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The Transmission Loss of Double Stud Walls with Layers of Gypsum Board Installed Inside the Wall Cavity

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Résumé

Un assemblage de mur de séparation qui est fréquemment spécifié pour les constructions de moyenne et grande hauteur est un assemblage de mur à double poteau en acier avec une ou plusieurs feuilles de plaques de plâtre résistantes au feu installées à l'intérieur de la cavité murale entre les rangées de poteaux, créant ainsi un mur à triple feuille. L'installation de la plaque de plâtre à l'intérieur de la cavité murale peut réduire considérablement la perte de transmission en dessous de la bande de tiers d'octave de 200 Hz en raison de la création de deux résonances masse-air-masse, centrées autour de la bande de tiers d'octave de 80 Hz. Pour les murs testés dans le cadre de cette étude, cette diminution de l'affaiblissement de transmission était de 14 à 17 dB. L'une des raisons pour lesquelles les plaques de plâtre sont spécifiées à l'intérieur de la cavité murale est la croyance que les plaques de plâtre dans la cavité murale maintiennent l'affaiblissement de transmission du mur même si les résidents créent de petits trous dans les couches extérieures de plaques de plâtre en accrochant des décorations au mur ou en fixant des meubles au mur. Pour réfuter cette théorie, un nombre croissant de trous a été percé dans les plaques de plâtre des deux côtés d'un mur afin de déterminer l'effet sur l'affaiblissement de la transmission. Il s'est avéré qu'un nombre important de trous, bien supérieur à l'utilisation normale d'un mur, devait être percé dans la plaque de plâtre avant que l'affaiblissement de la transmission ne soit affecté.

Mots clefs : Perte par transmission, mur à trois vantaux, mur de soubassement à deux montants

Abstract

A demising wall assembly that is frequently being specified for mid-rise and high-rise building constructions is a double steel stud wall assembly with one or more sheets of fire rated gypsum board installed inside the wall cavity between the rows of studs, creating a triple leaf wall. Locating the gypsum board inside the wall cavity can sharply decrease the transmission loss below the 200 Hz one-third octave band due to the creation of two mass-air-mass resonances centered around the 80 Hz one-third octave band. For the walls tested as part of this study, this decrease in the transmission loss was 14 to 17 dB. One theory for why gypsum board is being specified inside the wall cavity is the belief that the gypsum board in the wall cavity maintains the transmission loss of the wall even if residents create small holes in the outer gypsum board layers by hanging decorations on the wall or securing furniture to the wall. To disprove this theory, an increasingly larger number of holes were drilled into the gypsum board on both sides of a wall to determine the effect on the transmission loss. It was found that a significant number of holes, well in excess of normal use of a wall needed to be drilled into the gypsum board before the transmission loss was affected.

Keywords: Transmission loss, Triple-leaf wall, Double stud demising wall

1 Introduction

Many of the mid to high-rise buildings which are being planned or constructed in Canada have been designed with concrete floors and lightweight, steel stud interior walls. In order to demonstrate compliance with the acoustical requirements of the relevant provincial or territorial building code, an acoustical consultant will need to know the transmission loss or the sound transmission class (STC) rating of the steel stud demising walls. The National Research Council Canada (NRC) has measured the transmission loss of a number of steel studs walls (see for example Report IRC-IR-761 [1]) and the Part 9 tables of the National Building Code of Canada (NBC) [2] list the STC rating and the fire-resistance rating of several steel studs' walls.

However, a new demising wall assembly which is not included in the research reports or the NBC has been appearing in the wall schedules for new constructions. The wall assembly is a double steel stud wall with one or more layers of fire rated gypsum board directly attached to the outside of the studs and one or more layers of fire rated gypsum board installed inside the wall cavity between the rows of studs as shown in Figure 1.

Warnock and Quirt [3] investigated the transmission loss of double wood stud walls with internal layers of gypsum board and wrote that it is "detrimental to add layers of gypsum board in the middle of a double stud wall." The rigid connection between the internal layer of gypsum board and the studs allowed structure-borne sound to bypass the sound-absorbing material in the wall cavity. Furthermore, the

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internal layer reduced the depth of the cavity, thereby decreasing the transmission loss at the low frequencies.

