HVAC AIR SYSTEMS;
DUCTWORK, FANS, AIR HANDLING UNITS

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Duct Design Concepts

Overview

- *Duct Construction: Pressure/Leakage Classes*
- *Friction Rate vs. Velocity*
- *Fitting Losses = Impact Losses*
- *Calculating System Pressure Drop*
- *Minimizing System Pressure Drop*
- *Noise Control*
- *Fan Selection Principles*
- *How Ductwork is Made: Understand it to Design It*

Basic Duct System Design Concepts

ALWAYS:

- *Limit the number of transitions (size changes) in a run of ductwork.*
- *Transition where you need to. Know why you should.*
- *Think about access; dampers, terminal boxes, filters, coils. "Lowest ladder possible."*
- *Minimize Aspect Ratio; think "round/square/rectangular/flatter" in that order.*
- *Understand friction rate vs. velocity; Watch both, balance the two (and why the duct friction rate is only part of the story).*
- *Understand airflow and fittings; Elbow Aside. Make it easy to get there.*
- *Be aware of duct insulation, flanges and hangers. Ducts are bigger than you think.*

SMACNA STANDARDS

Pressure Classes, Metal Gauges and Reinforcement:

2" W.G. STATIC POS.OR NEG. / DUCT DIMENSION ①	NO REINFORCEMENT REQUIRED ②	RECTA… 10' ③
10"dn	26 ga.	
11, 12"	24 ga.	
13, 14"	22 ga.	
15, 16"	20 ga.	C-22
17, 18"	20 ga.	C-22
19, 20"	18 ga.	C-20
21, 22"	16 ga.	D-20
23, 24"	16 ga.	E-20
25, 26"		E-20
27, 28"		F-18
29, 30"		F-18

3" W.G. STATIC POS.OR NEG. / DUCT DIMENSION ①	NO REINFORCEMENT REQUIRED ②	RECTA… 10' ③
10"dn	24 ga.	NOT REQU…
11, 12"	22 ga.	
13, 14"	20 ga.	
15, 16"	18 ga.	
17, 18"	18 ga.	
19, 20"	16 ga.	D-18
21, 22"	16 ga.	E-18
23, 24"	16 ga.	E-18
25, 26"		F-18
27, 28"		F-16

4" W.G. STATIC POS. OR NEG. / DUCT DIMENSION ①	NO REINFORCEMENT REQUIRED ②	RECT… 10' ③
8"dn	24 ga.	NOT RE…
9, 10"	22 ga.	
11, 12"	20 ga.	B-22
13, 14"	18 ga.	C-20
15, 16"	18 ga.	C-18
17, 18"	16 ga.	D-18
19, 20"		E-18
21, 22"		E-18
23, 24"		F-18

6" W.G. STATIC POS. OR NEG. / DUCT DIMENSION ①	NO REINFORCEMENT REQUIRED ②	RECTANGULAR REINFO… REI… 10' ③	8' ④	… ⑤
8"dn.	24 ga.	NOT REQUIRED		
9, 10"	20 ga.			B-
11, 12"	18 ga.	C-20	C-20	C-
13, 14"	18 ga.	C-20	C-20	D-
15, 16"	16 ga.	D-18	D-18	D-
17, 18"		E-18	E-18	E-
19, 20"		F-16	F-18	F-
21, 22"		F-16	F-18	F-

Note sheet metal gauges per duct size, without reinforcing. *Thinner gauges can be used if with reinforcing, in various combinations.*

SMACNA STANDARDS

Pressure Classes, Metal Gauges and Reinforcement:

2" W.G. STATIC POS.OR NEG.	TABLE 1-5 RECTANGULAR DUCT REINFORCEMENT								
	NO REINFORCE-MENT REQUIRED	REINFORCEMENT CODE FOR DUCT GAGE NO.							
		REINFORCEMENT SPACING OPTIONS							
DUCT DIMENSION		10'	8'	6'	5'	4'	3'	21/2'	2'
①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
10"dn	26 ga.	NOT REQUIRED							
11, 12"	24 ga.		B-26	B-26	B-26	B-26	B-26	B-26	B-26
13, 14"	22 ga.		B-24	B-26	B-26	B-26	B-26	B-26	B-26
15, 16"	20 ga.	C-22	C-24	C-24	C-26	C-26	C-26	B-26	B-26
17, 18"	20 ga.	C-22	C-24	C-24	C-26	C-26	C-26	C-26	B-26
19, 20"	18 ga.	C-20	C-22	C-24	C-26	C-26	C-26	C-26	C-26
21, 22"	16 ga.	D-20	D-22	D-24	D-26	C-26	C-26	C-26	C-26
23, 24"	16 ga.	E-20	E-22	D-24	D-26	D-26	C-26	C-26	C-26
25, 26"		E-20	E-22	E-24	D-26	D-26	C-26	C-26	C-26
27, 28"		F-18	E-20	E-22	E-24	D-26	D-26	C-26	C-26
29, 30"		F-18	F-20	E-22	E-24	E-26	D-26	D-26	C-26
31-36"		G-16	G-18	F-20	F-22	E-24	E-26	D-26	D-26

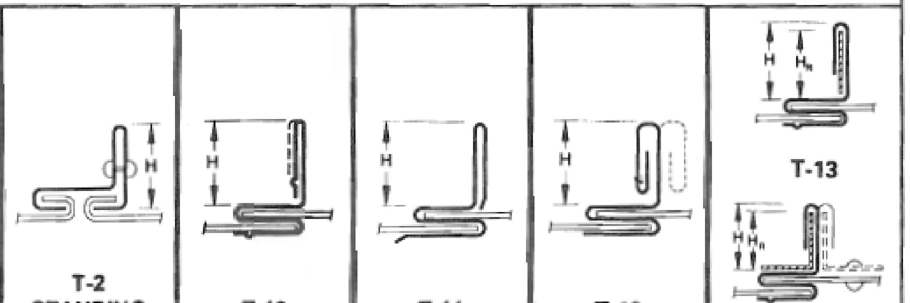
6" W.G. STATIC POS. OR NEG.	TABLE 1-8 RECTANGULAR DUCT REINFORCEMENT								
	NO REINFORCE-MENT REQUIRED	REINFORCEMENT CODE FOR DUCT GAGE NO.							
		REINFORCEMENT SPACING OPTIONS							
DUCT DIMENSION		10'	8'	6'	5'	4'	3'	21/2'	2'
①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
8"dn.	24 ga.	NOT REQUIRED			C-26	C-26	B-26	B-26	B-26
9, 10"	20 ga.			B-22	C-24	C-24	B-26	B-26	B-26
11, 12"	18 ga.	C-20	C-20	C-22	C-24	C-24	C-26	C-26	C-26
13, 14"	18 ga.	C-20	C-20	D-20	D-22	C-24	C-26	C-26	C-26
15, 16"	16 ga.	D-18	D-18	D-20	D-22	D-24	D-26	C-26	C-26
17, 18"		E-18	E-18	E-20	E-22	E-24	D-26	D-26	C-26
19, 20"		F-16	F-18	F-20	E-22	E-24	D-24	D-26	D-26
21, 22"		F-16	F-18	F-20	F-22	F-24	E-24	E-26	D-26
23, 24"			G-18	G-20	F-22	F-22	E-24	E-26	E-26
25, 26"			H-16G	G-18	G-20	F-22	F-24	E-24	E-24
27, 28"			H-16G	H-18G	H-20G	G-22	F-24	F-24	E-24
29, 30"				H-18G	H-18G	G-22	F-24	F-24	E-24
31-36"				I-16H	I-18H	H-20G	H-22G	G-24	F-24

Note sheet metal gauges per duct size, without reinforcing.
Thinner gauges can be used but with reinforcing, in various combinations.

SMACNA STANDARDS

Pressure Classes, Metal Gauges and Reinforcement:

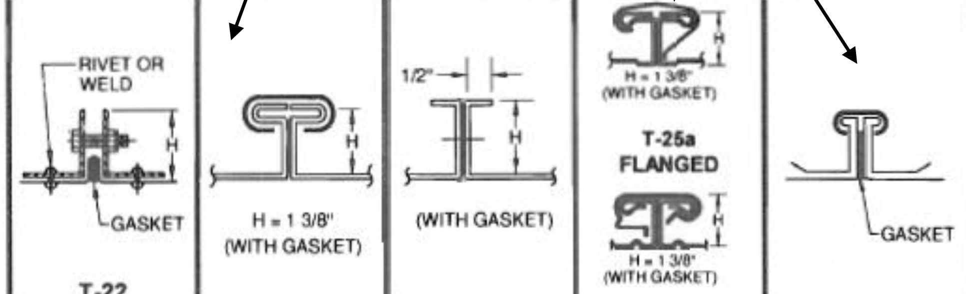
TABLE 1-11 TRANSVERSE JOINT REINFORCEMENT



REINF. CLASS	EI*	T-2 STANDING DRIVE SLIP H x T	WT LF	T-10 STANDING S H x T	WT LF	T-11 STANDING S H x T	WT LF	T-12 STANDING S H x T	WT LF	T-13 / T-14 STANDING S H x T x HR	WT LF
A	0.43	Use B		Use B		1/2 x 26 ga.	0.5	Use B		Use D	
B	1.0	1 1/8 x 26 ga.	0.4	1 x 26 ga.	0.6	1/2 x 22 ga. 1 x 26 ga.	0.6	1 x 26 ga.	0.7	Use D	
C	1.9	1 1/8 x 22 ga.	0.6	1 x 22 ga.	0.8	1 x 22 ga.	0.8	1 x 24 ga.	0.8	Use D	
D	2.7	1 1/8 x 18 ga.	0.8	1 1/8 x 20 ga. 1 x 22 ga. (+)	0.9	1 x 20 ga. 1 x 22 ga. (+)	0.9	1 1/2 x 22 ga.	1.0	1 5/8 x 24 ga. 1 1/2 x 1/8 Bar	1.4
E	6.5			1 1/8 x 18 ga.	1.0	1 x 18 ga. (+)	1.0	1 x 18 ga. 1 1/2 x 20 ga.	1.2	Use F	

Proprietary Types

TABLE 1-12 TRANSVERSE JOINT REINFORCEMENT



REINF. CLASS	EI*	T-22 COMPANION ANGLES H x T	WT LF	T-24 FLANGED T (Nom.)	WT LF	T-24a FLANGED H x T (Nom.)	WT LF	T-25b FLANGED T (Nom.)	WT LF	SLIP-ON FLANGE
A	0.43	Use E		Use D		Use D		Use D		
B	1.0	Use E		Use D		Use D		Use D		
C	1.9	Use E		Use D		Use D		Use D		
D	2.7	Use E		± 26 ga.	0.5	1 x 22 ga.	0.4	± 26 ga.	0.5	

Note shop-fabricated reinforcing vs. proprietary flange systems *(e.g. Ductmate, TDF, Ward Duct Connector). MOST ducts have a default reinforcing spacing of less than 5 feet, just for showing up. This means thinner gauges of sheet metal.*

SMACNA STANDARDS

SEAL THE DEAL: Moving air is costly. Loss of air to leakage cannot be economically recovered.

Control it.

TABLE 1-2		
STANDARD DUCT SEALING REQUIREMENTS		
SEAL CLASS	Sealing Requirements	Applicable Static Pressure Construction Class
A	Class A: All Transverse joints, longitudinal seams, and duct wall penetrations	4" w.g. and up (1000 Pa)
B	Class B: All Transverse joints and longitudinal seams only	3" w.g. (750 Pa)
C	Class C: Transverse joints only	2" w.g. (500 Pa)
In addition to the above, any variable air volume system duct of 1" (250 Pa) and 1/2" w.g. (125 Pa) construction class that is upstream of the VAV boxes shall meet Seal Class C.		

Always Remember: <u>Horsepower Varies with CFM as a Cube Function</u>.

Example: System design volume = 12,000 cfm at 4.5" WG static pressure and uses 13.0 brake HP, 15 HP Motor.

The fan *does move 12,000 cfm* but there is 10% leakage in the system which is needed for a critical space.

If you elect to speed up the fan to gain back this lost air it will cost a third more horsepower, <u>forever</u>:

12,000 *1.1=13,200 (13,200/12,000)^3 = 1.331 x 13.0 BHP = 17.30 BHP. A 20 HP motor is required.

This last 10% of air requires 4.3 BHP forever, assuming leakage remains constant. The most expensive air you will ever move.

<u>SEAL THE DUCTS; Seal Class A, Leakage Class 3 minimum.</u>

Duct Sealant is CFM You Buy Once.

SMACNA STANDARDS

SEAL THE DEAL: Moving air is costly enough. Loss of air to leakage cannot be economically recovered. A lack of sealing defeats the purpose of too many duct systems. Duct sealant is CFM you buy once.

