Effect of plenum absorption on ceiling attenuation

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Abstract

The influence of acoustic absorption laid directly on top of ceiling tiles installed in a two-way suspended grid system was examined to determine the effect that absorption played in ceiling attenuation. Glass fibre acoustic absorption material ranging in thickness from 15 mm to 100 mm was laid, in turn, directly over four different ceiling tile products. An increase in the transmission loss through the plenum sound path was seen when the acoustic absorption was laid over the ceiling tiles. The largest increase seen was with the thickest absorption, with the smallest increase seen with the 15 mm thick glass fibre acoustic absorption. The largest overall gain from a tile with no acoustic absorption behind, accounting for thickness was with the 25 mm thick glass fibre acoustic absorption. It was seen that a relatively poor performing ceiling tile can perform relatively well if a thick absorption product is laid directly on top of the tile in the plenum.

Original peer-reviewed paper

1. Introduction

The current typical design for office spaces in New Zealand is to create a single large open plan space. The tenant fit-out involves breaking the space up into smaller meeting rooms, private offices, reception areas, and so-forth (Hamme 1961, Haliwell & Quirt 1991). For ease of installation as well as long term flexibility, these separating fit-out walls are normally only constructed after the suspended ceiling is installed, and therefore are only constructed up to ceiling height. In addition to this, new seismic requirements in New Zealand may require a deflection plane at or around ceiling height, and therefore it may not be practical to construct full height acoustic walls. Because of these limitations, sound transmission between spaces is generally limited to that through the plenum sound path (sound travelling through ceiling tiles in one room, across the separating wall in the ceiling plenum space, and back through the ceiling tiles in an adjacent room), which may be less than a typical single stud wall system.

Hamme (1961) designed and constructed the first facility to determine the sound attenuation between rooms, which led to the development of the first International Standard to determine the ceiling attenuation of a ceiling product (AMA 1-II-1967). Using this facility, Hamme (1961) started to look at the effect of 'corrective' modifications to ceiling tiles to increase the ceiling attenuation of a ceiling tile specimen, by looking at installing fibrous insulation to the rear of the ceiling tile. An increase between 5 and 9 dB was seen below 1,000 Hz, with an increase of 31 dB at 4,000 Hz over the ceiling tile without any 'corrective' treatment. Royar and Schmelzer (2006) undertook measurements of absorption on side walls and on the roof of a 1:10 scale facility. There measurements were limited to frequencies above 500 Hz, however little difference was seen with and without acoustic absorption installed on the roof of their facility. Very little additional research has been published on this, with most completed by private ceiling tile manufacturers, so the results are not accessible. This research builds on that by Hamme, determining the effect of absorption in the plenum with four different ceiling tiles and four different thicknesses of acoustic absorption.

A Ceiling Flanking Noise (CFN) facility was designed and constructed at the University of Canterbury to establish the ceiling attenuation provided by a range of ceiling tile products, all installed in a 1200 mm x 600 mm two-way suspended ceiling grid. This ceiling flanking facility was designed, constructed, and commissioned to ASTM E1414-11a (ASTM International, 2011), the North American laboratory design and methodology standard for CFN facilities. After measuring the attenuation provided by four ceiling tile products using this facility, acoustic absorption with thicknesses of 15 mm, 25 mm, 40 mm, and 100 mm was laid, in turn, directly over the suspended ceiling system to determine the effect of the addition of absorption to the ceiling plenum cavity on the ceiling attenuation.

2. Test facility and product description

A CFN facility comprises of two separate rooms that are separated by a part height wall, with a suspended ceiling grid installed flush over the top of the separating wall, and sealed to ensure the predominant noise path is through the plenum sound path. A CFN facility is a small laboratory space, simulating two small private offices or

Figure 1: Overview of the CFN facility at the University of Canterbury

meeting rooms adjacent to each other with a common ceiling plenum above the common wall. To simulate a larger plenum, typical to that found in commercial or educational building, fibrous absorption is required to be installed on all four walls in the plenum, with minimum thickness and absorption coefficient requirements. The test facility at the University of Canterbury is described by Barclay et al. (2014), with further investigation conducted by van Hout et al (2016) to fully comply with ASTM E1414-11a. Figure 1 shows the two rooms of the CFN facility at the University of Canterbury.