In a separate study published in 1985, Warnock [4] made field measurements on a double wood stud walls assembly with layers of gypsum board installed inside the wall cavity and found similar results. Warnock described the gypsum board inside the wall cavity as a "misuse of materials" which led to a dip in the 160 Hz one-third octave band, resulting in a field sound transmission class (FSTC) rating of 40. Warnock argued that it would have been better to relocate the gypsum board from the wall cavity to the outside of the wall, a change which was predicted to result in a significantly higher FSTC rating of approximately 60.

Footnote 13 to Table 9.10.3.1.-A of the NBC advises that installing gypsum board on the inner face of one row of studs in a double stud assembly can reduce the STC rating by 3 if there is sound-absorbing material in both wall cavities. The footnote goes on to warn that attaching gypsum board to both inner faces can drastically reduce the STC rating.

Despite the guidance to the contrary, it appears that designers will find transmission loss data for steel studs walls and assume that adding the gypsum board inside the wall cavity has no effect on the transmission loss of the wall. In terms of the single number, STC rating, this assumption can sometimes be correct due to the obscuring of deficiencies in the transmission loss curves by the single number ratings, especially below the 125 Hz one-third octave band which are not included in the calculation of the STC rating. However, the evaluation of the transmission loss of double steel studs' walls with gypsum board installed inside the wall cavity as presented in Section 2 of this paper shows that there is a significant decrease in the transmission loss below the 200 Hz one-third octave band.

2 Transmission Loss Measurements

The evaluation of the transmission loss of double steel studs' walls with gypsum board installed inside the wall cavity began with the measurement of the transmission loss of a base wall assembly without layers of gypsum board installed inside the wall cavity as shown in Figure 2.

The steel studs were made of 18 gauge (1.09 mm, 0.043") thick steel. The studs were 92.1 mm (3 5/8") deep, had a 41.3 mm (1 5/8") wide flange and were spaced 610 mm (24") on center. There was a single header and footer track and there was a 25.4 mm (1") space between the rows of studs. Thermal insulation 92.1 mm (3 5/8") thick was installed in the inter-stud cavities. The screw spacing for the gypsum board conformed to the requirements of the NBC.

The base wall assembly was evaluated with two layers of 15.8 mm (5/8") normal weight Type X gypsum board (10.80 kg/m^2) installed on both sides of the wall and again with two layers of 12.7 mm (1/2") Type C gypsum board (9.80 kg/m^2) directly attached to both sides of the wall. The resulting transmission loss curves measured in full accordance with the standard, ASTM E90 [5] are compared in Figure ***3***. The wall assembly with the heavier, Type X gypsum board resulted in a higher transmission loss over much of the frequency range and an STC rating of 66 as opposed to 64 for the wall assembly with the Type C gypsum board.

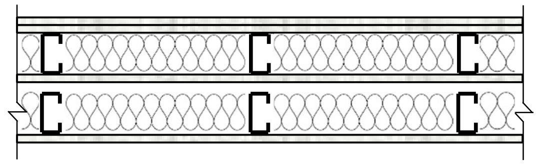


Figure 1: Example of a double steel stud wall with a layer of gypsum board installed inside the cavity between the rows of studs.

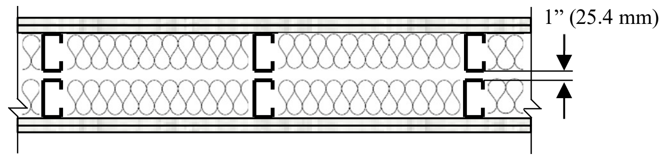


Figure 2: Configuration of the base wall assembly with two layers of fire rated gypsum board directly attached to both sides of the wall.

