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# RR-335
# Apparent Sound Insulation in Cross-Laminated Timber Buildings

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National Research Council Canada
Conseil national de recherches Canada

Canada

**Scope**

This Report presents the results from experimental studies of airborne sound transmission, together with an explanation of calculation procedures to predict the apparent airborne sound transmission between adjacent spaces in a building whose construction is based on cross-laminated timber (CLT) panels.

There are several types of CLT constructions which are commercially available in Canada, but this study only focused on CLT panels that have adhesive between the faces of the timber elements in adjacent layers, but no adhesive bonding the adjacent timber elements within a given layer. There were noticeable gaps (up to 3 mm wide) between some of the timber elements comprising each layer of the CLT assembly. These CLT panels could be called "Face-Laminated CLT Panels" but are simply referred to as CLT panels in this Report.

Another form of CLT panels has adhesive between the faces of the timber elements in adjacent layers as well as adhesive to bond the adjacent timber elements within a given layer. These are referred to as "Fully-Bonded CLT Panels" in this Report.

**Because fully-bonded CLT panels have different properties than face-laminated CLT panels, the sound transmission data and predictions in this Report do not apply to fully-bonded CLT panels.**

**Acknowledgments**

The research studies on which this Report is based were supported by a group of industry partners (Canadian Wood Council, FPInnovations, Régime du bâtiment du Québec, HER MAJESTY THE QUEEN IN RIGHT OF ONTARIO as represented by the Minister of Municipal Affairs and Housing). The development of this Report was supported by the Canadian Wood Council. The financial support is gratefully acknowledged.

**Disclaimer**

Although it is not repeated at every step of this Report, it should be understood that some variation in sound insulation is to be expected in practice due to changes in the specific design details, poor workmanship, substitution of "generic equivalents", or simply rebuilding the construction. It would be prudent to allow a margin of error of several ASTC points to ensure that a design will satisfy a specific requirement.

Despite this caveat, the authors believe that methods and results shown here do provide a good estimate of the apparent sound insulation for the types of constructions presented.

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## Contents

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# 1 Sound Transmission via Many Paths

The simplest approach to sound transmission between adjacent rooms in buildings considers only the sound transmission through the separating wall or floor. This perspective has been entrenched in North American building codes, which for many decades have considered only the ratings for the separating assembly: sound transmission class (STC) or field sound transmission class (FSTC) for airborne sources and impact insulation class (IIC) for footstep noise.

Implicit in this approach (illustrated in Figure 1.1) is the simplistic assumption that sound is transmitted only through the obvious separating assembly – the separating wall assembly when the rooms are side-by-side, or the floor/ceiling assembly when rooms are one-above-the-other. If the sound insulation is inadequate, this is attributed to errors in either the design of the separating assembly or the workmanship of those who built it, and remediation focusses on that assembly. Unfortunately, this paradigm is still common among designers and builders in North America.

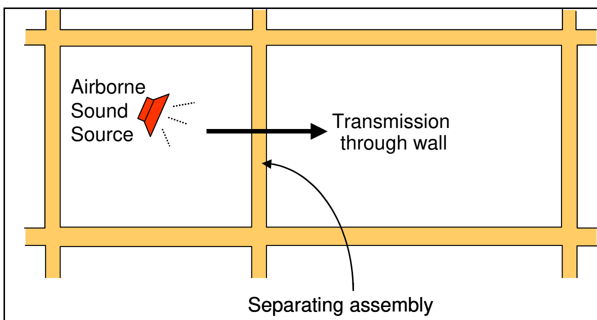



**Figure 1.1**: The drawings in Figure 1.1 and 1.2 show a cross-section through a building with two adjacent rooms. Part of the sound from an airborne source in one unit (represented by red loudspeaker in the drawings, which could include anything from a home theatre to people talking loudly) is transmitted to the adjacent unit. The historic approach, illustrated in Figure 1.1, considers *only* the direct sound transmission through the separating assembly.

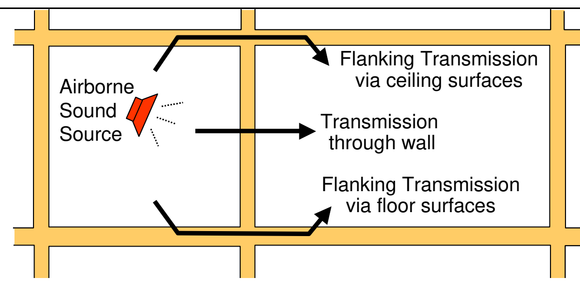



**Figure 1.2**: In reality, there are many paths for sound transmission between adjacent rooms, including both direct transmission through the separating assembly and indirect structure-borne paths, a few of which are indicated here. (See Section 1.4 for more detail.) The structure-borne paths usually significantly affect the overall sound transmission.

In reality, the technical issue is more complex, as illustrated in Figure 1.2. There is direct transmission of sound through the separating assembly, but that is only part of the story of how sound is transmitted between adjacent rooms. As shown in the figure, the airborne sound source excites all the surfaces in the source space and all of these surfaces vibrate in response. Some of this vibrational energy is transmitted as structure-borne sound across the surfaces abutting the separating assembly, through the junctions where these surfaces join the separating assembly, and into surfaces of the adjoining space. These surfaces in the receiving room then radiate part of the vibrational energy as airborne sound. The sound transmission by these paths is called flanking sound transmission.

It follows that the sound insulation between adjacent rooms is always worse than the sound insulation provided by the obvious separating assembly. Occupants of the adjacent room actually hear the combination of sound due to direct transmission through the separating assembly plus sound due to structure-borne flanking transmission involving all the other elements coupled to the separating assembly. Furthermore, there is also transmission of sound through leaks (openings) in the walls. The importance of including all of the transmission paths has long been recognized in principle (and the fundamental science was largely explained decades ago, by Cremer et al [8]). The challenge has been to reduce the complicated calculation process to manageable engineering that yields trustworthy quantitative estimates, and to standardize that process to facilitate its inclusion in a regulatory framework.

For design or regulation, there is well-established terminology to describe the overall sound transmission including all paths between adjacent rooms. ISO ratings such as the Weighted Apparent Sound Reduction Index ($R'_w$) have been used in many countries for decades, and ASTM E336 defines the corresponding apparent sound transmission class (ASTC), which is used in the examples in this Report.

Although measuring the ASTC in a building (following ASTM Standard E336) is quite straightforward, predicting the ASTC due to the set of transmission paths in a building is more complex. However, standardized frameworks for calculating the overall sound transmission have been developed. These start from standardized measurements to characterize sub-assemblies, and have been used for more than a decade to support performance-based European code systems.

In 2005, ISO published a calculation method, ISO 15712-1, “Building acoustics — Estimation of acoustic performance of buildings from the performance of elements — Part 1: Airborne sound insulation between rooms”. This is one part of a series of standards: Part 2 deals with “impact sound insulation between rooms”, Part 3 deals with “airborne sound insulation against outdoor sound”, and Part 4 deals with “transmission of indoor sound to the outside”.

There are two significant impediments to applying the methods of ISO 15712-1 in a North American context:

- ISO 15712-1 provides very reliable estimates for some types of construction, including CLT constructions, but not for the lightweight framed construction widely used for buildings in North America.
- ISO standards for building acoustics have many differences from the ASTM standards used by the construction industry in North America – both in their terminology and in specific technical requirements for measurement procedures and ratings.

The following sections of this chapter outline a strategy for dealing with these limitations, both explaining how to merge ASTM and ISO test data and procedures, and providing recommendations for adapting the calculation procedures for CLT constructions.

This Report was developed in a project established by the National Research Council of Canada and the Canadian Wood Council to support the transition of construction industry practice to using ASTC rather than STC for sound control objectives in the National Building Code of Canada (NBCC). However, the potential range of application goes beyond the minimum requirements of the NBCC. The Report also facilitates design to provide enhanced levels of sound insulation, and should be generally applicable to construction with CLT assemblies in both Canada and the USA.

## 1.1 Predicting Sound Transmission in a Building

As noted above, ISO 15712-1 provides reliable estimates of apparent sound transmission for buildings with CLT floors and walls, but it is significantly less accurate for some other common types of construction, especially for lightweight wood-framed and steel-framed constructions.

ISO 15712-1 has other limitations, too. For example, in several places the Standard identifies situations (especially for lightweight framed construction) where the detailed calculation is not appropriate. However, the Standard does not provide specific guidance on how to deal with such cases. Many of these limitations can be overcome by using data from laboratory testing according to the ISO 10848 series of standards which were developed to deal with measuring flanking sound transmission for various combinations of construction types and junctions. Because the current (2005) edition of ISO 15712-1 replicates a European standard developed before 2000, it does not reference more recent standards such as the ISO 10848 series, or the ISO 10140 series that have replaced the ISO 140 series referenced in ISO 15712-1. The 2015 edition of the National Building Code of Canada deals with this problem by specifying suitable procedures and test data to deal with calculating ASTC for different types of construction. These procedures are also explained in the NRC Research Report RR-331, “Guide to Calculating Airborne Sound Transmission in Buildings” [14].

For CLT constructions, the calculation procedure of ISO 15712-1 is sufficiently accurate (both the Detailed Method and the Simplified Method). This Report outlines the steps of the standardized calculation procedure.

This Report is restricted to consideration of buildings where all the walls and floors are CLT assemblies. This scope could be expanded to include the combination of CLT assemblies with lightweight framed assemblies by measuring the flanking sound transmission for such combinations according to the procedures of ISO 10848. However, at the time of publication of this Report, such data was not available.

In order to respect copyright, the Report does not reproduce the equations of ISO 15712-1, but it does indicate which equations apply in each context and provides key adaptations of the ISO expressions needed to apply the concepts in an ASTM context.

## 1.2 Standard Scenario for Examples in this Report

The prediction of the sound transmitted in buildings depends not only on the construction details of the transmission paths, but also on the size and shape of each of the room surfaces and on the sound absorption in the receiving room. The ability to adjust the calculation to fit the dimensions in a specific building or to normalize to different receiving room conditions enables a skilled designer to obtain more accurate predictions.

For purposes of this Report, where results will be presented for a variety of constructions, easy and meaningful comparison of results is facilitated by calculating all the examples for a common set of room geometry and dimensions. This is particularly useful where only small changes are made between the construction details in the examples, since any change in the ASTC rating can then be attributed to the changes that were made in the construction details.

Therefore, a Standard Scenario has been adopted for all the examples, with the following constraints:

- Sound is transmitted between adjacent rooms, either side-by-side or one-above-the-other.
- The adjacent rooms are mirror images of each other, (with one side of the separating assembly facing each room, and constituting one complete face of each rectangular room).

The Standard Scenario is illustrated in Figures 1.3 and 1.4, for the cases where one room is beside the other, or one is above the other, respectively.

**Figure 1.3:** Standard Scenario for the “horizontal room pair” case where the pair of rooms are side-by-side with a separating wall assembly between the two rooms.

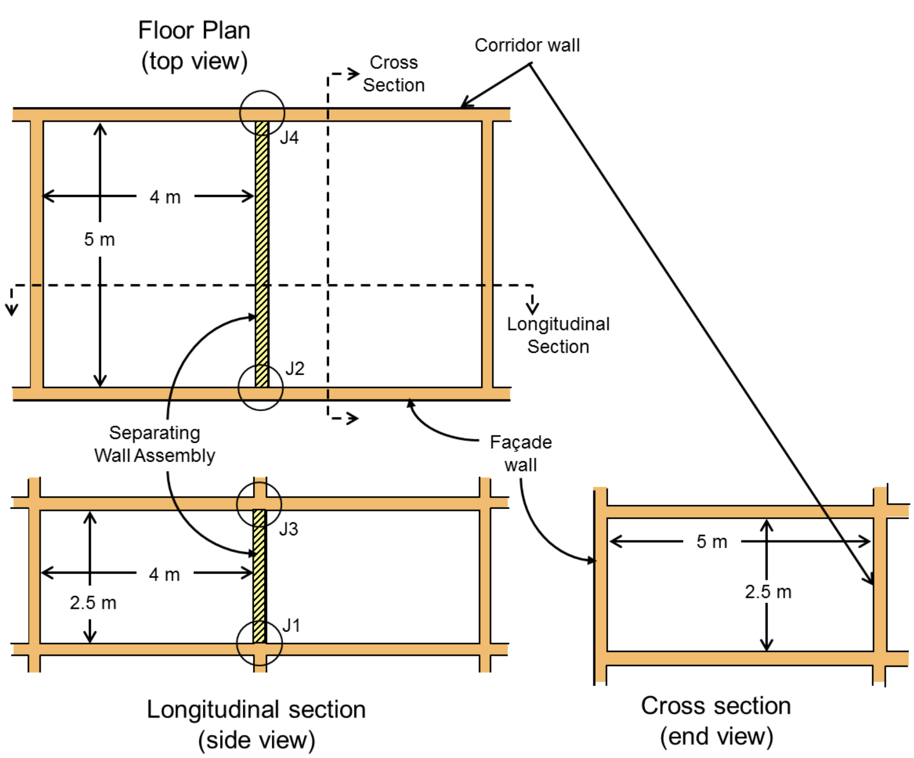
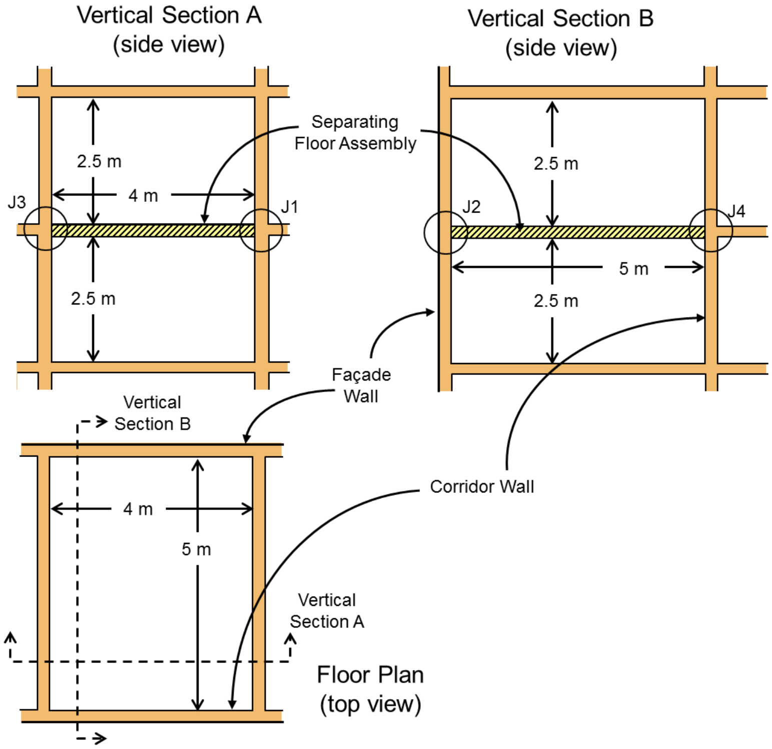


**Figure 1.4:**
Standard Scenario for the "vertical room pair" case where one of the pair of rooms is above the other, with the floor/ceiling assembly between the two rooms.




The pertinent dimensions and junction details are shown in Figures 1.3 and 1.4.

- Note the labelling of junctions at the four edges of the separating assembly (J1 to J4) in Figures 1.3 and 1.4. These junction designations are used in the design examples throughout this Report.
- For horizontal room pairs (i.e. rooms are side-by-side) the separating wall is 2.5 m high by 5 m wide, flanking floor/ceilings are 4 m by 5 m and flanking walls are 2.5 m high by 4 m wide.
- For vertical room pairs (i.e. one room is above the other) the separating floor/ceiling is 4 m by 5 m wide and flanking walls in both rooms are 2.5 m high.
- In general, it is assumed that junctions at one side of the room (at the separating wall if rooms are side-by-side) are cross-junctions, while one or both of the other two junctions are T-junctions. This enables the examples to illustrate typical differences between the two common junction cases.
- For a horizontal pair, the separating wall has T-junctions with the flanking walls at both the façade and corridor sides, and cross-junctions at floor and ceiling.
- For a vertical pair, the façade wall has a T-junction with the separating floor, but the opposing corridor wall has a cross-junction, as do the other two walls.

Deviations from the Standard Scenario, such as room pairs where one room is an end unit with T-junctions instead of cross-junctions, can be calculated by substituting the appropriate junction details in the calculation procedures and in the worked examples in this Report.

## 1.3 Applying the Concepts of ISO Standards in an ASTM Environment

Although the building acoustics standards developed by ASTM are very similar in concept to the corresponding ISO standards, there are differences in the terminology and technical requirements between the two which present numerous barriers to using a mix of standards from the two domains.

Although ASTM standard E336 recognizes the contribution of flanking to apparent sound transmission, there is neither an ASTM standard for measuring the structure-borne flanking sound transmission that often dominates sound transmission between rooms, nor an ASTM counterpart of ISO 15712-1 for predicting the combination of direct and flanking sound transmission. In the absence of suitable ASTM standards, this Report uses the procedures of ISO 15712-1 and data from the complementary ISO 10848 series for some constructions, but connects this ISO calculation framework to the ASTM terms and test data widely used by the North American construction industry. This methodology combines identifying where data from ASTM laboratory tests can reasonably be used in place of their ISO counterparts, and presenting the results using ASTM terminology (or new terminology for flanking sound transmission that is consistent with existing ASTM terms) to facilitate their use and understanding by a North American audience. Some obvious counterparts in the terminology are presented in Table 1.1.

| ISO Designation | Description | ASTM Counterpart |
|---|---|---|
| ISO 10140 Parts 1 and 2 (formerly ISO 140-3) | Laboratory measurement of airborne sound transmission through a wall or floor | ASTM E90 |
| sound reduction index, R (ISO 10140-2) | Fraction of sound power transmitted (in dB) at each frequency, in laboratory test | sound transmission loss, TL (ASTM E90) |
| weighted sound reduction index, $R_w$ (ISO 717-1) | Single-number rating determined from R or TL values in standard frequency bands | sound transmission class, STC (ASTM E413) |
| apparent sound reduction index, R’ (ISO 16283-1) | Fraction of sound power transmitted (in dB) at each frequency, including all paths in a building | apparent sound transmission loss, ATL (ASTM E336) |
| weighted apparent sound reduction index, $R'_w$ (ISO 717-1) | Single-number rating determined from R’ or ATL values in standard frequency bands | apparent sound transmission class, ASTC (ASTM E413) |

**Table 1.1**: Standards and terms used in ISO 15712-1 for which ASTM has close counterparts

Note that the description “counterpart” does not imply that the ASTM and ISO standards or terms are exactly equivalent. $R_W$ and STC are not interchangeable. Neither are $R'_W$ and ASTC because of systematic differences in the calculation procedures. However, the laboratory test used to measure airborne sound transmission through wall or floor assemblies – ASTM E90 and its counterpart ISO 10140-2 – are based on essentially the same procedure, with minor variants in facility requirements. Therefore, the measured quantities “sound transmission loss” from the ASTM E90 test and “sound reduction index” from the ISO standard are sufficiently similar so that data from ASTM E90 tests can be used in place of data from ISO 10140-2 tests in the calculations of ISO 15712-1 to obtain a sensible answer. Similarly, the simplified calculation of ISO 15712-1 may be performed using STC ratings to predict the ASTC rating. The close parallel between “sound reduction index” and “sound transmission loss” also means that results from ISO 15712-1 calculations (normally expressed as R’ values) can confidently be treated as calculated apparent sound transmission loss (ATL) values and then used in the procedure of ASTM E413 to calculate the ASTC rating, which is the objective for designers or regulators in the North American context.

For purposes of this Report, a glossary of new terms with counterparts in ISO 15712-1 (using terminology consistent with measures used in ASTM standards) and of other key terms from pertinent ISO standards such as ISO 15712-1 and ISO 10848 is presented in Table 1.2.

In addition, several scientific terms used in ISO 15712-1 at various stages of the calculation have been used without change. These include: radiation efficiency, internal loss factor, total loss factor, equivalent absorption length, and transmission factor. They are described in the glossary in Annex A of ISO 15712-1.

| Terms used in this Report | Description |
| --- | --- |
| Structural reverberation time ($T_S$) | Structural reverberation time is a measure indicating the rate of decay of vibration energy in an element and can apply either to a laboratory wall or floor assembly, or to a wall or floor assembly in-situ in a building. |
| Sound transmission loss in-situ ($TL_{situ}$) | Sound transmission loss in-situ is the counterpart of sound reduction index in-situ ($R_{situ}$) described in ISO 15712-1 as "the sound reduction index of an element in the actual field situation". |
| Change in sound transmission loss (ΔTL) | Change in sound transmission loss is the difference in sound transmission loss due to a lining applied on one side of a wall or floor assembly when measured according to ASTM E90, compared with the sound transmission loss of the same assembly without a lining. |
| Change in sound transmission class (ΔSTC) | Change in sound transmission class is the difference in single-number rating due to a lining applied on one side of a wall or floor assembly. The calculation procedure for ΔSTC is described in Appendix A2 of this Report. |
| Vibration reduction index ($K_{ij}$) | Vibration reduction index ($K_{ij}$) is described in ISO 15712-1 as "direction-averaged vibration level difference over a junction, normalised to the junction length and the equivalent sound absorption length to make it an invariant quantity". Depending on the type of building element, $K_{ij}$ values may be determined using equations in Annex E of ISO 15712-1 or the measurement procedures of ISO 10848. |
| Flanking sound transmission loss (Flanking $TL_{ij}$) | Flanking sound transmission loss is the counterpart of flanking sound reduction index ($R_{ij}$) in ISO 15712-1. It is a measure of sound transmission via the flanking path from element i in the source room to element j in the receiving room, normalised like apparent sound transmission loss, as described in Section 1.4 of this Report. |
| Flanking sound transmission class (Flanking $STC_{ij}$) | Flanking STC is the single-number rating calculated from the flanking sound transmission loss following the STC calculation procedure of ASTM E413. |

**Table 1.2**: Key terms used in this Report to deal with concepts from ISO 15712-1 and ISO 10848 for which current ASTM acoustics standards have no counterparts.

## 1.4 Combining Sound Transmitted via Many Paths

The calculations of ISO 15712-1 must deal with combining the sound power transmitted via the direct path and via a set of flanking paths. To keep track of the sound transmission paths, it is useful to introduce the labeling convention for the paths which is used in ISO 15712-1 and is shown in Figure 1.5.

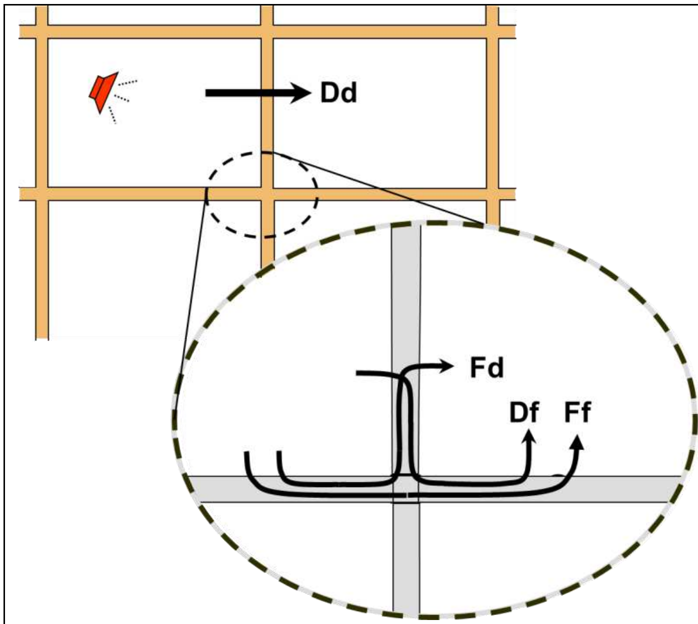



**Figure 1.5:** This figure shows the labelling convention for transmission paths used in ISO 15712-1. Consider the transmission of airborne sound from a source room (left) to a receiving room (right). Each transmission path involves one surface in the source room (denoted by a capital letter) and one in the receiving room (denoted by a lower case letter). Direct transmission through the separating assembly is path **Dd**. For each edge of the separating assembly there are three flanking paths: **Ff** from flanking surface F to flanking surface f, **Df** from direct surface D to flanking surface f, and **Fd** from flanking surface F to direct surface d.

Note that the letter "F" or "f" denotes **f**lanking surface, and "D" or "d" denotes the surface for **d**irect transmission, i.e. the surface of the separating assembly. These surfaces may be either wall or floor/ceiling assemblies.

The labels for the flanking surfaces of the Standard Scenarios are detailed in the following Table 1.3.

| Room Pair | Surfaces D and d | Flanking Surfaces F and f | Junction |
|---|---|---|---|
| Horizontal (Fig. 1.3) | Separating wall | Junction 1: floor F and f<br>Junction 2: façade wall F and f<br>Junction 3: ceiling F and f<br>Junction 4: corridor wall F and f | Cross-junction<br>T-junction<br>Cross-junction<br>T-junction |
| Vertical (Fig. 1.4) | Separating floor/ceiling | Junction 1: wall F and f<br>Junction 2: façade wall F and f<br>Junction 3: wall F and f<br>Junction 4: corridor wall F and f | Cross-junction<br>T-junction<br>Cross-junction<br>Cross-junction |

**Table 1.3:** Surfaces (D, d, F and f) for flanking paths at each junction, as in the Standard Scenario.

In Canada, building elements are normally tested according to the ASTM E90 standard, and building code requirements are given in terms of apparent sound transmission class (ASTC) determined from the apparent sound transmission loss (ATL) for the set of frequency bands from 125 Hz to 4000 Hz, following the procedure in ASTM E413. Merging this context with using the ISO 15712-1 procedures in this Report, the terms “direct sound transmission loss” and “flanking sound transmission loss” have been introduced to provide consistency with ASTM terminology while matching the function of the direct and flanking sound reduction indices defined in ISO 15712-1.

Section 4.1 of ISO 15712-1 defines a process to calculate the apparent sound transmission by combining the sound power transmitted via the direct path and the twelve first-order flanking paths (three paths at each of the four edges of the separating assembly, as illustrated in Figure 1.5). Equation 14 in ISO 15712-1 is recast here with slightly different grouping of the paths (treating the set of paths at each edge of the separating assembly in turn) to match the presentation approach chosen for the examples in this Report.

The apparent sound transmission loss (ATL) between two rooms (assuming the room geometry of Section 1.2 and neglecting sound that is by-passing the building structure, for example sound transmitted through leaks and ducts) is the resultant of the direct sound transmission loss ($\mathrm{TL}_{Dd}$) through the separating wall or floor assembly and the set of flanking sound transmission loss contributions of the three flanking paths ($\mathrm{TL}_{Ff,}$ $\mathrm{TL}_{Fd}$, and $\mathrm{TL}_{Df}$) for each junction at the four edges of the separating assembly as shown in Fig. 1.5.

$$ATL = -10 \cdot \log_{10}\left(10^{-0.1 \cdot TL_{Dd}} + \sum_{edge=1}^{4}\left(10^{-0.1 \cdot TL_{Ff}} + 10^{-0.1 \cdot TL_{Fd}} + 10^{-0.1 \cdot TL_{Df}}\right)\right) \quad \text{Eq. 1.1}$$

Note that this equation differs slightly from the calculation of the apparent sound transmission defined in Equation 14 of ISO 15712-1. Eq. 1.1 of this Report treats the set of paths at each edge of the separating assembly in turn to match the presentation for the examples in this Report. Eq. 1.1 is universally valid for all building systems, and the remaining challenge is to find the right expressions to calculate the sound transmission for the different paths for the chosen building system and situation.

Each of the flanking sound transmission loss values for a specific path is normalized like the apparent sound transmission loss (ATL), and can be considered as the ATL that would be observed if only this single path were contributing to the sound transmitted into the receiving room. Normalization of direct and flanking sound transmission input data so that the receiving room absorption is numerically equal to the area of the separating assembly (i.e. using apparent sound transmission loss and ASTC as the measure of system performance) requires suitable corrections to data calculated according to ISO 15712-1, or values of flanking sound transmission loss from laboratory testing according to ISO 10848, so that the set of path sound transmission loss values can be properly combined or compared. This normalization process is fully described in the calculation procedures in Chapter 4.

The standard ISO 15712-1 describes two methods of calculating the apparent sound insulation in a building: the Detailed Method and the Simplified Method. This Report describes both methods to calculate the apparent sound insulation in a building consisting of CLT assemblies. The Simplified Method uses the single-number ratings (STC or Flanking STC for each transmission path, as appropriate) instead of the frequency-dependent sound transmission loss values, and yields the ASTC directly:

$$ASTC = -10 \cdot \log_{10}\left[10^{-0.1 \cdot STC_{Dd}} + \sum_{edge=1}^{4}\left(10^{-0.1 \cdot STC_{Ff}} + 10^{-0.1 \cdot STC_{Fd}} + 10^{-0.1 \cdot STC_{Df}}\right)\right] \quad \text{Eq. 1.2}$$

The Simplified Method has been widely used by designers in Europe for many years for calculations based on $R_W$ data. Its primary advantage is the simplicity of the procedure, which makes it usable by non-specialists, as illustrated by the worked examples in Section 4.2. Although it is less rigorous than the Detailed Method presented in Section 4.3, the differences between the results using the two methods are small, and the calculations for the Simplified Method use approximations that should ensure the results are slightly conservative.

This Report provides both the data needed for the Simplified Method (in tables in Chapters 2 and 3) and the data needed for the Detailed Method (in the Appendices), for a variety of CLT building scenarios.

**Cautions and limitations to examples presented in this Report:**

This Report was developed to support the transition to ASTC ratings for sound control objectives in the National Building Code of Canada. Simplifications were made to meet the specific needs of that application, where sound insulation is addressed only in the context of multi-unit residential buildings. The simplifications include that:

- Transmission around or through the separating assembly due to leaks at its perimeter or penetrations such as ventilation systems are assumed negligible.
- Indirect airborne sound transmission (for example airborne flanking via an unblocked attic or crawl space) is assumed to be suppressed by normal fire blocking requirements.

For adjacent units in a multi-family residential building, these two issues should be dealt with by using normal good practice for fire and sound control between adjoining dwellings.

If this Report is applied to situations other than separation between adjacent units in multi-family residential buildings, some of these issues may have to be explicitly addressed in the calculation process. For example, for adjoining rooms within a single office or home, flanking paths such as ventilation ducts or open shared plenum spaces may be an issue. The flanking sound transmission associated with these additional paths should be determined and included in the calculated ASTC. ISO 15712-1 includes specific guidance for such issues, and the examples in this Report allow for such a correction.

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# 2 Sound Transmission through CLT Wall and Floor Assemblies

This chapter presents the results of direct sound transmission loss tests of wall and floor assemblies with several variants of CLT assemblies. The tested assemblies include assemblies with a wide variety of linings covering one or both surfaces of the CLT assemblies.

## *ASTM E90 Test Method*

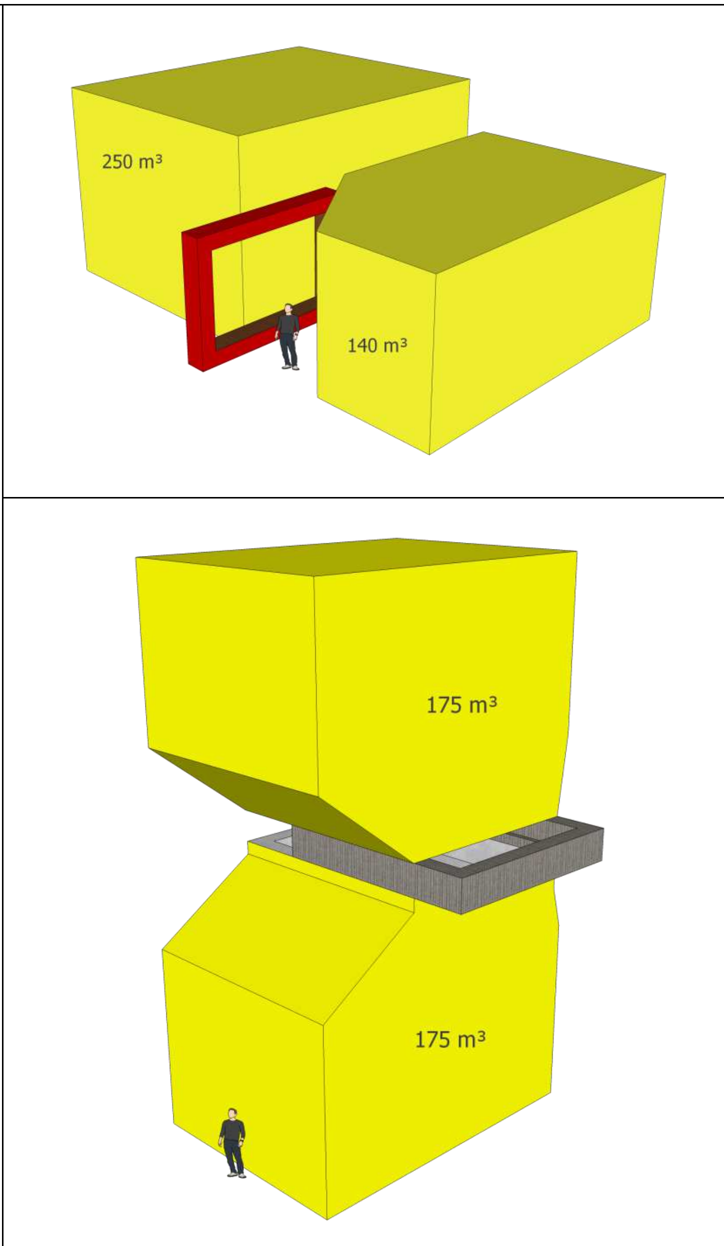
Direct sound transmission loss tests of wall and floor assemblies were conducted in NRC's Wall and Floor Sound Transmission Facilities according to the ASTM E90 test protocol [1]. Concept drawings of the sound transmission facilities are presented in Figure 2.1.

**Figure 2.1:** A concept drawing of the Wall Sound Transmission Facility at the NRC is presented in the upper drawing. The NRC Floor Sound Transmission Facility, shown in the lower drawing, is similar except that one room is above the other.

In both cases, full scale test assemblies are mounted in the massive concrete movable test frames between the two reverberant rooms. The test openings are 3.66 m wide and 2.44 m high for walls and 4.70 m by 3.78 m for floors.

For the wall facility, the rooms (designated "large chamber" and "small chamber") have approximate volumes of 250 $m^3$ and 140 $m^3$ respectively. In the floor facility, both chambers have volumes of approximately 175 $m^3$. All the facility rooms are hard-walled reverberation chambers that are vibration-isolated from each other and from the specimen frame. The rooms have fixed and/or moving diffusor panels to enhance diffusivity of the sound fields.

The facilities (including instrumentation) and the test procedures satisfy or exceed all requirements of ASTM E90.



Each facility is equipped with an automated measurement system for data acquisition and post-processing. In each room, a calibrated Brüel & Kjaer condenser microphone (type 4166 or 4165) with preamp is moved under computer control to nine positions, and measurements are made in both rooms using a National Instruments NI-4472 data acquisition system installed in a computer. Each room has four bi-amped loudspeakers driven by separate amplifiers and noise sources. To increase randomness of the sound field, there are fixed diffusing panels in each room.

Measurements of the direct airborne sound transmission loss (TL) were conducted in accordance with the requirements of ASTM E90-09, "Standard Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions". The sound transmission loss tests were performed in both directions – from the large chamber to the small chamber and vice-versa for walls, and from the upper chamber to the lower chamber and vice-versa for floors. The results presented in this Report are given as the averages of the two transmission directions to reduce measurement uncertainty due to factors such as calibration errors and local variations in the sound fields.

For every measurement, direct sound transmission loss values were calculated from the average sound pressure levels in the source room and the receiving room and the average reverberation times of the receiving room. One-third octave band sound pressure levels were measured for 32 seconds at nine microphone positions in each room and then averaged to get the average sound pressure level in each room. Five sound decays were averaged to get the reverberation time at each microphone position in the receiving room; these times were averaged to get the average reverberation times for each room.

The frequency-dependent direct sound transmission loss was measured in one-third octave bands in the frequency range from 50 Hz to 5000 Hz. However, only the frequency range between 125 Hz and 4000 Hz is considered in the calculation of the sound transmission class (STC) single-number rating in accordance with ASTM E413 [3].

The direct airborne sound transmission loss data are presented as follows in this Report:

- The sets of one-third octave band direct sound transmission loss results from 50 Hz to 5000 Hz are presented in Appendix A1.
- This chapter presents a more compact summary of results in terms of STC ratings.

In addition to the sound transmission measurements, additional measurements were made to characterize the CLT assemblies. Thickness and mass were determined, and the structural reverberation times were determined in accordance with the requirements in ISO 10140 for thick and heavy wall or floor assemblies. The structural reverberation times are presented in Section 2.4 and Appendix A1, and the corresponding loss factors are also presented in Section 2.4.

The loss factors are pertinent for the calculation of the apparent sound transmission loss following ISO 15712-1, as will be explained in Section 2.4 and Chapter 4. For the CLT assemblies evaluated as part of this study, it was established that the loss factors are high enough to justify ignoring corrections for edge losses in the detailed calculations in accordance with Section 4.3 of ISO 15712-1, which greatly simplifies those calculations.

## 2.1 CLT Walls and Floors without Linings

In this section, the focus is on the basic CLT[1] assemblies (wall or floor) without a lining such as an added gypsum board finish supported on some form of framing.

There are several types of CLT constructions which are commercially available in Canada, but this study only focused on CLT panels that have adhesive between the faces of the timber elements in adjacent layers, but no adhesive bonding the adjacent timber elements within a given layer. There were noticeable gaps between some of the timber elements comprising each layer of the CLT assembly. These CLT panels could be called “Face-Laminated CLT Panels” but are simply referred to as CLT panels in this Report.

Another form of CLT panels has adhesive between the faces of the timber elements in adjacent layers as well as adhesive to bond the adjacent timber elements within a given layer. These are referred to as “Fully-Bonded CLT Panels” in this Report. Because fully-bonded CLT panels have different properties than face-laminated CLT panels, the sound transmission data and predictions in this Report do not apply to fully-bonded CLT panels.

This study included tests on five types of CLT wall or floor assemblies:

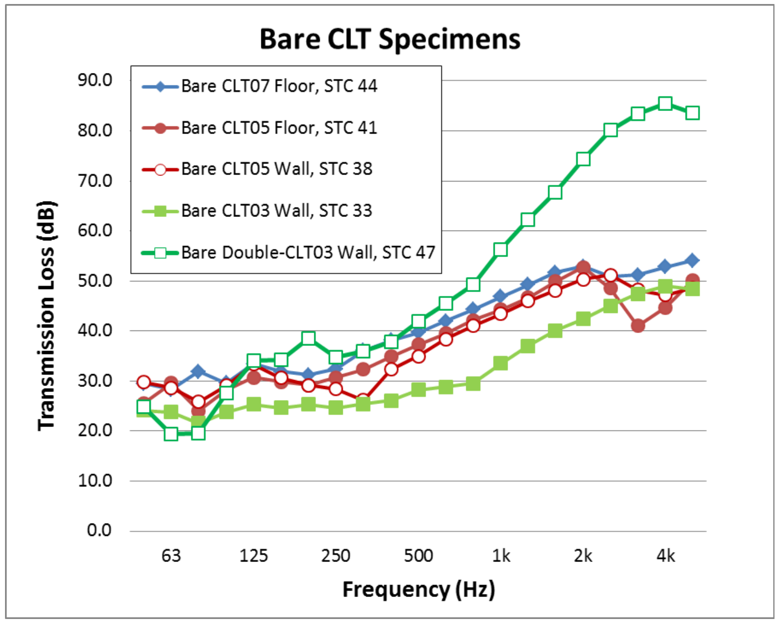
- 7-ply single-leaf floor (CLT07) 245 mm thick, with mass per area of 130 kg/m$^2$
- 5-ply single-leaf floor (CLT05) 175 mm thick, with mass per area of 91.4 kg/m$^2$
- 5-ply single-leaf wall (CLT05) 175 mm thick, with mass per area of 91.4 kg/m$^2$
- 3-ply single-leaf wall (CLT03) 78 mm thick, with mass per area of 42.4 kg/m$^2$
- Double-leaf 3-ply wall comprising two leafs of CLT03 separated by a 25 mm cavity filled with glass fiber insulation, with combined thickness of 181 mm and mass per area of 89.6 kg/m$^2$

While the sound insulation data provided in this Report is based on measurements conducted with CLT assemblies with the parameters listed above, the data may also be used as a conservative estimate for face-laminated CLT assemblies with the same number of plies but with greater thickness and higher mass. For example, a 5-ply single-leaf wall which is more than 175 mm thick and has a mass per area of more than 91.4 kg/m$^2$ can in general be expected to have an STC rating at least as high as the value reported in this Report. The data in this Report may not be used for fully-bonded CLT assemblies or for CLT assemblies with lower thickness or mass per area than the CLT assemblies described in this Report.

[1] For endnotes in this Report, please see page 115.

Each of the CLT assemblies described on the previous page was tested both with surfaces of the CLT assembly bare, and with one or both surfaces covered with a lining. Figure 2.1.1 presents the direct sound transmission loss determined for the bare CLT assemblies.

**Figure 2.1.1**:
Direct sound transmission loss for the bare CLT assemblies.




The figure shows that the double-leaf CLT03 assembly exhibits a frequency dependence that is quite different from that for the single-leaf CLT assemblies. Further discussion of the double-leaf assembly is therefore postponed to Section 2.3.

The remainder of Section 2.1 focuses on sound transmission through the single-leaf CLT assemblies without linings. Section 2.2 deals with determining the change in sound transmission due to adding a series of linings on the single-leaf CLT assemblies.

The measured direct sound transmission loss curves for the bare single-leaf CLT assemblies differ appreciably from the expected behaviour. The most obvious peculiarity is the difference between the results for the 5-ply floor and 5-ply wall as shown in Figure 2.1.2. The pair of 5-ply assemblies in the upper graph in Figure 2.1.2 are nominally equivalent (same number of plies, same thickness, and same mass per unit area). However, significant differences in the sound transmission loss curves are evident, especially the sharp dips around 300 Hz for the wall and around 3 kHz for the floor.

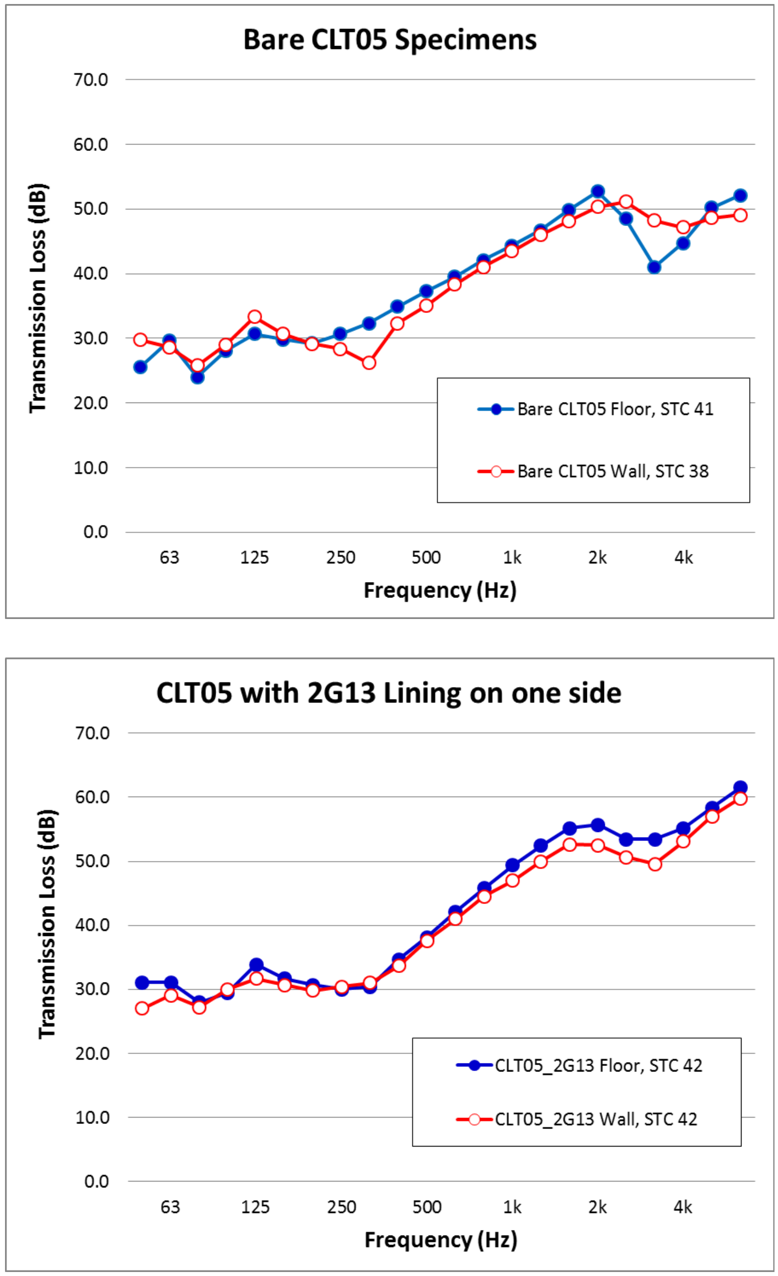
Differences in the resonance frequencies due to the difference in the sizes of the assemblies could explain some differences at low frequencies (below 200 Hz), especially since the CLT assemblies were each assembled from two sub-panels butted together, but not systematically bonded at the joint. Another reason for the differences between the two assemblies may be related to air leakage through or around the CLT assemblies.

