Addendum to RR-335: sound transmission through Nail-Laminated Timber (NLT) assemblies

Mahn, Jeffrey; Quirt, David; Hoeller, Christoph; Mueller-Trapet, Markus

For the publisher's version, please access the DOI link below./ Pour consulter la version de l'éditeur, utilisez le lien DOI ci-dessous.

https://doi.org/10.4224/40000417

NRC·CNRC Construction

Addendum to RR-335: Sound Transmission through Nail-Laminated Timber (NLT) Assemblies

Jeffrey Mahn, David Quirt, Christoph Hoeller, Markus Mueller-Trapet

March 2018

National Research Council Canada
Conseil national de recherches Canada

Canada

Scope

This report is published as an addendum to NRC Research Report RR-335 “Apparent Sound Insulation in Cross-Laminated Timber Buildings." It is intended that this addendum will be merged with RR-335 in the future as a report for predicting the sound insulation in buildings using mass-timber constructions including NLT assemblies.

This report presents the results from experimental studies of airborne sound transmission through assemblies of nail-laminated timber (NLT) with various linings. To put the data presented in this report in the proper context, this report begins with a brief explanation of calculation procedures to predict the apparent sound transmission class (ASTC) between adjacent spaces in a building whose structure is a combination of mass-timber assemblies such as nail-laminated timber (NLT) or cross-laminated timber (CLT) panels.

Acknowledgments

The research studies on which this Report is based were supported by Natural Resources Canada. Their 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 STC or 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 direct airborne sound transmission for the mass-timber assemblies for the types of constructions presented.

This page was intentionally left blank.

Contents

This page was intentionally left blank.

Executive Summary

Following the procedures explained in the NRC's Research Reports RR-331 and RR-335, the calculation of the ASTC rating of mass-timber constructions requires as inputs three sets of standard test data. This Addendum to the Research Report RR-335 provides two sets of the required data for nail-laminated timber (NLT) constructions: the airborne sound transmission through five thicknesses of base NLT assemblies and the change in the airborne sound transmission though these assemblies when a lining such as a gypsum board on wood furring strips is added to the basic NLT assembly.

The specimen descriptions and test data are located in this report as follows:

- The NLT assemblies are described at the beginning of Section 2.1
- STC values and one-third octave band sound transmission test data are listed in Appendix A1.1
- Trends in those data are discussed in Sections 2.1 and 2.2.
- Key single number STC and ΔSTC ratings determined from the tests are given in Table A1.2 and Table A1.3 of Appendix A1.

Key findings from this report include:

- The transmission loss of the NLT assemblies with a shear membrane which were evaluated are too low to be used in multi-tenancy, residential constructions without the addition of linings or toppings.

Nominal Timber Dimensions	Description	STC Rating
2x4	NLT89 with Plywood Shear Membrane	29
2x6	NLT140 with Plywood Shear Membrane	31
2x8	NLT184 with Plywood Shear Membrane	31
2x10	NLT235 with Plywood Shear Membrane	36
2x12	NLT286 with Plywood Shear Membrane	41

- For each thickness of NLT, the transmission loss of the NLT with a shear membrane of oriented strandboard (OSB) was also tested. In every case the substitution of OSB for plywood improved the transmission loss of the assembly at most frequencies, typically providing an increase of 1 STC point. Based on this finding, it is concluded that the STC ratings for assemblies with plywood provide a reliable conservative estimate for equivalent assemblies with OSB substituted for the plywood.
- Data presented in RR-335 for linings installed on CLT assemblies may be used in most cases as a conservative estimate of the use of the same linings used on NLT assemblies.
- For the NLT assemblies evaluated as part of this study, it was established that the loss factors were high enough to justify ignoring corrections for edge losses in the detailed calculations in accordance with ISO 15712-1, which greatly simplifies those calculations.

This page was intentionally left blank.

1 Introduction

The 2015 edition of the National Building Code of Canada (NBCC) includes changes to the acoustic requirements for residential constructions. Earlier editions of the NBCC described the acoustic requirements in terms of the sound transmission class (STC) rating of the assemblies that separate dwellings in a building. In the 2015 edition, the requirements based on a STC rating were replaced with new requirements based on the apparent sound transmission class (ASTC) rating.

One method of demonstrating compliance with the acoustic requirements of the NBCC is to predict the ASTC rating through calculations based on laboratory measured data. This prediction method is outlined in the NRC Research Report RR-331 "Guide to Calculating Airborne Sound Transmission in Buildings" [14]. The laboratory measured data includes the transmission loss of the walls and floors of the construction being considered.

This Addendum to Research Report RR-335 presents the results from experimental measurements of the airborne sound transmission through assemblies of nail-laminated timber (NLT)[1] with various linings that are required for the calculation of the ASTC rating of constructions that include NLT assemblies.

1.1 Sound Transmission via Many Paths

The simplest approach to controlling sound transmission between adjacent rooms in buildings considers only the sound transmission through the separating wall or floor. This approach has been entrenched in North American building codes which for many decades have considered only the single number ratings for the common assembly between dwellings. The single-number ratings used by this approach is the sound transmission class (STC) rating for airborne sources and impact insulation class (IIC) rating for footstep noise. Implicit in this approach is the simplistic assumption that sound is only transmitted through the obvious separating assembly between dwellings – the separating wall assembly when the rooms are side-by-side (illustrated in Figure 1.1.1) or the floor/ceiling assembly when rooms are one-above-the-other. Under this approach, inadequate sound insulation is often incorrectly 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 mindset is still common among designers and builders in North America.

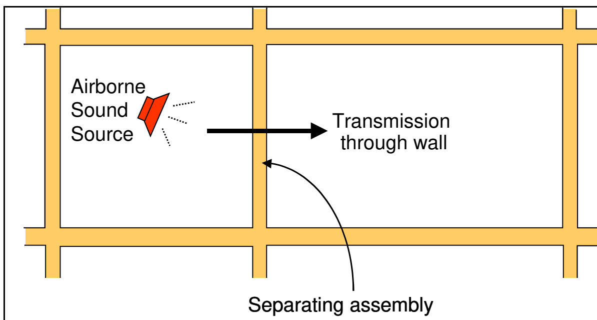


Figure 1.1.1: A cross-section through a building with two side-by-side rooms. This figure shows the historic perspective that only the direct sound transmission through the separating assembly needs to be considered. Part of the sound from an airborne source in one unit (represented by red loudspeaker in the drawings, which could include anything from a home theatre to people talking loudly) is transmitted to the adjacent unit.

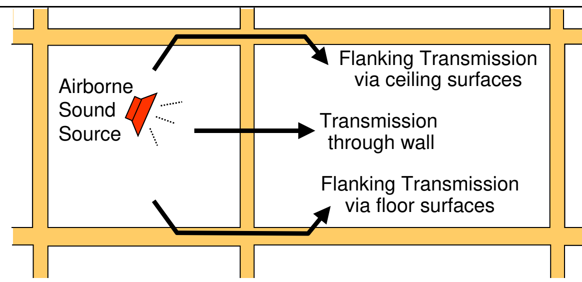


Figure 1.1.2: In reality, there are many paths for sound transmission between adjacent rooms, including both direct transmission through the separating assembly and indirect flanking paths, through the connected building elements, a few of which are shown here. The structure-borne paths usually significantly affect the overall sound transmission. See Section 1.4 for more detail.

In reality, the technical issue is more complex, as illustrated in Figure 1.1.2. There is the direct transmission of sound through the separating assembly, but that is only one of the ways that sound is transmitted between the adjacent rooms. As shown in the figure, the airborne sound source excites the surfaces in the source space and these surfaces vibrate in response. Some of this vibrational energy is transmitted as structure-borne sound through the junctions where these surfaces join the separating assembly and into surfaces of the adjoining space. The 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.

Occupants of the adjacent room 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. It follows that in reality, the sound insulation between adjacent rooms is always worse than the sound insulation provided by just the separating assembly. 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]. Although the measurement of the ASTC rating in a building according to ASTM E336 is quite straightforward, predicting the ASTC rating of a building is more complex. The challenge has been to reduce the complicated calculation of the sound transmission by multiple paths into 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 a standardized frameworks for calculating the overall sound transmission have been developed and have been in use to support performance-based European code systems. For example, ratings described in ISO standards such as the weighted apparent sound reduction index (R'_w) have been used in many countries for decades. The weighted apparent sound reduction index has a corresponding rating called the apparent sound transmission class (ASTC) rating as described in the standard, ASTM E336 [2]. The ASTC rating is used in the 2015 edition of the National Building Code of Canada and explained in detail in the NRC Report RR-331.

1.2 Predicting Sound Transmission in a Building

In 2005, ISO published the standard, ISO 15712-1, "Building acoustics — Estimation of acoustic performance of buildings from the performance of elements — Part 1: Airborne sound insulation between rooms" [7]. This standard describes a method of calculating the sound transmitted via many paths and is one part of a series of standards on the subject. Part 2 of ISO 15712 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". The procedures of ISO 15712-1 were specified in the 2015 edition of the National Building Code of Canada (NBCC) as appropriate methods for calculating the ASTC rating to establish that the sound control provisions of a proposed building design will conform to the acoustic requirements of the Building Code.

However, there were two significant impediments to applying the methods of ISO 15712-1 within a North American context:

- ISO 15712-1 provides reliable estimates for massive types of construction, including cross-laminated timber (CLT) constructions, but not for the lightweight framed construction widely used for buildings in North America.
- There are many differences between the ISO standards for building acoustics [5] and the ASTM standards [1] used by the construction industry in North America both in terms of terminology and in terms of the technical requirements for measurements and the calculations of ratings.

The 2015 edition of the National Building Code of Canada deals with these issues by specifying suitable procedures and test data to calculate the ASTC rating for different types of constructions. These procedures are explained with many worked examples in the NRC Research Report RR-331, "Guide to Calculating Airborne Sound Transmission in Buildings". Report RR-331 outlines a strategy for merging ASTM and ISO test data and procedures and provides recommendations and example calculations for adapting the calculation procedures for different building constructions.

The Report RR-331 was developed as part of a project established by the National Research Council of Canada along with industry partners including the Canadian Wood Council with the goal of supporting the transition of construction industry practices to adopt the ASTC rating rather than the STC rating for the sound control objectives in the National Building Code of Canada (NBCC). However, the potential range of applications for RR-331 goes beyond the minimum requirements of the NBCC. The Report also facilitates building designs to provide enhanced levels of sound insulation and should be generally applicable to construction with mass-timber assemblies both in Canada and in the USA.

For buildings constructed from NLT wall and floor assemblies, the Detailed Method and the Simplified Method of ISO 15712-1 provide predictions of the ASTC rating which are suitable to meet the requirements of the NBCC. Research Report RR-335 [15.3] gives a detailed description of the steps of the standardized calculation procedure for buildings with a structure of CLT assemblies, and it is anticipated that those same procedures will apply with some extensions to other types of mass-timber construction once the required test data has been measured.

For mass-timber constructions, there are three sets of standard test data which are required as inputs for the ASTC calculations following the procedures of ISO 15712-1:

1. The airborne transmission loss through the basic mass-timber assemblies measured according to ASTM E90. A requirement for the test data to be properly applied to the calculation of the flanking sound transmission is that there must be negligible air leakage through the specimens evaluated.
2. Data measured according to ASTM E90 to determine the change in transmission of airborne sound though the assemblies when a lining such as a floor surface or a gypsum board wall or ceiling finish mounted on lightweight wood or steel framing is added to the basic mass-timber element.
3. The vibration reduction index measured according to ISO 10848 [6] to determine the transmission of structure-borne vibration though the junctions where mass-timber wall and floor assemblies are connected.

In addition, pertinent physical properties of the assemblies such as their mass per unit area and structural loss factors are required.

This Addendum to Research Report RR-335:

- includes two of the three sets of standard test data described above
- details only part of the data needed to calculate the ASTC rating for adjacent units in a building. Measurement of the transmission of structure-borne noise through junctions between connected NLT assemblies in a subsequent project will provide the missing data for the calculation of the ASTC rating.