To ensure that the dominant noise path is through the plenum, all other sound paths were measured in-situ. The separating wall was constructed of the following:

- 1 layer of 13 mm GIB Noiseline + 1 layer of 18 m Medium Density Fibreboard + 4 kg/m^2 mass loaded barrier + 2 x 50 mm timber studs separated by 10 mm, with 90 mm R1.8 Pink Batts glass wool insulation + 1 layer of 18 mm plywood + GIB ST-001 resilient clips with Rondo battens with 50 mm Autex AAB 35-50 fibrous insulation to the cavity + 2 layers of 13 mm GIB Noiseline.

The external walls were constructed of the following:

- 1 layer of 18 mm plywood + 90 mm timber frame with R1.8, 90 mm Pink Batts glass wool insulation + 1 layer of 18 mm plywood.

Finally, each floor was constructed of the following:

- 1 layer of 21 mm particleboard + 1 layer of 10 mm Standard GIB plasterboard + 1 layer of 18 mm plywood.

To determine the acoustic separation provided by each element, the plenum sound path was blocked. This was achieved by installing three 10 mm plasterboard ceiling tiles in the two-way grid, along with a 4 kg/m^2 and a 6 kg/m^2 mass loaded barrier hung from the roof, and two 420 mm wide baffle stack (compressed 40%) installed above the separating wall in the plenum, each side of the mass loaded barrier. Absorption was installed over all ceiling tiles in the plenum. The in-situ transmission loss from one room to the other with the above is shown in Figure 2 below, with an overall Sound Transmission Loss (STC) and Weighted Reduction Index (R_w) rating of 61.

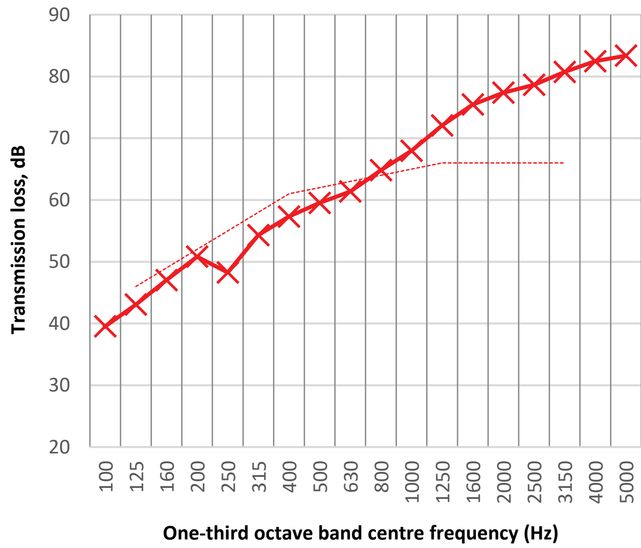

Figure 2: In-situ testing of all flanking sound paths for the CFN facility

2.1 Ceiling tile products

The ceiling attenuation provided by four ceiling tile products with and without acoustic absorption on the rear was determined. Three of the ceiling tile products are made of mineral fibre with the fourth a composite tile consisting of 25 mm fibrous absorption facing with a 10 mm plasterboard backing adhered to the plenum side of the tile. One mineral fibre ceiling tile was constructed of two different densities of mineral fibre, a denser backing (presumably to increase the transmission loss) and a more porous front (for absorption purposes). The random incidence sound absorption coefficients and resultant NRC value for the front face and back face of each ceiling tile specimen was determined using the method outlined in ISO 354:2003 mounted in Type-A[1] , by placing the products in turn in the Reverberation Room at the University of Canterbury. The key parameters of each ceiling tile product were measured or provided by each of the manufacturers, and are given in Table 1.

1 Each product was laid directly against the floor of the Reverberation Room, so there was no air gap between the floor and rear of the ceiling tile. Perimeter steels were installed around the edge of each product to mitigate the edge effect.

Table 1: Material properties of the ceiling tiles

Ceiling tile product	Material	Thickness (mm)	Surface density (kg/m^2)	Front face NRC	Back face NRC
Tile A	Mineral fibre	12	3.3	0.50	0.45
Tile B	Mineral fibre	19	4.7	0.70	0.45
Tile C	Mineral fibre	42	10.8	0.90	0.20
Tile D	25 mm glass fibre; 10 mm plasterboard	35	10.2	0.75	0.05

The sound absorption afforded by the back face of the ceiling tile was explored in order to determine the absorption provided in the plenum space by the ceiling tile products themselves. The results of the sound absorption measurements are given in Figure 3.