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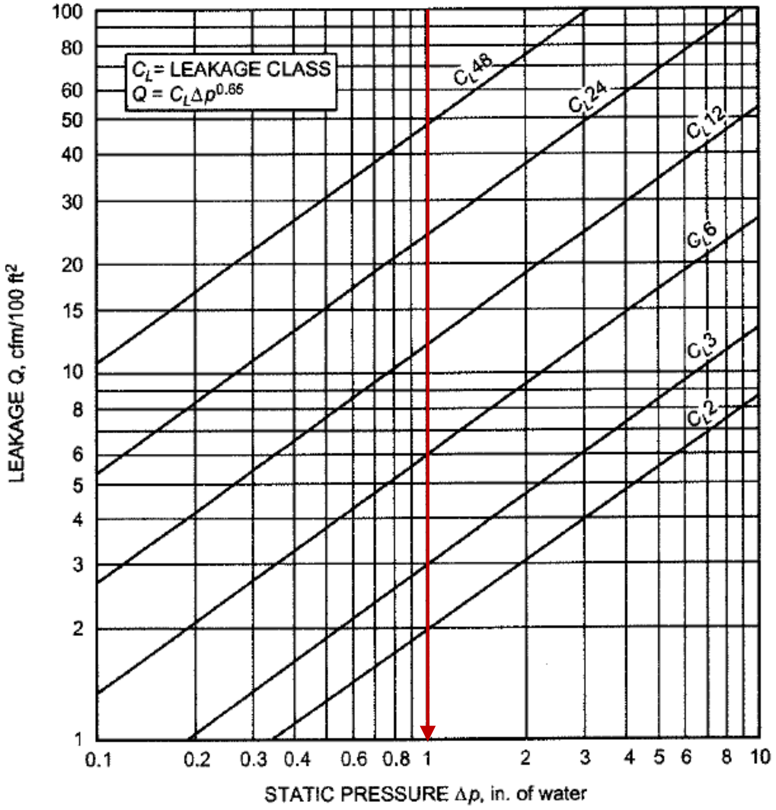


Fig. 13 Duct Leakage Classifications

Leakage Class = Cfm per 100 SF of duct surface area at 1.0" WG differential pressure.

This is why Leakage Class 3 makes sense in most systems. ~2% leakage vs. 4%, 8%, 16%, 33%...

Table 7 Leakage as Percentage of Airflow[a,b]

Leakage Class	System cfm per ft² Duct Surface[c]	Static Pressure, in. of water 0.5	1	2	3	4	6
48	2	15	24	38	49	59	77
	2.5	12	19	30	39	47	62
	3	10	16	25	33	39	51
	4	7.7	12	19	25	30	38
	5	6.1	9.6	15	20	24	31
24	2	7.7	12	19	25	30	38
	2.5	6.1	9.6	15	20	24	31
	3	5.1	8.0	13	16	20	26
	4	3.8	6.0	9.4	12	15	19
	5	3.1	4.8	7.5	9.8	12	15
12	2	3.8	6	9.4	12	15	19
	2.5	3.1	4.8	7.5	9.8	12	15
	3	2.6	4.0	6.3	8.2	9.8	13
	4	1.9	3.0	4.7	6.1	7.4	9.6
	5	1.5	2.4	3.8	4.9	5.9	7.7
6	2	1.9	3	4.7	6.1	7.4	9.6
	2.5	1.5	2.4	3.8	4.9	5.9	7.7
	3	1.3	2.0	3.1	4.1	4.9	6.4
	4	1.0	1.5	2.4	3.1	3.7	4.8
	5	0.8	1.2	1.9	2.4	3.0	3.8
3	2	1.0	1.5	2.4	3.1	3.7	4.8
	2.5	0.8	1.2	1.9	2.4	3.0	3.8
	3	0.6	1.0	1.6	2.0	2.5	3.2
	4	0.5	0.8	1.3	1.6	2.0	2.6
	5	0.4	0.6	0.9	1.2	1.5	1.9

[a]Adapted with permission from *HVAC Air Duct Leakage Test Manual* (SMACNA 1985, Appendix A).
[b]Percentage applies to airflow entering a section of duct operating at an assumed pressure equal to average of upstream and downstream pressures.
[c]Ratios in this column are typical of fan volumetric flow rate divided by total system surface. Portions of systems may vary from these averages.

SMACNA STANDARDS

Aspect Ratio Progression: Round –Square –Rectangular –Flat

4,000 CFM to be moved at 0.09”/100 lf friction rate. 2.0” WG Pressure Class ductwork. 1,250 fpm velocity;
Escalating Material Weight and Cost:

Round; 24” round duct: 79” material =6.6 sf/lf (24 ga.) =***7.63#/lf***

1:1: 22x22 square duct; 92” material = 7.7 sf/lf (24 ga.) =***8.90#/lf***

2:1: 32x16 rectangular; 101” material =8.4 sf/lf (20 ga.) =***13.91#/lf***

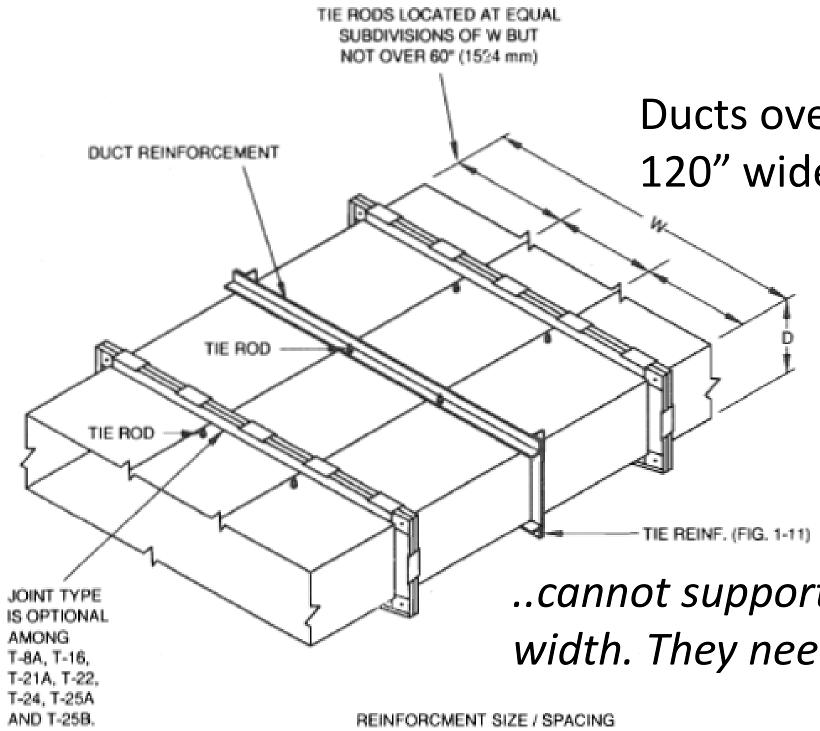
3.5:1: 42x12 rectangular; 113” material = 9.5 sf/lf (20 ga.) =***15.73#/lf***

5:1: 60x10 rectangular; 147” material = 12.3 sf/lf (18 ga.) =***26.51#/lf***

“Do what you have to do but know why and what the cost is.”

****24 ga: 1.156 lbs. per sf.***
22 ga: 1.406 lbs. per sf.
20 ga: 1.656 lbs. per sf.
18 ga: 2.156 lbs. per sf.
16 ga: 2.656 lbs. per sf.
“Ductwork sold by the pound”.

Ducts over 120” wide…



..cannot support their own width. They need tie rods.

REINFORCMENT SIZE / SPACING

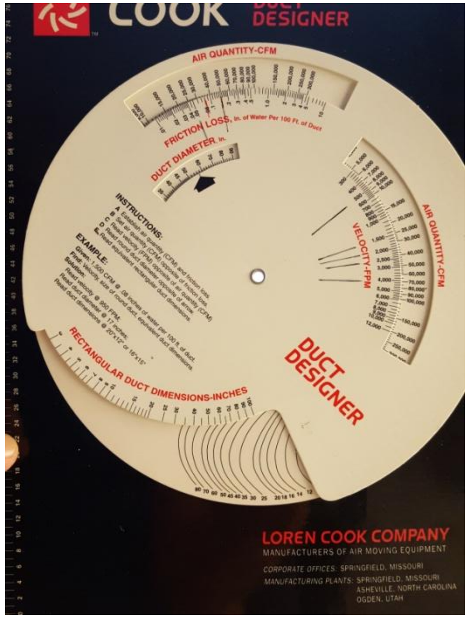
1/2 TO 3" W.G. (125 TO 750 Pa) ...... I, @ 2 1/2' (0.75 M)
4" W.G. (1000 Pa) .... J, @ 2 1/2' (0.75 M)
6" W.G. (1500 Pa) .... K, @ 2' (0.60 M)
10" W.G. (2500 Pa) .... L, @ 2' (0.60 M)

NOTES:

1. SEE TIE ROD TEXT.
2. USE 18 GAGE (1.31 mm) DUCT FOR 6" W.G. (1500 Pa) STATIC OR LESS AND 16 GAGE FOR 10" W.G. (2500 Pa).
3. ON 10" W.G. (2500 Pa) THE MAXIMUM TIE ROD INTERVAL ACROSS THE WIDTH IS 48" (1.2 M).
4. SEE REINFORCEMENT ATTACHMENT IN FIGURE 1-11.
5. SEE SUPPORT OF LARGE DUCTS IN FIGURE 4-6. DUCTS MUCH OVER 100" (2540 mm) WIDTH MAY REQUIRE OTHER INTERNAL SUPPORTS FOR SHAPE RETENTION UNLESS THEY ARE SUPPORTED AS SHOWN IN FIGURE 4-6.

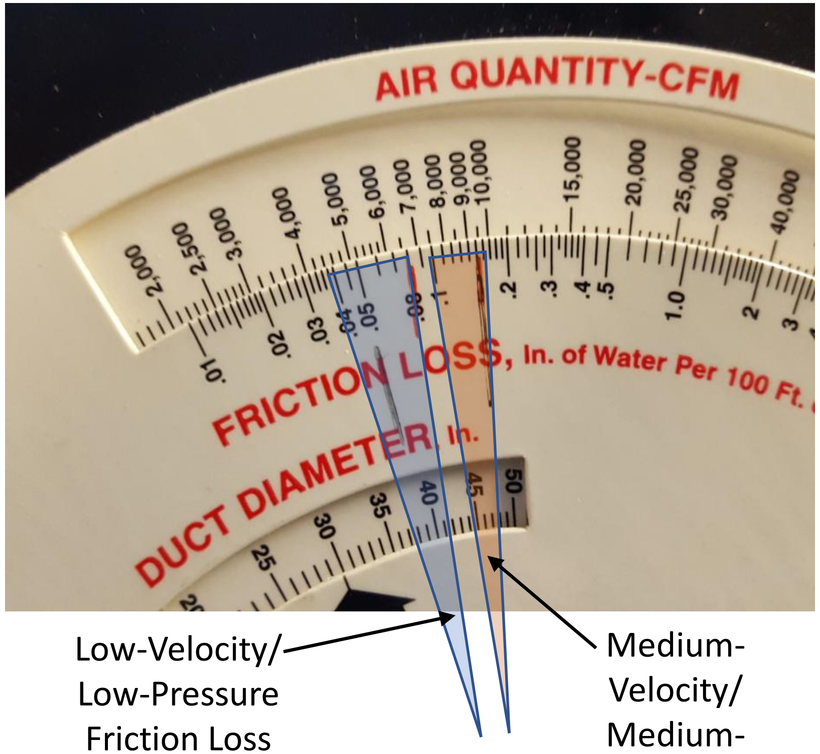
Duct Sizing:

Flow Friction vs. Velocity:



Duct Calculator

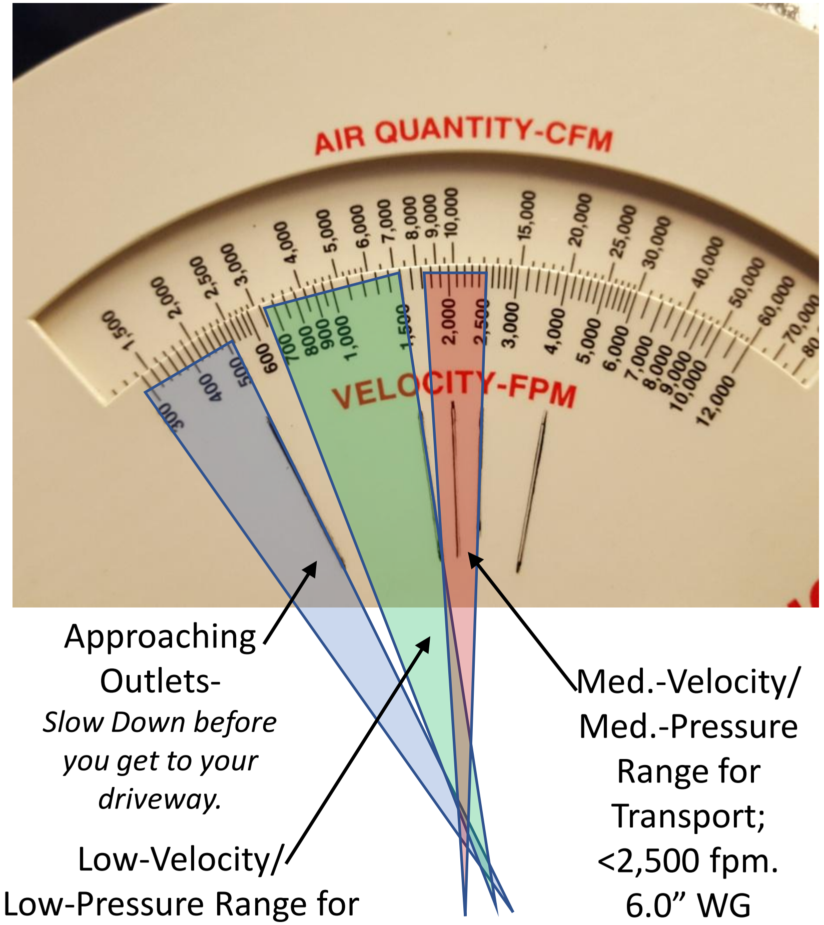
Friction Rate: *Inches W.G. per 100 LF of Straight Duct.*