2 Sound Transmission through NLT Wall and Floor Assemblies

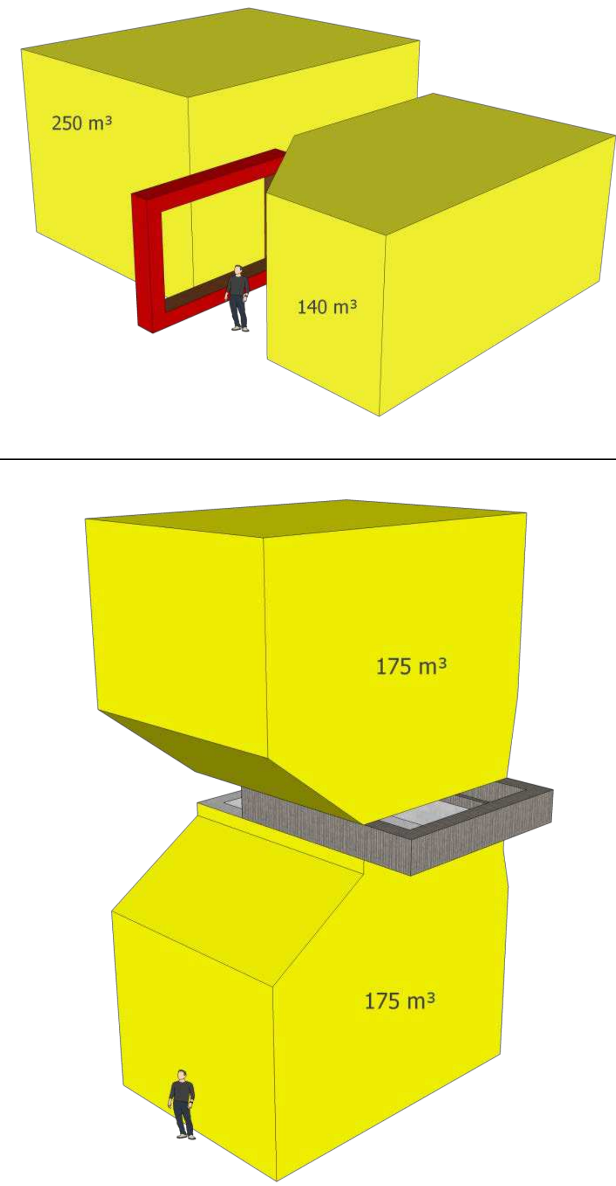
The direct sound transmission loss of wall and floor assemblies were measured in the NRC's wall and floor direct sound transmission facilities according to ASTM E90 [1]. Concept drawings of the NRC's direct sound transmission facilities are presented in Figure 2.1.

Figure 2.1: The upper drawing shows the NRC's direct wall sound transmission facility. The NRC's direct floor transmission facility, shown in the lower drawing, is similar except that one room is above the other.

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.

In both cases, full scale test assemblies are mounted in 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.

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



Each of the direct transmission facilities is equipped with an automated measurement system for data acquisition and post-processing. In each room, a calibrated Brüel & Kjær 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 the diffusivity of the sound field, there are diffusing panels installed 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 measurements were performed in both transmission 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 the average 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, the 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 one-third octave bands from 125 Hz to 4000 Hz were used for the calculation of the STC rating in accordance with ASTM E413-16 [3].

In addition to the sound transmission measurements, several additional measurements were also made to characterize the NLT assemblies. The mass and dimensions of the materials were recorded 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.

Location of the test data:

- Transmission loss data in one-third octave bands is listed in Appendix A1.
- Trends in those data are discussed in Sections 2.1 and 2.2.
- A summary of key single-number STC and ΔSTC ratings determined from the tests is given in Tables A1.1 and A1.2 in Appendix A1, together with corresponding one-third octave band values.

2.1 NLT Walls and Floors without Linings

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

Each of the NLT panels was fabricated by nailing together individual pieces of timber as illustrated conceptually in Figure 2.1.1 and discussed in more detail in Endnote 1 on page 49. This report includes test results on five thicknesses of NLT wall or floor assemblies which are listed in Table 2.1.1.

Figure 2.1.1:
A bare NLT assembly with no shear membrane or other lining on either side.

Table 2.1.1: Physical details of the five NLT assemblies evaluated in this report

NLT Designation	Common Timber Name	Mass / unit area (kg/m²)	Fabrication
NLT89	2x4	39.5	Fabricated from 2x4 timbers of nominal cross-section 38 mm x 89 mm
NLT140	2x6	65.8	Fabricated from 2x6 timbers of nominal cross-section 38 mm x 140 mm
NLT184	2x8	81.6	Fabricated from 2x8 timbers of nominal cross-section 38 mm x 184 mm
NLT235	2x10	89.5	Fabricated from 2x10 timbers of nominal cross-section 38 mm x 235 mm
NLT286	2x12	136.8	Fabricated from 2x12 timbers of nominal cross-section 38 mm x 286 mm

While the sound insulation data provided in this Report is based on measurements conducted with NLT assemblies with the specific parameters listed in Table 2.1.1, the data may also be used as a conservative estimate for NLT assemblies of similar construction but of greater thickness or higher mass.

Determination of the Base NLT assemblies for linings

Prior studies on concrete masonry walls as described in Research Report RR-334 and CLT assemblies as described in Research Report RR-335 have found that the application of linings to the bare assembly increases the transmission loss of the assembly both due to the lining and due to the sealing of voids or slits in the base assembly. It was concluded in those studies that in order to avoid overestimating the change the transmission loss when a lining was applied to the assembly with sound leakage, the change in the transmission loss due to stopping the leakage needed to be separated from the change in the transmission loss due to the lining. A procedure was developed where a thin layer of parge was applied to one side of the element to stop the leaks so that the transmission loss of just the element without leakage could be determined. The layer of parge was used because it effectively stopped the sound leakage without significantly changing the mass or stiffness of the element. The changes in the transmission loss of the parge itself could be determined by applying the parge to the other side of the element and subtracting the measured transmission loss of the element with parge on both sides from the transmission loss of the same element with parge on one side. Measurements were made on NLT89 and it was shown that the parge had a negligible transmission loss itself and therefore was a good means of sealing air leaks without affecting the transmission loss of the bare element.

For the NLT assemblies considered for this study, the appropriate Bare (with leakage) and the Base (no leakage) assemblies needed to be determined. This investigation is discussed in detail below. It was concluded that the Bare assembly would be the NLT assembly with a plywood shear element on one side since this is how the NLTs are used in practice.

Note that:

- The third-octave-band sound transmission loss data for the unsealed NLT assemblies with a plywood shear membrane on one side, referred to as the **Bare** assembly is shown in Table A1.1.
- The third-octave-band sound transmission loss data for the sealed NLT assemblies with a plywood shear membrane on one side, referred to as the **Base** assembly is shown in Table A1.2.

Each of the NLT assemblies listed in Table 2.1.1 was first tested with both surfaces of the assembly bare and then tested again with one or both of the surfaces parged with a thin layer of cementitious material that seals the openings of the cracks between the timber elements comprising the NLT. The purpose of the sealing of the cracks was to stop the leakage of sound through the cracks.

Figure 2.1.2: Comparison of the sound transmission loss of the basic NLT89 assembly with no lining on either side (bare) and with parge on one and on both sides of the assembly (sealed).

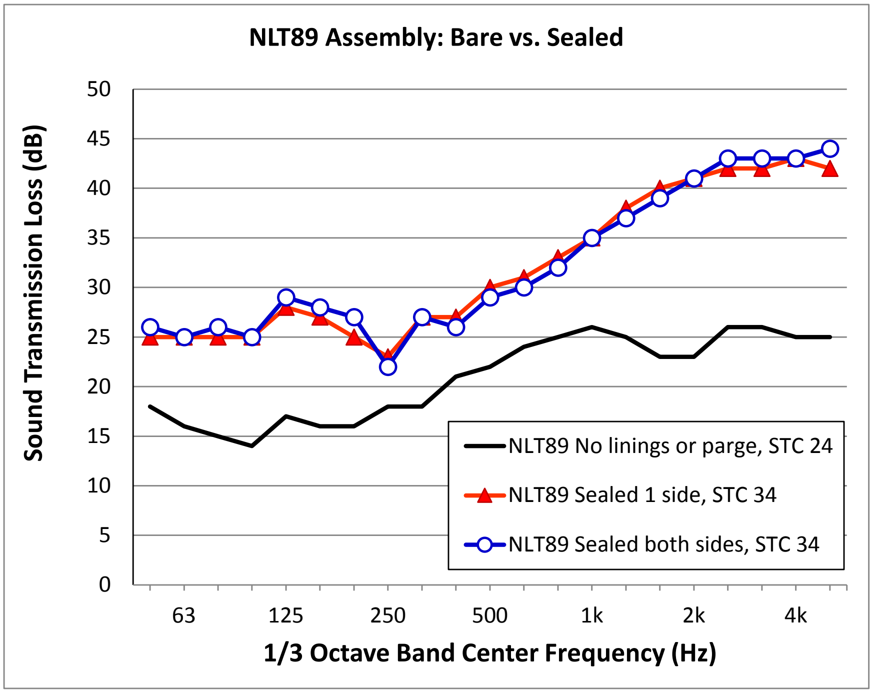


Figure 2.1.2 presents the direct sound transmission loss measured for NLT89 both without a shear membrane or other linings and with parge on one or both sides of the assembly (sealed cases). Several features are obvious:

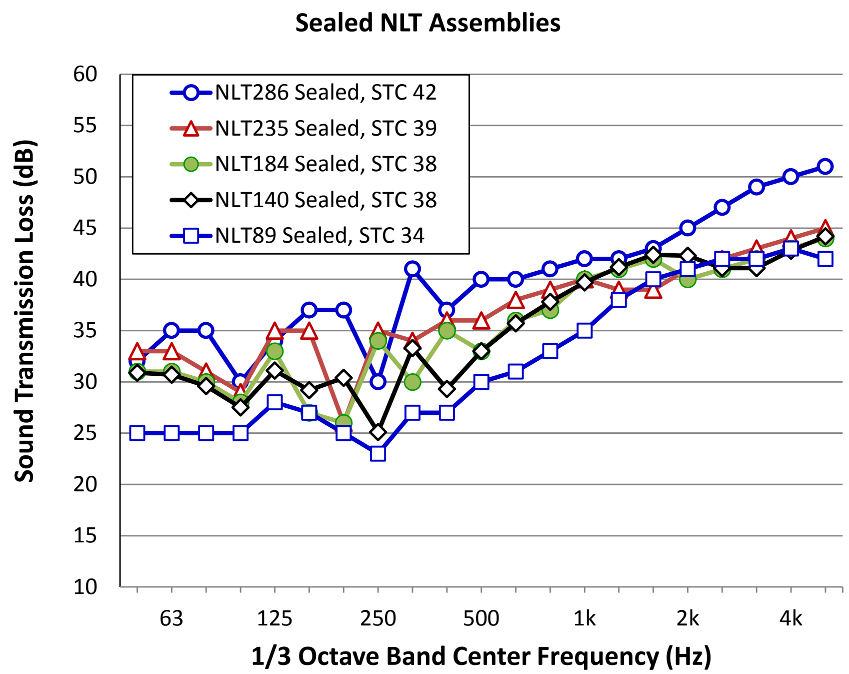
- The transmission loss curve for the bare NLT89 assembly is far below the transmission loss curve observed when the assembly was sealed with parge. The difference indicates that for this sample, there was significant sound leakage through the thin slits between the individual timbers of the NLT assembly.
- The result when both sides of the NLT assembly are sealed has the same STC rating as when only one side is sealed. The curves in the figure cross one another (mean difference = 0.2 dB) in the 250 Hz one-third octave band and the differences in any one-third octave band are smaller than the nominal measurement uncertainty. It was concluded that sealing the second side makes negligible practical difference compared to sealing one side of the NLT assembly and therefore subsequent assemblies were evaluated with parge on only one side.

