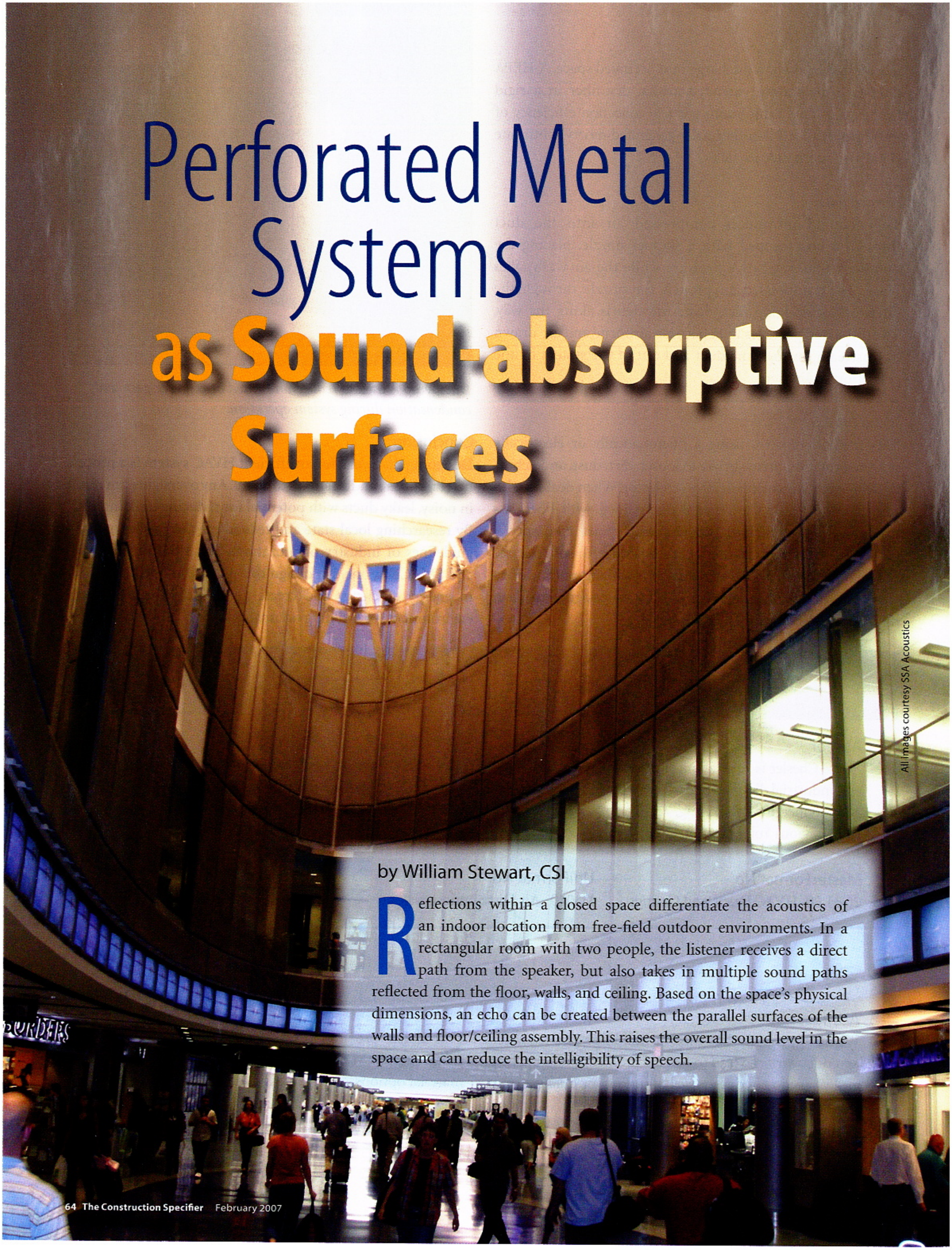
Perforated Metal Systems as Sound-absorptive Surfaces



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by William Stewart, CSI

Reflections within a closed space differentiate the acoustics of an indoor location from free-field outdoor environments. In a rectangular room with two people, the listener receives a direct path from the speaker, but also takes in multiple sound paths reflected from the floor, walls, and ceiling. Based on the space's physical dimensions, an echo can be created between the parallel surfaces of the walls and floor/ceiling assembly. This raises the overall sound level in the space and can reduce the intelligibility of speech.

