STUDY REPORT

SR 208 (2013)

Optimised Wall-to-Floor Junctions in Multi-Storey, Multi-Residential Light Timber-Framed Buildings

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Funded by BRANZ
from the Building Research Levy

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Preface

This is the first BRANZ report examining this topic. No further studies are currently planned.

Acknowledgments

This work was funded by the Building Research Levy.

Most of the materials used in the tests described in this report were provided by the manufacturers. In particular, plasterboard used in this project was provided by Winstone Wallboards Ltd.

All acoustic measurements and data reduction were performed by Grant Emms of Scion. Mr Emms also provided much of the acoustic design and advice.

Note

This report is intended for standards committees, the Ministry of Business, Innovation and Employment (MBIE), the Building and Housing Group, territorial authorities and designers of multi-storey, multi-residential light timber-framed buildings.

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Reference

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Abstract

Many research projects around the globe have considered acoustic, fire and structural solutions for multi-storey light timber-framed buildings. However, most have looked at these aspects in isolation, predominantly at the expense of the others. The need was identified to find optimum solutions covering all three disciplines.

Computer analysis of typical buildings under wind and earthquake loading identified that continuous floor diaphragms were generally required in multi-rise timber apartment buildings.

Acoustic tests were performed on construction using such diaphragms to determine a range of floor and wall combinations which achieved satisfactory acoustic performance. For this purpose a special two-storey test facility with two chambers on each floor was built at BRANZ to enable full-room boundaries to be acoustically assessed, including flanking sound transmission. Thus, the project considered room-to-room transmission rather than just through a single building element such as a wall or floor.

Fire resistance testing of the best-performing acoustic systems was then used to show that satisfactory fire performance could also be achieved.

This project has derived and verified by testing, a selection of construction details for walls, floors and their joints in multi-storey timber-framed buildings that can be economically used to satisfy the New Zealand Building Code (NZBC) requirements for suppression of sound transmission, suppression of fire spread and provide the required structural integrity. It presents details of construction which can be used to meet the performance requirements of Clause G6 (Airborne And Impact Sound).

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1. INTRODUCTION

1.1 Objective

The project objective was to devise a number of wall-to-floor joint systems for use in New Zealand multi-residential timber-framed structures that would provide acceptable and economic acoustic, fire and structural performance. This study was considered timely due to the proposed changes to Clause G6 (Airborne and Impact Sound) of the New Zealand Building Code.

The project gained additional importance when in April 2008 the New Zealand Government announced that all submitted tenders to the public sector would require a timber design solution for buildings up to four storeys in height.

1.2 Research Merit/Relevance

Multi-storey multi-residential structures utilising light timber framing, while structurally feasible, have not been used to the same extent as other construction materials such as reinforced concrete and structural steel. New Zealand building standards did not allow multi-residential timber buildings prior to the introduction of the performance-based building Code in 1991. Timber-framed construction lends itself to apartments and hotel/motel occupancies, where there are large numbers of rooms and therefore walls to support the structure above, with consequently shorter spans for floor joists between these walls.

Lightweight timber construction has the benefit that the lateral driving forces in an earthquake are lower than in reinforced concrete and structural steel frames.

A major impediment to construction with light timber framing has been the perception that it is not acoustically acceptable, particularly for low frequency impact sounds. The performance in fire is also sometimes perceived to be less than desirable. In contrast, there is the potential to prefabricate elements of the timber building off-site, allowing faster construction times. Foundation costs may be lower for light timber construction.

The needs of the acoustic engineer are often contradictory to those of the structural and fire engineer. That is, the structural engineer is looking for a structure that is well connected to ensure that it performs as one major element under earthquake loading. For this to be achieved, floor continuity across more than one occupancy is highly desirable. Fire engineers are similarly interested in ensuring continuity of fire resisting systems to prevent the spread of fire. Therefore, the needs of the structural and fire engineer are similar and complementary.

The ideal situation for the sound engineer is to have no connections between occupancies, thus ensuring that the transfer of either airborne or impact sound from one occupancy to another is kept to a minimum. These requirements are at odds with those for structure and fire and it is difficult to develop a satisfactory solution that meets the requirements of all disciplines. The key to optimum performance is considered to be joint details between walls and floors that can provide a balance of acceptable performance across the three disciplines.

The details of the wall construction influence airborne sound transfer. The main options for timber-framed walls include wall insulation, staggering studs (but these still have common plates), a double-stud wall (but these use up building footprint space) or having one of the linings spaced off the frame either by a resilient rail (e.g. Rondo rail) or by using resilient connections (i.e. the RSIC-1 clip made by Acoustical Surfaces, Inc). The linings can be also spaced off the framing on resilient rails or clips to improve the acoustic isolation of flanking sound. However, this spacing prevents the use of the lining as a structural bracing element, which is a major disadvantage structurally. Use of resilient rails on test specimen walls was not done in this project.

The transfer of impact (e.g. footfall) sound is influenced mainly by the detail of floor construction including floor coverings. Additional components are required to be added to a bare floor to achieve acceptable acoustic performance.

This project investigated many types of timber floor constructions and floor coverings. These included additional floor layers, floating floors and filling the cavity within the floors. The floor coverings included sheet material only (i.e. bare floor), various tiles, vinyl and strip timber. Carpet was not tested as research by others had indicated that this would usually result in better performance than the combinations considered in this investigation.

1.3 Research Process

First a literature survey was undertaken to ascertain what work had already been done in this area. It was expected that the amount of overseas research would be quite small given that the only other developed countries requiring both good acoustic and good earthquake performance in timber-framed multi-storey buildings were the USA and Canada.

Consideration was initially given to construction where the individual apartments comprising the building were effectively separated at apartment junctions – i.e. the floor diaphragms were structurally separated. This was to determine whether this was a structurally feasible option. A computer model was developed that consisted of a series of individual “towers” connected only at ground and roof levels in order to decide whether or not it was worthwhile pursuing such an alternative. It was determined that this was not a structurally viable alternative. More discussion on this analysis is given in Appendix D.

The next stage focused on finding systems that would provide the optimum acoustic performance while maintaining a structural floor diaphragm through the joint.

Pilot and full-scale fire tests were conducted on several acoustic alternatives to ensure that a good fire performance of the proposed joints could be achieved. These used a floor diaphragm across the wall/floor junctions as had been determined as necessary for structural integrity. Details and conclusions from the fire tests are given in Appendix C.

The body of this study report deals only with the acoustic investigation where a range of timber-framed wall/floor construction systems were tested to examine which would comply with the acoustic requirements of the proposed revision of Clause G6 (Airborne and Impact Sound) of the New Zealand Building Code (BIA 1995). The testing and analysis described in this report were based on the draft 2007 revision and thus the parameters used in the 2007 (DBH 2007) are briefly described. This report tabulates the ratings measured to allow direct comparison with the building Code criteria for both the current Code and the proposed draft 2010 (DBH 2010) revision.

Individual sound path airborne level differences and impact sound levels plotted against one-third octave frequency are given in Appendix B.

1.4 Sound Insulation Requirements of the Current New Zealand Building Code

Clause G6 (Airborne and Impact Sound) of the New Zealand Building Code (BIA 1995) including Amendment 2 for multi-unit housing complexes and high rise apartments stipulates that building elements such as walls, floors and ceilings shall have a laboratory-measured Sound Transmission Class (STC) of at least 55 and also that the laboratory-measured Impact Insulation Class (IIC) floors should be at least 55. Alternatively, the in-building measured Field Sound Transmission Class (FSTC) with no flanking transmission suppression shall be at least 50, or the in-building measured Field Impact Insulation Class (FIIC) with no flanking transmission suppression should be at least 50. The difference between the laboratory and in-building measurements of five is meant to compensate for any flanking transmission present in the in-building measurement (note: STC and IIC are laboratory-based measurements and FSTC and FIIC are in-situ measurements).

Acceptable Solution G6/AS1 includes four details for walls and two for floors and the corresponding floor/ceiling junctions. These comprise two timber-framed walls, a nominal 200 mm masonry block wall, a 150 mm concrete wall, a timber-framed floor and a 150 mm thick concrete floor.

The concrete floor is shown as continuous at wall intersections whereas the timber-framed floor is shown as discontinuous at wall intersections which consequently will pose problems in the seismic design.

Clause G6 is currently being reviewed. The review documents note various weaknesses in the clause and acceptable solution including:

- The sound insulation requirements are expressed in terms of the levels of transmission of sound through specific building elements, rather than the level of sound actually received in the spaces people occupy.
- The Code does not include any requirement related to low frequency sound.

1.5 Sound Requirements of the 2007 New Zealand Building Code Clause G6 Revision

The 2007 revisions included use of parameters C_{tr}, C and C_I. As this study was based on the 2007 revision this report gives measured values of C_{tr}, C and C_I.

1.6 Sound Insulation Requirements of the 2010 New Zealand Building Code Clause G6 Revision

This project has focused on the sound transmission from one household unit to another and only the criteria for this insulation are given below.

1.6.1 Airborne Sound Insulation

The airborne sound insulation from another household unit to the habitable spaces of a household unit shall satisfy:

- $D_{nT,w} \geq 53$ dB; and
- $R_W \geq 55$ dB.

Note $D_{nT,w}$ considers, in addition to acoustic attenuation of a building element (e.g. wall, floor), all the associated flanking paths contributing to the noise level received in a room (e.g. transmission via junctions, pipes and windows). It describes performance in a building and not in an ideal laboratory.

R_W is the ISO equivalent of STC and is typically within one or two dB of STC values. The R_W limitation ensures no localised areas of lower performance.

1.6.2 Impact Sound Insulation

The impact sound received in a habitable space of a household unit due to impact sound generated in another household unit shall satisfy $L'_{nT,w} \leq 57$ dB.

Note $L'_{nT,w}$ considers all the sound paths that may contribute to the noise level in a habitable space including flanking paths.

2. DEFINITIONS

The following definitions apply for the common terms used throughout this document:

Airborne sound originates from a sound source within a room such as a loudspeaker or a person talking. Airborne sound energy in a room passes from the air into the room boundary walls, floors and ceilings.

Airborne sound reduction is the difference in sound pressure level between the sound entering and sound leaving a *building element or volume element*. The amount of sound reduction varies with frequency. Single-figure rating measures for expressing *airborne sound reduction* are derived by considering values over a range of frequencies and reducing them to a single number (e.g. R_w, $D_{nT,w}$).

Airborne sound insulation expresses the degree to which sound travelling through the air is reduced when transmitted through a building element. A range of single-figure ratings, expressed in dB, are used. These ratings take into account the frequency dependence in relation to specific types of noise source.

Flanking is the transmission of sound from one room to another by any path other than directly through the partition(s) or floor(s) between them.

FIIC (Field Impact Insulation Class) is a single-number rating, derived as specified by standards, using field-measured values of normalised impact sound pressure levels providing an estimate of the impact sound insulating performance of a floor-ceiling assembly.

FSTC (Field Sound Transmission Class) is a sound transmission class determined as specified by standards, using values of field transmission loss.

IIC (Impact Insulation Class) is a single-number rating derived as specified by standards, from measured values of normalised impact sound pressure levels, providing an estimate of the impact sound insulating performance of a floor-ceiling assembly.

Impact sound is sound generated by striking the surface of a building element.

Pink noise is noise with a continuous frequency spectrum with equal power per constant percentage bandwidth, e.g. equal power in any one-third octave band.

STC (Sound Transmission Class) is a single-number rating determined as specified by standards, providing an estimate of the performance of a partition in certain common sound insulation problems.

White noise is noise with a continuous frequency spectrum with equal power per unit bandwidth.

The following terms are taken from relevant ISO Standards:

C_{tr} is the low frequency spectrum adaptation term and reflects a noise source containing low frequency content such as bass music.

C is the pink noise spectrum adaptation term which is appropriate for typical speech and music without any strong base content.

C_I is the impact spectrum term and was introduced to better relate to the problem of low frequency footfall noise and also high frequency impact sound such as chairs scraping on tiled surfaces.

***$D_{nT,w}$* (weighted standardised level difference)** is the airborne sound reduction between rooms in actual buildings. It is an ISO rating derived from a series of field one-third octave measurements with centre frequencies from 100 Hz to 3150 Hz. The higher the rating, the better the performance.

($D_{nT,w}$ + C_{tr}) obtained as prescribed in ISO Standards 140-4:1998 and 717-1:1996, this quantifies room-to-room insulation against home entertainment systems with emphasised or extended bass performance.

***$L_{n,w}$* (weighted normalised impact sound pressure level)** is defined in ISO 10140-3:2010 and is a rating for the impact performance of a floor-ceiling that has been tested in a laboratory. This rating is derived from a series of impact sound pressure levels measured in one-third octaves from 100 to 3150 Hz using a standard tapping machine as an impact source. The lower the value, the better the performance. A receiving room reference absorption of 10 m^2 is used to normalise underlying one-third octave impact level values.

***$L'_{nT,w}$* (weighted standardised impact sound pressure level)** is a rating for the impact performance of a floor-ceiling that has been tested in the field. A receiving room reference reverberation time of 0.5 seconds is used to standardise underlying one-third octave impact level values.

3. LITERATURE SEARCH

A collaborative detailed literature search was conducted at both BRANZ and Scion.

As expected, it was found that significant research had been conducted in each of the fire and acoustic disciplines, particularly acoustic, but there was little information relating to achieving the optimum performance of buildings under the combined effects of sound, fire and structural loads.

Additional to the literature search, contacts were made with overseas researchers known to the New Zealand research team.

3.1 Literature Search Results

Much of the overseas research had been conducted in Canada and the Scandinavian countries, where light timber-framed construction is popular.

Karjalainen (2004) reported that tens of multi-storey timber apartment buildings had been built in Finland, Sweden, Norway and Denmark over the period 1994 to 2003. He noted that even though the sound insulation requirements of each of the countries had been met, the feedback from residents suggested that the sound insulation actually achieved was less than satisfactory. This was attributed to poor low frequency sound insulation of the floors. The Scandinavians then developed timber-concrete composite floor slab designs which provided a measurable improvement in the perceived performance. The major concern for New Zealand is that the added mass increases the seismic demand on the structure and adding a wet trade adds to construction time.

Smith and Frangi (2008) note that using lightweight panel type systems such as timber framing with linings, creates ideal transmission paths for vibration and sound waves and that the most effective solutions are those that combine isolation of propagation sites from receptor sites with bulking of the mass at selected locations. They suggest that layered floors with a micro-reinforced concrete slab on sand over the timber floor system provide substantial acoustic and thermal insulation and contribute to overall system damping. They further suggest that it may be possible to construct two or three-storey “compartments” (occupancies) within the main frame with composite isolating layers both horizontally and vertically between compartments. Our computer models suggested that this was not practical in a seismically-active country like New Zealand.

Sewell and Alphey (1981) suggest that the type of resilient layer used in the floor system is probably the most significant single design factor with regard to impact performance. They investigated raft type floors and platform type floors, the major difference between the two being the position of the resilient layer. In the raft type floor the layer is fitted between the top of the joists and a packer, which is placed beneath the “raft” of plasterboard and particleboard. The platform type floor has a particleboard platform immediately on top of the joists and then a resilient layer is placed on top of this. Finally, a floating layer is placed over the resilient layer. Regarding airborne insulation performance, they suggest that it would likely be necessary to increase the mass of one or more of the elements of either type of floor to increase the airborne insulation performance, which again would be less than ideal in a seismically-active country.

Emms and Nebel (2010) wrote that the receiving room ceiling vibrations greatly influence transmission – particularly for low frequency sounds. Their paper recommended the use of floating gypsum concrete floors and sand-filled floors which they stated would perform similarly to 150 mm concrete slab floors. Both their recommended floors were tested in this study.

4. SOUND TRANSMISSION TESTING

4.1 General Overview and Objective

Sound transmission measurements were performed on a series of wall and floor ceiling constructions at BRANZ which enabled comparison with the performance requirements of Clause G6 of the current and proposed amended New Zealand Building Code to be measured. This required the construction of a facility that could be used to test a range of walls and floor/ceilings. Sound transmission was measured for airborne and impact sound, including direct and flanking paths.

As a starting point in this investigation, the results published by the Institute for Research into Construction of the National Research Council (NRC) in Canada (Nightingale, et al, 2006) were used to select test specimens that might meet the requirements of Clause G6.

4.2 Measurement Methods

4.2.1 Test Chamber

For the purposes of this project, a two-storey test facility with two chambers on each floor was built at BRANZ to enable full-room boundaries to be acoustically assessed, making this the only facility capable of testing flanking sound in Australasia.

The test rig consisted of an external envelope within which the test specimen was subdivided into four chambers (or rooms) as schematically illustrated in Figure 1. The basic test specimen was constructed at the same time as the external chamber, but was modified for the various tests described in this report. The chambers are shown in more detail in Figure 2.

The sound isolation design of the external chamber walls follows an NRC design for flanking sound measurements[1]. The test chamber external walls were constructed to minimise the transmission of sound via the exterior walls or from the outside. Schematic drawings illustrating the sound suppression are shown in Figure 3 and Figure 4. The location of the section where these elevations were drawn is shown in Figure 2.

To suppress sound transmission horizontally, the chambers were physically disconnected as shown in Figure 5, Figure 2 and Figure 6.

Photographs taken during construction of the chamber are shown in Figure 6 to Figure 10.

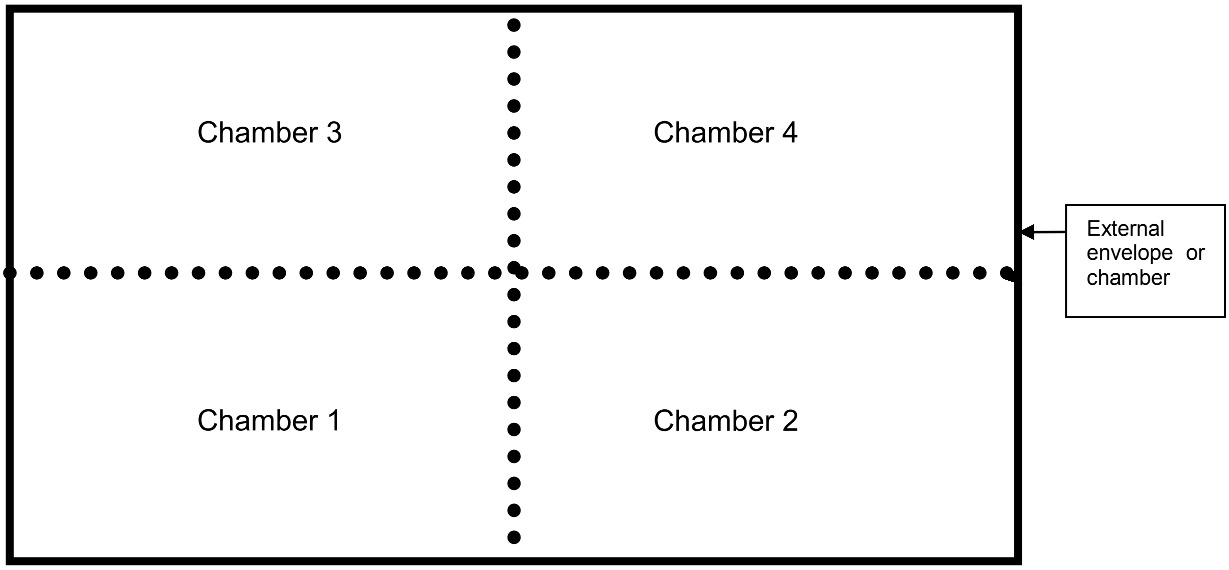

Figure 1. Schematic elevation view of the four test chambers. Solid lines represent the external envelope and the dotted lines represent the specimen walls and floors

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[1] See http://irc.nrc-cnrc.gc.ca/ie/facilities/flanking_e.html.

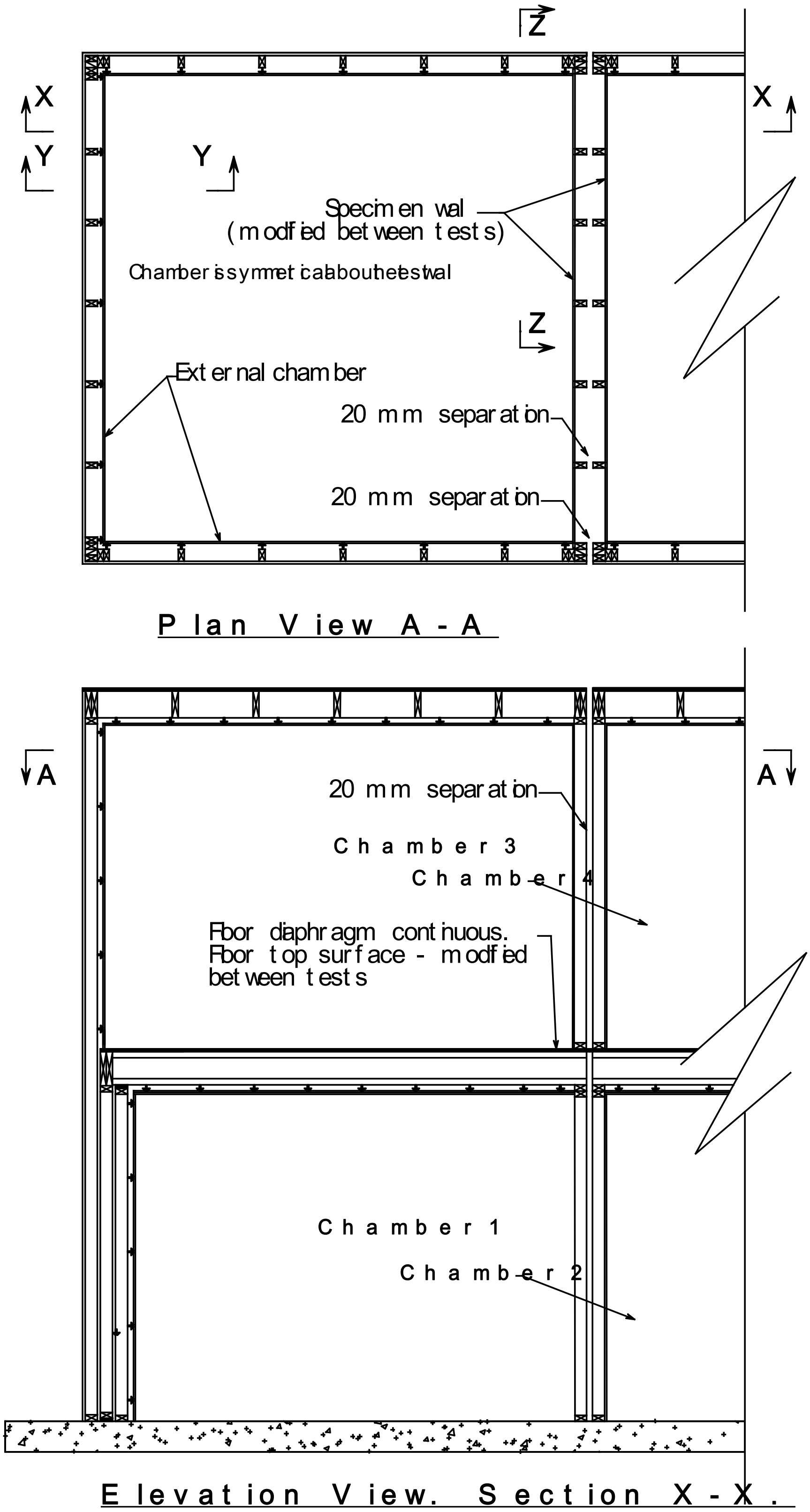
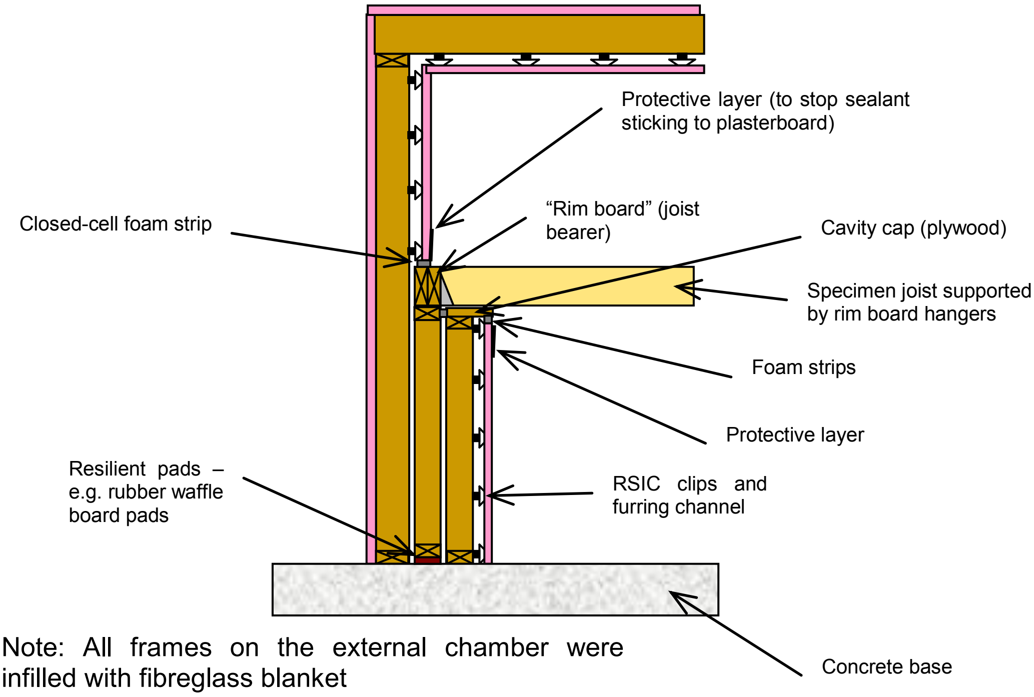


Figure 2. Scaled drawing of test chamber



Note: All frames on the external chamber were infilled with fibreglass blanket

Figure 3. Elevation view of end of chambers – section Y-Y (not to scale)

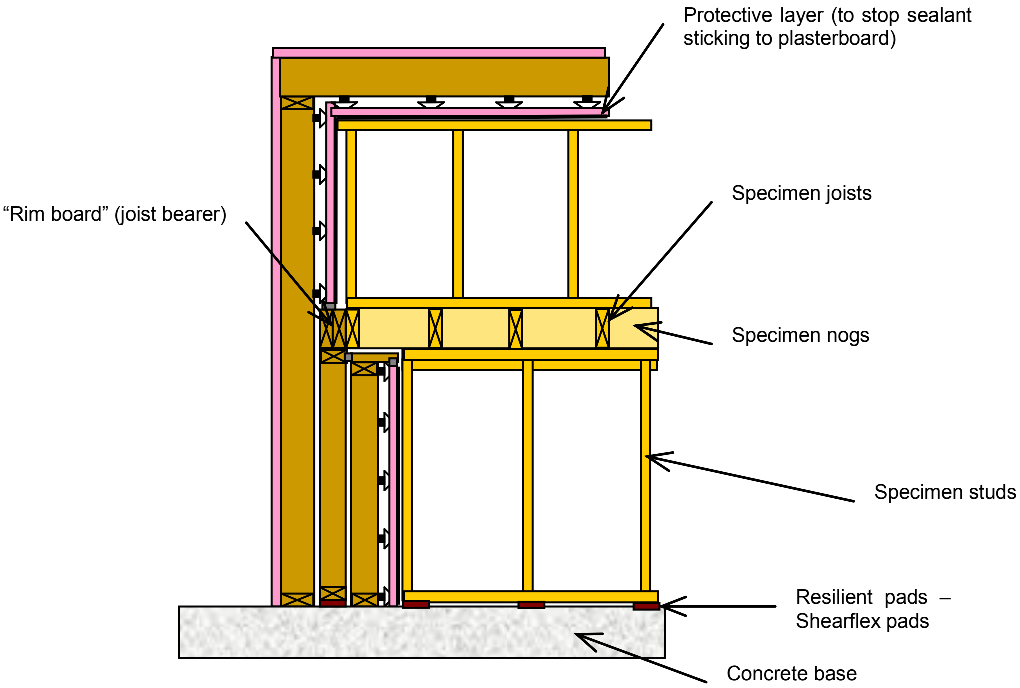


Figure 4. Elevation view of the side of the chamber – section Z-Z (not to scale)

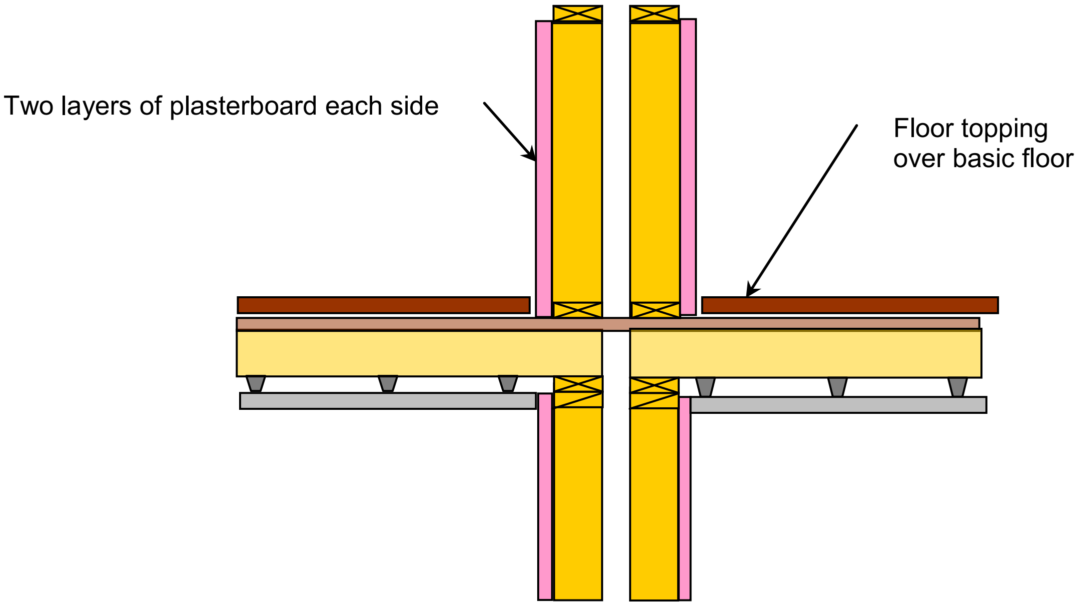


Figure 5. A schematic view of a test specimen

Figure 6. The 20 mm gap separating Chamber 1 from Chamber 2 and Chamber 3 from Chamber 4

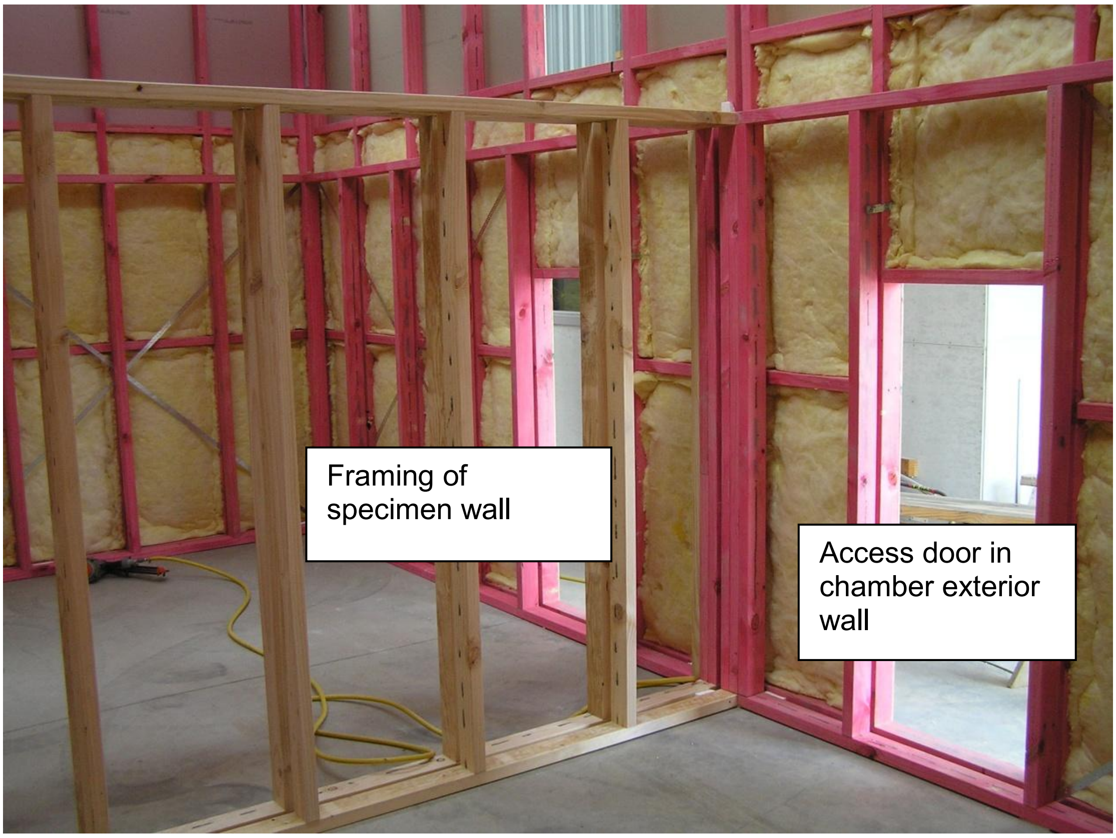


Figure 7. **Photograph within the lower floor of acoustic chamber taken during construction showing specimen framing**

Figure 8. **Photograph of exterior walls of the acoustic chamber taken during construction showing the acoustic absorption and furring channels connected to the frame with RSIC-1 clips.**

Figure 9. Photograph of the basic floor taken during construction

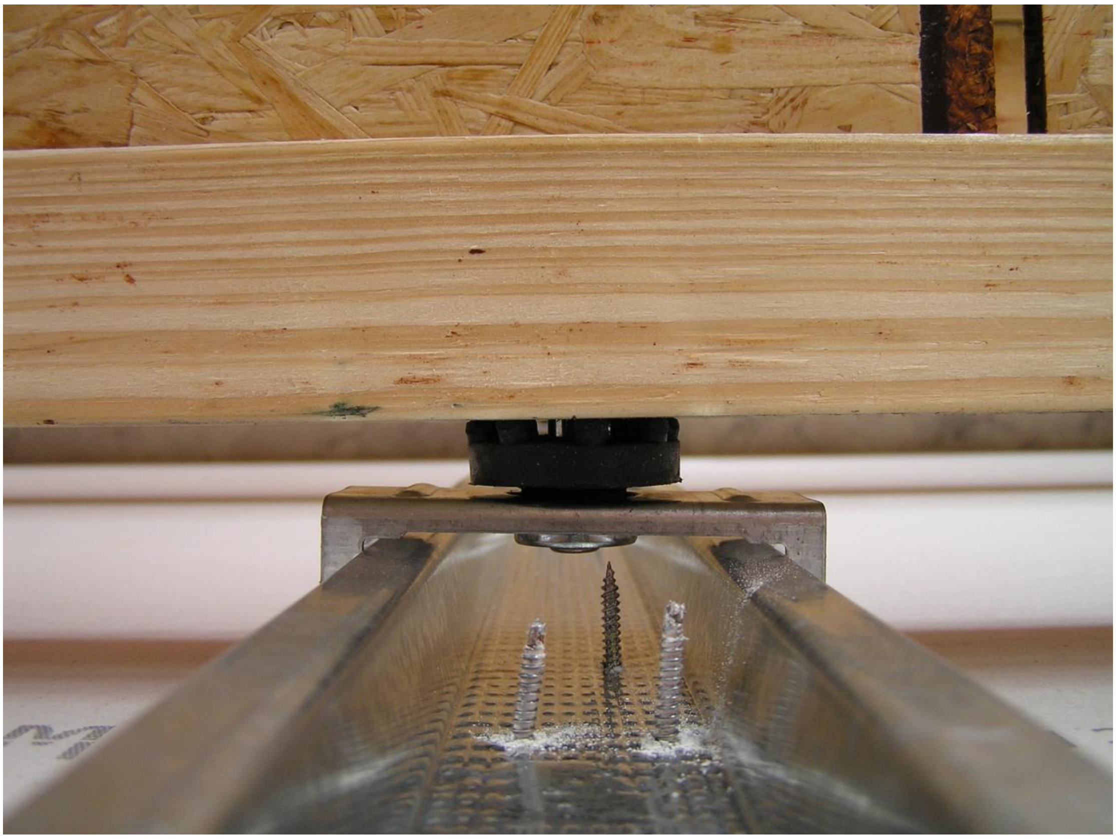


Figure 10. Photograph of the resilient mount and furring channel system used to support the ceiling under the timber floor joists taken during construction. The same system was used to support the linings of the chamber walls

4.2.2 Measurement Procedures

ISO Standard methods (ISO 140 Parts 3 and 7) were used to measure the sound levels in each chamber. Combining these sound levels with the reverberation time of each chamber and its volume enabled the standardised[2] sound level differences between each room or the standardised impact sound level to be calculated.

The equipment used conformed to that described in the ISO Standard. The sound levels were measured in each room using a fixed array of microphone positions. These positions were kept constant throughout the test series to enable good repeatability of measurements and better comparison between specimens. Similarly, loudspeaker and tapping machine positions were fixed.

A photograph of the tapping machine being used is shown in Figure 11.

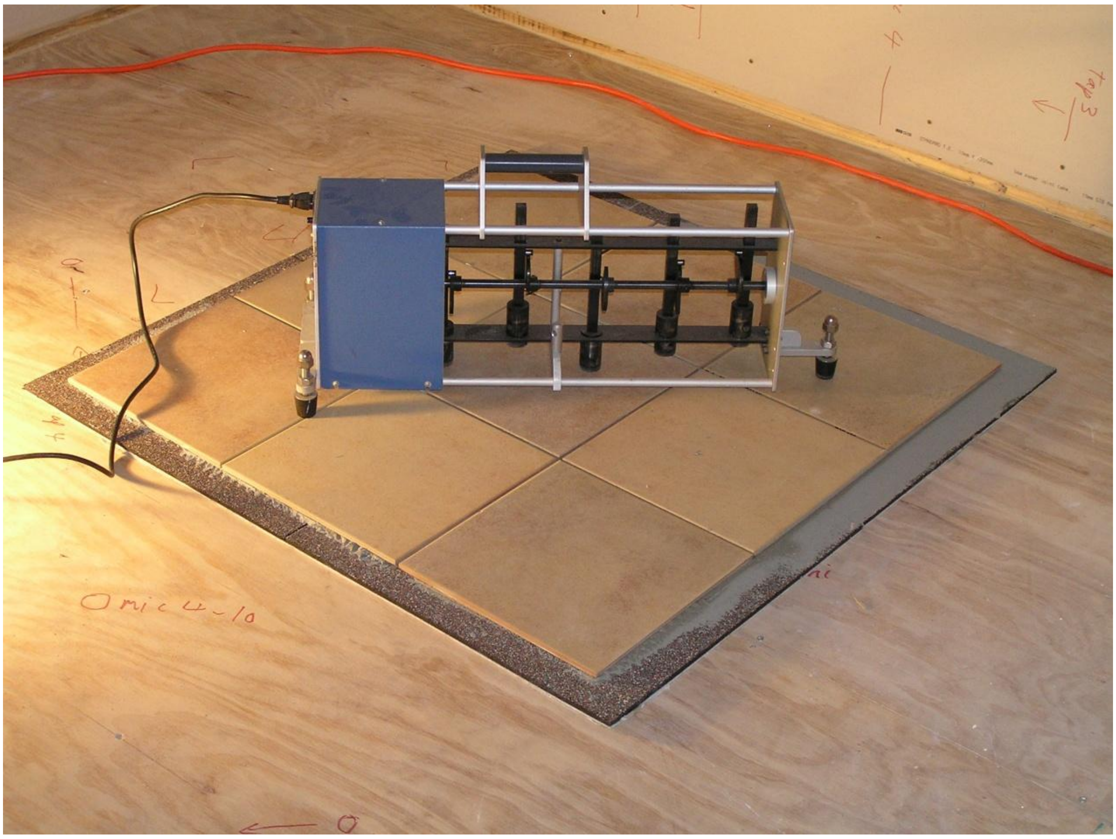


Figure 11. Tapping machine set up for testing

4.2.3 Screening Off Unwanted Transmission Paths

In order to obtain information about how much sound is transmitted from a particular building element (wall or floor/ceiling), the unwanted paths in the source and receiving rooms could be screened off as required. Screening off one building element enabled both sound paths to be determined by way of subtracting the overall (no screen) case

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[2] Standardised is defined in ISO 140 as being the airborne levels differences or impact levels adjusted to those that would be obtained for a receiving room with a reverberation time of 0.5 seconds. This reference time is deemed the standard, as most rooms have a reverberation time of about 0.5 seconds.

from the screened case. For ease of testing, the specimen walls rather than the floors were screened when required. Figure 12 illustrates the screens used to reduce sound transmission to or from a specimen wall.

The screen panels were made in two sections and edged with 6 mm thick closed cell foam so that they could be used to seal against the chamber, specimen walls and floors, as well as against each other when abutted to form the screen. The panels were put into place and the slotted top section slid up until it pushed against the ceiling and then the bolts in the slots tightened to hold the top section in place. The gap between the screen and the specimen walls was filled with polyester fibre insulation.

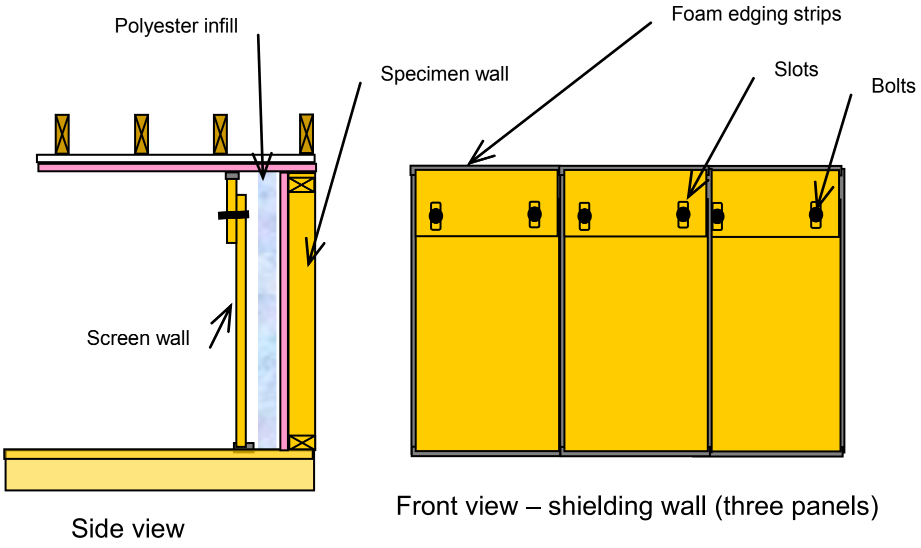

Figure 12. Screen wall made of 20 mm particleboard panels. Polyester fibre insulation was placed between the screen wall and the specimen wall

4.2.4 Determining the Sound Transmitted Along Each Path

This section discusses how the sound energy transmitted along each path was determined from measurements of total sound energy received at the microphones by using horizontal airborne transmission as an example. Detail on how flanking path results were separated into the individual components for vertical airborne transmission and horizontal and vertical impact transmission is given in Appendix A. Impact measurements are simplified because it is not necessary to screen off walls in the source room as the tapping machine predominantly transmits sound through the floor. Thus, transmission through the walls is assumed to be zero.

Figure 13 shows the sound transmission paths for airborne transmission between horizontally-connected rooms. F is the source room flanking element (i.e. the floor), D the source room direct path, f the receiving room flanking element, and d is the receiving room direct path. In this case the direct path is through the wall (Dd) and the flanking paths are various wall and floor combinations (Df, Fd, Ff).

Selective screening, and assuming the screening is 100% effective, provides the following sound energy measurements:

(1) Using no wall screening gives the sound transmission to the receiving room from all the paths (Dd + Df + Fd + Ff).

(2) Putting a screen over the source room wall gives the sound transmission from the source room floor paths (Fd + Ff).

(3) Putting a screen over the receiving room wall gives the sound transmission from the receiving room floor paths (Df + Ff).

(4) Putting screens over both the source and receiving walls leaves only the floor path (Ff).

The sound energy transmitted along each individual path was obtained by simple algebraic manipulation of the measurements listed above. However, small errors in measurements can potentially contribute to large errors in the results if one path contributes significantly more than the others. E.g. the sound transmission of path Dd is obtained from the sound transmission from measurements:

(1) – (2) – (3) + (4) = (Dd + Df + Fd + Ff) – (Fd + Ff) – (Df + Ff) + (Ff) = Dd

If the sound transmission from path Dd is small relative to the sound transmission from other paths, there will not be an accurate measure of the sound transmission through path Dd. This problem was overcome by choosing to base the calculation of Dd from tests where the other paths were much less significant. For all wall systems tested, this was achieved by obtaining the Dd value from tests where floating floor systems were used and thus the sound energy transmitted through the floor was small.

Another problem is that while the screens do a good job of shielding mid to high frequencies, their sound insulating ability at low frequencies is poor. This can result in overestimating the transmission from flanking paths. This was remedied by using a technique developed by Nightingale (2006), which made use of his finding that 6 dB/octave tails occurred for flanking paths at low frequencies.

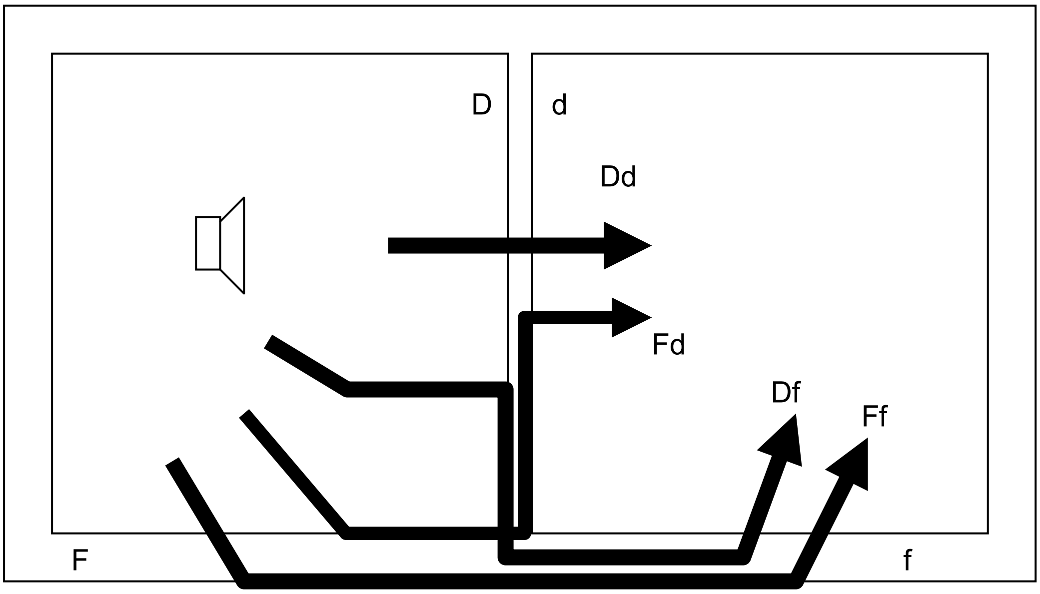

Figure 13. Schematic of the flanking paths for horizontal airborne transmission

4.2.5 Using Results to Evaluate Wall and Floor Combinations Not Actually Tested as a Combined System

One of the reasons for separating out the flanking paths is to enable results to be recombined to make predictions of combinations that were not measured, particularly for vertical transmission. For instance, although vertical performance was only measured with one flanking wall, predictions were made on sound transmission with two and four flanking walls. However, this introduces an error as is explained in the paragraph below.

The measurements undertaken were for joist ends mounted on the specimen wall. Other results show that this tends to produce the greatest flanking sound transfer. Walls which have joists running parallel tend to have less flanking sound transmitted through them. Hence, the predictions are expected to overestimate the sound transmission where flanking walls are parallel to the joists and thus the results in this report may sometimes be conservative in this regard.

4.2.6 Bridging Connections in Double-Stud Walls

If the floor diaphragms are separated at double-stud walls – i.e. not continuous – then the only significant sound path is through the air gap between the two halves of the wall. However, if there are continuous diaphragms at each level then there are additional sound transmission paths through the top diaphragm above the wall and through the bottom diaphragm under the wall. Figure 14 shows these sound paths.

