The sound insulation of autoclaved aerated concrete panels lined with gypsum plasterboard

John Laurence DAVY[1]; Mark DEBEVC[2]; Christophe BLANC[3]

[1] School of Science, RMIT University and Infrastructures Technology, CSIRO, Australia

[2] USG Boral Building Products, Australia

[3] USG Boral Building Products, Thailand

ABSTRACT

This paper gives the results of 27 laboratory measurements of the sound insulation of 75mm thick tongue and groove autoclaved aerated concrete (AAC) panels with stated nominal dry density of 510kg/m3 (a surface density of 38.2kg/m^2).which are lined with 13mm thick gypsum plasterboard. Two configurations that are presently common forms of construction in a region of Australia were tested; 1. Furring channel one side and stud wall the other that maintained an overall wall width of 243mm, and 2. Direct fix one side and stud wall the other. In both cases the gypsum plasterboard is mounted on 64mm steel studs. The gap between the panels and the steel studs is 20, 35 or 48mm. With the exception of one empty cavity, the cavity on this side contains 11kg/m^3 glass fibre batts with thickness of 50, 75, 90 or 110mm. On the other side of the panels, the gypsum plasterboard is mounted on furring channels and adjustable clips which are screwed to the panels or in 6 cases directly screwed to the panels. Except for the directly screwed cases, the gap between the panels and the gypsum plasterboard is 30, 43 or 58mm. The cavity is empty or contains 50 or 70mm thick 11kg/m^3 glass fibre batts or 25mm thick 24kg/m^3 glass fibre batts. The 13mm gypsum plasterboard has nominal surface densities of 7.2, 8.5 or 10.5kg/m^2. The aim was to develop a system which has a laboratory measured R_w+C_{tr} equal to or greater than 50dB which is required by the National Construction Code (NCC) of Australia for walls between separate dwellings. A system with cavities on both sides of the wall is desirable because it allows services to be accommodated without the need for chasing which is not permitted. The undesirable effect is a resultant large C_{tr} making it difficult to achieve an R_w +C_{tr} equal to or greater than 50dB.

Keywords: Sound insulation, Autoclaved aerated concrete, Gypsum plasterboard.
I-INCE Classification of Subjects Number(s): 51

1. INTRODUCTION

The National Construction Code of Australia (1, 2) requires a common wall between separate dwellings to have R_w+C_{tr} measured in a laboratory equal to or greater than 50dB. This reduced to a $D_{nT,w}$+C_{tr} equal to or greater than 45dB for field verification measurements in order to allow for the effects of flanking sound transmission via other paths than the direct path through the wall. A system with cavities on both sides of the common wall is desirable because it allows services to be accommodated without chasing which is not allowed. Moreover, and the reason why a stud wall was used on one side, the NCC also requires a common wall between separate dwellings to have impact sound insulation where a non-habitable room on one side i.e. a bathroom, sanitary compartment, laundry or kitchen, abuts a habitable room on the other side. To comply, a minimum 20mm gap is required in this instance between the 75mm AAC panel and the stud framing. Because space costs money it is desirable to keep the common wall as thin as possible. Unfortunately, narrow air cavities provided by the furring channel to accommodate services create mass-air-mass resonances in the frequency range which reduces the sound insulation of the wall. It was hoped that light weight gypsum

[1] johnldavy@gmail.com
[2] Mark.Debevc@usgboral.com
[3] Christophe.Blanc@usgboral.com

plasterboard (7.2kg/m²) could be used on the outside faces of the common wall to shift the mass-air-mass resonant frequency, but this also reduces the sound insulation of the wall compared to that obtained with standard weight (8.5kg/m²) or heavy weight (10.5kg/m²) fire rated gypsum plasterboard. Measurements were also made of walls with an air cavity only on one side of the wall.

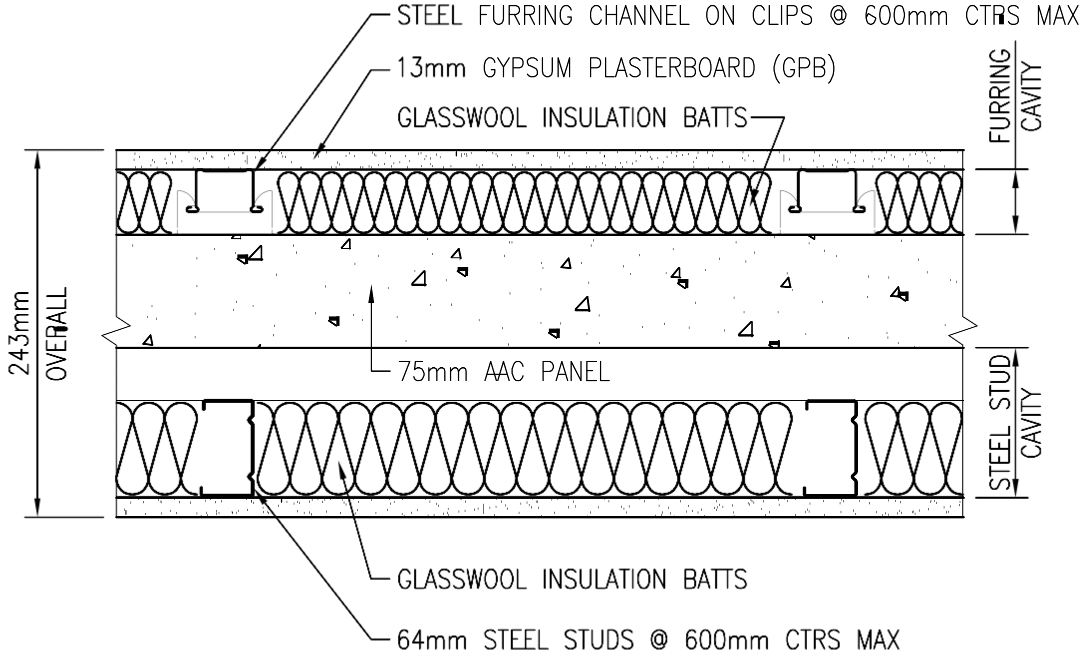

Figure 1. A two air cavity wall with furring channels on one side and steel studs on the other side.

