A case study in the isolation of flanking noise in prefabricated timber construction and buildings relying on load bearing internal timber cladding

Timothy Murray (1), Darren Tardio (2) and Andrew Lloyd (1)

(1) Octave Acoustics, 1a/3 Harris Street, Yarraville, Victoria, Australia
(2) Enfield Acoustics, PO Box 920, North Melbourne, Victoria, Australia

ABSTRACT

Previous testing and analysis have indicated that low-rise apartment buildings which utilise standard lightweight construction can comply with the sound insulation requirements under the National Construction Code (NCC) when joists, framing, plates or columns are used as the load bearing element and are typically not a direct radiating element (i.e. being enclosed by cladding).

The recent influx of prefabricated high-rise timber development, however, has also brought with it more unorthodox forms of load bearing construction and subsequent design considerations in mitigating structure-borne flanking noise via connected load bearing elements which may be exposed as a direct radiating element.

This paper presents analysis of the sound insulation properties of prefabricated timber building modules which rely on exposed internal timber cladding as the structural load bearing element in lightweight construction. The analysis applies to modern prefabricated buildings where timber 'slabs' such as Cross Laminated Timber (CLT), Laminated Veneer Lumber (LVL) and Oriented Strand Board (OSB), can be left exposed as finished cladding and where there is no additional plasterboard framed wall enclosing it.

Sound insulation testing was carried out using prefabricated cassette floor systems supported on both load bearing timber cladding and the timber framing behind the cladding. A comparison of results is presented between non-isolated and vibration isolated structural and load bearing connections using polyurethane foam to determine the effect on flanking transmission.

1 INTRODUCTION

Over the past decade in Australia, the use of loadbearing timber in mid-rise construction has increased substantially with new construction methods being tested that best utilise its features. Loadbearing timber comes in many forms, including Cross Laminated Timber (CLT), Laminated Veneer Lumber (LVL) and Oriented Strand Board (OSB). It is lightweight, sustainable and easy to install which makes it attractive to builders. The fact that timber construction is lightweight can, however, create issues with acoustic performance when compared with more traditional concrete construction methods.

In most lightweight buildings, the floor system is supported by the wall framing and plates (sometimes incorporating steel columns) which are enclosed by internal cladding (commonly plasterboard). Often, the plasterboard cladding provides the required fire protection around such critical structural elements but does not provide loadbearing support itself (Figure 1). Modern timber multi-storey buildings are, however, pushing the boundaries of construction engineering with unique fire and structural solutions which impact on noise transmission. Recently the authors assisted with the design and testing of one such unique situation in which the floor system was supported directly by the internal cladding in the room underneath (Figure 2).

This paper provides a case study for the testing, results and issues faced when working with this innovative design and the potential radiation of flanking noise transmission from exposed lightweight loadbearing elements.

