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Controlling air-borne and structure-borne sound in buildings

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ABSTRACT

In recent years, the science and engineering for controlling sound transmission in buildings have shifted from a focus on individual assemblies such as walls or floors, to a focus on performance of the complete system. Standardized frameworks for calculating the overall transmission including structure-borne flanking, combined with standardized measurements to characterize sub-assemblies, have advanced these issues from research concepts to engineering practice in many countries. From studies of relatively homogeneous and isotropic constructions of concrete and masonry in the 1990's, the technology is now expanding to include the more complicated behavior of lightweight framed constructions. These advances in measurement-based calculations offer the potential for better design based on comprehensive prediction of sound transmission between units in multifamily buildings. To realize that potential, we still must overcome several challenges. First, the acoustical prediction tools must be suitable for designers who integrate the many aspects of building performance. Second, the acoustical metrics must properly reflect how occupants respond to transmitted sound from both typical airborne sources and impact sources such as footsteps. These concerns pose major challenges for the next decade – both for research and for implementation.

1. INTRODUCTION

This paper attempts to provide an overview of some key advances in dealing with sound transmission within buildings. It is naturally limited by the author's personal biases, and hence focuses on issues from a North American perspective, and deals mainly with experimental results and experiment-based models used to translate the scientific concepts into engineering practice. Inevitably it overlaps to some degree with other presentations at this conference, and readers are directed to the obviously pertinent keynote paper on impact sound sources[1]. To minimize the overlap with that paper, and with other recent presentations on footstep noise[2], this paper focuses mainly on transmission of sound from airborne sources, especially in the context of multi-family residential buildings. To relate the discussion to practical concerns, the paper addresses:

- Can we accurately predict transmission to the receiver?
- What are the sound transmission paths of concern?
- Do available criteria reflect how people react to the transmitted sound?
- How can we effectively package the technology for the intended users?

A. Shifting to a new paradigm

Until the last decade (with some notable exceptions[3]), research on sound transmission between rooms in buildings has focused mainly on sound transmission through individual assemblies. This perspective is still evident in North American building codes, which for many decades have considered only the ratings for the assembly separating adjacent dwellings: Sound Transmission Class (STC) or Field Sound Transmission Class (FSTC) for airborne sources[4] or Impact Insulation Class (IIC) for footstep noise[5].

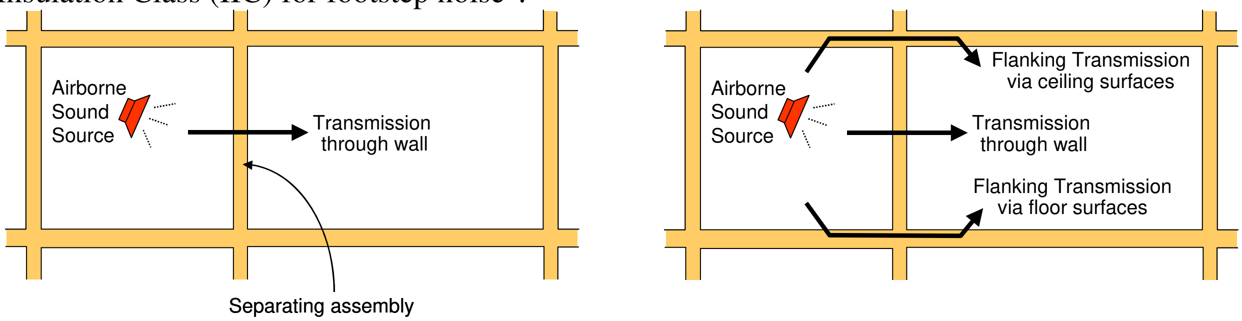


Figure 2: Drawings show a cross-section through a building with two adjacent dwellings. Some of the sound from an airborne source in one unit (represented by red loudspeaker in the drawings, which could represent anything from a home theatre to people talking loudly) is transmitted to the adjacent unit. The traditional approach (at left) focuses on *only* the direct sound transmission through the separating assembly. In reality there are many paths for sound transmission – a few are shown in the right hand drawing - and indirect paths often dominate.

Implicit in this approach is the simplistic assumption (illustrated at left in Figure 2) that sound is transmitted only through the obvious separating assembly—the separating wall assembly when the units are side-by-side or the floor/ceiling assembly when units are one above the other. If there is a problem with the sound insulation, this is ascribed to errors in either design of the separating assembly or the workmanship of those who built it. Unfortunately, this paradigm is still predominant among designers and builders in North America.

In reality, the problem is more complex (as illustrated at right in Figure 2)—the airborne sound source excites all the surfaces in the source space. All the surfaces vibrate in response, and some of this vibration is transmitted across the surfaces abutting the separating assembly, through the junctions where these surfaces join the separating assembly, and into surfaces of the adjoining space, where part is radiated as sound. It follows that the sound insulation between adjacent dwellings is always worse than the sound insulation provided by the obvious separating assembly. Of course, this has long been recognized in principle (and the fundamental science was largely explained by Cremer and Heckl[6] decades ago)—the problem was to reduce the complicated calculation process to manageable engineering that yields quantitative estimates.

Occupants of the adjacent space actually hear the combination of sound due to direct transmission through the separating assembly and any leaks, plus sound due to structure-borne flanking transmission involving all the other elements coupled to those assemblies. For design or regulation, the terminology to describe the overall sound transmission including all paths is well established. ISO ratings[7] such as the Weighted Apparent Sound Reduction Index (R'_w) have been used in many countries for decades, and ASTM has defined the corresponding Apparent Sound Transmission Class (ASTC), which is used in many examples in this talk. There are other variants using different normalization or weighting schemes that have arguable advantages, but this paper uses ASTC as the basic measure of sound insulation for airborne sound.

While measuring the ASTC in a building is quite straightforward, predicting the ASTC due to the set of transmission paths in a building is quite complex, and requires data on structure-borne transmission that is only gradually becoming available.

