OPTIMIZING ACOUSTIC PERFORMANCE

This article is part of the Continuing Education Unit of Think Wood, a U.S. industry-driven initiative which provides research and resources on the benefits of using timber in residential and commercial building applications to design and construction professionals. The Think Wood portal including its research library can be accessed here: www.thinkwood.com.

This article has been written for the North American context and follows US and Canadian legislation. Readers should be aware that certain definitions like the NRC and OITC values do not have the same relevance and/or meaning in New Zealand.

In New Zealand, Clause G6 "Airborne and Impact Sound" of the New Zealand Building Code provides the minimum requirements in terms of acoustic performance. During the design phase, inter-tenancy walls/floors and walls/floors to common spaces are required to achieve a design Sound Transmission Class (STC) of 55 dB. Floors to other tenancies or common spaces are required to achieve a design Impact Insulation Class (IIC) of 55 dB. Field testing on-site once the building is constructed is to be within 5 points of the design rating (i.e. no less than STC 50 dB or IIC 50 dB). These values should be considered as a bare minimum and care should be taken when designing floor and wall junctions in multi-storey buildings in order to reduce noise transmission by flanking. It is recommended to seek specialist advice from an acoustic engineer when designing multi-storey timber buildings due to its lightweight nature.

Figure 1: *WREN is a wood-frame, 6-building, 7 story development in LA's South Park community and is the city's first Type III double-podium design. Architect: Togawa Smith Martin | Photo: Kevin C. Korczyk*

1 THE IMPORTANCE OF OPTIMIZING ACOUSTICS

Acoustic comfort is realized when a person's activity is not disturbed by noise and their hearing does not suffer. The opposite occurs when exposure to noise causes psychological disorder, hinders performing normal activities and reduces the ability to concentrate. According to the Centers for Disease Control, "Continual exposure to noise can cause stress, anxiety, depression, high blood pressure, heart disease and many other health problems. Hearing loss is the third most common chronic health condition in the US; almost twice as many people report hearing loss as report diabetes or cancer."

There are many sources of noise throughout a building and around a site, from the continual background noise of an HVAC system to walking and talking among building occupants. Outside noises such as emergency vehicles and traffic can also have a significant impact on acoustics, and, of course, higher density equates to more noise. Such noise can travel around and through ceiling, deck and floor joists, as well as windows and doors. Sound can also travel through fixtures and fittings, such as electrical outlets and recessed light fixtures, as well as perimeter joints and wall partitions.

Figure 2: *Since we relax and sleep at home, it is important for sound mental health that noise is mitigated in our personal space. Residential noise issues can arise from floor/ceiling footfall, party (demising) walls, plumbing, HVAC and elevators and/or trash chutes. Orchards at Orenco | Architect: Ankrom Moisan Architects, Inc. | Photo: CBPhotography & Designs*

Noise has a great impact on the built environment and the occupants that live and work in it. Noise control can be particularly relevant in healthcare settings where patient recovery, mental health and patient privacy are so important, especially in regards to the Health Insurance Portability and Accountability Act (HIPAA), which provides data privacy and security provisions to safeguard medical information. Therefore, privacy is imperative in exam rooms, counsel rooms, doctor's offices and the lobby/waiting area. In schools, optimal acoustics are equally important, as the learning environment for students must be free from distractions. Productivity is essential in office environments too. In addition, since we relax and sleep at home, it is important to sound mental health that noise is mitigated in our personal space as well. Residential noise issues can arise from floor/ceiling footfall, party (demising) walls, plumbing, HVAC and elevators and/or trash chutes.

For centuries, wood has been a material of choice for architects and designers intent on delivering the highest quality acoustic performance. From a violin to a concert hall, wood plays a role in delivering memorable acoustic experiences. Wood produces sound by direct striking, and it amplifies or absorbs sound waves that originate from other bodies. For these reasons, wood is an ideal material for musical instruments and other acoustic applications, including architectural ones.

In large buildings with hundreds or even thousands of occupants, such as apartment buildings, condominiums, hotels or dormitories, every acoustic detail has a positive or negative effect on the quality of daily life. Post-occupancy evaluations of buildings have revealed that poor acoustic performance is a common problem in buildings with large areas of hard, acoustically reflective surfaces. Ironically, such surfaces are frequently found in buildings designed to be sustainable, where the use of absorbent materials is minimized due to indoor air-quality concerns.

Fortunately, wood is not as "acoustically lively" (translation: noisy) as other surfaces, so wood-frame construction is efficient in buildings where sound insulation is required. In particular, wood doesn't present the impact noise transmission issues commonly associated with other types of construction. A study by Canada's National Research Council's Institute for Research in Construction shows when it comes to acoustical performance, a properly designed and constructed wood floor/ceiling assembly performs on the same level as other construction types.

Architect Marcy Wong, whose firm Marcy Wong Donn Logan Architects frequently uses wood for its acoustic properties, articulates the connection between acoustics and sustainability in this way: "In addition to the usual sustainable advantages of wood—renewability, nontoxic, carbon storing—there is an additional aspect, that being acoustics. Sustainability is more than being responsible about the impact of a project on the earth's resources and climate, but also on the quality of environment for users."

