SOUND CONTROL IN MULTI-FAMILY WOOD-FRAME BUILDINGS

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ABSTRACT

Sound control in multi-unit residential construction affects occupant privacy and well-being. Insufficient sound isolation can lead to lawsuits against architects and builders.

This article explains how sound moves through buildings, and how designers can control airborne, impact and flanking noise transmission. It suggests ways to control sound in wood-frame, multi-family buildings and best practices for acoustic isolation.

OBJECTIVES

This article helps the reader to better understand:

- The properties of sound
- The importance of sound control to building quality and occupant satisfaction
- Code requirements for sound control
- Airborne sound control
- Impact sound control
- Flanking sound control
- Best design practices for sound control

Source—Photo by Sandra Marshall

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INTRODUCTION

Architects must consider many interacting factors in designing a building, including structural integrity, fire safety, energy efficiency and noise control. Understanding and implementing sound control has a major impact on occupants' comfort, concentration and happiness, not to mention neighbourly relations. Sound control is particularly important in multi-unit residential construction. This article focuses on wood-frame construction in many Canadian multi-unit residences and briefly discusses masonry party walls.

The rigid assemblies required to resist high wind loads or earthquakes make noise control difficult because they are pathways for sound vibrations. On the positive side, the sealing of penetrations to resist the spread of fire also blocks movement of certain sound. Some sound details control reduce the spread of odours and pests and improve comfort and durability.

This article examines *airborne sound,* such as loud music and *impact sound*, such as the thud of a dropped object. It describes the hidden routes that sound vibrations follow, such as *leaks* and *flanking paths*.

The article summarizes information from *the Best Practice Guide: Fire and Sound Control in Wood-Frame Multi-Family Buildings,* published by Canada Mortgage and Housing Corporation (CMHC).[1] This guide brings together years of research from numerous sources, including the National Research Council of Canada Institute for Research in Construction (NRCC/IRC) and the experience of acoustic consultants.

Sound transmission can be effectively controlled in multi-family buildings by isolating neighbouring units from one another with proper walls and floors between suites. An architect should select wall or floor assemblies in multi-family housing for both resistance to fire spread—*the fire-resistance rating*—and resistance to transmitting sound vibrations. Three indices—*sound transmission class* (STC), *impact insulation class* (IIC), and *outdoor–indoor transmission class* (OITC)—help designers select the suitable assemblies.

However, choosing a good floor or wall assembly doesn't guarantee acoustic privacy. To ensure the desired level of sound reduction, designers and builders must avoid any *leaks, flanking paths*, gaps or short-circuits through which sound may travel.

THE PROPERTIES OF SOUND

Sound is defined as:

'… an auditory sensation produced through the ear and created by fluctuations in the pressure of air.'[2]

A vibrating object, such as a plucked guitar string, often initiates the fluctuations. The outwardly moving layers of compression and rarefaction of the air particles produce sound wave motion. Sound energy radiates in waves through an elastic medium, such as air, until it hits an obstruction and is transmitted, deflected, absorbed or dissipates through friction.

As sound vibrations strike the eardrum and cause it to vibrate, hearing takes place. Annoying sounds in buildings are caused by:

- People walking, talking and working
- Televisions, audio systems and other entertainment equipment
- Appliances, tools and equipment
- HVAC equipment
- Water and wastewater piping
- Elevators and refuse chutes.

[1] Warnock, A.C.C., J.D. Quirt and M. Lio. *Fire and Sound Control in Wood-Frame Multi-Family Buildings*, Canada Mortgage and Housing Corporation, 2002. http://www.cmhc.ca/en/imquaf/himu/fisoco_001.cfm

[2] Pearsall, J. (Ed). *Concise Oxford English Dictionary, Tenth Edition, Revised*. Oxford University Press, 2002.

Frequency is a measure of the number of oscillations per second of particles set in motion by a sound source. The more rapidly a sound source vibrates, the higher the sound pitch it makes. For example, a piccolo's highest note has a frequency of approximately 5,000 Hz, whereas an upright bass can play as low as 40 Hz.

Virtually all sources of sound produce several different frequencies simultaneously. To our ears, discordant or unwanted sound is noise. Young, healthy people can hear sound frequencies as low as 20 Hz and as high as 20,000 Hz.

Low-frequency sounds are much more difficult to control in buildings and can be a major cause of complaints in multi-family buildings. Low-frequency sound vibrations move more easily through lightweight materials than heavy materials. A heavier wall or floor with the same sound rating as a lighter one may often absorb, or *attenuate*, more low-frequency sound than the lighter assembly. Conversely, high-frequency sound vibrations travel more freely through heavy materials, but are attenuated by lighter assemblies.

The *pressure* that a sound wave exerts on a surface is measured in decibels (dB) as its *sound pressure* level. The larger the vibration of the source, and thus the disturbance of the air, the greater the sound pressure level and the louder a sound is perceived by the ear.

The human ear can perceive a range of sounds whose pressures vary by a factor of one million. Few people can discern a change in sound pressure less than 3 dB. Humans also perceive loudness differently at different frequencies. For these reasons, a logarithmic scale that corresponds to the human assessment of overall loudness was developed to measure the energy associated with a sound wave. The units on the dBA scale are exponential. For example, an increment of 10 dBA is a doubling of perceived sound level. Table 1 shows typical sound levels for some common sources.

Noise source	Decibels (dBA)*
Jet takeoff, artillery fire	120 or more
Rock band or home theatre system	100–120
Unmuffled truck or motorcycle	80–100
Average radio or TV	70–90
Human voice at 1m (3.2 ft.)	55–60
Background in private office	35–40
Quiet home	25–35
Buzzing insect at 1 m (3.2 ft.)	15–25
Threshold of hearing	0
* Apparent loudness varies with the distance from the source	
Source—Bradley, J.S. and J.A. Birta. *Laboratory Measurements of the Sound Insulation of Building Façade Elements*, IRC Internal Report, IRCIR-818, 2000.	

Table 1—Sound pressure levels for common sound

When sound waves strike one side of a partition, pressure variations cause the face of the partition to vibrate as some of the power in the waves is transferred into the partition. A portion of this vibration energy reappears at the opposite side of the partition, where it is re-radiated as sound. The materials in the partition absorb part of the vibration energy, preventing some of the sound from re-radiating on the other side. This is the *sound transmission loss* of the assembly.

Sound vibrations from impact, such as those caused by a hammer dropped on a floor, can also pass through a building assembly. By understanding how sound behaves within a building, the designer can devise strategies to control it.

AIRBORNE SOUND

Sources such as voices and music produce airborne sound. It can originate in neighbouring rooms or from outside from sirens, machinery or traffic. Heavy layers that are not solidly connected at any point and that are separated by the thickest cavity possible effectively attenuates airborne sound in wall and floor assemblies. Attenuation improves when the cavity is filled with sound-absorbing material, such as insulation.

The effectiveness of a wall or floor assembly in attenuating airborne sound transmission depends on the frequency of the sound. Most assemblies attenuate high-frequency sounds more effectively than low-frequency sounds.

An assembly's *sound transmission class* (STC) is a single numerical rating derived from sound attenuations at various frequencies, which approximately describe a wall's ability to attenuate the typical frequency content of speech. STC is a measure of the average noise reduction in decibels for speech-like sounds that pass through an assembly. An assembly with a high STC rating has good sound attenuation characteristics. Table 2 shows how the STC ratings for walls relate to their ability to attenuate different types of sound.

STC	Noise source
45	Loud or amplified speech audible Loud music audible, especially notes
50	Loud or amplified speech faintly audible. Loud music barely audible, but bass notes quite noticeable
55	Loud music not generally audible, but bass notes still heard
60	Loud music inaudible except for very strong bass notes

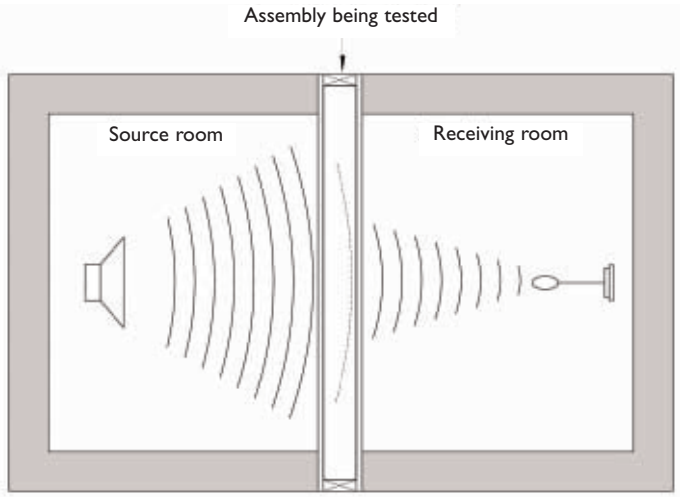
Source—National Commission on Building and Fire Codes, *National Building Code of Canada, 1995*. National Research Council Canada, Ottawa, 1997.

Table 2—The audibility of speech and music through walls of various STC ratings

Transportation noise from road traffic, trains and aircraft has greater low-frequency content than speech. The *outdoor-indoor transmission class* (OITC) is a single number rating of the attenuation of floor, wall and ceiling that better indicates the ability to attenuate transportation noise than the STC rating. Use OITC when considering intrusion of noise into a building from roads, trains or aircraft.

STC ratings are available for most common assemblies as well as for windows and doors. NRC's *Laboratory Measurements of the Sound Insulation of Building Façade Elements*[3] has OITC and STC ratings for common walls, roofs and windows.

[3] Bradley, J.S. and J.A. Birta. Laboratory Measurements of the Sound Insulation of Building Façade Elements, IRC Internal Report, IRCIR-818, 2000.



Source—Warnock, A.C.C., J.D. Quirt and M. Lio. *Fire and Sound Control in Wood-Frame Multi-Family Buildings*

Figure 1—Measuring sound transmission loss in the laboratory[4]

STC and OITC ratings are determined by testing assemblies under controlled laboratory conditions. Noise is generated in the source room and the sound pressure levels are measured in both the source room and the receiving room over a range of frequencies (see Figure 1). Unlike real buildings, the only sound transmission path between laboratory rooms is through the test wall or floor assembly, making it possible to accurately measure their sound attenuation properties.

Sound pressure levels are measured and corrected to account for the acoustical properties of the receiving room. Floor assemblies are tested in a similar way, and there may also be impact tests to measure their impact insulation.

The (STC) rating from these tests does not account for low-frequency sound transmission (below 125 Hz), which may come from mechanical systems, elevators and the lower frequencies of amplified music.