**Figure 2.1.2**:
The upper graph shows the direct sound transmission loss for the bare 5-ply floor and wall assemblies (designated CLT05 in the short descriptive code used throughout this Report).

Although these assemblies are nominally identical, there are obvious differences in the direct sound transmission loss, with one curve exhibiting a sharp dip around 300 Hz and the other curve showing a dip around 3 kHz.

The lower graph shows the direct sound transmission loss through the same CLT assemblies with a lining of 2 layers of 12.7 mm gypsum board screwed to one face. (The lining is designated 2G13 in the short descriptive code used throughout this Report, as explained in Section 2.2.)

With the addition of the lining, the two assemblies exhibit the close similarity expected, especially at frequencies below 1 kHz.



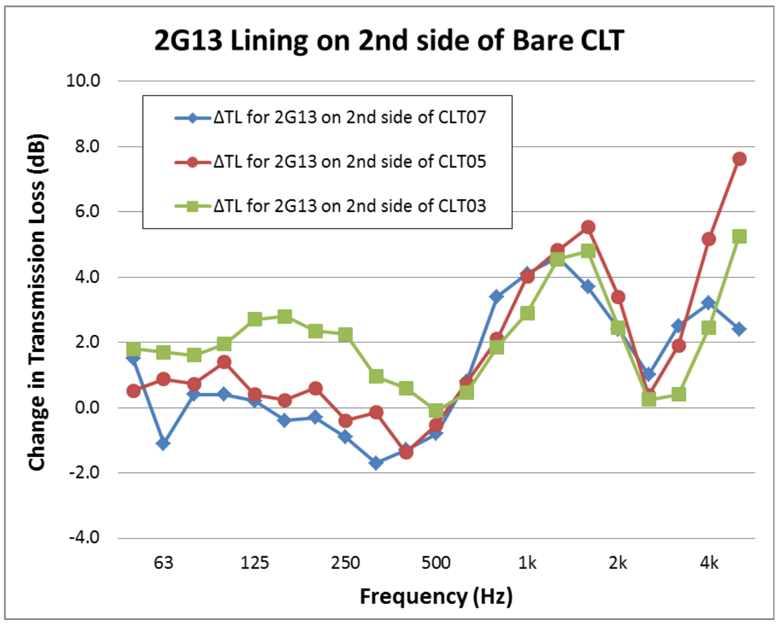

When a lining of 2 layers of gypsum board was directly screwed to each surface of the 5-ply CLT assemblies, the sharp dips in the direct sound transmission loss curves exhibited by the bare CLT assemblies vanished. While the added gypsum board lining did slightly alter the mass of each of the CLT assemblies, any such effect would be similar for both CLT assemblies. Therefore, the more likely reason for the difference in the direct sound transmission loss curves was that the linings blocked any leaks through gaps in the CLT assemblies, and thus eliminated sound transmission due to leakage, and that the linings provided additional damping and structural connections between the two sub-panels of each assembly.

The test series did not include a systematic sealing and re-testing all the bare CLT assemblies, and the mechanism for the change in direct sound transmission loss when the linings were added could not be clearly identified. However, one can extract a good estimate of the sound transmission for CLT assemblies without sound leaks by using the finding (illustrated in Figure 2.1.2) that adding a lining reduces the sound transmission due to leakage to insignificance. This is important information since the calculations of the flanking sound transmission in Chapter 4 must be based on the sound transmission of the bare assemblies without leakage.

The first step in the process of estimating the direct sound transmission loss of CLT assemblies without sound leaks was to establish the effect of screwing the two layers of 12.7 mm gypsum board directly to the CLT assemblies when a lining on the other side already suppressed the sound transmission due to leakage and introduced additional damping and structural connections, as shown in Figure 2.1.3.

**Figure 2.1.3:**
Change in the direct sound transmission loss, ΔTL due to adding a lining of two layers of 12.7 mm gypsum board to CLT assemblies where a lining on the other side has already dealt with the effects compromising the measured sound transmission loss for the bare CLT assemblies.

The features of these curves are discussed in Section 2.2, as part of the discussion of linings on single-leaf CLT assemblies.




Subtracting the changes in the direct sound transmission loss curves due to the addition of the lining on the second side from the corresponding measured direct sound transmission loss for the CLT03, CLT05, and CLT07 assemblies with the lining applied to one side, yields estimates for the direct sound transmission loss for the "**Base CLT"** assemblies. These derived direct sound transmission loss results for the Base CLT assemblies are shown in Figure 2.1.4.

The term **"Base CLT"** is used throughout the remainder of this Report to denote a CLT assembly without a lining but without any reduction of the direct sound transmission loss due to leakage. The term "**Bare CLT**" will be used to denote a CLT assembly which does include a reduction of the direct sound transmission loss due to leakage.

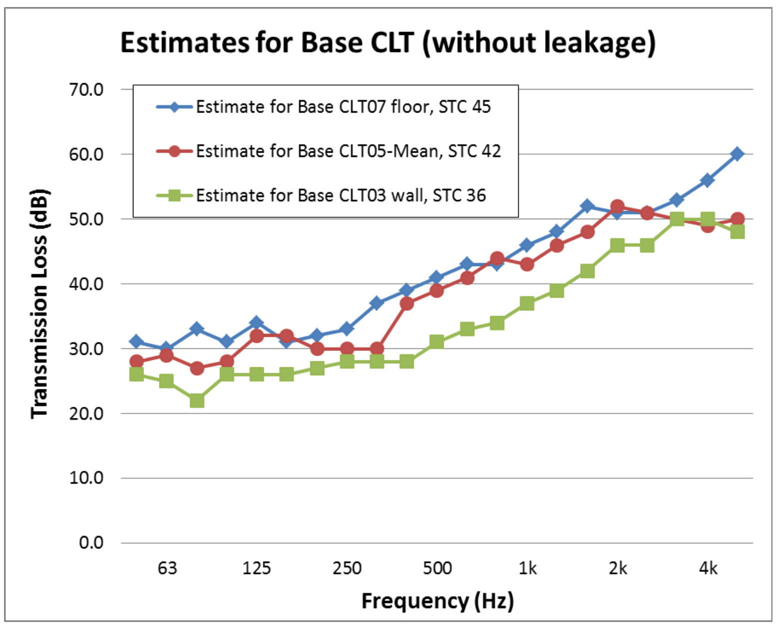
Any CLT assembly used as a wall or floor between dwelling units will usually require a lining on at least one side (to provide adequate sound insulation and, in some cases, adequate fire resistance). Hence, these Base CLT estimates are more appropriate for the determination of the effect of linings (presented in Section 2.2) and for the calculation of ASTC ratings (presented in Chapter 4) than the measured values for Bare CLT assemblies given in Figure 2.1.1.

Several differences between the Base CLT estimates and the Bare CLT results should be noted:

- In all cases, the STC rating for the Base CLT assembly without leakage is higher than the STC rating for the corresponding Bare CLT assembly. As a result, the STC ratings for Base CLT assemblies should not be used to quantify the direct sound transmission of CLT assemblies without linings.
- The changes in the direct sound transmission loss curves and in the STC rating are largest for the CLT03 assemblies, and smallest for the CLT07 assemblies. This is consistent with the expectation that there will be less leakage as the number of interior plies in a CLT assembly increases, and that the lining will have a smaller effect on the damping and structural properties of the heavier CLT assemblies.

**Figure 2.1.4:**
Direct sound transmission loss for the Base CLT assemblies without linings.

These values are used both for calculation of ΔTL values in Section 2.2 and in the calculation of ASTC ratings in Chapter 4.




The direct sound transmission loss curves for the Base CLT assemblies in Figure 2.1.4 exhibit behaviour broadly consistent with theory for thick homogeneous panels:

- The coincidence dips are not obvious due to high damping and orthotropic stiffness of the CLT assemblies. Below the coincidence frequency (approximately 200 Hz, 300 Hz and 400 Hz for CLT07, CLT05, and CLT03, respectively), the sound transmission loss curves exhibit little dependence on frequency other than minor dips and peaks due to resonances controlled by assembly dimensions and edge constraints.

- At frequencies below the coincidence frequency, the average sound transmission loss for the 3 curves differ by about 6 dB, which is close to the variation due to assembly mass expected from the theoretical “mass law.”
- Above the coincidence frequency, each curve rises at a rate of approximately 3 dB per one-third octave band.
- At higher frequencies, a dip due to a thickness resonance is expected and shown at approximately 2 kHz, 4 kHz and 6 kHz for CLT07, CLT05, and CLT03, respectively.

The STC ratings and one-third octave band direct sound transmission loss values for the CLT assemblies without linings (both directly measured values for the bare assemblies, and derived values for the Base CLT assemblies) are presented in the tables in Appendix A1.

## 2.2 Adding Linings on Single-Leaf CLT Wall or Floor Assemblies

It is common practice, especially in residential buildings, to add finishing surfaces to the basic structural floor or wall assemblies – for example, gypsum board wall and ceiling surfaces that conceal both the bare CLT surfaces and building services such as electrical wiring, water pipes and ventilation ducts. The finishing on walls or ceilings commonly comprises gypsum board panels, framing used to support the gypsum board panels, and often sound absorptive material filling the inter-framing cavities between the gypsum board and the face of the CLT. On floors, the finish may include toppings on the CLT such as concrete or a floating floor, as well as flooring such as hardwood or tiles. These elements are described in ISO 15712-1 as “linings” or “liners” or “layers” or “coverings”. The term “linings” is used in this Report.

The linings for CLT that were tested in this study are described in Tables 2.2.1 to 2.2.3. The ΔSTC values for these linings are listed in Table 2.2.2.1 in Section 2.2.2. The ΔTL values for these linings are provided in Appendix A1.

**Each Lining Code** in Tables 2.2.1 to 2.2.3 begins with “ΔTL-CLT” to indicate that the lining applied to a CLT assembly has an effect on the direct sound transmission loss (TL) through the lined assembly. For the first three linings in Table 2.2.1 (W01, W02, and W03), the initial part of the code also indicates the thickness (such as 5-ply) of the CLT base assembly to which the lining is applied. For the three other linings in Table 2.2.1 (W04, W05, and W06), the code does not indicate the thickness of the CLT base assembly because the thickness of the CLT base assembly did not have a significant effect on the change in direct sound transmission loss provided by the lining. The final part of the lining code is a letter (such as “W” to indicate a wall lining or “F” for a floor lining) followed by a unique number used to identify the lining in the table of ΔSTC ratings and in the worked examples in Chapter 4.

**The Descriptive Short Code** provides a compact physical description of each lining, which is used in figure captions and examples throughout this Report. This code identifies the elements of the lining, beginning at the exposed face and proceeding to the face of the supporting CLT wall or floor assembly. As detailed in the descriptions in Tables 2.2.1 to 2.2.3, each element of the lining is described by a short code (for example: G13 is gypsum board that is 12.7 mm thick, 2G13 is two connected G13 layers, and WFUR38 is 38 x 38 mm wood furring). Spacing between elements such as adjacent studs is indicated by a number in parentheses which is the spacing (on centre) in mm between the elements.

The spacing and type of fasteners are not stated in the tables, but they are assumed to conform to standard industry practice as specified in the endnotes on page 115. Where sound absorbing material such as glass fiber batts (GFB) was included in a tested assembly, the code indicates the specific material that was tested, but applicability to other sound absorbing materials is assumed, as explained in Endnote 2 on page 115 of this Report.

**Table 2.2.1**: Linings tested on Base CLT Wall Assemblies.

| Lining Code | Descriptive Short Code | Description of Lining |
|---|---|---|
| ΔTL-CLT(n-ply)-W01 | 2G13 | Two layers of 12.7 mm thick fire-rated gypsum board[3] screwed to the face of the CLT assembly |
| ΔTL-CLT(n-ply)-W02 | 2G13_WFUR38(400)_GFB38 | Two layers of 12.7 mm thick fire-rated gypsum board screwed to 38 x 38 mm wood furring (spaced 400 mm o.c. and mechanically attached to the face of the CLT) with 38 mm thick glass fiber batts[2] filling the spaces between the gypsum board and the CLT |
| ΔTL-CLT(n-ply)-W03 | 2G13_WFUR38(600)_GFB38 | Two layers of 12.7 mm thick fire-rated gypsum board screwed to 38 x 38 mm wood furring (spaced 600 mm o.c. and mechanically attached to the face of the CLT) with 38 mm thick glass fiber batts filling the spaces between the gypsum board and the CLT |
| ΔTL-CLT-W04 | 2G13_RC13(600)_ WFUR38(400)_GFB38 | Two layers of 12.7 mm thick fire-rated gypsum board screwed to 13 mm resilient metal channels[4] (spaced 600 mm o.c.) that are screwed to 38 x 38 mm wood furring (spaced 400 mm o.c. and mechanically attached to the face of the CLT) with 38 mm thick glass fiber batts filling the spaces between the gypsum board and the CLT |
| ΔTL-CLT-W05 | 2G13_WFUR64(600)_GFB65 | Two layers of 12.7 mm thick fire-rated gypsum board screwed to 64 x 38 mm wood furring (spaced 600 mm o.c. and mechanically attached to the face of the CLT) with 64 mm thick glass fiber batts filling the spaces between the gypsum board and the CLT |
| ΔTL-CLT-W06 | 2G13_WS64(600)_GFB65_AIR13 | Two layers of 12.7 mm thick fire-rated gypsum board screwed to 64 x 38 mm wood studs (spaced 600 mm o.c. and spaced 13 mm from the face of the CLT) with 64 mm thick glass fiber batts filling the spaces between the gypsum board and the CLT |

NOTES:
a. For the superscripts in this table please see the corresponding endnotes on page 115.
b. Linings listed here for wall assemblies may also be used on ceilings.
c. For linings W01, W02, and W03, the CLT thickness (3- or 5- or 7-ply) is indicated because it has an effect on the change in sound transmission loss provided by the lining; for the other linings, one short code applies for any of the three CLT thicknesses considered in this Report.

**Table 2.2.2**: Linings tested on Base CLT Floor Assemblies.

| Lining Code | Descriptive Short Code | Description of Lining |
|---|---|---|
| ΔTL-CLT-F01 | CON38(no bond) | 38 mm thick concrete with no bond to the supporting CLT |
| ΔTL-CLT-F02 | CON38_FOAM09 | 38 mm thick concrete on 9 mm thick closed-cell foam, covering the supporting CLT |
| ΔTL-CLT-F03 | CON38_WFB13 | 38 mm thick concrete on 13 mm thick wood fiber board, covering the supporting CLT |
| ΔTL-CLT-F04 | CON38_FELT19 | 38 mm thick concrete on 19 mm thick felt of recycled fiber, covering the supporting CLT |
| ΔTL-CLT-F05 | CON38_RESL13 | 38 mm thick concrete on mat of 13 mm rubber nuggets, covering the supporting CLT |
| ΔTL-CLT-F06 | CON38_RESL08 | 38 mm thick concrete on 8 mm thick shredded rubber mat, covering the supporting CLT |
| ΔTL-CLT-F07 | CON38_RESL17 | 38 mm thick concrete on 17 mm thick shredded rubber mat covering the supporting CLT |
| ΔTL-CLT-F08 | 2CEMBRD12_WFB13 | Two layers of 12 mm thick fiber-reinforced cement board on 13 mm thick wood fiber board, covering the supporting CLT |
| ΔTL-CLT-F09 | GCON38_FOAM09 | 38 mm thick gypsum concrete on 9 mm thick closed-cell foam, covering the supporting CLT |

NOTES: a. For all the floor linings listed, one short code applies for any of the three CLT thicknesses considered in this Report.

**Table 2.2.3**: Linings tested on Base CLT Ceiling Assemblies.

| Lining Code | Descriptive Short Code | Description of Lining |
|---|---|---|
| ΔTL-CLT-C01 | 2G13_WFUR38(600)_GFB38 | Two layers of 12.7 mm thick fire-rated gypsum board[3] screwed to 38 x 38 mm wood furring (spaced 600 mm o.c. and mechanically attached to the face of the CLT) with 38 mm thick glass fiber batts[2] filling the spaces between the gypsum board and the CLT |
| ΔTL-CLT-C02 | 2G13_UC22(600)_CC38(1200)_ GFB140 | Two layers of 12.7 mm thick fire-rated gypsum board screwed to metal grillage (U-channels spaced 600 mm o.c. supported by orthogonal 38 mm C-channels spaced 1200 mm o.c. that are supported on wires 140 mm below the bottom face of the CLT) with 140 mm thick glass fiber batts filling the space between the furring and the CLT |
| ΔTL-CLT-C03 | G16_UC22(600)_CC38(1200)_ GFB140_2G13 | One layer of 15.9 mm thick fire-rated gypsum board screwed to metal grillage (U-channels spaced 600 mm o.c. supported by orthogonal 38 mm C-channels spaced 1200 mm o.c. that are supported on wires 140 mm below the bottom face of 2 layers of 12.7 mm thick fire-rated gypsum board screwed to the CLT) with 140 mm thick glass fiber batts filling the spaces between the furring and the bottom of the gypsum board screwed to the CLT |

NOTES:
a. For the superscripts in this table please see the corresponding endnotes on page 115.
b. Linings listed in Table 2.2.1 for wall assemblies may also be used on ceilings.
c. For all the ceiling linings listed, one short code applies for any of the three CLT thicknesses considered in this Report.

### 2.2.1 Measured Change ΔTL due to Linings on Single-Leaf CLT Assemblies

The trends in the experimental sound transmission loss results when linings are added to single-leaf CLT assemblies are presented and discussed in this Section. The corresponding single-number ΔSTC ratings for each lining are given in the tables presented in Section 2.2.2. The ΔSTC ratings are needed for the Simplified Method of calculating the ASTC rating as presented in Section 4.1. The averaged one-third octave band changes in the direct sound transmission loss (ΔTL) for the set of linings applied to the CLT assemblies are given in Table A1.2 in Appendix A1. The data in Appendix A1 is needed for calculating the ASTC rating using the Detailed Method as presented in Section 4.3.

The assemblies tested in this study established the change in the direct sound transmission loss (ΔTL) due to adding a lining in 3 situations:

1. CLT assemblies with the lining applied on one side,
2. CLT assemblies with the same lining applied on both sides,
3. CLT assemblies with the lining applied on one side but a different lining on the other side.

Each type of lining was tested in the first situation with the lining applied only on one side of the CLT (sometimes several tests), and many were tested in one or both of the other situations.

| | |
|---|---|
| For the 1st situation: | The TL for the Base CLT assembly was subtracted from the TL with the added lining on one side to obtain the ΔTL. |
| For the 2nd situation: | The TL for the Base CLT assembly was subtracted from the TL with the same added lining on both sides, and the result was divided by 2 to obtain the ΔTL. |
| For the 3rd situation: | The TL for a CLT assembly with the other lining on one side was subtracted from the TL for the wall with the two different linings to obtain the ΔTL. |

Because the test results for assemblies with linings on both sides were quite likely to be compromised by the facility flanking limit, several precautions were included in the analysis process:

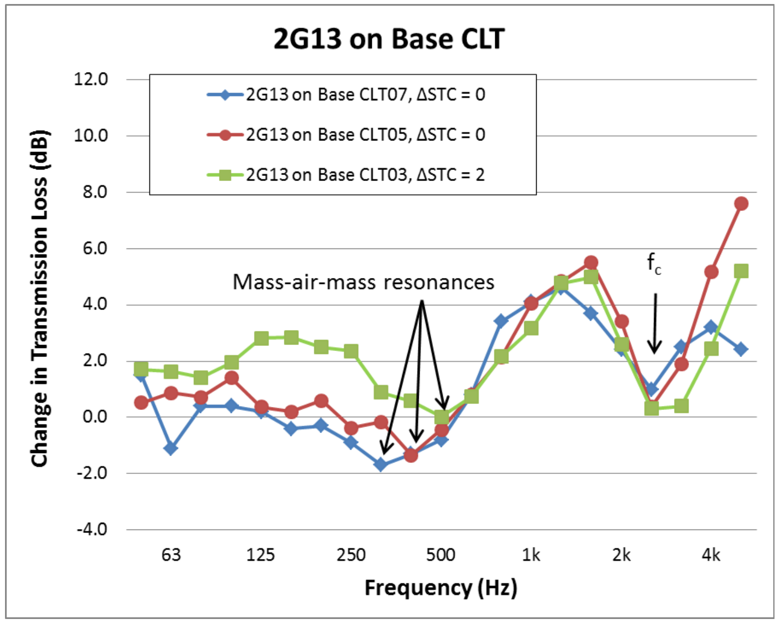
- A weighted average was used for the calculations (50% weighting for situation 1, and 50% for the mean of situations 2 and 3).
- Where the measured direct sound transmission loss was above the facility flanking limit (10 dB below the maximum sound transmission loss recorded for that frequency band in the facility) the potentially compromised results were excluded from the average.

The lining that was tested most often was the 2G13 lining which was comprised of 2 layers of 12.7 mm gypsum board screwed directly to the surface of the CLT assembly. This lining was tested when applied on one side of all thicknesses of CLT, and also on the second side of the CLT assemblies in most cases. Subsets of these test results were shown previously in Section 2.1 to explain the calculation of estimates of the direct sound transmission loss for Base CLT assemblies.

The results from averaging the full set of ΔTL data for all the test assemblies with the 2G13 lining are given in Figure 2.2.1.1.

**Figure 2.2.1.1:**
Change in direct sound transmission loss (ΔTL) due to the addition of the 2G13 lining on the Base CLT assemblies.

Note the close similarity among the results for all CLT thicknesses above the mass-air-mass resonances. Also note the higher ΔTL for the lighter CLT base assemblies below the mass-air-mass resonances.



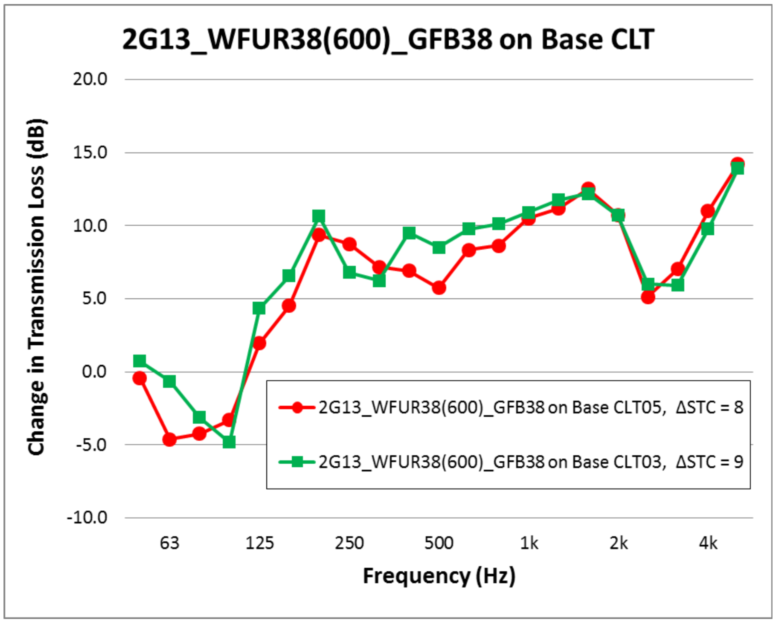

The results in Figure 2.2.1.1 illustrate the key features typical of all linings discussed in this Report:

- The obvious dip in ΔTL around 2500 Hz is due to the stiffness of the gypsum board panels. The critical frequency ($f_C$) in the 2500 Hz third octave band is typical for fire-rated 12.7 mm gypsum board. For 15.9 mm gypsum board of the same type, $f_C$ would move down to about 2000 Hz.
- A second dip can be observed in each of the ΔTL curves at the mid-frequencies, varying from about 300 Hz for the 7-ply to 500 Hz for the 3-ply. This is the mass-air-mass resonance due to the air which is trapped between the gypsum board and the CLT assembly acting like a spring. The effective depth of the air cavity was approximately 2 mm due to roughness of the CLT surface and the substantial gaps between the wood boards forming the surface plies of the CLT assemblies.
- Increasing the mass of either the gypsum board or the CLT layer, or increasing the trapped air volume (i.e. the space between the surfaces), or changing the spring stiffness by filling the cavity with sound absorbing material will shift this resonance to lower frequencies, resulting in higher values of ΔTL above the resonance frequency.
- Below the mass-air-mass resonance, values of ΔTL tend to increase as the mass of the CLT assembly is decreased. The mean increase of about 2 dB in ΔTL due to adding the 2G13 lining to 3-ply CLT vs. the smaller ΔTL for 7-ply CLT reflects the changing ratio of the lining's mass relative to that of the CLT.
- Above the mass-air-mass resonance, there is little dependence on the mass of the supporting CLT assembly.

As noted in the legend in Figure 2.2.1.1, the ΔSTC rating is slightly higher for this lining on 3-ply CLT than on the 5-ply CLT or the 7-ply CLT. Similar effects are observed for other linings with rather small cavity (under 40 mm) between the gypsum board and the CLT.

The averaged ΔTL data for all the test assemblies with the 2G13_WFUR38(600)_GFB38 lining are given in Figure 2.2.1.2.

**Figure 2.2.1.2:**
Change in direct sound transmission loss (ΔTL) due to the addition of the 2G13_WFUR38(600)_GFB38 lining on the Base CLT assemblies.



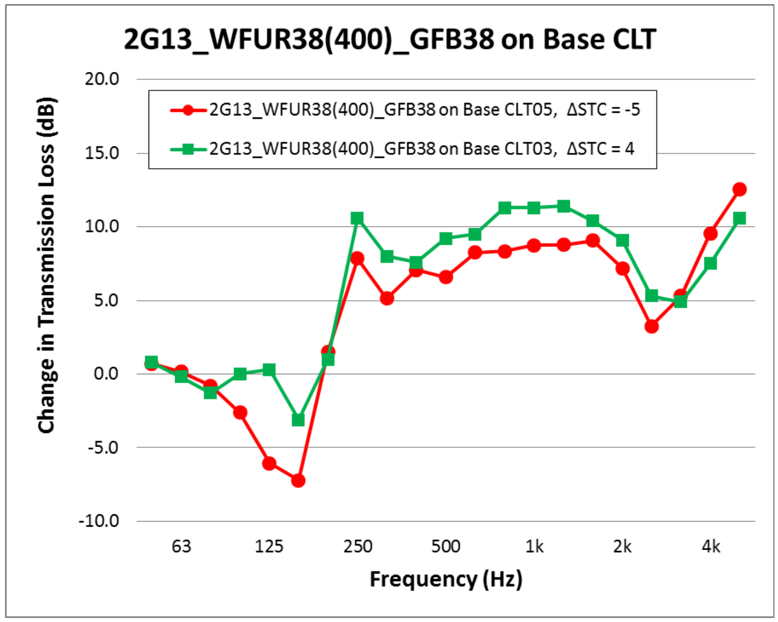

In this case, only data for CLT03 and CLT05 assemblies was available. The ΔTL curves for this lining show quite similar trends for the CLT03 and CLT05 assemblies, with the mass-air-mass resonance below 125 Hz. This is just below the frequency range that determines the STC, so the resonance has little influence on the single-number ΔSTC rating. Between 125 Hz and 2 kHz, most ΔTL values for the lining on the CLT03 assembly are higher than those for the CLT05 assembly, resulting in a slightly higher ΔSTC for the former.

The full ΔSTC results are listed in Table 2.2.2.1 in Section 2.2.2.

Figure 2.2.1.3 gives the corresponding ΔTL data for the assemblies with the 2G13_WFUR38(400)_GFB38 lining. The only change from the assemblies in the preceding figure is the reduction of the spacing between the furring strips from 600 mm to 400 mm, but this is shown to cause a large change in the ΔTL values at low frequencies and thereby a change in the ΔSTC ratings.

**Figure 2.2.1.3:**
Change in direct sound transmission loss (ΔTL) due to the addition of the 2G13_WFUR38(400)_GFB38 lining on the Base CLT assemblies.

Comparing this graph with the preceding figure, note that the low frequency resonance has moved from about 100 Hz up to 160 Hz, which significantly alters the calculated ΔSTC ratings.




Some features of the changes in the direct sound transmission loss in Figure 2.2.1.3 should be noted:

- The change in the sound transmission loss due to the addition of a lining is not always an improvement. In this case, the ΔTL is negative at frequencies below about 200 Hz – the sound transmission loss of the CLT with the added lining is below that for the Base CLT.
- Adding a matching lining on both sides of the wall approximately doubles the values of the ΔTL at each frequency relative to the change observed for adding a lining to one side of the Base CLT (so the negative dips become even more negative when both sides have this lining).
- Note that the change in STC does NOT usually double due to addition of the lining on the second side. Unfortunately, negative low frequency dips in ΔTL like those due to adding this lining have a strong influence on the STC rating. It is this sort of behaviour that forces the conservative process for calculating ΔSTC as presented in Appendix A2.

The resonance affecting the lining 2G13_WFUR38(400)_GFB38 is not a mass-air-mass resonance – the factors determining the mass-air-mass resonance frequency are exactly the same for the two sets of assemblies in Figures 2.2.1.2 and 2.2.1.3.

Changing the spacing of the wood furring from 600 mm to 400 mm introduces another form of resonance in the structure-borne sound transmission. Similar effects are observed for wood-framed walls with gypsum board attached directly to the studs.

The practical solution is to avoid supporting the gypsum board on rigid furring spaced less than 600 mm on centre. Spacing the furring at 400 mm on centre rather than at 600 mm on centre increases material and labor costs for the construction, and provides much worse sound insulation.

HENCE, THE USE OF LINING 2G13_WFUR38(400)_GFB38 IS NOT RECOMMENDED.

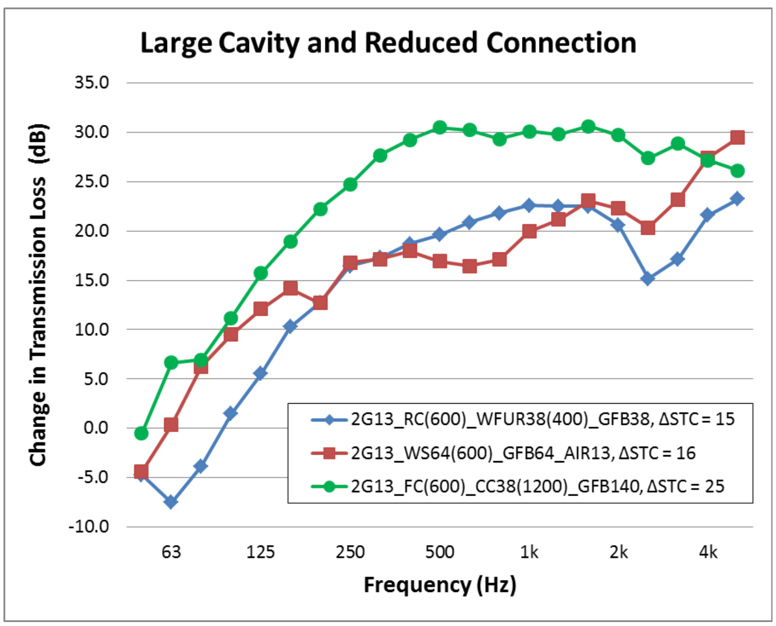
Fortunately, this was the only CLT lining considered in this study that exhibited a strong low frequency resonance that resulted in a significant reduction in the ΔSTC rating.

Figure 2.2.1.4 gives the ΔTL data for test assemblies with a variety of linings that rely on increased space between the gypsum board and the surfaces of the CLT, as well as reduced structural connections between those surfaces, to provide better sound insulation.

The larger cavity depth shifts the mass-air-mass resonance to lower frequencies, with the shift being most obvious for the suspended ceiling whose cavity is over 150 mm. Even for the wall lining with resilient metal channels with a cavity depth that is only 30% greater than the cases with 38 x 38 mm wood furring presented in Figures 2.2.1.2 and 2.2.1.3, the increase in cavity depth is enough to move the resonance well below 100 Hz, and therefore out of the frequency range controlling the STC rating.

**Figure 2.2.1.4:**
Change in direct sound transmission loss (ΔTL) due to the addition of a set of linings to the Base CLT05 assembly.

For these linings, the supporting framing provided reduced connection between the gypsum board surface and the CLT, and the cavity depth ranged from 50 mm to over 150 mm. The result of these detail differences is a large increase in ΔTL above 100 Hz, and hence large ΔSTC ratings.



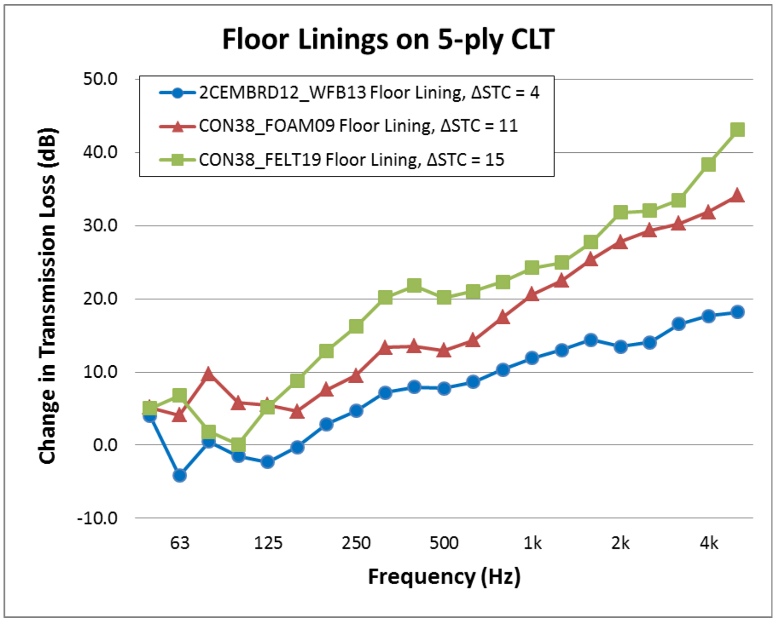

The significantly larger values of ΔTL exhibited in Figure 2.2.1.4 as opposed to those shown in earlier figures are only partly due to the increased cavity depth. These linings also provide fewer structural connections between the gypsum board and the surface of the Base CLT assembly:

- The suspended gypsum board ceiling (green circles in the figure) is supported from a grid of metal furring channels hung on wires which supress transmission of the bending waves that commonly dominate sound transmission.
- The independent studs supporting the gypsum board (red squares in the figure) approximately double the cavity depth (from 38 mm to about 76 mm) and provide structural connections to the surface of the CLT assembly only at the perimeter.
- The resilient metal channels (blue diamonds in the figure) increase the cavity depth by only 30%, but the channels also limit the vibration transmission between the two surfaces and provide much less rigid attachment points where the gypsum board is supported. This suppresses the strong resonance evident in Figure 2.2.1.3 at around 160 Hz.

A variety of floor linings were installed on top of the 5-ply CLT floor assemblies. Figure 2.2.1.5 gives the ΔTL data for a subset of these test assemblies. The findings show:

- Lighter floor toppings (such as the cement board on wood fiber board) provide appreciable ΔTL values in the mid- and high frequencies, but provide nearly zero ΔTL at the low frequencies.
- Higher values of ΔTL were observed for the heavier linings (concrete and gypsum concrete) and the choice of resilient underlayment altered the shape of the ΔTL curve as well as the overall ΔSTC rating. A mass-spring-mass resonance is expected at fairly low frequencies, but did not cause a significant negative dip in ΔTL for the floating floor toppings tested in this series.
- The resonance frequency depends on both the mass of the floating layer and the stiffness of the supporting resilient layer, and is higher than would be observed for the same lining on a structural concrete floor, because the CLT assembly is lighter and less rigid.
- Adding typical flooring materials on top of the floating concrete or gypsum concrete topping would have little effect on the ΔTL or ΔSTC values.

**Figure 2.2.1.5:**
Change in direct sound transmission loss (ΔTL) due to addition of various floor linings to the Base CLT05 assembly.



### 2.2.2 ΔSTC Ratings for Linings on Single-Leaf CLT Assemblies

To characterize the change in direct sound transmission loss due to adding a specific lining to a CLT assembly, a single-number rating called ΔSTC is introduced. ASTM does not define a rating like ΔSTC, but it has a counterpart ($\Delta R_W$) in the ISO standards. The procedure used here is adapted from its ISO counterpart, as explained in Appendix A2.

Section 2.2.1 presented and discussed the trends in results of sound transmission measurements for a series of assemblies comprising a single-leaf CLT wall or floor assembly with an added lining covering one side or both sides. This section presents the corresponding single-number ΔSTC ratings.

- The ΔSTC ratings for the linings are given in Table 2.2.2.1, together with the intermediate calculation steps for each lining.
- The detailed one-third octave band ΔTL data for each lining are listed in Appendix A1.

Key points regarding ΔSTC include:

- ΔSTC is a required input for the calculation of the ASTC rating using the Simplified Method of ISO 15712-1 which is discussed in Section 4.1 and used in the worked examples in Section 4.2.
- Values of ΔSTC are calculated from the experimental data in this Report using the procedure described in Appendix A2.
- Readers of this Report can simply use the tabulated ΔSTC values from Table 2.2.2.1 in calculations like those in the examples of Chapter 4, without the need to perform the calculations detailed in the Appendix.

**Table 2.2.2.1**: ΔSTC values for linings on single-leaf CLT wall, ceiling or floor surfaces.

| Lining Code | Lining Descriptive Code | Base CLT | Step 3: (1-side lined) $\Delta STC_{1\text{-}side}$ | Step 4: (2-sides lined) $\Delta STC_{2\text{-}sides}$ | Step 5: ΔSTC |
|---|---|---|---|---|---|
| **Wall Linings:** | | | | | |
| ΔTL-CLT-W01 | 2G13 | 3-ply<br>5- or 7-ply | 2<br>0 | 3<br>0 | **2**<br>**0** |
| ΔTL-CLT-W02 | 2G13_WFUR38(400)_GFB38 | 3-ply<br>5- or 7-ply | 8<br>0 | 6<br>-8 | **4**<br>**-5** |
| ΔTL-CLT-W03 | 2G13_WFUR38(600)_GFB38 | 3-ply<br>5- or 7-ply | 9<br>8 | 15<br>14 | **9**<br>**8** |
| ΔTL-CLT-W04 | 2G13_RC13(600)_ WFUR38(400)_GFB38 | Any | 16 | 23 | **15** |
| ΔTL-CLT-W05 | 2G13_WFUR64(600)_GFB65 | Any | 6 | 10 | **6** |
| ΔTL-CLT-W06 | 2G13_WS64(600)_GFB65_ AIR13 | Any | 16 | 31 | **16** |
| **Ceiling Linings:** | | | | | |
| ΔTL-CLT-C01 | 2G13_WFUR38(600)_GFB38 | Any | 7 | 12 | **7** |
| ΔTL-CLT-C02 | G16_UC22(600)_CC38(1200)_ GFB140_2G13 | Any | 25 | 39 | **25** |
| ΔTL-CLT-C03 | 2G13_UC22(600)_CC38(1200)_ GFB140 | Any | 25 | 41 | **25** |
| **Floor Linings:** | | | | | |
| ΔTL-CLT-F01 | CON38(no bond) | Any | 7 | 13 | **7** |
| ΔTL-CLT-F02 | CON38_FOAM09 | Any | 11 | 17 | **11** |
| ΔTL-CLT-F03 | CON38_WFB13 | Any | 10 | 19 | **10** |
| ΔTL-CLT-F04 | CON38_FELT19 | Any | 16 | 23 | **15** |
| ΔTL-CLT-F05 | CON38_RESL13 | Any | 11 | 13 | **9** |
| ΔTL-CLT-F06 | CON38_RESL08 | Any | 9 | 18 | **9** |
| ΔTL-CLT-F07 | CON38_RESL17 | Any | 11 | 18 | **11** |
| ΔTL-CLT-F08 | 2CEMBRD12_WFB13 | Any | 5 | 6 | **4** |
| ΔTL-CLT-F09 | GCON38_FOAM09 | Any | 7 | 13 | **7** |

NOTES:
a. Headings "Step 3", "Step 4", and "Step 5" refer to steps in the procedure of Appendix A2.
b. ΔTL values were determined using the Base CLT as the reference case without lining(s), and these values were combined with a reference curve as described in Appendix A2.
c. The values of ΔSTC should be appropriate for all walls or floor/ceilings with a core of single-leaf CLT of 3-ply to 7-ply; for W01, W02, and W03, each listed value applies for a specific Base CLT.

## 2.3 Adding Linings on Double-Leaf CLT Wall Assemblies

For CLT walls constructed with a core of double-leaf CLT assemblies, the change in sound transmission loss due to adding linings is quite different from the corresponding results for walls constructed with a single-leaf CLT assembly.

This study included a double-leaf CLT wall which was constructed from two leafs of 3-ply CLT03 (each leaf 78 mm thick, mass per area of 42.4 kg/$m^2$) with a 25 mm thick layer of glass fiber filling the cavity between the two leafs.

In addition to the bare double-leaf CLT assembly, the study included several additional assemblies with gypsum board linings applied to the double-leaf CLT assembly. The linings were installed either on one side or both sides of the base double-leaf CLT assembly.

**Table 2.3.1**: Linings tested on a double-leaf CLT wall (two leafs of CLT03 with a 25 mm thick layer of glass fiber filling the space between the two leafs).

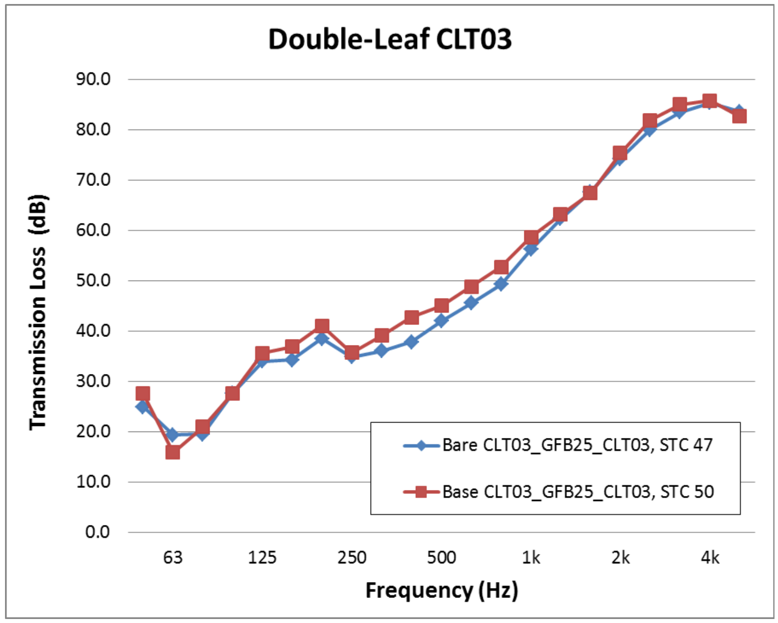
| Lining Code | Lining Descriptive Code | Description of Lining |
|---|---|---|
| ΔTL-2xCLT-W01 | 2G13 | Two layers of 12.7 mm thick fire-rated gypsum board[3] screwed to the face of the CLT assembly |
| ΔTL-2xCLT-W03 | 2G13_WFUR38(600)_GFB38 | Two layers of 12.7 mm thick fire-rated gypsum board screwed to 38 x 38 mm wood furring (spaced 600 mm o.c. and mechanically attached to the face of the CLT) with 38 mm thick glass fiber batts[2] filling the spaces between the gypsum board and the CLT |

NOTES: a. For the superscripts in this table please see the corresponding endnotes on page 115.
b. The descriptive codes for linings are explained in Section 2.2.

The linings that were tested on the double-leaf walls are described in Table 2.3.1, and the corresponding ΔSTC values are provided in Table 2.3.2. In addition, the analysis here uses ΔTL values from the tests on single-leaf CLT assemblies to extend the range of options for the system performance calculations in Chapter 4.

**Figure 2.3.1**:
Direct sound transmission loss for a wall assembly with two leafs of 3-ply CLT separated by a cavity of approximately 25 mm that is filled with 25 mm thick glass fiber batts.

The graph compares the direct sound transmission loss for the bare double-leaf 3-ply CLT wall (blue diamonds, STC 47) with the estimated Base CLT result for the same assembly (red squares, STC 50).




The evaluation of the double-leaf CLT assemblies followed the same procedure to establish the Base CLT direct sound transmission loss that was used for single-leaf assemblies in Section 2.1. The assemblies tested with the double-leaf CLT wall included walls with two layers of 12.7 mm gypsum directly attached to one side of the bare double-leaf CLT and then again on both sides. The results were used to derive an estimate for the direct sound transmission loss through the unlined double-leaf wall assembly. As shown in Figure 2.3.1, the difference between the direct sound transmission loss of the Base CLT compared with the direct sound transmission loss of the Bare CLT was a small but consistent increase between 125 Hz and 1600 Hz, which increased the STC from 47 to 50.

