Presented by
BRD Noise & Vibration Control, Inc.
PO Box 127
112 Fairview Avenue
Wind Gap PA 18091
610-863-6300, info@brd-nonoise.com
RTU Noise Control

- Acoustic Terminology
- Modeling Tools
- Acceptance Criteria
- RTU Indoor Noise Suppression
- RTU Outdoor Noise Suppression
What Are The Characteristics of Sound?

How Are These Characteristics Expressed?

The **amplitude** of sound is expressed in **decibels** (dB). This is a logarithmic compressed scale dealing in powers of 10 where small increments in dB correspond to large changes in acoustic energy.

The **frequency** of sound is expressed in cycles per second (CPS). It is more commonly referred to as **Hertz** (Hz). Low frequency noise is 250 Hertz and below. High frequency noise is 2000 Hz and above. Mid-frequency noise falls between 250 and 2000 Hz.

Note psychoacoustic concerns with cycling, natural vs. mechanical, transportation.
What Are Octave Bands?

Standardized octave bands are groups of frequencies named by the center frequency where the upper limit is always twice the lower limit of the range. Test data for performance of acoustical materials is standardized for easy comparison at the center frequencies. Equipment noise levels and measurement devices (dB meters) also follow the preferred octave bands.

<table>
<thead>
<tr>
<th>Octave Band Center Frequency, Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>31.5</td>
</tr>
<tr>
<td>22.1</td>
</tr>
</tbody>
</table>

| Octave Band Cut-Off Frequency, Hz |

Full Octave and 1/3 Octave Band Spectra
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 - a vibrating surface (among other things) produces compression and rarefaction of the air in contact with that surface. Sound pressure may be defined as fluctuations in air pressure, above and below atmospheric, caused by that compression and rarefaction.
A 1K Hz tone at 40 dB would require a 90 dB tone at 20 Hz to sound as loud to us.
Describe the difference between Sound Power and Sound Pressure.
**Sound Power** – is a rated value (of acoustical energy) and is not affected by the environment.

**Sound Pressure** – is a measured value (of fluctuations in air pressure) and is highly subject to environmental conditions.
A-weighting network is designed to approximate the human hearing response.
What is the purpose of the A-weighting network?
To adjust sound level values to be consistent with the typical human hearing response.
Converting Sound Power to Sound Pressure Level

**Sound Power to Sound Pressure:**

\[ dB = L_w - ((20 \log \text{dist in ft}) \ - \ 2.4) \]

For example, at 30'

\[ dB = L_w - ((20 \log 30) \ - \ 2.4) \]
\[ = L_w - (20 \times 1.477) \ - \ 2.4 \]
\[ = L_w - (29.5 \ - \ 2.4) = L_w - 27.1 \]
The Q Factor
(adds 3 dB to each octave band for each increase in Q value)

Spherical radiation
Q = 1

Hemispherical radiation
Q = 2

Quarter Sphere radiation
Q = 4

Eighth Sphere radiation
Q = 8
How Are Decibel Levels Added Together?

**Decibel Addition:**

\[ 10 \log \left( 10^{\text{dB}/10} + 10^{\text{dB}/10} + \ldots \right) \]

For example, 87 dB + 87 dB

\[ = 10 \log \left( 10^{87/10} + 10^{87/10} \right) \]
\[ = 10 \log \left( 10^{8.7} + 10^{8.7} \right) \]
\[ = 10 \log \left( 1.00237 \times 10^9 \right) \]
\[ = 10 \times (9.00103) = 90 \text{ dB} \]
50 dB + 50 dB = ?

50 dB + 60 dB = ?
50 dB + 50 dB = 53 dB

50 dB + 60 dB = 60 dB
Example at 30’

