Technical Paper:
Specifying “Quality Sound”

Proper acoustics, *the unobtrusive sum of all sounds,* is essential for a “comfortable” environment. The sound level at any particular location is typically the sum of sounds emanating from many sources. Office equipment (copiers, fax machines, telephones, personal computers), for example, contributes to the sound in the space, as do voices and the building’s HVAC system.

It’s easy to decide whether or not the aggregate sound in an existing environment is acceptable. It’s simply a matter of listening. Designers face a much greater challenge when asked to create an environment that meets the occupants’ acoustical needs. Not only must designers anticipate and specify the desired acoustical character of a finished space; they must also accurately predict the acoustical effect of the HVAC system.

There’s more to “quality sound” than low sound levels. Our objective here is threefold:

- To clarify the most commonly used descriptors of sound, including sound power, sound pressure, octave bands, noise criteria (NC), room criteria (RC) and the A-weighting network (dBA).
- To examine ways to specify desired acoustical comfort.
- To emphasize the importance of specifying acoustical performance based on an analysis that converts sound power to sound pressure.

Why Specify Sound?

The barking dog that keeps you awake at night … the annoying rattle in your car’s dashboard … the sound of a photocopier just outside your office cubicle. These are just a few examples of objectionable sound or **noise**.

Periodic surveys conducted by the Building Owners and Managers Association (BOMA) indicate just how closely people relate sound to comfort. Year after year, survey respondents consistently identify poor indoor air quality (IAQ), uncomfortable temperatures and noise as the principal motivators for relocating from one rented space to another. It’s also apparent that these factors are of relatively equal importance since their respective ranks change annually.

What’s considered “acceptable” sound varies dramatically with the intended use of the finished space. Obviously, a factory requires less stringent acoustics than a church, while an office has a different set of requirements altogether. But it’s not enough to know the type of application involved. The designer must identify the variety of spaces that exist within a particular building and determine the acoustical needs of each.

Background sound, for example, provides privacy in an open plan office by masking the sound of voices and equipment from adjacent areas. Yet this same level of background sound would be unacceptable for conference or board rooms in that same building.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., ASHRAE, provides designers with general guidelines for HVAC system noise in unoccupied spaces. To better understand the nature and limitations of these guidelines, let’s review some of the properties of sound.

Sound Power and Sound Pressure

“Sound power” and “sound pressure” are two distinct and commonly confused characteristics of sound. Both share the same unit of measure, the decibel (dB), and the term “sound level” is commonly substituted for each. However, to understand how to measure and specify sound, the HVAC system designer must first understand the difference between these properties.

Sound power is the acoustical energy emitted by the sound source, and is an absolute value. It is **not** affected by the environment.

Sound pressure is a pressure disturbance in the atmosphere whose intensity is influenced not only by the strength of the source, but also by the surroundings and the distance from the source to the receiver. Sound pressure is what our ears hear, what sound meters measure … and what ultimately determines whether a design achieves quality sound.

An Illuminating Analogy. The following comparison of sound and light may help illustrate the distinction between these terms. Think of **sound power** as the wattage rating of a light bulb; both measure a **fixed amount of energy**.

Sound pressure corresponds to the brightness in a particular part of the room; both can be measured with a meter and the immediate surroundings influence the magnitude of each. In the case of light, brightness is more than a matter of bulb wattage. How far is the bulb from the observer? What color is the room and how reflective is the wall surface? Is the bulb covered with a shade? All of these factors affect how much light reaches the receiver.

Similarly, sound pressure depends not only on the sound power emitted by the source, but also on the characteristics of the surroundings. Again, how far is the sound source from the receiver? Is the room carpeted or tiled … furnished or bare? As with light, environmental factors like these affect how much sound reaches the receiver.

Relating Power to Pressure. Equipment sound **power** ratings are determined in an acoustics laboratory, usually by the manufacturer. Specific standards qualify testing facilities and methods to promote data uniformity and objective comparisons of different units across the industry.

By contrast, sound **pressure** can be measured in an existing space with a sound meter, or predicted for a space not yet constructed by means of an acoustical analysis. Since the only accurate sound data a manufacturer can provide is expressed as sound power, the challenge of designing for quality sound is to examine the effect of environmental factors.