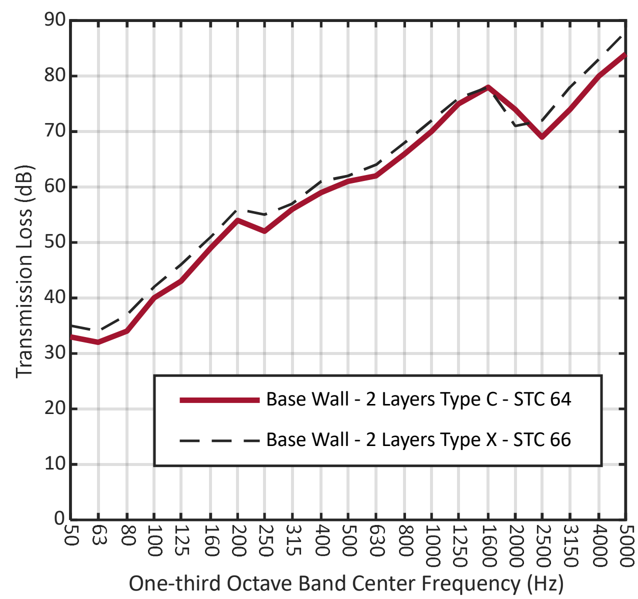
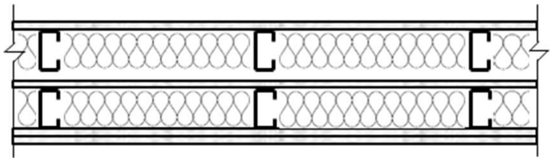
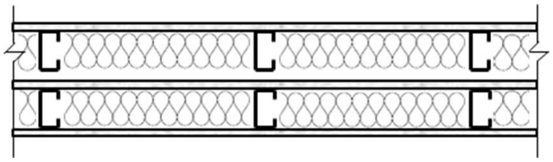
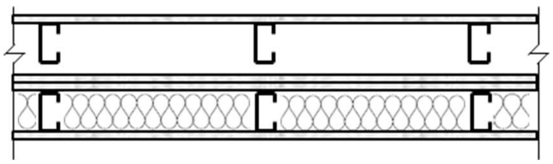
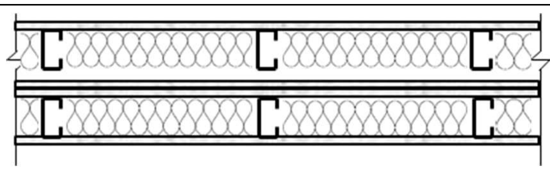


Figure 3: Transmission loss of the base wall assembly with two layers of 15.8 mm normal weight Type X gypsum board installed on both sides of the wall (STC 66) and two layers of 12.7 mm Type C gypsum board installed on both sides of the wall (STC 64).

Next, the transmission loss curves of the four wall assemblies shown in Table ***1*** were evaluated. Each wall had one or more layers of 12.7 mm Type C gypsum board directly attached on each side of the wall and one or more layers of 12.7 mm Type C gypsum board attached inside the wall cavity between the rows of studs. A distance of 25.4 mm between the gypsum board in the wall cavity and the adjacent row of studs was maintained for each of the wall assemblies. Wall Assembly C included thermal insulation installed in the inter-stud cavities of only one side of the wall. The transmission loss curves for the wall assemblies are compared in Figure ***4*** to the transmission loss of the base wall assembly with the Type C gypsum board. The differences between the transmission loss curves are shown in Figure 5.

Table 1: Drawings and short codes for the wall assemblies included in the evaluation. The framing was identical to that for the base wall assembly. All of the wall assemblies in this table have been specified as demising walls for multi-tenancy dwellings.

A	 GC12_SS92(610)_GFB92_AIR25_GC12_GFB92_SS92(610)_GC12_GC12
B	 GC12_SS92(610)_GFB92_AIR25_GC12_GFB92_SS92(610)_GC12
C	 GC12_SS92(610)_AIR25_GC12_GC12_GFB92_SS92(610)_GC12
D	 GC12_SS92(610) _GFB92_AIR25_GC12_GC12_GFB92_SS92(610)_GC12

