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Sound Decisions: Moving forward with Acoustics

Structural connections and the sound insulation of cavity walls and double glazing

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ABSTRACT

Structural connections between the wall leaves of double leaf cavity walls can reduce the sound insulation of the wall. Structural connections, which are rigid enough, can move the mass-air-mass resonant frequency to a higher frequency and decrease the sound insulation of the wall in the important low frequency region. At mid and high frequencies, the sound insulation of large air gap double glazed windows is controlled by vibration transmission between the two glass panes via the window frame. This problem can be partially overcome by using primary and secondary glazing rather than sealed double glazed units.

1 INTRODUCTION

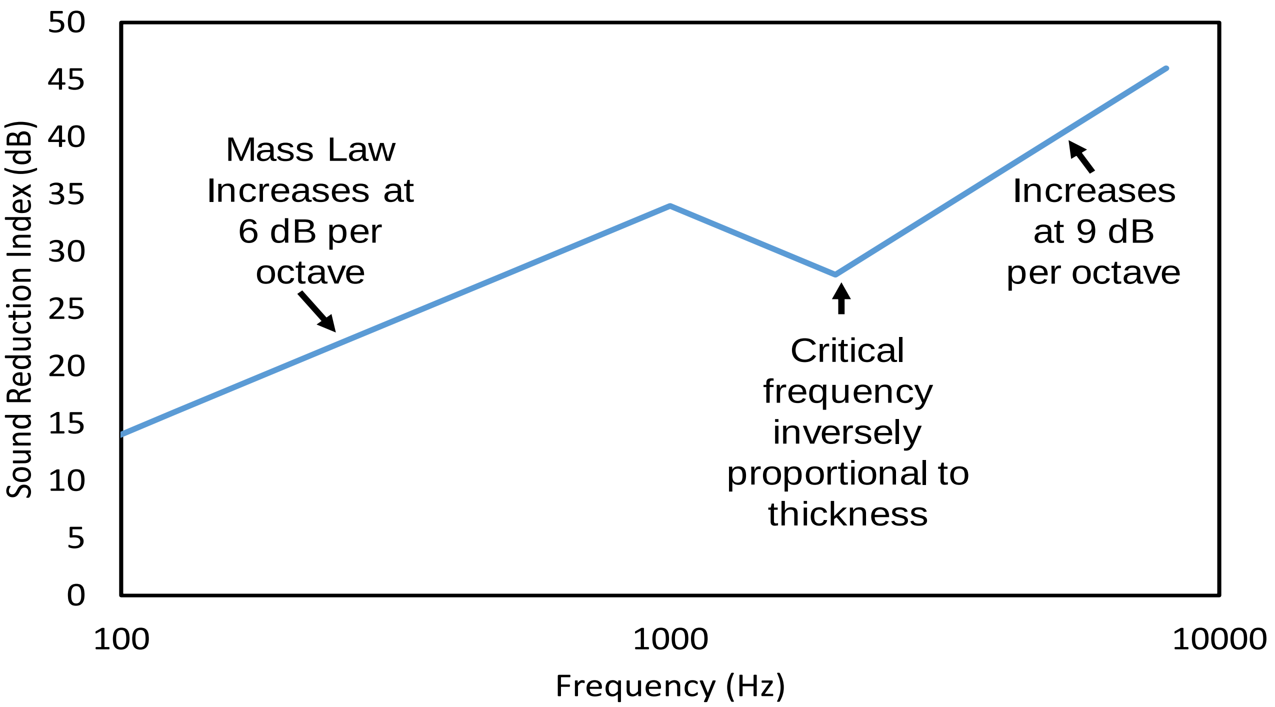


Figure 1: Typical sound insulation of a single leaf wall.

