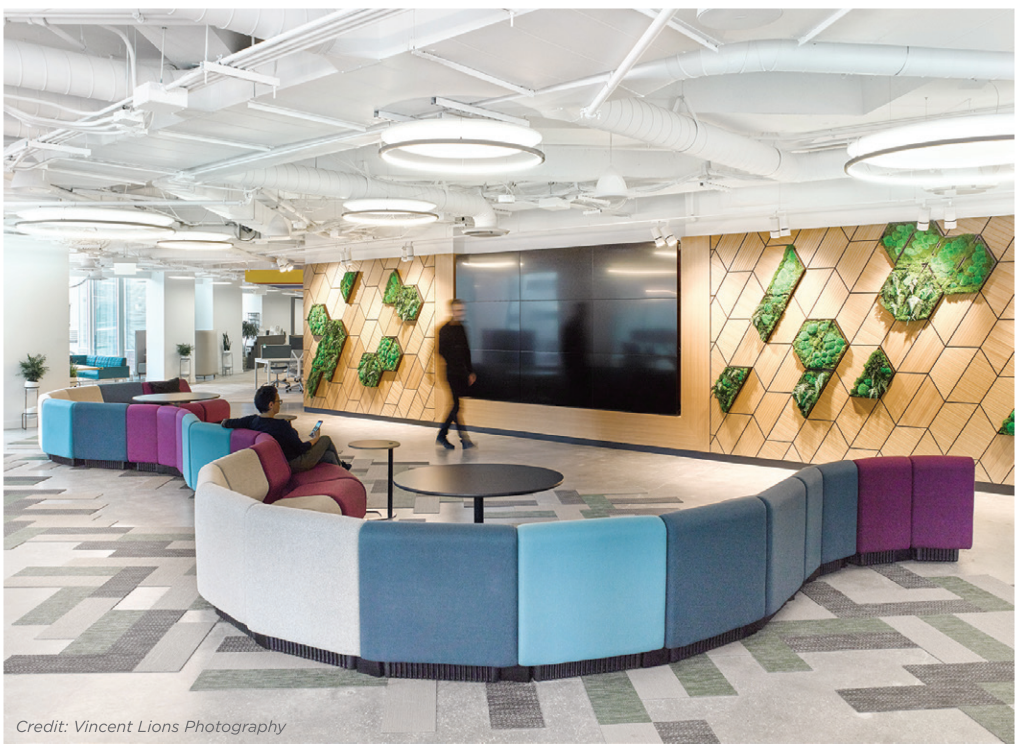
Presented By:

In Pursuit of Acoustical Equity



Credit: Vincent Lions Photography

LEARNING OBJECTIVES

1. Introduce the concept of acoustical equity
2. Discuss the role acoustical privacy plays in achieving acoustical equity
3. Describe the need to control the temporal, spatial, and spectral qualities of background sound within the built environment
4. Explain the importance of tuning minimum background sound to meet a masking spectrum

CONTINUING EDUCATION

This course is approved for AIA & IDCEC Learning Unit Credits. Use the learning objectives to focus your study as you read this article. For details on the learning units or credit information, and to earn credit and obtain a certificate of completion, visit http://go.hw.net/AR10211 to view the entire CEU and complete the quiz. If you are new to Hanley Wood University, CEU courses are free of charge once you create a new learner account; returning users log in as usual.

By Viken Koukounian, Ph.D., P.Eng., and Niklas Moeller

Given the intense focus on health and safety, as well as the changes in work/life balance precipitated by the COVID-19 outbreak, it is not surprising that the pandemic has accelerated the healthy-building movement and "people-first" mindset spearheaded by standards such as WELL and Fitwel. There is burgeoning consensus that buildings need to be designed with deep commitment to the well-being of their occupants.

Effective acoustics are key to healthy buildings. After all, noise is known to provoke physiological stress responses that can negatively impact occupants. The World Health Organization describes it as an "underestimated threat" that contributes to stress, high blood pressure, cardiovascular disease, dementia, and diabetes. Hence, WELL and Fitwel take acoustics into consideration; however, it remains a poorly understood Indoor Environmental Quality (IEQ) parameter, and the lowest rated.[1]

RETURNING TO THE WORKPLACE

Low ratings have added significance in today's climate. Many employees found a silver lining in the ways in which stay-at-home orders enriched their family lives, even as the scope of their work and social lives contracted. As companies start to bring—or attempt to draw—them back to the office, occupant satisfaction is more important than ever. Organizations need to implement strategies that not only keep staff safe and healthy but also happy and productive enough within their working environment that they actually want to come in.

Among the architecture and design community, there is growing conviction that these goals must be achieved through concern with *equity*—and applied to "real-world" needs such as acoustical privacy, rather than amenities like pool tables, private chefs, and other perks; in other words, that it is more a matter of how employees are treated than what they are being treated to.[2]

Firms such as Gensler point out that although employees are enjoying benefits (e.g., more time with family and less spent commuting) while working from home, many are also struggling with less-than-ideal conditions (e.g., poor internet connectivity, shared workspace with children and other family members, noisy neighbors and neighborhoods) that negatively impact their engagement and productivity. Whether an organization wants their office to be occupied full time post-pandemic or to serve as a critical part of a hybrid working model, it has the potential to act as a "great equalizer"—a shared facility that is specifically designed to support employees' work and overall well-being.[3]

According to the *2020 Gensler Work from Home Survey*, 88 percent of employees would like to return to the workplace in some capacity. One of the primary reasons the 2,300+ participants cite is the need for a quiet, distraction-free environment—a desire echoed by the 32,000+ people polled during studies Steelcase conducted across 10 countries.[4] It is clear that acoustics matter and, hence, are vital to ensuring that employees not only enjoy equal access to the facility itself but to the IEQ parameters needed to work comfortably and effectively.

But what is *acoustical equity*? And how does one achieve it?

THE SOUND THAT ACTUALLY EXISTS

En route to answering these questions, one must first consider the traditional approach to acoustics, which relies on "categorization" and "acceptable-level" schemes prevalent throughout building standards and codes. The former specifies sound-rating values [e.g., sound transmission class (STC), noise isolation class (NIC), impact isolation class (IIC), ceiling attenuation class (CAC)] for the boundaries of a room or building envelope, while the latter uses noise-rating values [e.g., noise criteria (NC), noise rating (NR), room criteria (RC)] to set maximum limits for noise, such as that generated by building systems, services, and utilities. However, neither offers insight into the *actual acoustics* (i.e., the sound actually present) within a space or occupant experience of it.

In order to improve results—a goal that one can, with a broad brushstroke, call "better acoustics"—and fulfill the objective of designing with occupants in mind, one must turn their attention to the sound actually present in a space and look at it through the lens of both architectural acoustics (i.e., the study of sound and its behavior in and due to a space) and psychoacoustics (i.e., the study of the psychological and physiological effects of sound and its perception). Indeed, one cannot be separated from the other, as psychoacoustical evaluation of a space considers the outcome of the combined performance of all acoustical features.