Figure 1 Recommended Reverberation Times by Space

Type of space	Reverberation time
Concert auditoria	0.9 to 1.5
Contemporary churches	1.1 to 1.8
Multipurpose auditoria	1.3 to 1.7
Movie theaters	0.3 to 0.8
Gymnasia	0.7 to 1.5
Cafeterias	0.7 to 1.2
Lecture halls	0.7 to 1.3
Classrooms	0.4 to 0.6
Meeting rooms	0.6 to 1.0
Fine restaurant	0.8 to 1.2
Lobby	1.2 to 1.8

Acceptable levels for reflectivity have been established to assist designers in developing solutions for different types of spaces. Reverberation time (RT_{60}) is defined as the number of seconds it takes a sound to decay by 60 decibels. This measurement is made over a wide range of frequencies (grouped into octave bands) to develop ideal levels of reflectivity for different types of spaces. Performing areas (*e.g.* concert halls) are more sensitive to these requirements than others, but general listening spaces (*e.g.* restaurants, conference rooms, libraries, and classrooms) can benefit from good reverberation times. Figure 1 provides a list of mid-frequency reverberation times for a variety of spaces.

While using acoustic products like fiberglass can help, these products are not always considered ideal for spaces where there will be a lot of contact with wall surfaces. A good example is a common area in a middle school where sound absorption is essential, but fabric wall panels are likely to be damaged in a relatively short time. However, in this type of environment, perforated metal decking can be furred over a framed wall and become the finished wall surface, protecting the sound-absorptive material beneath while adding to its acoustic capabilities.

Properties of absorptive materials

Before examining the use of perforated metal, a review of the basics of acoustics is in order. Materials are rated for their ability to absorb sound using absorption coefficients (α), which are measured in octave bands. (A rating of '1' is given for a 100-percent absorptive material, while something that is 100-percent reflective at a particular octave band garners a 'zero.') Procedures for measuring these values are established under ASTM International E 1110, *Standard Classification for Determination of Articulation Class.*

To better understand these coefficients, Figure 2 shows the absorption coefficients for a typical fiberglass tile ceiling panel at various octave band frequencies. At 1000 Hz, it absorbs 84 percent of the sound hitting the surface, provided the tile is mounted in the same manner in which the test was conducted. At 250 Hz, the tile has less than half the ability to absorb sound. Figure 3 (page 66) compares the absorptive properties of 152.4-mm (6-in.) fiberglass with 25.4-mm (1-in.) fiberglass.

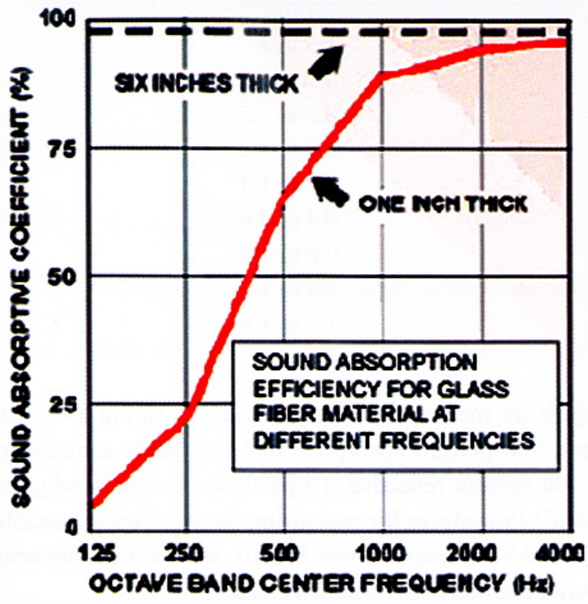
The size of the air space between the absorptive material and a flat surface has a dramatic impact. For example, an absorptive panel mounted directly to the surface of a wall or ceiling performs significantly lower than a panel mounted with an air space as small as 25.4 mm.

The ability of fiberglass to absorb sound is also dependent on its thickness and density. Figure 4 (page 66) shows the characteristics of four different fiberglass boards mounted directly to a hard surface. The figure illustrates high-frequency sound is easier to absorb than low-frequency, and that as the material gets thicker or denser, it absorbs sound better.

Figure 2 Absorption Coefficients for Fiberglass Acoustical Ceiling Tile

Octave band	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Absorption coefficient	0.36	0.41	0.65	0.84	0.90	0.88

Figure 3 Acoustical Performance of Fiberglass at Different Thicknesses



Perforated metals

Perforated metal is primarily made from steel, but it can also be fabricated—usually at a premium—from aluminum or other types of sheet metal. Generally, perforated sheet metal costs approximately $1.50 per 0.09 m^2 (1 sf) and can be purchased as prefabricated panels for wall coverings, attached using a Z channel. They can also be directly furred to the surface of a wall, with fiberglass between the wallboard and the perforated metal skin. In this manner, they can be designed into the assembly using floor-to-ceiling coverage. The products have also 'invaded' a wide range of other acoustical devices, including ceilings, highway barriers, telephone booths, or diesel engine enclosures.

