Optimizing Ceiling Systems and Lightweight Plenum Barriers

Gary S. Madaras, ROCKFON, Chicago, Illinois
Andrew E. Heuer, NGC Testing Services, Buffalo, New York

Acoustics is one of the lowest scoring indoor environmental quality metrics in building occupant surveys. This is in part due to the misconception that a modular, acoustical ceiling alone can be used to block noise when a room's demising walls do not extend full height. Acoustical codes, standards and guidelines typically require 40, 45 or 50 decibels (dB) of isolation between rooms, yet most ceiling panels only provide 20-35 dB of inter-room blocking. Penetrations for lights, grilles and diffusers can decrease the Ceiling Attenuation Class (CAC) by 10 points overall and 20 dB in the 1,000, 2,000 and 4,000 Hertz (Hz) octaves. A full-height wall is the preferred way to block inter-room noise, but when combined with the 20-25 dB of blocking provided by typical ceiling systems that have been penetrated by lighting and air distribution devices, it can result in unnecessary costs to the project. The isolation provided by the ceiling and upper wall exceeds that provided by the lower wall. Laboratory tests were conducted to optimize combinations of modular, acoustical ceilings and lightweight, top of wall, plenum barriers that result in CAC ratings of 40, 45 and 50 points. The ceiling systems and the plenum barriers contained multiple penetrations for building services, representing real-world applications.

Sound isolating construction between adjacent rooms can be important for speech privacy in spaces like medical office buildings. Achieving it often depends on the weakest link in the room construction. As a cost savings in some buildings, interior walls are stopped at the height of a suspended, modular, acoustical ceiling. This can result in sound transmitting more easily between rooms through the ceilings and the open plenum above.

Ceiling manufacturers test and report the sound blocking capacity of their ceiling panels as ceiling attenuation class (CAC_{panel}). They do not typically include any of the many devices that penetrate actual ceiling systems in buildings. The CAC_{panel} rating is then mistakenly used for the ceiling system rating (CAC_{system}), even though the actual ceiling system in the building is full of penetrations for lights, air devices, sprinklers, loudspeakers, etc.

Not accounting for the difference between CAC_{panel} and CAC_{system} leads to disappointing results in buildings. Studies by the Institute for Research in Construction, National Research Council Canada (NRCC) concluded that even if ceiling panels with high transmission loss are used, the attenuation between rooms is limited by leaks (noise flanking paths).[1] Figure 1 shows one of the findings from a study conducted by the authors on a ceiling system with 5/8-inch-thick, mineral fiber panels having a CAC_{panel} rating of 37.[2] When lights, diffusers and grilles were placed into the ceiling system (see Figure 2), the resulting noise flanking paths decreased the CAC_{system} rating by 10 points overall and decreased high-frequency isolation (1,000 Hz octave band and higher), which is more relevant to whether or not speech is intelligible, by 15-22 dB.

Noise flanking paths through ceiling systems can, at times, be prevented or remediated using site-built or commercially available noise control measures. The authors tested these and found that the CAC_{system} ratings can be brought back up to the CAC_{panel} ratings, but the details of those tests are beyond the scope of this article. Note that the noise control measures used to make CAC_{system} ratings equivalent to CAC_{panel} ratings are typically outside an interior contractor's normal installation processes. They can be difficult and time consuming to install and prevent easy access to the plenum by maintenance personnel.

The acoustics sections in building standards, guidelines and rating systems often have sound transmission class (STC) (or noise isolation class) requirements of STC 40, 45 or 50 between enclosed rooms. Studies by the authors show that even the highest performing lightweight, modular, acoustical ceilings by themselves are typically unable to meet even the lowest level of these isolation criteria once common noise flanking paths are taken into account.