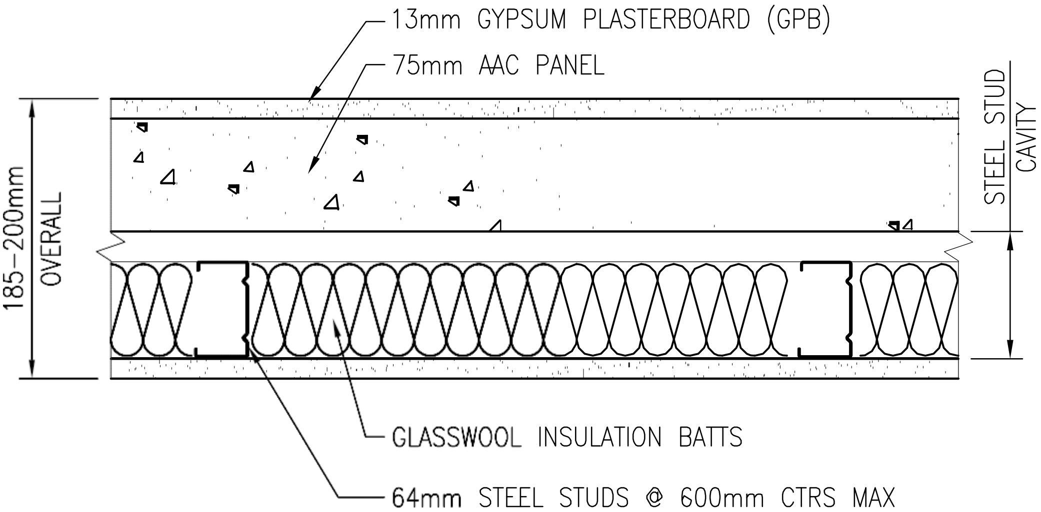

Figure 2. A single air cavity wall with direct fixing on one side and steel studs on the other side.

The centre layer of the wall systems was 75mm thick tongue and groove autoclaved aerated concrete (AAC) panels with a surface density of 38.2kg/m². The gypsum plasterboard layers were 13mm thick. The aim was to have a maximum wall thickness of 243mm. On one side of the walls, the gypsum plasterboard was screwed to 64mm steel studs spaced 20, 35 or 48mm from the AAC panels. With the exception of one empty cavity, the cavity on this side contains 11kg/m³ glass fibre batts with thickness of 50, 75, 90 or 110mm.On the other side of the panels, the gypsum plasterboard is screwed on furring channels and clips which are screwed to the panels or in 6 cases directly screwed to the panels. Except for the directly screwed cases, the gap between the panels and the gypsum plasterboard is 30, 43 or 58mm. The cavity is empty or contains 50 or 70mm thick 11kg/m³ glass fibre batts or 25mm thick 24kg/m³ glass fibre batts. The two types of wall construction are shown in Figure 1 and Figure 2.

The sound insulation of the walls was measured at the new CSIRO reverberation rooms in the Melbourne suburb of Clayton, just north of Monash University. The wall opening is 3m high by 3.6m wide. The reverberation rooms on either side of the wall opening are rectangular and have volumes of 200 and 100m^3. The rooms are vibration isolated from the ground and from each other. The 200m^3 room contains diffusing panels because it has been qualified for sound absorption coefficient measurements. The sound insulation was measured in both directions. An omnidirectional dodecahedron loudspeaker system was used in three different positions in each room. The sound pressure level was measured simultaneously in each room by using two rotating microphone booms.

2. MEASURED SOUND INSULATION

Table 1. The walls tested and their measured sound insulation.

	200m^3 - Furring Channels				Core	100m^3 – 64mm Steel Studs					
No.	GPB	Cavity	Batts	f_0	AAC	Batts	Cavity	GPB	f_0	$R_w(C;C_{tr})$	R_w+C_{tr}
	13mm	Width	mm-		75mm	mm-	Width	13mm			
	kg/m^2	mm	kg/m^3	Hz	kg/m^2	kg/m^3	mm	kg/m^2	Hz	dB	dB
1	7.2	43	50-11	118	38.2	75-11	99	7.2	78	62(-8;-16)	46
2	7.2	0	-		38.2	75-11	99	7.2	78	61(-2;-9)	52
3	7.2	30	-	141	38.2	75-11	112	7.2	73	55(-4;-10)	45
4	7.2	30	25-24	141	38.2	75-11	112	7.2	73	58(-6;-14)	44
5	7.2	30	-	141	38.2	90-11	112	7.2	73	58(-3;-10)	48
6	7.2	30	-	141	38.2	110-11	112	7.2	73	59(-4;-10)	49
7	7.2	30	25-24	141	38.2	110-11	112	7.2	73	62(-8;-16)	46
7R	7.2	30	25-24	141	38.2	110-11	112	7.2	73	61(-7;-15)	46
8	8.5	30	25-24	131	38.2	110-11	112	8.5	68	64(-8;-16)	48
9	8.5	30	-	131	38.2	110-11	112	8.5	68	60(-4;-11)	49
10	7.2	43	-	118	38.2	90-11	99	7.2	78	58(-4;-11)	47
11	7.2	43	50-11	118	38.2	90-11	99	7.2	78	64(-8;-17)	47
12	8.5	43	50-11	110	38.2	90-11	99	8.5	72	65(-8;-16)	49
13	8.5	43	-	110	38.2	90-11	99	8.5	72	59(-4;-11)	48
14	8.5	43	-	110	38.2	75-11	99	8.5	72	59(-4;-11)	48
15	8.5	43	50-11	110	38.2	75-11	99	8.5	72	65(-8;-17)	48
16	7.2	43	50-11	118	38.2	75-11	99	7.2	78	63(-8;-17)	46
17	7.2	43	-	118	38.2	75-11	99	7.2	78	57(-4;-10)	47
18	10.5	43	50-11	101	38.2	75-11	99	10.5	67	67(-7;-16)	51
19	10.5	43	-	101	38.2	75-11	99	10.5	67	61(-5;-12)	49
20	7.2	58	70-11	101	38.2	90-11	84	7.2	84	64(-8;-17)	47
21	7.2	58	-	101	38.2	90-11	84	7.2	84	57(-5;-12)	45
22	7.2	0	-	-	38.2	50-11	84	7.2	84	57(-3;-10)	47
23	7.2	0	-	-	38.2	-	84	7.2	84	47(-2;-7)	40
24	7.2	0	-	-	38.2	90-11	84	7.2	84	60(-3;-10)	50
25	8.5	0	-	-	38.2	75-11	84	8.5	79	62(-4;-10)	52
26	-	-	-	-	38.2	-	-	-	-	35(-1;-3)	32
27	7.2	0	-	-	38.2	75-11	84	7.2	84	60(-3;-10)	50

Table 1 shows the walls tested and their measured sound insulation. The first thing to note is that the furring channels were on the 200m^3 reverberation room side of the wall, while the 64mm steel studs were on the 100m^3 room side. Column 1 shows the wall number. Columns 2 to 5 and 7 to 10 give the surface density of the 13mm gypsum plasterboard, the air cavity width, the thickness and density of the sound absorbing glass fibre batts and the mass-air-mass resonant frequency (f_0) for the cavities on each side of the wall. Column 6 gives the surface density of the autoclaved aerated concrete panels. Columns 11 and 12 give $R_w(C;Ct_r)$ and R_w+C_{tr}. Note that wall 7 was retested a day after its first measurement (7R). Its R_w+C and R_w+C_{tr} were unchanged while its R_w decreased by 1dB.