To use perforated metal over sound-absorptive materials, the pattern of holes must be acoustically 'transparent'—the larger the number of small holes, the more easily the sound will pass through. (A standard sized hole for perforated metal is 3.2 mm [1/8 in.].) This quality is defined by the transparency index (TI), which is a function of the:

- hole diameter;
- number of holes per 645 mm^2 (1 si);
- metal thickness; and
- on-center (oc) spacing of the holes.

Theodore J. Schultz, PhD, studied this relationship in his *Acoustical Uses for Perforated Metals: Principles and Applications* (Industrial Perforators Association, 1986). It is described by the following equation:

$$TI = \frac{n \cdot d^2}{t \cdot a^2} = \frac{0.04 \cdot P}{\pi \cdot t\, a^2}$$

Where:
n = number of holes (per si);
b = on-center hole spacing (in.);
d = hole diameter (in.);
a = shortest distance between holes (a = b – d);
t = metal sheet thickness;1 and
P = percent open area.

The amount of energy reflected by perforated metal is determined using a frequency of 10,000 Hz and is calculated with this equation:[2]

$$Attenuation = -22.56 \log[\log(TI)] + 0.0008\sqrt{TI} + 13.79$$

A higher TI is preferable. Figure 5 presents five 20-gauge panels and their transparency index. It is important to note the small, closer spaced holes perform better than the larger ones at greater distances. For most applications, it is enough to be able to understand the higher the TI, the better the performance when the product is used in conjunction with an absorptive material. Simply specifying the transparency index as more than 2000 is usually a safe bet. Nevertheless, the

Figure 4 Absorptive Properties of Differing Thicknesses and Density of Fiberglass

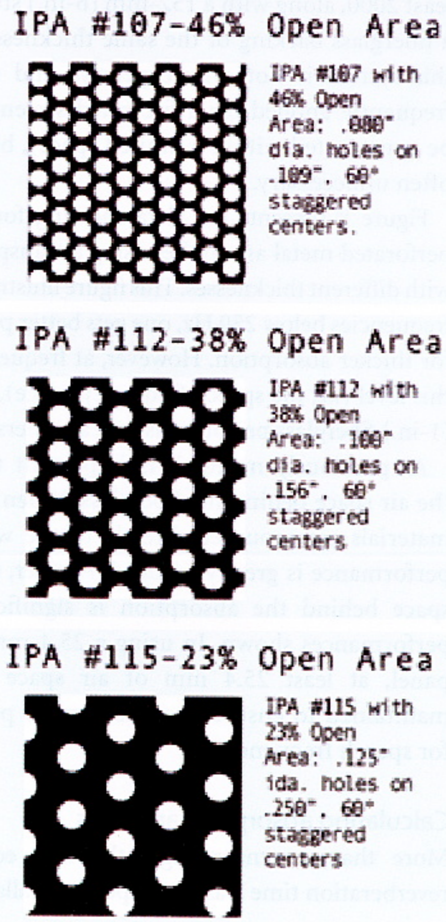
Density	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
25.4-mm (1-in.), 24 kg/m^3 (1.5 pcf)	0.17	0.33	0.64	0.83	0.90	0.92
50.8-mm (2-in.), 24 kg/m^3	0.22	0.67	0.98	1.02	0.98	1.0
25.4-mm, 48 kg/m^3 (3 pcf)	0.11	0.28	0.68	0.90	0.93	0.96
50.8-mm, 48 kg/m^3	0.17	0.86	1.14	1.07	1.02	0.98

Figure 5 Transparency Index (TI) for Various Perforated Metals

Perforated metal description	Transparency index
6.35-mm (0.25-in.) diameter round x 9.53-mm (0.375-in.) 60-degree staggered (*i.e.* off-set by 50 percent), open area (OA) = 40 percent	1000
12.7-mm (0.5-in.) diameter round x 15.88-mm (0.625-in.) 60-degree staggered, OA = 58 percent	1400
3.18-mm (0.125-in.) diameter round x 4.76-mm (0.1875-in.) 60-degree staggered, OA = 40 percent	4000
9.53-mm (0.375-in.) diameter round x 11.11-mm (0.4375-in.) 60-degree staggered, OA = 66 percent	6600
1.9-mm (0.075-in.) diameter round x 2.54-mm (0.10-in.) 60-degree staggered, OA = 51 percent	31,600

calculation can still come in handy for designers considering alternate materials, such as wood or plastic. The potential for using these alternative materials allows the ability to blend into different environments, adding warmth or character. For example, wood perforated ceiling or wall panels can be an ideal solution for a resort or community space.