STC ratings cannot be simply added or subtracted. A 10 dB increase in the rating of a wall actually means it reduces the sound energy passing through the wall by 10 times, which the human ear perceives as being about half as loud. A wall with STC 45 will allow about 10 times more sound to pass than a wall with STC 55: this sounds about twice as loud in the receiving room.

STC ratings of floors and walls can be measured in the field and given a *field sound transmission class* (FSTC) rating. To verify the intended acoustical privacy in a building, a field test can be done at an early stage in construction when all the essential components that make up the assembly are in place. It is useful for finding problems during construction, making improvements and avoiding repetition.

The National Building Code of Canada (NBCC) now only regulates airborne sound transmission for wall and floor assemblies separating suites in multi-family buildings. It does not provide for protection from the transmission of impact sounds between suites nor protection from outside airborne sound. The NBCC requires that walls and floors have an STC rating of:

- 50 to separate residential suites from every other space in a building (Sentences 3.3.4.6(2) and 9.11.2.1.(1)).
- 55 to separate residential suites from adjacent elevator shafts and refuse chutes (Sentences 3.3.4.6.(3) and 9.11.2.1.(2)).

Tables A-9.10.3.1.A. and A-9.10.3.1.B. in Appendix A of the NBCC (1995) illustrate common assemblies for walls and floors, ceilings and roofs and their STC and fire ratings. The values assigned to the different assemblies can be used where a proposed design exactly replicates the listed assembly. This is important, since small construction differences may adversely affect expected performance.

[4] Bradley, J.S. and J.A. Birta. Laboratory Measurements of the Sound Insulation of Building Façade Elements, IRC Internal Report, IRCIR-818, 2000.

Nonetheless, some minor variance in ratings will always exist between actual field performance and laboratory-rated performance. Historically, provincial and local authorities have accepted ratings listed by the NBCC. However, the designer should confirm with the building officials in his or her jurisdiction that they accept these ratings.

The most common situations requiring STC ratings are:

- Party walls between residential suites
- Walls between public corridors and residential suites
- Floor assemblies between residential suites, mechanical rooms and recreation areas
- Walls between residential suites and elevators, refuse chutes and service rooms

IMPACT SOUND

Good STC ratings do not necessarily satisfy occupants. Mechanical vibrations and impacts, such as foot traffic, dropped objects or objects sliding across a hard floor, also cause sound to move through construction materials. Although the code does not actually specify levels for impact ratings, it is important that architects design to reduce impact noise effects.

A floor or wall being vibrated by direct mechanical contact or impact causes impact sound. The vibration then spreads along or through the wall or floor into the assembly and its cavities, ultimately becoming sound in adjoining spaces. Floor vibrations can also be transmitted through the structure to walls and be re-radiated as airborne sound into adjoining spaces.

Impact sounds on concrete slabs finished with a hard surface, such as ceramic tile, are often described as "clacking" or "tapping." Most of such sound energy occurs at high frequencies. Impact sounds on lightweight joist floors—the result of low-frequency sound waves—are usually described as "booming" or "thudding."

Although airborne and impact sound have some things in common, impact transmission is far more complicated to measure and control. The character and level of impact noise generated in a living space below depends on many factors, including the nature of the object striking the floor, the force of the blow, the rigidity of the floor assembly and the resilience of the floor covering. NRC considers including impact noise requirements in future versions of the NBCC.

The standard test for *impact insulation class* (IIC) uses a tapping machine that lifts and drops five steel hammers on a floor 10 times per second. Sound pressure levels are measured in the room below at specific frequencies. The higher the IIC, the better the attenuation of impact sound, with 50 dB usually considered the minimum for occupant satisfaction in residential buildings. However, the IIC test method ignores sounds generated at the lower frequencies (below 100 Hz). People walking on lightweight joist floors generate these low-frequency sounds, often at frequencies below the range used for the IIC rating. Thus, while a low IIC rating indicates that there will be annoyance due to impact sound, a high IIC rating does not guarantee there will be no problems from low-frequency sound through lightweight floors.

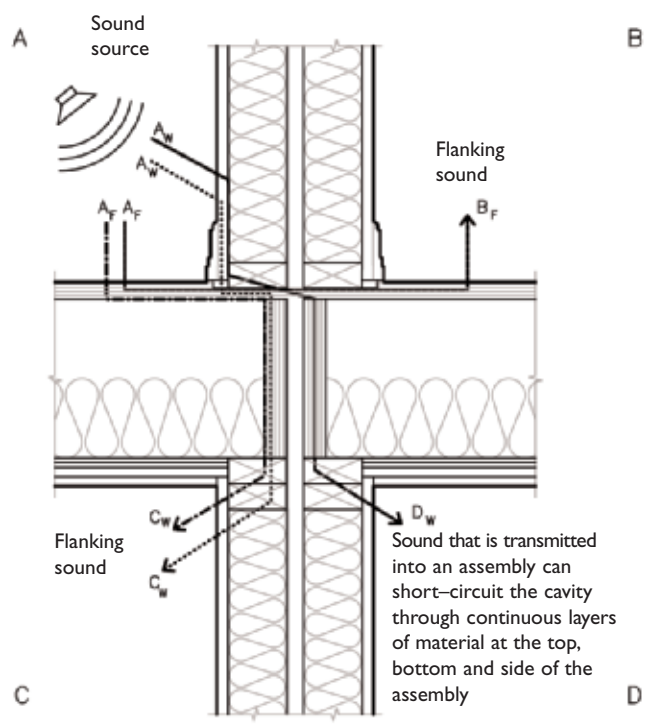
As for airborne sound, it is important to understand that field performance can vary considerably because of factors on-site that are not present in the laboratory. Recommended practice is to specify assemblies with IIC and STC ratings 5 to 10 points higher than required to compensate for the lower performance in the field. Table 3 summarizes the minimum STC and IIC sound attenuation for various building assemblies that are recommended in CMHC's *Fire and Sound Control in Wood-Frame Multi-Family Buildings*. The best practice is higher than the NBCC because the sound attenuation levels in completed buildings are often less than those produced in laboratory conditions.

Assemblies	NBCC-required STC	Best practice STC	Best practice IIC
Party walls or corridor walls	50	55	—
Bare party floors	50	55	55
Carpeted party floors	50	55	65
Source—Warnock, A.C.C., J.D. Quirt and M. Lio. *Fire and Sound Control in Wood-Frame Multi-Family Buildings*			

Table 3—Minimum recommended STC and IIC ratings

Impact sound insulation ratings depend greatly on the floor covering. The same basic floor structure can give extremely different IIC ratings depending on the surface layer. A floor design that relies on carpet and underpadding to control impact sound will be compromised if future occupants decide to remove the carpet. Some lightweight floors with an IIC of 55 dB or more may be subject to complaints because of low frequency and impact noise. Although carpet increases the IIC rating, it will not necessarily reduce low-frequency noise transmission. Good footstep noise rejection requires fairly heavy floor slabs or floating floors.

Good detailing reduces impact sound transmission. However, the elimination of impact noise is nearly impossible because paths exist in all buildings that allow sound vibrations to bypass sound attenuation measures. These *flanking* paths have more serious consequences for impact sound than for airborne sound, because impacts transmit more vibration energy to the structure. Vibrations at low frequencies are more difficult to control in wood-frame construction because considerable mass is needed to attenuate this energy. Conversely, high-frequency sounds are difficult to control in concrete, masonry and steel structures, which require resilient connections to dissipate this energy. To be effective, sound control measures must be suited to the type of construction.



Source—Warnock, A.C.C., J.D. Quirt and M. Lio. *Fire and Sound Control in Wood-Frame Multi-Family Buildings*

Figure 2—Flanking sound transmission

FLANKING SOUND TRANSMISSION

Flanking transmission consists of sound vibrations that bypass the sound attenuation components in wall or floor assemblies between rooms or suites to emerge as noise on the opposite side of the separation. Flanking exists in all buildings and its effect on apparent sound insulation (that perceived by the occupants) is influenced by the rigidity of the connections between walls, floors and their junctions. Indirect or flanking sound transmission occurs where the parts of a building are rigidly connected at cavities in hollow walls or floors and where continuous lightweight surfaces extend between apartments (*see* Figure 2). Flanking can undermine efforts to improve sound insulation and seriously reduce the apparent sound attenuation of walls and floors.

For the sound performance of the partition or floor to be fully realized, flanking transmission should not be permitted to be greater than direct transmission through the separating wall or floor assembly.

Sound travels as vibrations along surfaces and through walls, ceilings and floors to adjacent rooms. Many paths other than the direct one through the party wall or floor may be involved. The use of gaps between sheathing surfaces, double stud walls, resilient metal channels and floating floors are some of the techniques for controlling flanking sound that will be presented later in this article.

BARRIERS TO THE PASSAGE OF SOUND

This section describes the main, proven-effective techniques for reducing airborne, impact and flanking sound transmission. A sound barrier must be impervious to air, non-porous, solid and reasonably heavy—materials such as gypsum board, glass, plywood, OSB and concrete are commonly used to reduce sound transmission in buildings.

Heavy materials

The density of materials has a large affect on sound transmission. Heavier, denser, building materials tend to block sound better than lightweight building materials (*see* Figure 3). A double-layer of gypsum wallboard or floor sheathing, for instance, provides better sound isolation than a single layer.

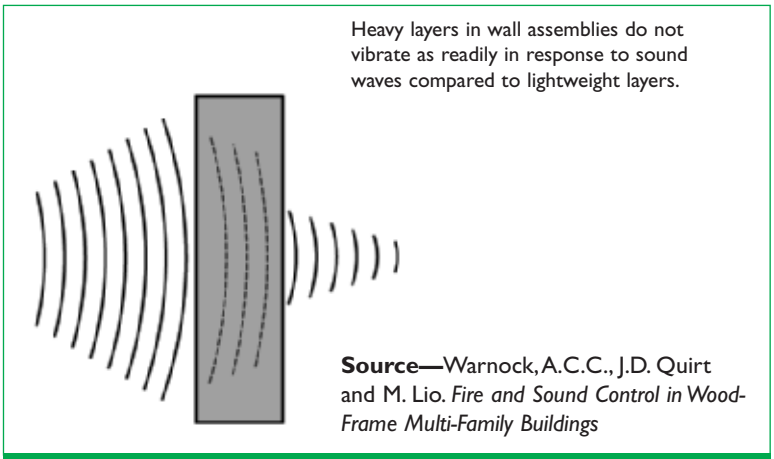


Figure 3—Heavy materials transmit less sound

Because wood-frame construction is relatively light, a combination of techniques is required to control sound. An STC of 50 cannot be obtained with a single layer of gypsum board on each side of 89-mm wood studs because the combination of mass per unit area, cavity depth and stud stiffness is not sufficient to produce the required transmission loss. Doubling the mass of gypsum board on both sides of the stud wall increases the STC by about 9 dB (*see* NBCC Table A-9.10.3.1.A. (8)).