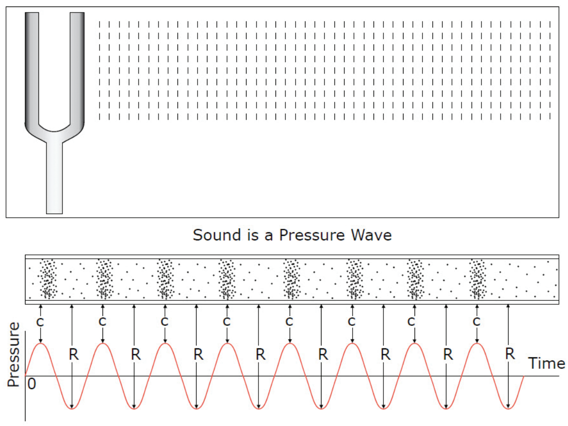


Figure 3: *Simplified illustration of sound (pressure wave) propagation through air/solid structure (Kappagantu, 2010). In this figure, C signifies regions of compression and R signifies regions of rarefaction of the air molecules. Furthermore, the "0" pressure line in the graph represents the atmospheric pressure level. Source: US CLT Handbook*

CASE STUDY: PEOPLES HEALTH NEW ORLEANS JAZZ MARKET

Peoples Health New Orleans Jazz Market | Architect: Kronberg Wall Architects | Photo: Peter Vanderwarker

For Atlanta-based Kronberg Wall Architects, one of the greatest challenges in designing this 14,000-square-foot contemporary jazz performance space was acoustics. Located in an historic building in the birthplace of jazz—and home to the New Orleans Jazz Orchestra—the acoustics needed to add vibrancy and energy to the music being performed. According to firm principal Eric Kronberg, part of the design brief was also that the aesthetics of the space should "feel as warm as Louis Armstrong's horn sounds."

Working with acoustics consultants Kirkegaard Associates, Kronberg Wall used wood for a majority of the reflective surfaces both to create the desired sound and warm aesthetic.

The team designed a carefully shaped pair of acoustic 'clouds' over the stage combined with curved, wood-clad cheek walls that extend out into the hall. These surfaces are designed to reflect sound back to the musicians for on-stage communication and out to the audience for a more exciting experience.

The hall includes salvaged wood planks that are oiled instead of polyurethaned to maintain a slightly porous surface. "The oil finish allowed the highest pitch sounds to be slightly absorbed by the wood," said Kronberg. "This helped to avoid excessive brightness and made the overall sound warmer." All of the wood was installed tongue and groove with hidden fasteners so it performs acoustically as a solid surface.

2 FACTORS AFFECTING ACOUSTICS

2.1 Environmental vs. Architectural Noise

There are two types of noise: environmental and architectural. Sources of environmental noise include automobiles, locomotives, rail cars, jet aircraft, industrial sources, telecommunications equipment, entertainment and construction vibration. The impacts of environmental noise include sleep disturbance, speech interference, occupant annoyance, reduced worker productivity and prolonged patient recovery in healthcare settings. Environmental noise can be controlled through measures such as noise barriers, sound-rated walls and sound-rated windows. Building codes dictate different land use categories that each have varying levels of acceptable exterior noise exposure, measured in decibels (the levels are Normally Acceptable, Conditionally Acceptable and Unacceptable).

Land use categories are categorized as

- Residential, Hotels and Motels
- Outdoor Sport and Recreation
- Schools, Libraries and Museums
- Auditoriums, Concert Halls and Amphitheaters
- Industrial, Manufacturing, Utilities and Agriculture

Land uses where people live and work have more stringent codes and standards for acceptable noise exposure than uses such as stadiums and manufacturing plants.

Architectural noise includes environmental noise but also mechanical/equipment noise, structural vibration and room acoustics, which can affect occupants in all building types including healthcare, schools, institutional/commercial, residential, performing arts, civic and industrial. The practice of architectural acoustics attempts to achieve good speech intelligibility, improve privacy, enhance the quality of performances in studios or venues and suppress noise to make schools, offices and residences more productive and pleasant places to work and live. This can be achieved by carefully specifying and detailing each building element and system to ensure the materials used work well together acoustically. Because of the complicated nature of this practice, architectural acoustic design is often performed by acoustic consultants in tandem with the rest of the design team.

Source of Sound	RMS Pressure (Pa)
Music club (loud)	≈10
Heavy traffic at 32.81 ft. (10 m)	≈1
Busy office	$\approx 10^{-1}$
Normal speech at 3.28 ft. (1 m)	≈10-2

Sound generated by various sources and their pressure (Pope, 2003). Source: US CLT Handbook

2.2 Airborne versus Impact Sound

Transfer of sound between adjacent spaces takes two forms. The first is the transfer of airborne sound such as speech or music. In airborne noise, the medium carrying the sound energy is air. The ability for a building element such as a wall or floor/ceiling to prevent the transfer of airborne sound is measured by STC ratings. The second form is the transfer of impact sound such as footfall. Impact sound is often more disruptive than airborne sound. For example, if a residential building is constructed of concrete, an eight-inch slab will effectively block the sound of voices from the suite above, but the sharp reports of someone walking in hard-soled shoes will be clearly audible. In contrast, it has been observed that very stiff wood-joisted floor/ceiling assemblies present greater low-frequency impact sound insulation. The ability of a floor/ceiling assembly to prevent the transfer of impact sound is measured by IIC ratings. Designers should determine the most appropriate rating to satisfy codes, regulations and owner requirements.

