Technical Development Program

COMMERCIAL DISTRIBUTION SYSTEMS

Duct Design
Level 1
Fundamentals

PRESENTED BY:
Ray Chow
Sales Engineer
Menu

Section 1  Introduction
Section 2  Duct Design Criteria
Section 3  Theory and Fundamentals
Section 4  Duct Design Process Steps
Section 5  Summary
SECTION 1

DUCT DESIGN LEVEL 1
FUNDAMENTALS

Introduction
Objectives

- Apply Duct Design Criteria
- Understand Theory and Fundamentals
- Use Duct Design Process Steps
- Size Ducts with a Friction Chart or Calculator
- Work on an Equal Friction Example
SECTION 2

DUCT DESIGN LEVEL 1 FUNDAMENTALS

Duct Design Criteria
Duct

- Different shapes and sizes
- Different materials
- Air tunnel that allows air to move from one end to another
- Heating, cooling, ventilation and etc.
Duct Design Criteria

- Space availability
- Installation cost
- Air friction loss
- Noise level
- Duct heat transfer and airflow leakage
- Codes and standards requirements
Fitting in the Ductwork

1. Boot Diffuser / Takeoff Duct
2. Speaker / Conduit
3. Header Duct
4. Sprinkler / Piping
5. Lights / Conduit

Section 2 – Duct Design Criteria
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Section 2 – Duct Design Criteria
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Ductwork Portion of HVAC Costs

Cost based on DX Packaged Split VAV System

- 33% Packaged Air Handler
- 22% Air-Cooled Condensing Unit
- 22% Ductwork
- 15% VAV Terminals
- 5% Diffusers
- 3% Controls
Limit Noise Levels

- Use Aerodynamic Fittings
- Line Short Runouts
- Don’t Place Diffusers In Trunk Ducts
- Keep Velocities Within Recommended Range
- Use Turning Vanes To Avoid Turbulence
- Place Balancing Dampers Upstream From Diffusers
- Place Insulated Flex Duct Close To Diffusers
- Keep Velocities Within Recommended Range

Section 2 – Duct Design Criteria
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## Minimum Duct Seal Level

<table>
<thead>
<tr>
<th>Duct Location</th>
<th>Duct Type</th>
<th>Supply ≤ 2 in. w.c.</th>
<th>Supply &gt; 2 in. w.c.</th>
<th>Exhaust</th>
<th>Return</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outdoors</td>
<td>A</td>
<td>A</td>
<td>C</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>Unconditioned Spaces</td>
<td>B</td>
<td>A</td>
<td>C</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td>Conditioned Spaces</td>
<td>C</td>
<td>B</td>
<td>B</td>
<td>C</td>
<td></td>
</tr>
</tbody>
</table>

### Duct Seal Levels

<table>
<thead>
<tr>
<th>Seal Level</th>
<th>Sealing Requirements *</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>All transverse joints and longitudinal seams, and duct wall penetrations. Pressure-sensitive tape shall not be used as the primary sealant.</td>
</tr>
<tr>
<td>B</td>
<td>All transverse joints and longitudinal seams. Pressure-sensitive tape shall not be used as the primary sealant.</td>
</tr>
<tr>
<td>C</td>
<td>Transverse joints only</td>
</tr>
</tbody>
</table>
Codes and Standards Requirements

- **Building Code** deals mostly with life safety issues
- **Mechanical Code** addresses construction and installation
- **Energy Conservation Code** directs designers to create systems that meet insulation, leakage, and static pressure requirements
SECTION 3

DUCT DESIGN LEVEL 1
FUNDAMENTALS

Theory and Fundamentals
Basic Definitions

- **Cfm**: measurement of airflow in cubic feet/minute
- **Fpm**: velocity or speed of air flow in feet/minute
- **Sq.ft**: cross-sectional area
Theory and Fundamentals

- CFM = fpm x cross sectional area
- 1000 CFM = 1000 fpm x 1 sqft.
- 1000 CFM = 500 fpm x 2 sqft.