Adding Decibels

Converting Lw to Lp

<table>
<thead>
<tr>
<th>Center Frequency</th>
<th>Unweighted Sound Power (dB)</th>
<th>Unweighted Sound Pressure (dB)</th>
<th>A-weighting Sound Pressure (dB)</th>
<th>A-weighted Sound Pressure (dB)</th>
<th>Decibel Addition</th>
<th>Overall Resultant Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>63</td>
<td>121</td>
<td>94</td>
<td>-26</td>
<td>68</td>
<td>78</td>
<td>91 dBA</td>
</tr>
<tr>
<td>125</td>
<td>113</td>
<td>86</td>
<td>-16</td>
<td>70</td>
<td>76</td>
<td></td>
</tr>
<tr>
<td>250</td>
<td>112</td>
<td>85</td>
<td>-9</td>
<td>76</td>
<td>76</td>
<td></td>
</tr>
<tr>
<td>500</td>
<td>116</td>
<td>89</td>
<td>-3</td>
<td>86</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>1,000</td>
<td>116</td>
<td>89</td>
<td>0</td>
<td>89</td>
<td>89</td>
<td></td>
</tr>
<tr>
<td>2,000</td>
<td>104</td>
<td>77</td>
<td>1</td>
<td>78</td>
<td>78</td>
<td></td>
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<tr>
<td>4,000</td>
<td>102</td>
<td>75</td>
<td>1</td>
<td>76</td>
<td>76</td>
<td></td>
</tr>
<tr>
<td>8,000</td>
<td>103</td>
<td>76</td>
<td>0</td>
<td>79</td>
<td>79</td>
<td></td>
</tr>
</tbody>
</table>
Common Acceptance Criteria

• Bldg criteria for human comfort
  (NC, RC, PNC, ANSI S12-60…)
• Specification
• OSHA, MSHA, etc.
• Mil (safe communications, equipment type…)
• Company policy
• Good neighbor concerns
• Regulatory mandates:
  generalcode.com
  municode.com
  noisepollution.org
  amlegal.com
Recommended NC Levels For Various Activities

<table>
<thead>
<tr>
<th>Activity</th>
<th>NC Level</th>
<th>Activity</th>
<th>NC Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broadcast studios (distant microphone pickup used)</td>
<td>10</td>
<td>Office buildings:</td>
<td></td>
</tr>
<tr>
<td>Concert halls, opera houses, and recital halls (listening to faint musical sounds)</td>
<td>15-18</td>
<td>executive</td>
<td>25-35</td>
</tr>
<tr>
<td>Small auditoriums</td>
<td>25-30</td>
<td>small, private</td>
<td>35-40</td>
</tr>
<tr>
<td>Large auditoriums, large drama theatres, and large churches (for very good speech articulation)</td>
<td>20-25</td>
<td>larger, with conference tables</td>
<td>30-35</td>
</tr>
<tr>
<td>TV and broadcast studios (close microphone pickup only)</td>
<td>15-20</td>
<td>Conference rooms</td>
<td></td>
</tr>
<tr>
<td>Legitimate theatres</td>
<td>20-25</td>
<td>large</td>
<td>25-30</td>
</tr>
<tr>
<td>Private residences:</td>
<td></td>
<td>small</td>
<td>30-35</td>
</tr>
<tr>
<td>Bedrooms</td>
<td>25-30</td>
<td>General secretarial areas</td>
<td>40-45</td>
</tr>
<tr>
<td>Apartments</td>
<td>30-40</td>
<td>Business machines/computers</td>
<td>40-45</td>
</tr>
<tr>
<td>Family rooms and living rooms</td>
<td>30-40</td>
<td>Public circulation</td>
<td>40-50</td>
</tr>
<tr>
<td>Schools:</td>
<td></td>
<td>Hospitals and clinics:</td>
<td></td>
</tr>
<tr>
<td>Lecture and classrooms</td>
<td></td>
<td>Private rooms</td>
<td>25-30</td>
</tr>
<tr>
<td>with areas less than 70 sq. m.</td>
<td>35-40</td>
<td>Wards</td>
<td>30-35</td>
</tr>
<tr>
<td>with areas greater than 70 sq. m.</td>
<td>30-35</td>
<td>Operating rooms</td>
<td>25-35</td>
</tr>
<tr>
<td>Open-plan classrooms</td>
<td>35-40</td>
<td>Laboratories</td>
<td>35-45</td>
</tr>
<tr>
<td>Hotels/motels:</td>
<td></td>
<td>Corridors</td>
<td>35-45</td>
</tr>
<tr>
<td>Individual rooms or suites</td>
<td>30-35</td>
<td>Public areas</td>
<td>40-45</td>
</tr>
<tr>
<td>Meeting/banquet rooms</td>
<td>25-35</td>
<td>Movie theatres</td>
<td>30-40</td>
</tr>
<tr>
<td>Service support areas</td>
<td>40-50</td>
<td>Courtrooms</td>
<td>30-35</td>
</tr>
<tr>
<td>Churches, small</td>
<td>30-35</td>
<td>Libraries</td>
<td>35-40</td>
</tr>
</tbody>
</table>
Standardized NC curves are plotted at left along with frequency spectrum data for a particular room application. The NC-65 rating for the example at left is determined by comparing the plotted data to the standardized curves and finding the highest penetration, which in this case is the 66 db peak at 500 Hz, just below the NC-65 curve.

