Look ~ do you see the noise leaking through that ceiling?

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ABSTRACT

Oftentimes, acousticians must convey complex, three-dimensional, acoustical, phenomena that occur within and between rooms in buildings to architects, interior designers and other visually-oriented people. The message can be lost during translation from quantitative acoustics metrics and their acronyms to the design and intersection of actual building elements such as walls and ceilings. The current phase of the Optimized Acoustics Research Program focuses on turning sound absorption and sound isolation performance visual by using color mapping. Much like how a thermal imaging camera shows differences in surface temperatures, a sound intensity probe is being used to produce high definition color sound mapping of noise transmitting through acoustical ceiling systems and sound reflecting off or being absorbed by surfaces with different absorption coefficients. This measurement and communication method helps to bridge the gap between the technical, quantitative side of acoustics and the visual side of design in an impactful and memorable way.

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1 INTRODUCTION

Since 2014, the Optimized Acoustic Research Program has been researching and testing ways to optimize the acoustic performance of various types of interior wall and ceiling configurations in order to comply with the acoustical criteria in building standards, guidelines and rating systems in cost efficient manners. Findings from prior phases have been useful to the architectural and acoustical fields and have influenced the development of industry standards. The negative impact of penetrations in a suspended acoustic ceiling when the wall does not extend full height and block off the plenum above the ceiling has been quantified.[1] The inability of a suspended acoustical ceiling alone to block noise transfer between rooms at a level required by the standards has been shown.[1-5] The optimal approach of combining lightweight acoustical plenum barriers above the walls with suspended acoustical ceilings to comply with requirements in standards has been well-proven.[4-5]

The results of these multiyear, ongoing efforts have taken the form of one-third, octave band, transmission loss values, ceiling attenuation class ratings (CAC), sound transmission class (STC) ratings, graphs, tables and various other quantitative parameters. The results are mainly intended for use by architects, interior designers, contractors and building owners. These visually-oriented people tend to be less knowledgeable about acoustic metrics than acousticians. As a result, communicating the main findings of the research often requires more time and complexity than it should. Some uncertainty always remains as to whether the full message was communicated. It was clear that a different method of communicating the research findings to visually-oriented professionals such as architects and interior designers had to be developed. The decision was made to convert the quantitative findings of the research program into easy-to-interpret color maps overlaid on top of high definition images of the actual architecture. It is believed that using this method expedites the communication process and helps architects, interior designers, contractors and building owners remember the information for application on subsequent projects.

2 METHOD

2.1 Test Facility and Procedure

All testing was completed at NGC Testing Services in Buffalo, NY. The laboratory is accredited by the National Voluntary Laboratory Accreditation Program (NVLAP) (Laboratory Code 200291-0). Tests were performed according to ASTM E 1414 and E 413. Figure 1 shows the layout of the test chamber and the general layout of the ceiling system test specimens.

2.2 Ceiling Panels and Suspension System

Ceiling panels of different types and acoustic performance levels were used. Wet-formed, mineral-fiber, panels had noise reduction coefficient (NRC) ratings per ASTM C 423 of 0.60, 0.70 and 0.80 and a CAC_{panel} rating per ASTM E1414 and E413 of 35. Stone wool ceiling panels had NRC ratings of 0.85 and 0.95 and a CAC_{panel} rating of 22. All panels were white and measured 1220 mm (48 inches) (nominal) in length by 610 mm (24 inches) (nominal) in width with square, lay-in edges.

The suspension system was a standard 24 mm (15/16 inch) wide, 38 mm (1-1/2 inches) high, steel, tee-bar suspension grid. Refer to Figure 1 for the layout of the suspension grid and ceiling panels in the test chamber. The grid was installed in an uninterrupted manner, meaning the grid ran continuously over the central demising wall. When a plenum barrier was not included in the test, the ceiling panels ran continuously over the central demising wall.

