of noise in offices and buildings.

ASTM E492 standard specifies the test method for laboratory measurement of impact sound transmission through floor/ceiling assemblies using a tapping machine. This test method is also used for tests conducted in a laboratory under controlled conditions, meaning without flanking. Figure 10 (IRC, 2002) provides the simple illustration of such a test with a receiving room. ASTM E989 standard provides the classification for determination of IIC from the measured sound pressure level in the receiving room produced by the tapping machine on the floor/ceiling assembly being tested.



(a) Acoustic chamber showing the floor specimen and tapping machine

(b) ISO tapping machine

Figure 10

Simple illustration of an acoustic chamber and impact insulation test on a floor (IRC, 2002)

2.4.3.2 Determination of FSTC and FIIC in Buildings

As discussed in section 2.4.2, some degree of flanking is unavoidable in buildings; therefore, STC and IIC measured on-site (i.e., during tests conducted in the field) are called Field Sound Transmission Class (FSTC), and Field Impact Insulation Class (FIIC). ASTM E336 standard specifies the test method for measurement of airborne sound insulation in buildings, and ASTM E413 standard is used to determine the FSTC from the measured sound transmission loss. ASTM E1007 standard specifies the test method for field measurement of tapping machine impact sound transmission through floor/ceiling assemblies and associated support structures. Finally, ASTM E989 standard is used to determine the FIIC from the measured sound pressure level of field floor/ceiling assemblies.

Figures 11 and 12 demonstrate the field measurements on a wall and a floor/ceiling assembly in a building under construction.

(a) Source room with an omnidirectional loudspeaker as the source and a sound level meter

(b) Receiving room with a sound level meter to measure the sound transmitted through the wall

Figure 11

Field wall sound transmission test for FSTC

(a) Source room with the tapping machine on the floor in a field floor/ceiling assembly

(b) Receiving room under the source room with a sound level meter to measure the impact sound transmitted through the floor/ceiling assembly

Figure 12
Field floor impact sound insulation test for FIIC using an ISO tapping machine

2.4.3.3 General Factors Affecting STC and IIC

In general, the most important factors affecting airborne sound insulation of wall and floor/ceiling assemblies, and impact sound insulation of floor/ceiling assemblies, are (IRC, 2002):

- Total weight per unit area: the heavier, the better sound insulation, especially for low frequency sound;
- Stiffness: in general, the stiffer, the better sound insulation. However, it has been observed that very stiff wood-joisted floor/ceiling assemblies present greater low-frequency impact sound insulation;
- Porosity: the less porosity, the better sound insulation;
- Multi-layers with air space: the larger the airspace, the better sound insulation;
- Contacts between layers: the softer the contacts, the better sound insulation;
- Sound absorption: sound absorbing material in the air space or the cavity between layers is beneficial;
- Floor surface hardness: the harder the surface, the poorer the impact sound insulation, especially with high-frequency impact sound.

3

ACOUSTIC PROPERTIES OF BARE CLT WALLS AND FLOORS

Mass and damping are the two properties of CLT elements that significantly affect CLT floor and wall sound insulation. Mass is the most important factor amongst other factors affecting CLT floor and wall sound insulating performance: the greater the mass, the better the performance. Laboratory tests at FPInnovations showed that bare CLT floors have a damping ratio of approximately 1% of the critical damping ratio (Hu, 2013b). Table 3 provides the area mass of some CLT elements assuming the density of the CLT elements is 31.2 pcf (500 kg/m^3). This table does not intend to extensively present all the CLT elements on the market, but merely to give some examples of the range in area mass of CLT elements. Understanding the area mass of CLT will greatly help in the sound insulation designs using CLT walls and floors.

Table 3

Area mass of some CLT elements for wall and floor applications

Number of Layers	Thickness in. (mm)	Area Mass lb./ft.^{2} (kg/m^2)
3	2.36 (60)	6.14 (30)
3	4.72 (120)	12.29 (60)
5	4.61 (117)	11.98 (58.5)
5	7.87 (200)	20.48 (100)
7	7.95 (202)	20.69 (101)
7	11.02 (280)	28.67 (140)
8	9.76 (248)	25.40 (124)
8	12.60 (320)	32.77 (160)

Table 4 provides the measured STC and IIC values for some bare CLT walls and floors in various laboratories (reported by Gagnon and Kouyoumji, 2011), and the FSTC and FIIC values measured by FPInnovations on bare CLT floors and walls in CLT buildings (Hu, 2013a). Since flanking paths were possibly present for the field test results, the FSTC and FIIC presented provide an indication of the sound insulating performance of bare CLT floors and walls in buildings.

Table 4

Sound insulation performance of bare CLT floors and walls

Number of Layers	Thickness in. (mm)	Assembly Type	STC	IIC
3	3.74 - 4.53 (95-115)	Wall	32-34	N/A
5	5.31 (135)	Floor	39	23
5	5.75 (146)	Floor	39	24
Measured on field bare CLT wall and floor (Hu, 2013a)				
Number of Layers	**Thickness in. (mm)**	**Assembly Type**	**FSTC**	**FIIC**
3	4.13 (105)	Wall	28	N/A
7	8.19 (208)	Floor	N/A	25

4

INTERNATIONAL BUILDING CODE (IBC) REQUIREMENTS FOR SOUND INSULATION OF DEMISING WALLS AND FLOOR/CEILING ASSEMBLIES

IBC (2009) provides the minimum requirements for sound insulation of demising walls and floor/ceiling assemblies between adjacent dwelling units or between dwelling units and public areas such as halls, corridors, stairs or service areas. Table 5 lists these requirements.

Table 5
IBC minimum requirements for sound insulation of demising walls and floor/ceiling assemblies

Assembly Type	Airborne Sound		Structure-borne Sound	
Wall	STC	50	N/A	
	FSTC	45 (field measured[1])		
Floor	STC	50	IIC	50
	FSTC	45 (field measured[1])	FIIC	45 (field measured[2])

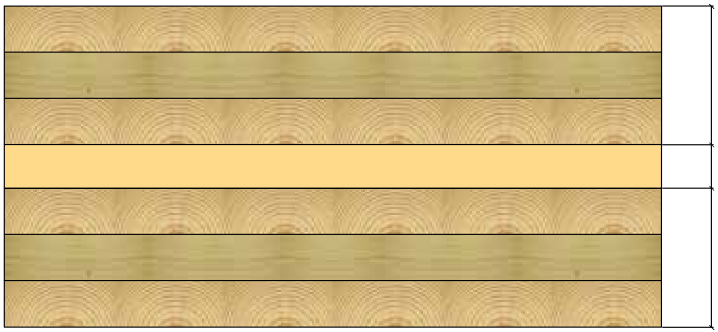
Notes:
1. When tested in accordance with ASTM E90 for STC and ASTM E336 for FSTC
2. When tested in accordance with ASTM E492 for IIC and ASTM E1007 for FIIC

