9

Acoustical Noise Emissions

9.1 ACOUSTICS

Acoustical noise emissions in datacom facilities are a combination of the noise emissions from the datacom equipment itself, as well as the noise emissions from the HVAC equipment used to provide the facility with air conditioning. The noise level of air-cooled datacom equipment has generally been increasing along with the power density and heat loads, so this is an important issue for datacom facility planners and equipment manufacturers alike. Densely populated datacom facilities may run the risk of exceeding OSHA noise limits (and thus potentially causing hearing damage unless personnel are provided with hearing protection) and reference should be made to the appropriate OSHA regulations and guidelines (OSHA 1996). European occupational noise limits are somewhat more stringent than OSHA's and are mandated in EC Directive 2003/10/EC (European Council 2003). Facility noise level calculations can be made following the methodology outlined in the "Sound and Vibration" chapter of *ASHRAE Fundamentals* (ASHRAE 2005c). An acoustical consultant may be needed to properly predict sound levels from multiple sources and paths, as is typically the case in a datacom facility.

In the past, the issue of acoustical noise levels in datacom facilities may not have been an issue of particular concern to data center managers or planners. There are at least two reasons for this. First, the noise levels of the individual datacom products on the floor were not noticeably high, and, second, data centers of the past were mostly in isolated "back room" areas where only a few operators or service personnel might have been located for relatively short periods of time. Certain trends over the last decade or so, however, have made the problem of excessive noise levels in data centers an important one for data center planners and equipment manufacturers alike. These trends include: (1) the packaging of higher and higher performance electronics, such as microprocessors, memory, and control logic into smaller and smaller modules; (2) the ability to package more and more of these modules into a standard-sized datacom rack, cabinet, or frame; (3) the desire to install as many of these racks, cabinets, and frames as possible over the available floor area, often "brick-walling" them across the length and width of the floor; (4) the resultant need for more computer room air-conditioning units or other cooling equipment to keep the datacom equipment running; and (5) the desire in some companies to proudly display their high-tech data centers to visitors or to locate employees and other personnel in the data center area itself.The first and second trends are responsible for the increase in the acoustical noise levels of the individual datacom racks themselves. The denser packaging of the electronics has caused dramatic increases in heat load density with an attendant demand for much greater cooling airflow through the individual rack modules and the overall rack itself. The principal sources of noise in datacom equipment are the air-moving devices (fans, blowers, motorized impellers) and the more airflow required, the more noise. The third trend, the higher density of installed equipment, further compounds the problem because not only are the individual datacom racks noisier but there are more of them on the floor. If two racks now occupy the same floor space taken up by one of them in the past, the noise level to which a person on the floor would be exposed will double. And if each rack were now twice as noisy as in the past, the noise level will be doubled yet again.

The fourth trend, which is a direct result of the increased heat load density of the equipment installed on the data center floor, is responsible for a further increase in the noise levels in the data center. The acoustical noise level of a typical computer room air-conditioning unit is invariably much higher than a typical datacom equipment rack. In the past, when there might have been only a few of these units, spaced well apart and located at the far end or along the perimeter of the floor, their higher noise levels were not a significant factor since there were so few of them compared to the number of datacom products on the floor. Today, however, not only are there many more air-conditioning units in the typical data center, but they are being installed throughout the floor space. Again, the result is that employees, visitors, and other personnel may now be exposed to higher noise levels on the data center floor than in the past.

The fifth trend, that of locating personnel in the data center, does not contribute to higher noise levels, of course, but makes the issue of data center noise levels more acute and in need of attention. Clearly, if human beings could be totally isolated from the datacom facility noise levels, there would be no problem. It is only when they are physically exposed to the noise that it becomes an issue, and the issue may be one of either safety and health or of employee comfort and productivity, as identified below.