Most of the remainder of this paper is an overview of experimental results and experiment-based models that have been developed to predict the overall sound insulation between adjacent spaces in a building. But first, to assess whether the predicted ASTC or R'_w is adequate, criteria must connect the physical performance to the reaction expected from building occupants.

B. Ratings and subjective criteria

For efficient design, we need design criteria—objectives that quantify "acceptable levels" of noise from obvious sources. For the occupants of a building, that includes noise from outdoor sources such as highways and aircraft, noise from appliances and building services (plumbing, ventilation, etc.) and noise from neighbours. This talk focuses on noise from neighbors in multi-family residential buildings.

Even with that restricted focus (and decades of refining pertinent regulations and standards) the criteria seem to be based more on tradition than on substantial scientific studies of human response. The ISO 717 standard offers 15 metrics for airborne sound insulation between rooms, 27 for insulation of facades, and 6 for impact sound insulation. As Rasmussen has periodically documented[8], even within "unified Europe" this has led to a bewildering array of national criteria, and many non-European countries have added further variants. One could make a strong case for the benefit of continuing recent research efforts in this area [9,10], especially to assess the most suitable ratings to handle low frequency sound and special sources such as footsteps and building services (ventilation, plumbing, etc.) to establish a credible foundation for improved consensus standards. That is clearly one of the key challenges for the next decade.

To maintain a manageable focus, this paper simply presents some existing consensus criteria for insulation against airborne sound, expressed in terms of the ASTC metric chosen for this presentation. Because of the wide variation in national approaches to regulation, comparing specific regulatory limits is not very instructive, but recent schemes for labeling housing—to provide potential buyers or tenants with a market indication of quality of sound insulation (among other factors) offer a clearer perspective, shown in Figure 3.

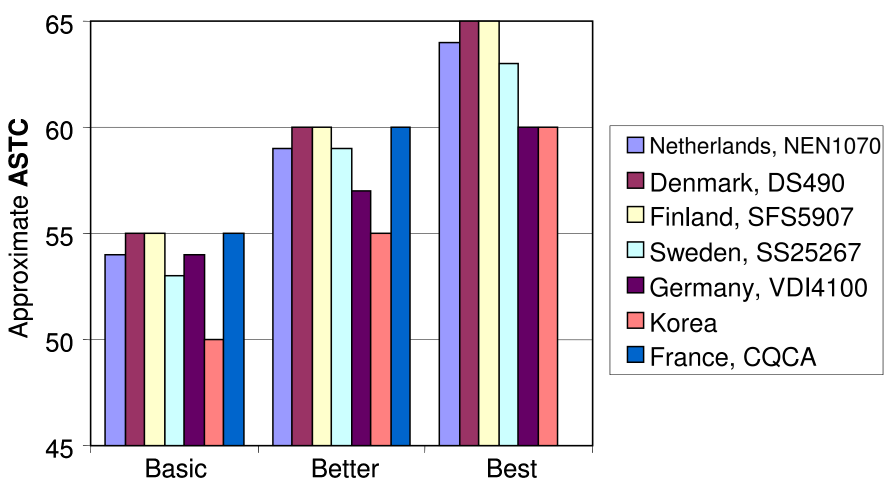


Figure 3: Criteria for enhanced sound insulation between adjacent units in multi-family buildings in acoustic quality classification systems for several countries, translated to approximate ASTC scale.

Most of these labeling systems have 2 or 3 classes for acoustic comfort better than the regulatory minimum; some also have lower classes directly connected with national requirements. The top categories have been grouped here as basic/better/best clusters in Figure 3. Because the various schemes use different metrics from the set in ISO 717, only an approximate conversion to ASTC is possible, but that suffices to illustrate the rather small range of criteria - the "Basic" quality class requires ASTC in the range from about 50 to 55, and the "Best" class requires 60 to 65. The existence of a range in requirements is not surprising given the different national traditions both for regulations and social expectations. But despite strong individualism in national expression of the requirements, it appears that there is a fairly clear consensus on how much sound insulation is good enough to satisfy occupants.

For practical design objectives, the requirements for typical occupants seem fairly clear:

- ASTC ~ 52 is good enough to satisfy most of the people, most of the time.
- ASTC ~ 65 (maximum of top class range) should provide satisfaction almost always.

From a Canadian perspective, these criteria are quite consistent with the social response data obtained by Bradley in a survey of 300 pairs of neighbors, living side-by-side in multi-family residential buildings[11]. After obtaining survey responses from each pair of neighbors, the survey team measured ASTC between the dwellings. As expected there was a range of responses, but there were clear trends in the mean responses, varying from significant annoyance when ASTC was under 50 to negligible annoyance (and reporting not hearing sound from the neighbors) when the ASTC approached 65. These results were broadly consistent with the criteria proposed above and with the market classification schemes shown in Figure 3.

However, it must be recognized that these criteria are at best fuzzy targets, because many factors (noisiness of individual neighbors, ambient levels due to building services and intruding outdoor sound, sensitivity of individual listeners, etc.) ensure that any assessment of social response versus sound insulation will exhibit significant variance.

Improved measures for the sound insulation should reduce the scatter in these responses, and would presumably shift the relative acceptability of some types of construction, especially for those cases where low frequencies dominate, which are problematic according to anecdotal evidence. Pursuing the refinement of the ratings is worthwhile, especially if clear international consensus can be established. But for purposes of this paper, the criteria noted above give reasonable working indications of acceptability in terms of the current metrics.