5

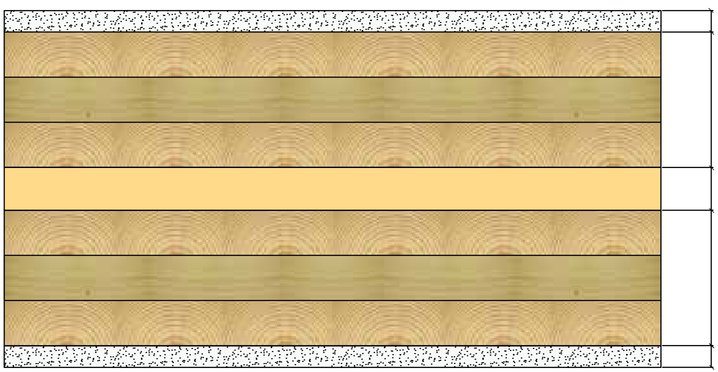
EXAMPLES OF CONSTRUCTION SOLUTIONS FOR CLT WALLS AND FLOORS MEETING IBC'S STC AND IIC REQUIREMENTS

Gagnon and Kouyoumji (2011) reported in the Canadian edition of the CLT Handbook several construction solutions for CLT walls and floors with STC and IIC ratings measured in laboratory acoustic chambers in various laboratories. Tables 6 to 11 list the wall and floor systems extracted from the Canadian CLT Handbook with the ratings meeting IBC's STC and IIC of 50 requirements.

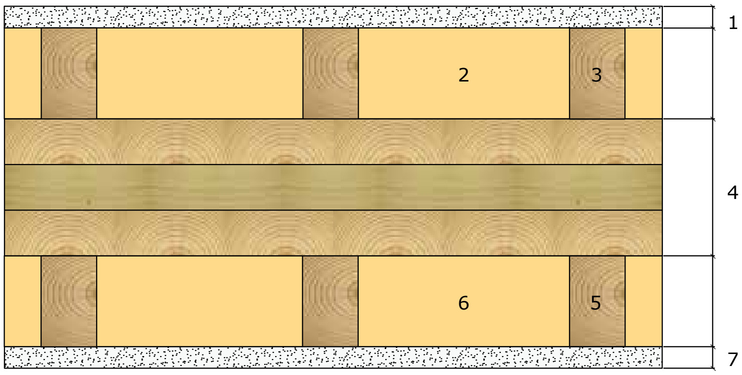
Table 6
STC of CLT wall assemblies



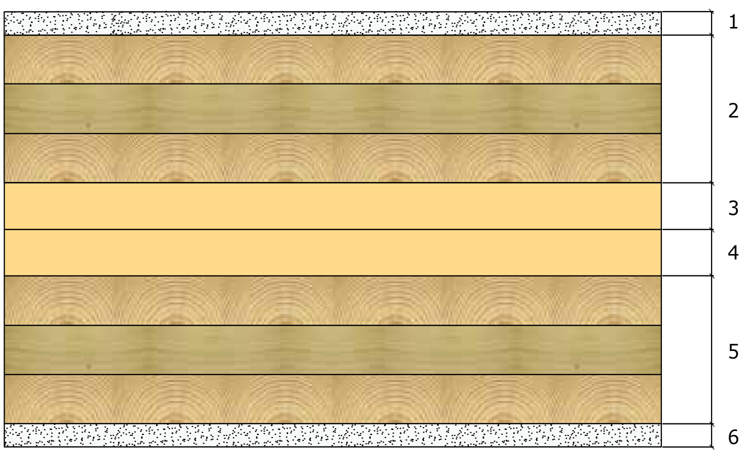
	Assembly Description from Top to Bottom (6.1)	STC
1	3-layer CLT panel of 3 3/4 in. ~ 4 1/2 in. (95 mm ~ 115 mm)	48 ~ 50
2	Mineral wool of about 1.18 in. (~ 30 mm)	
3	3-layer CLT panel of 3 3/4 in. ~ 4 1/2 in. (95 mm ~ 115 mm)	



	Assembly Description from Top to Bottom (6.2)	STC
1	Gypsum board of 5/8 in. (15 mm)	55 or above depending on CLT thickness
2	3-layer CLT panel of 3 3/4 in. ~ 4 1/2 in. (95 mm ~ 115 mm)	
3	Mineral wool of about 1.18 in. (~ 30 mm)	
4	3-layer CLT panel of 3 3/4 in. ~ 4 1/2 in. (95 mm ~ 115 mm)	
5	Gypsum board of 5/8 in. (15 mm)	



Assembly Description from Top to Bottom (6.3)		STC
1	Gypsum board of 5/8 in. (15 mm)	58 or above depending on CLT thickness
2	Mineral wool of about 2.36 in. (~ 60 mm)	
3	Lumber studs of 2 in. x 3 in. (38 mm x 63 mm) at least 16 in. (400 mm) o.c.	
4	3-layer CLT panel of 3 3/4 in. ~ 4 1/2 in. (95 mm ~ 115 mm)	
5	Mineral wool of about 2.36 in. (~ 60 mm)	
6	Lumber studs of 2 in. x 3 in. (38 mm x 63 mm) at least 16 in. (400 mm) o.c., attached to CLT and gypsum boards	
7	Gypsum board of 5/8 in. (15 mm)	



Assembly Description from Top to Bottom (6.4)		STC
1	Gypsum board of 5/8 in. (15 mm)	60 or above depending on CLT thickness
2	3-layer CLT panel of 3 3/4 in. ~ 4 1/2 in. (95 mm ~ 115 mm)	
3	Mineral or rock wool of about 1.18 in. (~ 30 mm)	
4	Sound insulation material (mineral or rock wool) of about 1.18 in. (~ 30 mm)	
5	3-layer CLT panel of 3 3/4 in. ~ 4 1/2 in. (95 mm ~ 115 mm)	
6	Gypsum board of 5/8 in. (15 mm)	

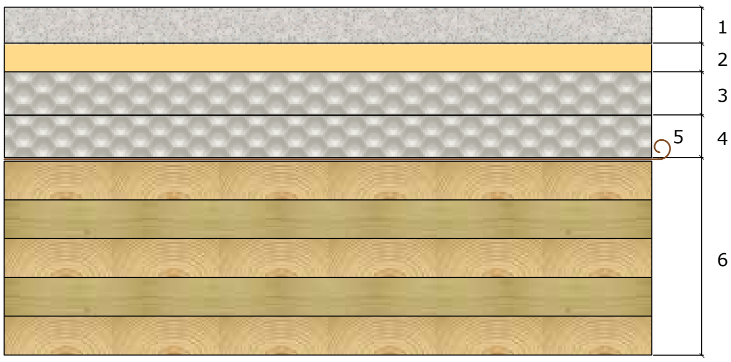
Note: Lumber in the outer layer of CLT is vertical. Observing Tables 6.1 to 6.4, we find that:

1. For double CLT walls with mineral wool in the gap between two walls, adding the 5/8 in. (15 mm) gypsum boards on the two surfaces increases the measured STC from 5 to 7 points.