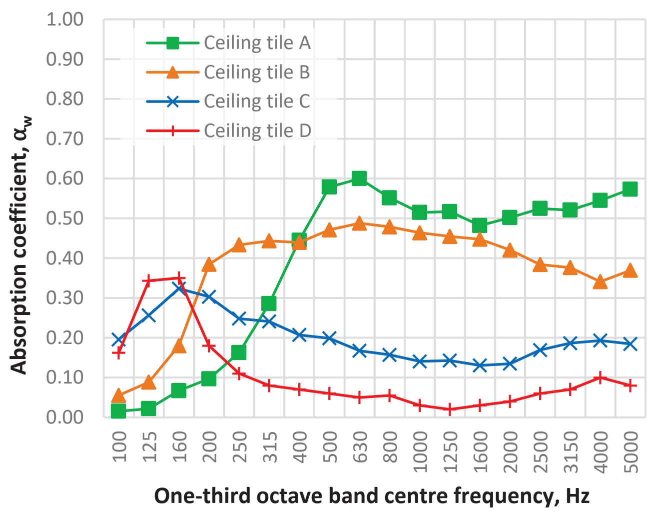

Figure 3: Absorption provided by the back face of the four ceiling tile products

Above 200 Hz, ceiling tile D provided little absorption, however below 160 Hz, this product had the highest measured absorption of the ceiling tile products. As this was a plasterboard layer effectively suspended above the floor (by the glass fibre front face), it is expected the face is acting similar to a resonant absorber. Ceiling tiles A and B provide absorption coefficient curves typical for mineral fibre material, albeit lower than that of the front face, as the back face is usually treated to provide more resistance to bumps and bangs. The front face is also slightly perforated (under the facing material) such that it provides better absorption. The denser mineral fibre backing of ceiling tile C limits the rear face absorption which is expected to be the reason that the absorption coefficient is low for this product.

2.2 Plenum absorption products

Four different thicknesses ranging from 15 mm to 100 mm of glass fibre acoustic absorption were added to the rear surface of the suspended ceiling system. The volumetric density (100 kg/m^3) of the acoustic absorption was kept constant, such that only the surface density changed with differing thickness. Key parameters of the acoustic absorption product are provided in Table 2.

Table 2: Material properties of the plenum absorption

Thickness	Material	Surface Density (kg/m^2)	NRC
15 mm	Glass fibre rigid board	1.5	0.75
25 mm	Glass fibre rigid board	2.5	0.85
40 mm	Glass fibre rigid board	4.0	0.95
100 mm	Glass fibre rigid board	10.0	1.05

Figure 4 shows the sound absorption provided by the different thicknesses of the absorption installed in the plenum space. The random incidence sound absorption coefficients for the different thicknesses of acoustic absorption were determined using the method outlined in ISO 354:2003 mounted in Type-A, using the Reverberation Room at the University of Canterbury. As with typical acoustic panel absorbers, as the thickness of the material increases, a larger increase in absorption coefficient is seen in the lower frequencies, as shown in Figure 4.

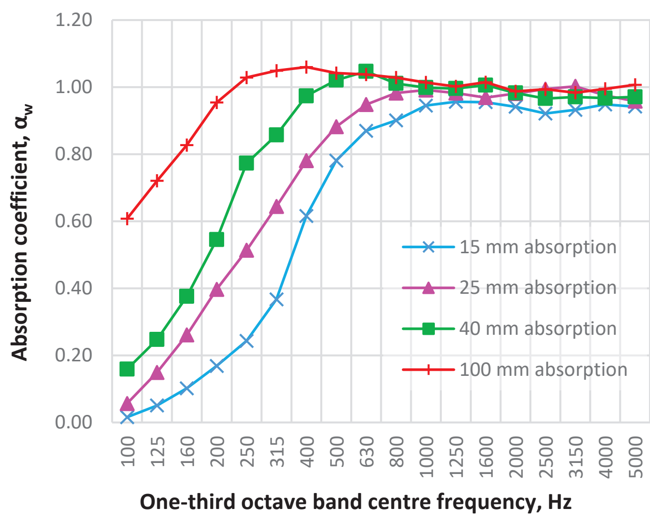

Figure 4: Absorption provided by the absorption installed in the plenum

Absorption coefficients greater than 1.0 were measured for some products that could be attributed to the 'edge effect' and change in diffusivity of the Reverberation Room around the product. Due to the highly absorptive products, the sound field is not fully diffuse around the test specimen. In addition, even though the side of the products were covered in steel angles the sides of the product some reverberant sound could be absorbed by the sides of the specimen, which then would provide a larger area of absorption than that used in the calculations (Bies and Hansen, 2005). These reasons may explain the unusually high absorption coefficients.