2. TRANSMISSION IN HEAVY MONOLITHIC CONSTRUCTION

Significant advances in predicting the sound transmission through the complete building system, including the direct and indirect paths, occurred first for heavy monolithic construction, with structural elements such as concrete floors and masonry walls. These systems are well-suited to modeling using statistical energy analysis (SEA) to calculate the transmission - the elements such as floors or walls can be treated as homogeneous and isotropic, they are lightly damped so they can reasonably be characterized by reverberant levels, and most energy losses are due to transfer to adjoining elements. Craik and others advanced this subject from research studies to text books[3]. By the mid 1990's SEA was part of widely accepted engineering practice.

This engineering concept was implemented in European standard EN 12354, which was published in 2000, with parts to address airborne and impact sound transmission between rooms within buildings and the transmission of outdoor sound into a building. In 2005 the Parts of EN 12354 were adopted as international standards, as ISO 15712, "Building acoustics – Estimation of acoustic performance of buildings from the performance of elements"[12]. Although they are most easily and accurately applied to heavy monolithic structures, these standards also include extensions to deal with other types of assemblies.

For two adjacent rooms, either side-by-side or one above the other, sound is transmitted both directly through the separating assembly and via a set of indirect paths involving all the surfaces connected at each junction common to both rooms. In the simple case, where room dimensions match, there would be four such junctions, one at each of the four edges of the separating wall or floor assembly. There is a set of indirect paths for each junction, each path involving the transfer of energy from a surface in the source room to one in the receiving room. For heavy monolithic constructions this transfer can be calculated, depending on junction geometry, and readily established properties of the joined assemblies. For more complex assemblies, measurement protocols were developed to characterize junction performance[13].

The practicality of the calculation framework comes from the rather straightforward extension to deal with the incremental effect of “linings” added to the basic structural elements. It is common practice, especially in residential buildings, to add finish surfaces to the basic structural wall and floor assemblies – for example, various multi-layer floor surfaces, or gypsum board wall and ceiling surfaces that mask both the bare concrete and the building services such as wiring and pipes. These additional layers can significantly improve the sound attenuation, both by reducing the transmission of vibration between the lining and the supporting assembly, and by changing radiation efficiency of the exposed surface. If the lining is treated as simply changing the sound power flow from the reverberant sound field in the room to the reverberant vibration in the structural assembly, then as shown conceptually in Figure 4, the practical calculation combines the basic flow of structure-borne power via the coupled structural elements, with simple incremental effects due to the linings. Fortunately this approach works well for heavy monolithic supporting structures.

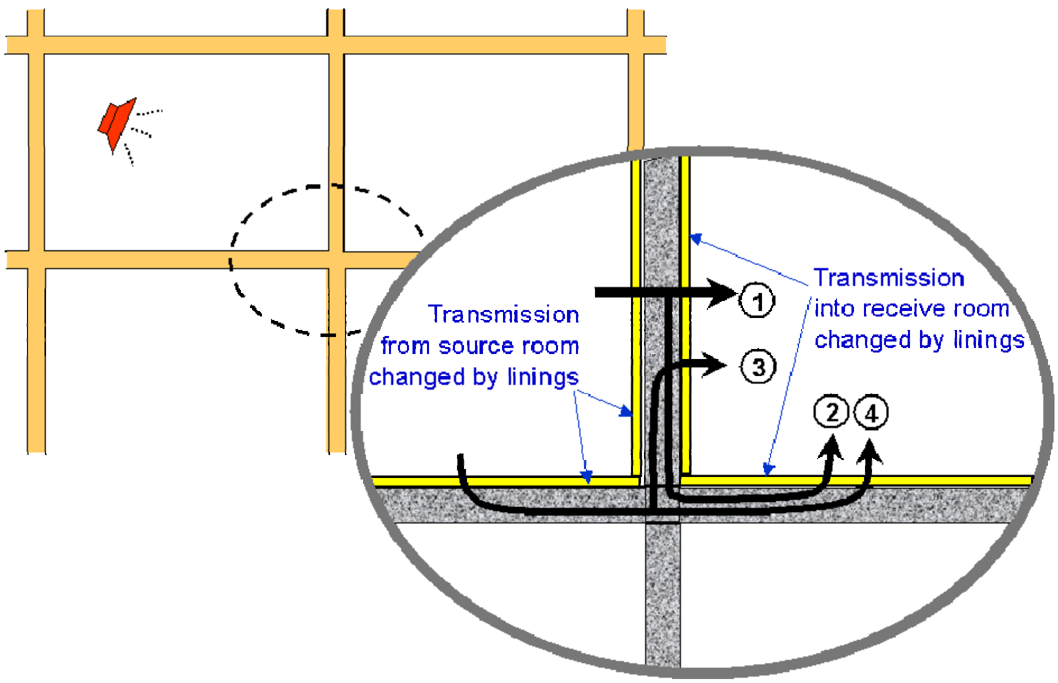


Figure 4: Transmission combines direct path through separating wall (1) and structure-borne flanking via: wall-floor path (2), floor-wall path (3) and floor-floor path (4), plus corresponding set of paths at other junctions. Transmission via these paths is altered by addition of linings in the source room and/or receiving room.

The effect of a lining added to a structural base assembly can be determined to first order by measuring the change in direct sound transmission when the lining is added to a similar base assembly separating the two rooms of a standard sound transmission laboratory suite. This process for evaluation of linings was outlined in ISO 15712, and subsequently fleshed out more completely with a set of reference base assemblies in ISO 140-16[14]. For the flanking paths, this estimate must be corrected to remove the non-resonant component, and the effect of the lining depends on the mobility of the base assembly, but the process can provide very good estimates of the overall performance, especially for heavy concrete or masonry constructions, for which ISO 15712 estimates should be within a standard deviation of 1.5 dB.

Although extensions to include other types of floor and wall assemblies in the ISO 15712 framework have been investigated, there are significant technical complications that must be considered for lightweight framed construction[15,16].

3. TRANSMISSION IN LIGHTWEIGHT FRAMED CONSTRUCTION

Rather than attempt to fit sound transmission for lightweight framed construction into the framework developed for heavy monolithic systems, research in Canada has focused on developing an approach customized for performance of typical North American wood-framed buildings.