The direct sound transmission loss curve for the unlined double-leaf CLT assembly exhibits a marked dip at 63 Hz, which is consistent with the expected mass-air-mass resonance due to the absorption-filled cavity between the two leafs of the wall assembly. The decreasing sound transmission loss above 3 kHz is consistent with the expected panel thickness resonance around 6 kHz (as discussed for single-leaf assemblies in Section 2.1), but may also be affected by perimeter leakage as well as the flanking limit of the direct sound transmission facility.

Only two types of lining were tested on the double-leaf walls. These had the same details as linings W01 and W03 for the single-leaf walls, and hence they were given corresponding Lining Codes in Table 2.3.1.

In Figure 2.3.2, the measured ΔTL values for linings W01 and W03 on the double-leaf wall assemblies are compared with the changes due to the same linings applied to a single-leaf 3-ply CLT. The data for the linings are only shown for frequencies up to 1600 Hz, because at higher frequencies, the measured results converged to the curve for the unlined double-CLT wall, a result which was interpreted as an indication that those test data were limited by the facility flanking limit or leakage at the assembly perimeter. From a practical perspective, this limitation does not compromise the useful data.

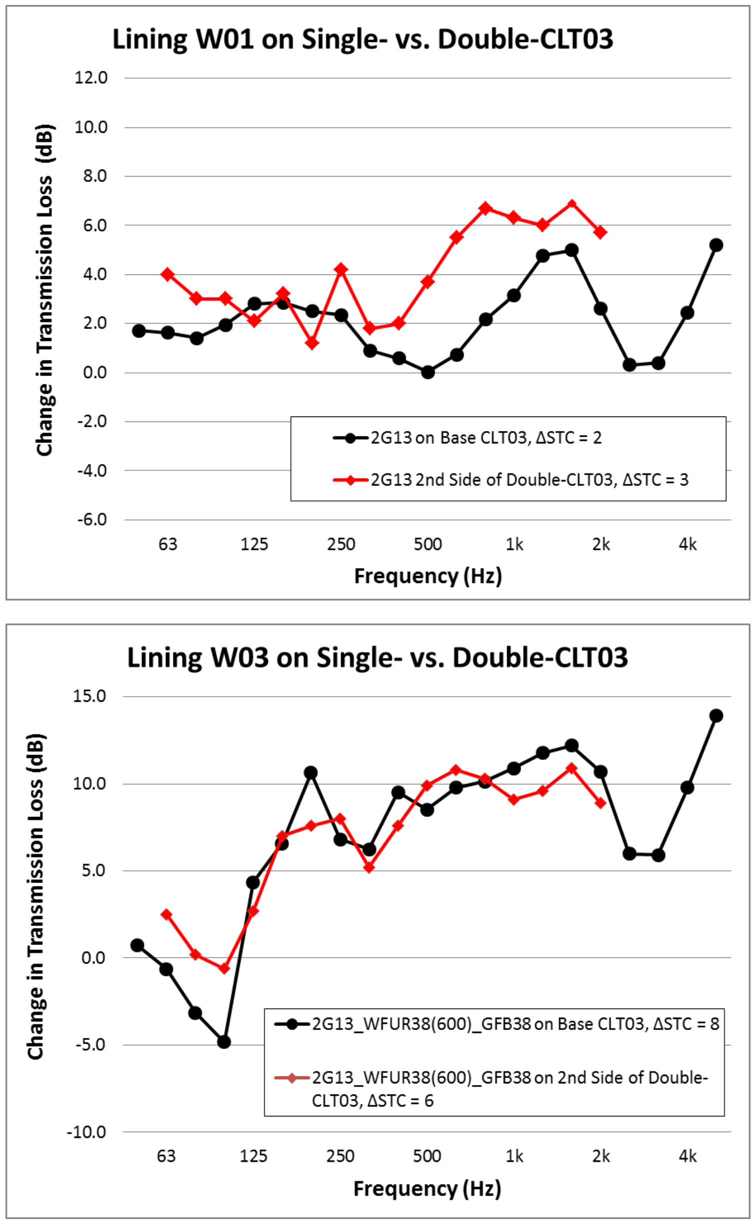
For lining W01, the ΔTL values measured on the double-leaf CLT wall were slightly higher than those measured on the single-leaf CLT wall. For lining W03, the ΔTL values measured on the double-leaf wall were very similar to those measured on the single-leaf CLT wall at the mid-frequencies, and the frequency dependence at low frequencies shows the sharp drop below 125 Hz in both cases. On average, these results suggest that linings provide similar changes on both the single-leaf and double-leaf walls.

The results of the ΔSTC calculations are shown in Table 2.3.2. To provide estimates for some additional linings, the ΔTL values determined when other linings were added to single-leaf walls were processed to determine what STC improvement these would provide when the sound transmission loss of the double-leaf wall is used as the reference curve.

**Figure 2.3.2**:
Change in direct sound transmission loss (ΔTL) for linings W01 and W03 added to CLT wall assemblies.

The upper graph shows ΔTL results for lining W01 (descriptive code 2G13) measured with the lining applied to the single-leaf and double-leaf wall assemblies.

The lower graph shows corresponding ΔTL results for lining W03 (descriptive code 2G13_WFUR38(600)_GFB38) measured with the lining applied to the single-leaf and double-leaf wall assemblies.



### 2.3.1 ΔSTC Ratings for Linings on Double-Leaf CLT Assemblies

The averaged one-third octave band values of the changes in direct sound transmission loss (ΔTL) for the set of linings applied to double-leaf CLT03 walls were calculated following similar procedures to those described in Appendix A2 for linings on single-leaf assemblies. Because the direct sound transmission loss curve for the unlined double-leaf wall differed appreciably from the single-leaf curves, the estimate of the direct sound transmission loss for the base double-leaf CLT03 assembly was used as the reference curve in place of the single-leaf CLT reference curve defined in Appendix A2. In practice, this change had little effect on the calculated values of the ΔSTC.

The calculated ΔSTC values for linings attached to double-leaf CLT walls are given in Table 2.3.2.

**Table 2.3.2**: Calculation of the ΔSTC values for linings on double-leaf CLT03 wall assemblies.

| Lining Code | Lining Descriptive Code | Step 3: (1-side lined) $\Delta STC_{1\text{-side}}$ | Step 4: (2-sides lined) $\Delta STC_{2\text{-sides}}$ | Step 5: ΔSTC |
|---|---|---|---|---|
| **Wall Linings:** | | | | |
| ΔTL-2xCLT-W01 | 2G13 | 3 | 5 | **3** |
| ΔTL-2xCLT-W03 | 2G13_WFUR38(600)_GFB38 | 6 | 12 | **6** |
| ΔTL-2xCLT-W04 | 2G13_RC13(600)_ WFUR38(400)_GFB38 | 15 | 21 | **14** |
| ΔTL-2xCLT-W05 | 2G13_WFUR64(600)_GFB65 | 6 | 11 | **6** |
| ΔTL-2xCLT-W06 | 2G13_WS64(600)_GFB65_AIR13 | 16 | 31 | **16** |

NOTES:

a. Headings "Step 3", "Step 4", and "Step 5" refer to steps in the procedure of Appendix A2.

b. For linings W01 and W03, the ΔTL values were calculated from measurement results with those linings on double-leaf CLT wall assemblies. For other linings, the values of ΔTL obtained for these linings on single-leaf assemblies (see Section 2.2) were used, as discussed above.

c. The calculation of the ΔSTC values followed the process described in Appendix A2, except that the sound transmission loss curve for the Base double-leaf assembly was substituted for the Reference curve of Figure A2.2, which introduces some small changes from the corresponding ΔSTC values for single-leaf assemblies that are presented in Table 2.2.2.1.

## 2.4 Structural Loss Factors for CLT Wall or Floor Assemblies

The structural reverberation times of each of the bare CLT wall and floor assemblies were measured according to ISO 10848 to determine the structural loss factors. The structural loss factors are required for the calculations of the ASTC rating using the Detailed Method.

The measured structural reverberation times are shown in Table A1.3 of Appendix A1. Following ISO 10848, the structural loss factor $\eta_{total}$ was calculated from the data using Equation 2.4.1:

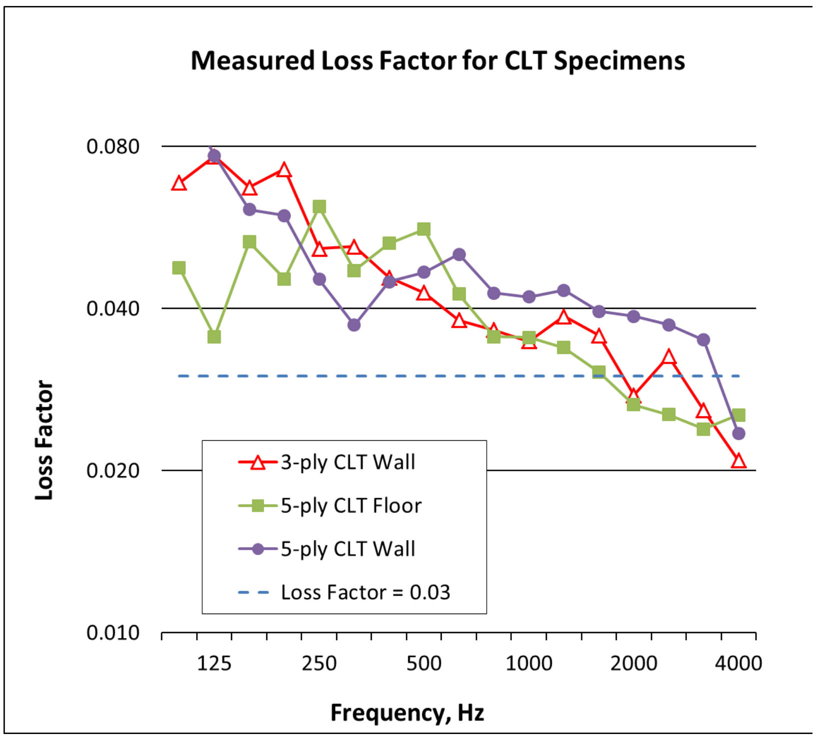
$$\eta_{total} = \frac{2.2}{f T_s} \quad \text{Eq. 2.4.1}$$

Here, f is the one-third octave band frequency in Hz and $T_s$ is the structural reverberation time per one-third octave band in seconds. The resulting loss factors are shown in Figure 2.4.1.

**Figure 2.4.1:**
Structural loss factors, $\eta_{total}$ for the CLT assemblies presented in this Report.

These loss factors were calculated from the structural reverberation times which are tabulated in Appendix A1.

The average values indicate that over much of the frequency range (below 2000 Hz) the loss factors tend to be above 0.03, which is the threshold for ignoring edge corrections when using the Detailed Method to calculate the ASTC rating.




Averaged over the frequency range used for the STC rating (125 Hz to 4000 Hz), the structural loss factors are over 0.04, and it is only at frequencies above 2000 Hz that the curves in Figure 2.4.1 fall below 0.03.

What is important for this study is that the loss factors are mostly above 0.03. For constructions whose structural loss factors exceed the threshold value of 0.03, the effect of edge conditions may be ignored when calculating the ASTC rating using the Detailed Method, which greatly simplifies the calculations.

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# 3 Flanking Sound Transmission in CLT Constructions

This chapter presents the results of experiments made on a series of mock junctions comprising CLT wall assemblies connected to CLT floor assemblies in accordance with the standard, ISO 10848. The standard describes a method of determining the vibration reduction index $K_{ij}$, which describes the vibrational power transmission through a junction between structural elements, normalized in order to make it an invariant quantity. The mock junctions included a set of full-size wall-wall and wall-floor junctions as shown in Figure 3.1 (a) and (b) and in Figure 3.2 (a) and (b). Both cross-junctions (X-junctions) as well as T-junctions were evaluated for the vertical (wall-wall) and for the horizontal (floor-wall) junctions.

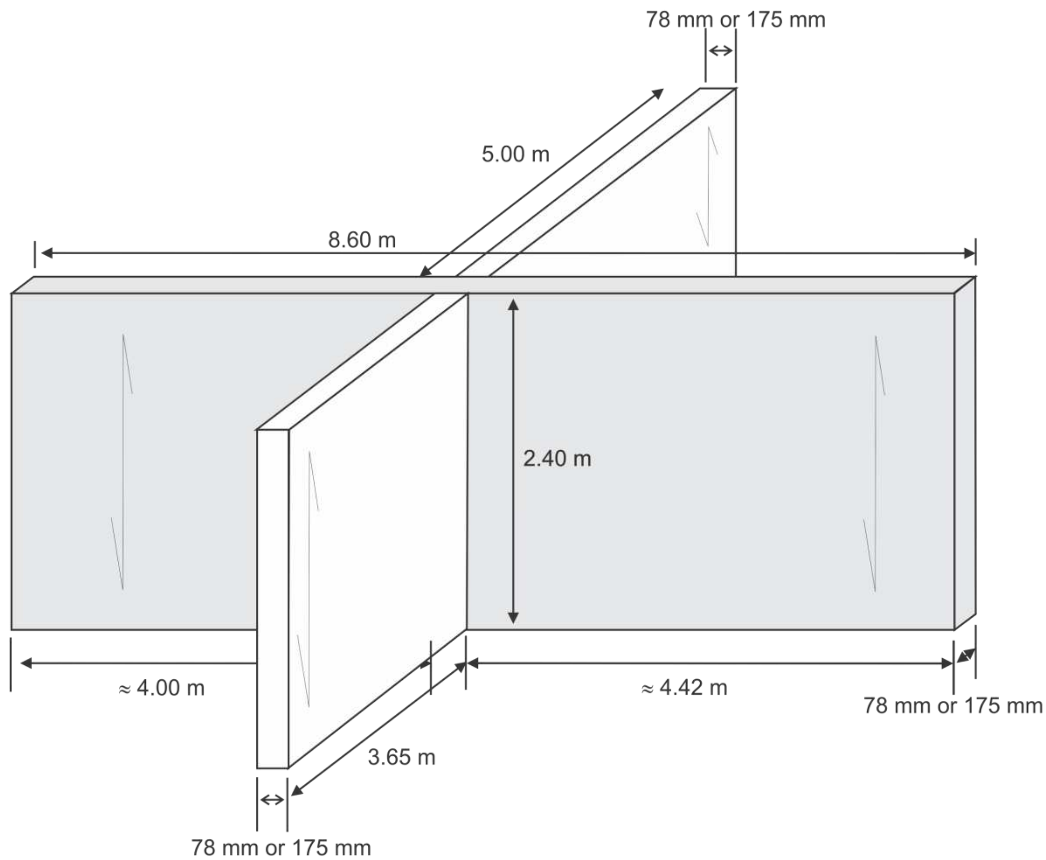



**Figure 3.1(a):** Dimensions of the vertical (wall-wall) junction mock-ups for measurement of the vibration reduction index according to ISO 10848 for wall-wall cross- (X-) junctions

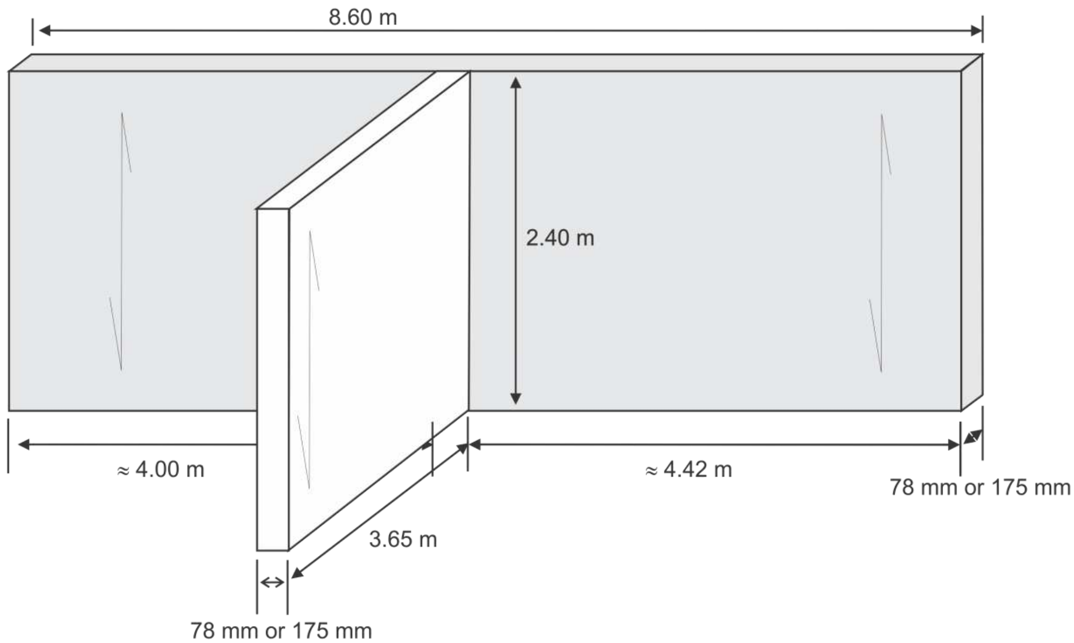



**Figure 3.1(b):** Dimensions of the vertical (wall-wall) junction mock-ups for measurement of the vibration reduction index according to ISO 10848 for wall-wall T-junctions

The dimensions of the mock junctions were in accordance with the requirements of ISO 10848. For the vertical junctions, the length of all coupled wall assemblies differed by at least 10% to avoid coupling of resonant modes. For the horizontal junctions, the length of the floors differed by 10%, but the height of the two walls were the same (which is typical in real buildings).

The wall-wall junctions were free-standing structures which stood on a massive rigid concrete floor. To further suppress structure-borne sound transmission from the walls into the rigid floor and back into the other wall, rubber pads were placed between the CLT wall assemblies and the concrete floor.

For the floor-wall junctions, the lower CLT wall was also placed on rubber pads on the rigid concrete floor. The CLT floor was then placed on top of the lower CLT wall and was supported by adjustable scaffolding at the free edges with rubber pads between the scaffolding and the surface of the CLT assembly. The upper wall was free standing on the CLT floor. To simulate compression forces that act on the junction in real buildings due to the dead load of upper stories, a steel loading beam spanned over the top wall on which a static force of 8000 lbs was applied by four hydraulic cylinders (see Figure 3.3). This load is sufficient to compress voids in the junction that could change the junction mechanics. Initial tests showed that the measured $K_{ij}$ values did not change significantly when the applied load was increased from 4000 lbs to 8000 lbs.

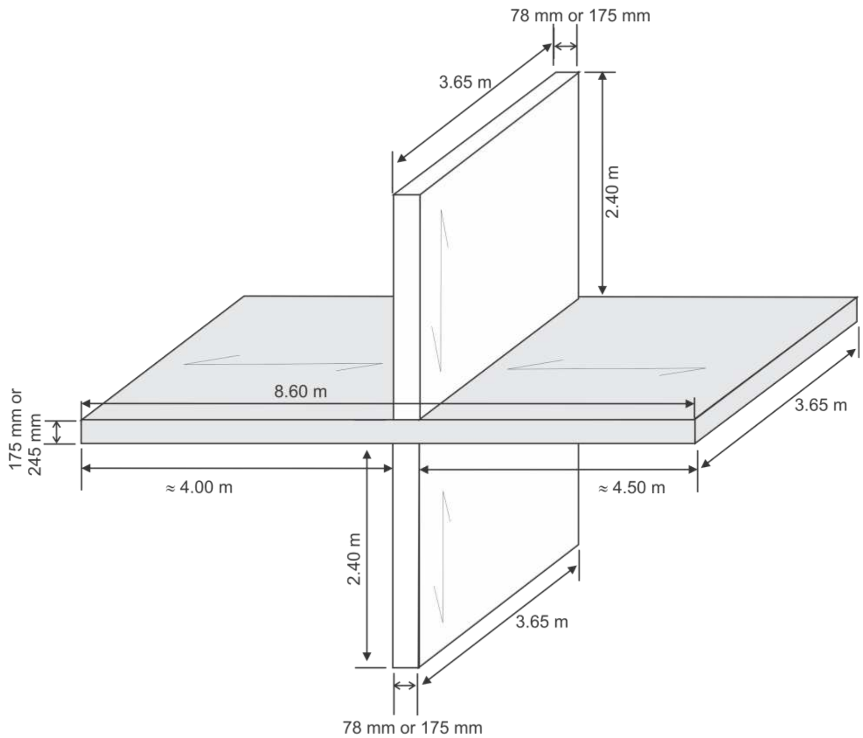



**Figure 3.2(a)**: Dimensions of the horizontal floor-wall junction mock-ups for measurement of the vibration reduction index according to ISO 10848 for floor-wall cross- (X-) junctions

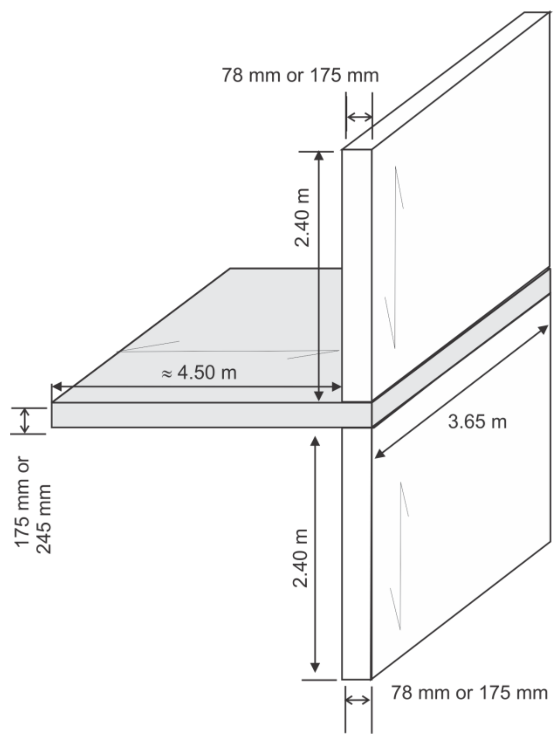



**Figure 3.2(b)**: Dimensions of the horizontal floor-wall junction mock-ups for measurement of the vibration reduction index according to ISO 10848 for floor-wall T-junctions

Figure 3.3 shows one of the tested floor-wall junctions. A static load was applied to the top of the upper wall by the hydraulic cylinders (shown in red) located between the CLT wall and the metal frame.

**Figure 3.3**: CLT floor-wall junction mock-up with loading frame and measurement system

The vibration reduction index $K_{ij}$ for elements with internal loss factors greater than 0.03 is defined in Equation 3.1 as a function of the direction-averaged velocity level difference $\overline{D_{v,ij}}$ between the elements i and j, with the junction length $l_{ij}$, the reference length $l_0$ = 1 m, and the areas $S_i$ and $S_j$ of both coupled elements.

$$K_{ij} = \overline{D_{v,ij}} + 10 \cdot \log_{10} \frac{l_{ij} \cdot l_0}{\sqrt{S_i S_j}} \ , \qquad with\ \overline{D_{v,ij}} = \frac{D_{v,ij} + D_{v,ji}}{2} \qquad \text{Eq. 3.1}$$

The average $\overline{D_{v,ij}}$ is the mean of the velocity level differences of $D_{v,ij}$ and $D_{v,ji}$ that are measured in opposite transmission directions. For $D_{v,ij}$ element "i" is excited and the difference of the velocity levels on both coupled elements "i" and "j" are measured, while for $D_{v,ji}$ element "j" is excited.

In this research project the velocity levels were measured with 16 accelerometers connected to a 16-channel data acquisition system at the cross-junctions and with 12 accelerometers at the T-junctions. In both cases, 4 accelerometers were distributed randomly on each element in the area defined by ISO 10848. During the measurement, the velocity levels were measured simultaneously with all channels while one element of the junction was excited with a hammer. For the excitation, the so-called rain-on-the-roof method was applied where the source element was hit with repeated hammer blows in an area of approximately 1 m x 1 m during a 30 s long measurement interval. Each of the coupled elements was excited in four different areas and for each excitation point 4 different accelerometer positions were used on all elements. In total the velocity levels were measured on 16 positions on each element for every source element. The analysis of the measurement data was done in compliance with ISO 10848.

## 3.1 Tested Junctions of CLT Floors with CLT Walls

The following tables present the mean vibration reduction index ($K_{ij}$) values determined from the measurements on the series of floor/wall mock junctions which were described in the previous section.

The results are presented as single-number values. The procedure used to calculate the single-number rating of the vibration reduction index differs from the procedure outlined in ISO 15712-1. The standard states that: "If the values for the vibration reduction index depend on frequency, the value at 500 Hz may be taken as a good approximation, but the result can then be less accurate." Rather than follow this procedure, the single-number ratings for the vibration reduction indices were calculated as the average value of the nine one-third octave bands between 200 Hz and 1250 Hz, inclusive. The mean $K_{ij}$ values are used in the ASTC calculations in Chapter 4, in worked examples of calculations according to the Simplified Method and the Detailed Method of ISO 15712-1.

Each of the tables presenting the mean vibration reduction index ($K_{ij}$) values has several parts:

- A generic description of the details of the wall and floor/ceiling assemblies and their connection.
- A drawing showing the general features of the junction.
- Note that each cross-junction of wall and floor/ceiling assemblies can be viewed in several ways:
  (a) as the wall-floor junction between two side-by-side rooms above the floor,
  (b) as the wall-ceiling junction between two side-by-side rooms below the ceiling, and
  (c) as the junction of a flanking wall with the floor/ceiling assembly separating two rooms that are one-above-the-other.
- Each T-junction of wall and floor/ceiling assemblies involves only option (c).
- Junction cases (a) to (c) are presented in the rows below, with stylized drawings to identify the paths in each case, and the mean vibration reduction index ($K_{ij}$) values for each flanking path.

The naming convention for the junctions follows a simple coding in four segments:

- The first segment of the code indicates that the junction consists of CLT assemblies.
- The second segment of the code indicates the junction type:
  - WF = wall/floor,
  - WC = wall/ceiling,
  - FW = floor/wall.
- The third segment of the code indicates the nature of the junction itself:
  - the first letter (X or T) indicates junction geometry,
  - the second letter (a, b, c, etc.) indicates how the elements are attached at their junction.
- The fourth segment of the code is a unique number for that junction detail.

Note that the floor-wall junctions were tested ***only*** for the cases where:

- Strands of the face ply of the CLT floor assembly were perpendicular to the connected wall.
- Strands of the face ply of the wall assembly were vertical.
- For cross-junctions, the CLT floor assembly was continuous across the junction.

These cases were considered to provide the worst case for sound transmission to the adjoining rooms, and therefore may be used as conservative estimates for cases where the orientation of the CLT or connections differs.

**Table 3.1.01: Transmission Paths**

Wall assembly:

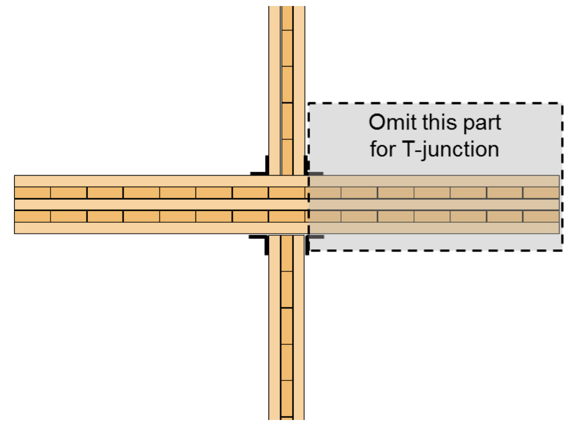
- 3-ply CLT[1] (78 mm thick, 42.4 kg/m²)
- Above and below the floor/ceiling assembly

Floor/ceiling assembly:

- 5-ply CLT[1] (175 mm thick, 91.4 kg/m²)

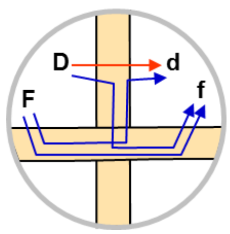
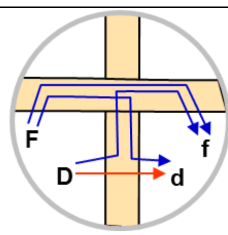
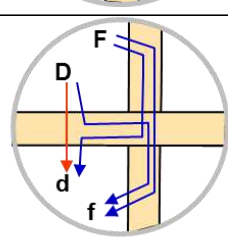
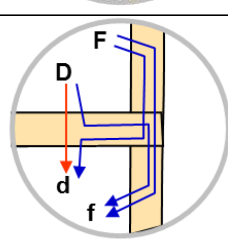
Junction of wall with floor/ceiling assembly:

- Floor/ceiling continuous across the X-junction, but ends beyond the junction for the T-junction
- Wall assemblies terminate at the surfaces of the floor/ceiling assembly
- Walls connected to the floor/ceiling assembly with 90 mm angle brackets spaced 300 mm o.c. on each side of the wall for X-junction and on one side of the wall for T-junction




Floor-Wall X-/T-junction for CLT constructions.

Vertical section, not to scale.

| Junction | Diagram | Path | Vibration Reduction Index, $K_{ij}$ |
|---|---|---|---|
| **CLT-WF-Xa-01**<br>Wall-Floor<br>X-junction |   | Ff<br>Fd<br>Df | 1.1<br>10.5<br>10.5 |
| **CLT-WC-Xa-01**<br>Wall-Ceiling<br>X-junction |   | Ff<br>Fd<br>Df | 1.1<br>10.5<br>10.5 |
| **CLT-FW-Xa-01**<br>Floor-Wall<br>X-junction |   | Ff<br>Fd<br>Df | 19.4<br>10.5<br>10.5 |
| **CLT-FW-Ta-01**<br>Floor-Wall<br>T-junction |   | Ff<br>Fd<br>Df | 15.7<br>7.2<br>7.2 |

(For the notes in this table please see the corresponding endnotes on page 115.)

**Table 3.1.02: Transmission Paths**

(same as 3.1.01 except different wall connection)

Wall assembly:

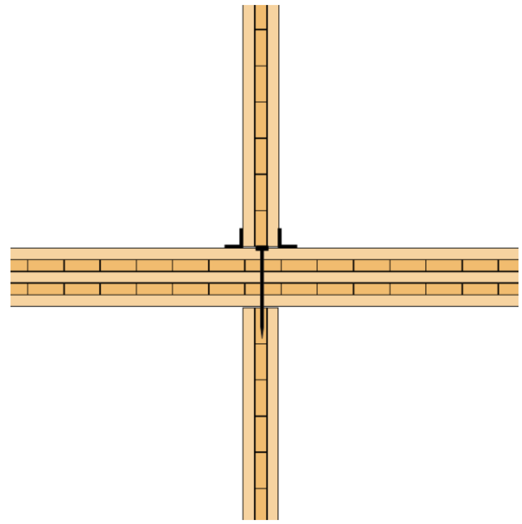
- 3-ply CLT[1] (78 mm thick, 42.4 kg/m$^2$)
- Above and below the floor/ceiling assembly

Floor/ceiling assembly:

- 5-ply CLT[1] (175 mm thick, 91.4 kg/m$^2$)

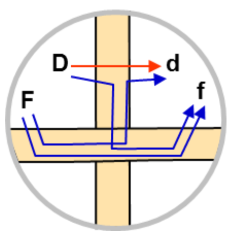
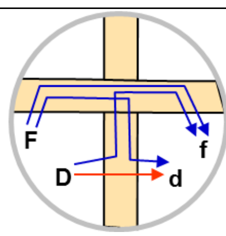
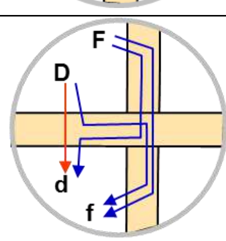
Junction of wall with floor/ceiling assembly:

- Floor/ceiling continuous across the X-junction
- Wall assemblies terminate at the surfaces of the floor/ceiling assembly
- Upper wall connected to the floor/ceiling assembly with 90 mm angle brackets spaced 300 mm o.c. on each side of the wall
- Lower wall connected using 280 mm self-tapping screws spaced 300 mm o.c. that pass through the floor/ceiling assembly into the core of the wall below



Floor-Wall X-junction for CLT constructions.

Vertical section, not exactly to scale.

| Junction | | Path | Vibration Reduction Index, $K_{ij}$ |
|---|---|---|---|
| **CLT-WF-Xc-02**<br>Wall-Floor<br>X-junction |  | Ff<br>Fd<br>Df | 0.7<br>9.5<br>9.5 |
| **CLT-WC-Xc-02**<br>Wall-Ceiling<br>X-junction |  | Ff<br>Fd<br>Df | 0.7<br>13.8<br>13.8 |
| **CLT-FW-Xc-02**<br>Floor-Wall<br>X-junction |  | Ff<br>Fd<br>Df | 21.4<br>9.5<br>13.8 |

(For the notes in this table please see the corresponding endnotes on page 115.)

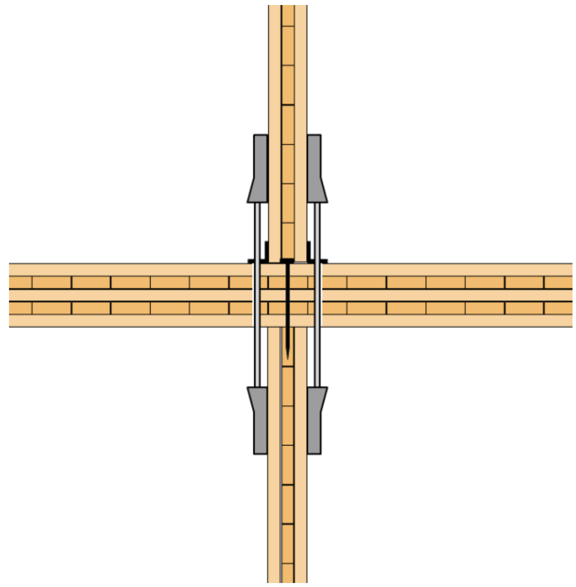
**Table 3.1.03: Transmission Paths**

(same as 3.1.01 except different wall connections)

Wall assembly:
- 3-ply CLT[1] (78 mm thick, 42.4 kg/$m^2$)
- Above and below the floor/ceiling assembly

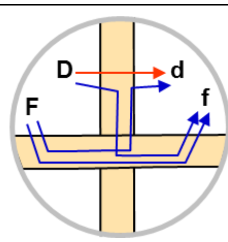
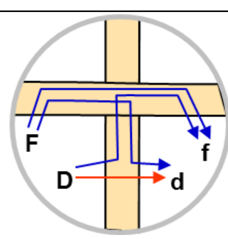
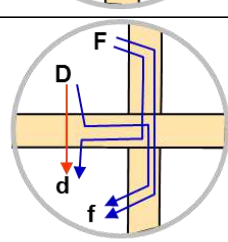
Floor/ceiling assembly:
- 5-ply CLT[1] (175 mm thick, 91.4 kg/$m^2$)

Junction of wall with floor/ceiling assembly:
- Floor/ceiling continuous across the X-junction
- Wall assemblies terminate at the surfaces of the floor/ceiling assembly
- Upper wall connected to the floor/ceiling assembly with 90 mm angle brackets spaced 300 mm o.c. on each side of the wall
- Lower wall connected using 280 mm self-tapping screws spaced 300 mm o.c. that pass through the floor/ceiling assembly into the core of the wall below
- Two hold-down brackets on each side of the wall, above and below the floor/ceiling



Floor-Wall X-junction for CLT constructions.

Vertical section, not exactly to scale.

| Junction | Diagram | Path | Vibration Reduction Index, $K_{ij}$ |
|---|---|---|---|
| **CLT-WF-Xb-03**<br>Wall-Floor<br>X-junction |  | Ff<br>Fd<br>Df | -2.1<br>7.6<br>7.6 |
| **CLT-WC-Xb-03**<br>Wall-Ceiling<br>X-junction |  | Ff<br>Fd<br>Df | -2.1<br>10.6<br>10.6 |
| **CLT-FW-Xb-03**<br>Floor-Wall<br>X-junction |  | Ff<br>Fd<br>Df | 12.4<br>7.6<br>10.6 |

(For the notes in this table please see the corresponding endnotes on page 115.)

**Table 3.1.04: Transmission Paths**

Wall assembly:

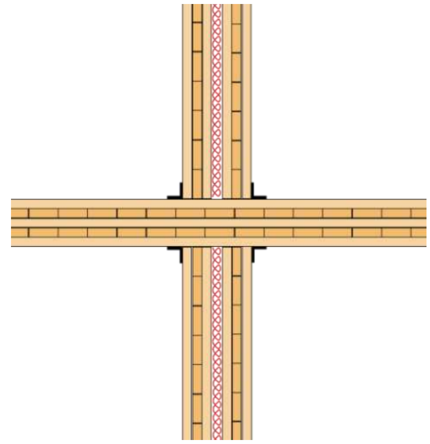
- Two leafs of 3-ply CLT[1] with glass fibre batts[2] filling the cavity between the leafs
- Above and below the floor/ceiling assembly
- Combined 181 mm thick, 89.6 kg/m$^2$

Floor/ceiling assembly:

- 5-ply CLT[1] (175 mm thick, 91.4 kg/m$^2$)

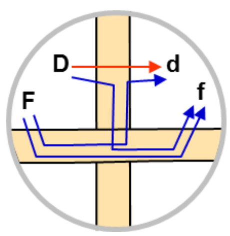
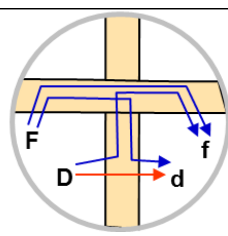
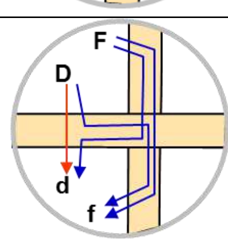
Junction of wall with floor/ceiling assembly:

- Floor/ceiling continuous across the X-junction
- Wall assemblies terminate at the surfaces of the floor/ceiling assembly
- Walls connected to the floor/ceiling assembly with 90 mm angle brackets spaced 300 mm o.c. on each side of the wall

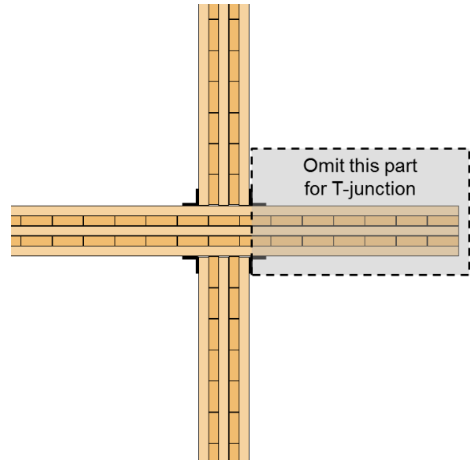


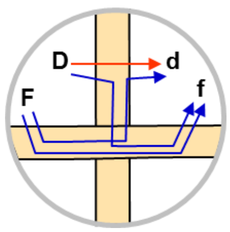
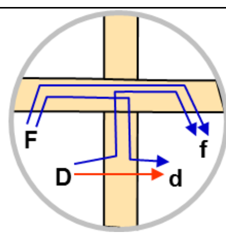
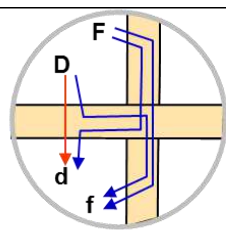
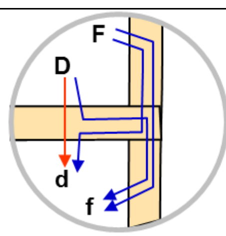
Floor-Wall X-junction for CLT constructions.

Vertical section, not exactly to scale.

| Junction | Diagram | Path | Vibration Reduction Index, $K_{ij}$ |
|---|---|---|---|
| **CLT-WF-Xa-04**<br>Wall-Floor<br>X-junction |  | Ff<br>Fd<br>Df | 1.8<br>13.0<br>13.0 |
| **CLT-WC-Xa-04**<br>Wall-Ceiling<br>X-junction |  | Ff<br>Fd<br>Df | 1.8<br>13.0<br>13.0 |
| **CLT-FW-Xa-04**<br>Floor-Wall<br>X-junction |  | Ff<br>Fd<br>Df | 19.5<br>8.2<br>8.2 |

(For the notes in this table please see the corresponding endnotes on page 115.)

<table>
<tr>
<td rowspan="2">Table 3.1.05: Transmission Paths<br><br><u>Wall assembly:</u><br>• 5-ply CLT[1] (175 mm thick, 91.4 kg/m²)<br>• Above and below the floor/ceiling assembly<br><u>Floor/ceiling assembly:</u><br>• 5-ply CLT[1] (175 mm thick, 91.4 kg/m²)<br><u>Junction of wall with floor/ceiling assembly:</u><br>• Floor/ceiling continuous across the X-junction, but ends beyond the junction for the T-junction<br>• Wall assemblies terminate at the surfaces of the floor/ceiling assembly<br>• Walls connected to the floor/ceiling assembly with 90 mm angle brackets spaced 300 mm o.c. on each side of the wall for X-junction and on one side of the wall for T-junction</td>
<td colspan="2">

Floor-Wall X-/T-junction for CLT constructions.<br>Vertical section, not exactly to scale.</td>
</tr>
<tr>
<td>Path</td>
<td>Vibration Reduction Index, $K_{ij}$</td>
</tr>
<tr>
<td>CLT-WF-Xa-05<br>Wall-Floor<br>X-junction<br>
</td>
<td>Ff<br>Fd<br>Df</td>
<td>0.6<br>10.2<br>10.2</td>
</tr>
<tr>
<td>CLT-WC-Xa-05<br>Wall-Ceiling<br>X-junction<br>
</td>
<td>Ff<br>Fd<br>Df</td>
<td>0.6<br>10.2<br>10.2</td>
</tr>
<tr>
<td>CLT-FW-Xa-05<br>Floor-Wall<br>X-junction<br>
</td>
<td>Ff<br>Fd<br>Df</td>
<td>17.6<br>10.2<br>10.2</td>
</tr>
<tr>
<td>CLT-FW-Ta-05<br>Floor-Wall<br>T-junction<br>
</td>
<td>Ff<br>Fd<br>Df</td>
<td>12.9<br>6.8<br>6.8</td>
</tr>
</table>

(For the notes in this table please see the corresponding endnotes on page 115.)

**Table 3.1.06: Transmission Paths**

(same as 3.1.05 except different wall connections)

Wall assembly:

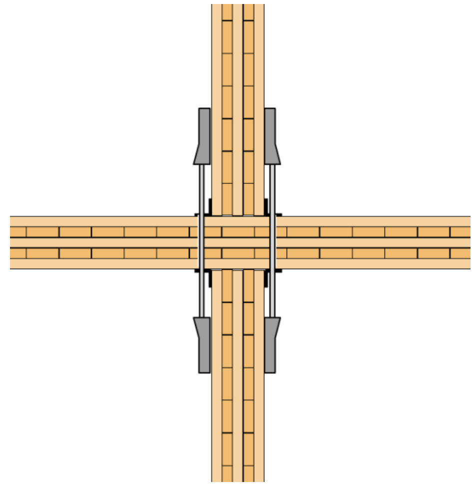
- 5-ply CLT[1] (175 mm thick, 91.4 kg/m[2])
- Above and below the floor/ceiling assembly

Floor/ceiling assembly:

- 5-ply CLT[1] (175 mm thick, 91.4 kg/m[2])

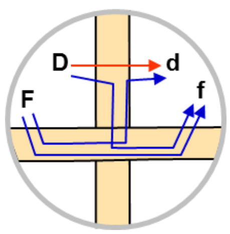
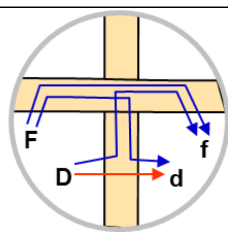
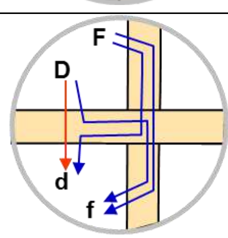
Junction of wall with floor/ceiling assembly:

- Floor/ceiling continuous across the X-junction
- Wall assemblies terminate at the surfaces of the floor/ceiling assembly
- Walls connected to the floor/ceiling assembly with 90 mm angle brackets spaced 300 mm o.c. on each side of the wall
- Two hold-down brackets on each side of the wall, above and below the floor/ceiling



Floor-Wall X-junction for CLT constructions.

Vertical section, not exactly to scale.

| Junction | Diagram | Path | Vibration Reduction Index, $K_{ij}$ |
|---|---|---|---|
| **CLT-WF-Xb-06**<br>Wall-Floor<br>X-junction |   | Ff<br>Fd<br>Df | -2.0<br>3.3<br>3.3 |
| **CLT-WC-Xb-06**<br>Wall-Ceiling<br>X-junction |   | Ff<br>Fd<br>Df | -2.0<br>3.3<br>3.3 |
| **CLT-FW-Xb-06**<br>Floor-Wall<br>X-junction |   | Ff<br>Fd<br>Df | 5.3<br>3.3<br>3.3 |

(For the notes in this table please see the corresponding endnotes on page 115.)