9.2 ASHRAE RESOURCES

It is not the intent of this section to address the issue of data center acoustical noise or its control in any technical depth but, rather, to give a broad overview of the problem. For the interested reader, the "Sound and Vibration" chapter of *ASHRAE Fundamentals* (ASHRAE 2005c) provides a good background on some of the basic issues in acoustics and noise control that might be helpful in understanding the problem of data center noise and its control. There is also the “Sound and Vibration Control” chapter in the *ASHRAE Handbook—HVAC Applications* (ASHRAE 2003e) that discusses in more practical terms the noise from mechanical equipment and HVAC systems and provides some guidelines for noise control. However, neither of these chapters deals specifically with datacom facilities themselves or the particular types of IT equipment and air-conditioning units that are typically found in these facilities. For data center managers and planners who are, or may be, faced with an excessive noise problem, the services of a qualified acoustical consultant may be required to solve or ameliorate the problem. A good starting point for finding a suitable consultant is the Web site for the National Council of Acoustical Consultants (http://www.ncac.com). General information about the field of noise control engineering, as well as many useful links and contacts, may be found on the Web site of the Institute of Noise Control Engineering (http://www.inceusa.org).

9.3 THREE ASPECTS OF THE NOISE PROBLEM: THE SOURCE, PATH, AND RECEIVER

A source of noise emits a certain amount of sound energy into the environment or room in which it is located. This is true whether or not there are people in the room to receive (or hear) this energy or, if there are, where they are located or how far away from the source they are. It is also true regardless of what happens to the sound after it is emitted from the source or whether or not there are other noise sources in the room also emitting sound. Thus, the sound emitted by the noise source is used to quantify the source itself, independent of the subsequent transmission and reception of the sound, and the term *emission* is applied to this aspect of the overall noise problem. The sound emitted may be characterized by its amplitude, frequency content, temporal variations, and directionality. The amplitude of the noise emitted by a sound source is quantified in terms of its *sound power level*, in either decibels (dB) or bels (B).

As the sound radiates away from the noise source, it may be reflected by walls and other obstacles in its path; it may be partially absorbed by the reflecting surfaces; it may be partially transmitted through the surfaces it strikes; and it may be scattered by, or diffracted around, the obstacles in its path. All of these are aspects of the *transmission* of sound, and each depends not only on the frequency content of the sound but also on the characteristics of the surfaces and obstacles it strikes. It is a very complex task to analyze what happens to the sound as it bounces around even the simplest of rooms.

The third aspect of the problem is the *reception* of sound, usually by a human being, but in some cases by a microphone or other recording device. The term *immission* (pronounced “eye-mission”) is often used to denote this aspect, to complement the use of *emission* at the source end. Contrary to the emission of sound by the source, the immission of sound at the listener’s ear *does* depend on the other noise sources in the room, the location of the listener in the room, the geometry of the room and characteristics of its surfaces, as well as many other factors. The sound received by a listener is usually characterized by its amplitude, frequency content, and temporal variations. As opposed to the noise emission from a source, the amplitude of the noise received by a listener is quantified in terms of its *sound pressure level*, in decibels (dB).

From the perspective of data center managers and planners, ultimate concern should be focused on the noise exposure of their employees, visitors, or other personnel in the data center—how loud is the noise, how long are they exposed, are they at risk of hearing damage, how is the noise interfering with their jobs or comfort, etc.? In this regard, the *sound pressure levels* that exist at various points in the datacom facility are of primary interest and should be measured and monitored. On the other hand, the main contributors to the sound pressure level in the room are the individual noise sources, so the *sound power levels* of the individual datacom racks, room air-conditioning units, and auxiliary equipment should also be of concern and should be reduced if possible. The lower the sound power levels of these individual pieces of equipment, the lower will be the sound pressure levels in the room. Information on the sound power levels of the equipment installed in the data center can usually be obtained from the product manufacturers. Finally, the transmission path may also be an important issue to data center managers. Installing absorptive materials on the walls or ceiling, prudently locating sound-attenuating screens and panels, or simply rearranging the equipment layout with respect to personnel work areas may be significant in reducing the sound pressure levels at listeners' ears (even when the source emission levels remain the same).