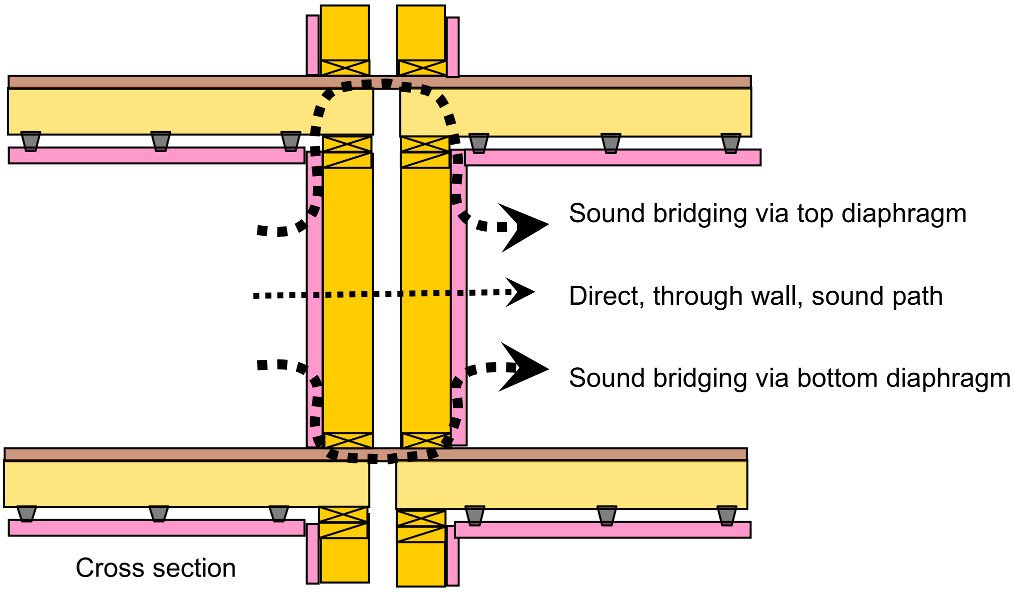

Figure 14. Additional sound paths in double-stud walls via continuous floor diaphragms

Only the bottom diaphragm of the test specimens was continuous and the top diaphragm stopped on either side of the gap in the double-stud wall as shown in section X-X of Figure 2. To determine the influence of a top diaphragm, the airborne sound transmission was also measured through the bottom two chambers, which had a top but not a bottom diaphragm. By combining these two measurements and removing the calculated through-wall sound transmission, predictions were made of the sound transmission expected for a top and bottom diaphragm in the top chambers.

4.2.7 Impact Insulation of Different Floor Coverings

When measuring direct path impact insulation through the floor all other paths were screened. Sound transmission was measured with the bare floor and also with five different 1 m square floor coverings in the sound source room (see Section 5 for details of the floor coverings used.) The floor coverings were moved to various positions on the floor to capture the range of transmission characteristics.

Carpet with an underlay was not tested as NRC results showed that this construction could be expected to meet the 2010 Clause G6 criteria for impact insulation (results from NRC [Nightingale, et al, 2006] showed that $L_{nT,w}$ was less than 55 dB for the most basic floor with carpet).

Work by NRC (Nightingale, et al, 2006) showed that floor covering patch tests tend to overestimate sound transmission for the heavier floor coverings compared to a whole floor being covered. This error is greater with lightweight floor systems and is due to the extra weight and damping of the floor covering reducing the sound being transmitted. The results of patch tests for lightweight, flexible coverings, such as vinyl, tend to compare well to results of the whole floor being covered. Thus, it is expected that the reported results are conservative and better performance will be achieved for complete floor coverage.

The samples tested were not adhered to the floor as may or may not be the case in practice. This can affect results, especially for rigid-bottomed samples and for high frequencies. More high frequency impact sound transmission is expected for the ceramic tile on fibre-cement board sample when glued or screwed to the floor. However, the overall performance ratings of these lightweight floor systems tend to be more driven by the lower frequencies and thus expected to have little effect on the single-figure ratings (such as $L'_{nT,w}$) for the lack of adhesion.

Taking the difference between the impact sound levels measured for the bare floor and those for a floor covering gives an impact sound level difference. This was determined for the direct path through the floor with all other paths screened. By applying this impact sound level difference to the bare floor measurements for the other paths, the impact sound transmission levels for all paths and all coverings was calculated.

4.2.8 Recombining Different Wall and Floor Systems

The test programme did not measure the performance of all wall and floor system combinations. Use of the separate sound path measurement, the symmetry of the systems tested and the fact that the floor and ceiling were not altered allowed the performance of other floor and wall system combinations to be calculated as explained below.

As an example, consider horizontal airborne transmission (see Figure 13) with Wall A and Floor B that have each been tested in other combinations but not in the same construction – that is not Wall A and Floor B together. To calculate the overall sound transmission with Wall A in the same construction as Floor B it is necessary to know the sound transmission through paths Dd, Ff, Fd and Df for this combination. Two of these variables are known already. However, path Dd was measured from other tests on Wall A and is independent of the floor topping system. Also, path Ff is independent of the wall and was measured from other tests on Floor B.

The remaining paths (i.e. paths Fd and Df) are the result of the wall combined with the floor and hence need extra consideration. These variables were found by:

(1) Recognising the symmetry of the construction which implies the sound transmission through path Fd should equal that through path Df.

(2) Making the assumption that, since there is no change in the framing and ceiling lining, there is a fixed, linear relationship between the average vibration levels of the ceiling and the average vibrations at the floor/wall junction. Now, if the ceiling radiation efficiency is unchanged (this is a reasonable assumption since the ceiling remains unchanged), the sound coming from the ceiling is directly proportional to the vibration of the ceiling and hence to the vibrations at the floor/wall junction. Similarly, the vibrations at the floor/wall junction are linearly related to the wall vibrations which are related to the sound emitted from the wall (via path Fd). Hence, there is a linear relationship between the direct, vertical sound path and the horizontal sound path Fd, which is only dependent on the wall.

(3) Combining this linear relationship with the direct, vertical sound transmission measured for a floor system, which is only dependent on the floor system, enabled the calculation of paths Fd and Df.

A similar procedure was applied to vertical airborne sound transmission and impact sound transmission.

4.2.9 Converting to Different Room Volumes and Element Sizes

The sound measurements were performed on a fixed set of building element sizes and room sizes:

- Horizontal transmission
    - Receiving room volume = 27 m^3
    - Wall area = 8.0 m^2.
- Vertical transmission
    - Receiving room volume = 20.4 m^3
    - Floor area = 11.0 m^2.

The ratings D_{nT} and L_{nT} are standardised in the sense of being referenced to a common reverberation time. This does mean that they are dependent on the receiving room volume. They are also, in general, dependent on the dividing element area and, for the flanking paths, the length of the connecting junction.

The recorded acoustic data in this study was corrected to standard room size volumes and areas using the conversion algorithms given in Section 4.2.9.1 and Section 4.2.9.2 below. This used the knowledge on flanking transmissions given in the following standards:

- EN 12354-1:2000 Building Acoustics – Estimation of acoustic performance of buildings from the performance of elements, Part 1: Airborne sound insulation between rooms; and
- EN 12354-2:2000 Building acoustics – Estimation of acoustic performance of buildings from the performance of elements, Part 2: Impact sound insulation between rooms.

4.2.9.1 Impact Insulation

For the **direct transmission** components it was assumed that the impact sound level was independent of the floor area. To convert from “Situation 1” (the actual test situation) to "Situation 2" (the standardised test situation) the following formula was used:

$$L_{nT,2} = L_{nT,1} + 10\log_{10}(V_1 / V_2)$$

where V_1 and V_2 are the volumes for the receiving room for Situations 1 and 2 respectively and where Situation 2 is for the standard sized room specified in the standard.

For the **flanking transmission** components it was assumed that the elements have significant attenuation and that the important factors are the junction length and the source room floor area. Using EN 12354 Part 2 (Eqns 16 and 20) to convert from Situation 1 to Situation 2 the following formula was used:

$$L_{nT,2} = L_{nT,1} + 10\log_{10}\left(\frac{V_1\, l_2\, S_1}{V_2\, l_1\, S_2}\right)$$

where V_1, l_1, S_1 and V_2 , l_2, S_2 are the volumes, junction lengths and dividing element area for the receiving room for Situations 1 and 2 respectively.

It is necessary to convert different flanking paths separately if the junction length is different.

After converting, the separate paths were totalled.

4.2.9.2 Airborne Insulation

For the **direct transmission** components it was assumed that the sound reduction index of the wall or floor was unchanged by varying the area. Therefore to convert from Situation 1 to Situation 2 the following formula was used:

$$D_{nT,2} = D_{nT,1} + 10\log_{10}\left(\frac{V_1\ S_1}{V_2\ S_2}\right)$$

where V_1, S_1 and V_2 , S_2 are the volumes and common building element area for the receiving room for Situations 1 and 2 respectively.

For the **flanking transmission** components, EN 12354 Part 1 (Eqn 25-b) was used to convert from Situation 1 to Situation 2:

$$D_{nT,2} = D_{nT,1} + 10\log_{10}\left(\frac{V_1\ l_2}{V_2\ l_1}\right)$$

where V_1, l_1 and V_2 , l_2 are the volumes and junction lengths for the receiving room for Situations 1 and 2 respectively.

5. SPECIMENS TESTED

5.1 Summary of Floors, Walls and Floor Coverings Tested

The specimen tested consists of the floor and walls shown in Figure 5. The basic floor of the specimen is shown in Figure 15. The ceiling lining was two layers of 13 mm GIB® standard plasterboard. Apart from sound transmission testing using the basic floor with no topping, sound transmission tests were also performed using the following floor toppings:

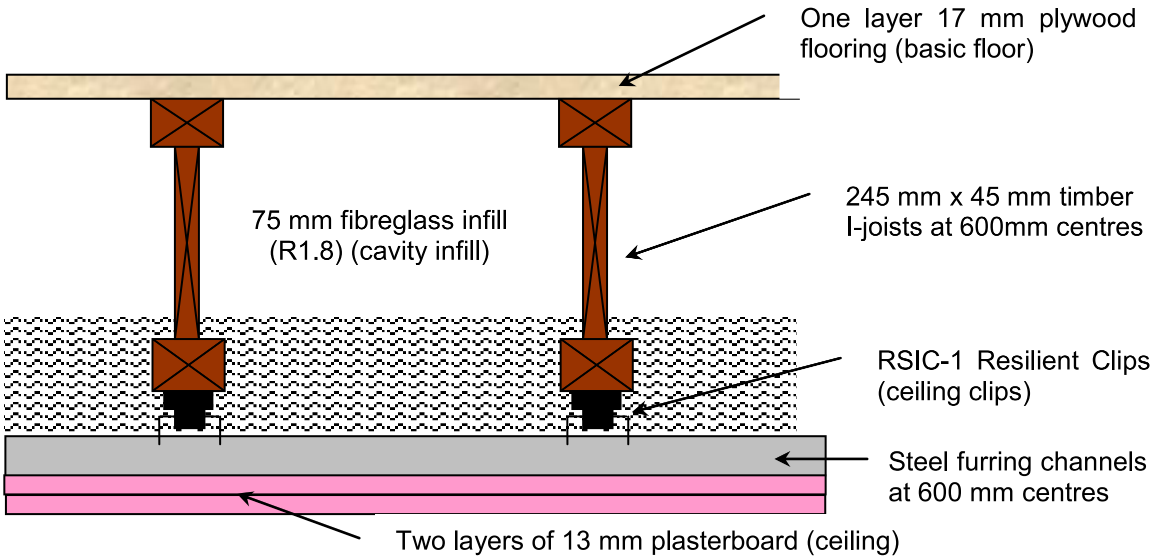

Figure 15. The basic floor/ceiling combination

(1) Two layers of 20 mm particleboard raft floating on a 20 mm Maxxon Acousti-Mat 3.

(2) One layer of 20 mm particleboard screwed to plywood floor.

(3) One layer of 20 mm particleboard screwed to 45 mm battens which were in turn screwed to the basic plywood floor. The cavity was filled with a dry sand/sawdust mixture (in a 2:1 ratio by volume).

(4) A 38 mm thickness of Maxxon gypsum concrete screed floating on a Maxxon Acousti-Mat 3.

(5) Two layers of 20 mm particleboard raft floating on a 13 mm thick layer of CSR Bradford Quietel rigid fibreglass insulation.

(6) Two layers of 20 mm particleboard raft floating on a 10 mm layer of Quietzone foam underlay.

Three wall lining options were tested:

(1) Two layers of 10 mm GIB Fyreline® paper-faced plasterboard of 7.0 kg/m² density each side of the wall.

(2) Two layers of 13 mm GIB Fyreline® paper-faced plasterboard surface of 9.6 kg/m² density each side of the wall.

(3) Two layers of 13 mm GIB Noiseline® paper-faced plasterboard surface of 12.4 kg/m² density each side of the wall.

The frames had one layer of 90 mm fibreglass Pink Batts.

In addition to tests using the basic floor with no floor covering, sound transmission was measured with 1 m square patches on the following floor coverings in the sound source room:

(1) 9 mm ceramic tiles glued to 6 mm fibre-cement board.

(2) 9 mm ceramic tiles glued to 4.5 mm Regupol 4515 tile underlay (supplied by Jacobsen, Wellington).

(3) 9 mm ceramic tiles glued to Mapefonic tile underlay. These were bitumen-filled tiles with fibreglass mesh reinforcing and a sound-absorbing cushion back. They were of 500 x 500 mm size, 11.5 mm thickness and 11.7 kg/m^3 density.

(4) Strip timber flooring over 3 mm Softlon foam underlay all glued together.

(5) 5 mm thick cushion-backed vinyl.

Note the floor coverings were moved to the various, fixed tapping machine positions on the floor.

Carpet was not tested for the reasons discussed in Section 4.2.7.

5.2 Details of the Tested Floor Systems

5.2.1 Basic Reference Floor

To gain reference values the continuous 17 mm plywood sheet floor without any floor topping was tested (see Figure 15).

5.2.2 Two Layers of 20 mm Particleboard Raft Floating on Maxxon Acousti-Mat 3

The floor was constructed using the basic floor plus a sound suppressing mat with two layers of 20 mm particleboard floating on top as shown in Figure 16. The two layers were screwed together. This is a conventional floating floor system using a proprietary product as the sound suppressing material (see Figure 17).

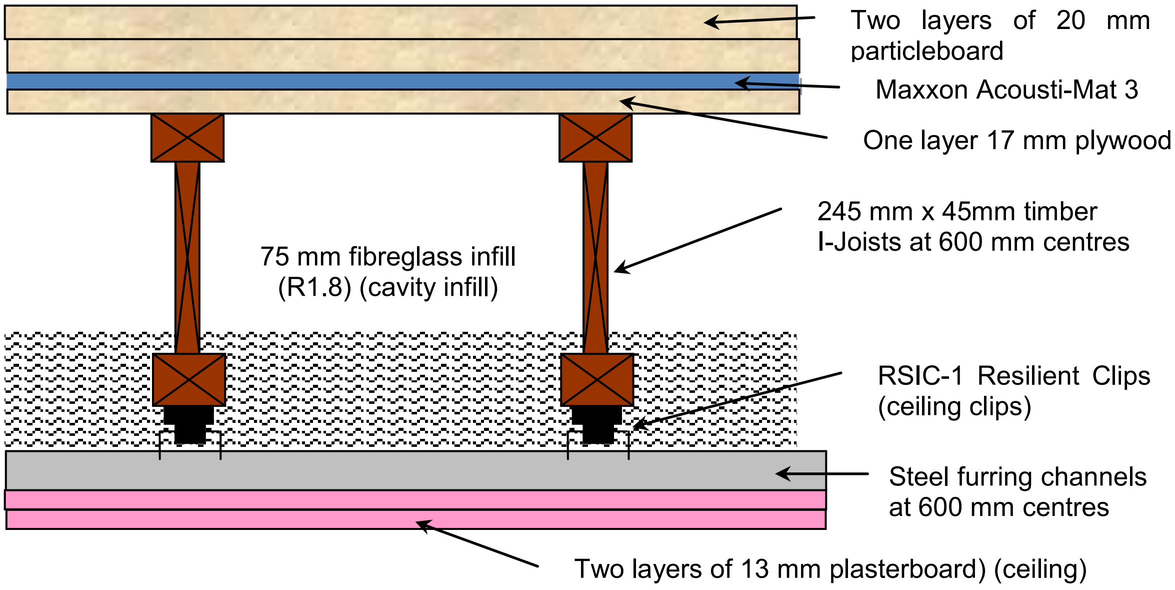

Figure 16. Two layers of 20 mm particleboard raft floating on Maxxon Acousti-Mat 3

Figure 17. Maxxon Acousti-Mat 3

5.2.3 20 mm Particleboard Screwed to Plywood Floor

The floor was the basic construction plus one layer of particleboard screwed to the plywood as shown in Figure 18.

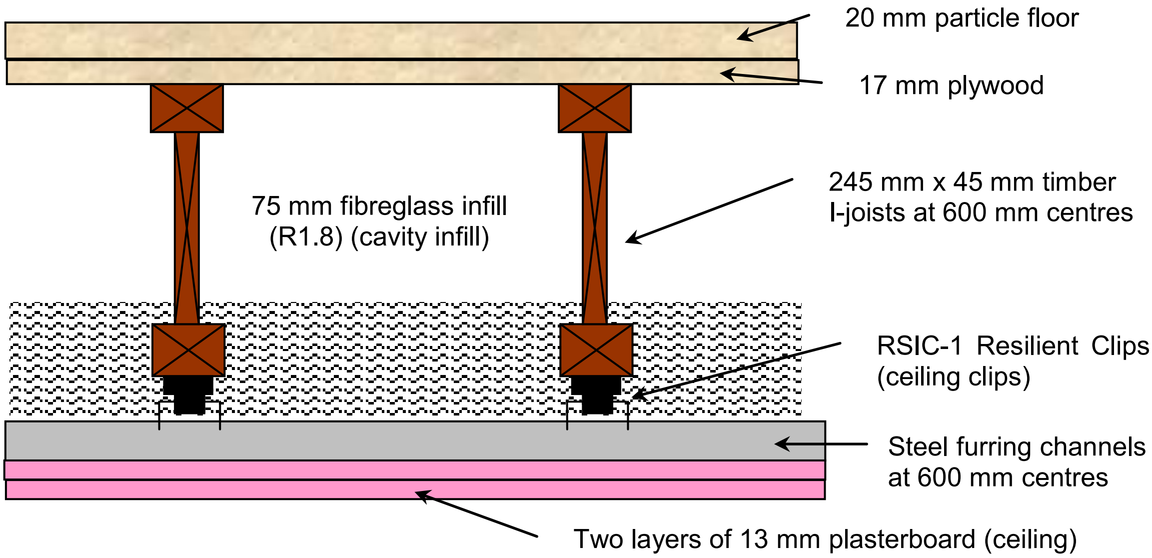

Figure 18. 20 mm particleboard screw-fixed to plywood flooring

5.2.4 20 mm Particleboard Screwed to 45 mm Battens with a Dry Sand/Sawdust Mixture Infill

The floor consisted of the basic construction plus 45 x 45 mm battens at 450 mm centres fixed to the plywood top surface of the basic floor and running at right angles to the joists. The 40 mm thick paving sand/sawdust infill (shown in Figure 19 and Figure 20) was then placed in the cavities between the battens and the top layer of 20 mm particleboard was screwed to the battens.

The extra weight of the sand/sawdust fill is not ideal from a structural point of view when the building is located in an earthquake-prone area as it attracts greater earthquake loads. However, research has shown that it significantly improves the low frequency acoustic insulation.

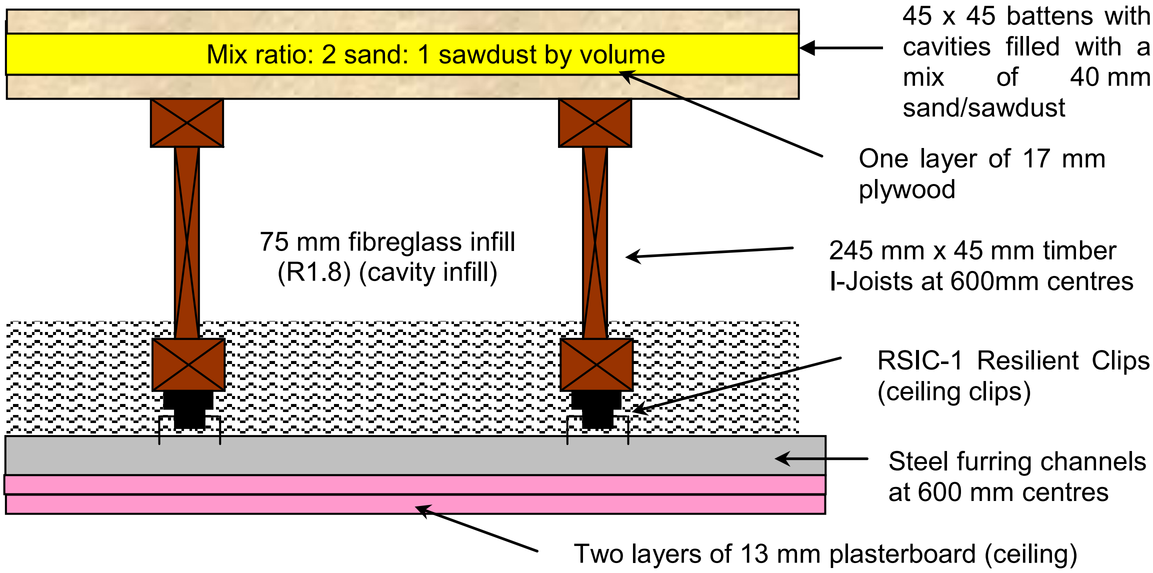

Figure 19. Sand/sawdust mix-filled cavity formed by battens

Figure 20. 45 x 45 mm thick batten frame with sand/sawdust mix infill

5.2.5 38 mm Maxxon Gypsum Concrete Screed Floating on Maxxon Acousti-Mat 3

The floor was the basic construction plus 20 mm Maxxon Acousti-Mat 3 and a 10 mm Crack Suppression Mat with 38 mm gypsum concrete poured on top (see Figure 21 to Figure 23).

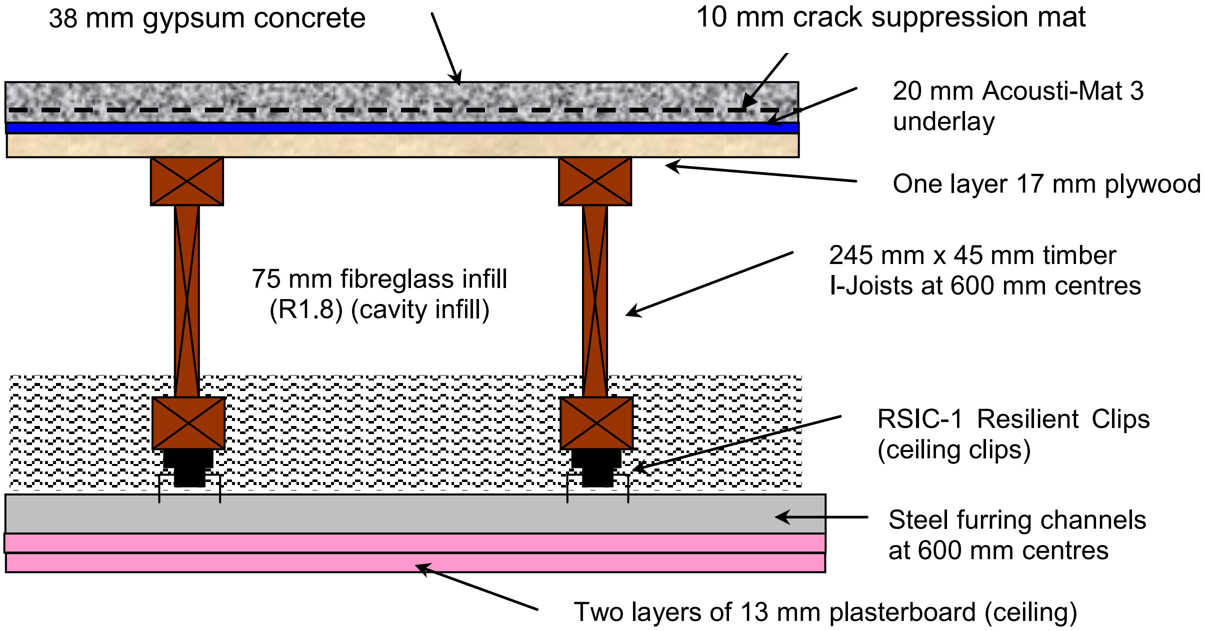

Figure 21. Floating gypsum/concrete mix

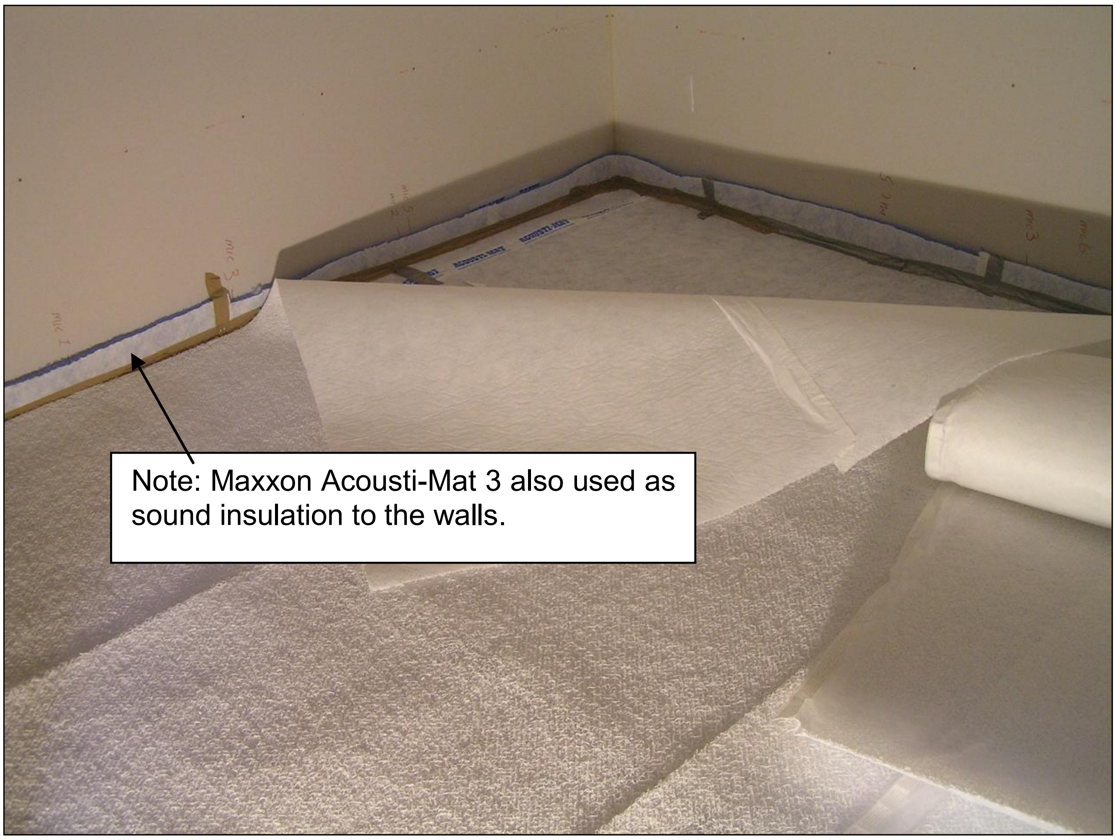

Figure 22. 10 mm Crack Suppression Mat over 20 mm Maxxon Acousti-Mat 3

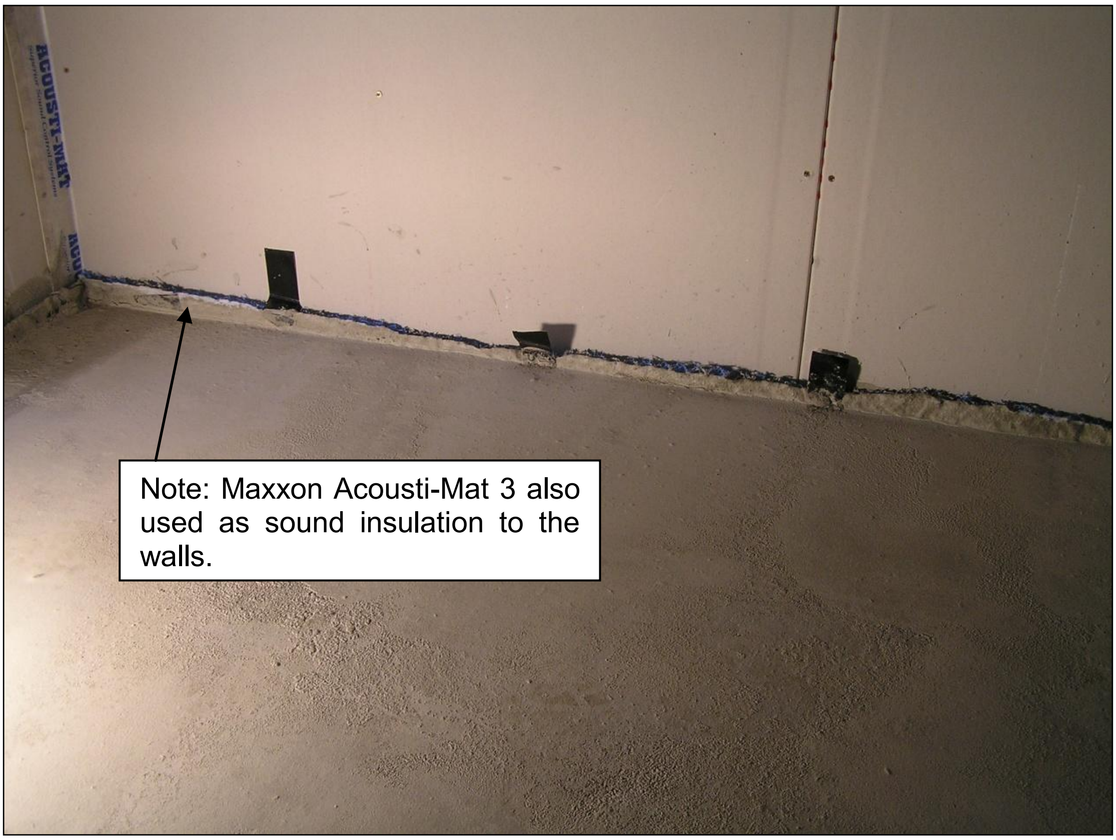

Figure 23. Installed gypsum/concrete mix

5.2.6 Two layers of 20 mm Particleboard Raft Floating on 13 mm CSR Bradford Quietel Fibreglass Board

The floor was the basic construction plus a sound suppressing mat plus two layers of 20 mm particleboard screwed together and floating on top as shown in Figure 24. This is a conventional floating floor system using a fibreglass product as a resilient layer.

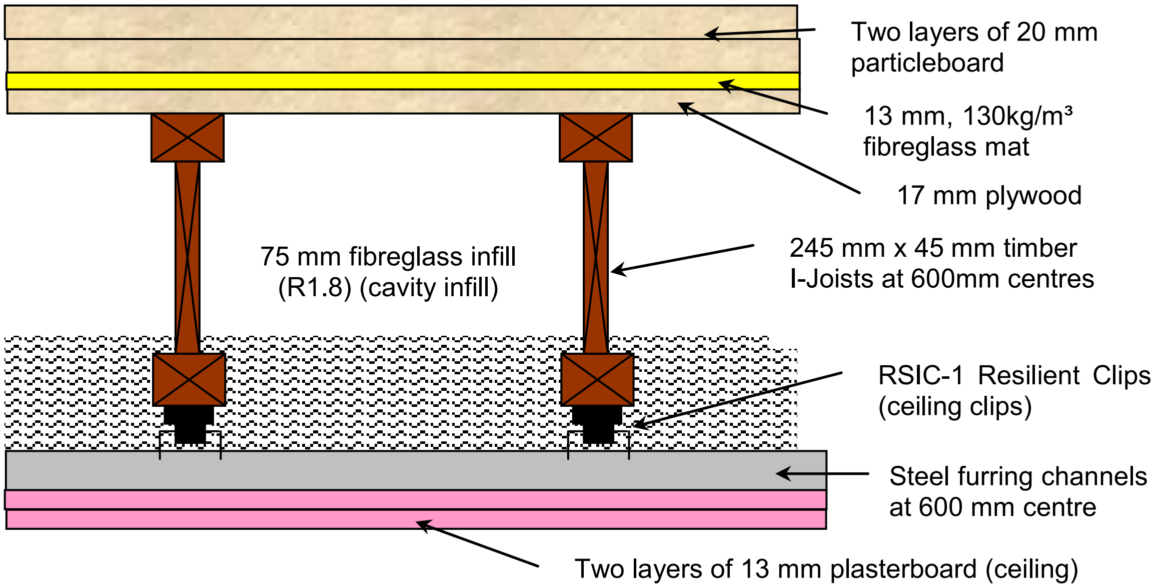

Figure 24. Two layers of 20 mm particleboard raft floating on a 13 mm high density fibreglass mat

Figure 25. 13 mm fibreglass sound-suppressing layer

5.2.7 Two layers of 20 mm Particleboard Raft Floating on 10 mm Pink Batts Quietzone Foam Underlay

The floor was the basic construction plus a 10 mm Quietzone sound-suppressing mat with two layers of 20 mm particleboard screwed together and floating on top as shown in Figure 26. This is a conventional floating floor system using 10 mm foam underlay as sound suppressing material (see Figure 27).

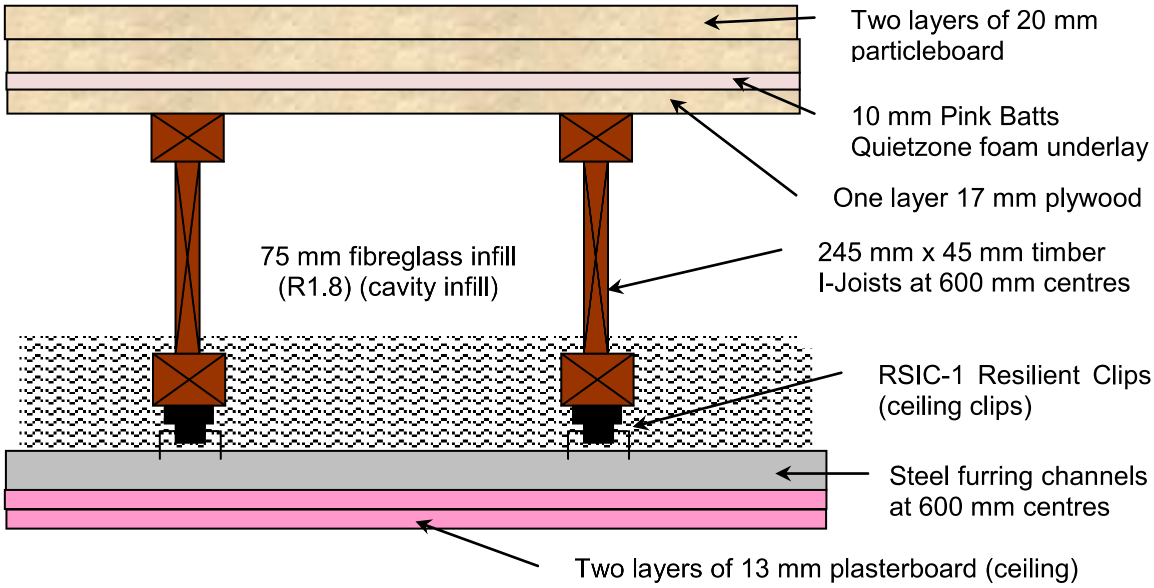

Figure 26. Two layers of 20 mm particleboard raft floating on 10 mm Pink Batts Quietzone foam underlay

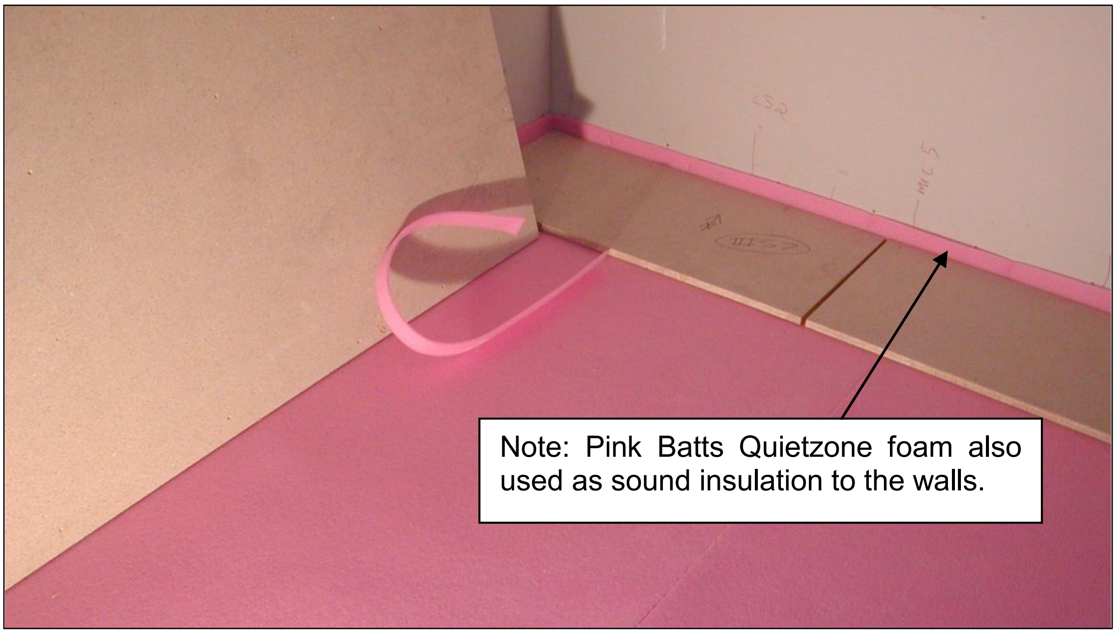

Figure 27. 10 mm Pink Batts Quietzone foam underlay

6. TEST RESULTS – SINGLE-FIGURE INSULATION RATINGS FOR ROOMS CONSTRUCTED FROM A RANGE OF FLOORS AND WALLS

ISO 717 Part 1 was followed to generate the ISO single-figure airborne sound ratings $D_{nT,w}$ and spectrum adaptation terms C and C_{tr}. ISO 717 Part 2 was followed to generate the ISO single-figure impact sound ratings $L'_{nT,w}$ and spectrum adaptation term C_i, ASTM E413 was followed to generate the single-figure airborne sound ratings FSTC and ASTM E989 was followed to generate the single-figure impact sound ratings FIIC. Note that ISO 140 Part 4 was followed to generate the transmission loss measurements used to calculate FSTC, which is not significantly different from following ASTM E336 (as required by the current G6 clause).

Table 5 to Table 8, given in Appendix E, provide the single-figure sound insulation ratings for floors and walls for the tested specimens (shown in light green cells) and they also include values for untested specimens based on the calculations using the method described in Section 4.2 (shown in light blue).

6.1 Vertical Airborne Insulation Results for Seven Floor Constructions and for Various Flanking Wall Combinations

Table 5, given in Appendix E, lists the vertical airborne insulation single-figure ratings for all of the tested floor systems including the basic floor. Each cell contains four numbers, three in the first row and the fourth in the second. In order these are $D_{nT,w}$, C, C_{tr} and STC. Thus, the top left cell for no flanking with the basic floor is $D_{nT,w}$ = 55, C = -3, C_{tr} = -8 and FSTC = 57. Note that the STC definition used above is referred to as the "apparent STC" (ASTC) according to current ASTM standards. The STC used herein is the G6 definition which is based on the 1990 ASTM standards.

The changes proposed in 2010 to Clause G6 use a parameter called R_W which is the ISO equivalent of STC and is typically within one or two dB of STC values. The pass/fail criteria for R_W in the 2010 proposal are the same values as for STC in the current Code. Hence the discussion regarding STC results below can be taken to approximately apply to R_W.

Rooms usually have up to four flanking walls. As expected, Table 5 shows that increasing the number of flanking walls reduces the vertical airborne insulation ratings and higher ratings occurred where walls used 13 mm rather than 10 mm thick sheets. Similar ratings were obtained for both GIB Fyreline® and GIB Noiseline® plasterboard linings.

6.1.1 Clause G6 of the New Zealand Building Code

The FSTC of all tested floors, including the basic floor, meets the current Code requirement for airborne insulation of FSTC ≥ 50.

6.1.2 Proposed Changes to Clause G6 in the Building Code Requirements for Protection from Noise, Circulated in 2010

Table 1 compares the ratings with the requirements of the 2010 proposed revision to Clause G6. Cells that comply ($D_{nT,w} \geq 53$) are shaded green and it can be seen that this encompasses all systems apart from most of the basic floor systems.

Table 1. Summary of compliance for vertical airborne insulation ($D_{nT,w}$) for the 2010 proposed Code revision

		Flanking walls									
	Topping on basic subfloor	No flanking	One 10 mm Fyreline wall	Two 10 mm Fyreline walls	Four 10 mm Fyreline walls	One 13 mm Fyreline wall	Two 13 mm Fyreline walls	Four 13 mm Fyreline walls	One 13 mm Noiseline wall	Two 13 mm Noiseline walls	Four 13 mm Noiseline walls
1	No topping (basic subfloor)	55	53	52	50	53	52	50	52	51	50
2	2 x 20 mm particleboard raft floating on Maxxon AcoustiMat 3	63	59	58	56	62	61	59	61	60	59
3	20 mm particleboard screwed to plywood	60	57	55	53	58	56	54	58	56	55
4	20 mm particleboard screwed to 45 mm battens. The cavity filled with dry sand/sawdust mixture	66	62	60	58	62	61	59	64	62	60
5	38 mm Maxxon gypsum concrete screed floating on Maxxon AcoustiMat 3	67	63	61	59	65	64	62	66	64	62
6	2 x 20 mm particleboard raft floating on 13 mm CSR Bradford Quietel fibreglass board	64	61	60	57	63	62	61	63	62	61
7	2 x 20 mm particleboard raft floating on 10 mm Pink Batts Quietzone foam underlay	62	59	57	55	61	60	58	60	60	59

6.2 Horizontal Airborne Sound Insulation Results for Seven Floor Constructions and Three Wall Types for Continuous Floor at Top as Well as Bottom

Table 6, given in Appendix E, lists the horizontal airborne insulation single-figure ratings for all the tested wall systems. The constructions considered were the same as for Table 5.

Each cell contains four numbers, in a similar manner to that described in Section 6.1 and the description is not repeated here.

6.2.1 Clause G6 of the New Zealand Building Code

The FSTC ratings for all constructions apart from the basic floor meet the current Code requirement for airborne insulation of FSTC ≥ 50. All of the six enhancements to the basic floor resulted in similar FSTC ratings within each wall lining/floor type. That is within each column of Table 6, given in Appendix E, the maximum variation within any column is three. Having the continuous floor at the top and bottom, rather than bottom only, had little effect (maximum of three units' reduction in FSTC rating). Use of GIB Noiseline® in place of GIB Fyreline® increased the FSTC rating by 0-4 units. Increasing the Fyreline thickness from 10 to 13 mm changed the rating by -2 to +2. Apart from the basic floor, the FSTC ratings varied from 53 to 58 except for one result which was 60.

6.2.2 Proposed Changes to Clause G6 in the Building Code Requirements for Protection from Noise, Circulated in 2010

Table 2 compares the ratings with the requirements of the proposed 2010 revised Clause G6. Cells that comply ($D_{nT,w} \geq 53$) are shaded green and those less than 53 are shaded red. This encompasses all the basic floor combinations and also the 10 mm GIB Fyreline® wall with the continuous floor at the top and bottom. All constructions which enhanced the basic floor passed.

Table 2. Summary of compliance for horizontal airborne sound insulation ($D_{nT,w}$) for the 2010 proposed Code revision

	Topping on basic subfloor	10 mm Fyreline wall - diaphragm at bottom	10 mm Fyreline wall - diaphragm at top and bottom	13 mm Fyreline walls - diaphragm at bottom	13 mm Fyreline walls - diaphragm at top and bottom	13 mmNoiseline walls - diaphragm at bottom	13 mm Noiseline walls - diaphragm at top and bottom
1	No topping (basic subfloor)	48	47	46	46	46	46
2	2 x 20 mm particleboard raft floating on Maxxon AcoustiMat 3	55	53	57	54	59	56
3	20 mm particleboard screwed to plywood	54	52	54	53	56	54
4	20 mm particleboard screwed to 45 mm battens. The cavity filled with dry sand/sawdust mixture	55	53	59	55	61	57
5	38 mm Maxxon gypsum concrete screed floating on Maxxon AcoustiMat 3	55	53	59	55	61	57
6	2 x 20 mm particleboard raft floating on 13 mm CSR Bradford Quietel fibreglass board	55	53	59	55	61	57
7	2 x 20 mm particleboard raft floating on 10 mm Pink Batts Quietzone foam underlay	55	53	58	55	60	57

6.3 Vertical Impact Insulation Ratings for Six Floor Coverings on Each of Seven Floor Constructions for Various Flanking Wall Combinations

Table 7, given in Appendix E, lists the vertical impact insulation single-figure ratings for six floor coverings including the bare floor combined with all tested floor constructions. Each cell contains four numbers, three in the first row and the fourth in the second. In order these are $L'_{nT,w}$, C_i, $C_{i50\text{-}2500}$ and apparent IIC. Thus, the top left cell for no flanking with the bare floor is $L'_{nT,w} = 62$, $C_i = -1$, $C_{i50\text{-}2500} = 6$ and FIIC = 50. As $C_{i50\text{-}2500}$ is not a parameter in the requirements of the current or proposed Clause G6 of the New Zealand Building Code it is not discussed further here.

6.3.1 Clause G6 of the New Zealand Building Code

The Code requires that the floor has a Field Impact Insulation Class (FIIC) ≥ 50. The basic floor with no covering (i.e. a bare floor) generally fails the criterion. Many of the floor coverings on the basic floor also fail the criterion. However, all six enhanced floors passed the criterion irrespective of whether there was any floor covering. One exception occurred when no floor covering was used and the basic floor was only enhanced with a single layer of particleboard.

Floors usually have up to four flanking walls. Table 7 shows that these reduce the vertical impact insulation values. Similar results were obtained for GIB Fyreline® and

GIB Noiseline® plasterboard ceiling linings. Slightly better (i.e. lower) impact insulation values occurred where walls used 13 mm rather than 10 mm thick sheets.

6.3.2 Proposed Changes to Clause G6 in the Building Code Requirements for Protection from Noise, Circulated in 2010

Table 3 summarises the ratings and compares these with the requirement of the proposed 2010 revision of Clause G6. Cells that fail ($L'_{nT,w} > 57$) are shaded red. Those less than ≤ 57 are shaded green. It can be seen that the basic floor fails the criterion for most floor coverings, the particleboard screwed to the basic floor fails for many floor coverings and the particleboard raft construction sometimes failed the criterion for bare floor and to a lesser extent for a covering of cushion-backed vinyl.

6.4 Horizontal Impact Insulation Results for Six Floor Coverings on Each of Seven Floor Constructions for Three Wall Types

Table 8 lists the vertical impact insulation single-figure ratings for six floor coverings including the bare floor combined with all tested floor constructions. Note this table was for a continuous floor at the bottom only.

Each cell contains four numbers, in a similar manner to that described in Section 6.3 and the description is not repeated here.

6.4.1 Clause G6 of the New Zealand Building Code

The current Code requires that the floor has an FIIC ≥ 50. The basic floor fails the criterion in all instances but all enhanced floor constructions pass.

6.4.2 Proposed Changes to Clause G6 in the Building Code Requirements for Protection from Noise Published in 2010

Table 4 summarises the ratings for comparison with the 2010 proposed revision of Clause G6. Cells that fail ($L'_{nT,w} > 57$) are shaded red. Those ≤ 57 are shaded green. It can be seen that the basic floor fails the criterion in all instances except when Mapefonic tiles are used. Failure also occurred in two instances where the particleboard was screwed to the bare floor.