ACOUSTICAL PRIVACY IS KEY

The reactions of building occupants are captured using psychoacoustic metrics, some of which are subjective (e.g., surveys evaluating comfort, distraction, perceived productivity) and others that are objective (e.g., intelligibility, audibility).

Research shows that our overall acoustical satisfaction is strongly correlated with acoustical privacy, a concept with clear ties to the workplace but one that is also relevant to other environments; for example, surveys of multi-unit residences demonstrate links between acoustical privacy and annoyance, fatigue, and sleeping problems (e.g., due to noise from traffic and neighbors).[5] In other words, although people tend to equate acoustical privacy with speech privacy, the former is not limited

GLOSSARY

ABC Rule—Refers to the strategies required to achieve effective acoustics within the workplace. 'A' is for 'absorption,' 'B' is for 'blocking' and 'C' stands for 'control,' which involves establishing an appropriate minimum background sound level and spectrum using a sound masking system.

Articulation Index—A measure of the intelligibility of speech, the articulation index (AI) is rated from 0.00 (no intelligibility) to 1.00 (perfect intelligibility). The range is divided into four qualitative privacy categories, including Confidential (0.00 to 0.05), Normal (0.05 to 0.20), Marginal (0.20 to 0.30), and None (0.30 to 1.00).

A-Weighted Sound Level—The standard measure of the sound pressure level that approximates the sensitivity of the human ear at moderate sound levels. A-weighted sound level (dBA) de-emphasizes high and low frequencies because the ear poorly perceives these.

dBA—The standard measure of the sound pressure level that approximates the sensitivity of the human ear at moderate sound levels. A-weighted sound level (dBA) de-emphasizes high and low frequencies because the ear poorly perceives these.

Masking Spectrum—A masking spectrum—also called a 'curve'—is engineered to balance effective acoustical control and comfort, and forms the basis for the synthesis of masking sound. When a masking system's measured output is professionally-tuned to meet this spectrum from 100 to 10,000 Hz, occupants' perception of the final product may be described as 'quiet' and 'comfortable.'

Pink Noise—Pink noise is similar to white noise, but rather than being constant in volume, it decreases at a steady rate as frequency increases (3 dB per octave); however, because these decreases are offset by the increases created by the doubling of frequencies in each octave, pink noise is constant in volume per octave. Pink noise is less hissy than white noise, but due to the relatively louder low frequency volumes tends to have a rumbling characteristic similar to that of a waterfall.

Psychoacoustics—The study of the psychological and physiological effects of sound and its perception.

Signal-to-Noise Ratio—The ratio of the desired or undesired sound to background sound levels.

Sound Masking System—An acoustical technology consisting of a series of loudspeakers installed in a grid-like pattern in the ceiling that distribute a background sound most often compared to that of softly blowing air. By raising the background sound level within a space, masking obscures conversations and noises that are lower in volume and reduces the disruptive impact of those that are higher by minimizing the degree of change perceived by listeners, improving privacy and productivity.

Sound Transmission Class—A sound transmission class (STC) rating indicates how well a building partition (e.g., walls, ceilings, floors, doors, windows) attenuates airborne sound. The higher the rating, the better the sound isolation; however, lab-tested results often differ from those performed in the field.

White Noise—A term often used interchangeably—but mistakenly—with 'sound masking.' This type of sound has a wide frequency range (typically from 20 to 20,000 Hz) generally randomly produced, with equal volume across the entire range. Occupants perceive it as 'static' with an uncomfortable, hissing quality.

to the intrusion of speech content; it also considers the audibility of unintelligible speech and other types of noise.

That said, it is challenging to use acoustical privacy as a starting point for a conversation about acoustical equity. The science around acoustical privacy is not sufficiently nuanced; it is not yet addressed by a standardized metric or even a proposed methodology.

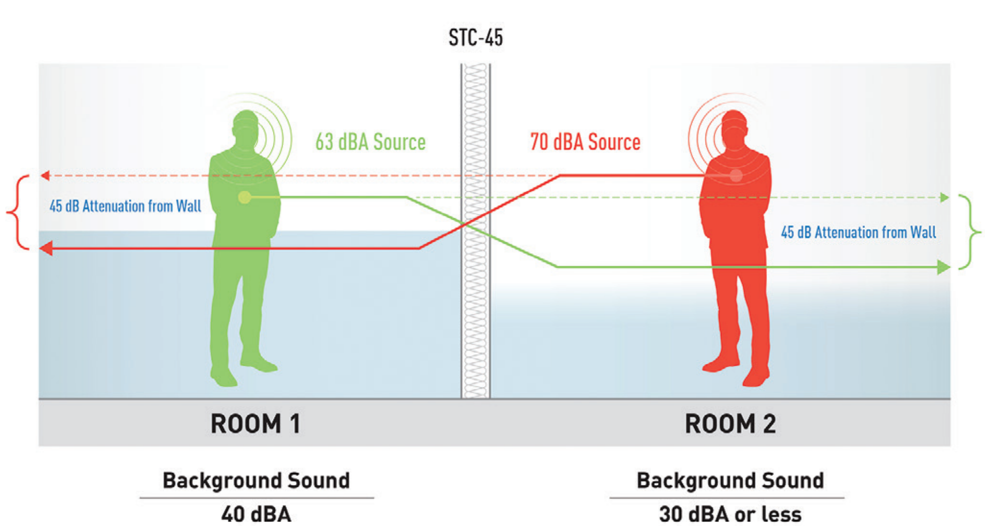
Speech privacy, on the other hand, is both well-defined and measurable (e.g., using articulation index or speech privacy class). Therefore, it is a psychoacoustic metric that can be used in both theoretical (i.e., to illustrate the concept of acoustical equity) and practical ways (i.e., to set expectations during design and estimate occupants' subjective impression of the built space). In this case, evaluation of acoustical privacy is effectively a review of the signal-to-noise ratio; it considers an intruding "signal" (speech) and its level relative to the background "noise" (or, rather, sound) in the receiving space.

By way of example, let us turn our attention to the rooms—and occupants—shown in Figure 1:

- Room 1: The red arrows depict an elevated level of intruding noise, compared with the green arrows. This case represents a well-designed space where the combination of the insulating properties of the wall (STC-45) and the constant background sound level of 40 A-weighted decibels (dBA) ensures the noise is not intelligible and/or audible.
- Room 2: The green arrows depict a lower level of intruding noise. This case represents a space that fails to consider occupant needs and/or expectations. The combination of the insulating properties of the wall (still STC-45) and the existing background sound level (30 dBA or less) in the receiving room is insufficient to ensure acoustical privacy. Although the intruding level of the green source is lower than the red example, it remains intelligible and/or audible.