A. Concepts for flanking in lightweight constructions

In this approach, developed by Nightingale et al[17], the power flow via each flanking path is defined by five transmission factors whose combined effect is characterized by a path transfer function specific to the type of excitation (airborne or impact) and the construction detail. This is most simply explained in the context of impact sources. Figure 5 identifies the factors controlling the transmission of structure-borne sound to the room beside, and the resulting vibration levels across the floor surface are illustrated in Figure 6, for one position of a standard tapping machine on a lightweight floor.

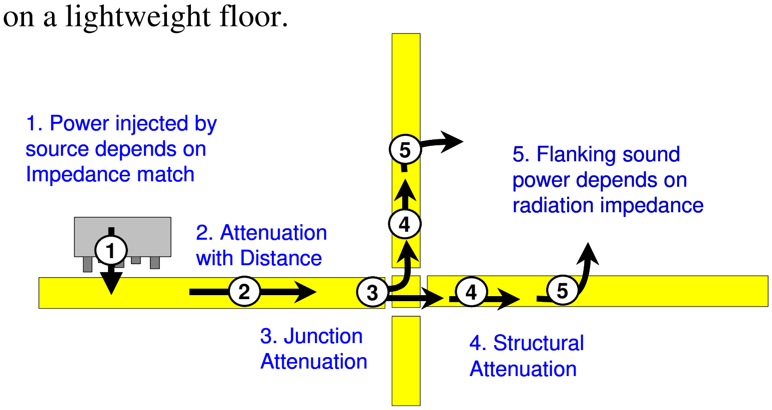


Figure 5: Five factors that affect flanking transmission via the floor/wall junction, with an impact source.

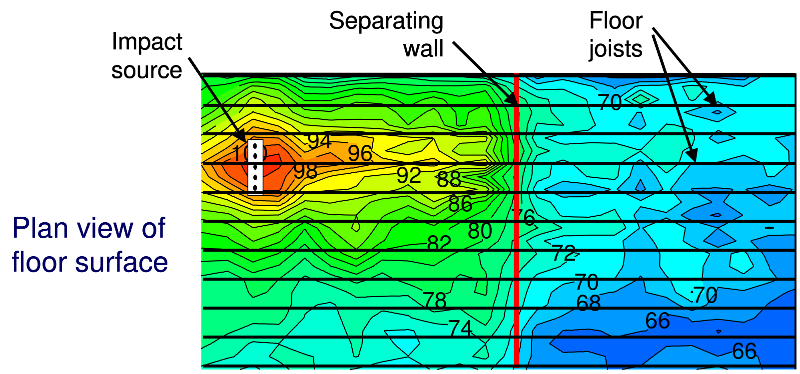


Figure 6: Variation across the floor surface of the vibration levels (2kHz band) due to an impact source. The floor construction has wood joists perpendicular to the separating wall between the two side-by-side rooms.

A general model for such a system must account for all five factors indicated in Figure 5, for a realistic range of source positions. Clearly the system is anisotropic and highly damped – the vibration field exhibits a strong gradient that is different in the directions parallel and perpendicular to the joists. In general, this vibration field is a poor approximation of a diffuse field, which limits the applicability of simple SEA models. Not only do vibration levels vary strongly across the surface of the structural assembly, but also some added linings (such as floor toppings) *change* the attenuation across the structural assembly, with different changes in the three orthogonal directions pertinent to direct and flanking transmission. Hence, a simple correction for a given lining (derived from measurement of direct transmission and then used to correct structure-borne flanking transmission via the supporting structural assemblies) is not generally applicable for lightweight framed assemblies. The direction of transmission relative to the framing members becomes an additional parameter needed for accurate prediction.

Essentially the same five factors apply to characterizing the propagation with an airborne source, as indicated in Figure 7. With an airborne source, the effect of source position is largely eliminated because there is fairly uniform incident sound power on the surfaces of the room, but all five factors still affect the sound power reaching the receiving room via the flanking paths as illustrated in Figure 7 for a subset of the paths at a floor/wall junction.

Changing construction details will alter one or more of the five factors. For example, linings commonly affect both the attenuation across the underlying structural assemblies and the power flow to/from the underlying assembly.

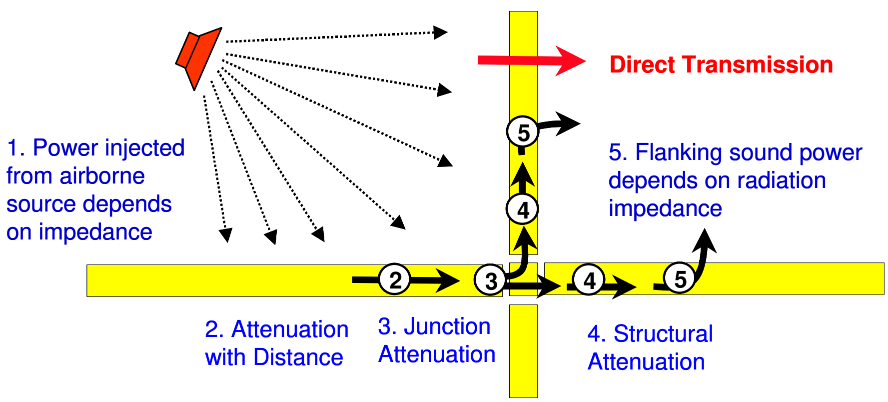


Figure 7: Five factors that affect flanking transmission, with an airborne source for the paths involving the floor surface in the source room. Similar factors apply for all other paths.

Experimental results demonstrating these behaviors, for both airborne and impact sources driving specific wood framed assemblies, were presented at preceding Inter-Noise conferences[18].