3.0 Influence of acoustic absorption on ceiling attenuation

Additional measurements of the ceiling attenuation of the four ceiling tile products as well as the four thicknesses of acoustic glass fibre absorption to that outlined by van Hout et al (2016) at the University of Canterbury's

CFN facility, in strict accordance with the methodology outlined in ASTM E1414. This was due to a different two-way suspended grid system used in the facility. A ceiling tile specimen was first installed to the manufacturer's specifications within the two-way grid, and the ceiling attenuation was measured three times at two different speaker positions. The four different thicknesses of fibrous absorption were laid directly over all the ceiling tiles in turn and measured with the same microphone and speaker positions. The Reverberation Time for each test in the receiving room was conducted to normalize the ceiling attenuation results to take into account the absorption provided by the ceiling tiles. The ceiling tile specimen was then substituted and the ceiling attenuation for this specimen and four thicknesses of acoustic absorption were then determined. This was then repeated for all four ceiling tile specimens. No seismic hold-down clips were used, as these are not used in the majority of locations around New Zealand. All ceiling tiles were checked before each test to ensure they were lying flat in the grid.

3.1 Ceiling attenuation of just the ceiling tiles

The normalized ceiling attenuation of the four ceiling tile products without acoustic absorption behind are presented in Figure 5.

The results are largely as expected, with ceiling tiles with a higher mass performing better than ceiling tiles with a lower mass. Ceiling tiles C and D exhibit a similar sound

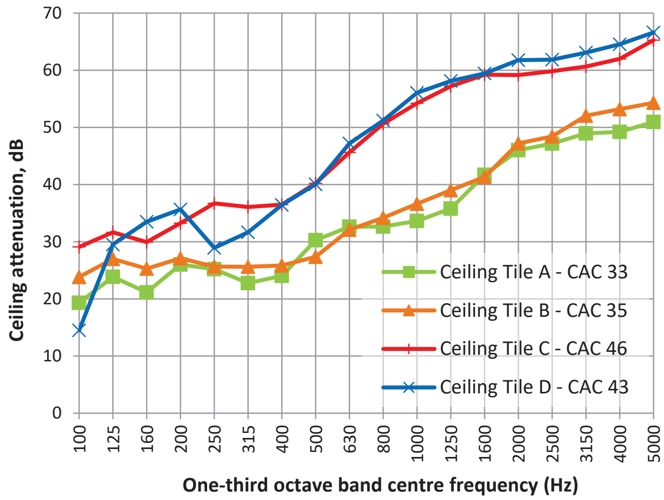

Figure 5: Ceiling attenuation of four ceiling tile products without absorption on the rear

transmission loss curve, as these ceiling tiles have a similar surface density (10.8 kg/m^2 for ceiling tile C and 10.2 kg/m^2 for ceiling tile D). The dip shown at 250 Hz for ceiling tile D is expected to be due to the acoustic modal coupling between the rear of the ceiling tile and the roof of the CFN facility, were the resonant sound in the plenum is transferred more easily through the plenum space, as the ceiling of the plenum (made from plywood) and the rear surface of the ceiling tile (made from plasterboard) are both acoustically reflective products. Ceiling tile A, with the lowest mass was generally shown to have the lowest ceiling attenuation, which was expected.

3.2 Ceiling attenuation with absorption over the ceiling tiles

Four different thicknesses of acoustic fibrous absorption were laid in turn over the rear face (facing the plenum) of the suspended ceiling system and tests were competed with each thickness of acoustic absorption installed. The different thicknesses of acoustic absorption were used to determine any trends between the increase of absorption in the plenum and the ceiling attenuation of each ceiling tile product. The resulting transmission loss with the four different acoustic absorption thicknesses are given in Figures 6 to 9.

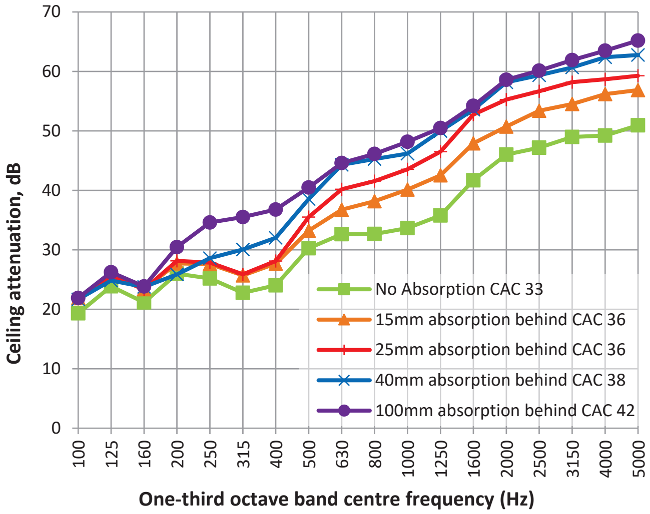

Figure 6: Transmission loss for ceiling tile A with various thicknesses of absorption in the plenum