Now, let us assume that the red and green signals are people speaking. The red talker's voice carries into Room 1; however, it is masked by the background sound. The listener in that room cannot identify and/or understand speech and the red talker enjoys speech privacy. The green talker's voice is carried into Room 2; however, it is not masked by the background sound and the listener can identify and/or understand speech. The green talker does not have speech privacy.

There are impacts beyond the one-way speech privacy. We accept that the red talker has speech privacy because the background sound in the adjoining room masks the received level of their voice. However, the red talker's *perception of privacy* is violated because they are able to hear the green talker. This discrepancy can cause reactive behavioral changes on the part of the red talker (e.g., lowering of voice, avoiding confidential topics). We also accept that the green talker does not have speech privacy because the background sound in the adjoining room does not mask the received level of their voice. However, the green talker has a false perception of privacy engendered by the fact that they are unable to hear the red talker. This discrepancy can result in breaches of confidentiality, the implications of which can run the gamut—or gauntlet, depending on the consequences—from embarrassment to legal proceedings.



Credit: KR Moeller Associates Ltd

Figure 1: The person (green) in Room 1 speaks at a "Casual" level, while the person (red) in Room 2 uses a "Normal" level (i.e., per Pearsons). Despite the latter's elevated vocal effort, they enjoy speech privacy due to the higher and consistent background sound level within Room 1. The person in Room 1, on the other hand, does not have speech privacy due to the lower and variable nature of the background sound in Room 2; however, they believe they have privacy, by virtue of the fact that they cannot hear the person in Room 2.

UNDERSTANDING ACOUSTICAL EQUITY

One can appraise this situation using the basic dictionary definition of "equity" (i.e., fairness or justice in the way people are treated, per Merriam-Webster) and conclude that the occupants do not have acoustical equity simply by virtue of the fact that they do not enjoy equal levels of speech privacy, or even perceived privacy. However, there is more to the concept of equity.

According to conversations occurring in philanthropic circles, equity is also "about each of us getting what we need to survive or succeed—access to opportunity, networks, resources, and supports—based on where we are and where we want to go. Nonet Sykes, director of race equity and inclusion at the Annie E. Casey Foundation, thinks of it as each of us reaching our full potential."[6] Because design impacts our well-being and level of functioning, it is one of the factors in our lives that—in the words of built-environment strategist Esther Greenhouse—has the "power to dis-able or enable."[7] Greenhouse maintains that if there is a "poor fit between a person and their environment, the environment acts as a stressor, pressing down on their abilities, pushing them to an artificially low level of functioning."[7]

The need to provide a supportive environment highlights the importance of providing beneficial acoustical conditions throughout the workplace. While occupants can be impacted by acoustical design in myriad ways, let us continue with the example of speech privacy. Some might consider it a niche application only relevant to particular offices (e.g., law firms), healthcare, and military environments, but surveys such as those conducted by the Center for the Built Environment show that lack of speech privacy is the top workplace complaint, indicating that it is a broadly applicable concern.[8] Furthermore, this deficiency is not only relevant to occupants of private offices but to those working within open plans. Although individuals within the latter group are more likely to characterize lowering speech intelligibility as “reducing distractions” rather than “improving speech privacy,” taking measures to achieve this goal means they will have an easier time concentrating on tasks, make fewer errors, and also suffer less stress and fatigue.

This article continues on http://go.hw.net/AR10211.
Go online to read the rest of the CEU course, complete the corresponding quiz for credit, and receive your certificate of completion.

SPONSOR INFORMATION

Industry leader KR Moeller Associates Ltd. has designed and manufactured sound masking systems for over 40 years, including the award-winning LogiSon Acoustic Network and MODIO Guestroom Acoustic Control. Worldwide distributors provide turnkey services and expert support. To learn more, visit www.logison.com and www.modio.audio.

QUIZ

1. Psychoacoustics is the study of:
   a. The impact of sound on occupants’ hearing
   b. Colors of sound (e.g., white, pink) and their influence on occupants’ mental health
   c. The psychological and physiological effects of sound and its perception
   d. Occupants’ reactions to noises

2. Research shows that occupants’ overall acoustical satisfaction is strongly correlated with:
   a. Acoustical privacy
   b. Acoustical comfort
   c. Use of absorptive materials
   d. Wearing headphones

3. Speech privacy is a psychoacoustic metric that:
   a. Is well-defined and measurable
   b. Can be used to set expectations during design
   c. Can be used to estimate occupants’ subjective impression of the built space
   d. All of the above

4. Achieving acoustical equity involves:
   a. Setting maximum limits for noise in both open and closed spaces
   b. Ensuring the design provides beneficial acoustical conditions throughout the workplace in order to allow all occupants to function at the highest possible level, in accordance with the goals the spaces are designed to meet and help fulfill
   c. Ensuring the design provides the same articulation index (AI) and/or speech privacy class (SPC) results for all occupants at all times
   d. Selecting walls with the highest STC ratings

5. The most important room variable affecting speech privacy is:
   a. Room noise criteria
   b. NC rating
   c. Background sound
   d. Dynamic range

6. The “ABC rule” is used to:
   a. Indicate the priority sequence that should be employed for acoustical treatments
   b. Provide a memorable abbreviation that reinforces the need for a holistic approach to acoustical design
   c. Analyze the effect of poor acoustics on occupants
   d. Assess the temporal, spatial, and spectral properties of sound

7. A sound-masking system can help control the following property of sound:
   a. Temporal
   b. Spatial
   c. Spectral
   d. All of the above

8. Two sounds equal in overall level:
   a. Will always be perceived as identical by occupants
   b. Can sound perceptibly different, depending on their frequency content
   c. Will provide equivalent masking of speech and noise
   d. Are always impossible to distinguish from one another

9. According to the experience of ASID and others, effective acoustics can positively impact employee:
   a. Collaboration
   b. Absenteeism
   c. Productivity
   d. All of the above

10. To deliver effective masking sound, the technician needs to:
    a. Install sound-masking equipment
    b. Divide the facility into zones based on general categories, such as “open plan”
    c. Tune the system’s output to meet the required spectrum and level
    d. Use downward-facing loudspeakers

THE NEED FOR CONTROL

Equity involves ensuring the design provides beneficial acoustical conditions throughout the workplace in order to allow all occupants to function at the highest possible level, in accordance with the goals the spaces are designed to meet and help fulfill. While acoustical privacy is not the only objective, it is a highly sought-after quality with widespread relevance that can serve as the foundation for an acoustical plan within many types of spaces. Any deviations from (e.g., to improve intelligibility in a large training room) or additions to (e.g., biophilic sounds or music in particular spaces) the acoustical conditions required to achieve it must be intentional (i.e., designed to meet a particular goal or occupant need), not unintentional. Essentially, there is a need for control of the acoustic environment and, specifically, background sound.