Table 3. Summary of compliance for vertical impact insulation ($L'_{nT,w}$) for the 2010 proposed Code revision

	Topping on basic subfloor	Floor covering	Flanking walls									
			No flanking	One 10 mm Fyreline wall	Two 10 mm Fyreline walls	Four 10 mm Fyreline walls	One 13 mm Fyreline wall	Two 13 mm Fyreline walls	Four 13 mm Fyreline walls	One 13 mm Noiseline wall	Two 13 mm Noiseline walls	Four 13 mm Noiseline walls
1	No topping (basic subfloor)	Bare floor	62	66	68	70	65	67	69	65	67	69
		Ceramic tiles on 6 mm Fibre-cement boad	58	63	65	68	62	64	66	62	64	67
		Ceramic tiles on Regupol	56	59	61	64	58	60	62	59	60	63
		Ceramic tiles on Mapefonic	52	56	58	61	55	57	59	56	57	59
		Strip timber on Softlon tuf	57	60	62	65	60	61	64	60	61	63
		Cushion backed Vinyl	61	64	66	69	64	65	67	63	65	67
2	2 x 20mm particleboard raft floating on Maxxon AcoustiMat 3	Bare floor	50	52	54	56	53	54	56	52	54	56
		Ceramic tiles on 6 mm Fibre-cement boad	45	48	50	52	48	50	52	48	50	52
		Ceramic tiles on Regupol	44	46	48	50	47	48	50	46	48	50
		Ceramic tiles on Mapefonic	43	45	46	48	45	47	49	45	46	48
		Strip timber on Softlon tuf	49	51	53	55	51	53	55	51	53	54
		Cushion backed Vinyl	49	51	53	55	51	53	55	51	52	54
3	20 mm particleboard screwed to plywood	Bare floor	56	59	61	63	60	62	64	59	61	63
		Ceramic tiles on 6 mm Fibre-cement boad	52	55	57	60	56	58	60	56	58	60
		Ceramic tiles on Regupol	50	53	55	57	54	56	58	53	55	57
		Ceramic tiles on Mapefonic	48	51	53	55	52	54	56	50	52	54
		Strip timber on Softlon tuf	54	57	59	61	58	60	62	56	58	60
		Cushion backed Vinyl	54	58	59	62	58	60	63	57	59	61
4	20 mm particleboard screwed to 45 mm battens. The cavity filled with dry sand/sawdust	Bare floor	48	51	52	54	50	52	54	51	53	55
		Ceramic tiles on 6 mm Fibre-cement boad	43	46	48	50	46	48	50	46	48	51
		Ceramic tiles on Regupol	41	44	45	47	43	45	47	44	46	48
		Ceramic tiles on Mapefonic	39	41	43	45	41	42	44	42	43	45
		Strip timber on Softlon tuf	45	47	48	50	46	48	50	47	49	51
		Cushion backed Vinyl	47	49	50	52	48	50	52	49	51	53
5	38 mm Maxxon Gypsum concrete screed floating on Maxxon AcoustiMat 3.	Bare floor	47	51	53	55	51	52	55	50	52	54
		Ceramic tiles on 6 mm Fibre-cement boad	43	46	48	50	46	48	50	45	47	49
		Ceramic tiles on Regupol	44	47	48	51	46	48	50	46	47	49
		Ceramic tiles on Mapefonic	43	46	48	50	46	47	49	45	46	48
		Strip timber on Softlon tuf	45	48	50	52	47	49	51	47	48	50
		Cushion backed Vinyl	46	49	51	53	49	50	53	48	50	52
6	2 x 20 mm particleboard raft floating on 13 mm CSR Bradford Quietel fibreglass board	Bare floor	51	54	56	58	54	56	58	53	55	57
		Ceramic tiles on 6 mm Fibre-cement boad	45	48	50	52	48	50	52	47	49	51
		Ceramic tiles on Regupol	46	48	50	52	48	49	51	48	49	51
		Ceramic tiles on Mapefonic	44	47	49	51	47	48	50	46	48	50
		Strip timber on Softlon tuf	47	50	52	54	50	51	53	50	51	53
		Cushion backed Vinyl	50	53	55	57	53	54	56	52	54	56
7	2 x 20 mm particleboard raft floating on 10 mm Pink Batts Quietzone foam underlay	Bare floor	51	54	56	58	54	56	58	54	56	58
		Ceramic tiles on 6 mm Fibre-cement boad	46	50	51	54	49	51	53	49	51	54
		Ceramic tiles on Regupol	45	49	50	53	48	50	52	49	50	53
		Ceramic tiles on Mapefonic	43	46	48	50	46	47	50	46	48	50
		Strip timber on Softlon tuf	49	52	54	56	52	54	56	52	54	56
		Cushion backed Vinyl	50	54	55	58	53	55	57	54	55	58

Table 4. Summary of compliance for horizontal impact insulation systems

			Walls		
	Topping on basic subfloor	Floor covering	10 mm Fyreline wall	13 mm Fyreline wall	13 mm Noiseline wall
1	No topping (basic subfloor)	Bare floor	67	67	67
		Ceramic tiles on 6 mm Fibre-cement boad	68	68	68
		Ceramic tiles on Regupol	61	61	61
		Ceramic tiles on Mapefonic	57	57	57
		Strip timber on Softlon tuf	60	59	59
		Cushion backed Vinyl	62	62	62
2	2 x 20mm particleboard raft floating on Maxxon AcoustiMat 3	Bare floor	43	46	44
		Ceramic tiles on 6 mm Fibre-cement boad	39	43	41
		Ceramic tiles on Regupol	38	41	39
		Ceramic tiles on Mapefonic	35	38	37
		Strip timber on Softlon tuf	41	45	43
		Cushion backed Vinyl	41	45	43
3	20 mm particleboard screwed to plywood	Bare floor	59	55	55
		Ceramic tiles on 6 mm Fibre-cement boad	59	54	54
		Ceramic tiles on Regupol	54	50	50
		Ceramic tiles on Mapefonic	49	46	46
		Strip timber on Softlon tuf	54	51	51
		Cushion backed Vinyl	54	52	51
4	20 mm particleboard screwed to 45 mm battens. The cavity filled with dry sand/sawdust mixture	Bare floor	44	43	42
		Ceramic tiles on 6 mm Fibre-cement boad	41	40	39
		Ceramic tiles on Regupol	37	38	38
		Ceramic tiles on Mapefonic	34	33	33
		Strip timber on Softlon tuf	39	39	38
		Cushion backed Vinyl	41	40	40
5	38 mm Maxxon Gypsum concrete screed floating on Maxxon AcoustiMat 3.	Bare floor	44	43	47
		Ceramic tiles on 6 mm Fibre-cement boad	37	37	39
		Ceramic tiles on Regupol	36	37	38
		Ceramic tiles on Mapefonic	34	36	36
		Strip timber on Softlon tuf	37	38	39
		Cushion backed Vinyl	39	40	40
6	2 x 20 mm particleboard raft floating on 13 mm CSR Bradford Quietel fibreglass board	Bare floor	44	45	43
		Ceramic tiles on 6 mm Fibre-cement boad	38	39	38
		Ceramic tiles on Regupol	38	39	37
		Ceramic tiles on Mapefonic	36	38	36
		Strip timber on Softlon tuf	40	41	39
		Cushion backed Vinyl	43	44	42
7	2 x 20 mm particleboard raft floating on 10 mm Pink Batts Quietzone foam underlay	Bare floor	46	46	44
		Ceramic tiles on 6 mm Fibre-cement boad	43	42	41
		Ceramic tiles on Regupol	40	40	39
		Ceramic tiles on Mapefonic	37	38	36
		Strip timber on Softlon tuf	43	44	42
		Cushion backed Vinyl	45	45	43

7. CONCLUSIONS

Computer analysis of typical timber-framed buildings under wind and earthquake loading identified that continuous floor diaphragms were generally required to maintain structural integrity in multi-rise apartment buildings. Acoustic tests were then performed on constructions using such diaphragms to determine a range of floor and wall combinations which achieved satisfactory acoustic performance. For this purpose a special two-storey test facility with two chambers on each floor was built at BRANZ to enable full-room boundaries' sound transmission to be assessed, making this the only facility capable of testing flanking sound in Australasia.

Fire testing was undertaken on acoustic systems which behaved successfully to demonstrate that satisfactory fire performance could also be achieved (see Appendix C). It was concluded that the fire resistance of the basic floor ceiling system was not prejudiced by the addition of the acoustic features up to a fire resistance period of at least 60 minutes.

The airborne and impact sound transmission via various sound paths was measured. These results showed the effectiveness of the measurement methods used and how the individual path results can be utilised to generate other flanking cases.

This project has derived, and verified by testing, a selection of construction details for walls, floors and their joints in multi-storey timber-framed buildings that can be used to satisfy the current Code requirements for suppression of sound transmission, suppression of fire spread and provide the required structural integrity.

Construction details have been verified as capable of meeting the requirements of the 2010 proposed amendment to the airborne and impact sound performance criteria in the New Zealand Building Code.

Single-figure sound transmission ratings are provided for a range of floor and wall constructions and floor coverings, with zero, one, two and four flanking walls. Also considered are the effects of a floor diaphragm above as well as below. These results are compared with the current and 2010 proposed New Zealand Building Code Clause G6 criteria. It was found that:

- Nearly all systems, apart from the basic floor, met the proposed 2010 revision for vertical airborne insulation and horizontal airborne insulation.
- Apart from when they were used on the basic floor or on the particleboard screwed to the basic floor, most of the floor coverings tested met the proposed 2010 revision criterion for horizontal and vertical impact insulation. However, if no floor covering was used (i.e. a bare floor) and to a lesser extent if the covering was cushion-backed vinyl, failure of the criterion sometimes occurred.

8. REFERENCES

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- ISO 140-4:1998 Acoustics – Measurement of sound insulation in buildings and of building elements – Part 4: Field measurements of airborne sound insulation between rooms.
- ISO 140-5:1998 Acoustics – Measurement of sound insulation in buildings and of building elements – Part 5: Field measurements of airborne sound insulation of facade elements and facades.
- ISO 140-7:1998 Acoustics – Measurement of sound insulation in buildings and of building elements – Part 7: Field measurements of impact sound insulation of floors.

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- ISO 717-2:1996 Acoustics – Rating of sound insulation in buildings and of building elements – Part 2: Impact sound insulation.

American Society for Testing and Materials (ASTM) Standards

- ASTM E 336: 1990 Method for measurement of airborne sound insulation in buildings.
- ASTM E 413: 1987 Classification for rating sound insulation.
- ASTM E 492: 1990 Test method for laboratory measurement of impact sound transmission through floor-ceiling assemblies using the tapping machine.
- ASTM E 989: 1989 Classification for determination of impact insulation class (IIC).

APPENDIX A SEPARATING FLANKING PATH RESULTS

A.1 Horizontal Airborne Sound Transmission

The labelling used for flanking paths for horizontal airborne transmission in Figure 28 follows the European Standard EN 123554. Note that there is sound transmission through the floor and wall, and all other paths, such as side walls have suppressed flanking). Because the ceiling is attached using resilient channels and clips in the test facility it is assumed that there is no sound transmission through the rooms below.

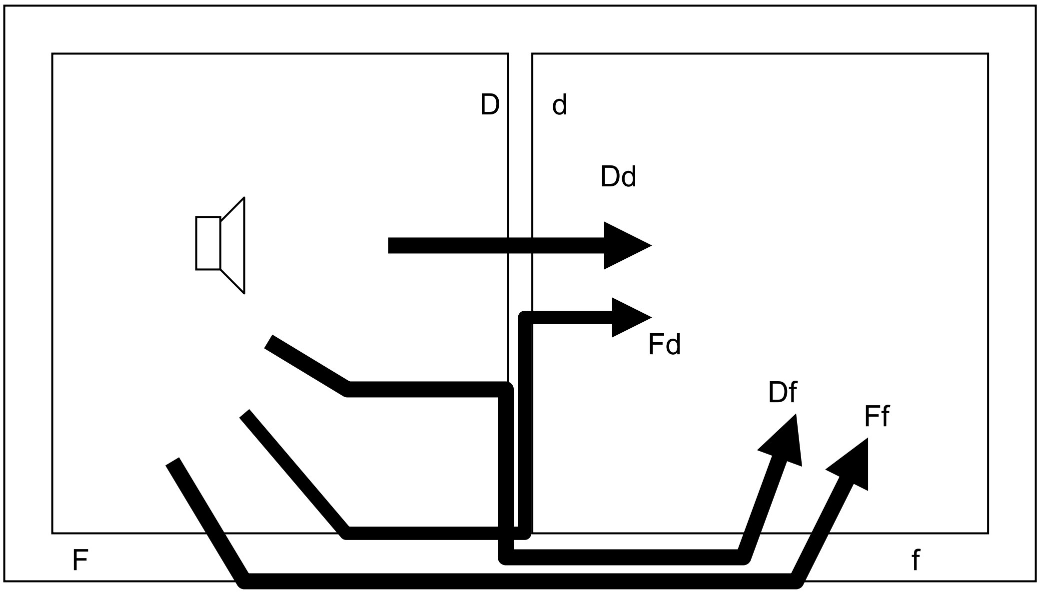


Figure 28. Schematic view of the flanking paths for horizontal airborne transmission

(This figure replicates Figure 13 but was reproduced here to keep all similar figures together in this Appendix.)

It is assumed that sound energy can be added and subtracted. If the change in sound energy in the receiving room is defined by Δ then it can be split into its components as follows:

$$\Delta = \Delta_{Dd} + \Delta_{Ff} + \Delta_{Df} + \Delta_{Fd}$$

Note the change in sound energy, Δ, is related to the measured sound level in dB, D_{nT} by: $\Delta = 10^{-D_{nT}/10}$

where:

Δ_{Dd} is the sound energy transmitted by path Dd.

Δ_{Ff} is the sound energy transmitted by path Ff.

Δ_{Df} is the sound energy transmitted by path Df.

Δ_{Fd} is the sound energy transmitted by path Fd.

By numbering the measurements as follows:

(1) No screening (i.e. sound received = Dd + Df + Fd + Ff).

(2) Source room wall screened (i.e. sound received = Fd + Ff).

(3) Receiving room wall screened (i.e. sound received = Df + Ff).

(4) Source and receiving room wall screened (i.e. sound received = Ff).

It can be shown that the individual sound paths are given by:

- $\Delta_{Dd} = (1) - (2) - (3) + (4)$
- $\Delta_{Fd} = (2) - (4)$
- $\Delta_{Df} = (3) - (4)$
- $\Delta_{Ff} = (4)$

A.2 Vertical Airborne Sound Transmission

The labels for the sound paths are laid out in Figure 29.

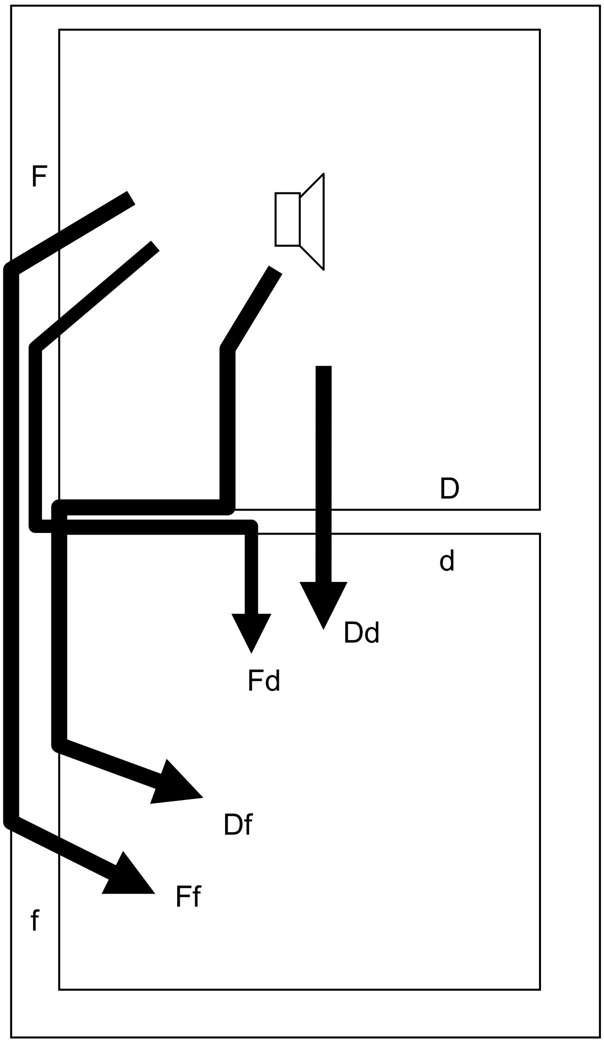


Figure 29. Schematic view of the flanking paths for vertical airborne transmission

By numbering the measurements as follows:

(1) No screening (i.e. sound received = Dd + Df + Fd + Ff).

(2) Source room wall screened (i.e. sound received = Dd + Df).

(3) Receiving room wall screened (i.e. sound received = Dd + Fd).

(4) Source and receiving room wall screened (i.e. sound received = Dd).

It can be shown that the individual sound paths are given by:

- $\Delta_{Dd} = (4)$
- $\Delta_{Fd} = (3) - (4)$
- $\Delta_{Df} = (2) - (4)$
- $\Delta_{Ff} = (1) - (2) - (3) + (4)$

For vertical airborne transmission in the chambers there is a direct path through the floor and one wall flanking path. However, it is assumed that path Fd is suppressed because a resiliently-attached ceiling was used.

A.3 Horizontal Impact Sound Transmission

Figure 30 illustrates the flanking paths for horizontal impact transmission. Impact measurements are simplified because the tapping machine basically only transmits sound through the floor and thus it was not necessary to screen off the wall in the source room.

Note that there are no direct paths in this case with just the two flanking paths f1 for the wall and f2 for the floor.

Without screening the sound transmission recorded is f1 + f2. Screening off the wall in the receiving room provides the flanking sound transmission f2. Thus, the difference between the two readings gives f1 and thus both components can be simply obtained.

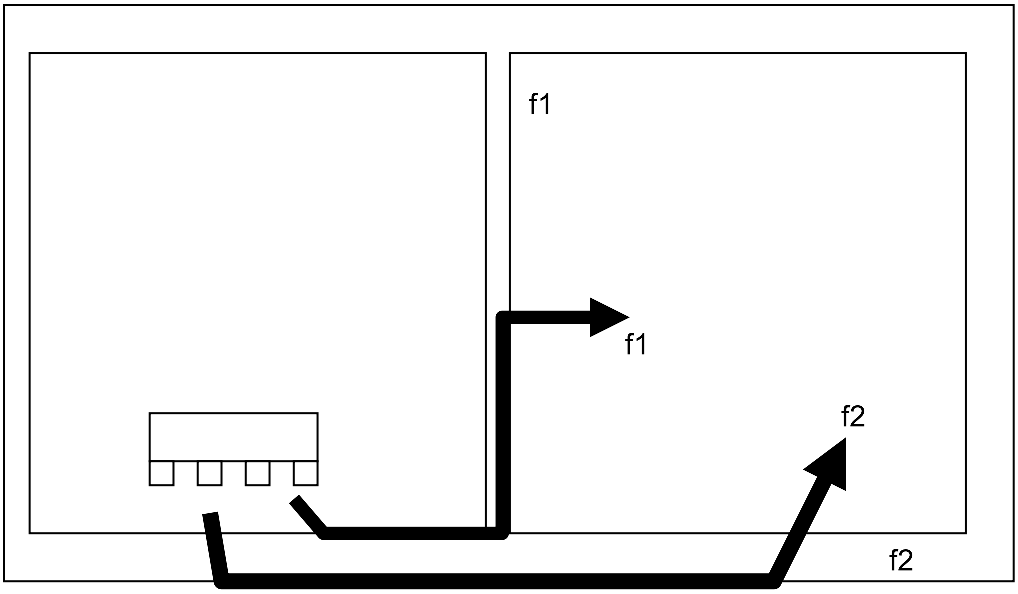


Figure 30. Schematic view of the flanking paths for horizontal impact sound transmission

A.4 Vertical Impact Sound Transmission

Figure 31 illustrates the flanking paths for vertical impact transmission. Impact measurements are simplified because the tapping machine basically only transmits sound through the floor and thus it was not necessary to screen off the wall in the source room.

Without screening the sound transmission recorded is f + d. Screening off the wall in the receiving room provides the direct sound transmission d. Thus, both components can be simply obtained.

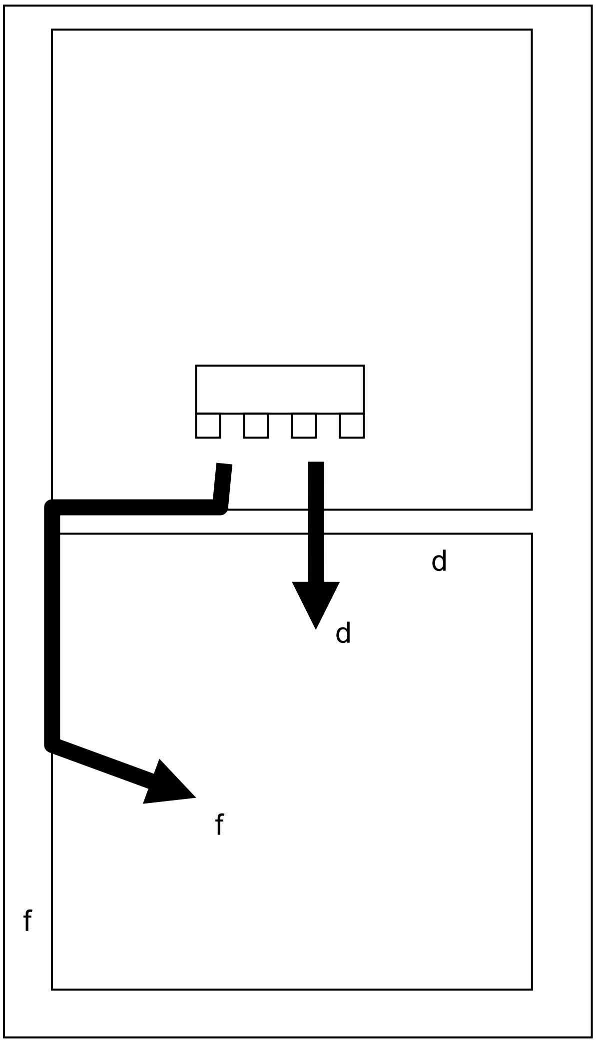


Figure 31. Schematic view of the flanking paths for vertical impact sound transmission

APPENDIX B INDIVIDUAL SOUND PATH TEST RESULTS

This Appendix presents the individual sound path airborne level differences and impact sound levels for various combinations of topping.

Sometimes (for certain one-third octave bands) the calculation of the sound path result is very uncertain, i.e. there is a lot of error. This is particularly true for paths which play a small contribution to the overall levels. Sometimes the results become negative, i.e. instead of energy flowing out of a path in the receiving room, the energy appears to be flowing into the path. While such a situation is physically possible, it is assumed that such a result is erroneous, the energy flow is assumed to be zero and the result is not displayed on a dB scale.

If for a particular path, all one-third octave bands required to calculate a single-figure rating are present then this ISO single-figure rating is displayed in the legend.

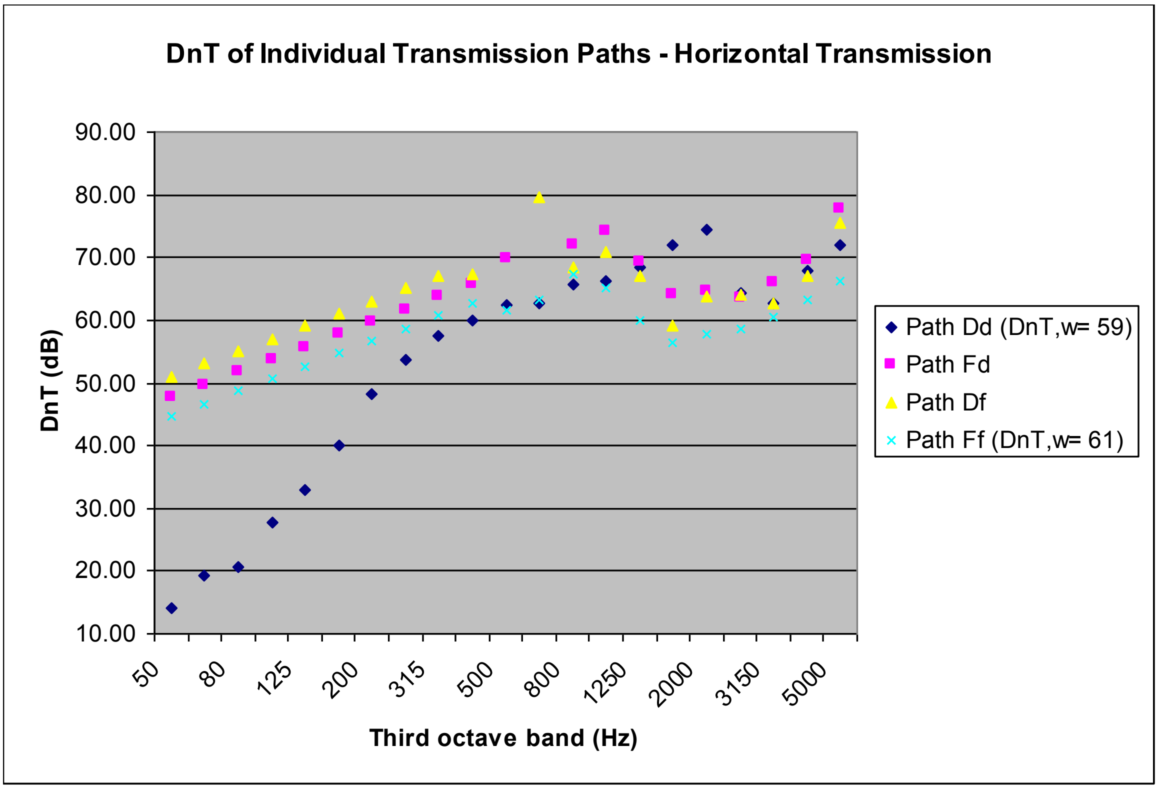


Figure 32(a). Individual airborne sound horizontal transmission for basic floor

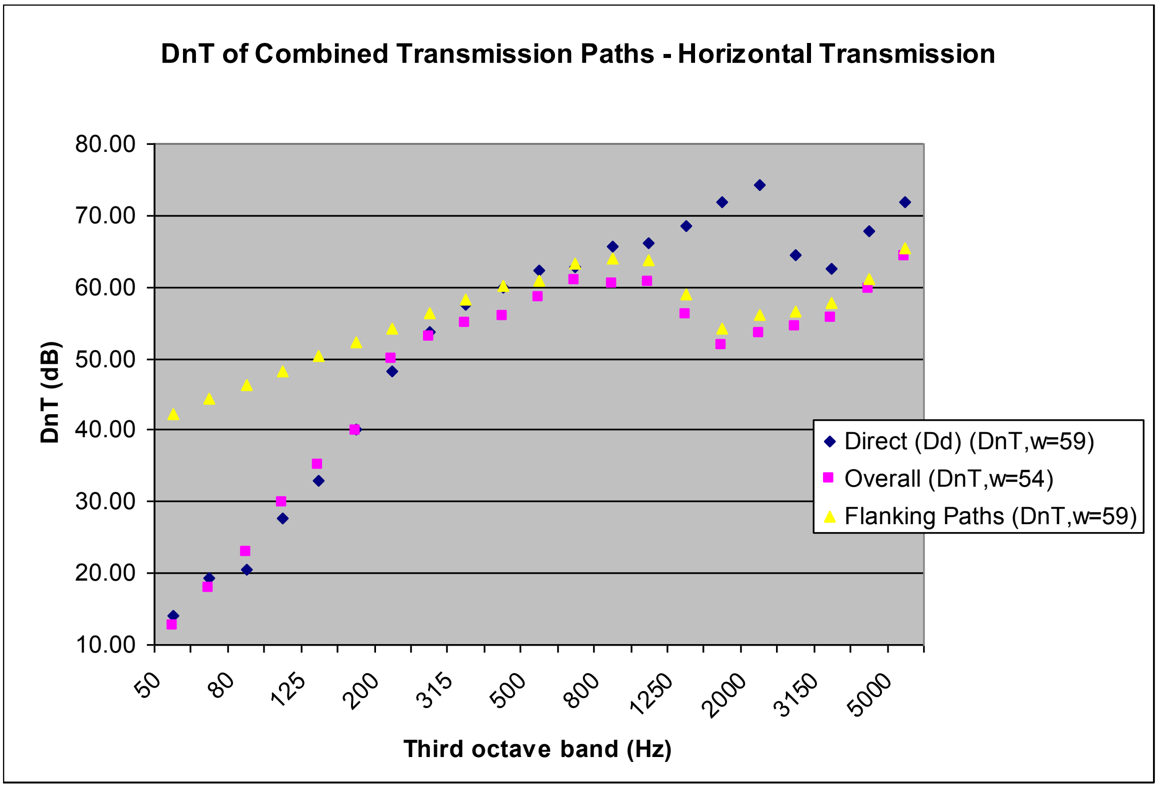


Figure 32(b). Combined airborne sound horizontal transmission for basic floor

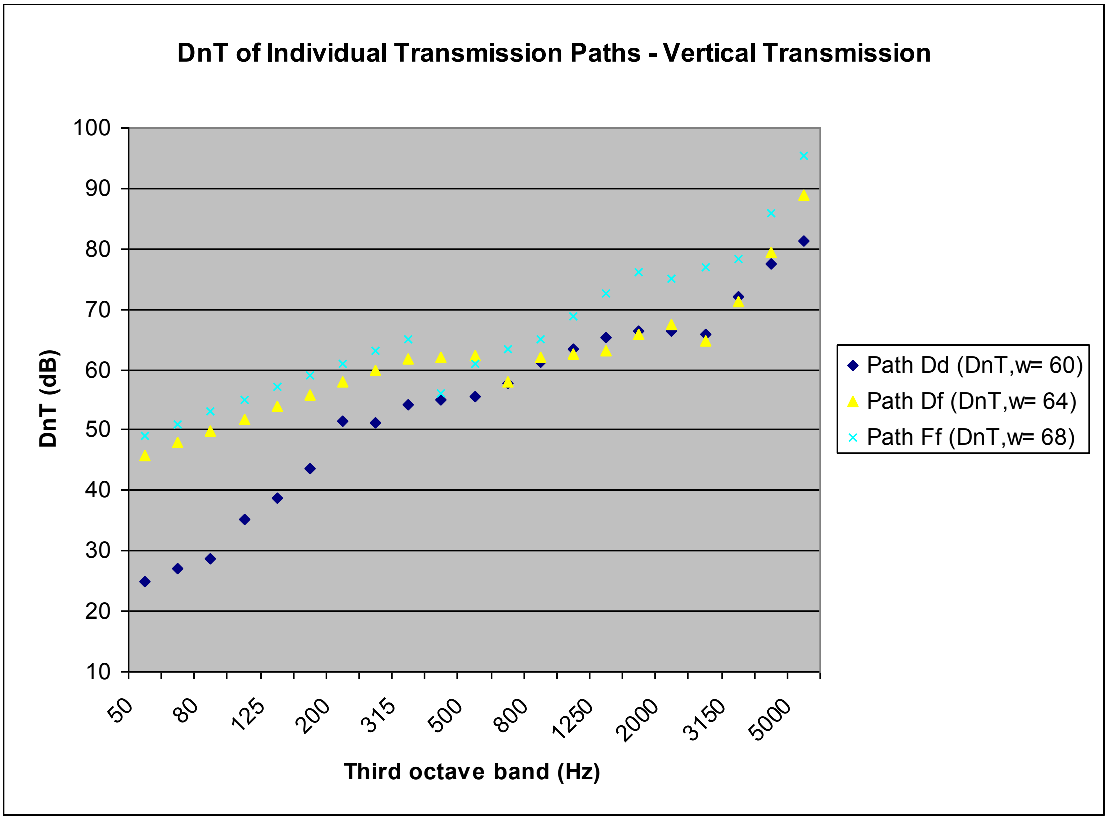


Figure 32(c). Individual airborne sound vertical transmission for basic floor

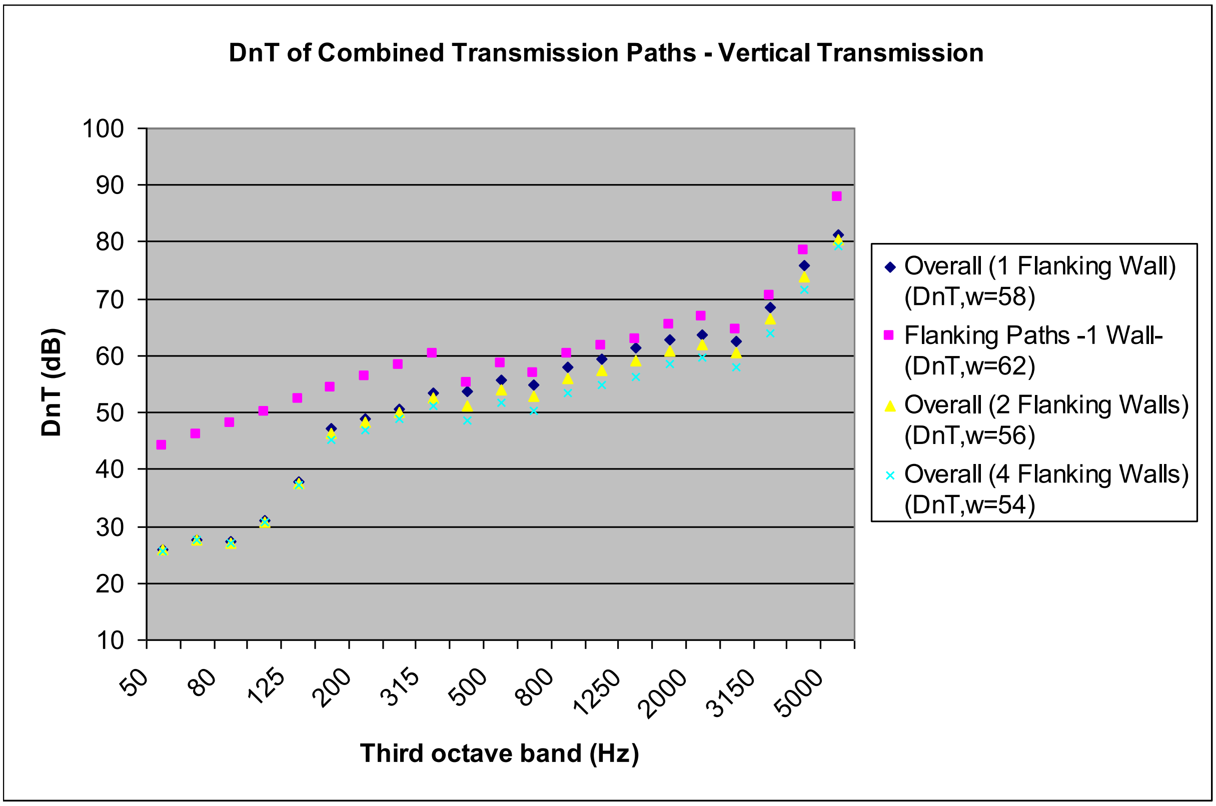


Figure 32(d). Combined airborne sound vertical transmission for basic floor

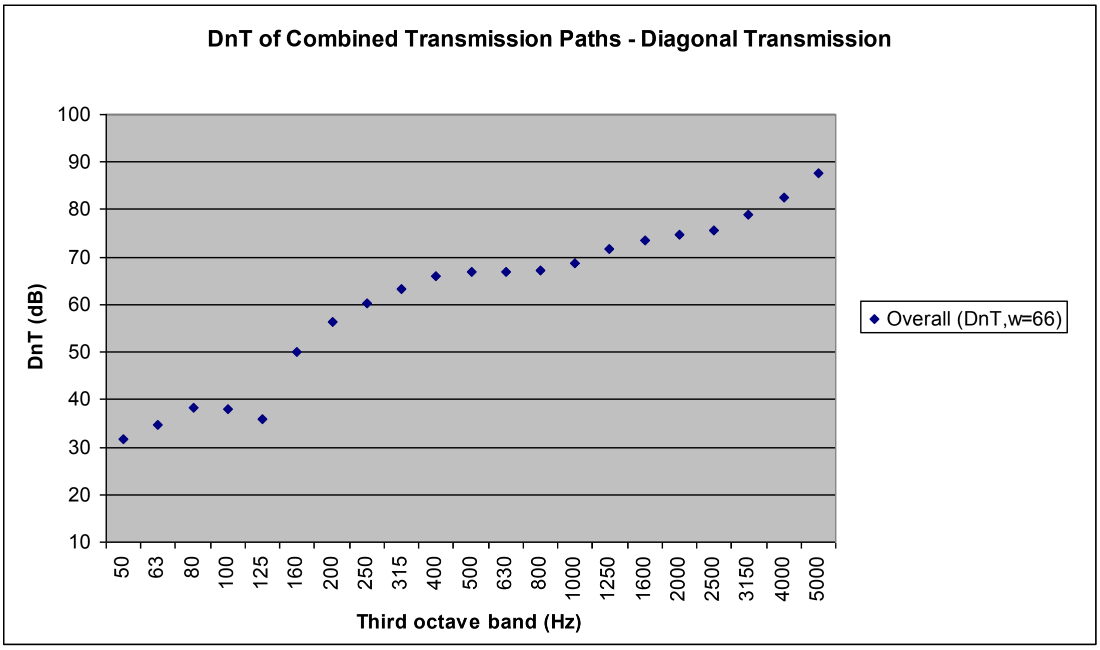


Figure 32(e). Combined airborne sound diagonal transmission for basic floor

Figure 32. Basic floor with no floor covering – airborne sound transmission

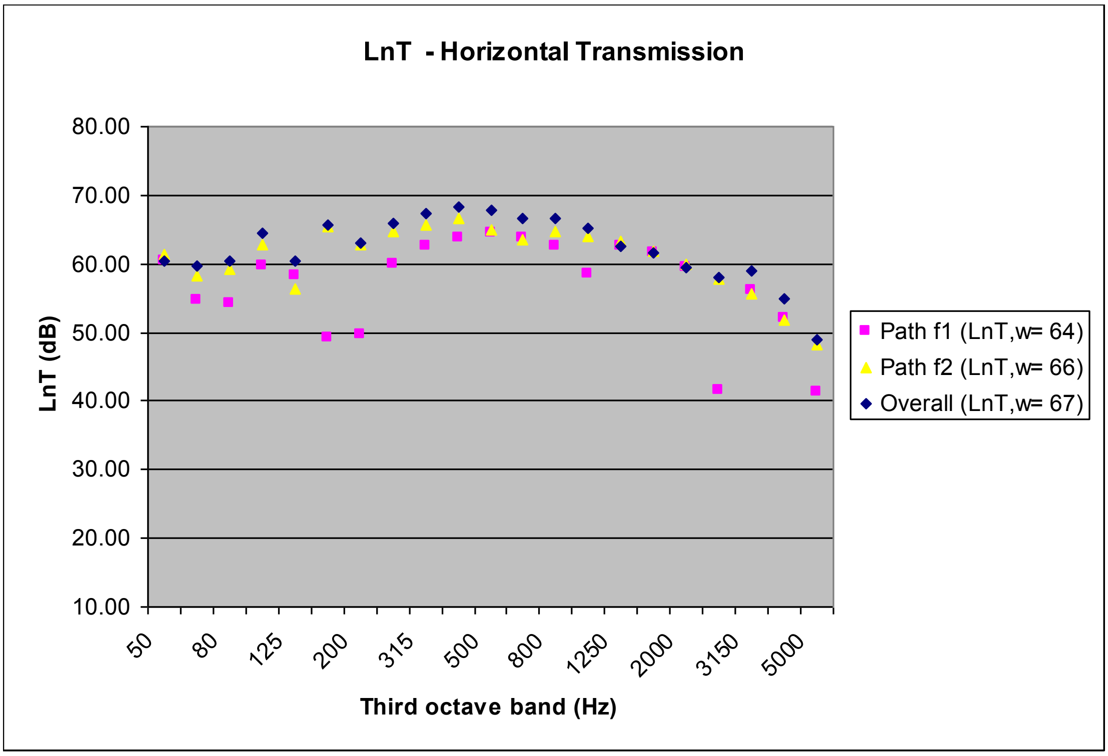


Figure 33(a). Impact sound horizontal transmission for basic bare floor

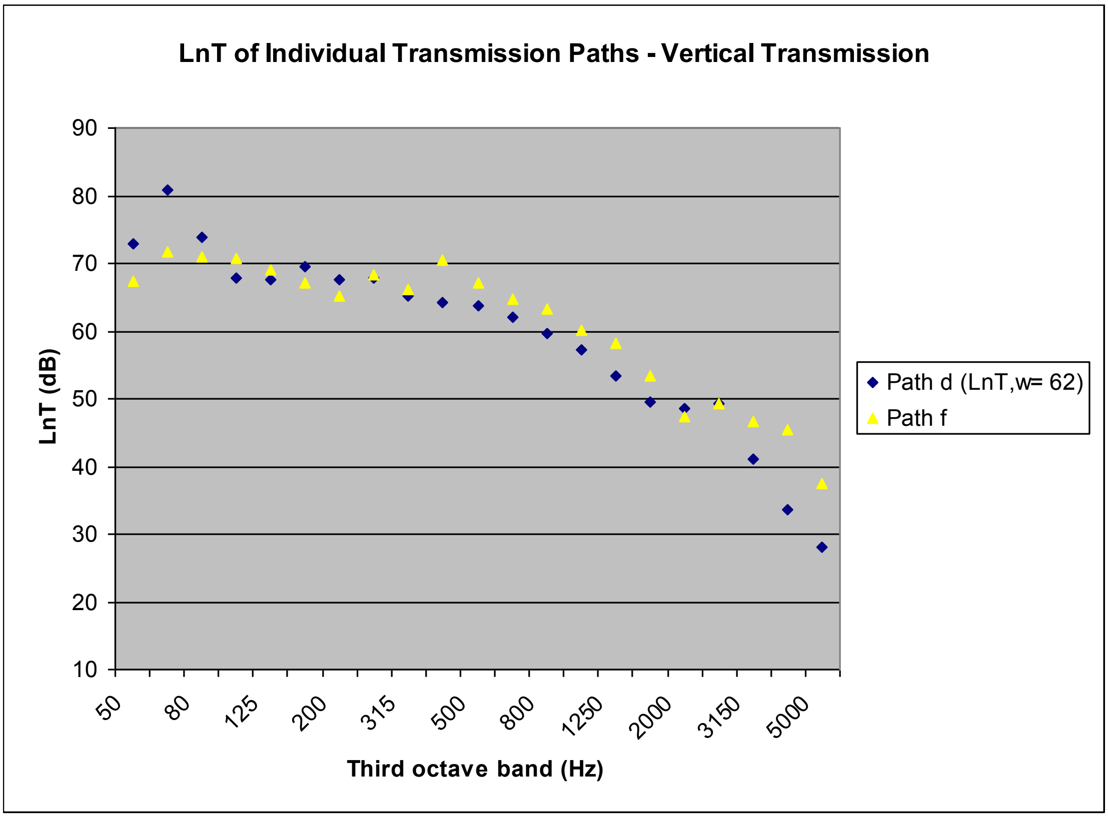


Figure 33(b). Individual impact sound vertical transmission for basic bare floor

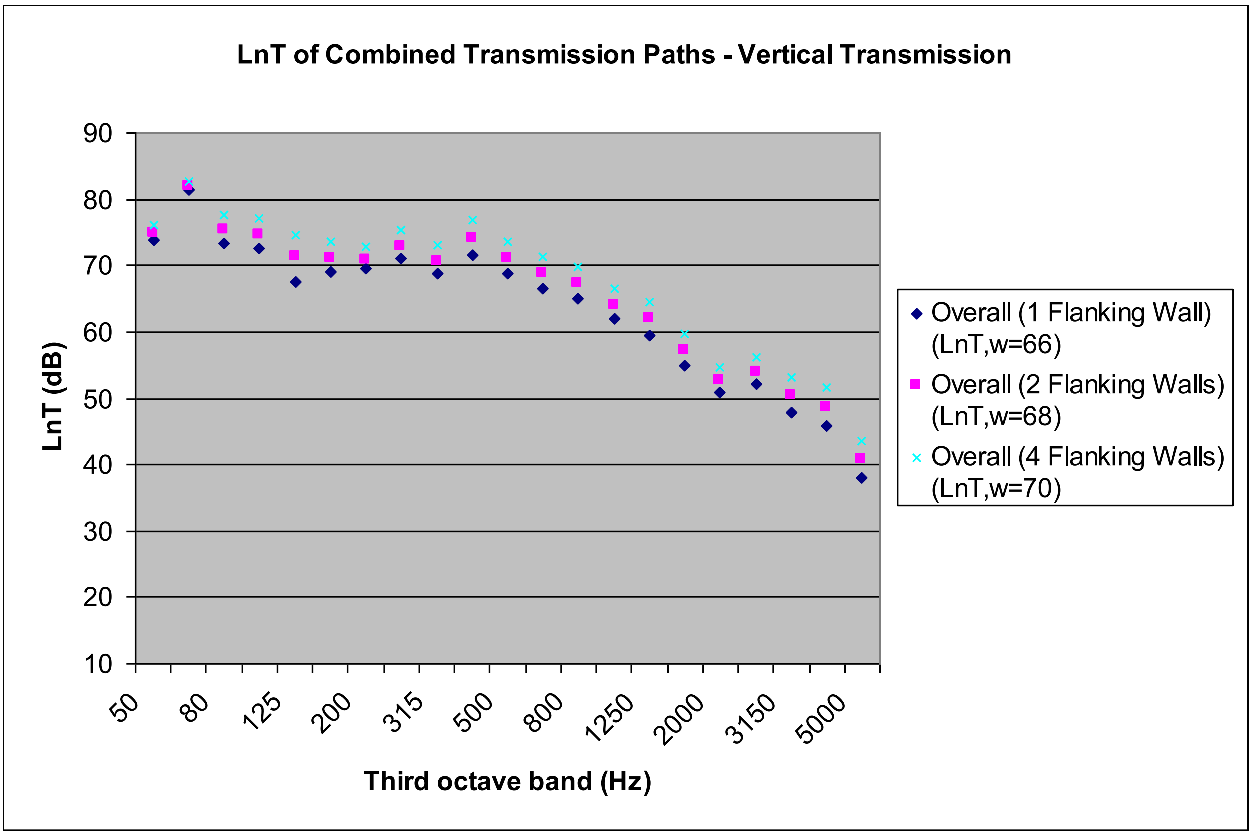


Figure 33(c). Combined impact sound vertical transmission for basic bare floor

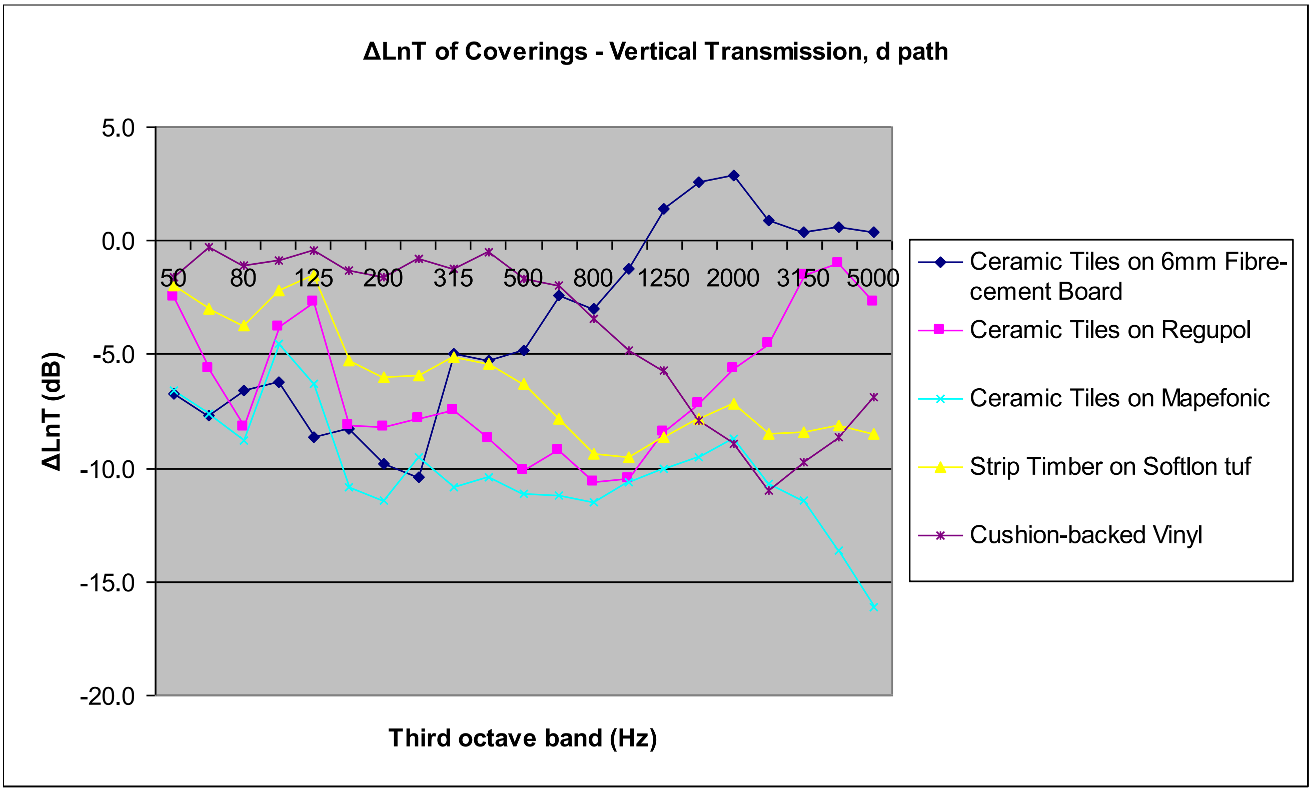


Figure 33(d). Impact sound vertical transmission for all coverings on basic floor

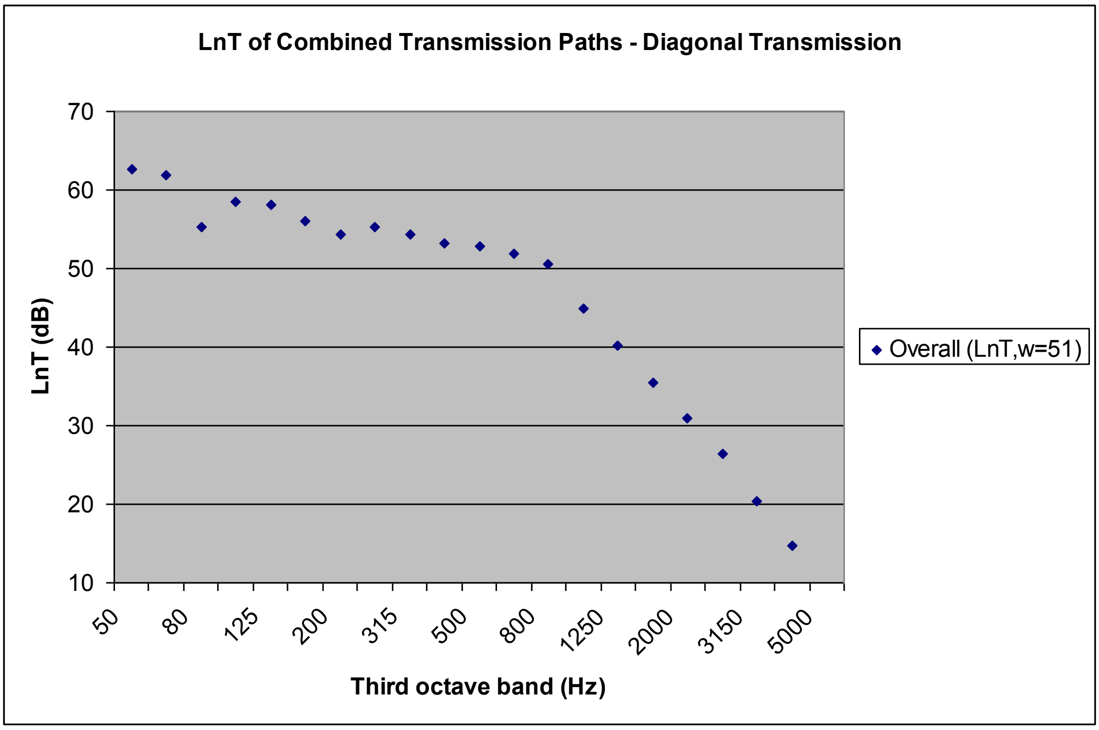


Figure 33(e). Combined impact sound diagonal transmission for basic bare floor

Figure 33. Basic floor – impact sound transmission with and without floor coverings