9.4 THE EFFECTS OF NOISE ON PEOPLE

There are two categories of effects that acoustical noise can have on people: auditory (or physiological) effects and nonauditory (or nonphysiological) effects. Auditory effects include hearing damage, in all of its forms. Hearing damage occurs when the noise level at the ear (noise immission) is very high or when the exposure is over a long period of time. From an employer's perspective, potential hearing damage is a serious issue, not only from the employee's health perspective, but also from the risk of law suits, regulatory fines, and negative publicity. Good sources for background information on the causes of and protection against hearing damage are the National Institute for Occupational Safety and Health and their Web site: http://www.cdc.gov/niosh/topics/noise/ and the World Health Organization and their guidelines and publications (WHO 2004). Nonauditory effects include annoyance, stress, diminished productivity and concentration, and interference with communication. Although not as serious as hearing damage, these "human factor" issues can negatively affect business due to lowered job satisfaction and motivation. A good source for background on the nonauditory effects of noise can be found in USEPA (1981), available at: http://www.nonoise.org/library/handbook/handbook.htm/, and an informative audio CD demonstrating some of the consequences of excessive noise in a workplace is available from NASA (Nelson 2003). In terms of today's datacom facilities, most of the problems associated with complaints about excessive noise will be those in the nonauditory category, particularly annoyance. However, in some large data centers, where datacom racks are lined up side by side over the entire floor and where a relatively large number of air-conditioning units are required for cooling, the sound pressure levels may be high enough to cause hearing damage (see below for more information on this).

9.5 THE SOUND POWER LEVEL OF A NOISE SOURCE

Clearly, the most effective way to reduce the sound pressure levels in a room containing datacom equipment is to reduce the sound power levels of the individual sources. This "source noise control" is always the first approach to a noise control problem and any noise control engineer or acoustical consultant will focus on this from the start. Secondarily, approaches dealing with the path (acoustical absorption, screens, etc.) should be attempted, and only as a last resort should noise control at the receiver (hearing protectors, isolation, rotating shifts, etc.) be looked at. The sound power level is defined as follows:

$$L_W = 10\log\,(W/W_0)$$

where

L_W = sound power level, decibels (dB)
W = sound power emitted, watts (W)
W_0 = reference sound power, internationally agreed upon as 10^{-12} W

The sound power level of a source cannot be measured directly but must be determined from measurements of the sound pressure level at many points around the source, usually with the source installed in a special acoustical environment, such as a hemi-anechoic chamber or reverberation room. The sound power radiated by a source is a function of frequency, and engineers generally measure L_W in individual frequency bands, such as one-third octave bands. However, to be able to use a convenient single-number descriptor to characterize the overall sound power level (or the sound pressure level, for that matter), several standardized "frequency weightings" have been internationally agreed upon. These are frequency-response characteristics, or "curves," that are applied to the raw data so that the data may be summed over frequency to yield a single number that represents the overall level.

By far the most common is the "A-weighting" frequency response curve. This curve weights the data to approximate how a human ear would respond to the sound, generally attenuating the levels at the lower frequencies where the ear is less sensitive (see ASHRAE [2005c] for more information). To indicate an A-weighted level, the subscript A is added to the symbol: L_{WA} for the A-weighted sound power level. Specifications for the noise emission levels of products, as well as the "declared" noise levels available to the public, are stated in terms of the A-weighted sound power level. To clearly distinguish between sound power levels and sound pressure levels (a common source of confusion), the former are usually stated in bels (B) rather than decibels (dB). This is particularly true in the information technology industry, where the A-weighted sound power levels of IT products are given in bels. (*Note*: Sound pressure levels are never given in bels, only decibels.)

A major component of the sound power level of IT equipment originates from the air-moving devices needed to provide cooling (fans, blowers, motorized impellers). Air-moving device noise is closely intertwined with the thermal design of the package because the sound power level of the fan or blower depends on the required airflow, backpressure, air-moving device type and operating point, and especially the details of the inlet conditions (airflow uniformity, turbulence ingestion, etc.). A joint thermal-acoustical approach to IT equipment design is essential. Fortunately, this is being facilitated as practical engineering information on air-moving devices becomes easier to obtain from the manufacturers and suppliers.

