the construction specifier

Acoustic Ceilings in Sustainable Buildings

by Gary Madaras, PhD, Assoc. AIA

Photos courtesy ROCKFON

WHEN SOME PEOPLE CONSIDER SUSTAINABLE BUILDINGS, THEY THINK OF WOOD FROM A CERTIFIED FOREST, WHETHER CARPETING WAS USED, OR IF HARVESTED RAINWATER WAS EMPLOYED FOR LANDSCAPING. OTHERS MAY THINK OF ENERGY EFFICIENCY, SOLAR PANELS, AND DAYLIGHTING TO REDUCE ELECTRIC LIGHT USAGE. IN OTHER WORDS, SUSTAINABILITY IS OFTEN SEEN AS BEING ABOUT THE IMPACT THE BUILDING MAKES ON THE NATURAL ENVIRONMENT, AND HOW MUCH ENERGY AND WATER THE BUILDING USES. WHILE THESE ARE VERY IMPORTANT CONSIDERATIONS, THEY ARE NOT THE MAIN FOCUS OF WHAT MAKES A BUILDING SUSTAINABLE.

The biggest resource expended in buildings is on its occupants—even more than the materials used to construct it or the energy used during its lifetime. The World Green Building Council's (WGBC's) 2014 report, "Health, Wellbeing, and Productivity in Offices: The Next Chapter for Green Building," says 90 percent of business operation costs are staff related.[1] Only one percent of costs are energy-related. Additionally, staff spends 62 percent of their time doing quiet work—'quiet' being the operative word. Sustainable buildings should actually be equated to the preservation and efficient use of human capital, and a quiet work environment is necessary for this.

Almost everyone can relate to the waste and inefficiency noise causes. The lost time, mistakes, and stress of each individual, multiplied by all the

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In an open-office environment, acoustic stone wool ceiling baffles should be spread uniformly across the space to create a good acoustic experience for the office workers. The exact location of these baffles is not critical, which makes it easier to accommodate other elements—such as structure, sprinklers, ducts, and lights—that have very specific locations.

To determine the amount of islands or baffles required above a space, the floor area should be calculated and divided in half. For example, a 92.9-m² (1000-sf) room will require 46.45 m² (500 sf) of islands or baffles. In noisier or sound-sensitive areas, the amount should be increased to 75 percent of the floor area.

people in a building, can be partially attributed to poor acoustic design, which, in turn, can indicate whether a building is sustainable or not.

This acoustics relating to sustainability paradigm shift is starting to materialize in both the U.S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design version 4 (LEED v4) and the Green Building Initiative's (GBI's) Green Globes certification program. In LEED 2009, there were only well-developed acoustic criteria sections for schools and healthcare facilities. LEED v4 has acoustic criteria for office buildings, multi-family residences, hotels, retail stores, courtrooms, laboratories, libraries, and gymnasia. Clearly, the importance of acoustic design in the definition of sustainability is increasing. However, there is more progress to be made with these sustainable rating systems. The acoustic sections need to better align with other, more developed, acoustics industry standards and guidelines. Additionally, the credits or points earned for good acoustic design need to be increased to better represent the effort, cost, and impact on occupants.

Important trends changing the rules

Trends in design seem to be at odds with acoustic requirements in the standards, guidelines, and rating systems. For instance, what may have been considered successful two years ago may no longer pass the test. Buildings are becoming more open with large collaboration spaces. The days of private, enclosed, offices are gone, with a limited number of public huddle rooms or quiet rooms replacing them. More people are occupying less space and spatial dividers between workstations are becoming lower or are disappearing altogether. Bare structural slabs are replacing carpeting and carpet tiles. More buildings—especially sustainable ones—are foregoing a once-standard suspended acoustic ceiling in favor of exposed structure above. Post-occupancy calls to acoustic consultants and acoustic material manufacturers are on the rise.

Whether it is a design for a building that has not yet been constructed, a fix for an original design gone wrong, or a renovation/adaptive-reuse, the solution is the same. With mostly open spaces, few walls, no carpeting, and a high concentration of people, most projects rely on a high-performing, sound absorptive system overhead. This can be a more traditional contiguous suspended ceiling, an array of acoustic islands, or baffles hung amongst the structure, lights, and ducts. Regardless, there must be a plan for some

Acoustic ceiling islands hang horizontally within a space. When horizontally oriented acoustic islands are used, designers and mechanical engineers have to be aware of how they can affect the capacity of the thermal slabs.

type of sound absorption in all spaces normally occupied by people.