## 3.2 Trends in Junction Attenuation for Floor-Wall Junctions

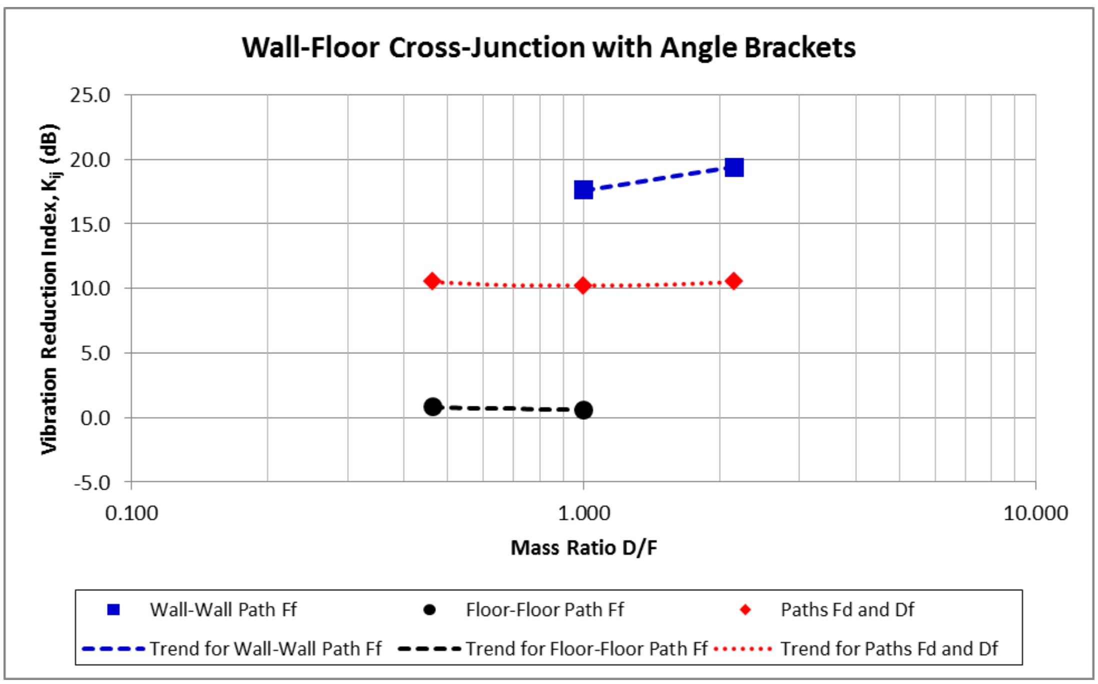
Only a limited selection of junction cases was tested:

- All tested cases had 3-ply CLT assemblies or 5-ply CLT assemblies or a combination of 3-ply and 5-ply CLT assemblies. None of the tested cases included 7-ply CLT assemblies. The process to partially compensate for this limited selection is discussed in Section 3.5.
- The tested wall/floor junctions included both cross-junctions (where the floor assembly was continuous across the junction) and T-junctions (where walls were attached to top and bottom of the floor assembly, very close to its end). In all cases, the wall/wall path was discontinuous – the upper and lower wall assemblies were mechanically attached to top and bottom of the intervening floor assembly.
- The tested wall/floor junctions included several variations on the attachment of the CLT assemblies at the junctions. All of these variations had mechanical attachment of the walls to the floor assembly, but in some cases the attachment of the upper wall differed from that of the lower wall.

### *Basic Wall/Floor Cross-Junctions*

Clear trends were apparent in the data for wall-floor cross-junctions with the basic attachment of the wall assemblies (90 mm angle brackets spaced 300 mm on centre). Figure 3.2.1 shows the mean $K_{ij}$ values as a function of the mass ratio between the floor assembly and the wall assemblies.

**Figure 3.2.1**: Measured $K_{ij}$ values and best fit curves for each path for cross-junction cases with angle brackets attaching the wall assemblies to the top and bottom of the continuous 5-ply floor assembly.



The measured values fall in three distinct ranges, one for each type of transmission path:

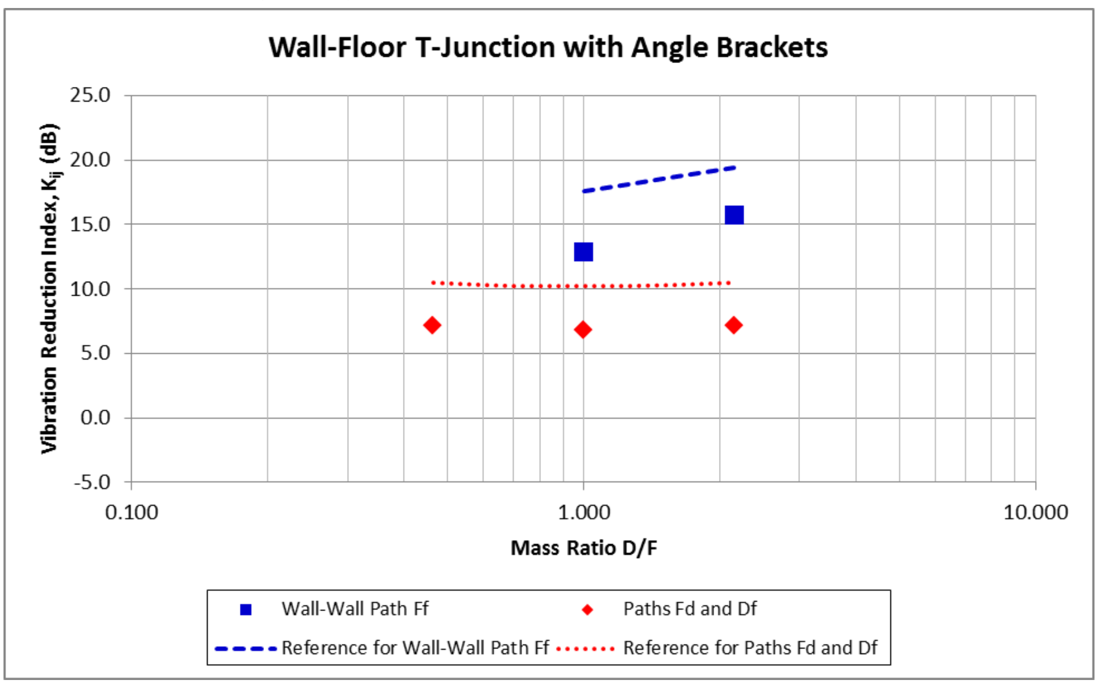
- The wall/wall path (designated Ff for the case where one room is above the other with the floor as the separating assembly) has the highest $K_{ij}$ values, indicating high attenuation and therefore a relatively weak connection.
- The floor/floor path (designated Ff for the case where one room is beside the other with the wall as the separating assembly) has the lowest $K_{ij}$ values, indicating little attention through the junction and therefore a very effective connection for the transmission of structure-borne sound across the continuous floor assembly.
- The floor/wall paths Fd and Df fall midway between.

Changes in $K_{ij}$ values with changes in the mass ratio are quite small. The trends are shown to be straight lines for the wall/wall and floor/floor paths and a simple quadratic fit for the floor/wall paths. These curves which indicate the performance for the simple cross-junction case in Figure 3.2.1 were re-used as reference curves in the following graphs to facilitate comparisons between the graphs.

## *Comparison of Wall/Floor T-Junctions vs. Cross-Junctions*

Some changes relative to the data for the cross-junction were evident in the data for wall/floor T-junctions with the same basic attachment of the wall assemblies (90 mm angle brackets spaced 300 mm on centre attaching the wall assemblies above and below the floor), as shown in Figure 3.2.2.

**Figure 3.2.2:** Measured $K_{ij}$ values for each path for the T-junction cases with angle brackets attaching the wall assemblies to the top and bottom of the 5-ply floor assembly. The dashed curves show the trends for the corresponding cross-junction for reference.

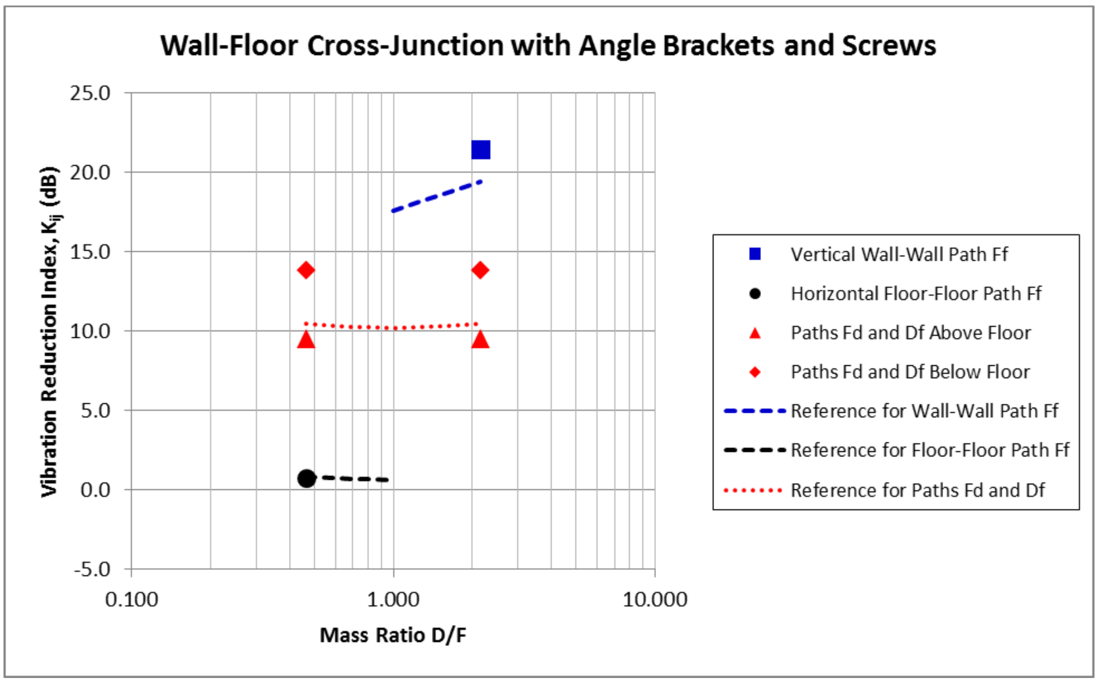


Clearly with the change from the cross-junction to the T-junction configuration, all the $K_{ij}$ values dropped by several dB relative to the cross-junction case. The difference is about 4 or 5 dB for the wall/wall path and about 3 dB for paths Fd and Df.

## *Comparison of Wall/Floor Cross-Junctions with Different Attachment Details*

More complicated changes relative to the basic cross-junction were evident in the mean $K_{ij}$ values for wall/floor cross-junctions which were constructed using different methods of attaching the wall assemblies to the floor assemblies as shown in Figures 3.2.3 and 3.2.4.

**Figure 3.2.3:** Measured $K_{ij}$ values for each path for the cross-junctions for the case where angle brackets were used to attach the wall assemblies to the bottom of the 5-ply floor assemblies and for the case where screws were used. The dashed curves show the trends for the corresponding cross-junction with assemblies attached with 90 mm angle brackets spaced 300 mm on centre for reference.

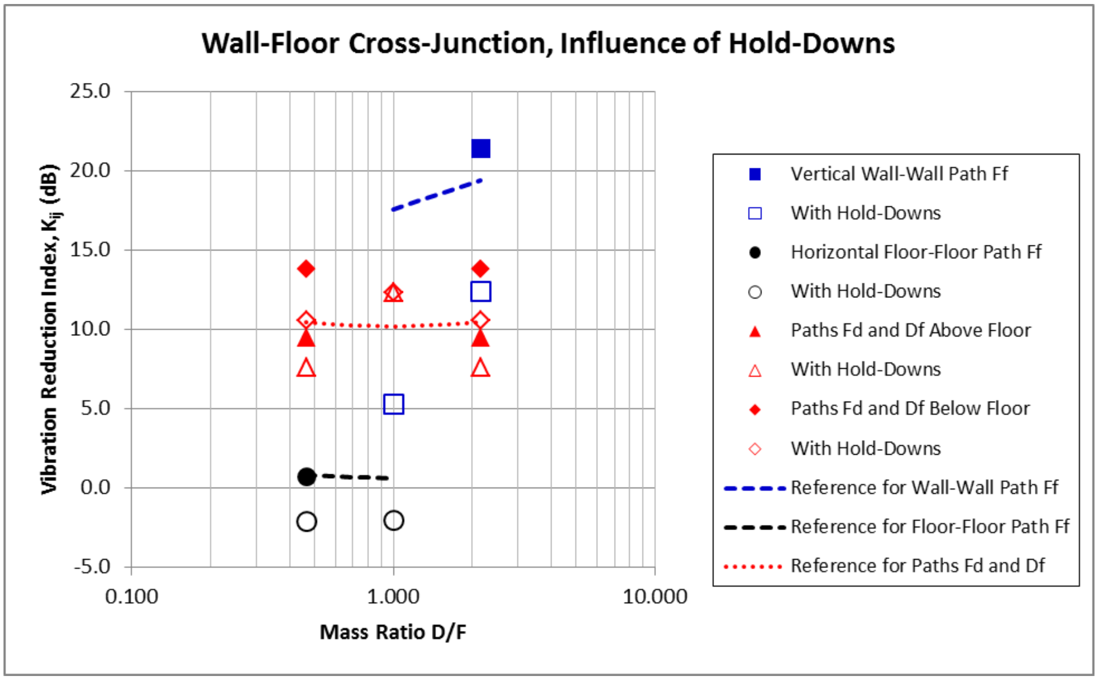



The change from brackets to screws for attaching the CLT assemblies altered the mean $K_{ij}$ values.

1. The original case (dashed lines) had CLT wall assemblies above and below the floor attached to the continuous floor with 90 mm angle brackets spaced 300 mm on centre.
2. The second case (shown by individual markers for each type of path) had screw attachments replacing the angle brackets holding the wall assembly below the floor. For the floor-floor path this change had little effect and the mean $K_{ij}$ values remained close to 0 dB. For the vertical wall/wall path the mean $K_{ij}$ value rose by about 2 dB, but remained close to 20 dB. The paths Fd and Df exhibited noticeable asymmetry with slightly higher mean $K_{ij}$ values for the Fd and Df paths to the wall below the floor, and slightly lower values for the paths to the wall above the floor. The mean value rose slightly (by less than 2 dB). Overall, these changes suggest slightly weaker attachment of the wall assembly below the floor.

Significantly larger changes were evident when hold-downs were added, as shown in Figure 3.2.4.

**Figure 3.2.4:** Measured change in the mean $K_{ij}$ values for each path for the cross-junction cases where hold-downs were added to the floor/wall junctions, as presented in Tables 3.1.03 and 3.1.06. The dashed curves show the trends for the corresponding cross-junction with 90 mm angle brackets spaced 300 mm on centre used above and below the floor for reference.




Adding hold-downs changed the mean $K_{ij}$ values by 2 dB up to 12 dB, depending on the flanking sound transmission path and the other attachments of the wall assemblies.

1. The original case (shown by dashed lines) had the CLT wall assemblies above and below the floor attached to the continuous CLT floor with 90 mm angle brackets spaced 300 mm on centre and no hold-downs.
2. The individual filled markers show again (as in the preceding Figure 3.2.3) the slightly altered mean $K_{ij}$ values when screw attachments replaced the 90 mm angle brackets holding the lower wall assembly.
3. The corresponding open markers show how the mean $K_{ij}$ values changed when hold-downs were added to the assemblies. For all paths, the mean $K_{ij}$ values for the cases with hold-down brackets differed appreciably from the corresponding case without hold-downs.
4. With angle brackets holding the lower wall (changes relative to the dashed curves, for the cases at mass ratio of 1.00), adding hold-downs changed the mean $K_{ij}$ values most dramatically: +2 dB for paths Fd and Df, but lower by 12 dB for the wall-wall path and lower by 3 dB for the floor-floor path.
5. With screw attachment of the lower wall, all of the mean $K_{ij}$ values dropped by about 3 dB, except for the vertical wall-wall path which dropped by about 7 dB.

The effect of the changes in the attachment of the CLT assemblies is complicated and the trends should not be treated as highly reliable, given the limited set of assemblies tested to sample so many attachment options.

Despite the many changes due to attachment details, an overall pattern remained fairly consistent:

- The vertical wall/wall paths had the highest mean $K_{ij}$ values (13 dB to 22 dB).
- The floor/floor paths had the lowest mean $K_{ij}$ values (-2 dB to 3 dB).
- The floor/wall paths Fd and Df were between these extremes (7 dB to 15 dB).
- T-junctions had lower mean $K_{ij}$ values than the corresponding cross-junctions (lower by 3 dB to 5 dB).
- The addition of hold-downs resulted in much lower mean $K_{ij}$ values for the vertical wall/wall paths (indicating much better connection between the upper and lower walls) but had smaller effects on the other paths.

Fortunately, the attachment changes are expected to have less effect on the calculated ASTC than one might assume from the variation evident in the comparisons above, because in most cases increasing the mean $K_{ij}$ value for one path will be accompanied by a lower value for another path when one considers the set of 12 flanking paths at all four junctions.

## 3.3 Tested Junctions of CLT Walls with CLT Walls

The following tables present the mean vibration reduction index ($K_{ij}$) values determined from the measurements on the series of floor/wall mock junctions which were described in the previous section.

The results are presented as single-number values. The procedure used to calculate the single-number rating of the vibration reduction index differs from the procedure outlined in ISO 15712-1. The standard states that: “If the values for the vibration reduction index depend on frequency, the value at 500 Hz may be taken as a good approximation, but the result can then be less accurate.” Rather than follow this procedure, the single-number ratings for the vibration reduction indices were calculated as the average value of the nine one-third octave bands between 200 Hz and 1250 Hz, inclusive. The mean $K_{ij}$ values are used in the ASTC calculations in Chapter 4, in worked examples of calculations according to the Simplified Method and the Detailed Method of ISO 15712-1.

Each of the tables presenting the mean vibration reduction index ($K_{ij}$) values has several parts:

- A generic description of the details of the wall assemblies and their connection.
- A drawing showing the general features of the junction.
- Note that each cross-junction of wall assemblies represents a combination of separating wall and flanking walls for two side-by-side rooms, but all the cases studied involved one wall assembly that was continuous across the junction. The continuous assembly could be either the separating wall or a flanking wall.
- Each T-junction of the wall assemblies involved a flanking wall assembly that was continuous across the junction.
- Several junction cases are presented in the rows below, with stylized drawings to identify the paths in each case, and the mean vibration reduction index ($K_{ij}$) values for each flanking path.

The naming convention for the junctions follows a simple coding in four segments:

- The first segment of the code indicates that the junction consists of CLT assemblies.
- The second segment of the code indicates the junction type: WW = wall-wall.
- The third segment of the code indicates the nature of the junction itself:
  - the first letter (X or T) indicates junction geometry,
  - the second letter (a, b, c, etc.) indicates how the elements are attached at their junction.
- The fourth segment of the code is the unique number for that junction detail.

Note that the wall-wall junctions were tested ***only*** for the cases where:

- Strands of the face ply of the wall assembly were vertical.
- For all wall-wall junctions, one of the CLT assemblies was continuous across the junction.

These cases were considered to provide the worst case for transmission to the adjoining rooms, and hence may be used as conservative estimates for cases where the CLT orientation or connection differs.

**Table 3.3.01: Transmission Paths**

Continuous wall assembly:

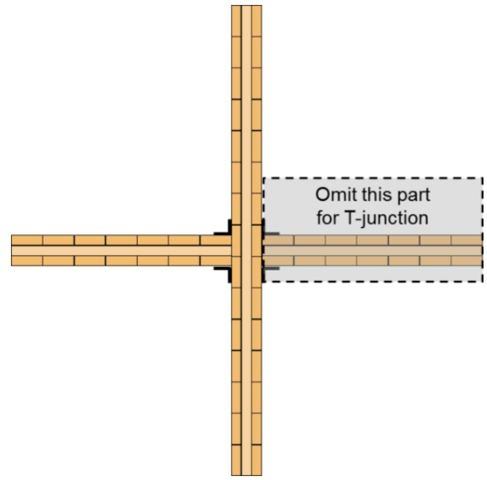
- 3-ply CLT[1] (78 mm thick, 42.4 kg/m$^2$)

Connected wall assemblies:

- 3-ply CLT[1] (78 mm thick, 42.4 kg/m$^2$)
- Terminating where they butt against the continuous wall assembly

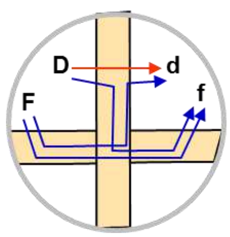
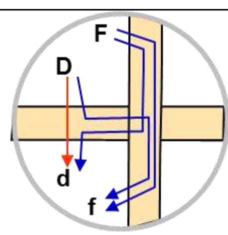
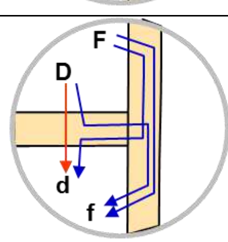
Junction:

- X-junction with two aligned CLT wall assemblies butted against opposite sides of the continuous CLT wall assembly, and fastened with 90 mm angle brackets spaced 600 mm o.c., or
- T-junction with one connected CLT wall assembly butted on one side of the continuous CLT wall assembly, and fastened with 90 mm angle brackets spaced 600 mm o.c.

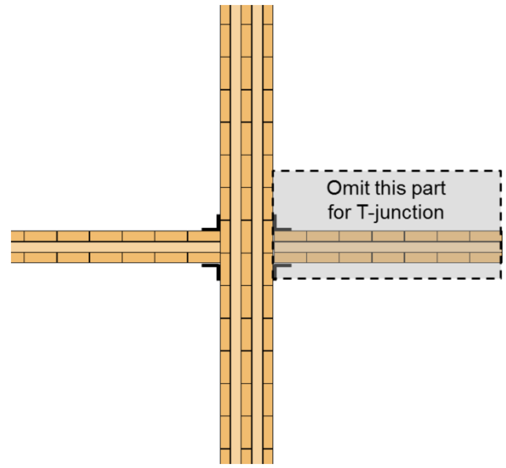


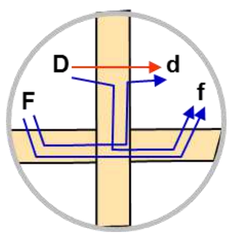
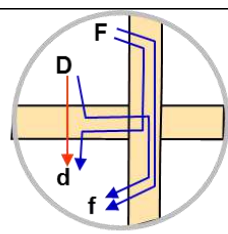
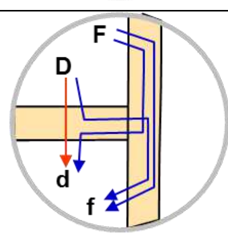

Wall-Wall X-/T-junction for CLT constructions.

Horizontal section, not exactly to scale.

| Junction | Path | Vibration Reduction Index, $K_{ij}$ |
|---|---|---|
| **CLT-WW-Xa-01** Wall-Wall X-junction with continuous separating wall   | Ff | 9.9 |
| | Fd | 5.8 |
| | Df | 5.8 |
| **CLT-WW-Xb-01** Wall-Wall X-junction with continuous flanking walls   | Ff | 5.2 |
| | Fd | 5.8 |
| | Df | 5.8 |
| **CLT-WW-Tb-01** Wall-Wall T-junction with continuous flanking walls   | Ff | 3.5 |
| | Fd | 5.7 |
| | Df | 5.7 |

(For the notes in this table please see the corresponding endnotes on page 115.)

<table>
<tr><th>Table 3.3.02: Transmission Paths</th><td colspan="2" rowspan="2">

Wall-Wall X-/T-junction for CLT constructions.<br>Horizontal section, not exactly to scale.</td></tr>
<tr><td rowspan="2"><u>Continuous wall assembly:</u><br>• 5-ply CLT[1] (175 mm thick, 91.4 kg/m²)<br><u>Connected wall assemblies:</u><br>• 3-ply CLT[1] (78 mm thick, 42.4 kg/m²)<br>• Terminating where they butt against the continuous wall assembly<br><u>Junction:</u><br>• X-junction with two aligned CLT wall assemblies butted against opposite sides of the continuous CLT wall assemblies, and fastened with 90 mm angle brackets spaced 600 mm o.c., or<br>• T-junction with one connected CLT wall assembly butted on one side of the continuous CLT wall assembly, and fastened with 90 mm angle brackets spaced 600 mm o.c.</td></tr>
<tr><th>Path</th><th>Vibration Reduction Index, $K_{ij}$</th></tr>
<tr><td>CLT-WW-Xa-02<br>Wall-Wall X-junction with continuous separating wall<br>
</td><td>Ff<br>Fd<br>Df</td><td>17.0<br>9.1<br>9.1</td></tr>
<tr><td>CLT-WW-Xb-02<br>Wall-Wall X-junction with continuous flanking walls<br>
</td><td>Ff<br>Fd<br>Df</td><td>2.6<br>9.1<br>9.1</td></tr>
<tr><td>CLT-WW-Tb-02<br>Wall-Wall T-junction with continuous flanking walls<br>
</td><td>Ff<br>Fd<br>Df</td><td>2.2<br>9.8<br>9.8</td></tr>
</table>

(For the notes in this table please see the corresponding endnotes on page 115.)

**Table 3.3.03: Transmission Paths**

Continuous wall assembly:

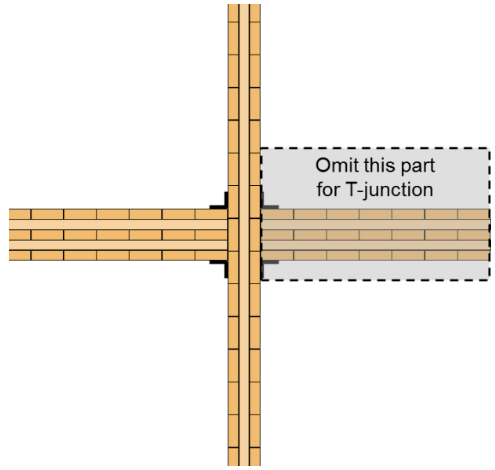
- 3-ply CLT[1] (78 mm thick, 42.4 kg/m$^2$)

Connected wall assemblies:

- 5-ply CLT[1] (175 mm thick, 91.4 kg/m$^2$)

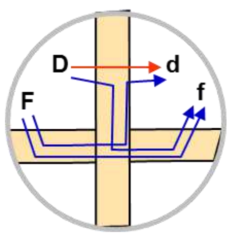
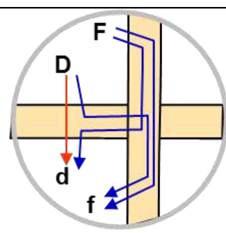
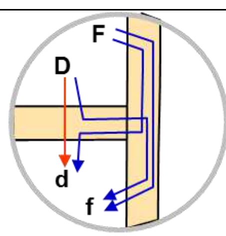
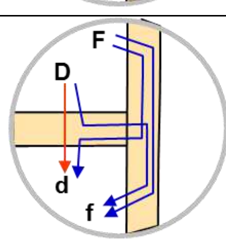
Junction:

- X-junction with two aligned CLT wall assemblies butted against opposite sides of the continuous CLT wall assemblies, and fastened with 90 mm angle brackets spaced 600 mm o.c., or
- T-junction with one connected CLT wall assembly butted on one side of the continuous CLT wall assembly, and fastened with 90 mm angle brackets spaced 600 mm o.c.




Wall-Wall X-/T-junction for CLT constructions.

Horizontal section, not exactly to scale.

| Junction | Diagram | Path | Vibration Reduction Index, $K_{ij}$ |
|---|---|---|---|
| **CLT-WW-Xa-03** Wall-Wall X-junction with continuous separating walls |  | Ff<br>Fd<br>Df | 11.0<br>8.7<br>8.7 |
| **CLT-WW-Xb-03** Wall-Wall X-junction with continuous flanking walls |  | Ff<br>Fd<br>Df | 5.4<br>8.7<br>8.7 |
| **CLT-WW-Tb-03** Wall-Wall T-junction with continuous flanking walls |  | Ff<br>Fd<br>Df | 1.0<br>7.7<br>7.7 |
| **CLT-WW-Tg-03** Like CLT-WW-Tb-03, but bonded with construction adhesive |  | Ff<br>Fd<br>Df | 9.1<br>5.3<br>5.3 |

(For the notes in this table please see the corresponding endnotes on page 115.)

**Table 3.3.04: Transmission Paths**

Continuous wall assembly:

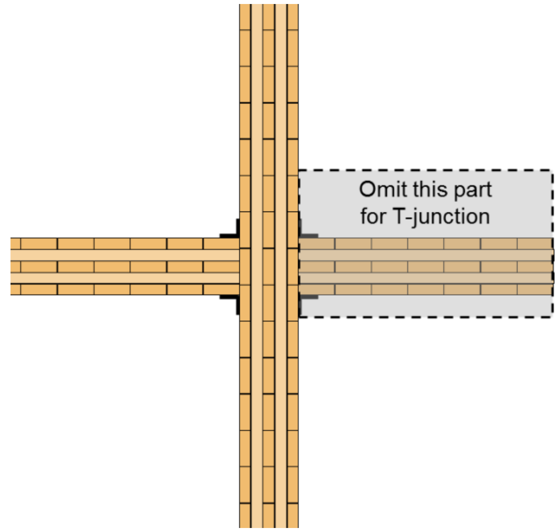
- 5-ply CLT[1] (175 mm thick, 91.4 kg/m²)

Connected wall assemblies:

- 5-ply CLT[1] (175 mm thick, 91.4 kg/m²)
- Terminating where they butt against the continuous wall assembly

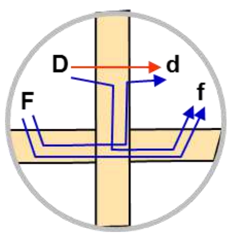
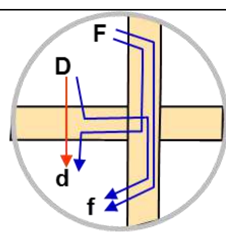
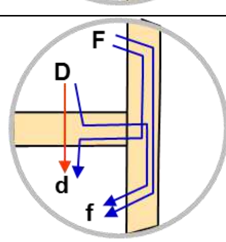
Junction:

- X-junction with two aligned CLT wall assemblies butted against opposite sides of the continuous CLT wall assembly, and fastened with 90 mm angle brackets spaced 600 mm o.c., or
- T-junction with one connected CLT assembly butted on one side of the continuous CLT wall assembly, and fastened with 90 mm angle brackets spaced 600 mm o.c.




Wall-Wall X-/T-junction for CLT constructions.

Horizontal section, not exactly to scale.

| Junction | Diagram | Path | Vibration Reduction Index, $K_{ij}$ |
|---|---|---|---|
| **CLT-WW-Xa-04**<br>Wall-Wall X-junction with continuous separating walls |  | Ff<br>Fd<br>Df | 15.6<br>9.3<br>9.3 |
| **CLT-WW-Xb-04**<br>Wall-Wall X-junction with continuous flanking walls |  | Ff<br>Fd<br>Df | 2.4<br>9.3<br>9.3 |
| **CLT-WW-Tb-04**<br>Wall-Wall T-junction with continuous flanking walls |  | Ff<br>Fd<br>Df | -0.7<br>10.1<br>10.1 |

(For the notes in this table please see the corresponding endnotes on page 115.)

## 3.4 Trends in Junction Attenuation for Wall-Wall Junctions

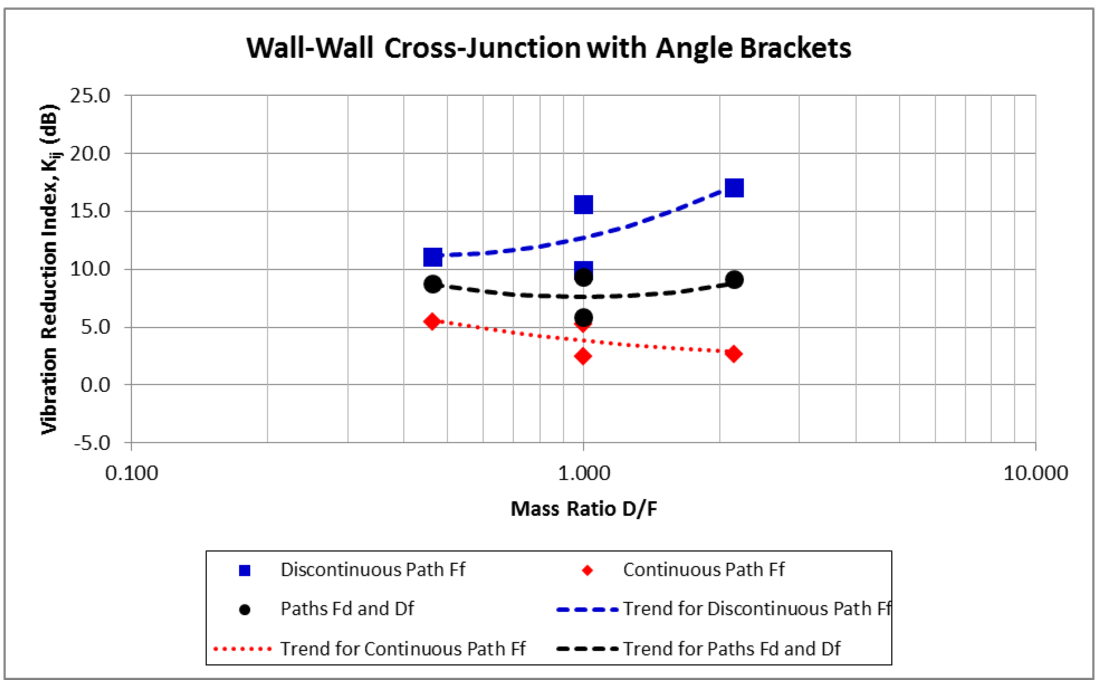
Only a limited selection of junction cases was tested:

- All tested cases had 3-ply CLT assemblies or 5-ply CLT assemblies or a combination of 3-ply and 5-ply CLT assemblies. None of the tested cases included 7-ply CLT assemblies. The process to partially compensate for this limited selection is discussed in Section 3.5.
- All of the wall/wall junctions included one wall which was continuous across the junction.
- Most wall/wall cases were tested with the same mechanical attachment using angle brackets (90 mm angle brackets spaced 600 mm on centre).
- One wall/wall junction was tested both with the assemblies mechanically attached using angle brackets and with the combination of the same mechanical attachment plus a construction adhesive.

### *Wall/Wall Cross-Junctions*

Although the small number of junctions evaluated limits the strength of some of the conclusions, a number of trends were observed in the mean $K_{ij}$ values shown in Figure 3.4.1.

**Figure 3.4.1**: The mean $K_{ij}$ values and best fit curves for cross-junctions using angle brackets.




The dashed lines are simple quadratic fits that pass through the mean of each pair of values with a mass ratio of D/F=1. These dashed lines which indicate the typical $K_{ij}$ values for the simple cross-junction case are used as reference curves in the following graph to facilitate comparisons between the graphs.

The mean $K_{ij}$ values fall in three distinct ranges, one for each type of transmission path:

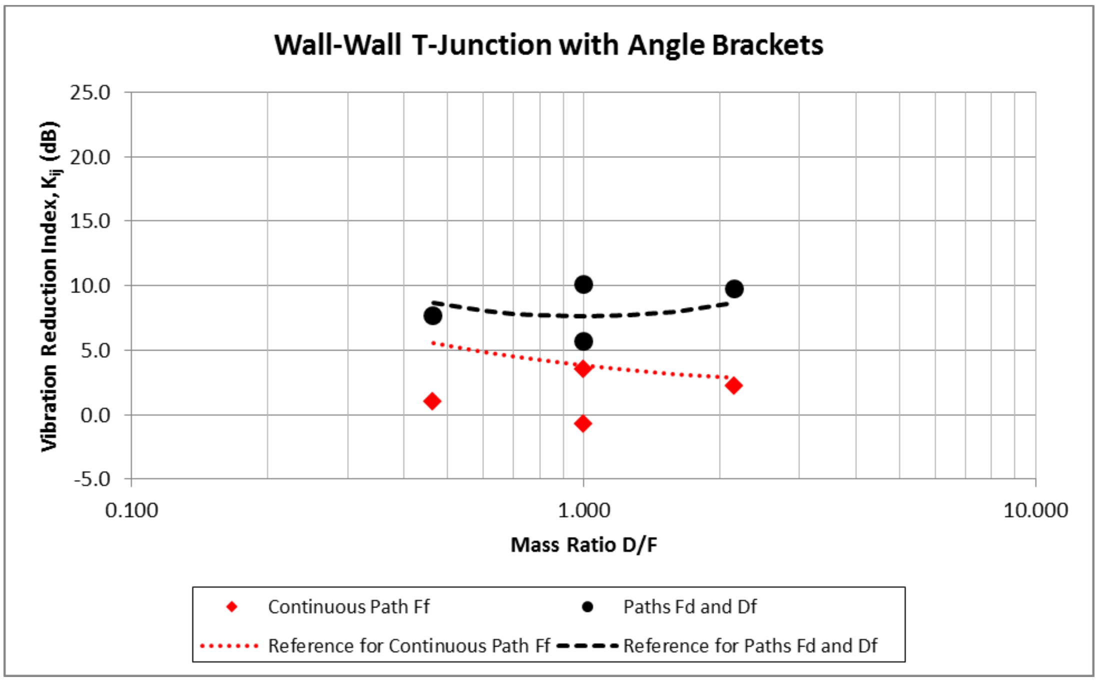
- The discontinuous wall/wall path (designated Ff for the case where part of the continuous wall separates the adjacent rooms and the two flanking walls are attached to the continuous wall) had the highest $K_{ij}$ values, indicating high attenuation and therefore a relatively weak connection.
- The continuous wall/wall path (designated Ff for the case where the continuous wall is a flanking wall for both adjacent rooms and one of the attached assemblies is the separating wall between the two rooms) had the lowest $K_{ij}$ values, indicating little attention through the junction and therefore a very effective connection for the transmission of structure-borne sound across the continuous wall assembly.
- The wall/wall paths Fd and Df fell midway between the other two cases.

Within each of these three sets of results, it is clear that the mass ratio does not fully account for trends in the mean $K_{ij}$ values. For each set, the two cases where the mass ratio is 1.0 are at or near the two extremes in the mean $K_{ij}$ values, indicating the importance of some other factor such as the angle bracket attachments for the different CLT assembly thicknesses.

## Comparison of Wall/Wall T-Junctions vs. Cross-Junctions

Some changes relative to the data for the wall/wall cross-junctions were evident in the data for the wall/wall T-junctions with the same basic attachment of the wall assemblies (90 mm angle brackets spaced 600 mm on centre attaching a wall assembly to one side of the continuous flanking wall near its midpoint), as shown in Figure 3.4.2.

**Figure 3.4.2:** Measured $K_{ij}$ values for each path for the T-junction cases with angle brackets attaching the wall assemblies. As a reference, the dashed curves show the trends for the corresponding cross-junction.




With the change from the cross-junction to the T-junction configuration, the mean $K_{ij}$ values for the continuous path Ff dropped slightly, but the values for paths Fd and Df were similar. Note that there is no discontinuous wall/wall path Ff for the T-junctions since the flanking wall was continuous for all the T-junctions that were evaluated.

Again, a strong difference was evident between the two cases with mass ratio equal to 1.0, but without data for junctions with CLT07 or heavier assemblies, a trend cannot be clearly established.

## 3.5 Extensions to Include Junction Cases That Have Not Been Tested

Additional test cases involving different combinations of CLT assemblies are needed to establish trends and permit useful interpolation.

It is clear from the results that the mean $K_{ij}$ values are affected by factors other than the ratio of the mass per unit area of the assemblies connected at a junction, especially for the case of wall/wall junctions. However, without further tests (including both heavier CLT assemblies and a broader range of mass ratios), the range of CLT wall and floor combinations for which one can predict overall ASTC is limited.

The effect of adding construction adhesive to bond the panel surfaces butted at a junction had a strong effect, but only one wall/wall case was tested. If such junctions are practical in on site construction, the significantly different mean $K_{ij}$ values might facilitate the use of exposed CLT surfaces in adjacent units.

# 4 Predicting Sound Transmission in CLT Buildings

This chapter presents calculation approaches for predicting the apparent sound transmission (apparent sound transmission loss, ATL, and apparent sound transmission class, ASTC) between adjacent rooms in a building. The calculation approaches use empirical calculation methods that combine laboratory measured data for the sound transmission loss of individual CLT wall and floor assemblies with vibration reduction index values measured on mock junctions between the CLT assemblies. The calculation approaches described in this chapter follow the procedures of the international standard, ISO 15712-1 [7].

All of the procedures presented here start from the concepts presented in Section 1.4 of this Report. The sound transmitted between two rooms is calculated from the combination of airborne sound transmission through the separating assembly and the structure-borne sound transmission via the set of first-order flanking paths at each of the edges of the separating assembly where it connects to the flanking assemblies.

Both the "Detailed Method" and the "Simplified Method" of ISO 15712-1 are presented.

- The **Detailed Method** uses frequency band data for sound transmission loss (TL and ΔTL) and vibration reduction index ($K_{ij}$) to determine the sound transmission via each transmission path (Dd, Ff, Fd, and Df). The method employs Equation 1.1 of this Report and yields the apparent sound transmission loss, ATL. From the apparent sound transmission loss for the standard set of frequency bands, the apparent sound transmission class, ASTC, can be calculated using the procedure described in ASTM E413.
- The **Simplified Method** is less rigorous than the Detailed Method, but also less complicated. It uses single-number values for sound transmission loss (STC and ΔSTC) and junction attenuation ($K_{ij}$) to determine the sound transmission via each transmission path (Dd, Ff, Fd, and Df). The method employs Equation 1.2 of this Report and directly yields the apparent sound transmission class, ASTC, but not the apparent sound transmission loss, ATL.
- For CLT constructions, the differences between the results of the two methods tend to be small, unless linings with a large ΔSTC value are used. In addition, the Simplified Method uses approximations that should ensure that the results are slightly more conservative than the results of the Detailed Method.

Section 4.1 describes the Simplified Method with a focus on CLT constructions. Section 4.2 presents worked examples that demonstrate the usage of the Simplified Method for CLT constructions. Section 4.3 describes the Detailed Method, and Section 4.4 includes worked examples using the Detailed Method.

## 4.1 Simplified Calculation Procedure for CLT Constructions

ISO 15712-1 presents a "Simplified model for structure-borne transmission" in Section 4.4 of the standard. This Simplified Method has some clearly stated limitations, and some implicit cautions:

ISO 15712-1 states that the application of the Simplified Method "is restricted to primarily homogeneous constructions", further restricted here to homogeneous lightly-damped structural assemblies. Here, "lightly-damped" implies a reverberant vibration field that can be characterized by a mean vibration level, and "homogeneous" implies similar bending stiffness in all directions across the surface. These definitions exclude wood-framed and steel-framed assemblies, but typical CLT wall or floor/ceiling assemblies are considered appropriate for the Simplified Method.

Within this restricted context, the Simplified Method has been structured to predict an ASTC which is slightly lower than that from the Detailed Method described in Section 4.3 of this Report.

The Simplified Method uses two main simplifications:

- The most significant simplification is that losses to connected assemblies are dealt with "in an average way", ignoring the variation of in-situ sound transmission loss due to edge losses to adjoining wall and floor constructions. This simplification eliminates much of the calculation process of the Detailed Method. Since the internal losses of CLT assemblies are high enough that the laboratory sound transmission loss can be used as in-situ sound transmission loss as described in Section 4.3, this simplification does not lead to a loss of accuracy for CLT constructions (unlike for less-damped constructions such as concrete or concrete block).
- The procedure uses only single-number quantities as input data, namely laboratory STC ratings for the wall and floor assemblies, ΔSTC values for any linings, and mean $K_{ij}$ values for the junction attenuation. The output of the calculations using the Simplified Method is the ASTC.

The Simplified Method predicts the overall ASTC, by following the steps in Figure 4.1.1, which are also explained in more detail below the figure.