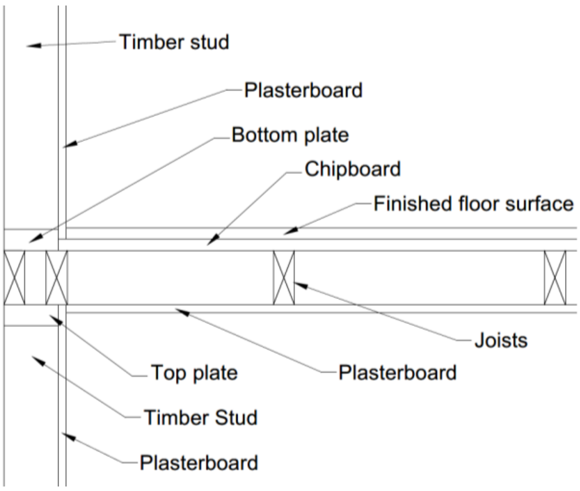

Figure 1: Typical Timber Frame Construction

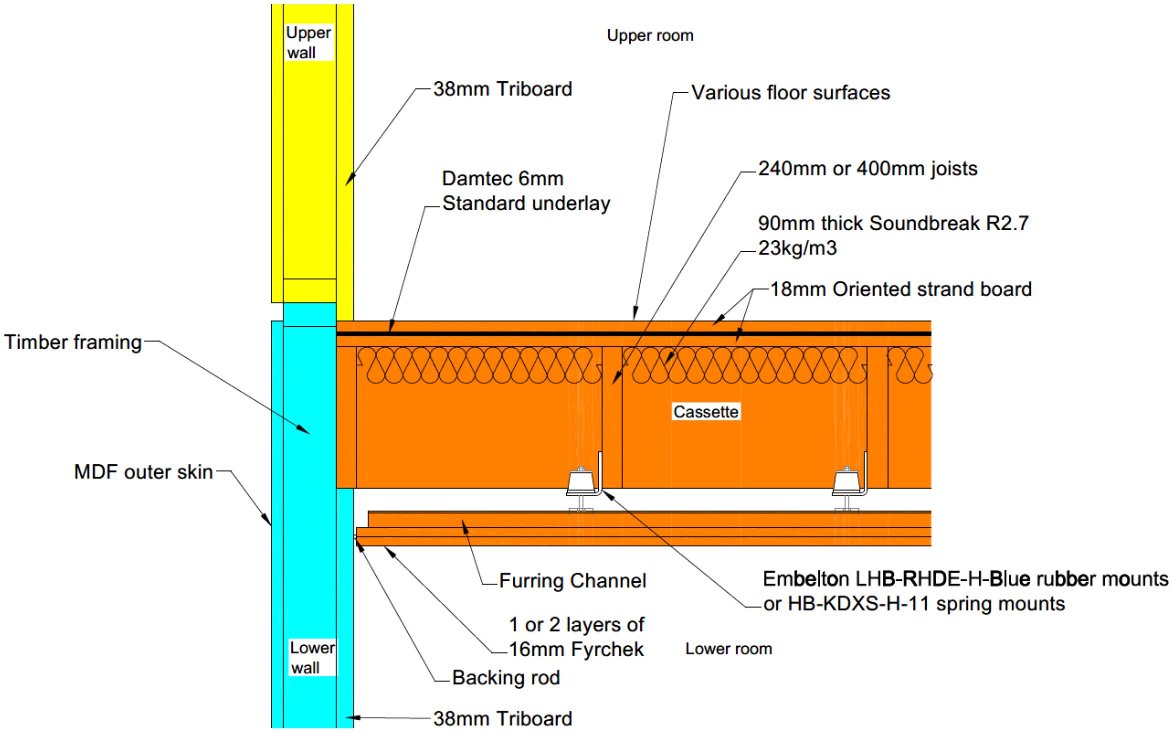

Figure 2: Initial test setup

2 TEST PROCEDURE

A test chamber was constructed consisting of two rooms that could be positioned one above the other with a floor/ceiling system “cassette” in the middle. The chamber was constructed to allow the top source room to be removed with an overhead gantry crane, allowing the floor system cassette to be swapped over to a cassette with a different configuration (see Figure 3). The floor cassette was carefully positioned on the inner wall cladding of Triboard in the bottom receiving room with no rigid fixings around the perimeter. Triboard is a 3 layered panel with a wood strand core sandwiched between an MDF outer “skin”. The ceiling on the cassette was sealed around the perimeter against the Triboard in the receiving room with flexible backing rod. The upper room was then installed so that the bottom plate of this room was resting on the top plate of the lower room and the internal Triboard of the upper room was resting on the upper OSB layer of the cassette (see Figure 2).

Figure 3: Test chamber

Floor impact and airborne transmission sound insulation testing was carried out in general accordance with ISO140-7 and ISO 717-2. While the room module sizes did not accord with all of the requirements AS/ISO 140, the test setup was deemed sufficient for the purposes of comparative testing.

The floor/ceiling cassette element itself was constructed in a way similar to other lightweight floor systems which have previously been shown to comply with the National Construction Code (NCC) performance requirements, being ≥R_w+C_{tr} 50 and ≤$L_{n,w}$ 62 between sole occupancy units, generally consisting of timber floor substrate with acoustic underlay over joists, bulk insulation, vibration isolation hangers and fire-rated plasterboard.

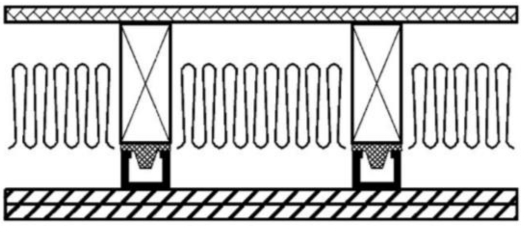

Figure 4: Similar Deemed to Satisfy Construction from the NCC

Four different floor finishes were tested on each cassette using 1m^2 patch samples:

- Bare OSB (the setup shown in Figure 2)
- An extra layer of 18mm OSB, making three layers in total
- Ceramic tiles directly adhered to 6mm fibre cement sheet
- 5mm thick vinyl planks on 2mm foam underlay

Four different cassettes were constructed:

