Acoustics - Illuminating the Dark Art

Kezia Lloyd + Alex Campbell
WHY WE’RE HERE

Kezia Lloyd – Kezia is an Associate at WSP | Parsons Brinckerhoff leading the New South Wales Acoustics team. Kezia is a Chartered Engineer specialising in building acoustics. While working out of New Zealand, the UK and Australia, she has and has worked on projects ranging from masterplans through standalone buildings to office fitouts.

Alex Campbell – Alex is a Director at WSP | Parsons Brinckerhoff and leads the Acoustics team in the Australia and New Zealand (ANZ) region. He has over 12 years industry experience in the UK and Australia, working on projects all across the globe. Alex specialises in architectural acoustic design and has wide ranging experience in building projects within many sectors.
ACOUSTICS FOR BUILDING SERVICES ENGINEERS

➔ Acoustics – It’s Science!
  • History of Acoustics
  • Acoustic principles

➔ Practical Acoustics
  • Acoustics in the built environment
  • Attenuation measures
  • Common coordination issues
  • Practical solutions
UNDERSTANDING ACOUSTICS
OVERVIEW

-> Background / History
-> Basics
-> Main principles
  ▪ Reverberation
  ▪ Sound Insulation
  ▪ Noise Levels
-> Problem Solving
-> Regulations / Standards
HISTORY OF BUILDING ACOUSTICS
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HISTORY OF BUILDING ACOUSTICS

Background | Basics | Reverberation | Sound Insulation | Noise Levels
Problem Solving | Regulations
HISTORY OF BUILDING ACOUSTICS
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\[ RT = \frac{0.16 \times Vol}{ABS} \]
HISTORY OF BUILDING ACOUSTICS

Lateral Energy = Enveloping
C-80 = Clarity
G = Strength (“Fullness”)
STI = Speech Intelligibility
EDT = Perceived RT
ACOUSTIC WHAT IS “BUILDING ACOUSTICS”?

Room Acoustics

Sound Insulation / Privacy

No this is not acceptable

N. thi is no, accep.....

Noise Emissions

Internal Noise Levels
ACOUSTICS TODAY

→ Quality driven
- To create place people want to be in
- Increase saleability

→ Regulatory
- State & National Policy (see later)
- Australian Standards

→ Guidance / Optional Rating Tools
- Green Star
- LEED
- Well Building
- BREEAM
- Etc
UNDERSTANDING ‘DB’

It’s a ratio.

The human ear has a large dynamic range in what it can hear.

→ At the threshold of pain the sound pressure is roughly 1 million times as large as the sound pressure at the threshold of hearing.

The decibel (dB) is a logarithmic ratio used to describe sound pressure levels. Used for all aspects of acoustics.
UNDERSTANDING FREQUENCY

→ Sound is a pressure wave, frequency is the number of cycles per second of that wave (in Hertz, Hz)

→ Most commonly banded into “Octaves” (the interval between two points where the frequency at the second point is twice the frequency of the first) or for higher resolution 1/3 octaves
UNDERSTANDING FREQUENCY

→ Weighting / Averaging
  - To allow a single-figure value to be used
  - Weighting applied prior to arithmetic average of frequency octave band levels
  - “A-Weighting” intended to replicate human hearing response
Sound bouncing around in a room

Measure reverberation as ‘Reverberation Time’ or RT60. This is time (in sec) it takes for sound to reduce by 60 dB when abruptly stopped.

Reverberation depends on

- Volume (size) of space
- Amount of acoustic absorption in space

\[ RT = \frac{0.16 \times Vol}{ABS} \]
ROOM ACOUSTICS - REVERBERATION

→ Effects of reverberation
  ▪ Noise build-up
  ▪ Low clarity
→ Acoustic finishes come in an array of styles.
→ Rated in ‘Absorption Coefficients’
  ▪ 0 = No absorption
  ▪ 1 = Fully absorbent
→ Abs coefficients are frequency dependent
→ Not all reverberation is bad
SOUND INSULATION - AIRBORNE

→ Relates to privacy / sound reduction between spaces
→ Wall / Floor construction
→ Weaknesses of construction
→ Double the mass of walls to get 6dB improvement
→ First gains are easy
→ Additional gains are hard
ONE BORING GRAPH
SOUND INSULATION – MASS LAW