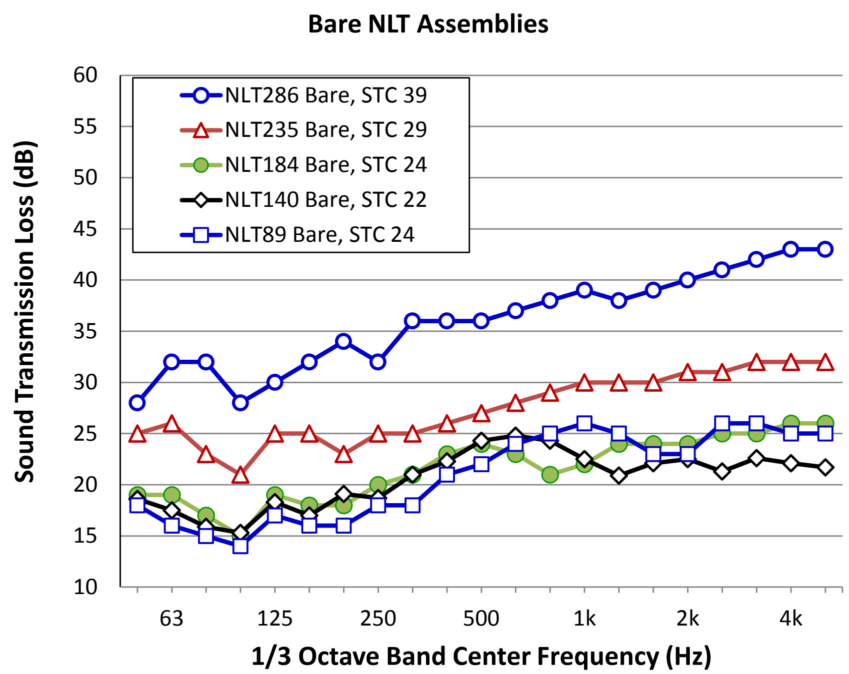
The change in the transmission loss due to sealing the NLT89 assembly shown in Figure 2.1.2 was found to be typical for the other NLT assemblies, as shown in Figure 2.1.3.

Figure 2.1.3: Comparison between the direct sound transmission loss for the bare and sealed NLT assemblies

The upper graph shows transmission loss data for the sealed NLT assemblies.

The lower graph shows transmission loss data for the bare NLT assemblies.

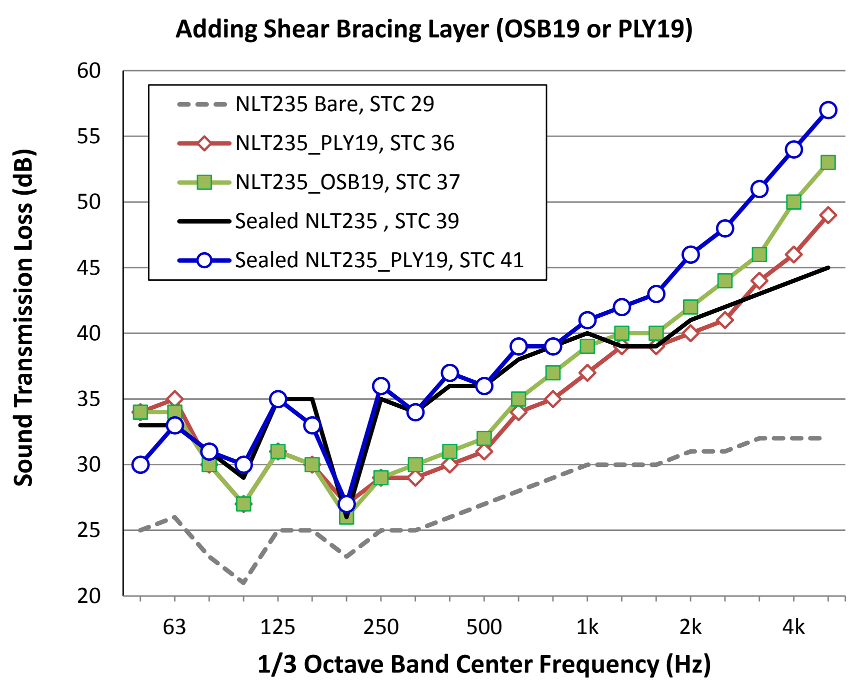




In every case, across the frequency range of interest the bare NLT assembly had an appreciably lower transmission loss than the comparable sealed NLT assembly although there was less of an effect due to sealing observed for the thickest NLT assemblies as compared to the thinner assemblies. Because the sealing process should have a negligible effect on the parameters that are significant for sound transmission such as the stiffness or weight of the assembly, the results are a clear indication that air leakage through the slits between the timber elements of the NLT assemblies dominated the sound transmission for the bare assembly. This result is not surprising since the slits between the timber elements of the NLT assemblies were a millimetre wide in some instances.

Normally, NLT assemblies in a building include a shear membrane which is a layer of plywood or oriented strandboard (OSB) mechanically fastened with nails or screws to one face of the NLT assembly to resist shear forces that could otherwise distort the assembly. Figure 2.1.4 illustrates how the addition of a shear membrane alters the sound transmission loss of a bare or sealed 235 mm thick NLT assembly.

Figure 2.1.4: Comparison of the sound transmission loss curves of NLT235 due to sealing the assembly and/or adding a shear membrane of 19 mm thick plywood (Ply19) or OSB (OSB19).



The trends evident for the NLT235 assemblies are typical for all of the thicknesses of the NLT assemblies:

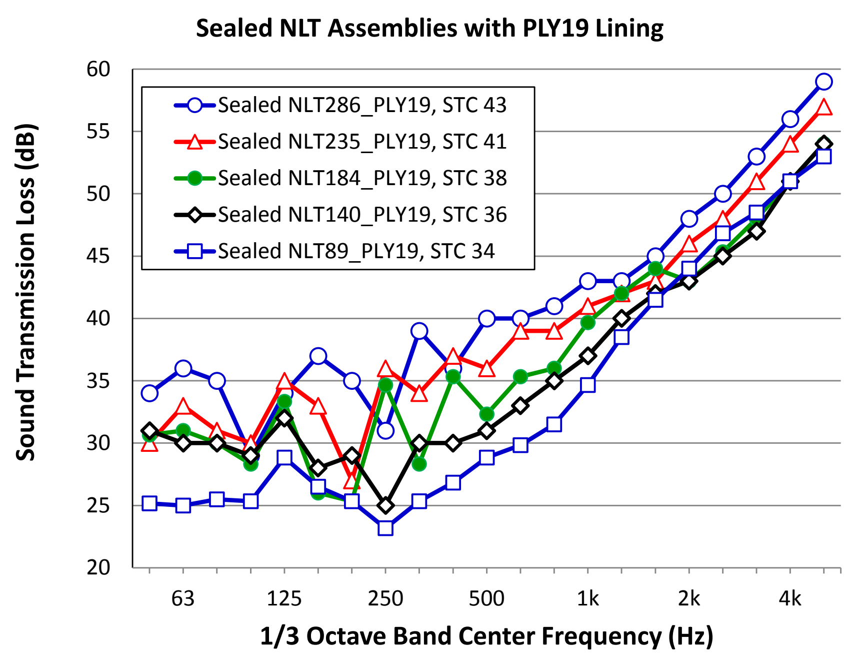
- Across all of the frequency range, adding a shear membrane or sealing the NLT assembly increases the transmission loss.
- At the lower frequencies (up to about 1 kHz), sealing the NLT assembly increases the transmission loss more than simply adding a shear membrane of plywood or OSB to the unsealed NLT. This indicates that leakage through the slits between the timber elements of the NLT assembly significantly reduces the transmission loss even when the shear membrane is fastened to one face.

- Above 1 kHz, adding the plywood shear membrane to a sealed NLT235 assembly results in an increase in the transmission loss, but below about 1 kHz, the transmission loss is not significantly changed.
- ***When OSB is substituted for plywood*** as the shear membrane, the transmission loss increases consistently for all frequencies above about 250 Hz and the STC rating increased by one point. This behaviour was observed for all thicknesses of NLT assemblies and provides good confidence that substituting OSB in place of plywood will give at least as good a sound transmission performance as the cases tested with plywood.

The magnitude and frequency of the peaks and dips shown in the figures below 500Hz are not consistent from one thickness of NLT to another. This is most evident in Figure 2.1.5 which shows the transmission loss curves for all five thicknesses of NLT assemblies with an attached shear membrane of 19 mm thick plywood. The dips are more pronounced than the corresponding peaks evident in the low frequency “plateau region” of the transmission loss curves presented for CLT panels in Research Report RR-335. The peaks and dips reflect the effect of the very different stiffness of the NLT assemblies in the directions parallel and perpendicular to the long axis of the timbers elements of the NLT assembly.

Despite the peaks and dips at the lower frequencies, one can still discern the division of the transmission loss curves into two regions: a region below 500 Hz where the curves show no consistent trend and a region above about 500 Hz where the curve steadily increases with increasing frequency.

Figure 2.1.5: Comparison of the direct sound transmission loss curves for NLT assemblies with an added shear membrane of 19 mm thick plywood (Ply19).



NLT assemblies used as a wall or floor in a building will typically have an attached layer of plywood or oriented strandboard on at least one side to provide adequate shear bracing. Hence, the sound transmission data in Figure 2.1.5 for the NLT assemblies with the shear element attached are an appropriate starting point for the evaluation of the expected sound transmission in a building with a structure of NLT wall and/or floor assemblies. These values are used as the reference for determining the effect of gypsum board linings (see Section 2.2) and would also be considered as the Base structure for the calculation of the ASTC rating as discussed in Research Report RR-335.

As noted previously, the results of the tests of the NLT assemblies with a plywood shear membrane should provide a conservative estimate for the transmission loss when OSB is substituted for the plywood.

The STC ratings and one-third octave band direct sound transmission loss values for all the tested NLT assemblies (for bare assemblies and for the corresponding assemblies with an added shear-membrane and or other linings) are presented in the tables in Appendix A1.

2.2 Adding Linings on NLT Wall or Floor Assemblies

It is common practice, especially in residential buildings, to add finishing surfaces to the basic structural floor or wall assemblies to conceal both the bare structure surfaces as well as the building services such as electrical wiring, water pipes and ventilation ducts. The finishing on walls or ceilings is commonly comprised of gypsum board panels, framing used to support the gypsum board panels and sound absorptive material in the inter-framing cavities between the gypsum board and the face of the basic structural floor or wall assemblies. On floors, the finish may include toppings 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.

Two methods of characterizing the change in the direct sound transmission loss of the NLT assemblies by adding a lining are used in this Report. The first method is the change in the transmission loss (ΔTL) which is calculated from the difference between the transmission loss values measured with the lining installed on the Base NLT assembly and the transmission loss values of the Base NLT assembly without a lining. The Base NLT assembly is the NLT with the shear membrane attached to one side without leakage. The ΔTL is used for the calculation of the ASTC rating using the Detailed Method of ISO 15712-1 which is discussed in Research Report RR-335.

The second method of characterizing the change in the direct sound transmission loss of the NLT assemblies by adding a lining is a single-number rating called the ΔSTC. The ASTM standards do not define a rating like ΔSTC, but there is a counterpart in the ISO standards called ΔR_W. The calculation of the ΔSTC rating is adopted from the ISO standard with modification as explained in Appendix A2 of this Report. The ΔSTC rating is used for the calculation of the ASTC rating using the Simplified Method of ISO 15712-1 which is discussed in Research Report RR-335.

The linings evaluated on NLT assemblies for this study are described in Tables 2.2.1 and 2.2.3. The ΔSTC ratings for the measured linings are listed in Table 2.2.2.1 of Section 2.2.2. The ΔTL values for the measured linings are provided in Appendix A1. Because of the strong similarity to measured performance of corresponding linings on CLT Base assemblies, some results for CLTs from Research Report RR-335 can also be used as conservative estimates on NLTs, as discussed later in Section 2.2.1.

<u>Each Lining Code</u> shown in Tables 2.2.1 to 2.2.3 begins with “ΔTL-NLT” to indicate that the lining applied to a NLT assembly has an effect on the direct sound transmission loss through the lined assembly. In some cases the thickness of the NLT assembly is indicated (as in “ΔTL-NLT235”) if the result applies only to that thickness. For the three linings in Table 2.2.2 (W03, W04, and W05), the code does not indicate the thickness of the Base assembly because these are conservative estimates based on results for CLT assemblies that are assumed to apply for all thicknesses of the NLT assemblies. 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.

The Descriptive Short Code provides a compact physical description of each lining, which is used in the figure captions and in the examples throughout this Report. This code identifies the elements of the lining beginning at the exposed side and proceeding to the face of the supporting NLT wall or floor assembly. As detailed in the descriptions in Tables 2.2.1 and 2.2.2, each component 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 a 38 mm x 38 mm wood furring. The distance between components such as adjacent studs is indicated by a number in parentheses which is the distance (on centre) between the components in millimetres.

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. 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 49.