- Type 1 - Two layers of 18mm OSB separated by 6mm of Damtec standard acoustic underlay, 240mm deep joists, Embelton LHB-RHDE-H-Blue rubber resilient ceiling mounts and 1 layer of 16mm Fyrchek with 90mm thick Soundbreak R2.8 23kg/m^3 insulation.
- Type 2 - Two layers of 18mm OSB separated by 6mm of Damtec standard acoustic underlay, 400mm deep joists, Embelton LHB-RHDE-H-Blue rubber resilient ceiling mounts and 1 layer of 16mm Fyrchek with 90mm thick Soundbreak R2.8 23kg/m^3 insulation.
- Type 3 - Two layers of 18mm OSB separated by 6mm of Damtec standard acoustic underlay, 400mm deep joists, Embelton LHB-RHDE-H-Blue rubber resilient ceiling mounts and 2 layers of 16mm Fyrchek with 90mm thick Soundbreak R2.8 23kg/m^3 insulation.
- Type 4 - Two layers of 18mm OSB separated by 6mm of Damtec standard acoustic underlay, 240mm deep joists, Embelton HB-KDXS-H-11 spring ceiling mounts and 2 layers of 16mm Fyrchek with 90mm thick Soundbreak R2.8 23kg/m^3 insulation.

An impact test was conducted using a standard tapping machine on each complete floor finish and an airborne test conducted on each cassette type.

3 IMPACT TESTING

After testing each system, it was noted that for each cassette type there was a variation of up to 12dB between floor surface tests. Comparing the variation between cassettes for a common floor surface there was only a 2dB variation. This strongly indicated that flanking was an issue from the cassette through to the receiving room, bypassing the ceiling system. None of the tested systems are likely to meet the NCC requirement of $L_{nT,w} \leq 62$ between sole occupancy units.