Separating masses means you can (almost) add the individual performance

20 kg/m² of plasterboard
23 dB $R_W$

29 dB $R_W$
23 dB $R_W$ each = 46 dB $R_W$ overall
SOUND INSULATION

→ Sound reduction between spaces

→ Lab test measured in dB $R_W$

→ On-site measured in dB $D_W$
WALL CONSTRUCTION

- 35 dB $D_w$ Drywall
- 40 dB $D_w$ Drywall
- 45 dB $D_w$ Drywall
- 50 dB $D_w$ Drywall
- 50 dB $D_w$ Concrete
NOISE LEVELS

→ Understanding ‘dB’
→ Noticeable Differences
→ Sources of noise
$1 + 1 = 3$

60 dBA
1 + 1 = 3

63 dBA
1 + 1 = 3

66 dBA
1 + 1 = 3

69 dBA
OVERKILL
WHY IS THIS IMPORTANT?

➔ To make a perceivable difference – you have to double the effort put it.
➔ First gains are easy, but the high performance you have, the more you have to put in to make a difference
Decibel ‘dB’
→ Logarithmic scale
→ < 3dBA
  Not Subjectively Noticeable
→ 3 dBA
  Just Noticeable
→ 5 dBA
  Clearly Noticeable
→ 10 dBA
  “Double as loud”
## SUBJECTIVE RESPONSE TO A CHANGE IN SOUND

<table>
<thead>
<tr>
<th>Reduction in dBA</th>
<th>Subjective Perception</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>3dBA</td>
<td>Barely Perceptible</td>
<td>half</td>
</tr>
<tr>
<td>4-5dBA</td>
<td>Noticeable</td>
<td>One third</td>
</tr>
<tr>
<td>6dBA</td>
<td>Sound appears to be reduced by 1/4</td>
<td>One quarter</td>
</tr>
<tr>
<td>7-9dBA</td>
<td>Major reduction</td>
<td>One sixth</td>
</tr>
<tr>
<td>10dBA</td>
<td>Sound appears to be less than half original</td>
<td>10 times less</td>
</tr>
</tbody>
</table>
→ Tonality is considered as an annoyance
→ 2 – 5 dB penalty is applied
SOUND POWER VS. SOUND PRESSURE

→ Sound Power Level
  - **Cause:** like light bulb wattage
  - SWL or \( L_w \)

→ Sound Pressure Level
  - **Effect:** like resulting Lux level
  - SPL or \( L_p \)
  - Contributing factors
    - Distance
    - Number of sources
    - Reflective surfaces
    - Room volume
CANT TREAT MANY THINGS IN ISOLATION

→ Privacy

Privacy Factor = \( D_W + L_{Aeq} \)

Where,
- \( D_W \) = on-site sound insulation of partition and
- \( L_{Aeq} \) = background noise level in room

→ Plant noise within room

- Source noise level
- Room Volume & Reverberation Time

→ Plant noise from adjacent room

- Source noise level
- Source room volume & reverberation rime
- Partition Sound Insulation
- Partition size
- Receiver room volume & reverberation rime
PRIMARY NSW REGULATIONS

→ **BCA Part F5**
  - Applies to Residential Developments (Class 2, 3 & 9c) only
  - Prescribes sound insulation levels between residences (no internal noise criteria)

→ **Infrastructure SEPP**
  - Applies to noise sensitive developments in proximity to major roads (>40,000 AADT) or railways

→ **NSW Industrial Noise Policy**
  - Typically applied to any new noise source which could impact a Residential or Commercial receiver

→ **City of Sydney DCP 2012**
  - Applies to Residential Developments only
  - Prescribes internal noise levels which must be achieved – including ventilation strategy
ADDITIONAL NSW REGULATIONS

→ Council Planning Conditions
  - City of Sydney are onerous
→ NSW Road Noise Policy
  - Applies to projects that involve new roads or significantly increased traffic on existing roads
→ NSW Rail Infrastructure Noise Guideline (RING)
  - Applies to residential projects that involve new railways or significantly increased traffic on existing railways
→ NSW Interim Construction Noise Guideline
  - Assessment and mitigation of construction noise and vibration
→ City of Sydney Construction Noise Guideline
  - Applies in City of Sydney jurisdiction
GUIDANCE DOCUMENTS