3 ACOUSTICAL CODES AND WOOD BUILDINGS

The International Building Code (IBC) provides the minimum requirements for sound insulation of demising walls and floor/ceiling assemblies between adjacent dwelling units or between dwelling units and public areas such as halls, corridors, stairs or service areas. In residential buildings, the IBC provides a minimum design requirement for unit-to-unit acoustical protection between floors. It requires an STC rating or IIC rating of 50, unless the "authority having jurisdiction" has its own more stringent requirement. The International Residential Code (IRC) has an appendix that provides for a minimum design separation of STC 45 for townhouses, where specifically adopted by the authority having jurisdiction. This minimum requirement is the same for entry level housing, market rate housing and luxury housing, whether it is dorms, apartments or condominiums. Beyond that, it is the responsibility of the design team to develop an acoustical design that meets owner/developer/tenant expectations for the project.

In a mixed-use project, consideration must be given to the acoustics between all of the adjacent spaces—not just dwelling unit to dwelling unit. Acoustical separation between residential and other occupancies can be a significant challenge, and this condition is not addressed in the IRC or IBC, though it is starting to be addressed in green building codes such as the California Green Building Standards Code (CALGreen).

For wood-frame mixed-use buildings, Section 1206 of the 2018 IBC includes the following:

> 1206.1 Scope. This section shall apply to common interior walls, partitions and floor/ceiling assemblies between adjacent dwelling units and sleeping units or between dwelling units and sleeping units and adjacent public areas such as halls, corridors, stairs or service areas.
>
> 1206.2 Airborne sound. Walls, partitions and floor/ceiling assemblies separating dwelling units and sleeping units from each other or from public or service areas shall have a sound transmission class of not less than 50 (45 if field tested) for airborne noise when tested in accordance with ASTM E90. Penetrations or openings in construction assemblies for piping; electrical devices; recessed cabinets; bathtubs; soffits or heating, ventilating or exhaust ducts shall be sealed, lined, insulated or otherwise treated to maintain the required ratings. This requirement shall not apply to dwelling unit entrance doors; however, such doors shall be tight fitting to the frame and sill.
>
> 1206.3 Structure-borne sound. Floor/ceiling assemblies between dwelling units and sleeping units or between a dwelling unit or sleeping unit and a public or service area within the structure shall have an impact insulation class rating of not less than 50 (45 if field tested) when tested in accordance with ASTM E492. Alternatively, the impact insulation class of floor-ceiling assemblies shall be established by engineering analysis based on a comparison of floor-ceiling assemblies having impact insulation class ratings as determined by the test procedures in ASTM E492.

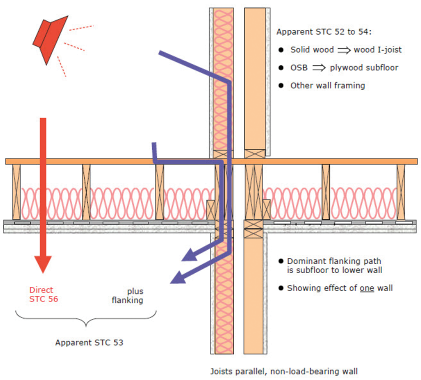


Figure 4: *Floor surface as flanking path (IRC, 2002). The red arrow indicates the direct path and the blue arrows indicate the flanking path. Source: US CLT Handbook*

4 ACOUSTICS AND GREEN BUILDING STANDARDS

Green-building certifications such as LEED are beginning to incorporate acoustics more prominently. LEED v4 Building Design and Construction (BD+C) and Interior Design and Construction (ID+C) both address acoustics under the Indoor Environmental Quality (EQ) Category: Acoustic Performance credit. This credit seeks to provide workspaces and classrooms that promote occupants' well-being, productivity and communications through effective acoustic design. One to two points are available under BD+C depending on whether it is applied to new construction, schools, data centers, warehouse and distribution centers, hospitality or healthcare (1–2 points). Two points are available under ID+C Commercial Interiors or ID+C Hospitality. Some of the considerations, depending on the certification a project is seeking, are HVAC noise; sound transmission; speech privacy and sound isolation; background noise; acoustical finishes and site exterior noise; reverberation time requirements; sound reinforcement and masking systems. Wood can contribute to optimal acoustic performance and can help projects earn points under the Indoor Environmental Quality category.

California Green Building Standards has prescriptive mandatory acoustical control for some building elements. These include maintaining site noise levels at or above community noise equivalent level (CNEL) 65 dB within the noise contour of an airport as well as wall and roof-ceiling assemblies with a composite STC rating of at least 50 and exterior windows with a minimum STC of 40. There are also performance factors stating that wall and floor-ceiling assemblies separating tenant spaces and tenant spaces and public places shall have an STC of at least 40 and the wall and roof-ceiling assemblies should be constructed to provide an interior noise environment attributable to exterior sources that does not exceed an hourly equivalent noise level (Leq -1Hr) of 50 dBA (A-weighted decibels) in occupied areas during any hour of operation. There are also voluntary measures offered, such as that schools have a maximum background level of 45 dB (from HVAC noise).