Absorptive materials

The cavities inherent in wood-frame construction are a convenient space for absorptive material, such as fibrous insulation. Installing sound-absorbing material that fills at least two-thirds of the wall cavity can increase sound transmission loss by 8 to 10 dB if the surface layers are properly isolated. The insulation is only effective in absorbing sound waves within the cavity, so other measures are needed to reduce the sound passing through the framing.

Absorptive materials are normally quite porous. They interact with sound passing through them, converting the vibrations into heat. Absorptive materials are not sound barriers. They reduce sound energy in an enclosed cavity as sound repeatedly reflects between the enclosing surfaces and passes through the sound-absorbing material many times. Each pass-through causes a small decrease in energy, with the cumulative effect being significant. A single pass provides very little sound attenuation unless the absorbent material is very thick. Thus, adding a carpet or acoustic tiles directly to a surface will not significantly improve the sound insulation of the separation.

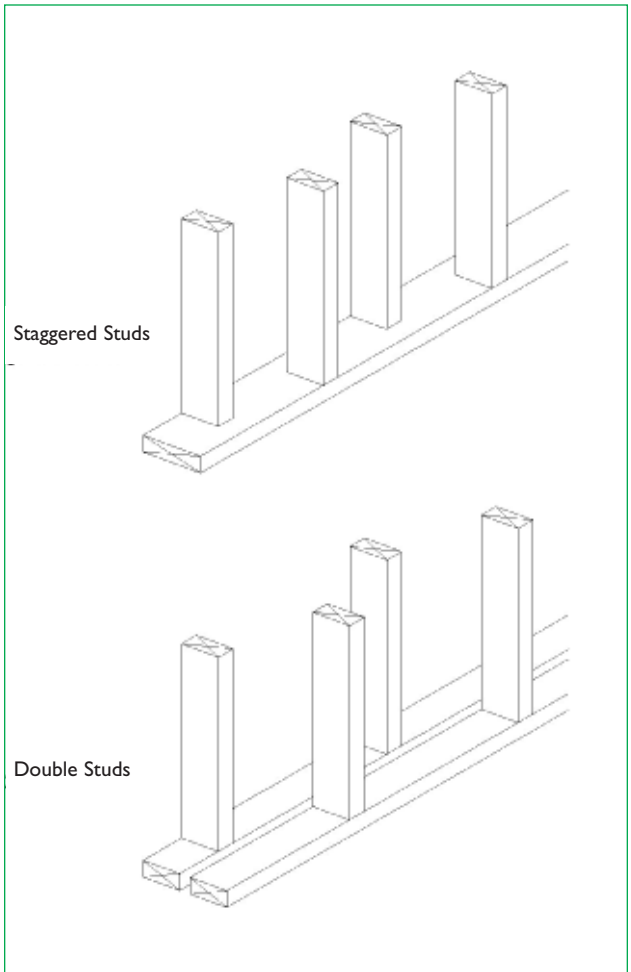
Vibration breaks and resilient connections

In wood-frame construction, materials and techniques that isolate or decouple layers of materials can reduce both airborne and impact sound. Gypsum board that is solidly fastened to wood framing allows much of the sound to be transmitted through the frame. Therefore, it is beneficial to interrupt the solid connections between the gypsum board and the wall framing. Using flexible fasteners between the gypsum board and the framing will reduce the sound transmitted through the assembly.

Staggered or double-stud walls (see Figure 4) are another way of isolating layers of materials. Staggered studs can increase the STC rating of a basic wood-frame wall by 10, and double studs can increase the STC rating of a basic wall by 20.

Resilient connections in walls

Resilient furring strips, or resilient channels, are flexible fasteners. They are commonly used to improve the sound insulation of walls and floors where the finish surfaces are attached to either side of the structural members. Adding resilient metal channels to at least one face of a single row of studs reduces sound transmission considerably and makes sound-absorbing material in the cavity more effective.



Source—Warnock, A.C.C., J.D. Quirt and M. Lio. *Fire and Sound Control in Wood-Frame Multi-Family Buildings*

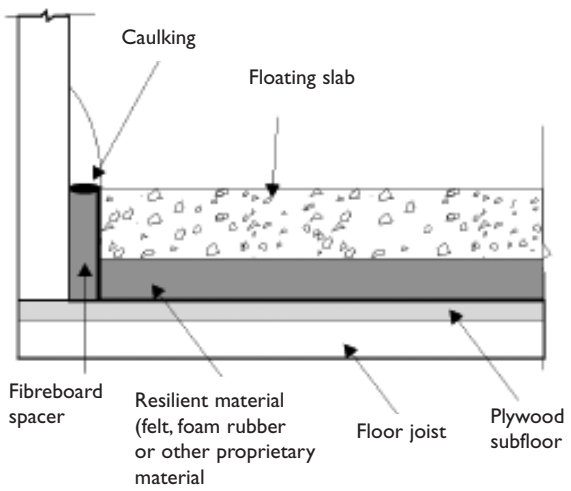
Figure 4—Staggered and double-stud walls

Most resilient channels have a "Z" profile, and there is some variation in the design of the web that connects the two parallel attachment surfaces and the gauge of sheet metal used. Their purpose is to detach the drywall membrane from its supporting frame, so that sound vibrations cannot pass directly through the structure and wall surface. Because some sound will pass through the resilient channels, spacing them further apart results in greater sound reduction.

Resilient connections in floors

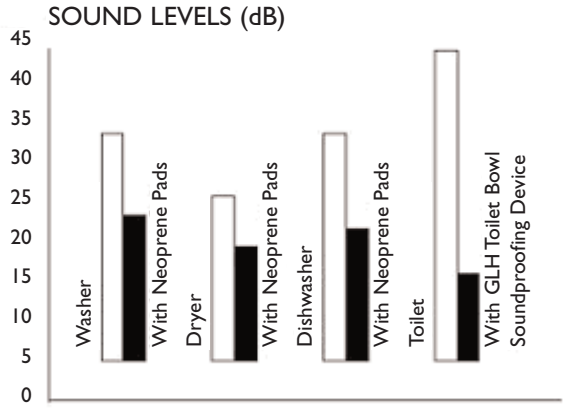
Resilient materials used in floor assemblies can also reduce airborne and impact sound. Resilient channels on a ceiling reduce both airborne and impact sound. Coverings, such as carpet and underpad or floating floors, also control impact sound.

Resilient channels are usually attached to the underside of floor joists at 400-mm (16-in.) or 600-mm (24-in.) centres. The drywall ceiling membrane should be fastened to the resilient channels using screws long enough to penetrate the metal furring, but not long enough that they penetrate the wood frame. Most channels will adequately support up to two layers of drywall with proper fastening. Because only a small amount of vibration energy passes through the channels, the sound attenuation of the floor assembly improves with increased resilient channel spacing.



Source—Warnock, A.C.C., J.D. Quirt and M. Lio. *Fire and Sound Control in Wood-Frame Multi-Family Buildings*

Figure 5. Resilient acoustic floor slab



Note: This date illustrates improvements in sound isolation for a specific building using proprietary components. These results may not necessarily be replicated in other buildings.

Source—*Cité BellevuePhase III, Quieter Condominiums*

Figure 6—Example of sound level improvements using resilient materials

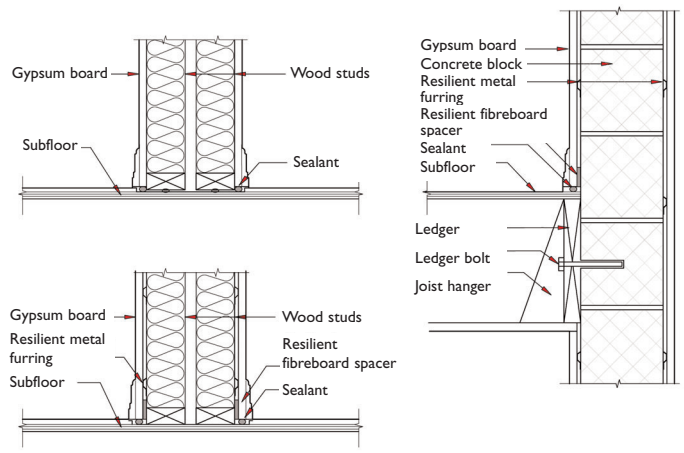
A floating floor consists of a finish floor separated from the subfloor by a resilient material (see Figure 5). The floating floor can be a concrete topping, a laminated-gypsum concrete board or a lighter wood flooring, while the resilient layer can be a continuous blanket or pads. It is very important that there be no solid contact between the floating floor or wood raft and the subfloor, or the walls around their periphery. A resilient spacer or a gap with sealant between the floating floor and walls avoids direct sound transmission.

SEPARATION OF USES

Building layouts should be designed with sensible vertical and horizontal separations between noise-generating spaces and spaces sensitive to transmitted sound. For example, elevators, garbage chutes, garage doors, plumbing, fans and heat pumps are common noise sources in buildings. Place them as far as possible from sensitive living areas, especially bedrooms. When it is practical to group kitchens and bathrooms together, concentrate plumbing noise in areas that are less sensitive. Avoid placing bedrooms above common-use automatic garage doors, or use sound-dampening components to isolate the door-opener and rollers from the building frame.

Vibrating parts should be isolated from the building structure with resilient materials, such as neoprene or rubber. Figure 6 shows how the retrofit of a multi-family building in Montréal used resilient sound-proofing materials to improve sound control.[5]

[5] *Cité BellevuePhase III, Quieter Condominiums*, Canada Mortgage and Housing Corporation, http://www.cmhc-schl.gc.ca/en/imquaf/himu/buin_016.cfm



Source—Adapted from Warnock, A.C.C., J.D. Quirt and M. Lio. *Fire and Sound Control in Wood-Frame Multi-Family Buildings*

Figure 7—Application of sealant to prevent sound leaks

SEALING

The perimeters of all demising walls should be air-sealed to reduce airborne sound transmission through the assembly (see Figure 7), using a non-hardening, permanently resilient caulking on both sides of the partition. It is important to place the caulking where it can be seen and inspected before applying the drywall. Debris under the plate impairs effective sealing and must be cleared away before applying the sealant. Even small holes can seriously affect the performance of the wall. The bottom and top of drywall applied over block or solid concrete walls must also be sealed.

The STC ratings shown in NBCC Table A-9.10.3.1. are for concrete block walls whose surfaces are sealed by at least two coats of paint or other finish, to prevent sound leakage.

DESIGNING FOR SOUND CONTROL

This section describes best practices for the selection of materials and installations that control the transmission of airborne and impact sound, and reduce noise transmitted by flanking paths. It is important to note that the sound attenuation provided by even the best assemblies for airborne and impact sound can be negated by inadequate control of *flanking* transmission.