Table 2.2.1: Linings tested on Base NLT wall assemblies. Linings W02 and W06 from Research Report RR-335 were chosen to give the key points for interpolating to relate other linings tested on CLT assemblies to expected performance of the same linings on NLT assemblies.

Lining Code	Descriptive Short Code	Description of Lining
ΔTL-NLT-W02	2G13_WFUR38(400)_GFB38	Two layers of 12.7 mm thick fire-rated gypsum board[3] screwed to 38 mm x 38 mm wood furring strips (spaced 400 mm on center and mechanically attached to the face of the NLT) with 38 mm thick glass fiber batts[2] filling the spaces between the gypsum board and the NLT
ΔTL-NLT-W06	2G13_WS64(600)_GFB65_AIR13	Two layers of 12.7 mm thick fire-rated gypsum board screwed to 64 mm x 38 mm wood studs (spaced 600 mm on center and offset 13 mm from the face of the NLT) with 64 mm thick glass fiber batts filling the spaces between the gypsum board and the NLT

NOTES: a. For the notes in this table please see the corresponding endnotes from page 49.
b. The linings listed for wall assemblies may also be used on ceilings.

Table 2.2.2: Linings tested on Base CLT wall assemblies (see Research Report RR-335) that could be used as conservative estimates for linings on NLT assemblies.

Lining Code	Descriptive Short Code	Description of Lining
ΔTL-NLT-W01	2G13	Two layers of 12.7 mm thick fire-rated gypsum board[2]
ΔTL-NLT-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 on center and mechanically attached to the face of the NLT) with 38 mm thick glass fiber batts filling the spaces between the gypsum board and the NLT
ΔTL-NLT-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 on center) that are screwed to 38 x 38 mm wood furring (spaced 400 mm on center and mechanically attached to the face of the NLT) with 38 mm thick glass fiber batts filling the spaces between the gypsum board and the NLT
ΔTL-NLT-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 on center and mechanically attached to the face of the NLT) with 64 mm thick glass fiber batts filling the spaces between the gypsum board and the NLT

NOTES:
a. For the notes in this table please see the corresponding endnotes from page 49.
b. The linings listed for wall assemblies may also be used on ceilings.

Table 2.2.3: Floor linings tested on Base CLT floor assemblies (see Research Report RR-335) that could be used as conservative estimates for linings on NLT assemblies.

Lining Code	Descriptive Short Code	Description of Lining
ΔTL-NLT-F01	CON38(no bond)	38 mm thick concrete with no bond to the supporting NLT
ΔTL-NLT-F02	CON38_FOAM09	38 mm thick concrete on 9 mm thick closed-cell foam, covering the supporting NLT
ΔTL-NLT-F03	CON38_WFB13	38 mm thick concrete on 13 mm thick wood fiber board, covering the supporting NLT
ΔTL-NLT-F08	2CEMBRD12_WFB13	Two layers of 12 mm thick fiber-reinforced cement board on 13 mm thick wood fiber board, covering the supporting NLT
ΔTL-NLT-F09	GCON38_FOAM09	38 mm thick gypsum concrete on 9 mm thick closed-cell foam, covering the supporting NLT

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

2.2.1 Measured Change ΔTL due to Linings on NLT Assemblies

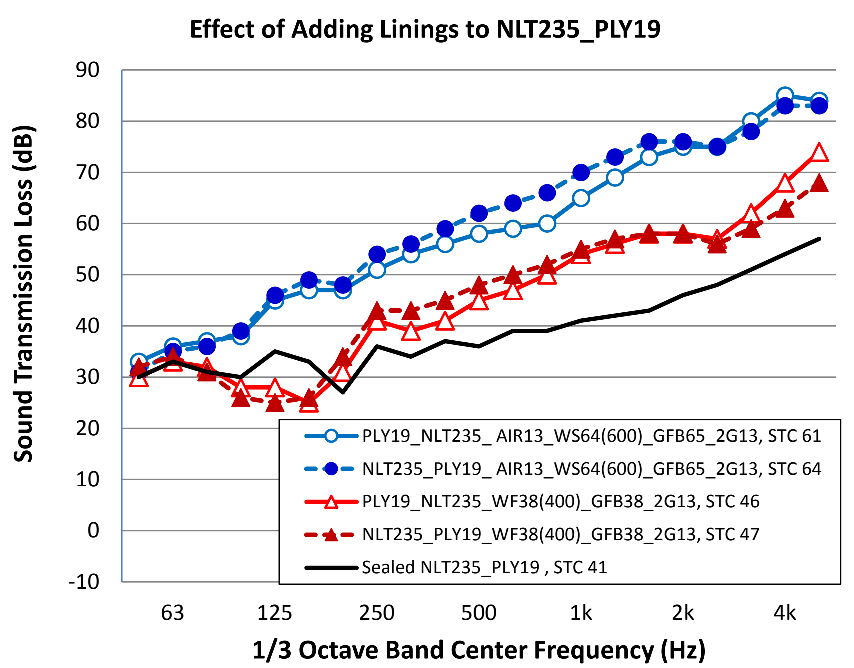
The trends in the measured sound transmission loss curves for the cases where linings were applied to NLT assemblies are presented and discussed in this Section. The corresponding ΔSTC ratings for each of the linings are shown in the tables presented in Section 2.2.2. The ΔSTC ratings are needed for the Simplified Method of calculating the ASTC rating as discussed in Reports RR-331 and RR-335. The averaged one-third octave band changes in the direct sound transmission loss (ΔTL) for the set of linings applied to the NLT assemblies are given in Table A1.3 in Appendix A1. The data in Appendix A1 is needed for calculating the ASTC rating using the Detailed Method as presented in Research Report RR-335.

Linings W02 and W06 were chosen to give the key points for relating linings tested on CLT assemblies to the expected performance on NLT assemblies. Each lining was tested with the lining applied on only one side of the Base NLT assembly which is comprised of the NLT and the plywood or OSB shear membrane fixed on one side. Because the Base assembly is asymmetric (with a shear membrane mechanically attached on one side of the NLT assembly) two configurations for each lining were tested:

a. With the lining applied on the same side as the plywood shear membrane
b. With the lining on the opposite side from the plywood shear membrane.

A comparison of the sound transmission loss curves for two linings (each installed first on the plywood side and then the opposite side of a Base NLT_PLY19 assembly) is presented in Figure 2.2.1.1.

Figure 2.2.1.1: Comparison of the transmission loss curves for the NLT235_PLY19 assembly with the W02 or W06 lining on either side of the assembly.



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

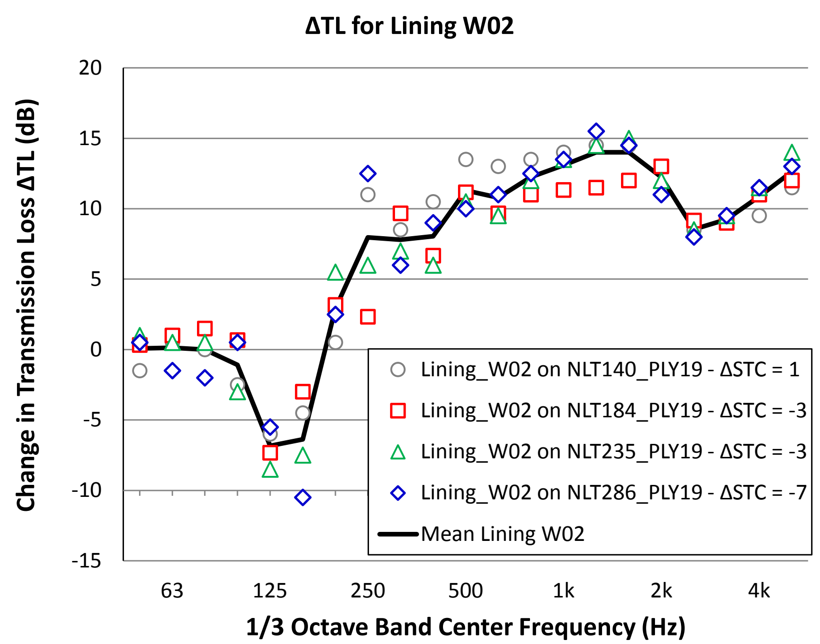
- For each lining, there is a slight difference in the sound transmission loss if the lining is mounted over the plywood shear membrane or on the bare NLT on the opposite side.
- A higher STC rating is achieved if the lining is mounted on the same side as the plywood shear membrane. The same pattern was observed for all four thicknesses of NLT on which this set of linings was tested.

In order to prevent confusion when the linings are used on NLT assemblies in practice and for compatibility with the calculation method presented in Reports RR-331 and RR-335, the structural assemblies should be symmetrical and the effect of adding a lining should be the same when it is added on either side. To work within that framework, some conservative simplifications were made in the process for calculating the change in the sound transmission loss (ΔTL) due to the addition of the linings:

- The Base NLT assembly comprised of the NLT assembly and the shear membrane is treated as acoustically symmetric, despite the shear membrane on one side.
- Use the lower of the measurements for the lining applied on each side of the NLT assembly to calculate the ΔTL to remove the effect of whether the plywood is on the same side as the lining or the opposite side. This gives the correct result if the same lining is on both sides, and permits use of the Simplified Method for the calculation of the ASTC rating.
- Determine the ΔTL values for all NLT thicknesses and use the average value the results are not significantly different.

The values of ΔTL derived from the measurements for the W02 lining (2G13_WFUR38(400)_GFB38) are presented in Figure 2.2.1.2. There is some scatter in the results, but for the most part, the data points are within the range of the experimental uncertainty.

Figure 2.2.1.2: Change in the sound transmission loss (ΔTL) due to the addition of the W02 lining (construction code 2G13_WFUR38(400)_GFB38) on the Base NLT assemblies of different thicknesses.

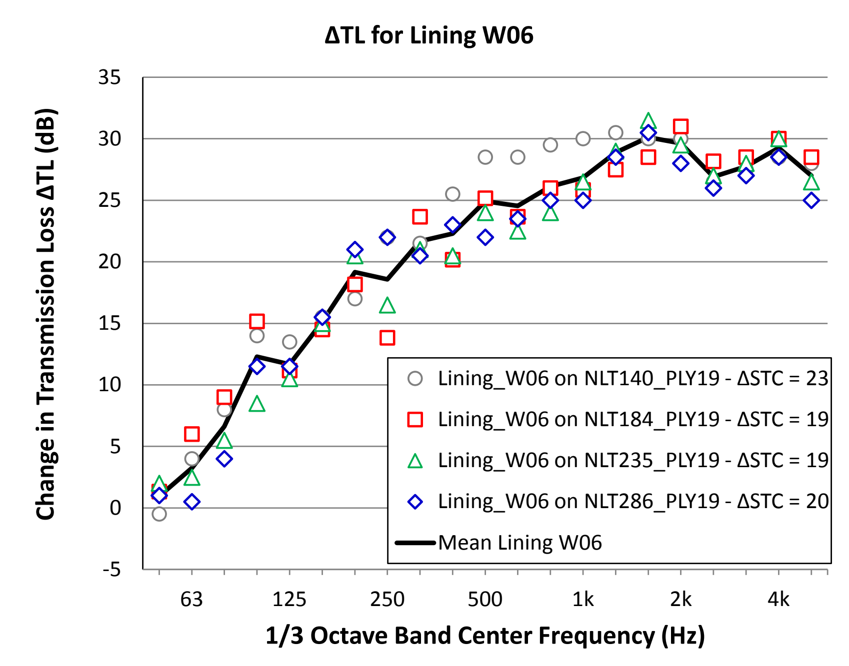


Data for NLT89 assemblies were not included in this analysis because that NLT assembly was not tested with the combination of a shear membrane and the gypsum board lining.

The ΔTL curves for lining W02 show similar trends for all of the thicknesses of the NLT assemblies with a well-defined mass-air-mass resonance at the 125 Hz one-third octave band and the gypsum board coincidence dip near the 2500 Hz one-third octave band. Note that due to the mass-air-mass resonance dip, the use of lining W02 negatively affects the transmission loss of the NLT assembly when it is applied.

There are differences in the magnitudes of the ΔTL curves and the ΔSTC rating for each thickness of NLT assembly. Therefore, the ΔTL curve and the ΔSTC rating used should be specific to the NLT assembly thickness rather than using an average of the values over all thicknesses for the calculation of the ASTC rating.