Low-Velocity/ Low-Pressure Friction Loss Range for Transport; *0.04" to 0.08" per 100 feet.*

Medium-Velocity/ Medium-Pressure Friction Loss Range for Transport; *0.10" to 1.5" per 100 feet.*

Velocity: *Feet Per Minute*



Approaching Outlets- *Slow Down before you get to your driveway.*

Low-Velocity/ Low-Pressure Range for Transport; *<1,500 fpm. 2.0" WG Pressure Class*

Med.-Velocity/ Med.-Pressure Range for Transport; <2,500 fpm. 6.0" WG Pressure Class

Air Velocity in Ducts:

Drives fitting losses:

- *Duct fitting losses are calculated in terms of velocity pressure loss. Duct friction rate is less of a pressure drop factor.*

- *Velocity pressure varies as the square of velocity.*

- *Benchmark: 4,005 fpm = 1.0" velocity pressure (Vp):* $Vp = (\frac{V}{4005})^2$

  - *Vp at 1,500 fpm: (1500/4005)^2 = 0.1403"*
  - *Vp at 2,000 fpm: (2000/4005)^2 = 0.2494"*
  - *Vp at 2,500 fpm: (2500/4005)^2 = 0.3896"*
  - *Vp at 3,000 fpm: (3000/4005)^2 = 0.5610"*

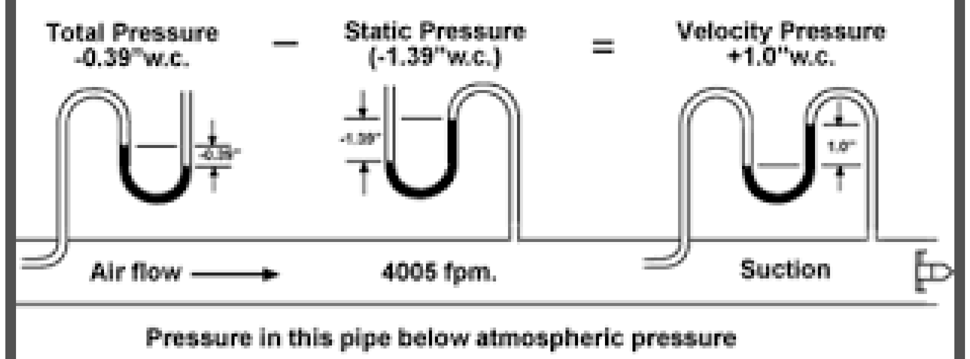


Figure 2.17 - Relationship between total Pressure, Static Pressure, and Velocity Pressure

Duct Fittings have ***"C"-coefficients****, which are multiplied by velocity pressure (Vp) to obtain their pressure drops.* *<u>Velocity Matters.</u>*

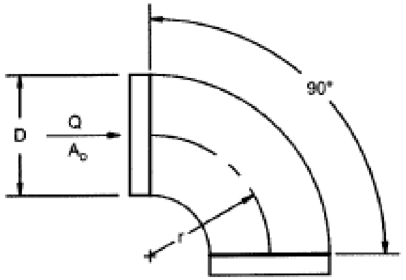
Air Velocity in Ducts:

Drives fitting losses:

ROUND FITTINGS

CD3-1 Elbow, Die Stamped, 90 Degree, $r/D = 1.5$

D, in.	3	4	5	6	7	8	9	10
C_o	0.30	0.21	0.16	0.14	0.12	0.11	0.11	0.11



Example:
6" round elbow at 500 fpm:
C=0.14 x 0.0156 Vp= 0.0022"

Same elbow at 1,500 fpm:
C=0.14" x 0.1403 = 0.0196"

RECTANGULAR FITTINGS

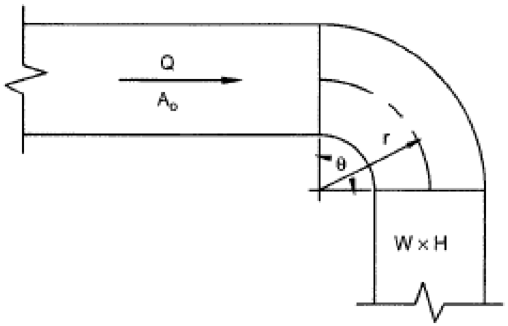
CR3-1 Elbow, Smooth Radius, Without Vanes

	C_p Values										
	H/W										
r/W	0.25	0.50	0.75	1.0	1.50	2.0	3.0	4.0	5.0	6.0	8.0
0.50	1.53	1.38	1.29	1.18	1.06	1.00	1.00	1.06	1.12	1.16	1.18
0.75	0.57	0.52	0.48	0.44	0.40	0.39	0.39	0.40	0.42	0.43	0.44
1.00	0.27	0.25	0.23	0.21	0.19	0.18	0.18	0.19	0.20	0.21	0.21
1.50	0.22	0.20	0.19	0.17	0.15	0.14	0.14	0.15	0.16	0.17	0.17
2.00	0.20	0.18	0.16	0.15	0.14	0.13	0.13	0.14	0.14	0.15	0.15

Angle Factor K

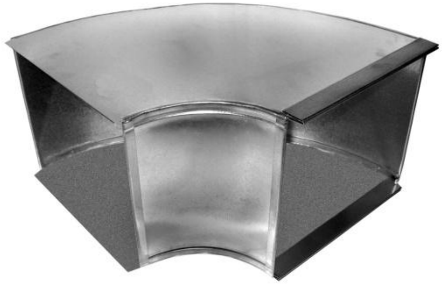
θ	0	20	30	45	60	75	90	110	130	150	180
K	0.0	0.31	0.45	0.60	0.78	0.90	1.00	1.13	1.20	1.28	1.40

$C_o = KC_p$ where K = angle factor



Example:
1.5 centerline radius 90° elbow, 12x12 size, at 1,500 fpm:
C=0.17 x 0.1403 Vp= 0.0238"

Same elbow at 3,000 fpm:
C=0.17 x 0.5610 Vp= 0.0954"



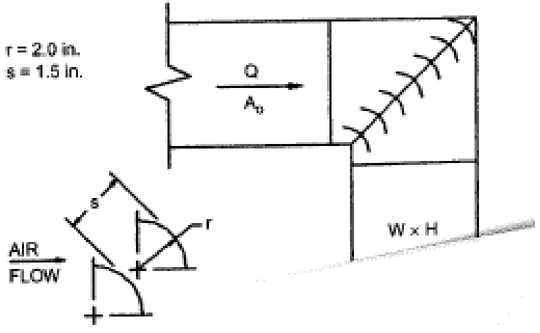
Vp at 500 fpm = 0.0156"
Vp at 1,000 fpm = 0.0623"
Vp at 1,500 fpm = 0.1403"
Vp at 2,000 fpm = 0.2494"
Vp at 3,000 fpm = 0.5610"

Air Velocity in Ducts:

Drives fitting losses: Turning vanes can help sometimes but can also have higher pressure drops.

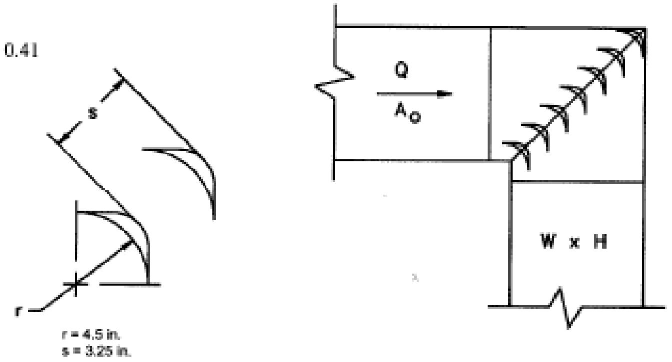
, Single-Thickness Vanes (1.5 in. Vane Spacing)

$C_o = 0.11$



Mitered, 90 Degree, Double-Thickness Vanes (3.25 in. Vane Spacing)

$C_o = 0.41$



<u>*Example:*</u>
Square-mitered elbow with <u>single-thickness</u> vanes closely spaced, at 1500 fpm:
C=0.11 x 0.1403 Vp= 0.0154”

Note: A radius elbow with a 1.5 centerline radius at the same velocity has an air pressure drop of 0.0238”. This type of elbow has a lower pressure drop and saves space but also costs 50% more shop labor to make.

<u>*Example:*</u>
Square-mitered elbow with <u>double-thickness</u> vanes more widely spaced, at 1500 fpm:
C=0.41 x 0.1403 Vp= 0.0575”

Same elbow at 3,000 fpm:
C=0.41 x 0.5610 Vp= 0.2300”

Vp at 500 fpm = 0.0156”
Vp at 1,000 fpm = 0.0623”
Vp at 1,500 fpm = 0.1403”
Vp at 2,000 fpm = 0.2494”
Vp at 3,000 fpm = 0.5610”

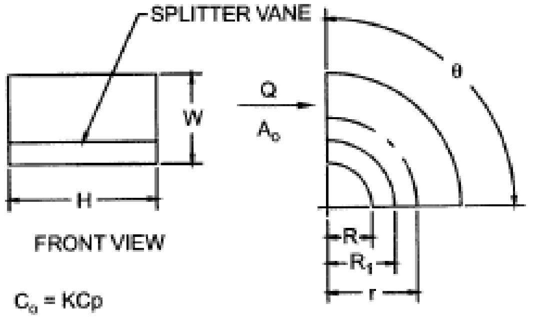
Air Velocity in Ducts:

Drives fitting losses: Radius splitter vanes are a good strategic fitting at critical points.

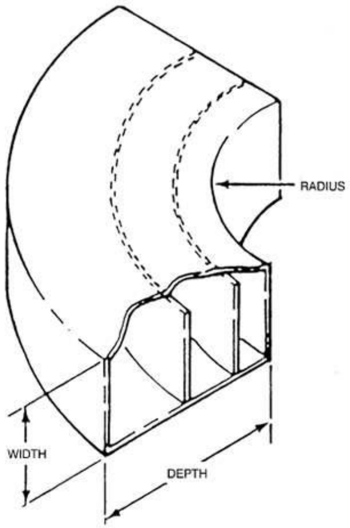
CR3-3 Elbow, Smooth Radius, One Splitter Vane

	C_p Values										
	H/W										
r/W	0.25	0.50	1.0	1.50	2.0	3.0	4.0	5.0	6.0	7.0	8.0
0.55	0.52	0.40	0.43	0.49	0.55	0.66	0.75	0.84	0.93	1.01	1.09
0.60	0.36	0.27	0.25	0.28	0.30	0.35	0.39	0.42	0.46	0.49	0.52
0.65	0.28	0.21	0.18	0.19	0.20	0.22	0.25	0.26	0.28	0.30	0.32
0.70	0.22	0.16	0.14	0.14	0.15	0.16	0.17	0.18	0.19	0.20	0.21
0.75	0.18	0.13	0.11	0.11	0.11	0.12	0.13	0.14	0.14	0.15	0.15
0.80	0.15	0.11	0.09	0.09	0.09	0.09	0.10	0.10	0.11	0.11	0.12
0.85	0.13	0.09	0.08	0.07	0.07	0.08	0.08	0.08	0.08	0.09	0.09
0.90	0.11	0.08	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07
0.95	0.10	0.07	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06
1.00	0.09	0.06	0.05	0.05	0.04	0.04	0.04	0.05	0.05	0.05	0.05

Angle Factor *K*					
θ	0	30	45	60	90
K	0.00	0.45	0.60	0.78	1.00



$C_o = KC_p$
$R_1 = R/CR$
where
R = throat radius
R_1 = splitter vane radius
CR = curve ratio
K = angle factor



Internal proportional-radius splitter vanes divide an elbow up into equivalent larger radius turns. The C-coefficient drops to very low values. Pressure drops can be almost negligible.

These fittings do come at a cost but at AHUs and fans can save significant capacity and reduce system effect penalties.