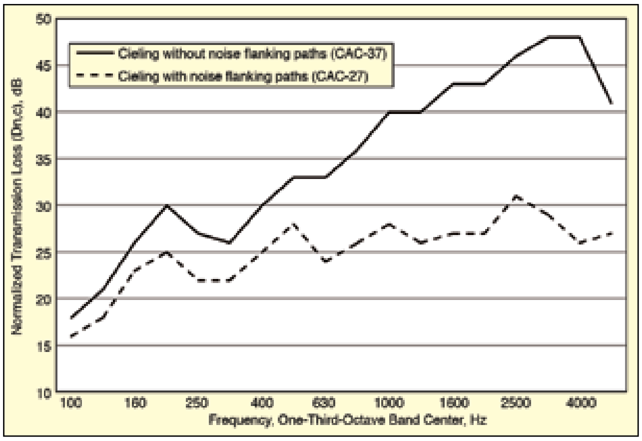

Figure 1. Noise flanking paths caused by common elements penetrating ceiling system can result in significant degradation to isolating capacity of ceiling system. [2]

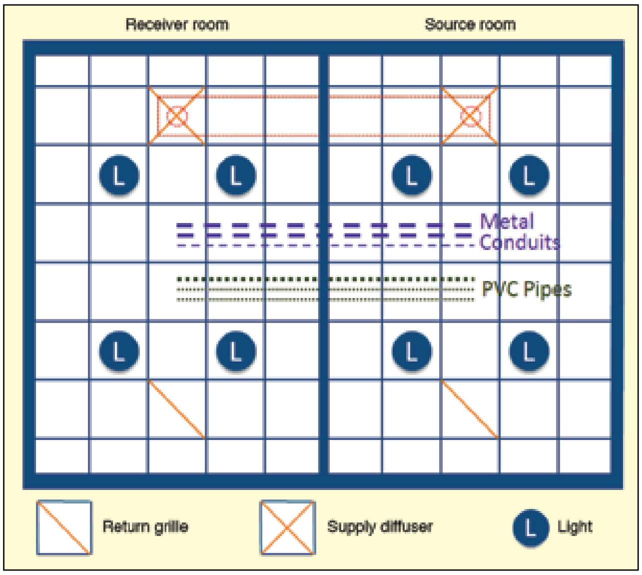

Figure 2. Reflected ceiling plan showing locations of lights and air devices during tests.

The Building Science Branch of the Alberta Public Works, Supply and Services has conducted extensive research on the sound isolation between rooms with suspended ceilings.[3] It states that attempting to match the CAC_{system} rating to the performance of the demising wall can lead to disappointing results. They conclude that the most effective method of reducing sound transmission through the ceiling is to introduce a barrier into the plenum. They found that the plenum barrier can be limited in length. It only has to be positioned above the demising wall between the two adjacent rooms. It does not need to extend around the entire perimeters of