- Velocity(A) * Area(A) = Velocity(B) * Area(B)
- 1000 fpm x 1 sqft. = 500 fpm x 2 sqft.
Conservation of mass

- air mass is neither created nor destroyed
- CFM (all inlet) = CFM (all outlet)
Conservation of energy

- Energy cannot be created or destroyed, only change from one form to another

Bernoulli’s Law

- When there is a change in velocity there is a corresponding and inverse change in static pressure
Static Pressure vs. Velocity Pressure

Static Pressure

Velocity Pressure
Total Pressure = Static Pressure + Velocity Pressure
Velocity Pressure Conversion

\[ V_1 = \frac{Q}{A_1} = \frac{1000 \text{ cfm}}{1 \text{ ft}^2} = 1000 \text{ fpm} \]

\[ V_2 = \frac{Q}{A_2} = \frac{1000 \text{ cfm}}{0.6 \text{ ft}^2} = 1667 \text{ fpm} \]

VELOCITY PRESSURE \( P_V \) = \( \left( \frac{V}{4005} \right)^2 \)

\[ P_{V1} = \left( \frac{1000}{4005} \right)^2 = 0.062 \text{ in. wg} \]

\[ P_{V2} = \left( \frac{1667}{4005} \right)^2 = 0.173 \text{ in. wg} \]
Factors Affecting Friction Loss

- Air Velocity
- Duct Size and Shape
- Duct Material Roughness Factor
- Duct Length
### RECOMMENDED & MAXIMUM DUCT VELOCITIES RANGES

<table>
<thead>
<tr>
<th>Designation</th>
<th>Schools, Theaters &amp; Public Buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fan Outlets</td>
<td>1300 – 2200</td>
</tr>
<tr>
<td>Main Ducts</td>
<td>1000 – 1600</td>
</tr>
<tr>
<td>Branch Ducts</td>
<td>600 – 1300</td>
</tr>
</tbody>
</table>

Velocities are for net free area.

### DESIGN VELOCITIES FOR HVAC COMPONENTS

<table>
<thead>
<tr>
<th>Component</th>
<th>Type</th>
<th>Velocities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Louvers</td>
<td>Intake</td>
<td>400 fpm</td>
</tr>
<tr>
<td></td>
<td>Exhaust</td>
<td>500 fpm</td>
</tr>
<tr>
<td>Filters</td>
<td>Electrostatic</td>
<td>150-350 fpm</td>
</tr>
<tr>
<td></td>
<td>HEPA</td>
<td>250 fpm</td>
</tr>
<tr>
<td></td>
<td>Bag / Cartridge</td>
<td>500 fpm</td>
</tr>
<tr>
<td></td>
<td>Pleated</td>
<td>750 fpm</td>
</tr>
<tr>
<td>Heating Coils</td>
<td>Steam / Water</td>
<td>500-1000 fpm</td>
</tr>
<tr>
<td>Cooling Coils</td>
<td>DX / Water</td>
<td>400-500 fpm</td>
</tr>
</tbody>
</table>
### Effects of Shape, Ducts of Equal Area

All ducts = 9 sq ft

<table>
<thead>
<tr>
<th>Aspect Ratio</th>
<th>Perimeter (ft)</th>
<th>Ratio of Perimeter to Area</th>
<th>Equivalent Round Duct (in.)</th>
<th>Friction At 15,000 cfm (in. wg / 100’ EL)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1:1</strong></td>
<td>10.7</td>
<td>1.18:1</td>
<td>40.7</td>
<td>0.070</td>
</tr>
<tr>
<td><strong>3 ft × 3 ft</strong></td>
<td>12</td>
<td>1.33:1</td>
<td>39.4</td>
<td>0.086</td>
</tr>
<tr>
<td><strong>2 ft × 4.5 ft</strong></td>
<td>13</td>
<td>1.45:1</td>
<td>38.7</td>
<td>0.095</td>
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<tr>
<td><strong>1.5 ft × 6 ft</strong></td>
<td>15</td>
<td>1.67:1</td>
<td>37.2</td>
<td>0.113</td>
</tr>
<tr>
<td><strong>1 ft × 9 ft</strong></td>
<td>20</td>
<td>2.22:1</td>
<td>34.5</td>
<td>0.156</td>
</tr>
</tbody>
</table>
### Surface Roughness of Ducts

<table>
<thead>
<tr>
<th>DUCTWORK DESCRIPTION</th>
<th>MULTIPLIER</th>
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</thead>
<tbody>
<tr>
<td>Rigid Fiberglass – Preformed Round Ducts – Smooth Inside</td>
<td>1.0</td>
</tr>
<tr>
<td>Rigid Fiberglass Duct Board</td>
<td>1.32</td>
</tr>
<tr>
<td>Duct Liner – Airside has Smooth Facing Material</td>
<td>1.32</td>
</tr>
<tr>
<td>* Flexible Metal Duct (Straight Installation)</td>
<td>1.6</td>
</tr>
<tr>
<td>Duct Liner – Airside Spray - Coated</td>
<td>1.9</td>
</tr>
<tr>
<td>* Flexible, Vinyl-Coated Duct with Helical Wire Core (Straight Installation)</td>
<td>3.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SUPPLY</th>
<th>RETURN</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>1.32</td>
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<tr>
<td>1.32</td>
<td>1.30</td>
</tr>
<tr>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>1.9</td>
<td>1.8</td>
</tr>
<tr>
<td>3.2</td>
<td>3.4</td>
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</tbody>
</table>