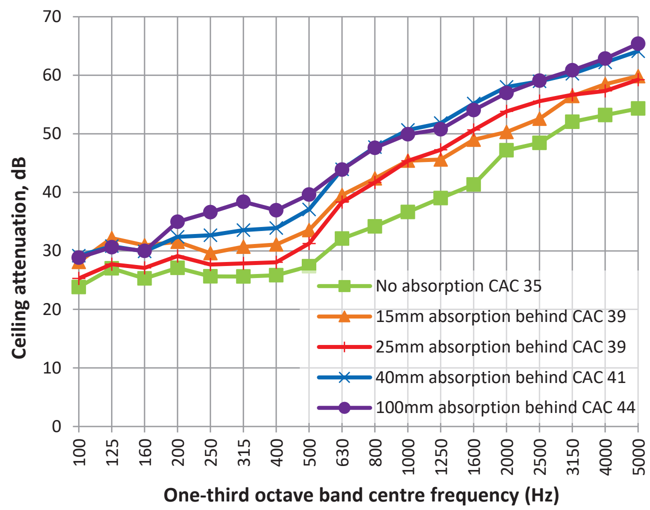

Figure 7: Transmission loss for ceiling tile B with various thicknesses of absorption in the plenum

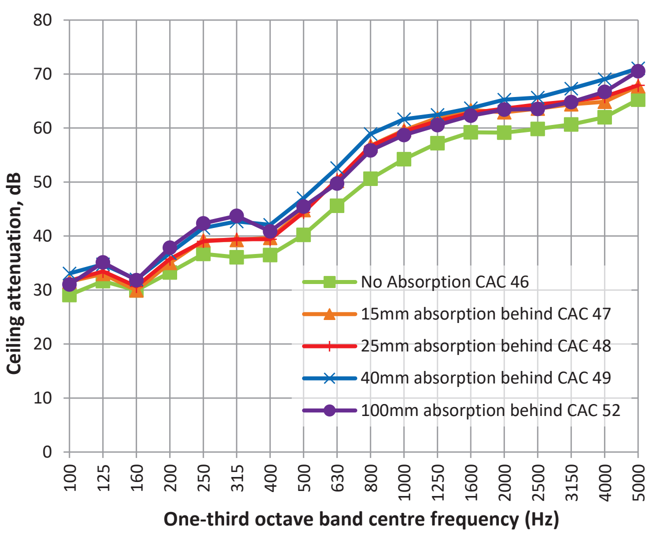

Figure 8: Transmission loss for ceiling tile C with various thicknesses of absorption in the plenum

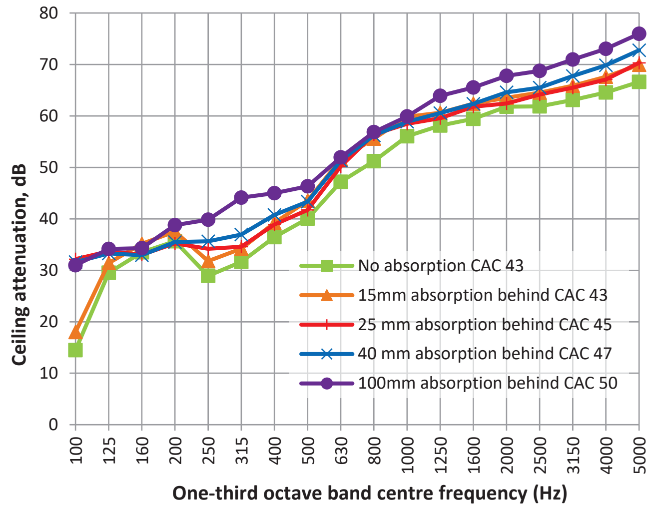

Figure 9: Transmission loss for ceiling tile D with various thicknesses of absorption in the plenum

It can be seen that as the thickness of the acoustic absorption laid on the rear of the ceiling tiles increases, the ceiling attenuation provided increases. A larger increase in the ceiling attenuation was provided to the lower mass ceiling tiles when the acoustic absorption was added to the plenum (ceiling tile A and ceiling tile B).

