DESIGNER’S GUIDE

Standards and Dimensional Data for Air Duct and Fittings as Manufactured by Members of SPIDA
FIGURE 1 VAV Supply Air Duct System

DESIGN CRITERIA

The above variable air volume (VAV) supply air system fan (Figure 1) requires 20,500 cfm @ 3 in.w.g. SP, which includes 400 cfm or 2 percent estimated duct air leakage. The VAV boxes need a minimum of 1 in.w.g. at the box inlet. Rectangular and flat oval duct aspect ratios cannot exceed 3:75 to 1. Ductwork shall be sealed as per ASHRAE/SMACNA seal classes B for 3 in.w.g. and C for 2 in.w.g. construction pressure classifications. All elbows will have $R/D = 1.5$, transitions $= 30^\circ$ slope, branch taps $= 45^\circ$ angle with $45^\circ$ elbows, and wye fitting $= 45^\circ$ angles with $45^\circ$ elbows. All duct branches to VAV boxes have balancing dampers. All ductwork will be galvanized steel with gauges and reinforcement as per the SMACNA HVAC Duct Construction Standards - 2005.

DUCT SYSTEM COSTS

The total fabrication and installation costs of the sheet metal duct work shown in Figure 1 are plotted in Figure 2, and are based on the following sizes:

- Round spiral duct - 32 inch diameter to 14 inch diameter.
- Flat oval spiral duct - 60 x 16 inch to 14 inch diameter.
- Rectangular duct - 60 x 16 inch to 12 x 14 inch.

All three duct systems were sized to have approximately the same static pressure drop. The estimated costs were obtained recently from sheet metal contractors in nine different cities throughout the U.S.A. and Canada.
DUCT CONSTRUCTION

Round: 22 gauge spiral duct from the fan to 28 gauge spiral ducts for the end branch ducts. No extra reinforcement required with beaded sleeve joints. . . A light weight system.

Flat Oval: 20 gauge flat oval duct from the fan to 28 gauge spiral round ducts for the end branch ducts. F-20 reinforcement is used on 4 foot centers for only the flat surfaces. . . A medium weight system.

Rectangular: 18 gauge duct from the fan with H-18 reinforcement plus F+ rod intermediate reinforcement to 22 gauge with no reinforcement or 26 gauge with A-26 reinforcement on 5 foot centers for the end branch ducts. . . A heavy weight system.

DUCT LEAKAGE CALCULATIONS

Duct system air leakage is based on the amount of total duct surface and leakage classes established by ASHRAE/SMACNA research (see Table 1). Round duct has the smallest perimeter per air volume. Flat oval and rectangular duct perimeters are greater in that order, depending on aspect ratio.

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>90 feet</td>
<td>32 or 60x16</td>
<td>754</td>
<td>1037</td>
<td>1140</td>
<td>2.5 in.w.g.</td>
</tr>
<tr>
<td>60 feet</td>
<td>26 or 38x16</td>
<td>409</td>
<td>471</td>
<td>540</td>
<td>2.5 in.w.g.</td>
</tr>
<tr>
<td>66 feet</td>
<td>26 or 38x16</td>
<td>449</td>
<td>518</td>
<td>594</td>
<td>1.5 in.w.g.</td>
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<tr>
<td>33 feet</td>
<td>18 or 20x14</td>
<td>146</td>
<td>164</td>
<td>187</td>
<td>1.5 in.w.g.</td>
</tr>
<tr>
<td>80 feet</td>
<td>16 or 16x14</td>
<td>336</td>
<td>336</td>
<td>400</td>
<td>2.5 in.w.g.</td>
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<tr>
<td>150 feet</td>
<td>14 or 12x14</td>
<td>550</td>
<td>550</td>
<td>650</td>
<td>1.5 in.w.g.</td>
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S q. ft. Totals @ 2.5 in.w. g. 1499 1844 2080