Result 26 shows that the AAC panels on their own only achieved an R_w+C_{tr} of 32dB. Adding light weight gypsum plasterboard (GPB) to both sides of the AAC panels with cavities of 43 and 99mm containing 50 and 75mm 11kg/m^3 glass fibre batts increased the R_w+C_{tr} to 46dB (result 1). Because this was less than the desired 50dB, the furring channels were temporarily removed and the GPB on that side was screwed directly to the AAC. This gave an R_w+C_{tr}. of 52dB (result 2). See Figure 3. It should be noted that many of the sound reduction indices in the figures are lower limits because some of the receiving room values were within 6dB of the background noise.

The cavities were now changed to 30 and 112mm with nil and 75mm 11kg/m^3 glass fibre batts to obtain, compared to result 1, a slightly decreased R_w+C_{tr} of 45dB (result 3). Adding 25mm 24kg/m^3 glass fibre batts to the empty furring channel cavity surprisingly further decreased the R_w+C_{tr}. to 44dB (result 4). See Figure 4. Removing the batts from the furring channel side and increasing the batt thickness from 75 to 90mm on the stud side increased the R_w+C_{tr} from 44 to 48dB (result 5). A further increase of batt thickness to 110mm on the stud side increased the R_w+C_{tr} to 49dB (result 6). Reinstalling the 25mm 24kg/m^3 glass fibre batts to the empty furring channel cavity was expected to give 50dB or more but it again surprisingly decreased the R_w+C_{tr} by 3dB to 46dB (result 7). See Figure 5. This result was so surprising that the measurement was repeated the next day as stated above and gave the same value of R_w+C_{tr}.(result 7R). See Figure 6.

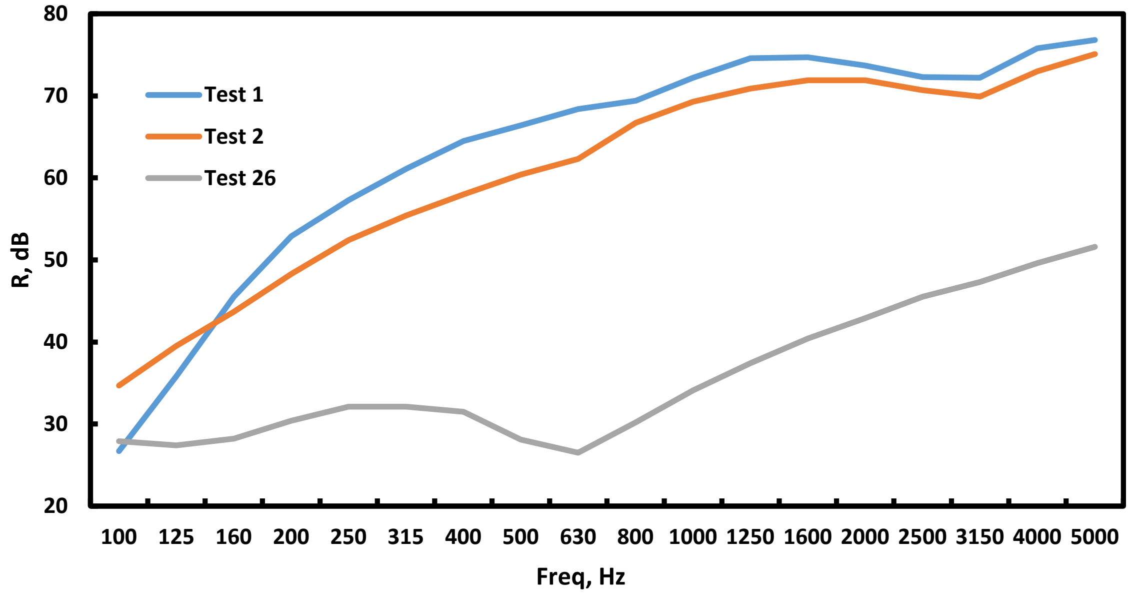

Figure 3. Test results 1, 2 and 26.

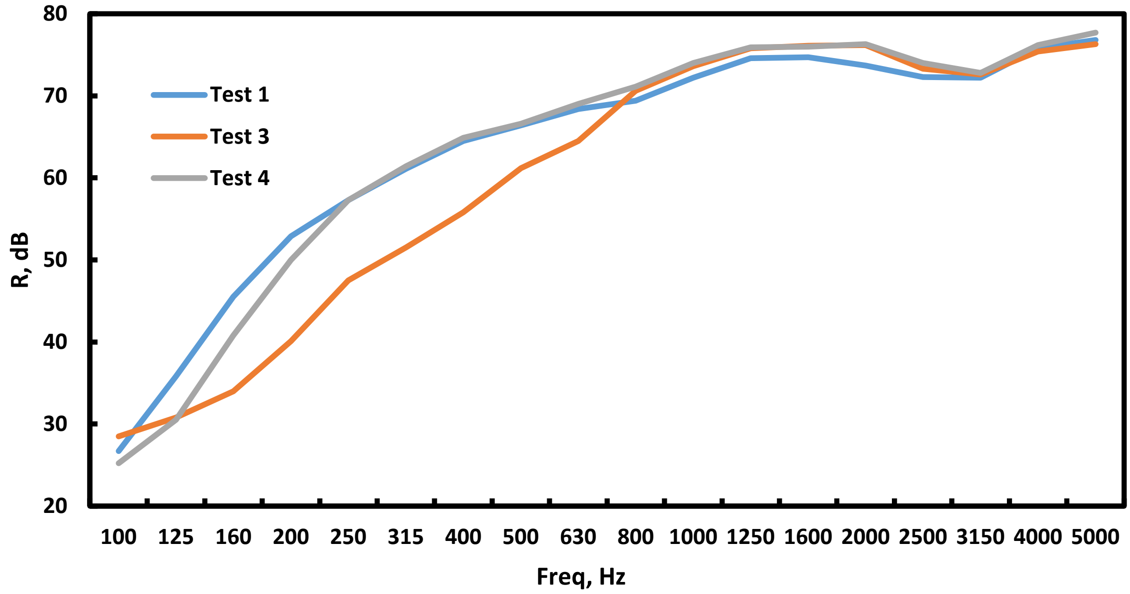

Figure 4. Test results 1, 3 and, 4.