At very low frequencies, the sound insulation of a single leaf homogenous wall is controlled by the first few modes of the wall. At low frequencies, as shown in Figure 1, the sound insulation increases by 6 dB/octave in the mass law region until half the critical frequency. The sound insulation then decreases until the critical frequency. Above the critical frequency the sound insulation increases at 9 dB/octave. In the mass law region below half the critical frequency and above the critical frequency, the sound insulation increases by 6 dB for each doubling of mass or thickness. Unfortunately, the critical frequency is inversely proportional to the thickness. Thus, the critical frequency dip limits the increase in sound insulation that can be obtained by increasing the thickness of a single leaf wall.

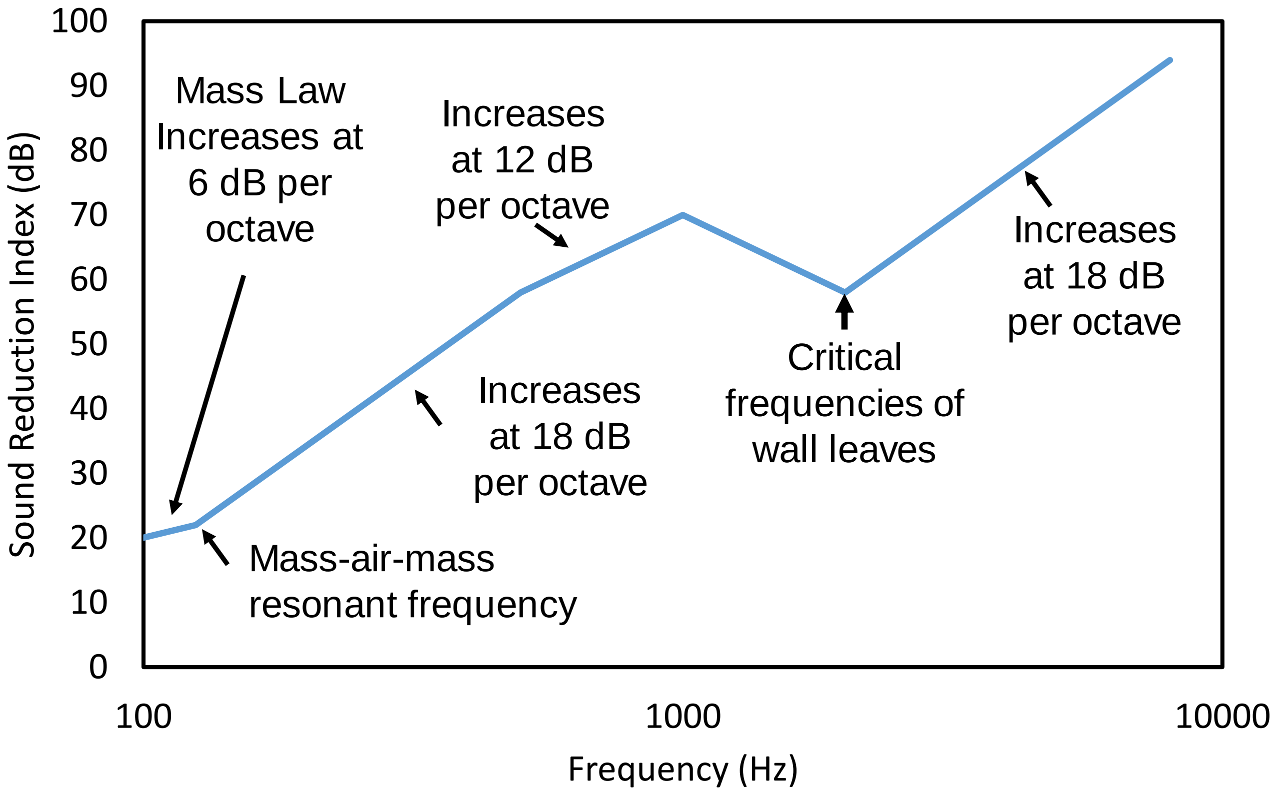


Figure 2: Typical sound insulation of a double leaf cavity wall with porous sound absorption in the cavity but without structural connnections between the two wall leaves.