→ **Australian Standard 2107:2000**
  - Compliance not mandatory unless imposed by planning, etc.
  - Guidance on big range of spaces, including:
    - Education
    - Commercial
    - Retail
    - Public Buildings
  - Outlines:
    - Recommended Noise Levels
    - Recommended Reverberation Times

→ **Association of Australian Acoustic Consultants (AAAC) Guidelines**
  - Commercial (including privacy)
  - Education
  - Healthcare (to be released)
  - Free to download
Practical Acoustics
For Building Services Engineers
THE BUILT ACOUSTIC ENVIRONMENT

- PA system design
- Architectural
  - Sound insulation
  - Privacy
  - Room acoustics
  - Façade
- Noise from services
  - Mechanical
  - Hydraulic
  - Electrical
HOW BUILDING SERVICES AFFECT THE ACOUSTIC ENVIRONMENT

- Services noise inside
- Services plant outside
- Hydraulic noise
- Sound insulation of walls (penetrations)
REQUIREMENTS AND RECOMMENDATIONS

External emissions

→ A must..
→ Local Council
→ NSW Industrial Noise Policy (legislative)
  ▪ Land zoning
  ▪ Background noise
    – Tonality
→ Project specific criteria

Internal Noise levels

→ Recommended..
→ AS/NZS 2107
→ Green Star
→ Client documents
RATING DESCRIPTORS

→ Standard
  ▪ A-weighting (dBA)
  ▪ C-weighting (dBC)
  ▪ Z-weighting (dBZ)

→ CIBSE/ASHRAE Guides
  ▪ Noise Curve (NC)
  ▪ Noise Rating (NR)
  ▪ Room Criteria (RC)
  ▪ Preferred Noise Curve (PNC)
  ▪ Room Noise Criteria (RNC)
  ▪ Room Criteria Mark II (RC 2)
  ▪ Etc..
UNDERSTANDING DATA SHEETS
NOISE DATA – SPL VS. SWL

→ Sound Power of unit
→ Sound Pressure at a distance
  ▪ Measurement conditions applied

### Example Chiller noise

<table>
<thead>
<tr>
<th></th>
<th>Octave Band Levels</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>63</td>
<td>125</td>
<td>250</td>
<td>500</td>
<td>1000</td>
<td>2000</td>
<td>4000</td>
<td>dBA</td>
</tr>
<tr>
<td>SWL</td>
<td>96</td>
<td>91</td>
<td>91</td>
<td>91</td>
<td>84</td>
<td>79</td>
<td>81</td>
<td>94</td>
</tr>
<tr>
<td>SPL @3m</td>
<td>71</td>
<td>70</td>
<td>66</td>
<td>66</td>
<td>59</td>
<td>54</td>
<td>56</td>
<td>70</td>
</tr>
</tbody>
</table>
TYPICALLY AVAILABLE DATA

- Chillers SPL at 1m - Spectral
- Pumps SPL at 1m
- Cooling Towers SWL, SPL at 3m, SPL at 15m - Spectral
- Air Cooled Chillers SWL, SPL at 3m, SPL at 15m - Spectral
- Transformers SPL at 1m
- Fans In-duct SWL - Spectral
- Air handling Units In-duct SWL - Spectral
- Fan Coil/ Packaged Units In-duct SWL - Spectral
- Generators SPL at 1m, 3m, and 15m - Spectral

- Prefer spectrum results
FCU/PAC – MEASUREMENT

→ Three distinct paths
  ▪ Supply In-duct
  ▪ Discharge In-duct
  ▪ Case breakout

→ Different measurement arrangements
→ Not directly comparable
  ▪ ISO standard (preferred)
    - Induct Sound Power Level
    - Fantech
    - Temperzone
  ▪ JIS standard measurement
    - Sound pressure
    - Daiken
    - Mitsubishi