The GPB was changed to standard weight on each side of the wall and the R_w+C_{tr} increased by 2dB to 48dB (result 8). Removing the batts from the furring channel side gave a consistent but surprising increase of R_w+C_{tr} by 1dB to 49dB (result 9). See Figure 7.

The cavities were changed back to the original 43 and 99mm. There were no batts in the furring channel side and 90mm 11kg/m^3 on the stud side. The GPB was changed back to light weight on both sides. The result was R_w+C_{tr} equals 47dB (result 10) which was 1dB better than result 1 which had batts on the furring channel side and slightly thinner batts on the stud side. Adding 50mm 11kg/m^3 batts on the furring channel side gave the same value of R_w+C_{tr} equals 47dB (result 11). See Figure 8. While it was surprising that this change did not provide an increase, at least it did not provide a decrease.

The GPB was changed again to standard weight. This increased the R_w+C_{tr} by 2dB to 49dB (result 12). Removing the batts from the furring channel side decreased the R_w+C_{tr} by 1dB to 48dB (result 13). Decreasing the thickness of the batts on the stud side from 90 to 75mm, made no change in the R_w+C_{tr} of 48dB (result 14). Reinstalling the 50mm 11kg/m^3 batts on the furring channel side also made no change (result 15). See Figure 9.

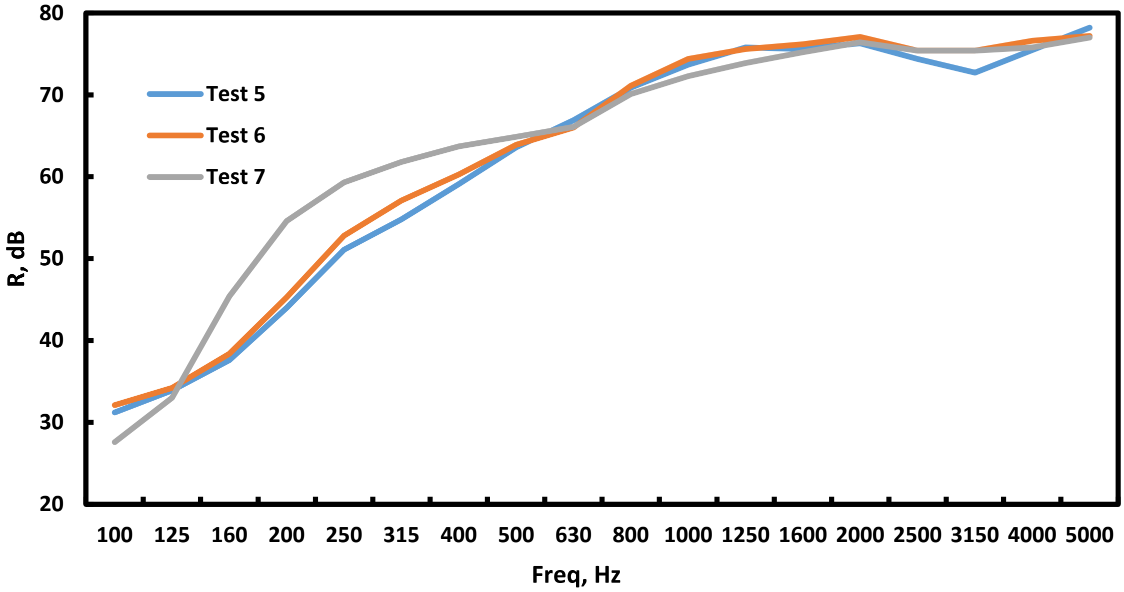

Figure 5. Test results 5, 6, and 7.

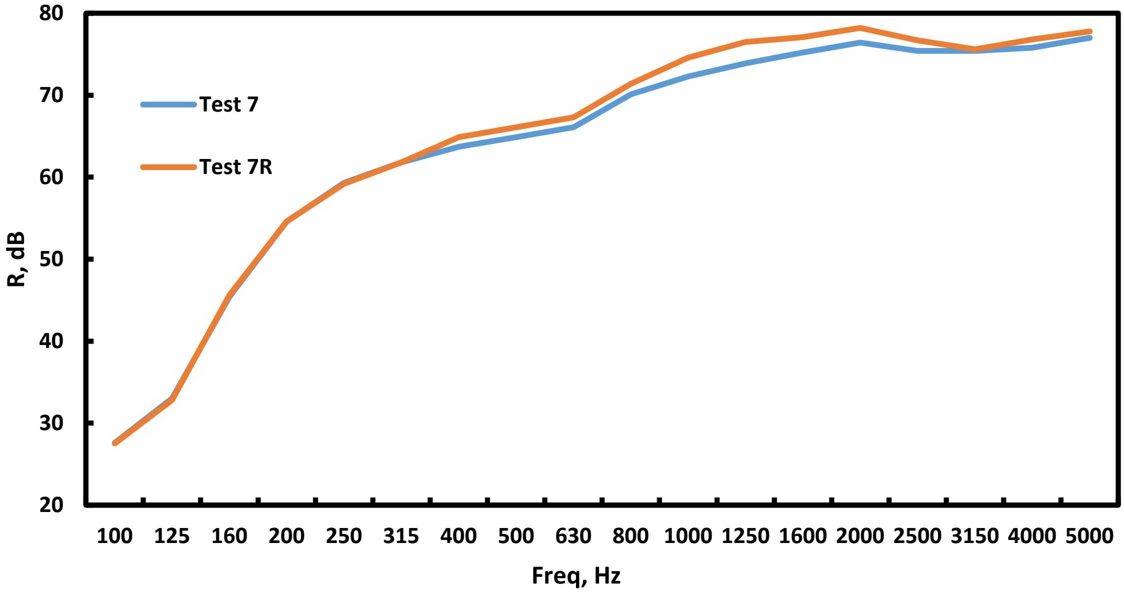

Figure 6. Test results 7 and 7R.

The GPB was changed back to light weight on both sides and the R_w+C_{tr} decreased by 2dB to 46dB (result 16). This was repeat of result 1 involving reconstruction. The R_w+C_{tr} was unchanged. Removing the batts from the furring channel side gave the reasonably consistent but surprising result of increasing the R_w+C_{tr} by 1dB to 47dB (result 17). See Figure 10.

Changing the GPB to heavy weight fire rated board increased the R_w+C_{tr} by 2dB to 49dB (result 19). Adding 50mm 11kg/m^3 batts on the furring channel side finally produced an expected increase of

2dB to an R_w+C_{tr} of 51dB (result 18). See Figure 11. This was the only one of the twenty walls with two air cavities that were tested in this series of tests to produce an R_w+C_{tr} of equal to or greater than 50dB.