Airborne sound

Demising walls

- Two or more layers that are not connected at any point by solid materials and provide a degree of air-tightness
- The heaviest layers that are practical
- The deepest cavity that is practical, filled with sound-absorbing material
- Airtight construction, especially at penetrations

Wood-frame walls

Wood-frame walls can provide STC ratings of 35 to 55 for a single row of studs, depending on the number of layers of gypsum board and method of attachment. Ratings of 50 to 60 are achievable with staggered and double-stud walls, depending on the thickness and number of layers of gypsum board and method of attachment. Refer to NBCC Appendix A Table A-9.10.3.1 for typical wood wall assemblies and their STC ratings.

Where possible, avoid rigid contact between the gypsum wallboard and the wood-framing members within the demising wall, which would allow sound vibrations to pass from the drywall to the studs. The use of resilient supports to attach the gypsum wallboard is a practical and economical approach to decrease the number of rigid connections found in typical wood-frame walls, and thus to reduce sound transmission through studs.

The correct installation of resilient channels can produce a significant improvement in sound insulation. They should be placed on wall framing with their unsupported edges facing upwards, so the weight of the wall finish ensures the maximum spacing from the studs. Oversized or improperly installed drywall screws can result in direct contact between the gypsum board and the framing that can short-circuit the sound control measures. Sound insulation improves when the spacing between framing members, such as studs, or between resilient channels is increased because there are fewer paths by which the sound vibrations can be transmitted.

Wood-frame construction usually contains a cavity between wall surfaces, which, when filled with sound-absorbing material, is an important means to control airborne sound. Staggered or double rows of studs provide generous cavities that can accommodate sound-absorbing material.

Sound transmission through wood-frame walls can be decreased by the following measures:

- Increasing mass by adding layers of gypsum board to each side
- Increasing the depth of the cavity
- Filling the cavity with insulation
- Spacing studs further apart
- Spacing resilient channels further apart
- Using staggered or double-stud walls, (with or without resilient channels).

Walls between apartments should provide sound attenuation of at least 55 dB—more than the minimum required by the NBCC—to ensure true acoustic privacy. Designers should specify assemblies in which the STC exceeds 55, in order to account for the degradation of sound insulation from construction and design errors that introduce flanking transmission.

Masonry block walls

Masonry and concrete construction is often used in wood-frame multi-family buildings for firewalls, and where higher levels of acoustic privacy and fire protection are required. Like wood-stud wall assemblies, the sound transmission of the masonry and concrete walls is affected by a number of system characteristics. NBCC Table A-9.10.3.1. gives fire resistance ratings (FRRs) and STC ratings for several concrete block wall assemblies.

The most important characteristic affecting the STC of a single-wythe, concrete-block wall is its mass per unit area. The higher the density of the materials, the better the sound performance of the wall. Table 4 shows that a single-wythe, concrete-block wall is heavy enough to provide STC ratings of about 40 to 50, depending on the density and thickness of the block.

Achieving an STC rating much greater than 50 with single-wythe walls requires the addition of gypsum board mounted on studs or furring. If the furring supporting the gypsum board is rigid, sound may travel directly through it from the gypsum board to the block. Sound transmission can be attenuated if the furring is sufficiently resilient or if the gypsum board is supported on standoff studs. Resilient metal furring may be used on its own or in combination with wood furring. Filling the core of the blocks with sand or grout can also improve the transmission loss by increasing the mass of the blocks. However, adding absorbent materials in the cores will not improve the sound insulation because the sound transmission in this case is primarily through the solid structure of the block.

	Lightweight (not less than 50% solid)		Normal weight (not less than –50% solid)	
Thickness mm (in.)	Kg (lbs)/ block	STC	Kg (lbs)/ block	STC
90 (4)	8 (17.6)	42	10 (22.1)	44
140 (6)	10 (22.1)	44	15 (33.1)	46
190 (8)	14 (30.9)	48	18 (39.7)	50
240 (10)	17 (37.5)	48	21 (46.3)	50
290 (12)	20 (44.1)	49	25 (55.1)	51

Source—Warnock, A.C.C., J.D. Quirt and M. Lio. *Fire and Sound Control in Wood-Frame Multi-Family Buildings*

Table 4—Typical STC ratings for single-wythe, hollow concrete-block walls with sealed units

Lightweight blocks are more porous than normal-weight blocks. The sealing of more-porous blocks can achieve greater transmission-loss reduction than the sealing of less-porous blocks. The STC of lightweight blocks may improve by 5 to 10 dB when the surface is sealed. Normal-weight blocks usually show little or no improvement after sealing. Lightweight block walls can provide STC ratings comparable to those of heavier blocks when finished as follows:

- Apply paint, plaster or block sealer to one side only. If a gypsum-board finish is required on this side, it should be glued or screwed directly to the block or attached to stand-off studs with absorptive material in the stud space.
- On the opposite side of the wall, use independent studs to support the gypsum board. Put sound-absorbing material in the cavity. For normal-weight blocks, the larger the cavity depth the better.
- Avoid narrow spaces, such as the 12.7 mm (1/2 in.) gap created by attaching drywall to a resilient channel on the block. A narrow cavity like this causes acoustic coupling that will actually reduce the assembly's sound attenuation.

Double-wythe, masonry-block cavity walls can provide very high sound insulation because they have features that make an ideal wall assembly—two independent heavy layers separated by a cavity.

Table 5 shows STC ratings for double-wythe, block-cavity walls. Note that double-wythe walls have considerably higher STC ratings than the single-wythe walls in Table 3.

Thickness of first block layer—normal weight, 50% solid	Cavity	Thickness of second block layer—normal weight, 50% solid	STC
190 mm (8 in.)	65 mm (2-1/2 in.) glass fibre panels in 135 mm (5-1/2 in.) air space	90 mm (4 in.) split rib	79
90 mm (4 in.)	65 mm (2-1/2 in.) glass fibre panels in 125 mm (5 in.) air space	90 mm (4 in.) split rib	77
90 mm (4 in.)	50 mm (2 in.) expanded polystyrene panels in 125 mm (5 in.) air space	90 mm (4 in.) split rib	69
90 mm (4 in.)	125 mm (5 in.)	90 mm (4 in.) split rib	69

Source—Warnock, A.C.C., J.D. Quirt and M. Lio. *Fire and Sound Control in Wood-Frame Multi-Family Buildings*

Table 5—STC rating for double, structurally isolated, block-cavity walls[1]

In practice, constructing two block walls in close proximity that are structurally isolated—not solidly connected—requires care. This is because flanking sound can be transmitted along masonry ties, mortar bridges, along the floor, ceiling and walls abutting the periphery of the double-wythe wall or through other parts of the structure. Flexible ties and physical breaks in the floor, ceiling, and abutting walls can reduce this flanking transmission.

Mortar droppings (fins) or other debris can also bridge the cavity and increase sound transmission, especially when cavities are less than 40 mm (1-½ in.) deep. Such construction oversights are usually concealed and nearly impossible to fix after the wall is complete. In one laboratory test, a cavity wall that was expected to attain an STC greater than 70 only provided STC 60 because of mortar fins that connected the two wythes of the wall.

Floors

Strategies for controlling airborne sound transmission through floors are similar to those used for walls. Airborne-sound transmission is best attenuated when the assembly includes two heavy layers that are not solidly connected at any point, are separated by the thickest cavity possible and filled with sound-absorbing material.

Number of layers		Rating	
Subfloors + topping	**Ceiling**	**STC**	**IIC***
1 + no topping	1	51	45
1 + no topping	2	56	49
2 + no topping	1	55	48
2 + no topping	2	58	52
1 + 35 mm (1-3/8 in.) concrete	1	67	40
1 + 25 mm (1 in.) gypsum concrete	1	65	28

Floor construction: 15 mm OSB subfloor, 240 mm deep joists @ 406 mm o.c., 152 mm glass fibre batts, resilient metal channels @ 610 mm o.c. and 15.9 mm gypsum board.
*These ratings are for bare subfloors. STC and ITC ratings can be improved with the addition of a suitable floor finish.
Source—Warnock, A.C.C., J.D. Quirt and M. Lio. *Fire and Sound Control in Wood-Frame Multi-Family Buildings*

Table 6—STC and IIC ratings for wood-frame floors

Floors should be designed to control impact sound from people walking and objects being dropped or moved. The tests setting IIC ratings do not take into account low-frequency noises from footsteps. This low-frequency phenomenon is true even for wood-frame floors with carpeting. While carpet improves a floor's STC rating, it does little to attenuate low-frequency impact sounds.

Wood-frame floors

To meet code airborne-sound requirements, typical wood-frame floor assemblies require a double gypsum board ceiling resiliently attached to the underside and an additional floor layer (other than resilient flooring) applied over the basic subfloor. The following general rules apply:

- Joist floors without resilient channels do not achieve STC 50 in any practical configuration.
- Adding sound-absorbing material to the cavity of a joist floor with a ceiling that is not resiliently suspended provides no significant increase in sound insulation.
- The type of structural member used in a floor assembly (solid wood joist, wood I-joist, or metal plate-connected wood truss) does not significantly affect the STC or the IIC of the assembly.

Table 6 shows the interrelationship of STC and IIC ratings for some typical wood-frame floors.

Impact sound

Two very important strategies for controlling impact sound in wood-frame construction are:

1. Using resilient metal channels to support the gypsum board ceiling
2. Applying sound-absorbing batts in the cavities

Table 6 shows that the IIC for a single-layer subfloor (plywood or OSB) with no topping is 45 dB. In simple joist floors, the total mass of the subfloor and the ceiling layers is the most important influence on the impact of sound attenuation. Doubling the mass of the subfloor gives an IIC of 47 dB; doubling that of the ceiling gives an IIC of 49 dB; and doubling the mass of both gives IIC 52 dB. Increasing the spacing between resilient metal channels or the thickness of the sound-absorbing material increases the IIC by one or two points.

Attaching gypsum board directly to the underside of the joists gives very poor impact sound attenuation. Mounting the gypsum board on wood or stiff metal furring gives a slight improvement relative to direct attachment, but the impact sound attenuation provided by the floor is still unsatisfactory. Resilient support or separate framing for the gypsum board ceiling is essential. Spring hangers or separate joists can be used, but resilient metal channels are less expensive and are adequate in most cases.

Occupants often complain about excessive "booming" or "thumping" when people walk on joist floors even when the IIC rating is greater than 50. Most of the energy is at lower frequencies than those used to determine the IIC, and the IIC rating does not fully reflect the annoyance caused by these sounds.