Ears and Sound Meters

Unlike a sound meter, which provides a repeatable, unbiased analysis of sound pressure, the sensitivity of our ears varies by frequency.

Our ears are also attached to a highly arbitrary evaluation device, a.k.a. the brain. A number of factors contribute to this subjectivity. It’s this “wild card” that motivates—and frustrates!—efforts to devise a method for quantifying and specifying acoustical comfort.

As a **selective** sensory organ, the human ear is more sensitive to high frequencies than low ones. Its sensitivity at a particular frequency also changes with loudness. Figure 1 illustrates these traits using contours; each contour represents a specific loudness level across the frequency range shown. Notice that the contours for “quiet” (< 90 dB) sounds slant downward as the frequency increases, indicating that our ears are less sensitive to low-frequency sounds. The contours flatten as the decibel level increases, indicating a more uniform response to “loud” (> 90 dB) sounds across the range of frequencies.

Tones, sounds that occur over a narrow frequency range, evoke a particularly strong response. Chalk squeaking on a blackboard, for example, produces a tone that is extremely irritating.

Octave Bands and Decibels

Sound is considerably more difficult to measure than temperature or pressure. Since it occurs over a range of distinct frequencies, or *ƒ,* its level must be measured (or predicted in the case of an analysis) **at each frequency** to understand how it will be perceived in a particular environment.

Our ears can sense sounds at frequencies ranging from 20 to 16,000 Hertz (Hz), but designers generally focus on sounds ranging from 44 to 11,300 Hz for room acoustics. Despite this limit, measuring a sound at each frequency would result in 11,256 data points per reading!

To make the amount of data more manageable, this 44-to-11,300-Hz spectrum is divided into octave bands. Each **octave band** is identified by its **center frequency** and is delimited such that the band’s highest frequency is twice its lowest frequency. The “octave band center frequency” is *20.5 x ƒlowest*, so the 44-to-11,300-Hz spectrum contains eight octave bands with center frequencies of 63, 125, 250, 500, 1000, 2000, 4000 and 8000 Hz.

Sound not only encompasses a wide spectrum of frequencies, but an extensive range of volumes as well. The loudest sound the human ear can hear (without damage) is 10 **million** times greater than the quietest perceptible sound. Numbers of this magnitude make using an arithmetic scale cumbersome, so a logarithmic scale is applied instead. Converting the arithmetic range of 1 to 10 million using a “base 10” logarithmic (log10) scale yields a range of 0 to 7.

The 0-to-7 scale must also be tied to a reference value, *Nref,* by which measured values, *N,* are subsequently divided. (The reference value for sound pressure is 20 micropascals; for sound power, it’s 1 picowatt.) The unitless result is described as “bels” or, more commonly, “decibels” (dB). “Deci-” is simply a prefix meaning 10–1. The relevant equation is:

$$dB = 10\ log10\ (N/Nref\ )$$

Measuring sound with a **logarithmic scale** means that logarithmic addition must be used to add and average sound levels. Sound measured in a particular octave band is the logarithmic sum of the sound at each of the band’s frequencies. The good news is that, unlike averaging, logarithmic summing doesn’t mask the magnitude of a tone. Unfortunately, it doesn’t indicate that the ear hears a difference between an octave that contains a tone and one that doesn’t, even when the overall magnitude of both octaves is identical. So the process of logarithmic summing, though practical, sacrifices valuable information about sound “quality.”

Single-Number Descriptors

Given the complex nature of sound, it’s not surprising that considerable work has been done to develop an effective system of single-number descriptors. With such a system, “quality sound” targets can be established for different building environments. These targets aid designers in specifying appropriate acoustical requirements that can be substantiated through measurement. For example, a designer can specify that “the background sound level in the Acme theater shall be *X*,” where *X* is a single number descriptor conveying the desired quality of sound.

The most frequently used single-number descriptors are the A-weighting network, noise criteria (NC) and room criteria (RC). All three share a common problem: they unavoidably lose valuable information about the character or “quality” of sound. Each of these descriptors is based on octave band data which, as noted earlier, already masks tones. The process of converting from eight octave bands to a single number overlooks even more sound data.