The cavity on the furring channel side was increased to 58mm with a corresponding decrease of the cavity on the stud side to 84mm. The cavities had 70 and 90mm 11kg/m^3 batts. The GPB was changed to lightweight on both sides of the wall. These changes produced an R_w+C_{tr} of 47dB (result 20). Removing the batts from the furring channel side cavity reduced the R_w+C_{tr} by 2dB to 45dB (result 21). See Figure 12.

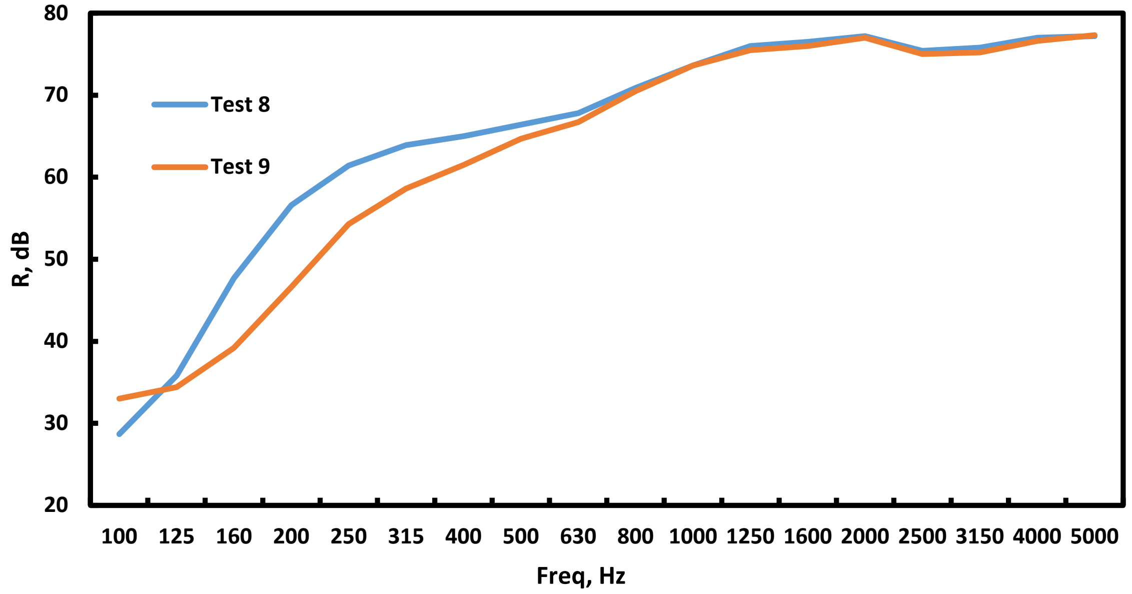

Figure 7. Test results 8 and 9.

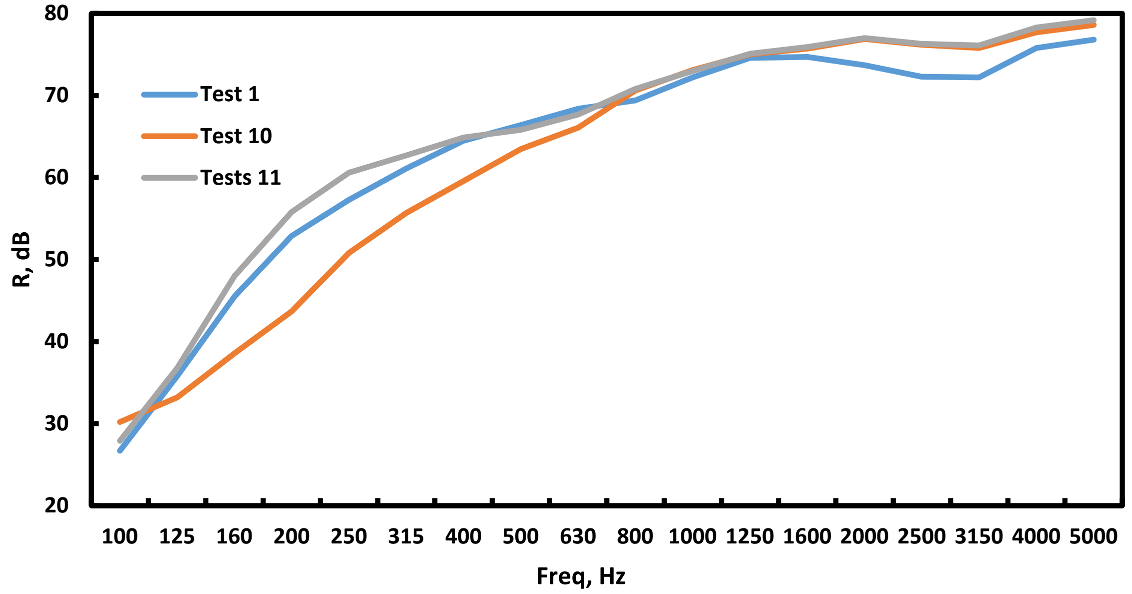

Figure 8. Test results 1, 10 and 11.

Because of the high value of R_w+C_{tr} equals 52dB given by result 2, the final measurements in this series of test were made with the furring channels removed and the GPB directly screwed to AAC panels on what had been the furring channel side. The cavity on the stud side was 84mm. With lightweight GPB on both sides and 90mm of 11kg/m3 batts in the cavity, the R_w+C_{tr} was 50dB (result 24). Reducing the thickness of the batts to 75mm gave an unchanged R_w+C_{tr} of 50dB (result 27). A further reduction to 50mm gave a 3dB reduction to an R_w+C_{tr} of 47dB (result 22). Removing the batts completely reduced the R_w+C_{tr} a further 7dB to 40dB (result 23). Replacing the GPB with standard weight board and using 75mm 11kg/m3 batts in the cavity gave an R_w+C_{tr} of 52dB (result 25). This is the same value as obtained in result 2. See Figure 13.