* Flexible duct multipliers assume that the duct is installed fully extended.
### Recommended Friction Rates

<table>
<thead>
<tr>
<th>Ductwork</th>
<th>Friction Rate Range (in. wg / 100 ft EL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure Classes ½, 1, 2</td>
<td>0.10 to 0.15</td>
</tr>
<tr>
<td>Pressure Class 3</td>
<td>0.20 to 0.25</td>
</tr>
<tr>
<td>Pressure Classes 4, 6, 10</td>
<td>0.40 to 0.45</td>
</tr>
<tr>
<td>Transfer Air Ducts</td>
<td>0.03 to 0.05</td>
</tr>
<tr>
<td>Outdoor Air Ducts</td>
<td>0.05 to 0.10</td>
</tr>
<tr>
<td>Return Air Ducts</td>
<td>80% of above supply duct values</td>
</tr>
</tbody>
</table>

**Notes:**

1. Higher friction rates should only be used when space constraints dictate.
2. Using higher friction rates permits smaller ducts but raises horsepower (energy) and velocity (noise).
3. Maximum aspect ratio is 4:1 unless space constraints dictate greater aspect ratios.
4. When diffusers, registers, and grilles are mounted to supply, return, and exhaust ducts, velocities should not exceed 1500 fpm or noise will result.
Fitting Losses

- **Equivalent Length (EL) Method** – converts fittings to straight duct (similar to piping)
- **Dynamic Loss (C_v) Method** – uses coefficients x velocity pressure
Fitting Losses

Duct Design Book Table 6 and 7

<table>
<thead>
<tr>
<th>ELBOW DIAMETER (in.)</th>
<th>90° SMOOTH</th>
<th>90° 3-PIECE</th>
<th>90° 3-PIECE</th>
<th>45° 3-PIECE</th>
<th>45° SMOOTH</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>R/D = 1.5</td>
<td>R/D = 1.5</td>
<td>R/D = 1.5</td>
<td>R/D = 1.5</td>
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<td>2.3</td>
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<td>4</td>
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<td>2.5</td>
<td>1.9</td>
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</tr>
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<td>8</td>
<td>6</td>
<td>8</td>
<td>16</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>9</td>
<td>—</td>
<td>9</td>
<td>18</td>
<td>4.5</td>
<td>—</td>
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<tr>
<td>10</td>
<td>—</td>
<td>10</td>
<td>20</td>
<td>4</td>
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<td>11</td>
<td>—</td>
<td>11</td>
<td>22</td>
<td>5.5</td>
<td>—</td>
</tr>
<tr>
<td>12</td>
<td>—</td>
<td>12</td>
<td>24</td>
<td>6</td>
<td>—</td>
</tr>
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<td>14</td>
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<td>14</td>
<td>28</td>
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<td>16</td>
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<td>44</td>
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<td>24</td>
<td>—</td>
<td>24</td>
<td>48</td>
<td>12</td>
<td>—</td>
</tr>
</tbody>
</table>

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Break
Sizing with the Duct Calculator

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Duct Calculator Scales

- cfm (airflow)
- Velocity Scale
- Round Duct Diameter
- Friction Loss
- Equivalent Rectangular Duct Sizes
- Velocity Pressure

Section 4 – Duct Design Process Steps
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**Given:** 12” round duct with 700 cfm flow rate

**Determine:** Velocity, friction loss and possible rectangular sizes (in even number increments)

1. Line up 12” with pointer

2. Read velocity (900 fpm)

3. Read friction loss (0.10 in. wg/100’ EL)

   Possible rectangular sizes: 16” x 8”, 12” x 10”, etc.

