Welcome to the 2007 HEATING/PIPING/AIR CONDITIONING HPAC ENGINEERING WEBCAST SERIES

System Effects in Ventilation Design

Sponsored By: ebmpapst

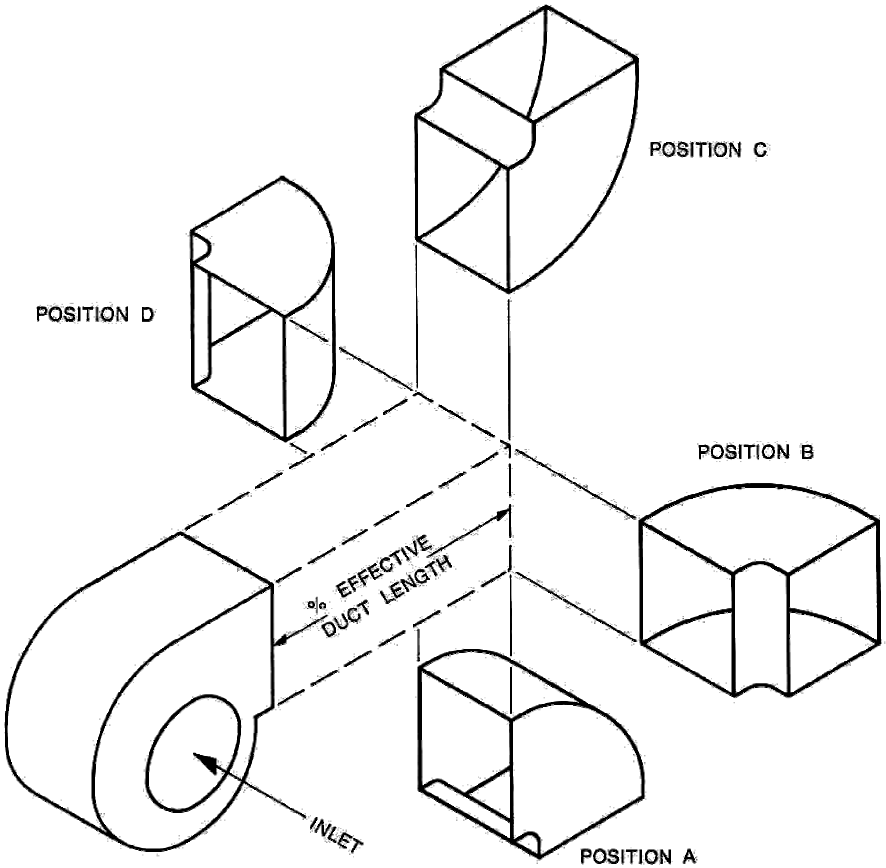
Presented By:
David Sellers, Senior Engineer
Facility Dynamics Engineering

Facility Dynamics Engineering

AMCA Definition

The effect of the system connections on the fan's performance.

- *Accounted for by a system effect factor*
- *Velocity dependent*
- *Connection configuration dependent*
  - *Relative to discharge velocity profile*
  - *Relative to distance from the fan*

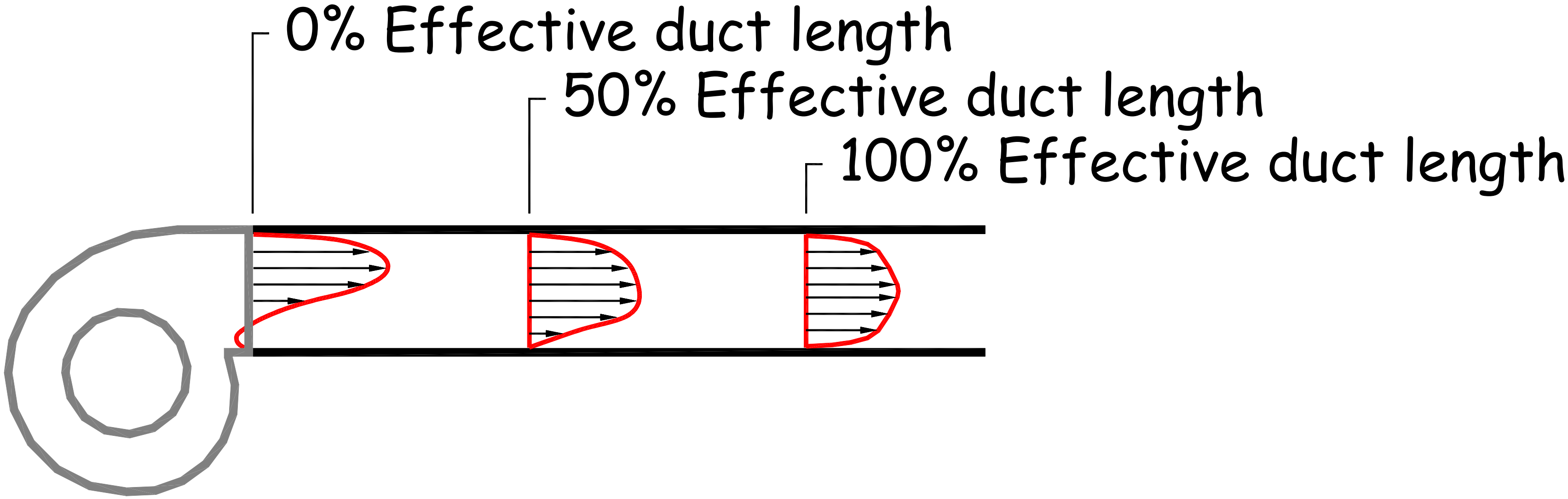


SWSI Centrifugal Fan Shown

Note: Fan Inlet and Elbow Positions Must be Oriented as shown for Proper Application of System Effect Factors (Figure 22).