Figure 6 Perforation Patterns Tested for Transparency

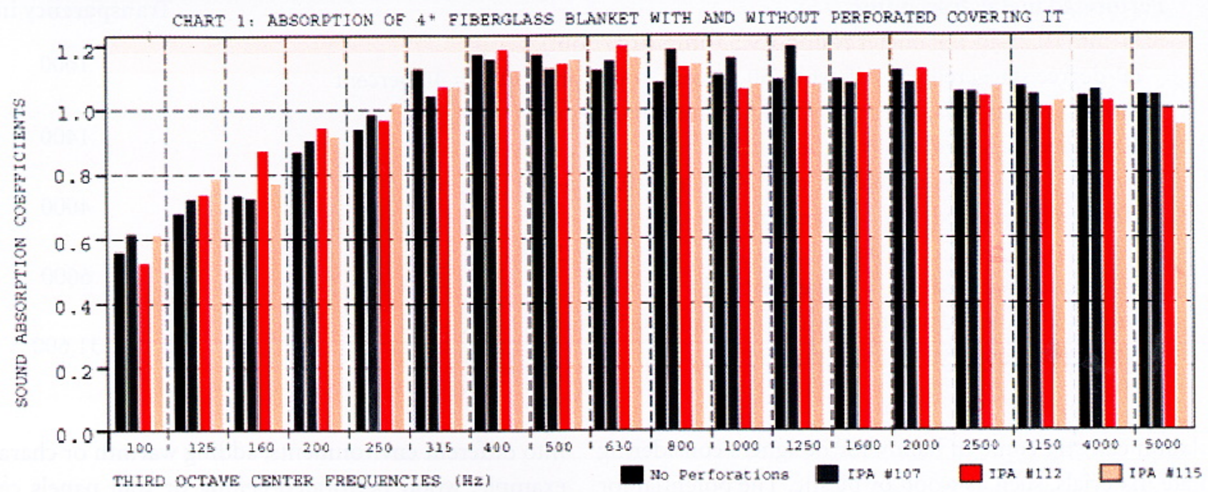


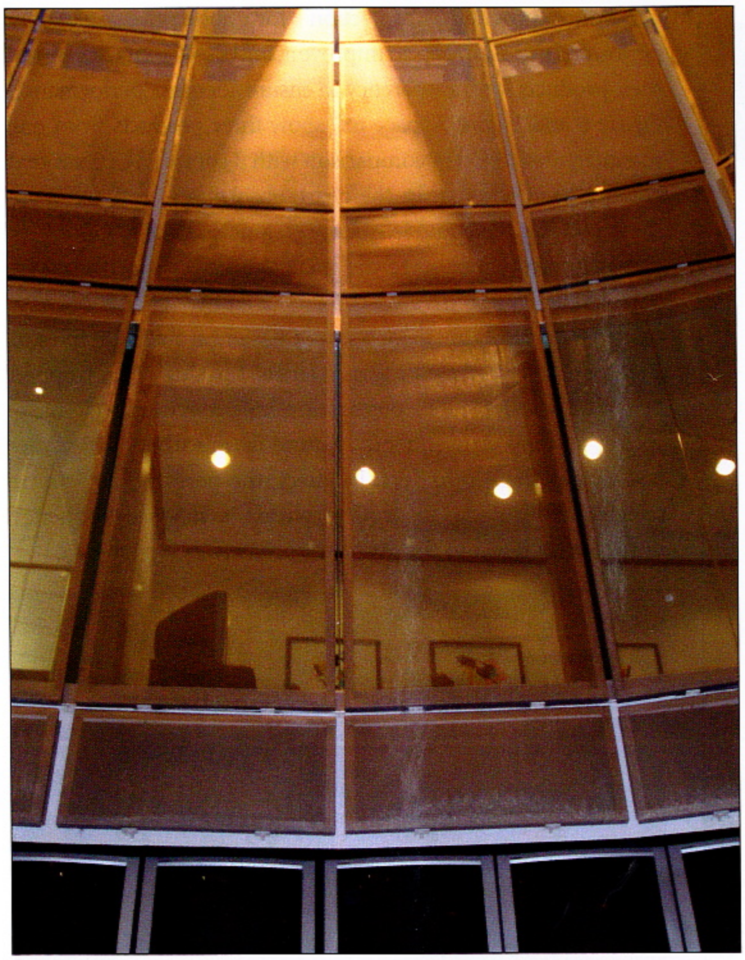
Beyond providing protection for absorptive materials, perforated metal appears to improve acoustics. Manufacturers test their products for transparency to ensure adequate performance. Figure 6 and Figure 7 (page 68) show three products from one manufacturer tested in comparison with a control fiberglass that has not been covered. In the chart, absorption coefficients are shown on the Y-axis and frequency is shown on the X-axis.