4. 14” x 9” rectangular duct
**Given:** Friction loss for sheet metal duct = 0.08 in. wg

**Determine:** Friction loss for other duct materials

- Duct board = 0.105 in. wg
- Metal flex (installed straight) = 0.13 in. wg
- Duct liner with airside spray coating = 0.15 in. wg
- Flexible, vinyl-coated duct (flex) = 0.26 in. wg
Using Equivalent Length

Total Length = 15' + 8' + 18' = 41' EL

Duct Pressure Loss = $f * \frac{EL}{100'}$

= 0.12 in. wg * 41'/ 100'

= 0.049 in. wg
Duct Sizing Methods

- Equal Friction
- Static Regain – for sizing with software
- Other Methods
Duct Design Process Steps 1-4

1. Determine Number of Zones
2. Perform Heating and Cooling Estimate
3. Determine Room / Zone Airflow Quantities
4. Select Duct Material, Shape, and Insulation
5. Layout Ductwork from AHU to Diffusers
6. Summarize Airflows and Label Ducts
7. Size Ducts from Fan Outlet to Diffusers
8. Calculate Air System Pressure Losses
9. Select Fan and Adjust System Pressures
Design Step 1

Determine Number of Zones

- Basic Zones of Similar Loads
- Unique Sub-Zones
Design Step 2

Perform Cooling and Heating Load Estimates

- Accurately enter the building info
- Set system parameters for block, zone, and space loads
- Run loads
Design Step 3

Determine Space, Zone, and System Airflows
Design Step 4

Select Duct Material, Shape, and Insulation

- Cost-effective material to fit the conditions
- Round, rectangular, or flat oval to fit the space and for efficient installation
- Adequate insulation to conserve energy and avoid condensation
# Common Duct Material Applications

<table>
<thead>
<tr>
<th>Duty / Material</th>
<th>Galvanized Steel</th>
<th>Carbon Steel</th>
<th>Stainless Steel</th>
<th>Aluminum</th>
<th>Fiberglass Board</th>
<th>FRP</th>
<th>PV Steel</th>
<th>Gypsum Board</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flues</td>
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<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture-laden</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kitchen</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fume Hood</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Air Shafts</td>
<td>X</td>
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<td></td>
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<td>Underground</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

FRP = Fiberglass Reinforced Plastic  
PV Steel = PVC-coated steel
### Showing Pressure Class

<table>
<thead>
<tr>
<th>SYMBOL MEANING</th>
<th>SYMBOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>POINT OF CHANGE IN DUCT CONSTRUCTION (BY STATIC PRESSURE CLASS)</td>
<td><img src="image1.png" alt="Symbol" /></td>
</tr>
<tr>
<td>DUCT (1ST FIGURE, SIDE SHOWN 2ND FIGURE, SIDE NOT SHOWN)</td>
<td><img src="image2.png" alt="Symbol" /></td>
</tr>
<tr>
<td>ACOUSTICAL LINING DUCT DIMENSIONS FOR NET FREE AREA</td>
<td><img src="image3.png" alt="Symbol" /></td>
</tr>
<tr>
<td>DIRECTION OF FLOW</td>
<td><img src="image4.png" alt="Symbol" /></td>
</tr>
</tbody>
</table>
Duct Assembly Joints

STANDING S T-10

JTS T-10 TO T-14 OR T-2

DRIVE SLIP T-2

USE MAXIMUM LENGTH OF CONNECTIONS

PLAIN “S” SLIP T-5

“S”-SLIP T-5 OR T-6S

CORNER HAMMERED OVER

OPEN HEM FOR DRIVE SEAM

DRIVE SLIP T-1

T-1 DRIVE SLIP

H

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Duct Design Process Steps 5-9

1. Determine Number of Zones
2. Perform Heating and Cooling Estimate
3. Determine Room / Zone Airflow Quantities
4. Select Duct Material, Shape, and Insulation
5. Layout Ductwork from AHU to Diffusers
6. Summarize Airflows and Label Ducts
7. Size Ducts from Fan Outlet to Diffusers
8. Calculate Air System Pressure Losses
9. Select Fan and Adjust System Pressures
Design Step 5

Lay Out Ductwork from AHU to Air Distribution Devices

Outdoor Air Inlet

Air Handling Unit

Return Registers

Zone Terminals

Supply Diffusers
100% EFFECTIVE DUCT LENGTH = A MINIMUM OF 2½ DUCT DIAMETERS. FOR 2500 FPM OR LESS. ADD 1 DUCT DIAMETER FOR EACH ADDITIONAL 1000 FPM.
Trunk Layout to Fit the Building

“Spine” Duct Layout

“Loop” Duct Layout

“H” Pattern Duct Layout
Design Step 6

Create System Sizing Schematic

Outdoor Air Inlet

2400 cfm

20’

500 cfm

Air Handling Unit

600 cfm

90’

100’

600 cfm

40’

20’

1300 cfm

Return Registers

800 cfm

500 cfm

500 cfm

Zone Terminals

Supply Diffusers

10.0’

30’

90’

20’

40’