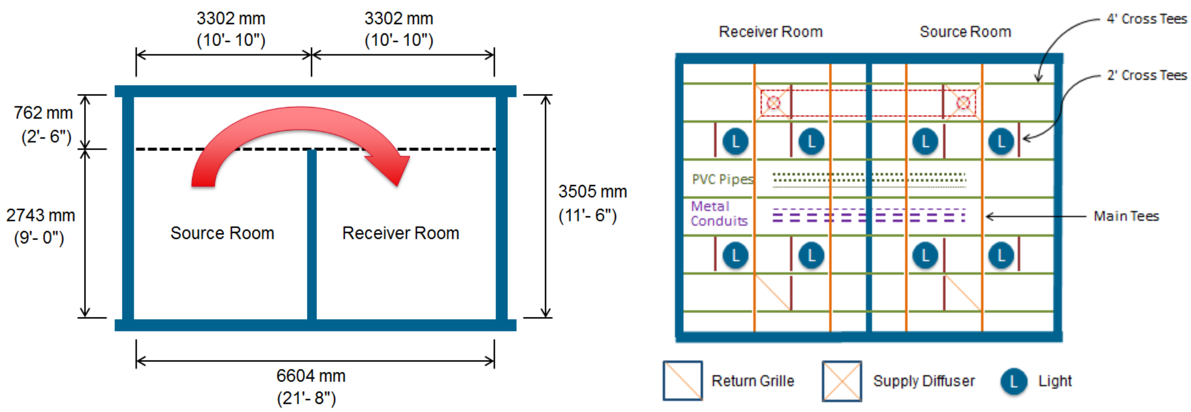

Fig. 1 – A section drawing showing the size and configuration of the test chambers (left) and a reflected ceiling plan drawing showing the layout of the suspended acoustic ceiling system including light fixtures, supply air diffusers, return air grilles as well as pipes, conduits and a duct in the plenum above the ceiling.

2.3 Air Distribution System Components

The return air grilles were MetalAire® model CC5-6. They were aluminum, 610 mm (24 inches) (nominal) in length and width and had a 13 mm (1/2 inch) by 13 mm (1/2 inch) by 13 mm (1/2 inch) open, egg-crate grille. This type of return air grille was selected because of its frequent use in a wide variety of commercial building types.

The supply air diffusers were Price® square plaque diffusers model SPD 40101505. They were 610 mm (24 inches) (nominal) in length and width by 89 mm (3-1/2 inches) high. They were steel with a white powder coat finish and had a 254 mm (10 inches) round duct connection. Square plaque diffusers were selected because they are one of the most commonly used types of air diffusers in commercial buildings.

The supply air diffusers were connected with a supply air duct. A rigid metal duct measuring 457 mm (18 inches) wide by 356 mm (14 inches) high by 3658 mm (12 feet) long and with 25 mm (1 inch) thick internal lining ran through the plenum from one side to the other over the demising wall. The supply diffusers were connected to the rigid metal duct above with insulated, round, flexible ducts with a 254 mm (10 inches) inside diameter made by Atco Rubber Products, Inc. There was no main duct that fed air into the supply air system. The air in the system was therefore not moving.

2.4 Light Fixtures

The light fixtures were Lithonia Lighting® general purpose T8 troffer model 2GT8 2 U316 A. They were 610 mm (24 inches) (nominal) in length and width. They had an eggcrate louvre with openings that were 19 mm (3/4 inch) by 19 mm (3/4 inch) by 13 mm (1/2 inch) high. No bulbs were installed in the lights and they did not have electrical connections. These were judged to have no effect on the parameters being studied.

2.5 Pipes and Conduits

In addition to the rigid metal duct described above in section 2.3, there were also three PVC pipes and three metal conduits of varying sizes between 25 mm (1 inch) and 100 mm (4 inches) suspended in the plenum and crossing over the chamber's central demising wall. The pipes and conduits were stuffed with stone wool insulation from both ends to a distance of about three to four feet to damp them and limit the potential for resonances that could interfere with the test results.

2.6 Plenum Barrier Components and Installation

Some tests included a lightweight, acoustic, plenum barrier made of stone wool insulation with the following properties: thickness 38 mm (1-1/2 inches), density 128 kg/m3 (8.0 pcf), surface weight 7.32 kg/m^2 (1.5 psf). The plenum barrier had a fiber-reinforced, aluminum foil facing adhered to one side. Some tests used a single-layer plenum barrier. Other tests used a double-layer plenum barrier, whereby the two layers were separated by a 42 mm (1-5/8" inches) airspace. When the double-layer plenum barrier was used, the foil was oriented towards the open ceiling plenum, not into the small, interstitial airspace between the two layers. Not all tests included a plenum barrier.