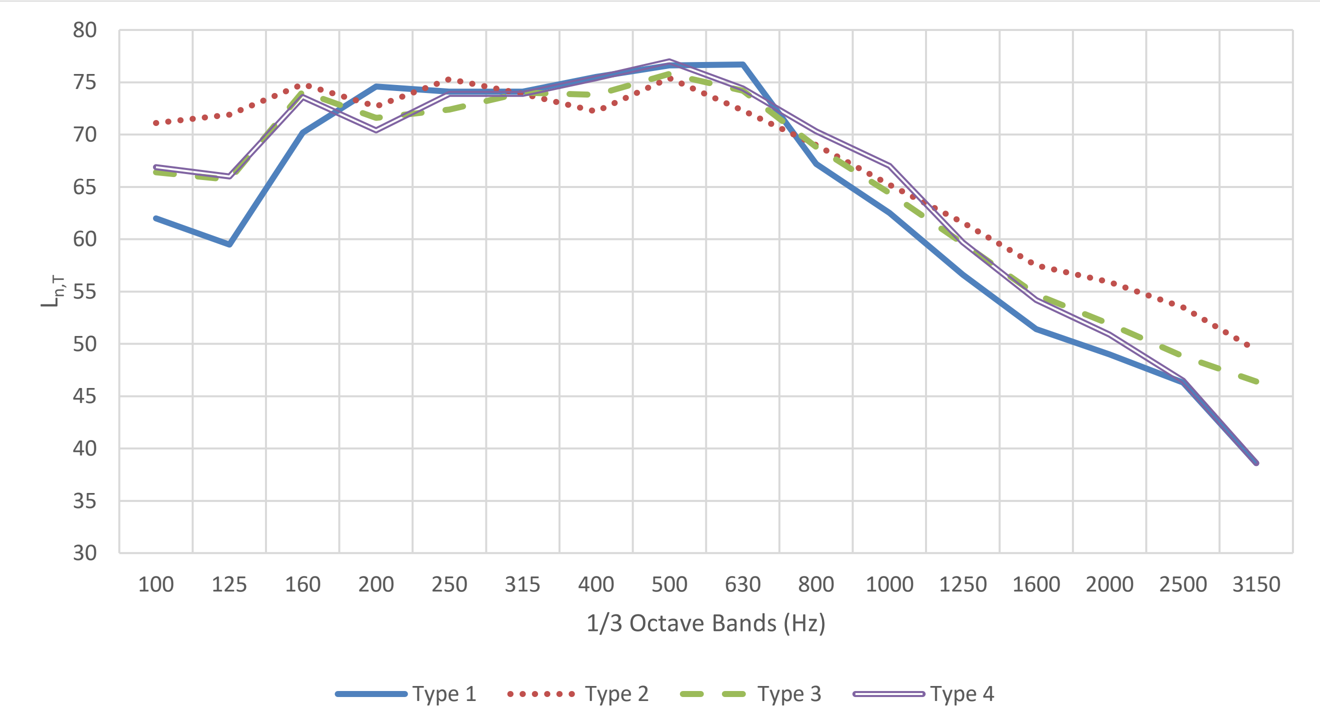

Figure 5: Variation between cassettes for bare floors

Figure 5 shows the variation between different cassettes for only the bare floor testing. The bare floor test has the highest $L_{nT,w}$ value (69-70) and so is more likely to have the largest variation between the different ceiling constructions due to the diminishing return associated with improvements to a system with a lower $L_{nT,w}$. Above approximately the 125Hz band there is minimal variation between the different cassettes. The variation is roughly in line with what would be expected with normal variation between tests of the same system considering the test set-up was dismantled and rebuilt between each change of cassette and relatively small room dimensions which would have effected deviation in low frequencies.

4 AIRBORNE TESTING

Airborne noise transmission was conducted on each cassette type and is presented in Figure 6 and Table 1 below.

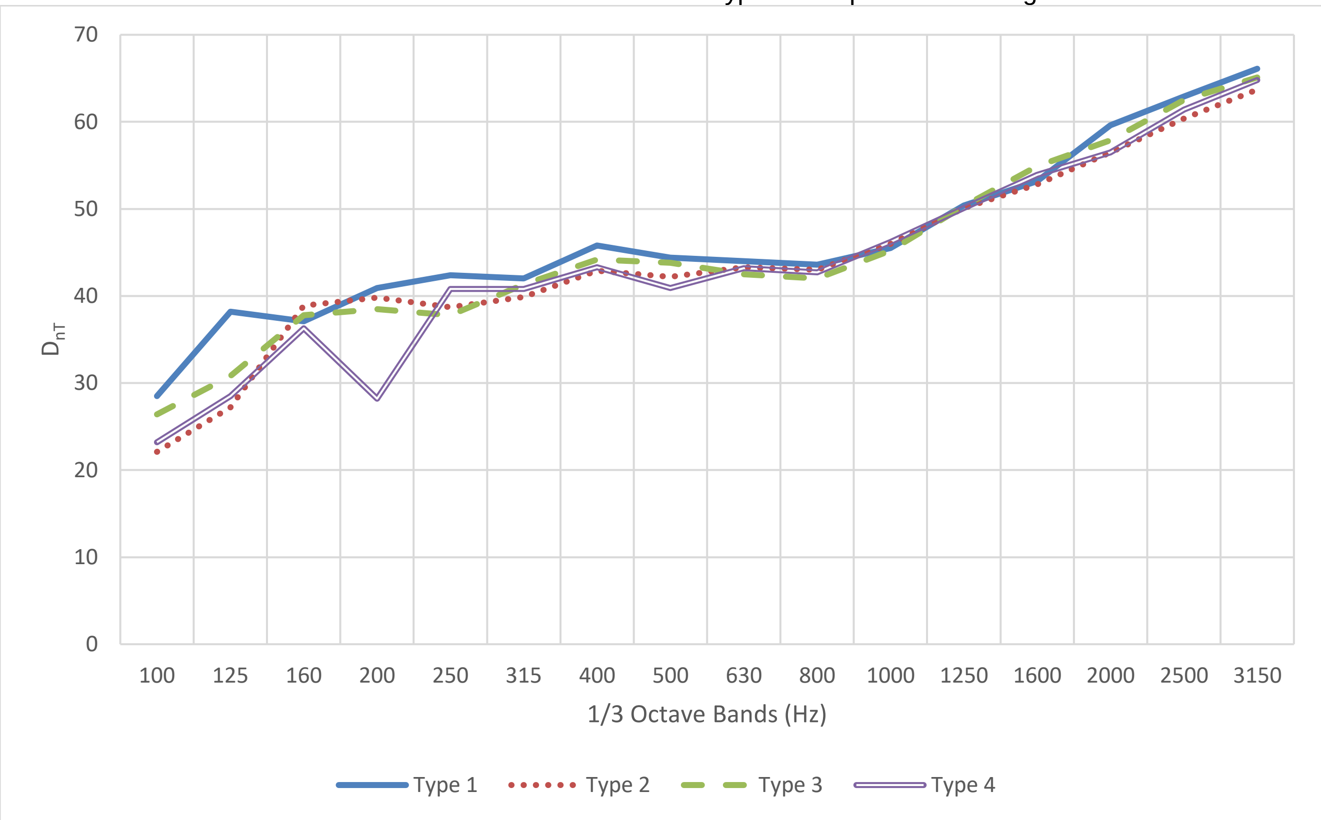

Figure 6 - Airborne Test Results

Once again, above the low frequencies where the room modes dominate, there was little meaningful difference between any of the tests.