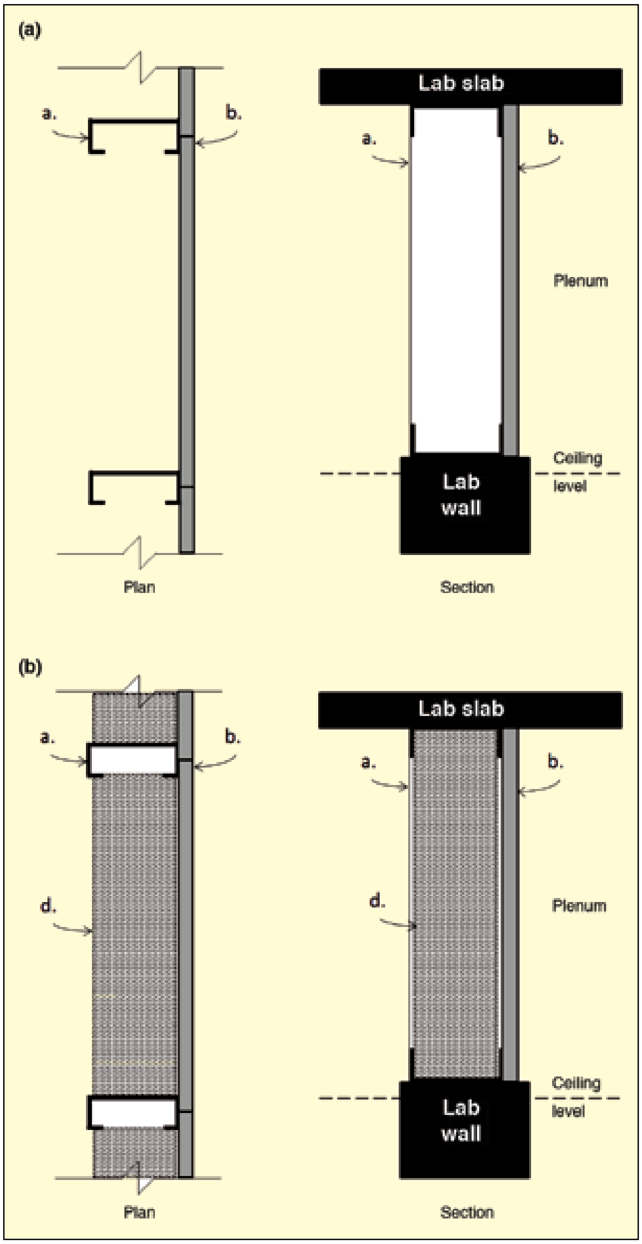

Figure 3. Drywall plenum barriers, (a) without insulation, (b) with insulation type "d" in the materials list.

Figure 4. A quick installation technique was used for some of the drywall barriers: (a) large openings were left around the penetrating elements so simple rectangular pieces of drywall could be used; those openings were stuffed with pieces of stone wool insulation; (b) large gaps between pieces of drywall and around the penetrating elements were not caulked or taped; light shining through the gaps from the opposite side of the barrier show their size and extent.

both rooms.

While the prior research is informative, it does not tell the industry exactly how to optimize ceilings and plenum barriers as they would appear in buildings to reach the specific performance levels required by the standards, guidelines and rating systems. Therefore, the current research investigates which lightweight plenum barrier materials and installation techniques, when combined with absorptive, suspended, acoustical ceiling systems, result in CAC_{system} ratings of 40, 45 and 50 points. Throughout the course of the research, the ceiling systems had recessed light fixtures, supply diffusers and open return air grilles that had no noise flanking remediation measures. In addition, the plenum had multiple pipes, conduits and a duct penetrating the top of wall barriers. These steps were incorporated to make the results as applicable to real-world conditions as possible.

Method

A series of CAC tests was performed at NGC Testing Services, (a fully accredited fire, acoustical, and structural/physical testing facility located in Buffalo, NY, NVLAP Laboratory Code 200291-0) per ASTM E 1414 and E 413 on a suspended, modular, acoustical ceiling system with and without various lightweight plenum barriers. For the baseline test, the specimen comprised a metal suspension grid, stone wool ceiling panels, light fixtures, return air grilles and supply air diffusers, but no plenum barrier above the demising wall. Subsequent tests added various lightweight plenum barriers.

Detailed descriptions of the components used during the testing can be provided upon request. The ceiling panels were 5/8-inch-thick stone wool (NRC 0.75, CAC_{panel} 23). The grid was a standard 15/16-inch tee-bar grid installed in an *interrupted* manner, meaning the wall stopped flush with the top of the grid and panels. No grid members or panels spanned over the top of the wall. The return air grilles were open, egg-crate style. The supply diffusers were square, plaque style. A rigid metal supply air duct internally lined with 1-inch-thick fiberglass duct lining connected the two diffusers. The light fixtures were general-purpose T8 troffers with open, egg-crate louvers. Along with the duct, there were three PVC pipes and three metal conduits up to 4 inches in diameter running through the plenum over the central demising wall. Figure 2 shows the reflected ceiling plan with the locations of all air distribution devices, light fixtures, pipes and conduits.

The various tested plenum barriers used different combinations of the materials listed below. The letter designations in this materials list are also used in the barrier construction drawings in this article:

- Metal stud, 3-5/8 inches wide, 24 inches on center, 25 gauge
- Drywall, Type X, 5/8-inch thick, 2.3 psf
- Limp, mass loaded vinyl (MLV), 0.10 inch thick, 1 psf
- Stone wool insulation #1, 3-1/2 inches thick, 0.78 pcf, unfaced

Figure 5. A sealed installation technique was used for some of the drywall barriers: (a) drywall was cut closely around the penetrating elements and caulked; (b) joints, screw heads and penetrations were sealed with metal tape.

