INTRODUCTION

Acoustical comfort is seen as equal to other environmental factors in evaluations of productivity and psychological well-being in the workplace, but the design industry has yet to adopt a standard of measure pertaining to this variable. While ASHRAE, OSHA and ASTM standards exist for various environmental conditions, these guidelines measure sound itself rather than gauging its associated potential for distraction, loss of privacy and the subsequent deterioration of comfort. Lencore has created an Acoustical Comfort Measurement Unit (ACMU) to be used in sound masking designs by the industry as a standard.

Quantification of these potentially detrimental noise factors is increasingly vital as workplace design trends dramatically shift toward open-plan layouts, collaborative “huddle” spaces and interior designs set for a mobile workforce. To achieve greater productivity and lower employee turnover - the goals of today’s facility management, the industry requires the identification of empirical variables which enhance or dilute acoustical comfort.These variable can then be measured and compared on a cumulative scale that translates into a picture of an environment conducive to communication and concentration for individual and group tasks.

Acoustical comfort, which influences focus and productivity in the workplace, requires the establishment of an environmental design that simultaneously prevents disruption and protects privacy, so speech is heard where it is intended to be received, and blotted out where it might distract.

For various reasons, recent design trends have seen the increasing absence of walls or ceilings and more hard, decorative surfaces, such as glass, concrete and metal in offices, all of which, when coupled, presents a greatly exaggerated risk for speech and unwanted noise to reflect and reverberate through a space. To counterbalance these effects and provide an acoustically comfortable workplace that enables individual focus alongside collaborative discussions, which must often happen in close quarters, requires an acoustical design approach that takes into account physical dampening and the addition of sound masking solutions that can smooth the spikes in atmospheric noise and buffer the transmission of unwanted speech.

Research and support is on the rise for greater consideration of acoustical attributes in workplace design. In addition to academic and industry-based studies, various national entities are publishing observations on this evolving field. An examination of recommendations from academic, architectural and governmental regulatory entities will exhibit a need for a standardized definition of the terms inherent to acoustical comfort. The following analysis provides a foundation for a prediction algorithm developed by Lencore Acoustics to achieve a conclusive rating on a scale to be known as an Acoustical Comfort Measurement Unit (ACMU).

RESEARCH

Field Studies

The proliferation of the "open plan office" trend has provided a number of challenges in their provision. But in a study conducted across a range of workspaces by the Center for the Built Environment (CBE) at the University of California Berkeley, deficiencies in acoustic quality, particularly where they pertained to a loss of speech privacy, were shown to be chief among workers' complaints: http://www.cbe.berkeley.edu/research/acoustic_poe.htm

CBE discovered how occupants perceive acoustical environments by analyzing data from its Indoor Environmental Quality (IEQ) surveys, which the organization has been tracking in commercial buildings since 1996. Information from 4,096 respondents in 15 buildings was parsed for CBE's 2007 report: "Acoustical Analysis in Office Environments Using Post Occupancy Evaluation (POE) Surveys."

The survey identified "overall acoustical satisfaction" as "a function of both the satisfaction with the background noise level and satisfaction with sound privacy." Discomfort, for respondents, was more directly attributable to a lack of privacy, as opposed to noise level, but a majority overall felt that poor acoustic conditions negatively affected their work:

> *From the database of occupant responses we see that people are significantly more dissatisfied with sound privacy than noise level (P< 0.01). Occupants in private offices are significantly more satisfied with the acoustics than occupants in cubicles (P< 0.01). Occupants' self-rated job performance shows that over 60% of occupants in cubicles think that acoustics interfere with their ability to get their job done.*

The survey's conclusions read like a litany of challenges long lamented by acoustical consultants:

Acoustics are an important attribute of commercial office building design. Studies have shown that noise is probably the most prevalent annoyance source in offices, and that noise can lead to increased stress for occupants. Speech privacy may be an even more important effect than noise. Yet acoustics in most cases do not receive the level of design attention as thermal, ventilation and other architectural and engineering considerations. The causes and consequences of poor acoustical performance are perhaps not adequately understood by designers and building owners.

Government Studies

The 2011 "Provide Comfortable Environments" White Paper for the "Whole Building Design Guide" program provided by the National Institute of Building Sciences (NIBS) [http://www.wbdg.org/design/provide_comfort.php], states that "Physical comfort is critical to work effectiveness, satisfaction, and physical and psychological well-being." The paper goes on to suggest steps to be taken at the earliest possible facility design and development phase, within which includes "Provide a superior acoustic environment.

To “provide a superior acoustic environment,” the NISB recommends practices long viewed as central to workplace acoustical design, but likely in need of revision in this age of open-plan spaces:

- Reduce sound reverberation time inside the workplace by specifying sound absorbing materials and by configuring spaces to dampen rather than magnify sound reverberation.
- Provide sound masking if necessary.
- Limit transmission of noise from outside the workplace by designing high sound transmission class (STC) walls between work areas and high noise areas inside and outside the building.
- Minimize background noise from the building's HVAC system and other equipment.
- Provide opportunities for privacy and concentration when needed in open plan offices.
- Enclose or separate group activity spaces from work areas where concentration is important.