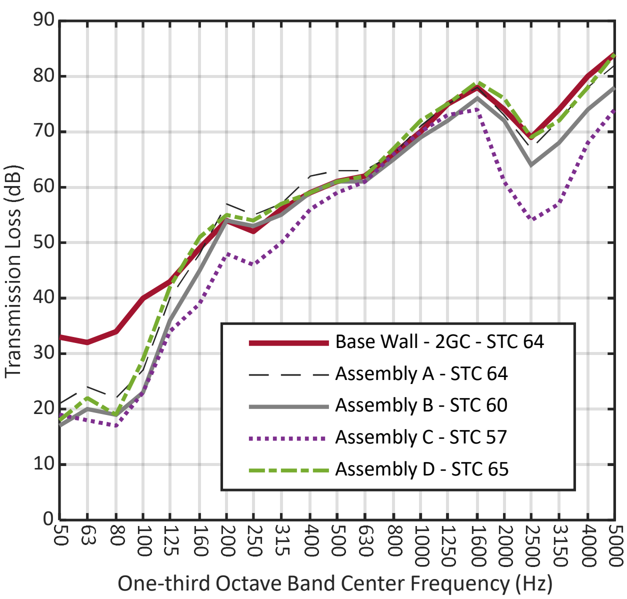


Figure 4: Comparison between the transmission loss values of the base wall assembly with two layers of Type C gypsum board installed on both sides of the wall and the transmission loss values of the wall assemblies listed in Table 1.

The transmission loss curve of Wall Assembly C shows a deep dip around the coincidence frequency in the 3150 Hz one-third octave band as well as a lower transmission loss in the mid frequencies compared to the curves of the other wall assemblies. The results are a reminder of the importance of

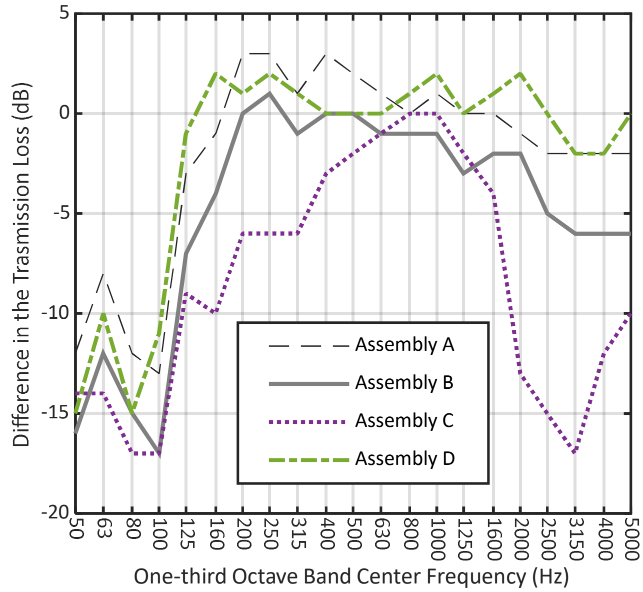


Figure 5: Difference in the measured transmission loss of the wall assemblies compared to the transmission loss of the base wall assembly with Type C gypsum board.

including thermal insulation in the inter-stud cavities on both sides of double stud walls. The transmission loss curve of Wall Assembly B also shows a deeper coincidence dip than the base wall assembly, indicating the importance of including dissimilar layers of gypsum board to improve the transmission loss of a wall. But the most striking feature of the curves in the figures is the sharp decrease in the transmission loss below 200 Hz for all of the walls with gypsum board inside the wall cavity. For walls B and C, the decrease was on the order of 17 dB. Uris, et al. [6] found a similar difference when comparing the transmission loss of triple leaves steel stud walls to that of a double leaf wall. This same effect has been seen when adding gypsum board linings to each side of concrete block masonry walls, creating a triple leaf wall [7]. However, despite the size of the dips, the STC ratings of Wall Assembly A and D were equal to or higher than the STC rating of the base wall assembly, giving no indication of the poor performance of the wall assemblies at the lower frequencies.

The cause for the dip in the transmission loss curves around the 80 Hz one-third octave band is the division of the wall cavity into two smaller cavities separated by the gypsum board installed between the rows of studs. Ballagh [8] notes that for a triple leaf system, the resonance frequencies are not simply the resonant frequencies of each cavity of the assembly, but rather the interactions of all of the components in the system must be taken into account.

