# The Acoustical Challenges for Modular Buildings Used for Residential Purposes

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## 1 Background

As the need for affordable housing increases throughout Canada, modular buildings, which were traditionally used for temporary construction trailers or portable classrooms, have now been adopted as a solution for permanent housing in both remote and urban locations. Modular buildings offer a cost-effective alternate to "*stick-built*" construction, that enables a rapid mobilization due to off-site pre-fabrication, with a flexible and ease-of-use approach to the spaces that can be readily adapted to both residential or ancillary support uses.

However, while the typical interior modular assemblies are well rehearsed for non-residential uses, there are currently no directly comparable assemblies contained within the Building Code, and published formal acoustical performance data of such assemblies is scarce which can lead to some ambiguities in the expected acoustical performances.

## 2 Building Code

The latest iteration of the National Building Code[1] (the Code), not only relies on objective sound isolation standards for separating assemblies but, along with many other provincial Housing Design Guidelines and Construction Standards, places much greater emphasis on the control of flanking sound within multi-family occupancy buildings.

Within Article 9.11.1.4, the Code requires that the adjoining constructions (i.e., flanking wall, floor and ceiling assemblies) end or be interrupted at the junction of the separating element. It also presents compliance options for the construction of assemblies with flanking elements, which are typical of stick-built buildings. However, these compliance options do not necessarily reflect the design construction of modular building elements.

Since modular wall and floor-ceiling systems are fabricated off-site as single contained units, and then shipped and assembled on-site, maintaining structural integrity is a key design element. To maintain the structural integrity of modular buildings, the interior wall systems often include additional sheathing layers on the inner side(s) of separating stud walls, and the flooring systems often include continuous flooring layer(s) across the two rows of the separated party-wall studs. Breaks in the flanking constructions generally only occur at the perimeter edge of the individual modules.

Since the modular units, some of which may be partially open, are often stacked, the longitudinal walls are typically load-bearing (with end walls only providing stability), and, therefore, bracing is required for multiple storeys. This bracing can present s

ome conflict with the design intent of Article 9.11.1.4.

## 3 Acoustical Challenges

### 3.1 Initial Field Testing

In 2018, BKL Consultants Ltd were invited to perform in-situ sound transmission testing in a number of a standard modular constructed units being used for residential purposes. The field measurements were generally conducted in accordance with ASTM E336-17[2], except noting that the available room volumes were less than 40 $m^3$ but greater than 25 $m^3$.

It was found that in general floor assemblies were able to maintain Apparent Sound Transmission Class (or ASTC) ratings consistent with the Code requirements. However, for the wall assemblies, constructions that were broadly similar to assemblies with tested acoustical performance ratings, demonstrated a wider range of ASTC ratings. In some cases, ASTC ratings were as much as 10 points lower than the published Sound Transmission Class (or STC) ratings due to the flanking conditions, while in others greater consistency with published laboratory data was achieved.

### 3.2 Structural Bracing

The assemblies listed within the "Fire and Sound Resistance Tables" of the Code do not include systems with structural (and seismic) loading, crush plates, or bracing (as needed in modular assemblies). The absence of reliable and laboratory tested acoustical data for various modular constructions introduces challenges in demonstrating compliance with the Code Sound Transmission Class (STC) requirements.

The post-construction field measurements of modular units established that the sound isolation ratings for separating floors and walls were commensurate with somewhat similar double stud (or joist) row assemblies in low rise buildings, where OSB sheathing or bracing is not being used.

However, where longitudinal walls include "fully sheathed" layers for structural bracing (thus forming a 2 or, in some cases, 3 cavity assembly arrangement), the effects of the "*mass-air-mass resonance*" appeared to significantly reduce the expected sound isolation rating, with reductions of 5 to 10 ratings points being found.

The challenge of providing structural bracing, particularly for seismic purposes, while not compromising the acoustical properties has meant that working actively with the manufacturing teams is encouraged. In some cases, the use of intermittent bracing panels is acceptable in lieu of the fully sheathed systems, although some recent developments have included the greater use of "*stud-packs*", (i.e., laminations of

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timber studs grouped together), 75 mm (3”) O.C. nail spacing on fastening walls or overlapping headers as an alternate approach without any overly detrimental effects to the sound isolation properties.