This makes the use of a double leaf walls containing sound absorbing material in their wall cavities an attractive option. Double leaf walls have a mass-air-mass resonance as shown in Figure 2. Below the mass-air mass resonant frequency, the air in the wall cavity rigidly couples the two wall leaves and the sound insulation of the double leaf wall is the same as the sound insulation of a single leaf wall with the same total mass per unit area of wall. At the mass-air-mass resonant frequency, the slope of the sound insulation curve increases and there may also be a dip in the sound insulation curve. Above the mass-air-mass resonant frequency, the wall leaves can move independently and the sound insulation initially increases at 18 dB/octave before the slope changes to 12 dB/octave in the region where the sound insulation is the sum of the sound insulation of the two wall leaves plus 6 dB. This change of slope occurs because of the influence of cross modes in the cavity. It occurs at a frequency of $55/d$ Hz, where d m is the width of the cavity. This frequency is equal to the the cut on frequency of the first cross mode divided by π. The sound insulation starts to decrease at half the critical frequency of the wall leaves. Above the critical frequency the sound insulation again increases at 18 dB/octave.

Thus, it is desirable to make the mass-air-mass resonant frequency as low as possible in order to increase the sound insulation. Unfortunately, the mass-air-mass resonant frequency is inversely proportional to the square root of the product of the cavity depth and the two masses per unit area of the wall leaves. Thus, lowering the mass-air-mass resonant frequency is expensive because building space and building material mass cost money.

For an empty double wall cavity, the mass-air-mass resonant frequency should be calculated using the usual adiabatic speed of sound. When the cavity contains porous sound absorbing material, the propagation in the pores of the material at low frequencies is isothermal and the isothermal speed of sound should be used. The isothermal mass-air-mass resonant frequency is lower than the adiabatic one by 15% which is nearly one third of an octave lower.

Adding sound absorption to a double wall cavity increases the high frequency sound insulation. For a narrow wall cavity, adding sound absorption to the cavity can lower the mass-air-mass resonant frequency and make it closer to 100 Hz and reduce $R_w + C_{tr}$ while still increasing R_w. For a wide wall cavity, adding sound absorption to the cavity can lower the mass-air-mass resonant frequency and make it further away from 100 Hz and increase both $R_w + C_{tr}$ and R_w.