Table 1: Airborne test results

Cassette type	*Ceiling hanger*	*Joist height (mm)*	*Ceiling layers*	$D_{nT,w}$	C_{tr}	$D_{nT,w}+C_{tr}$
1	*Rubber*	*240*	*1*	*48*	*-4*	*44*
2	*Rubber*	*400*	*1*	*47*	*-7*	*40*
3	*Rubber*	*400*	*2*	*46*	*-5*	*41*
4	*Spring*	*240*	*2*	*46*	*-6*	*40*

None of the systems tested would be likely to comply with the NCC requirement of $D_{nT,w}+C_{tr} \geq 45$ between sole occupancy units.

5 FLANKING REDUCTION

For most installations, the vibration travels in to the floor and from there into the structure and reradiates from the ceiling and plasterboard walls. In the test samples, the ceiling was well isolated for the frequencies of interest, however the floor cassette structure was directly supported by the internal wall lining. It appeared that this was resulting in vibration radiating as noise directly from the cladding while the relatively well isolated ceiling contributed less to the noise in the receiving room and so its construction had little effect on the noise level in the receiving room.

In the experimental setup, the structural connections occur at two locations:

1. Between the bottom framing plate of the upper wall and the top framing plate of the lower wall. This connection is not dissimilar to standard lightweight construction where structural links occur within cavities, except that typically, a floor beam may intermediate the upper and lower wall plates.
2. Between the floor cassette joist and the lower wall Triboard cladding.

An experimental investigation was conducted to confirm whether the major path of the flanking was from vibration exciting the framing structure or the cassette through the lower Triboard.

Each component was weighed, and the pressure calculated around the perimeter. From this, 12.5mm thick Isotec SD16 PURASYS Vibrafoam closed cell polyurethane foam was selected as an isolating element which would deflect under the load and help to seal the perimeter without crushing. The static deflection of the polyurethane isolation foam was approximately 2mm. A series of tests were repeated with the polyurethane foam installed between components of the chamber to determine where isolation was required to reduce flanking noise transmission.

The tests were conducted with the polyurethane foam located:

1. Between the upper and lower framing plate junction, including the small junction between upper room Triboard cladding and OSB flooring
2. Between the cassette perimeter joists and lower wall, on top of the Triboard.
3. Both locations 1 and 2.