B. Examples of flanking transmission in lightweight constructions

A few examples to illustrate the effects due to common variations in construction are presented and discussed here, to provide context for the semi-empirical prediction methods presented subsequently. The discussion concentrates mainly on one set of base assemblies, but other systems show comparable trends.

Figure 8 shows a specific set of constructions where a wall separates two side-by-side units; the wall has gypsum board screwed directly onto one side of the wood stud framing and mounted on resilient metal channels on the other, and achieves STC 52 in laboratory testing. The floor assembly has a bare oriented strand board (OSB) floor surface, with its gypsum board ceiling mounted on resilient channels (STC 55 in laboratory testing).

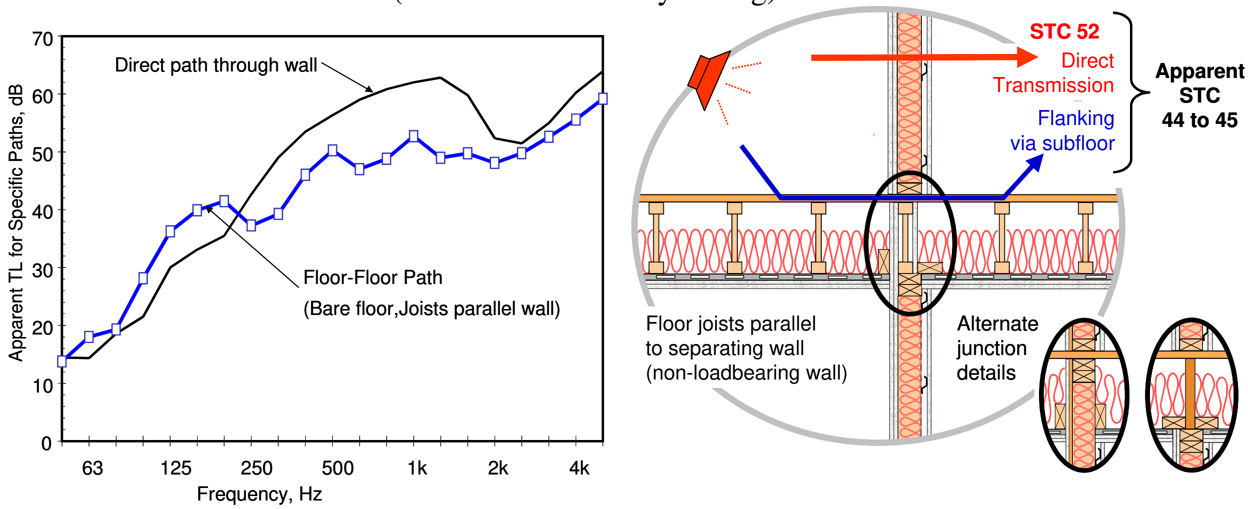


Figure 8: Sound transmission between side-by-side units with simple wood-frame wall and floor assemblies, as illustrated.

In repeated tests with minor variations of the materials and in the floor/wall junction details, the overall sound insulation observed between the side-by-side rooms was ASTC 43 to 45. Measurements of direct transmission through the wall itself showed that its sound transmission in the complete building system is very similar to laboratory results (STC 52). The difference in the system performance is due to flanking transmission via the floor assembly, which transmits far more sound than the separating wall assembly above 250 Hz.

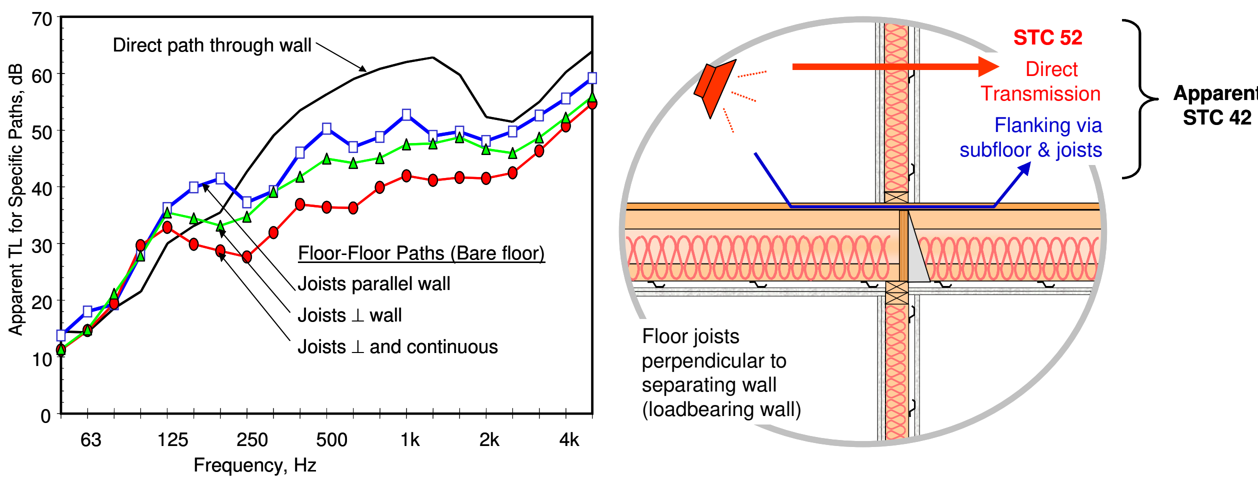


Figure 9: Modifying the wall/floor system of Figure 8 by reorienting the floor joists to run perpendicular to the separating wall lowers the ASTC for the system.

For the case shown in Figure 9, the measured ASTC was even lower than the ASTC observed when the joists were parallel to the separating wall (as illustrated in Figure 8). The problem here is not that the separating wall assembly is transmitting more sound than expected—it is performing as designed—but that most of the sound energy is able to circumvent the separating wall as structure-borne flanking transmission. Once again, the system ASTC is much lower than the STC of the separating assembly because flanking has not been properly considered in the design.