Although categorization and acceptable-level schemes endeavor to minimize occupants' negative reaction to the sound experienced within a space, they do not control the actual levels emitted by various noise sources (e.g., building systems), nor do they actively address

CASE STUDY

ASID Headquarters, Washington, D.C.
Architect/Designer: Perkins+Will
Project Manager: Savills Studley
Real Estate Broker: Savills Studley
General Contractor: Rand Construction
MEP Engineer: GHT Limited
Acoustical Consultants: Cerami
Lighting Consultants: Benya Burnett
Biophilia Consultants: Terrapin Bright Green
Commissioning Agent: Bios

Credit: ASID

Founded in 1975, the American Society of Interior Designers (ASID) is the oldest, largest, and only multi-disciplinary professional organization for interior designers and interior design students, as well as the manufacturers and suppliers who support the profession.

When the organization planned to move to a new 8,500 ft^2 (709 m^2) corporate headquarters in downtown Washington, D.C., it was determined to create a space that would reflect its strongly held belief in the power of design to positively impact people's lives, and one that could serve as a model for innovative workplace design—essentially, a living laboratory for the "Workplace of the Future."

In keeping with this goal, ASID decided to pursue Leadership in Energy and Environmental Design (LEED®) and WELL certification as part of its 10-year lease arrangement with the building's owner, Carr Properties. The organization covered many of the upgrade costs itself, knowing it would pay off in terms of energy savings, employee productivity, and retention.

A key criterion of the WELL Building Standard® involves implementation of an acoustical strategy that reduces exterior noise intrusion and controls indoor noise levels. ASID engaged acoustical consultants, who used a combination of space planning, material selection, and sound masking to provide an acoustical environment appropriate to each of the spatial zones within the facility. After the sound-masking system was installed, the sound was professionally tuned using a unique software application, ensuring the specified masking spectrum and levels (46 dBA in open plan, 42 dBA in private offices) were achieved within all treated areas so that all occupants can consistently enjoy the system's benefits.

The space became the first in the world to achieve Platinum Level Certification for both WELL (under WELL v1) and LEED (under LEED ID+C)—the highest recognition awarded by the U.S. Green Building Council (USGBC) and International WELL Building Institute™ (IWBI™).

In order to gain a deeper understanding of the impact the new headquarters has on their employees and their work, ASID partnered with Cornell University, Delos, and the Innovative Workplace Institute. The team conducted pre- and post-occupancy research, which involved interviews, surveys, and sociometric data collected from badges employees voluntarily wore, as well as real-time monitoring of indoor environmental qualities.

Here is a brief summary of their findings to date:

- Satisfaction with reduced noise and speech privacy increased significantly, with overall satisfaction in acoustical quality improving by 92 percent.
- Collaborative work increased by 9 percent.
- Physical and mental health scores improved.
- Staff retention is well above historical standards.
- Absenteeism scores improved (i.e., less absenteeism) by 19 percent.
- Productivity increased by 16 percent, adding an estimated $674,000 to ASID's bottom line during the first year of occupancy and expected to yield a $7 million increase during the 10-year lease.
- Employees' satisfaction with environmental variables such as noise reduction and speech privacy increased their sense of ownership and pride in their workplace (i.e., place attachment).

The research reveals the many ways in which workplace design—and a comprehensive approach to acoustics—positively influences health, wellness, employee satisfaction, and work performance. Study is ongoing, allowing ASID to make adjustments as needed to maintain occupant satisfaction and meet the organization's ever-evolving requirements.

the background—or ambient—sound that actually exists in the space, which experts maintain is "probably the most important room variable affecting speech privacy."[9, 10]

If one only implements maximum thresholds, one leaves this key variable up to "whatever is left" or "whatever happens." Because our ability to discern the intrusion of speech depends on the level and spectrum of background sound "which actually exists (not the background noise criterion) in the listening space,"[11] setting *minimum*—not maximum—levels for background sound is critical to attaining speech privacy. While maximum limits mitigate the impact of "unwanted sound" from noise sources (e.g., building systems), minimum levels call for "wanted sound" from dependable sources. These two criteria are exclusive of each other because wanted sound is needed to mask that which is unwanted.

A minimum background sound level can only be reliably achieved through the application of the C in the "ABC Rule." While A stands for "absorb" and B for "block," C stands for "cover"—or, more accurately, "control"—which requires use of a sound-masking system. While C is the final letter in the rule, it is only because the abbreviation is meant to be memorable and is, therefore, in alphabetic sequence. It is not intended to assign priority level to the acoustical strategies involved or indicate the extent of the role each plays in the outcome. Rather, the rule reinforces the fact that a holistic approach is required for the best results.

It is important to note that the interrelationship—and interdependency—of the acoustical features of a built environment is not a wholly occupant-centric consideration. Taking a holistic approach to the execution of an acoustical plan also allows one to gain "system-level" efficiencies that help manage construction-related costs (e.g., lowers STC requirements, permits walls to be built to the ceiling instead of up to the deck), allow for more effective and efficient operation of building-related systems, and avoid post-completion noise-mitigation efforts.[12, 13]

LOOKING BEYOND LEVEL

The role that C plays in providing beneficial acoustical conditions becomes even clearer when one considers that there is more to human experience of sound within the built environment than overall level—or, more colloquially, "volume"—particularly at the lower decibels established by minimum and maximum limits. At these levels, the psychoacoustical impacts have less to do with the magnitude of sound (i.e., in the sense that the mechanisms that cause temporary or permanent hearing loss due to sudden or prolonged exposure to sufficiently elevated sound levels are entirely absent) and more to do with its temporal, spectral, and spatial qualities.

These qualities are not as well-understood by those outside the acoustical community and, hence, not typically as well-considered when designing a space. If the sound that actually exists within a space is left to various noise sources (e.g., building systems), these qualities are also inherently variable—and will remain so, despite efforts to mitigate, absorb and block noise—unless C is implemented.

Temporal

The temporal component of sound refers to the variation in the level of sound as a function of time; in other words, from one moment to the next.

Neither HVAC nor MEP systems can be relied upon to provide continuous and constant (i.e., unchanging) control—and nor should they, for reasons relating to the spectral characteristics of these noise sources. Figure 2 illustrates the issue. While the receiver experiences a moment of privacy (highlighted in blue), they are not free from distraction the remainder of the time because the signal-to-noise ratio is positive. When C is applied, it not only improves speech privacy but also increases occupants' perception of acoustical consistency by reducing the frequency and severity of the intermittent changes in sound levels (i.e., dynamic range) caused by speech and noise, over time.

Spectral

The spectral component of sound is a more nuanced topic. Just as visible light is composed of a range of wavelengths, sound, as we hear it, is the result of combinations of frequencies.