4.0 Discussion

4.1 Ceiling attenuation of ceiling tiles

Three general regions could be identified from the ceiling attenuation results provided by the ceiling tiles. The first region (below approximately 500 Hz) shows there is little increase in ceiling attenuation as the frequency increases through this region (approximately an increase of 2 dB per octave). The second region (between approximately 500 Hz and 1,600 Hz), shows that as frequency increases, the ceiling attenuation increases steeply, which is likely mass controlled, as high mass ceiling tiles exhibit a higher increase per octave than that of lighter ceiling tiles. Finally, above approximately 1,600 Hz, the ceiling attenuation continues to increase however at a lower rate.

On average between 500 Hz and 5,000 Hz, the ceiling attenuation provided in each one-third octave band increases by 12 dB as the surface density doubles. This can be seen when comparing ceiling tile B (4.7 kg/m^2 surface density – Figure 5) to ceiling tile D (10.2 kg/m^2 – Figure 7). Above 500 Hz, the average difference between ceiling tile B and D is approximately 15 dB, where below 500 Hz this is approximately 4 dB.

The overall ceiling attenuation trend for the ceiling tiles generally show a similar ceiling attenuation curve with the difference between the curves attributed to the difference in surface density. This can be best seen by comparing ceiling tile A (low mass ceiling tile, 3.3 kg/m^2) and ceiling tile C (high mass ceiling tile, 10.8 kg/m^2) as ceiling tile C has a surface density over three times that of ceiling tile A. The increase in ceiling attenuation between these ceiling tiles is on average 10 dB below 500 Hz, on average 17 dB between 500 Hz and 1,600 Hz, and on average 13 dB above 1,600 Hz, and is shown in Figure 10.

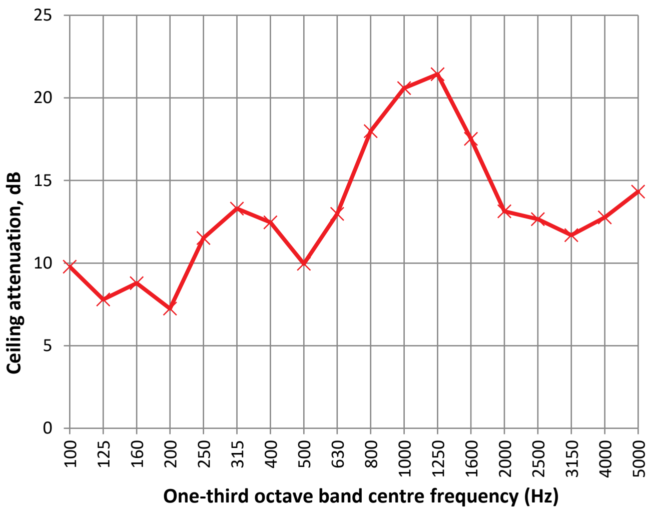

Figure 10: Difference in ceiling attenuation between ceiling tile A and ceiling tile C.

The decrease in ceiling attenuation seen in ceiling tile D at 250 Hz is probably due to the reflective surface of the roof of the plenum and the rear of the ceiling tile. When reviewing the back face absorption provided by ceiling tile D, this had the lowest absorption at this frequency compared to the other ceiling tiles measured in this research.

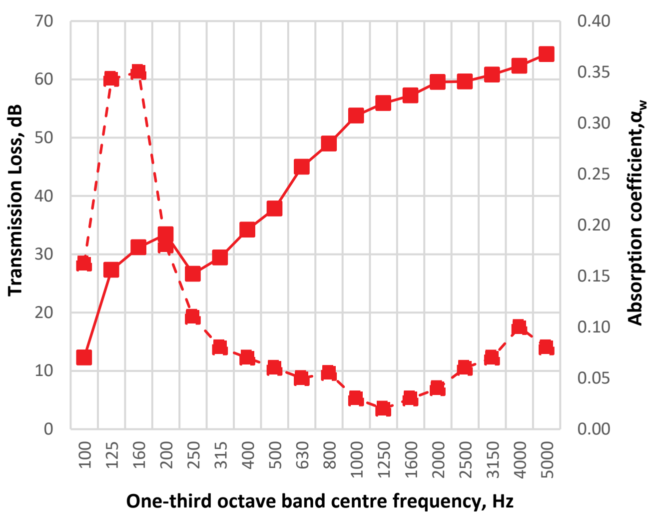

Figure 11: Ceiling attenuation (solid line) compared to the face absorption (dashed line) for ceiling tile

Figure 11 shows the ceiling attenuation provided by ceiling tile D and the absorption provided by the back face of the ceiling tile. The decrease at 250 Hz is attributed to a mode between the plasterboard backing of the ceiling tile and ceiling of the plenum above, as the height of the plenum from the back of the ceiling tile to the roof, corresponds well with a ½ wavelength at 250 Hz. The mineral fibre ceiling tiles used in this research did not show this trend probably due to these ceiling tiles having more absorptive backs and different thicknesses (so the standing wave may not be set up in the plenum).

