MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

Characterization of Laminated Timber Building Elements to Estimate Flanking Transmission

Mahn, Jeffrey[1]
National Research Council Canada
1200 Montreal Rd, Ottawa, Ontario, K1C 4N4 Canada

Müller-Trapet, Markus[2]
National Research Council Canada
1200 Montreal Rd, Ottawa, Ontario, K1C 4N4 Canada

ABSTRACT

Laminated timber constructions have been gaining popularity in Canada ever since provincial building codes were changed to allow for taller buildings constructed of laminated timber elements. Common laminated timber elements include cross-laminated timber, nail-laminated timber, dowel-laminated timber and glued laminated timber. The National Research Council Canada has undertaken a multi-year research project to characterize laminated timber elements in terms of transmission loss, loss factors and radiation efficiencies to be able to predict the apparent transmission loss and the apparent sound transmission class (ASTC) rating of mass timber buildings. The research project has also included the measurement of the vibration reduction index of junctions. This paper summarizes the results of the study of the laminated timber elements both with and without linings.

Keywords: Sound transmission, Timber, Flanking
I-INCE Classification of Subject Number: 51

1. INTRODUCTION

Multi-story laminated timber constructions are becoming more popular in Canada as taller timber buildings are allowed by the provincial building codes. Three of the laminated timber building elements that are commonly used in multi-story timber buildings in Canada include cross-laminated timber (CLT), dowel-laminated timber (DLT) and nail-laminated timber (NLT) elements. The National Building Code of Canada (NBCC) and now several of the provincial building codes require that multi-tenancy buildings achieve a minimum apparent sound transmission class (ASTC) rating of 47 between dwelling spaces. The ASTC rating is comparable, but not equal to the apparent sound reduction index R'_w.

[1] jeffrey.mahn@nrc-cnrc.gc.ca
[2] markus.mueller-trapet@nrc-cnrc.gc.ca

One method of demonstrating compliance with the acoustic requirements of the NBCC is to calculate the ASTC rating using the methodology outlined in the National Research Council Canada (NRC) Report RR-331: *Guide to calculating airborne sound transmission in buildings.*[1] Report RR-331 presents the calculation method using ASTM metrics as well as a number of examples including examples using CLT elements both with and without linings attached to the floors and walls. Report RR-331 is supported by two other documents which are specific to laminated timber buildings: Report RR-335: *Apparent sound insulation in cross-laminated timber buildings*[2] and Addendum to RR-335: *Sound transmission through Nail-Laminated Timber (NLT) assemblies.*[3] All of these documents are undergoing revisions with new editions of RR-331 and RR-335 due to be released in March of 2019. The revision of RR-335 will include new data for NLT and DLT elements.

2. ELEMENTS EVALUATED

Four thicknesses of cross-laminated timber were evaluated as shown in Table 1.

Table 1: The CLT elements included in the evaluation

Assembly	Nominal Thickness (mm)	Mass per Unit Area (kg/m^2)	Designation
3 Ply	78	42.4	CLT03
5 Ply	175	91.4	CLT05
7 Ply	245	130.0	CLT07
9 Ply	-	-	CLT09

Five thicknesses of nail-laminated timber were evaluated as shown in Table 2.

Table 2: The NLT elements included in the evaluation

Assembly	Nominal Thickness (mm)	Mass per Unit Area (kg/m^2)	Designation
2x4	89	39.5	NLT89
2x6	140	65.8	NLT140
2x8	184	81.6	NLT184
2x10	235	89.5	NLT235

Three thicknesses of dowel-laminated timber were evaluated as shown in Table 3

Table 3: The DLT elements included in the evaluation

Assembly	Nominal Thickness (mm)	Mass per Unit Area (kg/m^2)	Designation
2x4	90	44.4	DLT90
2x6	140	72.9	DLT140
2x8	186	95.9	DLT186

The dimensions shown are for the bare elements. The DLT elements were evaluated with plywood shear membranes since that is how they are commonly used.