The NC rating system should be used with caution in evaluating environments with dominant low frequency levels as the standardized curves do not extend down into the 16 Hz and 31.5 Hz octave bands. Another caution/limitation of this system is the inability to differentiate the subjective quality of the noise for equivalent rating values.
<table>
<thead>
<tr>
<th>Octave Band Center Frequency Measurement (Hz)</th>
<th>Residential Area</th>
<th>Residential in Industrial Area</th>
<th>Commercial Area</th>
<th>Industry Area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Daytime</td>
<td>Other Times</td>
<td>Daytime</td>
<td>Other Times</td>
</tr>
<tr>
<td>31.5</td>
<td>76</td>
<td>68</td>
<td>79</td>
<td>72</td>
</tr>
<tr>
<td>63</td>
<td>75</td>
<td>67</td>
<td>78</td>
<td>71</td>
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<tr>
<td>125</td>
<td>69</td>
<td>61</td>
<td>73</td>
<td>65</td>
</tr>
<tr>
<td>250</td>
<td>62</td>
<td>52</td>
<td>68</td>
<td>57</td>
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<tr>
<td>500</td>
<td>56</td>
<td>46</td>
<td>62</td>
<td>51</td>
</tr>
<tr>
<td>1,000</td>
<td>50</td>
<td>40</td>
<td>56</td>
<td>45</td>
</tr>
<tr>
<td>2,000</td>
<td>45</td>
<td>33</td>
<td>51</td>
<td>39</td>
</tr>
<tr>
<td>4,000</td>
<td>40</td>
<td>28</td>
<td>47</td>
<td>34</td>
</tr>
<tr>
<td>8,000</td>
<td>38</td>
<td>26</td>
<td>44</td>
<td>32</td>
</tr>
<tr>
<td>Single Number Equivalent (dB(A))</td>
<td>60</td>
<td>50</td>
<td>65</td>
<td>55</td>
</tr>
</tbody>
</table>
Acoustical Design

• Problem definition: where are now, where do we need to be, how are we going to get there.
• Use 3 to 5 dBA safety factor.
• Cursory review on every project; in-depth review when warranted.
• Assess site ambient noise levels.
• Evaluate airborne and structure-borne transmission paths.
• Minimize acoustic baseline.
Published Baseline Equipment Sound Ratings

Air Cooled Chillers ARI-370
Liquid Cooled Chillers ARI-575
Large RTU ARI-260/370
Fan Powered VAV ARI-880/885
What Can Be Accomplished Without the Need for Additional Acoustical Treatment?

- Optimize RTU configuration to minimize baseline sound.
- Dialogue with architect regarding roof mass.
- Thickened rooftop slab with large footprint
- Locate over utility space
- Keep away from skylights and operable windows
- Utilize RTU discharge plenums on the supply side with 2”– 4” thick liner.
- Evaluate fan wheel types, inlet vanes, fan speed. Backward inclined (BI) and airfoil (AF) wheels are preferred over forward curved models (FC).
Where Do We Need To Be?

Indoor

Outdoor

<table>
<thead>
<tr>
<th>Octave Band</th>
<th>Residential Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center Frequency Measurement (Hz)</td>
<td>Daytime</td>
</tr>
<tr>
<td>31.5</td>
<td>76</td>
</tr>
<tr>
<td>63</td>
<td>75</td>
</tr>
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<td>69</td>
</tr>
<tr>
<td>250</td>
<td>62</td>
</tr>
<tr>
<td>500</td>
<td>56</td>
</tr>
<tr>
<td>1,000</td>
<td>50</td>
</tr>
<tr>
<td>2,000</td>
<td>45</td>
</tr>
<tr>
<td>4,000</td>
<td>40</td>
</tr>
<tr>
<td>8,000</td>
<td>38</td>
</tr>
</tbody>
</table>

Single Number

| Equivalent (dB(A)) | 60 | 50 |
How are NC rating curves selected as a compliance criterion?
Based on intended room use or function.
Noise-hostile Challenges

- Less mass in building
- Less space between floors
- Suspended or open ceilings
- Premium for rentable/usable space
- Value Engineering
- Heightened sensitivity of owners/occupants
- ANSI S12.60
- CURB-MOUNTED RTUs
Transmission Path Challenges

- In-Duct Fan Noise
- Pan-radiated Noise
- Ductwork Breakout, Break-in Noise
- Roof Penetrations
- Structure-borne Transmission
- Outdoor Noise
In-Duct Supply Fan Noise
Reverse Flow Fan Noise Into Return Ductwork/Plenum
RTU Base Pan Radiated Noise
Over Cut Deck Openings For Return & Supply Ductwork
Cabinet Radiated Outdoor Noise
Structure-Borne Vibration Into Building Shell
Lightweight Roof Deflection
Duct Breakout Noise
Break In Noise Bypassing Through The Ductwork
How Are We Going to Get There?