- Stone wool insulation #2, 1-3/16 inches thick , 0.72 pcf, foil one side
- Fiberglass insulation, 3-1/2 inches thick, 0.16 pcf, unfaced

In addition to these materials, metal tape, acoustical caulk, fasteners, etc. were used to hold the barriers in place and, at times, to seal the joints and seams.

Three series of tests were conducted:

- Drywall plenum barriers
- Mass loaded vinyl (MLV) plenum barriers
- Stone wool insulation plenum barriers

The test series with drywall plenum barriers investigated the installation technique (quick and sealed) and the effect of adding insulation. Figure 3 shows the configurations of the drywall barriers without the stone wool insulation (*a*) and with the stone wool insulation (*b*); this is "d" in the materials list.

Two installation techniques were used for the drywall plenum barriers; *quick* and *sealed*. Figure 4 shows the quick installation technique using rough-cut, rectangular pieces of drywall. There were large gaps and openings, especially around the elements that penetrated the plenum barrier. Large openings were stuffed with scraps of stone wool insulation. Smaller gaps were left open. No tape or caulk was used. Some of the open gaps were as large as 1 inch wide and 24 inches long.

Figure 5 shows the *sealed* drywall installation technique using drywall that was cut close around the penetrating elements. Gaps were generally less than a half inch wide. Joints and screw heads were sealed with metal tape, and gaps around the penetrating elements were sealed with flexible caulk.

The test series with MLV plenum barriers investigated the effect of adding different types of insulation along with the MLV. Figure 6 shows the configurations of the MLV barriers without any insula-

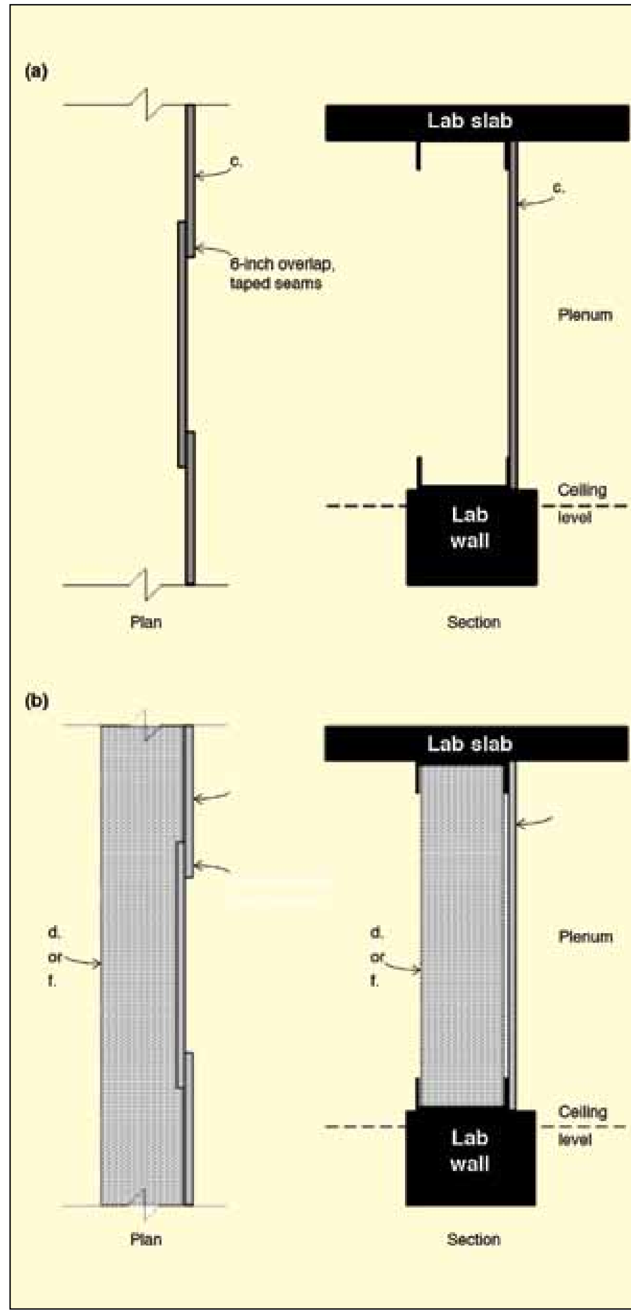

Figure 6. (a) Mass-loaded vinyl (MLV) plenum barriers without insulation; (b) with insulation type d or insulation type f in materials list.

tion (a) and with either fiberglass insulation (f in the materials list) or the stone wool insulation (b) d in the materials list. Adjacent pieces of the MLV were overlapped 6 inches and then taped on one side only to ensure they stayed in place.

