Sound pressure is dependent on the acoustic environment. The factors involved include the effects of nearby reflecting surfaces, receiver distance, type of space, the amount and location of absorption in the space, the location in the space, the presence of barriers, and the intrusion of ambient sounds.

Sound Power and Sound Pressure are also different in that Sound Power is a measure of total energy per unit time emitted by the source in all directions. Sound pressure is a measure of the pressure at the receiver’s location.

Typically, manufacturers provide equipment sound power data, in decibels (dB) per octave band. The quietest sound we might measure, such as a whisper about 10 feet away, represents 0.000000000001, or $10^{-12}$, watt. The loudest regularly measured noise, the space shuttle on takeoff, is 100,000,000, or $10^8$, watts. To avoid dealing with all these zeros, engineers use a logarithmic convention, labeled $L_w$, to express the watts in a decibel (dB) scale:

$$L_w = 10 \log \left( \frac{W}{W_{ref}} \right)$$

where $W_{ref} = 10^{-12}$ watt

So, the shuttle rates at 200 dB, the whisper is 0 dB, and a large AHU with 1 watt of acoustic power rates at 120 dB. Two of these AHUs would double the sound energy, and with logarithmic addition, the total sound power would be 123 dB.

To understand the relationship between sound power and sound pressure, we can look at two analogies common to HVAC applications:

**Electric Heater** – To represent power, a number expressed in BTUs or kilowatts is used to rate the heat release of the equipment. Just as the number of BTUs indicates the amount of heat released by a piece of equipment, the sound power indicates the power radiated from a piece of equipment.

**Light bulb** – A 100 watt light bulb has a source electrical power level of 100 watts. We can use the power rating as a relative indicator, but what we are really interested in is the brightness, or lumens, produced by the bulbs. And that depends on many things such as the size of the room, the reflectivity of the walls, and how far away we are from the light source.

Similarly, with building HVAC noise we are concerned about the sound pressure sensed by the occupant’s ears. Although we use the dB scale for both power and pressure, they are very different parameters. Sound pressure is the...
phenomenon we sense; it is also the physical property that we can measure with microphones. The sound pressure resulting from a given AHU-generated sound power depends on:

- Distance from the AHU to the room
- The size of the room
- The absorptive properties of interior furnishings
- Attenuating elements such as silencers, duct liner, duct branches, elbows, etc.

Propagating sound creates pressure fluctuations in the air, which vibrate the microphone diaphragm and cause it to make a voltage output proportional to the pressure. We use an RMS (Root Mean Square) value of the pressure fluctuations to obtain a logarithmic measure, expressed as $L_p$.

Sound energy can occur over a broad frequency range, and the human ear is sensitive from about 20 Hertz (Hz) to 20,000 Hz. We can measure the overall level, the sum across all these frequencies, but it is usually helpful to break this down into frequency bands. As in music, an **octave band** convention was chosen. Each progressive band has double the bandwidth of the previous. The center frequencies assigned for the bands for the full range of human hearing are: 31.5, 63, 125, 250, 500, 1000, 2000, 4000, 8000, and 16000 Hz. Usually, we disregard the last band.

We can show the range of human hearing in a plot of sound pressure against octave band frequencies.

At the highest levels, noise above 120 dB can cause instant hearing damage. The lowest levels represent the threshold of hearing, and it is evident that at lower levels our ears are less receptive to the lowest frequencies.

With this in mind, a sound measurement scheme – **A-weighting** – is sometimes used to filter microphone sound pressure readings to reflect human sensitivity, and give an overall sound pressure readings, in dBA.

This suggests that noise at 125 Hz would sound 15 dB quieter than 1000 Hz noise at the same sound pressure level, to most listeners.

Again considering the analogy relating sound power to BTUs and sound pressure to degrees, we are fully aware that temperature is only one measure of comfort. We use the temperature-humidity-index, THI, as a measure of humidity and temperature; further, ventilation flow patterns and on/off cycling also affect our comfort.

Similarly, our perception of noise depends on a combination of sound level, spectral content, and modulation. Sometimes the overall level is just too loud, but generally, if the noise has a balanced contour with energy in all bands, we don’t find it too objectionable. Unfortunately, the noise from the HVAC system usually has certain components that are emphasized. These are often defined as:

* **Rumble** – when the 31.5, 63 and 125 Hz bands are especially loud. The effect of this is to induce fatigue. The “6-o’clock” phenomenon is the sensorial relief we sometimes experience when the HVAC system shuts off for the day.

* **Hiss** – when the 2000, 4000, and 8000 Hz bands are emphasized. Typically caused by undersized diffusers. This sound is rather irritating.

* **Tonality** – when a particular octave band is more than 5 dB above its adjacent bands, often caused by the blade pass frequency of the fan in the AHU. Most people find this particularly annoying.
With regard to the frequency-dependent nature of hearing response, Noise Criterion (NC) curves were developed to plot octave band sound pressure level data measured in rooms.

On the NC curves to the right, four different noise spectra are shown. Three have the same overall dB(A) level. The green and black spectra have similar overall sound pressure levels to the blue one, but do not have a nice balanced character. The NC rating, which is determined by looking for the highest tangent point on the background curves, is a good indicator that the blue spectrum is much more desirable.

NC ratings must be used cautiously. Note that the red spectrum has the lowest dB(A) and NC rating, but would actually be perceived as the most annoying, because of the prominence of a discrete tone.

Of course each piece of HVAC equipment can contribute to the overall room sound in various ways, and to make predictions is a complicated process. But it is important to understand the acoustical goals and concerns of building design engineers, and what effect our equipment can have.

<table>
<thead>
<tr>
<th>Spectrum</th>
<th>dB(A)</th>
<th>NC-rating</th>
<th>Quality / Perception</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>44</td>
<td>35</td>
<td>Balanced - Pleasant</td>
</tr>
<tr>
<td>Green</td>
<td>44</td>
<td>40</td>
<td>Rumbly - Fatiguing</td>
</tr>
<tr>
<td>Black</td>
<td>44</td>
<td>41</td>
<td>Hissy - Irritating</td>
</tr>
<tr>
<td>Red</td>
<td>39</td>
<td>35</td>
<td>Tonal – Annoying</td>
</tr>
</tbody>
</table>