3. MASS-AIR-MASS RESONANT FREQUENCY

The mass-air-mass resonant frequency f_0 of two panels with surface densities m_1 and m_2 which are separated by cavity of width d containing an acoustic media with ambient density ρ_0 and speed of sound c is (3)

$$f_0 = \frac{c}{2\pi}\sqrt{\frac{\rho_0}{dm_r}}, \tag{1}$$

where the reduced surface density m_r is given by

$$m_r = \frac{m_1 m_2}{m_1 + m_2} = \frac{m_2}{1 + m_2/m_1}. \tag{2}$$

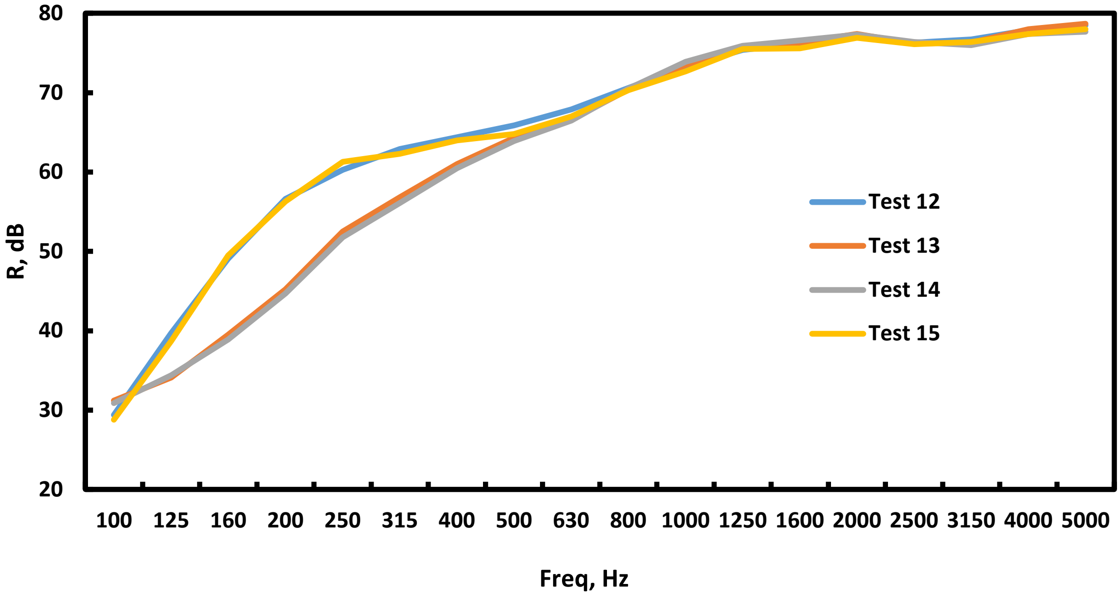

Figure 9. Test results 12, 13, 14, 15.

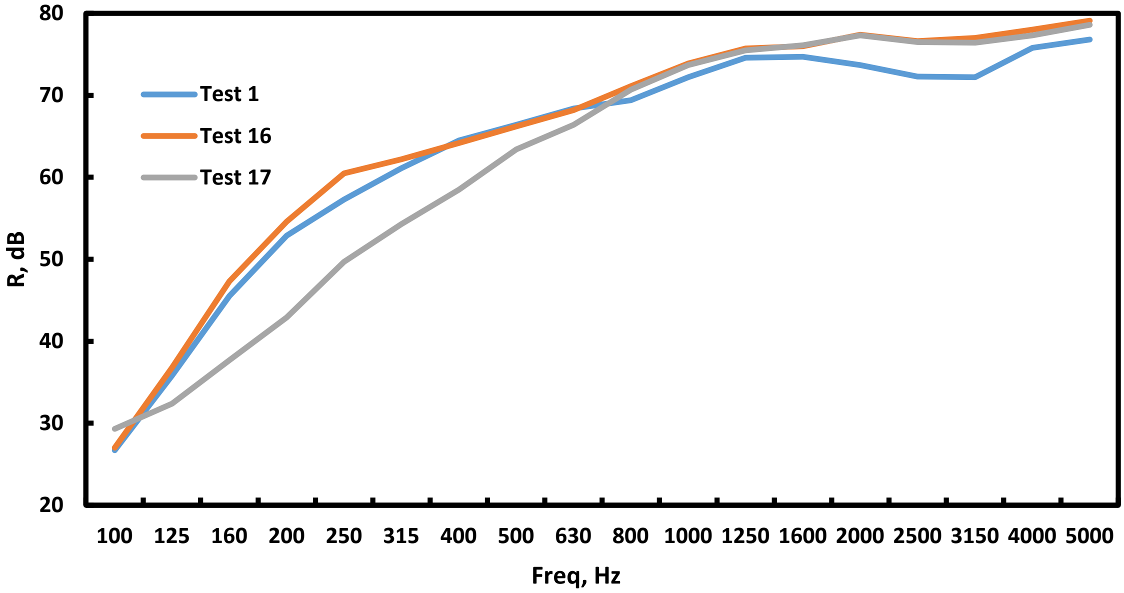

Figure 10. Test results 1, 16 and 17.

If m_1 equals m_2 equals m, then m_r equals $m/2$. If m_1 is very much greater than m_2, then m_r is approximately equal to m_2. Similarly, if m_2 is very much greater than m_1, then m_r is approximately equal to m_1. Thus, in this paper, because the surface density of the AAC panels is very much greater than the mass of the GPB panels, the reduced surface densities will be approximately equal to the surface densities of the GPB panels.

The effect of the mass-air-mass resonance of one cavity on the mass-air-mass resonance of the other cavity has been ignored. This effect will small because the surface density of the AAC panels is much greater than the surface densities of the GPB panels.

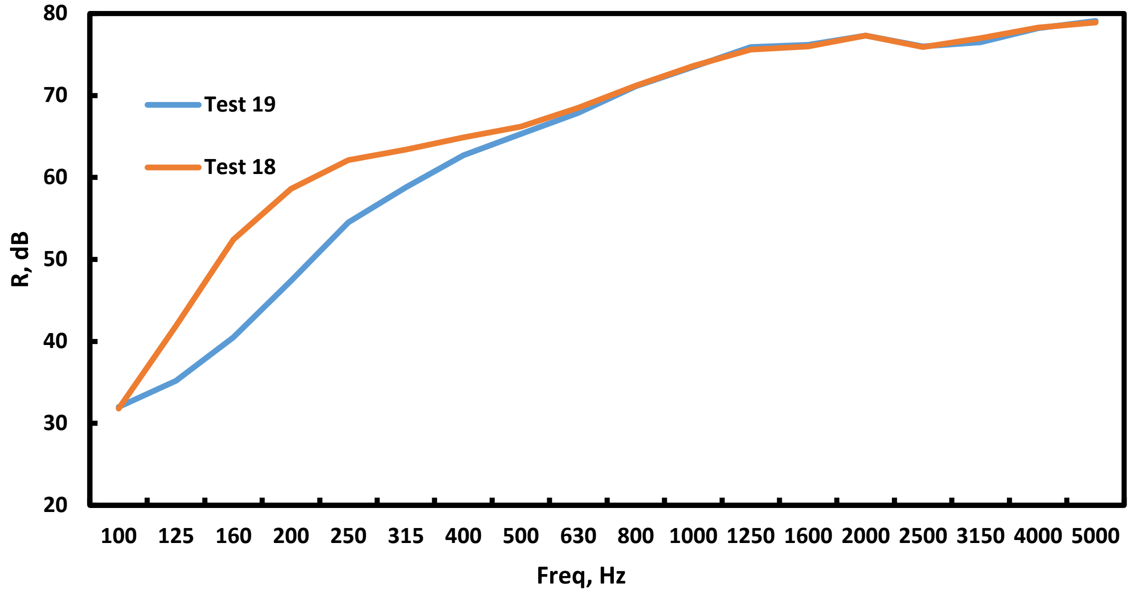

Figure 11. Test results 18 and 19.