Example:
Square duct elbow with single splitter vane, at 2000 fpm:
C=0.05 x 0.2494 Vp= 0.0125"

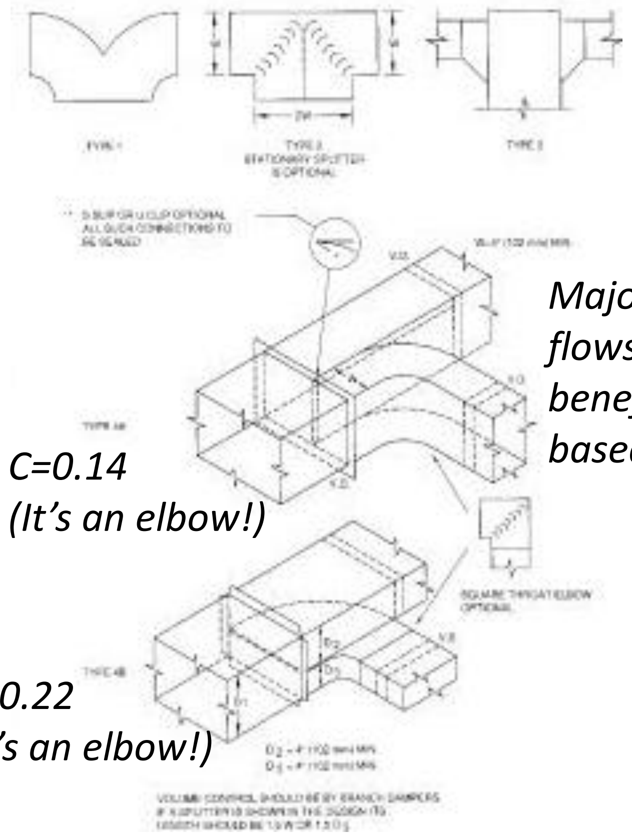
Same elbow without a splitter vane has a C-factor of 0.21
C=0.21 x 0. 2494 Vp= 0.0524"

Vp at 500 fpm = 0.0156"
Vp at 1,000 fpm = 0.0623"
Vp at 1,500 fpm = 0.1403"
Vp at 2,000 fpm = 0.2494"
Vp at 3,000 fpm = 0.5610"

Air Velocity in Ducts: *Branching Off.*

Note the "C" coefficients.

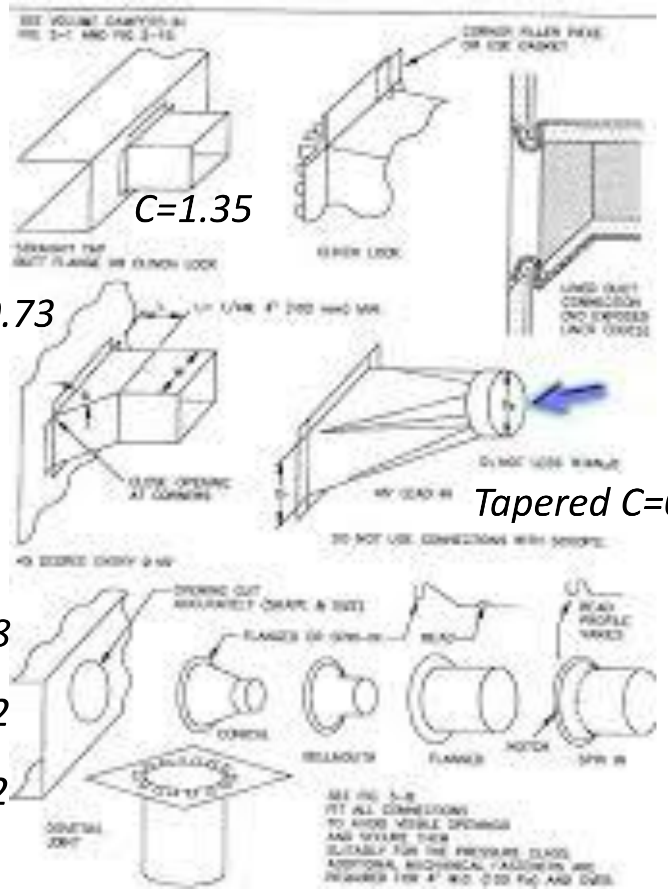
C=0.22 *C=0.11* *C=0.73*



C=0.14
(It's an elbow!)

C=0.22
(It's an elbow!)

Major main-to-branch flows, 25% or greater, benefit from velocity-based take-offs.



C=1.35

C=0.73

Tapered C=0.32

Hard-Tap C=1.58

Conical 30 ° C=0.32

Bellmouth C=0.22

Final branches to air distribution devices will be at lower velocities, so a high "C" coefficient still means a low pressure drop. Do not worry about the end runs.

Vp at 500 fpm = 0.0156"
Vp at 1,000 fpm = 0.0623"
Vp at 1,500 fpm = 0.1403"
Vp at 2,000 fpm = 0.2494"
Vp at 3,000 fpm = 0.5610"

Air Velocity in Components:

Necessary, unavoidable and they add up. Spend wisely:

The International Energy Conservation Code (IECC), places limits on fan system horsepower use relative to airflow.

Within air handling units (AHUs), these are of critical importance with many components in-series. Pressure drop is year-round.

The AHU internal static pressure is often 50-65% of the total system pressure drop. Spend wisely, using as large a cross-sectional area as possible to keep air pressure drops (APDs) as low as practical.

Table 8 Typical Design Velocities for HVAC Components

Duct Element	Face Velocity, fpm
Louvers[a]	
Intake	
7000 cfm and greater	400
Less than 7000 cfm	See Figure 14
Exhaust	
5000 cfm and greater	500
Less than 5000 cfm	See Figure 14
Filters[b]	
Panel filters	
Viscous impingement	200 to 800
Dry-type, extended-surface	
Flat (low efficiency)	Duct velocity
Pleated media (intermediate efficiency)	Up to 750
HEPA	250
Renewable media filters	
Moving-curtain viscous impingement	500
Moving-curtain dry media	200
Electronic air cleaners	
Ionizing type	150 to 350
Heating Coils[c]	
Steam and hot water	500 to 1000 200 min., 1500 max.
Electric	
Open wire	Refer to mfg. data
Finned tubular	Refer to mfg. data
Dehumidifying Coils[d]	400 to 500
Air Washers[e]	
Spray type	Refer to mfg. data
Cell type	Refer to mfg. data
High-velocity spray type	1200 to 1800

[a]Based on assumptions presented in text.
[b]Abstracted from Ch. 28, 2008 *ASHRAE Handbook—HVAC Systems and Equipment*.
[c]Abstracted from Ch. 26, 2008 *ASHRAE Handbook—HVAC Systems and Equipment*.
[d]Abstracted from Ch. 22, 2008 *ASHRAE Handbook—HVAC Systems and Equipment*.
[e]Abstracted from Ch. 40, 2008 *ASHRAE Handbook—HVAC Systems and Equipment*.

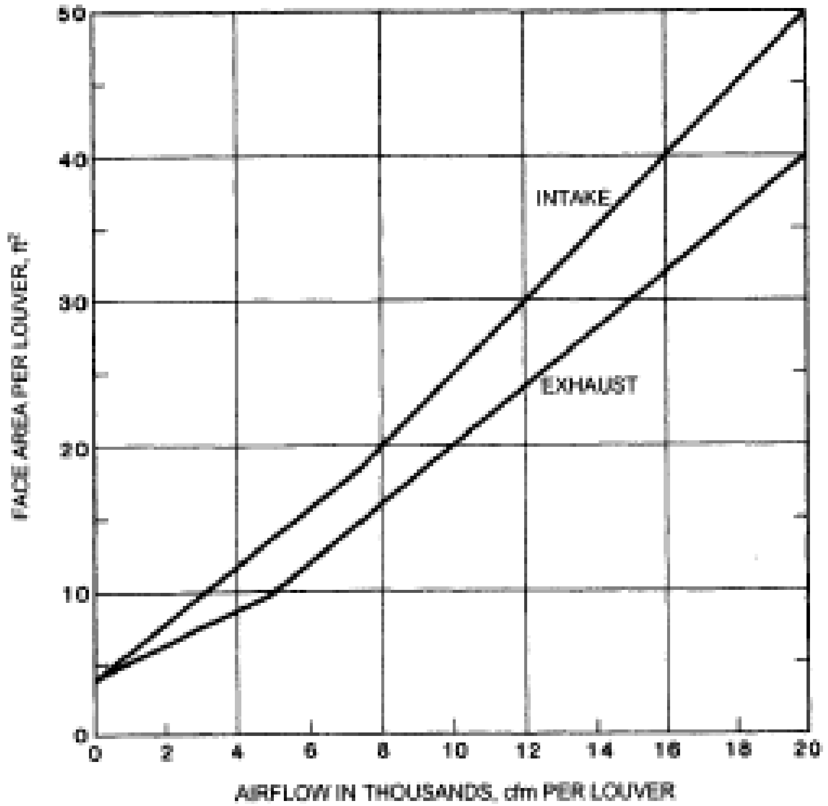
Air Velocity in Components:

Getting air in and out of your building:

Louver sizing for intake of outside air is a balancing act between keeping moisture out, reducing air pressure drop and keeping the architect happy.

Too small a louver can amplify draw-in of mist, light snow and normal rain, in addition to higher air pressure drops.

A solid company standard is essential . *Our client architects should be confident of getting consistent sizing criteria for their projects across the company, founded in appropriate criteria.*



Parameters Used to Establish Figure	Intake Louver	Exhaust Louver
Minimum free area (48 in. square test section), %	45	45
Water penetration, oz/(ft^2·0.25 h)	Negligible (less than 0.01)	N/A
Maximum static pressure drop, in. of water	0.15	0.25

Fig. 14 Criteria for Louver Sizing

Air Velocity in Components:

Getting air in and out of your building

<u>You can also be creative if the architect is on-board.</u>

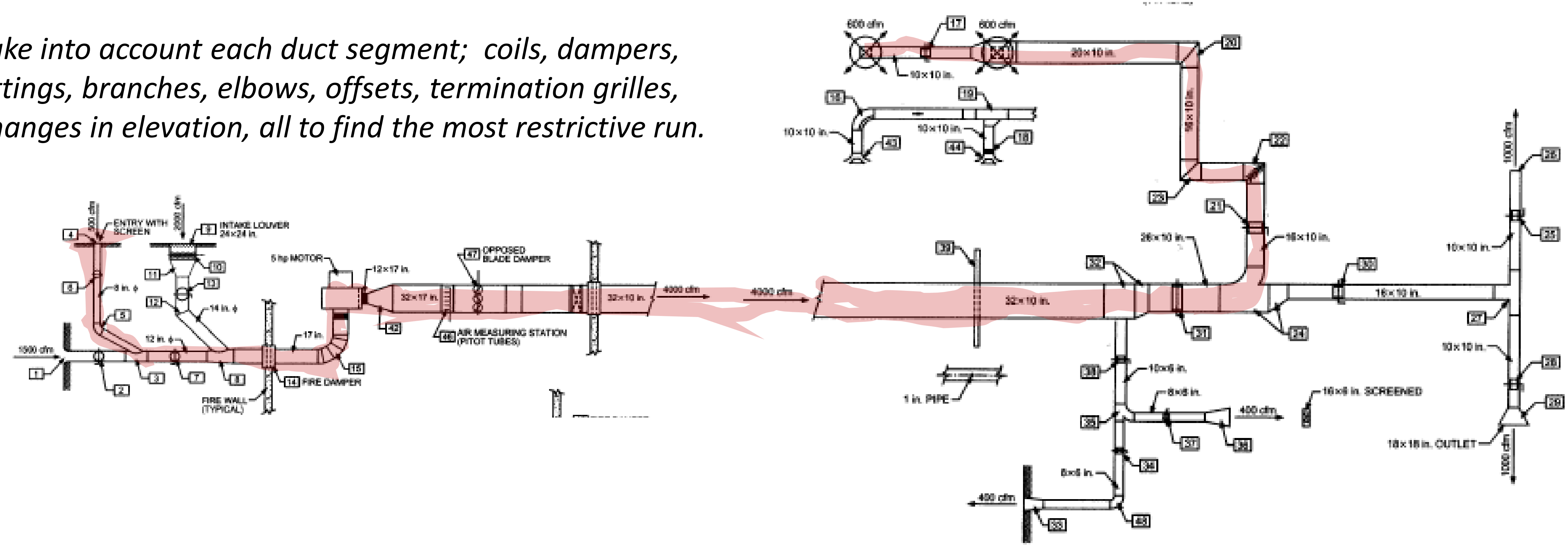
The full openings here were louvers sized in the early 1970's as gross area, not net free area. These were half the size they should have been. In addition, the top half was a spandrel beam, blocking the top half as well. Plenums were chronically wet and rusted out.

These cowls are now a design standard at Terminal B. Intake velocities are under 500 fpm and air pressure drop is negligible. No moisture entrainment either.

Air System Pressure Drops:

Calculated on the longest or most restrictive run, not on all system ductwork.

Take into account each duct segment; coils, dampers, fittings, branches, elbows, offsets, termination grilles, changes in elevation, all to find the most restrictive run.



If in doubt, check your second choice of most restrictive branch. It is not always obvious.

Air System Pressure Drops:

Calculated on the longest or most restrictive run, not on all system ductwork.