- Evaluate project specific criteria
  - Indoor criteria: NC, RC, NCB, PNC...
  - Outdoor criteria: Ordinance and NC...
- Use job-specific minimum design (prescriptive) and embedded performance specs.
- Place in equipment division.
- Specify single source for system solutions.
- Specify turnkey where installation is critical.
- Require curbs to be pre-assembled.
- Specify procedure for the HVAC contractor to cut and seal deck openings for SA and RA inside curb.
- Require acoustical material supplier to inspect & certify.
- Incorporate requirements to minimize impact on equipment operation and access.
Isolation Curb Kit Assembly
Pre-assembled Construction

Result: Performance, cost.
Seismic Vibration (S/V) Isolation Curb

- **Isolates structure-borne noise and vibration**
  - Seismic Vibration Isolation Curbs
  - Static deflection up to 3”
  - Requires resilient support and connection of all RTU ductwork, piping and utility lines
  - Internal isolation should be locked down or omitted
  - Design selection based on operating speed of fans, building steel spans, sensitivity of bldg. space and project seismic requirements
  - Optional sloped construction, filter curbs and transition curbs for RTU change-outs

3” deflection vibration curb
In-curb Acoustical Treatment

- Reduces unit casing radiated noise
  - Multi-Layer in-curb composite treatment
  - Decking flashed to 1/4” clearance around ducts
  - Acoustical sealant around ducts, inside curb perimeter and barrier overlaps
  - Tested per ASTM E-90 for sound transmission loss (TL)
  - TL values of 22, 28 and 40 at 250 Hz thru 1K Hertz

Finished system with fully caulked and sealed seams
S/V Curb Plus In-curb Treatment System

- Isolates structure-borne noise and vibration
- Reduces in-curb radiated noise
- Minimizes radiated, in-duct, and breakout noise

- Vibration/Seismic Curb
- Composite in-curb acoustical treatment
- Optional DUCT silencer or LINER for Fan Noise
Higher Performance Features

• Plenumized curbs.
• Acoustical bottom.
• Integral vibration/seismic curb
• Recessed or internal silencers.
• Acoustically seal duct drops
S/V Curb, In-curb, and Silencer System

- Isolates structure-borne noise and vibration
- Reduces unit casing radiated noise
- “Minimizes” radiated, in-duct, and breakout noise
  - Vibration/Seismic Curb
  - Composite in-curb acoustical treatment
  - DUCT Silencers at supply and return curb openings (below deck)

**DUCT silencer mounted directly below roof deck opening to minimize in-duct noise**
Solid bottom plenum curb with segregated SA & RA divider

Plenumized SVA Curb System

- Integrated In-Curb Design with complete acoustical plenum to reduce SA and RA noise
- Isolates structure-borne noise and vibration
  - Vibration/ Seismic Curb
  - Integrated in-curb Acoustical Plenum “box” design
  - Solid bottom modular acoustical panel floor
  - Ductwork connections to bottom of plenums offset from unit openings
  - Ductwork connections to bottom of plenums can be field cut upon request
  - Facilitates side by side SA and RA alignment
Plenumized SVA Curb System with External Silencers

- **Integrated In-Curb Design with complete acoustical plenum and “maximized” SA and RA radiated, in-duct and breakout noise**
- **Isolates structure-borne noise and vibration**
  - Vibration/ Seismic Curb
  - Integrated in-curb Acoustical Plenum “box” design
  - Solid bottom modular acoustical panel floor
  - Ductwork connections to bottom of plenums offset from unit openings
  - Ductwork connections to bottom of plenums can be field cut upon request
  - Facilitates side by side SA and RA alignment
  - DUCT Silencers at supply and return curb openings (below deck)
SVA Curb System with Recessed Vertical Silencers

- **Integrated In-Curb Design with recessed vertical DUCT silencers**
- **Isolates structure-borne noise and vibration**
- **Reduces unit casing radiated noise**
  - Vibration/ Seismic Curb
  - Integrated in-curb DUCT vertical duct silencers
  - Ductwork connections to discharge of downflow silencers
  - Integrated flex connectors
  - Solid bottom modular acoustical panel floor