Figure 2 shows how the plenum barriers were mechanically fastened along the top edge using common, self-tapping, sheet metal screws with insulation washers into a common 41 mm (1-5/8 inches) wide metal channel that was attached to the test chamber overhead slab. Screws were spaced approximately 305 mm (12 inches) to 457 mm (18 inches) on center. Typically each 610 mm (24 inch) panel had two screws along the top. The bottoms of the plenum barrier panels were only friction-fitted against the top track of the demising wall and the grid. They were not mechanically fastened, glued or caulked. Each panel was abutted to the adjacent panels along the sides with no overlap. The vertical seams between adjacent panels were taped using 50 mm (2 inch) wide metal tape for sealing butt-joints. When the double-layer plenum barriers were tested, the 610 mm (24 inch) wide panels were staggered 305 mm (12 inches) so that the seams were not aligned. This required a small cut along the bottom of one layer of the plenum barrier panels so that they could slide down over the grid bulb and allow the bottom of the plenum barrier panel to sit on the top track of the demising wall. No caulk or sealant was used. Small gaps around and in between some of the plenum barrier panels were visible. Most gaps were closed during installation due to the pliability of the stone wool. The panels were cut slightly oversized and then compressed vertically and laterally during installation, which helped prevent gaps.

2.7 Color Mapping Instrumentation

In addition to the standard CAC measurements performed on each ceiling or ceiling and plenum barrier combination, a commercially-available, sound color mapping system was used to create color sound maps superimposed over pictures of each architectural test specimen. The color sound maps were created by using specialty software to combine in real-time the acoustic data from a sound intensity probe with its position data from a position tracking device. Two different types of color sound maps were created.

Fig. 2 - Lightweight, stone wool, plenum barriers installed above the central demising wall of the laboratory's chamber during some tests. Top-left: Single-layer. Top-right: Double-layer with a 42 mm (1-5/8 inches) airspace in between. Bottom-left: Double-layer with seams staggered and small cuts at the bottom so the panels slide down over the grid bulb. Bottom-right: Intallation complete with tops screwed, seams taped and ceiling panels installed.

The first type of color sound maps show sound transmission through the test specimen from a sound source located in the adjacent chamber room (refer to Figures 4 and 5). After the test specimen was installed and the CAC rating was measured, the white noise sound source in the source room was turned back on. The sound intensity probe was then scanned over a large section of the ceiling in the chamber receiver room, creating the color sound transmission maps.

The second type of sound maps show sound absorption and reflection off the ceiling system (refer to Figures 6 and 7). After the test specimen was installed and the CAC rating was measured, the white noise sound source was moved into the chamber receiver room where the scanning with the probe was occurring. The sound intensity probe was then scanned over the same large section of the ceiling in the receiver room, creating the color absorption maps.

3 RESULTS

Figure 3 shows the typical ceiling layout in the chamber receiver room for reference purposes. The same ceiling layout was also installed in the adjacent chamber source room. The common wall between the two rooms, which stops at the underside of the ceiling and leaves the plenum open, occurs along the bottom of the image. The plaque-style, supply-air, diffuser is shown on the left side. The four recessed light fixtures are shown in the center. The return-air grille is shown on the right. Throughout the duration of the testing, different ceiling panels alone or different ceiling panel and plenum barrier combinations were installed and tested.

Fig. 3 – The typical ceiling system configuration used throughout the testing with various acoustic ceiling panels suspended in a metal grid and with light fixtures and supply and return air devices.