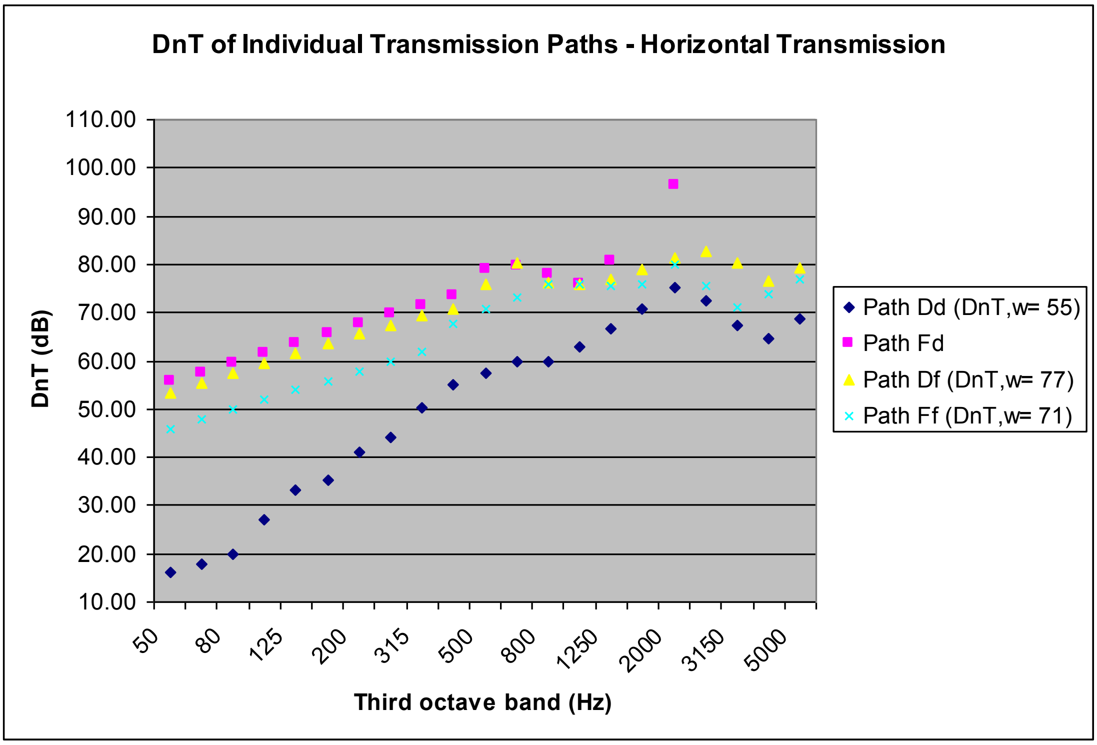


Figure 34(a). Individual airborne sound horizontal transmission for 2 x 20 mm particleboard raft on Acousti-Mat 3 underlay on basic floor with no floor coverings

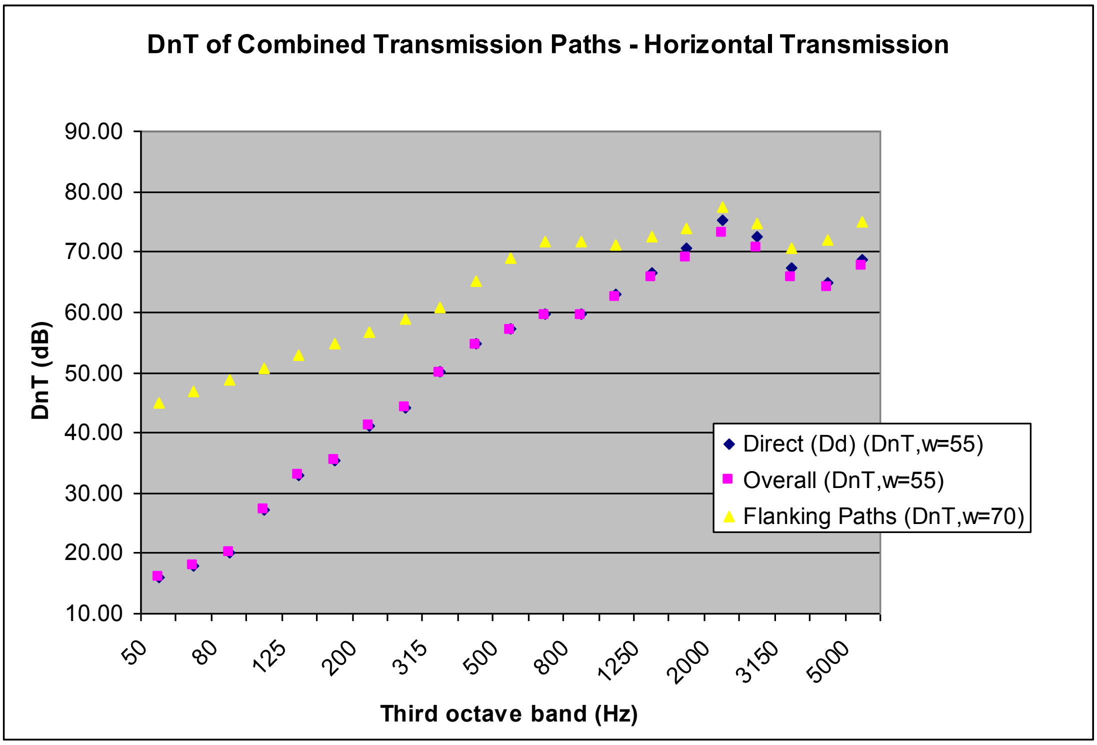


Figure 34(b). Combined airborne sound horizontal transmission for 2 x 20 mm particleboard raft on Acousti-Mat 3 underlay on basic floor with no floor coverings

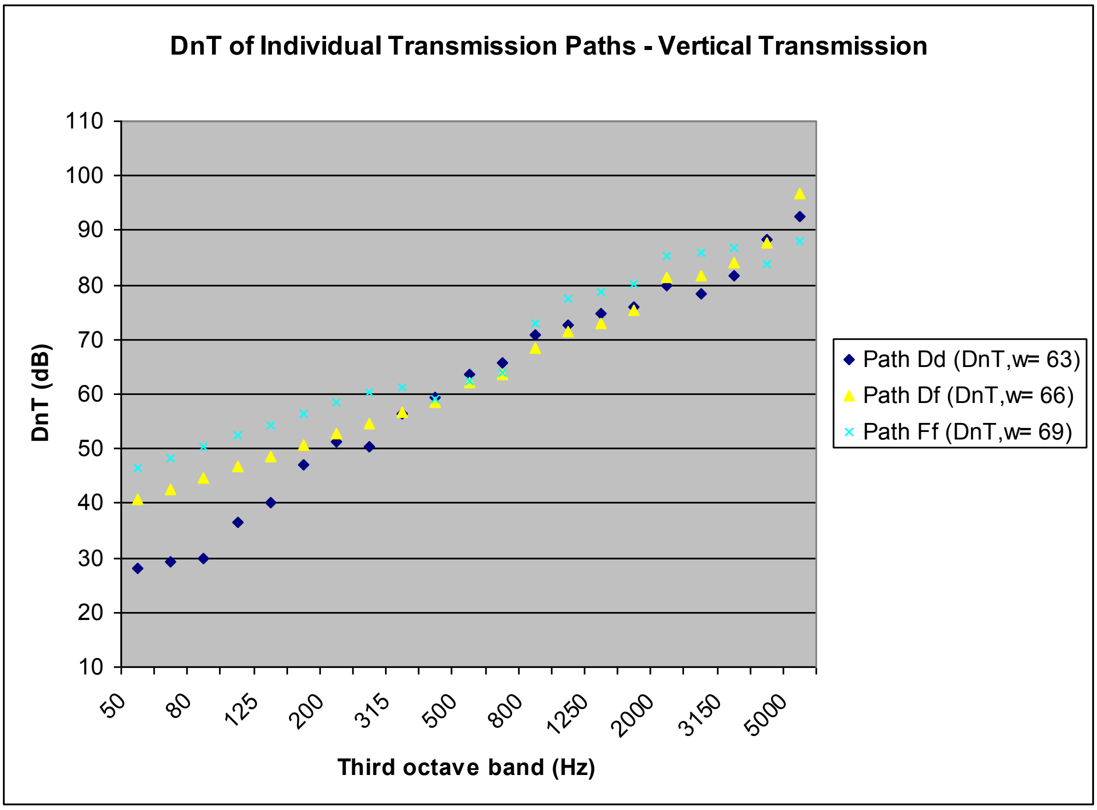


Figure 34(c). Individual airborne sound vertical transmission for 2 x 20 mm particleboard raft on Acousti-Mat 3 underlay on basic floor with no floor coverings

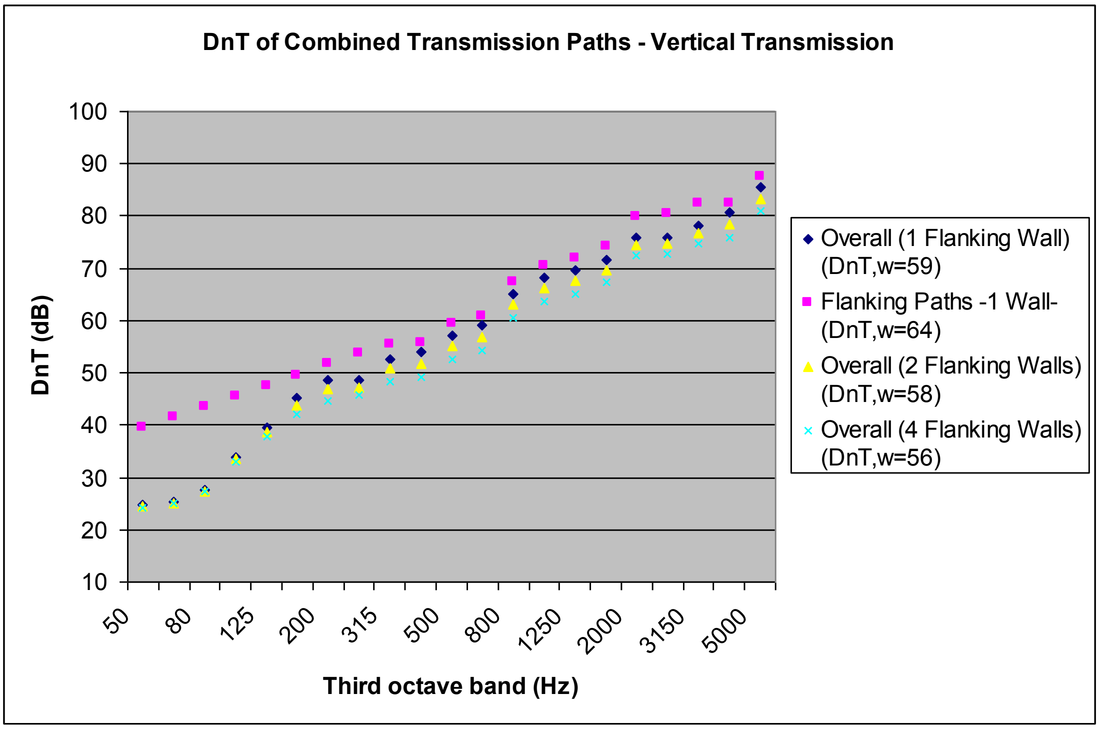


Figure 34(d). Combined airborne sound vertical transmission for 2 x 20 mm particleboard raft on Acousti-Mat 3 underlay on basic floor with no floor coverings

Figure 34. 2x20 mm particleboard raft on Acousti-Mat 3 underlay – airborne sound transmission.

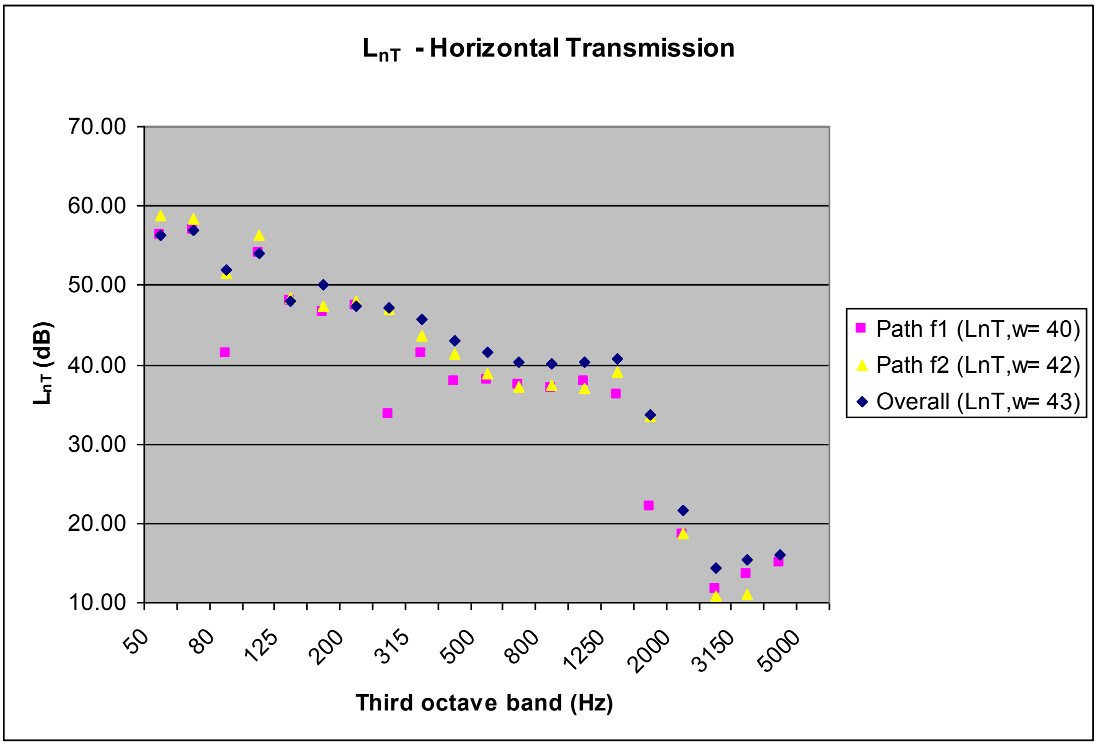


Figure 35(a). Impact horizontal transmission for 2 x 20 mm particleboard raft on Acousti-Mat 3 underlay on basic floor with no floor coverings

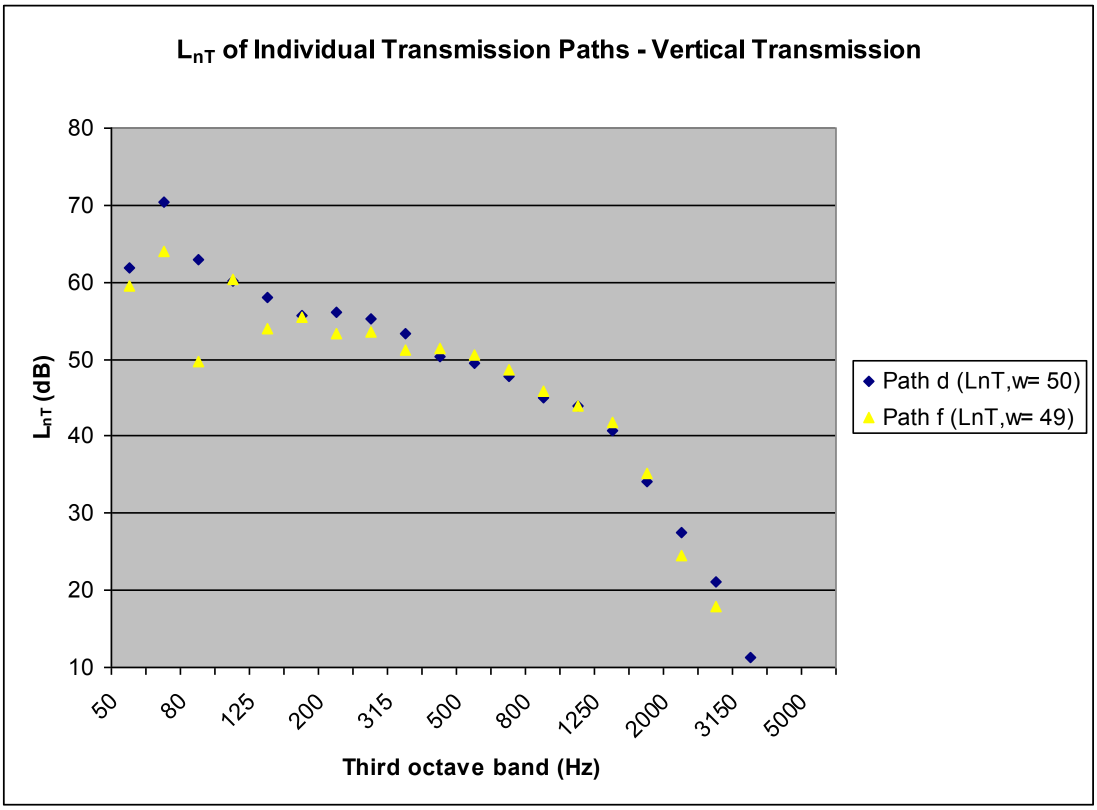


Figure 35(b). Individual impact vertical transmission for 2 x 20 mm particleboard raft on Acousti-Mat 3 underlay on basic floor with no floor coverings

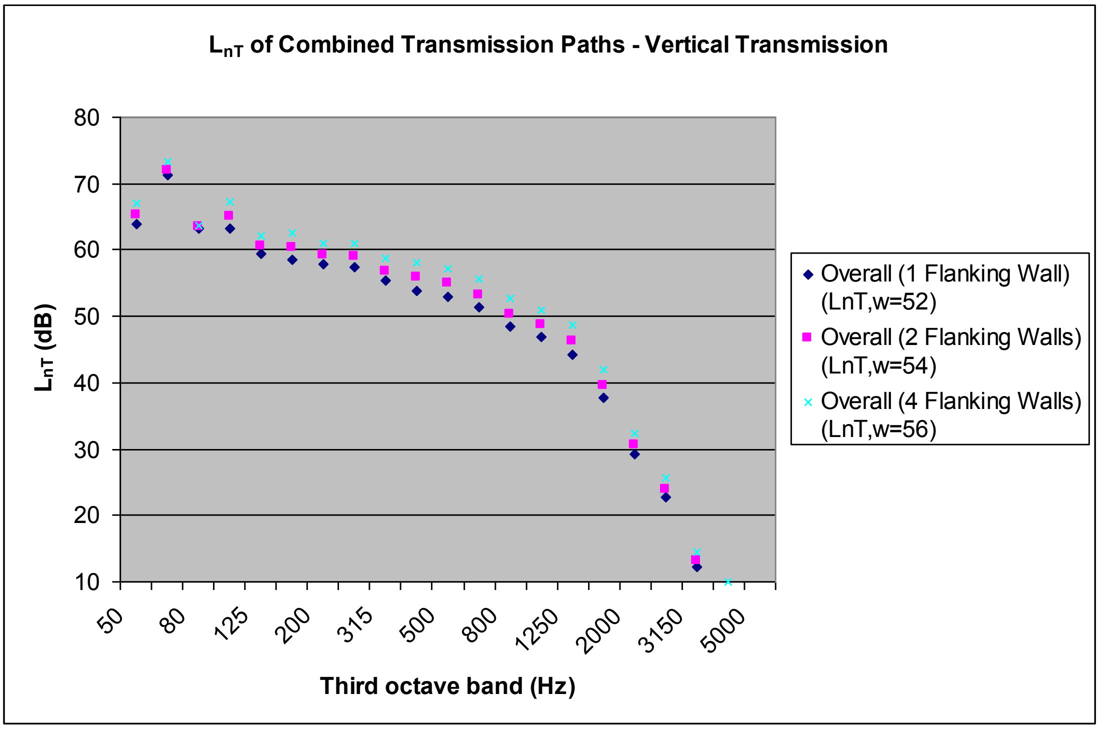


Figure 35(c). Combined impact vertical transmission for 2 x 20 mm particleboard raft on Acousti-Mat 3 underlay on basic floor with no floor coverings

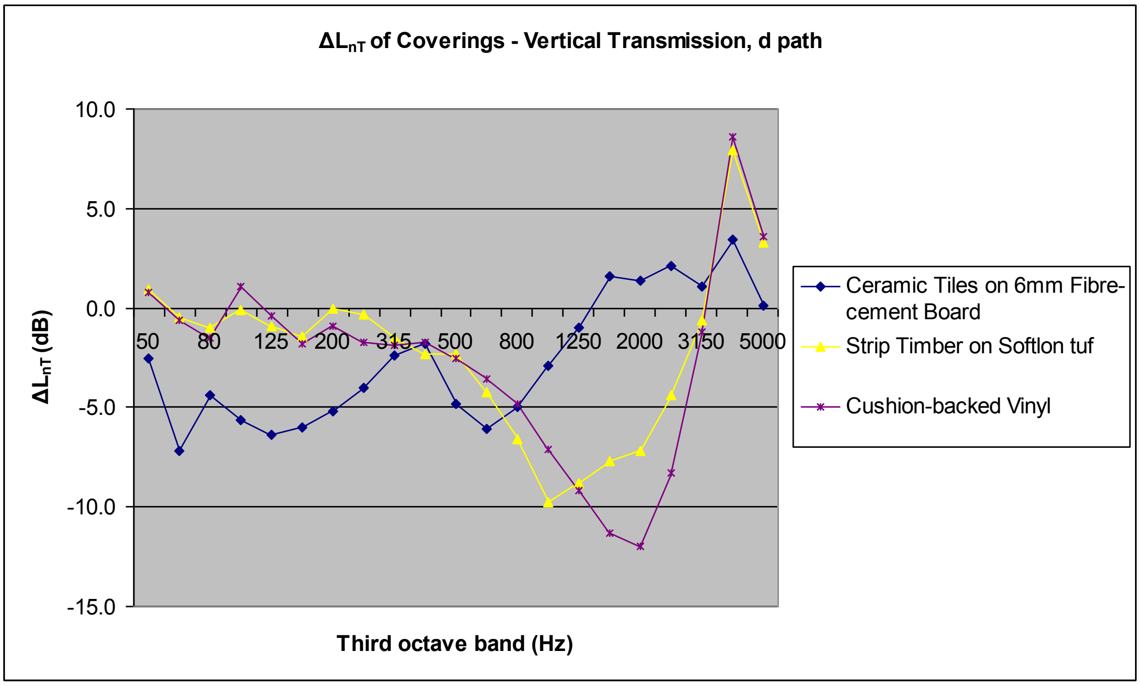


Figure 35(d). Impact vertical transmission for 2 x 20 mm particleboard raft on Acousti-Mat 3 underlay for all floor coverings

Figure 35. 2 x 20 mm particleboard raft on Acousti-Mat 3 underlay – impact sound transmission with and without floor coverings

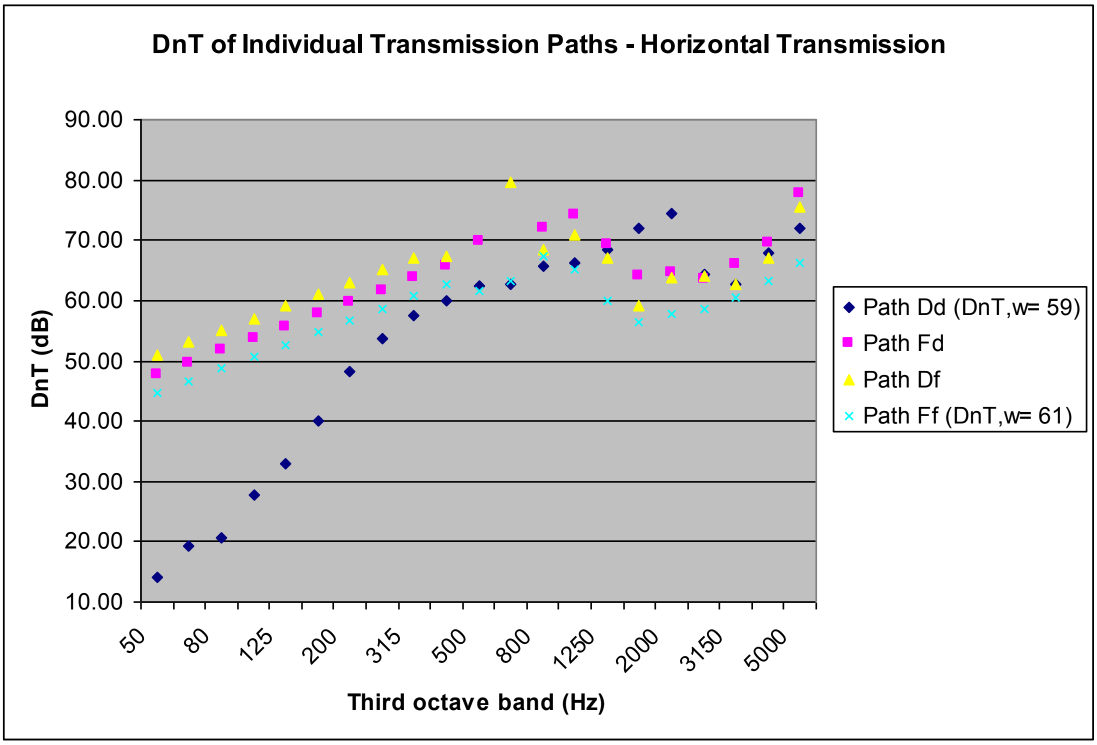


Figure 36(a). Individual airborne sound horizontal transmission for 1 x 20 mm particleboard on basic floor with no floor coverings

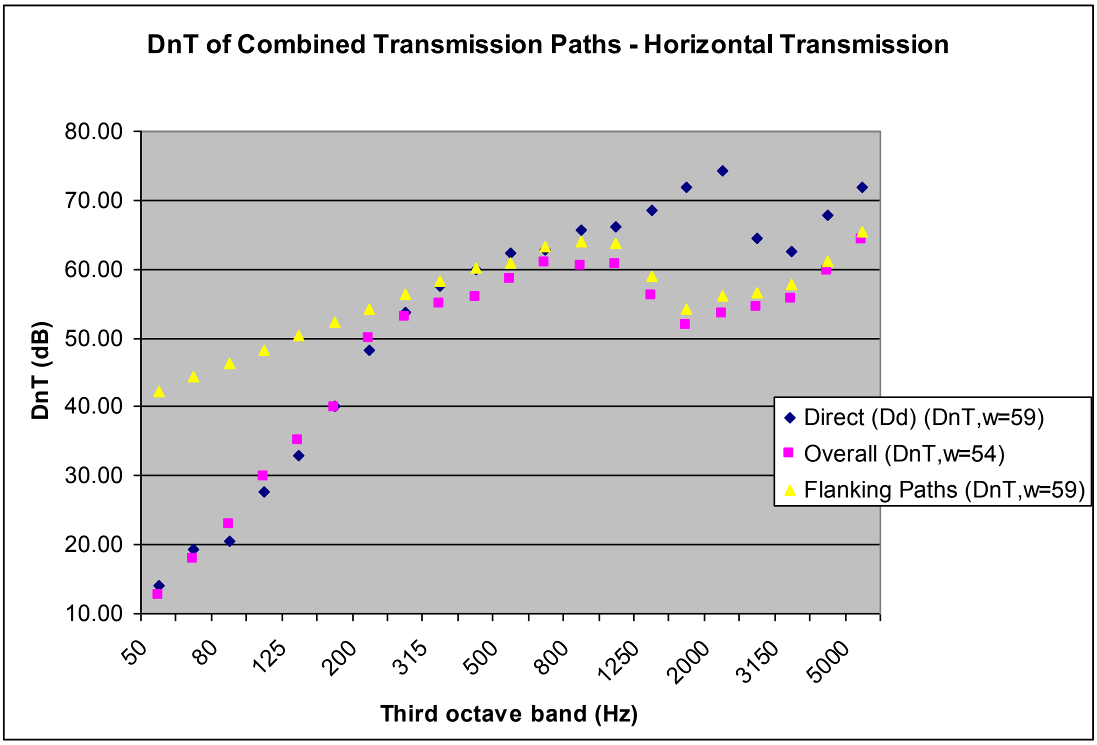


Figure 36(b). Combined airborne sound horizontal transmission for 1 x 20 mm particleboard on basic floor with no floor coverings

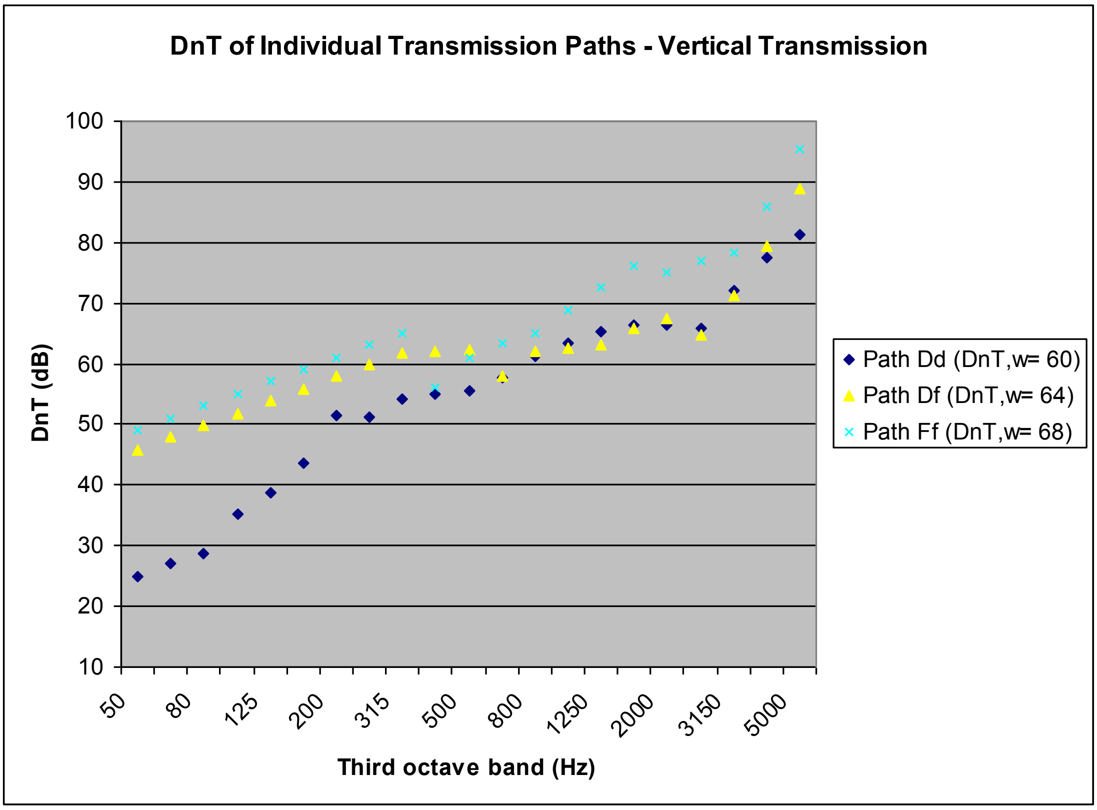


Figure 36(c). Individual airborne sound vertical transmission for 1 x 20 mm particleboard on basic floor with no floor coverings

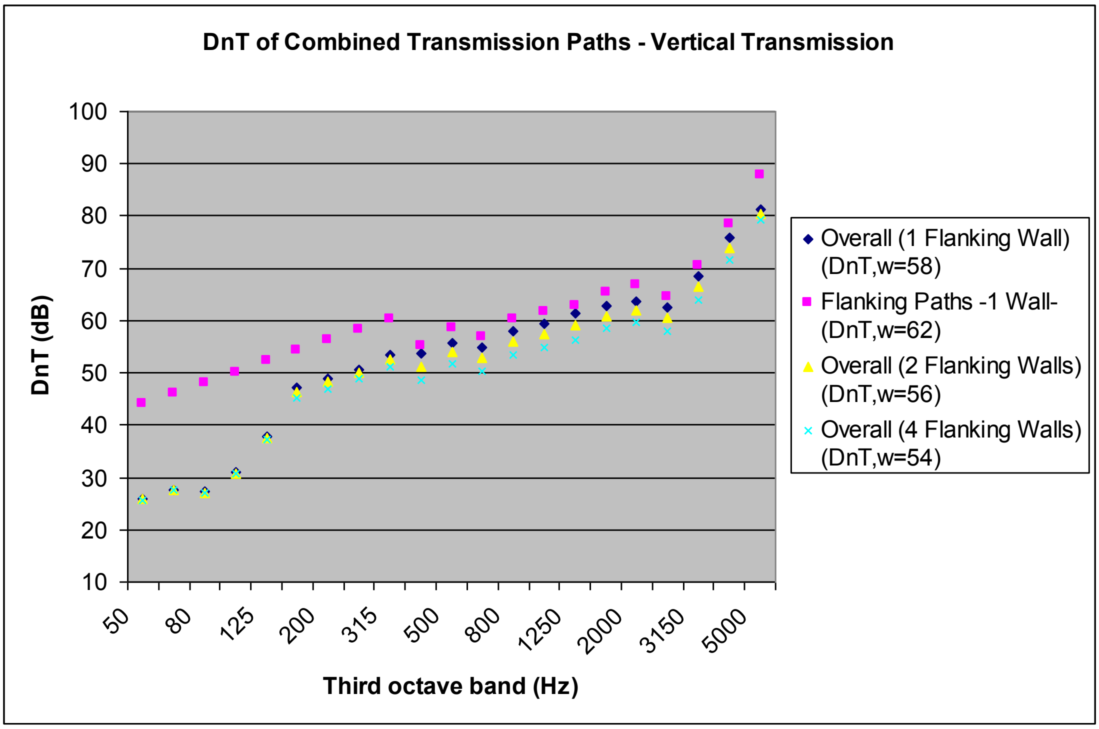


Figure 36(d). Combined airborne sound vertical transmission for 1 x 20 mm particleboard on basic floor with no floor coverings

Figure 36. 20 mm particleboard layer screw-fixed to basic floor – airborne sound transmission.

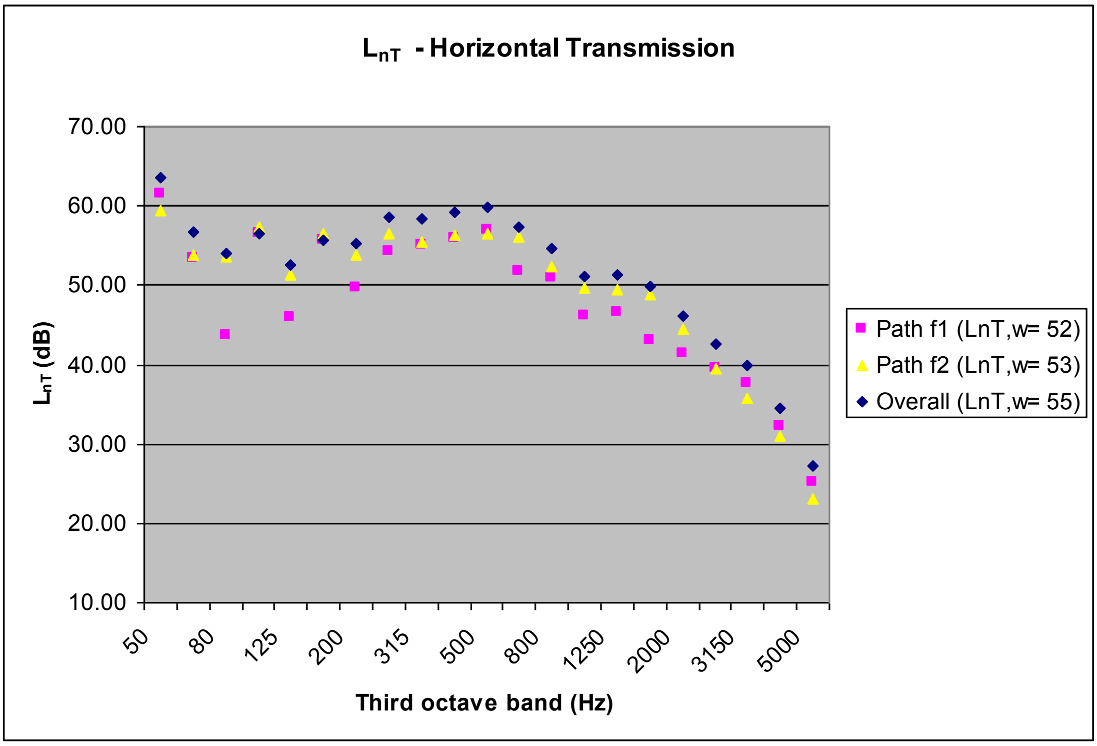


Figure 37(a). Impact horizontal transmission for 1 x 20 mm particleboard on basic floor with no floor coverings

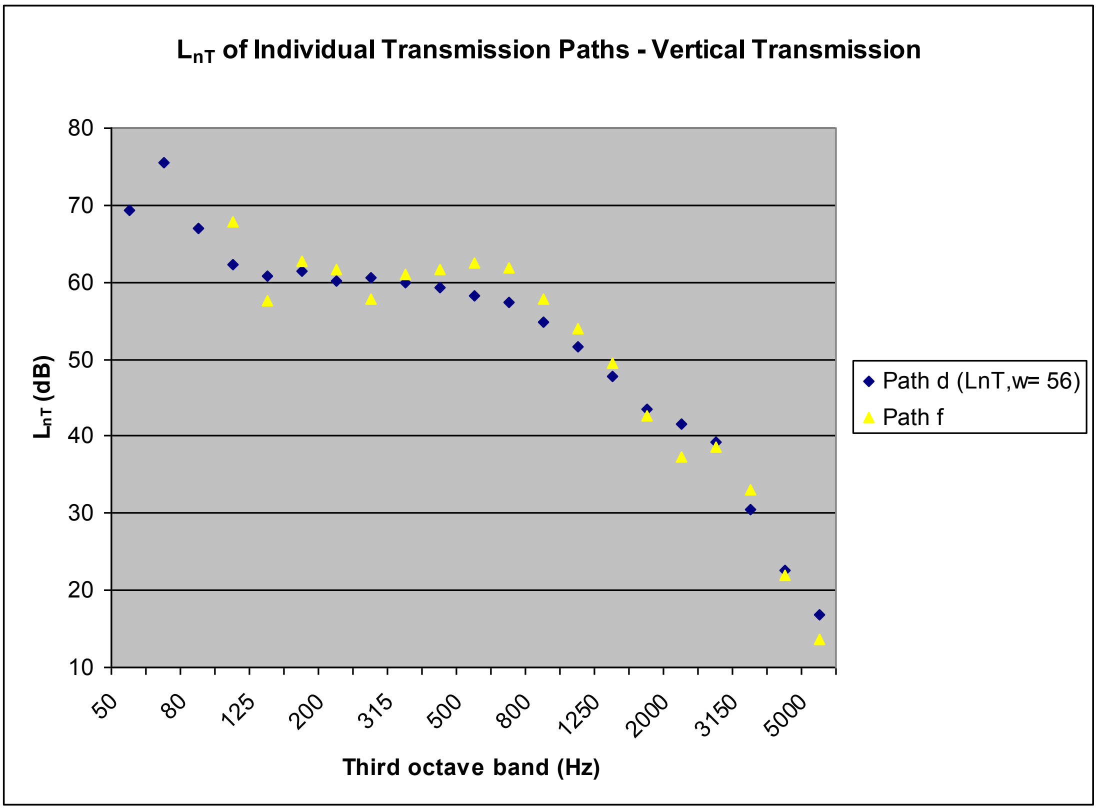


Figure 37(b). Individual impact vertical transmission for 1 x 20 mm particleboard on basic floor with no floor coverings

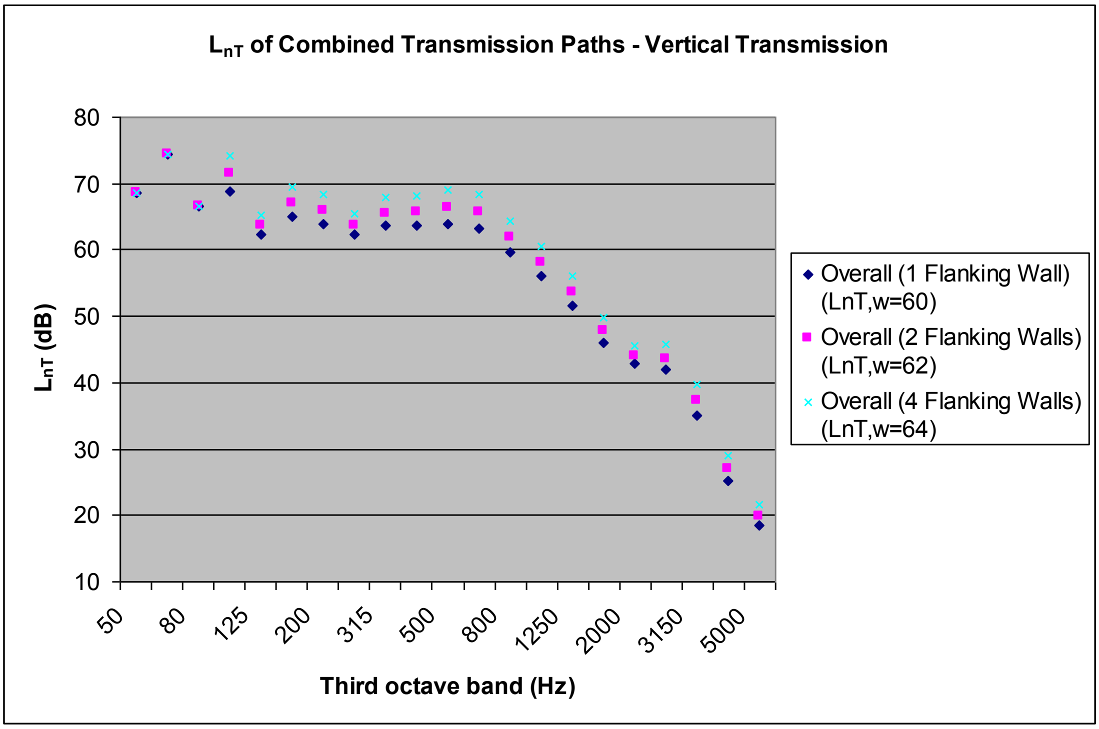


Figure 37(c). Combined impact vertical transmission for 1 x 20 mm particleboard on basic floor with no floor coverings

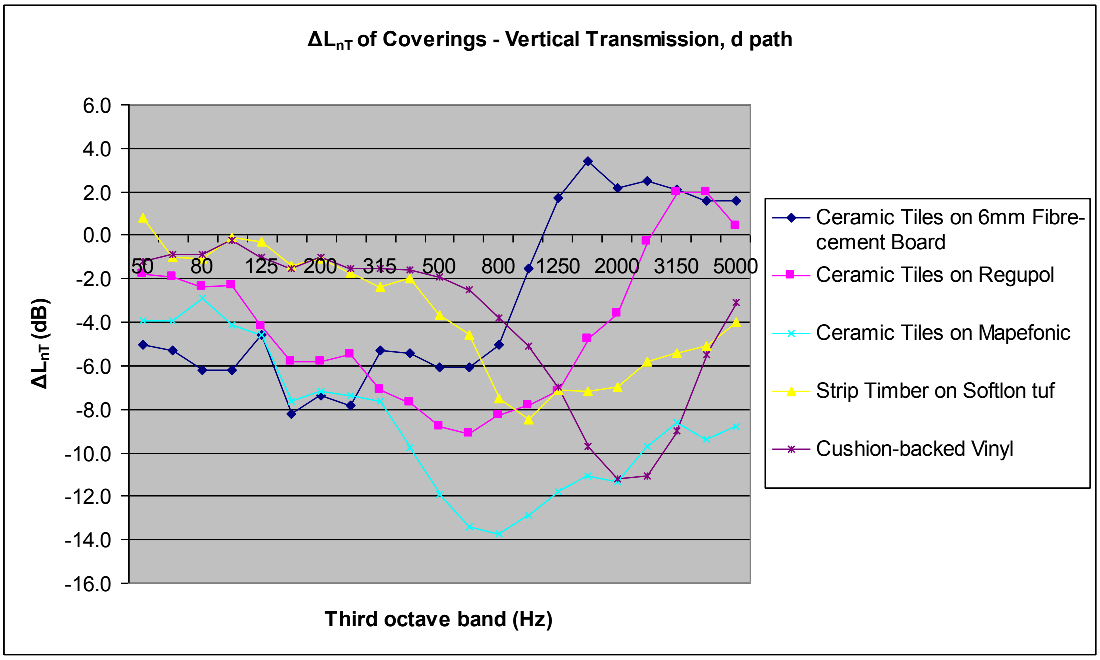


Figure 37(d). Impact vertical transmission for 1 x 20 mm particleboard screw-fixed to the basic floor for all floor coverings

Figure 37. 20 mm particleboard layer screw-fixed to the basic floor – impact sound transmission with and without floor coverings.