The values of ΔTL derived from the measurements for the W06 lining (2G13_WS64(600)_GFB65_AIR13) are presented in Figure 2.2.1.3. There is some scatter in the results, but the data points are within 5 dB.

Figure 2.2.1.3: Change in the sound transmission loss (ΔTL) due to the addition of the W06 lining (construction code 2G13_WS64(600)_GFB65_AIR13) on the Base NLT assemblies of different thicknesses.	

Data for NLT89 assemblies were not included in this analysis because that NLT assembly was not tested with the combination of a shear membrane and the gypsum board lining.

The ΔTL curves for this lining show similar trends for all of the NLT thicknesses, with the mass-air-mass resonance well below the frequency range of interest and the gypsum board coincidence dip at the 2500 Hz one-third octave band. The full set of ΔTL values are listed in Table A1.3 of Appendix A1, and the calculations of the ΔSTC rating are presented in Table 2.2.2.1 in Section 2.2.2.

2.2.2 ΔSTC Ratings for Linings on NLT Assemblies

Section 2.2.1 presented and discussed the trends in the sound transmission loss for a series of NLT assemblies comprising a Base NLT_PLY19 wall assembly with an added lining covering one side of the Base assembly. This Section 2.2.2 presents the corresponding single-number ΔSTC ratings for the assemblies.

Key points regarding the ΔSTC rating include:

- The ΔSTC rating is a required input for the calculation of the ASTC rating using the Simplified Method of ISO 15712-1 which is discussed in Research Report RR-335.
- The ΔSTC ratings 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 ratings from Table 2.2.2.1 in calculations like those in the examples of Research Report RR-335, without the need to perform the calculations detailed in the Appendix.

The ΔSTC ratings for the linings are presented in Table 2.2.2.1 and the corresponding ΔTL values are listed in Table A1.3 of Appendix A1.

ΔSTC ratings for linings tested on NLT wall assemblies

A quick scan of the calculated ΔSTC ratings in Table 2.2.2.1 shows that for lining W02 there is a strong variation in the results, from a slight improvement to a significant reduction of the STC rating, so using a mean value for all thicknesses of NLT is not recommended. Instead, the ΔSTC rating for W02 specific to the thickness of the NLT should be used.

Table 2.2.2.1: ΔSTC ratings for linings on NLT wall or floor surfaces.

Lining Code	Lining Descriptive Code	Base NLT	ΔSTC
	Wall Linings:		
ΔTL-NLT140-W02	2G13_WFUR38(400)_GFB38	NLT140	**1**
ΔTL-NLT184-W02	2G13_WFUR38(400)_GFB38	NLT184	**-3**
ΔTL-NLT235-W02	2G13_WFUR38(400)_GFB38	NLT235	**-3**
ΔTL-NLT286-W02	2G13_WFUR38(400)_GFB38	NLT286	**-7**
ΔTL-NLT140-W06	2G13_WS64(600)_GFB65_AIR13	NLT140	**23**
ΔTL-NLT184-W06	2G13_WS64(600)_GFB65_AIR13	NLT184	**19**
ΔTL-NLT235-W06	2G13_WS64(600)_GFB65_AIR13	NLT235	**19**
ΔTL-NLT286-W06	2G13_WS64(600)_GFB65_AIR13	NLT286	**20**
ΔTL-NLT-W06	2G13_WS64(600)_GFB65_AIR13	NLT Mean	**21**
	Wall Lining Estimates from Linings on Base CLT:		
ΔTL-NLT-W01 [d]	2G13	Estimate, see note d	**0**
ΔTL-NLT-W03 [d]	2G13_WFUR38(600)_GFB38	Estimate, see note d	**8**
ΔTL-NLT-W04 [d]	2G13_RC13(600)_WFUR38(400)_GFB38	Estimate, see note d	**15**
ΔTL-NLT-W05 [d]	2G13_WFUR64(600)_GFB65	Estimate, see note d	**6**
	Floor Linings:		
ΔTL-NLT-F01	CON38(no bond)	NLT286	**8**
ΔTL-NLT-F02	CON38_FOAM09	NLT286	**12**
ΔTL-NLT-F03	CON38_WFB13	NLT286	**13**

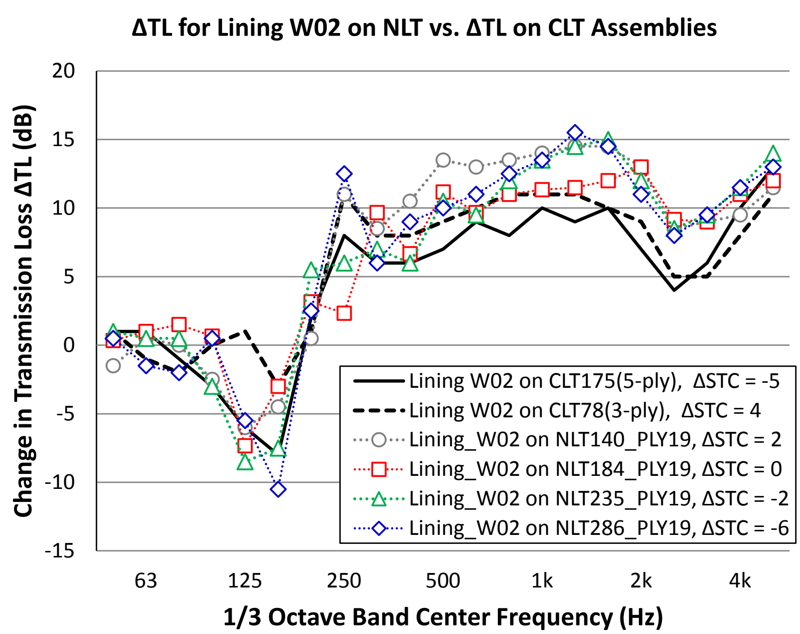
NOTES:
a. See Appendix A2 for an explanation of the calculation of the ΔSTC ratings
b. ΔTL values were determined using the Base NLT as the reference case without lining(s), and these values were combined with a reference curve as described in Appendix A2.
c. The ΔSTC ratings should be appropriate for all walls or floor/ceilings with a core of NLT
d. For W01, W03, W04, and W05, each listed value was determined for application on a CLT Base assembly (see RR-335) but gives a conservative estimate of the ΔSTC rating on the Base NLT.

Comparison between Linings Tested on NLT and CLT assemblies

For both Lining W02 and W06, the measured values of ΔTL consistently show very similar frequency dependence when added to NLT or CLT assemblies, but are slightly higher when added to NLT assemblies. The results demonstrate that it is reasonable to use ΔSTC ratings measured for CLT assemblies as credible but conservative estimates of the ΔSTC ratings for the same linings applied to NLT assemblies.

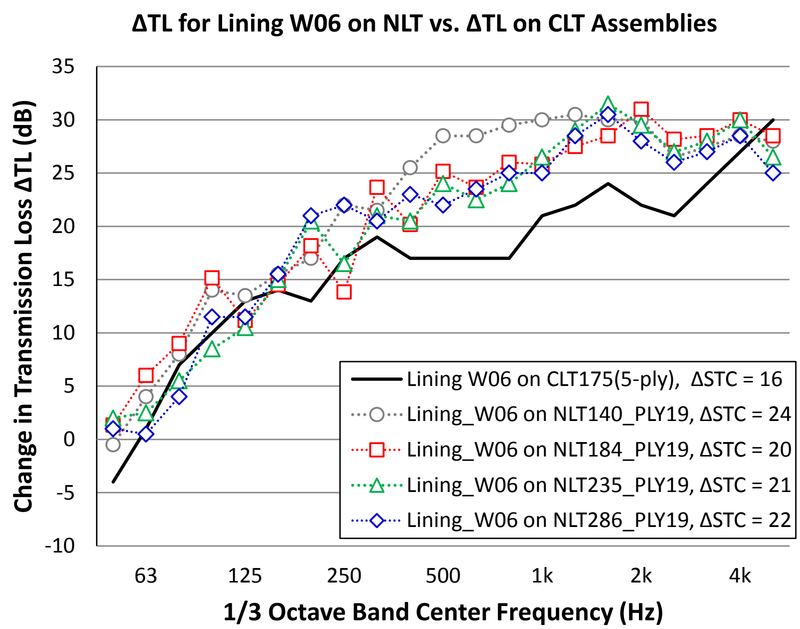
The similarities in the ΔTL curves for linings applied to NLT and CLT assemblies can be seen in Figure 2.2.2.1 which compares the ΔTL curves of lining W02 installed on the different assemblies and in Figure 2.2.2.2 which compares the ΔTL curves of lining W06 installed on the different assemblies. Both figures show that there are strong similarities both in the frequency dependence of the individual curves and in the variation of the ΔSTC rating with the thickness of the mass-timber Base assembly.

Figure 2.2.2.1: Change in the sound transmission loss (ΔTL) due to the addition of the W02 lining (construction code 2G13_WFUR38(400)_GFB38) on the Base NLT and CLT assemblies of different thicknesses.



For lining W02, the strong variation in the ΔSTC ratings vs thickness (and weight) of the mass-timber assemblies results from the method of calculating the STC rating which can be limited by a sharp dip in the transmission loss curve. For lining W02, the sharp dip is caused by a mass-air-mass resonance around the 125 Hz one-third octave band. The dip can result in negative values for the ΔTL in the one-third octave bands at and below 160 Hz meaning that the addition of the linings decreases the transmission loss of the assembly. When the mass-air-mass resonance is shifted to a lower frequency by increasing the depth of the cavity between the gypsum board and the timber assembly (as for Lining W06), then the resonance and its adverse effect on the STC ratings are reduced as shown in Figure 2.2.2.2.

Figure 2.2.2.2: Change in the sound transmission loss (ΔTL) due to the addition of the W06 lining (construction code 2G13_WS64(600)_GFB65_AIR13) on the Base NLT and CLT assemblies of different thicknesses.



For Lining W06, the variation in ΔTL with the thickness of the NLT assembly is small and there is no consistent trend in the ΔSTC rating for different thicknesses of the NLT assemblies. It is reasonable to use a mean value of the ΔSTC rating for lining W06 with for all thicknesses of NLT when calculating the ASTC rating.

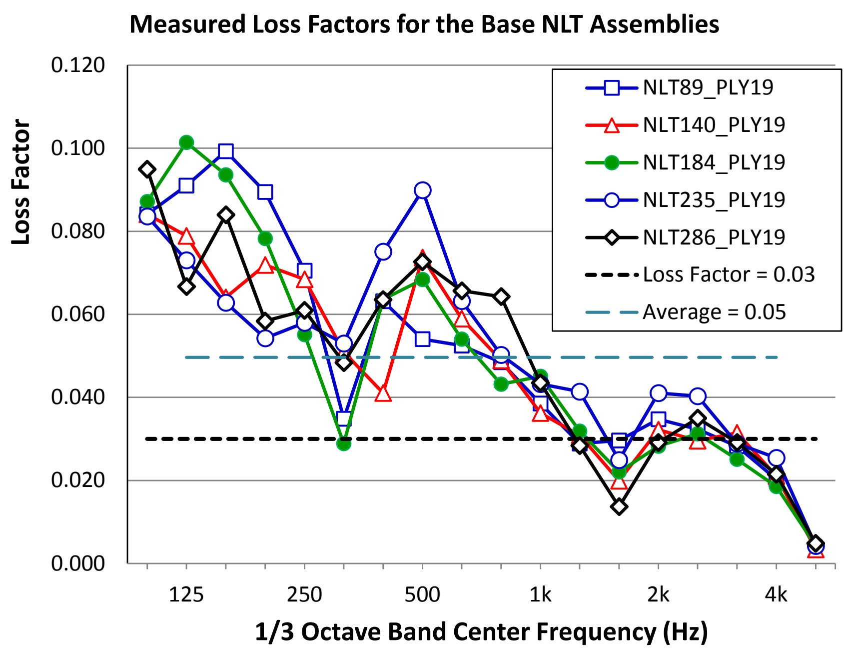
2.3 Structural Loss Factors for NLT Wall or Floor Assemblies

The structural loss factors required for the calculation of the ASTC rating using the Detailed Method were calculated from the structural reverberation times measured for each NLT assembly according to the standard, ISO 10848. Following ISO 10848, the structural loss factor η_{total} was calculated from the measured structural reverberation time such that:

$$\eta_{total} = \frac{2.2}{f T_s} \qquad \text{Eq. 2.3.1}$$

where 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 compared in Figure 2.3.1. and are listed in Table A1.9 of Appendix A1.