$$f_{mam} = \frac{\sqrt{2}}{4\pi}\sqrt{\frac{(\lambda_1+\lambda_2)\pm\sqrt{(\lambda_1-\lambda_2)^2+4k_1k_2m_1^2m_3^2}}{m_1m_2m_3}} \qquad (1)$$

where: $\lambda_1 = k_1m_3(m_1+m_2)$, $\lambda_2 = k_2m_1(m_2+m_3)$, $k_1 = \rho_o c_o^2/d_1$, $k_1 = \rho_o c_o^2/d_1$, ρ_o is the density of air, c_o is the speed of sound in air, d_1 and d_2 are the depths of the two wall cavities in meters and m_1, m_2 and m_3 are the mass per unit area of the layers of gypsum board in kg/m^2. The calculated mass-air-mass resonances for each wall assembly are listed in Table 2. The mass-air-mass frequency for the base wall assembly in Table 2 is calculated according to Equation (2). Since the mass-air-mass resonance occurs in the low frequency range where isothermal compression occurs due to heat conduction by the fibers of the thermal insulation, Hopkins [10] estimates the frequency at which the resonance occurs as:

$$f_{mam,insulation} = 51\sqrt{\frac{m_1 + m_2}{m_1 m_2 d}} \tag{2}$$

While the one mass-air-mass resonance of the base wall assembly occurred in the 40 Hz one-third octave band, all of the other wall assemblies had two resonances which fell into the 63 Hz, 80 Hz or 100 Hz one-third octave bands. The resulting decrease in the transmission loss due to the mass-air-mass resonances of the triple leaf walls was on the order of 14 to 17 dB for the wall assemblies included in the evaluation. The depth of the dips in the transmission loss curves around 80 Hz shows the negative effect of installing the gypsum board inside the wall cavity and why the practice should be avoided.

3 The Effect of Holes in the Gypsum Board on the Transmission Loss

One theory for why the gypsum board is being specified inside the wall cavity is that it maintains the transmission loss of the wall if residents were to screw or nail into the outer layers of gypsum board to hang decorations, to mount televisions or to secure shelving. Warnock [4] referred to the layer of gypsum board in the wall cavity as "noise stop" board and he argued that the design was poor and that the extra layer of gypsum board was not necessary since double studs were being used. To evaluate the effect of holes caused by fasteners on the transmission loss of a wall, holes were systematically drilled into the gypsum board on both sides of a single stud wall assembly shown in Figure 6. The mass-air-mass resonance for the wall assembly was estimated to be in the 100 Hz one-third octave band.

The holes in the gypsum board were made using either a 6.4 mm (1/4") drill bit or a 12.5 mm (1/2") drill bit. The holes were randomly located along the height of the cavity between the studs. A list of the tests including the number of holes per bay and the total number of holes per side of the wall are listed in Table ***3***. An image of the wall with twenty holes drilled per cavity (Case 12 from Table 3) is shown in Figure *7*.

The transmission loss curves of the twelve cases are compared in Figure ***8***. The differences between the transmission loss curves for the wall assembly with the holes and the wall with no holes are compared in Figure ***9***. The figure shows that the 6.4 mm diameter holes drilled in the gypsum board had little effect on the transmission loss of the wall assembly until there were forty-eight 6.4 mm diameter holes drilled into the gypsum board on each side of the wall. Even then, the difference was only 1 dB in the 125 Hz and 160 Hz one-third octave bands. It wasn't until ninety-six 6.4 mm diameter holes were drilled into the gypsum board on each side of the wall that the STC rating dropped further due to the changes between the 100 Hz and 250 Hz one-third octave bands. Drilling larger, 12.5 mm diameter holes in the gypsum board further decreased the transmission loss between the 100 Hz and 250 Hz one-third octave bands as well as at 5000 Hz.

A significant number of holes, well beyond what could be referred to as normal use for a wall were required before the transmission loss of the single stud wall was negatively affected. It is expected that the double stud wall designs with layers of thermal insulation in the wall cavities will show less effect due to holes in the gypsum board caused by normal use.

Table 2: Estimated mass-air-mass resonances of the wall assemblies.

Freq. (Hz)	Wall Assembly				
	Base	A	B	C	D
f_1	36.0	51.3	59.6	59.4	59.4
f_2	-	99.2	104.7	85.8	85.8

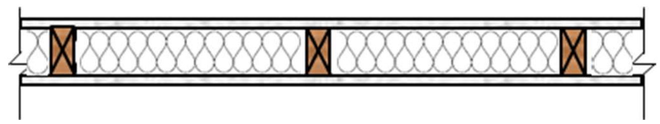


Figure 6: The single-stud wall assembly used to evaluate the effect of holes in the gypsum board on the transmission loss. The 89 mm wood studs were located 610 mm on center. Short code: GUX16_WS89(610)_GFB89_GUX16.