3. MEASUREMENTS

The measurements which have been made to date or will be conducted in the near future include the measurement of the vibration reduction index between elements, the transmission loss of the elements both bare and with linings, the loss factors of the elements, the airborne and structurally excited radiation efficiencies of the elements and the wave numbers. The vibration reduction index measurements are reported in part in RR-335 with further work planned this year. It is the other measurements which are discussed in this paper.

3.1. Transmission Loss

The transmission loss of the laminated timber elements both with and without linings were measured at the NRC's wall testing facility according to the ASTM standard, ASTM E90[4]. The change in the transmission loss and the ΔSTC rating due to the addition of the wall or ceiling linings or floor toppings (all referred to as linings in this paper) were determined for each of the laminated timber elements by comparing the transmission loss with the lining versus the transmission loss of the sealed laminated timber element following the procedure outlined in RR-335.

3.2. Loss Factors

The structural reverberation time of the bare laminated timber elements was measured while they were mounted in a test frame for the transmission loss measurements. The excitation signal used for the measurements was a linear sweep covering the frequency range of interest. The surface velocity was measured using a Scanning Laser Doppler Vibrometer (SLDV).

3.3. Structural Wave-numbers

Structural wavenumbers were determined for each wall specimen with the SLDV to measure surface velocity and a mechanical shaker to excite the specimen from the opposite side. The measurements were made at equi-distant positions along two straight lines (perpendicular and parallel to the orientation of the surface layer of timber) away from the point of excitation. The excitation signal used for the measurements was a linear sweep covering the frequency range of interest.

3.4. Radiation Efficiency

The airborne excited radiation efficiency was measured while the elements were mounted in a test frame. Airborne noise from loudspeakers was used to excite one side of the bare element and the surface velocity on the other side of the element was measured in over 20 positions using the SLDV. The sound power in the receiving room due to the radiating element was also determined. The surface velocity and the sound power were used to calculate the total radiation efficiency which includes contributions from both the resonant and non-resonant radiation efficiencies.

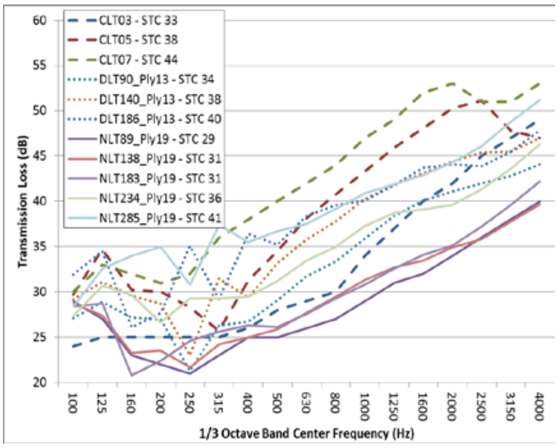
The mechanically excited radiation efficiency was determined by exciting the element using an electromagnetic shaker in three different positions and measuring the surface velocity in approximately 20 positions per excitation as well as determining the sound power level in the receiving room. The surface velocity and the sound power were used to calculate the resonant radiation efficiency.

4. RESULTS

4.1. Transmission Loss

Experience has shown that all laminated timber elements are affected by sound leaking through gaps between the individual timber elements. The amount of leakage can be profound for nail-laminated timber elements and is less for cross-laminated timber elements. Removing the effect of sound leakage is important when determining the change in the transmission loss due to the application of linings since sound leakage is not relevant when linings are applied to the elements along flanking transmission paths. Failure to consider leakage when testing linings will tend to overestimate the change in the transmission loss due to the application of the linings.

The transmission loss values and the single number ratings of the bare assemblies (with leakage) are compared in Figure 1. Note that the NLT and DLT elements include plywood shear elements.