Figure 2.3.1: Comparison of the structural loss factors, η_{total} for the five NLT Base assemblies.



For the calculation of the ASTC rating using the Detailed Method, the effect of edge conditions may be ignored for building elements with structural loss factors greater than 0.03. Figure 2.3.1 shows that over the frequency range used for the STC rating (125 Hz to 4000 Hz), the loss factors tend to be above 0.03 and the loss factor averaged across the NLT assemblies and the frequencies is above 0.03. The loss factor greater than 0.03 greatly simplifies the calculation of the ASTC rating for constructions which include NLT assemblies.

3 Appendices of Sound Transmission Data

Appendix A1 presents data in one-third octave bands. The data includes:

A1. 1. Airborne sound transmission loss for the Bare NLT assemblies including a 19 mm plywood shear membrane attached on 1 side of the NLT assembly (see page 9 for an explanation of the Bare NLT).

A1. 2. Airborne sound transmission loss for the Base NLT assemblies including a 19 mm plywood shear membrane attached on 1 side of the sealed NLT assembly (see page 9 for an explanation of the Base NLT).

A1. 3. One-third octave band ΔTL values for the change in sound transmission loss due to the addition of linings to the Base NLT assemblies (See Section 2.2)

A1. 4. Airborne sound transmission loss data for NLT89 assemblies

A1. 5. Airborne sound transmission loss data for NLT140 assemblies

A1. 6. Airborne sound transmission loss data for NLT184 assemblies

A1. 7. Airborne sound transmission loss data for NLT235 assemblies

A1. 8. Airborne sound transmission loss data for NLT286 assemblies

A1. 9. Structural reverberation times for the tested NLT assemblies

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

Appendix A2 presents the procedure for calculating the ΔSTC rating for linings on NLT assemblies. 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".

3.1 Appendix A1: Transmission Loss Data for NLT Wall and Floor Assemblies

Table A1.1: Sound transmission loss data for **Bare NLT** assemblies which have a shear membrane of 19 mm plywood attached on one side and the other side is unsealed. Attaching a shear membrane to the NLT assembly is normal practice to provide structural rigidity in typical applications, as explained in Section 2.1. The data in the table is the data that should be used if just the direct transmission of the NLT assembly is required.

Specimen Code	Description	STC	63 Hz			125 Hz			250 Hz		
Bare NLT89	NLT89_PLY19	**29**	27	25	28	29	27	23	22	21	23
Bare NLT140	NLT140_PLY19	**31**	32	33	34	29	27	23	24	22	24
Bare NLT184	NLT184_PLY19	**31**	35	36	33	28	29	21	22	25	26
Bare NLT235	NLT235_PLY19	**36**	34	35	30	27	31	30	27	29	29
Bare NLT286	NLT286_PLY19	**41**	30	34	33	29	31	33	34	33	36

Note 1: For NLT assembly thicknesses not listed, use the data from a listed NLT assembly with a smaller thickness as a conservative estimate.

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

500 Hz			1000 Hz			2000 Hz			4000 Hz			Reference
25	25	26	27	29	31	32	34	36	38	40	42	TLA-17-143
25	26	28	30	31	33	34	35	36	38	40	42	TLA-18-027
26	26	28	29	31	33	34	35	37	40	42	45	TLA-18-004
30	31	34	35	37	39	39	40	41	44	46	49	TLA-18-038
36	37	38	40	41	42	43	44	46	49	52	54	TLA-18-051, TLF-18-021

Table A1.2: Sound transmission loss data for **Base NLT** assemblies which have a shear membrane of 19 mm plywood attached on one side of the sealed NLT assembly. Attaching a shear membrane to the NLT assembly is normal practice to provide structural rigidity in typical applications, as explained in Section 2.1. The **Base NLT** data is used to calculate the ΔTL values and the ΔSTC rating as explained in Appendix 2. When used as the bare common partition for the calculation of the ASTC rating, the data in the table is adjusted for leakage. For example, see Example 4.2-H1 of Research Report RR-335.

Specimen Code	Description	STC	63 Hz			125 Hz			250 Hz		
Base NLT89	NLT89_PLY19	**34**	25	25	26	25	29	27	25	23	25
Base NLT140	NLT140_PLY19	**36**	31	30	30	29	32	28	29	25	30
Base NLT184	NLT184_PLY19	**38**	31	31	30	28	33	26	25	35	28
Base NLT235	NLT235_PLY19	**41**	30	33	31	30	35	33	27	36	34
Base NLT286	NLT286_PLY19	**43**	30	35	35	29	32	35	35	33	38

Note 1: ΔPLY19 is change adding PLY19 for TLA-18-048vs.036, TLA-18-046vs.047, TLA-18-060vs.061
Note 2: For NLT assembly thicknesses not listed, use the data from a listed NLT assembly with a smaller thickness as a conservative estimate.

Table A1.3: Change in sound transmission loss (ΔTL) due to linings on NLT wall assemblies

Lining Code	Lining Description	ΔSTC	63 Hz			125 Hz			250 Hz		
ΔTL-NLT140-W02	2G13_WFUR38(400)_GFB38	**1**	-2	0	-1	-4	-6	-5	-1	10	7
ΔTL-NLT184-W02	2G13_WFUR38(400)_GFB38	**-3**	-1	1	1	0	-9	-4	3	1	10
ΔTL-NLT235-W02	2G13_WFUR38(400)_GFB38	**-3**	0	0	0	-4	-10	-8	4	5	5
ΔTL-NLT286-W02	2G13_WFUR38(400)_GFB38	**-7**	-1	-2	-2	0	-6	-11	2	11	3
ΔTL-NLT140-W06	2G13_WS64(600)_GFB65_AIR13	**23**	-2	4	8	13	11	14	17	22	21
ΔTL-NLT184-W06	2G13_WS64(600)_GFB65_AIR13	**19**	0	6	9	14	9	14	18	13	23
ΔTL-NLT235-W06	2G13_WS64(600)_GFB65_AIR13	**19**	1	2	5	8	10	14	20	15	20
ΔTL-NLT286-W06	2G13_WS64(600)_GFB65_AIR13	**20**	1	-1	3	11	11	15	20	21	17
Mean ΔTL-NLT-W06	2G13_WS64(600)_GFB65_AIR13	**21**	0	3	6	11	10	14	19	18	20
ΔTL-NLT286-F01	CON38(no bond)	**8**	7	3	-1	6	6	1	3	7	9
ΔTL-NLT286-F02	CON38_FOAM09	**12**	7	0	1	6	4	3	7	10	14
ΔTL-NLT286-F03	CON38_WFB13	**13**	7	0	0	8	10	7	9	11	14

Note 1: A + symbol indicates that the values are from an averaging of test data.

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

500 Hz			1000 Hz			2000 Hz			4000 Hz			Reference
27	29	30	32	35	39	42	44	47	49	51	53	TLA-17-152, ∆PLY19[1]
30	31	33	35	37	40	42	43	45	47	51	54	TLA-18-048
35	32	35	36	40	42	44	43	45	48	51	54	TLA-18-022, ∆PLY19[1]
37	36	39	39	41	42	43	46	48	51	54	57	TLA-18-046
37	40	41	42	43	43	45	48	50	53	56	59	TLF-18-016, TLF-18-035

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

500 Hz			1000 Hz			2000 Hz			4000 Hz			Reference
10	13	13	13	13	13	12	12	7	7	7	9	TLA-18-029,035,048
7	11	10	11	10	11	12	12	8	7	9	10	TLA-18-013,021,022+
4	9	8	11	13	14	15	12	8	8	9	11	TLA-18-040,043,046
7	8	9	12	13	15	14	11	8	9	10	11	TLA-18-052,057,060
25	28	28	29	29	29	28	29	26	27	27	27	TLA-18-031,033,048
20	25	24	26	25	26	27	30	28	28	29	28	TLA-18-014,019,022+
19	22	20	21	24	27	30	29	27	27	29	26	TLA-18-029,041,045
19	19	20	22	23	27	29	27	25	26	28	25	TLA-18-053,059,060
21	23	23	25	25	27	29	29	26	27	28	27	
12	10	7	11	14	16	19	21	23	24	24	25	TLF-18-023,035
16	13	10	14	18	23	28	32	36	37	35	33	TLF-18-026,035
17	14	12	16	19	20	23	26	28	29	31	30	TLF-18-029,035

Table A1.4: Measured sound transmission loss data for **NLT89 assemblies** with and without a lining.

Specimen Code	STC	63 Hz			125 Hz			250 Hz		
Bare NLT89	**24**	18	16	15	14	17	16	16	18	18
PLY19_NLT89	**29**	27	25	28	29	27	23	22	21	23
PLY19_NLT89_PLY19	**33**	26	26	27	26	30	29	28	25	25
NLT89_OSB19	**30**	28	27	28	29	31	24	22	21	23
NLT89_WF38(400)_GFB38_2G13	**40**	29	26	23	19	21	19	25	33	36
NLT89_AIR13_WS64(600)_GFB65_2G13	**52**	23	19	18	22	28	31	36	41	45
PLSTR_NLT89	**34**	25	25	25	25	28	27	25	23	27
PLSTR_NLT89_PLSTR	**34**	26	25	26	25	29	28	27	22	27

Table A1.5 Measured sound transmission loss data for **NLT140 assemblies** with and without a lining

Specimen Code	STC	63 Hz			125 Hz			250 Hz		
Bare NLT140	**22**	19	18	16	15	18	17	19	19	21
PLY19_NLT140	**31**	32	33	34	29	27	23	24	22	24
NLT140_OSB19	**32**	32	34	32	27	24	23	23	22	25
PLSTR_NLT140	**38**	31	31	30	28	31	29	30	25	33
NLT140_PLY19_WF38(400)_GFB38_2G13	**44**	30	31	31	28	26	23	28	35	37
PLY19_NLT140_WF38(400)_GFB38_2G13	**45**	29	30	29	25	26	24	31	37	40
NLT140_PLY19_AIR13_WS64(600)_GFB65_2G13	**60**	29	34	38	42	43	42	46	47	51
PLY19_NLT140_AIR13_WS64(600)_GFB65_2G13	**62**	32	34	38	44	48	45	46	47	52
PLSTR_NLT140_PLY19	**36**	31	30	30	29	32	28	29	25	30

(Continuation of Table A1.4 from opposite page):

500 Hz			1000 Hz			2000 Hz			4000 Hz			Reference
21	22	24	25	26	25	23	23	26	26	25	25	TLA-17-142
25	25	26	27	29	31	32	34	36	38	40	42	TLA-17-143
26	27	28	30	33	36	38	41	43	46	49	52	TLA-17-144
25	25	26	28	31	33	33	35	37	40	43	46	TLA-17-147
37	41	44	46	48	50	52	51	50	52	55	58	TLA-17-148
50	54	57	60	62	64	64	62	61	64	67	71	TLA-17-151
27	30	31	33	35	38	40	41	42	42	43	42	TLA-17-152
26	29	30	32	35	37	39	41	43	43	43	44	TLA-17-153

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

500 Hz			1000 Hz			2000 Hz			4000 Hz			Reference
22	24	25	24	23	21	22	23	21	23	22	22	TLA-18-023
25	26	28	30	31	33	34	35	36	38	40	42	TLA-18-027
26	28	30	32	33	34	35	36	38	40	43	47	TLA-18-032
29	33	36	38	40	41	42	42	41	41	43	44	TLA-18-036
40	44	46	48	50	53	54	55	52	54	58	63	TLA-18-029
41	45	46	49	52	56	59	57	55	58	63	68	TLA-18-035
55	59	61	64	66	69	70	72	71	74	78	81	TLA-18-031
56	60	62	65	68	72	74	74	72	75	81	83	TLA-18-033
30	31	33	35	37	40	42	43	45	47	51	54	TLA-18-048

Table A1.6 Measured sound transmission loss data for **NLT184 assemblies** with and without a lining