→ Project risk

<table>
<thead>
<tr>
<th>Approx. equivalent units</th>
<th>Octave Band Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>125</td>
</tr>
<tr>
<td>Mitsubishi data (SPL)</td>
<td>42</td>
</tr>
<tr>
<td>Temperzone data (SWL)</td>
<td>62</td>
</tr>
</tbody>
</table>
ATTENUATION PRINCIPLES
REDUCED SPEED - FAN LAW

→ 50\log\left(\frac{RPM_1}{RPM_2}\right)

→ Large loss in SWL for small change
  - -2.3dB for -10% speed
  - -3.5dB for -15% speed
  - -5dB for -20% speed
  - -6dB for -25% speed

→ Maximised reduction at 40% speed reduction
  - Other noise elements control at this point
3DB HALVING

→ Halving of energy
  - Number of sources
  - Increase distance
  - Remove reflective surface

\[ \text{SWL} +3\text{dB} \quad -3\text{dB per double of distance} \]

\[ \text{SPL} \quad -6\text{dB} \quad -12\text{dB} \quad -18\text{dB} \]

\[ d \quad 2d \quad 4d \quad 8d \]
EXTERNAL PROPAGATION

→ Distance
→ Barrier
  - Weight
  - Height
→ Acoustic louvre
  - Small open area
→ Enclosure
DUCTED SYSTEM NOISE

→ Noise Sources
   - Fan
     • Speed
     • Volume
     • Static pressure
   - Flow

→ Acoustic Losses
   - Ductwork
   - Lined bend
   - Flexible duct
   - Split
   - Grilles
   - Attenuators
ATTENUATOR SPECIFICATION

- Insertion Loss
  - Open area
  - Length

<table>
<thead>
<tr>
<th>Property</th>
<th>Low freq attenuation</th>
<th>High freq attenuation</th>
<th>Pressure drop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thicker splitters</td>
<td>up</td>
<td>up</td>
<td>up</td>
</tr>
<tr>
<td>Increase open area</td>
<td>down</td>
<td>down</td>
<td>down</td>
</tr>
<tr>
<td>Tapered splitters</td>
<td>down</td>
<td>up</td>
<td>down</td>
</tr>
<tr>
<td>Melinex coating</td>
<td>down</td>
<td>down a lot</td>
<td>nil</td>
</tr>
<tr>
<td>Increase height</td>
<td>nil</td>
<td>nil</td>
<td>down</td>
</tr>
<tr>
<td>Increase length</td>
<td>up</td>
<td>up</td>
<td>up</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unit</th>
<th>Description</th>
<th>Air Vol. (m³/s)</th>
<th>Max. Press. Drop (Pa)</th>
<th>Dimensions W x H x L (mm)</th>
<th>63</th>
<th>125</th>
<th>250</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>4000</th>
<th>8000</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATT-1</td>
<td>AHU south Supply Att</td>
<td>1.025</td>
<td>34</td>
<td>350 x 700 x 1800</td>
<td>4</td>
<td>7</td>
<td>16</td>
<td>21</td>
<td>28</td>
<td>28</td>
<td>24</td>
<td>19</td>
</tr>
</tbody>
</table>
TYPICAL COORDINATION ISSUES
# FREQUENT COORDINATION ASPECTS

## Property / Refurbishments
- Full height walls
- Raised access floors
- Return air openings
- Noise control measures to units
- Penetrations
- Cable trunking
- Cable trays
- Cross talk
- Grille selections
- Sound Insulating ceilings
- Transfer duct lengths

## New build / Base build
- Ventilation (facade design)
- Large plant room locations
- Noise sensitive spaces
- External plant noise emissions
- Plant room noise
- Plant vibration
- Cross talk
FULL HEIGHT WALLS

- Closed ceiling voids to prevent noise transfer
- Closed air path
  - No path for return air
  - Requires transfer ducts
- Wall sound insulation
  - Room front walls
    - Medium acoustic importance
    - Often baffled
  - Separating walls
    - High acoustic importance
    - Wall built full height
Avoid in full height walls if possible
Can be difficult to detail on site
**PENETRATIONS**