The test series with stone wool insulation plenum barriers investigated the effect of one layer versus two layers separated by an air space. Figure 7 shows the configurations of the stone wool insulation barriers (e in the materials list) with one layer (a) and two layers with a ¾-inch-wide airspace between them (b). Adjacent pieces of insulation were butted end to end, and then metal tape was applied to the foil facing on one side of the insulation over the vertical seams.

Results

Figures 8, 9 and 10 show the results of the testing. The baseline condition in all three figures is a ceiling system with stone wool panels and all of the noise flanking paths shown in Figure 2. No flanking path noise remediation was used. For each of the tested plenum barriers, this baseline ceiling system was maintained.

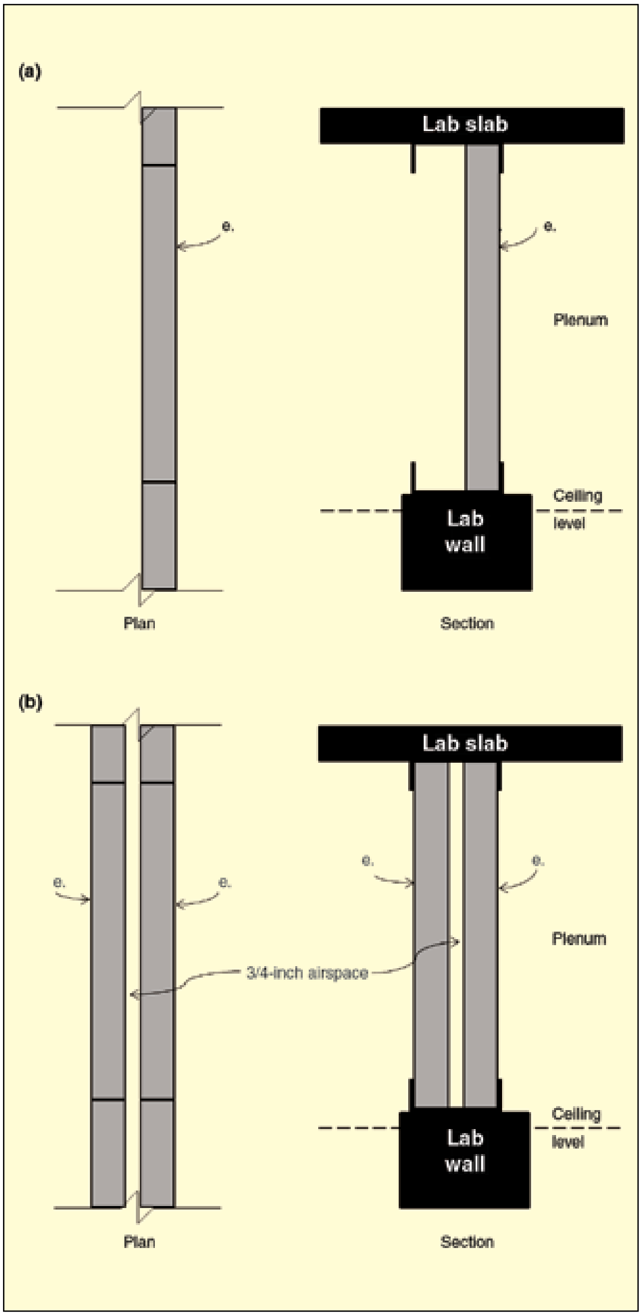

Figure 7. (a) Stone wool plenum barriers (insulation type e in materials list) one layer only (b) two layers separated by a ¾-inch air space.