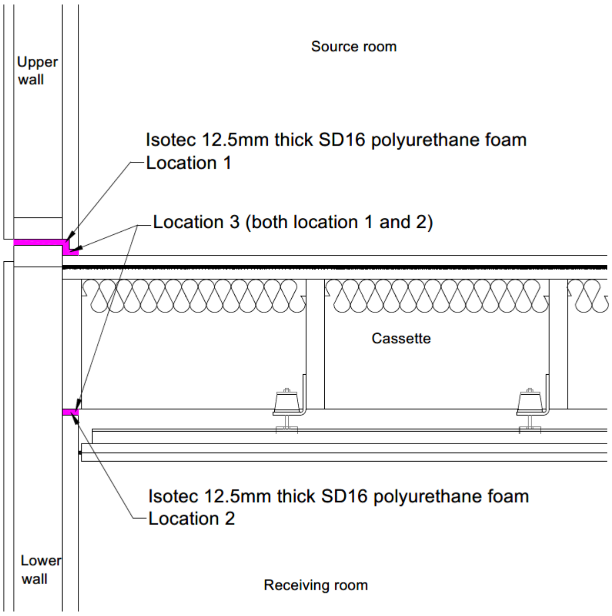

Figure 7: Flanking isolation locations

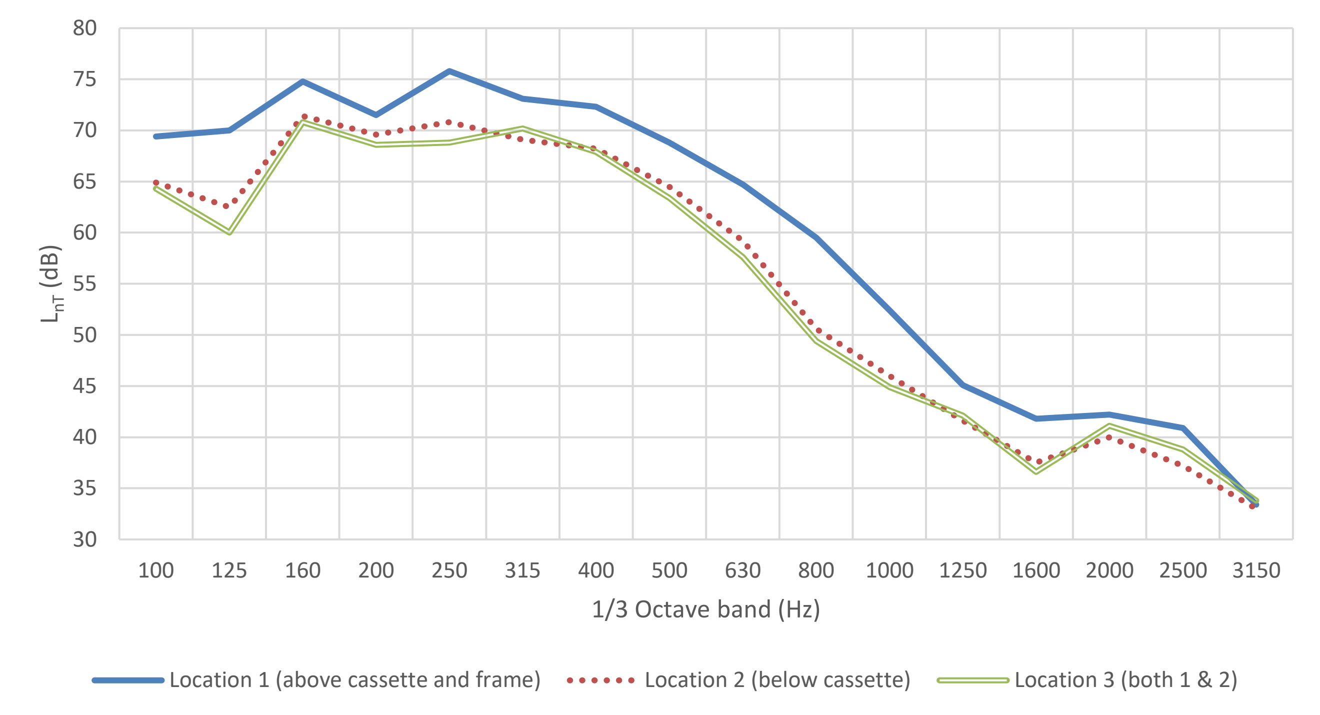

Figure 8: Polyurethane foam – flanking isolation performance

The improved performance shown when polyurethane foam was installed in location 2 and 3 confirms that flanking was indeed an issue. There was no significant difference between installing the polyurethane foam only below the cassette (location 2) and having it in both locations (location 3). This indicates that the dominant path of flanking noise was via the joist connection to the lower wall cladding.

6 Tapping tests with isolated cassette

Once it was ascertained that only the foam below the cassette was required, the floor surfaces were retested and compared with the original results which did not have isolation under the cassette.

Table 2: Impact test results

Cassette type	*Floor surface*	*Ceiling hanger*	*Joist Height (mm)*	*Ceiling layers*	*$L_{nT,w}$*	
					Without isolation foam	*With isolation foam*
3	*OSB*	*Rubber*	*240*	*2*	*65*	*58*
3	*Tiles*	*Rubber*	*240*	*2*	*64*	*58*
3	*Vinyl*	*Rubber*	*240*	*2*	*65*	*59*
3	*Bare*	*Rubber*	*240*	*2*	*69*	*63*

Installing the polyurethane foam flanking isolation below the cassette provided a consistent improvement to the impact sound insulation of 6-7 dB. For all tests except for the bare OSB test, this is enough to comply with the BCA requirement for impact sound insulation of floors of $L_{nT,w} \leq 62$.