It is interesting to note the metal improves the absorptive performance in some areas of the assembly. This is because perforated metal can absorb sound based on the principles of a Helmholtz resonator.[3] In basic terms, the slug of air trapped by the dimension of the perforation hole functions as a mass-spring system; consequently, sound is absorbed by energy loss within these cylinders. In effect, the perforations can be selected to provide absorption within a narrow frequency range (in addition to the absorptive materials it protects).

On this cafeteria wall at Woodward Middle School (Bainbridge Island, Washington), perforated metal provides not only protection for other sound-absorbing surfaces, but also acoustic improvement of its own.

Figure 7 Perforated, Covered Fiberglass versus Non-covered Fiberglass





At George Bush Intercontinental Airport (Houston, Texas), perforated metal systems can help weary travellers hear where they are supposed to be headed to meet their connecting flights. The material also serves as a nice aesthetic complement to other wall systems.

Designing a perforated metal wall

The ideal application for a perforated metal wall includes a large air space and a high-performance absorptive lining. Theoretically, one might conclude the best situation is a perforated metal with a TI of at least 2000, along with a 152-mm (6-in.) stud wall and a fiberglass backing of the same thickness. However, this system is not only expensive and thick (it is frequently applied for a fire-rated system and must be constructed within a limited space), but it is also often unnecessary.

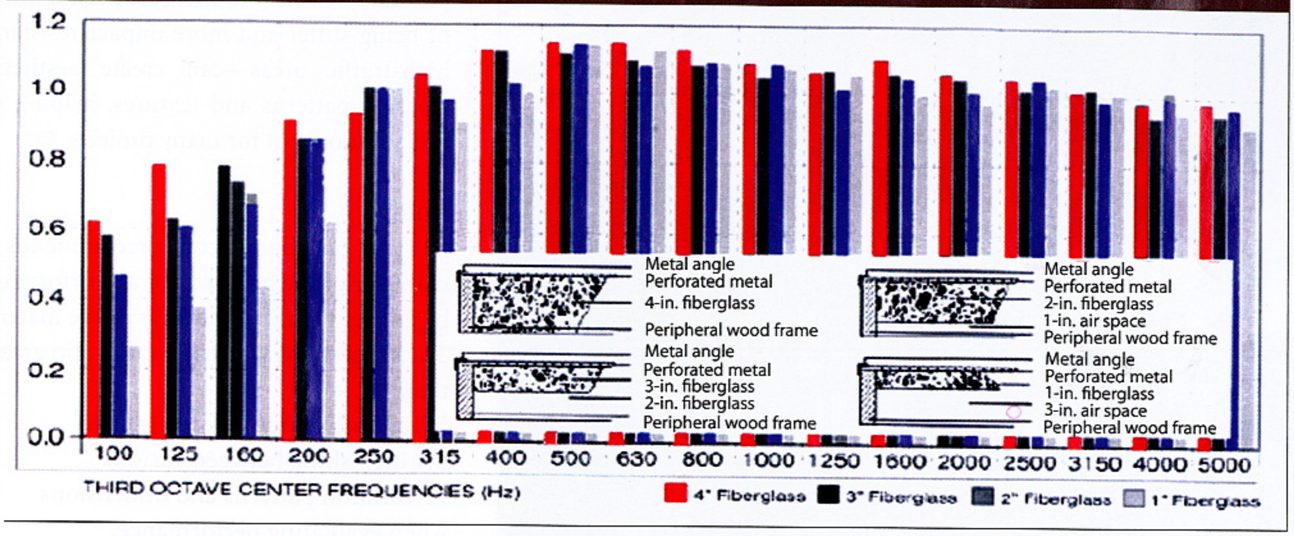
Figure 8 presents test data showing four different perforated metal assemblies using a transparent cover with different thicknesses. This figure illustrates that for frequencies below 250 Hz, one gets better performance for thicker absorption. However, at frequencies above this level (*i.e.* the speech frequency range), a 25.4-mm (1-in.) fiberglass performs as well as others.