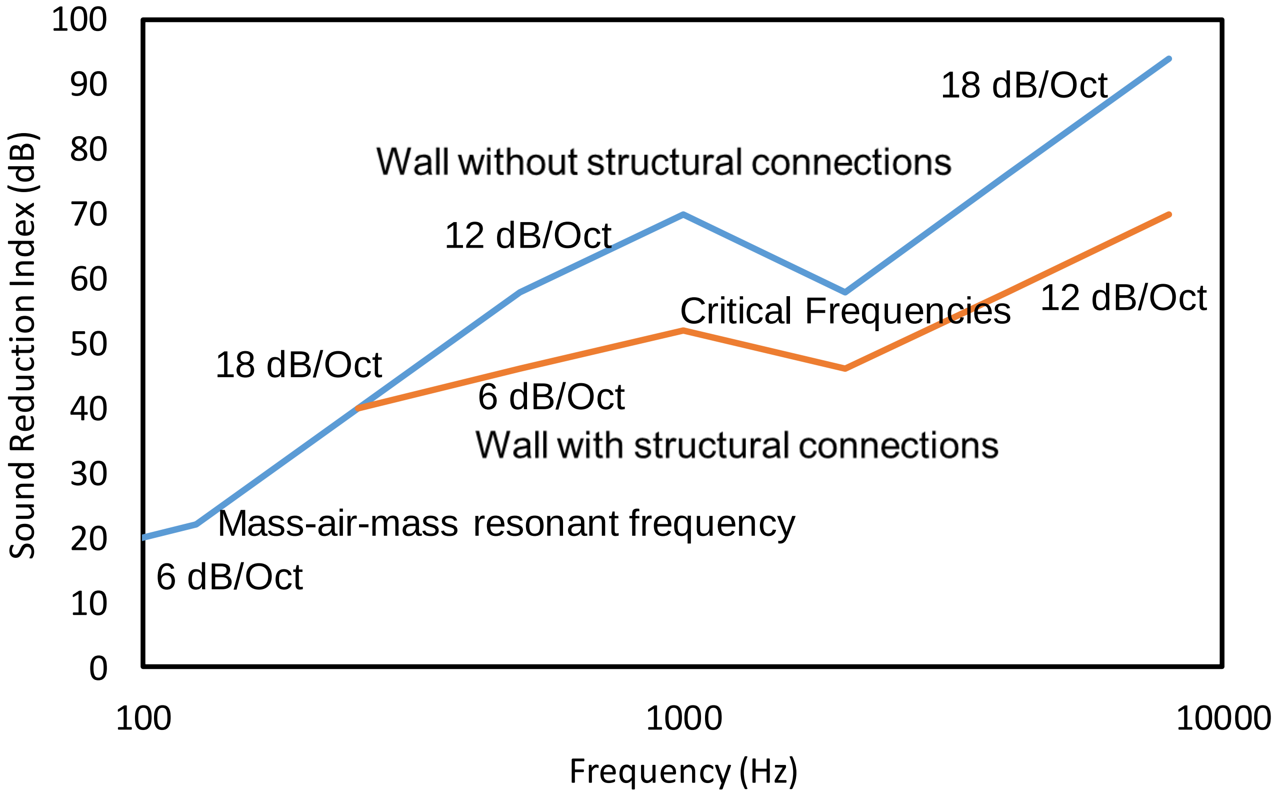


Figure 3: The effect of structural connections between the wall leaves on the sound insulation of a double leaf cavity wall with porous sound absorption in the cavity. The sound insulation of the wall without structural connections is the same as that of the wall in Figure 2.

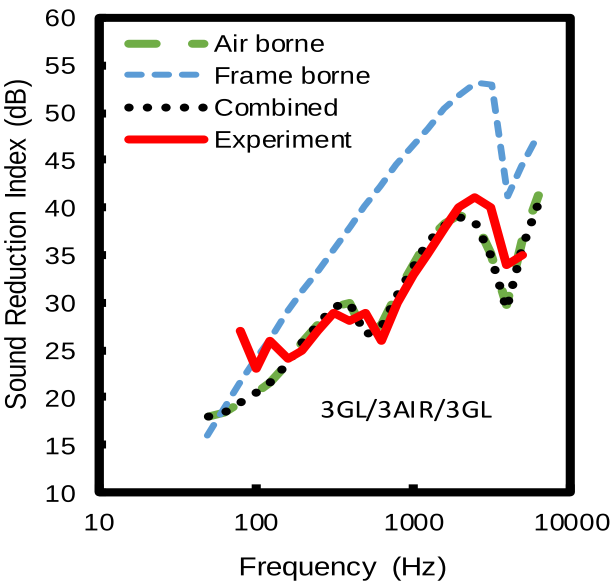
2 STRUCTURAL CONNECTIONS BETWEEN THE WALL LEAVES

2.1 The effect of structural connections at medium and high frequencies

As Figure 3 shows, rigid structural point or line connections between the two wall leaves mean that the 18 dB per octave increase eventually changes back to a 6 dB per octave increase. The effect of structural connections can be reduced by making the connections resilient. However, there are structural limitations to how flexible the structural connections can be made, particularly for high rise facades. As with any vibration isolator, the effective stiffness of resilient connections increases with frequency because of the effects of higher order modes of the resilient connections. Thus, resilient connections do not provide as big an increase in sound insulation as might be expected, although it is still worthwhile to use resilient connections if possible.