4.2 Ceiling attenuation with acoustic absorption

4.2.1 15 mm acoustic absorption

With 15 mm of acoustic absorption added to the rear of the ceiling tiles, there is little increase in ceiling attenuation below 250 Hz compared to ceiling tiles without absorption to the rear. The highest increase seen in on ceiling tile B which shows a constant 1 – 4 dB increase though this range. Other ceiling tiles exhibit a 0 – 2 dB increase through this range. Between 250 Hz and 500 Hz, there is a small increase in the ceiling attenuation of ceiling tiles A, C, and D, with the ceiling attenuation of ceiling tile B staying constant as below 250 Hz.

Above 500 Hz, a larger increase in the ceiling attenuation is seen between the no absorption scenario and 15 mm absorption scenario. This increase is the highest for Ceiling tile A (lightest ceiling tile, 3.3 kg/m^2), with the smallest increase seen in ceiling tile D (high mass ceiling tile). The larger increase seen in ceiling tile A and B is probably due to the relative increase in mass over that of the tile itself (approximately 10 % increase in mass for ceiling tiles C and D, with approximately a 50 % increase for ceiling tile A).

Negligible increase was seen at the expected modal dip (250 Hz) for ceiling tile D. It was expected that the largest increase for this ceiling tile would be apparent at this frequency because of the absorption that is now present as well as the increased height of the tile. However, it could be deduced that the absorption may not be thick enough to absorb 250 Hz sound waves readily enough (therefore pass through the absorption layer rather than be 'absorbed').

4.2.2 25 mm acoustic absorption

An increase of the ceiling attenuation is shown most readily for ceiling tile D when 25 mm of acoustic absorption is installed to the rear of this ceiling tile specimen. The dip at 250 Hz (as well as the large drop off at 100 Hz) has been effectively removed from the ceiling attenuation curve, as shown in Figure 7.

As with the 15 mm absorption, generally there is little increase at the low frequencies, with increase between 0 and 4 dB below 500 Hz (apart from at 100 Hz and 250 Hz in ceiling tile D). The increase seen above 500 Hz (approximately 8 dB) is most prominent on the low density ceiling tiles (ceiling tiles A and B), but an increase is also seen in the higher density ceiling tiles, however to a much less extent (approximately 4 dB). The increase seen is expected to be due to the increase in mass that the acoustic absorption provides.

The increase above 500 Hz for ceiling tile C was on average 3 dB (ranging between 1 dB and 4 dB), with ceiling tile D average increase of 2 dB (ranging between 1 dB and 5 dB). Ceiling tile B showed an average increase above 500 Hz of 6 dB (ranging between 4 dB and 9 dB), and ceiling tile A showed an average increase of 7.5 dB (ranging between 4 and 10 dB). This increase is a bit more than that predicted by the mass law equation of doubling the surface density to increase the transmission loss of a product by 6 dB, as the surface density of ceiling tile A is 3.3 kg/m^2, and the surface density of 25 mm acoustic absorption was approximately 2.5 kg/m^2, however there is an average increase above 500 Hz of 7.5 dB. Therefore, it is expected that this additional increase seen over that predicted by mass law is from some sound being dissipated by the addition of the absorption in the plenum. This is also seen in the results of ceiling tile B, with a surface density of 4.7 kg/m^2, the increase in ceiling attenuation with the absorption added over should be less than 3 dB, however an average of a 6 dB increase is seen above 500 Hz.

4.2.3 40 mm acoustic absorption

With 40 mm of acoustic absorption laid over the ceiling tile products, little increase is seen below 250 Hz, however a marked improvement is seen for the low density ceiling tiles between 250 Hz and 500 Hz. An increase is now seen more readily in the higher mass ceiling tiles (as there is an approximately 40 % increase in mass with the absorption added to the rear of these ceiling tiles, compared to 25 % or less when less thick absorption was installed behind).

The ceiling attenuation afforded by ceiling tiles A and B are approaching that offered by a high mass ceiling tile without the addition of absorption to the rear, as the combination of densities are between 8 kg/m^2 and 9 kg/m^2. The increase in ceiling attenuation at 100 Hz and 250 Hz for ceiling tile D effectively flattens out the ceiling attenuation curve (as there are no large troughs), and shows a similar curve to that of the mineral fibre ceiling tiles used in this research.