### 3.3 Within Module Separating Walls

While scaling through repetitive module construction is economically beneficial, many designers want to explore the spatial options on the units to increase floor space or room uses. In some cases, this has meant that a wall assembly separating two dwelling units is contained within a single modular unit to offer greater occupancy options. However, these arrangements result in a conflict with the need to have discontinuous or interrupted junctions with the adjoining constructions.

The structural stability of the flanking wall, floor and ceiling elements rely on them remaining continuous across separating junctions. Now while this is a common occurrence with timber floors where structural subfloors are often continuous in stick-built constructions, then an additional layer (having a mass of no less than 8 kg/$m^2$ per Article 9.11.1.4) is laid over the subfloor. The off-site construction of each unit means that there is sometimes an unpredictable floor height at the module edge, meaning a mismatch at the junction of the additional floor layers.

Early field measurements of “in-unit” separating bedroom walls found that that sound isolation ratings were not able to consistently achieve ASTC 47 ratings even for enhanced wall assemblies due to the contribution from the flanking sound paths. To some extent the smaller room volumes (i.e., $\leq 40$ $m^3$) associated with the module sizing did appear to influence the measured noise reductions at the 125 Hz and 160 Hz one-third octave centre band frequencies.

However, greater success in achieving ASTC ratings of at least 47 were achieved with ad-hoc treatments, such as additional floor layers over elastomeric or foam interlayers, additional or “checker-boarding” gypsum board layers to flanking walls and ceiling boards on resilient bars to minimize the effects of flanking sound transmission between the units. Nevertheless, these are relatively labor intensive and costly fixes at the assembly stage, which off-set some of the cost benefits of modular construction.

### 3.4 Service Penetrations

Through experience, the acoustic treatment of building service penetrations and riser shafts within modular buildings has been generally poor. Common services, such as piping or waste water lines, kitchen or bathroom exhaust ducts and Packaged Terminal Air Conditioners (PTAC) gas lines have historically been located within overly large dimensioned shafts that can accommodate a wide variety of services. It is often overlooked that all riser shafts separating dwellings from other parts of the same building require a minimum STC 50 rating, with adjoining constructions that conform to the control of flanking sound.

In one instance, a common open building services shaft was found to be located within a utility cupboard in the stacked kitchen-dining rooms of a residential building, meaning each the neighboring families could hear even normal dinner table speech from each unit. In fact, it was possible to conduct 2-way conversations from the utility cupboard to neighbours some floors away.

The acoustical detailing requirements of riser shafts and common penetrations through separating assemblies is the responsibility of the assembly team, but checking and enhancing the acoustical detailing during the early design is critical to achieving the necessary airborne sound isolation. While space constraints inhibit airborne sound testing of services shafts, typically, the best practice for reducing flanking sound transmission can include enclosing the riser shafts with materials having a mass per unit area of at least 15 kg/$m^2$ lining the shaft with unfaced mineral fibre and packing openings.

## 4 Conclusion

The design of established modular constructed buildings has been found to require architectural enhancements in order to demonstrate consistency with the requirements of the Code. The need for structural stability both within individual modules and stacked modules creates flanking sound transmission paths that, unless adequately treated, provides conflict with both the need for discontinuous junctions at the perimeter of separating elements and the objective field-tested sound isolation ratings set out in the Code.

Project experience has found that measures to mitigate the effects of flanking sound transmission will need to be commensurate with the design intent of the Code and, moreover, be included at an early stage of the module design in collaboration with the structural team of the manufacturers.

The use of additional materials or layers, along with upgraded or amended assemblies can be targeted to optimize the sound isolation qualities of the separating assemblies, and has been found to achieve ratings consistent with those required by the Building Code in Canada when tested in the field.

## References

[1] Canadian Commission on Building and Fire Codes National Research Council of Canada. National Building Code of Canada Volume 2, 2020.

[2] ASTM International. Designation: E-336-17 Standard Test Method for Measurement of Airborne Sound Attenuation between Rooms in Buildings, 2017.