The figures also include the results of a ceiling system with mineral fiber panels for reference purposes only. The test specimen was a ceiling system comprised of 5/8-inch-thick mineral fiber panels (CAC_{panel} 37) and all of the same noise flanking paths shown in Figure 2. The flanking paths decreased the CAC_{panel} from 37 to CAC_{system} of 27. The data for the mineral fiber ceiling panels are included in the figures so that the relatively small effect of the type of ceiling panel on overall isolation can be seen compared to the more substantial effect of the plenum barriers being studied. Also, people are more familiar with mineral fiber panels than with stone wool ceiling panels, so including their data preempts the anticipated question of how a mineral fiber ceiling panel would compare.

The plenum barriers were not tested with the mineral fiber ceiling panels in the ceiling system, because testing time and resources were limited. The combined effect of the plenum barriers with mineral fiber ceiling panels is unknown. It is reasonable to speculate that it would not be any lower in performance than the results with the stone wool ceiling panels.

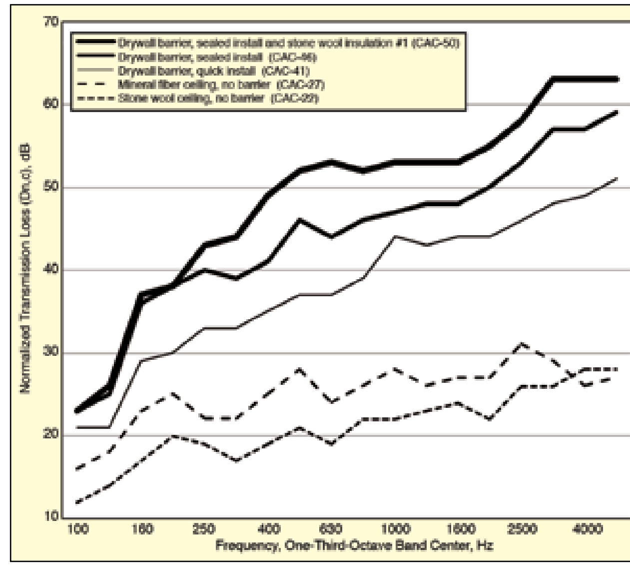

Figure 8. Use of lightweight, drywall, plenum barriers with ceiling systems increases inter-room sound isolation by 14 - 28 CAC points compared with using ceiling systems alone; plenum barriers make total blocking capacity of the ceiling/plenum path more similar to blocking capacity of STC 40, 45 and 50 walls below the ceiling.

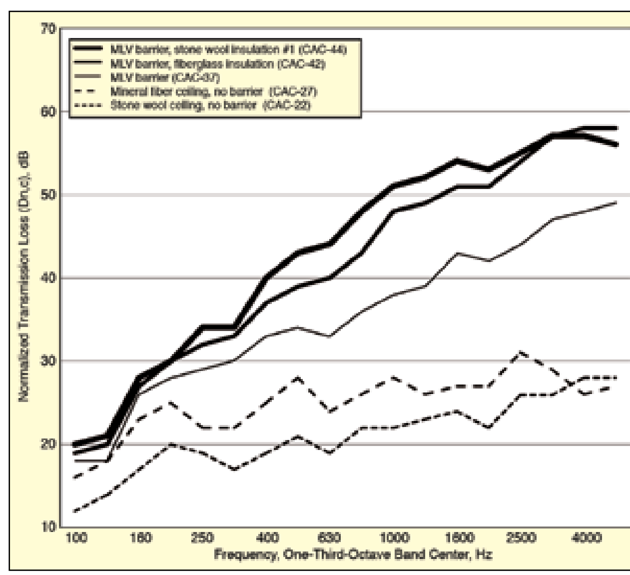

Figure 9. Use of lightweight, MLV, plenum barriers with ceiling systems increases inter-room sound isolation by 10 - 22 CAC points compared with using ceiling systems alone; plenum barriers make total blocking capacity of the ceiling/plenum path similar to blocking capacity of STC 40 and STC 45 walls below the ceiling.