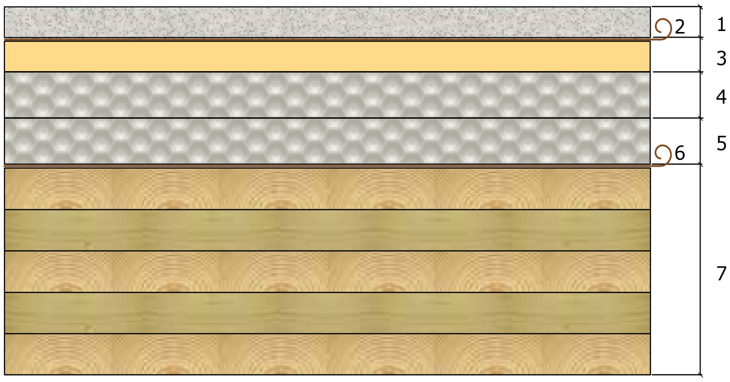
2. For double CLT walls with mineral wool in the gap between two walls, increasing the gap from 1.18 in. (30 mm) to 2.36 in. (60 mm) increases the STC by at least 5 points.
3. For a single CLT wall with two 2 in. x 3 in. (38 mm x 63 mm) lumber stud walls directly attached to the CLT walls and with 5/8 in. (15 mm) gypsum boards on the surfaces and mineral wool in the wall cavities, the STC was 3 points higher than the double CLT walls with 5/8 in. (15 mm) gypsum boards on surfaces, and 1.18 in. (30 mm) gap between two CLT walls and the gap filled with insulation material.

Table 7

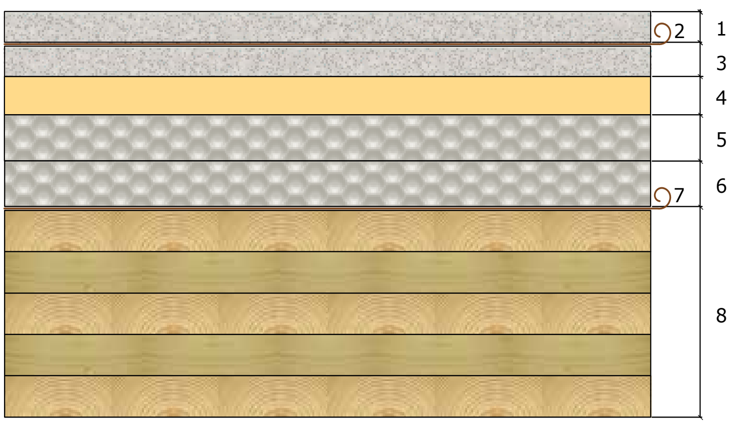
STC and IIC of CLT floor assemblies without a ceiling



Assembly Description from Top to Bottom (7.1)		STC	IIC
1	Gypsum fiberboard FERMACELL of 1.0 in. (25 mm)	62	59
2	Sub-floor ISOVER EP3 of 0.79 in. (20 mm)		
3	Honeycomb acoustic infill FERMACELL of 1.18 in. (30 mm)		
4	Honeycomb acoustic infill FERMACELL of 1.18 in. (30 mm)		
5	Kraft paper underlayment		
6	5-layer CLT panel of 5 5/16 in. (135 mm)		



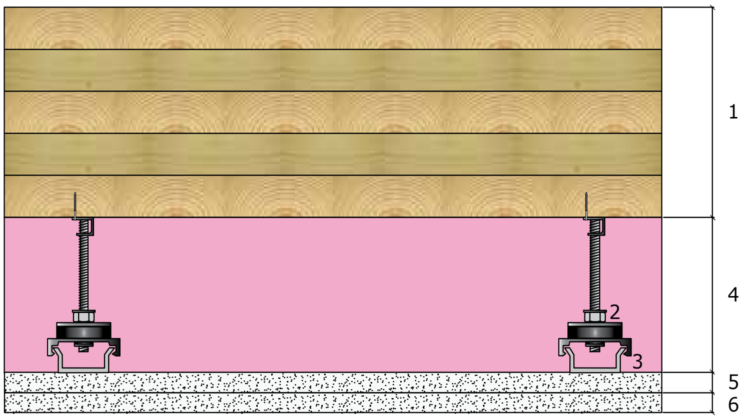
Assembly Description from Top to Bottom (7.2)		STC	IIC
1	Prefabricated concrete topping of 0.79 in. (20 mm)	64	60
2	Kraft paper underlayment		
3	Subfloor ISOVER EP2 of 1 in. (25 mm)		
4	Honeycomb acoustic infill FERMACELL of 1.18 in. (30 mm)		
5	Honeycomb acoustic infill FERMACELL of 1.18 in. (30 mm)		
6	Kraft paper underlayment		
7	5-layer CLT panel of 5 5/16 in. (135 mm)		



Assembly Description from Top to Bottom (7.3)		STC	IIC
1	Prefabricated concrete topping of 0.79 in. (20 mm)	64	72
2	Kraft paper underlayment		
3	Prefabricated concrete topping of 0.79 in. (20 mm)		
4	Subfloor ISOVER EP1 of 1.18 in. (30 mm)		
5	Honeycomb acoustic infill FERMACELL of 1.18 in. (30 mm)		
6	Honeycomb acoustic infill FERMACELL of 1.18 in. (30 mm)		
7	Kraft paper underlayment		
8	5-layer CLT panel of 5 5/16 in. (135 mm)		

Table 8

STC and IIC of CLT floors without topping and with only a ceiling



Assembly Description from Top to Bottom (8.1)		STC	IIC
1	5-layer CLT panel of 5 3/4 in. (146 mm)	64	59
2	Sound isolation clips of 4 in. (100 mm) high (Figure 13)		
3	Metal hat channel at minimum spacing of 16 in. (400 mm) o.c.		
4	Sound absorption material (such as fiberglass) of 4 in. (100 mm)		
5	Gypsum board of 1/2 in. (13 mm)		
6	Gypsum board of 1/2 in. (13 mm)		
1	5-layer CLT panel of 5 3/4 in. (146 mm)	63	62
2	Sound isolation clips of 8 in. (200 mm) high (Figure 13)		
3	Metal hat channel at minimum spacing of 16 in. (400 mm) o.c.		
4	Sound absorption material (such as fiberglass) of 8 in. (200 mm)		
5	Gypsum board of 1/2 in. (15 mm)		
6	Gypsum board of 1/2 in. (15 mm)		

Observations:

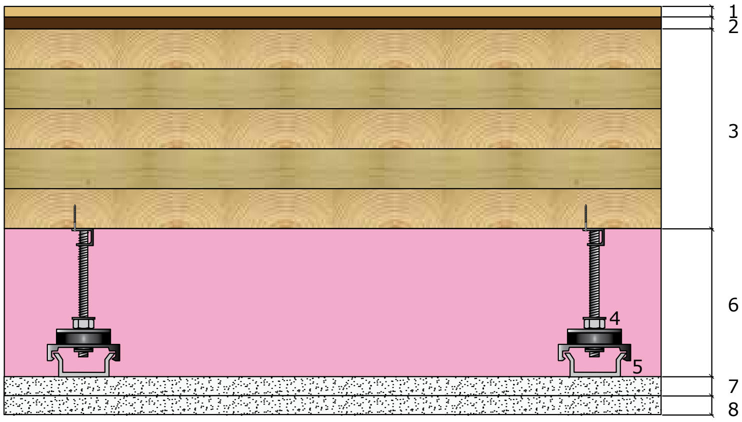
1. With a suspended ceiling, without the need of a topping, this CLT construction can achieve higher STC and IIC than the code requirement of STC 50 and IIC 50 for floor/ceiling assemblies.
2. When increasing the ceiling cavity depth from 4 in. (100 mm) to 8 in. (200 mm), and the thickness of gypsum boards from 1/2 in. (13 mm) to 5/8 in. (15 mm), the STC of the CLT floor/ceiling assembly was not affected, but the IIC increased by 3 dB.

(a) (b)

Figure 13
Sound isolation clip (a) and resiliently suspended gypsum board ceiling from CLT floor with sound isolation clips supporting metal hat channels and gypsum boards (b)

Table 9

STC and IIC of CLT floors with flooring and ceiling



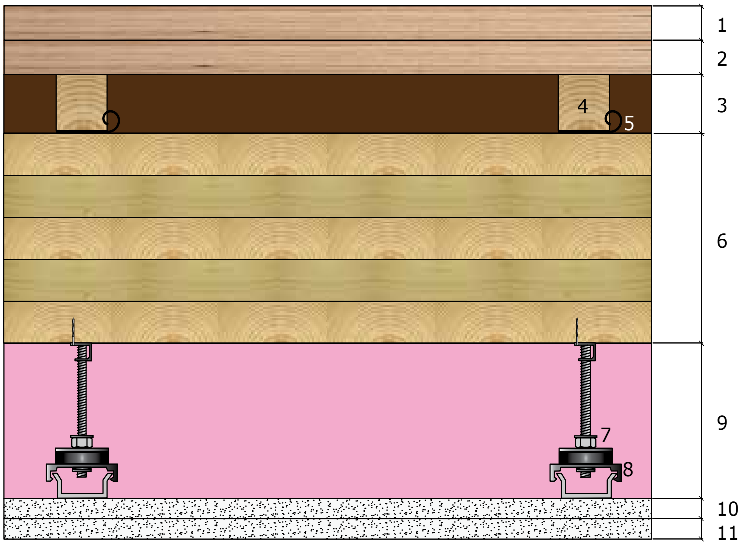
Assembly Description from Top to Bottom (9.1)		STC	IIC
1	Laminated flooring of 1/4 in. (6.4 mm)	62	63
2	Low-density wood fiberboard of 0.2 in. (5 mm) (PHALTEX)		
3	5-layer CLT panel of 5 3/4 in. (146 mm)		
4	Sound isolation clips of 4 in. (100 mm) high (Figure 13)		
5	Metal hat channel at minimum spacing of 16 in. (400 mm) o.c.		
6	Fiberglass of 4 in. (100 mm)		
7	Gypsum board of 1/2 in. (13 mm)		
8	Gypsum board of 1/2 in. (13 mm)		
1	Laminated flooring of 1/4 in. (6.4 mm)	63	64
2	Low-density wood fiberboard of 0.4 in. (10 mm) (PHALTEX)		
3	5-layer CLT panel of 5 3/4 in. (146 mm)		
4	Sound isolation clips of 4 in. (100 mm) high (Figure 13)		
5	Metal hat channel at minimum spacing of 16 in. (400 mm) o.c.		
6	Fiberglass of 4 in. (100 mm)		
7	Gypsum board of 1/2 in. (13 mm)		
8	Gypsum board of 1/2 in. (13 mm)		

Observations:

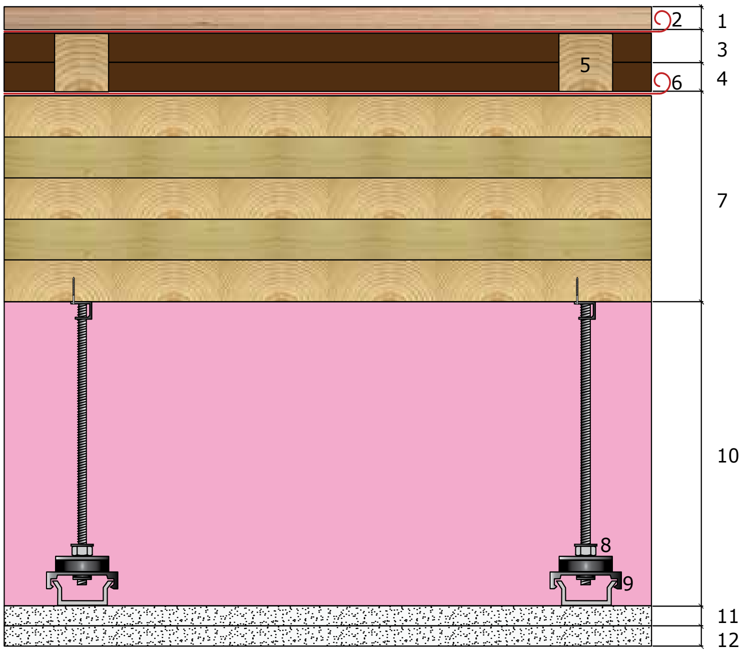
1. Adding a floating floor to the CLT floor with the suspended ceiling system increased the IIC by 4 points
2. Increasing the thickness of underlayment for the floating floor did not significantly improve the STC and IIC

Table 10

STC and IIC of CLT floors with topping and ceiling (a)



	Assembly Description from Top to Bottom (10.1)	STC	IIC
1	Particleboard panel of 7/8 in. (22 mm)	67	62
2	Particleboard panel of 7/8 in. (22 mm)		
3	Mineral wool of about 1 5/8 in. (~ 40 mm)		
4	Lumber sleepers of 1 5/8 in. x 1 5/8 in. (40 mm x 40 mm) at least 16 in. (400 mm) o.c. attached to particleboard		
5	REGULPOL underlayment		
6	5-layer CLT panel of 5 3/4 in. (146 mm)		
7	Sound isolation clips of 4 in. (100 mm) high (Figure 13)		
8	Metal hat channel at minimum spacing of 16 in. (400 mm) o.c.		
9	Fiberglass of 4 in. (100 mm)		
10	Gypsum board of 1/2 in. (13 mm)		
11	Gypsum board of 1/2 in. (13 mm)		