- **Steel collar**
- **Tightly packed Rockwool or Fibreglass**
- **2mm steel angle around entire opening set in continuous bead of mastic**
- **Opening / Steel collar to be no greater than 2 x height of cable tray, and tight fitting to Within 20mm width of cable tray**
- **1.6mm steel collar or conduit, preformed and inserted into wall, sealed with continuous non-drying mastic**
- **Closed-cell expanding polyurethane foam, max depth: 50mm**
- **Cables to be tightly bunched / cable tied into groups as they pass through steel collar**
- **Ceiling, minimum CAC 30 (8 mineral fibre) or Plasterboard**
- **13mm plasterboard around entire opening set in continuous bead of mastic**
- **Tightly packed Rockwool or Fibreglass**
- **Non-hardening mastic - gap no greater than 12mm**
- **1 x 13mm high density plasterboard patrix (or equivalent) material of minimum 110kg/m³ mass, cut with circular holes to allow cable groups to pass through. Holes to be no greater than 15mm larger than radius of the bunched cables, and well sealed with non-drying mastic**
- **Cables to be tightly bunched / cable tied into groups as they pass through steel collar**
- **Steel collar or conduit preformed and inserted into wall, sealed with continuous non-drying mastic**
FLEXIBLE DUCT

- Flexible
  - Sealing
  - Deformable
  - Cannot pass through room front wall (baffled)
- Fabric based
  - Significant down-duct losses
  - Break-out from duct
  - Cannot pass across separating wall
RETURN AIR SHAFTS

→ No ceiling void obstruction (i.e. no full height walls or baffles)
→ Possible solution
  ▪ Relocating sensitive rooms
  ▪ Alternate servicing arrangements
  ▪ Set plasterboard ceilings
    – Sound Insulating
    – Coordination issues
    – Penetrations to be avoided
ACOUSTICALLY CRITICAL SPACES

Studios and Performance spaces...

- Acoustics is driving factor
- Coordinated approach essential at concept stage
- Critical challenges
  - Low velocity system
  - Spatial (duct sizing, orientation and location)
    - Needs visualization very early in the project
  - Proximity of units
  - Higher attenuation requirement
  - Cost/budget
EQUIPMENT AND TYPICAL TREATMENTS
# CHILLERS AND PUMPS

SPL at 1m

## Noise paths requiring treatment

<table>
<thead>
<tr>
<th>Path / mechanism</th>
<th>Treatment / comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airborne Plantroom</td>
<td>Tonal energy at low frequency. Enclosure, acoustic louvres, sealed penetrations, increased plantroom construction</td>
</tr>
<tr>
<td>Breakout</td>
<td></td>
</tr>
<tr>
<td>Structure Borne Vibration</td>
<td>Restrained spring and pads, inertia base plinths, floating slabs, floor span stiffness, flexible connections and hangers</td>
</tr>
</tbody>
</table>

---

**Path / mechanism**

**Treatment / comments**
### Noise paths requiring treatment

<table>
<thead>
<tr>
<th>Path / mechanism</th>
<th>Treatment / comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airborne – fan noise and water noise</td>
<td>Barriers, acoustic louvres, low noise units, reduced fan speed, location</td>
</tr>
<tr>
<td>Structure Borne Vibration</td>
<td>Pad mountings and plinths</td>
</tr>
</tbody>
</table>
Noise paths requiring treatment

<table>
<thead>
<tr>
<th>Path / mechanism</th>
<th>Treatment / comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ductborne</td>
<td>Internally line duct, attenuators, reduce speed</td>
</tr>
<tr>
<td>Breakout</td>
<td>Lagging, bulkheads</td>
</tr>
<tr>
<td>Regenerated</td>
<td>Maintain acceptable air velocities</td>
</tr>
<tr>
<td>Structure Borne Vibration</td>
<td>Resilient hangers or mounts</td>
</tr>
</tbody>
</table>
# AIR HANDLING UNITS