5 SOUND ISOLATION FUNDAMENTALS

Acoustic design considers a number of factors, including building location and orientation, as well as the insulation or separation of noise-producing functions and building elements. According to the IRC, the most important factors affecting airborne and impact sound insulation of wall and floor/ceiling assemblies, are

- Total weight per unit area—heavier equates to better sound insulation, especially for low-frequency sound
- Stiffness—stiffer equates to better sound insulation. It has been observed that very stiff wood-joisted floor/ceiling assemblies present greater low-frequency impact sound insulation
- Porosity—the less porous, the better the sound insulation
- Multi-layers with air space—the larger the airspace, the better the sound insulation
- Contacts between layers—the softer the contacts (such as neoprene isolators), the better the sound insulation

Flanking Path	Treatment
Leaks around the edge of partitions (ASTM E336)	Seal the leaks with tape, gaskets or caulking compound (ASTM E336)
Cracks at wall/floor junctions	Caulk joint between gypsum board and floor, Figure 6 (IRC, 2002)
Debris between floor and wall sill plates	Clean floor and caulk sill plate (IRC, 2002)
Leaks through electrical outlets	Avoid back-to-back outlets by offsetting them 16 in. (400 mm) or at least one stud space from side to side, Figure 7 (IRC, 2002)
If gypsum board is rigidly attached to studs or the wall framing, the wall could contribute to flanking (IRC, 2002)	Attach gypsum board on resilient channels (IRC, 2002)
Joint between the flooring, topping and the surrounding walls, especially if the flooring topping is floating or not rigidly attached to the subfloor	Leave a gap around the entire flooring topping assembly and walls. Fill it with resilient perimeter isolation board or backer rod and seal the joint with acoustical caulk
Continuous subflooring, joists and CLT elements between two adjacent units	Discontinue subflooring, joists and CLT as much as possible. Add floating topping and floating flooring if the continuity is not avoidable

Flanking path checklist. Source: CLT Handbook

CASE STUDY: STUDENT HOUSING GETS EXTRA COLLEGE CREDIT FROM WOOD UNIVERSITY OF WASHINGTON WEST CAMPUS STUDENT HOUSING

In 2012, the University of Washington (UW) completed a $109 million, five-building construction project, adding nearly 1,700 student housing beds. Known as West Campus Student Housing—Phase I, the 668,800-square-foot project was the first of four phases planned by UW to add much-needed student housing to its Seattle campus, which has an enrollment of more than 42,000 students. The West Campus structures were the first new residence halls to be built on UW's main campus since the early 1970s.

Mixed-use student housing that integrates layers of public and private amenities. West Campus Housing, Elm Hall and Elder Hall, University of Washington, Seattle | Architect: Mahlum Architects | Photos: Benjamin Benschneider

To meet burgeoning demand and shrinking budgets, a growing number of colleges and universities are choosing to use wood for their new student housing facilities. Wood-frame construction offers cost savings as well as other benefits, including design flexibility, structural integrity and environmental advantages.

UW's need was great, but the budget was limited. The IBC allows five stories of Type III wood-frame construction when the building is equipped with an automatic sprinkler system that complies with the National Fire Protection Association's code NFPA 13. Designers across the country are increasingly choosing this option as a lower-cost alternative to steel and concrete. However, Seattle's building code is unique in that it also allows five stories of wood with a Type V-A structure (when the building has an NFPA-compliant sprinkler system), which is even more cost effective and is being considered by a growing number of other jurisdictions as a way to encourage urban infill development. With this in mind, Mahlum Architects worked with engineers at Coughlin Porter Lundeen to make the most of the urban campus location, designing each of the buildings with five stories of light frame Type V-A wood construction over a two-story Type I-A concrete podium. This two-story podium helped them meet both ambitious design goals and the university's tight budget.

Acoustics are important for any multi-family housing project, but particularly so for student housing. Mitigation measures must be weighed against the budget, which is why the design team brought in experts from Seattle-based SSA Acoustics. While the science of sound is fairly complicated, many mitigation measures are relatively simple. For example, SSA recommended a strategic combination of staggered stud and double stud walls to minimize sound transmission between residential units themselves, between the units and common spaces and between the units and service areas. Because they knew single stud walls would not provide adequate performance, SSA recommended staggered stud walls between residential units. "Since there is no rigid connection between the gypsum board on each side except at the plate, a staggered stud wall performs better than a single stud wall," said Mohamed Ait Allaoua, with SSA Acoustics. "Double stud walls perform better than a staggered stud design because plates are separated by an air space, so we specified double stud walls between residential units and common spaces (lounges, staircases, elevators, etc.) and service areas."

