Good, Better, & Best Duct Design

An Overview for ASHRAE Bi State Chapter
March 14, 2012
Introduction

• Why Duct Design?
• How to Design?
• Design Process (8 steps)
• Fundamentals
• Design Methods
Introduction

- Ductwork Types
- Sound Control
- Leakage Control
- Exposed Ductwork
- Specifications
FUNDAMENTALS

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Flow Rate (Q)

\[ Q = V \times A \]

**WHERE:**

- **Q** – volume flow rate of airflow (cfm)
- **V** – velocity (ft/min)
- **A** – area (sq ft)
Fundamentals

Total Pressure = Static Pressure + Velocity Pressure

TP = SP + VP

WHERE:

TP – in wg
SP – in wg
VP – in wg
Fundamentals

Duct static pressure on various duct shapes

Round Duct

Flat Oval Duct

Rectangular Duct
Fundamentals

Fan and duct pressure changes in duct

Entry → Airflow → Exit Diffuser

ATMOSPHERIC PRESSURE

Δ SP

Δ TP

Total Pressure

Static Pressure

Velocity Pressure

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Fundamentals

Fan Laws

\[
\frac{Q_2}{Q_1} = \frac{RPM_2}{RPM_1}
\]

\[
\frac{BHP_2}{BHP_1} = \left(\frac{Q_2}{Q_1}\right)^3
\]

\[
\frac{FTP_2}{FTP_1} = \left(\frac{Q_2}{Q_1}\right)^2
\]

- **Q** = volume flow rate of airflow (cfm)
- **RPM** = fan speed (revolutions/minute)
- **BHP** = brake horse power (hp)
- **FTP** = fan total pressure (in wg)

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Design Considerations

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Duct Types

**Round** — spiral and longitudinal seam duct

**Flat Oval** — spiral and longitudinal seam duct

**Rectangular**

**Other** — semi/quarter round, triangular

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Design Considerations

Fitting Types

Elbows

- Pressed – 45° and 90°, 3- to 12-inch diameter
Design Considerations

Fitting Types

Elbows

- Pleated – 45° and 90°, 3- to 16-inch diameter
Design Considerations

Fitting Types

**Elbows**

- Gored – std
- Gored – long radius
Design Considerations

Fitting Types

**Elbows**

- Mitered – vanes
- Mitered – no vanes
Design Considerations

Ping-Pong Ball Fitting Loss
demonstration

click to play video

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Design Considerations

Fitting Types

Divided Flow

- Straight Tee
Design Considerations

Fitting Types

Divided Flow
- Conical Tee

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Design Considerations

Fitting Types

Divided Flow

- LoLoss™ Tee
Design Considerations

Fitting Types

Divided Flow

• Y-Branch

• Reducing Y-Branch
Design Considerations

Fitting Types

Divided Flow

• Bullhead Tee – vanes

• Bullhead Tee – no vanes

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Design Considerations

Fitting Types

Divided Flow

• Laterals

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Design Considerations

Fitting Types

Converging Flow

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Supply Design Methods

1. Equal friction
2. Static regain
3. Velocity reduction
4. “T” method
Design Considerations

Exhaust/Return Design Methods

1. Exhaust
   a. Constant velocity
   b. Equal friction

2. Return
   a. Equal friction
   b. Velocity reduction
Energy Consumption

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Energy Consumption

• Factors
  1. cfm, sp, efficiency, fuel cost, and hours
  2. Operation cost vs aspect ratio

• System Annual Operating Cost
Performance Considerations

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Annual Operational Costs

\[
\frac{\text{Cost}}{\text{Year}} = \left( \frac{Q_{\text{fan}} \times \text{FTP}}{8,520 \times \text{eff}} \right) \times \frac{\text{Hours}}{\text{Year}} \times \frac{\$}{\text{kwh}}
\]

WHERE:

- **Cost/Year** = system first year operating cost ($)
- **Q_{\text{fan}}** = system volume flow rate (cfm)
- **FTP** = system total operating pressure (in wg)
- **Hours/Year** = number of hours the system operates in one year
- **$/\text{kwh}** = cost of energy
- **eff** = fan/motor drive combined efficiency
- **8,520** = conversion factor to kwh (kilowatt hours)
Sound Control

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Sound Control

Design Process

1. Determine acceptable noise criteria (NC) rating for the space
2. Determine the sound source spectrum
3. Calculate the resultant sound level criteria
4. Compare resultant sound levels
5. Select the appropriate noise control products to attain the needed NC level
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Sound Control

Calculate Resultant Sound Levels

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Sound Control Devices

Pressurized enclosure

Round duct silencer

k-27 duct and fittings

Rectangular duct silencers

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Why Leakage Control?