9.6 LIMITS ON THE SOUND POWER LEVELS OF DATACOM EQUIPMENT

Acoustical noise limits for individual products to be installed in typical data centers have been endorsed by the Information Technology Industry Council (http://www.itic.org/). Limits are given for a wide range of equipment intended for different environments (the data processing area being one). The noise emission limits are given in terms of statistical upper limit A-weighted sound power levels (or "declared" A-weighted sound power level) and are published in the Swedish "Statskontoret" regulation that has become the de facto standard for the worldwide IT industry (see Sweden 2004), available at http://www.statskontoret.se/upload/2619/TN26-6.pdf). The noise emission limits were selected to ensure that the resulting sound pressure levels in the applicable environment would not be excessive. As an example, the declared A-weighted sound power level for an individual computer rack or frame with a footprint of 1 m^2 or less and intended for "generally attended data processing areas" should not exceed 7.5 B. The "declared" value (as opposed to a measured, or mean, value) represents a statistical upper limit for the sound power level below which a stated large percentage (in this case, 93.5%) of the product noise emission levels can be expected to fall with a high degree of confidence (in this case, 95%). For more information on the use of statistical upper limits for noise emission declarations, see ISO 7574 [ISO 1985]). The information technology industry has developed its own internationally standardized test codes for measuring the noise emission levels of its products: ISO 7779 (ISO 1999a), ECMA 74 (ECMA 2003), as well as a test code for uniformly declaring and verifying the noise emission levels, ISO 9296 (ISO 1988). In view of this, noise emission levels of most IT equipment installed or planning to be installed in a datacom facility should be available from the IT manufacturer.

The manufacturers of chillers and other air-conditioning units for datacom facilities, unfortunately, have not been as active as the IT industry in terms of attention to noise control or the development of industry test codes. As a result, the noise emission levels of computer room air-conditioning equipment are generally higher (on an equivalent floor area basis) than the IT products that populate the data center. Furthermore, lacking industry test codes for uniform noise declaration procedures, it is difficult to obtain the sound power level information for these types of products. This situation is expected to change in the coming years as the need for data center cooling increases and the number of air-conditioning units on the floor increases proportionately. The overall noise level in the data center may then be governed by the air-conditioning equipment, not the IT equipment, and perhaps there will be more pressure on the industry to lower its product noise levels.

9.7 THE SOUND PRESSURE LEVEL IN A ROOM

The sound pressure level that exists at any point in a datacom facility results from an accumulation of the sound energy from all the noise sources in the room. This includes noise that may be radiating from overhead HVAC ducts as well as noise that radiates from underfloor cooling, through perforated floor tiles. As mentioned above, this level is affected not only by the strength of each source but by the physical arrangement of the products on the floor and the sound reflective and absorptive characteristics of the room surfaces and the surfaces of the products and other objects in the room.

The sound pressure level is defined at a point in space as follows:

$$Lp = 10\log\left(p^2 / p_0^2\right)$$

where

L_p = sound pressure level, decibels (dB)

p = root-mean-square sound pressure at a point, pascals (Pa)

p_0 = reference sound pressure, internationally agreed upon as 20 μPa

As opposed to the sound power level discussed above, the sound pressure level *can* be measured directly, and rather easily, using a sound level meter. These are available in many types and ranges of sophistication, but a basic, relatively inexpensive model is good enough to allow a data center manager or industrial hygienist to get an idea of what the typical sound pressure levels in the room are and where the problem areas might be. Sound pressure level is also a function of frequency and is often measured in frequency bands such as one-third octave bands. The comments above relating to the A-weighting curve apply to sound pressure level as well, and it is the A-weighted sound pressure level, L_{pA}, that is most commonly measured and stated.

Although the sound pressure level at a particular receiver location in a room is *related* to the sound power levels of the noise sources in that room, the relationship is complicated and depends on many factors. These include the number of sound sources, the relative levels of each source, the distance of each source to the receiver, the directivity of each source, the acoustical absorption properties of the walls, floors, ceiling, and obstacles in the room, and the reflection and scattering of the sound from the equipment and other obstacles in the room. If the data center already exists and is operational, it is no problem to simply measure the sound pressure levels at various locations in the room. However, if major changes are being proposed or a new data center is being planned, the services of an acoustical consultant or the use of a commercial software package will most likely be needed to make predictions of the sound pressure levels. The sound *power* levels of the individual pieces of datacom equipment will be needed to make such predictions, and manufacturers should have that information available for their products. Regardless of the complexity of the prediction problem, however, one thing is clear: the higher the sound power levels of the equipment in the room, the higher will be the resulting sound pressure levels. Thus, selecting IT equipment or air-conditioning equipment with the lowest sound power levels at the outset is the most prudent approach to low-noise data center planning.