2.2 Double glazed windows

A double-glazed window cannot have porous sound absorbing material in its air cavity, except around the edges, because this would block the transmission of light through the window. Because window cavities do not contain sound absorbing material, it was thought that they would not be affected by structural connections. As shown in



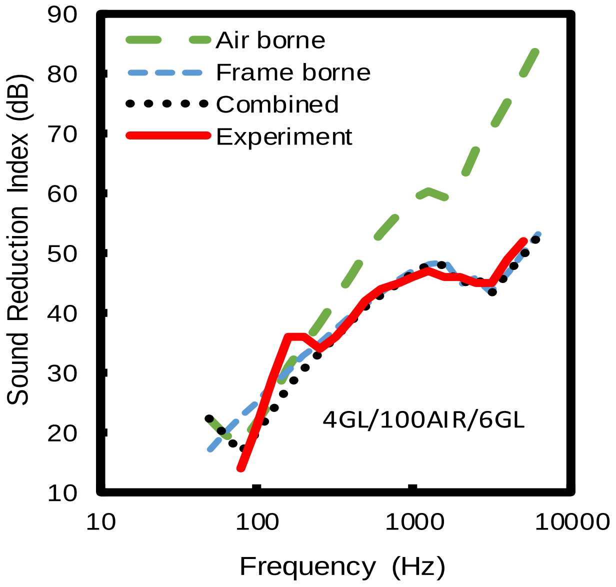


Figure 4: Sound insulation of two 3 mm glass panes separated by a 3 mm thick air cavity (left) and 4- and 6-mm glass panes separated by a 100 mm thick air cavity (right), both mounted in a wooden frame with two vertical wooden dividers. The calculated sound insulation due to transmission across the air cavity via the air and via the frame and the total calculated sound insulation are compared with experimental results.