Details count when it comes to acoustics, so all penetrations were sealed using resilient caulk. Whenever possible, they located junction boxes using minimum 24-inch spacing and avoided placing them back to back. When this was not possible, contractors placed putty pads on the backside of the junction boxes. "In the floor/ceiling assembly, we paid careful attention to the installation of resilient channels, which are often one of the main causes of failed floor/ceiling assemblies from an acoustical standpoint," said Ait Allaoua. "In fact, there is a difference of 8 to 10 IIC and STC points between assemblies with resilient channels versus those without." SSA specified straightforward requirements for channel installation; for example, the length of screws was specified for the first layer and for the second layer of gypsum board to never touch the framing behind the resilient channel.

Bathrooms and kitchens feature drop ceilings to accommodate ducting and plumbing, which provided additional noise reduction between units. Where the finish floor was stained concrete, they installed a resiliently suspended gypsum wallboard ceiling using neoprene clips to reduce footfall impact noise below.

Fire protection measures often benefit acoustical efforts. Where putty pads were required at electrical boxes for fire code (in one- or two-hour fire rated wall assemblies), there was no additional acoustical mitigation required. Penetrations through one- or two-hour rated demising walls, corridor walls, shaft walls, floor/ceiling assemblies and others were sealed with fire resilient caulk, which also met acoustical recommendations.

SSA also made structural recommendations to reduce floor vibration. They recommended that the live load deflection of the floor assembly between residential units should achieve a max L/480; the code only requires L/360. They also recommended that plywood sheathing be placed only on the outer side (not the inner side) of double stud walls, since air space between the layers of mass on each side of the studs is critical for achieving the specified acoustical performance.

Sustainability also appeals to an increasing number of students, and the University of Washington prides itself as being "one of the country's preeminent leaders in environmental practices," committing itself to offer students what they call an "urban eco-lifestyle." Cedar Apartments received certification at the LEED Silver level, while Poplar, Alder and Elm Halls earned a LEED Gold designation.

In addition, four of the five buildings in West Campus Student Housing—Phase I meet The 2030 Challenge (requiring 60 percent reduction over baseline fossil fuel energy consumption) with the purchase of green power. Design strategies included use of high-efficiency heating and ventilation systems, low building envelope air infiltration, elimination of building envelope thermal bridges, efficient light fixtures and lighting control systems and others. While on-site renewable energy production was not part of the project, they made provisions on the roof structures to allow future installation of solar hot water systems, which significantly increased roof loading.

The five buildings are testament to the fact that wood construction can not only save time and money but also create elegant, durable, urban structures that contribute positively to city and campus vitality. The West Campus Housing project represented a paradigm shift at the University of Washington, symbolizing its first embrace of large-scale light wood-frame construction.

- Sound absorption—sound absorbing material in the air space of the cavity between layers is beneficial
- Floor surface hardness—the harder the surface, the poorer the impact sound insulation, especially with high-frequency impact sound

5.1 Flanking Transmission

Flanking transmission is the sound along paths other than the direct path through the common wall or floor/ceiling assembly. Flanking always exists to some degree in buildings, allowing sound to bypass a wall or floor/ceiling assembly. Therefore, a high performance floor/ceiling assembly or wall does not guarantee good isolation unless proper attention has been given to eliminating or minimizing flanking paths. The basics of flanking control are to seal the openings, to decouple the surfaces and to discontinue the structural elements if it does not affect the structural safety and serviceability.

Typical flanking sound transmission paths can include

- Above and through the ceiling (plenum) spaces
- Through floor deck and floor joist space
- Through windows and doors
- Through fixtures and electrical outlets, light switches, telephone outlets and recessed lighting fixtures
- Shared structural building components such as floor boards, floor joists, continuous drywall partitions, continuous concrete floors and cement block walls
- Perimeter joints at wall and floor, through wall and ceiling junctions
- Through plumbing chases and joints between the wall and floor slab above or at the exterior wall juncture
- Around the edges of partitions through the adjacent wall

Number of Layers	Thickness in. (mm)	Area Mass lb./ft.^{2} (kg/m^2)
3	2.36 (60)	6.14 (30)
3	4.72 (120)	12.29 (60)
5	4.61 (117)	11.98 (58.5)
5	7.87 (200)	20.48 (100)
7	7.95 (202)	20.69 (101)
7	11.02 (280)	28.67 (140)
8	9.76 (248)	25.40 (124)
8	12.60 (320)	32.77 (160)

Area of mass of some CLT elements for wall and floor applications. Source: US CLT Handbook

5.2 Mass, Decoupling and Air Space

A designer has numerous options for mitigating noise, each with their own advantages. Mass, decoupling and air space are three fundamental building techniques for sound isolation. Sound travels through a wall by vibrating the walls. Increasing the mass of a building's walls aids in sound isolation. Simply put, a heavier wall will not move as easily as a lighter wall. Therefore, a wall with greater mass will conduct less sound than a wall with less mass. Mass can be increased through multiple layers of material, whether gypsum wallboard, plywood, lightweight concrete or CMU.