The proliferation of the “open plan office” trend has provided a number of challenges in the provision of these acoustical ideals. Increasingly, reverberation is less the issue than the loss of speech privacy and subsequent distractions caused by conversations overheard in the workplace. Furthermore, in addition to delineating areas where increased concentration is important, it is necessary to treat an entire space for consistency and comfort.

It may be time to eliminate the “if necessary” and “when needed” caveats associated with the use of sound masking and face the real possibility that this acoustical treatment option is increasingly essential to workplace comfort and productivity.

Further government-generated evidence of the need for greater emphasis on acoustical comfort in workplace design can be found in the GSA Public Buildings Service report, “Sound Matters: How to achieve acoustic comfort in the contemporary office,” [http://www.wbdg.org/ccb/GSAMAN/gsa_soundmatters.pdf] published in 2011.

In this document, having undergone its own renovation process at its Washington, D.C. headquarters, the GSA emphasized: “Acoustic performance will need to transition from a ‘side issue’ to a ‘core issue’” in design.

The agency’s report cited the Privacy Index (PI) as central to acoustical comfort, specifying the widely accepted standards of a PI of 95 for “confidentiality” and 80 for “normal speech privacy.” The report goes into analysis of present-day work conditions and stated that most commercial office spaces have a PI of less than 80, especially in open-plan conditions.

Citing its own research among occupants of seven renovated federal office buildings, the GSA’s conclusions were similar to those reached by UC Berkeley:

> “At the present time, work environments are doing a poor job of providing acoustical comfort…. [In the survey results there was data finding] substantial improvements in almost all environmental factors except noise and voice privacy. The percent satisfied with noise and privacy was even lower than for temperature conditions, which are notoriously dissatisfying…. It should be noted that satisfaction with acoustics was low

> even before the renovations. Acoustic conditions have been a concern since the adoption of the open plan office decades ago."

In a baseline survey for the GSA WorkPlace 20•20 program (which provided research and pilot feedback that the Center for Workplace Strategy follows), 60% of the 3,700 respondents said they could get more done if it were quieter; 56% said the ability to insulate themselves from distractions was very important; and 50% said noise keeps them from being as productive as they could be.

QUANTIFICATION OF ACOUSTICAL COMFORT

The gold standard of acoustical measurement, used mainly in the rarified venues of concert halls, has long had a focus on reverberation (early and late decay), sound levels, and speech intelligibility evaluated in terms of Speech Clarity (C50), Speech Transmission Index (STI), Reverberation Times (EDT, T20, T30) and Strength (G), as well as Rate of Spatial Decay (DL2) and Excess of Sound Pressure Level (DLf) in open and long spaces.

In environments where a ceiling is in place, the Articulation Class (AC) value is an additional factor. The AC value is determined in accordance with ASTM E 1110 (2001), which recommends an AC value of at least 180.

For its part, the NIBS "Whole Building Design Guide" makes the following recommendations in its section focused on "Acoustical Comfort." Many of these specifications refer to a cubicle style office environment, and now seem slightly antiquated in the contemporary era of "desking" or "benching" and wide-open workspaces:

- Specify acoustical ceilings with noise reduction coefficient (NRC) of 0.75.
- Choose systems furniture with a 60 inch minimum height and have sound absorbing surfaces on both sides.
- Avoid placing lighting fixtures directly over partitions - they reflect sound to the adjacent cubicle.
- Locate copy machines in separate rooms away from offices and provide separate ventilation to minimize ozone in the workspace.
- The ideal office environment would give workers individual control of temperature, lighting, and acoustics in their personal workspace.
- Extend walls from floor to structural deck above.
- Insulate partition cavity/increase partition sound transmission class (STC).
- Employ a ducted air return system.
- Do not locate mechanical equipment rooms next to offices and conference rooms.
- STC values for various occupancies can be found in UFC 3-450-01, Design: Noise and Vibration Control and Architectural Graphic Standards.
- For office areas with exposed ceiling structure, specify low reverberation times (0.6-0.8 seconds) to minimize echoing and unwanted sound reinforcement.

These guidelines provide a lot of guidance about partitions and walls, but not a lot of information about the most common workplace design in use today, the open-plan setup. Suggesting that reverberation times be kept low is not enough, as a near total lack of absorptive material or buffers to break up the open space makes that type of noise abatement difficult.

Alternatively, many of the values above can be attained through the use of sound masking systems, which introduce noise into a space and gently cover indirect speech or distracting sounds from HVAC systems and other office equipment. A properly tuned sound masking system can minimize distraction and allow collaborative and individual work to coexist. Meanwhile, masking will also deliver speech privacy. But care must be taken to ensure that a sound masking system is set at levels and calibrated such that its tone is unnoticed and thus comfortable for employees in the office. Discomfort caused by a grating sound masking tone or a short wraparound time that perpetually calls attention to the system working above not only causes disruption, but also time lost to employees feeling as though they have to relocate to find somewhere “quiet” to get work done.