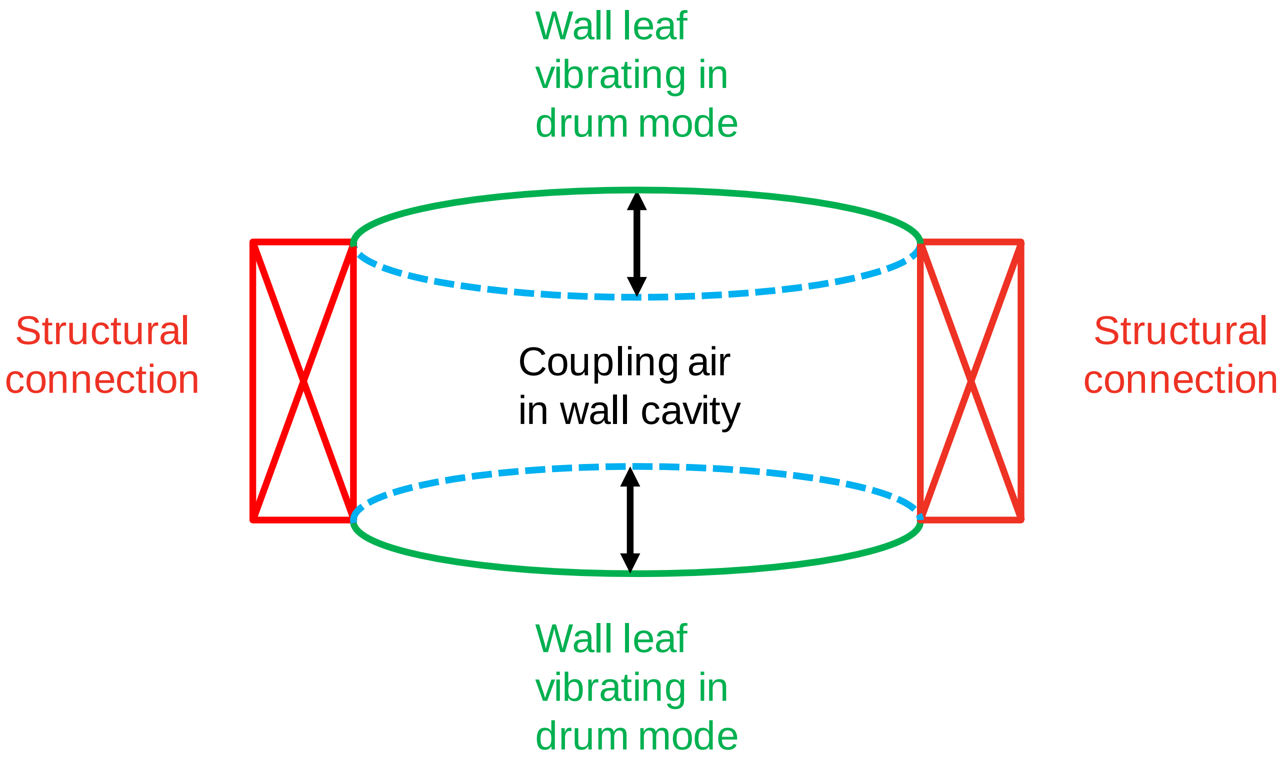


Figure 5: Effective mass-air-mass resonant frequency mode of vibration.

Figure 4, this is not correct for large air gap double glazing (Davy 2012). For two 3 mm glass panes separated by a 3 mm thick air cavity with a wooden frame with two vertical wooden dividers, the sound insulation is controlled by the transmission between the two glass panes via the air in the wall cavity. For 4- and 6-mm glass panes separated by a 100 mm thick air cavity with a wooden frame with two wooden vertical dividers, the sound insulation is controlled by the transmission between the two glass panes via the wooden frame and the two wooden dividers.

2.3 The effect of structural line connections on the sound insulation

Structural line connections can move the effective mass-air-mass resonant frequency to a higher frequency. This is because, as Figure 5 shows, the effective mass-air-mass resonant frequency is the combination of the mass-air-mass resonant frequency and the first one-dimensional drum modes of the wall leaves between the structural line connections. The air spring of the cavity couples the drum modes of the wall leaves rather than wall leaf masses.

Because the wall leaves are vibrating out of phase at the mass-air-mass resonant frequency, a rigid line connection will stop the wall leaves from moving at the line connection as shown in Figure 6. Because the vibration of a wall leaf is symmetrical about a line connection at the mass-air-mass resonant frequency, the part of the wall leaf on one side of the line connection will stop the part of the same wall leaf on the other side rotating at the line connection. Thus, the boundary conditions are likely to be close to clamped.

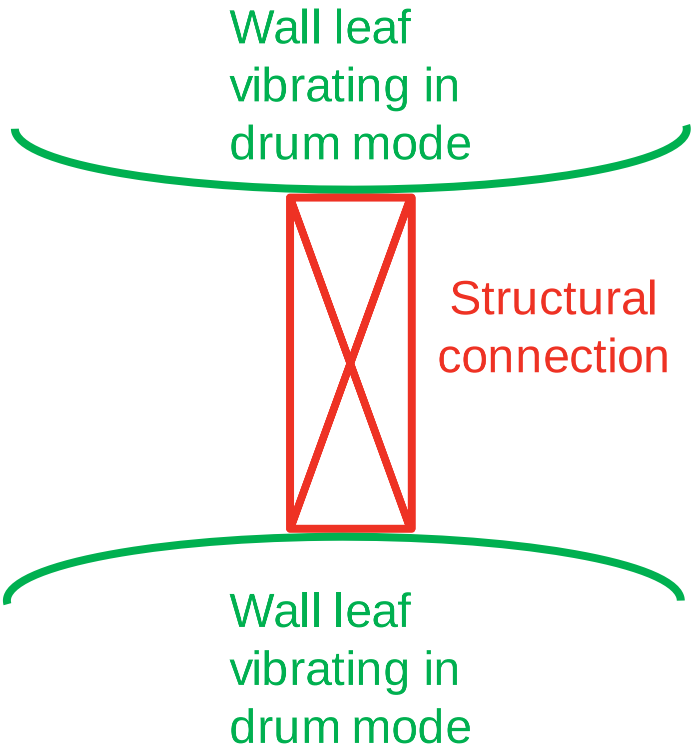


Figure 6: The boundary conditions of the drum mode between the structural connections.