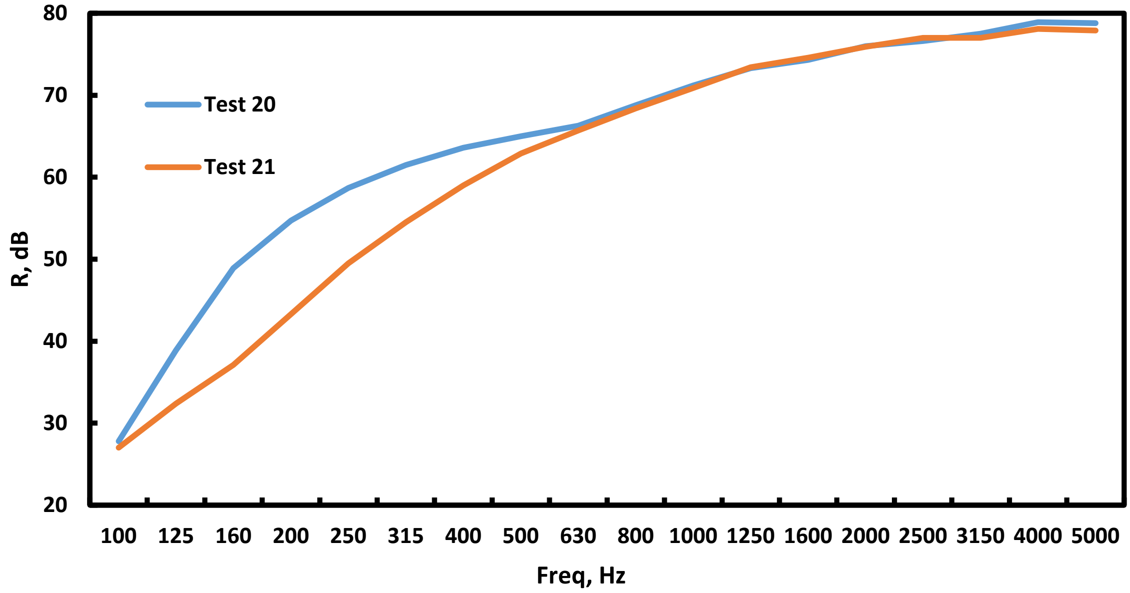

Figure 12. Test results 20 and 21.

The speed of sound c is

$$c = \sqrt{\frac{\gamma p_0}{\rho_0}}, \quad (3)$$

where p_0 is the ambient pressure and γ is the adiabatic constant. For air, the adiabatic constant γ is approximately equal to 1.4 because air is composed mainly of diatomic molecules. The mass-air-mass resonant frequency f_0 calculated using equations (1) to (3) is shown for each cavity in Table 1. When porous sound absorbing material is installed in the cavity, Narang (4) has suggested that the sound propagation in the pores of the material is isothermal and hence that the isothermal speed of sound should be used. The isothermal speed of sound is obtained by setting γ equal to 1. This means that the mass-air-mass resonant frequency f_0 is reduced by 15% compared to the values given in Table 1 because

$$\frac{1}{\sqrt{1.4}} = 0.85 \,. \tag{4}$$

Below the mass-air-mass resonant frequency f_0, the cavity is stiff enough to rigidly couple the two panels together. In this frequency range, porous sound absorbing material in the cavity has no effect on the sound insulation (5). At the mass-air-mass resonant frequency f_0, the slope of the sound insulation as a function of frequency increases when the frequency increases and there is often a dip in the sound insulation (5). Above the mass-air-mass resonant frequency f_0, the panels can move independently and the sound insulation increases as the sound absorption in the cavity increases (5).

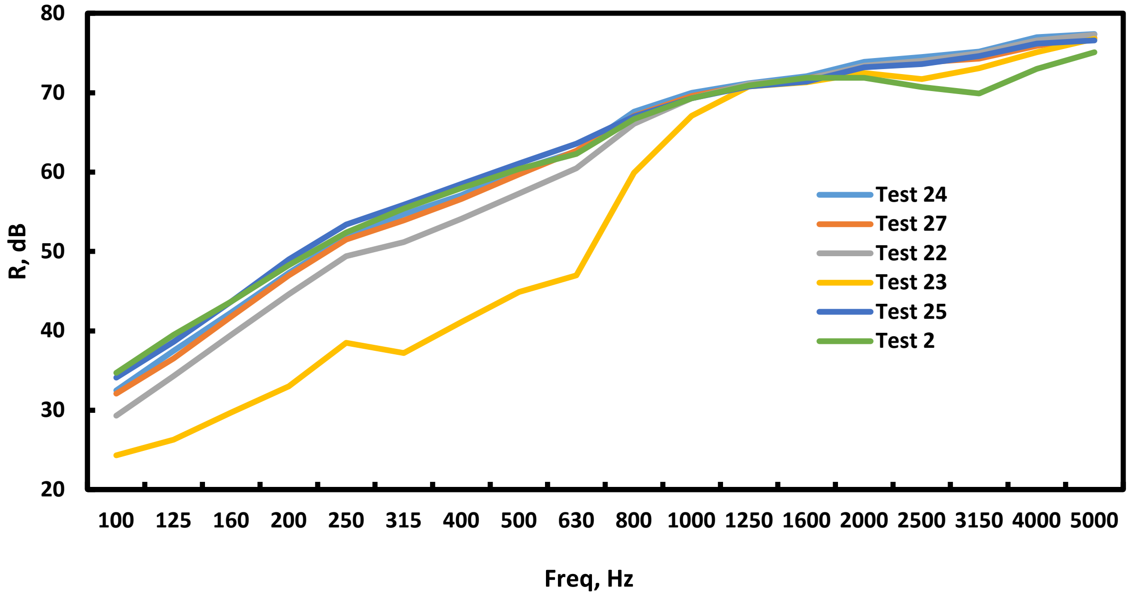

Figure 13. Test results 2, 22, 23, 24, 25, 27.