Sound can travel from one side of a wall to the other via the wall studs, because wall studs act as a bridge for sound to vibrate both sides of the wall. Decoupling the wall studs restricts sound's ability to pass from one side of a wall to the other side. Low-frequency decoupling can be achieved through resilient channels, acoustic clips, neoprene isolators, spring isolators and independent studs. The advantages of resilient channels (STC 50) are that they are inexpensive and provide good acoustical performance for single stud walls. But they are easily short-circuited acoustically and have a low load- carrying capacity. Acoustical clip (STC 55+) advantages are that they can be installed in retrofits and with fewer installation errors, they provide greater acoustical performance for a single stud wall, particularly at low frequencies, and they have a higher load carrying capacity. But acoustical clips are more expensive than resilient channels. High frequency damping can be achieved with acoustical mat/underlayment.

While wall studs can increase the amount of noise transmitted between walls, air space in the wall assembly can mitigate noise transmission. That being said, a wood-finished building with wood studs is not as noisy as a complete steel or concrete structure. A staggered stud (STC 55+) solution has a moderate cost and good acoustical performance, but fire rating can be problematic. Double stud (STC 55+) solutions provide high acoustic performance, even at low frequencies. They are fire rated and have a high load bearing capacity. However, double stud construction results in loss of space.

Ceiling penetrations, soffits, outlet boxes and other penetrations can be a source of acoustical breaches and should be considered as well.

6 METHODS TO CONTROL NOISE IN WOOD BUILDING SYSTEMS

Wood is generally hard, flat and smooth, making it inherently sound-reflecting, with properties similar to a concrete slab system, so it is important to control noise and achieve optimal acoustics with wood building systems. The most basic acoustical detailing is to always ensure the wall or floor/ceiling cavity is insulated with batt insulation and that it is sealed air tight, which can be achieved by floating a topping slab under the base of the gypsum board, by lapping the joints in the corner and taping or with fire caulking/ sealant. All holes, recessed light fixtures, plumbing penetrations and outlet boxes should be sealed, because wherever air can flow, sound can travel.

Airborne sound can travel through wood systems for two reasons. First, the material may not have enough mass to mitigate airborne sound on its own, but also because it is composed of linear elements fastened together mechanically. Gaps can develop between laminations in mass timber elements, and any gap through which air can pass is also a path for airborne sound. Accordingly, wood without continuous plywood or OSB sheathing will not provide effective attenuation of airborne sound. Airborne sound also travels along the grooves on the surface of lumber, which can provide potential paths for airborne sound. Therefore it is important to pay special attention to interface details and apply acoustic sealants where necessary.

*Please refer to Chapter 9 of the CLT Handbook and Section 2.5 of the NLT Design and Construction Guide for additional guidance about detailing mass timber for optimal acoustics.

6.1 Wood Wall Framing

Occupant experience is improved in wood buildings when party walls or exterior walls do not transmit sound between units. For walls in wood structures, sound isolation can be accomplished in two ways: Use partitions with a high mass (75 psf or greater) or use low mass systems (2 to 5 psf) separated by air spaces of 3 to 6 inches. A rating of approximately STC 63 can be achieved when a double stud wall is insulated with batt insulation and covered with two layers of gypsum wallboard on the outside faces of the studs. After double stud construction, the next best framing solutions are staggered stud and then single stud construction. Acoustically, a single stud wall creates a bridging point for sound to be conducted along every stud.

When the gypsum wallboard on one side of the wood stud is disconnected from the other side in a double or staggered stud wall system, the transmitted sound is reduced and the assembly has a higher STC rating. The advantage of the double stud wall over the staggered stud wall is twofold: The greater the separation between the gypsum wallboard on each face of the wall, the more the noise is reduced and the greater the STC rating becomes. The second advantage is that building utilities can be isolated from the stud system for the unit they serve. If the staggered stud wall has plumbing or electrical run through the cavity, there is a greater chance that the studs will be connected together by the utilities, acoustically bridging the two lines of studs.

Please reference WoodWorks' Acoustical Considerations for Mixed-Use Wood-Frame Buildings paper at *http://www.woodworks.org/wp-content/uploads/Acoustics_Solutions_Paper.pdf* for additional framing details.

6.2 Sheathing

In a light-frame wood building, the mass of the

Number of Layers	Thickness In. (mm)	Assembly Type	STC	IIC
3	3.74–4.53 (95–115)	Wall	32-34	N/A
5	5.31 (135)	Floor	39	23
5	5.75 (146)	Floor	39	24
Measures on field bare CLT wall and floor (Hu, 2013a)				
Number of Layers	**Thickness In. (mm)**	**Assembly Type**	**FSTC**	**FIIC**
3	4.13 (105)	Wall	28	N/A
7	8.19 (208)	Floor	N/A	25

Sound Insulation performance of bare CLT floors and walls. This table provides the measured STC and IIC values for some bare CLT walls and floors in various laboratories (reported by Gagnon and Kouyoumji, 2011) and the FSTC and FIIC values measured by FPInnovations on bare CLT floors and walls in CLT buildings (Hu, 2013a). Since flanking paths were possibly present for the field test results, the FSTC and FIIC presented provide an indication of the sound insulating performance of bare CLT floors and walls in buildings.

sheathing is just as important as the air space provided by the stud or joist cavity. In acoustical detailing, 5/8-inch-thick type X gypsum board is typically required, at a minimum. Alternatively, acoustically enhanced 5/8-inch XP panels may be used where type X gypsum panels are specified in some fire-rated wall and floor-ceiling assemblies. Used in the construction of high-rated STC wall assemblies, this 5/8-inch-thick gypsum board consists of a layer of viscoelastic damping polymer sandwiched between two pieces of high density mold resistant gypsum board, providing constrained layer damping. Acoustically enhanced gypsum board can be used as a single-layer application or as a component of multi-layered wall assemblies where sound transmission between rooms or dwelling units is a concern.