S q. ft. Totals @ 1.5 in.w. g. 1155 1232 1431

Total Square footage 2654 3076 3511

ROUND DUCT
Class 6 1499 sq.ft. x 11 cfm/100 sq.ft. = 165 cfm Leakage
Class 12 1155 sq.ft. x 15 cfm/100 sq.ft. = 173 cfm Leakage
Total = 338 cfm Leakage

338 cfm/20,100 cfm = 1.68% Leakage

FLAT OVAL DUCT
Class 6 1844 sq.ft. x 11 cfm/100 sq.ft. = 203 cfm Leakage
Class 12 1232 sq.ft. x 15 cfm/100 sq.ft. = 185 cfm Leakage
Total = 388 cfm Leakage

388 cfm/20,100 cfm = 1.93% Leakage

RECTANGULAR DUCT
Class 12 2080 sq.ft. x 22 cfm/100 sq.ft. = 458 cfm Leakage
Class 24 1431 sq.ft. x 30 cfm/100 sq.ft. = 429 cfm Leakage
Total = 887 cfm Leakage

887 cfm/20,100 cfm = 4.41% Leakage
NEW PROBLEM FOR RECTANGULAR DUCT SYSTEM

The rectangular duct exceeds the estimated leakage of 400 cfm by 487 cfm (887-400), so that the duct system now requires about 21,000 cfm from the supply air fan. This increase in fan volume will cause slight increases in system velocities and static pressures. To be prudent, the system designer should increase the initial rectangular duct pressure classification to 4 in.w.g. to allow for pressure increases that could occur with system balancing, as the calculated system static pressure drop was 2.98 in. w.g. The changes to a 4 in.w.g. rectangular duct pressure class also would reduce the leakage for that portion of duct by half because of the "A seal class", but the costs (and weight) of that part of the rectangular duct system would increase above those shown in Figure 2. Duct gauge and reinforcement would change from H-18 to I-16. Another option would be to seal all rectangular ducts to "A seal class". The initial round spiral ductwork specified can handle up to 10 in.w.g., so no change would be required even if there were major duct system pressure increases due to the balancing work.

| TABLE 1 METAL DUCT LEAKAGE CLASSES (ASHRAE/SMACNA) |
|-----------------|----------------|-----------------|
| DUCT CLASS      | 1/2, 1, 2 in.w.g. | 3 in.w.g.       | 4,6,10 in.w.g. |
| SEAL CLASS      | C               | B               | A              |
| SEALING         | TRANSVERSE JOINTS ONLY | TRANSVERSE JOINTS AND SEAMS | JOINTS, SEAMS AND ALL WALL PENETRATIONS |
| RECTANGULAR LEAKAGE CLASS | 24             | 12             | 6              |
| ROUND METAL LEAKAGE CLASS | 12             | 6              | 3              |

SPIRAL DUCTS

QUICK DELIVERY

Round spiral duct and fittings mostly are stock items that can be delivered quickly. Once delivered, many round spiral duct sizes can be handled easily by one man.

LOWER INSTALLATION COSTS

Round spiral and flat oval ducts:
- have longer lengths between joints,
- are easy to adjust to exact lengths,
- are easier to hang and have less hangers,
- are lighter in weight,
- have easier to seal joints,
- require less or no reinforcement,
- often require less space.

FLAT OVAL SPIRAL DUCTS

Flat oval spiral ducts offer an alternative to rectangular sheet metal ducts, falling in between round spiral and rectangular ducts in most areas. As noted before, air leakage, rigidity, the use of slip joints and lighter weight are characteristics similar to those of round spiral ducts.

Extra reinforcement requirements and additional duct surface area puts flat oval duct somewhere in between round spiral and rectangular duct, and flat oval duct and fittings normally are not quick delivery stock items.
DUCT HEAT GAIN

The first 90 feet of the round duct system in Figure 1 has an average velocity of about 3470 fpm and conveys 55°F air through a 115°F uncooled attic space. Each system is insulated with 2 inch, 0.75 lb/ft² exterior insulation (U is obtained from Figure 3). Compare the heat gain in the 90 foot duct segment for each type of duct.