For the cavity with the 64mm studs, the width of the cavity was large enough that the mass-air-mass resonant frequency was always below the bottom of the 100Hz third octave band. Increasing the thickness of the porous sound absorbing material in this cavity resulted in an increased or the same R_w, R_w+C and R_w+C_{tr}.

For the 30mm furring channel cavity with the light weight GPB, the mass-air-mass resonant frequency is 141Hz. Adding porous sound absorbing material to this cavity increased the R_w but reduced the R_w+C_{tr} (see results 3, 4, 6, 7 and 7R). This is due to sound absorbing material lowering the mass-air-mass resonant frequency because of the reduction of the sound speed in the cavity. This reduction in the mass-air-mass resonant frequency reduced the two lowest values of sound insulation in the R_w+C_{tr} evaluation range which occurred in the 100 and 125Hz third octave bands. These two reductions caused the reduction in the R_w+C_{tr} because they occurred in the low frequency range where the R_w+C_{tr}. is most sensitive due to the general increase in sound insulation with frequency.

With the standard weight GPB, the mass-air-mass resonant frequency of the 30mm furring channel cavity was reduced to 131Hz. The same directions of change as previously in both R_w and R_w+C_{tr} was observed when porous sound absorbing material was added to the cavity, but because of the reduction in the mass-air-mass resonant frequency only the lowest value of sound insulation in the R_w+C_{tr} evaluation range which occurred in the 100Hz third octave band was reduced (see results 8 and 9).

For the 43mm furring channel cavity with the light weight GPB, the mass-air-mass resonant frequency is 118Hz. Adding porous sound absorbing material to this cavity increased the R_w and the R_w+C but left the R_w+C_{tr} unchanged or decreased by 1dB (see results 10, 11, 1, 16 and 17). The lower mass-air-mass resonant frequency meant that while the lowest value of sound insulation in the R_w+C_{tr} evaluation range, which was in the 100Hz third octave band, was reduced, the reduction was only sufficient to leave the R_w+C_{tr} unchanged or reduce it by 1dB.

The use of standard weight GPB with the 43mm furring channel cavity reduced mass-air-mass resonant frequency to 110Hz. The addition of porous sound absorbing material to this cavity either increased by 1dB or left unchanged the R_w+C_{tr}. (see results 12,13,14 and 15). This is because there was only a small reduction in the lowest value of sound insulation in the R_w+C_{tr} evaluation range which occurred in the 100Hz third octave band.

The 43mm furring channel cavity and heavy weight fire rated GPB have a mass-air-mass resonance of 101Hz. Adding porous sound absorbing material to this cavity increased the R_w, R_w+C and R_w+C_{tr} (see results 18 and 19). The lower value of the mass-air-mass resonant frequency meant that there was only a 0.2dB decrease in the lowest value of sound insulation in the R_w+C_{tr} evaluation range which occurred in the 100Hz third octave band. This is the reason why the R_w+C_{tr} was able to increase.

The 58mm furring channel cavity and the light weight GPB also have a mass-air-mass resonance of 101Hz. Because of this, adding porous sound absorbing material to this cavity also increased the R_w, R_w+C and R_w+C_{tr} (see results 20 and 21). In this case, all the lowest values of sound insulation in the R_w+C_{tr} evaluation range actually increased when the porous sound absorbing material was added.

When the furring channel cavity was removed, a single cavity wall with a cavity of 84mm was obtained. With light weight GPB, this cavity had a mass-air-mass resonant frequency of 84Hz and the R_w, R_w+C and R_w+C_{tr} of this wall increased as the thickness of the sound absorbing material was increased from 0 to 50 to 75mm (see results 23, 22, 27). The R_w, R_w+C and R_w+C_{tr} of this wall remained the same when the thickness of the sound absorbing material was further increased from 75 to 90mm (see results 27 and 24). When the light weight GPB was replaced with the standard weight GPB in the 75mm thick sound absorbing material case, the mass-air-mass resonant frequency decreased to 79Hz and the R_w, R_w+C and R_w+C_{tr} all increased further (see results 27 and 25). Increasing the cavity to 99mm rather than changing the GPB gave a mass air-mass resonant frequency of 78Hz and also increased the R_w, R_w+C and R_w+C_{tr} (see results 27 and 2).

This section has shown that as the mass-air-mass resonant frequency of a cavity in a double cavity wall is gradually reduced from 141 to 84Hz, the effect of adding porous sound absorbing material to the cavity gradually changes from reducing the R_w+C_{tr} to increasing the R_w+C_{tr}. This observation is consistent with the observation that adding porous sound absorbing material to a single cavity wall with an 84mm cavity which has a mass-air-mass resonant frequency of 84Hz increases R_w+C_{tr}.

This section also shows that unless there are special considerations, like thermal performance or the provision of services as was the situation in the case considered in this paper, it is better to use a single cavity wall and concentrate the surface density in two wall leaves rather than three wall leaves and concentrate the width in one cavity rather than two cavities, in order to obtain the best sound insulation

4. CONCLUSIONS

The National Construction Code of Australia (1, 2) requires that a common wall between separate dwellings to have R_w+C_{tr} measured in a laboratory equal to or greater than 50dB. The research described in this paper attempted to satisfy this requirement with a wall consisting of a 75mm autoclaved aerated concrete core with cavities and 13mm gypsum plasterboard on each side so that services could be installed. Because space costs money, the wall was restricted to a maximum thickness of 243mm. The only one configuration of this wall, out of 20 configurations which were tested, satisfied the requirement. This configuration needed the use of heavy weight fire rated gypsum plasterboard and porous sound absorbing material on each side of the autoclaved aerated concrete core.

Four configurations of the single cavity version of this wall, out of 6 configurations that were tested, satisfied the requirement. Three of these configurations used light weight gypsum plasterboard and one configuration used standard weight gypsum plasterboard. All four walls had porous sound absorbing material of at least 75mm thickness in their cavity. This shows that single cavity walls provide better sound insulation than double cavity walls of the same thickness. In this paper, the single cavity walls were actually thinner than the double cavity walls.

This paper has also explained why adding porous sound absorbing material to a narrow cavity can sometimes reduce the R_w+C_{tr}. The reason is that the isothermal sound propagation in the pores of the porous sound absorbing material reduces the mass-air-mass resonant frequency of the cavity. This reduction in the mass-air-mass resonant frequency can reduce the lowest values of sound insulation in the R_w+C_{tr} evaluation range, which often occur in the 100 and 125Hz third octave bands, if the mass-air-mass resonant frequency of the empty cavity is not low enough.

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