3.1 Transmission Color Mapping

Figures 4 and 5 show two example color maps of sound transmitting from the chamber source room into the chamber receiver room via the plenum above the ceiling. In Figure 4, the test specimen included wet-formed, mineral-fiber, acoustic ceiling panels with a NRC rating of 0.60 and tested CAC rating of 37. The declared CAC rating was 35, two points lower. No plenum barrier was included. In addition to seeing a lot of noise leaking through the light fixtures and air devices, noise can also be seen leaking between the top of the wall and the underside of the ceiling along the bottom of the image. The combined effects of all the noise leaks are visually evident in red and yellow colors. Note that the entire ceiling was not scanned with the sound intensity probe. Some areas of the ceiling (e.g., top and left edges) do not have data/color overlaid. The noise leaks decrease the CAC_{panel} rating of 37 down to a CAC_{system} rating of 27, a 10 point decrease.

In Figure 5, the test specimen included stone wool acoustic ceiling panels with a NRC of 0.95 and a CAC_{panel} rating of 22. A double-layer plenum barrier was installed. The improved acoustic performance is visually evident when compared with Figure 4. There are no red or yellow areas. The predominantly purple color map indicates that this design approach results in any transmitted noise being 20-25 dB lower in level. The use of the plenum barrier increased the CAC_{system} rating to 49, despite the CAC_{panel} rating being lower at 22.

3.2 Absorption Color Mapping

Figures 6 and 7 show two example color maps of sound being either reflected off a low NRC ceiling or being absorbed by a high NRC ceiling. In Figure 6, the test specimen is wet-formed, mineral-fiber panels with a NRC rating of 0.60. During absorption tests, the presence or absence of a plenum barrier is irrelevant. It is useful to evaluate the sound reflecting off the ceiling panels (yellow) relative to that being reflected off the sound-reflective, metal, housings of the supply-air diffuser and light fixtures (red). The sound reflecting off the ceiling panels is only 3-4 dB less than that reflecting off these other hard surfaces. In contrast, the sound being 'absorbed' by the open return air grille (blue), represents complete absorption because the sound is passing through the grille. This area of the map is eight dB lower in level than that reflecting off the light fixtures and air devices. Ideally, as the color of the sound reflecting off the ceiling approaches blue, the absorption performance of the ceiling is maximized.

In Figure 7, the test specimen is stone wool ceiling panels with NRC rating of 0.95. In this example we see the sound not reflecting off the ceiling panels in blue color, the same ideal performance level provided by the open return air grille. The sound reflecting off the hard metal light fixtures and supply air diffuser is still shown in red and is approximately 9 dB louder than the sound reflecting off the ceiling panels.

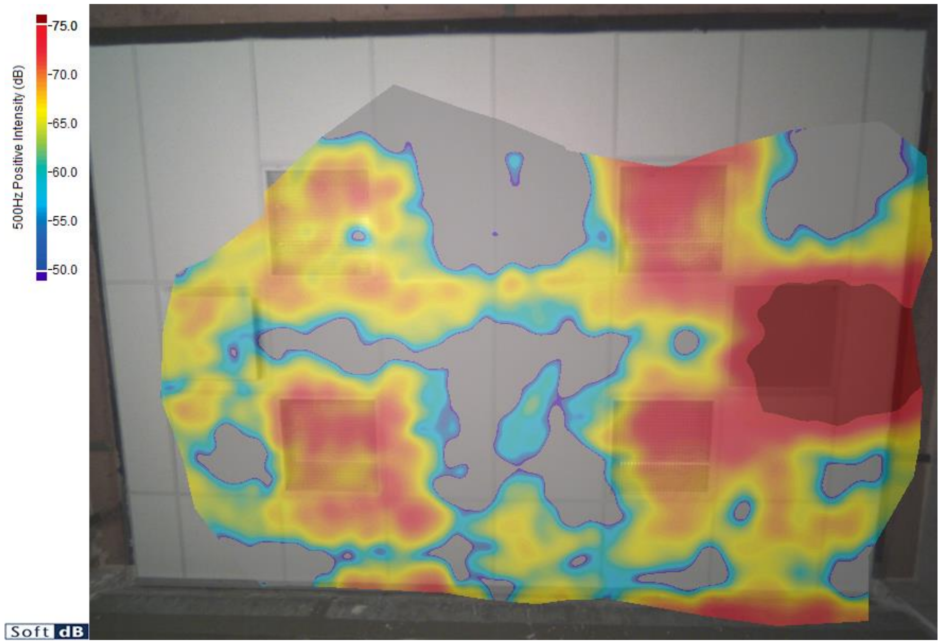

Fig. 4 – A color map showing sound transmission through the ceiling, 500 Hz octave band, mineral fiber ceiling panels (NRC 0.60, CAC_{panel} 37), no plenum barrier. The sound transmitting through the ceiling penetrations for lights and air devices decreases CAC_{panel} 37 to CAC_{system} 27.