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Leakage Control

Performance considerations

1. Airflow quantities
2. Airflow quality
3. Airflow pressure
4. Energy consumption
5. Annual operational cost
6. Balanced airflow
Fundamentals

Duct static pressure on various duct shapes

- Round Duct
- Flat Oval Duct
- Rectangular Duct
Fan and duct pressure changes in duct

Entry → Airflow → Exit Diffuser

- ATMOSPHERIC PRESSURE
- Δ SP
- Δ TP
- Static Pressure
- Velocity Pressure
- Total Pressure

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What does SMACNA say?

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Leakage cfm/100 sq ft vs Test Pressure
Leakage Classes

TABLE 4-1

<table>
<thead>
<tr>
<th>DUCT CLASS</th>
<th>1/2&quot;, 1&quot;, 2&quot; W.G.</th>
<th>3&quot; W.G.</th>
<th>4&quot;, 6&quot;, 10&quot; W.G.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEAL CLASS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SEALING APPLICABLE</td>
<td>TRANSVERSE JOINTS ONLY</td>
<td>TRANSVERSE JOINTS AND SEAMS</td>
<td>JOINTS, SEAMS AND ALL WALL PENETRATIONS</td>
</tr>
<tr>
<td>RECTANGULAR METAL</td>
<td>24</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>ROUND METAL</td>
<td>12</td>
<td>6</td>
<td>3</td>
</tr>
</tbody>
</table>

NOTES:
1. Leakage classes in Table 4-1 apply when the designer does not designate other limits and has specified Seal Class C for 1/2" and 1" w.g. See text on sealing in the HVAC-OCS manual.
2. Unsealed rectangular metal duct may follow Leakage Class 48.
3. Fibrous glass duct may follow Leakage Class 6 (at 2" w.g. or less).
4. Unsealed flexible duct leakage average is estimated to be Class 30. Sealed nonmetal flexible duct is an average of Class 12.
5. See SMACNA HVAC Duct Systems Design manual Table 5-1 for longitudinal seam leakage rates.
6. Although Seal Class A or B might be assigned for lower pressures, the leakage class may not conform to those associated with the higher pressure. Other construction details influence results.
7. Leakage Class \( C_L \) is defined as being the leakage rate (CFM/100 S.F.) divided by \( P^2 \) where \( P \) is the static pressure (IN. W.G.). When \( P \) is numerically equal to \( 1" \) the leakage rate is \( C_L \). See Figure 4-1.
8. The duct pressure classification is not the fan static pressure nor the external static pressure (on an HVAC unit) unless the system designer has made such an assignment in his contract documents. Unless construction class is otherwise specified it means a static pressure classification in the SMACNA HVAC-OCS. Those classifications pertain to maximum operating pressure in the duct as follows:
   - 0.5" w.g. maximum: 3.1" to 4" w.g. maximum
   - 0.6" to 2" w.g. maximum: 4.1" to 6" w.g. maximum
   - 1.1" to 2" w.g. maximum: 6.1" to 10" w.g. maximum
   - 2.1" to 3" w.g. maximum

SMACNA HVAC Air Duct Leakage Test Manual—1st Ed.
Duct Geometry and Leakage

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Duct Geometry and Leakage

Typical Duct Geometries

1. Round
2. Flat oval
3. Rectangular

SMACNA Leakage Class at Seal Class A

1. Round: 3 cfm/100 sq ft
2. Flat oval: 3 cfm/100 sq ft
3. Rectangular: 6 cfm/100 sq ft

WHAT IS WRONG WITH THIS PICTURE???

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Cost of Leakage

\[
\text{Cost/Year} = \left( \frac{Q_{\text{fan}} \times FTP}{8,520 \times \text{eff}} \right) \times \frac{\text{Hours}}{\text{Year}} \times \frac{\$}{\text{kwh}}
\]

WHERE:

- **Cost/Year** = system first year operating cost ($)
- **Q_{\text{fan}}** = system volume flow rate (cfm)
- **FTP** = system total operating pressure (in wg)
- **Hours/Year** = number of hours the system operates in one year
- **$/\text{kwh}** = cost of energy
- **eff** = fan/motor drive combined efficiency
- **8,520** = conversion factor to kwh (kilowatt hours)
# Duct Geometry and Leakage