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Design Step 6

Summarize Duct cfm and Label Duct Schematic

Outdoor Air Inlet

500 cfm

Air Handling Unit

2400 cfm

Supply Diffusers

1300 cfm

1100 cfm

Zone Terminals

1100 cfm

500 cfm

Return Registers

600 cfm

1300 cfm

Supply Diffusers

500 cfm

600 cfm

Design Step 6

Section 4 – Duct Design Process Steps
Design Step 7

Size Ductwork from Fan to Extremities

- Pick an initial velocity
- Size duct sections using equal friction
- Pick efficient fittings
- Tabulate results in a Duct Sizing Worksheet
# Duct Sizing Worksheet

<table>
<thead>
<tr>
<th>Duct Run From-To</th>
<th>Duct Section (Element)</th>
<th>Lining (in.)</th>
<th>Insul. (in.)</th>
<th>Other Item</th>
<th>Airflow</th>
<th>Velocity in Round duct (fps)</th>
<th>Velocity Pressure $P_V$</th>
<th>Fitting Value $n$</th>
<th>Length (ft)</th>
<th>Equivalent Length (ft)</th>
<th>EL</th>
<th>Material Correction Factor</th>
<th>Friction Losses (fr/100')</th>
<th>Unknown Losses (in. wg)</th>
<th>Round Duct Size (in.)</th>
<th>Equivalent Rectangular Size (W x H)</th>
<th>Total Item Loss (in. wg)</th>
<th>Cumulative Loss (in. wg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-E</td>
<td>A-B</td>
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<td>-</td>
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<tr>
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<td>OUTLET</td>
<td></td>
<td>2500</td>
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<td>-</td>
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**NOTES:** All duct sizes indicated are inside clear dimensions.

**LARGEST STATIC PRESSURE LOSS (in. wg)** 0.247

**FOR RUN = A-G**

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Ceiling Plenum and Ducted Return

- Some buildings use ceiling plenum return.
- Reduce duct cost.
- Reduce pressure drop.
Design Step 8

Calculate Air System Pressure Losses

- Summarize losses for greatest pressure loss circuit or run
- This is not always the longest run, look at terminal and diffuser losses
- Double-check that sizes will fit into the space available.
Design Step 9

Select Fan and Adjust System Airflows

- Add safety factor to the total external pressure drop
- For exhaust/supply fan selection, external static pressure drop is equal to total static pressure drop
- Use external static pressure for AHU/RTU/FCU
Design Step 9

Select Fan and Adjust System Airflows

- Evaluate if the static pressure makes sense
- Fine tune air distribution device or air path to minimize pressure drop
Example 3 – Equal Friction Sizing

Using the Duct Friction Table

40” × 20” Fan Outlet

Supply Diffuser Loss = 0.10 in. wg @ 2500 cfm each
## Duct Sizing Worksheet

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<thead>
<tr>
<th>Duct Section</th>
<th>Lining (in.)</th>
<th>Insul. (in.)</th>
<th>Other Item</th>
<th>Airflow</th>
<th>Velocity in Round duct (ft/min)</th>
<th>Velocity Pressure $P_v$</th>
<th>Fitting Value $n$</th>
<th>Length (ft) $L$</th>
<th>Equiv. Length (ft) $EL$</th>
<th>Material Correction Factor</th>
<th>Friction Loss $S$ per 100’ duct</th>
<th>Friction Loss $S =$</th>
<th>Known Loss $S =$</th>
<th>Round Duct Size (in.)</th>
<th>Equivalent Rectangular Size (W x H)</th>
<th>Total Item Loss (in. wg)</th>
<th>Cumulative Loss (in. wg)</th>
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**LARGEST STATIC PRESSURE LOSS (in. wg)** 0.247

**FOR RUN =** A - G
SECTION 5

DUCT DESIGN LEVEL 1
FUNDAMENTALS

Summary
• Cost-effective duct design is as much an art as it is a science.

• Bernoulli’s Law is used to explain the relationship between velocity and static pressures.

• Use of straight-forward layouts with efficient fittings is critical in duct design.

• Friction loss charts and duct calculators are important tools in reinforcing duct design principles and improving the duct design process.
1. Define the following terms:

   Total Pressure: _________________________________________________________
   Velocity Pressure: _______________________________________________________
   Static Pressure: __________________________________________________________

2. Which of the following affects duct friction loss? (Choose all that apply): __________________

   a.) duct size  d.) air velocity
   b.) duct length  e.) duct construction material
   c.) thickness of duct wrap  f.) fitting type

3. True or False? A fan begins to convert static pressure into velocity pressure in the first few feet of supply duct. _____________________
Thank You

This completes the presentation.

TDP-504  Duct Design Level 1 Fundamentals

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