Table 3: The number of holes drilled into the gypsum board in the bay between studs for the case study of the effect of the holes on the transmission loss. The holes were drilled randomly along the height of the cavity. The total wall size was 2.44 m x 3.66 m (8' x 12').

Case	Hole Diameter	Holes per Cavity Side 1	Holes per Cavity Side 2	Total Holes Side 1	Total Holes Side 2	STC Rating
1	1/4"	None	None	None	None	43
2	1/4"	4	None	24	None	43
3	1/4"	4	4	24	24	43
4	1/4"	8	4	48	24	43
5	1/4"	8	8	48	48	42
6	1/4"	12	8	72	48	42
7	1/4"	12	12	72	72	42
8	1/4"	16	12	96	72	42
9	1/4"	16	16	96	96	38
10	1/2"	16	16	96	96	38
11	1/2"	20	16	120	96	38
12	1/2"	20	20	120	120	37

Figure 7: Image of the wall with twenty holes per bay (Case 12), resulting in one hundred and twenty holes in the wall.

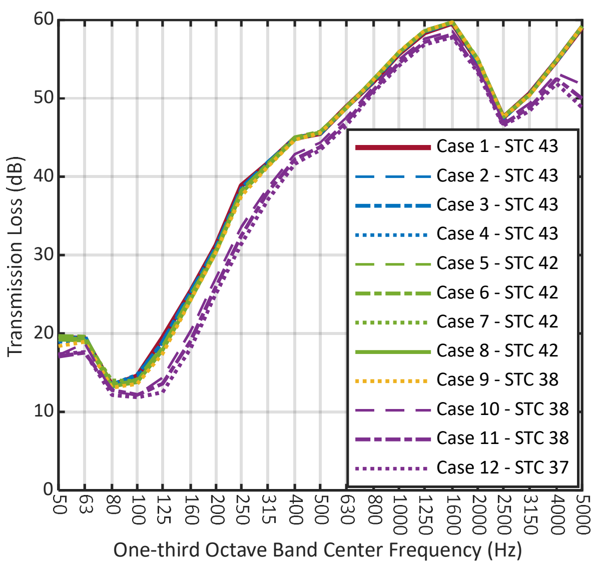


Figure 8: Comparison between the transmission loss values of a single stud wall as an increasing number of holes were drilled into the gypsum board on each side of the wall. The list of cases is shown in Table 3.

4 Discussion

4.1 Noise Annoyance

Unwanted neighbor noise in multi-tenancy dwellings can be a significant source of annoyance and complaints. While sound conditions usually play a minor role when choosing a new home, they can often be the main reason for moving away [11]. Residents of multi-tenancy dwellings with poor sound insulation are more likely to want to move out as well as to think that their neighbors are less considerate [12]. Of those who reported in one study [13] that they would like to move, 94 to 100% of them gave a noise-related reason.

When it comes to neighboring noise, not all noises that are heard are always perceived as being annoying. Perceptions of the noises are often made at the outset of the noise being heard according to the meaning of the noise. For example, for some people, background noise can be perceived as being part of a familiar environment. However, exceptions to this

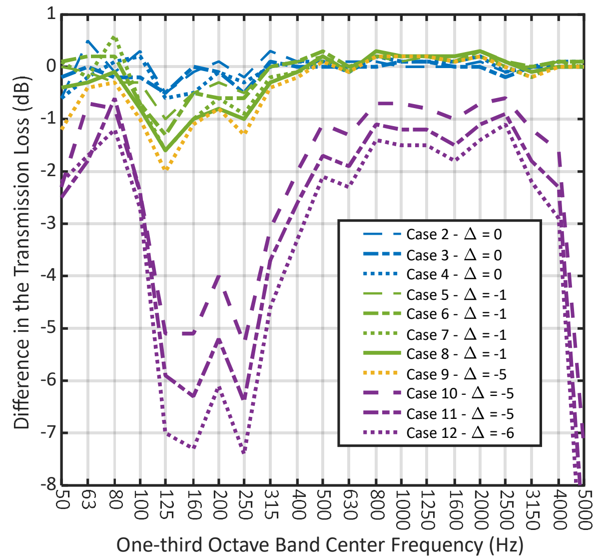


Figure 9: Change in the transmission loss of a single stud wall as an increasing number of holes were drilled into the gypsum board on each side of the wall.

neighbors are often cited as a prime cause of annoyance and complaints [15].are sounds such as slamming doors, hammering, running televisions and stereos can be perceived as annoying due to the volume of the noises, the time of day that the noises occur and the noise maker's behavior [14]. Music sounds from neighbors are often cited as a prime cause of annoyance and complaints [15].