The systems illustrated in Figures 8 and 9 would result in noise that most neighboring occupants would find annoying and would complain about. To remedy this, a builder's first impulse would likely be to 'fix' the separating wall assembly by, for example, sealing any possible leaks and adding a second layer of gypsum board on the side with resilient channels. The added gypsum board should increase the wall assembly's STC by about 5. Detailed testing would show that the sound transmission directly through the wall was reduced (i.e. Field STC increased) as expected, but that the system performance was barely affected and only increased to ASTC 43 because the dominant sound transmission path (i.e., structure-borne flanking via the floor) was not dealt with.

In recent years many enhanced products have been introduced, such as wallboard incorporating constrained-layer damping, or resilient mountings that improve on the traditional generic resilient metal channels of the walls in Figures 8 and 9. Such products could increase this basic wall assembly's sound insulation to a rating of STC 60 or more, but the complete system would still provide only ASTC 43.

To address the problem, one must identify the key sound transmission paths and take appropriate measures to manage them. As illustrated in Figure 10, since transmission via the floor is the dominant problem with the floor/wall systems illustrated in Figures 8 and 9, treating the floor must be part of the solution. But a rational approach to the design must balance changes to the floor surface with changes to the separating wall, to achieve a cost-effective system with the desired ASTC performance. If the target were ASTC of at least 50, then a rather complex and expensive treatment of the floor would be required if using the basic wall illustrated in Figure 9. A simpler floor treatment could provide the target ASTC if the wall were improved to STC 57 with an extra layer of gypsum board. With further enhancement of the wall surfaces, the ASTC could be increased to ~60 when combined with the best floor treatment illustrated in Figure 10.

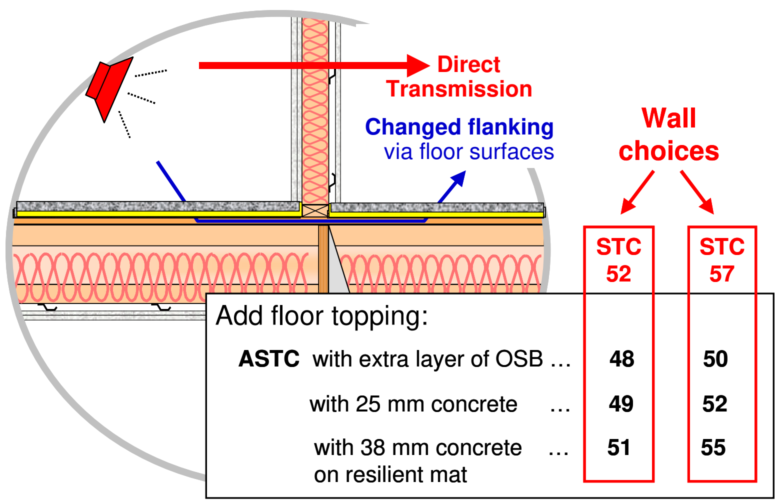


Figure 10: With a range of choices for the wall and floor, the builder can look sensibly at cost/performance tradeoffs for improvements to the elements that affect the dominant paths, which are the separating wall and the floor surface in this illustration.

Unfortunately, making improvements to the floor and separating wall is not a complete solution, as other paths may also be significant, and once better floor and wall assemblies have been put in place, the sound transmission via other paths will become more obvious. Ceilings and sidewalls also need to be considered as possible paths of sound transmission.

Only at this stage, can acoustical benefits of specific changes be properly weighed and balanced against their cost to optimize the cost/benefit for the complete system. The examples above have focused on side-by-side spaces, but a similar set of tradeoffs is involved when one considers the case where one dwelling is above another.

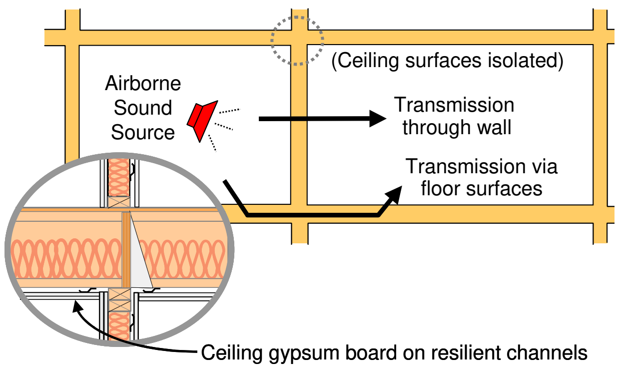
This highlights the practical need for a more complicated design framework, as discussed in the next section.

C. Designing for system performance in lightweight constructions

A simplified guide for design of wood-framed buildings was developed[19], using a tabular approach to present alternative choices for all the surfaces likely to be significant to the overall sound transmission between adjacent spaces. The Guide presents single-number ratings for the transmission of sound from both air-borne and impact sources, for adjacent units that are side-by-side, or one above the other, for a limited set of the most common constructions.

A few examples for airborne sources are presented here to highlight the strengths and weaknesses of such an approach.

Figure 11 illustrates the situation typically found in apartment buildings. In single-level apartments, the gypsum board ceiling is normally mounted on resilient channels to enhance the sound insulation from the apartment above. This also reduces flanking transmission between the side-by-side units via the ceiling/ceiling path to an insignificant level.