Discussion and Conclusions

Acoustical standards, guidelines and rating systems generally require isolation between rooms to be STC/CAC 40, 45 or 50. It is possible to achieve the lowest level of acceptable sound isolation, STC/CAC 40, using ceiling systems alone without a plenum barrier. This approach requires a ceiling panel with a CAC_{panel} rating of 40 or higher that also maintains a good sound absorption rating. Otherwise, meeting the maximum reverberation time requirements might require additional absorption on the walls.

In addition to using ceiling panels with ratings of CAC_{panel} 40 or higher, all noise flanking paths through the ceiling system need to be either prevented or be remediated. This is possible, but it could affect aesthetics. Examples include: needing to use suspended lights versus recessed lights, or selecting a return air grille that works with a certain remediation device, such as lined elbow duct or silencer, as opposed to one that is more aesthetically pleasing. Noise flanking path remediation such as insulation and MLV placed over elements including recessed light fixtures and supply diffus-

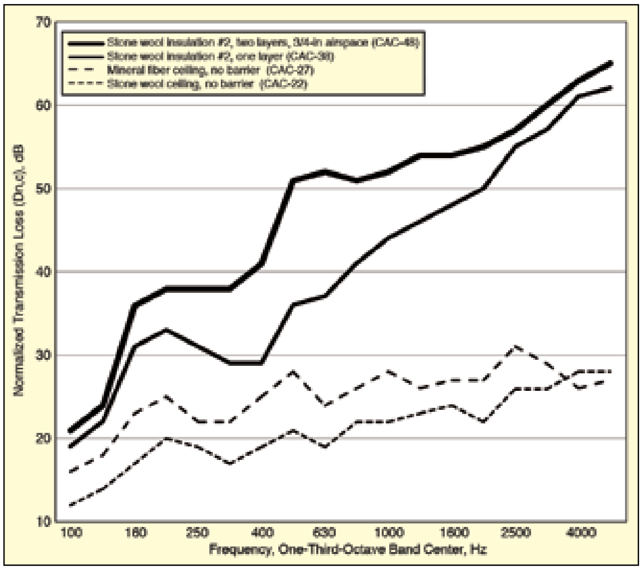

Figure 10. Use of lightweight, stone wool insulation, plenum barriers with ceiling systems increases inter-room sound isolation by 11 - 26 CAC points compared with using ceiling systems alone; plenum barriers make total blocking capacity of the ceiling/plenum path similar to blocking capacity of STC 40, 45 and 50 walls below the ceiling.

ers can inhibit access to the plenum by maintenance personnel.

It is much easier in principal to achieve the required STC/CAC 40, 45 and 50 levels of sound isolation using full-height walls. This approach eliminates the need for the ceiling panels to block sound that would otherwise flank over the top of a partial-height wall. This approach also eliminates the need for any remediation of noise flanking paths through the ceiling. The designer is not limited in aesthetic options due to noise-related constraints. Most importantly, this approach also permits the ceiling panels themselves to be highly sound absorptive. One does not need to sacrifice absorption for blocking capacity, since the two are often inversely related.

All of these benefits are why acoustical standards, guidelines and rating systems either require or prefer full-height walls. The downside to this preferred approach is that it can be expensive to extend the entire wall construction full height.

The results of this research are consistent with prior research.[1,3] Using a lightweight plenum barrier that extends from the top of the demising wall to the underside of the deck above, in combination with a suspended, acoustical, ceiling system, may be optimal. These plenum barriers can be made of drywall, MLV, stone wool insulation or a combination.

The resulting CAC values can reach the STC/CAC 40, 45 and 50 levels required by the acoustical standards, guidelines and rating systems. If the lowest level of isolation (STC/CAC 40) is compliant, then the installing plenum barriers can be quick and does not necessarily require airtight sealing of all joints and gaps. The monetary savings associated with using plenum barriers is the focus of the next phase of the research. Previous studies by the Institute for Research in Construction, National Research Council of Canada[1] report that lightweight, plenum barriers made of insulation can be one-third the cost of extending the demising walls full height.

References

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3. K. Kruger, "The Effect of Various Parameters on the Sound Isolation between Offices with Suspended Ceilings," *Canadian Acoustics*, Vol. 16, No. 2, pp.9-23, 1988.

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The author can be reached at: gary.madaras@rockfon.com.