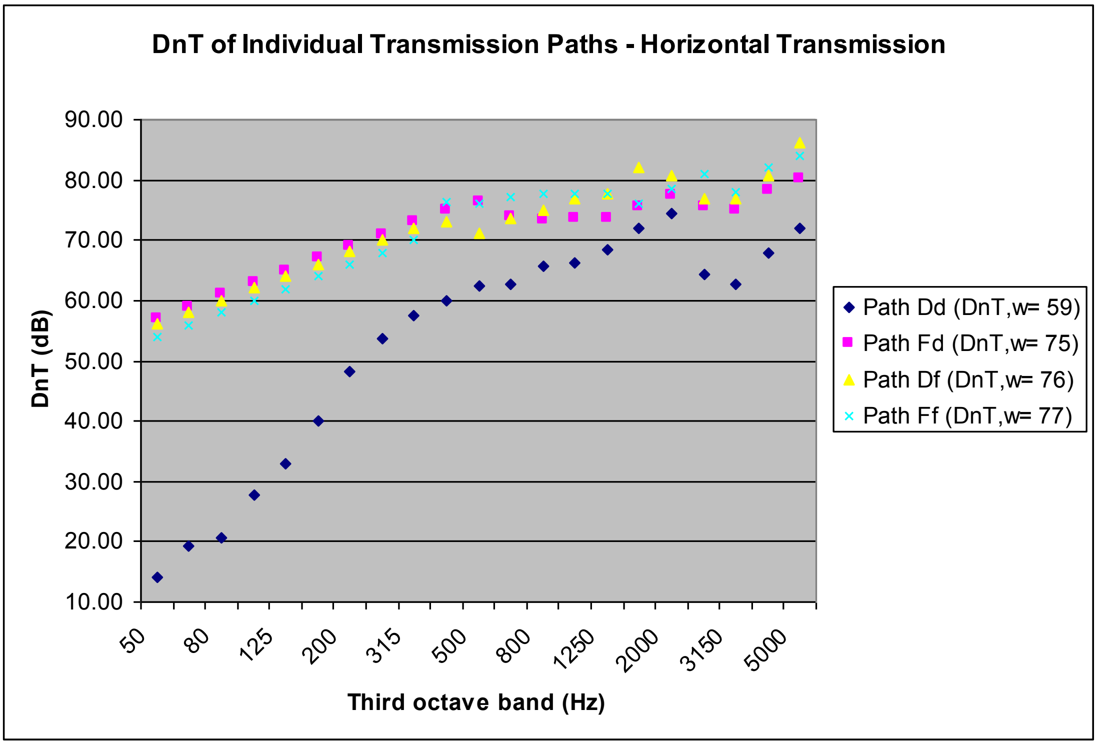


Figure 38(a). Individual airborne horizontal transmission for 1 x 20 mm particleboard over filled cavity on basic floor with no floor coverings

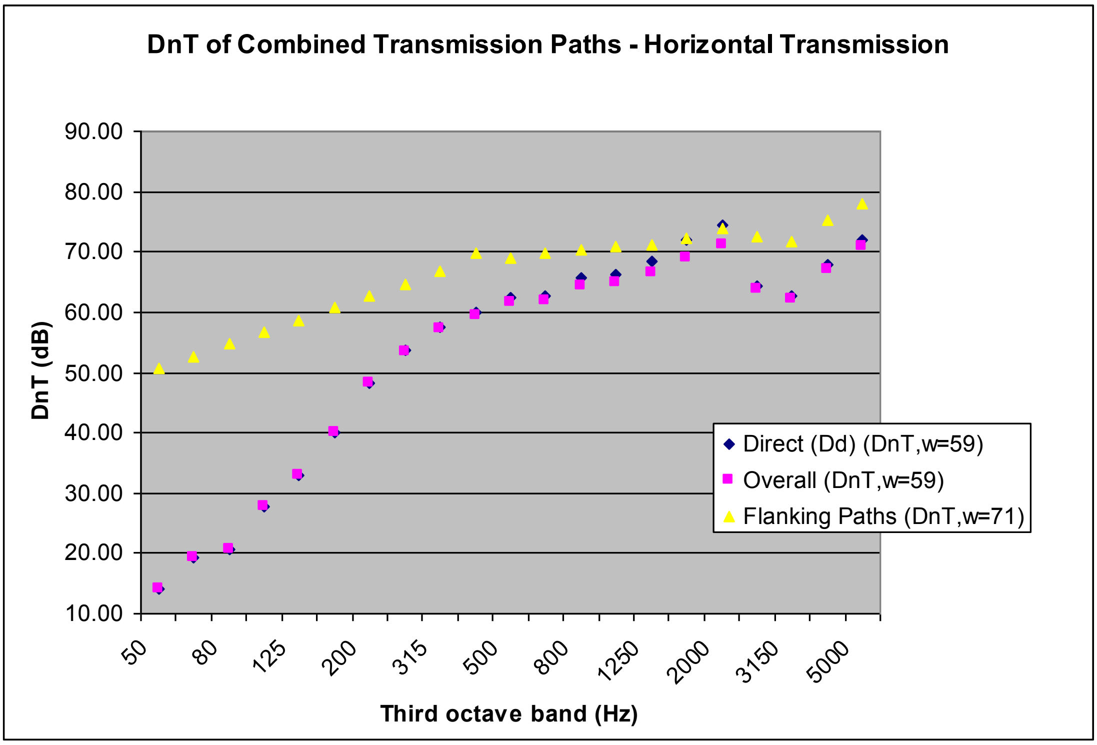


Figure 38(b). Combined airborne horizontal transmission for 1 x 20 mm particleboard over filled cavity on basic floor with no floor coverings

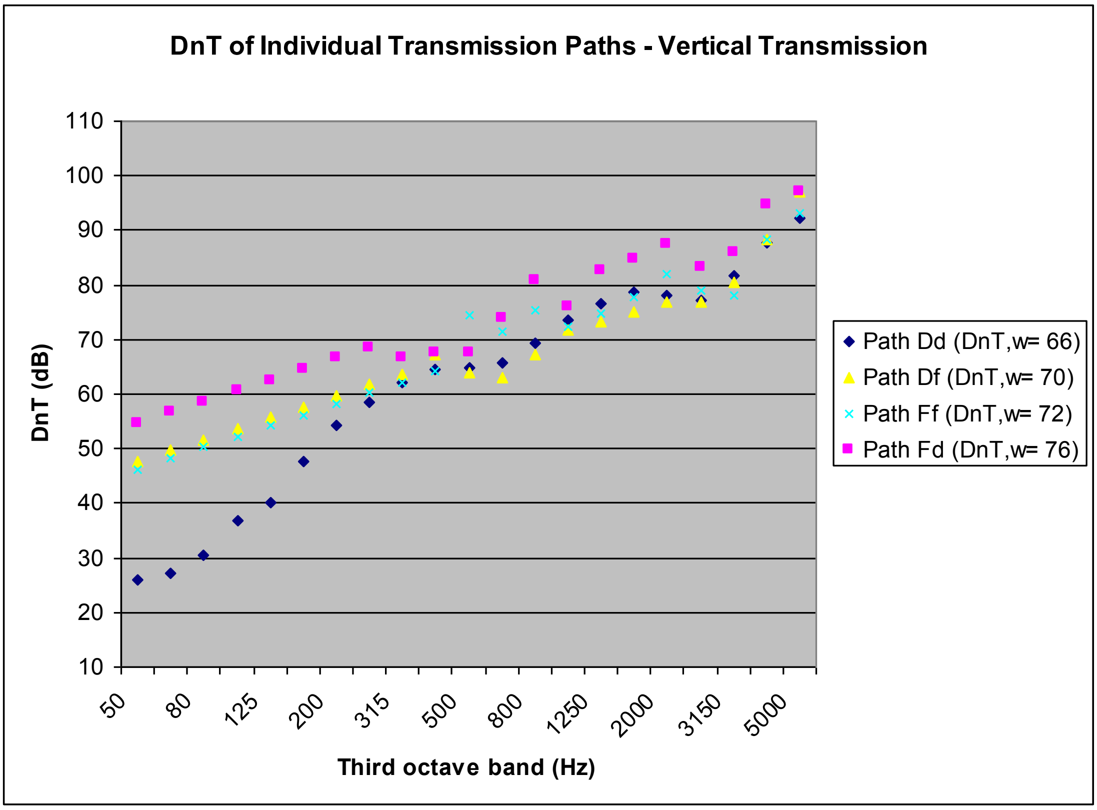


Figure 38(c). Individual airborne vertical transmission for 1 x 20 mm particleboard over filled cavity on basic floor with no floor coverings

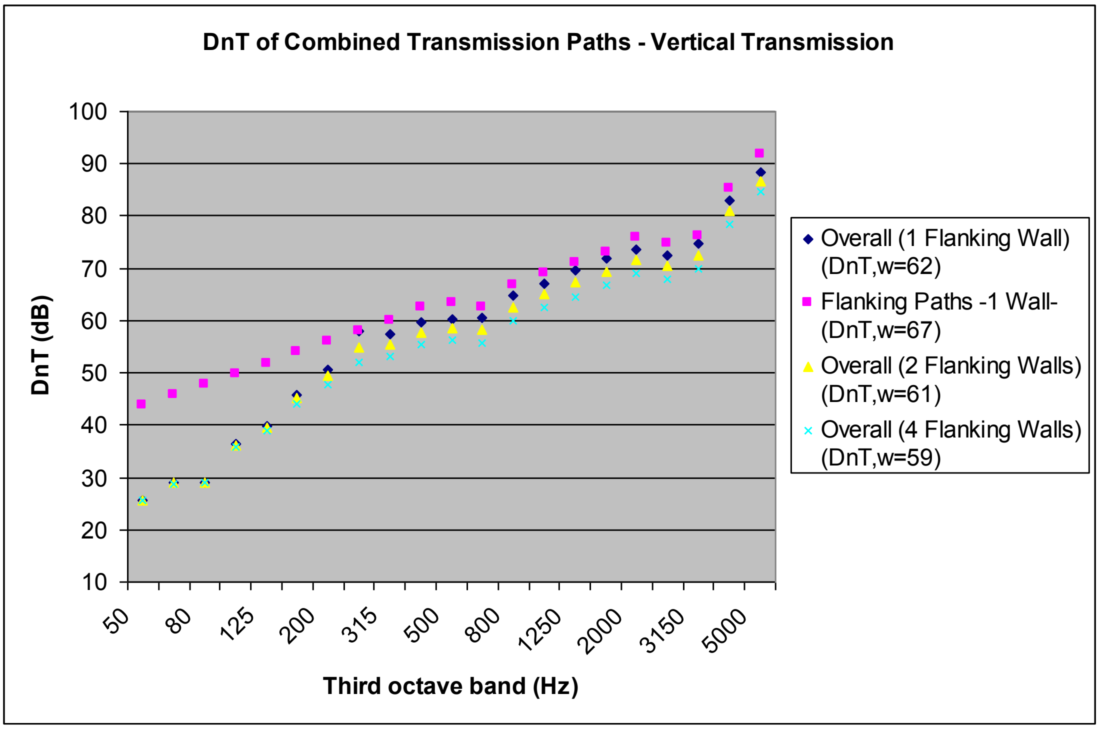


Figure 38(d). Combined airborne vertical transmission for 1 x 20 mm particleboard over filled cavity on basic floor with no floor coverings

Figure 38. 20 mm particleboard layer screw-fixed to 45 mm battens with cavity filled with sand and sawdust – airborne sound transmission.

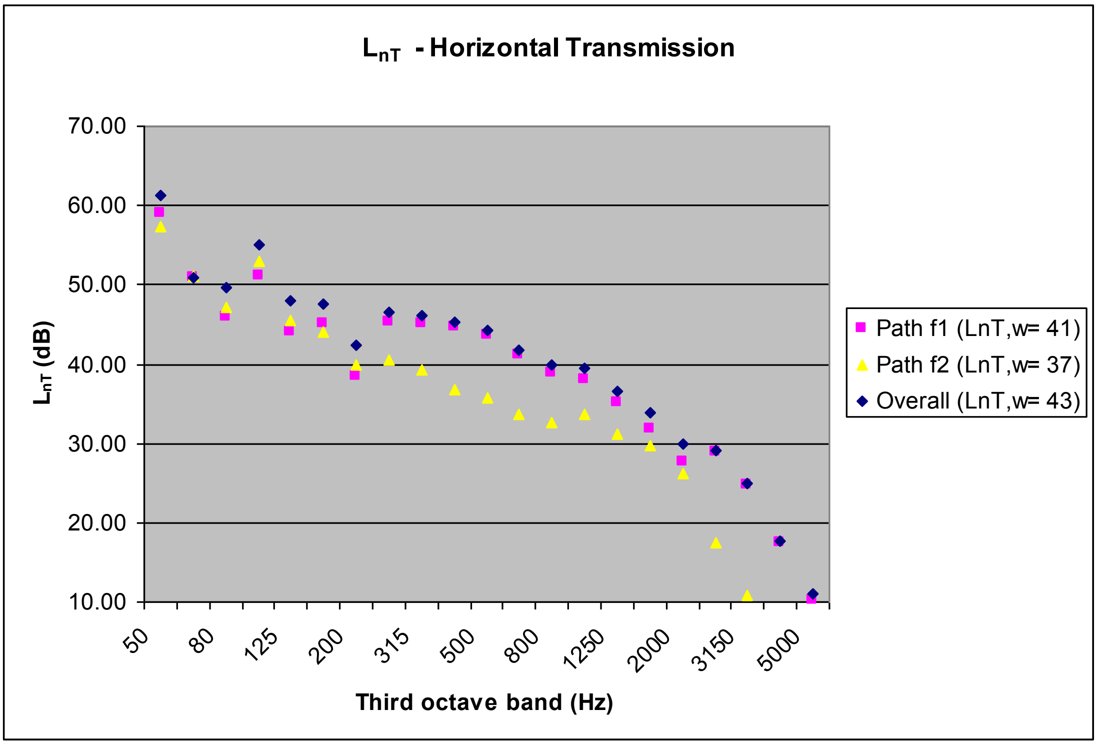


Figure 39(a). Impact horizontal transmission for 1 x 20 mm particleboard over filled cavity on basic floor with no floor coverings

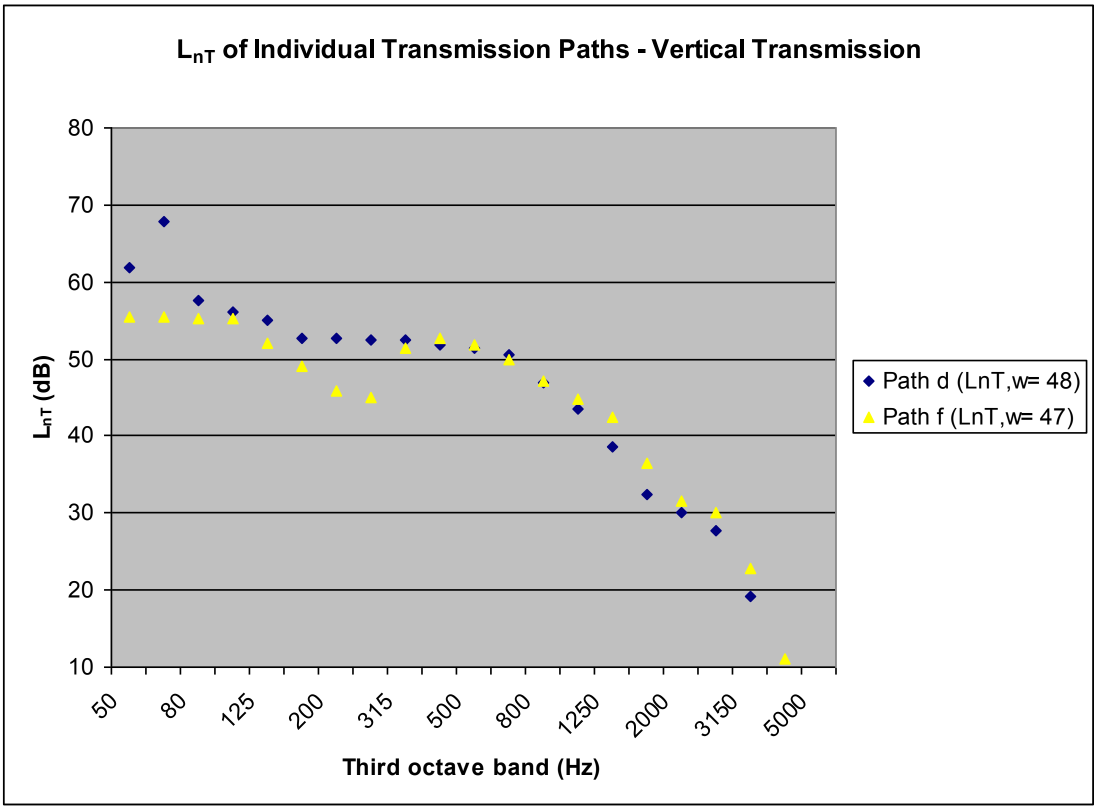


Figure 39(b). Individual impact vertical transmission for 1 x 20 mm particleboard over filled cavity on basic floor with no floor coverings

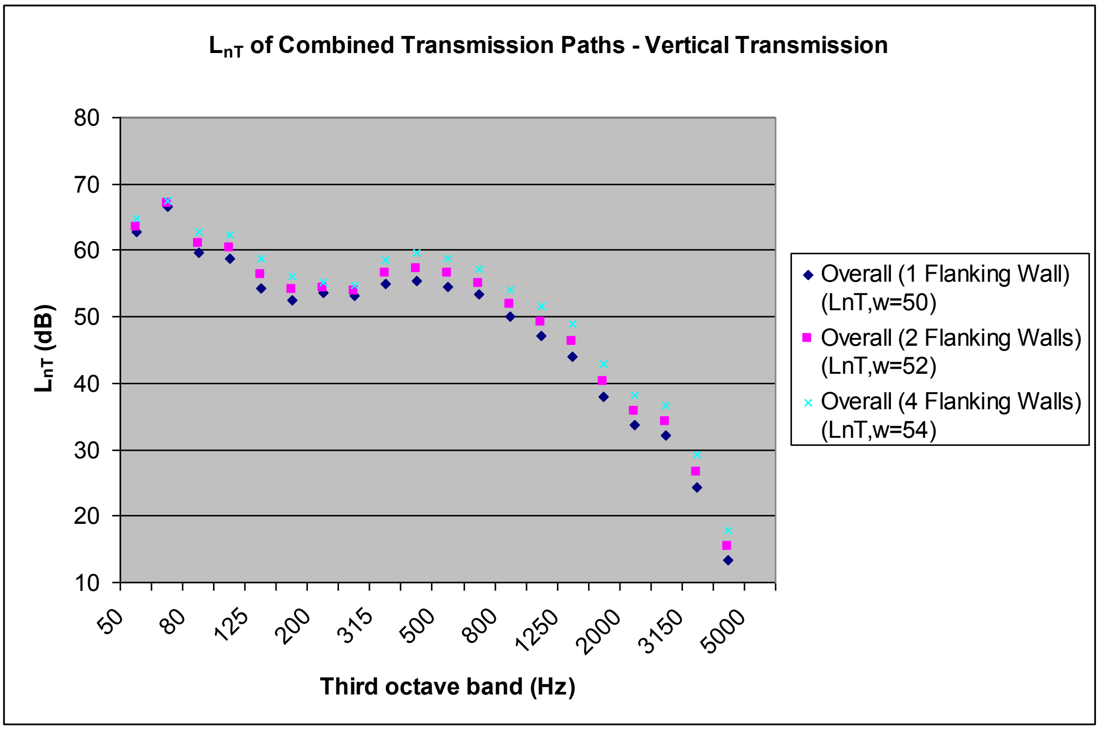


Figure 39(c). Combined impact vertical transmission for 1 x 20 mm particleboard over filled cavity on basic floor with no floor coverings

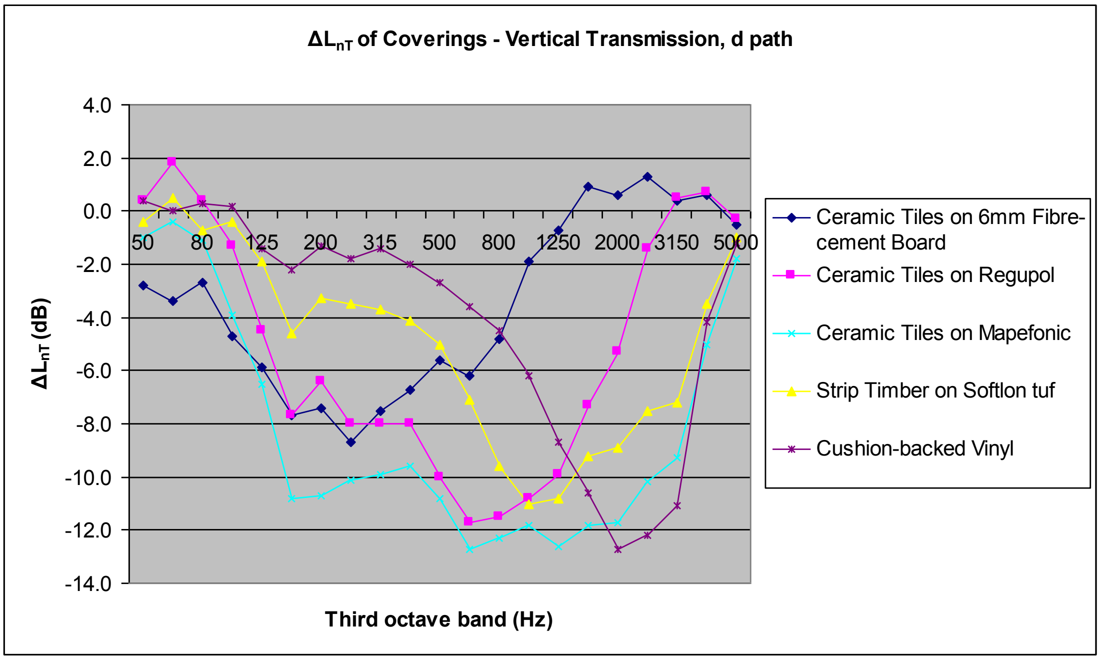


Figure 39(d). Impact vertical transmission for 1 x 20 mm particleboard over filled cavity for all floor coverings

Figure 39. 20 mm particleboard layer screw-fixed to 45 mm battens with cavity filled with sand and sawdust – impact sound transmission with and without floor coverings.

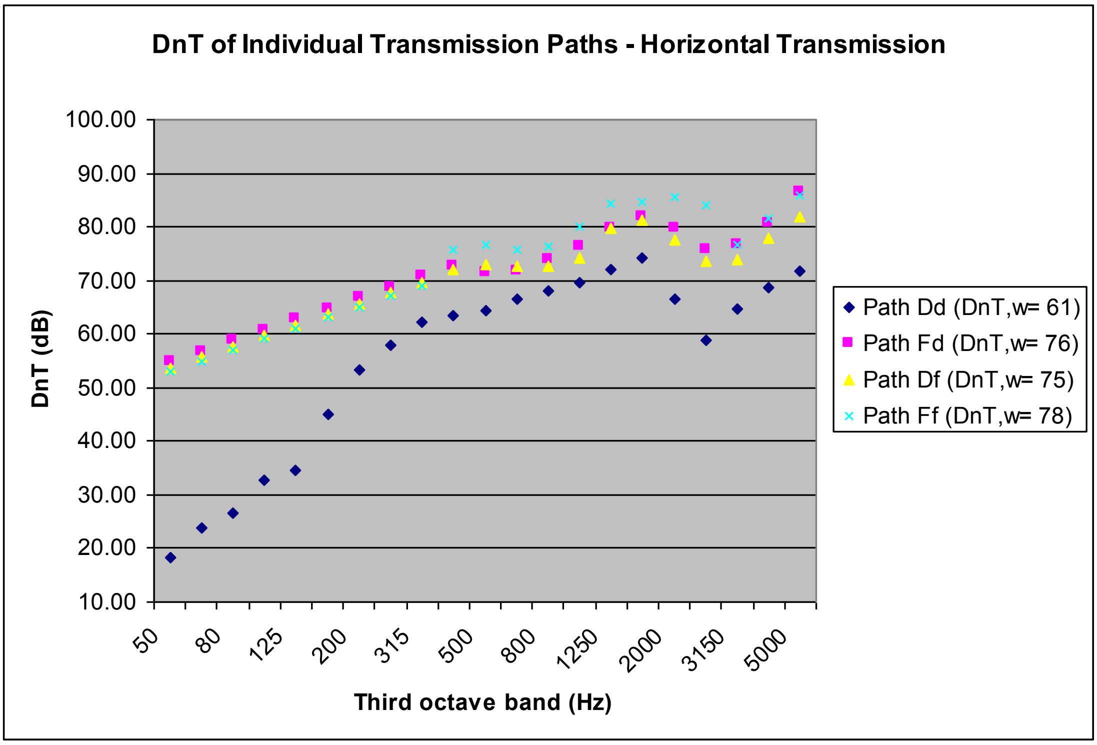


Figure 40(a). Individual airborne horizontal transmission for 38 mm Maxxon gypsum concrete screed on Acousti-Mat 3 on basic floor with no floor coverings

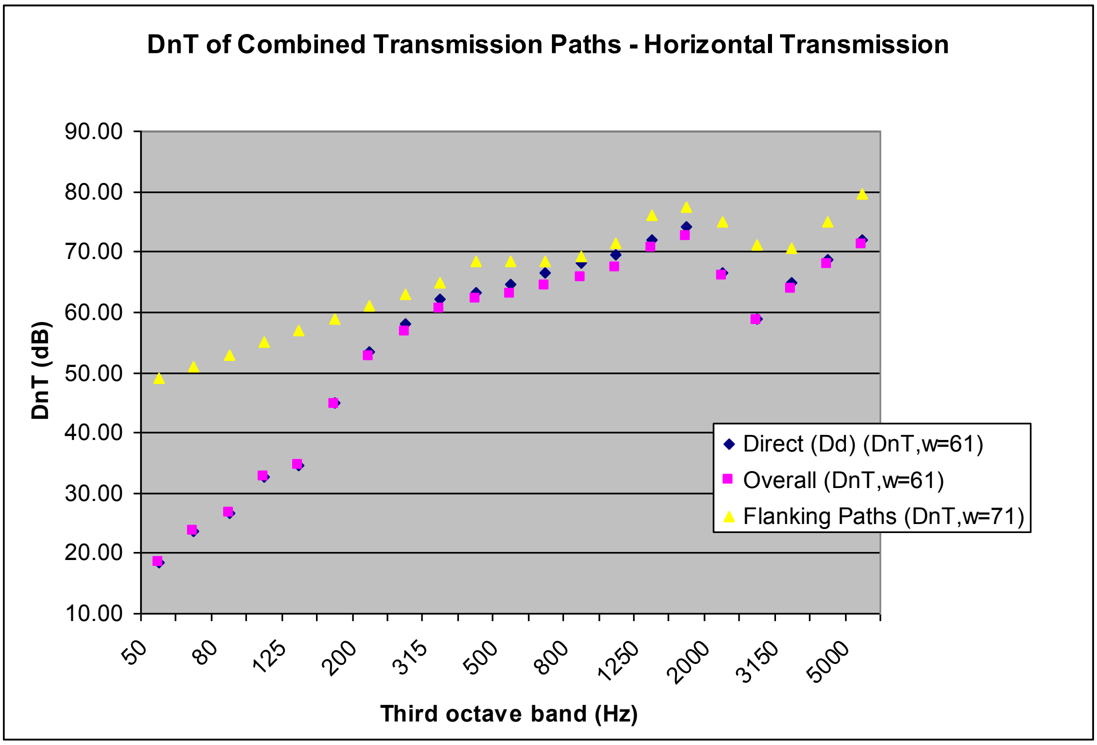


Figure 40(b). Combined airborne horizontal transmission for 38 mm Maxxon gypsum concrete screed on Acousti-Mat 3 on basic floor with no floor coverings

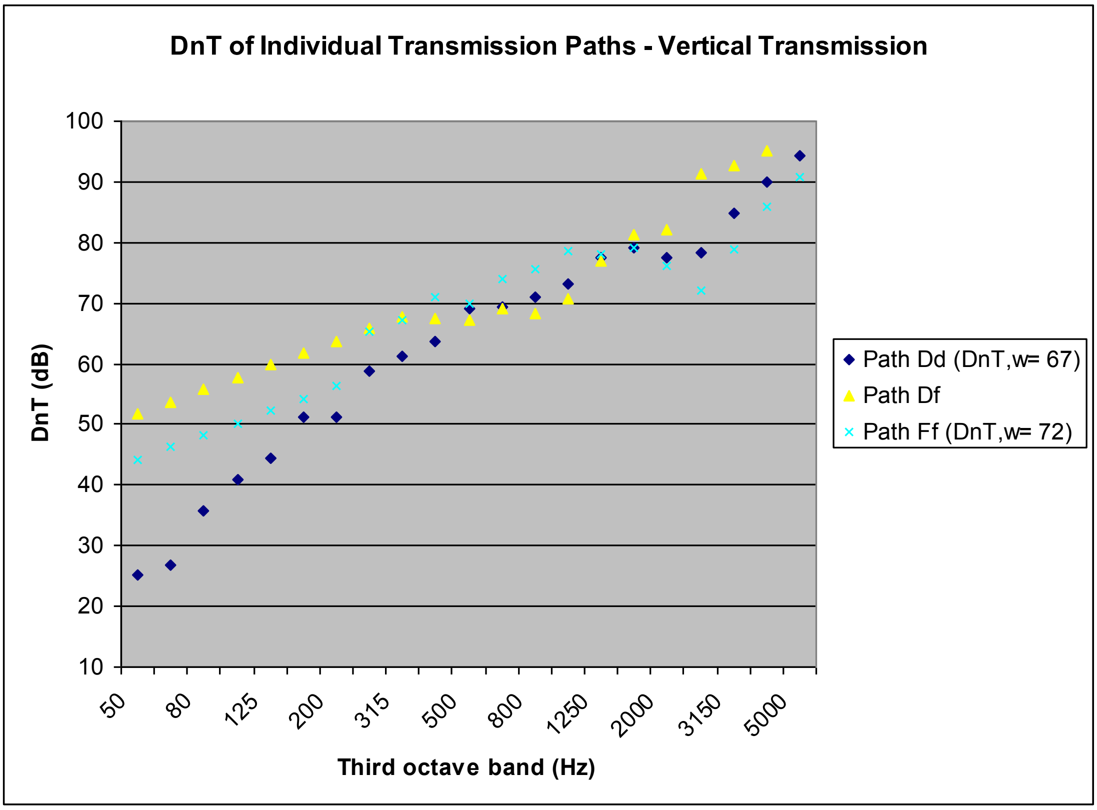


Figure 40(c). Individual airborne vertical transmission for 38 mm Maxxon gypsum concrete screed on Acousti-Mat 3 on basic floor with no floor coverings

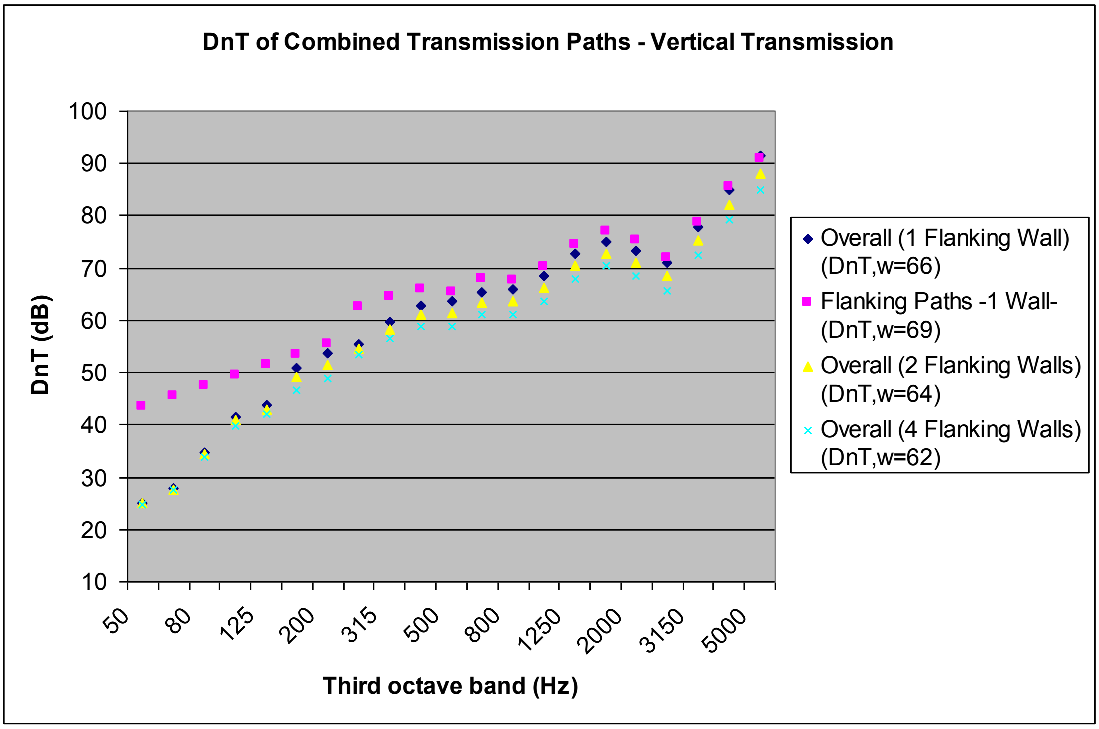


Figure 40(d). Combined airborne vertical transmission for 38 mm Maxxon gypsum concrete screed on Acousti-Mat 3 on basic floor with no floor coverings

Figure 40. 38 mm Maxxon gypsum concrete screed on Acousti-Mat 3 – airborne sound transmission.

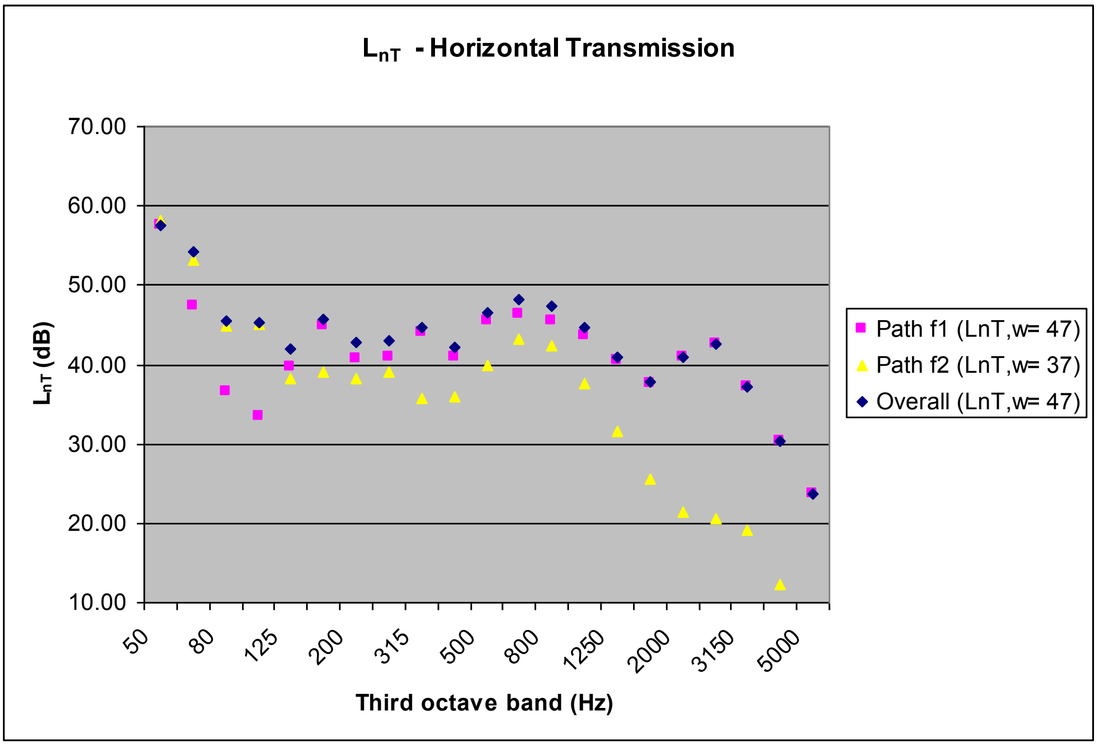


Figure 41(a). Impact horizontal transmission for 38 mm Maxxon gypsum concrete screed on Acousti-Mat 3 on basic floor with no floor coverings

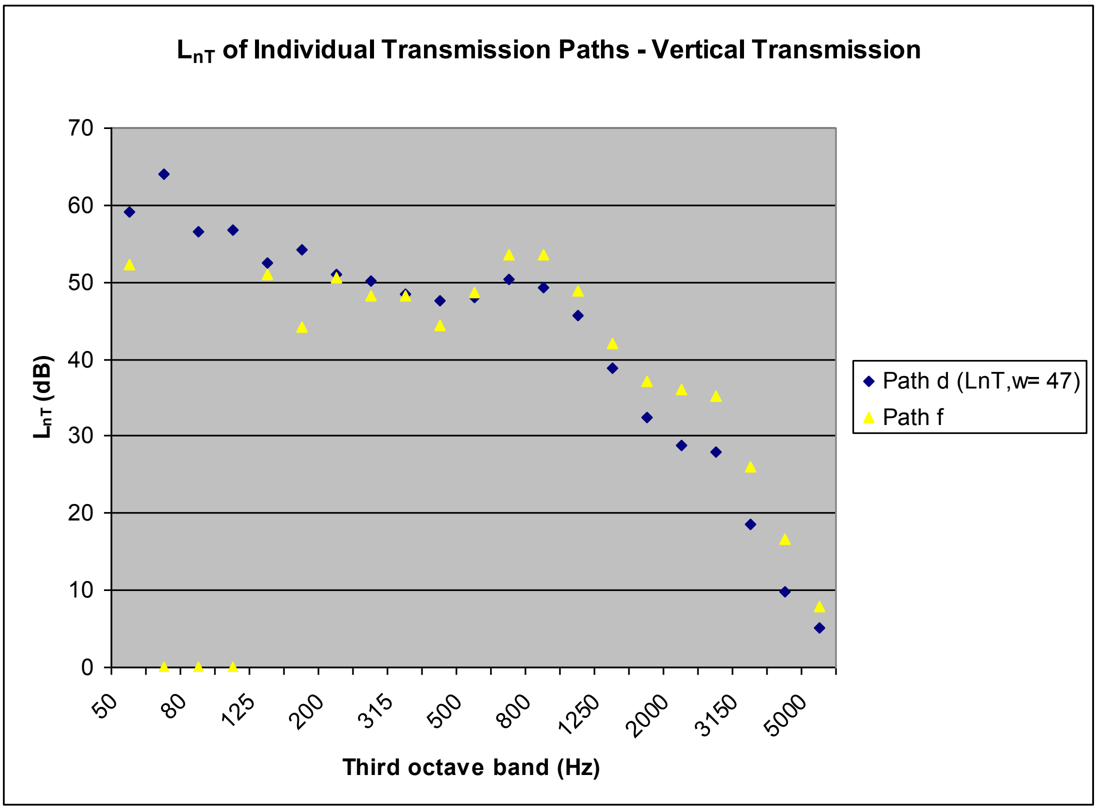


Figure 41(b). Individual impact vertical transmission for 38 mm Maxxon gypsum concrete screed on Acousti-Mat 3 on basic floor with no floor coverings

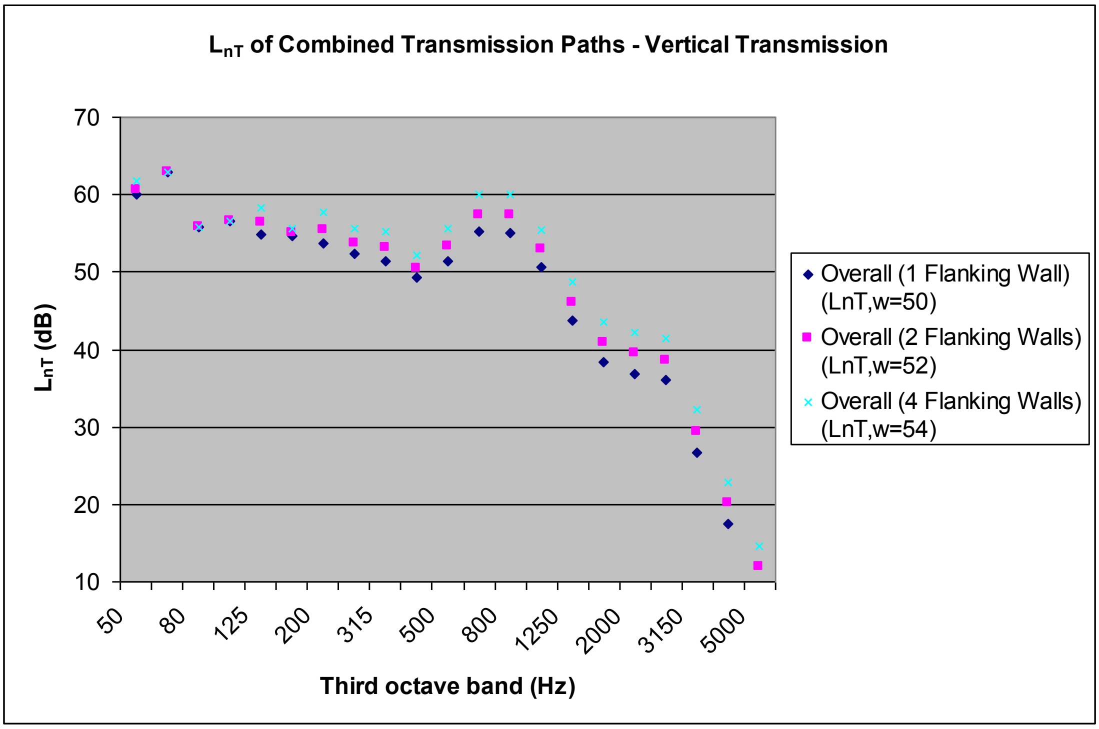


Figure 41(c). Combined impact vertical transmission for 38 mm Maxxon gypsum concrete screed on Acousti-Mat 3 on basic floor with no floor coverings

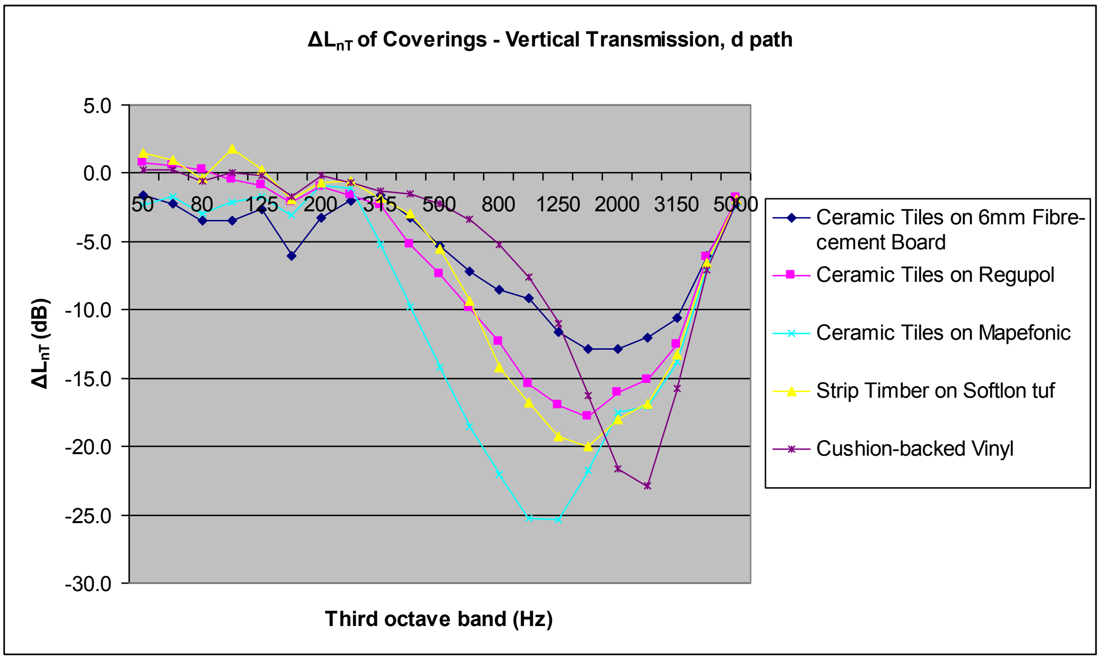


Figure 41(d). Individual impact vertical transmission for 38 mm Maxxon gypsum concrete screed on Acousti-Mat 3 for all floor coverings

Figure 41. 38 mm Maxxon gypsum concrete screed on Acousti-Mat 3 – impact sound transmission with and without floor coverings.

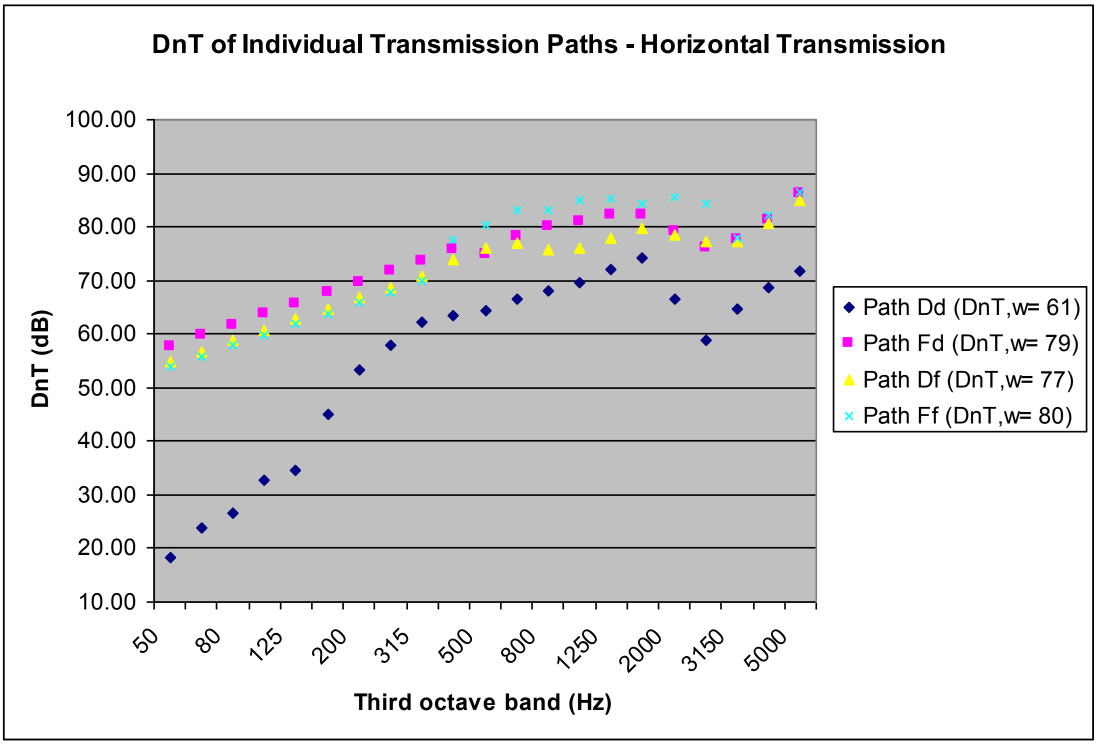


Figure 42(a). Individual airborne horizontal transmission for 2 x 20 mm particleboard raft on 13 mm Bradford Quietel fibreglass board on basic floor with no floor coverings

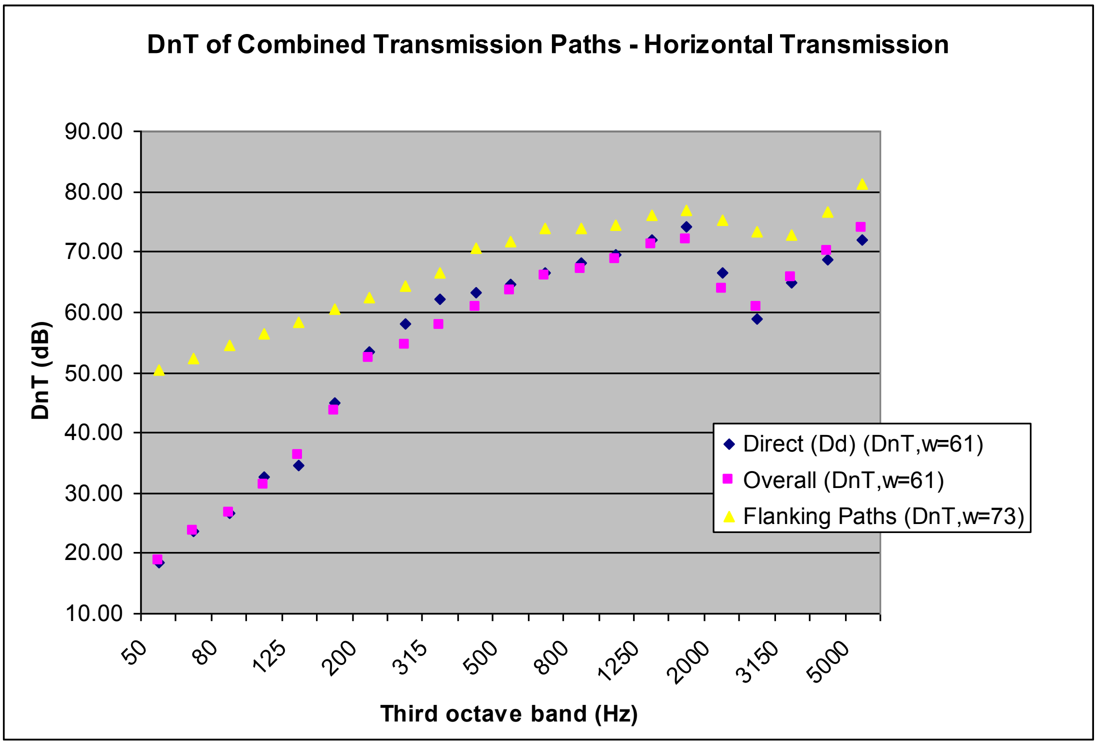


Figure 42(b). Combined airborne horizontal transmission for 2 x 20 mm particleboard raft on 13 mm Bradford Quietel fibreglass board on basic floor with no floor coverings

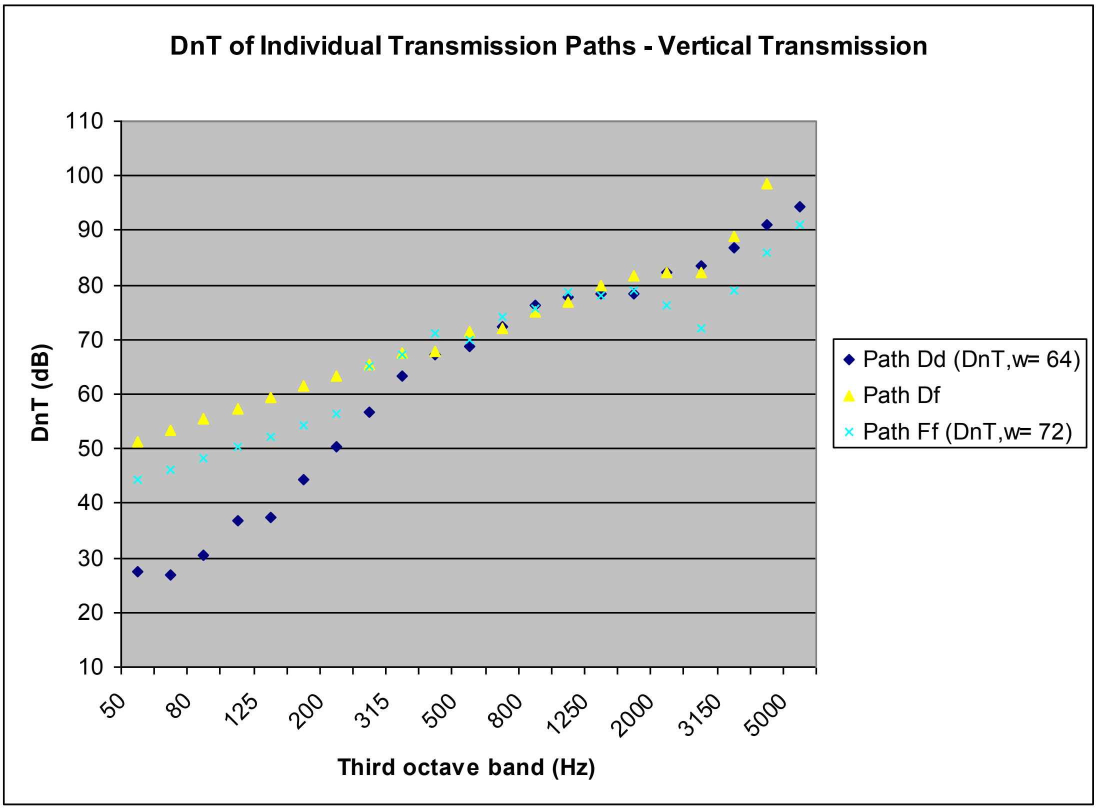


Figure 42(c). Individual airborne vertical transmission for 2 x 20 mm particleboard raft on 13 mm Bradford Quietel fibreglass board on basic floor with no floor coverings

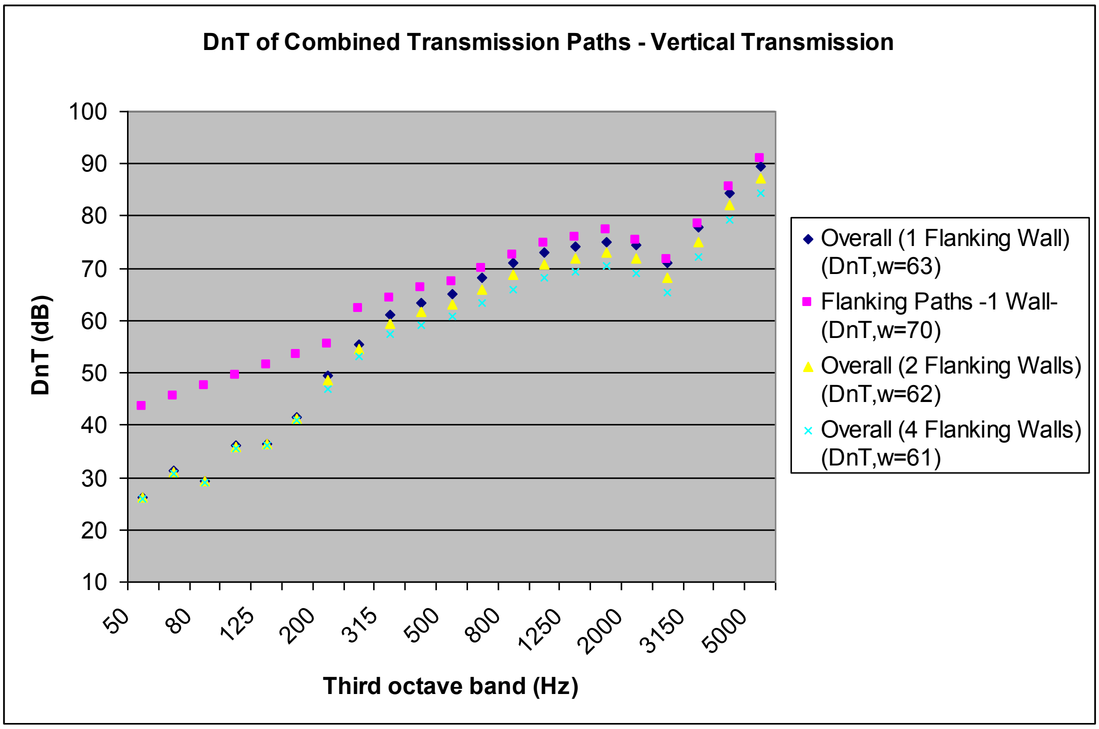


Figure 42(d). Combined airborne vertical transmission for 2 x 20 mm particleboard raft on 13 mm Bradford Quietel fibreglass board on basic floor with no floor coverings

Figure 42. 2 x 20 mm particleboard raft on 13 mm Bradford Quietel fibreglass board – airborne sound transmission.