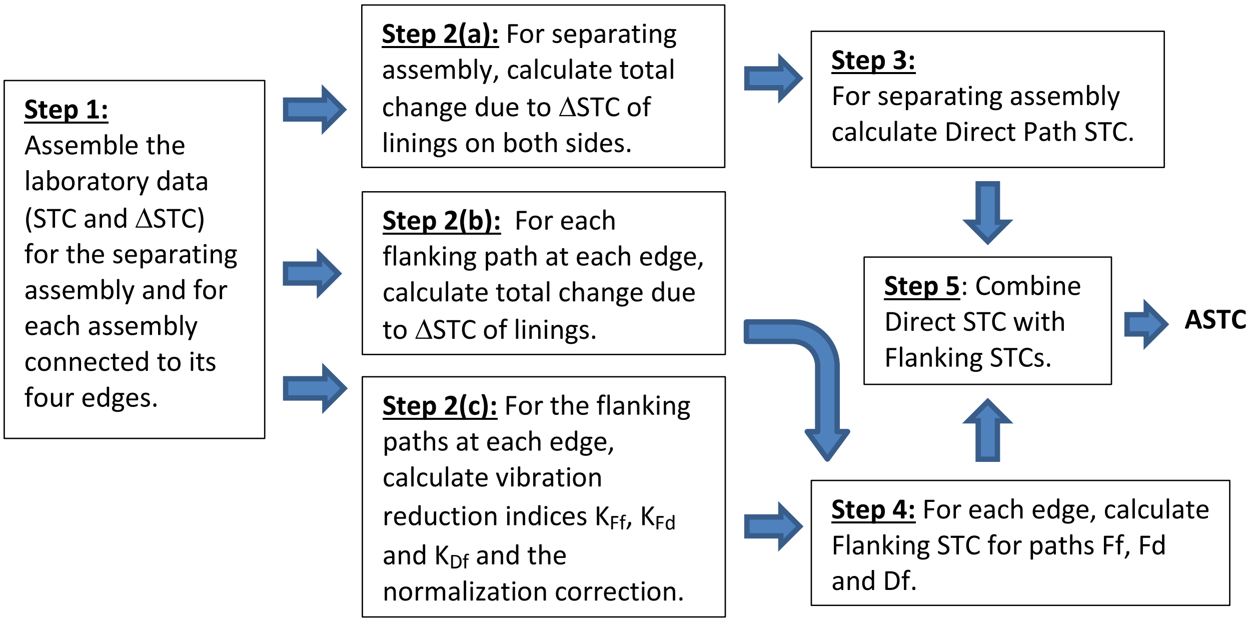



**Figure 4.1.1**: Steps to calculate the ASTC using the Simplified Method.

**Step 1**: Assemble the required laboratory test data for the constructions:

- Laboratory sound transmission class (STC) values based on direct sound transmission loss data measured according to ASTM E90 for the CLT floor or wall assemblies;
- Measured change in sound transmission class (ΔSTC) determined according to Sections 2.2 and 2.3 for each lining that will be added to the base floor or wall assemblies.

**Step 2:** Determine the correction terms as follows:

a) For linings on the separating assembly, the correction $\Delta STC_{Dd}$ is the sum of the larger of the ΔSTC values for these two linings plus half of the smaller ΔSTC value.

b) For each flanking path ij, the correction $\Delta STC_{ij}$ for linings on the source surface i and/or the receiving surface j is the sum of the larger of the ΔSTC values for these two linings plus half of the smaller ΔSTC value.

c) For each edge of the separating assembly, determine the vibration reduction indices $K_{Ff}$, $K_{Fd}$, and $K_{Df}$ for the flanking paths between the assembly in the source room (D or F) and the attached assembly in the receiving room (f or d) using the data in Chapter 3. Also calculate the normalization correction, which depends on the length of the flanking junction and the area of the separating assembly.

**Step 3**: Calculate the Direct STC for direct sound transmission through the separating assembly ($STC_{Dd}$) according to Eq. 27 of ISO 15712-1 (and Eq. 4.1.2 in this Report) using the laboratory STC rating for the Base CLT assembly plus any correction for linings $\Delta STC_{Dd}$ from Step 2(a).

**Step 4**: Calculate the Flanking STC for sound transmission via each pair of connected assemblies at each edge of the separating assembly according to Eq. 28a of ISO 15712-1 (and Eq. 4.1.3 in this Report) with the following inputs:

- laboratory STC rating for each Base CLT assembly plus lining correction $\Delta STC_{ij}$ from Step 2(b);
- $K_{ij}$ value and normalization correction for this path from Step 2(c).

**Step 5**: Combine the sound transmission via the direct and flanking paths, using Equation 1.2 in Section 1.4 of this Report (equivalent to Eq. 4.1.1 below and to Eq. 26 in Section 4.4 of ISO 15712-1).

## *Expressing the Process using Equations*

The ASTC rating between two rooms (neglecting sound that is by-passing the building structure, e.g. through leaks or ducts) is estimated using the Simplified Method from the logarithmic expression of the combination of the Direct STC rating ($STC_{Dd}$) of the separating wall or floor assembly and the combined Flanking STC ratings of the three flanking paths for every junction at the four edges of the separating assembly. This may be expressed as:

$$ASTC = -10\log_{10}\left[10^{-0.1\cdot STC_{Dd}} + \sum_{edge=1}^{4}\left(10^{-0.1\cdot STC_{Ff}} + 10^{-0.1\cdot STC_{Fd}} + 10^{-0.1\cdot STC_{Df}}\right)\right] \quad \text{Eq. 4.1.1}$$

Eq. 4.1.1 is appropriate for all types of building systems with the geometry of the Standard Scenario, and is applied here using the following expressions to calculate the transmission for each individual path:

- For the direct path, $STC_{Dd}$ is obtained according to Eq. 4.1.2 from the laboratory STC of the Base CLT assembly and the ΔSTC changes due to linings on source "D" and/or receiving side "d" of the separating assembly. This is the counterpart in ASTM metrics for Eq. 30 of ISO 15712-1.

$$STC_{Dd} = STC_{lab} + \max(\Delta STC_D, \Delta STC_d) + \frac{\min(\Delta STC_D, \Delta STC_d)}{2} \quad \text{Eq. 4.1.2}$$

- For each flanking path, $STC_{ij}$ is calculated using Eq. 4.1.3 where index i and j refer to the coupled flanking assemblies; thus, "i" can either be "D" or "F" and "j" can be "f" or "d". The geometric correction factor at the end depends on the surface area of the separating assembly ($S_s$) and the length of the junction between flanking and separating assemblies ($l_{ij}$), with $l_0$ = 1 m. Eq. 4.1.3 is the counterpart in ASTM metrics for Equations 28a and 31 of ISO 15712-1.

$$STC_{ij} = \frac{STC_i}{2} + \frac{STC_j}{2} + K_{ij} + \max(\Delta STC_i, \Delta STC_j) + \frac{\min(\Delta STC_i, \Delta STC_j)}{2} + 10\cdot\log_{10}\frac{S_S}{l_0\cdot l_{ij}} \quad \text{Eq. 4.1.3}$$

## 4.2 Examples of Calculating Sound Transmission using the Simplified Method

This section presents a number of worked examples that demonstrate the calculation of the ASTC rating of CLT constructions according to the Simplified Method described in Section 4.1. Each worked example in this section presents all the pertinent physical characteristics of the assemblies and junctions, together with a summary of key steps in the calculation process for these constructions.

Within the table for each worked example, the "References" column presents the source of input data (combining the NRC report number and identifier for each laboratory test result or derived result), or identifies applicable equations and sections of ISO 15712-1 at each stage of the calculation, or their counterparts using ASTM ratings as presented in Equations 4.1.1 to 4.1.3. Symbols and subscripts identifying the corresponding variable in ISO 15712-1 are given in the adjacent column.

Under the single heading "STC or ΔSTC", the examples present input data determined in laboratory tests according to ASTM E90, including:

- STC ratings for laboratory sound transmission loss data for wall or floor assemblies; and
- ΔSTC values measured in the laboratory for the change in STC due to adding a lining to the base wall or floor assembly.

Under the heading "STC or ASTC", the examples present the calculated values for sound transmission via specific paths, including:

- Direct STC ratings for the in-situ sound transmission through the separating assembly including linings;
- Flanking STC ratings for each flanking sound transmission path including the change due to linings;
- ASTC ratings for the combination of direct and flanking sound transmission paths.

When the calculated Flanking STC for a given path exceeds 90 dB, the value is limited to 90, to allow for the inevitable effect of higher-order flanking paths which make the higher calculated value not representative of the true situation. Further enhancements to elements in these paths will give negligible benefit. The consequence of this limit is that the Junction STC for the set of 3 paths at each edge of the separating assembly cannot exceed 85 and the Total Flanking STC for all 4 edges cannot exceed 79.

The numeric calculations present the arithmetic step-by-step in each worked example, using compact notation consistent with spreadsheet expressions:

- For the calculation of the Direct STC and the Flanking STC, these expressions are easily recognized as equivalent to Equations 4.1.2 and 4.1.3, respectively.

- For illustrating the combined sound power transmitted via specific paths, the calculation of Eq. 4.1.1 is broken down into several stages. Note that in the compact notation, a term for transmitted sound power fraction such as $10^{-0.1 \cdot TL_{ij}}$ becomes 10^-7.4, if $TL_{ij}$ =74.
- At each stage (such as the Flanking STC for a given junction) the result is converted into decibel form by calculating -10*$\log_{10}$( *transmitted sound power fraction* ), to facilitate comparison of each path or junction with the Direct STC and the final ASTC result.
- The ASTC rating is calculated from the combined sound power transmitted via the direct path and the 12 individual flanking paths.

The numbering of the tables presenting the worked examples end in an alphanumeric such as “H1” or “V2” to indicate Horizontal Case 1 (with rooms side-by-side) or Vertical Case 2 (with rooms one-above-the-other), respectively.

All examples conform to the Standard Scenario presented in Section 1.2 of this Report. The worked examples include both scenarios for CLT wall and floor assemblies without linings and scenarios where linings are included.

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**EXAMPLE 4.2-H1: (SIMPLIFIED METHOD)**

- **Rooms side-by-side**
- **Bare CLT Floors and CLT Walls**

Separating wall assembly (loadbearing) with:

- 3-ply 78 mm thick CLT[1] wall assembly with mass 42.4 kg/m$^2$, oriented so that face ply strands are vertical
- No added linings on either side

Junction 1: Bottom Junction (separating wall / floor) with:

- 5-ply 175 mm thick CLT[1] floor assembly with mass 92.1 kg/m$^2$, continuous through cross-junction with separating assembly and oriented so that face ply strands are perpendicular to the junction
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- No added topping or flooring

Junction 2 or 4: Each Side (separating wall / abutting side wall) with:

- 3-ply 78 mm thick CLT[1] wall assembly with mass 42.4 kg/m$^2$, continuous through T-junction with separating assembly and oriented so that face ply strands are vertical
- Connected with 90 mm equal leg angle brackets nailed/screwed at 600 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- No added linings

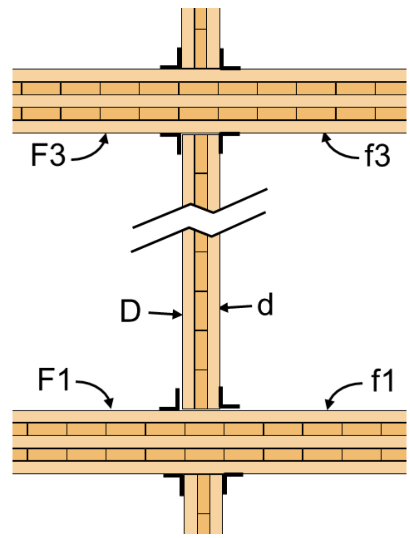
Junction 3: Top Junction (separating wall / ceiling) with:

- 5-ply 175 mm thick CLT[1] ceiling assembly with mass 92.1 kg/m$^2$, continuous through cross-junction with separating assembly and oriented so that face ply strands are perpendicular to the junction
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- No added ceiling lining

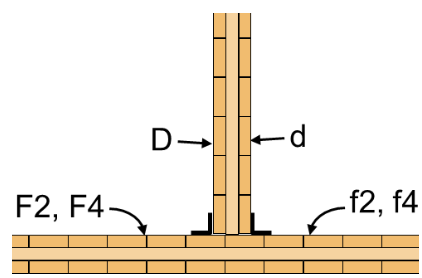
Acoustical Parameters:

| | | | | |
|---|---|---|---|---|
| Separating partition area ( m$^2$ ) = | | | 12.5 | |
| Floor/separating wall junction length ( m ) = | | | 5.0 | |
| Wall/separating wall junction length ( m ) = | | | 2.5 | |
| | Path Ff | Path Fd | Path Df | Reference |
| For Junctions 1 and 3: | | | | |
| Kij [dB] = | 1.1 | 10.5 | 10.5 | RR-335, CLT-WF-Xa-01 |
| 10*log(Sep. Area/Junction) = | 4.0 | | | or CLT-WC-Xa-01 |
| For Junctions 2 and 4: | | | | |
| Kij [dB] = | 3.5 | 5.7 | 5.7 | RR-335, CLT-WW-Tb-01 |
| 10*log(Sep. Area/Junction) = | 7.0 | | | |

Illustration for this case




Cross-junctions of 78 mm thick 3-ply CLT separating wall with 175 mm thick 5-ply CLT floor and ceiling. (Side view of Junctions 1 and 3)




T-junction of separating wall with side wall, both of 78 mm thick 3-ply CLT. (Plan view of Junctions 2 and 4)

(For the notes in this table please see the corresponding endnotes on page 115.)

| | ISO Symbol | Reference | STC or ΔSTC | STC or ASTC |
|---|---|---|---|---|
| **Separating Partition (78 mm 3-ply CLT)** | | | | |
| Laboratory STC for Dd | R_s,w | RR-335, Base CLT03 | 36 | |
| ΔSTC change by Lining on D | ΔR_D,w | No Lining | 0 | |
| ΔSTC change by Lining on d | ΔR_d,w | No Lining | 0 | |
| If airborne flanking or bare CLT | | RR-335, STC(Bare CLT03) - STC(Base CLT03) | -3 | |
| **Direct STC in-situ** | R_Dd,w | RR-335, Eq. 4.1.2 | 36 + MAX(0,0) + MIN(0,0)/2 + -3 = | **33** |
| | | | | |
| **Junction 1 (Cross-Junction, 78 mm 3-ply CLT Separating Wall / 175 mm 5-ply CLT Floor)** | | | | |
| Flanking Element F1: | | | | |
| Laboratory STC for F1 | R_F1,w | RR-335, Base CLT05-Mean | 42 | |
| ΔSTC change by Lining on F1 | ΔR_F1,w | No Lining | 0 | |
| Flanking Element f1: | | | | |
| Laboratory STC for f1 | R_f1,w | RR-335, Base CLT05-Mean | 42 | |
| ΔSTC change by Lining on f1 | ΔR_f1,w | No Lining | 0 | |
| **Flanking STC for path Ff_1** | R_ Ff,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 + MAX(0,0) + MIN(0,0)/2 + 1.1 + 4 = | **47** |
| **Flanking STC for path Fd_1** | R_ Fd,w | RR-335, Eq. 4.1.3 | 42/2 + 36/2 + MAX(0,0) + MIN(0,0)/2 + 10.5 + 4 = | **54** |
| **Flanking STC for path Df_1** | R_ Df,w | RR-335, Eq. 4.1.3 | 36/2 + 42/2 +MAX(0,0) + MIN(0,0)/2 + 10.5 + 4 = | **54** |
| **Junction 1: Flanking STC for all paths** | | Subset of Eq. 4.1.1 | - 10*LOG10(10^-4.7 + 10^- 5.4 + 10^- 5.4 ) = | 46 |
| | | | | |
| **Junction 2 (T-Junction, 78 mm 3-ply CLT Separating Wall / 78 mm 3-ply CLT Flanking Wall)** | | | | |
| Flanking Element F2: | | | | |
| Laboratory STC for F2 | R_F2,w | RR-335, Base CLT03 | 36 | |
| ΔSTC change by Lining on F2 | ΔR_F2,w | No Lining | 0 | |
| Flanking Element f2: | | | | |
| Laboratory STC for f2 | R_f2,w | RR-335, Base CLT03 | 36 | |
| ΔSTC change by Lining on f2 | ΔR_f2,w | No Lining | 0 | |
| **Flanking STC for path Ff_2** | R_ Ff,w | RR-335, Eq. 4.1.3 | 36/2 + 36/2 + MAX(0,0) + MIN(0,0)/2 + 3.5 + 7 = | **47** |
| **Flanking STC for path Fd_2** | R_ Fd,w | RR-335, Eq. 4.1.3 | 36/2 + 36/2 + MAX(0,0) + MIN(0,0)/2 + 5.7 + 7 = | **49** |
| **Flanking STC for path Df_2** | R_ Df,w | RR-335, Eq. 4.1.3 | 36/2 + 36/2 +MAX(0,0) + MIN(0,0)/2 + 5.7 + 7 = | **49** |
| **Junction 2: Flanking STC for all paths** | | Subset of Eq. 4.1.1 | - 10*LOG10(10^-4.7 + 10^- 4.9 + 10^- 4.9 ) = | 43 |
| | | | | |
| **Junction 3 (Cross-Junction, 78 mm 3-ply CLT Separating Wall / 175 mm 5-ply CLT Ceiling)** | | | | |
| Flanking Element F3: | | | | |
| Laboratory STC for F3 | R_F3,w | RR-335, Base CLT05-Mean | 42 | |
| ΔSTC change by Lining on F3 | ΔR_F3,w | No Lining | 0 | |
| Flanking Element f3: | | | | |
| Laboratory STC for f3 | R_f3,w | RR-335, Base CLT05-Mean | 42 | |
| ΔSTC change by Lining on f3 | ΔR_f3,w | No Lining | 0 | |
| **Flanking STC for path Ff_3** | R_ Ff,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 + MAX(0,0) + MIN(0,0)/2 + 1.1 + 4 = | **47** |
| **Flanking STC for path Fd_3** | R_ Fd,w | RR-335, Eq. 4.1.3 | 42/2 + 36/2 + MAX(0,0) + MIN(0,0)/2 + 10.5 + 4 = | **54** |
| **Flanking STC for path Df_3** | R_ Df,w | RR-335, Eq. 4.1.3 | 36/2 + 42/2 +MAX(0,0) + MIN(0,0)/2 + 10.5 + 4 = | **54** |
| **Junction 3: Flanking STC for all paths** | | Subset of Eq. 4.1.1 | - 10*LOG10(10^-4.7 + 10^- 5.4 + 10^- 5.4 ) = | 46 |
| | | | | |
| **Junction 4 (T-Junction, 78 mm 3-ply CLT Separating Wall / 78 mm 3-ply CLT Flanking Wall)** | | | | |
| Flanking Element F4: | | | | |
| Laboratory STC for F4 | R_F4,w | RR-335, Base CLT03 | 36 | |
| ΔSTC change by Lining on F4 | ΔR_F4,w | No Lining | 0 | |
| Flanking Element f4: | | | | |
| Laboratory STC for f4 | R_f4,w | RR-335, Base CLT03 | 36 | |
| ΔSTC change by Lining on f4 | ΔR_f4,w | No Lining | 0 | |
| **Flanking STC for path Ff_4** | R_ Ff,w | RR-335, Eq. 4.1.3 | 36/2 + 36/2 + MAX(0,0) + MIN(0,0)/2 + 3.5 + 7 = | **47** |
| **Flanking STC for path Fd_4** | R_ Fd,w | RR-335, Eq. 4.1.3 | 36/2 + 36/2 + MAX(0,0) + MIN(0,0)/2 + 5.7 + 7 = | **49** |
| **Flanking STC for path Df_4** | R_ Df,w | RR-335, Eq. 4.1.3 | 36/2 + 36/2 +MAX(0,0) + MIN(0,0)/2 + 5.7 + 7 = | **49** |
| **Junction 4: Flanking STC for all paths** | | Subset of Eq. 4.1.1 | - 10*LOG10(10^-4.7 + 10^- 4.9 + 10^- 4.9 ) = | 43 |
| | | | | |
| **Total Flanking STC (for all 4 junctions)** | | Subset of Eq. 4.1.1 | Combining 12 Flanking STC values: | 38 |
| **ASTC due to Direct plus Flanking Paths** | | Eq. 4.1.1 | **Combining Direct STC and 12 Flanking STC values:** | **32** |

**EXAMPLE 4.2-H2:** **(SIMPLIFIED METHOD)**

- **Rooms side-by-side**
- **CLT Floors and CLT Walls**
  **(Same as example 4.2-H1, plus linings)**

Separating wall assembly (loadbearing) with:
- 3-ply 78 mm thick CLT[1] wall assembly with mass 42.4 kg/$m^2$, oriented so that face ply strands are vertical
- Two layers of 12.7 mm gypsum board[3] supported on 38 x 38 mm wood furring spaced 600 mm o.c., absorptive material[2] in cavities

Junction 1: Bottom Junction (separating wall / floor) with:
- 5-ply 175 mm thick CLT[1] floor assembly with mass 92.1 kg/$m^2$, continuous through cross-junction with separating assembly and oriented so that face ply strands are perpendicular to the junction
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- Floor lining of 38 mm concrete over 13 mm wood fiber board

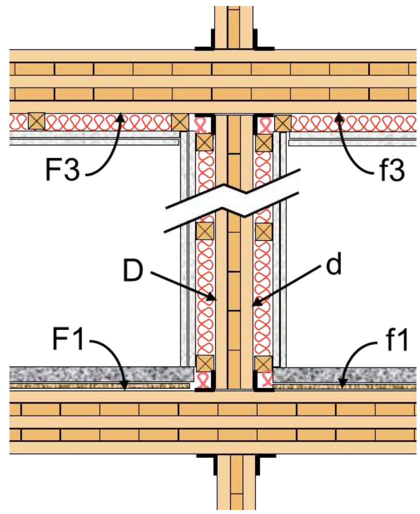
Junction 2 or 4: Each Side (separating wall / abutting side wall) with:
- 3-ply 78 mm thick CLT[1] wall assembly with mass 42.4 kg/$m^2$, continuous through T-junction with separating assembly and oriented so that face ply strands are vertical
- Connected with 90 mm equal leg angle brackets nailed/screwed at 600 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- Two layers of 12.7 mm gypsum board[3] supported on 38 x 38 mm wood furring spaced 600 mm o.c., absorptive material[2] in cavities

Junction 3: Top Junction (separating wall / ceiling) with:
- 5-ply 175 mm thick CLT[1] ceiling assembly with mass 92.1 kg/$m^2$, continuous through cross-junction with separating assembly and oriented so that face ply strands are perpendicular to the junction
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- Two layers of 12.7 mm gypsum board[3] supported on 38 x 38 mm wood furring spaced 600 mm o.c., absorptive material[2] in cavities

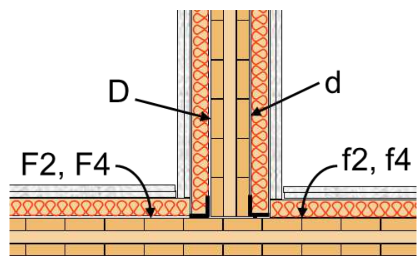
Acoustical Parameters:

| | | | | |
|---|---|---|---|---|
| Separating partition area ( $m^2$ ) = | | | 12.5 | |
| Floor/separating wall junction length ( m ) = | | | 5.0 | |
| Wall/separating wall junction length ( m ) = | | | 2.5 | |
| | | | | |
| | Path Ff | Path Fd | Path Df | Reference |
| For Junctions 1 and 3: | | | | |
| Kij [dB] = | 1.1 | 10.5 | 10.5 | RR-335, CLT-WF-Xa-01 |
| 10*log(Sep. Area/Junction) = | 4.0 | | | or CLT-WC-Xa-01 |
| For Junctions 2 and 4: | | | | |
| Kij [dB] = | 3.5 | 5.7 | 5.7 | RR-335, CLT-WW-Tb-01 |
| 10*log(Sep. Area/Junction) = | 7.0 | | | |

Illustration for this case




Cross-junctions of 78 mm thick 3-ply CLT separating wall with 150 mm thick 5-ply CLT floor and ceiling. (Side view of Junctions 1 and 3)




T-junction of separating wall with side wall, both of 78 mm thick 3-ply CLT. (Plan view of Junctions 2 and 4)

(For the notes in this table please see the corresponding endnotes on page 115.)

| | ISO Symbol | Reference | STC or ΔSTC | STC or ASTC |
|---|---|---|---|---|
| **Separating Partition (78 mm 3-ply CLT)** | | | | |
| Laboratory STC for Dd | R_s,w | RR-335, Base CLT03 | 36 | |
| ΔSTC change by Lining on D | ΔR_D,w | RR-335, ΔTL-CLT03-W03 | 9 | |
| ΔSTC change by Lining on d | ΔR_d,w | RR-335, ΔTL-CLT03-W03 | 9 | |
| If airborne flanking or bare CLT | | RR-335, STC(Bare CLT03) - STC(Base CLT03) | N/A | |
| **Direct STC in-situ** | R_Dd,w | RR-335, Eq. 4.1.2 | 36 + MAX(9,9) + MIN(9,9)/2 = | **50** |
| | | | | |
| **Junction 1 (Cross-Junction, 78 mm 3-ply CLT Separating Wall / 175 mm 5-ply CLT Floor)** | | | | |
| Flanking Element F1: | | | | |
| Laboratory STC for F1 | R_F1,w | RR-335, Base CLT05-Mean | 42 | |
| ΔSTC change by Lining on F1 | ΔR_F1,w | RR-335, ΔTL-CLT-F03 | 10 | |
| Flanking Element f1: | | | | |
| Laboratory STC for f1 | R_f1,w | RR-335, Base CLT05-Mean | 42 | |
| ΔSTC change by Lining on f1 | ΔR_f1,w | RR-335, ΔTL-CLT-F03 | 10 | |
| **Flanking STC for path Ff_1** | R_ Ff,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 + MAX(10,10) + MIN(10,10)/2 + 1.1 + 4 = | **62** |
| **Flanking STC for path Fd_1** | R_ Fd,w | RR-335, Eq. 4.1.3 | 42/2 + 36/2 + MAX(10,9) + MIN(10,9)/2 + 10.5 + 4 = | **68** |
| **Flanking STC for path Df_1** | R_ Df,w | RR-335, Eq. 4.1.3 | 36/2 + 42/2 +MAX(9,10) + MIN(9,10)/2 + 10.5 + 4 = | **68** |
| **Junction 1: Flanking STC for all paths** | | Subset of Eq. 4.1.1 | - 10*LOG10(10^-6.2 + 10^- 6.8 + 10^- 6.8 ) = | 60 |
| | | | | |
| **Junction 2 (T-Junction, 78 mm 3-ply CLT Separating Wall / 78 mm 3-ply CLT Flanking Wall)** | | | | |
| Flanking Element F2: | | | | |
| Laboratory STC for F2 | R_F2,w | RR-335, Base CLT03 | 36 | |
| ΔSTC change by Lining on F2 | ΔR_F2,w | RR-335, ΔTL-CLT03-W03 | 9 | |
| Flanking Element f2: | | | | |
| Laboratory STC for f2 | R_f2,w | RR-335, Base CLT03 | 36 | |
| ΔSTC change by Lining on f2 | ΔR_f2,w | RR-335, ΔTL-CLT03-W03 | 9 | |
| **Flanking STC for path Ff_2** | R_ Ff,w | RR-335, Eq. 4.1.3 | 36/2 + 36/2 + MAX(9,9) + MIN(9,9)/2 + 3.5 + 7 = | **60** |
| **Flanking STC for path Fd_2** | R_ Fd,w | RR-335, Eq. 4.1.3 | 36/2 + 36/2 + MAX(9,9) + MIN(9,9)/2 + 5.7 + 7 = | **62** |
| **Flanking STC for path Df_2** | R_ Df,w | RR-335, Eq. 4.1.3 | 36/2 + 36/2 +MAX(9,9) + MIN(9,9)/2 + 5.7 + 7 = | **62** |
| **Junction 2: Flanking STC for all paths** | | Subset of Eq. 4.1.1 | - 10*LOG10(10^-6 + 10^- 6.2 + 10^- 6.2 ) = | 56 |
| | | | | |
| **Junction 3 (Cross-Junction, 78 mm 3-ply CLT Separating Wall / 175 mm 5-ply CLT Ceiling)** | | | | |
| Flanking Element F3: | | | | |
| Laboratory STC for F3 | R_F3,w | RR-335, Base CLT05-Mean | 42 | |
| ΔSTC change by Lining on F3 | ΔR_F3,w | RR-335, ΔTL-CLT-C01 | 7 | |
| Flanking Element f3: | | | | |
| Laboratory STC for f3 | R_f3,w | RR-335, Base CLT05-Mean | 42 | |
| ΔSTC change by Lining on f3 | ΔR_f3,w | RR-335, ΔTL-CLT-C01 | 7 | |
| **Flanking STC for path Ff_3** | R_ Ff,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 + MAX(7,7) + MIN(7,7)/2 + 1.1 + 4 = | **58** |
| **Flanking STC for path Fd_3** | R_ Fd,w | RR-335, Eq. 4.1.3 | 42/2 + 36/2 + MAX(7,9) + MIN(7,9)/2 + 10.5 + 4 = | **66** |
| **Flanking STC for path Df_3** | R_ Df,w | RR-335, Eq. 4.1.3 | 36/2 + 42/2 +MAX(9,7) + MIN(9,7)/2 + 10.5 + 4 = | **66** |
| **Junction 3: Flanking STC for all paths** | | Subset of Eq. 4.1.1 | - 10*LOG10(10^-5.8 + 10^- 6.6 + 10^- 6.6 ) = | 57 |
| | | | | |
| **Junction 4 (T-Junction, 78 mm 3-ply CLT Separating Wall / 78 mm 3-ply CLT Flanking Wall)** | | | | |
| Flanking Element F4: | | | | |
| Laboratory STC for F4 | R_F4,w | RR-335, Base CLT03 | 36 | |
| ΔSTC change by Lining on F4 | ΔR_F4,w | RR-335, ΔTL-CLT-W03 | 9 | |
| Flanking Element f4: | | | | |
| Laboratory STC for f4 | R_f4,w | RR-335, Base CLT03 | 36 | |
| ΔSTC change by Lining on f4 | ΔR_f4,w | RR-335, ΔTL-CLT-W03 | 9 | |
| **Flanking STC for path Ff_4** | R_ Ff,w | RR-335, Eq. 4.1.3 | 36/2 + 36/2 + MAX(9,9) + MIN(9,9)/2 + 3.5 + 7 = | **60** |
| **Flanking STC for path Fd_4** | R_ Fd,w | RR-335, Eq. 4.1.3 | 36/2 + 36/2 + MAX(9,9) + MIN(9,9)/2 + 5.7 + 7 = | **62** |
| **Flanking STC for path Df_4** | R_ Df,w | RR-335, Eq. 4.1.3 | 36/2 + 36/2 +MAX(9,9) + MIN(9,9)/2 + 5.7 + 7 = | **62** |
| **Junction 4: Flanking STC for all paths** | | Subset of Eq. 4.1.1 | - 10*LOG10(10^-6 + 10^- 6.2 + 10^- 6.2 ) = | 56 |
| | | | | |
| **Total Flanking STC (for all 4 junctions)** | | Subset of Eq. 4.1.1 | Combining 12 Flanking STC values: | 51 |
| **ASTC due to Direct plus Flanking Paths** | | Eq. 4.1.1 | **Combining Direct STC and 12 Flanking STC values:** | **48** |

**EXAMPLE 4.2-H3: (SIMPLIFIED METHOD)**

- **Rooms side-by-side**
- **CLT Floors and CLT Walls**
  **(Same as example 4.2-H2, except enhanced linings)**

Separating wall assembly (loadbearing) with:

- 3-ply 78 mm thick CLT[1] wall assembly with mass 42.4 kg/m$^2$, oriented so that face ply strands are vertical
- Two layers of 12.7 mm gypsum board[3] on resilient metal channels[4] spaced 600 mm o.c., on 38 x 38 mm wood furring spaced 400 mm o.c. with absorptive material[2] in cavities

Junction 1: Bottom Junction (separating wall / floor) with:

- 5-ply 175 mm thick CLT[1] floor assembly with mass 92.1 kg/m$^2$, continuous through cross-junction with separating assembly and oriented so that face ply strands are perpendicular to the junction
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- Floor lining of 38 mm concrete over 13 mm wood fiber board

Junction 2 or 4: Each Side (separating wall / abutting side wall) with:

- 3-ply 78 mm thick CLT[1] wall assembly with mass 42.4 kg/m$^2$, continuous through T-junction with separating assembly and oriented so that face ply strands are vertical
- Connected with 90 mm equal leg angle brackets nailed/screwed at 600 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- Two layers of 12.7 mm gypsum board[3] supported on 38 x 38 mm wood furring spaced 600 mm o.c., absorptive material[2] in cavities

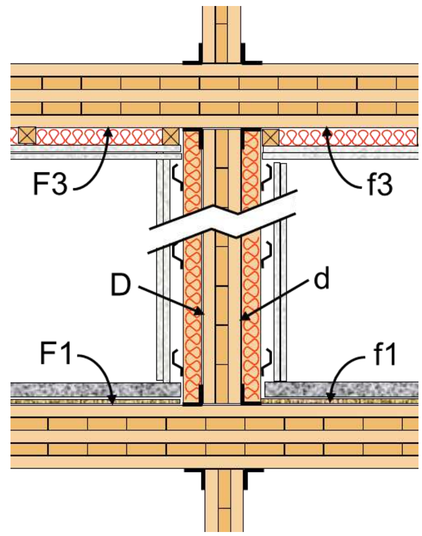
Junction 3: Top Junction (separating wall / ceiling) with:

- 5-ply 175 mm thick CLT[1] ceiling assembly with mass 92.1 kg/m$^2$, continuous through cross-junction with separating assembly and oriented so that face ply strands are perpendicular to the junction
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- Two layers of 12.7 mm gypsum board[3] supported on 38 x 38 mm wood furring spaced 600 mm o.c., absorptive material[2] in cavities

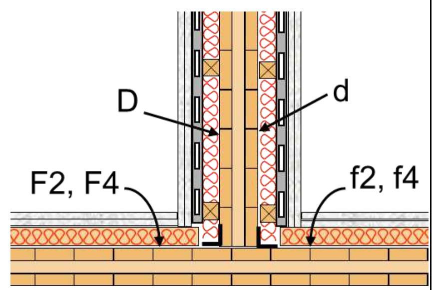
Acoustical Parameters:

| | | | | |
|---|---|---|---|---|
| Separating partition area ( m$^2$ ) = | | | 12.5 | |
| Floor/separating wall junction length ( m ) = | | | 5.0 | |
| Wall/separating wall junction length ( m ) = | | | 2.5 | |
| | Path Ff | Path Fd | Path Df | Reference |
| For Junctions 1 and 3: | | | | |
| Kij [dB] = | 1.1 | 10.5 | 10.5 | RR-335, CLT-WF-Xa-01 |
| 10*log(Sep. Area/Junction) = | 4.0 | | | or CLT-WC-Xa-01 |
| For Junctions 2 and 4: | | | | |
| Kij [dB] = | 3.5 | 5.7 | 5.7 | RR-335, CLT-WW-Tb-01 |
| 10*log(Sep. Area/Junction) = | 7.0 | | | |

Illustration for this case




Cross-junctions of 78 mm thick 3-ply CLT separating wall with 150 mm thick 5-ply CLT floor and ceiling.
(Side view of Junctions 1 and 3)




T-junction of separating wall with side wall, both of 78 mm thick 3-ply CLT.
(Plan view of Junctions 2 and 4)

(For the notes in this table please see the corresponding endnotes on page 115.)

| | ISO Symbol | Reference | | STC or ΔSTC | STC or ASTC |
|---|---|---|---|---|---|
| **Separating Partition (78 mm 3-ply CLT)** | | | | | |
| Laboratory STC for Dd | R_s,w | RR-335, Base CLT03 | | 36 | |
| ΔSTC change by Lining on D | ΔR_D,w | RR-335, ΔTL-CLT-W04 | | 15 | |
| ΔSTC change by Lining on d | ΔR_d,w | RR-335, ΔTL-CLT-W04 | | 15 | |
| If airborne flanking or bare CLT | | RR-335, STC(Bare CLT03) - STC(Base CLT03) | | N/A | |
| **Direct STC in-situ** | R_Dd,w | RR-335, Eq. 4.1.2 | 36 + MAX(15,15) + MIN(15,15)/2 = | | **59** |
| | | | | | |
| **Junction 1 (Cross-Junction, 78 mm 3-ply CLT Separating Wall / 175 mm 5-ply CLT Floor)** | | | | | |
| Flanking Element F1: | | | | | |
| Laboratory STC for F1 | R_F1,w | RR-335, Base CLT05-Mean | | 42 | |
| ΔSTC change by Lining on F1 | ΔR_F1,w | RR-335, ΔTL-CLT-F03 | | 10 | |
| Flanking Element f1: | | | | | |
| Laboratory STC for f1 | R_f1,w | RR-335, Base CLT05-Mean | | 42 | |
| ΔSTC change by Lining on f1 | ΔR_f1,w | RR-335, ΔTL-CLT-F03 | | 10 | |
| **Flanking STC for path Ff_1** | R_ Ff,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 + MAX(10,10) + MIN(10,10)/2 + 1.1 + 4 = | | **62** |
| **Flanking STC for path Fd_1** | R_ Fd,w | RR-335, Eq. 4.1.3 | 42/2 + 36/2 + MAX(10,15) + MIN(10,15)/2 + 10.5 + 4 = | | **74** |
| **Flanking STC for path Df_1** | R_ Df,w | RR-335, Eq. 4.1.3 | 36/2 + 42/2 +MAX(15,10) + MIN(15,10)/2 + 10.5 + 4 = | | **74** |
| **Junction 1: Flanking STC for all paths** | | Subset of Eq. 4.1.1 | - 10*LOG10(10^-6.2 + 10^- 7.4 + 10^- 7.4 ) = | | 61 |
| | | | | | |
| **Junction 2 (T-Junction, 78 mm 3-ply CLT Separating Wall / 78 mm 3-ply CLT Flanking Wall)** | | | | | |
| Flanking Element F2: | | | | | |
| Laboratory STC for F2 | R_F2,w | RR-335, Base CLT03 | | 36 | |
| ΔSTC change by Lining on F2 | ΔR_F2,w | RR-335, ΔTL-CLT03-W03 | | 9 | |
| Flanking Element f2: | | | | | |
| Laboratory STC for f2 | R_f2,w | RR-335, Base CLT03 | | 36 | |
| ΔSTC change by Lining on f2 | ΔR_f2,w | RR-335, ΔTL-CLT03-W03 | | 9 | |
| **Flanking STC for path Ff_2** | R_ Ff,w | RR-335, Eq. 4.1.3 | 36/2 + 36/2 + MAX(9,9) + MIN(9,9)/2 + 3.5 + 7 = | | **60** |
| **Flanking STC for path Fd_2** | R_ Fd,w | RR-335, Eq. 4.1.3 | 36/2 + 36/2 + MAX(9,15) + MIN(9,15)/2 + 5.7 + 7 = | | **68** |
| **Flanking STC for path Df_2** | R_ Df,w | RR-335, Eq. 4.1.3 | 36/2 + 36/2 +MAX(15,9) + MIN(15,9)/2 + 5.7 + 7 = | | **68** |
| **Junction 2: Flanking STC for all paths** | | Subset of Eq. 4.1.1 | - 10*LOG10(10^-6 + 10^- 6.8 + 10^- 6.8 ) = | | 59 |
| | | | | | |
| **Junction 3 (Cross-Junction, 78 mm 3-ply CLT Separating Wall / 175 mm 5-ply CLT Ceiling)** | | | | | |
| Flanking Element F3: | | | | | |
| Laboratory STC for F3 | R_F3,w | RR-335, Base CLT05-Mean | | 42 | |
| ΔSTC change by Lining on F3 | ΔR_F3,w | RR-335, ΔTL-CLT-C01 | | 7 | |
| Flanking Element f3: | | | | | |
| Laboratory STC for f3 | R_f3,w | RR-335, Base CLT05-Mean | | 42 | |
| ΔSTC change by Lining on f3 | ΔR_f3,w | RR-335, ΔTL-CLT-C01 | | 7 | |
| **Flanking STC for path Ff_3** | R_ Ff,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 + MAX(7,7) + MIN(7,7)/2 + 1.1 + 4 = | | **58** |
| **Flanking STC for path Fd_3** | R_ Fd,w | RR-335, Eq. 4.1.3 | 42/2 + 36/2 + MAX(7,15) + MIN(7,15)/2 + 10.5 + 4 = | | **72** |
| **Flanking STC for path Df_3** | R_ Df,w | RR-335, Eq. 4.1.3 | 36/2 + 42/2 +MAX(15,7) + MIN(15,7)/2 + 10.5 + 4 = | | **72** |
| **Junction 3: Flanking STC for all paths** | | Subset of Eq. 4.1.1 | - 10*LOG10(10^-5.8 + 10^- 7.2 + 10^- 7.2 ) = | | 58 |
| | | | | | |
| **Junction 4 (T-Junction, 78 mm 3-ply CLT Separating Wall / 78 mm 3-ply CLT Flanking Wall)** | | | | | |
| Flanking Element F4: | | | | | |
| Laboratory STC for F4 | R_F4,w | RR-335, Base CLT03 | | 36 | |
| ΔSTC change by Lining on F4 | ΔR_F4,w | RR-335, ΔTL-CLT03-W03 | | 9 | |
| Flanking Element f4: | | | | | |
| Laboratory STC for f4 | R_f4,w | RR-335, Base CLT03 | | 36 | |
| ΔSTC change by Lining on f4 | ΔR_f4,w | RR-335, ΔTL-CLT03-W03 | | 9 | |
| **Flanking STC for path Ff_4** | R_ Ff,w | RR-335, Eq. 4.1.3 | 36/2 + 36/2 + MAX(9,9) + MIN(9,9)/2 + 3.5 + 7 = | | **60** |
| **Flanking STC for path Fd_4** | R_ Fd,w | RR-335, Eq. 4.1.3 | 36/2 + 36/2 + MAX(9,15) + MIN(9,15)/2 + 5.7 + 7 = | | **68** |
| **Flanking STC for path Df_4** | R_ Df,w | RR-335, Eq. 4.1.3 | 36/2 + 36/2 +MAX(15,9) + MIN(15,9)/2 + 5.7 + 7 = | | **68** |
| **Junction 4: Flanking STC for all paths** | | Subset of Eq. 4.1.1 | - 10*LOG10(10^-6 + 10^- 6.8 + 10^- 6.8 ) = | | 59 |
| | | | | | |
| **Total Flanking STC (for all 4 junctions)** | | Subset of Eq. 4.1.1 | Combining all 12 Flanking STC values: | | 53 |
| | | | | | |
| **ASTC due to Direct plus Flanking Paths** | | Eq. 4.1.1 | **Combining Direct STC and 12 Flanking STC values:** | | **52** |

**EXAMPLE 4.2-V1: (SIMPLIFIED METHOD)**

- **Rooms one-above-the-other**
- **Bare CLT Floors and CLT Walls**

Separating floor assembly with:

- 5-ply 175 mm thick CLT[1] floor assembly with mass 92.1 kg/m², continuous through cross-junction with CLT wall assemblies at Junctions 1 and 3 and oriented so that face ply strands are perpendicular to loadbearing Junctions 1 and 3
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting wall assemblies
- No added linings (floor topping or ceiling)

Junction 1, 3 or 4: Separating floor / walls with:

- 5-ply 175 mm thick CLT[1] wall assembly with mass 94.1 kg/m², above and below cross-junctions with separating assembly that is continuous or lapped and glued across these junctions
- CLT wall assembly oriented so face ply strands are vertical
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to the wall assemblies and to the floor assembly
- No added lining on walls

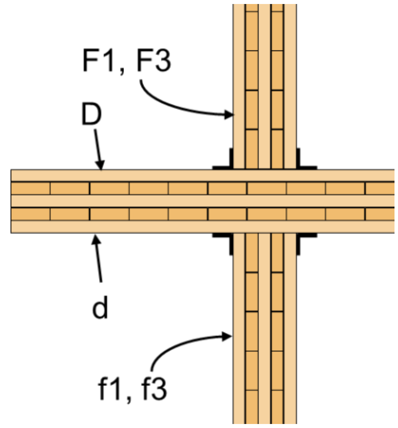
Junction 2: Separating floor / walls with:

- 5-ply 175 mm thick CLT[1] wall assembly with mass 94.1 kg/m², above and below T-junction with separating assembly that terminates at this junction
- CLT wall assembly oriented so face ply strands are vertical
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to one side of the wall assembly and to the abutting floor assemblies
- No added lining on walls

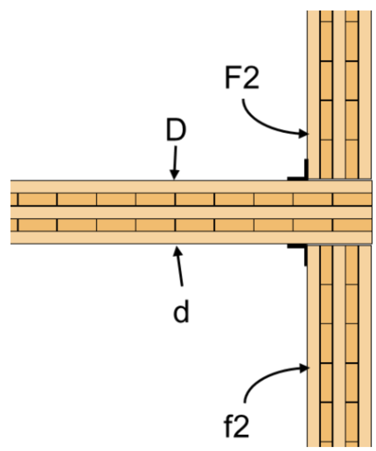
Acoustical Parameters:

| | | | | |
|---|---|---|---|---|
| Separating partition area ( $m^2$ ) = | | | 20.0 | |
| Wall/separating floor junction length ( m ) = | | | 5.0 | |
| Wall/separating floor junction length ( m ) = | | | 4.0 | |
| | | | | |
| | Path Ff | Path Fd | Path Df | Reference |
| For Junctions 1 and 3 and 4: | | | | |
| Kij [dB] = | 17.6 | 10.2 | 10.2 | RR-335, CLT-FW-Xa-05 |
| 10*log(Sep. Area/Junction) = | 6.0 | For Junctions 1 and 3 | | |
| 10*log(Sep. Area/Junction) = | 7.0 | For Junction 4 | | |
| For Junction 2: | | | | |
| Kij [dB] = | 12.9 | 6.8 | 6.8 | RR-335, CLT-FW-Ta-05 |
| 10*log(Sep. Area/Junction) = | 7.0 | | | |