## Impact of Leakage

<table>
<thead>
<tr>
<th>Leakage %</th>
<th>CFM (cu ft/min)</th>
<th>RPM (rev/min)</th>
<th>SP (in wg)</th>
<th>VP (in wg)</th>
<th>TP (in wg)</th>
<th>BHP (hp)</th>
<th>Oper/yr ($/year)</th>
<th>Extra Oper/yr ($/year)</th>
<th>Increased Oper/yr (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>20,000</td>
<td>530</td>
<td>1.5</td>
<td>0.39</td>
<td>1.89</td>
<td>6.68</td>
<td>5,600</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>21,000</td>
<td>557</td>
<td>1.65</td>
<td>0.43</td>
<td>2.08</td>
<td>7.73</td>
<td>6,481</td>
<td>881</td>
<td>15.7</td>
</tr>
<tr>
<td>10</td>
<td>22,000</td>
<td>583</td>
<td>1.82</td>
<td>0.47</td>
<td>2.29</td>
<td>8.89</td>
<td>7,452</td>
<td>1,852</td>
<td>33.3</td>
</tr>
<tr>
<td>15</td>
<td>23,000</td>
<td>610</td>
<td>1.98</td>
<td>0.52</td>
<td>2.50</td>
<td>10.16</td>
<td>8,515</td>
<td>2,915</td>
<td>52.1</td>
</tr>
<tr>
<td>20</td>
<td>24,000</td>
<td>636</td>
<td>2.16</td>
<td>0.56</td>
<td>2.72</td>
<td>11.54</td>
<td>9,675</td>
<td>4,075</td>
<td>73</td>
</tr>
<tr>
<td>30</td>
<td>26,000</td>
<td>689</td>
<td>2.54</td>
<td>0.66</td>
<td>3.20</td>
<td>14.68</td>
<td>12,301</td>
<td>6,701</td>
<td>120</td>
</tr>
</tbody>
</table>

### Assumed:
- Electric rate $0.15
- 52 wk x 6 d/wk x 24 hr
- Fan/motor eff (%)
- Initial velocity

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Duct Geometry and Leakage

Suggested Leakage Levels

<table>
<thead>
<tr>
<th>Test Pressure (in wg)</th>
<th>SMACNA Class 3 (cfm/100 sq ft)</th>
<th>Leakage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>3.0</td>
<td>2</td>
</tr>
<tr>
<td>1-2</td>
<td>4.6</td>
<td>2</td>
</tr>
<tr>
<td>2-3</td>
<td>6.0</td>
<td>1</td>
</tr>
<tr>
<td>3-4</td>
<td>7.4</td>
<td>1</td>
</tr>
<tr>
<td>4-6</td>
<td>9.6</td>
<td>0.5</td>
</tr>
<tr>
<td>6-10</td>
<td>13.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

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Duct Geometry and Leakage

Leakage Specification (minimum requirements)

1. Test pressure (in wg)
2. Allowable leakage (cfm/100 sq ft)
3. Test procedure
4. Report of findings
5. Certified test equipment
Exposed Ductwork

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Exposed Ductwork

A. Duct types
   1. Round
   2. Flat oval
   3. Rectangular
   4. Other: semi/quarter round, triangular

B. Elbow types
   1. Pressed
   2. Pleated
   3. Gored

C. Divided flow fittings
   1. Straight tee
   2. Conical tee
   3. LoLoss™ tee

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Exposed Ductwork

Institutional

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Exposed Ductwork

Commercial

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Exposed Ductwork

Industrial

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Exposed Ductwork

Controlled Air Distribution
Exposed Ductwork

High Bay and Boot Taps

McGill AirFlow LLC

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Material Considerations

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Material Considerations

Metallic

1. Galvanized steel, G60/G90/phosp.
2. Stainless steel, 304/316/finish #2d/#4
3. Aluminum, type 3003-H14
4. PVC-coated
5. SilverGuard™ antimicrobial
Material Considerations

Non-metallic

1. FRP (fiberglass reinforced plastic)
2. Fibrous duct board
3. Flexible
4. Dry wall
5. Fabric, open or closed weave
Sealants and Adhesives
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Sealants and Adhesives

Types

1. Water based
2. Solvent based

Common Properties

1. No surface preparation
2. +/- 40 in wg
3. High solids content
4. Curing time 24-48 hours
Sealants and Adhesives

**LEED Applications**
1. Solvent/water based
2. Low VOCs <250 g/l

**Outside/Underground Applications**
1. Solvent based
2. Resistant to weather and ultraviolet rays

**Tapes**
1. 2-part tape/sealant
2. +/- 40 in wg
3. Flexible
4. Butyl gasket for flange face

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*Good, Better, & Best Duct Design – An Overview*
Diffusers, what type?

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Diffusers, what type?

Exposed Features

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Diffusers, what type?

Exposed Features

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Specification Considerations

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Specification Considerations

1. SMACNA duct construction standards 2005
2. Joint types
3. Hanging and support
4. Handling/shipping/cleaning
5. Finish welding/pacification/grinding
6. Double-wall and lining
7. Painting
8. Material types
9. Leakage testing
Conclusions

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Conclusions

1. Fundamentals
2. Design methods
3. Energy consumption
4. Sound control
5. Leakage control
6. Exposed ductwork
7. Materials
8. Specifications