AHU-1	Serves:	West Side of Academic Building						CFM at	Design SP
Exhaust									2.87
Fittings	Fitting	Section	Duct			Coeff.			
Quan.	Description	CFM	H	W	Vp	"C"	SP Ea.	SubT	Total SP
1	Louver/Plenum	44000	126	144	0.01	1.0	0.007603	0.007603	
1	OAD Econo.	44000	126	42	0.09	0.52	0.046472	0.046472	
4	Elbow	43570	42	86	0.19	0.18	0.033859	0.135435	
2	Takeoff	43570	42	86	0.19	0.1	0.01881	0.037621	
1	Transition	34085	42	68	0.18	0.01	0.001841	0.001841	
3	Takeoff	34085	42	68	0.18	0.11	0.020255	0.060764	
1	Transition	25120	36	60	0.17	0.02	0.003497	0.003497	
1	Takeoff	21975	36	60	0.13	0.05	0.00669	0.006690	
1	Takeoff	18060	36	60	0.09	0.02	0.001807	0.001807	
1	Transition	18060	40	44	0.14	0.01	0.001361	0.001361	
1	Takeoff	15605	40	44	0.10	0.6	0.060978	0.060978	
1	Takeoff	10675	40	44	0.05	0.6	0.028535	0.028535	
1	Transition	10675	28	36	0.14	0.14	0.020298	0.020298	
1	Takeoff	5340	20	35	0.08	0.48	0.036112	0.036112	
1	Transition	5340	12	46	0.12	0.01	0.00121	0.001210	
2	Elbow	5340	12	46	0.12	0.06	0.007259	0.014518	
2	Takeoff	5340	12	46	0.12	0.50	0.060491	0.120983	
1	Transition	4440	12	46	0.08	0.01	0.000836	0.000836	
2	Takeoff	4440	10	52	0.09	0.03	0.002827	0.0056550	
1	Transition	4090	10	48	0.09	0.01	0.000939	0.000939	
1	Takeoff	4090	10	48	0.09	0.29	0.02722	0.027220	
1	Takeoff	2975	10	44	0.06	0.23	0.013593	0.013593	
1	Elbow	2310	10	32	0.07	0.18	0.012126	0.012126	
4	Elbow	2310	10	32	0.07	0.20	0.013473	0.053893	
1	Takeoff	2310	10	32	0.07	0.85	0.057262	0.057262	
1	Transition	1370	10	32	0.02	0.03	0.000711	0.000711	
1	Elbow	1370	10	22	0.05	0.07	0.003509	0.003509	
2	Elbow	1370	10	22	0.05	0.06	0.003008	0.006016	
1	Takeoff	1370	10	22	0.05	0.48	0.024063	0.024063	
3	Elbow	685	10	16	0.02	0.26	0.006161	0.018482	
SubT									0.81

(Continued, above right.)

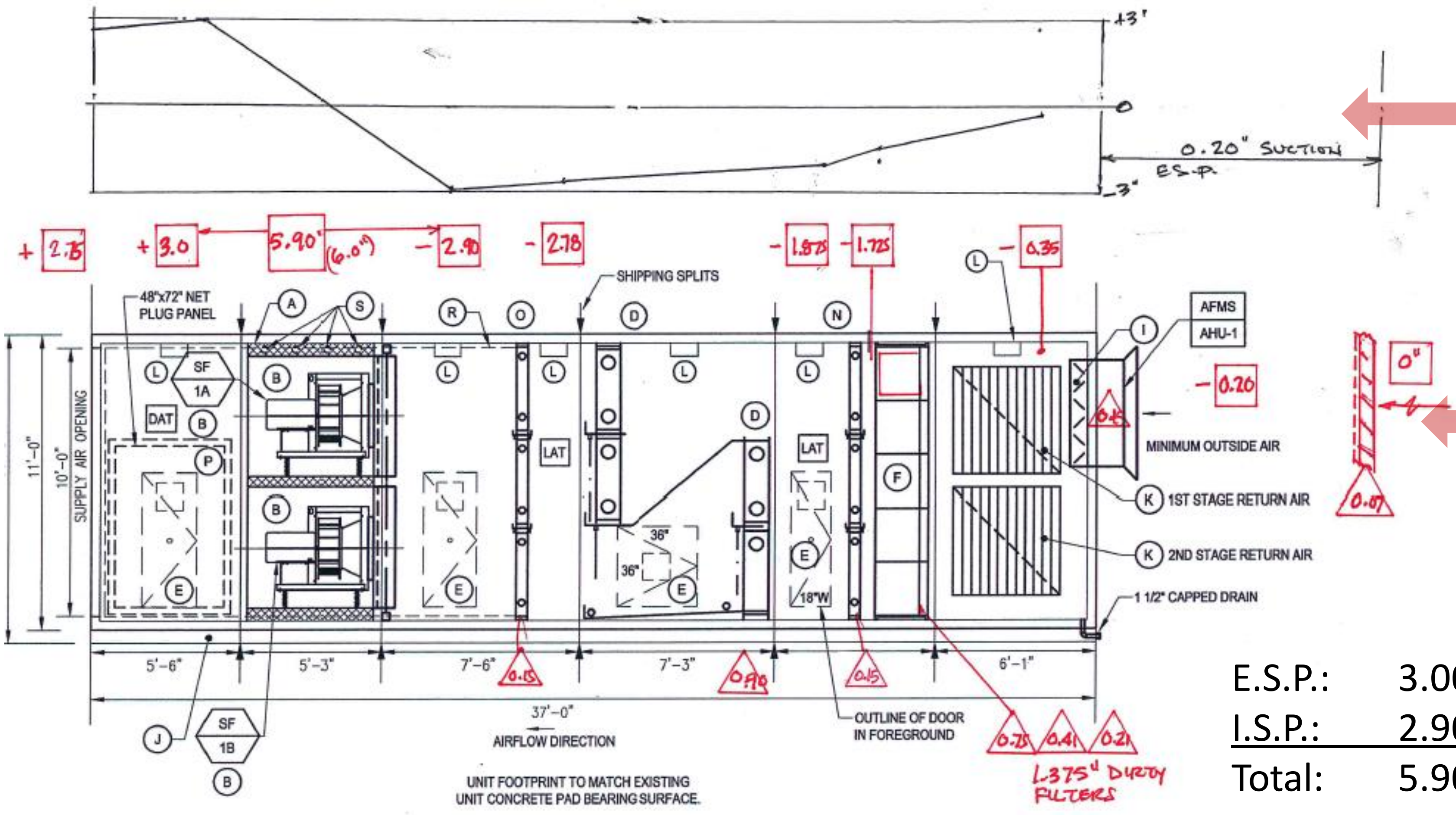
Equipm't	Equipm't						PD/Sect.		
Quan.	Description	CFM	H	W	Vp	"C"	SP Ea.	SubT	Total SP
1	FD	5340	12	46	0.12	0.325	0.039319	0.04	
1	FD	43570	42	86	0.19	0.368	0.069223	0.07	
3	Vol.D/S.D.	43570	36	100	0.19	0.52	0.098468	0.30	
1	S.A.-D1.2	43570	36	100	0.20	1	0.2	0.2	
1	Induction Box	685	10	15	0.03	1	0.02696	1	
1	Intake Vp/Sp	17200	36	48	0.13	-	0.2	0.20	
SubT									1.80
DUCT	SP/100'						PD/Sect.		
Length	Friction							SubT	
13	0.09						0.0117		0.01
13	0.13						0.0169		0.02
13	0.1						0.013		0.01
13	0.11						0.0143		0.01
13	0.12						0.0156		0.02
9	0.17						0.0153		0.02
20	0.18						0.036		0.04
6	0.19						0.0114		0.01
24	0.11						0.0264		0.03
32	0.17						0.0544		0.05
24	0.13						0.0312		0.03
14	0.07						0.0098		0.01
194								0.26	
									Des. SP
TOTALS									2.87
								Schedule@	3.00

Observations:

1. The highest system pressure drop tends to be in 100% OA economizer mode, because the supply fan has to draw all air through louvers, dampers, AFMS, without assistance from the return fan.
2. These are EXTERNAL static pressure (ESP) values and do not count “internal” AHU components, coils, filters, sound attenuators and casing losses.
3. Note the sum of duct friction vs. that of fittings and devices, less than 10% of total in this case, 10-15% typically and incidentally. Thus, fittings and devices truly define system pressure drop.

Air System Pressure Drops:

Internal Static Pressure, sum of worst-case, in-series devices within the AHU.
To this is added the External Static Pressure losses, some of which are on the inlet side of the AHU.



S.P. Gradient Graph

S.P. Profile.
Useful for TAB process!

E.S.P.:	3.00”
I.S.P.:	2.90”
Total:	5.90”- schedule at 6.0”

44,000 cfm/4 fans = 11,000 cfm each at 6.0” s.p.

Fan Selection:

"Bracket" your fan selections to demonstrate that the fan you chose is the most appropriate.
Criteria are: Meet the duty, have the lowest brake horsepower, highest efficiency and demonstrate stable operation with system changes.
A "sensitivity analysis", to examine "what-ifs" is always a good exercise.

Duty: 44,000 cfm/4 fans = 11,000 cfm each at 6.0" s.p.

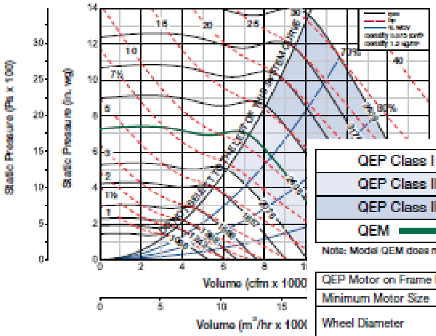
20"

QEP Class I	Maximum rpm 2075
QEP Class II	Maximum rpm 2706
QEP Class III	Maximum rpm 3409
QEM	Maximum rpm 2435

Note: Model QEM does not utilize class designations.

QEP Motor on Frame Limit	254T
Minimum Motor Size	1/3 [hp]
Wheel Diameter	20.00 [in.] 508 [mm]
Peak Power	(rpm / 1086)³ [hp] (rpm / 1198)³ [kW]
Wheel Outlet Velocity	cfm / 3.05 [ft/min] m³/s / 1.80 [m/s]
Tip Speed	rpm x 5.24 [ft/min] rpm x 0.0266 [m/s]
% Wide Open Volume (%WOV)	cfm / (rpm x 0.0488) [%] m³/hr / (rpm x 0.0830) [%]

Imperial data — Metric data



CFM	OV	STATIC PRESSURE (in. wg) 1		2		3		4		5		6		7		8
		RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM
6000	1967	1428	1.86	1602	2.96	1759	4.11	1908	5.37							
6500	2131	1517	2.16	1682	3.34	1832	4.57	1970	5.85	2108	7.27					
7000	2295	1609	2.51	1763	3.77	1907	5.06	2041	6.41	2168	7.84	2295	9.40			
7500	2459	1703	2.90	1847	4.23	1986	5.60	2114	7.02	2236	8.50	2355	10.1	2472	11.8	
8000	2622	1797	3.34	1934	4.73	2066	6.19	2190	7.69	2308	9.22	2418	10.8	2531	12.5	2640
8500	2786	1892	3.83	2022	5.27	2147	6.83	2268	8.39	2381	10.0	2490	11.7	2592	13.4	2700
9000	2950	1988	4.37	2111	5.87	2230	7.51	2347	9.15	2457	10.8	2562	12.6	2663	14.3	2759
9500	3114	2085	4.96	2202	6.52	2317	8.23	2428	9.97	2535	11.7	2637	13.5	2736	15.4	2830
10000	3278	2182	5.62	2295	7.24	2404	9.00	2509	10.9	2614	12.7	2713	14.5	2809	16.4	2902
10500	3442	2279	6.33	2388	8.03	2493	9.84	2594	11.8	2695	13.7	2792	15.6	2884	17.6	2975
11000	3606	2377	7.11	2482	8.88	2582	10.7	2681	12.7	2776	14.8	2871	16.8	2962	18.8	3049
11500	3770	2475	7.93	2577	9.79	2672	11.7	2768	13.8	2859	15.9	2952	18.0	3041	20.1	3126

20" Fan: 2871 RPM, 16.8 BHP

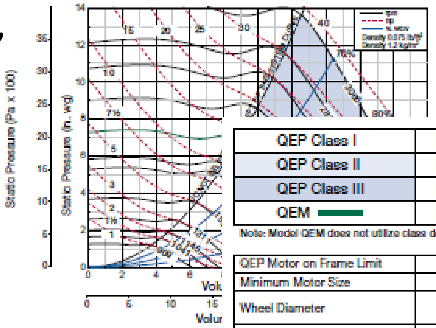
22"

QEP Class I	Maximum rpm 1865
QEP Class II	Maximum rpm 2433
QEP Class III	Maximum rpm 3065
QEM	Maximum rpm 2190

Note: Model QEM does not utilize class designations.