## In-duct SWL

## Noise paths requiring treatment

<table>
<thead>
<tr>
<th>Path / mechanism</th>
<th>Treatment / comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ductborne Noise</td>
<td>Internally line duct, attenuators, reduce speed</td>
</tr>
<tr>
<td>Plantroom Breakout</td>
<td>Enclosure, acoustic louvres, plantroom wall constructions</td>
</tr>
<tr>
<td>Regenerated</td>
<td>Air velocities &lt;7.5m/s in main supply and 6m/s in branches</td>
</tr>
<tr>
<td>Structure Borne Vibration</td>
<td>Restrained spring and pads, inertia base or plinths Flexible connections and hangers</td>
</tr>
</tbody>
</table>
## Noise paths requiring treatment

<table>
<thead>
<tr>
<th>Path / mechanism</th>
<th>Treatment / comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ductborne - Supply air</td>
<td>Internally line duct, attenuators, reduce speed</td>
</tr>
<tr>
<td>Ductborne - Return air</td>
<td>Internally lined duct, add a lined bend, reduce speed</td>
</tr>
<tr>
<td>Regenerated</td>
<td>Air velocities &lt;2.5m/s in supply</td>
</tr>
<tr>
<td>Structure Borne Vibration</td>
<td>Resilient hangers, resilient connections to ductwork and pipework, no rigid connections to building fabric.</td>
</tr>
</tbody>
</table>
## GENERATORS

SPL at 1m, 3m and 15m
SPL of exhaust

### Noise paths requiring treatment

<table>
<thead>
<tr>
<th>Path / mechanism</th>
<th>Treatment / comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airborne Plantroom Breakout</td>
<td>Enclosure, acoustic louvres, sealed penetrations, etc</td>
</tr>
<tr>
<td>Air path noise</td>
<td>Internally line duct, attenuators, acoustic louvres</td>
</tr>
<tr>
<td>Flue noise breakout</td>
<td>Insulated flue, directionality</td>
</tr>
<tr>
<td>Structure borne Vibration</td>
<td>Floating slabs, restrained spring and pads, inertia base or plinths, floor span stiffness</td>
</tr>
</tbody>
</table>
Noise paths requiring treatment

<table>
<thead>
<tr>
<th>Path / mechanism</th>
<th>Treatment / comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airborne Breakout</td>
<td>Highly tonal at 50Hz / 100Hz. Packaged unit, barriers, acoustic louvres</td>
</tr>
</tbody>
</table>
IDENTIFYING AN ISSUE ON SITE
IDENTIFYING NOISE SOURCES
IDENTIFYING NOISE SOURCES
ACOUSTIC CAMERA
More often than not the acoustic design has a flow on effect to other disciplines, architectural, structural, mechanical, ESD etc. A coordinated approach is required.

If the project acoustic requirements are strict then early involvement is essential if a cost effective outcome is to be achieved.

Be prepared to get involved, it’s often an iterative process.
# REGENERATED NOISE

- Air velocity
- Open area

## Maximum Duct and Riser Air Velocities

<table>
<thead>
<tr>
<th>CRITERION:</th>
<th>NR 40</th>
<th>NR 38</th>
<th>NR 35</th>
<th>NR 30</th>
<th>NR 25</th>
</tr>
</thead>
<tbody>
<tr>
<td>45 dBA</td>
<td>9</td>
<td>8</td>
<td>7.5</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>43 dBA</td>
<td>6.5</td>
<td>5.5</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>40 dBA</td>
<td>3</td>
<td>2.5</td>
<td>2.5</td>
<td>2</td>
<td>1.5</td>
</tr>
<tr>
<td>35 dBA</td>
<td>2.5</td>
<td>2</td>
<td>2</td>
<td>1.5</td>
<td>1</td>
</tr>
<tr>
<td>30 dBA</td>
<td>2</td>
<td>2</td>
<td>1.5</td>
<td>1</td>
<td>1.5</td>
</tr>
</tbody>
</table>

## Maximum Air Velocity (m/s)

<table>
<thead>
<tr>
<th></th>
<th>Riser</th>
<th>Main Branch</th>
<th>Grille</th>
<th>Diffuser</th>
<th>Extract stub ducts (above ceiling)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>9</td>
<td>6</td>
<td>3</td>
<td>2.5</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>5.5</td>
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## Notes

- Maximum air velocities for different duct and riser types are provided.
- NR values correspond to noise reduction criteria.
- Air velocity and open area values are indicated for various parts of the system.