SVA curb with acoustical “solid bottom” and “in-curb” vertical silencers (below deck view – open return)
SVA Curb System with Recessed Horizontal Silencers

- **Integrated In-Curb Design with recessed horizontal DUCT silencers**
  - Vibration/Seismic Curb
  - Integrated in-curb DUCT horizontal silencers
  - Solid bottom modular acoustical panel floor
  - Ductwork connections offset in curb bottom panel from unit openings
  - Ductwork connections can be field cut upon request
  - Facilitates side by side SA and RA alignment
Curb with Below-deck Fiber-free Duct Liner

- Reduces in duct fan noise transmitted to occupied spaces via the ductwork system.
  - Fiber-free open cell acoustic foam duct liner.
  - Noise Reduction Coefficient acoustic rating of NRC .80 for 1” thick.
  - Air Erosion Evaluation complies with requirements of UL 181, section 16.
  - Resistant to microbial growth.
  - Flammability rating of Class 1 per ASTM E84 and NFPA 255.
  - Installs with traditional adhesives and methodologies.
  - Non Fiberglass Construction

Supply/discharge plenum with internal acoustic insulation liner.
Curb with Below-deck Duct Wrap

- **Reduces supply and return duct breakout and radiated noise**
- **Composite exterior acoustic insulation using quilted fiberglass and loaded vinyl flexible barriers**
  - Wrap with dual density construction
  - Sound Transmission Class acoustic performance rating of STC-30
  - Tested for Insertion Loss per ASTM E-1222 acoustic performance
  - Installs with banding, adhesives and/or mechanical insulation clip fasteners
  - Double layer of wrap recommended on first 20’ of supply ductwork for low frequency applications
  - Seams and overlaps sealed with matching FSK tape

Supply ductwork with external wrap for rooftop curb mounted AC unit

[Diagram of HVAC unit with wrap around supply and return ducts on rooftop deck]
When would you use an acoustically absorptive duct liner versus an acoustical composite wrap?
The acoustical liner would be used inside the ductwork to reduce fan noise being transmitted down/up the duct.

The composite wrap would be used on the outside of the duct to contain duct breakout noise.
Outdoor Emissions
Scroll Compressor Sound Blankets
Coil Intake Acoustical Louvers
Condenser Fan Discharge Stacks
Utilizing Unit Support
Acoustical Barriers and Screens
Condenser Section Enclosures
Time for Questions?

Have a noise-free day!
Ductwork Design

- Duct type and sizing need to be consistent with NC target criteria
- Duct layout and configuration needs to follow SMACNA and ASHRAE design guidelines
Guidelines for Minimizing Regenerated Noise In Takeoffs
Guidelines for Minimizing Regenerated Noise in Duct Tees

Noisy
No Vanes to Direct the Airflow

Better
Two Square Elbows Back-to-Back

Best
Dual Radius Split
Guidelines for Minimizing Regenerated Noise in Transitions and Offsets
Regenerated Noise at Fittings: High- and medium-velocity airflow impinging on any obstruction (e.g., damper, sound trap, elbow, turning vane, etc.) will cause regenerated noise. Following the SMACNA duct design and construction guidelines and designing the duct system for the lowest possible airflow velocities and pressure drop will avoid most regenerated noise and rumble problems.
NC Level as a Function of Flow Rates at Supply Registers and Return Grilles

<table>
<thead>
<tr>
<th>Noise Criteria</th>
<th>Air Velocity at Supply register (fpm)</th>
<th>Air Velocity at Return grille (fpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NC-15 to NC-20</td>
<td>250 to 300</td>
<td>300 to 360</td>
</tr>
<tr>
<td>NC-20 to NC-25</td>
<td>300 to 350</td>
<td>360 to 420</td>
</tr>
<tr>
<td>NC-25 to NC-30</td>
<td>350 to 425</td>
<td>420 to 510</td>
</tr>
<tr>
<td>NC-30 to NC-35</td>
<td>425 to 500</td>
<td>510 to 600</td>
</tr>
<tr>
<td>NC-35 to NC-40</td>
<td>500 to 575</td>
<td>600 to 690</td>
</tr>
<tr>
<td>NC-40 to NC-45</td>
<td>575 to 650</td>
<td>690 to 780</td>
</tr>
</tbody>
</table>
Sealing Penetration to Corrugated Deck

Clean out debris. Surface should be moisture and frost free.

Install high-density acoustical pre-formed speed plugs.

Spray Acoustic Sealant obtaining 100% coverage, and overlap all surrounding surfaces a minimum of 3”. 