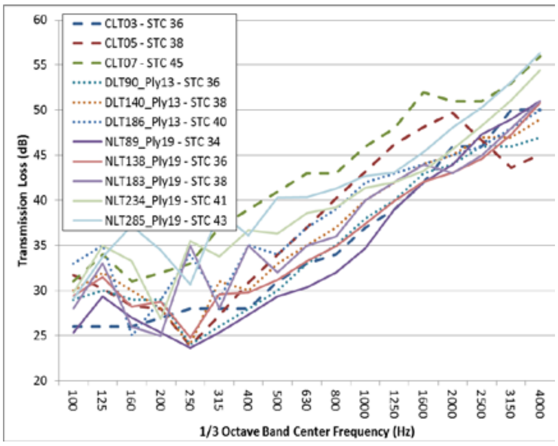


Assembly	Thickness (mm)	m' (kg/m^2)	STC	R_w
NLT89_Ply19	108	48.6	29	29
NLT138_Ply19	157	74.9	31	31
NLT183_Ply19	202	90.7	31	31
CLT03	78	42.4	33	33
DLT90_Ply13	103	50.5	34	34
NLT234_Ply19	253	98.6	36	36
DLT140_Ply13	153	79.0	38	38
CLT05	175	91.4	38	40
DLT186_Ply13	199	101.9	40	40
NLT285_Ply19	304	145.9	41	41
CLT07	245	130.0	44	44

Figure 1: Comparison of the transmission losses of the "bare" elements. The data on the right ranks the elements in increasing order of the STC ratings.

The curves and single number ratings presented in the figure represent what would be expected for the direct transmission loss of the elements.

The transmission loss values and the single number ratings of the "base" assemblies (no leakage) are compared in Figure 2. The sound leakage was eliminated by sealing the elements with a thin layer of cementitious material. Note that the NLT and DLT elements include plywood shear elements.



Assembly	Thickness (mm)	m' (kg/m^2)	STC	R_w
NLT89_Ply19	108	48.6	34	34
CLT03	78	42.4	36	36
DLT90_Ply13	103	50.5	36	36
NLT138_Ply19	157	74.9	36	36
DLT140_Ply13	153	79.0	38	38
CLT05	175	91.4	38	38
NLT183_Ply19	202	90.7	38	38
DLT186_Ply13	199	101.9	40	40
NLT234_Ply19	253	98.6	41	41
NLT285_Ply19	304	145.9	43	43
CLT07	245	130.0	45	45

Figure 2: Comparison of the transmission losses of the "base" elements which have been sealed with a thin layer of cementitious material. The data on the right ranks the elements in increasing order of the STC ratings.

The transmission loss curves for the "base" elements are shown to follow more similar trends than the transmission loss curves of the "bare" elements shown in Figure 1. In terms of the ranking by the single number ratings, sealing the elements brings the ranking into more of an alignment with what would be expected. Thicker elements have higher single number ratings which was not the case for the "bare" elements in Figure 1.

In terms of efficiency, overall the CLT elements tested were the best in terms of providing the highest STC rating for a given thickness. For example, the CLT07 which is 245 mm thick had an STC rating which was four points higher than the 253 mm thick NLT234_Ply19. Likewise, the DLT elements had higher STC ratings than the comparable NLT elements.

4.2. The Effect of Linings

Lining data is provided in more detail in the 2nd edition of RR-335 with more data to be added to the third edition. An example of the lining data provided for NLT elements is shown in Table 4. Further information about these linings and how the ratings were calculated can be found in the Addendum to RR-335.

Table 4: ΔSTC ratings for linings on the NLT elements. The linings which are noted as CLT indicate linings which were evaluated on CLTs, but are expected to perform the same on NLTs.

Lining Code	Description	NLT Assembly	ΔSTC
W02	Two layers of 12.7 mm thick fire-rated gypsum board 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 filling the spaces between the gypsum board and the NLT	NLT140	1
		NLT184	-3
		NLT235	-3
		NLT286	-7
W06	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	All	21
W01	Two layers of 12.7 mm thick fire-rated gypsum board	CLT	0
W03	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	CLT	8
W04	Two layers of 12.7 mm thick fire-rated gypsum board screwed to 13 mm resilient metal channels (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	CLT	15
W05	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	CLT	6

Linings such as W02 have different ΔSTC ratings for the different thicknesses of the NLT elements and similar behavior has been seen for this lining on other layered timber elements. Other linings such as W06 achieve the same ΔSTC ratings regardless of the thickness of the NLT element.

4.3. Loss Factors

The loss factors for the elements are compared in Figure 3.