QEP Motor on Frame Limit	254T
Minimum Motor Size	1/2 [hp]
Wheel Diameter	22.25 [in.] 565 [mm]
Peak Power	(rpm / 909)³ [hp] (rpm / 1002)³ [kW]
Wheel Outlet Velocity	cfm / 3.77 [ft/min] m³/s / 2.22 [m/s]
Tip Speed	rpm x 5.83 [ft/min] rpm x 0.0296 [m/s]
% Wide Open Volume (%WOV)	cfm / (rpm x 0.0672) [%] m³/hr / (rpm x 0.114) [%]

Imperial data — Metric data



CFM	OV	STATIC PRESSURE (in. wg) 1		2		3		4		5		6		
		RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM
7000	1856	1229	2.07	1392	3.36	1537	4.73	1678	6.27					
7800	2068	1332	2.52	1483	3.94	1620	5.42	1747	6.99	1874	8.73			
8600	2281	1438	3.06	1577	4.61	1707	6.20	1828	7.86	1943	9.63	2058	11.6	
9400	2493	1547	3.69	1675	5.35	1799	7.07	1913	8.84	2022	10.7	2127	12.6	2232
10200	2705	1657	4.42	1777	6.17	1892	8.03	2002	9.92	2106	11.9	2205	13.9	2301
11000	2917	1768	5.25	1880	7.09	1988	9.11	2094	11.1	2193	13.2	2288	15.3	2379
11800	3129	1880	6.19	1985	8.13	2088	10.3	2187	12.4	2284	14.6	2375	16.8	2463
12600	3342	1993	7.26	2093	9.30	2190	11.5	2282	13.8	2376	16.1	2464	18.5	2550
13400	3554	2106	8.46	2202	10.6	2293	12.9	2383	15.3	2470	17.8	2556	20.2	2638
14200	3766	2220	9.76	2312	12.1	2397	14.4	2484	17.0	2566	19.6	2649	22.2	2729
15000	3978	2334	11.2	2423	13.6	2505	16.1	2586	18.7	2666	21.5	2744	24.2	2822
15800	4190	2448	12.7	2534	15.4	2613	18.0	2690	20.7	2767	23.5	2841	26.4	2916

22" Fan: 2288 RPM, 15.3 BHP

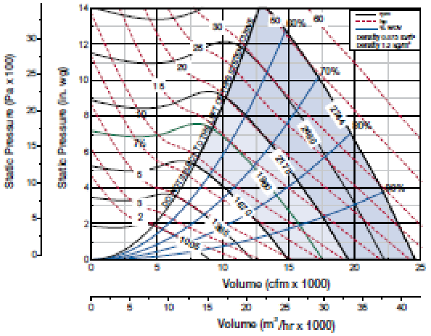
24"

QEP Class I	Maximum rpm 1670
QEP Class II	Maximum rpm 2178
QEP Class III	Maximum rpm 2744
QEM	Maximum rpm 1960

Note: Model QEM does not utilize class designations.

QEP Motor on Frame Limit	256T
Minimum Motor Size	3/4 [hp]
Wheel Diameter	24.50 [in.] 622 [mm]
Peak Power	(rpm / 798)³ [hp] (rpm / 880)³ [kW]
Wheel Outlet Velocity	cfm / 4.58 [ft/min] m³/s / 2.69 [m/s]
Tip Speed	rpm x 6.41 [ft/min] rpm x 0.0326 [m/s]
% Wide Open Volume (%WOV)	cfm / (rpm x 0.0896) [%] m³/hr / (rpm x 0.152) [%]

Imperial data — Metric data



CFM	OV	STATIC PRESSURE (in. wg) 1		2		3		4		5		6		7		8		9	
		RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP
8000	1750	1087	2.08	1245	3.59	1389	5.22	1520	6.88	1644	8.62								
9000	1969	1180	2.54	1329	4.18	1463	5.98	1587	7.81	1703	9.68	1815	11.6						
10000	2188	1275	3.07	1418	4.86	1541	6.77	1659	8.82	1770	10.8	1873	12.9	1976	15.1	2073	17.3		
11000	2407	1373	3.69	1509	5.64	1625	7.66	1737	9.82	1841	12.1	1942	14.3	2036	16.6	2131	18.9	2221	21.3
12000	2625	1474	4.41	1601	6.49	1714	8.66	1817	10.9	1918	13.3	2013	15.8	2106	18.2	2193	20.7	2280	23.2
13000	2844	1577	5.23	1695	7.44	1805	9.78	1903	12.2	1997	14.7	2090	17.3	2178	20.0	2264	22.6	2345	25.3
14000	3063	1681	6.17	1790	8.51	1896	11.0	1992	13.5	2081	16.2	2169	18.9	2255	21.8	2336	24.7	2416	27.5
15000	3282	1785	7.23	1886	9.71	1989	12.3	2083	15.0	2169	17.8	2250	20.6	2333	23.6	2413	26.6	2489	29.8
16000	3501	1890	8.42	1986	11.0	2083	13.8	2174	16.7	2259	19.6	2338	22.5	2414	25.6	2491	28.7	2566	32.0
17000	3719	1996	9.74	2088	12.5	2178	15.4	2267	18.4	2349	21.5	2427	24.6	2500	27.7	2572	31.0	2645	34.4
18000	3938	2103	11.2	2191	14.1	2274	17.1	2360	20.3	2441	23.5	2517	26.8	2589	30.1	2658	33.4	2726	36.9
19000	4157	2210	12.8	2294	15.9	2372	19.1	2455	22.3	2534	25.7	2608	29.2	2679	32.6				

24" Fan: 1942 RPM, 14.3 BHP

Fan Selection:

"Bracket" your fan selections to demonstrate that the fan you chose is the most appropriate.
Criteria are: Meet the duty, have the lowest brake horsepower, highest efficiency and demonstrate stable operation with system changes.

A "sensitivity analysis", to examine "what-ifs" is always a good exercise.

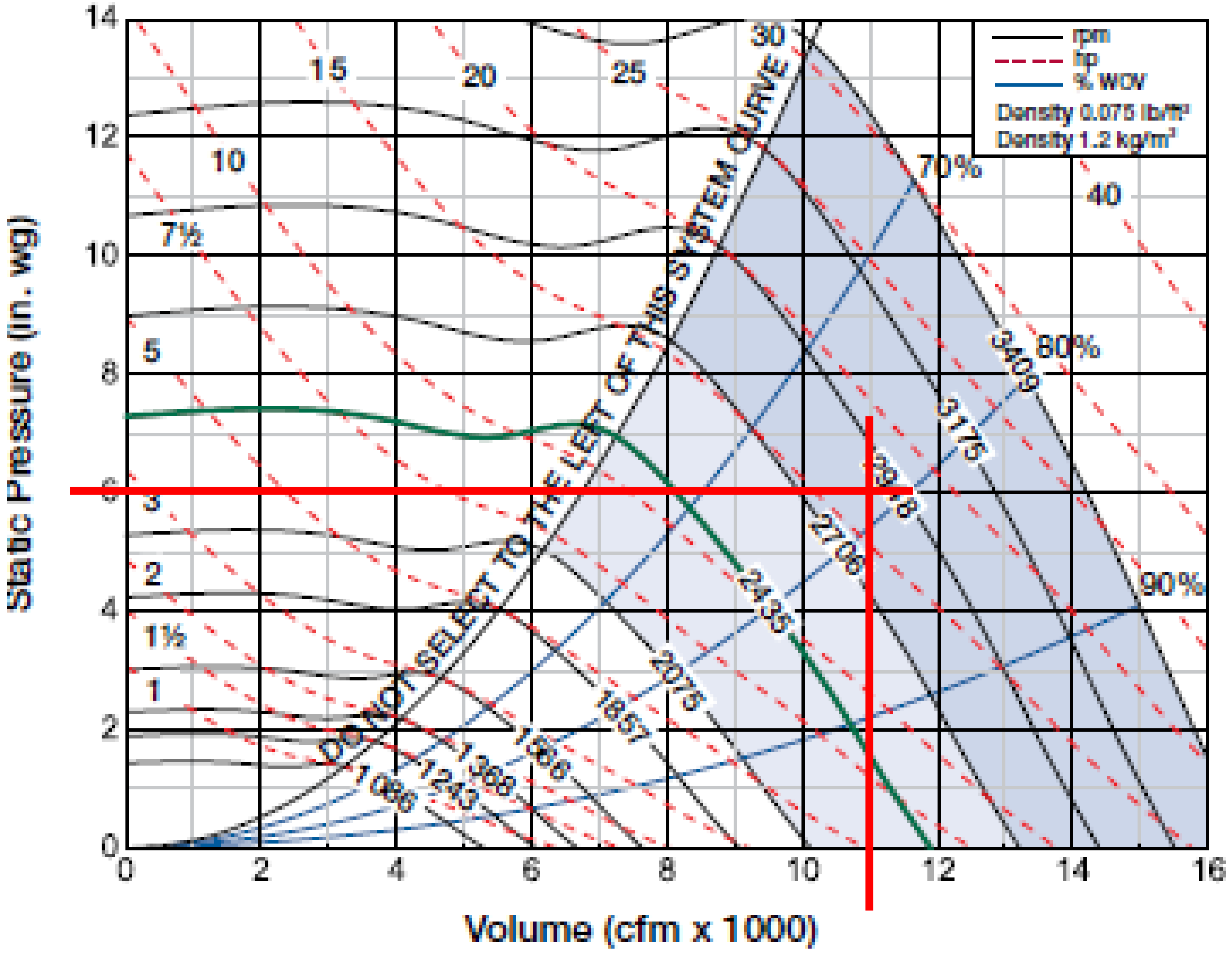
Duty: 44,000 cfm/4 fans = 11,000 cfm each at 6.0" s.p.

20" Fan: 2871 RPM, 16.8 BHP

QEP Class I	Maximum rpm 2075
QEP Class II	Maximum rpm 2706
QEP Class III	Maximum rpm 3409

RPM puts this into Class III.
Brake HP is higher than other fan selections.
A 20 HP motor will be required.

Efficiency: 61.8%



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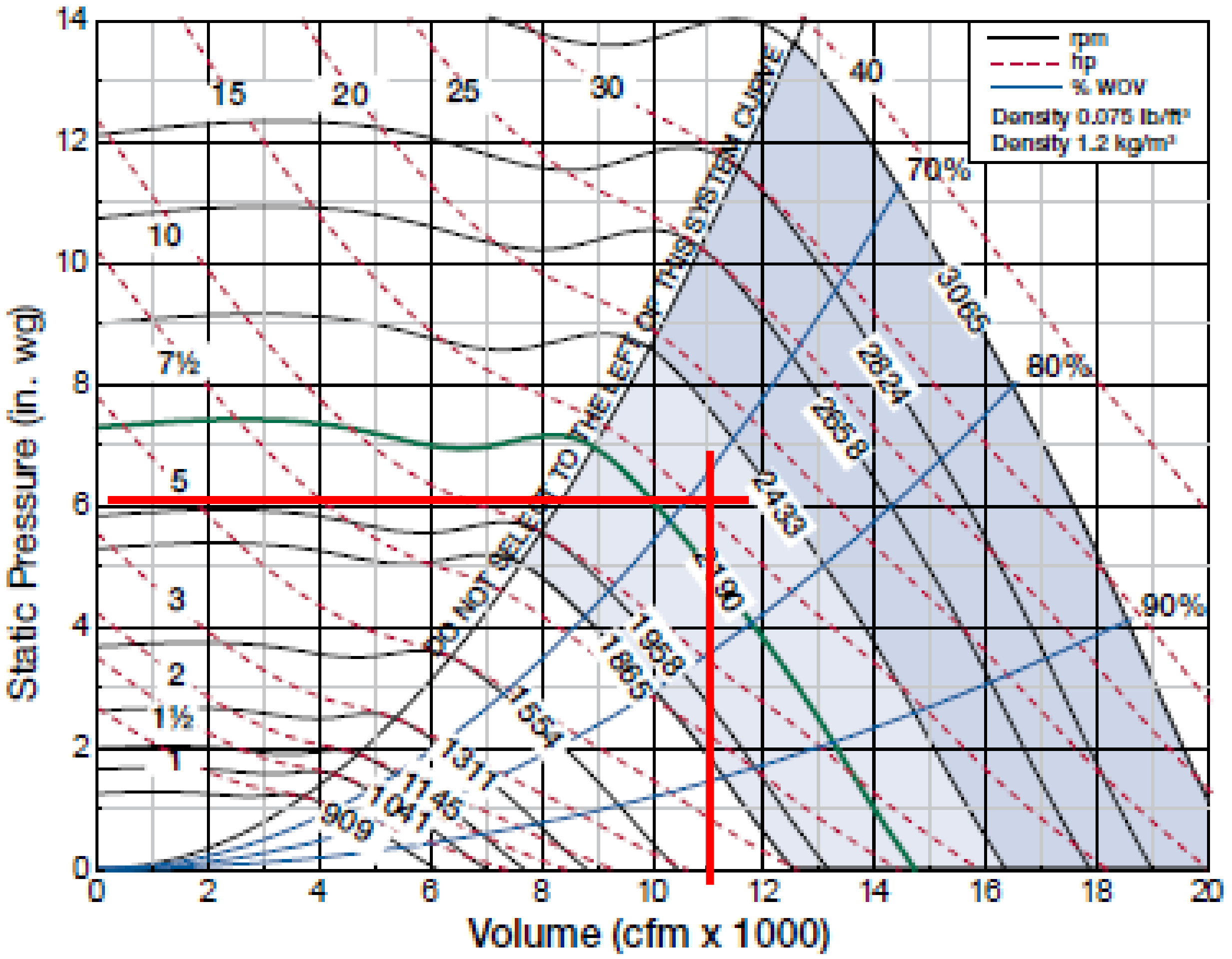
Duty: 44,000 cfm/4 fans = 11,000 cfm each at 6.0" s.p.

22" Fan: 2288 RPM, 15.3 BHP

QEP Class I	Maximum rpm 1865
QEP Class II	Maximum rpm 2433
QEP Class III	Maximum rpm 3065

RPM puts this into Class II.
Brake HP is 1 bhp higher than the next larger selection (24").
A 20 HP motor will be required.

Efficiency: 67.9%



Fan Selection:

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Criteria are: Meet the duty, have the lowest brake horsepower, demonstrate stable operation with system changes.