**ROUND DUCT (Equations from ASHRAE):**

\[
y = \frac{0.6 \ \text{DVs}}{\text{UL}} = \frac{0.6 \times 32^2 \times 3470 \ \text{fpm} \times 0.075 \ \text{lb/ft}^3}{0.15 \times 90'} = 370.1
\]

\[
t_i = \frac{t_s (y - 1) + 2 \ t_s}{(y + 1)} = \frac{55^\circ (370.1 - 1) + 2 \ (115^\circ)}{(370.1 + 1)} = \frac{20301 + 230}{371.1} = 55.32^\circ \text{F}
\]

\[
Q = \frac{\text{UPL}}{12} \left( \frac{t_i - t_s}{2} \right) - t_s = \frac{0.15 \times 100.5^\circ \times 90'}{12} - \left( \frac{55^\circ + 55.32^\circ}{2} \right) - 115^\circ
\]

\[
Q = 113.06 \ (55.16^\circ - 115^\circ) = -6766 \text{ Btu/h heat gain}
\]

**FLAT OVAL DUCT (Average Velocity = 3050 fpm):**

\[
y = \frac{2.4 \ \text{AVd}}{\text{UPL}} = \frac{2.4 \times 904.3 \times 3050 \times 0.075}{0.15 \times 138.2 \times 90} = 266.1
\]

\[
t_i = \frac{t_s (y - 1) + 2 \ t_s}{(y + 1)} = \frac{55^\circ (266.1 - 1) + 2 \ (115^\circ)}{(266.1 + 1)} = \frac{14,581 + 230}{267.1} = 55.45^\circ \text{F}
\]

\[
Q = \frac{\text{UPL}}{12} \left( \frac{t_i - t_s}{2} \right) - t_s = \frac{0.15 \times 138.2'' \times 90'}{12} \left( \frac{55.23^\circ - 115^\circ}{2} \right)
\]

\[
Q = 155.5 \ (-59.77^\circ) = -9293 \text{ Btu/h heat gain}
\]

**RECTANGULAR DUCT (Average Velocity = 2875 fpm):**

\[
y = \frac{2.4 \ \text{AVd}}{\text{UPL}} = \frac{2.4 \times 960.3 \times 2875 \times 0.075}{0.18 \times 152 \times 90} = 201.8
\]

\[
t_i = \frac{t_s (y - 1) + 2 \ t_s}{(y + 1)} = \frac{55^\circ (201.8 - 1) + 2 \ (115^\circ)}{(201.8 + 1)} = \frac{11,044 + 230}{202.8} = 55.59^\circ \text{F}
\]

\[
Q = \frac{\text{UPL}}{12} \left( \frac{t_i - t_s}{2} \right) - t_s = \frac{0.18 \times 152'' \times 90'}{12} \left( \frac{55.30^\circ - 115^\circ}{2} \right)
\]

\[
Q = 205.2 \ (-59.7^\circ) = -12,250 \text{ Btu/h heat gain}
\]
90 FOOT OF DUCT SYSTEM HEAT GAIN COMPARISON (with round):

Round spiral duct - 6766 Btuh heat gain
Flat oval duct - 9293 Btuh or 2527 Btuh (37%) greater
Rectangular duct - 12,250 Btuh or 5484 Btuh (81%) greater

TOTAL DUCT SYSTEM HEAT GAIN (approximate):

Round Spiral duct - 23,825 Btuh (7.0 kWh)
Flat oval duct - 32,820 Btuh (9.6 kWh)
Rectangular duct - 43,100 Btuh (12.6 kWh)

DUCT SYSTEM OPERATION COSTS

Based on actual values established earlier for each type of system, yearly operation costs may be based on the following assumptions:

VAV percentage of maximum = 90%
Fan efficiency = 75%
Drive efficiency = 75%
Annual hours of operation = 5000
Electrical costs = $0.08/kWh
Heat gain (50% of maximum) = $0.04/kWh

Equation:

$ Cost = \frac{\text{cfm} \times \text{S.P.}}{6356 \times E_r \times E_a} \times 0.746 \text{ kW/Bhp} \times \$/$kWh \times \text{hr/yr}

With above numbers substituted:

$ Cost = \text{cfm} \times \text{S.P.} \times 0.076

Round Spiral Duct System:

Fan operation cost = 20,338 x 2.90 x 0.076 = $4483/year
System heat gain = 7.0 x 5000 x $0.04 = $1400/year
Total = $5883/year

Flat Oval Duct System:

Fan operation cost = 20,388 x 2.92 x 0.076 = $4525/year
System heat gain = 9.6 x 5000 x $0.04 = $1920/year
Total = $6445/year (or 10% greater than round duct)

Rectangular Duct System:

Fan operation cost = 20,887 x 3.0 x 0.076 = $4762/year
System heat gain = 12.6 x 5000 x $0.04 = $2520/year
Total = $7282/year (or 24% greater than round duct)

If the rectangular duct system was lined with spray coated 1 inch, 1.5 pound per square foot fibrous glass instead of being externally insulated, the yearly operation costs would change to:

Fan operation cost = 20,887 x 4.33 x 0.076 = $6874/year
System heat gain = 30.0 x 5000 x $0.04 = $6000/year
Total = $12,874/year (or 119% greater than round duct)
NOISE CONTROL

Low frequency noises or "rumble" in duct systems come from the fan and from fitting turbulence. Low frequency noises create the most serious problems as they are the hardest to attenuate and the easiest to break out through flat duct surfaces.

TRANSMISSION LOSS

Transmission loss is a measurement of the capability of a duct to contain noise within the duct. The higher the transmission loss, the less the noise will radiate from the duct. This noise will pass into the occupied spaces through acoustic ceilings, as they are "sound transparent". A comparison of the transmission losses for round spiral, flat oval spiral and rectangular sheet metal ducts is shown in Figure 4. Although not shown below 63 Hz, the transmission loss for round spiral duct increases as the frequencies lower. This is important as typical HVAC motors and fans generate noise in the low 15 to 30 Hz range. Although rectangular ducts have a higher transmission loss at easier to attenuate higher frequencies, most higher frequency noises are generated by terminal devices such as registers and diffusers.

NATURAL SOUND ATTENUATION

Rectangular ducts have less natural attenuation, but are more easily lined with sound-absorbing materials. However, the sound lining attenuation is limited, especially at frequencies 250 Hz and lower where "rumble" occurs. The natural attenuation of unlined ducts is shown in Table 2 for rectangular ducts and in Table 3 for round spiral ducts. Rectangular fibrous glass ducts have natural attenuation, but have no transmission loss as the duct material, like acoustic ceilings, is sound transparent.

| TABLE 2 Natural Sound Attenuation in Unlined Rectangular Sheet Metal Ducts (ASHRAE) |
|----------------------------------------|----------------|----------------|----------------|
| P/A Ratio* in/n² | Octave-Band Center Frequency, Hz | 63 | 125 | 250 and Over |
|------------------|----------------|----------------|----------------|
| Over 3.1 | 0 | 0.3 | 0.1 | 0.1 |
| 3.1 to 0.13 | 0.3 | 0.1 | 0.1 | 0.1 |
| Under 0.13 | 0.1 | 0.1 | 0.1 | 0.1 |

*Perimeter divided by area
Double these values if the duct is externally insulated

| TABLE 3 Natural Sound Attenuation in Unlined Straight Round Ducts (ASHRAE) |
|----------------------------------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Diam. in. | Approximate Attenuation, dB/ft | Octave-Band Center Frequency, Hz | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 |
|-----------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| 6 | 0.2 | 0.5 | 1.0 | 1.8 | 2.2 | 2.2 | 2.0 |
| 12 | 0.15 | 0.3 | 0.7 | 1.5 | 2.2 | 2.2 | 1.5 |
| 24 | 0.1 | 0.2 | 0.5 | 1.0 | 1.7 | 0.9 | 0.5 |
| 48 | 0.04 | 0.1 | 0.3 | 0.6 | 0.6 | 0.8 | 0.5 |

FIGURE 4 Breakout Sound Transmission Loss (dB) Comparison (ASHRAE)