Illustration for this case




Cross-junction of separating floor of continuous 175 mm thick 5-ply CLT with 5-ply CLT wall assemblies above and below.
(Side view of Junctions 1, 3 and 4, except orientation of floor assemblies differs for Junction 4)




T-junction of 175 mm thick 5-ply CLT floor with 5-ply CLT walls above and below.
(Side view of Junction 2)

(For the notes in this table please see the corresponding endnotes on page 115.)

| | ISO Symbol | Reference | STC or ΔSTC | STC or ASTC |
|---|---|---|---|---|
| **Separating Partition (175 mm 5-ply CLT)** | | | | |
| Laboratory STC for Dd | R_s,w | RR-335, Base CLT05-Mean | 42 | |
| ΔSTC change by Lining on D | ΔR_D,w | No Lining | 0 | |
| ΔSTC change by Lining on d | ΔR_d,w | No Lining | 0 | |
| If airborne flanking or bare CLT | | RR-335, STC(Bare CLT05) - STC(Base CLT05) | -1 | |
| **Direct STC in-situ** | R_Dd,w | RR-335, Eq. 4.1.2 | 42 + MAX(0,0) + MIN(0,0)/2 + -1 = | **41** |
| | | | | |
| **Junction 1 (Cross-Junction, 175 mm 5-ply CLT Separating Floor / 175 mm 5-ply CLT Wall)** | | | | |
| Flanking Element F1: | | | | |
| Laboratory STC for F1 | R_F1,w | RR-335, Base CLT05-Mean | 42 | |
| ΔSTC change by Lining on F1 | ΔR_F1,w | No Lining | 0 | |
| Flanking Element f1: | | | | |
| Laboratory STC for f1 | R_f1,w | RR-335, Base CLT05-Mean | 42 | |
| ΔSTC change by Lining on f1 | ΔR_f1,w | No Lining | 0 | |
| **Flanking STC for path Ff_1** | R_ Ff,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 + MAX(0,0) + MIN(0,0)/2 + 17.6 + 6 = | **66** |
| **Flanking STC for path Fd_1** | R_ Fd,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 + MAX(0,0) + MIN(0,0)/2 + 10.2 + 6 = | **58** |
| **Flanking STC for path Df_1** | R_ Df,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 +MAX(0,0) + MIN(0,0)/2 + 10.2 + 6 = | **58** |
| **Junction 1: Flanking STC for all paths** | | Subset of Eq. 4.1.1 | - 10*LOG10(10^-6.6 + 10^- 5.8 + 10^- 5.8 ) = | 55 |
| | | | | |
| **Junction 2 (T-Junction, 175 mm 5-ply CLT Separating Floor / 175 mm 5-ply CLT Wall)** | | | | |
| Flanking Element F2: | | | | |
| Laboratory STC for F2 | R_F2,w | RR-335, Base CLT05-Mean | 42 | |
| ΔSTC change by Lining on F2 | ΔR_F2,w | No Lining | 0 | |
| Flanking Element f2: | | | | |
| Laboratory STC for f2 | R_f2,w | RR-335, Base CLT05-Mean | 42 | |
| ΔSTC change by Lining on f2 | ΔR_f2,w | No Lining | 0 | |
| **Flanking STC for path Ff_2** | R_ Ff,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 + MAX(0,0) + MIN(0,0)/2 + 12.9 + 7 = | **62** |
| **Flanking STC for path Fd_2** | R_ Fd,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 + MAX(0,0) + MIN(0,0)/2 + 6.8 + 7 = | **56** |
| **Flanking STC for path Df_2** | R_ Df,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 +MAX(0,0) + MIN(0,0)/2 + 6.8 + 7 = | **56** |
| **Junction 2: Flanking STC for all paths** | | Subset of Eq. 4.1.1 | - 10*LOG10(10^-6.2 + 10^- 5.6 + 10^- 5.6 ) = | 52 |
| | | | | |
| **Junction 3 (Cross-Junction, 175 mm 5-ply CLT Separating Floor / 175 mm 5-ply CLT Wall)** | | | | |
| Flanking Element F3: | | | | |
| Laboratory STC for F3 | R_F3,w | RR-335, Base CLT05-Mean | 42 | |
| ΔSTC change by Lining on F3 | ΔR_F3,w | No Lining | 0 | |
| Flanking Element f3: | | | | |
| Laboratory STC for f3 | R_f3,w | RR-335, Base CLT05-Mean | 42 | |
| ΔSTC change by Lining on f3 | ΔR_f3,w | No Lining | 0 | |
| **Flanking STC for path Ff_3** | R_ Ff,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 + MAX(0,0) + MIN(0,0)/2 + 17.6 + 6 = | **66** |
| **Flanking STC for path Fd_3** | R_ Fd,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 + MAX(0,0) + MIN(0,0)/2 + 10.2 + 6 = | **58** |
| **Flanking STC for path Df_3** | R_ Df,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 +MAX(0,0) + MIN(0,0)/2 + 10.2 + 6 = | **58** |
| **Junction 3: Flanking STC for all paths** | | Subset of Eq. 4.1.1 | - 10*LOG10(10^-6.6 + 10^- 5.8 + 10^- 5.8 ) = | 55 |
| | | | | |
| **Junction 4 (Cross-Junction, 175 mm 5-ply CLT Separating Floor / 175 mm 5-ply CLT Wall)** | | | | |
| Flanking Element F4: | | | | |
| Laboratory STC for F4 | R_F4,w | RR-335, Base CLT05-Mean | 42 | |
| ΔSTC change by Lining on F4 | ΔR_F4,w | No Lining | 0 | |
| Flanking Element f4: | | | | |
| Laboratory STC for f4 | R_f4,w | RR-335, Base CLT05-Mean | 42 | |
| ΔSTC change by Lining on f4 | ΔR_f4,w | No Lining | 0 | |
| **Flanking STC for path Ff_4** | R_ Ff,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 + MAX(0,0) + MIN(0,0)/2 + 17.6 + 7 = | **67** |
| **Flanking STC for path Fd_4** | R_ Fd,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 + MAX(0,0) + MIN(0,0)/2 + 10.2 + 7 = | **59** |
| **Flanking STC for path Df_4** | R_ Df,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 +MAX(0,0) + MIN(0,0)/2 + 10.2 + 7 = | **59** |
| **Junction 4: Flanking STC for all paths** | | Subset of Eq. 4.1.1 | - 10*LOG10(10^-6.7 + 10^- 5.9 + 10^- 5.9 ) = | 56 |
| | | | | |
| **Total Flanking STC (for all 4 junctions)** | | Subset of Eq. 4.1.1 | Combining all 12 Flanking STC values: | 48 |
| | | | | |
| **ASTC due to Direct plus Flanking Paths** | | Eq. 4.1.1 | **Combining Direct STC and 12 Flanking STC values:** | **40** |

**EXAMPLE 4.2-V2: (SIMPLIFIED METHOD)**

- **Rooms one-above-the-other**
- **CLT Floors and CLT Walls**
  **(Same as example 4.2-V1, plus linings)**

Separating floor assembly with:

- 5-ply 175 mm thick CLT[1] floor assembly with mass 92.1 kg/m$^2$, continuous through cross-junction with CLT wall assemblies at Junctions 1 and 3 and oriented so that face ply strands are perpendicular to loadbearing Junctions 1 and 3
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting wall assemblies
- Floor lining of 38 mm concrete over 13 mm wood fiber board
- Ceiling lining of 15.9 mm gypsum board[3] fastened to hat-channels supported on cross-channels hung on wires, cavity of 150 mm between CLT and ceiling, with 140 mm absorptive material[2]

Junction 1, 3 or 4: (separating floor / flanking walls) with:

- 5-ply 175 mm thick CLT[1] wall assembly with mass 94.1 kg/m$^2$, above and below cross-junctions with separating assembly that is continuous or lapped and glued across these junctions
- CLT wall assembly oriented so face ply strands are vertical
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to the wall assemblies and to the floor assembly
- Two layers of 12.7 mm gypsum board[3] supported on 38 x 38 mm wood furring spaced 600 mm o.c., absorptive material[2] in cavities

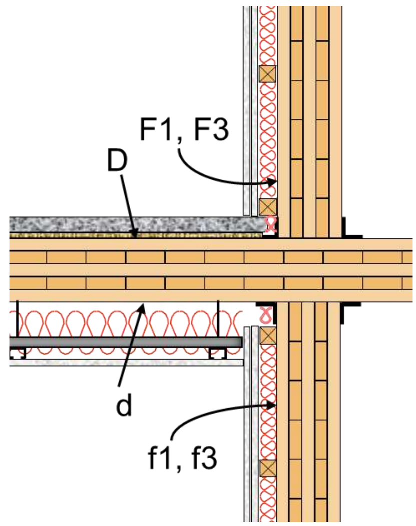
Junction 2: Each Side (separating floor / flanking walls) with:

- 5-ply 175 mm thick CLT[1] wall assembly with mass 94.1 kg/m$^2$, above and below T-junction with separating assembly that terminates at this junction
- CLT wall assembly oriented so face ply strands are vertical
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to one side of the wall assembly and to the abutting floor assemblies
- Two layers of 12.7 mm gypsum board[3] supported on 38 x 38 mm wood furring spaced 600 mm o.c., absorptive material[2] in cavities

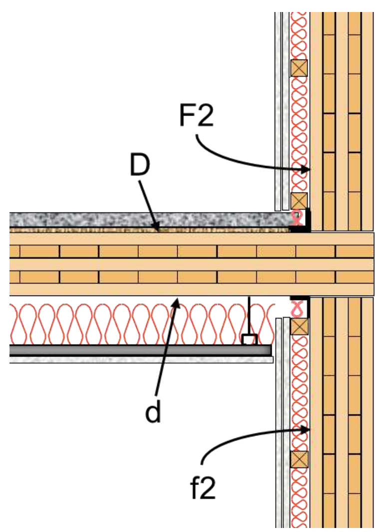
Acoustical Parameters:

| | | | | |
|---|---|---|---|---|
| Separating partition area ( m$^2$ ) = | 20.0 | | | |
| Wall/separating floor junction length ( m ) = | 5.0 | | | |
| Wall/separating floor junction length ( m ) = | 4.0 | | | |
| | | | | |
| | Path Ff | Path Fd | Path Df | Reference |
| For Junctions 1 and 3 and 4: | | | | |
| Kij [dB] = | 17.6 | 10.2 | 10.2 | RR-335, CLT-FW-Xa-05 |
| 10*log(Sep. Area/Junction) = | 6.0 | For Junctions 1 and 3 | | |
| 10*log(Sep. Area/Junction) = | 7.0 | For Junction 4 | | |
| | | | | |
| For Junction 2: | | | | |
| Kij [dB] = | 12.9 | 6.8 | 6.8 | RR-335, CLT-FW-Ta-05 |
| 10*log(Sep. Area/Junction) = | 7.0 | | | |

Illustration for this case




Cross-junction of separating floor of continuous 175 mm thick 5-ply CLT with 5-ply CLT walls above and below.
(Side view of Junctions 1, 3 and 4, except orientation of floor assemblies differs for Junction 4)




T-junction of 175 mm thick 5-ply CLT floor with 5-ply CLT walls above and below.
(Side view of Junction 2)

(For the notes in this table please see the corresponding endnotes on page 115.)

| | ISO Symbol | Reference | | STC or ΔSTC | STC or ASTC |
|---|---|---|---|---|---|
| **Separating Partition (175 mm 5-ply CLT)** | | | | | |
| Laboratory STC for Dd | R_s,w | RR-335, Base CLT05-Mean | | 42 | |
| ΔSTC change by Lining on D | ΔR_D,w | RR-335, ΔTL-CLT-F03 | | 10 | |
| ΔSTC change by Lining on d | ΔR_d,w | RR-335, ΔTL-CLT-C03 | | 25 | |
| If airborne flanking or bare CLT | | RR-335, STC(Bare CLT05) - STC(Base CLT05) | | N/A | |
| **Direct STC in-situ** | R_Dd,w | RR-335, Eq. 4.1.2 | 42 + MAX(10,25) + MIN(10,25)/2 = | | **72** |
| | | | | | |
| **Junction 1 (Cross-Junction, 175 mm 5-ply CLT Separating Floor / 175 mm 5-ply CLT Wall)** | | | | | |
| Flanking Element F1: | | | | | |
| Laboratory STC for F1 | R_F1,w | RR-335, Base CLT05-Mean | | 42 | |
| ΔSTC change by Lining on F1 | ΔR_F1,w | RR-335, ΔTL-CLT05-W03 | | 8 | |
| Flanking Element f1: | | | | | |
| Laboratory STC for f1 | R_f1,w | RR-335, Base CLT05-Mean | | 42 | |
| ΔSTC change by Lining on f1 | ΔR_f1,w | RR-335, ΔTL-CLT05-W03 | | 8 | |
| **Flanking STC for path Ff_1** | R_ Ff,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 + MAX(8,8) + MIN(8,8)/2 + 17.6 + 6 = | | **78** |
| **Flanking STC for path Fd_1** | R_ Fd,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 + MAX(8,25) + MIN(8,25)/2 + 10.2 + 6 = | | **87** |
| **Flanking STC for path Df_1** | R_ Df,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 +MAX(10,8) + MIN(10,8)/2 + 10.2 + 6 = | | **72** |
| **Junction 1: Flanking STC for all paths** | | Subset of Eq. 4.1.1 | - 10*LOG10(10^-7.8 + 10^- 8.7 + 10^- 7.2 ) = | | 71 |
| | | | | | |
| **Junction 2 (T-Junction, 175 mm 5-ply CLT Separating Floor / 175 mm 5-ply CLT Wall)** | | | | | |
| Flanking Element F2: | | | | | |
| Laboratory STC for F2 | R_F2,w | RR-335, Base CLT05-Mean | | 42 | |
| ΔSTC change by Lining on F2 | ΔR_F2,w | RR-335, ΔTL-CLT05-W03 | | 8 | |
| Flanking Element f2: | | | | | |
| Laboratory STC for f2 | R_f2,w | RR-335, Base CLT05-Mean | | 42 | |
| ΔSTC change by Lining on f2 | ΔR_f2,w | RR-335, ΔTL-CLT05-W03 | | 8 | |
| **Flanking STC for path Ff_2** | R_ Ff,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 + MAX(8,8) + MIN(8,8)/2 + 12.9 + 7 = | | **74** |
| **Flanking STC for path Fd_2** | R_ Fd,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 + MAX(8,25) + MIN(8,25)/2 + 6.8 + 7 = | | **85** |
| **Flanking STC for path Df_2** | R_ Df,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 +MAX(10,8) + MIN(10,8)/2 + 6.8 + 7 = | | **70** |
| **Junction 2: Flanking STC for all paths** | | Subset of Eq. 4.1.1 | - 10*LOG10(10^-7.4 + 10^- 8.5 + 10^- 7 ) = | | 68 |
| | | | | | |
| **Junction 3 (Cross-Junction, 175 mm 5-ply CLT Separating Floor / 175 mm 5-ply CLT Wall)** | | | | | |
| Flanking Element F3: | | | | | |
| Laboratory STC for F3 | R_F3,w | RR-335, Base CLT05-Mean | | 42 | |
| ΔSTC change by Lining on F3 | ΔR_F3,w | RR-335, ΔTL-CLT05-W03 | | 8 | |
| Flanking Element f3: | | | | | |
| Laboratory STC for f3 | R_f3,w | RR-335, Base CLT05-Mean | | 42 | |
| ΔSTC change by Lining on f3 | ΔR_f3,w | RR-335, ΔTL-CLT05-W03 | | 8 | |
| **Flanking STC for path Ff_3** | R_ Ff,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 + MAX(8,8) + MIN(8,8)/2 + 17.6 + 6 = | | **78** |
| **Flanking STC for path Fd_3** | R_ Fd,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 + MAX(8,25) + MIN(8,25)/2 + 10.2 + 6 = | | **87** |
| **Flanking STC for path Df_3** | R_ Df,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 +MAX(10,8) + MIN(10,8)/2 + 10.2 + 6 = | | **72** |
| **Junction 3: Flanking STC for all paths** | | Subset of Eq. 4.1.1 | - 10*LOG10(10^-7.8 + 10^- 8.7 + 10^- 7.2 ) = | | 71 |
| | | | | | |
| **Junction 4 (Cross-Junction, 175 mm 5-ply CLT Separating Floor / 175 mm 5-ply CLT Wall)** | | | | | |
| Flanking Element F4: | | | | | |
| Laboratory STC for F4 | R_F4,w | RR-335, Base CLT05-Mean | | 42 | |
| ΔSTC change by Lining on F4 | ΔR_F4,w | RR-335, ΔTL-CLT05-W03 | | 8 | |
| Flanking Element f4: | | | | | |
| Laboratory STC for f4 | R_f4,w | RR-335, Base CLT05-Mean | | 42 | |
| ΔSTC change by Lining on f4 | ΔR_f4,w | RR-335, ΔTL-CLT05-W03 | | 8 | |
| **Flanking STC for path Ff_4** | R_ Ff,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 + MAX(8,8) + MIN(8,8)/2 + 17.6 + 7 = | | **79** |
| **Flanking STC for path Fd_4** | R_ Fd,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 + MAX(8,25) + MIN(8,25)/2 + 10.2 + 7 = | | **88** |
| **Flanking STC for path Df_4** | R_ Df,w | RR-335, Eq. 4.1.3 | 42/2 + 42/2 +MAX(10,8) + MIN(10,8)/2 + 10.2 + 7 = | | **73** |
| **Junction 4: Flanking STC for all paths** | | Subset of Eq. 4.1.1 | - 10*LOG10(10^-7.9 + 10^- 8.8 + 10^- 7.3 ) = | | 72 |
| | | | | | |
| **Total Flanking STC (for all 4 junctions)** | | Subset of Eq. 4.1.1 | Combining all 12 Flanking STC values: | | 64 |
| | | | | | |
| **ASTC due to Direct plus Flanking Paths** | | Eq. 4.1.1 | **Combining Direct STC and 12 Flanking STC values:** | | **64** |

## *Summary for Section 4.2: Calculation Examples using the Simplified Method*

The worked examples (4.2-H1 to H3 and 4.2-V1 to V2) illustrate the use of the Simplified Method for calculating the sound transmission between rooms in a building with CLT floor and wall assemblies, with or without linings added to some or all of the walls and floors.

The examples show the performance for two cases with bare CLT assemblies without linings (Examples 4.2-H1 and 4.2-V1) and for three cases with improvements in direct and/or flanking sound transmission loss via specific paths due to the addition of some common types of linings using gypsum board, supporting framing, and absorptive material. Many other lining options are possible using the ΔSTC values for linings in Tables 2.2.2.1 to 2.2.2.3.

For a side-by-side pair of rooms, Examples 4.2-H2 and 4.2-H3 show typical improvements relative to Example 4.2-H1. Even with the rather light 3-ply CLT separating wall assembly, the addition of a gypsum board lining screwed directly to wood furring on all wall surfaces (Example 4.2-H2) brings the ASTC rating up to 48. Inspection of the path STC ratings in Example 4.2-H2 shows that direct sound transmission through the separating wall is dominant, and that flanking paths involving the surfaces of the separating wall are also significant. Improving these weak paths by adding resilient channels to the lining on the separating wall, raises the Direct STC to 59 and the overall ASTC rating to 52. Further improvement is possible but would require changes to all the flanking surfaces to raise the value above ASTC 60.

For a vertical room pair, Example 4.2-V2 shows the improvement relative to Example 4.2-V1 when some typical linings are added. Even with rather basic wall linings with ΔSTC = 8, the ASTC rating is increased to 64, and higher values could be achieved by better wall linings and/or improvements to the floor surface.

Section 4.4 presents worked examples for the same set of constructions presented in Section 4.2, but uses the Detailed Method for calculating the sound transmission between rooms. Comparison of the corresponding examples in the two sections provides a clear indication of the difference in results with the two calculation methods.

## 4.3 Detailed Calculation Procedure for CLT Constructions

Airborne sound in a source room excites vibration of the wall and floor assemblies that form the bounding surfaces of the room. As discussed in Chapter 1, the apparent sound transmission loss between adjacent rooms includes the combination of direct airborne sound transmission through the separating assembly and structure-borne flanking sound transmission via the three pairs of wall and floor surfaces (one in the source room and the other in the receiving room) that are connected at each of the four edges of the separating assembly. The detailed calculation process of ISO 15712-1 is focused on the balance between the input sound power and power losses (due to internal losses, sound radiation, and power flow into adjoining assemblies). This balance alters both direct sound transmission through each floor or wall assembly, and the strength of structure-borne sound transmission via the flanking surfaces.

The calculation process of the Detailed Method is designed for constructions involving heavy, homogeneous surfaces which support reverberant vibration fields. However, CLT assemblies differ in some meaningful ways from other heavy, homogenous constructions such as concrete floors or walls. Some issues specific to CLT are:

1. The internal loss factors for CLT assemblies are much higher than those typical of concrete and masonry (which range from 0.006 for solid concrete to 0.015 for typical concrete masonry). For CLT assemblies, measurements of the loss factors for laboratory wall and floor assemblies have established values of 0.03 or higher for most of the frequency range of interest (see Section 2.4 in this Report). This is above the threshold specified in ISO 15712-1 above which the effect of edge losses can be safely ignored, and hence there is no need to apply an absorption correction to obtain the in-situ sound transmission loss from the laboratory sound transmission loss in Equation 19 of ISO 15712-1. Thus, the direct sound transmission loss of the bare separating CLT wall or floor (and the in-situ sound transmission loss for each bare CLT flanking surface) is taken as equal to the laboratory sound transmission loss determined according to ASTM E90.
2. For flanking surfaces, Section 4.2.2 in ISO 15712-1 notes that only resonant sound transmission should be included. This requires a correction of the sound transmission loss measured in the laboratory below the critical frequency. For bare concrete and masonry assemblies, the critical frequency is below 125 Hz, so no correction to remove the non-resonant sound transmission is needed. For 3-ply CLT assemblies, the critical frequency is about 500 Hz, i.e. in the middle of the frequency range of interest when calculating the ASTC rating. Corrections to the laboratory sound transmission loss are therefore recommended at lower frequencies. Unfortunately, the current version of ISO 15712-1 does not specify a method to obtain the resonant sound transmission loss from the measured sound transmission loss. Hence, in the procedure below and in the worked examples in Section 4.4, the uncorrected laboratory sound transmission loss is used as input data. This should lead to conservative results, especially for the flanking sound transmission loss of thin 3-ply CLT assemblies.
3. Because the connections provided by angle brackets at CLT junctions are not consistent with the symmetric rigid junction assumptions of Annex E of ISO 15712-1 (which are suitable for mortar-

bonded junctions of concrete and masonry), the junction attenuation for a range of cases needs to be determined using measurements of junction transmission following the appropriate parts of ISO 10848, as discussed in Chapter 3 of this Report.

4. Because of the high internal losses in CLT assemblies, the equivalent absorption length $a_{situ}$ is set numerically equal to the surface area of the CLT assembly when calculating the velocity level difference from measured $K_{ij}$ values using Equation 21 of ISO 15712-1, following Section 4.2.2 of ISO 15712-1.

The input data required for the calculations include both laboratory sound transmission loss data measured according to ASTM E90 (for the Base CLT assemblies and for the change in sound transmission loss due to linings applied to these assemblies) and junction attenuation data measured according to ISO 10848.

The calculation process follows the steps illustrated in Figure 4.3.1, and explained in detail below.

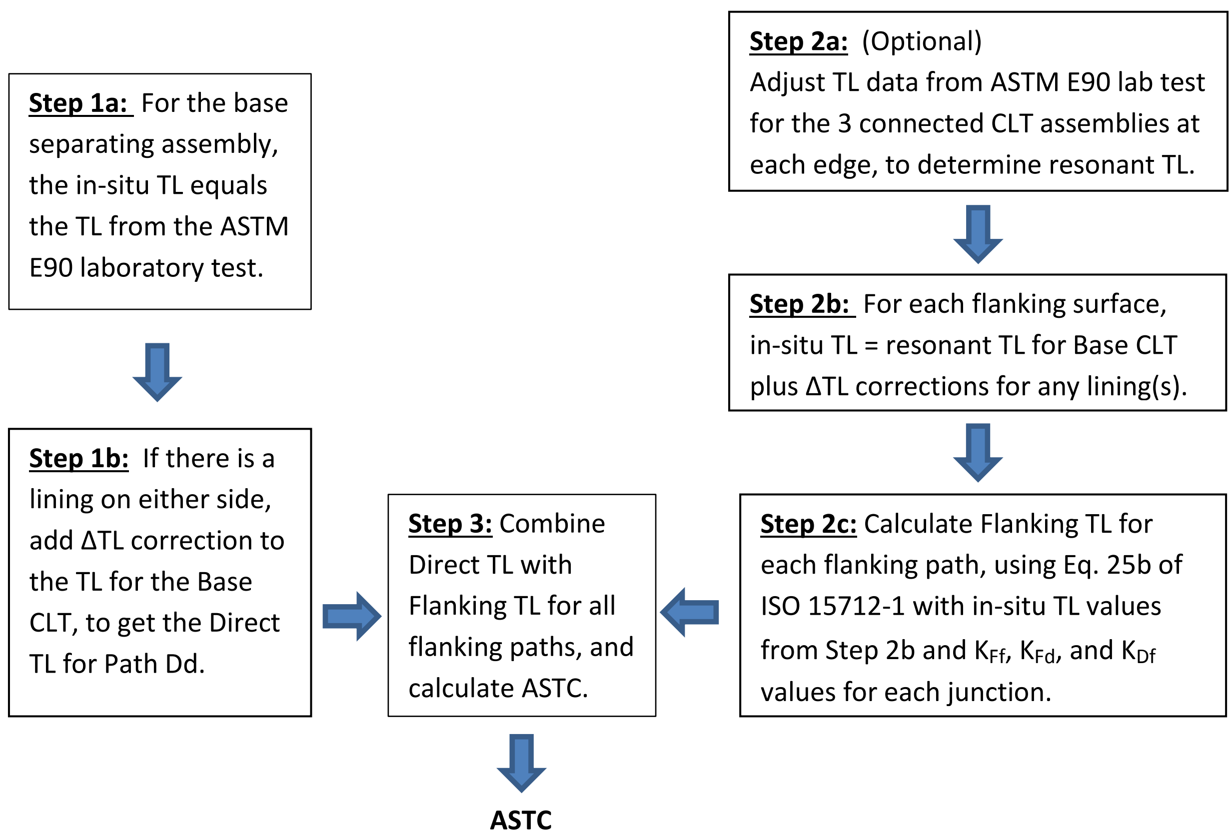



**Figure 4.3.1**: Steps to calculate the ASTC using the Detailed Method.

**Step 1:** Determine the sound transmission loss of the separating assembly (Direct TL):

(a) For the base separating assembly, the in-situ sound transmission loss for each frequency is equal to the sound transmission loss measured in the laboratory according to ASTM E90.

(b) Add ΔTL corrections obtained following the procedures of ASTM E90 for changes due to added lining(s) on the source room and/or receiving room side of the separating assembly (surfaces D and d) to obtain the Direct TL.

**Step 2:** Determine the sound transmission loss of the flanking assemblies (Flanking TL):

(a) For each flanking surface, use the laboratory sound transmission loss determined according to ASTM E90 as a conservative estimate of the resonant sound transmission loss. A correction to calculate the resonant sound transmission loss is recommended in ISO 15712-1, but not defined, and hence not used here. Set the equivalent absorption length for each surface numerically equal to the area of the CLT assembly, as required in Section 4.2.2 of ISO 15712-1.

(b) Add ΔTL corrections, obtained in accordance with ASTM E90 for changes due to adding a lining on a matching CLT assembly, to calculate the in-situ sound transmission loss values.

(c) For each flanking path, combine the values of the vibration reduction index ($K_{Ff}$, $K_{Fd}$, and $K_{Df}$ measured following the procedures of ISO 10848) with in-situ sound transmission loss values (including the change due to linings from Step 2b) using Eq. 25b of ISO 15712-1 to obtain the Flanking TL values.

**Step 3:** Calculate the Apparent TL by combining Direct TL and Flanking TL:

Combine the sound transmission via the direct path and the flanking paths, using Equation 1.1 in Chapter 1 of this Report (equivalent to Eq. 26 in Section 4.4 of ISO 15712-1), and calculate the ASTC rating using the combined sound transmission loss values as apparent transmission loss in the procedure of ASTM E413.

## 4.4 Examples of Calculating Sound Transmission using the Detailed Method

This section presents a number of worked examples that demonstrate the calculation of sound transmission in CLT constructions according to the Detailed Method described in Section 4.3. Each worked example presents all the pertinent physical characteristics of the assemblies and junctions, together with a summary of key steps in the calculation process for these constructions.

Within the table for each worked example, the "References" column presents the source of input data (combining the NRC report number and identifier for each laboratory test result or derived result), or identifies applicable equations and sections of ISO 15712-1 at each stage of the calculation. Symbols and subscripts identifying the corresponding variable in ISO 15712-1 are given in the adjacent column.

Under the single heading "STC or ASTC" the examples present single-number ratings at each step (calculated from a set of one-third octave band data according to the rules for STC ratings defined in ASTM E413) to provide a consistent set of summary measures at each stage of the calculation:

- STC ratings for laboratory sound transmission loss data for wall or floor assemblies;
- Direct STC ratings for the in-situ sound transmission through the separating assembly including linings;
- Flanking STC ratings for each flanking sound transmission path including the change due to linings;
- ASTC ratings for the combination of direct and flanking sound transmission paths.

Note that these STC ratings shown at each stage of the calculation are presented only to provide readers with a convenient indication of the relative strength of the 13 sound transmission paths. The actual calculation at each step is performed in the individual one-third octave bands, and at the final steps, the sound transmission loss values for the 13 paths are combined to arrive at the overall apparent sound transmission loss (ATL) for each frequency band. These one-third octave values of ATL are used as inputs to the calculation of ASTM E413 to determine the ASTC rating.

When the calculated Flanking TL for a given path exceeds 90 dB, the value is limited to 90, to allow for the inevitable effect of higher-order flanking paths which make the higher calculated value not representative of the true situation. Further enhancements to elements in these paths will give negligible benefit. The consequence of this 90 dB limit is that the Junction TL for the set of 3 paths at each edge of the separating assembly cannot exceed 85 and the Total Flanking TL for all 4 edges cannot exceed 79.

The tables present extracts from calculations performed with a more detailed spreadsheet that includes values for all the one-third octave bands from 125 Hz to 4 kHz. To condense the examples to 2-page format, the extracts here present just the single-number ratings (such as ASTC and Path STC) and a subset of the calculated values for some one-third octave frequency bands.

The numbering of the tables presenting the worked examples end in an alphanumeric such as “H1” or “V2” to indicate Horizontal Case 1 (with rooms side-by-side) or Vertical Case 2 (with rooms one-above-the-other), respectively.

All examples conform to the Standard Scenario presented in Section 1.2 of this Report. The worked examples include both scenarios for CLT wall and floor assemblies without linings and scenarios where linings are included, for the same set of cases presented in Section 4.2.

**EXAMPLE 4.4-H1: (DETAILED METHOD)**

- **Rooms side-by-side**
- **Bare CLT Floors and CLT Walls**

Separating wall assembly (loadbearing) with:

- 3-ply 78 mm thick CLT[1] wall assembly with mass 42.4 kg/m$^2$, oriented so that face ply strands are vertical
- No added linings on either side

Junction 1: Bottom Junction (separating wall / floor) with:

- 5-ply 175 mm thick CLT[1] floor assembly with mass 92.1 kg/m$^2$, continuous through cross-junction with separating assembly and oriented so that face ply strands are perpendicular to the junction
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- No added topping or flooring

Junction 2 or 4: Each Side (separating wall / abutting side wall) with:

- 3-ply 78 mm thick CLT[1] wall assembly with mass 42.4 kg/m$^2$, continuous through T-junction with separating assembly and oriented so that face ply strands are vertical
- Connected with 90 mm equal leg angle brackets nailed/screwed at 600 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- No added linings

Junction 3: Top Junction (separating wall / ceiling) with:

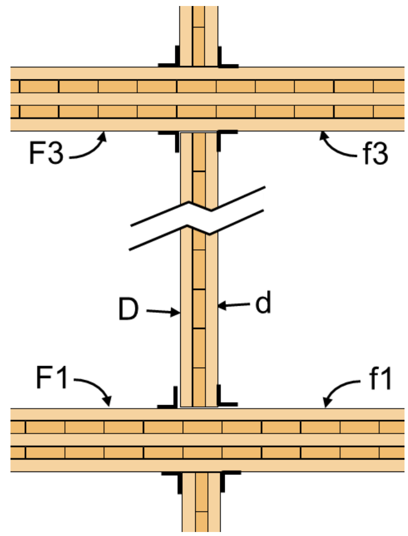
- 5-ply 175 mm thick CLT[1] ceiling assembly with mass 92.1 kg/m$^2$, continuous through cross-junction with separating assembly and oriented so that face ply strands are perpendicular to the junction
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- No added ceiling lining

Acoustical Parameters:

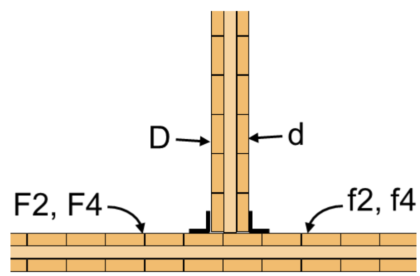
| | | | |
|---|---|---|---|
| Separating wall area ( m$^2$ ) = | 12.5 | Sep. wall internal loss, η_i = | >0.03 |
| Floor/sep. wall junction ( m ) = | 5.0 | Floor internal loss, η_i = | >0.03 |
| Wall/sep. wall junction ( m ) = | 2.5 | Flanking wall int. loss, η_i = | >0.03 |

| | Path Ff | Path Fd | Path Df | Reference |
|---|---|---|---|---|
| For Junctions 1 and 3: | | | | |
| Kij [dB] = | 1.1 | 10.5 | 10.5 | RR-335, CLT-WF-Xa-01 |
| 10*log(Sep. Area/Junction) = | 4.0 | | | or CLT-WC-Xa-01 |
| For Junctions 2 and 4: | | | | |
| Kij [dB] = | 3.5 | 5.7 | 5.7 | RR-335, CLT-WW-Tb-01 |
| 10*log(Sep. Area/Junction) = | 7.0 | | | |

Illustration for this case




Cross-junctions of 78 mm thick 3-ply CLT separating wall with 175 mm thick 5-ply CLT floor and ceiling. (Side view of Junctions 1 and 3)




T-junction of separating wall with side wall, both of 78 mm thick 3-ply CLT. (Plan view of Junctions 2 and 4)

(For the notes in this table please see the corresponding endnotes on page 115.)

| | ISO Symbol | Reference | 125 | 250 | 500 | 1000 | 2000 | 4000 | STC or ASTC |
|---|---|---|---|---|---|---|---|---|---|
| **Separating Partition (78 mm 3-ply CLT)** | | | | | | | | | |
| Laboratory Transmission Loss | R_D,lab | RR-335, Base CLT03 | 26 | 28 | 31 | 37 | 46 | 50 | 36 |
| Correction Resonant Transmission | | N/A | 0 | 0 | 0 | 0 | 0 | 0 | |
| ΔTL change by Lining on D | ΔR_D | No Lining | 0 | 0 | 0 | 0 | 0 | 0 | |
| ΔTL change by Lining on d | ΔR_d | No Lining | 0 | 0 | 0 | 0 | 0 | 0 | |
| If airborne flanking or bare CLT | | RR-335, TL(Bare CLT03) - TL(Base CLT03) | -1 | -3 | -3 | -3 | -4 | -1 | |
| **Direct TL in-situ** | R_D,situ | ISO 15712-1, Eq. 24 | **25** | **25** | **28** | **34** | **42** | **49** | **33** |
| | | | | | | | | | |
| **Junction 1 (Cross-Junction, 78 mm 3-ply CLT Separating Wall / 175 mm 5-ply CLT Floor)** | | | | | | | | | |
| **Transmission Loss of Flanking Elements** | | | | | | | | | |
| TL of element F1, laboratory | R_F1,lab | RR-335, Base CLT05 | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| TL of element f1, laboratory | R_f1,lab | RR-335, Base CLT05 | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| Correction Resonant Transmission F1 | | N/A | 0 | 0 | 0 | 0 | 0 | 0 | |
| Correction Resonant Transmission f1 | | N/A | 0 | 0 | 0 | 0 | 0 | 0 | |
| TL of element F1, in-situ | R_F1,situ | ISO 15712-1, Eq. 19, T_s,situ = T_s,lab | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| TL of element f1, in-situ | R_f1,situ | ISO 15712-1, Eq. 19, T_s,situ = T_s,lab | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| ΔTL change by Lining on F | ΔR_F1 | No Lining | 0 | 0 | 0 | 0 | 0 | 0 | |
| ΔTL change by Lining on f | ΔR_f1 | No Lining | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | | | | | | | | |
| **Junction Coupling** | | | | | | | | | |
| Vibration Reduction Index for Ff | K_Ff,1 | RR-335, CLT-WF-Xa-01 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | |
| Vibration Reduction Index for Fd | K_Fd,1 | RR-335, CLT-WF-Xa-01 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | |
| Vibration Reduction Index for Df | K_Df,1 | RR-335, CLT-WF-Xa-01 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | |
| | | | | | | | | | |
| **Flanking Transmission Loss** | | | | | | | | | |
| **Flanking TL for path Ff_1** | R_ Ff | ISO 15712-1, Eq. 25b | **37** | **35** | **44** | **48** | **57** | **54** | **47** |
| **Flanking TL for path Fd_1** | R_ Fd | ISO 15712-1, Eq. 25b | **44** | **44** | **50** | **55** | **64** | **64** | **54** |
| **Flanking TL for path Df_1** | R_ Df | ISO 15712-1, Eq. 25b | **44** | **44** | **50** | **55** | **64** | **64** | **54** |
| **Junction 1: Flanking TL for all paths** | | | 36 | 34 | 42 | 47 | 56 | 53 | 46 |
| | | | | | | | | | |
| **Junction 2 (T-Junction, 78 mm 3-ply CLT Separating Wall / 78 mm 3-ply CLT Flanking Wall)** | | | | | | | | | |
| **Transmission Loss of Flanking Elements** | | | | | | | | | |
| TL of element F2, laboratory | R_F2,lab | RR-335, Base CLT03 | 26 | 28 | 31 | 37 | 46 | 50 | 36 |
| TL of element f2, laboratory | R_f2,lab | RR-335, Base CLT03 | 26 | 28 | 31 | 37 | 46 | 50 | 36 |
| Correction Resonant Transmission F2 | | N/A | 0 | 0 | 0 | 0 | 0 | 0 | |
| Correction Resonant Transmission f2 | | N/A | 0 | 0 | 0 | 0 | 0 | 0 | |
| TL of element F2, in-situ | R_F2,situ | ISO 15712-1, Eq. 19, T_s,situ = T_s,lab | 26 | 28 | 31 | 37 | 46 | 50 | 36 |
| TL of element f2, in-situ | R_f2,situ | ISO 15712-1, Eq. 19, T_s,situ = T_s,lab | 26 | 28 | 31 | 37 | 46 | 50 | 36 |
| ΔTL change by Lining on F | ΔR_F2 | No Lining | 0 | 0 | 0 | 0 | 0 | 0 | |
| ΔTL change by Lining on f | ΔR_f2 | No Lining | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | | | | | | | | |
| **Junction Coupling** | | | | | | | | | |
| Vibration Reduction Index for Ff | K_Ff,2 | RR-335, CLT-WW-Tb-01 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | |
| Vibration Reduction Index for Fd | K_Fd,2 | RR-335, CLT-WW-Tb-01 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 | |
| Vibration Reduction Index for Df | K_Df,2 | RR-335, CLT-WW-Tb-01 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 | |
| | | | | | | | | | |
| **Flanking Transmission Loss** | | | | | | | | | |
| **Flanking TL for path Ff_2** | R_ Ff | ISO 15712-1, Eq. 25b | **37** | **39** | **42** | **48** | **57** | **61** | **47** |
| **Flanking TL for path Fd_2** | R_ Fd | ISO 15712-1, Eq. 25b | **39** | **41** | **44** | **50** | **59** | **63** | **49** |
| **Flanking TL for path Df_2** | R_ Df | ISO 15712-1, Eq. 25b | **39** | **41** | **44** | **50** | **59** | **63** | **49** |
| **Junction 2: Flanking TL for all paths** | | | 33 | 35 | 38 | 44 | 53 | 57 | 43 |
| | | | | | | | | | |
| **Junction 3 (Cross-Junction, 78 mm 3-ply CLT Separating Wall / 175 mm 5-ply CLT Ceiling)** | | | | | | | | | |
| All values the same as for Junction 1 | | | | | | | | | |
| **Flanking TL for path Ff_3** | R_ Ff | ISO 15712-1, Eq. 25b | **37** | **35** | **44** | **48** | **57** | **54** | **47** |
| **Flanking TL for path Fd_3** | R_ Fd | ISO 15712-1, Eq. 25b | **44** | **44** | **50** | **55** | **64** | **64** | **54** |
| **Flanking TL for path Df_3** | R_ Df | ISO 15712-1, Eq. 25b | **44** | **44** | **50** | **55** | **64** | **64** | **54** |
| **Junction 3: Flanking TL for all paths** | | | 36 | 34 | 42 | 47 | 56 | 53 | 46 |
| | | | | | | | | | |
| **Junction 4 (T-Junction, 78 mm 3-ply CLT Separating Wall / 78 mm 3-ply CLT Flanking Wall)** | | | | | | | | | |
| All values the same as for Junction 2 | | | | | | | | | |
| **Flanking TL for path Ff_4** | R_ Ff | ISO 15712-1, Eq. 25b | **37** | **39** | **42** | **48** | **57** | **61** | **47** |
| **Flanking TL for path Fd_4** | R_ Fd | ISO 15712-1, Eq. 25b | **39** | **41** | **44** | **50** | **59** | **63** | **49** |
| **Flanking TL for path Df_4** | R_ Df | ISO 15712-1, Eq. 25b | **39** | **41** | **44** | **50** | **59** | **63** | **49** |
| **Junction 4: Flanking TL for all paths** | | | 33 | 35 | 38 | 44 | 53 | 57 | 43 |
| | | | | | | | | | |
| **Total Flanking (for all 4 junctions)** | | | 28 | 29 | 34 | 39 | 48 | 49 | 38 |
| | | | | | | | | | |
| **ASTC due to Direct plus Flanking Paths** | | RR-335, Eq. 1.1 | **23** | **23** | **27** | **33** | **41** | **46** | **32** |

**EXAMPLE 4.4-H2: (DETAILED METHOD)**

- **Rooms side-by-side**
- **CLT Floors and CLT Walls**
  **(Same as example 4.4-H1, plus linings)**

Separating wall assembly (loadbearing) with:

- 3-ply 78 mm thick CLT[1] wall assembly with mass 42.4 kg/$m^2$, oriented so that face ply strands are vertical
- Two layers of 12.7 mm gypsum board[3] supported on 38 x 38 mm wood furring spaced 600 mm o.c., absorptive material[2] in cavities

Junction 1: Bottom Junction (separating wall / floor) with:

- 5-ply 175 mm thick CLT[1] floor assembly with mass 92.1 kg/$m^2$, continuous through cross-junction with separating assembly and oriented so that face ply strands are perpendicular to the junction
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- Floor lining of 38 mm concrete over 13 mm wood fiber board

Junction 2 or 4: Each Side (separating wall / abutting side wall) with:

- 3-ply 78 mm thick CLT[1] wall assembly with mass 42.4 kg/$m^2$, continuous through T-junction with separating assembly and oriented so that face ply strands are vertical
- Connected with 90 mm equal leg angle brackets nailed/screwed at 600 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- Two layers of 12.7 mm gypsum board[3] supported on 38 x 38 mm wood furring spaced 600 mm o.c., absorptive material[2] in cavities

Junction 3: Top Junction (separating wall / ceiling) with:

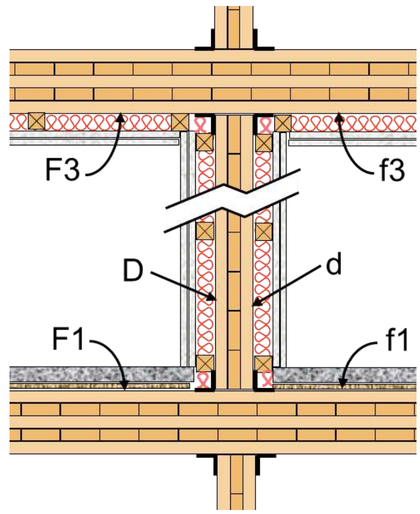
- 5-ply 175 mm thick CLT[1] ceiling assembly with mass 92.1 kg/$m^2$, continuous through cross-junction with separating assembly and oriented so that face ply strands are perpendicular to the junction
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- Two layers of 12.7 mm gypsum board[3] supported on 38 x 38 mm wood furring spaced 600 mm o.c., absorptive material[2] in cavities

Acoustical Parameters:

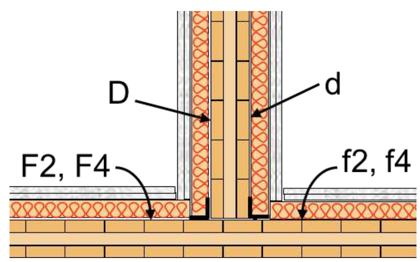
| | | | |
|---|---|---|---|
| Separating wall area ( $m^2$ ) = | 12.5 | Sep. wall internal loss, η_i = | >0.03 |
| Floor/sep. wall junction ( m ) = | 5.0 | Floor internal loss, η_i = | >0.03 |
| Wall/sep. wall junction ( m ) = | 2.5 | Flanking wall int. loss, η_i = | >0.03 |

| | Path Ff | Path Fd | Path Df | Reference |
|---|---|---|---|---|
| For Junctions 1 and 3: | | | | |
| Kij [dB] = | 1.1 | 10.5 | 10.5 | RR-335, CLT-WF-Xa-01 |
| 10*log(Sep. Area/Junction) = | 4.0 | | | or CLT-WC-Xa-01 |
| For Junctions 2 and 4: | | | | |
| Kij [dB] = | 3.5 | 5.7 | 5.7 | RR-335, CLT-WW-Tb-01 |
| 10*log(Sep. Area/Junction) = | 7.0 | | | |

Illustration for this case




Cross-junctions of 78 mm thick 3-ply CLT separating wall with 150 mm thick 5-ply CLT floor and ceiling. (Side view of Junctions 1 and 3)




T-junction of separating wall with side wall, both of 78 mm thick 3-ply CLT. (Plan view of Junctions 2 and 4)

(For the notes in this table please see the corresponding endnotes on page 115.)

| | ISO Symbol | Reference | 125 | 250 | 500 | 1000 | 2000 | 4000 | STC or ASTC |
|---|---|---|---|---|---|---|---|---|---|
| **Separating Partition (78 mm 3-ply CLT)** | | | | | | | | | |
| Laboratory Transmission Loss | R_D,lab | RR-335, Base CLT03 | 26 | 28 | 31 | 37 | 46 | 50 | 36 |
| Correction Resonant Transmission | | N/A | 0 | 0 | 0 | 0 | 0 | 0 | |
| ΔTL change by Lining on D | ΔR_D | RR-335, ΔTL-CLT03-W03 | 4 | 7 | 9 | 12 | 10 | 10 | |
| ΔTL change by Lining on d | ΔR_d | RR-335, ΔTL-CLT03-W03 | 4 | 7 | 9 | 12 | 10 | 10 | |
| If airborne flanking or bare CLT | | N/A | 0 | 0 | 0 | 0 | 0 | 0 | |
| **Direct TL in-situ** | R_D,situ | ISO 15712-1, Eq. 24 | **34** | **42** | **49** | **61** | **66** | **70** | **52** |
| | | | | | | | | | |
| **Junction 1 (Cross-Junction, 78 mm 3-ply CLT Separating Wall / 175 mm 5-ply CLT Floor)** | | | | | | | | | |
| **Transmission Loss of Flanking Elements** | | | | | | | | | |
| TL of element F1, laboratory | R_F1,lab | RR-335, Base CLT05 | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| TL of element f1, laboratory | R_f1,lab | RR-335, Base CLT05 | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| Correction Resonant Transmission F1 | | N/A | 0 | 0 | 0 | 0 | 0 | 0 | |
| Correction Resonant Transmission f1 | | N/A | 0 | 0 | 0 | 0 | 0 | 0 | |
| TL of element F1, in-situ | R_F1,situ | ISO 15712-1, Eq. 19, T_s,situ = T_s,lab | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| TL of element f1, in-situ | R_f1,situ | ISO 15712-1, Eq. 19, T_s,situ = T_s,lab | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| ΔTL change by Lining on F | ΔR_F1 | RR-335, ΔTL-CLT-F03 | 4 | 11 | 8 | 21 | 29 | 32 | |
| ΔTL change by Lining on f | ΔR_f1 | RR-335, ΔTL-CLT-F03 | 4 | 11 | 8 | 21 | 29 | 32 | |
| | | | | | | | | | |
| **Junction Coupling** | | | | | | | | | |
| Vibration Reduction Index for Ff | K_Ff,1 | RR-335, CLT-WF-Xa-01 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | |
| Vibration Reduction Index for Fd | K_Fd,1 | RR-335, CLT-WF-Xa-01 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | |
| Vibration Reduction Index for Df | K_Df,1 | RR-335, CLT-WF-Xa-01 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | |
| | | | | | | | | | |
| **Flanking Transmission Loss** | | | | | | | | | |
| **Flanking TL for path Ff_1** | R_ Ff | ISO 15712-1, Eq. 25b | **45** | **57** | **60** | **90** | **90** | **90** | **67** |
| **Flanking TL for path Fd_1** | R_ Fd | ISO 15712-1, Eq. 25b | **52** | **62** | **67** | **88** | **90** | **90** | **73** |
| **Flanking TL for path Df_1** | R_ Df | ISO 15712-1, Eq. 25b | **52** | **62** | **67** | **88** | **90** | **90** | **73** |
| **Junction 1: Flanking TL for all paths** | | | 44 | 55 | 59 | 84 | 85 | 85 | 65 |
| | | | | | | | | | |
| **Junction 2 (T-Junction, 78 mm 3-ply CLT Separating Wall / 78 mm 3-ply CLT Flanking Wall)** | | | | | | | | | |
| **Transmission Loss of Flanking Elements** | | | | | | | | | |
| TL of element F2, laboratory | R_F2,lab | RR-335, Base CLT03 | 26 | 28 | 31 | 37 | 46 | 50 | 36 |
| TL of element f2, laboratory | R_f2,lab | RR-335, Base CLT03 | 26 | 28 | 31 | 37 | 46 | 50 | 36 |
| Correction Resonant Transmission F2 | | N/A | 0 | 0 | 0 | 0 | 0 | 0 | |
| Correction Resonant Transmission f2 | | N/A | 0 | 0 | 0 | 0 | 0 | 0 | |
| TL of element F2, in-situ | R_F2,situ | ISO 15712-1, Eq. 19, T_s,situ = T_s,lab | 26 | 28 | 31 | 37 | 46 | 50 | 36 |
| TL of element f2, in-situ | R_f2,situ | ISO 15712-1, Eq. 19, T_s,situ = T_s,lab | 26 | 28 | 31 | 37 | 46 | 50 | 36 |
| ΔTL change by Lining on F | ΔR_F2 | RR-335, ΔTL-CLT03-W03 | 4 | 7 | 9 | 12 | 10 | 10 | |
| ΔTL change by Lining on f | ΔR_f2 | RR-335, ΔTL-CLT03-W03 | 4 | 7 | 9 | 12 | 10 | 10 | |
| | | | | | | | | | |
| **Junction Coupling** | | | | | | | | | |
| Vibration Reduction Index for Ff | K_Ff,2 | RR-335, CLT-WW-Tb-01 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | |
| Vibration Reduction Index for Fd | K_Fd,2 | RR-335, CLT-WW-Tb-01 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 | |
| Vibration Reduction Index for Df | K_Df,2 | RR-335, CLT-WW-Tb-01 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 | |
| | | | | | | | | | |
| **Flanking Transmission Loss** | | | | | | | | | |
| **Flanking TL for path Ff_2** | R_ Ff | ISO 15712-1, Eq. 25b | **45** | **53** | **60** | **72** | **77** | **81** | **63** |
| **Flanking TL for path Fd_2** | R_ Fd | ISO 15712-1, Eq. 25b | **47** | **55** | **62** | **74** | **79** | **83** | **65** |
| **Flanking TL for path Df_2** | R_ Df | ISO 15712-1, Eq. 25b | **47** | **55** | **62** | **74** | **79** | **83** | **65** |
| **Junction 2: Flanking TL for all paths** | | | 41 | 49 | 56 | 68 | 73 | 77 | 59 |
| | | | | | | | | | |
| **Junction 3 (Cross-Junction, 78 mm 3-ply CLT Separating Wall / 175 mm 5-ply CLT Ceiling)** | | | | | | | | | |
| All values the same as for Junction 1, except linings | | | | | | | | | |
| ΔTL change by Lining on F | ΔR_F3 | RR-335, ΔTL-CLT-C01 | 2 | 11 | 5 | 12 | 11 | 11 | |
| ΔTL change by Lining on f | ΔR_f3 | RR-335, ΔTL-CLT-C01 | 2 | 11 | 5 | 12 | 11 | 11 | |
| | | | | | | | | | |
| **Flanking Transmission Loss** | | | | | | | | | |
| **Flanking TL for path Ff_3** | R_ Ff | ISO 15712-1, Eq. 25b | **41** | **57** | **54** | **72** | **79** | **76** | **62** |
| **Flanking TL for path Fd_3** | R_ Fd | ISO 15712-1, Eq. 25b | **50** | **62** | **64** | **79** | **85** | **85** | **70** |
| **Flanking TL for path Df_3** | R_ Df | ISO 15712-1, Eq. 25b | **50** | **62** | **64** | **79** | **85** | **85** | **70** |
| **Junction 3: Flanking TL for all paths** | | | 40 | 55 | 53 | 71 | 77 | 75 | 60 |
| | | | | | | | | | |
| **Junction 4 (T-Junction, 78 mm 3-ply CLT Separating Wall / 78 mm 3-ply CLT Flanking Wall)** | | | | | | | | | |
| All values the same as for Junction 2 | | | | | | | | | |
| **Flanking TL for path Ff_4** | R_ Ff | ISO 15712-1, Eq. 25b | **45** | **53** | **60** | **72** | **77** | **81** | **63** |
| **Flanking TL for path Fd_4** | R_ Fd | ISO 15712-1, Eq. 25b | **47** | **55** | **62** | **74** | **79** | **83** | **65** |
| **Flanking TL for path Df_4** | R_ Df | ISO 15712-1, Eq. 25b | **47** | **55** | **62** | **74** | **79** | **83** | **65** |
| **Junction 4: Flanking TL for all paths** | | | 41 | 49 | 56 | 68 | 73 | 77 | 59 |
| | | | | | | | | | |
| **Total Flanking (for all 4 junctions)** | | | 35 | 45 | 50 | 64 | 70 | 72 | 55 |
| | | | | | | | | | |
| **ASTC due to Direct plus Flanking Paths** | | RR-335, Eq. 1.1 | **32** | **40** | **46** | **59** | **64** | **68** | **50** |

**EXAMPLE 4.4-H3:** **(DETAILED METHOD)**

- **Rooms side-by-side**
- **CLT Floors and CLT Walls**
  **(Same as example 4.4-H2, except enhanced linings)**

Separating wall assembly (loadbearing) with:
- 3-ply 78 mm thick CLT[1] wall assembly with mass 42.4 kg/m$^2$, oriented so that face ply strands are vertical
- Two layers of 12.7 mm gypsum board[3] on resilient metal channels[4] spaced 600 mm o.c., on 38 x 38 mm wood furring spaced 400 mm o.c. with absorptive material[2] in cavities

Junction 1: Bottom Junction (separating wall / floor) with:
- 5-ply 175 mm thick CLT[1] floor assembly with mass 92.1 kg/m$^2$, continuous through cross-junction with separating assembly and oriented so that face ply strands are perpendicular to the junction
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- Floor lining of 38 mm concrete over 13 mm wood fiber board

Junction 2 or 4: Each Side (separating wall / abutting side wall) with:
- 3-ply 78 mm thick CLT[1] wall assembly with mass 42.4 kg/m$^2$, continuous through T-junction with separating assembly and oriented so that face ply strands are vertical
- Connected with 90 mm equal leg angle brackets nailed/screwed at 600 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- Two layers of 12.7 mm gypsum board[3] supported on 38 x 38 mm wood furring spaced 600 mm o.c., absorptive material[2] in cavities

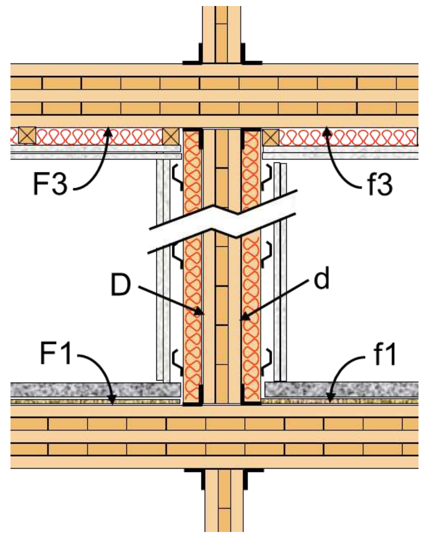
Junction 3: Top Junction (separating wall / ceiling) with:
- 5-ply 175 mm thick CLT[1] ceiling assembly with mass 92.1 kg/m$^2$, continuous through cross-junction with separating assembly and oriented so that face ply strands are perpendicular to the junction
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting assemblies
- Two layers of 12.7 mm gypsum board[3] supported on 38 x 38 mm wood furring spaced 600 mm o.c., absorptive material[2] in cavities

Acoustical Parameters:

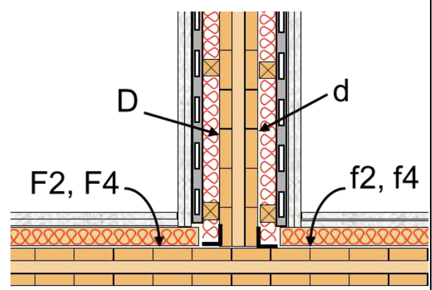
| | | | |
|---|---|---|---|
| Separating wall area ( m$^2$ ) = | 12.5 | Sep. wall internal loss, η_i = | >0.03 |
| Floor/sep. wall junction ( m ) = | 5.0 | Floor internal loss, η_i = | >0.03 |
| Wall/sep. wall junction ( m ) = | 2.5 | Flanking wall int. loss, η_i = | >0.03 |

| | Path Ff | Path Fd | Path Df | Reference |
|---|---|---|---|---|
| For Junctions 1 and 3: | | | | |
| Kij [dB] = | 1.1 | 10.5 | 10.5 | RR-335, CLT-WF-Xa-01 |
| 10*log(Sep. Area/Junction) = | 4.0 | | | or CLT-WC-Xa-01 |
| For Junctions 2 and 4: | | | | |
| Kij [dB] = | 3.5 | 5.7 | 5.7 | RR-335, CLT-WW-Tb-01 |
| 10*log(Sep. Area/Junction) = | 7.0 | | | |

Illustration for this case




Cross-junctions of 78 mm thick 3-ply CLT separating wall with 150 mm thick 5-ply CLT floor and ceiling.
(Side view of Junctions 1 and 3)




T-junction of separating wall with side wall, both of 78 mm thick 3-ply CLT.
(Plan view of Junctions 2 and 4)

(For the notes in this table please see the corresponding endnotes on page 115.)

| | ISO Symbol | Reference | 125 | 250 | 500 | 1000 | 2000 | 4000 | STC or ASTC |
|---|---|---|---|---|---|---|---|---|---|
| **Separating Partition (78 mm 3-ply CLT)** | | | | | | | | | |
| Laboratory Transmission Loss | R_D,lab | RR-335, Base CLT03 | 26 | 28 | 31 | 37 | 46 | 50 | 36 |
| Correction Resonant Transmission | | N/A | 0 | 0 | 0 | 0 | 0 | 0 | |
| ΔTL change by Lining on D | ΔR_D | RR-335, ΔTL-CLT-W04 | 6 | 17 | 20 | 24 | 20 | 22 | |
| ΔTL change by Lining on d | ΔR_d | RR-335, ΔTL-CLT-W04 | 6 | 17 | 20 | 24 | 20 | 22 | |
| If airborne flanking or bare CLT | | N/A | 0 | 0 | 0 | 0 | 0 | 0 | |
| **Direct TL in-situ** | R_D,situ | ISO 15712-1, Eq. 24 | **38** | **62** | **71** | **85** | **86** | **90** | **62** |
| | | | | | | | | | |
| **Junction 1 (Cross-Junction, 78 mm 3-ply CLT Separating Wall / 175 mm 5-ply CLT Floor)** | | | | | | | | | |
| **Transmission Loss of Flanking Elements** | | | | | | | | | |
| TL of element F1, laboratory | R_F1,lab | RR-335, Base CLT05 | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| TL of element f1, laboratory | R_f1,lab | RR-335, Base CLT05 | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| Correction Resonant Transmission F1 | | N/A | 0 | 0 | 0 | 0 | 0 | 0 | |
| Correction Resonant Transmission f1 | | N/A | 0 | 0 | 0 | 0 | 0 | 0 | |
| TL of element F1, in-situ | R_F1,situ | ISO 15712-1, Eq. 19, T_s,situ = T_s,lab | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| TL of element f1, in-situ | R_f1,situ | ISO 15712-1, Eq. 19, T_s,situ = T_s,lab | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| ΔTL change by Lining on F | ΔR_F1 | RR-335, ΔTL-CLT-F03 | 4 | 11 | 8 | 21 | 29 | 32 | |
| ΔTL change by Lining on f | ΔR_f1 | RR-335, ΔTL-CLT-F03 | 4 | 11 | 8 | 21 | 29 | 32 | |
| | | | | | | | | | |
| **Junction Coupling** | | | | | | | | | |
| Vibration Reduction Index for Ff | K_Ff,1 | RR-335, CLT-WF-Xa-01 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | |
| Vibration Reduction Index for Fd | K_Fd,1 | RR-335, CLT-WF-Xa-01 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | |
| Vibration Reduction Index for Df | K_Df,1 | RR-335, CLT-WF-Xa-01 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | |
| | | | | | | | | | |
| **Flanking Transmission Loss** | | | | | | | | | |
| **Flanking TL for path Ff_1** | R_ Ff | ISO 15712-1, Eq. 25b | **45** | **57** | **60** | **90** | **90** | **90** | **67** |
| **Flanking TL for path Fd_1** | R_ Fd | ISO 15712-1, Eq. 25b | **54** | **72** | **78** | **90** | **90** | **90** | **78** |
| **Flanking TL for path Df_1** | R_ Df | ISO 15712-1, Eq. 25b | **54** | **72** | **78** | **90** | **90** | **90** | **78** |
| **Junction 1: Flanking TL for all paths** | | | 44 | 57 | 60 | 85 | 85 | 85 | 67 |
| | | | | | | | | | |
| **Junction 2 (T-Junction, 78 mm 3-ply CLT Separating Wall / 78 mm 3-ply CLT Flanking Wall)** | | | | | | | | | |
| **Transmission Loss of Flanking Elements** | | | | | | | | | |
| TL of element F2, laboratory | R_F2,lab | RR-335, Base CLT03 | 26 | 28 | 31 | 37 | 46 | 50 | 36 |
| TL of element f2, laboratory | R_f2,lab | RR-335, Base CLT03 | 26 | 28 | 31 | 37 | 46 | 50 | 36 |
| Correction Resonant Transmission F2 | | N/A | 0 | 0 | 0 | 0 | 0 | 0 | |
| Correction Resonant Transmission f2 | | N/A | 0 | 0 | 0 | 0 | 0 | 0 | |
| TL of element F2, in-situ | R_F2,situ | ISO 15712-1, Eq. 19, T_s,situ = T_s,lab | 26 | 28 | 31 | 37 | 46 | 50 | 36 |
| TL of element f2, in-situ | R_f2,situ | ISO 15712-1, Eq. 19, T_s,situ = T_s,lab | 26 | 28 | 31 | 37 | 46 | 50 | 36 |
| ΔTL change by Lining on F | ΔR_F2 | RR-335, ΔTL-CLT03-W03 | 4 | 7 | 9 | 12 | 10 | 10 | |
| ΔTL change by Lining on f | ΔR_f2 | RR-335, ΔTL-CLT03-W03 | 4 | 7 | 9 | 12 | 10 | 10 | |
| | | | | | | | | | |
| **Junction Coupling** | | | | | | | | | |
| Vibration Reduction Index for Ff | K_Ff,2 | RR-335, CLT-WW-Tb-01 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | |
| Vibration Reduction Index for Fd | K_Fd,2 | RR-335, CLT-WW-Tb-01 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 | |
| Vibration Reduction Index for Df | K_Df,2 | RR-335, CLT-WW-Tb-01 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 | |
| | | | | | | | | | |
| **Flanking Transmission Loss** | | | | | | | | | |
| **Flanking TL for path Ff_2** | R_ Ff | ISO 15712-1, Eq. 25b | **45** | **53** | **60** | **72** | **77** | **81** | **63** |
| **Flanking TL for path Fd_2** | R_ Fd | ISO 15712-1, Eq. 25b | **49** | **65** | **73** | **86** | **89** | **90** | **73** |
| **Flanking TL for path Df_2** | R_ Df | ISO 15712-1, Eq. 25b | **49** | **65** | **73** | **86** | **89** | **90** | **73** |
| **Junction 2: Flanking TL for all paths** | | | 42 | 52 | 60 | 72 | 76 | 80 | 63 |
| | | | | | | | | | |
| **Junction 3 (Cross-Junction, 78 mm 3-ply CLT Separating Wall / 175 mm 5-ply CLT Ceiling)** | | | | | | | | | |
| All values the same as for Junction 1, except linings | | | | | | | | | |
| ΔTL change by Lining on F | ΔR_F3 | RR-335, ΔTL-CLT-C01 | 2 | 11 | 5 | 12 | 11 | 11 | |
| ΔTL change by Lining on f | ΔR_f3 | RR-335, ΔTL-CLT-C01 | 2 | 11 | 5 | 12 | 11 | 11 | |
| | | | | | | | | | |
| **Flanking Transmission Loss** | | | | | | | | | |
| **Flanking TL for path Ff_3** | R_ Ff | ISO 15712-1, Eq. 25b | **41** | **57** | **54** | **72** | **79** | **76** | **62** |
| **Flanking TL for path Fd_3** | R_ Fd | ISO 15712-1, Eq. 25b | **52** | **72** | **75** | **90** | **90** | **90** | **76** |
| **Flanking TL for path Df_3** | R_ Df | ISO 15712-1, Eq. 25b | **52** | **72** | **75** | **90** | **90** | **90** | **76** |
| **Junction 3: Flanking TL for all paths** | | | 40 | 57 | 54 | 72 | 78 | 76 | 61 |
| | | | | | | | | | |
| **Junction 4 (T-Junction, 78 mm 3-ply CLT Separating Wall / 78 mm 3-ply CLT Flanking Wall)** | | | | | | | | | |
| All values the same as for Junction 2 | | | | | | | | | |
| **Flanking TL for path Ff_4** | R_ Ff | ISO 15712-1, Eq. 25b | **45** | **53** | **60** | **72** | **77** | **81** | **63** |
| **Flanking TL for path Fd_4** | R_ Fd | ISO 15712-1, Eq. 25b | **49** | **65** | **73** | **86** | **89** | **90** | **73** |
| **Flanking TL for path Df_4** | R_ Df | ISO 15712-1, Eq. 25b | **49** | **65** | **73** | **86** | **89** | **90** | **73** |
| **Junction 4: Flanking TL for all paths** | | | 42 | 52 | 60 | 72 | 76 | 80 | 63 |
| | | | | | | | | | |
| **Total Flanking (for all 4 junctions)** | | | 36 | 48 | 51 | 67 | 72 | 73 | 57 |
| | | | | | | | | | |
| **ASTC due to Direct plus Flanking Paths** | | RR-335, Eq. 1.1 | **34** | **48** | **51** | **67** | **72** | **73** | **57** |

**EXAMPLE 4.4-V1: (DETAILED METHOD)**

- **Rooms one-above-the-other**
- **Bare CLT Floors and CLT Walls**

Separating floor assembly with:

- 5-ply 175 mm thick CLT[1] floor assembly with mass 92.1 kg/m², continuous through cross-junction with CLT wall assemblies at Junctions 1 and 3 and oriented so that face ply strands are perpendicular to loadbearing Junctions 1 and 3
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting wall assemblies
- No added linings (floor topping or ceiling)

Junction 1, 3 or 4: Separating floor / walls with:

- 5-ply 175 mm thick CLT[1] wall assembly with mass 94.1 kg/m², above and below cross-junctions with separating assembly that is continuous or lapped and glued across these junctions
- CLT wall assembly oriented so face ply strands are vertical
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to the wall assemblies and to the floor assembly
- No added lining on walls

Junction 2: Separating floor / walls with:

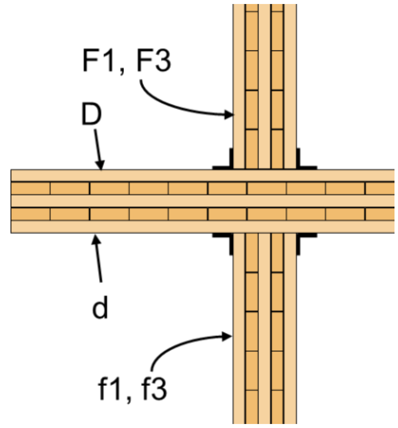
- 5-ply 175 mm thick CLT[1] wall assembly with mass 94.1 kg/m², above and below T-junction with separating assembly that terminates at this junction
- CLT wall assembly oriented so face ply strands are vertical
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to one side of the wall assembly and to the abutting floor assemblies
- No added lining on walls

Acoustical Parameters:

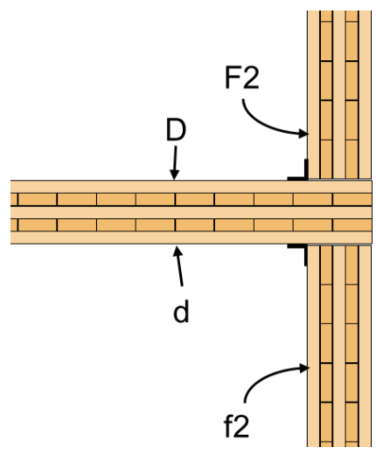
| | | | |
|---|---|---|---|
| Separating floor area ( m² ) = | 20.0 | Floor internal loss, η_i = | >0.03 |
| ɔor/wall junctions 1 and 3 ( m ) = | 5.0 | Wall internal loss, η_i = | >0.03 |
| ɔor/wall junctions 2 and 4 ( m ) = | 4.0 | Wall internal loss, η_i = | >0.03 |

| | Path Ff | Path Fd | Path Df | Reference |
|---|---|---|---|---|
| For Junctions 1 and 3 and 4: | | | | |
| Kij [dB] = | 17.6 | 10.2 | 10.2 | RR-335, CLT-FW-Xa-05 |
| 10*log(Sep. Area/Junction) = | 6.0 | For Junctions 1 and 3 | | |
| 10*log(Sep. Area/Junction) = | 7.0 | For Junction 4 | | |
| For Junction 2: | | | | |
| Kij [dB] = | 12.9 | 6.8 | 6.8 | RR-335, CLT-FW-Ta-05 |
| 10*log(Sep. Area/Junction) = | 7.0 | For Junction 2 | | |

Illustration for this case




Cross-junction of separating floor of continuous 175 mm thick 5-ply CLT with 5-ply CLT wall assemblies above and below.
(Side view of Junctions 1, 3 and 4, except orientation of floor assemblies differs for Junction 4)




T-junction of 175 mm thick 5-ply CLT floor with 5-ply CLT walls above and below.
(Side view of Junction 2)

(For the notes in this table please see the corresponding endnotes on page 115.)

| | ISO Symbol | Reference | 125 | 250 | 500 | 1000 | 2000 | 4000 | STC or ASTC |
|---|---|---|---|---|---|---|---|---|---|
| **Separating Partition (175 mm 5-ply CLT)** | | | | | | | | | |
| Laboratory Transmission Loss | R_D,lab | RR-335, Base CLT05 | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| Correction Resonant Transmission | | N/A | 0 | 0 | 0 | 0 | 0 | 0 | |
| ΔTL change by Lining on D | ΔR_D | No Lining | 0 | 0 | 0 | 0 | 0 | 0 | |
| ΔTL change by Lining on d | ΔR_d | No Lining | 0 | 0 | 0 | 0 | 0 | 0 | |
| If airborne flanking or bare CLT | | RR-335, TL(Bare CLT05) - TL(Base CLT05) | 0 | -1 | -3 | 1 | -1 | -3 | |
| **Direct TL in-situ** | R_D,situ | ISO 15712-1, Eq. 24 | **32** | **29** | **36** | **44** | **51** | **46** | **40** |
| | | | | | | | | | |
| **Junction 1 (Cross-Junction, 175 mm 5-ply CLT Separating Floor / 175 mm 5-ply CLT Wall)** | | | | | | | | | |
| **Transmission Loss of Flanking Elements** | | | | | | | | | |
| TL of element F1, laboratory | R_F1,lab | RR-335, Base CLT05 | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| TL of element f1, laboratory | R_f1,lab | RR-335, Base CLT05 | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| Correction Resonant Transmission F1 | | N/A | 0 | 0 | 0 | 0 | 0 | 0 | |
| Correction Resonant Transmission f1 | | N/A | 0 | 0 | 0 | 0 | 0 | 0 | |
| TL of element F1, in-situ | R_F1,situ | ISO 15712-1, Eq. 19, T_s,situ = T_s,lab | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| TL of element f1, in-situ | R_f1,situ | ISO 15712-1, Eq. 19, T_s,situ = T_s,lab | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| ΔTL change by Lining on F | ΔR_F1 | No Lining | 0 | 0 | 0 | 0 | 0 | 0 | |
| ΔTL change by Lining on f | ΔR_f1 | No Lining | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | | | | | | | | |
| **Junction Coupling** | | | | | | | | | |
| Vibration Reduction Index for Ff | K_Ff,1 | RR-335, CLT-FW-Xa-05 | 17.6 | 17.6 | 17.6 | 17.6 | 17.6 | 17.6 | |
| Vibration Reduction Index for Fd | K_Fd,1 | RR-335, CLT-FW-Xa-05 | 10.2 | 10.2 | 10.2 | 10.2 | 10.2 | 10.2 | |
| Vibration Reduction Index for Df | K_Df,1 | RR-335, CLT-FW-Xa-05 | 10.2 | 10.2 | 10.2 | 10.2 | 10.2 | 10.2 | |
| | | | | | | | | | |
| **Flanking Transmission Loss** | | | | | | | | | |
| **Flanking TL for path Ff_1** | R_ Ff | ISO 15712-1, Eq. 25b | **56** | **54** | **63** | **67** | **76** | **73** | **66** |
| **Flanking TL for path Fd_1** | R_ Fd | ISO 15712-1, Eq. 25b | **48** | **46** | **55** | **59** | **68** | **65** | **58** |
| **Flanking TL for path Df_1** | R_ Df | ISO 15712-1, Eq. 25b | **48** | **46** | **55** | **59** | **68** | **65** | **58** |
| **Junction 1: Flanking TL for all paths** | | | 45 | 43 | 52 | 56 | 65 | 62 | 55 |
| | | | | | | | | | |
| **Junction 2 (T-Junction, 175 mm 5-ply CLT Separating Floor / 175 mm 5-ply CLT Wall)** | | | | | | | | | |
| **Transmission Loss of Flanking Elements** | | | | | | | | | |
| TL of element F2, laboratory | R_F2,lab | RR-335, Base CLT05 | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| TL of element f2, laboratory | R_f2,lab | RR-335, Base CLT05 | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| Correction Resonant Transmission F2 | | N/A | 0 | 0 | 0 | 0 | 0 | 0 | |
| Correction Resonant Transmission f2 | | N/A | 0 | 0 | 0 | 0 | 0 | 0 | |
| TL of element F2, in-situ | R_F2,situ | ISO 15712-1, Eq. 19, T_s,situ = T_s,lab | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| TL of element f2, in-situ | R_f2,situ | ISO 15712-1, Eq. 19, T_s,situ = T_s,lab | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| ΔTL change by Lining on F | ΔR_F2 | No Lining | 0 | 0 | 0 | 0 | 0 | 0 | |
| ΔTL change by Lining on f | ΔR_f2 | No Lining | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | | | | | | | | |
| **Junction Coupling** | | | | | | | | | |
| Vibration Reduction Index for Ff | K_Ff,2 | RR-335, CLT-FW-Ta-05 | 12.9 | 12.9 | 12.9 | 12.9 | 12.9 | 12.9 | |
| Vibration Reduction Index for Fd | K_Fd,2 | RR-335, CLT-FW-Ta-05 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | |
| Vibration Reduction Index for Df | K_Df,2 | RR-335, CLT-FW-Ta-05 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | |
| | | | | | | | | | |
| **Flanking Transmission Loss** | | | | | | | | | |
| **Flanking TL for path Ff_2** | R_ Ff | ISO 15712-1, Eq. 25b | **52** | **50** | **59** | **63** | **72** | **69** | **62** |
| **Flanking TL for path Fd_2** | R_ Fd | ISO 15712-1, Eq. 25b | **46** | **44** | **53** | **57** | **66** | **63** | **56** |
| **Flanking TL for path Df_2** | R_ Df | ISO 15712-1, Eq. 25b | **46** | **44** | **53** | **57** | **66** | **63** | **56** |
| **Junction 2: Flanking TL for all paths** | | | 42 | 40 | 49 | 53 | 62 | 59 | 52 |
| | | | | | | | | | |
| **Junction 3 (Cross-Junction, 175 mm 5-ply CLT Separating Floor / 175 mm 5-ply CLT Wall)** | | | | | | | | | |
| All values the same as for Junction 1 | | | | | | | | | |
| **Flanking TL for path Ff_3** | R_ Ff | ISO 15712-1, Eq. 25b | **56** | **54** | **63** | **67** | **76** | **73** | **66** |
| **Flanking TL for path Fd_3** | R_ Fd | ISO 15712-1, Eq. 25b | **48** | **46** | **55** | **59** | **68** | **65** | **58** |
| **Flanking TL for path Df_3** | R_ Df | ISO 15712-1, Eq. 25b | **48** | **46** | **55** | **59** | **68** | **65** | **58** |
| **Junction 3: Flanking TL for all paths** | | | 45 | 43 | 52 | 56 | 65 | 62 | 55 |
| | | | | | | | | | |
| **Junction 4 (Cross-Junction, 175 mm 5-ply CLT Separating Floor / 175 mm 5-ply CLT Wall)** | | | | | | | | | |
| Transmission loss values of flanking elements are the same as for Junction 2, but Kij values are the same as for Junction 1 and 3 (cross-junction). | | | | | | | | | |
| **Flanking TL for path Ff_4** | R_ Ff | ISO 15712-1, Eq. 25b | **57** | **55** | **64** | **68** | **77** | **74** | **67** |
| **Flanking TL for path Fd_4** | R_ Fd | ISO 15712-1, Eq. 25b | **49** | **47** | **56** | **60** | **69** | **66** | **59** |
| **Flanking TL for path Df_4** | R_ Df | ISO 15712-1, Eq. 25b | **49** | **47** | **56** | **60** | **69** | **66** | **59** |
| **Junction 4: Flanking TL for all paths** | | | 46 | 44 | 53 | 57 | 66 | 63 | 56 |
| | | | | | | | | | |
| **Total Flanking (for all 4 junctions)** | | | 38 | 36 | 45 | 49 | 58 | 55 | 48 |
| | | | | | | | | | |
| **ASTC due to Direct plus Flanking Paths** | | RR-335, Eq. 1.1 | **31** | **28** | **36** | **43** | **50** | **46** | **40** |

**EXAMPLE 4.4-V2: (DETAILED METHOD)**

- **Rooms one-above-the-other**
- **CLT Floors and CLT Walls**
  **(Same as example 4.4-V1, plus linings)**

Separating floor assembly with:

- 5-ply 175 mm thick CLT[1] floor assembly with mass 92.1 kg/m$^2$, continuous through cross-junction with CLT wall assemblies at Junctions 1 and 3 and oriented so that face ply strands are perpendicular to loadbearing Junctions 1 and 3
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to both sides of the separating assembly and to the abutting wall assemblies
- Floor lining of 38 mm concrete over 13 mm wood fiber board
- Ceiling lining of 15.9 mm gypsum board[3] fastened to hat-channels supported on cross-channels hung on wires, cavity of 150 mm between CLT and ceiling, with 140 mm absorptive material[2]

Junction 1, 3 or 4: (separating floor / flanking walls) with:

- 5-ply 175 mm thick CLT[1] wall assembly with mass 94.1 kg/m$^2$, above and below cross-junctions with separating assembly that is continuous or lapped and glued across these junctions
- CLT wall assembly oriented so face ply strands are vertical
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to the wall assemblies and to the floor assembly
- Two layers of 12.7 mm gypsum board[3] supported on 38 x 38 mm wood furring spaced 600 mm o.c., absorptive material[2] in cavities

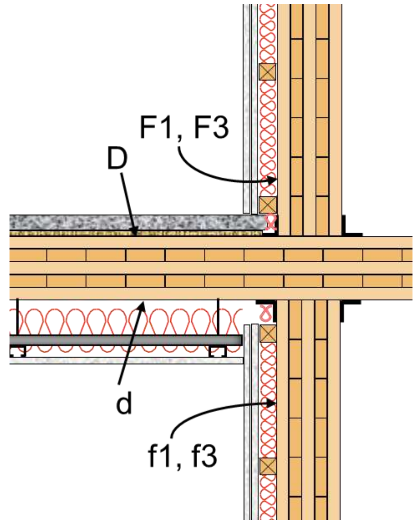
Junction 2: Each Side (separating floor / flanking walls) with:

- 5-ply 175 mm thick CLT[1] wall assembly with mass 94.1 kg/m$^2$, above and below T-junction with separating assembly that terminates at this junction
- CLT wall assembly oriented so face ply strands are vertical
- Connected with 90 mm equal leg angle brackets nailed/screwed at 300 mm o.c. to one side of the wall assembly and to the abutting floor assemblies
- Two layers of 12.7 mm gypsum board[3] supported on 38 x 38 mm wood furring spaced 600 mm o.c., absorptive material[2] in cavities

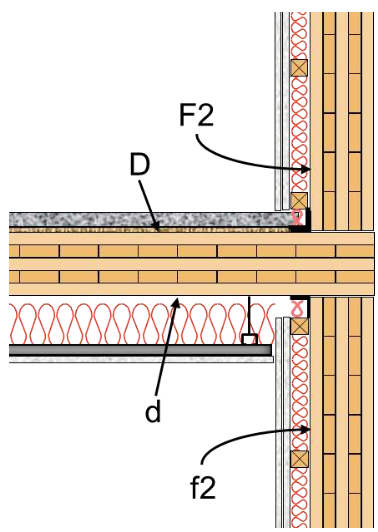
Acoustical Parameters:

| | | | | |
|---|---|---|---|---|
| Separating floor area ( m$^2$ ) = | 20.0 | | Floor internal loss, η_i = | >0.03 |
| ɔor/wall junctions 1 and 3 ( m ) = | 5.0 | | Wall internal loss, η_i = | >0.03 |
| ɔor/wall junctions 2 and 4 ( m ) = | 4.0 | | Wall internal loss, η_i = | >0.03 |
| | Path Ff | Path Fd | Path Df | Reference |
| For Junctions 1 and 3 and 4: | | | | |
| Kij [dB] = | 17.6 | 10.2 | 10.2 | RR-335, CLT-FW-Xa-05 |
| 10*log(Sep. Area/Junction) = | 6.0 | For Junctions 1 and 3 | | |
| 10*log(Sep. Area/Junction) = | 7.0 | For Junction 4 | | |
| For Junction 2: | | | | |
| Kij [dB] = | 12.9 | 6.8 | 6.8 | RR-335, CLT-FW-Ta-05 |
| 10*log(Sep. Area/Junction) = | 7.0 | For Junction 2 | | |

Illustration for this case




Cross-junction of separating floor of continuous 175mm thick 5-ply CLT with 5-ply CLT walls above and below.
(Side view of Junctions 1, 3 and 4, except orientation of floor assemblies differs for Junction 4)




T-junction of 175mm thick 5-ply CLT floor with 5-ply CLT walls above and below.
(Side view of Junction 2)

(For the notes in this table please see the corresponding endnotes on page 115.)

| | ISO Symbol | Reference | 125 | 250 | 500 | 1000 | 2000 | 4000 | STC or ASTC |
|---|---|---|---|---|---|---|---|---|---|
| **Separating Partition (175 mm 5-ply CLT)** | | | | | | | | | |
| Laboratory Transmission Loss | R_D,lab | RR-335, Base CLT05 | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| Correction Resonant Transmission | | N/A | 0 | 0 | 0 | 0 | 0 | 0 | |
| ΔTL change by Lining on D | ΔR_D | RR-335, ΔTL-CLT-F03 | 4 | 11 | 8 | 21 | 29 | 32 | |
| ΔTL change by Lining on d | ΔR_d | RR-335, ΔTL-CLT-C03 | 15 | 25 | 30 | 36 | 34 | 30 | |
| If airborne flanking or bare CLT | | N/A | 0 | 0 | 0 | 0 | 0 | 0 | |
| **Direct TL in-situ** | R_D,situ | ISO 15712-1, Eq. 24 | **51** | **66** | **77** | **90** | **90** | **90** | **75** |
| | | | | | | | | | |
| **Junction 1 (Cross-Junction, 175 mm 5-ply CLT Separating Floor / 175 mm 5-ply CLT Wall)** | | | | | | | | | |
| **Transmission Loss of Flanking Elements** | | | | | | | | | |
| TL of element F1, laboratory | R_F1,lab | RR-335, Base CLT05 | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| TL of element f1, laboratory | R_f1,lab | RR-335, Base CLT05 | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| Correction Resonant Transmission F1 | | N/A | 0 | 0 | 0 | 0 | 0 | 0 | |
| Correction Resonant Transmission f1 | | N/A | 0 | 0 | 0 | 0 | 0 | 0 | |
| TL of element F1, in-situ | R_F1,situ | ISO 15712-1, Eq. 19, T_s,situ = T_s,lab | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| TL of element f1, in-situ | R_f1,situ | ISO 15712-1, Eq. 19, T_s,situ = T_s,lab | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| ΔTL change by Lining on F | ΔR_F1 | RR-335, ΔTL-CLT05-W03 | 3 | 8 | 5 | 11 | 10 | 11 | |
| ΔTL change by Lining on f | ΔR_f1 | RR-335, ΔTL-CLT05-W03 | 3 | 8 | 5 | 11 | 10 | 11 | |
| | | | | | | | | | |
| **Junction Coupling** | | | | | | | | | |
| Vibration Reduction Index for Ff | K_Ff,1 | RR-335, CLT-FW-Xa-05 | 17.6 | 17.6 | 17.6 | 17.6 | 17.6 | 17.6 | |
| Vibration Reduction Index for Fd | K_Fd,1 | RR-335, CLT-FW-Xa-05 | 10.2 | 10.2 | 10.2 | 10.2 | 10.2 | 10.2 | |
| Vibration Reduction Index for Df | K_Df,1 | RR-335, CLT-FW-Xa-05 | 10.2 | 10.2 | 10.2 | 10.2 | 10.2 | 10.2 | |
| | | | | | | | | | |
| **Flanking Transmission Loss** | | | | | | | | | |
| **Flanking TL for path Ff_1** | R_ Ff | ISO 15712-1, Eq. 25b | **62** | **70** | **73** | **89** | **90** | **90** | **81** |
| **Flanking TL for path Fd_1** | R_ Fd | ISO 15712-1, Eq. 25b | **66** | **79** | **90** | **90** | **90** | **90** | **88** |
| **Flanking TL for path Df_1** | R_ Df | ISO 15712-1, Eq. 25b | **55** | **65** | **68** | **90** | **90** | **90** | **76** |
| **Junction 1: Flanking TL for all paths** | | | 54 | 64 | 67 | 85 | 85 | 85 | 75 |
| | | | | | | | | | |
| **Junction 2 (T-Junction, 175 mm 5-ply CLT Separating Floor / 175 mm 5-ply CLT Wall)** | | | | | | | | | |
| **Transmission Loss of Flanking Elements** | | | | | | | | | |
| TL of element F2, laboratory | R_F2,lab | RR-335, Base CLT05 | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| TL of element f2, laboratory | R_f2,lab | RR-335, Base CLT05 | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| Correction Resonant Transmission F2 | | N/A | 0 | 0 | 0 | 0 | 0 | 0 | |
| Correction Resonant Transmission f2 | | N/A | 0 | 0 | 0 | 0 | 0 | 0 | |
| TL of element F2, in-situ | R_F2,situ | ISO 15712-1, Eq. 19, T_s,situ = T_s,lab | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| TL of element f2, in-situ | R_f2,situ | ISO 15712-1, Eq. 19, T_s,situ = T_s,lab | 32 | 30 | 39 | 43 | 52 | 49 | 42 |
| ΔTL change by Lining on F | ΔR_F2 | RR-335, ΔTL-CLT05-W03 | 3 | 8 | 5 | 11 | 10 | 11 | |
| ΔTL change by Lining on f | ΔR_f2 | RR-335, ΔTL-CLT05-W03 | 3 | 8 | 5 | 11 | 10 | 11 | |
| | | | | | | | | | |
| **Junction Coupling** | | | | | | | | | |
| Vibration Reduction Index for Ff | K_Ff,2 | RR-335, CLT-FW-Ta-05 | 12.9 | 12.9 | 12.9 | 12.9 | 12.9 | 12.9 | |
| Vibration Reduction Index for Fd | K_Fd,2 | RR-335, CLT-FW-Ta-05 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | |
| Vibration Reduction Index for Df | K_Df,2 | RR-335, CLT-FW-Ta-05 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | |
| | | | | | | | | | |
| **Flanking Transmission Loss** | | | | | | | | | |
| **Flanking TL for path Ff_2** | R_ Ff | ISO 15712-1, Eq. 25b | **58** | **66** | **69** | **85** | **90** | **90** | **77** |
| **Flanking TL for path Fd_2** | R_ Fd | ISO 15712-1, Eq. 25b | **64** | **77** | **88** | **90** | **90** | **90** | **87** |
| **Flanking TL for path Df_2** | R_ Df | ISO 15712-1, Eq. 25b | **53** | **63** | **66** | **89** | **90** | **90** | **74** |
| **Junction 2: Flanking TL for all paths** | | | 52 | 61 | 64 | 83 | 85 | 85 | 72 |
| | | | | | | | | | |
| **Junction 3 (Cross-Junction, 175 mm 5-ply CLT Separating Floor / 175 mm 5-ply CLT Wall)** | | | | | | | | | |
| All values the same as for Junction 1 | | | | | | | | | |
| **Flanking TL for path Ff_3** | R_ Ff | ISO 15712-1, Eq. 25b | **62** | **70** | **73** | **89** | **90** | **90** | **81** |
| **Flanking TL for path Fd_3** | R_ Fd | ISO 15712-1, Eq. 25b | **66** | **79** | **90** | **90** | **90** | **90** | **88** |
| **Flanking TL for path Df_3** | R_ Df | ISO 15712-1, Eq. 25b | **55** | **65** | **68** | **90** | **90** | **90** | **76** |
| **Junction 3: Flanking TL for all paths** | | | 54 | 64 | 67 | 85 | 85 | 85 | 75 |
| | | | | | | | | | |
| **Junction 4 (Cross-Junction, 175 mm 5-ply CLT Separating Floor / 175 mm 5-ply CLT Wall)** | | | | | | | | | |
| Transmission loss values of flanking elements are the same as for Junction 2, but Kij values are the same as for Junction 1 or 3 (cross-junction). | | | | | | | | | |
| **Flanking TL for path Ff_4** | R_ Ff | ISO 15712-1, Eq. 25b | **63** | **71** | **74** | **90** | **90** | **90** | **82** |
| **Flanking TL for path Fd_4** | R_ Fd | ISO 15712-1, Eq. 25b | **67** | **80** | **90** | **90** | **90** | **90** | **88** |
| **Flanking TL for path Df_4** | R_ Df | ISO 15712-1, Eq. 25b | **56** | **66** | **69** | **90** | **90** | **90** | **77** |
| **Junction 4: Flanking TL for all paths** | | | 55 | 65 | 68 | 85 | 85 | 85 | 76 |
| | | | | | | | | | |
| **Total Flanking (for all 4 junctions)** | | | 47 | 57 | 60 | 78 | 79 | 79 | 68 |
| | | | | | | | | | |
| **ASTC due to Direct plus Flanking Paths** | | RR-335, Eq. 1.1 | **46** | **57** | **60** | **78** | **79** | **79** | **67** |

## *Summary for Section 4.4: Calculation Examples using the Detailed Method*

The worked examples (4.4-H1 to H3 and 4.4-V1 to V2) illustrate the use of the Detailed Method for calculating sound transmission between rooms in a building with CLT floor and wall assemblies, with or without linings added to some or all of the walls and floors.