A "sensitivity analysis", to examine "what-ifs" is always a good exercise.

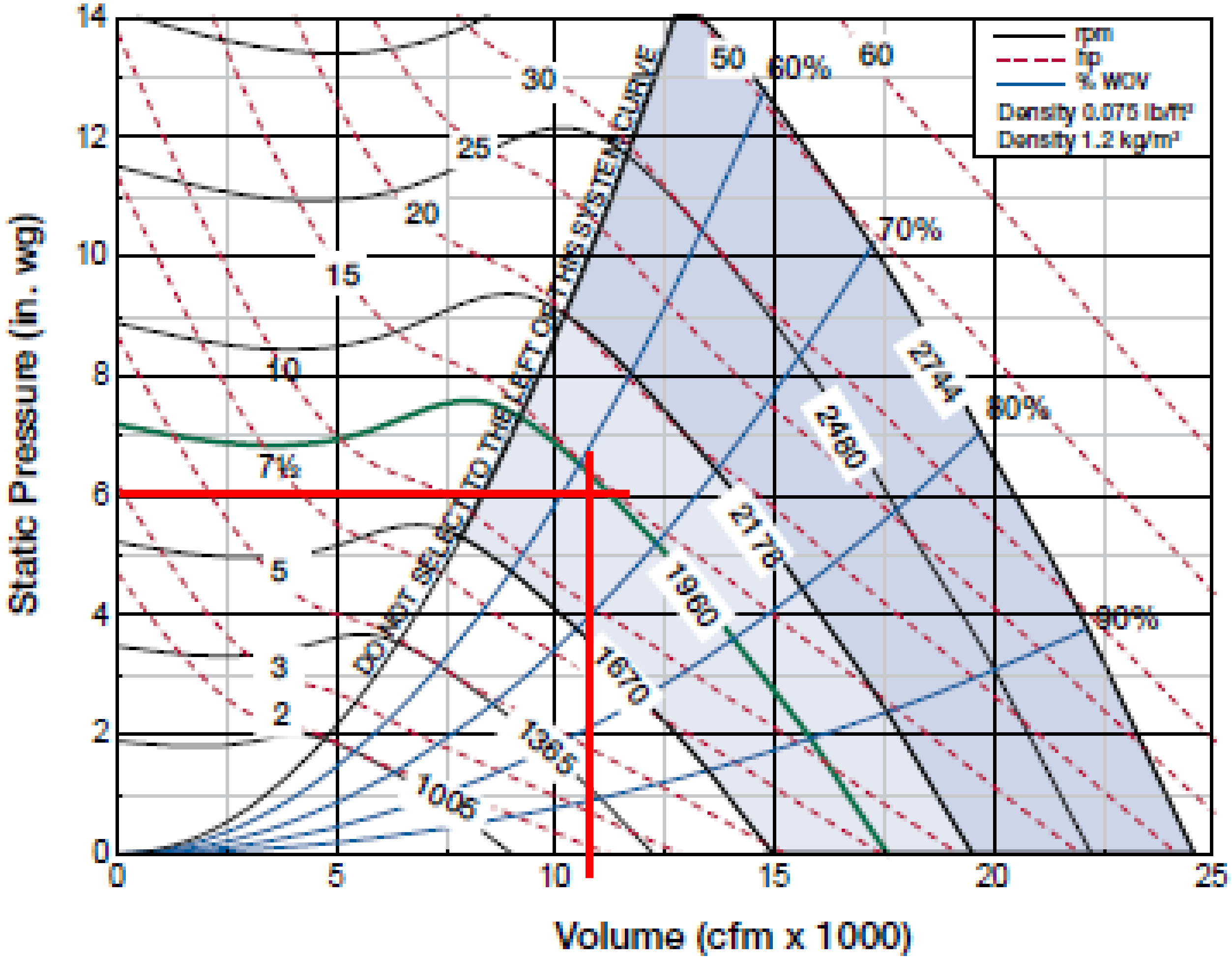
Duty: 44,000 cfm/4 fans = 11,000 cfm each at 6.0" s.p.

24" Fan: 1942 RPM, 14.3 BHP

QEP Class I	Maximum rpm 1670
QEP Class II	Maximum rpm 2178
QEP Class III	Maximum rpm 2744

RPM puts this into Class I.
Brake HP is 1 bhp lower than the next smaller selection (22").
A 20 HP motor will still be required.

Efficiency: 72.6%



Fan Selection- This was the winner:

But not just because of lowest brake horsepower. The system turn-down was limited by a minimum static pressure at the terminal boxes, of 0.75" and total pressure of 1.0".
The more aggressive curve held more closely to unit performance.
Maximum turndown was limited to about 2" of 6" total and 60% of airflow. Fans operated at less than 3 bhp at this forced low-load.
Operationally, system ran at 90% airflow on average; tightly sized to load including ventilation. Net operating bhp per fan was 10.4.

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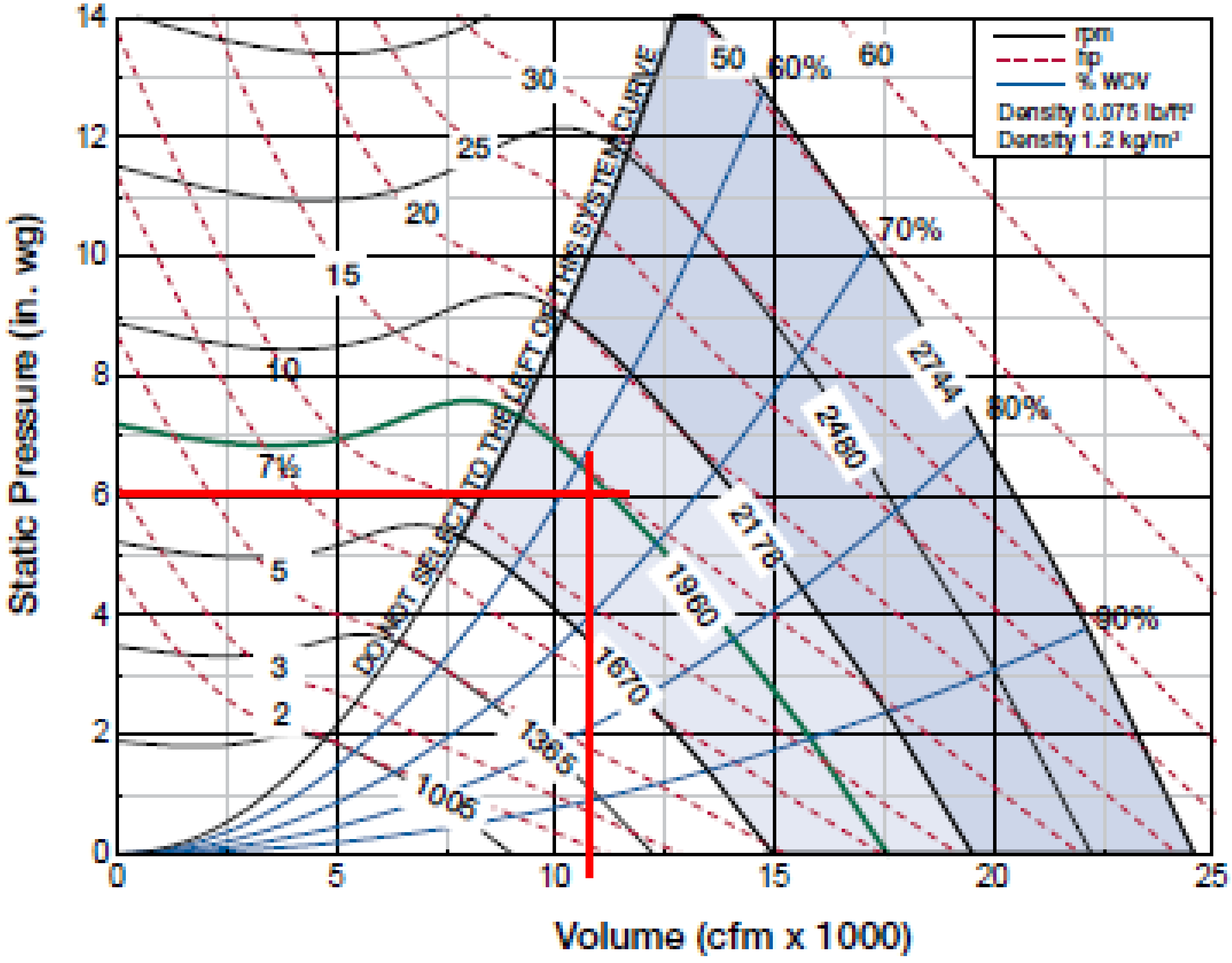


Sound Attenuation:

There are several means to reduce air-borne and duct-borne sound in an HVAC system.
Start with dampening vibration transmission.

<u>Isolate Noise and Vibration At the Source.</u>

Packaged units should be specified with internal vibration isolation and flexible connectors at fans.

Insulated flexible connectors are available. Use them on cooling systems.

Use flexible connector assemblies at building expansion joints.

Be careful using flexible connectors too close to a fan inlet. They can get "sucked-in" and affect fan performance. Instead, install a straight duct section of at least 1.5 diameters between fan and flexible connector.

<u>Do not use vibration isolators in-series</u>. Use one set.

Sound Attenuation:

There are several means to reduce air-borne and duct-borne sound in an HVAC system.

Sound Attenuators
AKA "~~Silencers~~"

Excellent for targeted noise reduction at source, for specific frequencies and for acoustically sensitive spaces.

When leaving a mechanical room, acoustic sealing is essential. Detailing at fire/smoke dampers for access doors can be a challenge.

Use near noise sources for greatest effectiveness. AHUs, fans; within mechanical rooms.

-Longer units are more effective, especially for lower frequencies. 3-foot nominal lengths are a minimum.

"Break-out noise" can be of concern especially at mechanical room walls. Mass lagging or double-wall duct is recommended.

"Packless" (fill-free) types are available for fiber-sensitive applications such as hospitals.

These can add appreciable pressure drop to a system. Higher sound attenuation characteristics often have higher air pressure drops.

Lower pressure drop attenuators may not be as effective in lower frequencies which are the most difficult to attenuate.

Sound Attenuation:

There are several means to reduce air-borne and duct-borne sound in an HVAC system.

Duct Liner

Excellent for high-frequency noise reduction. Not as effective on low-frequency sound.

Relatively low-cost; may be automated at sheet metal shop.

Difficult to clean lined ducts; may be shredded by the process.

1-Inch thick is a commonly available application, but unless at least 1.5-inch thickness is used, *it alone will not meet the energy code for R-Value.*

Full-adhesive coverage and mechanical weld-pin fasteners must be specified.

Leading-edge nosing recommended at velocities >1500 fpm.

Not allowed in health care facilities. Is less and less favored in general for the same reasons, fibers in airstream for example.

Best application is in low-velocity transfer ducts between rooms, in combination with dead-end, non-vaned elbows.

Sound Attenuation:

There are several means to reduce air-borne and duct-borne sound in an HVAC system.

“Double-Wall Ductwork”

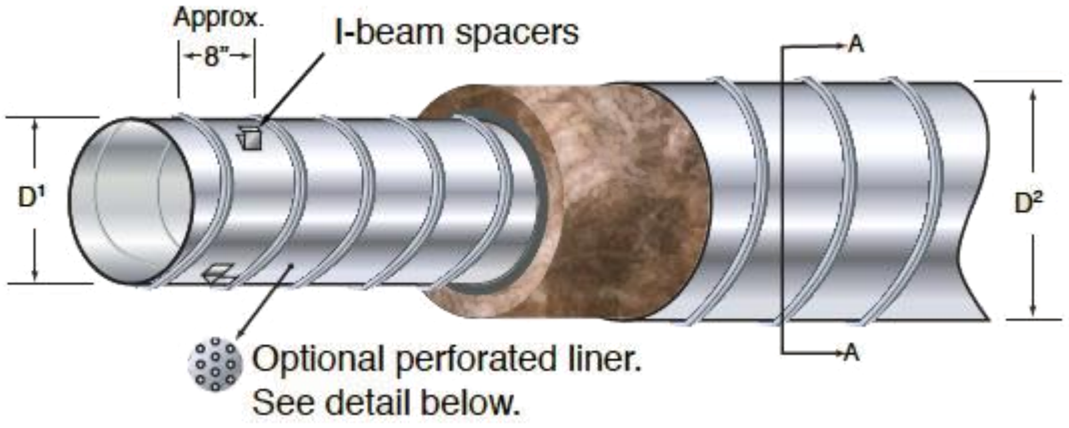
Most of the advantages of lined ductwork but sheet metal liner protects the fiberous liner from erosion.

Solid or perforated inner walls available.