The increase above 500 Hz for ceiling tile C was on average 3 dB (ranging between 2 dB and 5 dB), with ceiling tile D average increase of 4 dB (ranging between 2 dB and 6 dB). Ceiling tile B showed an average increase above 500 Hz of 8 dB (ranging between 6 dB and 11 dB), and Ceiling tile A showed an average increase of 11 dB (ranging between 10 and 12 dB). The increase above 250 Hz is more than that predicted by the mass law equation as described previously. Therefore, it is anticipated that some sound is dissipated with the addition of the absorption in the

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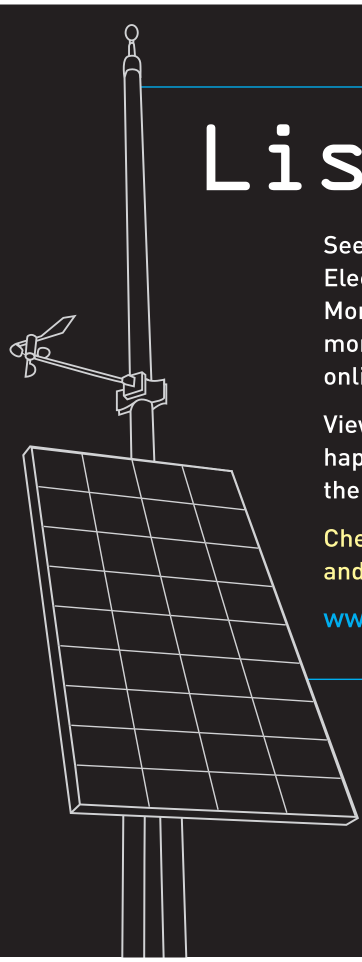

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plenum. Between 200 Hz and 500 Hz, the increase is over half that expected according to mass law of 4 dB.

4.2.4 100 mm acoustic absorption

With 100 mm of acoustic absorption installed to the rear of the ceiling tiles, an increase in ceiling attenuation is seen over all one-third octave band frequencies between 100 Hz and 5,000 Hz. The increase in surface density was approximately double for ceiling tiles C and D, as the acoustic absorption provided a mass of 10 kg/m^2 by itself (therefore a total mass of 20.8 kg/m^2 for ceiling tile C and 20.2 kg/m^2 for ceiling tile D). The total surface mass for ceiling tiles A and B were approximately 13.3 kg/m^2 and 14.7 kg/m^2 with the 100 mm of acoustic absorption installed in the plenum, however the ceiling attenuation curve of these ceiling tiles was only similar to the high mass ceiling tiles (ceiling tiles C and D) below 500 Hz and above 2,500 Hz. At the frequencies between these, the ceiling attenuation of ceiling tiles A and B was much lower than that of ceiling tiles C and D without acoustic absorption behind (by up to 10 dB at some frequencies). The material structure of the glass fibre therefore is expected to have an effect on the ceiling attenuation.

The increase at low frequencies had a large effect on ceiling tiles C and D that had a higher surface density, with a difference of approximately 3 dB below 200 Hz for ceiling tile C, and approximately 7 dB for ceiling tile D. The large increase seen in ceiling tile D is due to the large increase at 100 Hz. With this removed the average ceiling attenuation below 250 Hz is 3 dB. The lower mass ceiling tiles exhibited a lower increase in ceiling attenuation below 250 Hz, with an average increase of 2 dB for the ceiling tile B and 1.5 dB for ceiling tile A.

The increase above 250 Hz for ceiling tile C was on average 6 dB (ranging between 4 dB and 7 dB), with ceiling tile D average increase of 7 dB (ranging between 4 dB and 10 dB). Ceiling tile B showed an average increase above 250 Hz of 9 dB (ranging between 7 dB and 11 dB), and ceiling tile A showed an average increase of 12 dB (ranging between 11 and 13 dB). The increase above 250 Hz is more than that predicted by the mass law equation of doubling the surface density to increase the transmission loss of a product by 6 dB for the lower surface density ceiling tiles. The higher surface density ceiling tiles showed a trend very similar to the mass law. The surface density of the absorption was 10 kg/m^2, so for ceiling tile D, the mass was effectively doubled, and an average of a 7 dB increase was seen.

5.0 Acknowledgements

This work would not have been possible without the support of John Pearse from the University of Canterbury. The use of the use of the Ceiling Flanking Noise facility and the Reverberation Room that was extensively used in this research would not have been possible without his help.

6.0 References

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