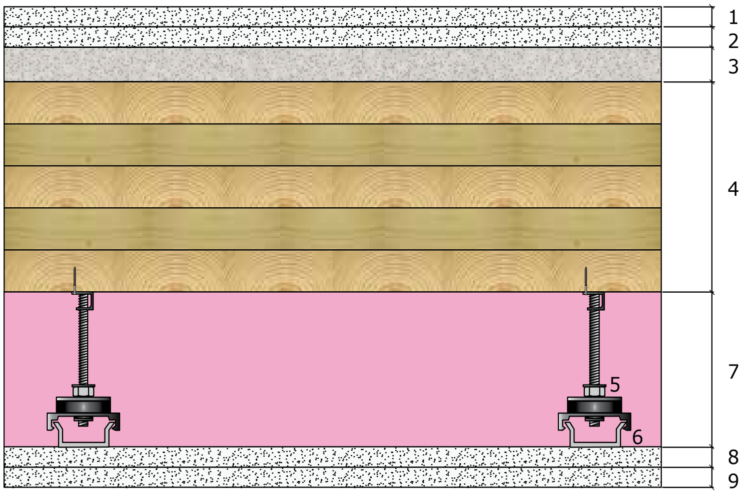
	Assembly Description from Top to Bottom (10.2)	STC	IIC
1	OSB panel of 5/8 in. (15 mm) attached to sleepers	62	62
2	Flooring underlayment ROBERTS		
3	Low-density wood fiberboard THERMISOREL of 0.78 in. (20 mm)		
4	Low-density wood fiberboard THERMISOREL of 0.78 in. (20 mm)		
5	Lumber sleepers of 1 5/8 in. x 1 5/8 in. (40 mm x 40 mm) at least 16 in. (400 mm) o.c. attached to OSB		
6	Flooring underlayment ROBERTS		
7	5-layer CLT panel of 5 3/4 in. (146 mm)		
8	Sound isolation clips of 8 in. (200 mm) high (Figure 13)		
9	Metal hat channel at minimum spacing of 16 in. (400 mm) o.c.		
10	Fiberglass of 8 in. (200 mm)		
11	Gypsum board of 5/8 in. (15 mm)		
12	Gypsum board of 5/8 in. (15 mm)		

Observations:

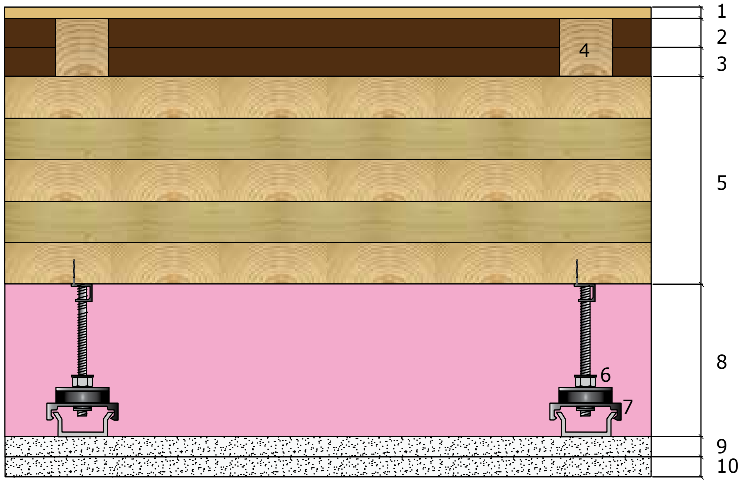
- The effect of the topping systems seems almost equivalent to that of the floating floor (Table 8) in terms of the effectiveness of improving STC and IIC, except that the topping was on the lumber sleepers. In comparison with the floating floor in Table 8, adding this topping to the CLT floor with the suspended ceiling increased the STC by 3 points.

Table 11

STC and IIC of CLT floors with topping and ceiling (b)



Assembly Description from Top to Bottom (11.1)		STC	IIC
1	Gypsum board of 1/2 in. (13 mm)	63	63
2	Gypsum board of 1/2 in. (13 mm)		
3	Dry topping of at least 0.78 in. (20 mm) and 7.17 lb./ft.^{2} (35 kg/m^2), ex. FERMACELL, cement-fiberboard, etc.		
4	5-layer CLT panel of 5 3/4 in. (146 mm)		
5	Sound isolation clips of 4 in. (100 mm) high (Figure 13)		
6	Metal hat channel at minimum spacing of 16 in. (400 mm) o.c.		
7	Fiberglass of 4 in. (100 mm)		
8	Gypsum board of 1/2 in. (13 mm)		
9	Gypsum board of 1/2 in. (13 mm)		



Assembly Description from Top to Bottom (11.2)		STC	IIC
1	Floorboard attached to sleepers	64	65
2	Low-density wood fiberboard THERMISOREL of 0.78 in. (20 mm)		
3	Low-density wood fiberboard THERMISOREL of 0.78 in. (20 mm)		
4	Lumber sleepers of 1 5/8 in. x 1 5/8 in. (40 mm x 40 mm) at least 16 in. (400 mm) o.c. attached to CLT		
5	5-layer CLT panel of 5 3/4 in. (146 mm)		
6	Sound isolation clips of 4 in. (100 mm) high (Figure 13)		
7	Metal hat channel at minimum spacing of 16 in. (400 mm) o.c.		
8	Fiberglass of 4 in. (100 mm)		
9	Gypsum board of 1/2 in. (13 mm)		
10	Gypsum board of 1/2 in. (13 mm)		