Despite this shortcoming, the single number descriptors summarized below are valuable tools for defining sound and are widely used to specify acoustical requirements.

“A” Weighting. One simple method for combining octave band readings into a single-number descriptor is **A-B-C weighting**. These weighting networks compensate for the ear’s varying sensitivity at different frequencies. “C” weighting is applied to high-volume (loud) sound levels where the ear’s response is relatively flat, while “B” weighting is applied to medium volume sound levels. “A” weighting, which is used for low-volume (quiet) sound pressures, best approximates human hearing levels in the comfort range where no protection is needed.

The following steps describe how to calculate an A-weighted (dBA) descriptor.

1 Subtract these decibel values from the octave band cited: 26 dB from 63 Hz, 16 dB from 125 Hz, 9 dB from 250 Hz, and 3 dB from 500 Hz.

2 Add 1 dB each to the 2000-Hz and 4000-Hz octave bands.

3 Logarithmically add all eight octave bands together to arrive at an overall A-weighted sound level (dBA).

Data about the relative magnitude of each octave band is lost with the completion of Step 3. So, even though the target dBA level is achieved, an objectionable tonal quality or spectrum imbalance may exist.

Most sound level meters automatically calculate and display A-weighted sound values, providing a simple and objective means of verifying acoustical performance.

“A” weighting is often used to definesound in **outdoor** environments. For example, local sound ordinances typically regulate dBA levels at property lines. Hearing-related safety standards written by such bodies as the Occupational Safety and Health Organization (OSHA) also commonly refer to A-weighted sound readings.

Note: *As a rule, “A” weighting is applied to octave-band* ***sound pressure*** *data and combined into a single number … but an exception exists. ARI Standard 270 recommends the use of A-weighted* ***sound power****. To avoid confusion with A-weighted sound pressure values, A-weighted sound power is expressed as bels rather than decibels. Ideally, both “A” weighting of sound pressure while displaying all eight octave bands and any A-weighting of sound power (except in accordance with ARI Standard 270) should be avoided.*

Noise Criteria. “Noise criteria” or NC curves are probably the most common single-number descriptor used to define the sound quality of **indoor** environments. Like the equal loudness contours (Figure 1) on which they’re based, the loudness along each NC chart curve is about the same. Each NC curve also slopes downward to reflect the ear’s increasing sensitivity at higher frequencies.

Determining the NC value for a given set of octave band data is easy. Simply plot the octave band data on the NC chart … the highest NC curve crossed by the data curve determines the NC rating. Of course, this strategy still doesn’t account for the tonal nature and relative magnitude of each octave band even though it avoids logarithmic addition.

Why is this “lost” information so critical? The answer is best explained with an example. Figure 3 shows octave band data measured in an open-plan office area and plotted on an NC curve. Notice that the resulting value, NC 39, is acceptable for this environment. Also observe that the NC level is set by the 63-Hz octave band, and that the sound in the upper bands quickly drops off. In this particular example, sound produced by the air handling unit travels through the ductwork and radiates into the office area through the duct wall. To achieve the desired NC level, two layers of sheet rock were added to the duct exterior to sufficiently block the low frequency sound.

Unfortunately, because high-frequency sounds are much more easily attenuated than low ones, the upper octave bands are now overattenuated. Although an objective analysis deems the resulting NC 39 sound level acceptable, most listeners probably wouldn't as the unbalanced spectrum produces an annoying rumble.

Interestingly enough, quality sound could be achieved in this example by **adding sound** to the space. Placing speakers in the room (or above the ceiling tile) to introduce sound in the upper bands would balance the sound spectrum. The subjective analysis of the office occupants would then agree with the objective acoustical data.

Room Criteria. Sound spectrums can be unbalanced in other ways that result in poor acoustical quality. While a lot of low-frequency sound results in a rumble, too much high-frequency sound produces a hiss. Room criteria (RC) curves provide a means of identifying these imbalances. Calculating an RC value from a set of octave band data isn't quite as easy as determining an NC value. Yet, it's still a simple process that yields a single-number descriptor followed by one or more letters indicating sound character:

- **N** identifies a "neutral" or balanced spectrum.
- **R** indicates "rumbly."
- **H** represents "hissy."
- **RV** denotes "perceptible vibration."