Mechanics of sound absorption

There are different types of sound absorption, but what most experts refer to when talking about sound absorption is frictional or porous absorption. This alone begins to describe what is needed from a material like a ceiling panel, island, or baffle for it to absorb sound. First, the sound energy must be able to penetrate the ceiling panel's surface. This means the surface must be porous. Otherwise, the sound energy reflects off the surface and continues to propagate around the room.

Ceiling panel manufacturers take great care when painting their panels to not close the pores and decrease absorption. This typically requires special paint and mechanized sprayers, or curtain-coaters applying unbelievably thin coats of paint. The important concept is that painting ceiling panels in any other conditions—for example, by contractors in the field to match a custom color—will most likely decrease the sound absorption by as much as half.

Surface porosity alone is not enough. The sound energy must get trapped inside the core material until it is converted to heat energy via friction in the internal pores or cells. This requires a tortuous, maze-like fiber structure, similar to those found in stone wool. For example, a piece of wood with 12.7-mm (½-in.) diameter holes drilled through it is very porous, but not very sound absorptive. The sound energy simply passes through the holes; it does not get trapped inside and converted to heat. Essentially, tortuosity results in greater airflow resistance, which relates strongly to sound absorption. This can be tested by trying to blow air through a material. If it is easy to blow through it, then the internal structure is not tortuous enough. Conversely, if air can be blown through it, but only with effort or force, it is probably a good sound-absorber.

The thickness of the material is also important. Thinner materials are efficient absorbers of high- and mid-frequency sound, but their performance at low frequencies quickly diminishes. That is why ceiling panels, which are thicker than carpeting and wall coverings, are generally much better sound absorbers. Sound absorption varies with frequency or pitch, and most porous absorbers less than 50 mm (2 in.) thick are efficient absorbers of mid- and high-frequency sound.

There is an extra benefit with ceiling panels when they are suspended in a metal grid with a plenum above (*i.e.* an architectural E mount). That airspace helps boost the low frequency absorption of the entire ceiling system. It is important to assess the sound absorbing capability of materials in the actual application in the building. If the ceiling panels are glued directly to a solid substrate such as gypsum board (*i.e.* an architectural A mount), one should review and specify the correct test report data. The information from the manufacturer or laboratory should define the mounting type as E-mount, A-mount, or another.

Quantifying absorption performance

The most common method of characterizing and specifying the absorption performance of a material is by noise reduction coefficient (NRC), which is a single numerical metric that varies between 0 and 1. A higher number means more sound absorption.

To make buildings as energy-efficient as possible, islands can provide three advantages: helping reflect natural light throughout the building, providing the air circulation required by thermal mass principles, and achieving a high level of acoustic comfort.

While values of 0.50 and 0.60 may seem like they represent decent absorption, the acoustics industry generally refers to these as 'sound reflective' because so much sound energy is being bounced off them. NRC performance can be broken down into:

- NRC-0.90: best (high performance);
- NRC-0.80: better;
- NRC-0.70: good; and
- NRC-0.60: poor (reflective).

NRC is a calculated average of the absorption coefficients in the 250-, 500-, 1000-, and 2000-Hz octave bands. That average is then rounded to the nearest 0.05. This means two materials having NRC values differing by only 0.05 should not be viewed as substantially different. The difference could just be the result of rounding the average. Two materials that have the same NRC rating could, and likely do, perform differently at the individual octave bands. In some rooms, such as those used for group education, the differences in absorption at various frequencies may be important to speech intelligibility.

The octave bands used in the calculation of NRC (250 to 2000 Hz) relate to speech intelligibility. That does not mean absorption performance below 250-Hz and above 2000-Hz octave bands is unimportant. In some applications, such as those rooms intended for music or multi-media presentations, low-frequency absorption performance may be important.

Specifiers might need to specify absorption coefficients by individual octave bands down to the 63-Hz octave band as opposed to relying on a single, multiband indicator such as NRC. Manufacturers cannot get NRC values without starting with the individual octave band data. Any manufacturer publishing NRC ratings should be able to provide specifiers with a detailed absorption test report per ASTM C423, *Standard Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method*. Those test reports should be from an independent, third-party, National Voluntary Laboratory Accreditation Program (NVLAP)-certified acoustics laboratory.