Singular—or discrete—frequency values are called "tones," and we are able to hear between approximately 20 and 20,000 hertz (Hz). In order to simplify reporting data for the nearly 19,980 individual frequencies, it is common practice to divide this range into sections called "fractional octave bands." The customary fractions are full octave bands (also referred to as "1/1") and one-third octave bands (or "1/3"). Between 20 and 20,000 Hz, there are 29 one-third octave bands. The combination of all audible frequencies of a sound sums to its overall level.

Credit: KR Moeller Associates Ltd

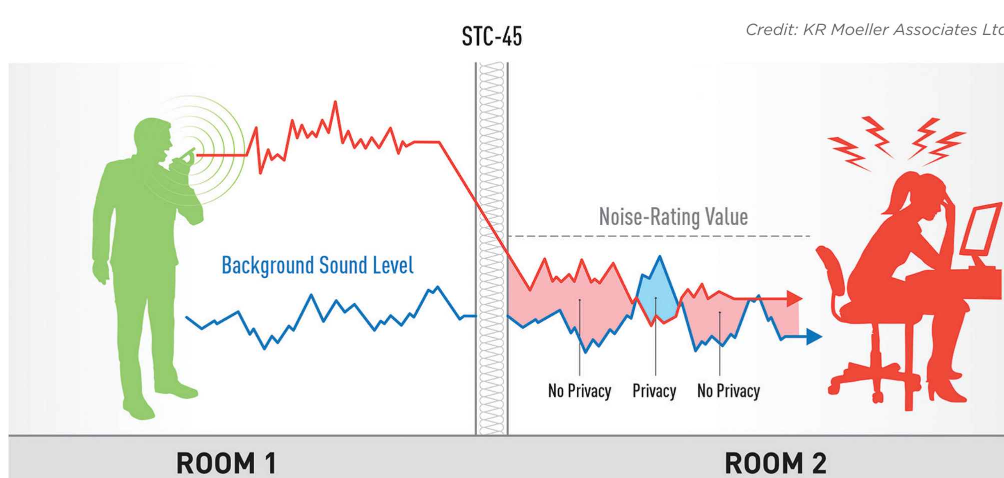
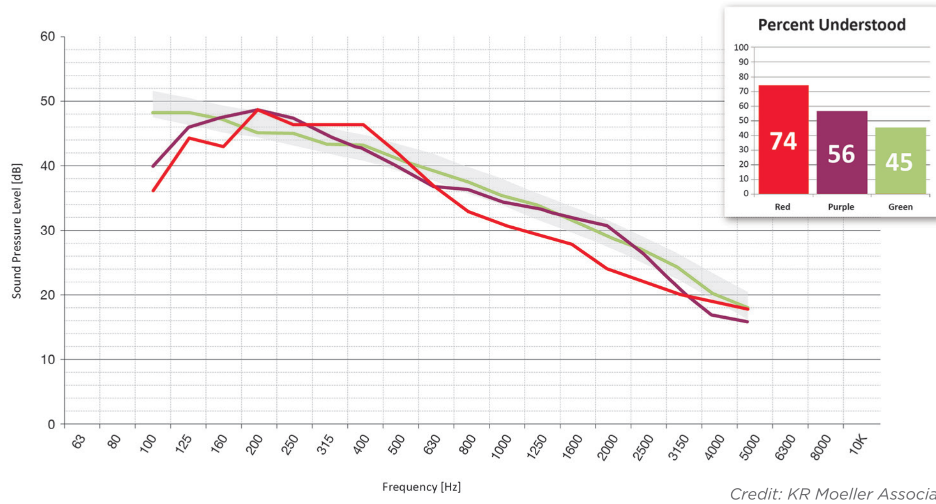


Figure 2: The person in Room 1 briefly has speech privacy—and the person in Room 2 a corresponding reprieve from disruption—when the background noise produced by the HVAC system temporarily reaches the level required for privacy, highlighting the need to establish minimum background sound levels in addition to maximum noise thresholds.



Credit: KR Moeller Associates Ltd

Sounds equal in overall level can be perceptibly different, depending on their frequency content. Differing spectrums also impact speech privacy. Here, a masking system is tuned with varying degrees of precision. Despite the fact that the resulting sounds are at exactly the same overall level (i.e., 47 dBA), note the impact on comprehension (i.e., privacy) when the frequencies defined by the National Research Council (NRC) masking spectrum are not met.

It is possible for two sounds equal in overall level to be perceptibly different. Borrowing descriptors from the American Society of Heating, Refrigerating and Air-Conditioning Engineers, one can generally state that a sound that has too much low-frequency content is "too rumbly," while a sound that has too much high-frequency content is "too hissy," and sound that has too much mid-frequency content has a strong "hum" or "buzzing" quality.

If empowered with the ability to adjust the frequency content for a fixed level of sound (e.g., 45 dBA), there exists a favorable combination of frequencies that is "most comfortable" or balanced. This "shape of sound" is documented in literature by Beranek (and BBN) and Warnock—and, more recently and precisely, by the National Research Council (NRC)—and forms the basis for the synthesis of masking sound.[14] When professionally tuned to meet this "shape" (typically called a "spectrum" or "curve") for the majority of the audible frequency range (100 to 10,000 Hz), background sound resides in the "Goldilocks zone." Occupants' perception of the final product may be described as "quiet"—free from rumble, hiss, or buzz, and absent of hum or buzzing; furthermore, the overall level is neither too high to disturb occupant comfort nor too low to compromise acoustical privacy.

Spatial

The spatial component of sound is no less complex. It refers to the variability of the level—also, inherently, that of the spectra—of sound, in space. These variations are a function of many parameters, including not only the source and location from where the sound originates (e.g., building systems, occupants, appliances, and even oneself) but also the space's architecture (i.e., size, shape, geometry) and fit out (i.e., finishings, fixtures, furnishings).

As sound from a source is generated, it propagates with its level decaying as a function of distance, and by the number of times it is reflected (loses energy) from other surfaces or at room boundaries. While its energy continually dissipates, its eventual inaudibility is not because its level is attenuated below one's auditory threshold but because it drops below the background

Credit: KR Moeller Associates Ltd

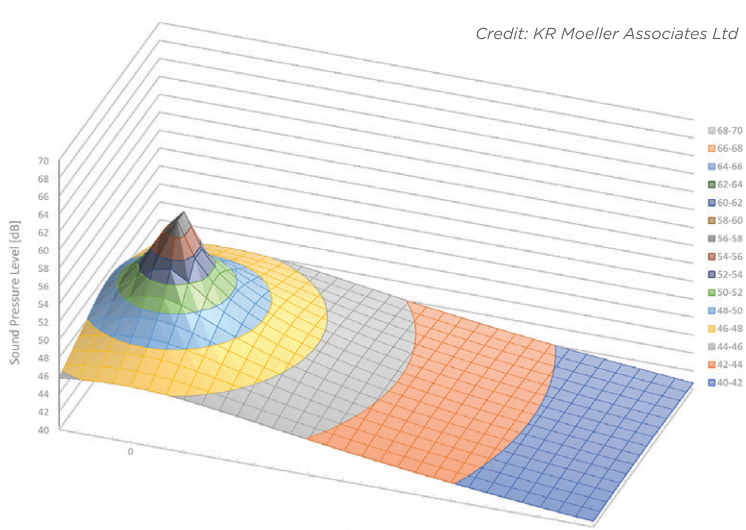


Figure 3: A simplified model showing how sound propagates as it moves away from a source, across—or, rather, throughout—a space. Each notch along the horizontal axis represents 1 foot, with 0 marking the origin of the noise.