Specimen Code	STC	63 Hz			125 Hz			250 Hz		
Bare NLT184	**24**	19	19	17	15	19	18	18	20	21
PLY19_NLT184	**31**	35	36	33	28	29	21	22	25	26
PLY19_NLT184_PLY19	**35**	31	32	31	31	35	23	26	28	27
NLT184_OSB119	**32**	33	35	34	30	28	21	22	24	25
NLT184_WF38(400)_GFB38_2G13	**41**	31	29	25	21	23	20	25	37	38
NLT184_AIR13_WS64(600)_GFB65_2G13	**55**	19	18	20	26	32	36	39	45	49
PLSTR_NLT184	**38**	31	31	30	28	33	27	26	34	30
NLT184_PLY19_WF38(400)_GFB38_2G13	**43**	32	32	32	30	24	22	29	36	38
PLY19_NLT184_WF38(400)_GFB38_2G13	**45**	30	32	31	28	28	24	28	38	38
NLT184_PLY19_ AIR13_WS64(600)_GFB65_2G13	**59**	31	37	39	42	42	40	43	48	51
PLY19_NLT184_ AIR13_WS64(600)_GFB65_2G13	**60**	33	37	39	45	47	41	44	49	53

Table A1.7 Measured sound transmission loss data for **NLT235 assemblies** with and without a lining

Specimen Code	STC	63 Hz			125 Hz			250 Hz		
Bare NLT235	**29**	25	26	23	21	25	25	23	25	25
PLY19_NLT235	**36**	34	35	30	27	31	30	27	29	29
NLT235_OSB119	**37**	34	34	30	27	31	30	26	29	30
PLSTR_NLT235	**39**	33	33	31	29	35	35	26	35	34
NLT235_PLY19_WF38(400)_GFB38_2G13	**47**	32	34	31	26	25	26	34	43	43
PLY19_NLT235_WF38(400)_GFB38_2G13	**46**	30	33	32	28	28	25	31	41	39
NLT235_PLY19_ AIR13_WS64(600)_GFB65_2G13	**64**	31	35	36	39	46	49	48	54	56
PLY19_NLT235_ AIR13_WS64(600)_GFB65_2G13	**61**	33	36	37	38	45	47	47	51	54
PLSTR_NLT235_PLY19	**41**	30	33	31	30	35	33	27	36	34

(Continuation of Table A1.6 from opposite page):

500 Hz			1000 Hz			2000 Hz			4000 Hz			Reference
23	24	23	21	22	24	24	24	25	25	26	26	TLA-18-003
26	26	28	29	31	33	34	35	37	40	42	45	TLA-18-004
28	29	31	34	37	39	41	43	46	49	53	56	TLA-18-005
26	27	29	31	32	34	36	37	39	42	45	48	TLA-18-012
43	46	47	48	51	53	55	54	51	53	56	60	TLA-18-021
52	55	57	57	60	64	66	65	62	65	68	71	TLA-18-016
35	33	36	37	40	41	42	40	41	42	43	44	TLA-18-022
42	43	45	47	50	53	56	55	53	55	60	64	TLA-18-013
42	44	45	47	52	54	56	57	56	59	64	68	TLA-18-020
55	57	59	62	65	68	71	73	73	76	80	82	TLA-18-014
56	58	59	62	66	71	74	75	74	77	82	83	TLA-18-019

(Continuation of Table A1.7 from opposite page):

500 Hz			1000 Hz			2000 Hz			4000 Hz			Reference
26	27	28	29	30	30	30	31	31	32	32	32	TLA-18-037
30	31	34	35	37	39	39	40	41	44	46	49	TLA-18-038
31	32	35	37	39	40	40	42	44	46	50	53	TLA-18-042
36	36	38	39	40	39	39	41	42	43	44	45	TLA-18-047
45	48	50	52	55	57	58	58	56	59	63	68	TLA-18-040
41	45	47	50	54	56	58	58	57	62	68	74	TLA-18-043
59	62	64	66	70	73	76	76	75	78	83	83	TLA-18-041
56	58	59	60	65	69	73	75	75	80	85	84	TLA-18-045
37	36	39	39	41	42	43	46	48	51	54	57	TLA-18-046

Table A1.8 Measured sound transmission loss data for **NL286 assemblies** with and without a lining

Specimen Code	STC	63 Hz			125 Hz			250 Hz		
Bare NLT286	**39**	32	31	31	27	30	32	34	29	37
PLY19_NLT286	**41**	32	33	33	28	33	34	35	31	37
NLT286_OSB119	**41**	32	33	34	28	32	34	35	31	38
PLSTR_NLT286	**42**	32	35	35	30	34	37	37	30	41
NLT286_PLY19_WF38(400)_GFB38_2G13	**48**	33	34	33	29	28	27	38	45	48
PLY19_NLT286_WF38(400)_GFB38_2G13	**47**	36	35	33	30	29	26	37	42	42
NLT286_PLY19_ AIR13_WS64(600)_GFB65_2G13	**68**	35	35	38	40	46	53	57	54	63
PLY19_NLT286_ AIR13_WS64(600)_GFB65_2G13	**63**	35	38	40	41	45	52	55	52	56
PLSTR_NLT286_PLY19	**43**	34	36	35	29	34	37	35	31	39
CON38(no bond)_NLT286	**53**	34	38	34	35	36	34	38	43	47
CON38_FOAM09_NLT286	**56**	34	35	36	35	34	36	42	46	52
CON38_WFB13_NLT286	**58**	34	35	35	37	40	40	44	47	52

Table A1.9: Structural reverberation times for the tested NLT assemblies

Specimen Code	63 Hz	125 Hz			250 Hz		
NLT89_PLY19		0.262	0.193	0.143	0.123	0.125	0.200
NLT140_PLY19		0.262	0.223	0.222	0.153	0.129	0.137
NLT184_PLY19		0.252	0.174	0.152	0.141	0.160	0.242
NLT235_PLY19		0.263	0.241	0.226	0.203	0.152	0.132
NLT286_PLY19		0.232	0.264	0.169	0.188	0.144	0.144

(Continuation of Table A1.8 from opposite page):

500 Hz			1000 Hz			2000 Hz			4000 Hz			Reference
36	36	36	38	40	39	40	41	42	43	44	44	TLA-18-050
36	37	38	39	41	42	43	44	46	49	51	54	TLA-18-051
36	37	38	40	42	42	43	45	48	51	53	56	TLA-18-055
37	40	40	41	42	42	43	45	47	49	50	51	TLA-18-061
47	52	53	54	57	59	60	59	58	62	66	70	TLA-18-052
43	48	49	53	56	58	59	59	58	63	69	74	TLA-18-057
63	65	67	69	70	73	77	77	77	81	84	84	TLA-18-053
55	59	60	63	66	70	74	75	75	79	85	84	TLA-18-059
36	40	40	41	43	43	45	48	50	53	56	59	TLA-18-060
12	10	7	11	14	16	19	21	23	24	24	25	TLF-18-023
16	13	10	14	18	23	28	32	36	37	35	33	TLF-18-026
17	14	12	16	19	20	23	26	28	29	31	30	TLF-18-029

(Continuation of Table A1.9 from opposite page**):**

500 Hz			1000 Hz			2000 Hz			4000 Hz	
0.087	0.081	0.067	0.057	0.057	0.061	0.046	0.032	0.027	0.025	0.027
0.134	0.060	0.059	0.056	0.061	0.057	0.069	0.034	0.030	0.022	0.026
0.086	0.064	0.065	0.064	0.049	0.055	0.062	0.039	0.028	0.028	0.030
0.073	0.049	0.055	0.055	0.051	0.043	0.055	0.027	0.022	0.024	0.022
0.087	0.061	0.053	0.043	0.051	0.062	0.101	0.038	0.025	0.024	0.026

3.2 Appendix A2: Calculating ΔSTC rating for Linings on NLT Assemblies

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

Key issues concerning the ΔSTC rating include:

- The ΔSTC rating is a required input for the calculation of ASTC using the Simplified Method of ISO 15712-1 as discussed in RR-335.
- ΔSTC ratings calculated from the experimental data in this Report are presented in Table 2.2.2.1 in Section 2.2.2. Readers of this Report can simply use the tabulated ΔSTC ratings without the need to perform the calculations procedure outlined in this Appendix.
- The procedure for calculating the ΔSTC rating 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".

ASTM does not define a ΔSTC rating, but there is a counterpart in the ISO standards called ΔR_W. The procedure presented in this Appendix is modified from its ISO counterpart in several 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 wall assemblies. The reference curves for the ISO procedure to calculate ΔR_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." They may be used for other constructions which have a transmission loss curve that exhibits a similar dependence on frequency.
3. For calculations of the ΔSTC rating for CLT assemblies, another reference curve was added in RR-335 and RR-331 since CLT assemblies fall between the two ISO wall cases. The additional reference curve is denoted as Reference Wall 2, and is described as "wall with medium-low coincidence frequency." This approach is consistent with the recommendations of ISO 10140 for dealing with other types of construction.
4. A curve designated as "NLT Mean Reference Curve" was created by averaging the transmission loss curves of the 5 Base NLT assemblies and smoothing the low frequency region by setting the transmission loss values for frequency bands from 50 to 250 Hz equal to the mean value for those bands. The use of this curve was assessed as part of the study.

In selecting the appropriate reference curve for the calculation of the ΔSTC rating, 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 a slope rising at about 2 dB per one-third octave band.

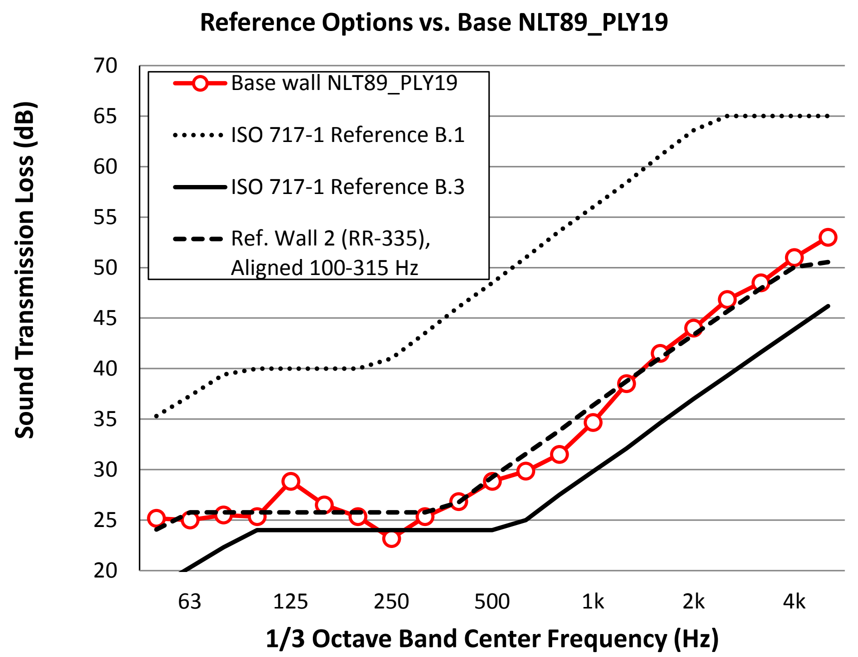
To establish the best reference curve for a given base wall or floor assembly, the reference curve was shifted up or down to match the transmission loss of the tested assembly in the "plateau region" below the frequency where the curve bends up. The reference curve can be shifted up or down (changing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

The fitting procedure was as follows:

- The reference curve was shifted to match the Base NLT_PLY19 assembly in the plateau region (the frequency bands from 100 Hz to 315 Hz, inclusive).
- The fit above the frequency where the curve bends up was determined by calculating the sum of the discrepancies (transmission loss for the tested specimen minus transmission loss for the reference curve) and the sum of squared discrepancies for the frequency bands from 400 Hz to 4 kHz, inclusive.
- This fitting procedure was used for all the five Base NLT assemblies for each of the four reference curves.

The measured sound transmission loss data for the three base assemblies are compared with pertinent reference curves in Figures A2.1, A2.2, and A2.3 respectively to illustrate the quality of the fit.

As shown in Figure A2.1, neither Reference B.1 nor Reference B.3 was a very good match to the measured curve for Base NLT89_PLY19. The transition from the plateau to the rising segment occurs at lower frequency (~250 Hz) for B.1 and at higher frequency (~500 Hz) for B.3. However, reference Wall 2 fit both the plateau and the rising segments quite well.

Figure A2.1: Sound transmission loss for the base assembly NLT89_PLY19 compared to the reference curves for the calculation of the ΔSTC ratings for all NLT linings.	