A carpet and pad on top of the subfloor can give high IIC values with lightweight joist construction. These floors may still draw complaints about low-frequency impact sound if the total mass of the layers is too low. Although the IIC rating may be high, the floor can still have a low airborne STC.

Attaching ceramic tiles directly to the subfloor significantly reduces the IIC because the hardness of the tiles increases the high-frequency component of the sound. The same effect occurs to a lesser degree when hardwood flooring is laid on top of the subfloor. In both cases, a resilient interlayer should be between the finished floor and subfloor to reduce impact noise transmission. The material above the resilient layer must be rigid enough to support the finish flooring. This is discussed in detail in the following section.

Subfloor toppings and floating floors

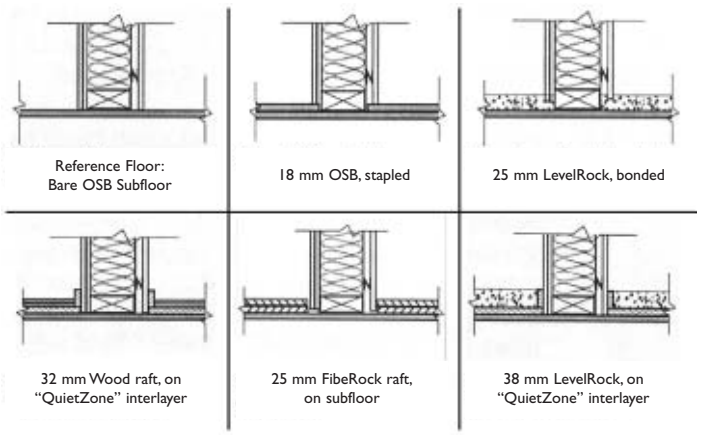
Adding layers of OSB or plywood, gypsum cement, lightweight concrete and regular concrete can increase the mass of a floor assembly and its attenuation of airborne and impact sound. Subfloor toppings usually vary in depth from about 15.9 mm (⅝ in.) for OSB or plywood to 38 mm (1-½ in.) for concrete. Thicker toppings, such as gypsum and concrete, require doubling the sole plate to provide backing for drywall and trim.

A National Research Council study[6] demonstrated the benefits of increasing both the mass and compliance of the floor layers over wood joists. Three classifications of toppings were examined:

- *bonded* toppings applied directly over and mechanically attached to the subfloor framing
- *unbonded* toppings applied directly over the subfloor without mechanical attachment
- *floating floors* separated from the subfloor by a resilient cushion, or interlayer

The tests measured airborne and impact sound transmitted between four rooms separated by a vertical demising wall capable of producing STC 52 and a floor capable of producing STC 55. The OSB floor sheathing extended unbroken across the demising wall in the test assembly so that the effects of flanking transmission could be measured. Figure 8 shows the toppings.

[6] Nightingale, T.R.T., R.E. Halliwell and J. D. Quirt. *Flanking Transmission in Multi-Family Dwellings, Phase II*, National Research Council Final Report: A1080.4, 2002



Source—Nightingale, T.R.T., R.E. Halliwell and J. D. Quirt.
Flanking Transmission in Multi-Family Dwellings, Phase II

Figure 8—Reference floor and tested floor toppings

Although all the toppings improved the apparent airborne sound insulation of a bare OSB floor, the compliant and floating toppings also improved impact sound isolation, while the bonded cementitious topping *decreased* it in one instance. Comparing the test results leads to the following observations:

1. Airborne and impact sound moving both vertically and horizontally through the floor structure can be attenuated by applying various toppings to the subfloor.
2. Toppings that are bonded to the subfloor (stapled OSB and bonded LevelRock) transmit more impact noise than similar toppings that float on resilient interlayers (wood raft on "QuietZone" and LevelRock on "QuietZone").
3. Cementitious toppings must be accompanied by resilient floor finishes or "interlayers" for their full potential to reduce impact sound transmission to be realized.
4. The attenuating effect of the interlayer is much less pronounced for compliant floor toppings (OSB), which will reduce impact sound transmission without an interlayer.

The IIC value provided by unbonded toppings depends on the resilient material used. Shredded or foamed rubber, foamed plastic, mesh or cork mats are effective at reducing impact noise. Increasing the thickness of the resilient material usually, but not always, increases the IIC. In all cases, the impact ratings attributed to floating floor systems should be supported to be accredited laboratory testing.

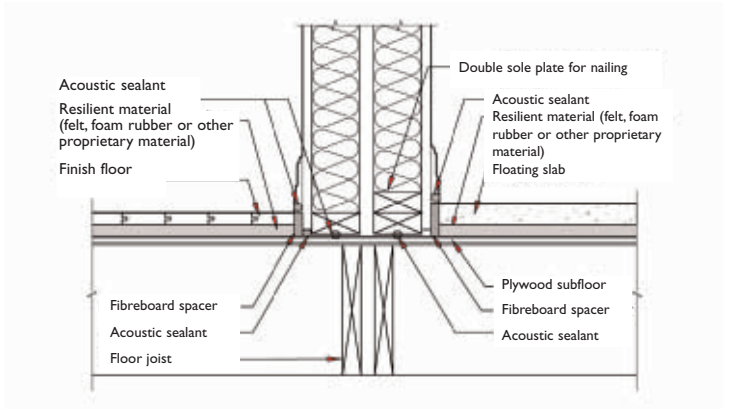


Figure 9—Installation and edge details for floating floors and slabs

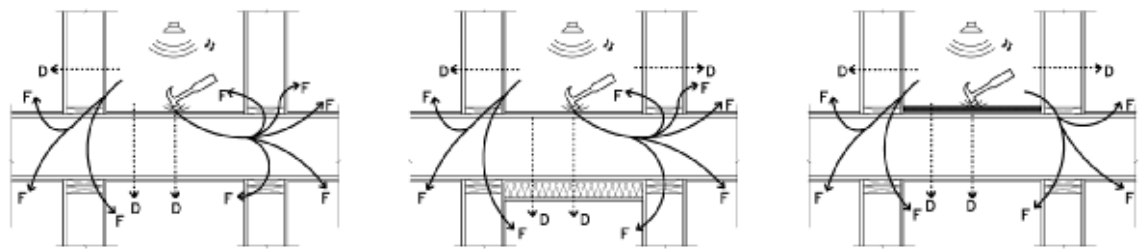
In addition to the composition of the floating floor or topping, attention must also be paid to the floor–wall interface (see Figure 9). A resilient edge-strip prevents the transmission of vibrations from the subfloor topping to the walls, and acoustic caulking prevents the entry of debris or fluids. The baseboard should not contact the floor finish, as this also provides a path for sound energy to bypass the floating floor.

In designing and building a floating floor, consider the following:

- Avoid penetrations of the floating floor by pipes, ducts, etc. Where a penetration such as a drainage pipe is essential, ensure that it does not form a rigid connection between the floating floor and the structure.
- To avoid a short-circuit connection of the floating topping to the structure caused by debris, ensure the structural floor is clean and smooth before laying down the resilient supports.
- Ensure that the finished floor levels are compatible in all parts of the building. Position elevator and suite doors, trims, stair landings and guards to correspond to the heights of the floor finishes to avoid steps, slopes and raised thresholds. Note that this amount of co-ordination may not be possible when floating floors and toppings are offered as options to purchasers and tenants, or introduced late in design.

Controlling flanking sound

Flanking sound transmission may severely compromise even the best efforts to achieve acoustic isolation in multi-family dwellings. Although designers may select appropriate assemblies to provide the required sound ratings, poor attention to detail and rigid connections in the structure will negate some of the sound control capabilities of the assemblies. A typical flanking path might include the floor sheathing, joists, wall plates and drywall finish. Flanking noise is a particular concern with wood-frame construction because of the large number of rigid connections between walls, floors and ceilings. Figure 10 is a schematic showing how airborne and impact sound can bypass sound control assemblies.



D - Direct path (airborne sound transmission)
F - Flanking path (vibrational sound transmission)

Suspended ceiling provides limited flanking noise control

Floating floor more effectively controls flanking noise, particularly from impacts

Source—Warnock, A.C.C., J.D. Quirt and M. Lio. *Fire and Sound Control in Wood-Frame Multi-Family Buildings*

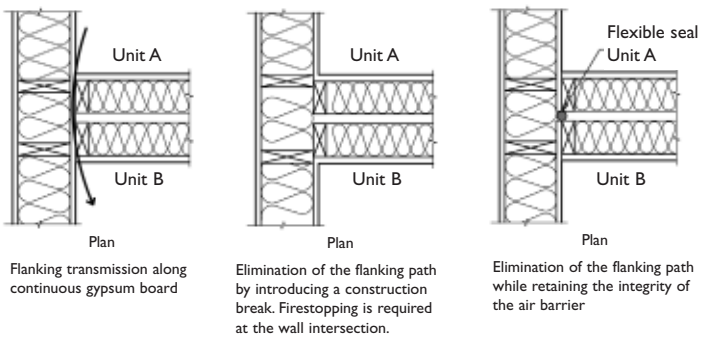
Figure 10—Controlling flanking sound

Horizontal flanking paths

Exterior walls are common paths for the passage of flanking noise in multi-family buildings. Rigid structural connections needed to resist wind and seismic loads, and continuous membranes acting as fire stops provide pathways for the movement of sound vibrations from one dwelling to the next. The walls between apartments and common corridors may also conduct flanking noise.

Except where required for resisting wind and seismic loads, building elements, such as floor sheathing, gypsum board, joists, and so on, should not be continuous across or under a partition as these can be major flanking paths. For a situation where the floor sheathing, joists, or both, are continuous under the partition wall separating two rooms, the dominant flanking path is from the floor in one room to the floor in the other room.

Figure 11 shows how flanking transmission can occur where party walls meet exterior walls or corridor walls in multi-family buildings. It illustrates how to introduce a break to interrupt the flanking path along the corridor or exterior wall. Careful construction should introduce a resilient break in the flanking path while keeping a continuous barrier to air leakage and maintaining a fire stop.



