Fundamentals of Acoustics & Practical HVAC Design Considerations
What is sound?

Sound is a mechanical wave that is an oscillation of pressure transmitted through some medium (like air or water), composed of frequencies which are within the range of hearing.

In 20 °C (68 °F) air at sea level, the speed of sound is approximately 343 m/s (1,230 km/h; 767 mph)

Propagation of sound

<table>
<thead>
<tr>
<th>Source</th>
<th>Medium - Air</th>
<th>Receiver</th>
</tr>
</thead>
<tbody>
<tr>
<td>moving</td>
<td>air particles, transfer of energy</td>
<td>pressure at receiver</td>
</tr>
<tr>
<td>membrane</td>
<td>to next particles</td>
<td>oscillates with source freq.</td>
</tr>
</tbody>
</table>

![Sound wave diagram](image)
What is frequency?

- The term Frequency applies to periodic events - such as sound waves.
- The time for one event to take place is $T$. $T$ is measured in seconds.
- The Frequency is the number of times the event happens per second.
- The unit of measurement for Frequency is Hertz or Hz.
- 1 Hz means that the event takes place once per second.
- 100 Hz means that the event takes place 100 times per second.
Frequency range of speech and music

Fig. 7 Place of music within the sensitivity range of human hearing. All limits are approximate and statistically determined.
Frequency bands

- The most common frequency bands have their centers at octave or 1/3 octave intervals.

Octave Bands

<table>
<thead>
<tr>
<th>63</th>
<th>125</th>
<th>250</th>
<th>500</th>
<th>1k</th>
<th>2k</th>
<th>4k</th>
<th>8k</th>
</tr>
</thead>
<tbody>
<tr>
<td>🎹</td>
<td>🎹</td>
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</tr>
</tbody>
</table>
Frequency Characteristics of HVAC Eq.
Sound Power & Sound pressure

- Sound pressure level of everyday noise sources
  - Pressure $p \ [N/m^2 = Pa]$
  - $L_p \ [dB]$
  - Power $P[W]$

- Electric Heater
  - Temperature $t \ [^\circ C]$
  - Power $P[W]$
Sound pressure level

- Sound pressure level of everyday noise sources

\[ L_p = 20 \log_{10} \left( \frac{p}{p_0} \right) \text{ in dB} = L_I = 10 \log_{10} \left( \frac{I}{I_0} \right) \text{ in dB} \]

\[ L_{p} \text{ (dBSPL)} = 20 \cdot \log_{10} \left( \frac{p}{p_0} \right) \]
\[ p_0 = 0.00002 \text{ Pa} \]
\[ p \text{ (Pa)} = p_0 \cdot 10^{\frac{L_{p} \text{ (dBSPL)}}{20}} \]

\[ L_{I} \text{ (dBSIL)} = 10 \cdot \log_{10} \left( \frac{I}{I_0} \right) \]
\[ I_0 = 10^{-12} \frac{W}{m^2} \]
\[ I \left( \frac{W}{m^2} \right) = I_0 \cdot 10^{\frac{L_{I} \text{ (dBSIL)}}{10}} \]
Noise Criteria Curves (NC)

- One of the most commonly used single-number readings is the Noise Criteria (NC) standard.
- NC is defined as single number noise rating system commonly used to rate the steady-state noise levels in a room. They consist of a family of curves which defines the maximum allowable sound pressure levels in octave bands.

<table>
<thead>
<tr>
<th>Conditions</th>
<th>NC level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleeping</td>
<td>25-35</td>
</tr>
<tr>
<td>Living</td>
<td>35-45</td>
</tr>
<tr>
<td>Office</td>
<td>30-45</td>
</tr>
<tr>
<td>Audio Studio</td>
<td>15-20</td>
</tr>
<tr>
<td>Restaurant</td>
<td>35-50</td>
</tr>
<tr>
<td>Laboratory</td>
<td>40-45</td>
</tr>
<tr>
<td>Computer room</td>
<td>45-60</td>
</tr>
</tbody>
</table>

![Diagram showing Noise Criteria Curves (NC) with NC 35 highlighted.](chart.png)
Types of Sound Transmission

- **Airborne Sound**: Airborne sound refers to sources which produce sound by directly setting the air around them into vibration.

- **Impact Sound**: Impact sound refers to sources which produce sound by impulsive mechanical excitation of part of a building (e.g. by footsteps, electric light switches, slamming doors). Many sources of impact sound also produce significant levels of airborne sound.

- **Structure-borne Sound**: Structure-borne sound is often used to refer to sound that travels for long distances via the structure, especially in connection with vibrating machinery linked directly to the structure.
Sound Absorption VS Sound Insulation

• **Sound Insulation:** Sound insulation refers to the act of impeding the transmission of sound from one area to another or from a source to a receiver. Typical examples include the sound insulation between adjacent apartment units or between a busy highway and one’s bedroom. The best way to improve the insulation between two areas typically involves the use of heavy materials such as concrete or gypsum board.

• **Sound Absorption:** Sound absorption refers to the phenomenon whereby some or all of the sound energy incident on a surface is either converted into heat or passes through the absorber.
Noise Paths for HVAC Equipment

- **Path A**: Structure-borne path through floor
- **Path B**: Airborne path through supply air system
- **Path C**: Duct breakout from supply air duct
- **Path D**: Airborne path through return air system
- **Path E**: Airborne path through mechanical equipment room wall
HVAC Noise Control

- Duct Velocities
  Air velocity within a duct system influences the noise levels significantly. Regenerated noise can be created by transition pieces, bends, dampers, grilles and diffusers. Regenerated noise can be avoided by limiting the air velocities within the duct system.