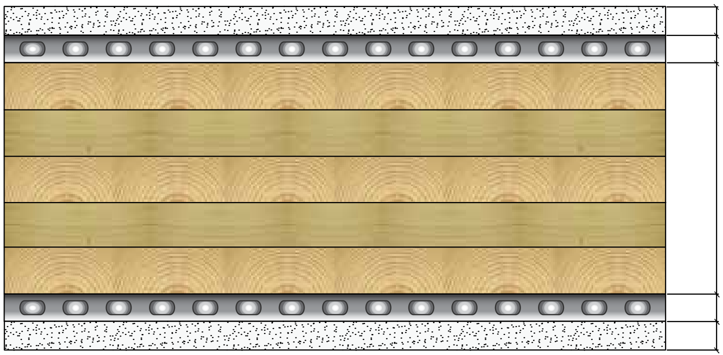
6

EXAMPLES OF CONSTRUCTION SOLUTIONS FOR CLT WALLS AND FLOOR/CEILING ASSEMBLIES MEETING IBC'S FSTC AND FIIC REQUIREMENTS

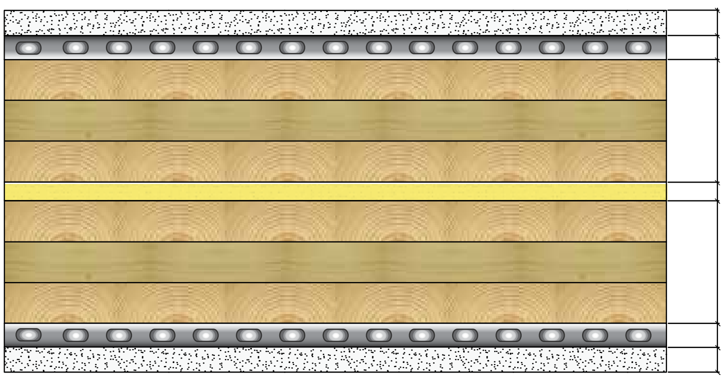
Field sound insulation tests were conducted on some CLT wall and floor/ceiling assemblies in two new CLT buildings. Tables 12 and 13 summarize the CLT wall assemblies that were tested in the two CLT buildings (Hu, 2013a) meeting the IBC's sound insulation requirements of FSTC 45. Tables 14 and 15 summarize the CLT floor/ceiling assemblies that were tested at FPInnovations' acoustic facility, i.e. the mock-up of a two-story CLT condominium meeting IBC's requirements of FSTC 45 and FIIC 45. It must be noted that, if the flanking paths can be minimized (i.e., avoidable flanking paths can be eliminated), then the FSTC and FIIC are expected to be higher than those provided in these tables.

Table 12

FSTC of CLT wall assemblies in complete CLT building-1

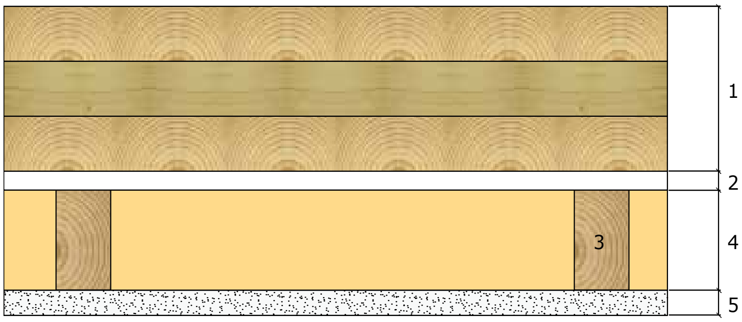


Assembly Description from Top to Bottom (12.1)		FSTC
1	Gypsum board of 5/8 in. (16 mm) about 2.25 lb./ft.^{2} (11 kg/m^2)	46
2	Type RC-1 (one-leg) 25 gauge resilient channels at 24 in. (600 mm) o.c.	
3	5-layer CLT panel of 7 1/4 in. (184 mm)	
4	Type RC-1 (one-leg) 25 gauge resilient channels at 24 in. (600 mm) o.c.	
5	Gypsum board of 5/8 in. (16 mm) about 2.25 lb./ft.^{2} (11 kg/m^2)	

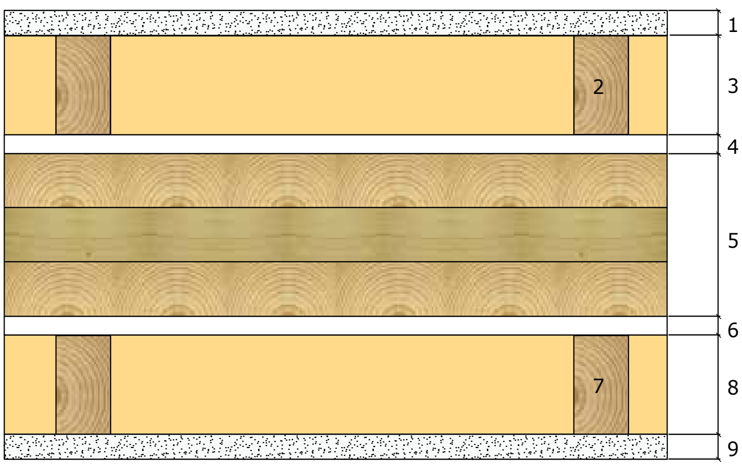


Assembly Description from Top to Bottom (12.2)		FSTC
1	Gypsum board of 5/8 in. (16 mm) about 2.25 lb./ft.^{2} (11 kg/m^2)	47
2	Type RC-1 (one-leg) 25 gauge resilient channels at 24 in. (600 mm) o.c.	
3	3-layer CLT panel of 3 in. (78 mm)	
4	Air gap of 1 in. (25 mm) filled with mineral wool	
5	3-layer CLT panel of 3 in. (78 mm)	
6	Type RC-1 (one-leg) 25 gauge resilient channels at 24 in. (600 mm) o.c.	
7	Gypsum board of 5/8 in. (16 mm) about 2.25 lb./ft.^{2} (11 kg/m^2)	

Table 13
FSTC of CLT wall assemblies in CLT building-2 without finishing



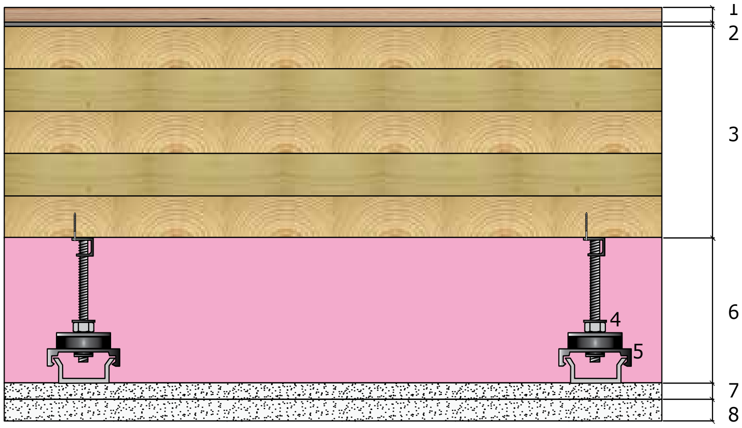
	Assembly Description from Top to Bottom (13.1)	FSTC
1	3-layer CLT of 4 1/8 in. (105 mm)	47
2	Air gap of 1/2 in. (12 mm)	
3	Wood studs of 2 in. x 3 in. (38 mm x 64 mm) at 16 in. (400 mm) o.c.	
4	Mineral wool of 2 1/2 in. (64 mm) in the wall cavity	
5	Gypsum board of 5/8 in. (16 mm) about 2.25 lb./ft.^{2} (11 kg/m^2)	