Credit: KR Moeller Associates Ltd

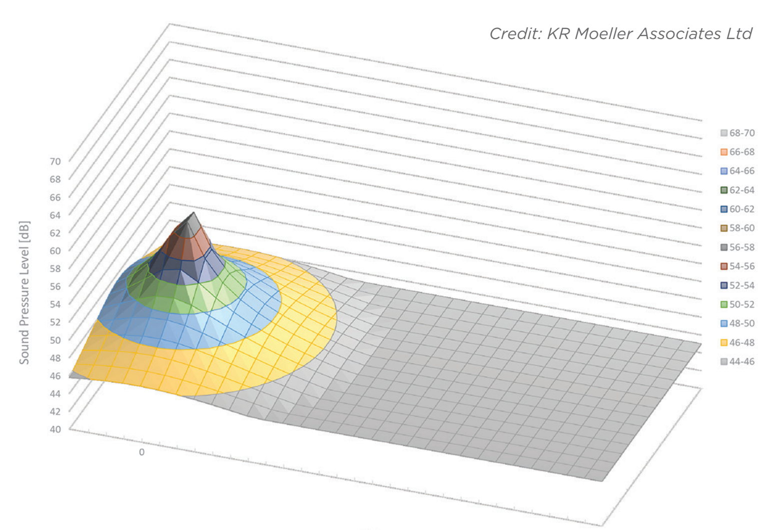


Figure 4: A simplified model showing how masking reduces the distance over which the noise shown in Figure 3 can be heard. The effect is noticeable in terms of where the propagating signal reaches and falls below the level of masking sound (gray shaded area).

sound in one's environment—the background sound that actually exists. This phenomenon is known as the "Masking Effect," where the background sound covers the propagating noise. Figures 3 and 4 provide simplified modeling of this effect. Not only does masking sound reduce the distance over which a noise can be heard (sometimes referred to as the "radius of distraction"), it creates a more consistent—and equitable—acoustical experience for occupants, both in their individual work areas and as they move throughout the space.

CONTROL VS. COVER

While many still associate the C in the ABC Rule with "cover," "control" is a more accurate term for a number of reasons.

Use of the word "cover" can unintentionally reinforce the view that this crucial element of architectural acoustics simply involves placing any sound overtop of others—like a blanket—strengthening the historical misperception that only level matters; in other words, that a sound only needs to be "louder" than other sounds in order to provide the masking effect and, hence, meet the requirements of C. This misperception opens the door to commoditization of sound-masking systems—the notion that the effect will simply be provided by the product, rather than in tandem with a service that ensures the sound actually meets the specified masking spectrum.

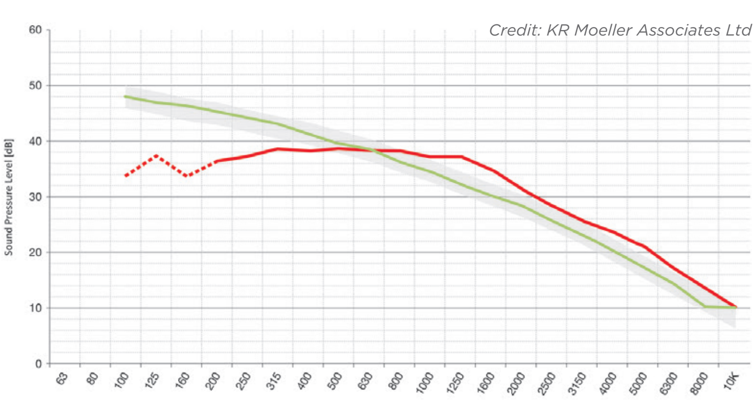
The study of architectural acoustics demonstrates that the physics of the behavior of sound within the built environment is exceedingly complex—and this is true for *any* sound, even that introduced via a sound-masking system. Regardless of the sophistication of the technology, the system's layout or loudspeaker orientation (e.g., upward-facing within the plenum or downward-facing using cut-throughs), the masking effect can only be achieved through skilled field commissioning—or "tuning"—which adapts the sound actually produced in the room/space by accounting for its architecture and fit out. Small zones (i.e., no larger than one to three loudspeakers in size) offering fine volume (in 0.5 dBA steps) and frequency (1/3-octave) adjustment capabilities provide the technician with frequent and precise control points across the environment, helping to consistently achieve the masking effect throughout the space and, hence, a better outcome for the occupants.

Post-installation tuning and performance verification are crucial to ensuring that the sound-masking system is, in fact, effectively controlling the spectrum and level of the sound that actually exists within the built environment—and, hence, dependably providing the masking effect throughout the space. It is only under these assured conditions—temporally, spectrally, and spatially consistent acoustics—that occupants can appreciate acoustical privacy.

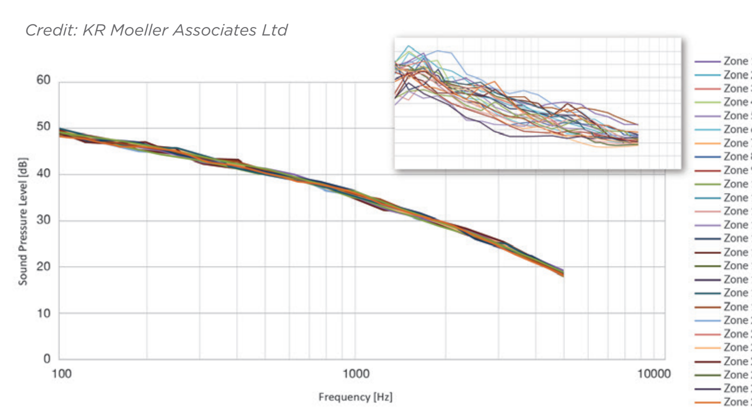
IN CONCLUSION

In 1962, William Cavanaugh et al., authors of *Speech Privacy in Buildings*, affirmed that acoustical satisfaction could not be assured by any single parameter, forming the foundation for the ABC Rule of architectural acoustics. However, until rather recently, building codes, standards, and certification programs largely focused on A and B, while C often succumbed to a historical preoccupation with limiting the "loudness" of sound and the corresponding belief that the goal is to make spaces as silent as possible. But we are in the midst of a paradigm shift.