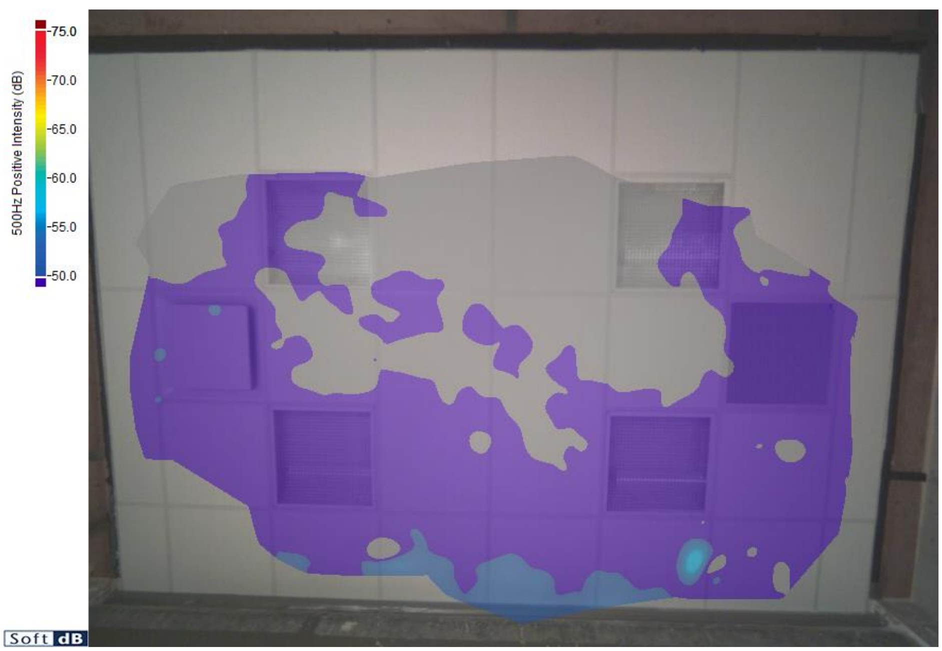

Fig. 5 – A color map showing sound transmission through the ceiling and plenum barrier combination, 500 Hz octave band, stone wool ceiling panels (NRC 0.95, CAC_{panel} 22), double-layer plenum barrier. Using a plenum barrier improved overall performance to CAC_{system} 49.

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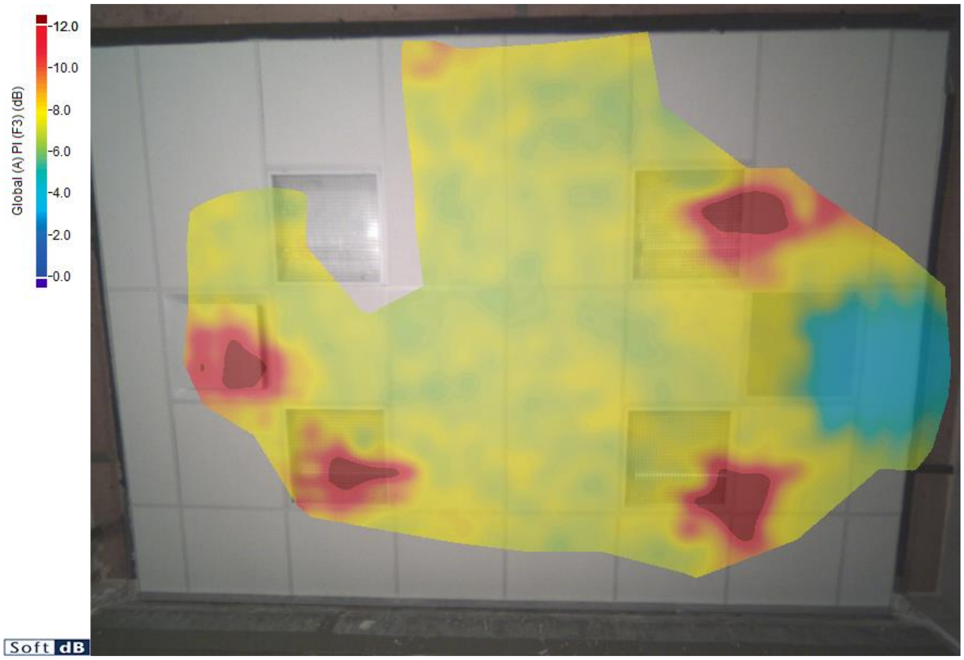