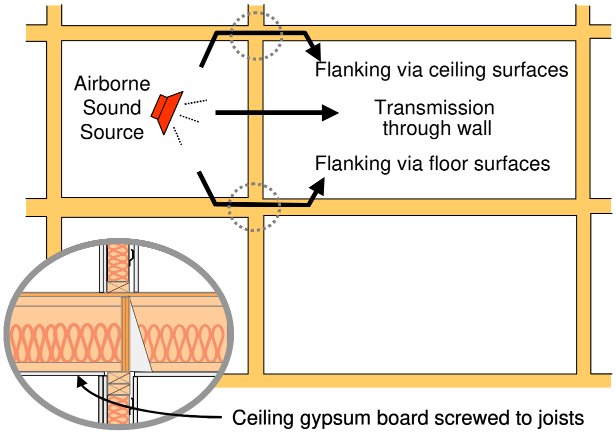


Separating wall	Basic wall (STC 52)	Better wall (STC 57)	
Attachment of gypsum board on sidewall	Direct or resilient	Direct	Resilient
Floor surface	Apparent STC (ASTC)		
• No topping (basic)	43	43	43
• 19-mm OSB stapled to subfloor	48	50	50
• 25-mm gypsum concrete bonded to subfloor	49	51	52
• 38-mm gypsum concrete + resilient mat on subfloor	51	53	55

Figure 11 and Table 1: Typical sound transmission paths between adjacent one-level apartment units. The sidewalls abutting the separating wall also transmit sound, but resilient channels supporting the gypsum board ceiling block transmission via the ceiling/ceiling path. The table presents the apparent STC for the specific separating wall and floor constructions illustrated, with various treatments of floor and wall surfaces.

From Table 1, the effects of variations in the construction are readily seen. For example, with no topping added over the basic plywood or OSB floor surface, flanking via the floor surfaces is so strong that the ASTC between the adjacent units does not rise above 43 no matter what improvements are made in the separating wall or the sidewalls. Once the floor has been treated, then the effect of improving the separating wall becomes obvious. With the combination of a better floor and better separating wall, then the effect of improving the sidewalls also becomes significant. A paper by Nightingale at this conference[20] addresses this issue in more detail.

In applications where transmission between storeys within a dwelling unit is not a concern (e.g., row housing), the ceiling is typically screwed directly to the bottom of the joists, as shown in Figure 12. In such cases, the flanking paths via the ceiling also become significant, and this reflected in the lower ASTC values in Table 2 for this building design scenario.



Separating wall	Basic wall (STC 52)	Better wall (STC 57)	
Attachment of gypsum board on sidewall	Direct or resilient	Direct	Resilient
Floor surface	Apparent STC (ASTC)		
• No topping (basic)	42	43	43
• 19-mm OSB stapled to subfloor	47	48	49
• 25-mm gypsum concrete bonded to subfloor	48	49	50
• 38-mm gypsum concrete + resilient mat on subfloor	49	51	52

Figure 12 and Table 2: . Typical sound transmission paths between side-by side units in multi-level row housing. The sidewalls abutting the separating wall also transmit sound. The table presents the ASTC for the specific separating wall and floor constructions illustrated, with various treatments of floor and wall surfaces.

The corresponding effects when one unit is below another are less dramatic, but still warrant design consideration. The only significant flanking paths involve the floor surface and the walls in the room below. Transmission via the wall/wall paths shown in Figure 13 is typically weak enough so that it can be ignored. The flanking transmission in this case is essentially the same for all the framing variants tested. The effect of joist orientation (stronger flanking via the walls supporting the floor joists) averages out if all wall surfaces in the room below are the same, because the joists are perpendicular to two walls and parallel to the others.

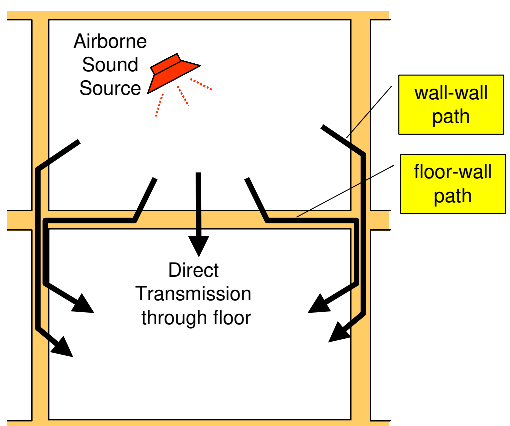


Figure 13. Transmission paths between upper and lower units include both direct transmission through the separating floor and flanking transmission involving the floor and wall assemblies.

Table 3 shows the combined effect of changes to the floor surface, the ceiling and the walls, and allows one to perform a cost/benefit analysis for different design options. This approach (which follows the same pattern as that used for side-by-side units) is especially helpful when used with lightweight floor surfaces.

Walls in room below	Floor surface	**Worse ceiling** 1 layer gypsum board on resilient metal channels spaced 400 mm o.c. (STC 51 if no topping)	**Better ceiling** 2 layers gypsum board on resilient metal channels spaced 600 mm o.c. (STC 59 if no topping)
		Apparent STC (ASTC)	
Basic walls: All walls with 1 layer of gypsum board fastened directly to the studs	• No topping (OSB subfloor)	49	52
	• 19-mm OSB stapled to subfloor	54	59
	• 25-mm gypsum concrete bonded to subfloor	59	61
	• 38-mm gypsum concrete + resilient mat on subfloor	63	64
Flanking suppressed: All walls with 1 layer of gypsum board supported on resilient channels	• No topping (OSB subfloor)	51	59
	• 19-mm OSB stapled to subfloor	55	64
	• 25-mm gypsum concrete bonded to subfloor	62	70
	• 38-mm gypsum concrete + resilient mat on subfloor	66	74

Table 3. Apparent STC between units (one unit below another) for selected variations of the floor/ceiling assembly and the wall surfaces in the room below.

Comparison of the ASTC values in Table 3 for a chosen floor topping show that because flanking transmission via the walls of the room below is comparable to direct transmission through typical ceilings with resilient channels, expensive solutions to improve the ceiling are not likely to provide much improvement in the ASTC, unless combined with wall improvements. Because both the direct transmission path and the significant flanking paths involve the floor surface, adding extra materials over the bare floor surface is often the most effective way to improve the sound insulation between units. When all three surfaces (floor, ceiling, and walls below) are improved, then very good overall performance can be achieved.