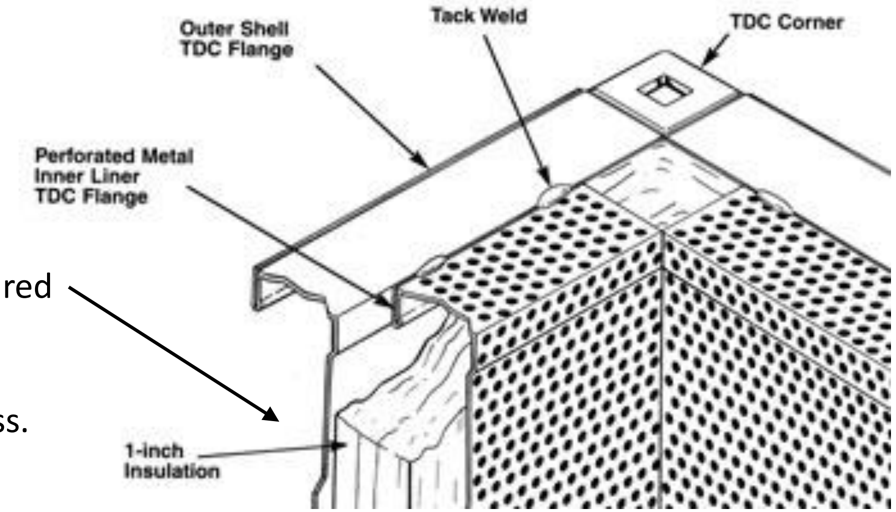
Good compromise between bona-fide attenuators and regular lined ductwork.

Allows exposed architectural ducts without unsightly external foil wrapped insulation. Paintable.

Can be shop or factory-made. Adds approximately 75% to the cost of the bare duct. Use judiciously at AHU sources and where leaving a mechanical room.

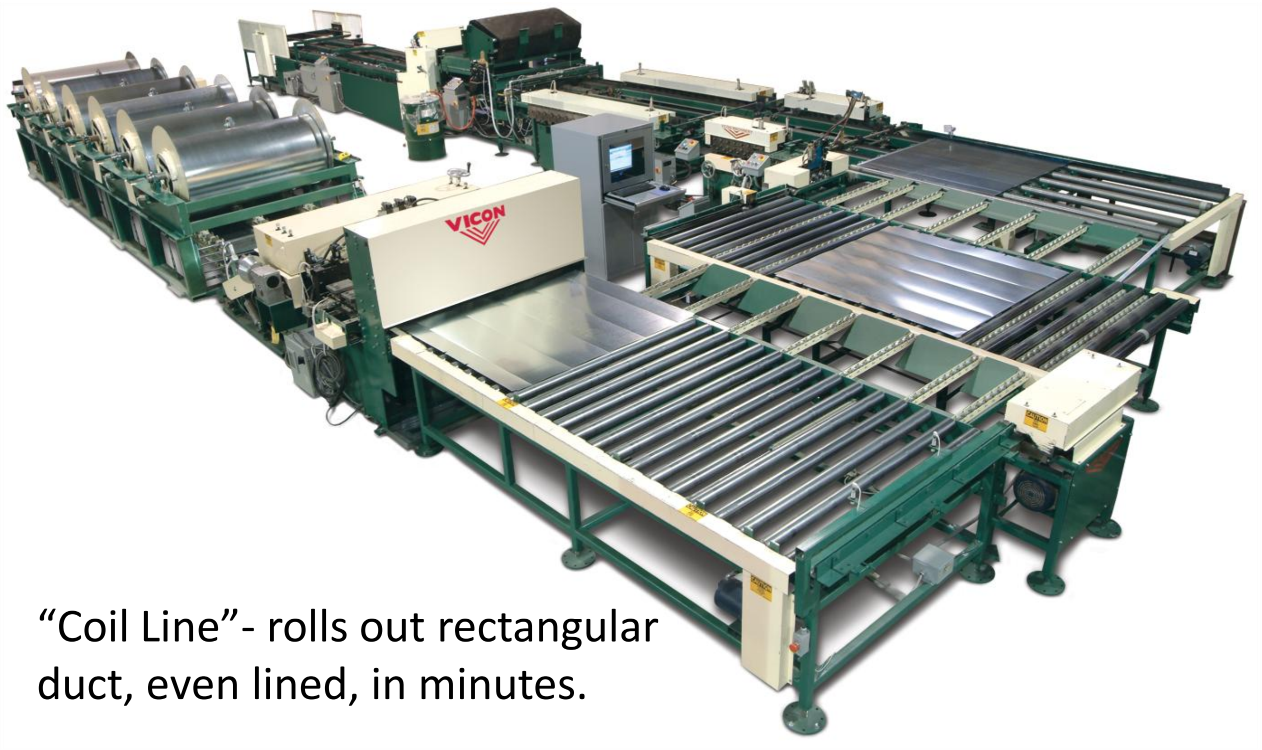


Minimum 1.5” required for energy code. Otherwise must be wrapped to thickness.



Sheet Metal Duct Fabrication:

Straight duct is mostly automated but still with some hand-labor. Fittings are semi-automated for cutting but require significant hand labor at the shop.



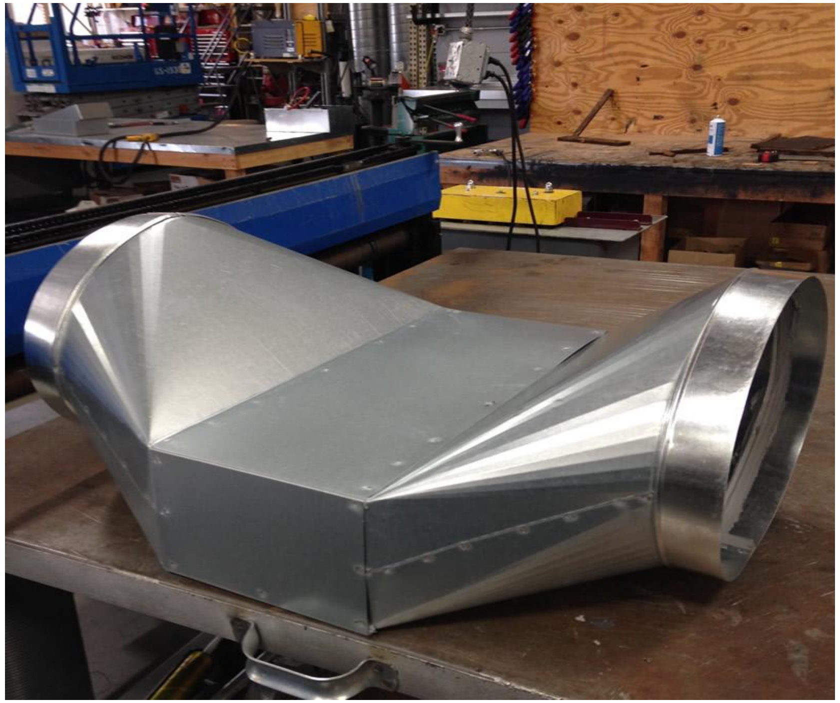
"Coil Line"- rolls out rectangular duct, even lined, in minutes.

Round duct and its child, "flat oval" are made on a spool coil machine.

Sheet Metal Duct Fabrication:

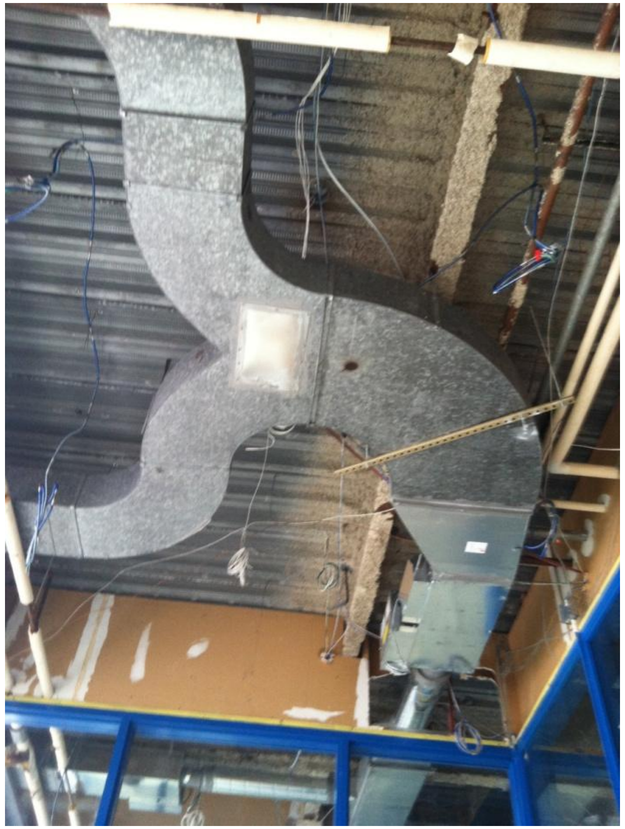
Straight duct is mostly automated but still with some hand-labor. Fittings are semi-automated for cutting but Have significant hand labor at the shop.

Fitting hand-labor. Tack-welding a transition.



Slip-fit 2-piece transition/offset

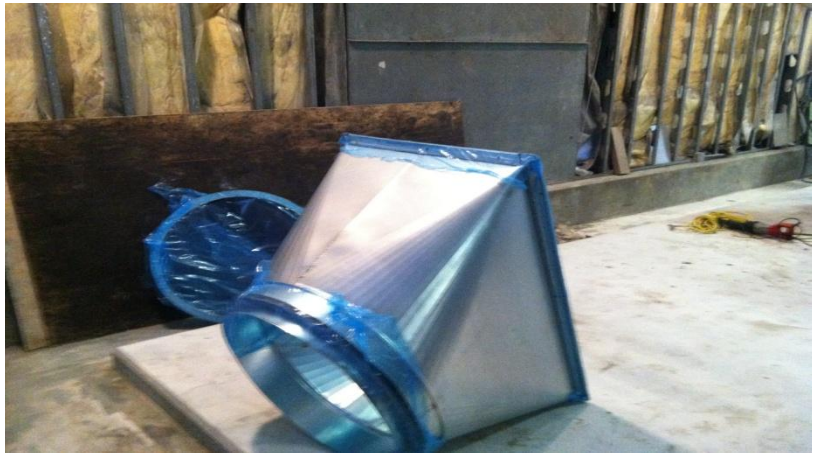
Sheet Metal Duct Field Installation:



Graceful ductwork from 1977, with new terminal induction box.

Graceful offset ductwork, 2013

Build-Clean/Install Clean: Specify plastic wrap on ends of all ducts from shop to site.



Sheet Metal Duct Field Installation:

Heat Recovery AHU. Note in-duct coils and access doors for fire dampers and coil cleaning.

AHU Discharge, 56,000 CFM with Turning Vanes

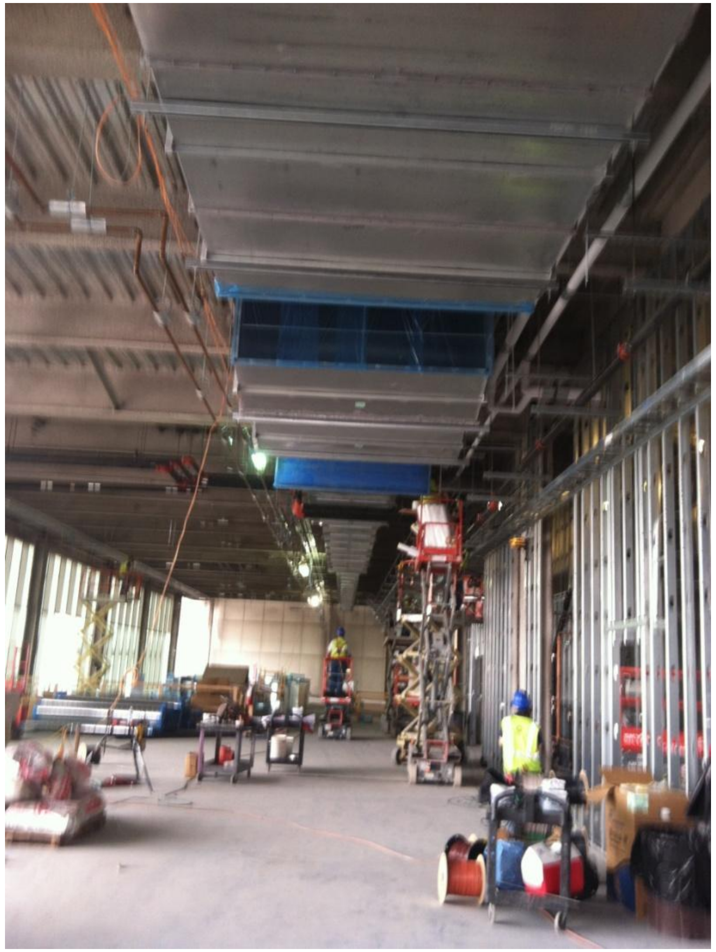
Sheet Metal Duct Field Installation:

In-Duct HW Coils

Rectangular Ductwork with
Flanges and Tie-Rods

Sheet Metal Duct Field Installation:

Exposed Spiral Round DW Ductwork
Note "Gripple" cable hangers.



Size and height of ductwork above floor affects field labor costs by +15-20% when lifts are required.

Sheet Metal Duct Field Installation:

Install filters for fan-coil devices accessibly, low above ceilings or in ceiling grilles. Easier servicing!

Air Handing Unit Drop; Ease the throats. Make it easy for air to flow.

Sheet Metal Duct Field Installation:

Walk-In Plenum behind louvers.
Pitched floor to drain out over bottom louver blades.
Depth of plenum helps moisture drop-off.

Outside View of Same Louvers

Questions?
Discussion?

Thank you for
watching this
Ductumentary!
(I quack myself up.)