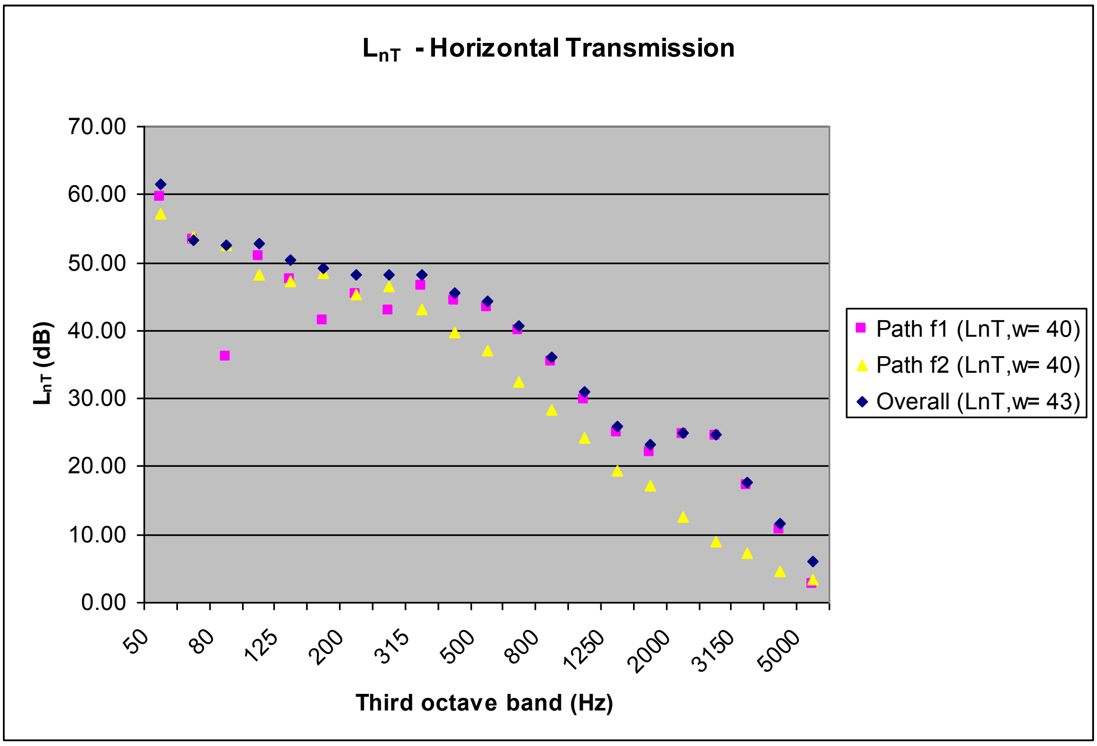


Figure 43(a). Impact horizontal transmission for 2 x 20 mm particleboard raft on 13 mm Bradford Quietel fibreglass board on basic floor with no floor coverings

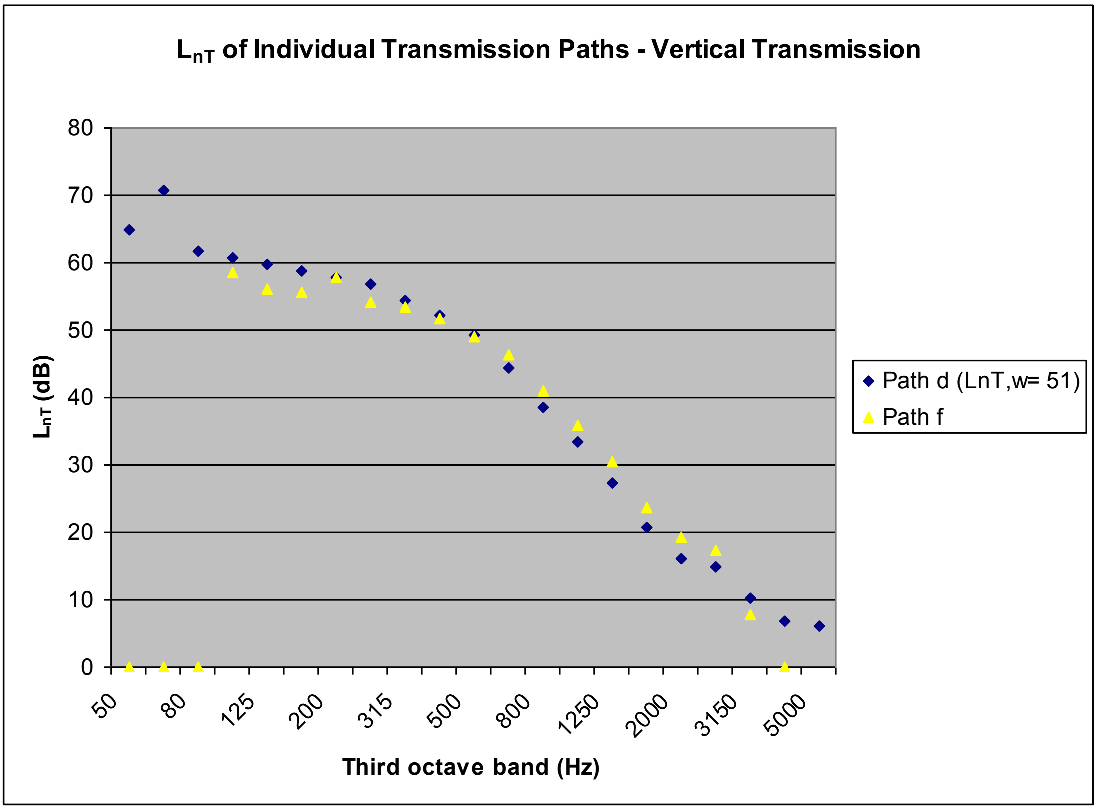


Figure 43(b). Individual impact vertical transmission for 2 x 20 mm particleboard raft on 13 mm Bradford Quietel fibreglass board on basic floor with no floor coverings

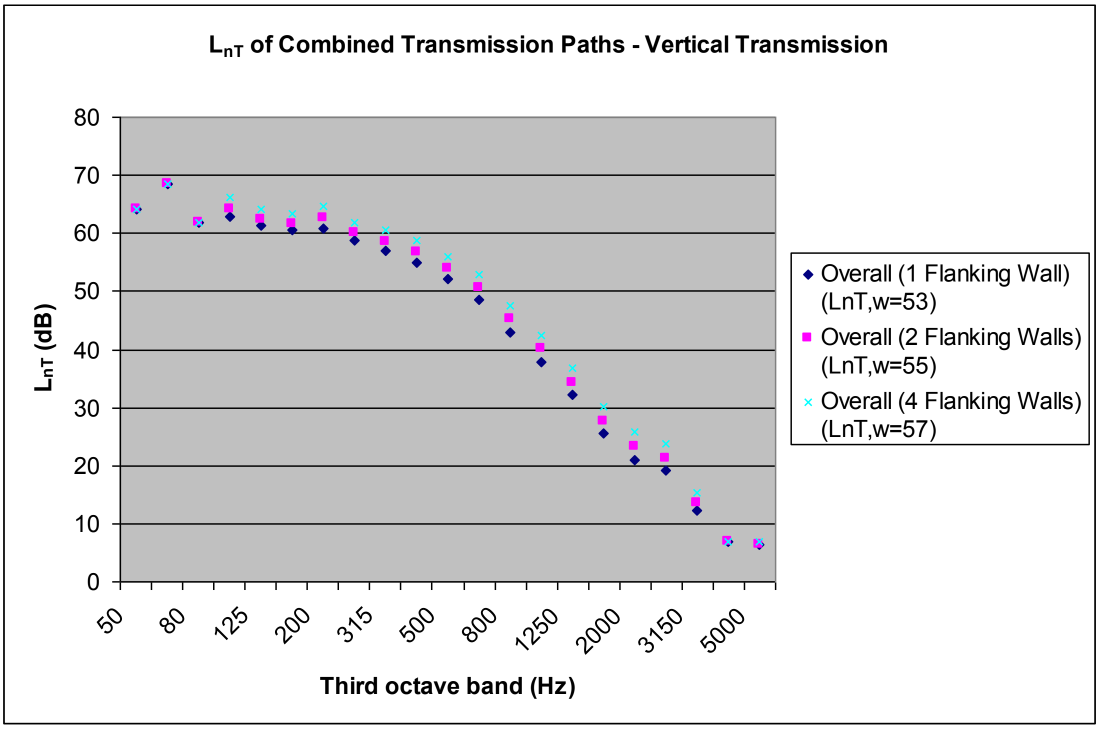


Figure 43(c). Combined impact vertical transmission for 2 x 20 mm particleboard raft on 13 mm Bradford Quietel fibreglass board on basic floor with no floor coverings

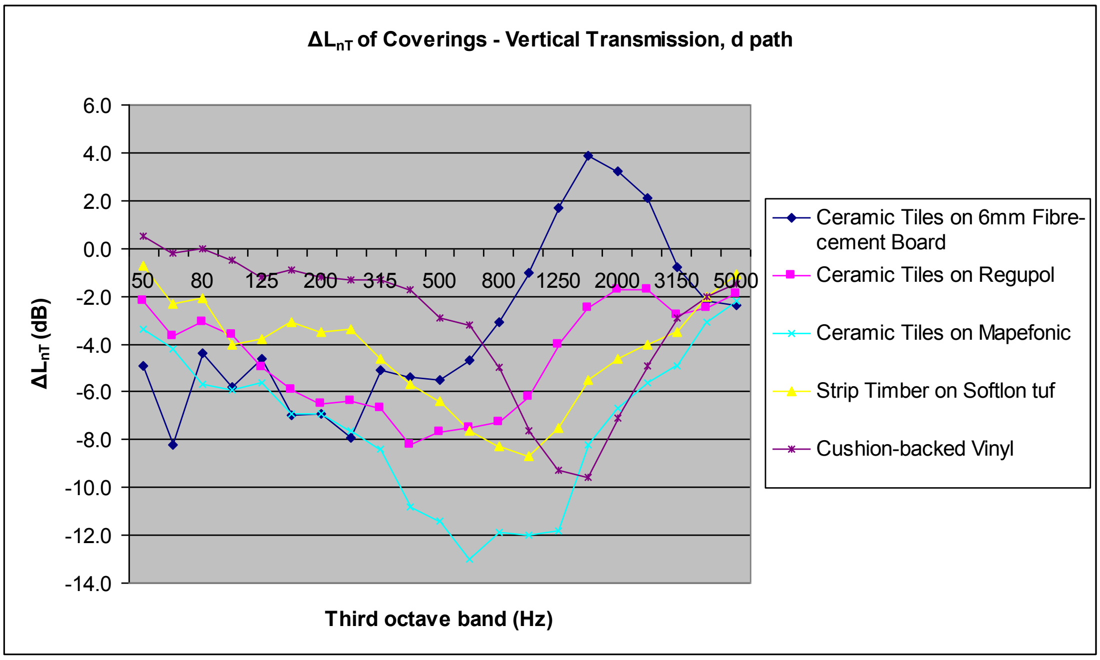


Figure 43(d). Impact vertical transmission for 2 x 20 mm particleboard raft on 13 mm Bradford Quietel fibreglass board on basic floor for all floor coverings

Figure 43. 2 x 20 mm particleboard raft on 13 mm Bradford Quietel fibreglass board – impact sound transmission with and without floor coverings.

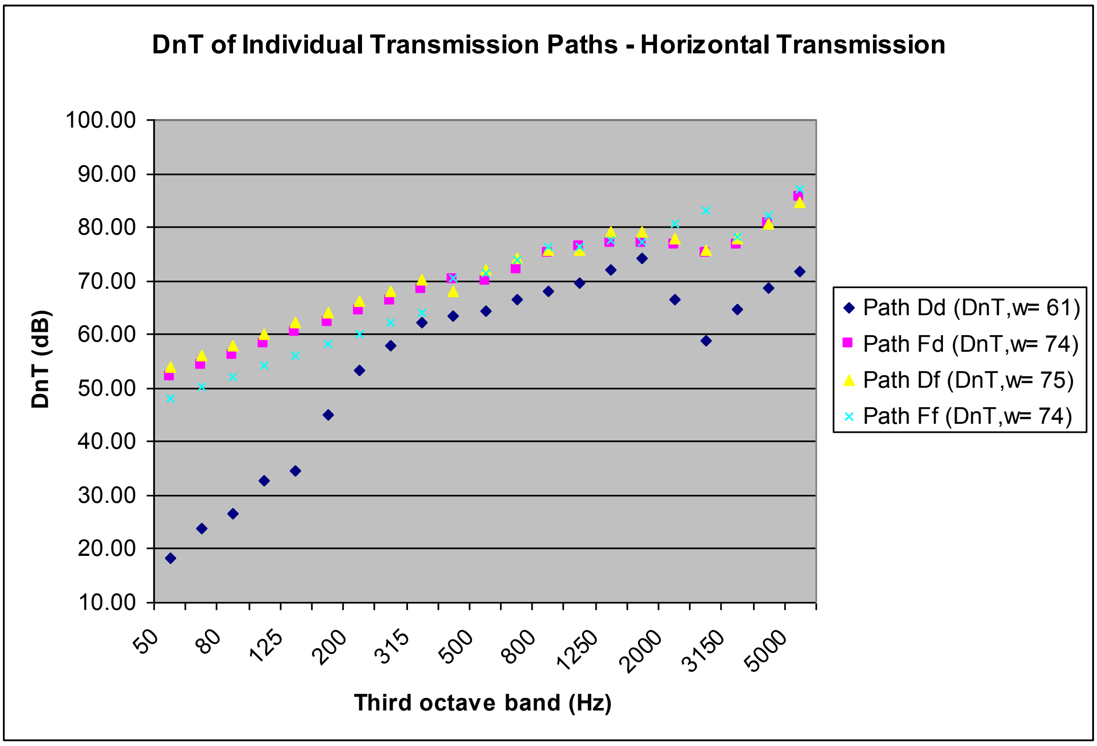


Figure 44(a). Individual airborne horizontal transmission for 2 x 20 mm particleboard raft on 10 mm Pink Batts Quietzone underlay on basic floor with no floor coverings

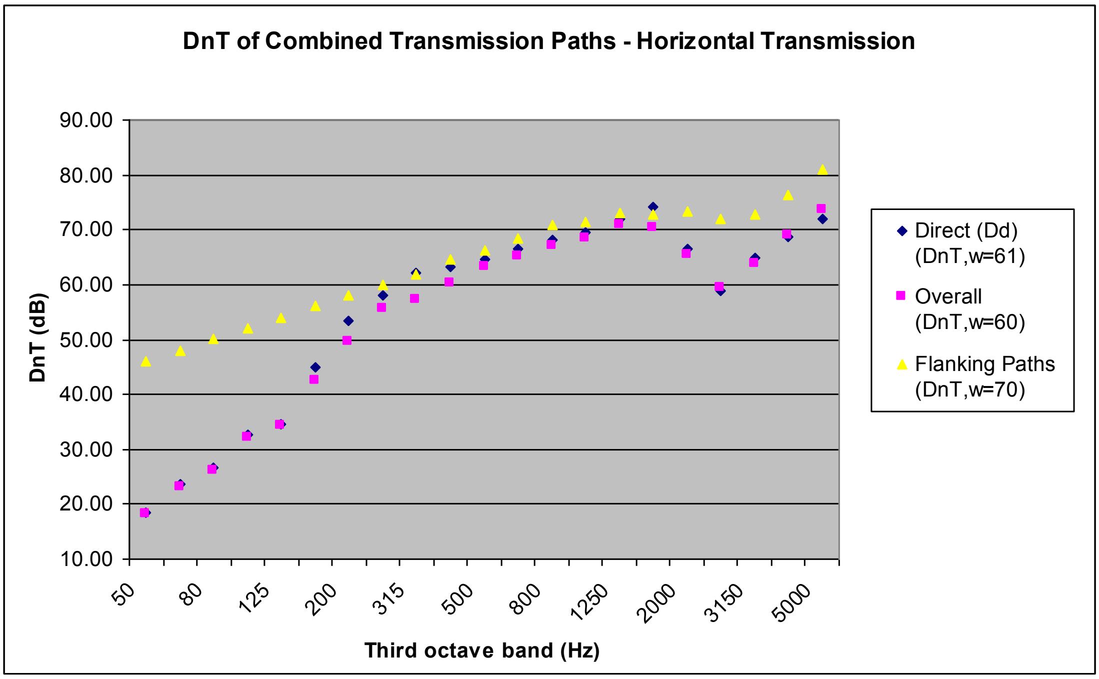


Figure 44(b). Combined airborne horizontal transmission for 2 x 20 mm particleboard raft on 10 mm Pink Batts Quietzone underlay on basic floor with no floor coverings

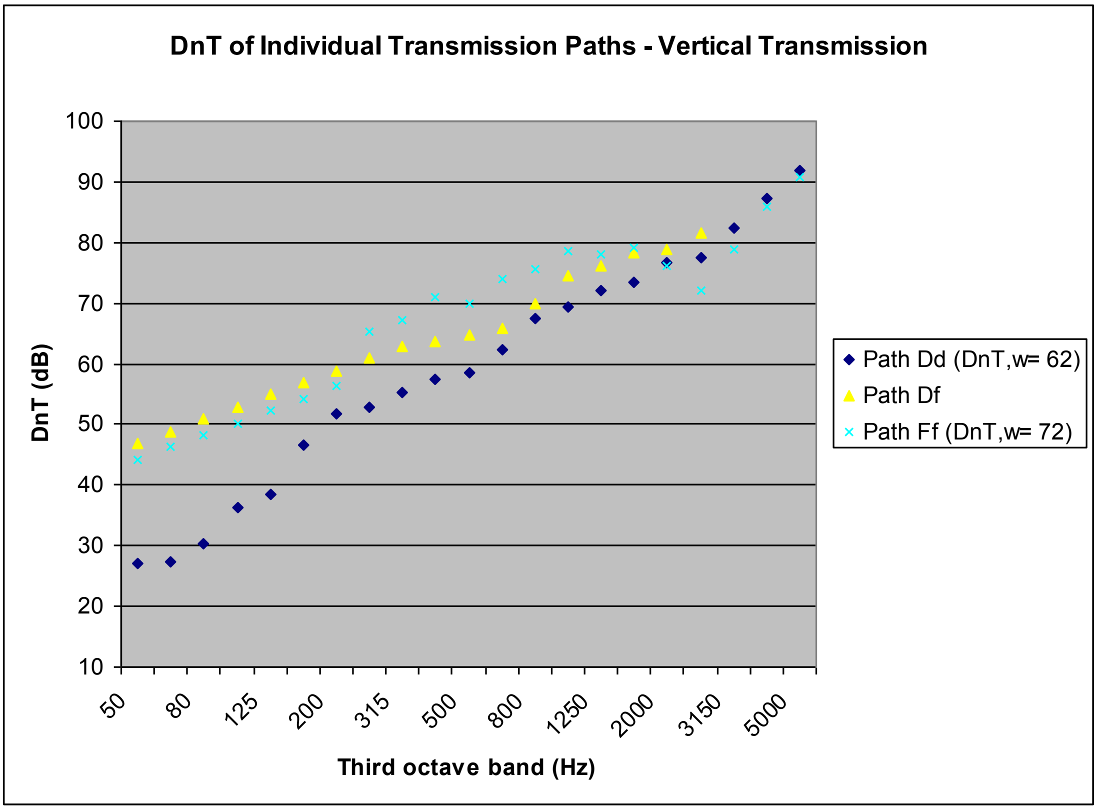


Figure 44(c). Individual airborne vertical transmission for 2 x 20 mm particleboard raft on 10 mm Pink Batts Quietzone underlay on basic floor with no floor coverings

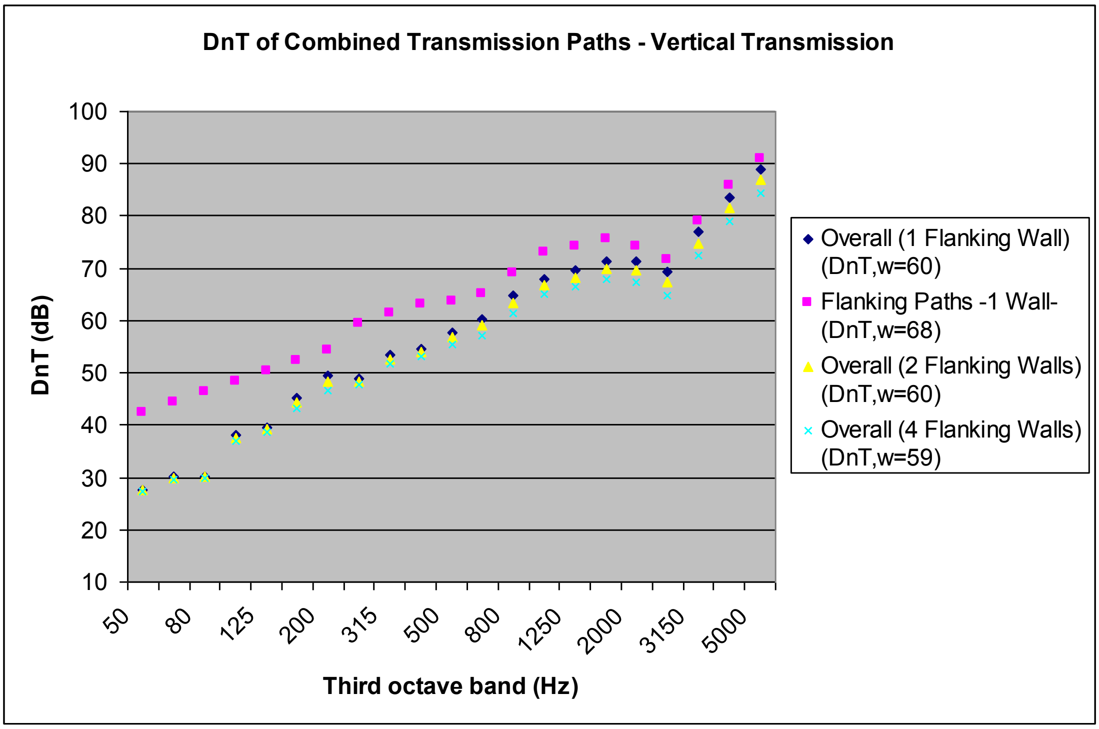


Figure 44(d). Combined airborne vertical transmission for 2 x 20 mm particleboard raft on 10 mm Pink Batts Quietzone underlay on basic floor with no floor coverings

Figure 44. 2x20 mm particleboard raft on 10 mm Pink Batts Quietzone underlay – airborne sound transmission.

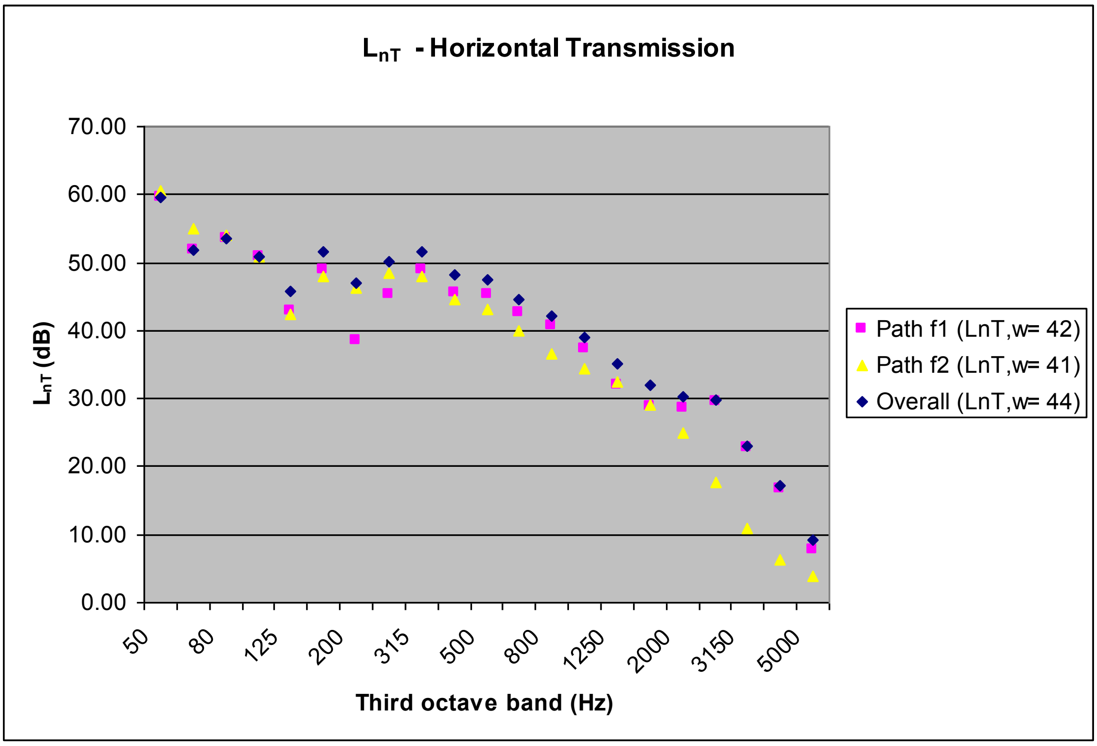


Figure 45(a). Impact horizontal transmission for 2 x 20 mm particleboard raft on 10 mm Pink Batts Quietzone underlay on basic floor with no floor coverings

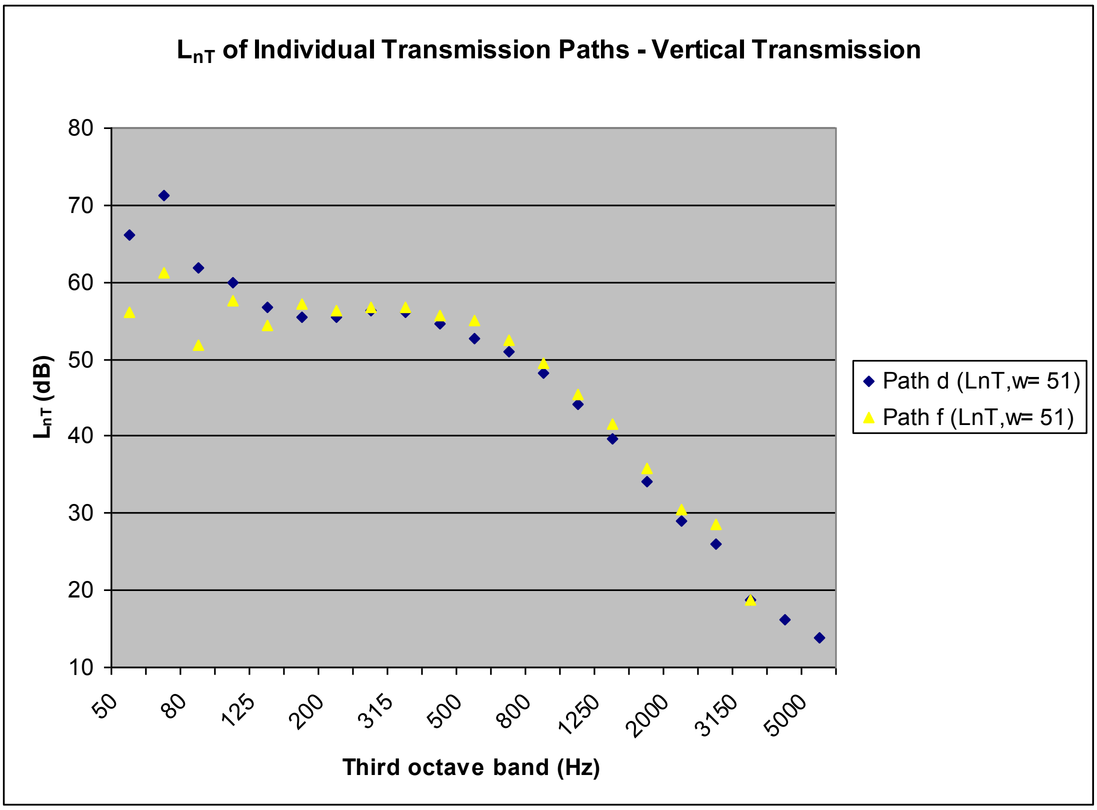


Figure 45(b). Individual impact vertical transmission for 2 x 20 mm particleboard raft on 10 mm Pink Batts Quietzone underlay on basic floor with no floor coverings

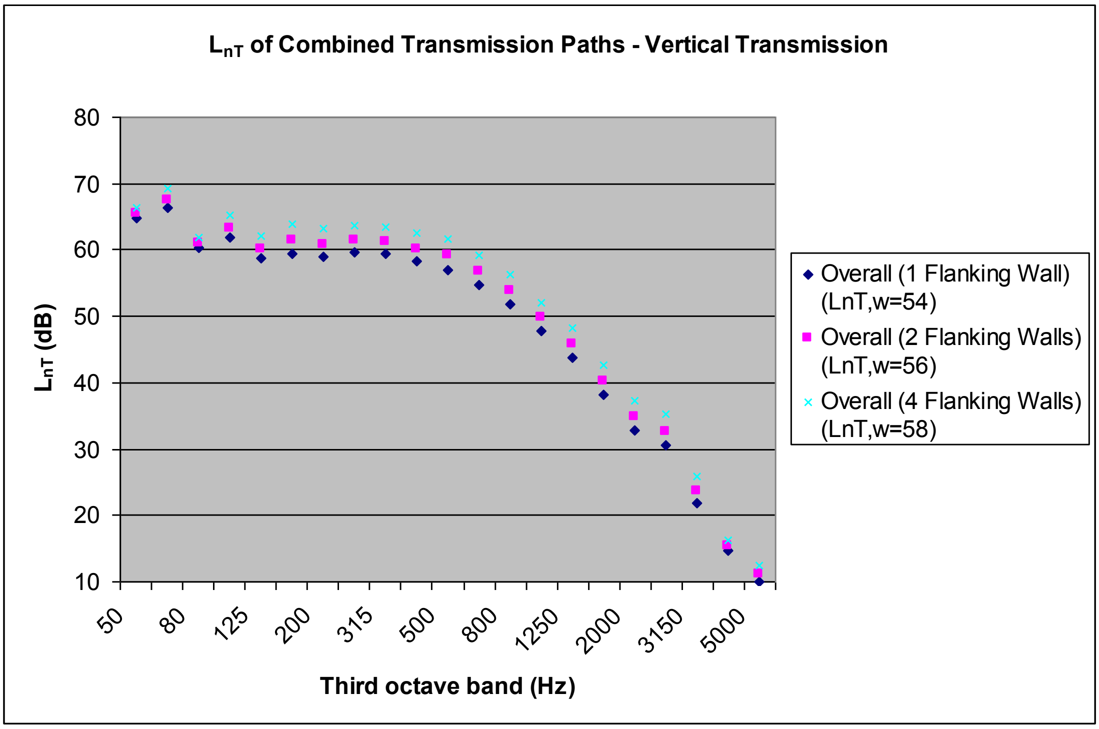


Figure 45(c). Combined impact vertical transmission for 2 x 20 mm particleboard raft on 10 mm Pink Batts Quietzone underlay on basic floor with no floor coverings

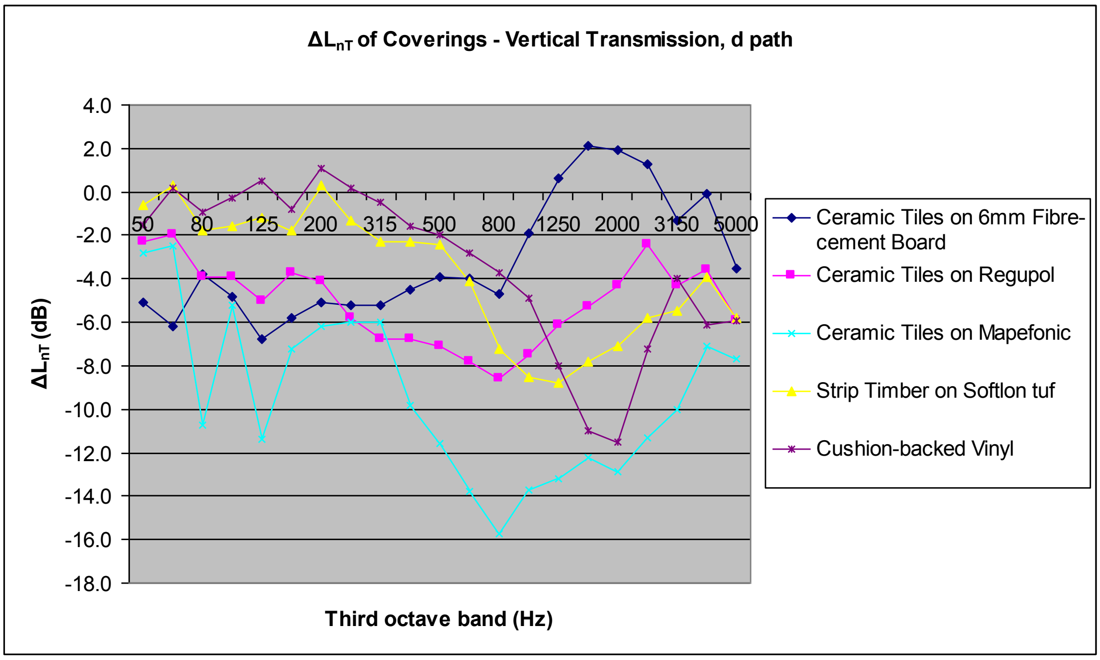


Figure 45(d). Impact vertical transmission for 2 x 20 mm particleboard raft on 10 mm Pink Batts Quietzone underlay on basic floor for all floor coverings

Figure 45. 2x20 mm particleboard raft on 10 mm Pink Batts Quietzone underlay – impact sound transmission with and without floor coverings.

APPENDIX C FIRE TESTING

C.1 Introduction

Three fire resistance tests were performed to determine whether the wall/floor and joint systems developed in the acoustic investigation would provide an acceptable degree of fire resistance.

The first two of these tests were undertaken on the BRANZ pilot furnace and the third on the main test furnace. The internal dimensions of the pilot furnace are 2200 mm long by 1050 mm wide and the internal dimensions of the main furnace are 4000 mm long by 3000 mm wide.

In the two pilot fire tests, sections of wall were constructed above and below a section of floor, for which the joists spanned across the short direction of the furnace. This allowed a portion of wall, floor and the joints to be exposed to furnace heating as shown in Figure 46. Failure was when the fire test criteria was exceeded for the floor, walls or the wall/ceiling joints.

The purpose of the main furnace test was to determine if the extra acoustic absorption and features required for acoustic design would cause an earlier failure of the floor system than the case with no acoustic provisions (i.e. just the 17 mm plywood flooring). The specimen was similar to the acoustic floor shown in Figure 47. The joists spanned across the short direction in the main furnace test and the floor was loaded to 1.2 kPa live load.

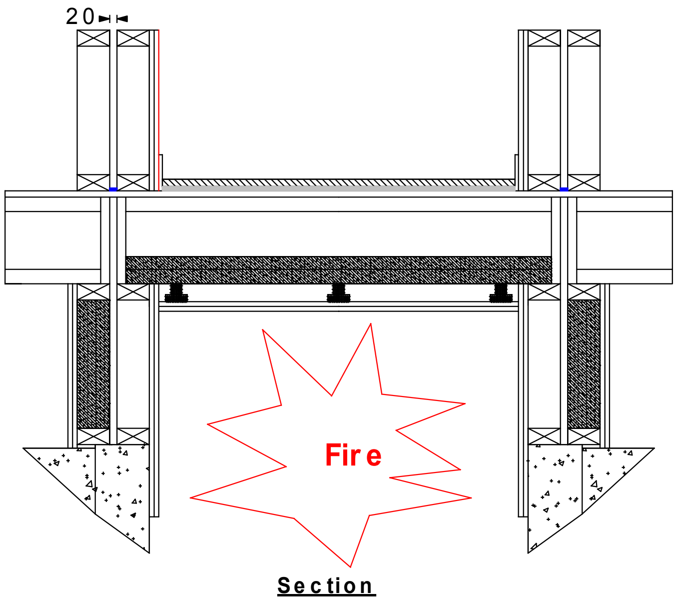
C.2 Summary of Pilot Fire Test 1

A photograph during construction is shown in Figure 48. The details of the construction are given in Figure 49 and Figure 50. The specimen consisted of a floor bounded below on two of its edges, with the 13 mm GIB Fyreline® lined walls described as lining option (2) in Section 5.1. The other two edges were sealed off. The I-beams created a compartment below the floor which was exposed to the furnace temperatures.

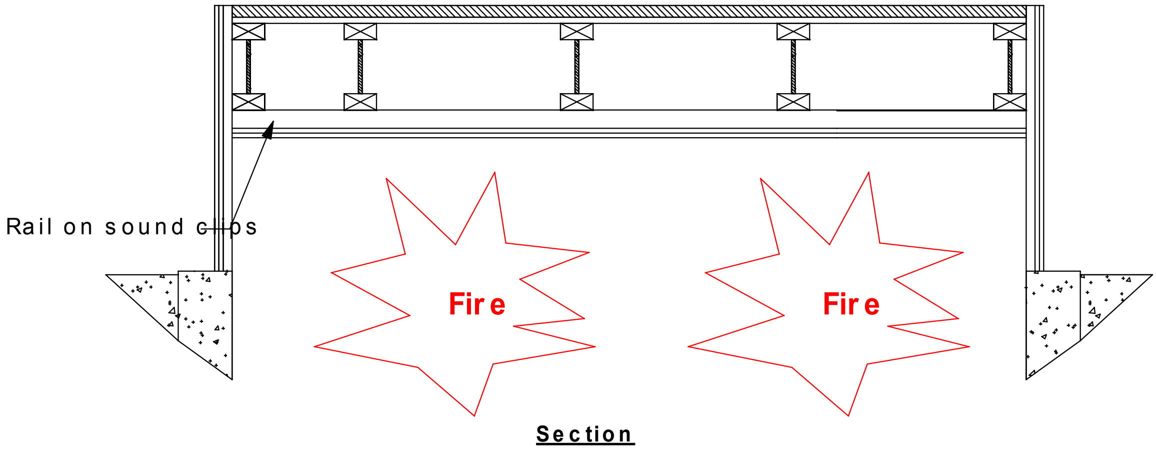
The specimen was built so that a comparison could be made between the behaviour of the basic floor (i.e. bare 17 mm plywood floor) and Acoustic Floor 5 as described in Section 5.1, which was the basic floor plus a raft of two layers of 20 mm particleboard floating on 13 mm CSR Bradford Quietel fibreglass board. The 17 mm plywood floor continued through the joint between the two elements of the individual walls on both sides of the furnace. The exposed ends of the specimen were blanked off with two layers of 13 mm GIB Fyreline® board.

The test continued until just less than 90 minutes when fire broke through the 17 mm plywood of the basic floor (Figure 51). An analysis of test thermocouples indicated that the fire resistance of the Acoustic Floor 5 was better than the basic floor. Both indicated a fire resistance greater than 60 minutes.

Thus, the recorded temperature data for the construction details tested indicated that the fire resistance of the basic floor ceiling system is not prejudiced by the addition of the acoustic features up to a period of at least 60 minutes.



(a) Cross-sectional view No 1 of test arrangement



(b) Cross-sectional view No 2 (orthagonl direction) of test arrangement

Figure 46. General views of pilot fire tests

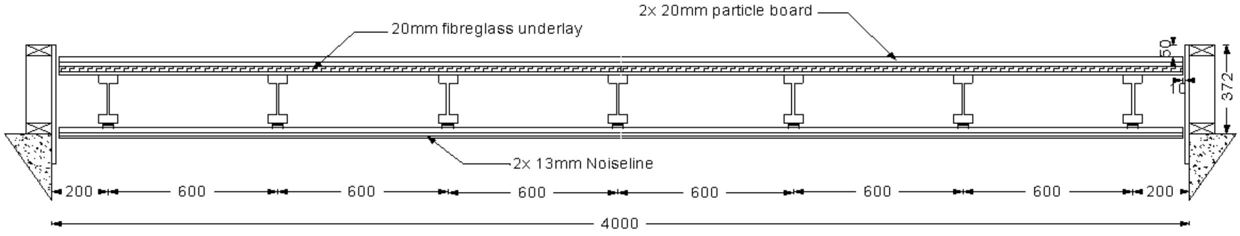
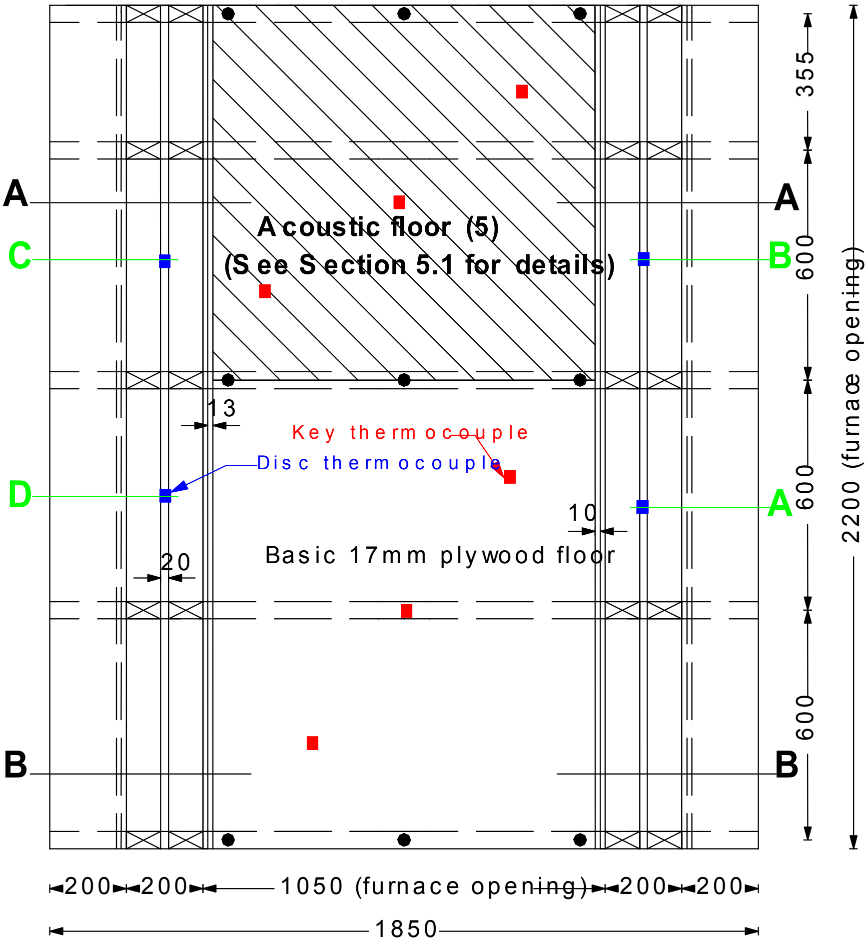


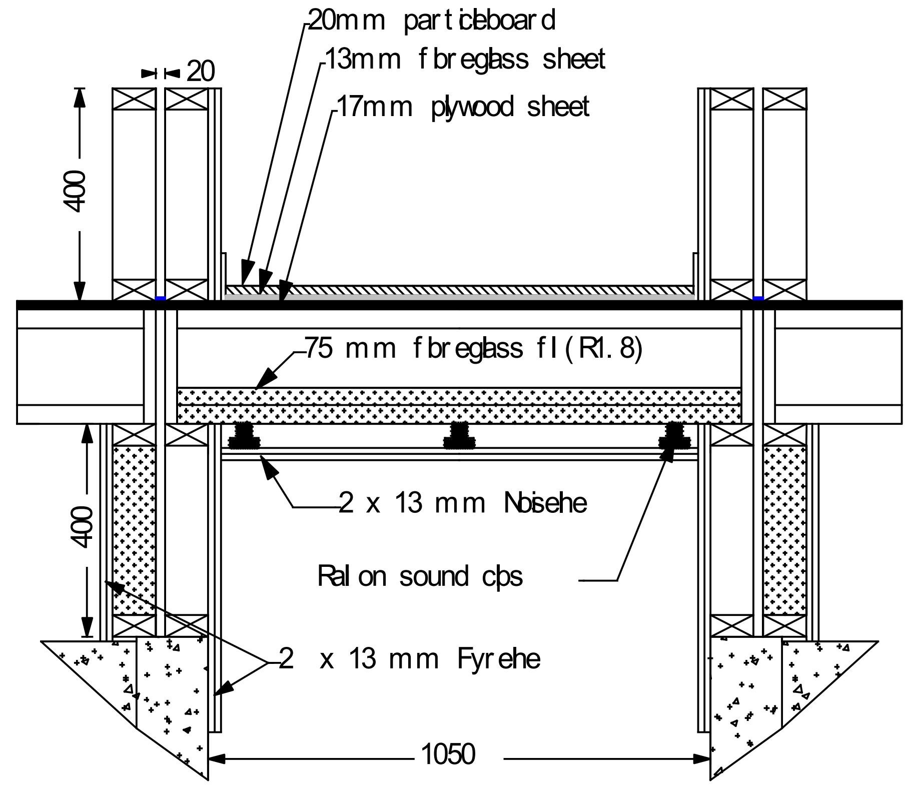
Figure 47. Cross section of floor/ceiling system in the main furnace

Figure 48. Photograph during construction of Pilot Fire Test Specimen 1

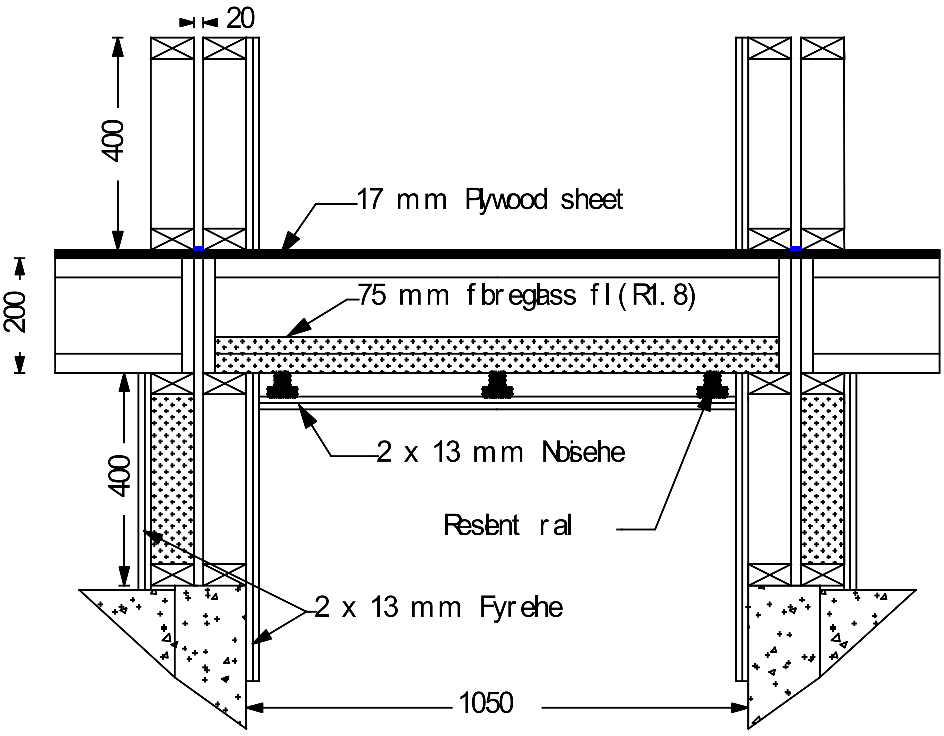


Note, A to D are thermocouples

Figure 49. Plan view of Pilot Fire Test Specimen 1



Section A-A (See Fig 49 for location)



Section B-B (See Fig 49 for location)

Figure 50. Cross sections through Pilot Fire Test Specimen 1

Figure 51. Pilot Fire Test Specimen 1 when fire broke through the floor

C.3 Summary of Pilot Fire Test 2

This tested additional acoustic features. The objectives were to evaluate the effect on the fire resistance of continuous and discontinuous 17 mm plywood floors at the junction with different acoustic walls on the sides. At the side wall-to-ceiling junction the two layers of 13 mm GIB Noiseline® ceiling was installed first with a 35 x 35 x 0.55 mm angle along the upper surface edge and in turn fixed at 600 centres at the studs. Walls of one layer of 13 mm and two layers of 10 mm GIB Fyreline® were installed against the downward side of the angle.