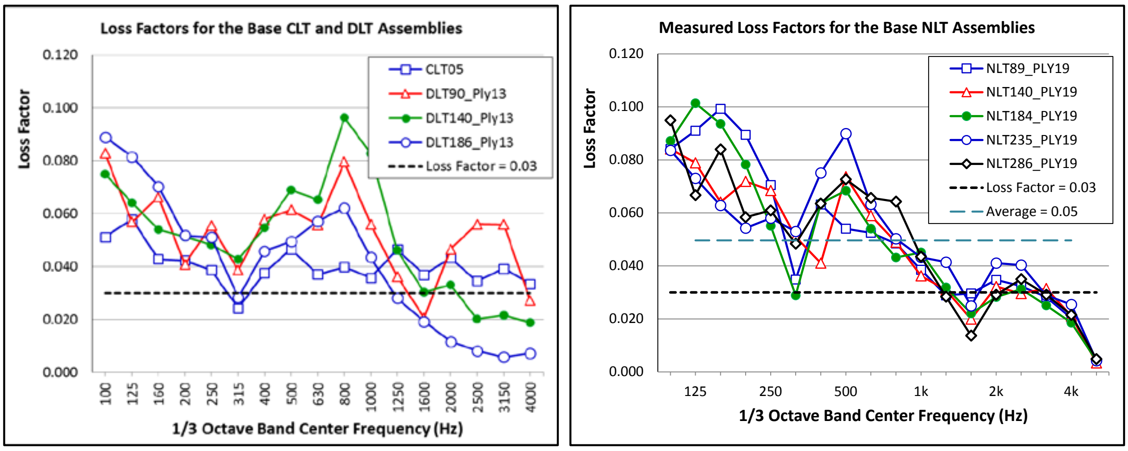


Figure 3: Loss factors of the CLT05 and the DLT elements (left) and the NLT elements (right).

The figure shows that the loss factor for the laminated timber elements is greater than 0.03 over most of the frequency range. The standard, ISO 12354-1[5] states that for elements with an internal loss factor greater than 0.03, $R_{situ} = R_{lab}$ which greatly simplifies the calculation of the flanking transmission loss. The Standard does not specify if the value of 0.03 is in one of the 1/3 octave bands or an average, so an average value from the frequency range of 125 Hz to 4000 Hz was used. In each case, the loss factors of the elements exceeded 0.03.

4.4. Wave-numbers

The wave-numbers for the elements measured both perpendicular and parallel to the orientation of the face layer of the elements are compared in Figure 4.