Three factors reduce the potential acoustical isolation:

- First is a smaller air space between the sheathing systems.
- Second is the common resonance of the two thinner wall systems. In this case, the walls radiate at the same frequency, coupling with each other, which reduces the wall system's acoustical effectiveness.
- Third is the air space between the walls. In the case of lot-line walls for townhouses or row housing, the air space is typically sealed air tight. In the case of trapped air, one to two inches of air becomes very stiff, adding to the walls' ability to couple together.

6.3 Insulation

The most cost-effective acoustical improvement to a sound isolation system is the addition of batt insulation or any open cell foam system to the stud or joist cavity. Batt or open cell insulation reduces the sound that makes it into the stud cavity in the same manner as sound absorption works in a room. While closed cell spray foams have higher R-values and offer improved building envelope energy performance by sealing the partition and improving air tightness, the closed cells do not allow the vibrating air molecules to interact with the insulation product so the sound attenuation is less. The cavity should be filled at least halfway to achieve a measurable improvement. In single stud walls, a single stud bay is filled; for staggered or double stud wall systems, insulation is only acoustically needed in one of the stud bays.

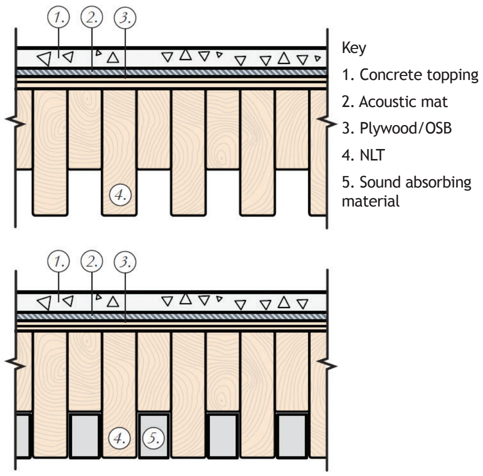


Figure 5: *Alternating 2x4 and 2x6 lumber with and without sound absorbing material. Source: NLT US Design and Construction Guide*

6.4 Resilient Connections

Finally, when double or staggered wood stud construction is not possible, decoupling the sheathing from the framing provides a similar form of isolation. Decoupling happens when the framing system functions like a spring. The spring system deforms as sound strikes the gypsum wallboard. As the spring or resilient system expands back to its original shape, it converts some of the acoustical energy from the sound into mechanical energy so there is not as much acoustical energy to transfer through the framing system.

6.5 Floor/Ceiling Systems

Noise reduction techniques for walls also apply to floor systems. While the main sources of noise complaints relative to walls are televisions or loudspeakers attached to party walls, footfall or impact noise from above can be an issue in multifamily projects if proper design steps are not taken. The second major noise complaint is floor squeaks.

Attenuation of impact sound, as opposed to airborne sound, is typically what governs for a floor assembly. As with most structural floor systems, floor finish material can have a significant effect on a floor assembly's IIC rating. For horizontal applications (floors and roofs), additional materials will typically be applied on top of the wood structure, below it or both. As with all construction types, careful control of flanking paths is required.

Numerous studies of noise transmission through wood frame floors have concluded that lack of sufficient mass is the major cause of poor sound insulation in these floors. Logically, mass has to be added to the wood joisted floors to achieve satisfactory sound insulation, so floating a cementitious topping over an insulation underlayment on top of wood floors became popular practice. However, while this successfully controls the noise transmission through wood floor/ ceiling assemblies, the solution can negatively impact the floor vibration performance, leading to occupant complaints about excessive vibrations in the wood joist floors with concrete topping.

It appears that using mass alone to control noise transmission is not adequate. FPInnovations' research on the effect of concrete topping on wood joisted floors found that the floor spans should be reduced to improve stiffness. Therefore, the strategy for controlling the transient vibration AND noise transmission of wood joisted floors is to control the proper combination of floor stiffness (through span) and mass.

In wood-frame buildings, one effective floor/ceiling option features a base system construction consisting of the following:

- Gypcrete or light-weight concrete
- Impact isolation matt
- Tongue and groove subfloor (glued and screwed to the joist)
- Joist system (with 6 inches of batt insulation)
- Resilient channel or puck system (resilient system)
- Two layers of 5/8-inch type X gypsum board

This system has a rating of STC 62, which is the highest rating possible without moving to construction methods found in recording studios, and is well above the required STC 50.