While NRC is probably the single most-known and important acoustic characteristic for interior surface materials, the value actually does not relate directly to human perception. People perceive reverberation, not NRC. Reverberation is how long sound reflects inside a room before dying off below the room's background noise level. More technically, reverberation time (RT60) is the time in seconds it takes a loud sound, once terminated at the source, to decrease 60 decibels (dB) in loudness. It has two main variables:

- room volume/size; and
- the amount of absorption provided by the surface materials.

Larger rooms have longer RT60. Adding more sound absorption, either by increasing the amount of sound-absorbing materials or by increasing the NRC, decreases RT60. Since RT60 depends on absorption, and absorption varies with frequency, RT60 also varies with frequency. In medium- to large-size assembly rooms, RT60 is generally calculated at octave band resolution. However, for less-critical spaces, using the NRC value in a single RT60 calculation is sufficient.

For speech to be intelligible, RT60 should be under one second. Many acoustic standards, guidelines, and rating systems recommend a maximum RT60 of 0.60 seconds. This is a fairly stringent performance level. Trends in the acoustic standards, guidelines, and rating systems are to apply maximum RT60 or minimum NRC values to more and more type of spaces. Additionally, they are progressively increasing the amount of required absorption. When not specifying high-performance ceilings of NRC 0.90 or higher, more materials are generally needed to meet those requirements, perhaps on the floors or walls. In an average-sized conference room, if the carpeting and fabric wall panels are removed, the ceiling NRC should be increased from 0.60 to 0.90 to maintain the same reverberation time.

Reverberation time is not applicable to all spaces. Open offices, nurses' stations, and corridors are not typically enclosed and do not have the size and

Since staff costs make up such a large part of company expenditures, even small changes in the acoustic experience may significantly affect business over time.

Image courtesy World Green Building Council

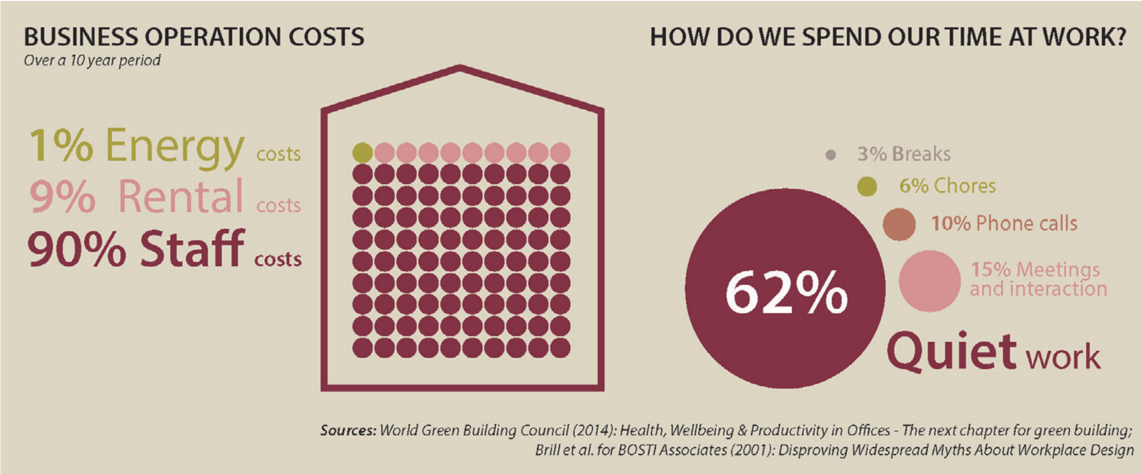
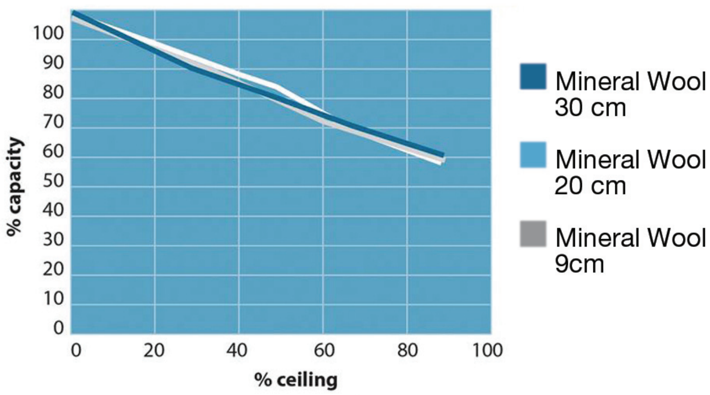


Figure 1



Thermal capacity of 40-mm (1 ½ in.) mineral wool ceiling tiles mounted at different heights and metal baffles, but for different sizes of the ceiling elements.