Fig. 6 – A color map showing sound reflecting off a mineral-fiber panel acoustic ceiling with a NRC rating of 0.60 (yellow).

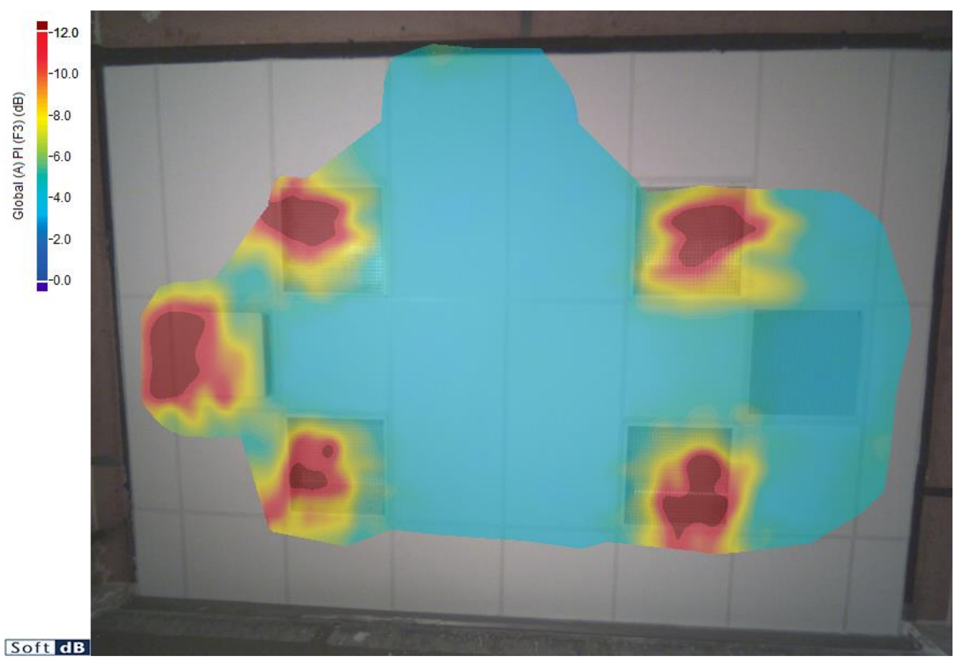

Fig. 7 - A color map showing sound being absorbed by a stone wool panel acoustic ceiling with a NRC rating of 0.95 (blue).

4 CONCLUSIONS

While only four example color maps are provided in the results section, there are many more opportunities to compare visually the performance of different design approaches, materials and assemblies at different frequencies. The goal of this phase of the research is not to compare design approaches, but instead to demonstrate that a valid method of turning acoustic performance, both sound absorption and sound transmission, visual has been found. Initial use of these visual tools with architects, interior designers, contractors and building owners has shown that they greatly aid communication of complex acoustic phenomena. The main points of the acoustic design conversation are quickly conveyed and understood. As such, it is assumed that the information will more likely be applied to projects in the future.

5 ACKNOWLEDGEMENTS

The author wishes to acknowledge Rockfon for conducting the Optimized Acoustics Research program, NGC Testing Services for their long-term commitment to the program and A3 Acoustics for conducting the sound intensity scanning and producing the color absorption and transmission loss maps.

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