Fine tuning the acoustical signature of select areas via sound masking helps to provide the widely recommended Articulation Index (AI) or Speech Transmission Index (STI). This provides further guidance on ensuring that ambient noise levels are in the sweet spot for obscuring disruptive sounds and protecting speech privacy. The Acoustical Comfort Measurement Unit has been developed to insure that the creation of privacy will not simultaneously create audible distractions which would diminish comfort. The ACMU will measure when both speech privacy and comfort are obtained concurrently.

Once the sound levels generated by the system are evenly distributed throughout a treated area, further adjustments can be made to boost masking levels for specific privacy requirements or noise abatement in any given area. However, it’s important to look beyond noise levels and consider the frequency spectrum. The noise caused by mechanical systems as they cycle on and off may not produce wide variations in sound level, but they cause more unsettling disturbances in low or high frequency ranges outside the accepted spectrum of comfort. Sound masking can smooth out that spectrum, and create a more comfortable environment.

The question then is, how is the sound masking system then evaluated for effectiveness in terms of providing a comfortable and effective workplace? The sound may be consistent throughout an environment, but is it a sound that is experienced as jarring or grating on the spectrum of human hearing? And does the sound imperceptibly mask unpleasant distractions without adding to the disruptions in the form of noticeable cycling noises? These upsetting factors can derail an entire sound masking solution.

MEASURING ACOUSTICAL COMFORT

Having considered the published observations of research analysts, academics and government agencies, it’s clear that the modern workplace is in need of greater acoustical consideration to foster productivity and ensure privacy. But further to that is the question of how to provide a solution which will work for the long-term.

It’s important to consider the entire picture when developing a work environment, which is often a place where individuals will spend more consecutive waking hours on more days than just about anywhere else. To make that a positive place, and one that fosters collaboration and productivity, the overall contentment (ergo, comfort) of employees must be considered.

Typically when a workplace is treated with sound masking, metrics for speech privacy are the predominant method of guidance in tuning a system to achieve an acceptable PI and STI. But an environment which has been evaluated and set up for privacy may not boost productivity or reduce complaints and turnover rates.

While established empirical methods serve the privacy question well, that metric may be relative where comfort is considered. To use an extreme example, a lawnmower can provide speech privacy, but the sound it makes certainly wouldn't foster concentration, improve focus or enable collaboration.

To fully rectify the discomfort associated with workplaces that are perceived as "too quiet" or "too disruptive," speech privacy certainly must be addressed, but in a manner that does not distract further or cause barely perceptible mental anguish. This means that in addition to privacy, a seemingly unquantifiable aspect of the human experience must be addressed: comfort.

It's easy to dismiss comfort as being subjective, but there are in fact data points which can be gathered and analyzed in order to assess the comfort of a sound masked space. These include:

- Reverberation Time - (RT)
- Wraparound Time - (WA)
- Uniformity (dB) - (U)
- Measured Generated Ambient Background Sound - (MGABS)
- Articulation Index - (SP)
- Audio Frequency Range - (AFR)

These factors quantify the various aspects of disruptive sound in a space. Reverberation must be reasonable so an individual can both speak and keep their thoughts straight in a listening situation. Wraparound time of the digital audio loop generated by a sound masking system should be as long as possible, otherwise the "hiccup" between its stop and start will disrupt attention of those working below. Uniformity should be established with the same care used in lighting a space, prizing an even tone for greatest comfort. A Measured Generated Ambient Background Sound should be established slightly above the typical indirect speech range, typically around 47 dB, in order to ensure masked speech performance. The Articulation Index should be high enough to establish privacy. And, finally, the Audio Frequency Range, or sound source, must be capable of producing the entire spectrum of human speech.

These factors, when assessed on a consistent rating scale between 1-5, tallied together and then factored against the ACMU algorithm's audio frequency spectrum achieved by the narrower of the two offered by source and speaker, can produce an empirical result that can then be compared to a scale of effectiveness.

Most significant to this measurement process is the factorization of frequency range, as it quantifies the tonal quality of a sound masking system, and thereby addresses the previously considered "subjective" component of the equation.

Lencore proposes the following Acoustical Comfort Measurement Unit for industry adoption:

ACMU = (RT + WA + U + MGABS + SP)*AFR

See the following page for performance criteria and ratings as an example as to how to calculate the ACMU.

By adopting a uniform, standard-setting guideline such as the above for comfort in sound masking applications, the acoustical consulting community can establish a metric such as those used by ASHRAE or the Sound Transmission Coefficient (STC) rating established by United States Gypsum Corporation (USG).

The fixed numbers derived through systems adopted by these organizations and others within the building trade have established a vocabulary for what is and is not acceptable on a build out. The time has come to establish a similarly assertive quantification for acoustical comfort in sound masking applications.