The frequency of the drum mode for clamped boundary conditions is 2.27 times the frequency for simply supported boundary conditions. The resonant frequency which makes the sound insulation predictions agree best with the experimental results for gypsum plaster board cavity stud walls has been determined. The ratio of this resonance frequency to the simply supported resonance frequency has been calculated and the ranges of this ratio are given inTable 1.

For concrete floor slabs, Japanese researchers use the approximate formula for a clamped panel with a multiplier of 0.8 (Masuda and Tanaka 2018). This is the same as a multiplier of 1.8 times the simply supported resonant frequency.

The depth of the dip in sound insulation in the vicinity of the effective mass-air-mass resonant frequency is difficult to predict. Empirical multipliers for the cavity sound absorption ranging from 0.15 to 1 which need to be applied at frequencies up to a maximum frequency varying between 63 and 160 Hz have been determined for the walls described above. Note that Davy's theory (Davy 2009, 2010, 2012) limits the maximum cavity sound absorption coefficient at low frequencies to obtain the 18 dB/octave increase.

Table 1: Ratio of the experimentally determined drum mode resonance frequency of the gypsum plaster board between adjacent studs to the simply supported drum mode resonance frequency of the gypsum plaster board between adjacent studs for gypsum plaster board cavity stud walls with sound absorbing material in their wall cavities.

No. of walls	Gypsum plasterboard each side	Studs	Stud spacing	Sample size	Ratio range
8	1 or 2 layers, 13 or 16 mm	Wood	0.0406 m	3.05 x 2.44 m	1.4 to 1.9
12	1 or 2 layers, 16 mm	16 or 20 gauge steel	0.406 or 0.61 m	3.66 x 2.44 m	1.3 to 1.7
6	1 or 2 layers, 16 mm	25 gauge steel	0.406 or 0.61 m	3.66 x 2.44 m	0.6 to 0.8
24	1 or 2 layers, 16 mm	16, 18, 20 and 20E gauge steel	0.406 or 0.61 m	3.66 x 4.57 m	1.3 to 1.7
6	1 or 2 layers, 16 mm	25 gauge steel	0.406 or 0.61 m	3.66 x 4.57 m	1