As we seek to better understand how we can be psychologically and physiologically supported by the spaces we inhabit, the important role played by C becomes apparent. Sound will always remain within our built environment, and the impact of such low-level background sound—that which actually exists in the space—cannot be separated from acoustical satisfaction and its equitable delivery. Therefore, controlling it is as important as controlling the "signals."



The behavior of sound within the built environment is highly complex, including that introduced via a sound-masking system, regardless of its design or the orientation of its loudspeakers. If the measured output—the background sound actually produced in the space—is to meet the specified spectrum, the system must be professionally tuned post-installation. Here, a tuned system (green line) with upward-facing, in-plenum loudspeakers meets the NRC spectrum (gray shaded area), while an untuned system (red line) featuring download-facing or "direct field" loudspeakers fails to do so; also note that, in the latter case, levels below 200 Hz (dashed red line) are contributed by building systems rather than the loudspeaker.



These background sound level measurements were taken in 26 locations within an open plan. Without masking (inset), the occupants experienced varying acoustical conditions across the space. Since masking sound was applied and tuned to reliably meet the NRC masking spectrum within each small zone, occupants experience a far more consistent level of acoustical privacy and comfort throughout the space.

As Greenhouse states, the built environment "impacts us whether designed well or poorly, so why not design well?" If one is to reliably design buildings to function acoustically for their users (e.g., provide adequate speech privacy, freedom from distraction, reduced annoyance, a good night's sleep, and so on), one needs to establish a known level of spectrally neutral (or balanced) background sound, rather than leaving it—and the end result—in question. ■

ABOUT THE AUTHORS

Viken Koukounian, Ph.D., P.Eng., is an acoustical engineer at K.R. Moeller Associates Ltd. He is an active and participating member of many international standardization organizations, such as the Acoustical Society of America (ASA); the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE); the American Society of Testing and Materials (ASTM); the Green Building Initiative (GBI); the International WELL Building Institute (IWBI); the Standards Council of Canada (SCC); and also represents Canada at International Organization of Standardization (ISO) meetings. He completed his doctorate at Queen's University (Kingston, Ontario, Canada) with foci in experimental and computational acoustics and vibration.

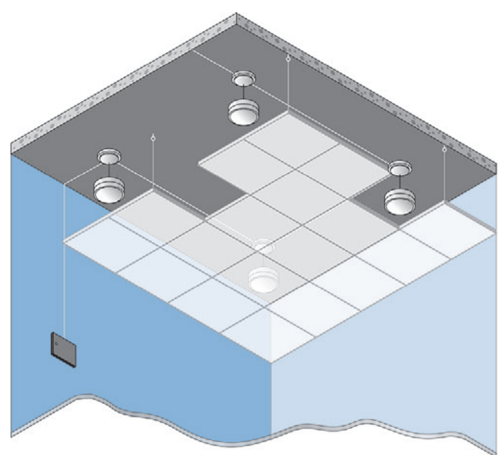
Niklas Moeller is the vice president of K.R. Moeller Associates Ltd., manufacturer of the LogiSon Acoustic Network and MODIO Guestroom Acoustic Control. He has over 25 years' experience in the sound-masking industry.

THE EVOLUTION OF SOUND-MASKING TECHNOLOGY

Considering that sound-masking technology has been available since the late 1960s, one might wonder why the building community is only just beginning to embrace it as the foundation for interior acoustical planning. To understand this delay, one has to consider the technology's history.

Early systems used a *centralized* architecture, which assigns areas to general categories—for example, open plan, closed room, and reception—based on the belief they have the same or similar acoustics. Each one is covered by a single zone composed of a large number of loudspeakers, limiting local adjustment. The resulting inconsistencies in volume and spectrum impact the sound's performance and occupant comfort. In the 1970s, the introduction of *decentralized* architecture reduced zone size to a maximum of three loudspeakers. Volume and frequency can be adjusted where needed, without affecting large areas. In the early 2000s, engineers took this approach further, making system components addressable within a *networked* architecture. Networking permits changes to be made from software, as well precise computer tuning of specific frequencies, ensuring tight compliance with the curve. All three types of architecture are available on the market today.

Developing the masking spectrum was also an iterative process spanning several decades. With the development of methodology to assess the acoustical privacy of spaces—namely, the articulation index (AI)—discussion turned toward specification of reasonable targets for acoustical privacy and renewed interest in determining what type of background sound would work best and how it could be delivered. After all, if the intention is to improve privacy, one not only needs to control the level of background sound but also ensure the sound has specific qualities. In the 2000s,



Credit: K.R. Moeller Associates Ltd

A sound-masking system—often mistakenly referred to by the term "white noise"—consists of a series of electronic components and loudspeakers integrated in a grid-like pattern above a suspended ceiling or in an open ceiling, as well as a method of controlling their zoning and output.

the National Research Council (NRC) refined the spectrum, based on tests measuring both comfort and effectiveness, resulting in the cost-effective open-plan environment (COPE) masking spectrum.

It is important to note delivery of effective masking is not a product of the sound generating and control equipment (i.e., the electrical signal) but, rather, the ability of the sound-masking system to adapt the generated sound that is actually delivered to the space and which is dependent on the space's architecture—its layout, furnishings, and finishings. To achieve the desired effect, the sound produced within the space must be adjusted to the masking spectrum through a post-installation process called tuning.

Ensuring effective performance also requires verification. ASTM E1573-18, *Standard Test Method for Evaluating Masking Sound in Open Offices Using A-Weighted and One-Third Octave Band Sound Pressure Levels*, offers guidance and instruction on the measurement procedure to evaluate the performance of a fully commissioned masking system. Measurements are performed in every 93 m^2 (1,000 ft^2) of open space and a representative number of closed rooms to review effectiveness of the tuning process against performance targets and tolerances, and to provide an indication of the spatial uniformity of the masking sound.

ASTM acknowledges that variations as small as 2 dBA can significantly influence speech privacy, while other studies indicate that even a single dBA affects comprehension by up to 10 percent. Variations in spectral quality can have similarly negative effects. Therefore, it is incumbent upon those responsible for acoustic planning to ensure that the sound-masking solution is designed and implemented with due consideration for these stringent requirements. A poorly designed or improperly tuned system can allow as much as 4 to 6 dBA variation, meaning the system's effectiveness will be halved in unpredictable areas within the facility.

When designed with small zones no larger than 21 to 63 m^2 (225 to 625 ft^2) offering fine volume (i.e., 0.5 dBA) and frequency (i.e., 1/3 octave) control, a networked architecture can provide consistency in the overall masking volume not exceeding ±0.5 dBA, as well as highly consistent masking spectrums, yielding much better tuning results than possible with previous architectures. Some systems can also be automatically tuned using software, which first measures the sound within a zone and then rapidly adjusts the volume and frequency settings to achieve the specified curve. These advances mean that minimum background sound is now a readily deliverable component of architectural acoustic design.