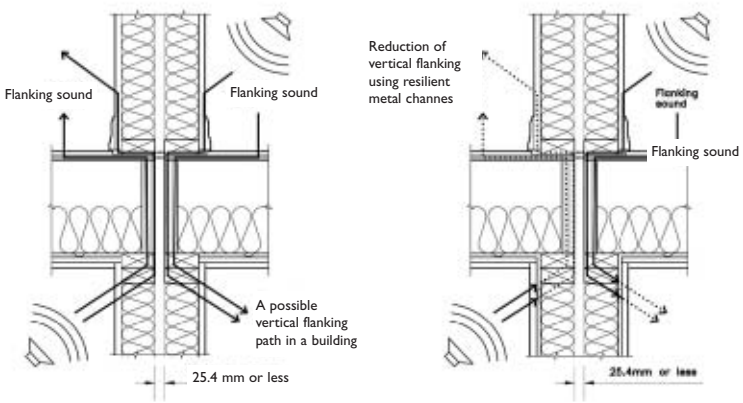
Source—Warnock, A.C.C., J.D. Quirt and M. Lio. *Fire and Sound Control in Wood-Frame Multi-Family Buildings*

Figure 11—Plan: Eliminating flanking paths around wall intersections[1]

Vertical flanking paths

Figure 12 shows how flanking sound can move through wall and floor framing to reach rooms above or below. Even though double studs are used for the party wall, there may be flanking transmission between vertically separated units that can be reduced by using resilient channels to attach the gypsum wallboard on each side of the partition in the lower unit.

The first defence against flanking is proper construction details that eliminate unnecessary connections between occupancies. A correctly designed and applied floor topping can also help to control the flanking paths between horizontally and vertically separated rooms. The designer must be aware that the optimal physical properties of the topping system are different for airborne sound than for impact insulation.



Source—Warnock, A.C.C., J.D. Quirt and M. Lio. *Fire and Sound Control in Wood-Frame Multi-Family Buildings*

Figure 12—Use of resilient channels to eliminate vertical flanking paths[1]

For resisting airborne flanking, the most important factor is the mass of the floor topping. For impact sound insulation, there are two important factors—the mass, and the hardness of the exposed topping surface. A significant increase in mass is required to improve low-frequency impact sound insulation. High frequency impact sound is reduced if the topping material is harder than the subfloor material.

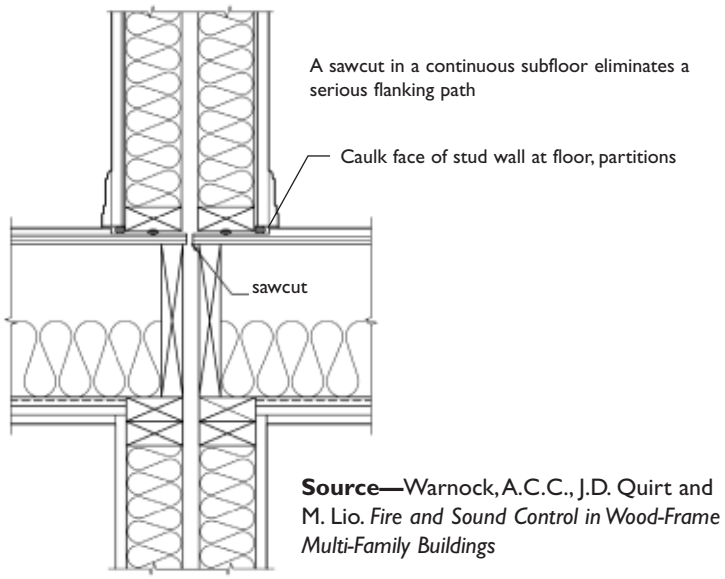
The full benefit of a concrete or gypsum concrete topping to control impact sound is achieved only when the topping is used in conjunction with a resilient material. This may be an interlayer (used to isolate the topping and subfloor) or it may be a floor covering such as carpet.

The effectiveness of a topping to control flanking sound depends on the orientation of the joists with respect to the wall junction. With a plywood or OSB subfloor, flanking sound transmission between two rooms on the same level will be greater when the joists are perpendicular to the demising wall. This is because the floor sheathing is rigidly supported on top of the joists, yet has a tendency to flex between the joists, causing more of the vibration energy to move in the direction of the joists. These effects are explained by examining structure borne attenuation in the floor surface. A saw cut or gap in the floor sheathing at the center of a party wall will eliminate a horizontal and a vertical flanking path between adjacent apartments.

Flanking from air leakage can also be reduced in wood-frame construction by using sealants to close openings and gaskets to provide a resilient cushion between assemblies (Figure 13). It is recommended that a continuous bead of acoustic sealant be placed around the perimeter of the stud party wall where it abuts the floor and wall framing, before the drywall is applied. In this way, the sealant is visible and can be properly inspected prior to completion of the wall. Leaks can also occur where sound absorbing material has been omitted, such as behind electrical boxes and ducts.

Service penetrations

Careful planning, design and construction is required to ensure that STC and IIC ratings are not compromised by noise moving through and around penetrations in walls and floors. Special attention to detail is critical for providing an effective barrier. This includes the proper location and installation of doors, electrical outlets, heating ducts and mechanical equipment.



Source—Warnock, A.C.C., J.D. Quirt and M. Lio. *Fire and Sound Control in Wood-Frame Multi-Family Buildings*

Figure 13—Sealants and cuts eliminate vertical flanking paths

A number of techniques may be used to reduce the likelihood of electrical, mechanical and plumbing services becoming undesirable sources of noise. The following are the most common items that require attention. Figure 14 shows how some of these techniques are used to isolate noise transmission through service penetrations:

Heating, cooling and ventilating ducts

- Avoid oversized and undersized HVAC equipment that can cause unnecessary noise.
- Use duct wrap material to reduce sidewall transmission and fan noise in the duct. (A heavy duct wrap will significantly reduce breakout noise in ducts. Drywall ceilings under ducts are more effective barriers than acoustic tiles.)
- Use good quality, quiet equipment.
- Use vibration isolators when attaching fans, motors and ducts to framing.
- Seal all joints in ducts.

Plumbing

- Install pipe runs with hangers or resilient sleeves so expansion and contraction can occur without binding.
- Isolate piping from surrounding structures with resilient pads.
- Provide air chambers at each outlet to eliminate water hammer due to the abrupt stopping of the moving water.
- Use oversized pipes and reduced water pressures where possible.
- Size all penetrations to permit gaskets or caulking to be placed around pipes.
- Use cast iron waste piping to provide better sound attenuation than PVC or ABS.
- Locate common plumbing in insulated pipe chases where possible.

Source—Photo by Sandra Marshall

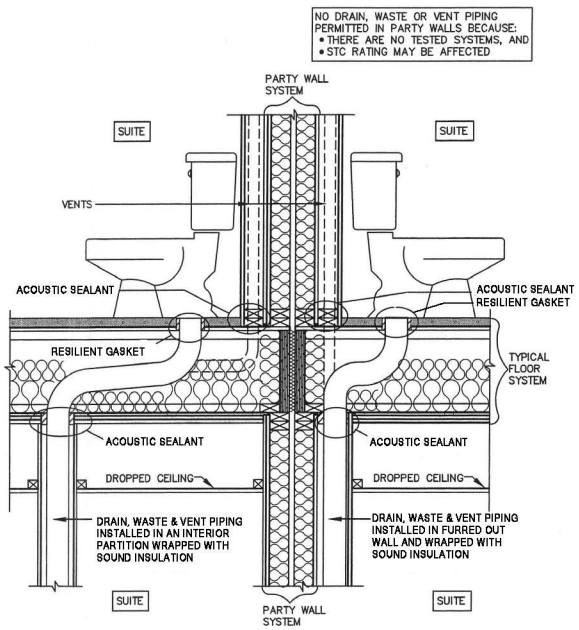
Figure 14—Water pipes isolated with resilient sleeves

Electrical services

- Offset light switches and outlets at least 400 mm (16 in.) horizontally on opposite sides of demising walls between suites.
- Place sound insulation behind electrical outlets.
- Install surface-mounted, not recessed, ceiling fixtures in floor assemblies separating suites. Seal the openings around associated electrical boxes.
- Do not place electrical panels, telephone, doorbell, intercom and built-in audio on walls separating suites or on corridor walls.
- Separate wiring to each suite to avoid sound transmission through wiring from one suite to another.
- Use flexible wiring connections to equipment that vibrates.

Exterior and corridor walls

The NBCC does not regulate walls or roofs subject to exterior noise sources. Regardless, for some building locations, designers need to provide sound control for walls (for example, close to major highway traffic) or for walls and roofs (for example, close to airport flight paths[7]). Use OITC ratings, if available, to assess sound transmission for exterior wall and roof assemblies. Because the solid portions of exterior walls usually have high OITC ratings, the windows and doors are likely to provide the least sound attenuation. These, and other penetrations through the exterior wall, require particular attention, in order to assure effective sound control for noise from external sources. (see Table 1).



Source—Adapted from Building Reculations Division of the City of Calgary. *Fire Stopping Service Penetrations in Buildings: Explanatory material to the Alberta Building Code 1997*, Calgary, 2003

Figure 15—Toilet penetrations through wood-frame assembly

Provincial or municipal authorities may require noise studies for proposed residential developments near busy roads, railways and airports. These studies may result in minimum requirements for the sound transmission ratings of facade materials, windows and doors to meet indoor noise standards. They may also result in restrictions on window areas facing noisy directions.

[7] Birta, J., J. S. Bradley and T. Estabrooks. *IBANA-Calc User's Manual*, National Research Council Canada, November 2001. (*IBANA-Calc* software estimates of indoor sound levels for given levels of aircraft noise.)

Windows

Windows generally provide less sound insulation than the surrounding walls. Carefully placing and sizing windows may reduce outdoor noise. Double- and triple-glazing, perimeter sealing and weatherstripping also improve sound transmission loss.

The most common types of standard operable windows now being installed in residential construction are casements, horizontal sliders, vertical sliders and awnings. In an open position, casements and awnings can deflect external noise into the living space. They should be planned to open away from the dominant noise direction so there is some noise reduction from deflection.

Until relatively recently, acoustical data about windows typically assumed that the composition of the glazing was the primary influence on sound transmission properties. The data did not consider that the type of operable window could also influence sound transmission.

Recent research shows that window STC ratings are affected by:

- Type (casement, sliding or awning, physical characteristics, and cost) of window
- Window size
- Composition of the glazing unit (type of glazing; width of airspace between panes; thickness of the glass; type of spacer)
- Leakage through and around the window unit

Table 7 shows examples of STC ratings for some fixed and operating windows with different glazing configurations. Typical STC ratings for windows vary from 25 to 40 depending on type, glazing, frame and airspace.