A study by Bradley [12] suggested that more sound insulation is required for walls to protect residents from music related sounds than from other types of sounds, due in part to the likely strength of these sounds and the potential disturbance that they would create. The annoyance from neighbor noise is due not only to the sound level of the noise in the receiving room, but is also strongly related to the recognition of the content of the sounds, especially if the sound is music [16]. The high and the low frequency extremes of music contribute most to the audibility of music with the low frequencies (e.g. 63 Hz to 200 Hz) contributing the most to the audibility [17]. Since the frequency spectrum of music noise and the background noise in a dwelling will be different due to the high tonal content and strong rhythmic structure of music, music is easily discernible even when it is played at a level below that of the background noise. If the music noise level is equal to the background noise level, between 60 % to 90 % of people will be dissatisfied. Very few people will be satisfied even if the music noise level is 5 dB or even 10 dB below the background noise level [18].

Therefore, the dip in the transmission loss curves of the triple leaf walls around 80 Hz by up to 17 dB compared to double leaf walls will be a significant source of annoyance when neighbors play music on their stereos or TVs. Typically, a 10 dB increase in the level of music is perceived as a doubling of the loudness [19]. Rindel [20] writes that in one study, an increase of 16 dB in the level of music noise from neighbors resulted in an increased number of persons who felt annoyed from 20% to 80%. Clark [21] conducted subjective studies of annoyance due to music using generated transmission loss curves. Individual dips at 500 Hz, 1000 Hz and 2000 Hz were introduced at 5 dB increments to the transmission loss curves. All of the dips in the curves increased the perceived annoyance due to the music.

It should be remembered that the poor sound insulation of a party wall adversely affects not only the neighbor who doesn't want to hear their neighbor's music, but also the person who wants to be able to listen to music in their own home [11]. An extensive socio-acoustic survey comprising multi-unit houses carried out in Norway found that while around 11% of respondents reported being moderately to extremely annoyed by hearing their neighbor's music, around 37% reported that they were worried about disturbing others while playing their own music. This indicates that people are likely to limit themselves to a certain extent in consideration of their neighbors [22].

Due to the anticipated negative effect on the well-being of the residents of multi-tenancy buildings which feature these triple leaf wall designs, there must be a justifiable reason for specifying triple leaf walls as opposed to double leaves walls to offset the negative impact of the triple leaves wall designs on the well-being of the residents of the building.

4.2 The Myth of the Noise Stop Board

It has been shown in this paper that the transmission loss of a wall assembly with thermal insulation in the wall cavity remains largely unaffected when screw or nail holes are made in the wall to hang decorations, to secure furniture or to hang televisions as part of "normal use." In fact, the number of holes in the wall had to be increased far past what could be considered to be "normal use" to affect the transmission loss of the wall assembly which was evaluated. Therefore, relocating one or more layers of gypsum board into the wall cavity between the rows of the studs is unnecessary to preserve the transmission loss of the wall, if that is the motivation for the wall designs.

Alternatively, the "noise stop" board may be specified to reduce the effect of back-to-back electrical boxes. Gover and Bradley [23] examined the effect on the transmission loss of a single steel studs wall due to holes cut in the drywall on one side of the wall or electrical boxes installed on both sides of the wall. For one measurement, a 0.20 m x 0.20 m hole was cut into the double layer of gypsum board on one side of the wall. Cutting the hole decreased the STC rating by 1 and the transmission loss curve was decreased by a few dB in the one-third octave bands between 125 Hz and 1600 Hz.

The installation of back-to-back electrical boxes also only decreased the STC rating by 1, but the transmission loss curve decreased by up to 10 dB at 1000 Hz. Conversely, offset electrical boxes in the same bay had no effect on the STC rating or the transmission loss curve.