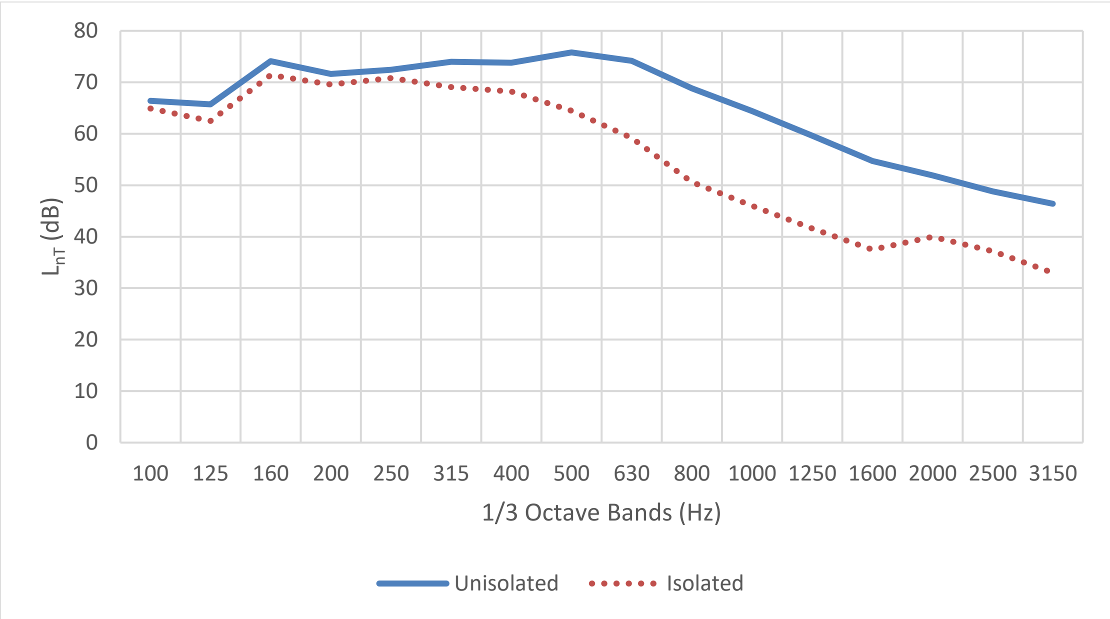

Figure 9 – Cassette 3, Bare floor impact test comparison between isolated and unisolated systems

7 Airborne tests with isolated cassette

The airborne test was repeated with the isolated Type 3 cassette and the results are presented below in Table 3.

Table 3: Airborne test results

Cassette type	*Ceiling hanger*	*Joist height (mm)*	*Ceiling layers*	$D_{nT,w}$	C_{tr}	$D_{nT,w}+C_{tr}$
1	*Rubber*	*240*	*1*	*48*	*-4*	*44*
2	*Rubber*	*400*	*1*	*47*	*-7*	*40*
3	*Rubber*	*400*	*2*	*46*	*-5*	*41*
4	*Spring*	*240*	*2*	*46*	*-6*	*40*
3 isolated	*Rubber*	*400*	*2*	*55*	*-7*	*48*

It would have been interesting to retest all the different cassette types when isolated from the internal cladding to compare the contribution of each ceiling system when isolated, as well as compare velocity levels for each test scenario. Unfortunately changing the cassettes took considerable time and time was limited in the facility, so the test was not practical at this stage.

Isolating the cassette from the Triboard provided a significant improvement of 7dB compared with the unisolated system and was enough to meet the BCA requirement of $D_{nT,w}+C_{tr} \geq 45$. While this level of improvement is unlikely to apply to all the systems, it is expected that isolating the cassettes would likely provide a sufficient improvement to achieve $D_{nT,w}+C_{tr}$ 45 for each of the other systems.