Window type	Type of frame–sash	Thermal glazing composition	Notes	Weight/ thickness	STC
Non-operable (fixed) windows					
Thermopane installed directly in test opening and sealed at perimeter	No frame; no sash (not operable)	Glass 3 mm; airspace 19 mm; glass 3 mm	Standard thermopane used in aluminium casement windows	62 lbs/24.5 mm	27
		Glass 5 mm; airspace 38 mm; glass 5 mm	Glazing composition designed for a sealed window or for the most economical sliding window	104 lbs/48 mm	32
		Glass 6 mm; airspace 9 mm; glass 8 mm	Maximizes acoustical performance of aluminium, wood, PVC windows	146 lbs/23 mm	34
Operable windows					
Casement window, 2 sashes (1 fixed 1 operable)	PVC sash; wood frame covered with PVC	Glass 3 mm; airspace 16 mm; glass 3 mm	Standard PVC casement window	98 lbs/22 mm	28
Sliding window, 4 sashes sliding horizontally	Sash and frame made out of vinyl-covered pine	Glass 5 mm; airspace 34 mm; glass 5 mm	Most economical four-sash sliding windows	120 lbs/44 mm	32
Sliding window, 4 sashes sliding horizontally	Aluminum sash and frame	Glass 3 mm; airspace 108 mm; glass 3 mm	Standard aluminium sliding window	95 lbs/114 mm	41

Source—Adapted from: Morin, M. *Noise Isolation Provided by Windows in Residential Projects,* CMHC, Ottawa, 1997

Table 7—Examples of noise isolation provided by residential windows

A window rating of STC 30 is usually acceptable for dwellings on residential streets with low to moderate- traffic volumes. Ratings of STC 40 are recommended for high-noise locations, such as arterial roads, factories and airports. Specialty acoustic windows can be manufactured to produce transmission-loss ratings ranging from the mid-40s to the low-50s. The high performance results from a larger airspace separation between the panes (about 38 mm or 1-½ in.) and an acoustically absorbent perimeter material between the panes of glass to absorb the sound waves.

In addition, acoustical isolation is needed to separate the glazing units from each other and from the surrounding wall or frame. Low air infiltration through the operational crack space on any window is also critical, because air leaks transmit sound. Acoustic windows usually have low air infiltration.

Exposure to exterior noise can be affected by site design and building orientation. For example, berms or noise barriers can reduce sound reaching a building. Trees and shrubs may serve as visual screens, but are not effective as acoustical barriers.

Suite doors

Suite doors in multiple-unit buildings provide moderate fire resistance and sound control, although gaps around their frames or at their thresholds allow a significant amount of noise to enter a dwelling. Compressible weather stripping at the top and sides of the door frame will improve the STC of the door. Threshold closures or air seals also reduce sound transmission, but they may reduce the supply of air into the apartment.

Corridors are often pressurized with fresh air in multi-family buildings to keep smoke and odours inside the suites, and to compensate for the air exhausted by bathroom and kitchen fans and clothes dryers. However, the space that is usually provided below the door to permit airflow from the corridor to the dwelling greatly diminishes the door's soundproofing ability. If corridor pressurization is a requirement, the adverse affects on sound control can be reduced by placing the gap above the door and covering it with a piece of lined duct or a silencer that provides a transmission loss consistent with the noise isolation provided by the door.

STC ratings for standard doors range from 27 to 32. With improvements to gaskets, the ratings may be increased by up to 5 dB. Table 8 compares the sound insulation of some conventional suite doors. Note that the STC ratings for doors are considerably lower than for conventional walls.

Specialty acoustical doors are available with STC levels of more than 50 dB. They are much heavier than conventional doors, and have frames and hinges built to support the additional weight. Particular attention is paid to the design of the perimeter seals to obtain optimum sound reduction.

An entry consisting of an external door, vestibule and internal door can achieve sound insulation levels of 50 STC or more with standard building components and doors.

Door type	Surface weight		STC (with gaskets)
	Kg/m²	psf	
Filled metal door	29.5	6.5	27
Solid-core wood 45-57 mm (1-¾ in.–2-¼ in.)	23-28.6	5.2-6.3	28
Sound-rated door	36.3	8	32

Source—Birta, J., J. S. Bradley and T. Estabrooks. *IBANA-Calc User's Manual*

Table 8—Examples of sound insulation provided by conventional doors

CASE STUDY: ACOUSTIC RETROFIT IN A HERITAGE APARTMENT BUILDING

Introduction

This case study describes the strategies and outcomes of one renovation project and is not meant as a guide for other retrofit projects.

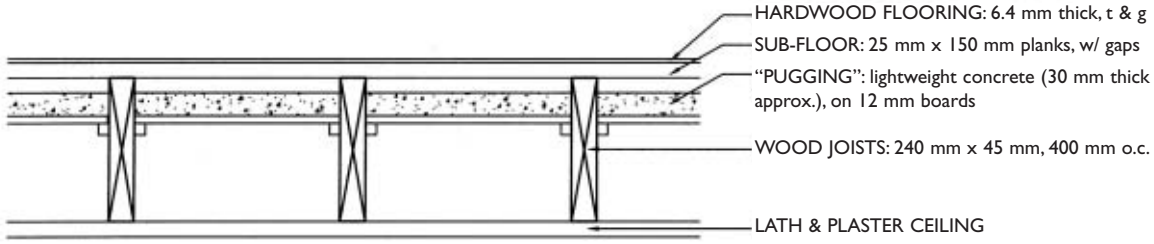
Several units in a five-story, 1927 apartment building in Ottawa were recently renovated. The original walls and ceilings were finished with lath and plaster. Some walls were balloon-framed, with vertical framing continuous for two or more floors.

The owner tested the noise reduction of the floor between two apartments of identical floor plans, one above the other, and wanted to improve the sound isolation between the apartments. The NBCC3[8] has test data on STC and IIC ratings for new materials and construction. However, there is little data available on the sound transmission characteristics of lath and plaster construction.

Hugh Williamson Associates provided acoustical advice on the selection of retrofit methods, and evaluated and documented the case study. CMHC supported the project.

The project's aim was to test and document the acoustical effectiveness of several retrofit techniques for the floor-ceilings in the apartment and evaluate the effectiveness on technical merit, cost, airborne sound and impact isolation.

Selection of retrofit details



Source—Williamson, H. *Case Study: Retrofit Acoustic Treatments in a Heritage Apartment Building, Canada Mortgage and Housing Corporation, 2004*

Figure 16—Original floor-ceiling construction

Figure 16 shows the floor–ceiling construction before renovation. It consisted of

- 6 mm (¼ in.) hardwood tongue-and-groove flooring
- 25 mm x 150 mm (1 in. x 6 in.) plank subfloor, with 3 mm (⅛ in.) gaps between the planks
- 240 mm x 45 mm (9.5 in. x .75 in.) wood joists on 400 mm (16 in.) centres
- "pugging": 12 mm (½ in.) boards covered with approximately 30 mm (1.25 in.) of lightweight concrete set 75 mm (3 in.) below the top of the joists (see Figure 16). Note that the pugging was not a solid continuous layer. Holes and gaps were common
- lath and plaster ceiling

Because it would be too costly to replace the floor, it was decided to replace the existing lath and plaster ceiling with two layers of 12.7 mm (½ in.) gypsum board suspended from the joists on resilient channels, and to provide acoustic insulation in the cavity space above the gypsum board.

The pugging was left in place because there was no obvious benefit in removing it. The extra mass of the pugging, approximately 20 kg/m^2, could be of some acoustic benefit. Having four rooms available for testing, including the living–dining room and three bedrooms, meant that four variants of the above approach could be evaluated (see Table 9).

[8] National Commission on Building and Fire Codes, *National Building Code of Canada, 1995*

Original construction	Retrofitted construction			
All rooms	**Living–dining room**	**Bedroom 1**	**Bedroom 2**	**Bedroom 3**
6 mm hardwood flooring	as original	as original	as original	as original
25 mm planking subfloor, with gaps	as original	as original	as original	as original
240 mm by 45 mm wood joists	as original	as original	as original	as original
"pugging": lightweight concrete on boards	as original	as original	as original	as original
no insulation	100 mm mineral wool bats	blow-in cellulose, about 100 mm thick	blow-in cellulose, about 100 mm thick	blow-in cellulose, about 100 mm thick
lath and plaster ceiling	lath and plaster ceiling removed (approx. free area: 100%)	hammer holes in lath and plaster ceiling, approx. 100 mm dia., on 400 mm grid (approx. free area: 15%)	hammer holes in lath and plaster ceiling, approx. 100 mm dia., on 800 mm grid (approx. free area: 8%)	drilled holes in lath and plaster ceiling, 25 mm dia., on 400 mm grid (approx. free area: 0.3%)
	no sheeting	polyethylene sheet to hold blow-in insulation	polyethylene sheet to hold blow-in insulation	polyethylene sheet to hold blow-in insulation
	resilient channels on 400 mm centres	resilient channels on 400 mm centres	resilient channels on 400 mm centres	resilient channels on 400 mm centres
	two layers of gypsum board 12.7 mm, Type X, fire rated	two layers of gypsum board 12.7 mm, Type X, fire rated	two layers of gypsum board 12.7 mm, Type X, fire rated	two layers of gypsum board 12.7 mm, Type X, fire rated

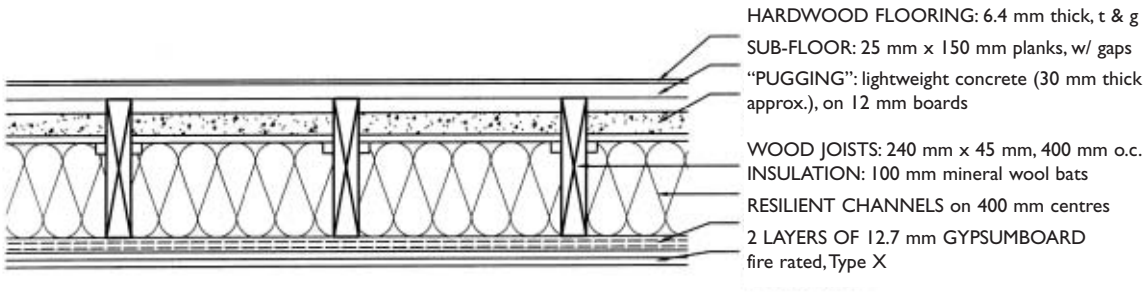
Source—Williamson, H. *Case Study: Retrofit Acoustic Treatments in a Heritage Apartment Building*

Table 9—Ceiling construction, before and after retrofit

Testing has shown that leaving an existing ceiling in place and adding one or two layers of gypsum board on resilient channels results in poor acoustical performance. The small air space between the old ceiling and the new gypsum board causes sound *resonance*, defined as:

… the reinforcement or prolongation of sound by reflection or synchronous vibration.'