As previously noted, it is important to consider the air space behind the fiberglass. When absorption materials are mounted directly to the wall surface, performance is greatly reduced. Further, the existing space behind the absorption is significant to the performances shown. In using a 25.4-mm fiberglass panel, at least 25.4 mm of air space should be maintained to ensure good absorptive performance for speech frequencies.

Calculating absorption amounts

More than a century ago, the first equation for reverberation time was developed by Wallace Clement

Figure 8 Acoustic Performance of Different Wall Systems



Sabine (the unit of sound absorption, the sabin, is derived from his name). His original equation is still applicable to develop solutions for basic room acoustics.

$$RT_{60} = \frac{0.05V}{(\Sigma S\ \alpha)}$$

Where:

RT_{60} = reverberation time (seconds);
V = room volume (cf);
S = surface area (sf);
α = absorption coefficient of material(s) at given frequency; and
Σ = the summation of all the surface areas multiplied by their absorption coefficients.

To use perforated metal over sound-absorptive ceiling materials, the pattern of holes must be acoustically 'transparent'—the larger the number of small holes, the more easily the sound will pass through.

By using this equation for each octave band, predictions can be developed based on the material choices for perforated wall systems. The following is an example for a small space, at the absorption for 500 Hz:

Space volume: 30 ft wide by 25 ft long by 10 ft high = 7500 cf

Vinyl tile over concrete floor: (25) (30) = 750 [0.03]
Windows: (2) (5) (7.5) = 75 [0.18]
Doors: (3) (7) = 21 [0.09]
Absorptive panel: (4) (25) = 100 [1.00]
Gypsum wallboard walls and ceiling: 750 + (10) (110) – 75 – 21 – 100 = 1654 [0.06]

$\Sigma S\ \alpha$ = (750) (0.03) + (75) (0.18) + (21) (0.09) + (100) (1.00) + (1654) (0.06) = 237.13

RT_{60} = 0.05(7500)/237.13 = 1.58 seconds at 500 Hz

When this same space is calculated for hard surfaces in place of the absorptive panels, the 500-Hz reverberation time is more than 2.5 seconds. Unfortunately, if the application in question is a classroom, a much lower acoustical performance is necessary for it to be considered acceptable. In this case, adding an absorptive ceiling would be appropriate.

Conclusion

Perforated metals offer a durable, high-performance acoustic treatment that can be incorporated into the design of a project with standard materials. They provide a simple alternative

Perforated metal can absorb sound based on the principles of a Helmholtz resonator—basically, air trapped by the dimensions of the holes functions as a mass-spring system. The result is sound is absorbed by energy loss within these cylinders.

to applied acoustical panels and can be built into wall assemblies. A variety of corrugated products—which have the added advantage of being stiffer and more impact-resistant for high-traffic areas—can create aesthetically pleasing patterns and textures, helping make this solution a fit for many projects.

Notes

[1] At least one manufacturer recommends the diameter of the hole size for all perforations be greater than the thickness of the material. The suggestion is to maintain a ratio greater than 1:1.

[2] This high frequency is helpful in distinguishing between various perforation patterns and dimensions when evaluating performance.

[3] This refers to the phenomenon of air resonance in a cavity. A device was created in the 1860s by Hermann von Helmholtz to show the height of the various tones. An example of this resonance is the sound created when one blows across the top of an empty bottle.

Additional Information

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William Stewart, CSI, is a senior acoustic consultant and managing partner with SSA Acoustics. He is a member of the American Society of Acoustics (ASA), the Council of Education Facilities Planners International (CEFPI), and the Construction Specifications Institute (CSI), and is part of the Noise and Vibration Committee 2.6 with the American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE). Stewart has been specializing in acoustics since 1991, serving as a lead designer for more than 100 condominiums, apartments, hotels, and resorts. He can be contacted by phone at (206) 839-0819.

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Abstract

No matter how efficient a sound-absorber it is, an easily damaged acoustical product is always a challenge in spaces where there is bound to be contact with wall surfaces. Fortunately, 'transparent' perforated metal can be a two-fold boon. Not only can they be furred over a frame wall to protect the specialty materials underneath, but the holes also have sound properties of their own.