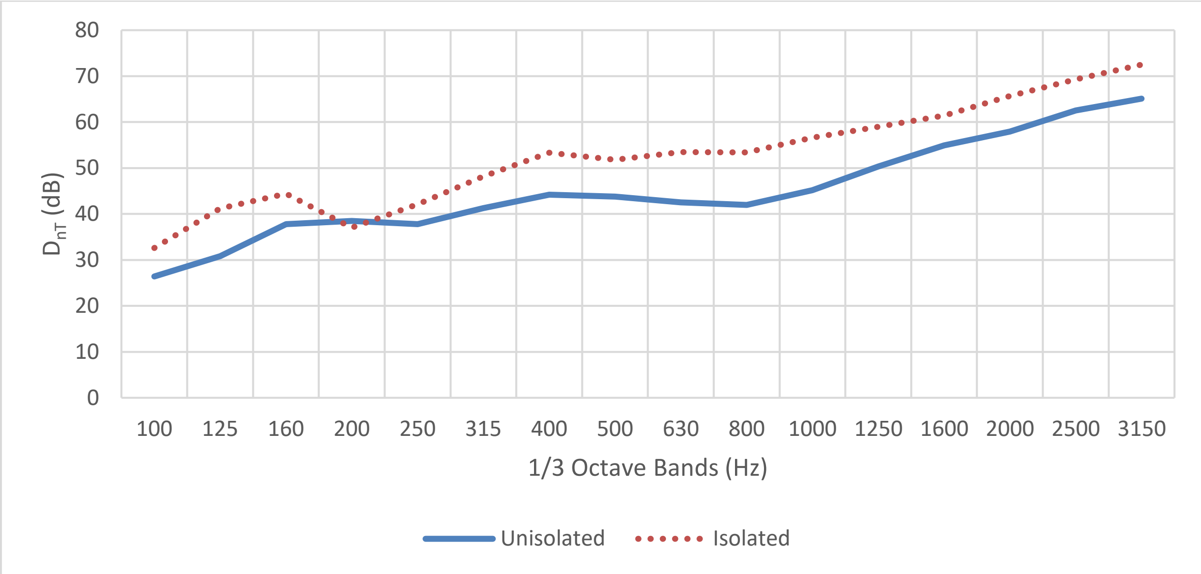

Figure 10 - Cassette 3 airborne testing unisolated and isolated systems

8 Comparison to previous testing

While the authors were unable to find previous testing where the wall cladding was used as a structural element, a review of other papers and manufacturers' installation recommendations showed that the results presented in this paper were comparable to similar tests done by others for pure CLT construction systems. There appears to be a common consensus that for solid timber construction, unless there is a separating element such as furring channels between the exposed wall surface and the main structure, isolation is required between structural elements to reduce flanking noise transmission. Timpte, A. et al., 2017 showed that introducing a resilient element into a CLT structure can reduce flanking vibration transmission between structural elements by 5-10dB above 125Hz which is broadly consistent with the results presented here.

9 CONCLUSIONS

Currently, construction using internal cladding as a loadbearing structural support is rare. As the use of innovative lightweight timber structures is expected to increase, using cladding or other exposed building elements as a loadbearing structural support may increase proportionately.

Flanking isolation is not often required in heavy concrete structures, nor traditional framing structures where:

1. The floor system is the intermediate structural element between walls; and is thus
2. Supported only by non-exposed framing and columns.

The transmission from floor, through the frame and furring channels before being reradiated out from internal cladding likely provides a reasonable level of attenuation and this theory was supported by the comparative isolation testing which indicated immaterial flanking noise via the framing connection. In the case where the floor systems are supported directly by the cladding, a significantly higher level of flanking transmission must be addressed to meet relevant building codes for acoustics. This is likely because there are relatively few building material and radiating surface area transitions in the tested structure compared with typical construction.

Isolating the junction between cladding and floor structure was shown to significantly reduce the noise transmission from flanking from the source room to the receiving room.

REFERENCES

Standards Australia. 2006. *Acoustics - Measurement of sound insulation in buildings and of building elements Field measurements of impact sound insulation of floors*. SAI Global (AS/NZS ISO 140.7:2006).

Standards Australia. 2006. *Acoustics - Measurement of sound insulation in buildings and of building elements Field measurements of airborne sound insulation between rooms*. SAI Gloval (AS ISO 140.4-2006)

Standards Australia. 2004. *Acoustics - Rating of sound insulation in buildings and of building elements Airborne sound insulation*. SAI Global (AS/NZS ISO 717.1:2004)

Standards Australia. 2004. *Acoustics - Rating of sound insulation in buildings and of building elements Impact sound insulation*. SAI Global (AS ISO 717.2-2004)

International Organization for Standardization. 2017. *Building Acoustics – Estimation of acoustic performance of building from the performance of elements- Part 1: Airborne sound insulation between rooms*. SAI Global (ISO 12354-1:2017)

Bies, D. A., Hansen, C. H., and Howard, C. Q. 2018. "Engineering Noise Control". 5th Ed. Boca Raton, Florida. CRC Press.

Reichelt, H., Gerhaher, U., Wiederin, S., Maderebner, R. 2016. "Characteristics of Acoustic Layers for Structural Design of Timber Constructions", World Conference on Timber Engineering.

Australian Building Codes Board. 2016. *National Construction Code 2016– Volume One*. http://www.abcb.gov.au/ncc-online/NCC

Sutton, A. and Black, D. 2011. "Cross-Laminated Timber: An introduction to low-impact building materials". Watford, UK. IHS BRE Press.

Timpte, A., Mecking, S., Schanda, U. and Rabold, A. 2017. "Vibration Reduction Indices of CLT Junctions". 24th International Congress on Sound and Vibration.

Stora Enso, 2016. "Soundproofing for CLT" Version 3. http://www.clt.info/soundproofing-for-clt-by-stora-enso

Hoeller, C., Quirt, D., Mueller-Trapet, M., 2017. "RR-336 Apparent Sound Insulation in Wood-Framed Buildings". NRC Publications Archive.