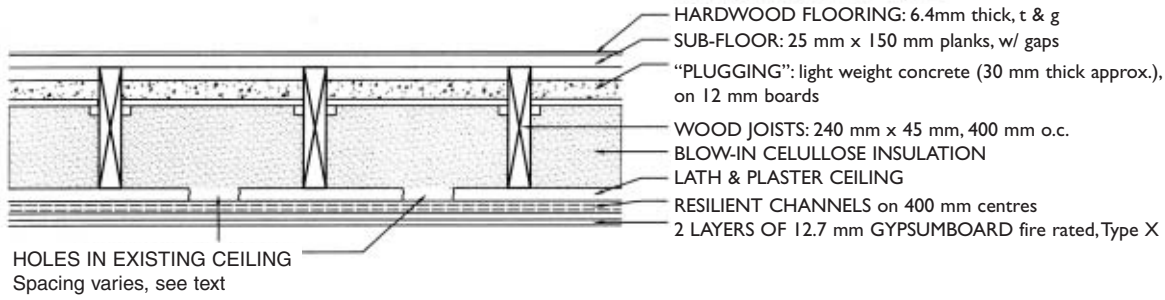
This leads to poor sound isolation and can increase sound transmission, especially at low frequencies. It was decided to completely remove the lath and plaster ceiling and to install batt insulation, resilient channels and two layers of gypsum board in the living–dining room ceiling (see Fig. 17.)



Source—Williamson, H. *Case Study: Retrofit Acoustic Treatments in a Heritage Apartment Building, Canada Mortgage and Housing Corporation, 2004*

Figure 17—Retrofit floor–ceiling construction in living–dining room

A different strategy was used for each bedroom. Varying patterns of holes were made in the lath and plaster ceilings of bedrooms 1, 2 and 3 (*see* Table 9). Figure 18 shows the retrofit construction in the bedrooms. In bedroom 1, 100 mm (4 in.) diameter holes were made in the lath and plaster ceiling at approximately 400 mm (16 in.) centres in a grid pattern. A hammer was used to punch the holes into the ceiling. However, because of the crude technique, the holes were irregular and extended further in the direction parallel to the lath.



Source—Williamson, H. *Case Study: Retrofit Acoustic Treatments in a Heritage Apartment Building*

Figure 18—Retrofit floor–ceiling construction in bedrooms

In bedroom 2, nominal 100 mm (4 in.) diameter hammer holes were spaced on an 800 mm (32 in.) grid pattern.

In bedroom 3, 25 mm (1 in.) diameter drill holes were spaced on a 100-mm (16-in.) grid.

In all three bedrooms, the ceiling cavity was filled with blown-in cellulose insulation. Test data suggests that the type of cavity insulation, such as fibreglass and mineral wool batts or blown-in cellulose, is of little importance in the acoustic performance of a wall or ceiling. A sheet of polyethylene was stapled to the ceilings of bedrooms 1 and 2 before blowing in the insulation. This prevented the insulation from falling through the large holes during the installation of the resilient channels and gypsum board layers.

Care was taken to ensure that there were no direct air paths between the apartments. After an air-seal test, all leaks were sealed with caulking.

Test methodology and results

Testing standards

Sound insulation tests and impact insulation tests were conducted between upper and lower rooms using the American Society of Testing Materials (ASTM) standard for determining Field Sound Transmission Class (FSTC) and Field Impact Insulation Class, (FIIC).

Field-measured FSTC and FIIC results will often be less than the laboratory-determined STC and IIC ratings for a wall or floor–ceiling of the same construction because a field test includes sound transferred between the rooms by flanking paths in addition to the direct airborne sound transmission through the wall or floor–ceiling being tested.

Testing procedure

When possible, before and after sound transmission and impact tests were conducted in each of the four sets of rooms (*see* Table 10).

It was not possible to conduct before-retrofit tests on the living–dining room because the lath and plaster ceiling was removed before the case study started. The before results are from tests of living–dining rooms of other nominally identical apartments in the same building. Because construction work had already commenced in bedroom 3 before the case study started, the before tests for this bedroom could not be done.

Room	State	FSTC–improvement	FIIC–improvement
Bedroom 1	Before—lath and plaster ceiling	42	41
	After—large holes on 400 mm centres in old lath and plaster ceiling, blow-in insulation, resilient channels, 2 layers of 12.7 mm gypsum board	52/+10	48/+7
Bedroom 2	Before—lath and plaster ceiling	42	43
	After—large holes on 800 mm centres in old lath and plaster ceiling, blow-in insulation, resilient channels, 2 layers of 12.7 mm gypsum board	50/+8	47/+4
Bedroom 3	Before—not available for testing	—	—
	After—drilled 25 mm holes on 400 mm centres in old lath and plaster ceiling, blow-in insulation, resilient channels, 2 layers of 12.7 mm gypsum board	46/estimate +4	46/estimate +3–5
Living–dining room	Before—lath and plaster ceiling*	39	39
	After—old lath and plaster ceiling removed, 100 mm mineral wool insulation bats, resilient channels, 2 layers of 12.7 mm gypsum board	46/+7	45/+6

*Measured in another set of apartments of identical floor plan in the same building.
Source—Williamson, H. *Case Study: Retrofit Acoustic Treatments in a Heritage Apartment Building*

Table 10—STC and IIC test results

Discussion

The improvements in FSTC from the retrofit measures vary from 4 to 10 points and in FIIC from 3 to 7 points (*see* Table 9). An improvement of only 3 points in these measures is considered just noticeable, but improvements of 6 or more are considered significant and useful.

The smallest improvements were in bedroom 3, where only small holes were drilled in the old lath and plaster ceiling. The percentage of open area for the drilled holes in bedroom 3 is much lower than that produced by the larger hammer holes in bedrooms 1 and 2 (*see* Table 9). This suggests that the number and size of holes placed in the old ceiling may not have been adequate to remove the acoustic coupling. However, the differences in acoustic isolation of the bedroom ceilings might also be influenced by hidden leaks and flanking paths.

In the rooms where the old lath and plaster ceiling was removed or breached with large holes of about 100 mm (4 in.) diameter, the FSTC improvements are very significant (7 to 10 points), while improvements in FIIC are moderately significant (4 to 7 points). Impact sounds are less affected by the retrofits than airborne sounds because impact transmission is more strongly affected by the structure of the floor, which was not changed.

In absolute terms, best results were in bedrooms 1 and 2 while poorest results were in the living–dining room and in bedroom 3.

The following construction, comparable to the retrofitted floor–ceiling construction in the apartment, achieves STC 56 and IIC 50 in laboratory tests[9].

- Floor: 15-mm thick OSB
- Wood joists: 235 mm depth, on 406-mm centres
- 153-mm glass fibre cavity insulation
- Resilient channels on 510-mm centres
- Two layers of gypsum board 12.7 mm, Type X, fire rated

Given that the testing of the apartment floor–ceilings was done under field conditions, the results in bedrooms 1 and 2, FSTC 52 and 50, FIIC 48 and 47, are comparable and satisfactory. The lower values in the field test may be due to minor amounts of flanking (for example, transmission along walls) and differences in the construction of the floors. For example, the apartment floor (6 mm [¼ in.] hardwood plus 25 mm [1 in.] planks with gaps) is probably less of a noise barrier than the 15 mm of OSB in the laboratory tests.

On the other hand the FSTC 46 and FIIC 45 results of the retrofit in the living–dining room are considerably below the laboratory test results, and below the results in bedroom 1 and 2. As the construction details of the retrofit were carefully executed, the test results suggest that there may be a major flanking path in the living–dining room, such as balloon framing that extends into the upper and lower apartment, which prevents the achievement of higher acoustic insulation values.

[9] Morin, M. *Noise Isolation Provided by Windows in Residential Projects*, Canada Mortgage and Housing Corporation, 1997

Conclusions

Caution should be taken in applying the results of this case study to other buildings. The results show that:

- Both airborne and impact sound insulation were significantly improved by adding fibrous cavity insulation, and replacing the lath and plaster ceiling with two layers of 12.7 mm (½ in.) fire rated, Type X gypsum board suspended on resilient channels.
- It appears to be unnecessary to completely remove the lath and plaster ceiling. Good results were obtained when large holes equivalent to approximately 10 per cent of the ceiling area were made in the original ceiling prior to applying the resilient channels and gypsum board. Poor results were obtained when a series of small holes were drilled in the original ceiling.
- In two cases, sound and impact transmission values were obtained which are close to laboratory test values for similar modern construction. In another case, where it appears that sound was being carried between floors by flanking paths, lower isolation results were obtained.
- In an existing building, it is difficult to determine the significance of flanking before a planned renovation. The effectiveness of an acoustic renovation applied to a wall or ceiling may be significantly reduced by the presence of flanking paths. During a renovation, all reasonable steps should be taken to reduce flanking transmission.

SUGGESTIONS FOR FURTHER READING

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Sound Attenuation Calculator for Wood-frame Floors http://www.cmhc schl.gc.ca/en/imquaf/himu/soateswofl/index.cfm

Morin, M.J., MJM Acoustical Consultants Inc. *Research Project on Plumbing Noise in Multi-Dwelling Buildings*, Canada Mortgage and Housing Corporation, Ottawa, 1993.

Morin, M.J., MJM Acoustical Consultants Inc. *Noise Isolation Provided by Windows in Residential Projects*, Canada Mortgage and Housing Corporation, Ottawa, 1997.

Morin, M.J., MJM Acoustical Consultants Inc. *Research Project on Noise Isolation Provided by Floor/Ceiling Assemblies in Wood Construction*, Canada Mortgage and Housing Corporation, Ottawa, 1990.

QUESTIONS

1. List two ways that sound can move between suites in multi-unit residential construction, and provide three examples of each.
2. There are several material and material arrangement techniques that are barriers to sound transmission. List five of these.
3. What is the NBCC-required STC rating for walls between suites? What is the Best Practice STC rating?
4. Explain what impact noise is and name three techniques that might be used to reduce impact noise transmission.
5. In addition to noise control between suites, what other factors should the designer consider for good acoustic comfort?
6. Give three reasons why field sound transmission class (FSTC) may differ from the sound transmission class (STC) measured in a laboratory.
7. Explain whether the addition of a concrete topping over an OSB subfloor on wood 'I' joists be likely to improve the impact insulation class of the floor assembly.
8. If a builder attaches resilient channels and two layers of gypsum board to the underside of an existing plaster ceiling, will the STC of the assembly likely be improved? Explain.
9. Will filling the voids in a concrete block wall with cellulose insulation result in a significant improvement to the STC? Explain.
10. For optimum sound attenuation, when should a concrete block wall be sealed? When should it not be sealed?
11. Do the following calculation: What is the difference in sound attenuation (STC) of a floor with nominal 200 mm wood joists at 400 mm centres, 150 mm glass fibre batt insulation and 12.7 mm gypsum board, compared with the same wood joist floor with resilient channels at 600 mm centres supporting the gypsum board? What is the change in STC of the second floor assembly if the gypsum board is doubled? (Use the sound attenuation calculator tool on the CMHC website at http://www.cmhc-schl.gc.ca/en/imquaf/himu/soateswofl/index.cfm).