6.6 Impact Isolation

Impact noise can be reduced considerably with the use of soft floor finishes such as carpet. When carpeting is not practical or desired, the entire finish system must be considered. Floating engineered hardwood or tile floor systems offer the next best solution. A floating engineered hardwood floor offers the advantage of an isolation membrane that can be installed beneath the finished wood system. However, placing a resilient isolation mat or buffer under hard finish flooring systems requires coordination. Buffer systems include mats under the topping mass such as foam, cork or rubber mats made from recycled tires. Each of these buffer materials creates its own set of compromises on the installation process, with the total thickness of the finished floor system being one of the biggest coordination points.

7 CONCLUSION

Noise has a great impact on the built environment and the occupants that live and work in it, with numerous exterior and interior sources ranging from emergency vehicles and airplanes to HVAC systems, music and talking. Acoustic design considers a number of factors, including building location and orientation, as well as the insulation or separation of noise-producing functions and building elements. You should now have a better understanding of how design teams can integrate acoustic design to create high performance wood buildings that also enhance the health and

	FLOOR ASSEMBLY (TOP TO BOTTOM)	STC	IIC
1	1/2 in. plywood + 2x6 NLT (baseline measurement)	34	32
2	Bare CLT (5-ply, 6-7/8 in. thick)	39	25
3	4 in. normal weight concrete topping + Pliteq GenieMat FF06 acoustical mat + 1/2 in. plywood + 2x6 NLT	51	44
4	Carpet + 4 in. normal weight concrete topping + Pliteq GenieMat FF06 acoustical mat + 1/2 in. plywood + 2x6 NLT	51	58
5	4 in. normal weight concrete topping + Pliteq GenieMat FF25 acoustical mat + 1/2 in. plywood + 2x6 NLT	54	50
6	4 in. normal weight concrete topping + Pliteq GenieMat FF50 acoustical mat + 1/2 in. plywood + 2x6 NLT	56	52
7	4 in. normal weight concrete topping + Pliteq GenieMat FF06 acoustical mat + 1/2 in. plywood + 2x6 NLT + RC + 5/8 in. Type C Gypsum	55	49
8	4 in. normal weight concrete topping + Pliteq GenieMat FF06 acoustical mat + 1/2 in. plywood + 2x6 NLT + Pliteq GenieClip RST Clip + R8 Fiberglass batts + 5/8 in. Type C Gypsum	60	59

This table provides STC and IIC testing data completed for NLT floors. Included in the table for comparison is the acoustic performance of bare NLT (with plywood topping) and bare CLT. While the industry builds a more complete database of tested assemblies for NLT, designers may opt to use other mass timber assembly tests as a guide to predict the performance of NLT.

well-being of occupants. Acoustical codes, green rating systems and reference sources such as the CLT Handbook and NLT Design and Construction Guide for mass timber buildings can help you to decipher the myriad considerations that go into optimizing acoustic design.

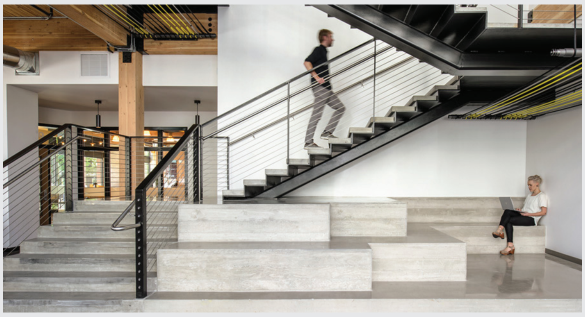
END NOTES:

Please reference WoodWorks' Acoustical Considerations for Mixed-Use Wood-Frame Buildings at http://www.woodworks.org/wp-content/uploads/Acoustics_Solutions_Paper.pdf for architectural details and additional information regarding this topic.

WoodWorks provides free one-on-one project assistance related to the code-compliant design, engineering and construction of non-residential and multi-family wood buildings. Contact help@woodworks.org.

American Wood Council provides code support to assure safe and efficient wood building design. Contact info@awc.org.

CASE STUDY: THE HUDSON: SUSTAINABLE MIXED-USE OFFICE BUILDING USES WOOD TO ADVANCE LIVE/WORK/PLAY PHILOSOPHY



The Hudson | Architect: Mackenzie Architects | Photos: Christian Columbres

As the first newly constructed office building in recent memory in downtown Vancouver, Washington, the Hudson serves as bridge between the community's rich history and promising future. The building is open and airy, with 15' ceilings, custom 2×4 decking, extensive use of wood including exposed glue-laminated timber columns and beams.

Sustainable design was a key project goal, with a target of LEED Gold for the core and shell, and Four Green Globes awarded in Sustainable Interiors. Sustainable elements include an efficient variable refrigerant flow system, high-performance window glazing, and combinations of LED and natural daylighting.

Wood can be an ideal choice in office environments because it is not as acoustically lively as other surfaces and can offer acoustically absorptive qualities. Generally, a wood-finished building is not as noisy as a complete steel or concrete structure. (Building Green with Wood Toolkit, Acoustics). As home to Mackenzie's Vancouver Washington office, The Hudson serves as an example of the firm's emphasis on employee well-being.


The Hudson | Architect: Mackenzie Architects | Photos: Christian Columbres