A similar set of tables in the Guide present impact (footstep noise) ratings for the same set of constructions. Thus the simple table-based design guide does provide information on sound transmission by the complete system, in a form that generalists can use, for a limited set of practical constructions.

D. Making the design process usable in practice

The tabular approach discussed above does show the effect of changes to all of the surfaces controlling sound transmission—both the separating assembly and the key flanking paths (hence indicating obvious choices)—and it also provides ASTC estimates for designers. Because tables are readily presented in conventional technical documents, distribution of the tabular Guide provided an effective means to convey concepts to builders and their generalist designers. But there are some obvious limitations:

- Each table (such as Table 1 or Table 2 above) applies to one specific combination of wall and floor constructions; therefore, many tables were required.
- A table can only present a few variants on each of the possible elements such as choices for floor toppings, or for floor coverings, or for gypsum board type and attachment on flanking surfaces. This seriously limits the range of options that can be presented.
- The tabular approach does not readily support comparison of different designs, or show the relative significance of the direct and flanking transmission paths in each case.

The obvious means to display more choices for each of the component materials—and to facilitate a more detailed analytic approach—is to implement the calculation framework in software, linked to a database of sound transmission data for each path, for the matrix of construction options that have been characterized. For the SEA approach (which is applicable to heavy monolithic construction as described in Part 2 of this paper) commercial software packages are available.

A software system is also being developed to implement the approach outlined in Part 3 for lightweight framed constructions. Such software can easily present a much broader range of construction options than the tabular approach illustrated in Part 3C. A screen image of the user interface is shown in Figure 14, to illustrate the potential of such tools to provide acoustical performance estimates in a form useful for generalists dealing with building design.

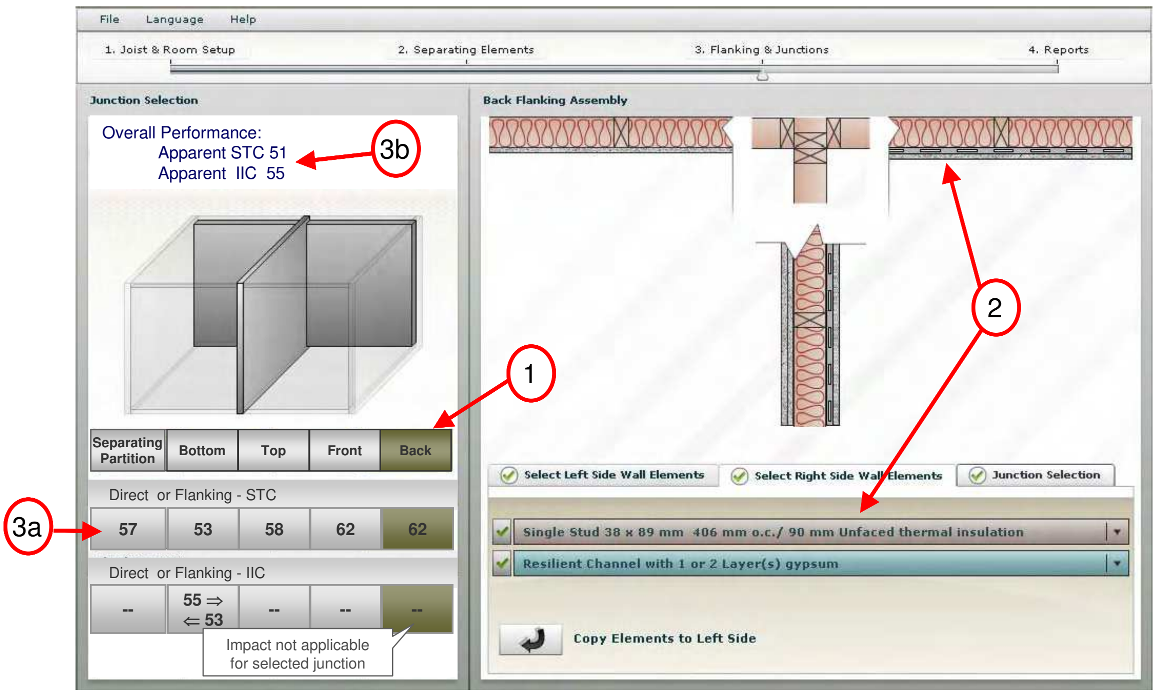


Figure 14: Example of user interface to illustrate how software can facilitate the display of sound transmission estimates for the set of transmission paths between adjacent spaces, to guide design decisions and estimate system performance. Parts of the interface include: (1) buttons to select between the separating assembly or each of the four flanking junctions at its edges, (2) drop down menus to select details of framing and other components affecting transmission via the selected junction, (3a) calculated sound transmission ratings for each set of paths, (3b) calculated overall sound insulation estimate.

An interface like that shown in Figure 14 can provide an interactive framework where the designer can explore changes in the building assemblies and materials to balance the sound transmission via the separating assembly and the set of flanking paths for the four junctions, in addition to giving ratings of the overall sound insulation.

These acoustical performance estimates provide the acoustical part of the information matrix needed by a design team for rational tradeoffs between the effect of specific changes in the building elements on the noise control, versus their impact on cost and other design objectives for building performance, such as fire resistance, structural capacity and energy use.

The balancing of many performance requirements is central to efficient design, and at the heart of the integrated design process central to modern "green building" schemes. Providing tools to support the acoustics part of satisfying the design requirements is essential to having acoustical performance effectively integrated into such schemes.

4. SUMMARY

The engineering framework to deal with sound transmission between neighboring units in complete buildings—both experimental techniques to characterize subsystems and calculation methods to turn the experimental data into estimates of sound insulation—has largely been developed. Design tools to make the knowledge readily accessible to design generalists are rapidly becoming available. This is enabling a paradigm shift from the traditional simplistic focus on the separating assembly, to properly evaluating performance of the complete building system.

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