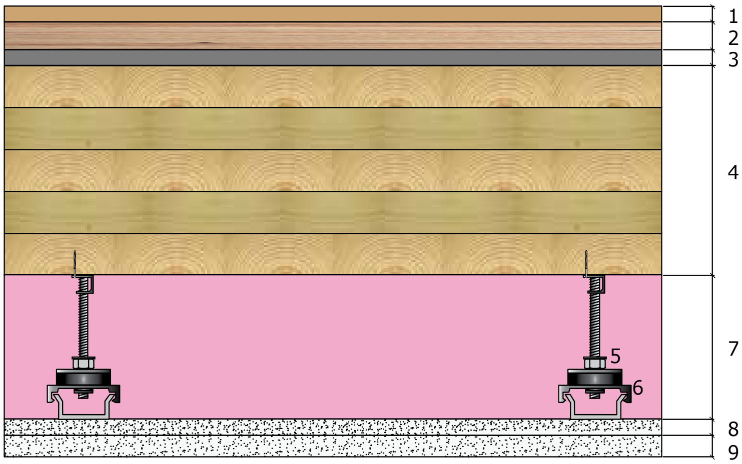
	Assembly Description from Top to Bottom (13.2)	FSTC
1	Gypsum board of 5/8 in. (16 mm) about 2.25 lb./ft.^{2} (11 kg/m^2)	50
2	Wood studs of 2 in. x 3 in. (38 mm x 64 mm) at 16 in. (400 mm) o.c.	
3	Mineral wool of 2 1/2 in. (64 mm) in the wall cavity	
4	Air gap of 1/2 in. (12 mm)	
5	3-layer CLT of 4 1/8 in. (105 mm)	
6	Air gap of 1/2 in. (12 mm)	
7	Wood studs of 2 in. x 3 in. (38 mm x 64 mm) at 16 in. (400 mm) o.c.	
8	Mineral wool of 2 1/2 in. (64 mm) in the wall cavity	
9	Gypsum board of 5/8 in. (16 mm) about 2.25 lb./ft.^{2} (11 kg/m^2)	

Table 14

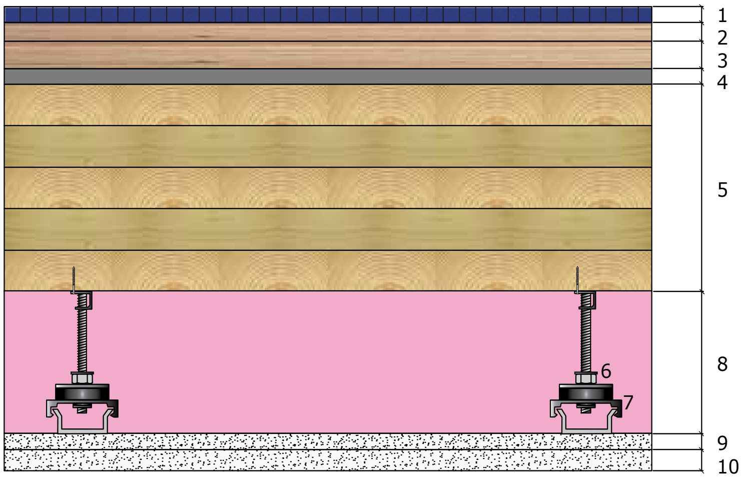
FSTC and FIIC of CLT floors with flooring and a suspended ceiling



Assembly Description from Top to Bottom (14.1)		FSTC	FIIC
1	Around 2/5 in. (10 mm) laminated or engineered wood flooring	>50 Depending on the thickness of CLT and flooring, RC spacing and cavity height	>50 Depending on the type of underlayment, thickness of flooring and CLT, RC spacing and cavity height
2	Around 0.12 in. (3 mm) resilient underlayment (rubber mat, e.g. InsonoBois or similar; textured felt, e.g. Thermason HD or similar)		
3	5-layer CLT panel of 6 7/8 in. (175 mm)		
4	Sound isolation clips of 4 in. (100 mm) high (Figure 13)		
5	Metal hat channel at minimum spacing of 16 in. (400 mm) o.c.		
6	Fiberglass of 4 in. (100 mm)		
7	Gypsum board of 1/2 in. (12 mm) type C about 1.84 lb./ft.^{2} (9 kg/m^2)		
8	Gypsum board of 5/8 in. (15 mm) type X about 2.25 lb./ft.^{2} (11 kg/m^2)		



Assembly Description from Top to Bottom (14.2)		FSTC	FIIC
1	Hardwood flooring attached to the plywood	>53 Depending on the thickness of CLT and flooring, RC spacing and cavity height	>53 Depending on the type of underlayment, thickness of flooring and CLT, RC spacing and cavity height
2	3/4 in. (18 mm) plywood		
3	Around 2/5 in. (10 mm) underlayment (rubber mat, e.g. InsonoMat or similar; textured felt, e.g. Felt S-125 or similar)		
4	5-layer CLT panel of 6 7/8 in. (175 mm)		
5	Sound isolation clips of 4 in. (100 mm) high (Figure 13)		
6	Metal hat channel at minimum spacing of 16 in. (400 mm) o.c.		
7	Fiberglass of 4 in. (100 mm)		
8	Gypsum board of 1/2 in. (12 mm) type C about 1.84 lb./ft.^{2} (9 kg/m^2)		
9	Gypsum board of 5/8 in. (15 mm) type X about 2.25 lb./ft.^{2} (11 kg/m^2)		

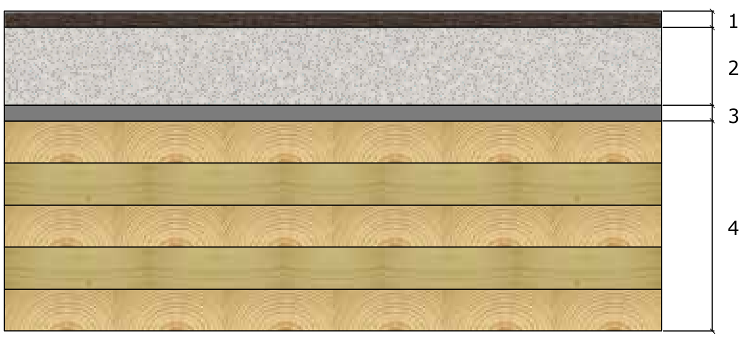


	Assembly Description from Top to Bottom (14.3)	FSTC	FIIC
1	Ceramic tiles glued to plywood	>53 Depending on the thickness of CLT and tile, RC spacing and cavity height	>53 Depending on the thickness of CLT and tile, the type of tile and underlayment, RC spacing and cavity height
2	1/2 in. (12 mm) plywood		
3	3/4 in. (19 mm) plywood		
4	Around 2/5 in. (10 mm) underlayment (rubber mat, e.g. InsonoMat or similar; textured felt, e.g. Felt S-125 or similar)		
5	5-layer CLT panel of 6 7/8 in. (175 mm)		
6	Sound isolation clips at 4 in. (100 mm) high (Figure 13)		
7	Metal hat channel at minimum spacing of 16 in. (400 mm) o.c.		
8	Fiberglass of 4 in. (100 mm)		
9	Gypsum board of 1/2 in. (12 mm) type C about 1.84 lb./ft.^{2} (9 kg/m^2)		
10	Gypsum board of 5/8 in. (15 mm) type X about 2.25 lb./ft.^{2} (11 kg/m^2)		