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If we plot the acoustical data for our example open-plan office on an RC chart, we find that it results in a rating of RC 31 (R). This time, our objective and subjective analyses lead to the same conclusion: though "quiet" enough, the background sound in the space is rumbly. Similarly, a sound spectrum curve falling into the RC "neutral" category would be judged as excellent by most observers. It's this conformity of analysis results that makes the RC noise rating method a better tool than its predecessors for specifying acoustical requirements.

Despite this advantage, the RC rating system is less widely used than other single-number descriptors. Perhaps system designers are unfamiliar with its benefits or are comfortable with the more easily calculated NC rating. They may also question the usefulness of the RC rating system's letter descriptors which identify the nature of a sound quality problem, but don't convey its magnitude.

Specifying Quality Sound

From our discussion of sound-related terminology, we can infer that specifying quality sound for an application requires us to:

- Determine the desired acoustical character, and …
- Choose an appropriate single number descriptor, keeping in mind the limitations inherent in each numbering scheme.

For example, suppose an air-cooled chiller will be placed adjacent to a building where a local ordinance limits sound to 50 dBA. Such a requirement might be stated in the specification as:

"The A-weighted sound pressure level shall not exceed 50 dB re 20 Pa, measured on the slow response scale, anywhere along the property line. The period of observation shall be at least 60 seconds at each measurement location." Similarly, the specification for an air handling unit to be situated indoors might state:
"The sound pressure measured re 20 Pa shall not exceed NC 40 anywhere in the occupied space. Measurements shall be taken on the slow setting, and the period of observation shall be at least 60 seconds at each measurement location."

Analysis Is Key. Both examples highlight an important point: including a single-number descriptor in the specification means that ***someone* must make an acoustical analysis** to determine if the proposed HVAC equipment will satisfy acoustical requirements. To make such a prediction, the analysis must convert equipment sound power ratings to sound pressure and assess the effect of environmental factors.

Unless the application is extraordinarily simple, sound that reaches the occupied space will be altered by ductwork, room furnishings and the like. The validity of an acoustical analysis, therefore, depends on the analyst's familiarity with construction details.

The **source–path–receiver model** provides a systematic approach to acoustical analysis. As its name suggests, this modeling method traces sound from its origin (e.g., at a fan or compressor) to the site at which it's heard (e.g., around a conference table). Everything that sound encounters as it travels between these two points constitutes the "path."

Sound emanating from a source will likely follow more than one path, so the sound level at the receiver will be the collective sum of the paths' analyses.

Acoustical Alchemy. Defining the model's endpoints is straightforward. Manufacturers provide **sound power** data for source equipment and owners set **sound pressure** targets for the receiver rooms. The work, and **art**, of acoustical analysis lies in identifying and quantifying the path elements that attenuate or amplify sound. Theoretical equations aid the analysis of some path elements, but prediction equations based on test data and experience prevail.

ASHRAE collected and developed numerous logarithmic prediction equations for path components in HVAC systems, and subsequently published them in their *Algorithms for HVAC Acoustics* handbook. (Fortunately, software tools are available to spare analysts from solving these iterative, calculation-intensive equations manually.)

An acoustical analysis based on the source–path–receiver model can help the system designer write a specification that's more likely to satisfy the acoustical target and provide "quality sound." From such an analysis, the designer knows the path attenuation provided and can directly specify the maximum allowable equipment sound power. For example, a typical sound power specification for an air handler might read:

"Sound power levels for the unit shall be determined in accordance with AMCA 300–95, and shall not exceed the values in the following table at design conditions… "

Putting It Together
Sound is one of three key ingredients that contribute to a comfortable building environment. Prerequisite to an effective specification of sound power levels are (a) acoustical analyses of the HVAC system layout and building construction, and (b) an understanding of the singlenumber descriptors used to define the acoustical nature of an environment.

The inclusion of sound performance in an equipment specification should automatically suggest an acoustical analysis. Ideally, the analysis should be made **before** the specification is written.

Acoustical requirements can then be included in terms of sound power, facilitating an “apples-to-apples” comparison of the products offered by various manufacturers.

Omitting this step means that each bidder must conduct their own analysis … and each will make their own assumptions about how the building’s construction will affect that analysis.

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