The upper surface of the floor was divided into four sectors in order to evaluate all combinations. Two of the four had the single layer of 17 mm plywood and the other two sectors had the additional covering of the Acoustic Floor 5 as per Pilot Fire Tests 1.

Details of the test specimen set up are given in Figure 52 and Figure 53.

The recorded temperatures indicated that the fire resistance of the basic floor ceiling system was not prejudiced by the addition of the acoustic features up to a period of at least 60 minutes.

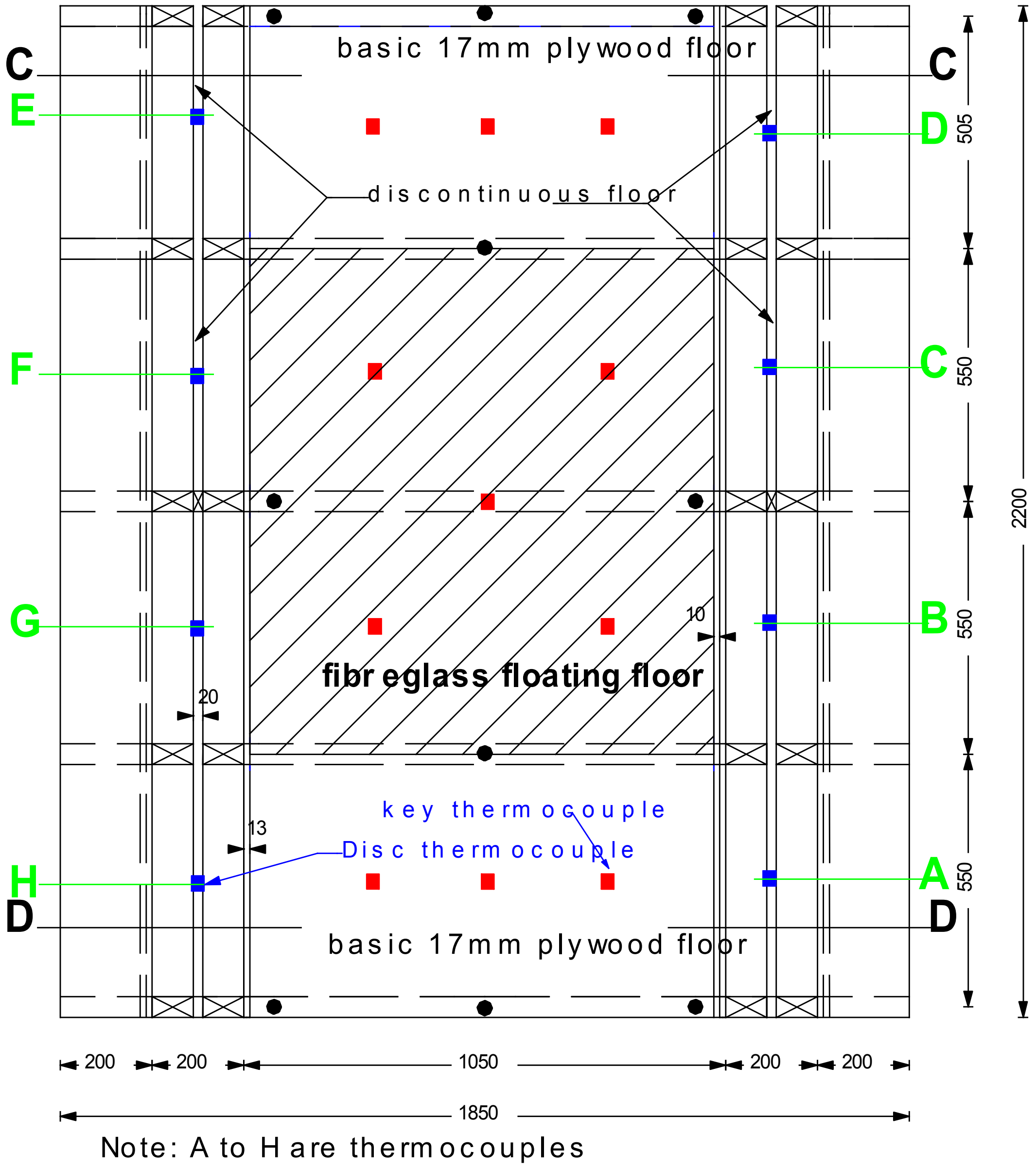
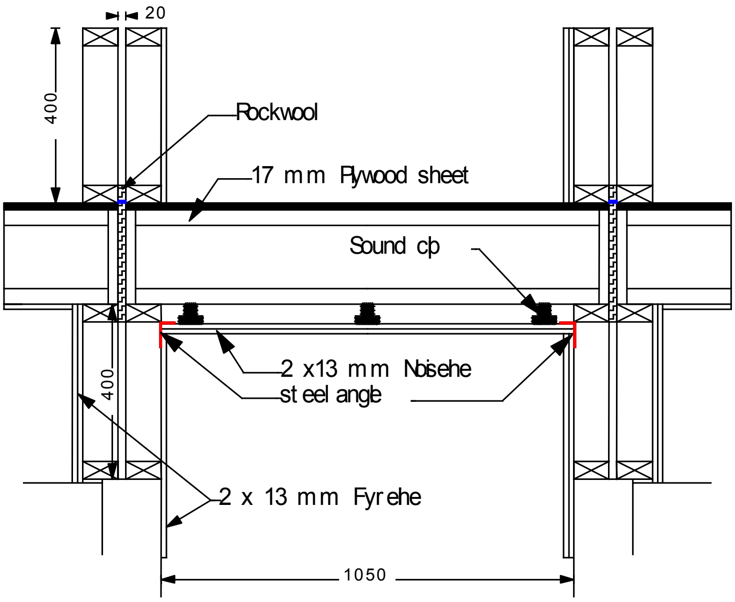
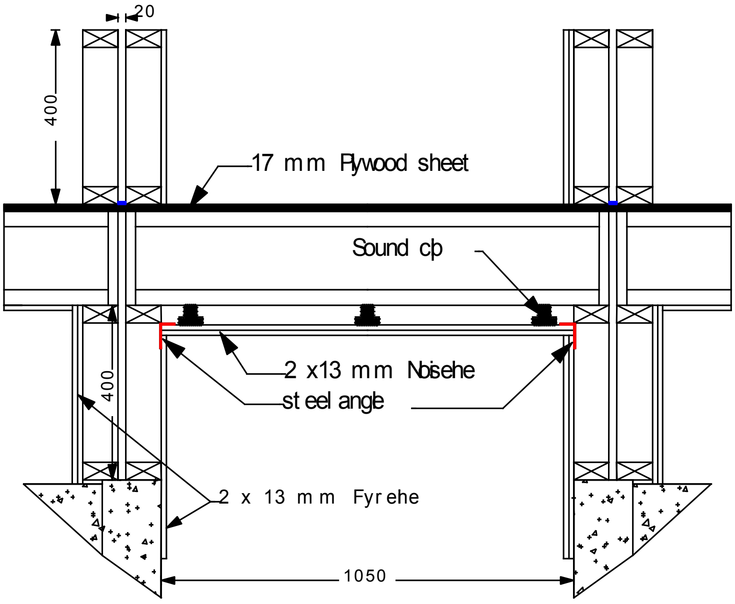


Figure 52. Plan view of Pilot Fire Test Specimen 2



Side Elevation C-C (See Fig 52 for location)



Side Elevation D-D (See Fig 52 for location)

Figure 53. Cross sections through Pilot Fire Test Specimen 2

C.4 Summary of Main Furnace Fire Test

For this test the floor/ceiling system had two layers of 13 mm GIB Noiseline® ceiling attached to 200 mm deep timber I-joists via sound clips and rails (Figure 47). The joists were covered on the upper side with 17 mm plywood, 20 mm rigid fibreglass and two layers of 20 mm particleboard (i.e. Acoustic Floor 5 described in Section 5.1). The flooring assembly was then loaded to 1.2 kPa for fire testing.

The fire resistance of the loadbearing acoustic floor/ceiling system under simulated live loading conditions was at least 60 minutes. It was determined that this had not been prejudiced by the acoustic features.

C.5 Detailed Results of Pilot Fire Test 1

The test followed the time-temperature curve in Figure 54 and continued until just less than 90 minutes when fire broke through the plain 17 mm plywood floor as shown in Figure 59.

The recorded temperatures within the specimen are shown in Figure 54 to Figure 58 and indicate that the fire resistance of 60 minutes has not been prejudiced.

The floor surface temperature in Figure 55 indicates a marginally more rapid rise on the basic floor compared with the fibreglass form. This is because the additional insulating effect of the fibreglass and particleboard delays the temperature rise on the upper surface. A parallel effect is that more heat is trapped within the system resulting in higher temperatures on the 17 mm plywood such that it chars more rapidly under the insulating fibreglass. The photograph of Figure 60 (taken post test) shows the area of Integrity failure where flaming was initiated at the junction of the two floor surfaces.

Temperatures recorded at the top of the continuous floor diaphragm within the cavity of the double-frame acoustic wall evaluated the relative effectiveness of the two wall/ceiling junctions below. These are discussed in the three paragraphs below.

Both the two-layer 10 mm and 13 mm thick GIB Fyreline® wall to 2 x 13 mm GIB Noiseline® junctions performed satisfactorily to 60 minutes. After 60 minutes a marginal and non-significant difference did manifest itself where temperatures increased at a slightly faster rate for the 10 mm lined wall as shown in Figure 56, and this was for both the basic and fibreglass floor. The discontinuous nature of the temperature at point B (see Figure 49) was attributed to a minor thermocouple fault at 70 minutes and it can be assumed that the temperature continued to rise in a roughly straight line up to 81 minutes when the thermocouple gave a more consistent reading.

The temperatures inside the floor/ceiling cavity in Figure 57 show no variations up to and just beyond 60 minutes indicating that the ceiling and wall linings remain attached. Subsequently, in the range of 65 to 70 minutes, rapid temperature rises occur and increases up to 800-900°C indicated substantial loss of the wall and ceiling lining and exposure to furnace conditions.

The temperatures between boundary joists in the wall cavities between floors in Figure 58 show that for the 2 x 10 mm lining of GIB Fyreline®, temperatures rapidly increase from 44 minutes. If it is considered that timber begins to char at 300°C then no charring at thermocouple locations occurred until 60 minutes had passed. For the 13 mm lined wall, rapid temperature rise beyond 100°C does not occur until after 70 minutes' exposure.

In summary, there is no indication that the fire resistance of the basic floor ceiling system is prejudiced by the addition of the acoustic features up to a period of at least 60 minutes.

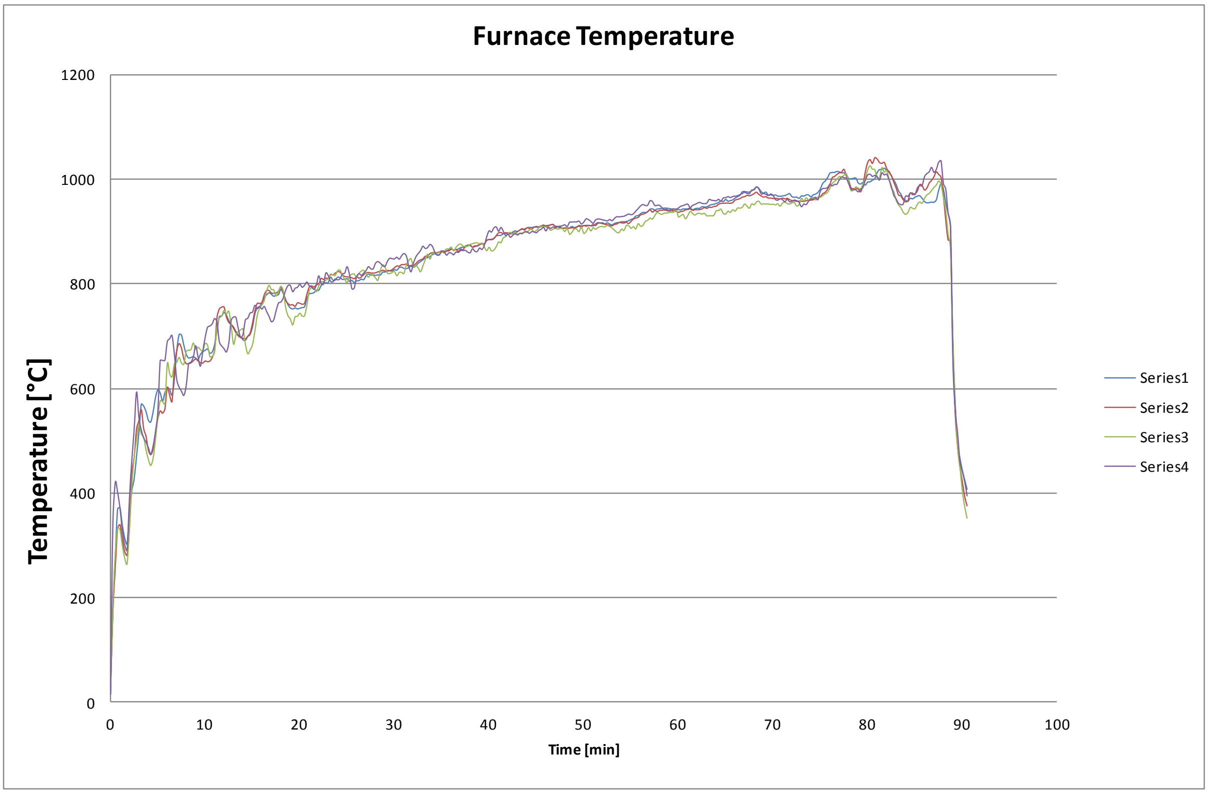


Figure 54. Time-temperature exposure in Pilot Fire Test 1

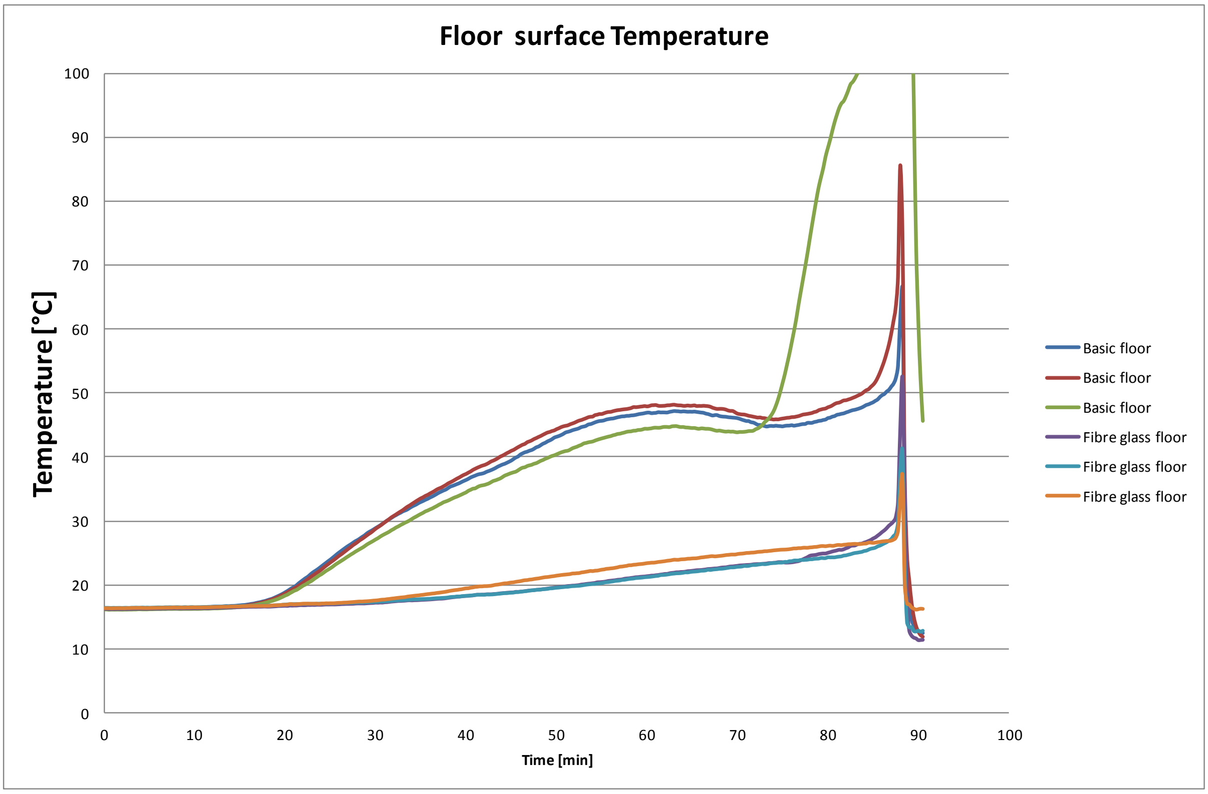


Figure 55. Floor surface temperature in Pilot Fire Test 1

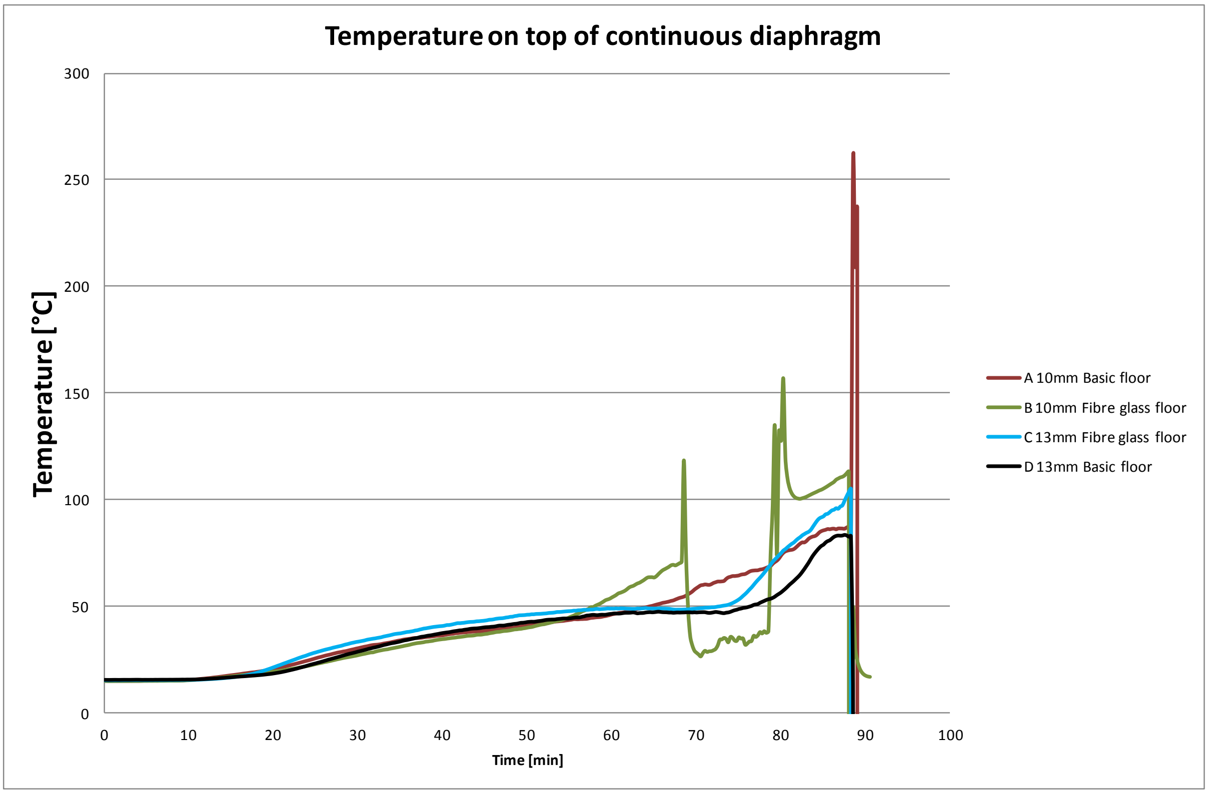


Figure 56. Temperature on top of continuous diaphragm in Pilot Fire Test 1

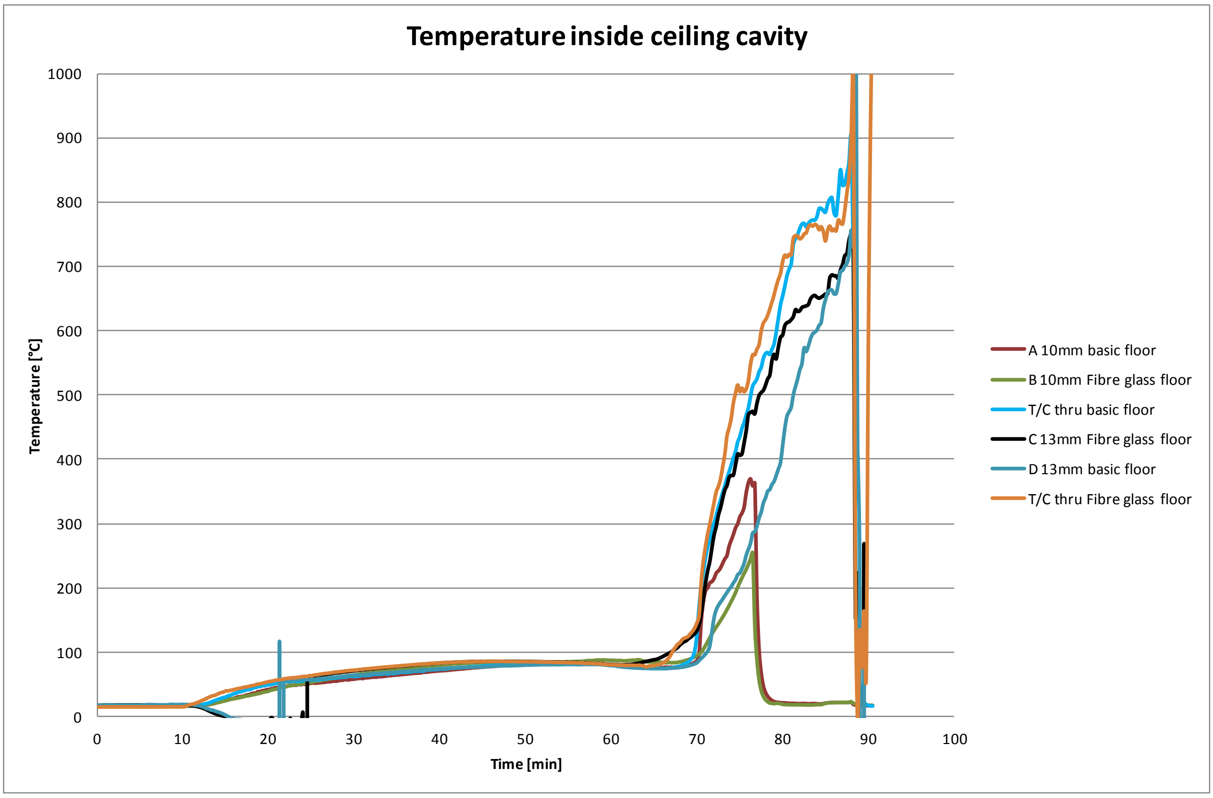


Figure 57. Temperature inside ceiling cavity in Pilot Fire Test 1

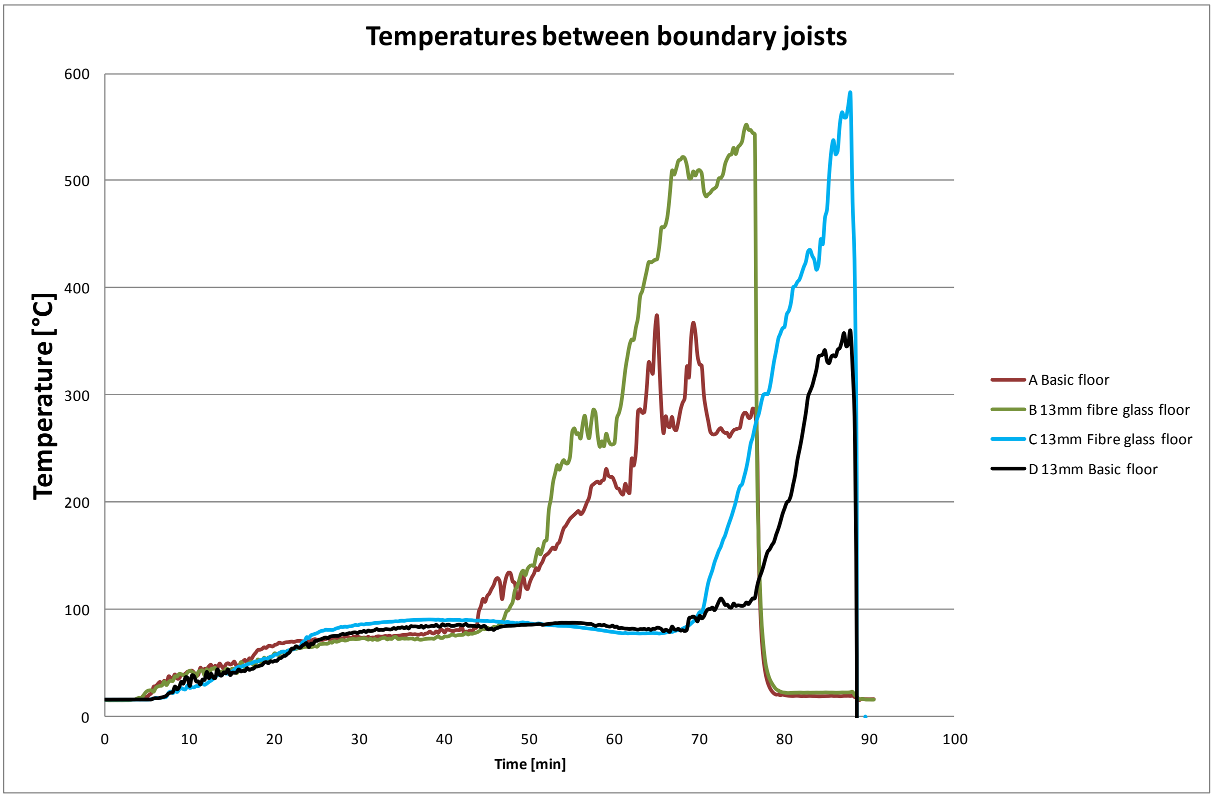


Figure 58. Temperature between boundary joists in Pilot Fire Test 1

Figure 59. Pilot Fire Test 1 when fire broke through the floor at about 89 minutes

Figure 60. Area of Integrity failure on floor surface in Pilot Fire Test 1

C.6 Detailed Results of Pilot Fire Test 2

This test specimen introduced further acoustic features (described in Section C.3) to investigate whether these prejudiced the original fire resistance. Details of the test specimen are given in Figure 52 and Figure 53.

The test results are evaluated on the basis of whether the acoustic provisions will prejudice the 60-minute fire rating when exposed to the fire test curve in Figure 61. The recorded temperatures within the specimen are shown in Figure 62 to Figure 65.

Considering the recorded temperature data up to 60 minutes there is no indication that the 60-minute fire resistance has been prejudiced.

The floor surface temperature in Figure 62 indicates a marginally more rapid rise on the basic floor compared with the fibreglass form. This is because the additional insulating effect of the fibreglass and particleboard delays the temperature rise on the upper surface. A parallel effect is that more heat is trapped within the system resulting in higher temperatures on the 17 mm plywood such that it chars more rapidly under the insulating fibreglass and eventually the region of Integrity failure is at the junction of the basic and fibreglass floor. The post-test photograph in Figure 66 shows the area under the fibreglass wool and 20 mm particleboard. In this test the plywood had not burnt through and there was no Integrity failure at the junction of the two floor surfaces as there was in Pilot Fire Test 1.

Temperatures recorded at the top of the continuous and discontinuous floor diaphragm within the cavity of the double-frame acoustic wall evaluated the relative effectiveness of the two wall/ceiling junctions below as well as the effect of continuity of the diaphragm. Both the two-layer 10 mm and 13 mm thick GIB Fyreline® wall to 2 x 13 mm GIB Noiseline® junctions performed satisfactorily to 60 minutes. After 60 minutes the same trend continued and no discernible difference between the 2 x 10 mm or 1 x 13 mm was noted. There was a marginal increase in temperature of 10-20°C for the discontinuous diaphragm above the 1 x 13 mm GIB Fyreline® lined wall as shown in Figure 63.

The temperatures inside the floor/ceiling cavity in Figure 64 show no variations up to and slightly beyond 60 minutes indicating that the ceiling and wall linings remain attached. Subsequently, in the range of 75 to 90 minutes, rapid temperature rises occur and increases up to 600-700°C indicated some loss of the wall and ceiling lining and the beginning of exposure to furnace conditions. This effect was not as marked as in Pilot Fire Test 1 and may be attributable to a better performance of the different fixing at the wall/ceiling junction giving more security to the ceiling lining. The ceiling below the floor with the fibreglass covering performed worse, due to more heat being trapped.

The temperatures between boundary joists in the wall cavities between floors in Figure 65 show an improvement compared with the results of Test 1. Temperatures below 300°C continue till about 75 minutes and then it is only for the continuous floor above the 2 x 10 mm wall. The boundary joists below the discontinuous floor are subjected to lower temperatures, but that may be attributable to the hot gases being able to escape further up the cavity in the double-framed wall limiting the temperature rise on the joists to below 100°C at the test end of 90 minutes.

Thus, there is no indication that the fire resistance of the basic floor ceiling system is prejudiced by the addition of the acoustic features up to a period of at least 60 minutes.

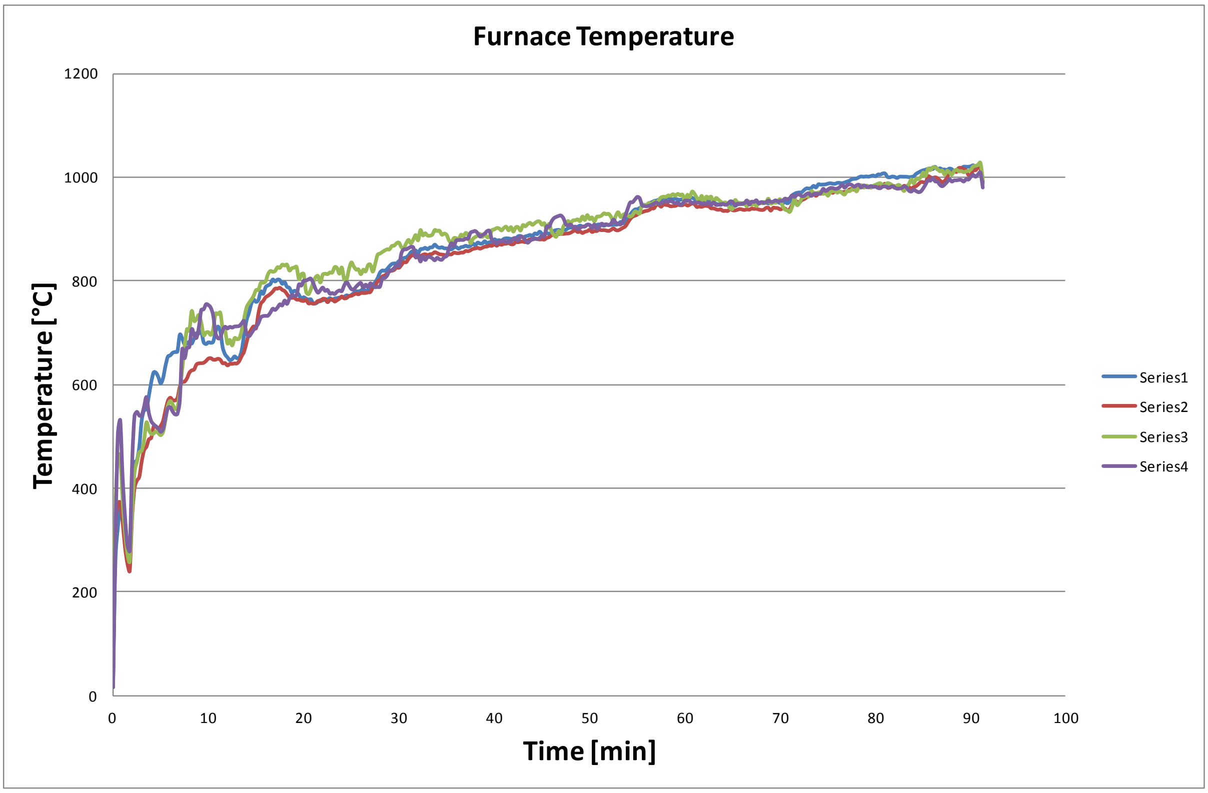


Figure 61. Time-temperature exposure in Pilot Fire Test 2

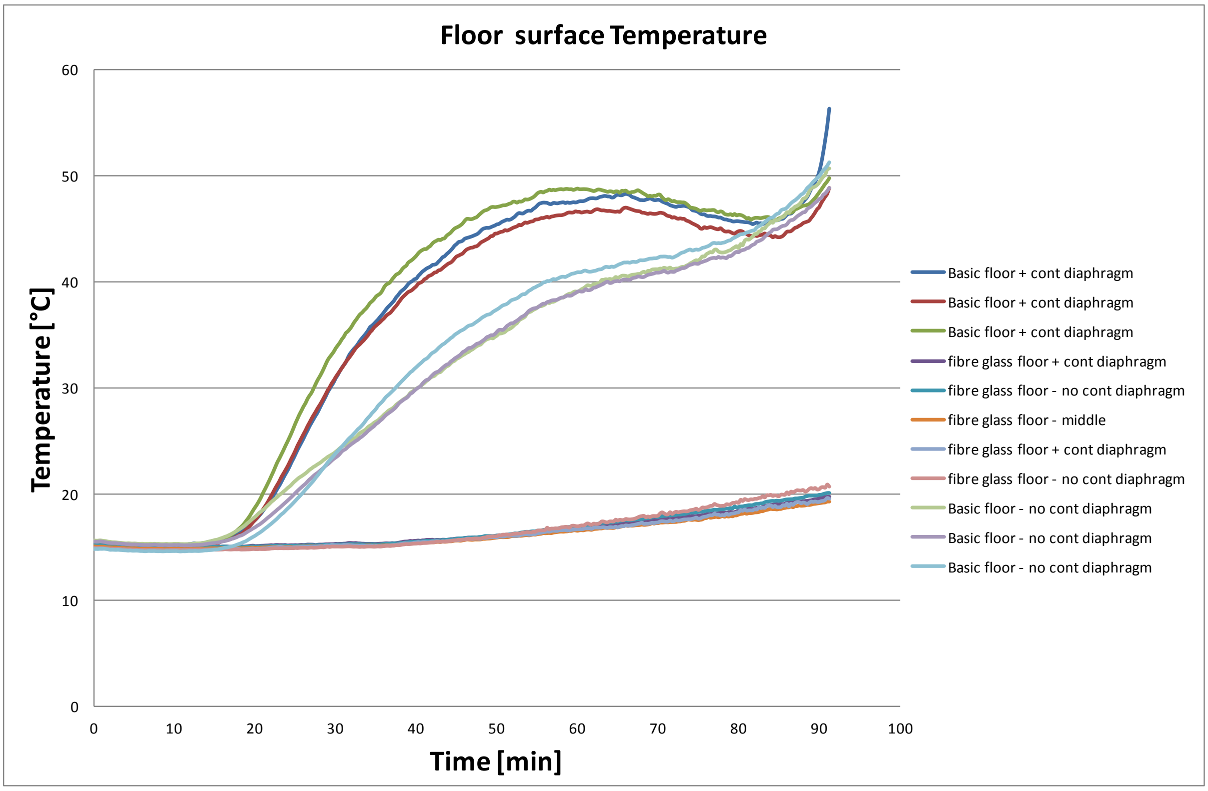


Figure 62. Floor surface temperature in Pilot Fire Test 2

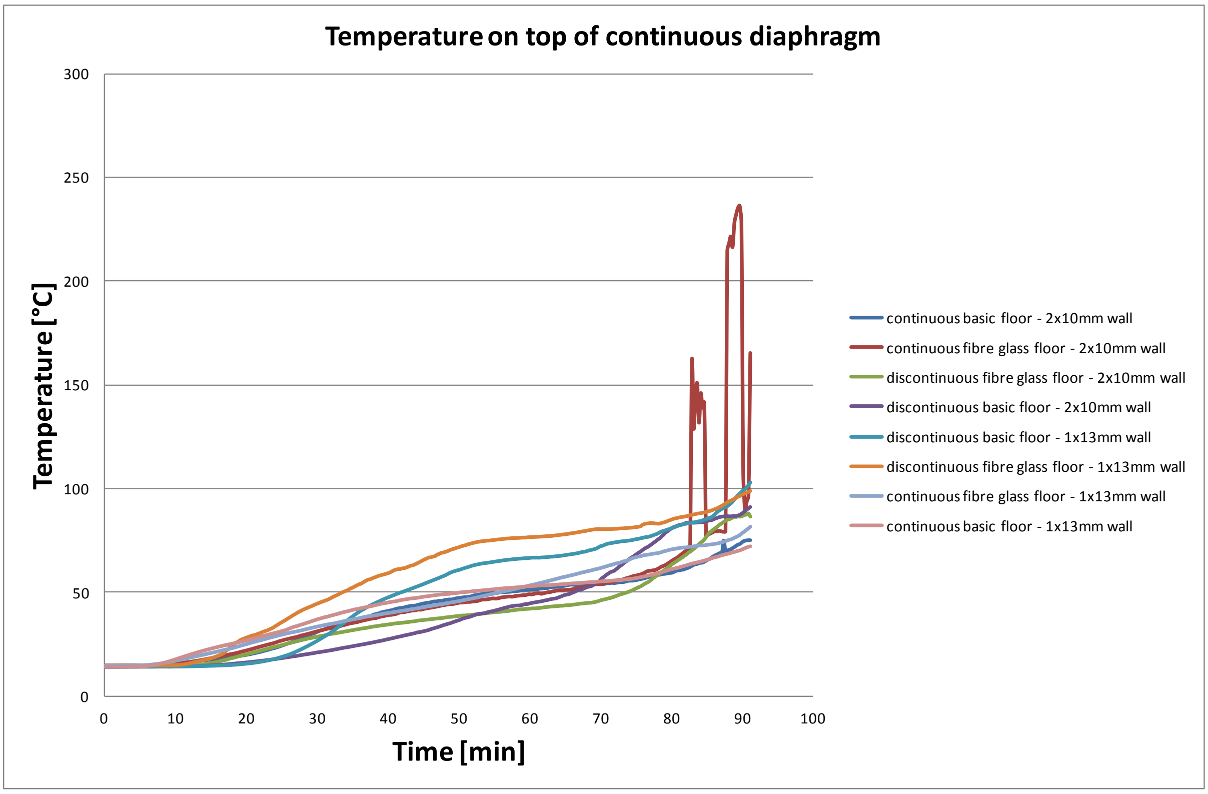


Figure 63. Temperature on top of diaphragm in Pilot Fire Test 2

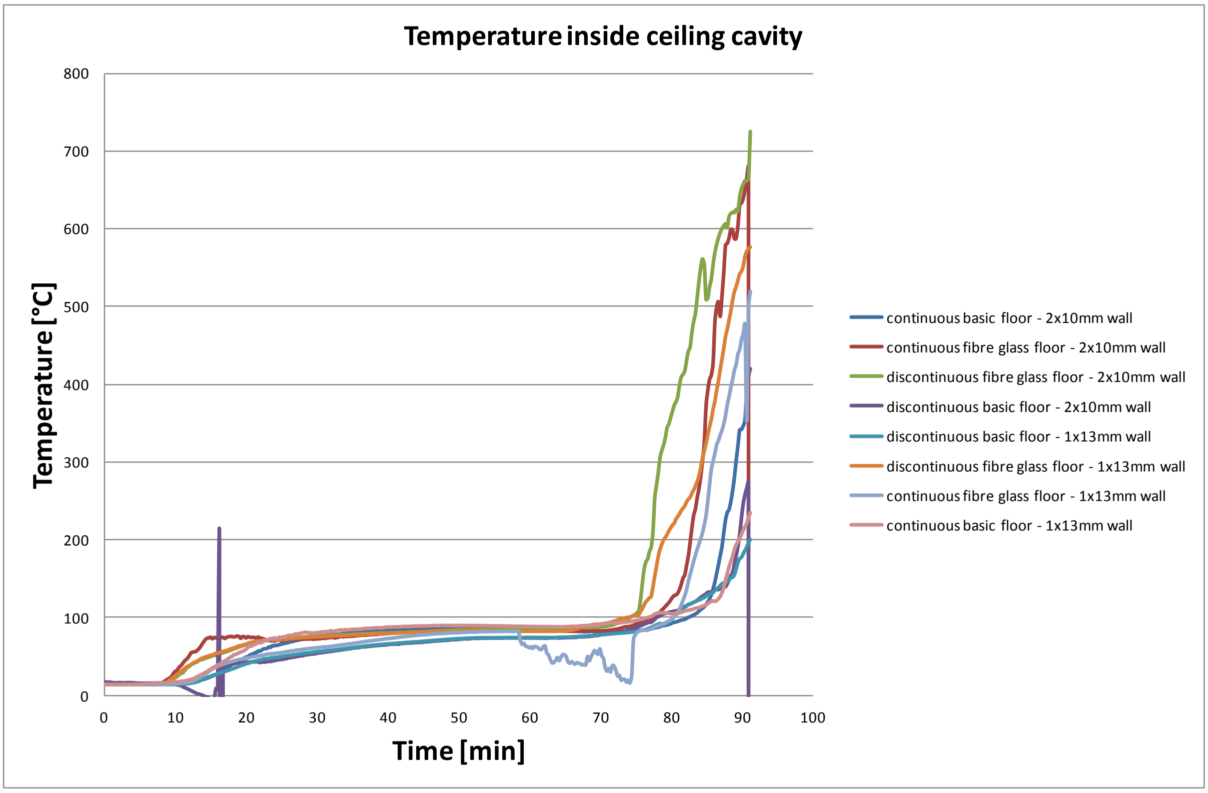


Figure 64. Temperature inside ceiling cavity in Pilot Fire Test 2

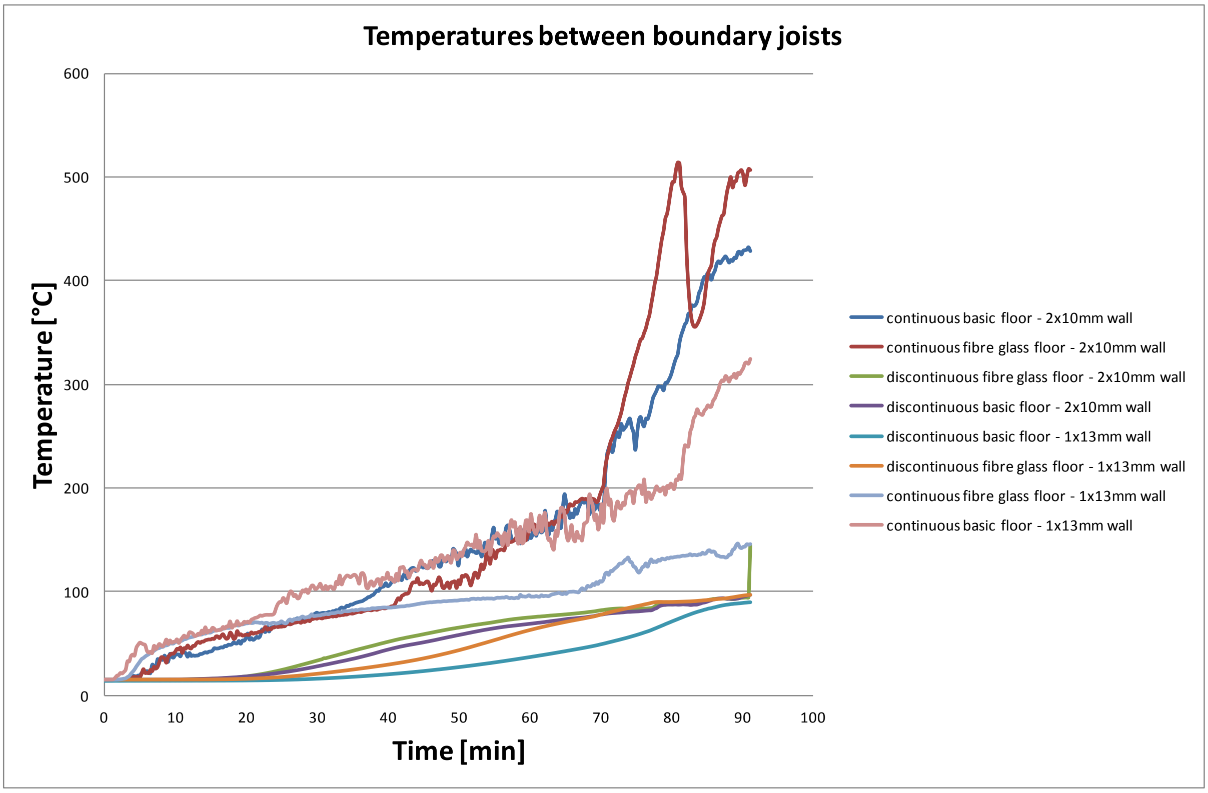


Figure 65. Temperatures between boundary joists in Pilot Fire Test 2

Figure 66. Area of Integrity failure on floor surface in Pilot Fire Test 2

C.7 Detailed Results of Main Furnace Fire Test

Details of the test specimen set up are given in Figure 47, Figure 67 and Figure 68 and the furnace temperature is presented in Figure 69.

The times of significant events in the 78-minute fire test are listed below:

- At seven minutes: the exposed paper facing had burnt off and the stopping was still intact.
- At 15 minutes: plaster stopping on joints had mostly fallen away, with only the white ash remaining, slight wrinkling and crazing of the gypsum surface was visible but no large cracks could be seen.
- At 24 minutes: stopping around perimeter of floor had fallen off over 75% of that visible in view port.
- At 48 minutes: there was a perceptible concave deflection on the top of the floor.
- At 57 minutes: on the exposed layer of ceiling some downward deflection between fixing points had established.
- At 59 minutes: the exposed layer was slumping down between fixing points (screws) with gaps between lining sheets opening up.
- At 60 minutes: the exposed lining (first layer) had started to fall off in small pieces.
- At 70 minutes: most of exposed layer had fallen off and the second layer had started to slump.
- At 75 minutes: a hole had formed in the second layer.
- At 77 minutes: the fibreglass Batts were visible and it appeared that the fibres were in the process of fusing into thicker masses.

The average temperatures for each thermocouple location A to E at the vertical locations within the floor/ceiling systems are presented in Figure 70 and Figure 71.

The average temperature rises across the location A to E in Figure 70 indicate the progressive destruction of the floor/ceiling assembly and correspond with the observations above.

The temperature (Ave 1) on the upper surface of the exposed layer of 13 mm GIB Noiseline® rises progressively to 600°C at 60 minutes at which time it was observed to be falling off. The next layer of 13 mm GIB Noiseline® on direct exposure to the furnace conditions commences a rapid rise in temperature (Ave 2) to the time it was observed to be falling off at about 75 minutes. Only at this time does the temperature (Ave 3 and 5) in cavity begin to rise. The temperature (Ave 4) within the web of the joists only reaches about 100°C at about the same time temperature on the outside increases past 300°C, the point when charring of the timber would be expected to commence.

The temperature rises in the upper part of the floor/ceiling (Ave 6, 7 and 8 in Figure 71) were below 100°C at the end of the test. The five key thermocouples stipulated by the standard for determining an insulation failure were only 14°C at this stage.

The deflection of the floor downwards under the floor loading of 1.2 kPa is shown in Figure 72. The floor steadily deflects downwards to about -10 mm at 70 minutes' fire exposure and then the rate of deflection increases in the period between 70 and 80 minutes to between -20 to -30 mm at which time the test was stopped.

Considering the recorded temperature data up to 60 minutes there is no indication that the 60-minute fire resistance been prejudiced.