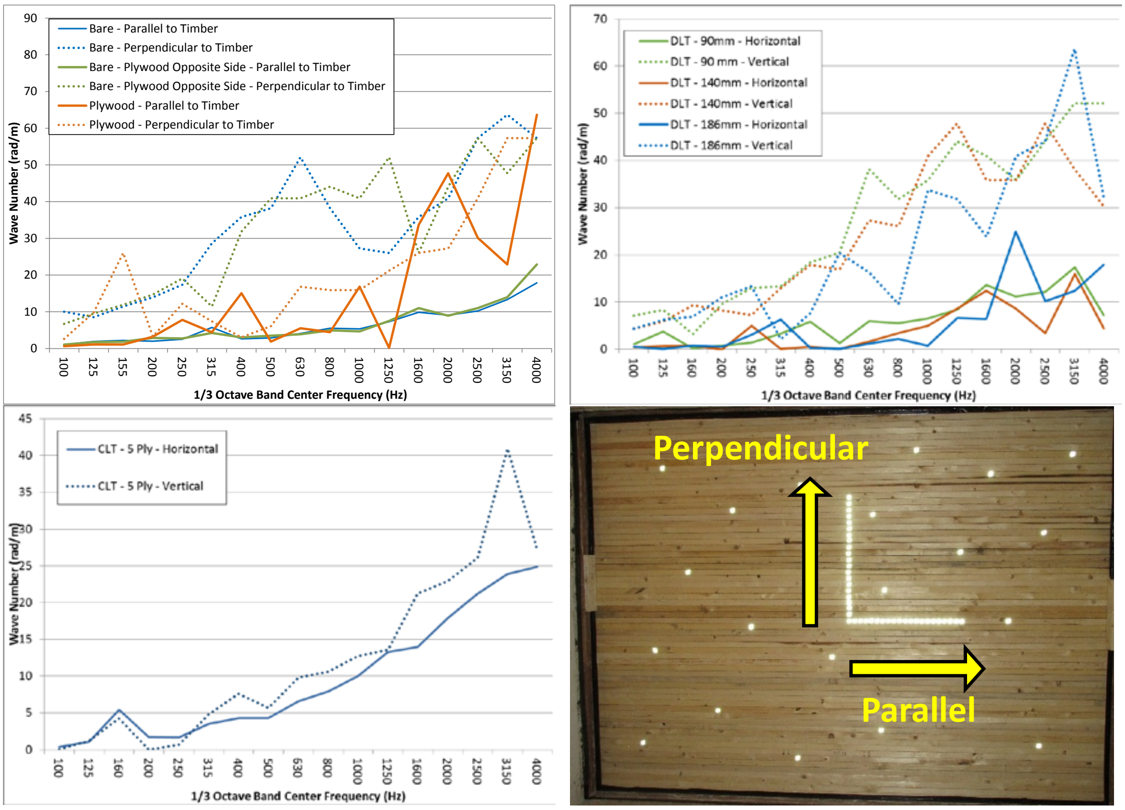


Figure 4: Clockwise starting at the top, left corner are presented the wave numbers of the: NLT elements both on the bare side and on the plywood shear element, DLT elements, and the CLT05.

The figure shows that the wave numbers measured for the NLTs and the DLTs depended strongly on the direction of propagation which is to be expected, especially given the gaps between the individual pieces of timber that made up the NLTs. Therefore, the NLTs and DLTs are orthotropic and will have different critical frequencies in the different orientations. The addition of the plywood shear element reduced the orthotropicity. The CLT05 is shown to be significantly less orthotropic and it will be interesting to assess the wave number of the 7 and 9 ply CLTs once the data is available.

4.5. Radiation Efficiencies

Due to the sound leakage of the laminated timber elements, the radiation efficiency of the elements is challenging to measure. The radiation efficiencies which have been measured to date are compared in Figure 5.