Uris et al. [6] noted in a similar study of wall assemblies with gypsum board installed inside the wall cavity that the decrease in the transmission loss of a wall assembly due to the addition of a layer of gypsum board in the wall cavity is greater than the degradation due to electrical outlet boxes installed in a wall without the gypsum board inside the wall cavity. Nightingale and Quirt [24] tested a double stud wall with a gypsum board baffle directly attached inside the wall cavity and thermal insulation in the cavity. The baffle extended from the bottom plate to a height of 300 mm above the top of the electrical box and only extended across the wall cavity where the electrical box was located. The transmission loss of the wall assembly with the baffle was significantly improved compared to the transmission loss of the wall without the baffle, but only if thermal insulation was present in the wall cavity. Furthermore, there were no decreases in the transmission loss at the low frequencies due to the baffle. If there was concern about the effect of electrical boxes on the transmission loss of a double steel stud demising wall, the baffle would be a better solution than the layer of gypsum board installed across the inside of the entire wall cavity as was the case for the wall assemblies evaluated for this study. But a more cost-effective solution would be to ensure that the electrical boxes are specified to be offset which Gover and Bradley found to result in no decrease in the STC rating of the wall.

Based on the results of these studies, it can be concluded that additional layers of gypsum board installed inside the wall cavity of double stud walls are not required to maintain the transmission loss of typical demising walls subjected to normal use or when electrical boxes are installed with a correct spacing between them

4.3 The Effect on the Fire Rating

Another theory that has been suggested for the popularity of the walls with a layer of gypsum board installed in the cavity between the studs is the belief that the layers of gypsum board installed inside the wall cavity maintain the fire-resistance rating of the wall assembly despite possible holes from fasteners due to normal use. Typically, the fire-resistance ratings for wall assemblies with gypsum board installed inside the wall cavity have not been measured. Instead, the fire-resistance rating is estimated based on the measured fire-resistance rating of a single stud wall and the component additive method from the NBC. Section A-3.1.10.2.(4) of the NBC [2] states that "*inherent in the use of a firewall is the intent that this specialized wall construction provide the required fire-resistance rating while also being designed to resist physical damage—arising out of normal use—that would compromise the rating of the assembly*." The fire-resistance rating of a framed assembly depends primarily on the time during which the membrane on the fire-exposed side remains in place [2]. A study at the NRC [25] found that two layers of gypsum board on a wall provided a higher fire-resistance rating than one layer due in part to the staggering of seams between the layers. Furthermore, Note 13 to Table 9.10.3.1.-A of the NBC states that the fire resistance rating is not affected by the inclusion of bracing such as gypsum board installed inside the wall cavity. Therefore, wall designs such as those in Table 1 have lower fire resistance ratings than the base wall assemblies from this study.

If despite the advice to the contrary, the layer of gypsum board is installed in the cavity between the rows of studs in an attempt to persevere the fire-resistance rating of the wall, then it should be understood that doing so is not without cost. The wall design results in poor transmission loss below the 200 Hz one-third octave band which is likely to result in noise complaints by residents. Since the fire-resistance rating is determined primarily on the time during which the membrane on the fire-exposed side remains in place and is not affected by the addition of layers of gypsum board inside the wall cavity [2], measurement data for the fire-resistance should be required from the designer to substantiate the claim that the gypsum board inside the wall cavity maintains the fire-resistance rating of a wall under normal use.

5 Conclusions

The inclusion of the gypsum board inside the wall cavity creates two mass-air-mass resonances centered around 80 Hz, resulting in a sharp decrease of up to 17 dB in the transmission loss below the 200 Hz one-third octave band in the walls tested for this study. These triple leaf walls are being specified despite almost forty years of guidance that adding a layer of gypsum board in the cavity between the rows of studs of a double stud wall will degrade the transmission loss of the wall due to the mass-air-mass-air-mass resonances the wall cavities create. The triple leaves wall design neither protects the transmission loss due to the creation of holes in the wall due to normal use, nor does it improve the fire-resistance rating of the wall assembly.

It is important for the acoustic community to explain to those who specify the triple leaf wall designs for multi-tenancy dwellings that there are negative consequences for doing so in terms of the well-being of those who live in the dwellings and to challenge the use of triple leaves wall designs.

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