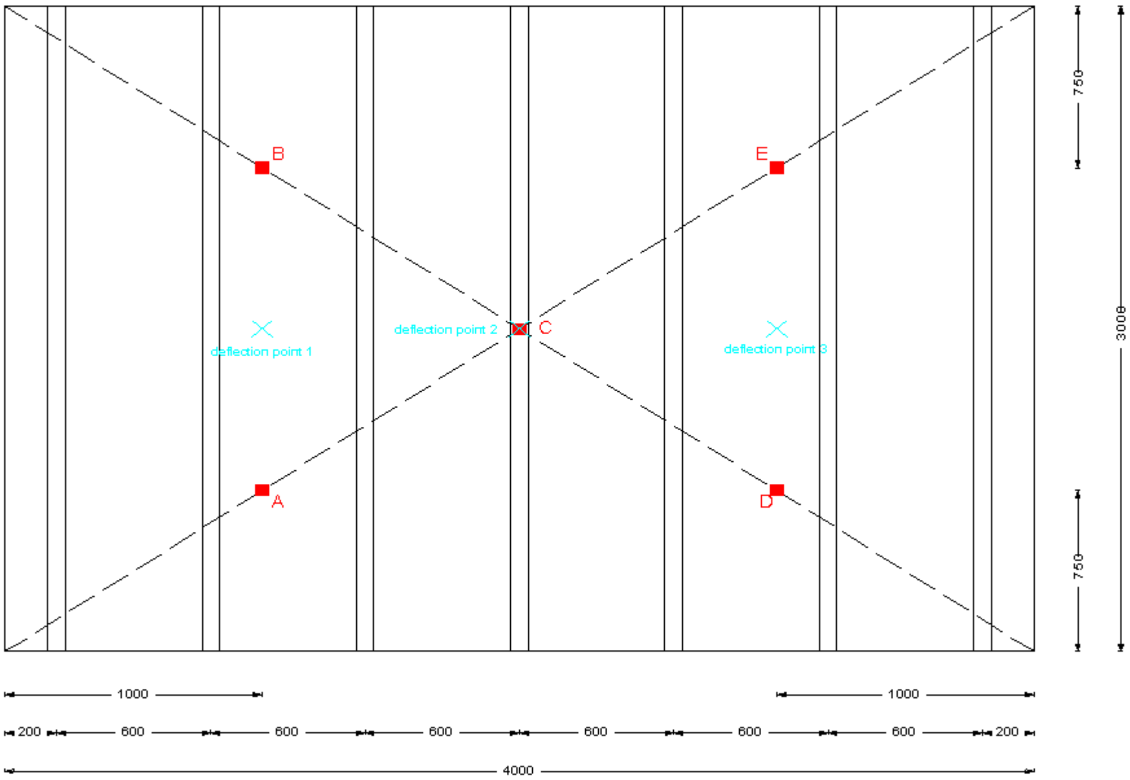


Figure 67. Plan view of floor/ceiling showing thermocouple and deflection locations in the main furnace test

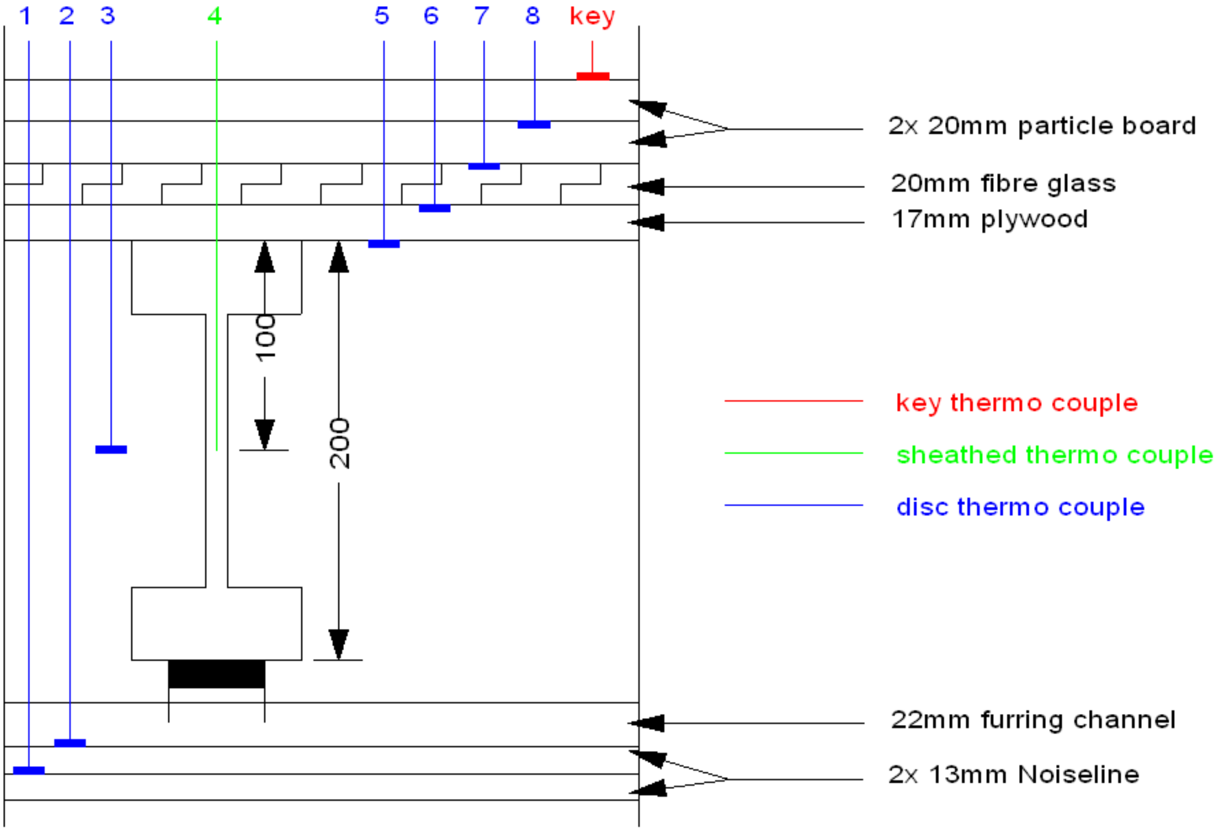


Figure 68. Vertical positions of thermocouples in the main furnace test at locations A to E in Figure 67.

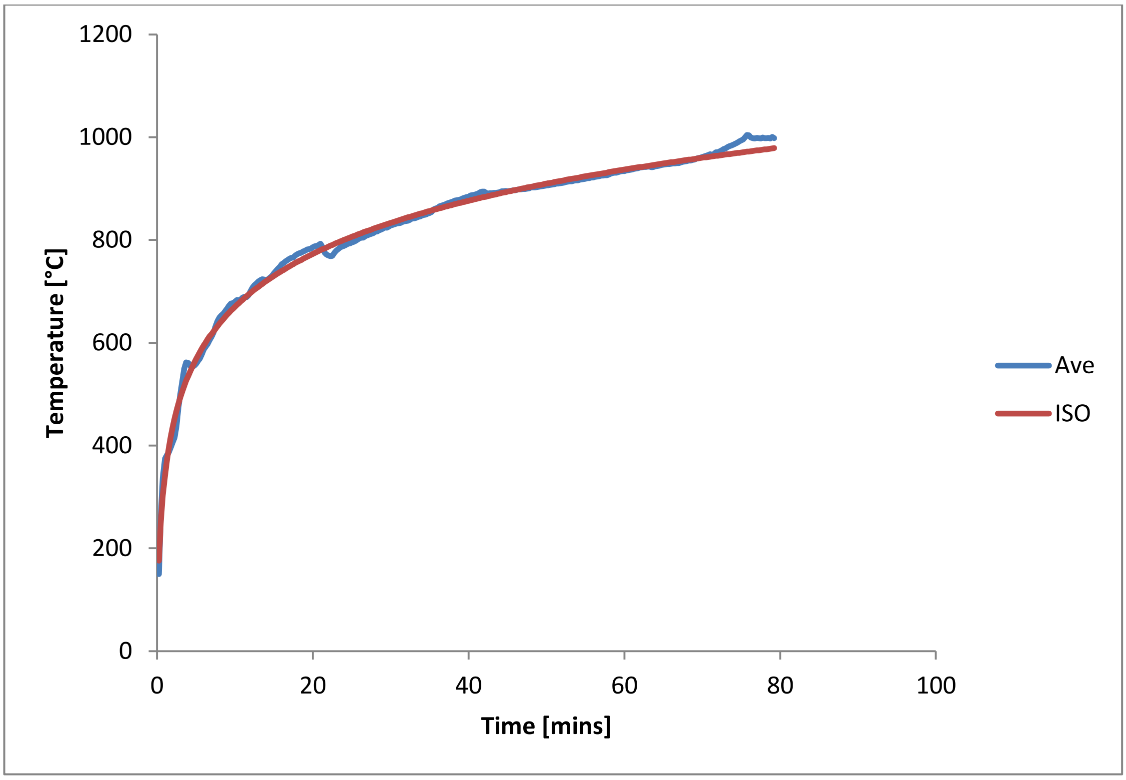


Figure 69. Furnace temperature in the main furnace test

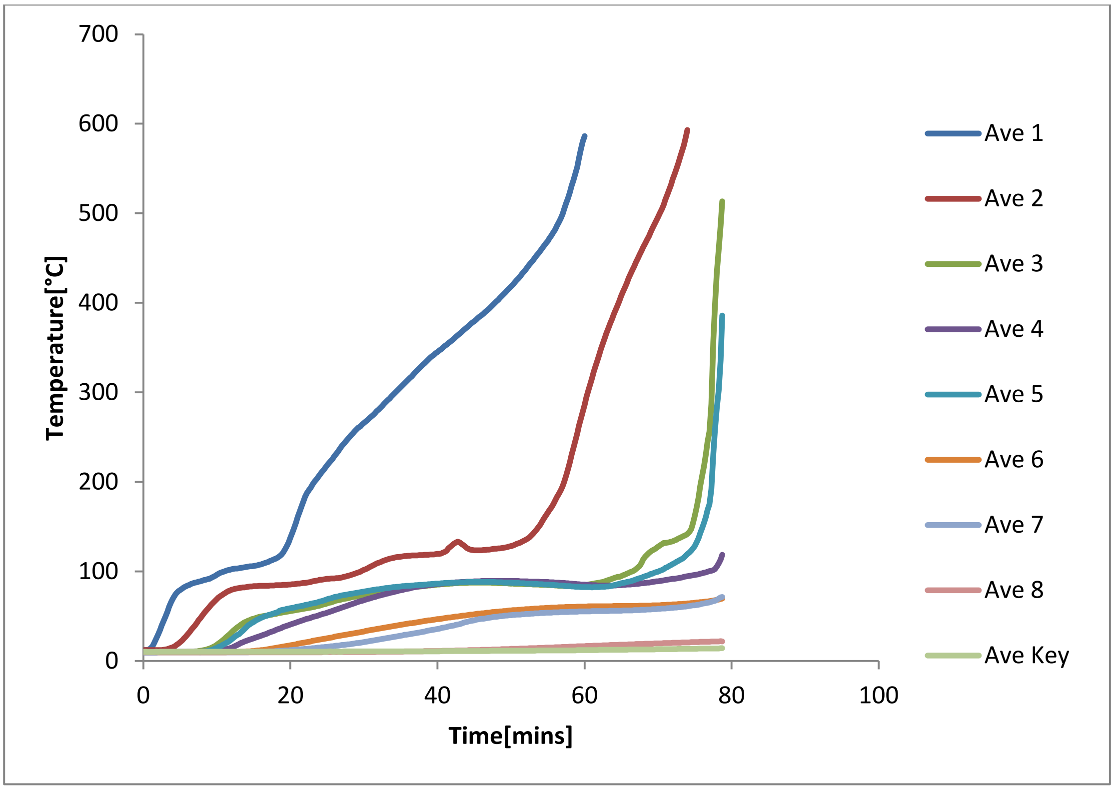


Figure 70. Average temperatures in the main furnace test

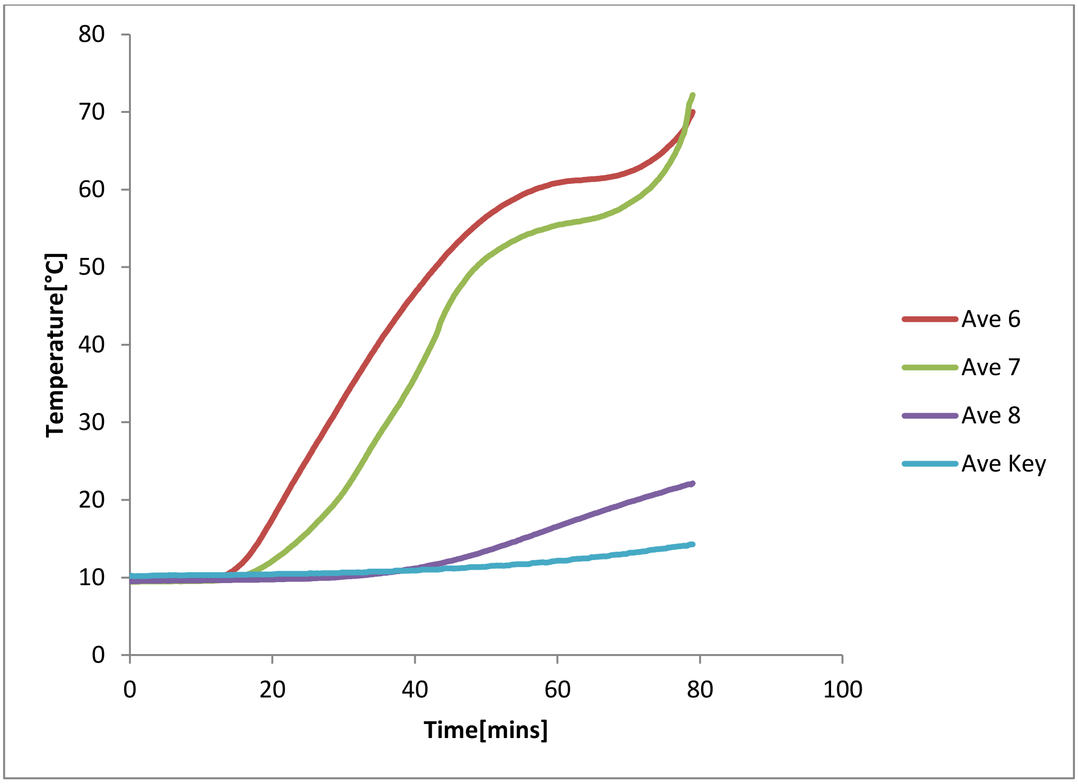


Figure 71. Average temperatures within upper floor in the main furnace test

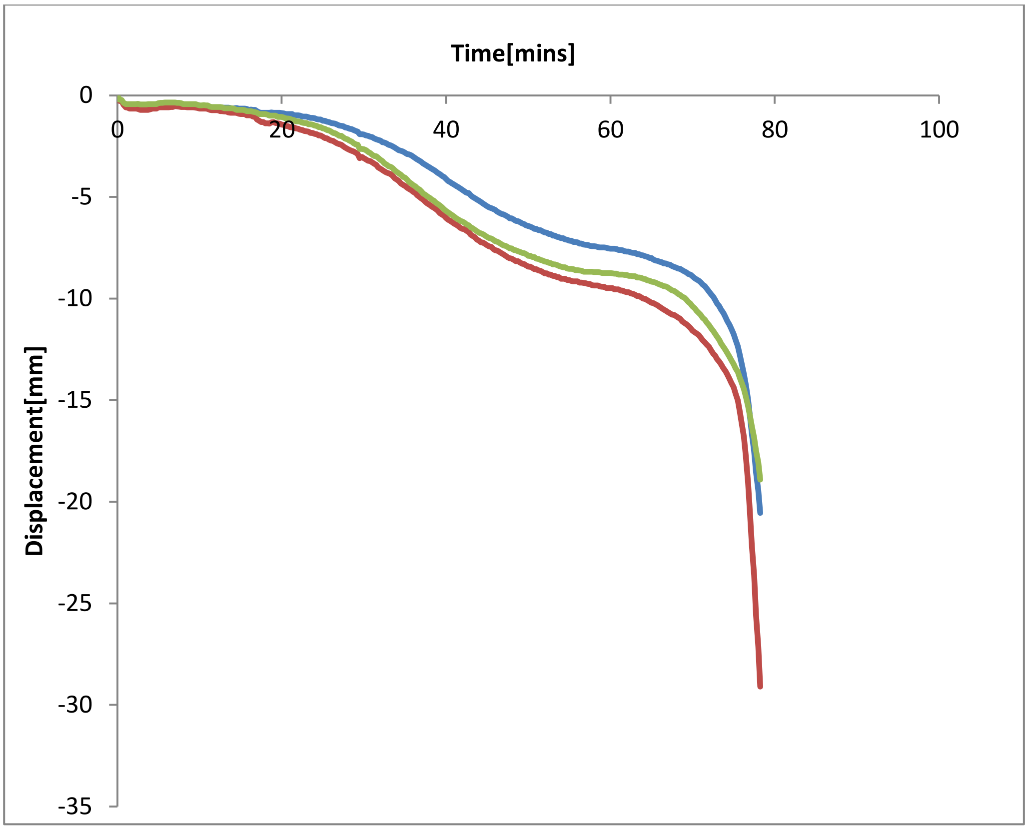


Figure 72. Deflections of floor in the main furnace test

APPENDIX D STRUCTURAL COMPUTER MODELLING

D.1 Structural Computer Modelling

Computer modelling of structural performance of timber-framed buildings under lateral load found that it is unlikely that fully discontinuous floors will be used in high wind or earthquake-prone areas. Since a case-by-case analysis is the only practical solution and no generic “one that fits all” solution with discontinuous diaphragms was possible, this study focused on construction having continuous diaphragms/floors.

However, the research team considered various solutions and thoughts on those can be found in the following sections.

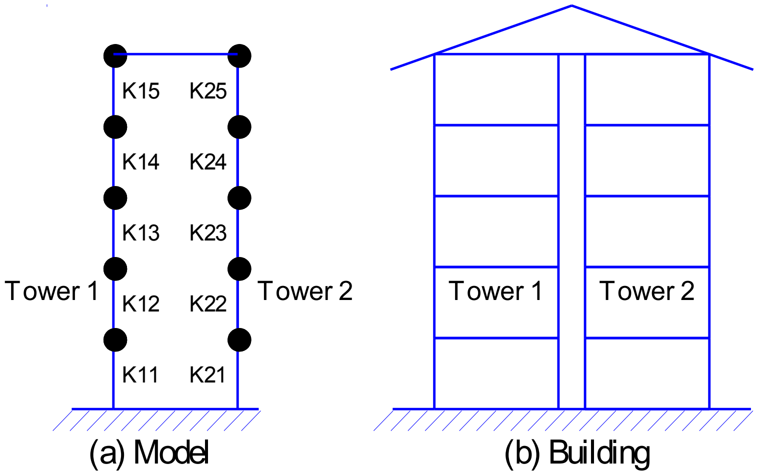
D.2 Discontinuous Floor Designs

A discontinuous floor solves most acoustic-related issues, but shifts the issue from an acoustic one to a structural one under wind and earthquake loading. For this reason it was decided to undertake computer modelling of a building with discontinuous floors. The cities of Auckland, Christchurch, Whakatane and Wellington were chosen for model locations because they provide a good representation of the various earthquake zones with their lateral load factors (seismic hazard factors) of 0.13, 0.2 (at the time of modelling), 0.3, 0.42 for Auckland, Christchurch, Whakatane and Wellington respectively.

D.3 Standalone Apartment Blocks

It was considered that it might be possible to create individual towers of occupancies (e.g. apartments) adjacent to each other but not rigidly connected to each other, except for the roof of the building, to provide the best acoustic performance. Models were set up using SPACE GASS (ITS, 2012) to investigate the seismic performance of the building “towers”. Figure 73 gives a depiction of the model. The floor masses and stiffnesses were combined into two “lollipops” and the displacements of the floors were recorded under dynamic excitation. The simplified computer models were run to see how they performed under service limit state (SLS) inputs. The outcome was that when designing a building in highly earthquake-prone areas like Whakatane and certainly Wellington, the issue of pounding at mid-height of these blocks needed specific considerations. The same applies to highly wind-prone areas (e.g. Wellington).

If it was determined that a discontinuous floor must be used for acoustic reasons, methods of providing appropriate structural connections between the two sides of the joint that as best as possible maintain the acoustic separation but at the same time are capable of shear transfer, would need to be developed. This is a difficult challenge without compromising acoustic performance. A bolted solution has been used in a multi-storey, multi-residential light timber-framed construction in New Zealand in the past. However, the design engineer for this building said that he would favour a continuous floor solution without the need to use the “elaborate” connection.



(a) Model (b) Building

Figure 73. SPACE GASS model of the building

APPENDIX E : SINGLE-FIGURE RATINGS FOR AIRBORN AND IMPACT ACOUSTIC INSULATION DETERMINED IN THIS PROJECT

Table 5 to Table 8 in this Appendix provide the single-figure horizontal and vertical sound insulation ratings determined for a range of combinations of floor systems, floor coverings and wall systems. Light green cells are measured results. Cells with cyan (light blue) background are predicted results obtained from combining measurements and theory as described in Section 4.2.

Standard ISO 717 Part 1 was followed to generate the ISO single-figure airborne sound ratings, $D_{nT,w}$, and spectrum adaptation terms, C and C_{tr}. ISO 717 Part 2 was followed to generate the ISO single-figure impact sound ratings $L'_{nT,w}$, and spectrum adaptation term, C_i. ASTM E413 was followed to generate the single-figure airborne sound ratings, FSTC, and ASTM E989 was followed to generate the single-figure impact sound ratings, FIIC. Note that ISO 140 Part 4 was followed to generate the transmission loss measurements used to calculate FSTC, which is not significantly different from following ASTM E336 (as required by the current G6 clause).

Table 5. Vertical airborne insulation single-figure ratings

	Flanking Walls									
	No Flanking	One 10mm Fyreline Walls	Two 10mm Fyreline Walls	Four 10mm Fyreline Walls	One 13mm Fyreline Walls	Two 13mm Fyreline Walls	Four 13mm Fyreline Walls	One 13mm Noiseline Walls	Two 13mm Noiseline Walls	Four 13mm Noiseline Walls
Basic Subfloor	**55(-3;-8)** 57	**53(-2;-8)** 56	**52(-2;-7)** 55	**50(-1;-6)** 53	**53(-2;-7)** 55	**52(-2;-6)** 54	**50(-2;-5)** 52	**52(-1;-6)** 55	**51(-1;-6)** 54	**50(-2;-6)** 52
Plus 2x20mm particleboard raft on AcoustiMat 3	**63(-3;-9)** 66	**59(-1;-8)** 63	**58(-2;-7)** 61	**56(-1;-7)** 59	**62(-3;-9)** 65	**61(-2;-8)** 64	**59(-2;-7)** 62	**61(-2;-8)** 64	**60(-2;-7)** 63	**59(-2;-7)** 62
Plus 20mm particleboard layer screw-fixed to subfloor	**60(-2;-8)** 63	**57(-2;-6)** 59	**55(-1;-6)** 58	**53(-1;-5)** 56	**58(-3;-9)** 61	**56(-2;-7)** 59	**54(-1;-6)** 57	**58(-2;-7)** 60	**56(-1;-6)** 59	**55(-2;-6)** 57
Plus 20mm particleboard layer screw-fixed to 45mm battons with cavity filled with sand and sawdust	**66(-4;-12)** 66	**62(-2;-9)** 65	**60(-2;-8)** 63	**58(-2;-7)** 61	**62(-2;-8)** 66	**61(-2;-8)** 64	**59(-2;-7)** 62	**64(-4;-10)** 66	**62(-2;-9)** 65	**60(-2;-8)** 63
Plus 38mm Maxxon Gypsum Concrete Screed on AcoustiMat 3	**67(-3;-9)** 71	**63(-2;-7)** 66	**61(-1;-6)** 64	**59(-1;-6)** 61	**65(-2;-8)** 68	**64(-2;-8)** 67	**62(-2;-7)** 64	**66(-2;-8)** 69	**64(-2;-7)** 67	**62(-2;-7)** 64
Plus 2x20mm particleboard raft on 13mm Bradford Quietel fibreglass	**64(-4;-11)** 64	**61(-3;-9)** 63	**60(-3;-9)** 62	**57(-2;-7)** 60	**63(-4;-10)** 63	**62(-3;-10)** 63	**61(-3;-9)** 63	**63(-5;-11)** 63	**62(-4;-10)** 63	**61(-4;-10)** 62
Plus 2x20mm particleboard raft on 10mm PinkBatts Quietzone underlay	**62(-3;-9)** 65	**59(-2;-7)** 62	**57(-1;-6)** 60	**55(-1;-6)** 58	**61(-3;-8)** 63	**60(-2;-8)** 63	**58(-2;-7)** 61	**60(-1;-7)** 63	**60(-2;-7)** 62	**59(-2;-7)** 61

Notes: Ratings are given for $D_{nT,w}$ (C,C_{tr}) and STC (in dB)
Light green cells are measured results, cyan cells are predicted results based on combining measurements.

Table 6. Horizontal airborne insulation single-figure ratings

		Wall					
		10mm Fyreline Wall - continuous floor at bottom	10mm Fyreline Wall - continuous floor at top and bottom	13mm Fyreline Wall - continuous floor at bottom	13mm Fyreline Wall - continuous floor at top and bottom	13mm Noiseline Wall - continuous floor at bottom	13mm Noiseline Wall - continuous floor at top and bottom
Floor	Basic Subfloor	**48(-1;-3)** 47	**47(-1;-4)** 47	**46(-1;-3)** 45	**46(-2;-4)** 45	**46(0;-1)** 46	**46(-1;-2)** 45
	Plus 2x20mm particleboard raft on AcoustiMat 3	**55(-3;-10)** 56	**53(-4;-11)** 53	**57(-5;-13)** 55	**54(-4;-11)** 54	**59(-5;-12)** 57	**56(-4;-10)** 56
	Plus 20mm particleboard layer screw-fixed to subfloor	**54(-3;-9)** 54	**52(-3;-10)** 53	**54(-2;-6)** 54	**53(-2;-8)** 53	**56(-2;-7)** 56	**54(-2;-7)** 54
	Plus 20mm particleboard layer screw-fixed to 45mm battons with cavity filled with sand and saw dust	**55(-3;-10)** 56	**53(-4;-10)** 53	**59(-6;-13)** 57	**55(-4;-10)** 55	**61(-4;-11)** 58	**57(-3;-9)** 57
	Plus 38mm Maxxon Gypsum Concrete Screed on AcoustiMat 3	**55(-3;-10)** 56	**53(-4;-10)** 53	**59(-6;-13)** 57	**55(-4;-10)** 55	**61(-4;-11)** 58	**57(-3;-9)** 57
	Plus 2x20mm particleboard raft on 13mm Bradford Quietel fibreglass board	**55(-3;-10)** 56	**53(-4;-10)** 53	**59(-6;-13)** 56	**55(-4;-10)** 55	**61(-4;-11)** 60	**57(-3;-10)** 57
	Plus 2x20mm particleboard raft on 10mm PinkBatts Quietzone underlay	**55(-4;-10)** 56	**53(-4;-11)** 53	**58(-5;-12)** 56	**55(-4;-11)** 55	**60(-4;-11)** 58	**57(-4;-10)** 57

Notes: Ratings are given for $D_{nT,w}$ (C,C_{tr}) and STC (in dB)

Light green cells are measured results, cyan cells are predicted results based on combining measurements and theory.

Table 7. Vertical impact insulation single-figure ratings

(Note, table extends over three pages)

			Flanking Walls									
			No Flanking	One 10mm Fyreline Walls	Two 10mm Fyreline Walls	Four 10mm Fyreline Walls	One 13mm Fyreline Walls	Two 13mm Fyreline Walls	Four 13mm Fyreline Walls	One 13mm Noiseline Walls	Two 13mm Noiseline Walls	Four 13mm Noiseline Walls
Floor and covering	Basic Subfloor	Bare Floor	**62(-1; 6)** 50	**66(-1; 3)** 46	**68(-1; 3)** 44	**70(0; 2)** 42	**65(-1; 4)** 47	**67(-1; 3)** 45	**69(-1; 3)** 43	**65(-1; 4)** 47	**67(-2; 3)** 45	**69(-2; 2)** 43
		Ceramic Tiles on 6mm Fibre-cement Board	**58(-3; 3)** 54	**63(-4; 0)** 49	**65(-4;-1)** 47	**68(-4;-2)** 44	**62(-4; 0)** 50	**64(-4; 0)** 48	**66(-4;-1)** 49	**62(-4; 0)** 48	**64(-4;-1)** 47	**67(-5;-2)** 44
		Ceramic Tiles on Regupol	**56(-1; 7)** 56	**59(-1; 5)** 53	**61(0; 4)** 51	**64(-1; 3)** 48	**58(0; 6)** 53	**60(0; 5)** 51	**62(0; 4)** 49	**59(-2; 4)** 53	**60(-1; 4)** 52	**63(-2; 2)** 49
		Ceramic Tiles on Mapefonic	**52(1; 8)** 59	**56(0; 6)** 54	**58(1; 5)** 52	**61(0; 4)** 49	**55(1; 7)** 54	**57(1; 6)** 52	**59(1; 5)** 50	**56(-1; 5)** 57	**57(0; 5)** 55	**59(-1; 4)** 53
		Strip Timber on Softlon tuf	**57(0; 8)** 55	**60(0; 6)** 52	**62(0; 5)** 49	**65(0; 4)** 47	**60(0; 6)** 52	**61(1; 6)** 50	**64(0; 4)** 47	**60(-1; 6)** 52	**61(0; 6)** 51	**63(0; 5)** 49
		Cushion-backed Vinyl	**61(-1; 7)** 51	**64(0; 5)** 48	**66(0; 4)** 46	**69(-1; 3)** 43	**64(-1; 5)** 48	**65(0; 5)** 47	**67(0; 4)** 45	**63(0; 5)** 49	**65(-1; 4)** 47	**67(-1; 3)** 45
	Basic floor .... plus 2x20mm particleboard raft on AcoustiMat 3	Bare Floor	**50(0; 8)** 62	**52(1; 7)** 59	**54(0; 6)** 57	**56(0; 5)** 55	**53(0; 6)** 57	**54(1; 6)** 55	**56(1; 5)** 53	**52(0; 6)** 60	**54(0; 5)** 58	**56(0; 4)** 56
		Ceramic Tiles on 6mm Fibre-cement Board	**45(0; 7)** 67	**48(0; 5)** 64	**50(-1; 4)** 62	**52(0; 4)** 60	**48(0; 5)** 63	**50(0; 4)** 61	**52(0; 4)** 64	**48(0; 5)** 61	**50(-1; 4)** 62	**52(-1; 3)** 60
		Ceramic Tiles on Regupol	**44(1; 10)** 65	**46(2; 9)** 62	**48(1; 8)** 60	**50(1; 7)** 58	**47(1; 8)** 61	**48(2; 8)** 59	**50(2; 7)** 56	**46(1; 8)** 64	**48(0; 7)** 63	**50(0; 6)** 62
		Ceramic Tiles on Mapefonic	**43(0; 10)** 68	**45(1; 9)** 65	**46(2; 9)** 63	**48(2; 8)** 61	**45(2; 9)** 63	**47(1; 8)** 61	**49(2; 7)** 59	**45(0; 8)** 66	**46(1; 8)** 65	**48(1; 7)** 64
		Strip Timber on Softlon tuf	**49(0; 8)** 62	**51(1; 7)** 59	**53(1; 6)** 57	**55(1; 6)** 55	**51(2; 7)** 58	**53(1; 6)** 55	**55(2; 5)** 53	**51(0; 7)** 61	**53(0; 6)** 59	**54(1; 6)** 57
		Cushion-backed Vinyl	**49(1; 8)** 61	**51(1; 7)** 58	**53(1; 6)** 56	**55(1; 6)** 54	**51(2; 7)** 56	**53(2; 6)** 54	**55(2; 6)** 52	**51(1; 7)** 59	**52(1; 6)** 58	**54(1; 6)** 57

Floor and covering	Basic floor .... plus 20mm particleboard layer screw-fixed to subfloor	Bare Floor	**56(-1; 7)** 56	**59(-1; 5)** 53	**61(-1; 4)** 51	**63(0; 4)** 49	**60(-1; 3)** 52	**62(0; 2)** 50	**64(0; 2)** 48	**59(-1; 5)** 53	**61(-2; 3)** 51	**63(-2; 3)** 49
		Ceramic Tiles on 6mm Fibre-cement Board	**52(-3; 5)** 60	**55(-2; 4)** 57	**57(-2; 3)** 55	**60(-3; 1)** 52	**56(-2; 2)** 56	**58(-2; 1)** 54	**60(-2; 0)** 56	**56(-4; 2)** 54	**58(-4; 1)** 54	**60(-4; 0)** 52
		Ceramic Tiles on Regupol	**50(0; 10)** 62	**53(0; 8)** 58	**55(0; 7)** 56	**57(0; 7)** 54	**54(0; 6)** 55	**56(1; 5)** 53	**58(1; 4)** 50	**53(-1; 8)** 59	**55(-2; 7)** 57	**57(-2; 6)** 55
		Ceramic Tiles on Mapefonic	**48(0; 11)** 64	**51(0; 9)** 60	**53(0; 8)** 58	**55(0; 7)** 55	**52(1; 6)** 57	**54(1; 5)** 55	**56(1; 4)** 52	**50(0; 9)** 62	**52(0; 8)** 60	**54(0; 7)** 58
		Strip Timber on Softlon tuf	**54(-1; 8)** 58	**57(0; 6)** 55	**59(0; 5)** 53	**61(0; 5)** 51	**58(0; 4)** 53	**60(0; 3)** 51	**62(0; 3)** 48	**56(0; 7)** 56	**58(-1; 6)** 54	**60(-1; 5)** 52
		Cushion-backed Vinyl	**54(0; 8)** 58	**58(-1; 5)** 54	**59(0; 5)** 52	**62(-1; 4)** 50	**58(0; 4)** 53	**60(0; 3)** 51	**63(0; 2)** 48	**57(-1; 6)** 55	**59(-1; 4)** 53	**61(-1; 3)** 51
	Basic floor .... plus 20mm particleboard layer screw-fixed to 45mm battons with cavity filled with sand and sawdust	Bare Floor	**48(0; 7)** 63	**51(-1; 5)** 61	**52(0; 5)** 60	**54(0; 4)** 57	**50(0; 5)** 62	**52(-1; 4)** 60	**54(-1; 3)** 58	**51(-1; 5)** 61	**53(-1; 4)** 59	**55(-1; 3)** 57
		Ceramic Tiles on 6mm Fibre-cement Board	**43(-1; 8)** 69	**46(-2; 6)** 66	**48(-2; 5)** 64	**50(-2; 4)** 62	**46(-2; 5)** 66	**48(-2; 4)** 64	**50(-2; 4)** 65	**46(-2; 6)** 64	**48(-2; 5)** 64	**51(-3; 3)** 61
		Ceramic Tiles on Regupol	**41(2; 15)** 67	**44(1; 12)** 64	**45(2; 12)** 63	**47(2; 11)** 61	**43(2; 12)** 64	**45(1; 11)** 63	**47(1; 10)** 61	**44(1; 12)** 66	**46(0; 11)** 65	**48(0; 10)** 63
		Ceramic Tiles on Mapefonic	**39(1; 15)** 70	**41(2; 13)** 67	**43(1; 12)** 65	**45(1; 11)** 63	**41(1; 12)** 67	**42(2; 12)** 65	**44(2; 11)** 63	**42(0; 12)** 68	**43(1; 12)** 67	**45(0; 11)** 66
		Strip Timber on Softlon tuf	**45(0; 10)** 66	**47(0; 8)** 64	**48(1; 8)** 62	**50(1; 7)** 60	**46(1; 9)** 64	**48(0; 7)** 62	**50(0; 6)** 60	**47(0; 8)** 65	**49(0; 7)** 63	**51(0; 6)** 61
		Cushion-backed Vinyl	**47(-1; 8)** 65	**49(0; 7)** 63	**50(0; 6)** 61	**52(0; 6)** 59	**48(0; 7)** 63	**50(0; 6)** 61	**52(0; 5)** 59	**49(0; 7)** 63	**51(-1; 5)** 61	**53(-1; 4)** 59
	Basic floor .... plus 38mm Maxxon Gypsum Concrete Screed on AcoustiMat 3	Bare Floor	**47(0; 5)** 65	**51(-1; 3)** 61	**53(-1; 2)** 59	**55(0; 2)** 57	**51(-1; 3)** 61	**52(0; 3)** 59	**55(0; 2)** 56	**50(-1; 3)** 61	**52(-1; 2)** 60	**54(-1; 1)** 57
		Ceramic Tiles on 6mm Fibre-cement Board	**43(0; 7)** 69	**46(0; 5)** 65	**48(0; 4)** 63	**50(0; 4)** 60	**46(0; 5)** 64	**48(0; 4)** 62	**50(0; 4)** 67	**45(0; 5)** 62	**47(-1; 4)** 65	**49(-1; 3)** 63
		Ceramic Tiles on Regupol	**44(1; 8)** 66	**47(1; 7)** 62	**48(2; 7)** 60	**51(1; 5)** 57	**46(2; 8)** 61	**48(2; 7)** 59	**50(2; 6)** 57	**46(0; 6)** 66	**47(0; 6)** 65	**49(0; 5)** 63
		Ceramic Tiles on Mapefonic	**43(1; 7)** 67	**46(1; 6)** 63	**48(1; 5)** 61	**50(1; 4)** 59	**46(1; 5)** 63	**47(2; 5)** 61	**49(2; 5)** 58	**45(0; 5)** 67	**46(0; 5)** 66	**48(0; 4)** 64
		Strip Timber on Softlon tuf	**45(1; 8)** 63	**48(2; 6)** 59	**50(2; 6)** 57	**52(2; 5)** 55	**47(3; 7)** 59	**49(3; 6)** 57	**51(3; 6)** 54	**47(0; 6)** 64	**48(0; 6)** 63	**50(0; 5)** 62
		Cushion-backed Vinyl	**46(0; 6)** 65	**49(0; 5)** 61	**51(0; 4)** 59	**53(0; 4)** 57	**49(0; 5)** 61	**50(1; 5)** 59	**53(0; 3)** 56	**48(0; 4)** 64	**50(-1; 3)** 62	**52(-1; 2)** 60

Floor and covering			No Flanking	One 10mm Fyreline Walls	Two 10mm Fyreline Walls	Four 10mm Fyreline Walls	One 13mm Fyreline Walls	Two 13mm Fyreline Walls	Four 13mm Fyreline Walls	One 13mm Noiseline Walls	Two 13mm Noiseline Walls	Four 13mm Noiseline Walls
	Basic floor .... plus 2x20mm particleboard raft on 13mm Bradford Quietel fibreglass board	Bare Floor	**51(0; 7)** 61	**54(0; 6)** 57	**56(0; 5)** 55	**58(1; 4)** 53	**54(0; 5)** 57	**56(0; 4)** 55	**58(0; 4)** 52	**53(1; 5)** 58	**55(0; 4)** 57	**57(0; 3)** 55
		Ceramic Tiles on 6mm Fibre-cement Board	**45(1; 6)** 67	**48(1; 5)** 63	**50(0; 4)** 61	**52(1; 4)** 59	**48(1; 5)** 63	**50(0; 4)** 60	**52(0; 4)** 64	**47(1; 4)** 60	**49(0; 3)** 63	**51(0; 3)** 61
		Ceramic Tiles on Regupol	**46(0; 9)** 65	**48(1; 8)** 61	**50(1; 7)** 59	**52(2; 6)** 56	**48(1; 8)** 60	**49(2; 8)** 58	**51(2; 7)** 56	**48(0; 6)** 63	**49(1; 6)** 61	**51(1; 5)** 59
		Ceramic Tiles on Mapefonic	**44(1; 10)** 67	**47(1; 8)** 63	**49(1; 7)** 61	**51(1; 6)** 59	**47(1; 8)** 63	**48(2; 7)** 61	**50(2; 6)** 58	**46(1; 7)** 65	**48(0; 6)** 64	**50(0; 5)** 62
		Strip Timber on Softlon tuf	**47(1; 9)** 64	**50(1; 7)** 61	**52(0; 6)** 59	**54(1; 6)** 57	**50(0; 7)** 61	**51(1; 7)** 59	**53(1; 6)** 56	**50(0; 5)** 62	**51(0; 5)** 61	**53(0; 4)** 59
		Cushion-backed Vinyl	**50(0; 8)** 62	**53(0; 6)** 58	**55(0; 5)** 56	**57(0; 5)** 53	**53(0; 6)** 57	**54(1; 6)** 55	**56(1; 5)** 53	**52(1; 5)** 60	**54(0; 4)** 58	**56(0; 4)** 56
	Basic floor .... plus 2x20mm particleboard raft on 10mm PinkBatts Quietzone underlay	Bare Floor	**51(0; 8)** 61	**54(0; 6)** 58	**56(0; 5)** 56	**58(0; 4)** 53	**54(0; 6)** 58	**56(0; 5)** 55	**58(0; 4)** 53	**54(0; 3)** 58	**56(0; 2)** 56	**58(0; 2)** 54
		Ceramic Tiles on 6mm Fibre-cement Board	**46(0; 7)** 66	**50(-1; 4)** 62	**51(0; 5)** 60	**54(-1; 3)** 58	**49(0; 5)** 62	**51(0; 4)** 60	**53(0; 4)** 62	**49(0; 3)** 60	**51(0; 2)** 61	**54(-1; 1)** 58
		Ceramic Tiles on Regupol	**45(1; 11)** 66	**49(0; 8)** 62	**50(1; 8)** 60	**53(0; 6)** 58	**48(1; 9)** 62	**50(1; 8)** 59	**52(1; 7)** 57	**49(0; 5)** 63	**50(0; 5)** 61	**53(0; 4)** 59
		Ceramic Tiles on Mapefonic	**43(1; 12)** 67	**46(1; 10)** 63	**48(1; 9)** 61	**50(1; 9)** 59	**46(1; 10)** 63	**47(2; 10)** 61	**50(1; 8)** 58	**46(1; 6)** 65	**48(0; 6)** 64	**50(0; 5)** 62
		Strip Timber on Softlon tuf	**49(0; 9)** 63	**52(0; 8)** 59	**54(0; 6)** 58	**56(0; 6)** 55	**52(0; 7)** 59	**54(0; 6)** 57	**56(0; 5)** 55	**52(0; 4)** 60	**54(0; 3)** 58	**56(0; 3)** 55
		Cushion-backed Vinyl	**50(0; 8)** 61	**54(0; 6)** 58	**55(0; 6)** 56	**58(0; 4)** 54	**53(0; 6)** 58	**55(0; 5)** 56	**57(0; 4)** 53	**54(-1; 3)** 58	**55(0; 3)** 56	**58(-1; 2)** 54

Notes: Ratings are given for $L'_{nT,w}$ (Ci,$C_{i50-2500}$) - on top and in bold - and Apparent-IIC (in dB).

Light green cells are measured results, cyan cells are predicted results based on combining measurements and theory.

Table 8. Horizontal impact insulation single-figure ratings

(Note, table extends over two pages)

			Walls		
			10mm Fyreline Wall - continuous floor at bottom	13mm Fyreline Wall - continuous floor at bottom	13mm Noiseline Wall - continuous floor at bottom
Floor and covering	Basic Subfloor	Bare Floor	**67(-5;-5)** 42	**67(-6;-5)** 44	**67(-6;-5)** 44
		Ceramic Tiles on 6mm Fibre-cement Board	**68(-9;-9)** 41	**68(-10;-9)** 43	**68(-10;-10)** 43
		Ceramic Tiles on Regupol	**61(-7;-6)** 43	**61(-7;-5)** 46	**61(-7;-6)** 46
		Ceramic Tiles on Mapefonic	**57(-5;-4)** 53	**57(-5;-4)** 54	**57(-6;-4)** 54
		Strip Timber on Softlon tuf	**60(-4;-4)** 50	**59(-3;-2)** 51	**59(-4;-2)** 51
		Cushion-backed Vinyl	**62(-2;-2)** 48	**62(-2;-1)** 49	**62(-3;-2)** 49
	Basic floor .... plus 2x20mm particleboard raft on AcoustiMat 3	Bare Floor	**43(0; 4)** 66	**46(1; 4)** 62	**44(2; 6)** 63
		Ceramic Tiles on 6mm Fibre-cement Board	**39(-1; 4)** 71	**43(-1; 3)** 68	**41(0; 5)** 69
		Ceramic Tiles on Regupol	**38(0; 6)** 70	**41(1; 6)** 66	**39(2; 8)** 67
		Ceramic Tiles on Mapefonic	**35(1; 8)** 72	**38(2; 7)** 68	**37(2; 9)** 69
		Strip Timber on Softlon tuf	**41(1; 6)** 67	**45(1; 5)** 62	**43(2; 7)** 63
		Cushion-backed Vinyl	**41(2; 6)** 65	**45(2; 5)** 61	**43(2; 7)** 62
	Basic floor .... plus 20mm particleboard layer screw-fixed to subfloor	Bare Floor	**59(-4;-4)** 52	**55(-2;-1)** 55	**55(-3; 0)** 56
		Ceramic Tiles on 6mm Fibre-cement Board	**59(-8;-7)** 50	**54(-6;-4)** 56	**54(-7;-4)** 56
		Ceramic Tiles on Regupol	**54(-6;-4)** 53	**50(-4; 0)** 59	**50(-3; 1)** 59
		Ceramic Tiles on Mapefonic	**49(-3;-1)** 62	**46(-2; 2)** 65	**46(-2; 3)** 65
		Strip Timber on Softlon tuf	**54(-2;-1)** 56	**51(-1; 2)** 59	**51(-1; 3)** 60
		Cushion-backed Vinyl	**54(-2; 0)** 56	**52(-1; 1)** 59	**51(0; 2)** 59
	Basic floor .... plus 20mm particleboard layer screw-fixed to 45mm battons with cavity filled with sand and sawdust	Bare Floor	**44(-1; 3)** 66	**43(0; 5)** 65	**42(0; 5)** 67
		Ceramic Tiles on 6mm Fibre-cement Board	**41(-3; 2)** 70	**40(-2; 5)** 70	**39(-2; 5)** 71
		Ceramic Tiles on Regupol	**37(2; 10)** 67	**38(2; 10)** 67	**38(1; 9)** 68
		Ceramic Tiles on Mapefonic	**34(3; 11)** 70	**33(4; 14)** 69	**33(3; 12)** 71
		Strip Timber on Softlon tuf	**39(2; 7)** 67	**39(2; 9)** 66	**38(2; 9)** 67
		Cushion-backed Vinyl	**41(1; 6)** 66	**40(2; 8)** 65	**40(1; 7)** 66

Floor and covering			10mm Fyreline Wall - diaphragm at bottom	13mm Fyreline Wall - diaphragm at bottom	13mm Noiseline Wall - diaphragm at bottom
	Basic floor .... plus 38mm Maxxon Gypsum Concrete Screed on AcoustiMat 3	Bare Floor	**44(-3; 3)** 67	**43(-1; 4)** 68	**47(-6;-1) *** 61 *
		Ceramic Tiles on 6mm Fibre-cement Board	**37(0; 7)** 73	**37(0; 8)** 72	**39(-3; 4)** 72
		Ceramic Tiles on Regupol	**36(2; 10)** 70	**37(2; 10)** 69	**38(-2; 8)** 73
		Ceramic Tiles on Mapefonic	**34(2; 10)** 72	**36(2; 8)** 70	**36(-1; 7)** 74
		Strip Timber on Softlon tuf	**37(3; 10)** 68	**38(3; 10)** 66	**39(-2; 7)** 72
		Cushion-backed Vinyl	**39(0; 7)** 70	**40(0; 7)** 68	**40(-2; 6)** 71
	Basic floor .... plus 2x20mm particleboard raft on 13mm Bradford Quietel fibreglass board	Bare Floor	**44(0; 5)** 66	**45(1; 5)** 64	**43(0; 6)** 67
		Ceramic Tiles on 6mm Fibre-cement Board	**38(1; 5)** 72	**39(1; 5)** 70	**38(0; 6)** 73
		Ceramic Tiles on Regupol	**38(1; 7)** 69	**39(2; 8)** 68	**37(1; 9)** 71
		Ceramic Tiles on Mapefonic	**36(2; 8)** 72	**38(1; 7)** 70	**36(0; 9)** 74
		Strip Timber on Softlon tuf	**40(0; 7)** 70	**41(1; 7)** 68	**39(0; 8)** 72
		Cushion-backed Vinyl	**43(0; 6)** 66	**44(1; 6)** 65	**42(0; 7)** 68
	Basic floor .... plus 2x20mm particleboard raft on 10mm PinkBatts Quietzone underlay	Bare Floor	**46(-1; 4)** 65	**46(0; 5)** 65	**44(0; 4)** 66
		Ceramic Tiles on 6mm Fibre-cement Board	**43(-2; 2)** 68	**42(-1; 4)** 68	**41(-2; 2)** 70
		Ceramic Tiles on Regupol	**40(0; 7)** 69	**40(1; 8)** 68	**39(0; 6)** 72
		Ceramic Tiles on Mapefonic	**37(1; 9)** 71	**38(1; 10)** 70	**36(1; 8)** 74
		Strip Timber on Softlon tuf	**43(0; 6)** 67	**44(0; 6)** 66	**42(0; 5)** 68
		Cushion-backed Vinyl	**45(0; 4)** 66	**45(0; 5)** 65	**43(0; 4)** 67

Notes: Ratings are given for $L'_{nT,w}$ (C_i,$C_{i50-2500}$) - on top and in bold - and Apparent-IIC (in dB).

Light green cells are measured results, cyan cells are predicted results based on combining measurements and theory.
Low impact levels tend to have higher relative uncertainties - expect LnT,w values less than 50dB to have errors of 2 to 3 dB.

* These values are the result of higher high-frequency impact sound levels - perhaps caused by a lower critical frequency for 13mm Noiseline