Image courtesy H. Peperkamp and M. Vercammen's "Thermally Activated Concrete Slabs and Suspended Ceilings"

proportions to establish a reverberant sound field. In these types of areas, the acoustic goal is not speech intelligibility, but rather noise control and privacy. The goal is to quickly attenuate any sound as it propagates through a space or down a corridor. The higher the ceiling's NRC, the faster the traveling noise is attenuated and the fewer people that are disturbed. If there is no carpeting, limited walls, and low or no workstation dividers, a high-performance ceiling may be the only thing determining if the space actually is useable by occupants. Both the 2016 WELL Building Standard and the U.S. General Services Administration's (GSA's) *Facilities Standards for the Public Buildings Service* (P100), mandate open-plan offices have a ceiling with a minimum NRC rating of 0.90 over 100 percent of the space.[2]

Designing with sound absorption

The first design decision for sound absorption is the main format of the overhead system. Is a contiguous ceiling desired or not? Is the intent to have an open-plenum concept where the underside of the floor or roof above is exposed? This might be more than an aesthetic decision. It could depend on other factors—for example, whether a chilled beam or thermal slab heating and cooling system is used. Successful acoustics can result from a standard ceiling, or by using other types of sound-absorbing units such as modular islands hung horizontally or baffles hung vertically in the space. Typically, using acoustic islands and baffles achieves the same acoustic performance with less material than standard suspended ceiling systems. This is because the sound energy interacts with all the sides of these units as opposed to mainly the exposed, underside of a full ceiling. Using baffles and islands means using fewer materials, along with more eco-conscious and efficient heating and cooling systems. These systems also are quieter than traditional forced air systems.

To determine the amount of islands or baffles that are required above a space, the floor area should be calculated and divided in half. For example, a 92.9-m^2 (1000-sf) room requires 46.45 m^2 (500 sf) of islands or baffles. If the baffles are 1.22 m (4 ft) long and 0.6 m (2 ft) high with an area of 0.74 m^2 (8 sf) each, then approximately 60 to 65 baffles are required in the room. Only the front side of the islands and baffles should be considered in the calculation. In noisier or sound-sensitive areas, such as cafeterias or telemarketing areas, the amount of islands or baffles should be increased to 75 percent of the floor area. There is generally little additional acoustic benefit to using more than 75 percent of the floor area. Conversely, if budget does not permit 50 percent of the floor area in sound-absorbing islands or baffles, improvement can still be realized by using as little as 25 percent of the floor area. However, this is the bare minimum and will only provide a noticeable improvement if there are no other absorption materials, such as carpeting or wall panels.

The exact location of these islands and baffles is not critical, which is good because other elements, such as structure, sprinklers, ducts, and lights have very specific locations. As long as the required amount of baffles and islands are spread somewhat uniformly over the space, occupants benefit from a good acoustic experience. Fortunately, an acoustic island and a light or a sprinkler head can occupy the same space. Islands are easy to cut, and the light or sprinkler head can be flush-mounted into it.

If the building has a type of radiant cooling/heating system, such as thermal slabs or chilled beams, then using a more traditional, contiguous ceiling system is not an option. The sound absorptive ceiling will also be a thermal barrier. In these cases, designers have to opt for acoustic islands and baffles, which maintain openness for vertical thermal flow, or convection. The main design consideration in this situation is the number of islands and baffles that can be added before, they too, begin to affect the capacity of the thermal slab or other radiant system. The answer is dependent on the orientation of the sound absorption.

Baffles are oriented vertically, so they do not prevent vertical, thermal flow like horizontally oriented islands. In fact, up to 75 percent of the floor area in vertically oriented baffles will not affect the cooling/heating capacity of the thermal slab more than a few percent. However, when horizontally oriented acoustic islands are used, designers and mechanical engineers have to be aware of how they can affect the capacity of the thermal slabs. Figure 1 shows the relationship between the ceiling percentage versus the capacity of the thermal slab system for three different mounting heights.[3] A 100 percent ceiling represents a traditional, full, suspended ceiling, while '0 percent' represents no ceiling elements at all. The 50 percent area for sound absorption previously recommended keeps the capacity of the thermal slab at about 80 percent. Even if the amount of absorption increases to the upper end of the recommended range at 70 to75 percent, the capacity of the thermal slab stays above 60 percent. If these decreases in the capacity of the thermal system are unacceptable in the application, one should consider using vertical baffles or supplementing the overhead absorption with additional absorption elsewhere in the room.