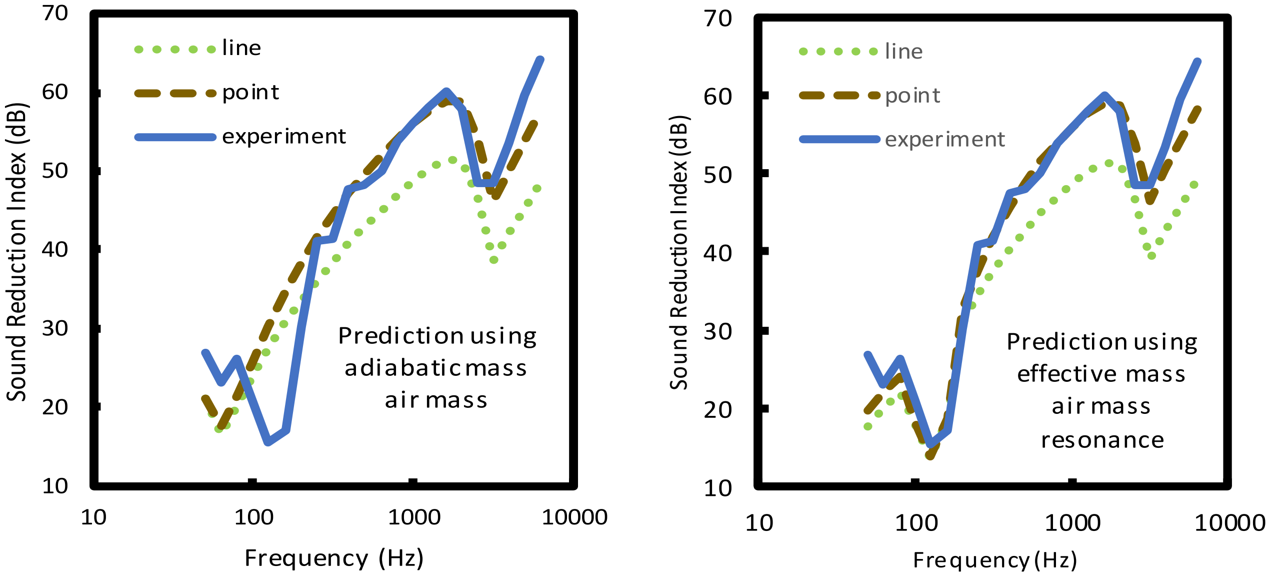


Figure 7: Comparison of using the adiabatic (left) or effective (right) mass-air-mass resonant frequency when calculating the sound insulation of two layers of 13 mm gypsum plaster board on each side of 90 mm wood studs with 406 mm spacing and sound absorbing material in the cavity using the line or point (at 0.406 m spacing) model.

Figure 7 shows the result of using the adiabatic or effective mass-air-mass resonant frequency for two layers of 13 mm gypsum plaster board on each side of 90 mm wood studs with 406 mm spacing and sound absorbing material in the cavity. Both the line connection and point connection (0.406 m spacing) calculations are shown. The calculations were made by replacing the 90 mm depth of the wall cavity with a depth that made the adiabatic mass-air-mass resonant frequency equal to the effective mass-air-mass resonant frequency in Davy's theory. The deep dip was obtained by multiplying the cavity absorption by a constant empirical multiplier below an empirically determined upper frequency limit.

2.4 The history of the effective mass-air-mass resonance

There is some evidence of the effective mass-air-mass resonance in early North American sound insulation data on wood stud gypsum plaster board walls, but this was not completely obvious because the data started at 125 Hz. For thin 25-gauge steel stud walls or walls with resilient channel bars, the adiabatic mass-air-mass resonant frequency gives a reasonable estimate of the effective mass-air-mass resonance. Lin and Garrelick (Lin and Garrelick 1977) used Fourier series to show the occurrence of a resonance at 170 Hz, although their non-dimensional parameters do not correspond to the gypsum plaster board wall that they claimed to be considering. Bradley and Birta (Bradley and Birta 2000, 2001) showed in the laboratory that the resonance occurred in wood stud exterior walls at about 125 Hz and that resilient channel bars improved the sound insulation at and above this resonant frequency. However Bradley (Bradley 2002) and Bardley *et al*. (Bradley, Lay, and Norcross 2002) showed that the resonance did not appear in field sound insulation measurements with flying aircraft as the sound source. Thus, it appears that a reasonable fraction of the sound energy needs to be incident close to normal before the resonance shows up in the sound insulation measurements.

2.5 Case study

Measurements on a double glazed unit with a third layer of glass mounted on it 600 mm away by a jockey sash gave lower sound insulation than predicted by the sound insulation prediction software INSUL (INSUL 2019) , which appears not to include vibration transmission by the frame (jockey sash). Mounting the third layer of glass as a secondary glazing unit for the primary double-glazed unit improved the sound insulation because of the much more complicated vibration path via the building envelope than via the jockey sash. Low frequency helicopter noise was the concern in this case. Because this was a commercial test, further details cannot be given.

3 CONCLUSIONS

Structural connections between the wall leaves of a cavity wall can significantly decrease the sound insulation of the wall. This also occurs with wide air gap double glazed windows whose lack of sound absorption in their air cavities might be thought to exclude such decreases because of their lower air borne values due to lack of sound absorption in the air cavity. The effective mass-air-mass resonant frequency is much higher than the adiabatic mass-air-mass resonance frequency unless the connections are fairly resilient. If resilient connections cannot be used for structural reasons, the vibration transmission path between the wall leaves should be made as complicated as possible in order to reduce the transmission of vibration between the wall leaves via the structural connections.

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