A good fit between the proposed reference curve (Reference Wall 2) and the sound transmission loss data for the base NLT184_PLY19 assembly is also evident in Figure A2.2. In the plateau region, the average of the measured transmission loss matches the reference curve. In the rising segment of the transmission loss curve, the proposed alternate reference based on the mean of the Base NLT curves was closer above 2 kHz, but the Reference Wall 2 curve (shown) was better from 500 to 1600 Hz.

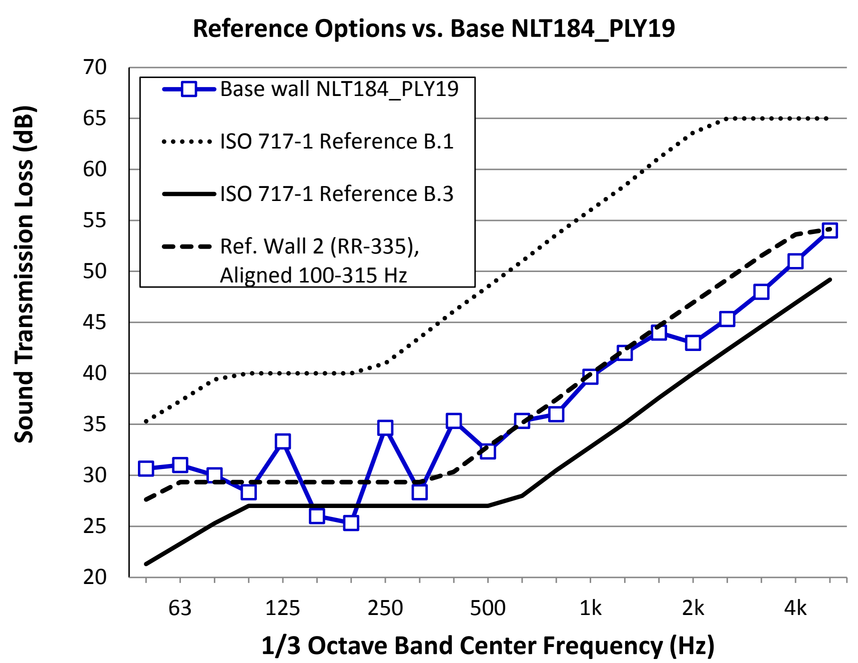
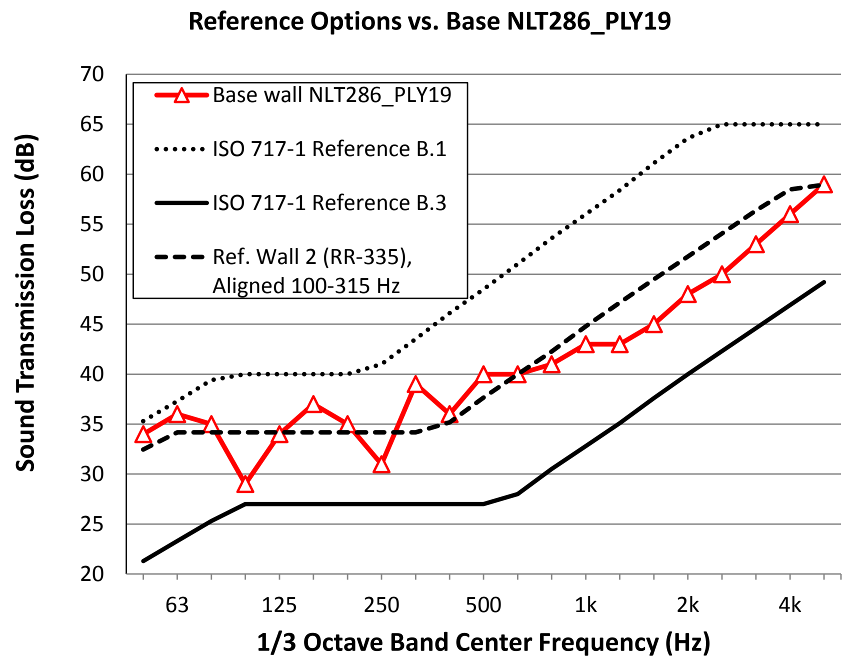
Figure A2.1: Sound transmission loss for the base assembly NLT235_PLY19 compared to the reference curves for the calculation of the ΔSTC ratings for all NLT linings.	

Figure A2.3 shows the measured sound transmission loss curve for Base NLT286_PLY19 with the same set of Reference curves.

Figure A2.1: Sound transmission loss for the base assembly NLT286_PLY19 compared to the reference curves for the calculation of the ΔSTC ratings for all NLT linings.



On average, the line segments match in the low frequency plateau region (between 100 Hz and 315 Hz). In the rising section (between 400 Hz and 2 kHz) the fit is not good because the measured results are not a straight line. But, the fit is near ideal up to 1 kHz, which includes the frequency range controlling the STC rating for the tested linings.

Each of these reference curves was also applied for the calculation of the ΔSTC rating for linings W02 and W06 on all the tested thicknesses of base NLT_PLY19.

Based on the analysis of the reference curves, it was concluded that Reference Wall 2 was the preferred reference curve for the NLT specimens. This choice gives consistency with the set of reference curves used for CLT assemblies, and will simplify the merging of this Addendum into Research Report RR-335.

Procedure for Calculating the ΔSTC Ratings

The procedure to calculate the change in the sound transmission loss ΔTL due to the addition of linings is presented in Section 2.2. Based on the ΔTL values in one-third octave bands, the ΔSTC rating may be calculated using the following procedure.

The following steps are shown schematically in Figure A2.4:

Step 1. The change in the sound transmission loss (ΔTL) due to the addition of the lining on the Base assembly 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.

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 $\Delta STC_{2\text{-Sides}}$ divided by 1.5, rounded to integers (e.g. 20/1.5 ⇨ 13).

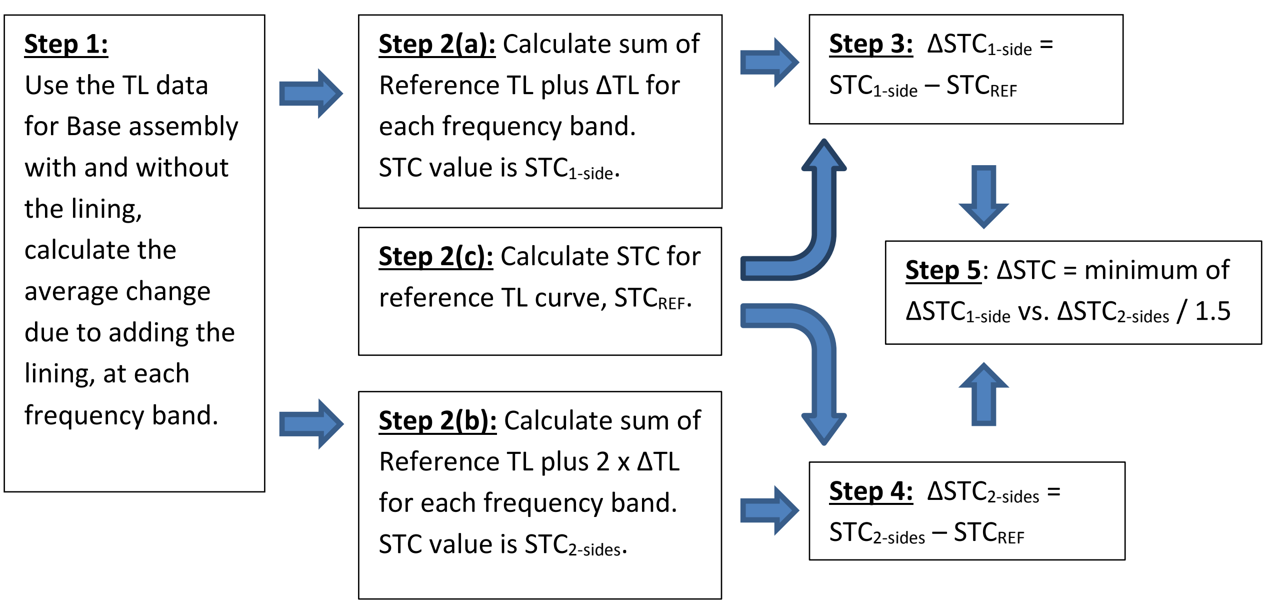


Figure A2.4: Steps to calculate the single-number rating ΔSTC for the addition of linings (as detailed above).

The 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 reference curve are presented in Table A2.1 on the next page.

<u>Table A2.1</u>: Reference Curve for the calculation of the ΔSTC rating for linings applied to NLT and CLT wall or floor assemblies. The values are based on the set of reference curves for calculating ΔR_W in the relevant ISO standards. The comparison process for the selection of the most suitable reference curve for each type of base NLT assembly is shown in Figures A2.1 to A2.3 and the associated discussion.

Frequency (Hz)	**Reference Wall 2 for calculating ΔSTC**
50 Hz	25.3
63 Hz	27.0
80 Hz	27.0
100 Hz	27.0
125 Hz	27.0
160 Hz	27.0
200 Hz	27.0
250 Hz	27.0
315 Hz	27.0
400 Hz	28.0
500 Hz	30.5
630 Hz	32.8
800 Hz	35.1
1000 Hz	37.6
1250 Hz	40.0
1600 Hz	42.3
2000 Hz	44.6
2500 Hz	46.9
3150 Hz	49.2
4000 Hz	51.3
5000 Hz	51.3
STC	**36**
Source:	Reference Wall 2 in App. A1 of RR-331 (Reference Curve B.3 in Annex B of ISO 140-16, shifted two one-third octaves)

4 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 E336-16, "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", Building Acoustics, Vol. 6, No. 3, pp. 259-268 (1999), (Validation 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", 3rd Edition, 2017, C. Hoeller, D. Quirt, J. Mahn. RR-331, which presents both the "Detailed Method" and the "Simplified Method" of ISO 15712-1 for calculating sound transmission in buildings.
15. The direct and flanking sound transmission loss data that is used in RR-331 and in soundPATHS is provided in a series of accompanying NRC Research Reports:
    15.1. RR-333, "Apparent Sound Insulation in Concrete Buildings", (expected 2018).
    15.2. RR-334, "Apparent Sound Insulation in Concrete Block Buildings", B. Zeitler, D. Quirt, S. Schoenwald, J. Mahn, (2015).
    15.3. RR-335, "Apparent Sound Insulation in Cross-Laminated Timber Buildings", C. Hoeller, J. Mahn, D. Quirt, S. Schoenwald, B. Zeitler, (2017).
    15.4. RR-336, "Apparent Sound Insulation in Wood-Framed Buildings", C. Hoeller, D. Quirt, M. Mueller-Trapet, (2017).
    15.5. RR-337, "Apparent Sound Insulation in Cold-Formed Steel-Framed Buildings", C. Hoeller, D. Quirt, B. Zeitler, I. Sabourin, (2017).

Endnotes

1 Nail-Laminated Timber (NLT) assemblies are structural panels fabricated from timber elements that are nailed together to form an assembly with aligned timber elements. The NLT panels in this study included:

- NLT89 assembly fabricated from nominal 2x4 lumber (38 x 89 mm cross-section),
- NLT140 assembly fabricated from nominal 2x6 lumber (38 x 140 mm cross-section),
- NLT184 assembly fabricated from nominal 2x8 lumber (38 x 184 mm cross-section),
- NLT235 assembly fabricated from nominal 2x10 lumber (38 x 235 mm cross-section),
- NLT286 assembly fabricated from nominal 2x12 lumber (38 x 286 mm cross-section),

Each timber element in a NLT assembly is attached to adjacent timbers by rows of 100 mm nails, with the rows spaced 300 mm on center. The actual physical properties of the tested bare NLT panels are:

- 89 mm thick assembly of 2x4 timbers attached with 2 nails per row, weight 39.5 kg/m^2,
- 138 mm thick assembly of 2x6 timbers attached with 3 nails per row, weight 65.8 kg/m^2,
- 183 mm thick assembly of 2x8 timbers attached with 3 nails per row, weight 81.6 kg/m^2,
- 234 mm thick assembly of 2x10 timbers attached with 4 nails per row, weight 89.5 kg/m^2,
- 285 mm thick assembly of 2x12 timbers attached with 4 nails per row, weight 136.8 kg/m^2.

In typical application, the Base NLT assembly includes a layer of plywood or OSB sheets mechanically attached to one face of the NLT assembly to provide shear bracing.

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 CLTs or NLTs. 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 a 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)