<table>
<thead>
<tr>
<th>NR or NC design requirement</th>
<th>In-duct air velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Main</td>
</tr>
<tr>
<td>20</td>
<td>4.5</td>
</tr>
<tr>
<td>25</td>
<td>5.0</td>
</tr>
<tr>
<td>30</td>
<td>6.5</td>
</tr>
<tr>
<td>35</td>
<td>7.5</td>
</tr>
<tr>
<td>40</td>
<td>9.0</td>
</tr>
</tbody>
</table>
HVAC Noise Control

- Regenerated Noise From Duct Elements

* Airflow velocity and proximity of upstream and downstream fittings and fans determine which type is preferable.

** Trailing edge length should be at least 3 times the vane spacing.

[Diagrams showing various duct elements and their noise control effectiveness]
HVAC Noise Control

- Regenerated Noise From Duct Elements
HVAC Noise Control

- Sound Breakout from the Ducts
- Breakout is the sound associated with fan or airflow noise inside a duct that radiates through duct walls into the surrounding area.
HVAC Noise Control

- Silencer positioning for low regenerated noise and low pressure drop
  \[ L > 3 \text{ to } 4 \text{ duct diameters} \]

- Silencers positioning for minimizing breakout noise
HVAC Noise Control

• Cross-talk
When two adjacent or closely positioned rooms are sharing the same ductwork, sound travels within ducts and decrease the sound insulation dramatically.

<table>
<thead>
<tr>
<th>Requirement in receiver room</th>
<th>Attenuator Length (mm)</th>
<th>Noise reduction at 500 Hz (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NR - NC 40</td>
<td>750</td>
<td>25</td>
</tr>
<tr>
<td>NR - NC 35</td>
<td>1000</td>
<td>30</td>
</tr>
<tr>
<td>NR - NC 30</td>
<td>1250</td>
<td>35</td>
</tr>
<tr>
<td>NR - NC 25</td>
<td>1500</td>
<td>40</td>
</tr>
</tbody>
</table>
Practical Design Recommendations

- HVAC design for Auditoriums

<table>
<thead>
<tr>
<th>System Description</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Overhead supply under seat to extract to plenum         | - Lower cost                                                               | - Fights natural convection  
- Underseat noise break in weakness  
- Difficult to avoid draughts  
- Throw and noise produced too great for concert halls |
| Underseat Supply, High level extract                    | - Standart practice in quality halls, best for concert halls and low noise auditoria  
- High degree of control on airflow                      | - Higher cost  
- Suits fixed seating only                                |
| Overhead supply, high level extract                     | - Suitable for flexible seating halls                                       | - Cluttered ceiling void with both supply and extract duct runs clashing with lighting bridges  
- Underseat noise break in weakness  
- Difficult to achieve <NR25 criteria  
- Greater running costs/energy need                      |
Practical Design Recommendations

- **FCU Design**
  - Do not expect very low NR levels from a fan coil unit installation; levels lower than NR30 are generally unrealistic unless special measures are taken.
  - For ceiling void units, noise from the inlet is more of an issue.
  - For floor standing units, noise from the discharge of a fan coil is more of an issue.
  - Use maximum number of discharge outlets possible on the unit to reduce air resistance hence the fan noise.
  - For ceiling void installations don’t position the return grilles directly under or near the unit inlet. Badly placed return grilles can increase overall noise levels 3-4 dB.
Practical Design Recommendations

• FCU Design
• False ceiling with good acoustic grade is necessary
• Filters of the units needs to be cleaned before acoustic commissioning checks on site. Fan coil units are often used for drying the building and dust in site conditions blocks the filters hence increase the noise levels.
• Beware of fresh air ducted directly to the inlet of a fan coil unit with no air break as this can impose a significant air resistance across some units.
• Minimize the air leakage from ducts since higher fan speeds is required to produce the specified duty.
Practical Design Recommendations

- **FCU Design**
  - Chassis unit fixed to slab
    - (Hard room 6m x 6m x 3.2m h) FCU @ 240 l/s 30 pa
    - No Room absorption, No Ductwork, No Ceiling
  - Chassis unit fixed to slab
    - (Furnished room 6m x 6m x 3.2m h) FCU @ 240 l/s 30 pa
    - With room absorption, No Ductwork, No Ceiling
  - Chassis fixed to slab with acoustic discharge ductwork
    - (Furnished room 6m x 6m x 3.2m h) FCU @ 240 l/s 30 pa
    - With Room absorption, 1 m of Acoustic Ductwork, Plenum & Grille
  - Chassis unit mounted above a false ceiling with acoustic flex discharge ductwork (poor return air position)
    - (Furnished room 6m x 6m x 3.2m h) FCU @ 240 l/s 30 pa
    - With Room absorption, 1 m of Acoustic Ductwork, Plenum & Grille, false ceiling, poor return air position just under the unit
Practical Design Recommendations

- FCU Design

Chassis unit mounted above a false ceiling with acoustic flex discharge ductwork (good return air position)

(Furnished room 6m x 6m x 3.2m h) FCU @ 240 l/s 30 pa

With Room absorption, 1 m of Acoustic Ductwork, Plenum & Grille, false ceiling, good return air position just under the unit
Practical Design Recommendations

- FCU Design examples for a hotel guestroom

Resultant noise $\geq$ NC 35

Resultant noise $\leq$ NC 30
Thank You, Any Questions?