The following simplified formula may be used to provide a general idea of how the *sound pressure level* at a point in the data center can be estimated from the *sound power level* of a source.

$$L_p = L_W + 10\log_{10}\left(\frac{1}{2\pi r^2} + \frac{4}{R}\right)$$

where Lp is the sound pressure level at a particular receiver location in the room (either the A-weighted level or the level in a particular frequency band), L_W is the sound power level of the source, r is the distance from the source to the receiver, and R is the so-called *room constant* of the space: $R = \alpha/(1 - \alpha)$, where α is the average sound absorption coefficient of the surfaces of the room, including those of the installed equipment (typical values are available in the literature, such as Harris [1994]).

In practice, there are many sources in the room, and this equation is modified as follows to take this into account:

$$L_p = L_W + 10\log_{10}\left(\sum_i 10^{0.1L_{Wi}}\left(\frac{1}{2\pi r_i^2} + \frac{4}{R}\right)\right)$$

where L_{Wi} is the sound power level of the ith source and r_i its distance to the receiver. The first term in parentheses accounts for “direct” sound that travels directly from a source to the receiver, and the second term accounts for “reverberant” sound, which reflects from room surfaces and arrives at the receiver from many different directions. Since the sound power level of each source contributes to both the direct and reverberant sound, the most effective noise mitigation approach is to minimize the sound power of the sources themselves. As a secondary measure, the reverberant sound field can be reduced through the use of generous amounts of suitably selected sound-absorbing materials on the room surfaces.

9.8 LIMITS ON THE SOUND PRESSURE LEVELS IN DATACOM FACILITIES

Various regulatory agencies in the industrialized countries have established acoustical noise exposure limits in the workplace to protect employees against permanent hearing loss. As examples, in the United States, the regulatory agency is the Occupational Safety and Health Administration (OSHA) and in Europe, it is the European Union (EU). The regulations vary in their specific limits, with the European occupational noise limits being a bit more stringent than OSHA's. As a general statement, however, the A-weighted sound pressure levels averaged over an eight-hour period should not exceed 90 dB(A) under the OSHA regulations or 87 dB(A) under the EU regulations under any circumstances. Lower levels, such as 80 dB(A) and 85 dB(A), are defined to trigger certain mandatory actions by the employer or owner, including initiating hearing conservation and monitoring programs or making hearing protection freely available to employees. Although these levels are relatively high and aimed more at protecting factory and manufacturing area workers, densely populated data centers may still run the risk of exceeding the OSHA or EU noise limits and potentially causing hearing damage. To be safe and certain, datacom managers and planners should consult the appropriate OSHA regulations and guidelines (USDOL 1991) and the EU Directives (EU 2003) or enlist the services of a qualified acoustical consultant or industrial hygienist.

The noise levels in smaller, more typical data centers are not usually high enough to cause hearing damage but should be controlled to avoid employee or customer complaints due to annoyance, difficulty concentrating, interference with communication, or other nonauditory effects of the noise. To protect against these effects, many guidelines have been published over the years by various agencies and organizations, specifying maximum sound pressure levels for different environments. For commercial business areas, which might include datacom centers, the consensus is that the average sound pressure levels should not exceed 70 dB(A) where personnel are located. The World Health Organization (WHO) Guidelines (Berglund 1999) recommend this level but in a note state that the goal is also to prevent hearing damage. To put this level in perspective, the WHO guideline (to avoid annoyance) for classrooms and homes is L_{pA} = 35 dB(A) and for general outdoor residential areas, L_{pA} = 55 dB(A). The emission sound power level limits, mentioned above, defined for generally attended data centers, were derived, in fact, to allow data centers with typical equipment layout densities to meet this L_{pA} = 70 dB(A) specification.