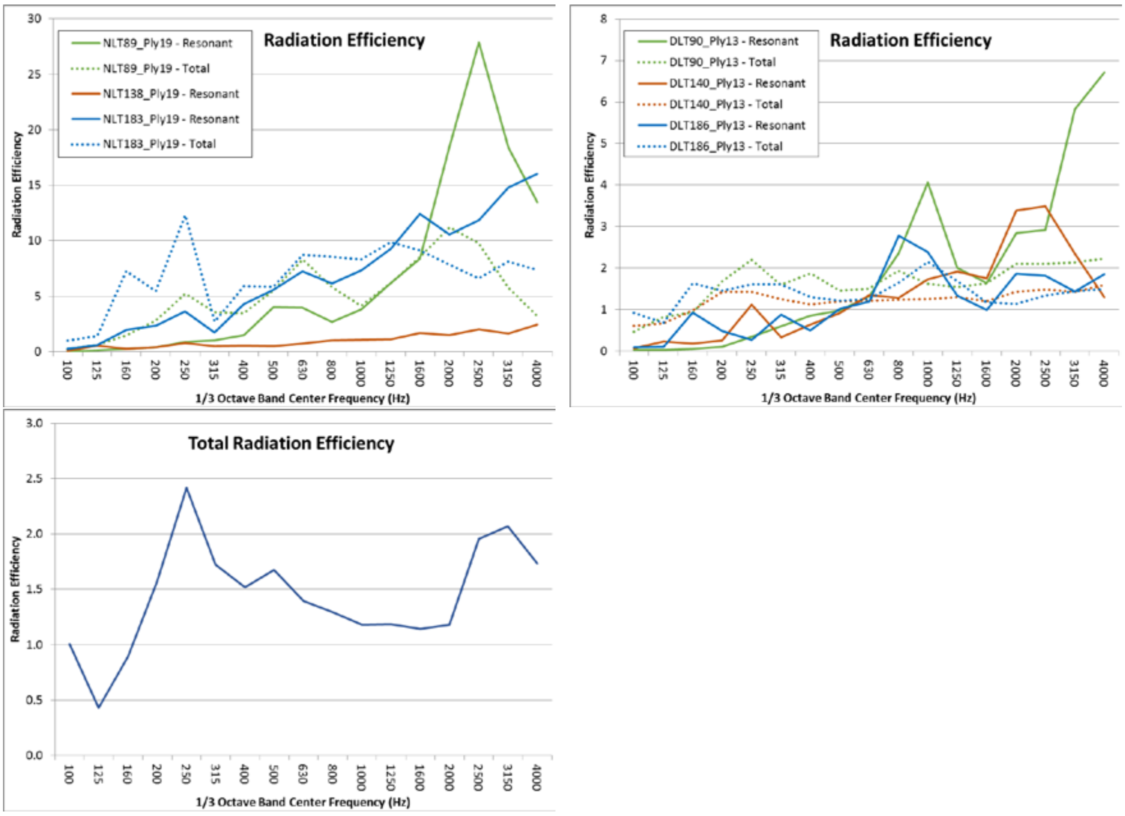


Figure 5: Clockwise starting at the top, left corner are presented the radiation efficiencies measured for the: NLT elements, DLT elements, and the CLT05.

The radiation efficiency values measured for the NLT elements are unrealistic due to the contamination of the measurements with sound leaking through the elements resulting in higher magnitude values than expected. However, the peaks in the curves line up well with dips in the transmission loss curves for these elements. For example, the NLT183_Ply19 has a peak in the airborne excited total radiation efficiency in the 160 Hz 1/3 octave band that aligns with a dip in the transmission loss curve for this element. The Data for the DLT elements was a bit better in terms of the magnitude, but still higher than expected, especially at the higher frequencies. But, again the peaks lined up well with dips in the transmission loss curves.

5. DISCUSSION

Measurements on the laminated timber elements will continue. Future work will include more measurements of the vibration reduction index of CLT elements to be made in the NRC's brand new vibration reduction index measurement facilities. Future work will also include the determination of the material properties of the elements. The results will be presented in the 3nd edition of the report, RR-335 to be published in 2019 or 2020.

6. CONCLUSIONS

The transmission loss data for the laminated timber elements which have been presented show that laminated timber elements will require linings or toppings to meet the acoustic requirements of most building codes. Calculations of the flanking transmission which include linings must take into account the "base" element which has had the effects of leakage removed in order to avoid an overestimation of the improvement due to the lining. The loss factor measurements have shown that the calculation of the flanking transmission loss is simplified because the laminated timber elements have a high enough loss factor that the structural reverberation time for the actual field situation does not need to be considered. The wave number measurements have shown that NLT and DLT elements are orthotropic while the CLT elements may be less so.

7. ACKNOWLEDGEMENTS

The work being reported in this paper was funded by the Canadian Wood Council, Natural Resources Canada and the Building Regulations for Market Access Program at the National Research Council Canada. The authors gratefully acknowledge their financial support.

8. REFERENCES

1. Christoph Hoeller, David Quirt and Jeffrey Mahn, "Guide to calculating airborne sound transmission in buildings", Report RR-331, Third Edition, National Research Council Canada, Ottawa, Canada (2017). https://doi.org/10.4224/23002279

2. Christoph Hoeller, Jeffrey Mahn, David Quirt, Stefan Schoenwald and Berndt Zeitler, "Apparent sound insulation in cross-laminated timber buildings", Report RR-335, National Research Council Canada, Ottawa, Canada (2017). https://doi.org/10.4224/23002009

3. Jeffrey Mahn, David Quirt, Christoph Hoeller and Markus Mueller-Trapet, "Addendum to RR-335: Sound transmission through Nail-Laminated Timber (NLT) assemblies", National Research Council Canada, Ottawa, Canada (2018).

4. ASTM E90-09(2016), Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements, ASTM International, West Conshohocken, PA, (2016).

5. ISO 12354-1:2017, Building acoustics -- Estimation of acoustic performance of buildings from the performance of elements -- Part 1: Airborne sound insulation between rooms, International Organization for Standardization, Geneva, Switzerland, (2017).