Table 15

FSTC and FIIC of CLT floors with flooring and topping, wood exposed on ceiling side

	Assembly Description from Top to Bottom (15.1)	FSTC	FIIC
1	About 2/5 in. (10 mm) carpet or floating flooring on 0.12 in. (3 mm) resilient underlayment (rubber mat, e.g. InsonoBois or similar; textured felt, e.g. Thermason HD or similar)	>45 Depending on the thickness of CLT, topping and flooring	>45 Depending on the thickness of CLT, topping and flooring, and the type of flooring, topping and underlayment
2	At least 5.12 lb./ft.^{2} (25 kg/m^2) dry topping, e.g. 0.8 in. (20 mm) Fermacell, cement fiberboard, Fibrerock or similar		
3	Resilient underlayment, e.g. 2/5 in. (10 mm) rubber mat (IsonoMat), 3/4 in. (18 mm) textured felt (Felt S-125), 1/2 in. (12 mm) low density wood fiberboard, or similar		
4	5-layer CLT of 6 7/8 in. (175 mm)		



	Assembly Description from Top to Bottom (15.2)	FSTC	FIIC
1	About 2/5 in. (10 mm) carpet or floating flooring on 0.12 in. (3 mm) resilient underlayment (rubber mat, e.g. InsonoBois or similar; textured felt, e.g. Thermason HD or similar)	>50 Depending on the thickness of CLT, topping and flooring	>50 Depending on the thickness of CLT, topping and flooring, and the type of flooring, topping and underlayment
2	At least 15.6 lb./ft.^{2} (76 kg/m^2) wet topping (concrete, gypcrete, gypsum, or similar)		
3	Resilient underlayment, e.g. 2/5 in. (10 mm) rubber mat (Insonomat), 3/4 in. (18 mm) textured felt (Felt S-125), 1/2 in. (12 mm) low density wood fiberboard, etc.		
4	5-layer CLT of 6 7/8 in. (175 mm)		

7

THE BEST PRACTICES FOR ENSURING OCCUPANTS' SATISFACTIONS - STEP BY STEP GUIDE

While Sections 5 and 6 provide examples of solutions to meet IBC requirements for sound insulation, this Section provides step-by-step guidance towards satisfactory sound insulation for CLT projects. If in doubt or if sound insulation is critical, it is strongly recommended to engage the services of an acoustical consultant.

7.1 Step 1: Selecting Construction Solutions for FSTC and FIIC 50

Experts experience in field surveys and investigations has shown that even meeting the minimum IBC requirements (i.e., FSTC and FIIC of 45) does not always eliminate occupants complaints. While not always possible, it is suggested to strive for FSTC and FIIC ratings of 50 or more, particularly in multiple dwelling units.

7.2 Step 2: Eliminating Avoidable Flanking Paths

To optimize the efficiency of the sound insulation solutions selected in Sections 5 and 6, a quality-controlled installation protocol must be implemented in order to eliminate avoidable flanking paths.

There are two types of flanking transmission, i.e. sound leaking through any openings, and vibration transfer between the coupled surfaces or through the continuous structure elements. The basics of flanking control are to seal the openings, to decouple the surfaces, and to discontinue the structural elements if it does not affect the structural safety and serviceability. However, there is always a trade-off. Table 16 provides a flanking path check list and corresponding treatment. The list includes the most obvious and crucial flanking paths that must be controlled or eliminated. If the flanking paths can be controlled, then the solutions provided should provide satisfactory sound insulation for CLT buildings.

Table 16
Flanking path check list and general treatment; not limited to CLT buildings

Flanking Path	Treatment
Leaks around the edge of partitions (ASTM E336)	Seal the leaks with tape, gaskets, or caulking compound (ASTM E336)
Cracks at wall/floor junctions	Caulk joint between gypsum board and floor, Figure 6 (IRC, 2002)
Debris between floor and wall sill plates	Clean floor and caulk sill plate (IRC, 2002)
Leaks through electrical outlets	Avoid back-to-back outlets by offsetting them 16 in. (400 mm) or at least one stud space from side to side, Figure 7 (IRC, 2002)
If gypsum board is rigidly attached to studs or the wall framing, the wall could contribute to flanking (IRC, 2002)	Attach gypsum board on resilient channels (IRC, 2002)
Joint between the flooring, topping and the surrounding walls, especially if the flooring topping is floating or not rigidly attached to the subfloor	Leave a gap around the entire flooring topping assembly and walls. Fill it with resilient perimeter isolation board or backer rod and seal the joint with acoustical caulk
Continuous subflooring, joists, and CLT elements between two adjacent units	Discontinue subflooring, joists, and CLT as much as possible. Add floating topping and floating flooring if the continuity is not avoidable

7.3 Step 3: Measuring FSTC and FIIC after Finishing

To ensure your trust in the airborne and impact sound insulation of the finished walls and floors, it is a good idea to measure the FSTC and FIIC to confirm that they meet or exceed expected values. In the worst case scenario, a flag can be raised to remedy this situation before the occupants move in and raise the issue in the form of a complaint.

8 CONCLUSION

A great deal of the task of achieving adequate and acceptable airborne and impact sound insulation is simply giving adequate attention to details in the design and construction. Such details consist in proper use of sealants or caulking to seal sound leaks, avoiding rigid contact between building elements where the transfer of vibrational energy between spaces is possible, and using appropriate materials (e.g., materials with sufficient mass). Laboratory and field testing to date show that buildings constructed using CLT materials can provide satisfactory sound insulation if proper design and installation are implemented. While many acoustical tests have been conducted using CLT materials, there are many CLT construction methods and assemblies still to be tested. As these tests are completed, there will be additional confidence that the application of CLT materials will prove to be useful in achieving the acoustical criteria required by building codes and by occupants of buildings we construct.

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9 RECOMMENDATION

This Chapter illustrates state of the art solutions for buildings using CLT materials to achieve satisfactory sound insulations based on research and experience to date. It is recommended that implementation of the solutions provided in this document, be checked and/or validated prior to use with the installation specifications of the various flooring materials with respect to other requirements, such as allowable maximum deformation, moisture stability, etc. Furthermore, in critical situations or when assurance or written documentation is needed that the chosen design meets the building code STC (FSTC) and/or IIC (FIIC) minimum requirements, it is strongly recommend engaging the services of an acoustical consultant to assist.

In closing, the authors would like to point out that, considering the short history of CLT construction, the journey is only beginning. It is hoped that this document will spark inner creative stirrings and be inspiring when considering the sound insulation materials and solutions that have been developed for CLT buildings. We encourage you to share your feedback concerning the application of the solutions provided in your CLT projects.

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