The examples present the calculations for the same set of scenarios used to illustrate the Simplified Method in Section 4.2.

- For the cases without linings (4.4-H1 and 4.4-V1) the detailed calculations give the same ASTC ratings as the simplified calculations. This agreement (aside from possible rounding errors of ±1) is to be expected since they simply combine the same data in slightly different order.
- For the cases with linings, the differences are larger, because the Simplified Method treats the ΔSTC improvement due to linings using a deliberately conservative approximation. In the Detailed Method, the value of ΔTL for the two linings in each transmission path are simply added to the sound transmission loss values for the base assemblies, which tends to give higher predicted values of ASTC.
- In each of the cases with linings shown in these examples, the Detailed Method gives a result that is higher by 2 to 5 ASTC points than the Simplified Method. For linings with higher values of ΔSTC, the difference between the two methods would increase further.

# 5 Appendices of Sound Transmission Data

This Appendix presents one-third octave band sound transmission data.

This includes:

- Airborne sound transmission loss data, measured according to ASTM standard E90, for the Bare CLT and the Base CLT wall and floor assemblies (without added linings);
- The corresponding one-third octave band ΔTL data for the change in sound transmission loss due to the addition of linings to the Base CLT assemblies.

Details of the test facilities and the measurement procedures are given in Chapter 2 and Chapter 3.

The process for determining the ΔTL values is described in Chapter 2. The one-third octave band ΔTL data given in this Appendix may be used for calculations according to the Detailed Method of ISO 15712-1, as described in Section 4.3. The single-number STC and ΔSTC data given in this Appendix may be used for calculations according to the Simplified Method of ISO 15712-1, as described in Section 4.1.

The procedure for calculating ΔSTC is presented in Appendix A2. It is a subset of a more general set of procedures presented in NRC Research Report RR-331, "Guide to Calculating Airborne Sound Transmission in Buildings" [14].

## 5.1 Appendix A1: Transmission Loss Data for CLT Wall and Floor Assemblies

**Table A1.1**: Sound transmission loss data for **Bare CLT** assemblies. Note that the results are compromised by leakage, as explained in Section 2.1.

| Specimen Code | Description | STC | 63 Hz | | | 125 Hz | | | 250 Hz | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bare CLT03 | One leaf of 3-ply CLT, 42.4 kg/m$^2$, 78 mm thick | **33** | 24 | 24 | 22 | 24 | 25 | 25 | 25 | 25 | 25 |
| Bare CLT05 (mean) | One leaf of 5-ply CLT, 91.4 kg/m$^2$, 175 mm thick | **41** | 28 | 30 | 25 | 29 | 32 | 31 | 29 | 30 | 29 |
| Bare CLT07 | One leaf of 7-ply CLT, 130 kg/m$^2$, 245 mm thick | **44** | 30 | 28 | 32 | 30 | 33 | 32 | 31 | 32 | 36 |
| Bare 2-leaf CLT03 | Two leafs of 3-ply CLT, total 89.6 kg/m$^2$, 181 mm thick | **47** | 25 | 19 | 20 | 28 | 34 | 34 | 39 | 35 | 36 |

**Table A1.2:** Sound transmission loss data for **Base CLT** assemblies. Note that the data has been corrected to eliminate sound transmission due to leakage, as explained in Section 2.1.

| Specimen Code | Description | STC | 63 Hz | | | 125 Hz | | | 250 Hz | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Base CLT03 | One leaf of 3-ply CLT, 42.4 kg/m$^2$, 78 mm thick | **36** | 26 | 25 | 22 | 26 | 26 | 26 | 27 | 28 | 28 |
| Base CLT05 | One leaf of 5-ply CLT, 91.4 kg/m$^2$, 175 mm thick | **42** | 28 | 29 | 27 | 28 | 32 | 32 | 30 | 30 | 30 |
| Base CLT07 | One leaf of 7-ply CLT, 130 kg/m$^2$, 245 mm thick | **45** | 31 | 30 | 33 | 31 | 34 | 31 | 32 | 33 | 37 |
| Base 2-leaf CLT03 | 2 leafs of 3-ply CLT, total 89.6 kg/m$^2$, 181 mm thick | **50** | 28 | 16 | 21 | 28 | 36 | 37 | 41 | 36 | 39 |

**Table A1.3**: Structural reverberation times for the tested CLT assemblies

| Specimen Code | Description | | 63 Hz | | | 125 Hz | | | 250 Hz | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CLT03 | One leaf of 3-ply CLT, 42.4 kg/m$^2$, 78 mm thick | | | | | .321 | .230 | .205 | .151 | .170 | .134 |
| CLT05-Wall | One leaf of 5-ply CLT, 91.4 kg/m$^2$, 175 mm thick | | | | | .217 | .229 | .225 | .185 | .194 | .187 |
| CLT05-Floor | One leaf of 5-ply CLT, 91.4 kg/m$^2$, 175 mm thick | | | | | .462 | .496 | .258 | .242 | .142 | .148 |
| CLT07 | One leaf of 7-ply CLT, 130 kg/m$^2$, 245 mm thick | | | | | | | | | | |

(Continuation of Table A1.1 from opposite page):

| 500 Hz | | | 1000 Hz | | | 2000 Hz | | | 4000 Hz | | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 26 | 28 | 29 | 30 | 34 | 37 | 40 | 42 | 45 | 47 | 49 | 48 | TLA-12-197,223 |
| 34 | 36 | 39 | 42 | 44 | 47 | 49 | 52 | 50 | 45 | 46 | 50 | TLA-12-170:171 |
| 38 | 40 | 42 | 44 | 47 | 49 | 52 | 53 | 51 | 51 | 53 | 54 | TLF-13-025 |
| 38 | 42 | 46 | 49 | 56 | 62 | 68 | 74 | 80 | 84 | 85 | 84 | TLA-12-222 |

**(Continuation of Table A1.2** from opposite page**):**

| 500 Hz | | | 1000 Hz | | | 2000 Hz | | | 4000 Hz | | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 28 | 31 | 33 | 34 | 37 | 39 | 42 | 46 | 46 | 50 | 50 | 48 | TLA-12-197:199,223 |
| 37 | 39 | 41 | 44 | 43 | 46 | 48 | 52 | 51 | 50 | 49 | 50 | TLA-12-170:176 |
| 39 | 41 | 43 | 43 | 46 | 48 | 52 | 51 | 51 | 53 | 56 | 60 | TLF-13-023:025 |
| 43 | 46 | 48 | 52 | 59 | 63 | 67 | 75 | 82 | 86 | 87 | 83 | TLA-12-218:222 |

**(Continuation of Table A1.3** from opposite page**):**

| 500 Hz | | | 1000 Hz | | | 2000 Hz | | | 4000 Hz | | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .120 | .103 | .092 | .075 | .063 | .045 | .039 | .040 | .027 | .027 | .026 | .020 | |
| .123 | .094 | .069 | .064 | .052 | .041 | .035 | .028 | .024 | .020 | .023 | .019 | |
| .104 | .078 | .082 | .078 | .062 | .052 | .045 | .041 | .035 | .029 | .022 | .020 | |
| | | | | | | | | | | | | N/A, Data problem |

**Table A1.4**: Change in sound transmission loss (ΔTL) due to linings on single-leaf CLT assemblies

| Lining Code | Lining Description | ΔSTC | 63 Hz | | | 125 Hz | | | 250 Hz | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Wall Linings** | | | | | | | | | | | |
| ΔTL-CLT03-W01 | 2G13 | **2** | 2 | 2 | 2 | 2 | 3 | 3 | 2 | 2 | 1 |
| ΔTL-CLT05-W01 | 2G13 | **0** | 1 | 1 | 1 | 2 | 1 | 0 | 1 | 0 | 1 |
| ΔTL-CLT03-W02 | 2G13_WFUR38(400)_GFB38 | **4** | 1 | -1 | -2 | 0 | 1 | -3 | 1 | 11 | 8 |
| ΔTL-CLT05-W02 | 2G13_WFUR38(400)_GFB38 | **-5** | 1 | 1 | -1 | -3 | -6 | -8 | 2 | 8 | 6 |
| ΔTL-CLT03-W03 | 2G13_WFUR38(600)_GFB38 | **9** | 1 | -1 | -2 | -5 | 4 | 6 | 10 | 7 | 6 |
| ΔTL-CLT05-W03 | 2G13_WFUR38(600)_GFB38 | **8** | -1 | -5 | -6 | -4 | 3 | 7 | 10 | 8 | 8 |
| ΔTL-CLT-W04 | 2G13_RC13(600)_ WFUR38(400)_GFB38 | **15** | -4 | -8 | -4 | 2 | 6 | 11 | 13 | 17 | 18 |
| ΔTL-CLT-W05 | 2G13_WFUR64(600)_GFB65 | **6** | -1 | -6 | -6 | 1 | 7 | 6 | 11 | 6 | 7 |
| ΔTL-CLT-W06 | 2G13_WS64(600)_GFB65 _AIR13 | **16** | -4 | 1 | 7 | 10 | 13 | 14 | 13 | 17 | 19 |
| **Ceiling Linings** | | | | | | | | | | | |
| ΔTL-CLT-C01 | 2G13_WFUR38(600)_GFB38 | **7** | 1 | -4 | -2 | -2 | 2 | 2 | 9 | 11 | 9 |
| ΔTL-CLT-C02 | 2G13_UC22(600)_ CC38(1200)_GFB140 | **25** | -3 | 3 | 5 | 10 | 14 | 17 | 23 | 24 | 28 |
| ΔTL-CLT-C03 | G16_UC22(600)_CC38(1200) GFB140_2G13 | **25** | 0 | 7 | 8 | 11 | 15 | 18 | 22 | 25 | 27 |
| **Floor Linings** | | | | | | | | | | | |
| ΔTL-CLT-F01 | CON38(no bond) | **7** | 9 | 3 | 9 | 4 | 5 | 5 | 7 | 9 | 11 |
| ΔTL-CLT-F02 | CON38_FOAM09 | **11** | 6 | 4 | 10 | 6 | 6 | 4 | 8 | 10 | 15 |
| ΔTL-CLT-F03 | CON38_WFB13 | **10** | 6 | 7 | 9 | 5 | 4 | 6 | 10 | 11 | 13 |
| ΔTL-CLT-F04 | CON38_FELT19 | **15** | 6 | 7 | 2 | 1 | 6 | 8 | 13 | 17 | 21 |
| ΔTL-CLT-F05 | CON38_RESL13 | **9** | 8 | 5 | 8 | 3 | 1 | 4 | 8 | 12 | 16 |
| ΔTL-CLT-F06 | CON38_RESL08 | **9** | 7 | 6 | 10 | 6 | 4 | 5 | 9 | 11 | 13 |
| ΔTL-CLT-F07 | CON38_RESL17 | **11** | 6 | 7 | 9 | 5 | 4 | 5 | 9 | 12 | 15 |
| ΔTL-CLT-F08 | 2CEMBRD12_WFB13 | **4** | 4 | -4 | 1 | -2 | -2 | -1 | 3 | 5 | 8 |
| ΔTL-CLT-F09 | GCON38_FOAM09 | **7** | 9 | -3 | 9 | 4 | 2 | 3 | 5 | 5 | 9 |

(Continuation of Table A1.4 from opposite page)

| 500 Hz | | | 1000 Hz | | | 2000 Hz | | | 4000 Hz | | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 1 | 2 | 3 | 5 | 5 | 2 | 1 | 0 | 3 | 6 | TLA-12-197:203 vs.Base03 |
| -2 | -1 | 1 | 2 | 5 | 5 | 6 | 3 | 1 | 2 | 5 | 8 | TLA-12-170:177 vs.Base05 |
| 8 | 9 | 10 | 11 | 11 | 11 | 10 | 9 | 5 | 5 | 8 | 11 | TLA-12-201:202 vs.Base03 |
| 6 | 7 | 9 | 8 | 10 | 9 | 10 | 7 | 4 | 6 | 10 | 13 | TLA-12-172:178 vs.Base05 |
| 10 | 9 | 10 | 11 | 12 | 12 | 12 | 10 | 7 | 6 | 10 | 14 | TLA-12-197:203 vs.Base03 |
| 6 | 5 | 9 | 9 | 11 | 11 | 12 | 10 | 6 | 7 | 11 | 15 | TLA-12-181:184 vs.Base05 |
| 19 | 20 | 21 | 22 | 24 | 23 | 23 | 20 | 16 | 18 | 22 | 24 | TLA-12-177:180 vs.Base05 |
| 4 | 5 | 8 | 7 | 9 | 9 | 10 | 8 | 6 | 8 | 12 | 16 | TLA-12-181:184 vs.Base05 |
| 17 | 17 | 17 | 17 | 21 | 22 | 24 | 22 | 21 | 24 | 27 | 30 | TLA-12-185 vs.Base05 |
| 7 | 5 | 8 | 8 | 12 | 12 | 14 | 11 | 5 | 7 | 11 | 14 | TLF-13-014 vs. Base05F |
| 29 | 33 | 36 | 35 | 38 | 38 | 36 | 29 | 28 | 30 | 35 | 38 | TLF-13-012 vs. Base05F |
| 27 | 30 | 32 | 31 | 36 | 36 | 37 | 34 | 28 | 28 | 30 | 33 | TLF-13-016:21 vs. Base05F |
| 6 | 5 | 6 | 6 | 10 | 11 | 14 | 16 | 20 | 22 | 26 | 31 | TLF-13-010 vs. Base05F |
| 13 | 12 | 15 | 17 | 22 | 23 | 26 | 27 | 30 | 30 | 32 | 35 | TLF-12-048 vs. Base05F |
| 10 | 8 | 11 | 15 | 21 | 23 | 27 | 29 | 28 | 28 | 32 | 36 | TLF-12-049 vs. Base05F |
| 21 | 19 | 21 | 22 | 25 | 25 | 28 | 31 | 32 | 33 | 38 | 44 | TLF-12-044 vs. Base05F |
| 13 | 12 | 16 | 19 | 25 | 28 | 32 | 34 | 30 | 31 | 38 | 43 | TLF-13-009 vs. Base05F |
| 10 | 8 | 10 | 12 | 17 | 19 | 22 | 24 | 28 | 30 | 35 | 38 | TLF-12-052, 13-001 vs. Base05F |
| 13 | 12 | 16 | 18 | 24 | 26 | 29 | 32 | 34 | 36 | 39 | 42 | TLF-13-004 vs. Base05F |
| 7 | 8 | 11 | 12 | 17 | 19 | 21 | 17 | 15 | 16 | 20 | 25 | TLF-13-017:018 vs.Base05F |
| 9 | 9 | 11 | 12 | 15 | 17 | 20 | 21 | 24 | 24 | 25 | 23 | TLF-13-020:021 vs. Base05F |

**Table A1.5**: Change in sound transmission loss (ΔTL) due to linings on double-leaf CLT03 wall assemblies

| Lining Code | Lining Description | ΔSTC | 63 Hz | | | 125 Hz | | | 250 Hz | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ΔTL-2xCLT03-W01 | 2G13 | **3** | -3 | 4 | 3 | 3 | 2 | 3 | 1 | 4 | 2 |
| ΔTL-2xCLT03-W03 | 2G13_WFUR38(600)_GFB38 | **6** | -7 | 2 | 0 | -1 | 2 | 7 | 8 | 8 | 5 |

(Continuation of Table A1.5 from opposite page):

| 500 Hz | | | 1000 Hz | | | 2000 Hz | | | 4000 Hz | | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 3 | 6 | 7 | 6 | 6 | 7 | 6 | 3 | 2 | 1 | 1 | TLA-12-220,221 vs. Base 2xCLT03 |
| 7 | 9 | 12 | 11 | 9 | 10 | 11 | 9 | 5 | 4 | 2 | 2 | TLA-12-218 vs. Base 2xCLT03 |

## 5.2 Appendix A2: Calculating ΔSTC for Linings on Single-Leaf CLT Assemblies

To characterize the change in sound transmission loss due to adding a specific lining to a heavy base wall or floor (a CLT assembly in this case) a single-number rating called ΔSTC is introduced.

Key issues concerning ΔSTC include:

- The ΔSTC is a required input for the calculation of ASTC using the Simplified Method of ISO 15712-1 as discussed in Section 4.1.
- Values of ΔSTC calculated from the experimental data in this Report using the procedure here are presented in Table 2.2.2 at the end of Section 2.2.2. Readers of this Report can simply use the tabulated ΔSTC values without the need to perform the calculations detailed here.
- The procedure for calculating the ΔSTC value is presented here for completeness. It is a subset of a more general set of procedures presented in NRC Research Report RR-331, "Guide to Calculating Airborne Sound Transmission in Buildings" [14].

ASTM does not define a ΔSTC rating, but it has a counterpart ($\Delta R_W$) in the ISO standards. The procedure used here is modified from its ISO counterpart in two ways:

1. The STC calculation according to ASTM E413 is substituted for the ISO calculation of $R_W$, plus additional Steps 4 and 5 are included, as explained in Figure A2.4 and the adjacent text.
2. A reference curve to represent the base assembly is required for the calculation. The ISO standards provide a set of three reference curves, one for heavy concrete floors and two for base wall assemblies. For calculations of the ΔSTC value for CLT assemblies, a fourth reference curve has been added for wall assemblies that fall between the two ISO wall cases. The new reference curve is denoted as Reference Wall 2, and is described as "wall with medium-low coincidence frequency."

The reference curves for the ISO procedure to calculate $\Delta R_W$ are smoothed average sound transmission loss curves for some constructions common in Europe – a homogeneous concrete floor (140 mm thick with mass per unit area of 300 kg/m$^2$), a heavy masonry wall with low coincidence frequency (mass per unit area of 350 kg/m$^2$) and a lighter masonry wall of gypsum blocks (mass per unit area of 70 kg/m$^2$) described as a "wall with medium-high coincidence frequency."

In selecting the appropriate reference curve for the calculation of ΔSTC, the mass or thickness of the unlined base wall or floor assembly is irrelevant. What matters is the frequency dependence of its sound transmission loss curve, especially around the frequency where the curve transitions from a comparatively flat plateau at low frequencies to rising at about 2 dB per one-third octave band.

To establish the best reference curve for a given base wall or floor assembly, the reference curve should be shifted up or down to match the STC of the tested assembly. This permits clear identification of the fit below and above the frequency where the curve bends up. The reference curve can be shifted up or down (changing the sound transmission loss at all frequency bands by the same amount) without altering the calculation of ΔSTC because, as detailed in the calculation procedure below, ΔSTC is the *difference* between the STC for the reference curve and the STC calculated for the curve obtained by adding the ΔTL values at each frequency to the reference curve.

The measured sound transmission loss data for the CLT07, CLT05, and CLT03 base assemblies are compared with pertinent reference curves in Figures A2.1, A2.2, and A2.3 respectively.

**Figure A2.1:**
Sound transmission loss for the Base CLT07 assembly, together with the proposed reference curve shifted down to match the STC of the CLT07 assembly.

The line segments match very well: in the low frequency plateau region (100 Hz to 200 Hz) mean deviation is 0.0 dB. In the rising section (250 Hz to 1 kHz) mean deviation is -0.2 dB.

This reference curve is used for the calculation of ΔSTC values for CLT07 linings in Section 2.2.

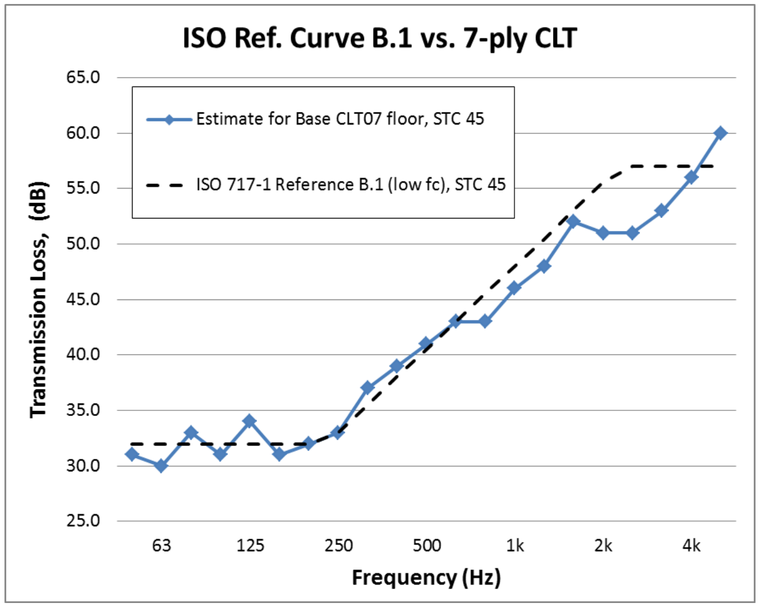
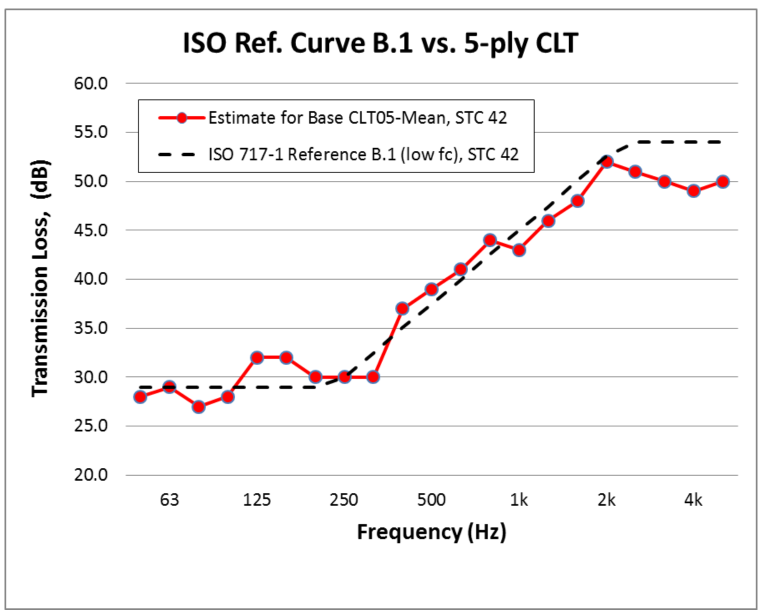



**Figure A2.2:**
Sound transmission loss for the Base CLT05 assembly, together with the proposed reference curve (dashed line) shifted down to match the STC of the CLT05 assembly.

The line segments match quite well: in the low frequency plateau region (100 Hz to 250 Hz) mean deviation is +1.0 dB. In the rising section (250 Hz to 1 kHz) mean deviation is +0.2 dB.

This reference curve is used for the calculation of ΔSTC values for CLT05 linings in Section 2.2.



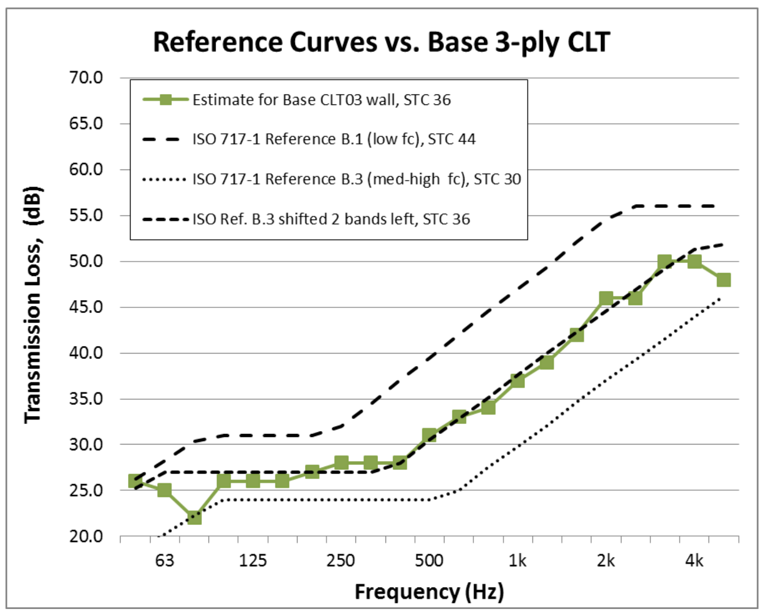
A good fit between the proposed reference curve and the sound transmission loss data for the CLT07 and CLT05 assemblies is evident in Figures A2.1 and A2.2. **Hence this reference curve (named B.1 in the ISO standards and Reference Wall 1 in NRC Research Report RR-331) was used in Section 2.2 for the calculation of ΔSTC values for linings applied to CLT07 and CLT05 assemblies.**

Figure A2.3 shows the sound transmission loss curve for the 3-ply CLT wall and the two reference curves from ISO 717-1. It is evident that the fit between the measured sound transmission loss curve for the Base CLT03 and the ISO reference curves is much less satisfactory than the fit shown in Figures A2.1 and A2.2. The frequency for transition from the plateau to the rising curve is at too low a frequency for Reference Curve B.1 and at too high a frequency for ISO Reference Curve B.3. In order to calculate ΔSTC values for linings on 3-ply CLTs, it was therefore necessary to introduce a third reference curve, also shown in Figure A2.3. This curve for Reference Wall 2 was obtained by shifting the ISO Reference Curve B.3 to lower frequencies by two one-third octave bands, placing it midway between ISO Reference Curves B.1 and B.3 as evident in Figure A2.3.

**Figure A2.3:**
Sound transmission loss for the Base CLT03 assembly, together with the proposed Reference Wall 2 curve (dashed line) shifted to match the STC of the CLT03 assembly.

The line segments match very well: in the low frequency plateau region (between 100 Hz and 315 Hz) the mean deviation is -0.2 dB. In the rising section (between 400 Hz and 2 kHz) the mean deviation is -0.1 dB.

This Reference Curve is used for the calculation of ΔSTC values for CLT03 linings in Section 2.2.




A good fit between the proposed reference curve and the sound transmission loss data for the Base CLT03 assembly is evident in Figure A2.3. **This reference curve (called Reference Wall 2) was used in Section 2.2 for calculating ΔSTC values for the linings applied to CLT03 assemblies.**

## *Procedure for Calculating ΔSTC Ratings*

The procedure to establish the change in sound transmission loss ΔTL due to adding linings is presented in Section 2.2. The following procedure uses those values for ΔTL (in one-third octave bands) for each lining to calculate the corresponding single-number ΔSTC ratings.

Steps in the procedure are detailed here and shown schematically in Figure A2.4:

**Step 1.** The change in sound transmission loss (ΔTL) due to adding the lining is calculated from the laboratory test results according to ASTM E90 (for the base assembly without any added lining and for that assembly with lining(s) added) for each frequency band, including at least 125 Hz to 4 kHz. This may involve averaging results from several pairs of assemblies as explained in Section 2.2.

**Step 2.** (a) Calculate the sum of the sound transmission loss for the chosen reference curve (from Table A2.1) plus ΔTL for each frequency band. The STC rating for this case is $STC_{1\text{-Side}}$.
(b) Calculate the sum of the sound transmission loss for the Reference curve (from Table A2.1) plus 2 x ΔTL for each frequency band. The STC rating for this case is $STC_{2\text{-Sides}}$.
(c) Calculate the STC rating for the reference curve ($STC_{REF}$).

**Step 3.** Subtract the STC rating of the reference curve ($STC_{REF}$) from $STC_{1\text{-side}}$ to obtain $\Delta STC_{1\text{-Side}}$.

**Step 4.** Subtract the STC rating of the reference curve ($STC_{REF}$) from $STC_{2\text{-sides}}$ to obtain $\Delta STC_{2\text{-Sides}}$.

**Step 5.** Calculate the ΔSTC value: ΔSTC is the smaller of $\Delta STC_{1\text{-Side}}$ and $\Delta STC_{2\text{-Sides}}/1.5$, rounded to integers (e.g. 20/1.5 ⇨ 13).

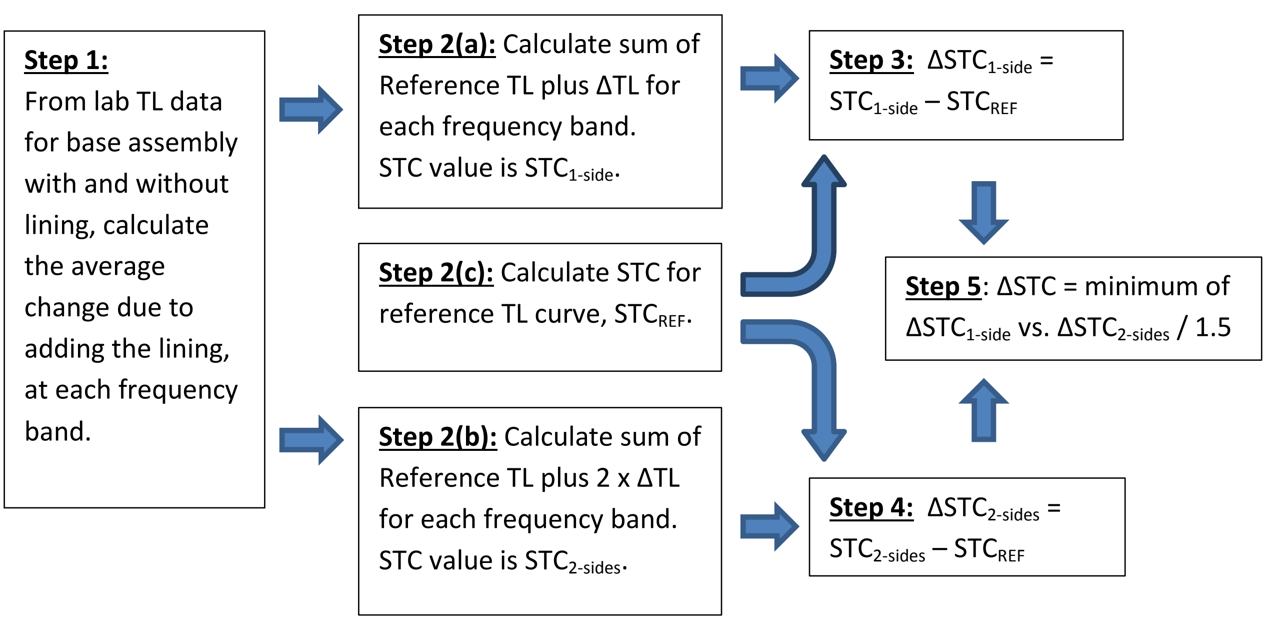



**Figure A2.4**: Steps to calculate the single-number rating ΔSTC for added linings (as detailed above).

Consideration of the change in STC when there is a lining on both sides of the wall (Step 4) and dividing $\Delta STC_{2\text{-sides}}$ by 1.5 in Step 5 can be understood by considering the use of ΔSTC values in Eq. 4.1.1 and 4.1.2 and in the worked examples in Section 4.2.

Selection of the more conservative value (at Step 5) is required to avoid a misleading (over-optimistic) ΔSTC rating in the calculation procedure of the Simplified Method.

The numerical sound transmission loss values for the two reference curves are presented in Table A2.1 on the next page.

**Table A2.1**:
Reference Curves for the calculation of ΔSTC for linings applied to specific base wall or floor assemblies. These curves are based on the set of reference curves for calculating $\Delta R_W$ in the relevant ISO standards.

The comparison process for selection of the most suitable reference curve for each type of base CLT assembly (3-ply, 5-ply, or 7-ply CLT) is shown in Figures A2.1 to A2.3.

| **Frequency (Hz)** | **Reference Curve for calculating ΔSTC for linings applied to 3-ply CLT** | **Reference Curve for calculating ΔSTC for linings applied to 5-ply or 7-ply CLT** |
|---|---|---|
| 50 Hz | 25.3 | 35.3 |
| 63 Hz | 27.0 | 37.3 |
| 80 Hz | 27.0 | 39.4 |
| 100 Hz | 27.0 | 40.0 |
| 125 Hz | 27.0 | 40.0 |
| 160 Hz | 27.0 | 40.0 |
| 200 Hz | 27.0 | 40.0 |
| 250 Hz | 27.0 | 41.0 |
| 315 Hz | 27.0 | 43.5 |
| 400 Hz | 28.0 | 46.1 |
| 500 Hz | 30.5 | 48.5 |
| 630 Hz | 32.8 | 51.0 |
| 800 Hz | 35.1 | 53.6 |
| 1000 Hz | 37.6 | 56.0 |
| 1250 Hz | 40.0 | 58.4 |
| 1600 Hz | 42.3 | 61.1 |
| 2000 Hz | 44.6 | 63.6 |
| 2500 Hz | 46.9 | 65.0 |
| 3150 Hz | 49.2 | 65.0 |
| 4000 Hz | 51.3 | 65.0 |
| 5000 Hz | 51.3 | 65.0 |
| **STC** | **36** | **53** |
| Source: | Reference Wall 2 in App. A1 of RR-331 (aka Reference Curve B.3 in Annex B of ISO 140-16, shifted two one-third octaves) | Reference Wall 1 in App. A1 of RR-331 (aka Reference Curve B.1 in Annex B of ISO 140-16) |

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# 6 References and Endnotes

## *Technical Standards*

1. ASTM E90-09, “Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements”, ASTM International, West Conshohocken, PA, USA.
2. ASTM E336-10, “Standard Test Method for Measurement of Airborne Sound Insulation in Buildings”, ASTM International, West Conshohocken, PA, USA.
3. Other ASTM standards referenced and used in ASTM E90 and E336 include: ASTM E413-10, “Classification for Rating Sound Insulation” and ASTM E2235-04 “Standard Test Method for Determination of Decay Rates for Use in Sound Insulation Test Methods”, ASTM International, West Conshohocken, PA, USA.
4. ISO 717:2013, “Acoustics—Rating of sound insulation in buildings and of building elements—Part 1: Airborne Sound Insulation, Part 2: Impact Sound Insulation” International Organization for Standardization, Geneva.
5. ISO 10140:2011, Parts 1 to 5, “Laboratory measurement of sound insulation of building elements”, International Organization for Standardization, Geneva. Note: In 2011 the ISO 10140 series replaced ISO 140 Parts 1, 3, 6, 8, 10, 11 and 16. In 2014, ISO 140-4 was replaced by ISO 16283-1, “Field measurement of sound insulation in buildings and of building elements.”
6. ISO 10848:2006, Parts 1 to 4, “Laboratory measurement of flanking transmission of airborne and impact sound between adjoining rooms”, International Organization for Standardization, Geneva.
7. ISO 15712:2005, Part 1, “Estimation of acoustic performance of buildings from the performance of elements”, International Organization for Standardization, Geneva.

## *Other Technical References*

8. L. Cremer and M. Heckl, “Structure-borne sound”, edited by E.E. Ungar, Springer-Verlag, New York (original edition 1973, 2nd edition 1996).
9. E. Gerretsen, “Calculation of the sound transmission between dwellings by partitions and flanking structures”, Applied Acoustics, Vol. 12, pp 413-433 (1979), and “Calculation of airborne and impact sound insulation between dwellings”, Applied Acoustics, Vol. 19, pp 245-264 (1986).
10. R.J.M. Craik, “Sound transmission through buildings: Using statistical energy analysis”, Gower Publishing (1996).
11. D.B. Pedersen, “Evaluation of EN 12354 part 1 and 2 for Nordic Dwelling Houses”, Applied Acoustics, Vol. pp 259-268 (2000), (Validation and background studies for the ISO 15712 procedures).

## *Sources for Sound Transmission Data*

Source references for sound transmission data (both collections of conventional laboratory test results for wall and floor assemblies according to ASTM E90, and flanking sound transmission tests according to ISO 10848) including many NRC Construction reports in the RR- and IR- series are available from the Publications Archive of the National Research Council Canada at http://nparc.cisti-icist.nrc-cnrc.gc.ca/npsi/ctrl?lang=en.

12. The software application *soundPATHS* is accessible online at the website of the National Research Council Canada. The calculations are based on experimental studies in the laboratories of the NRC: http://www.nrc-cnrc.gc.ca/eng/solutions/advisory/soundpaths/index.html
13. Technical details concerning the measurement protocol (consistent with ISO 10848) and discussion of the findings of the experimental studies are presented in a series of NRC reports:
    13.1. Report A1-100035-02.1, "Report to Research Consortium for Wood and Wood-Hybrid Mid-Rise Buildings, Acoustics – Sound Insulation in Mid-Rise Buildings" (2013)
    13.2. IR-754, "Flanking Transmission at Joints in Multi-Family Dwellings. Phase 1: Effects of Fire Stops at Floor/Wall Intersections", T.R.T. Nightingale and R.E. Halliwell, (1997)
    13.3. RR-103, "Flanking Transmission in Multi-Family Dwellings Phase II: Effects of Continuous Structural Elements at Wall/Floor Junctions", T.R.T. Nightingale, R.E. Halliwell, and J.D. Quirt (2002)
    13.4. RR-168, "Flanking Transmission at the Wall/Floor Junction in Multifamily Dwellings - Quantification and Methods of Suppression", T.R.T. Nightingale, R.E. Halliwell, J.D. Quirt and F. King (2005)
    13.5. RR-218, "Flanking Transmission in Multi-Family Dwellings Phase IV", T.R.T. Nightingale, J.D. Quirt, F. King and R.E. Halliwell, (2006)
    13.6. RR-219, "Guide for Sound Insulation in Wood Frame Construction", J.D. Quirt, T.R.T. Nightingale, and F. King (2006). See also NRC Construction Technology Update 66, "Airborne Sound Insulation in Multi-Family Buildings", J.D. Quirt and T.R.T. Nightingale (2008)
    13.7. J. K. Richardson, J. D. Quirt, R. Hlady, "Best Practice Guide on Fire Stops and Fire Blocks and their Impact on Sound Transmission", NRCC #49677 (2007)
    13.8. IR-832, "Sound Insulation of Load-Bearing Shear-Resistant Wood and Steel Stud Walls", T.R.T. Nightingale, R.E. Halliwell, J.D. Quirt and J.A. Birta (2002)
    13.9. RR-169, "Summary Report for Consortium on Fire Resistance and Sound Insulation of Floors: Sound Transmission and Impact Insulation Data", A.C.C. Warnock (2005)
14. RR-331, "Guide to Calculating Airborne Sound Transmission in Buildings" (2nd Edition, 2016) is a companion to this Report, which presents both the "Detailed Method" and the "Simplified Method" of ISO 15712-1 for calculating sound transmission in buildings.
15. The databases of flanking sound transmission data used in Guide RR-331 and in *soundPATHS* will be consolidated in a series of NRC publications presenting data from recent studies:
    15.1. RR-333 Apparent Sound Insulation in Concrete Buildings (2017)
    15.2. RR-334 Apparent Sound Insulation in Concrete Block Buildings (2015)
    15.3. RR-335 Apparent Sound Insulation in Cross-Laminated Timber Buildings (2017)
    15.4. RR-336 Apparent Sound Insulation in Wood-Framed Buildings (2017)
    15.5. RR-337 Apparent Sound Insulation in Cold-Formed Steel-Framed Buildings (2017)

1 Cross-Laminated Timber (CLT) assemblies are structural panels fabricated by bonding wood elements together in layers with alternating perpendicular orientation of the timber elements. The CLT panels evaluated in this study had adhesive bonding between the faces of timber elements in adjacent layers, but no adhesive bonding the adjacent timber elements within a given layer. There were noticeable gaps between the timber elements comprising each layer of the CLT assembly. These CLT panels could be called "Face-laminated CLT Panels" but are simply referred to as CLT panels in the body of this Report. For the 3-ply panels considered in this Report, each layer or ply has a thickness of 26 mm and is comprised of parallel wood boards whose cross section is 26 x 89 mm. For the 5-ply and 7-ply panels, the ply thickness increases from 26 mm to 35 mm. The physical properties of the tested bare laminated panels are:

- 3-ply panels: 78 mm thick, 42.4 kg/m$^2$
- 5-ply panels: 175mm thick, 91.4 kg/m$^2$
- 7-ply panels: 245 mm thick, 130 kg/m$^2$

2 Sound absorbing material is porous (closed-cell foam is not included) and readily-compressible, and includes fiber processed from rock, slag, glass or cellulose fiber. Such material provides acoustical benefit for direct transmission through lightweight framed wall or floor assemblies, and for flanking transmission when installed in the cavities between lining surfaces and heavy homogeneous structural elements such as CLT. Note that overfilling the cavity could diminish the benefit of the sound absorbers.

3 Gypsum board panels commonly form the exposed surface on lightweight framed wall or floor assemblies and on linings for heavy homogeneous structural wall or floor assemblies of concrete, concrete block or CLT. The gypsum board in this study had nominal thickness of 12.7 mm (1/2 inch) or 15.9 mm (5/8 inch) denoted in specimen codes as 13 mm and 16 mm respectively.

"Fire-rated gypsum board" is typically heavier than non-fire-rated gypsum board. The higher mass of the fire-rated gypsum board gives improved resistance to sound transmission through the assembly. The descriptor "fire-rated" is used in this Report to denote gypsum board with proven fire-resistant properties, with mass per unit area of at least 8.7 kg/m$^2$ for 12.7 mm thickness, or 10.7 kg/m$^2$ for 15.9 mm thickness. Gypsum board panels are installed with framing, fasteners and fastener spacing conforming to installation details required by CSA A82.31 M or ASTM C754. The sound transmission results should only be used where the actual construction details correspond to the details of the test assemblies on which the ratings are based.

4 Resilient metal channels are formed from steel with a maximum thickness of 0.46 mm (25 gauge), with a profile essentially as shown in Figure 6.1, with slits or holes in the single "leg" between the faces fastened to the framing and to the gypsum board. Installation of the resilient channels must conform to ASTM C754.

**Figure 6.1:** Drawing to illustrate the typical profile of resilient metal channels; approximate dimensions in cross-section are 13 mm x 60 mm (not precisely to scale).

(Copied from Figure A-9.10.3.1 of the National Building Code of Canada, used with permission)