DAT Tilburg architects relied on stone wool acoustic ceiling panels when designing Meeting Square Bitswijk in Uden, Netherlands, to balance acoustics with the natural air ventilation system. In an average-sized conference room, if the carpeting and fabric wall panels are removed, the ceiling's noise-reduction coefficient (NRC) should be increased from 0.60 to 0.90 to maintain the same reverberation time and a comfortable acoustic environment.

Common absorption mistakes

One of the two most common mistakes when designing overhead absorption is using too much overhead absorption where medium to large groups of people assemble to listen. If it is a lecture room, chapel, meeting center, training room, or similar facility and a person speaking needs to be heard by an audience of 20 to 100 people, the ceiling, especially the part above the speaker, needs to be sound-reflective. This projects or passively amplifies the speaker's voice. Many designers treat these larger, more-critical rooms like smaller ones, leaving the walls as sound-reflective and placing a highly absorptive ceiling over the entire room. Reverberation control is still important, but the sound absorption should be located strategically on the upper sidewalls, rear wall, and back half of the ceiling. When dealing with these types of rooms, it is often best to rely on the recommendations of a credentialed and experienced acoustical consultant, such as a member of the National Council of Acoustical Consultants.[4]

The other common mistake made by designers and specifiers is sacrificing sound absorption (*i.e.* accepting lower NRC values) because other product characteristics, both acoustical and

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nonacoustical, that do not pertain to the application at hand are in the specification. For example, Ceiling Attenuation Class (CAC) is a metric indicating how much sound is blocked from transmitting through a ceiling panel. It relates to sound transfer between adjacent rooms and not reverberation control. Yet, CAC is left in some specifications where it is not needed, such as airport concourses, open offices, restaurants, and retail stores. Leaving CAC in the specification on its own would not be problematic, but it is typically at the sacrifice of higher NRC values since panels with higher CAC values typically have lower NRC ratings. One should be sure not to sacrifice necessary absorption for some product characteristic that is not needed.

Achieving good acoustic experiences in sustainable buildings is possible. Despite design trends that tend to pull the building toward loud, echoic chaos, the knowledgeable designer and specifier can select the desired format (ceiling, islands, or baffles), calculate the correct amount of material, understand which ceiling materials offer high-performance absorption, and specify them correctly. **CS**

Notes

[1] The full report can be downloaded from www.worldgbc.org/files/6314/1152/0821/WorldGBC__Health_Wellbeing__productivity_Full_Report.pdf.

[2] The WELL building Standard can be viewed at www.wellcertified.com. The U.S. General Services Administration (GSA). P100 facility standards can be viewed online by visiting www.gsa.gov/portal/content/104821.

[3] This information was gathered from H. Peperkamp et al.'s proceedings, "Thermally Activated Concrete Slabs and Suspended Ceilings," at the 2009 NAG-DAGA International Conference on Acoustics in Rotterdam, Netherlands.

[4] To review and select potential acoustical consultants from National Council of Acoustical Consultants, visit www.NCAC.com.

ADDITIONAL **INFORMATION**

Author

Gary Madaras, PhD, Assoc. AIA, is an acoustics specialist at ROCKFON. He helps designers and specifiers select the appropriate acoustical ceiling products and apply them effectively. He is a member of the Acoustical Society of America (ASA), Canadian Acoustical Association (CAA), and Institute of Noise Control Engineering (INCE). He authors technical articles and speaks publically on the topic of optimizing acoustic experiences, including on www.OptimizedAcoustics.com. Madaras can be reached via e-mail at gary.madaras@rockfon.com.

Abstract

Some of the major tenets of sustainable design can be very positive for the environment, utility bill, and even occupant productivity—however, a few aspects of 'green'—especially with respect to wall and ceiling finishes—can be detrimental when it comes to a space's acoustics. This article looks at trends affecting design/specification and occupant acoustic experience, guidelines and rating systems (including LEED and Green Globes) and what they require of sound control, and important tactics for incorporating sound absorption.

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