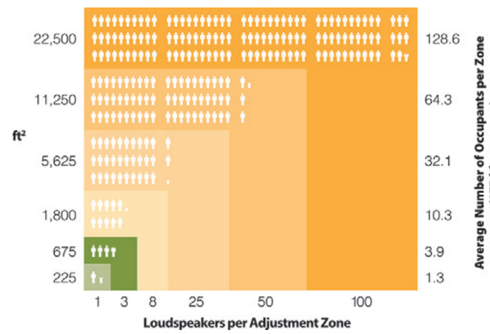
PREPARING A PERFORMANCE-BASED SPEC

Preparing or even evaluating a sound-masking specification can be challenging, but the payoff is worth the effort. These systems typically have a long lifespan. When properly designed, they help to keep acoustics under control even as densities swell, and, if included in a project's planning stages, they also increase flexibility, typically allowing an organization to remain in their facility for a longer period. In other words, the user can end up living with their system for quite some time.

Currently, sound-masking systems are often specified according to the aforementioned types—centralized, decentralized, or networked—limiting the number of vendors that can bid on a given project. Bidding opportunities are further restricted when the specification incorporates proprietary elements such as the dimensions of components, types of inputs/outputs, and other minor details. At the other end of this spectrum are specifications that merely state "provide a sound-masking system." When compared to the manner in which most other building systems such as HVAC or fire alarms are specified, the contrast is striking.

The single most important factor within a sound-masking specification is to place an upper limit on control zone size. Control zones are groups of loudspeakers for which the technician can establish individual volume and frequency settings. From a performance perspective, one loudspeaker in each zone is ideal, but it can be an acceptable compromise—and more budget-friendly—to have up to three, at least across open plans.

Acoustical conditions and user needs vary



Credit: KR Moeller Associates Ltd

The larger the zone, the less control one has over the masking volume and frequency—and the more occupants affected by compromises between performance and comfort.

between private offices, meeting rooms, corridors, and reception areas, as well as across open plans. Designs that use large adjustment zones (e.g., involving more than a few loudspeakers) require one to make ever-increasing compromises. For example, if the volume needs to be raised to improve masking effectiveness in one area, it might be too loud in another, affecting comfort. If comfort is desired, masking effectiveness may be diminished in some areas. Furthermore, as shown in the graph, the larger the zone, the greater the number of occupants it affects. The numbers ramp up very quickly, from an average of 1.3 people in a one-loudspeaker zone to literally hundreds of people and tens of thousands of square feet in a hundred-loudspeaker zone.

Zone size also affects the ease with which the technician can make changes in response to, for example, renovations or moving personnel. Large zones require the system's design to be altered, which usually involves moving loudspeakers and rewiring.

In this case, less truly is more: one to three loudspeakers in each zone (i.e., covering 30 to 62 m^2 or 225 to 675 ft^2) provides a high degree of control and flexibility, enabling technicians to adjust their volume and frequency to achieve a consistently effective and comfortable masking sound.

Even if the specification is well-written, the user can end up with a non-conforming sound-masking system unless someone is appointed as a guardian who is responsible for ensuring that bids—and the system ultimately selected—meet the criteria. Requiring drawings as part of the bid submission process can help because they make it easier to spot design shortcuts. Asking vendors to complete a compliance form that indicates their adherence to each aspect of the specification—and explains any deviations—is also useful.

Because a sound-masking system's ability to provide the intended effect is directly related to the ability to closely match the target curve throughout the space, the vendor should also provide the client with a detailed tuning report demonstrating that the desired curve is consistently provided throughout their space; if there are any areas where the masking sound is outside tolerance, this document should clearly identify the location and reason (e.g., noise from mechanical equipment or HVAC). In this way, the client can be confident that their sound-masking system's benefits are enjoyed by all occupants in their facility.

REFERENCES

[1] G. J. Allen, P. MacNaughton, J. G. Cendeno Laurent, S. S. Flanigan, E. S. Eitland and J. D. Spengler, "Green buildings and health," Global Environmental Health and Sustainability, vol. 2, 2015.

[2] Talitha Liu and Lexi Tsien in "The Office as We Knew It No Longer Exists," *Azure*, September 2020.

[3] See Hao Ko and Lisa Cholmondeley's "Equity, Interrupted: How a Return to the Office Is Needed to Rebuild Equity" at https://www.gensler.com/research-insight/blog/how-a-return-to-the-office-is-needed-to-rebuild-equity.

[4] For more information, see Steelcase's "Work Better: It's time for an experience that's fundamentally better" at https://www.steelcase.com/research/articles/topics/work-better/work-better/.

[5] B. Rasmussen and O. Ekholm, "Is noise annoyance from neighbours in multi-storey housing associated with fatigue and sleeping problems?" in Proceedings of the 23rd International Congress on Acoustics (ICA), Aachen, Germany, 2019.

[6] For a brief but insightful discussion of what "equity" means, see Kris Putnam-Walkerly & Elizabeth Russels "What the Heck Does 'Equity' Mean?" at https://ssir.org/articles/entry/what_the_heck_does_equity_mean.

[7] For more on this subject, see "Equity by Design: Redefining 'Senior Living' | A Conversation with Stephanie Firestone, Esther Greenhouse, and Dr. Bill Thomas" at https://genslerpodcast.medium.com/equity-by-design-redefining-senior-living-a-conversation-with-stephanie-firestone-esther-12a288bd852

[8] See K.L. Jensen's "Acoustical quality in office workstations, as assessed by occupant surveys," presented at Indoor Air 2005, as well as D. Artan, E. Ergen and I. Tekce's "Acoustical Comfort in Office Buildings" from the proceedings of the 7th Annual International Conference - ACE 2019 Architecture and Civil Engineering.

[9] J. Keranen and V. Hongisto, "Prediction of the spatial decay of speech in open-plan offices," *Applied Acoustics*, vol. 74, 2013.

[10,11] W.J. Cavanaugh, W.R. Farrell, P.W. Hirtle, and B.G. Watters, "Speech privacy in buildings," *The Journal of the Acoustical Society of America*, vol. 34, no. 4.

[12] Breaking out of our entrenched ways requires a coordinated effort, not only of building professionals, but of the tools available at their disposal. There is growing realization that improvement at a "component level" is reaching practical limits, promoting new interest in gaining "system-level" efficiencies through a more holistic approach to acoustical design. To learn more about the project savings engendered by a holistic approach, see "A New Approach to Acoustics: Using sound masking as a design platform" on Hanley Wood University.

[13] Although the evaluation of all contributing sound sources is complex, if engineers are able to align their specifications with acoustical expectations of the built environment, one can argue that it is even possible to avoid circumstances where overly stringent noise criteria force building systems to comply to unnecessarily low criteria.

[14] Although they are still often referred to as "white noise" systems, modern sound-masking technologies synthesize the spectrum *and* level of the sound that actually exists within the space.