OUTLET DUCT ELBOWS

Fan Tests are Based on Ideal Conditions



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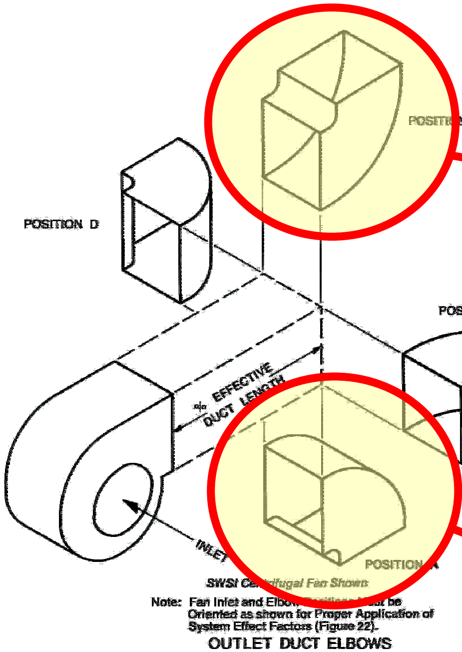
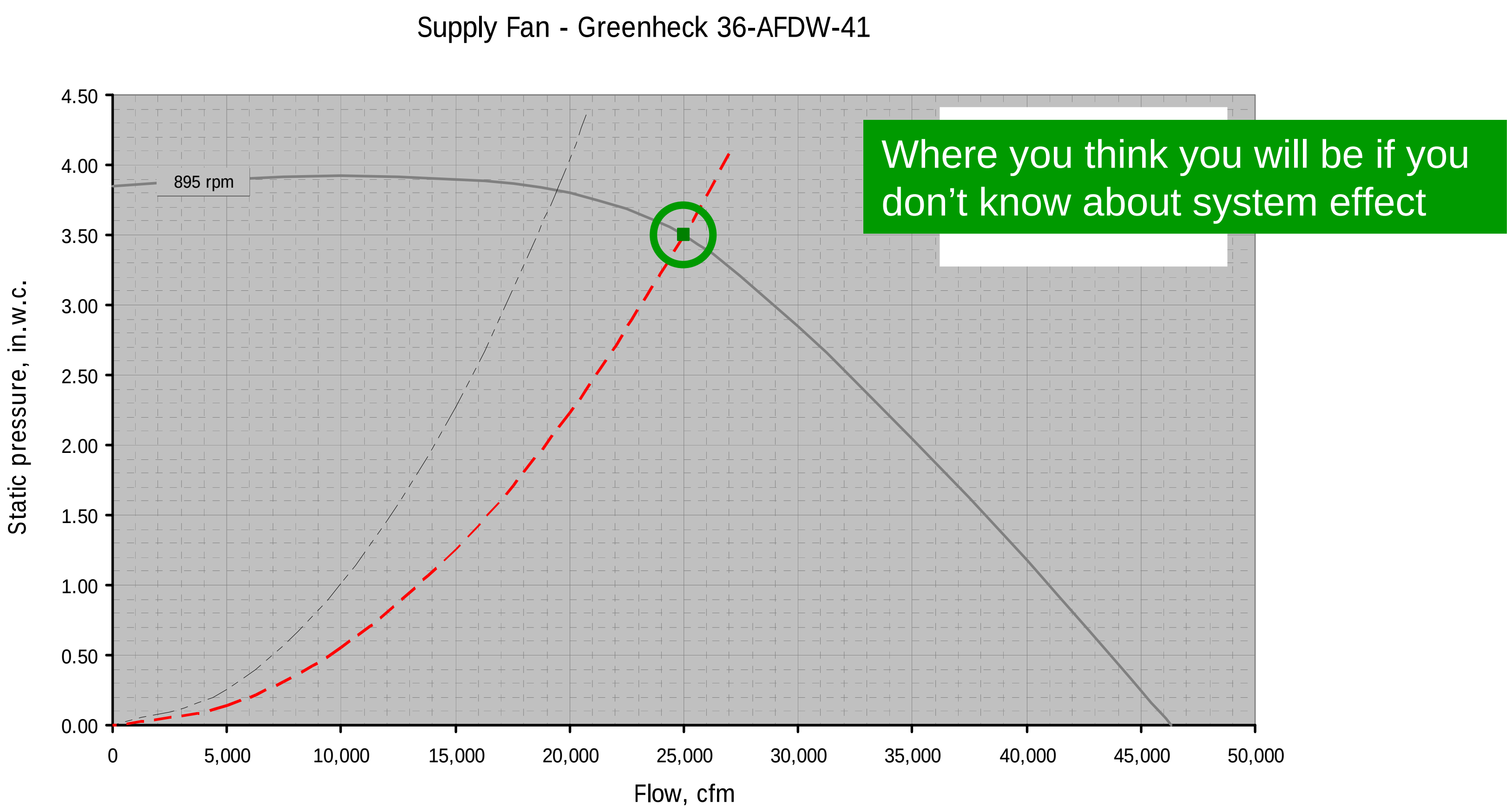


- .55 in.w.c. at 0% effective duct length
- .18 in.w.c. at 50% effective duct length

- .20 in.w.c. at 0% effective duct length
- .05 in.w.c. at 50% effective duct length

System effect assessed at 2,500 fpm and an outlet area to blast area ratio of 70%

Performance Implications



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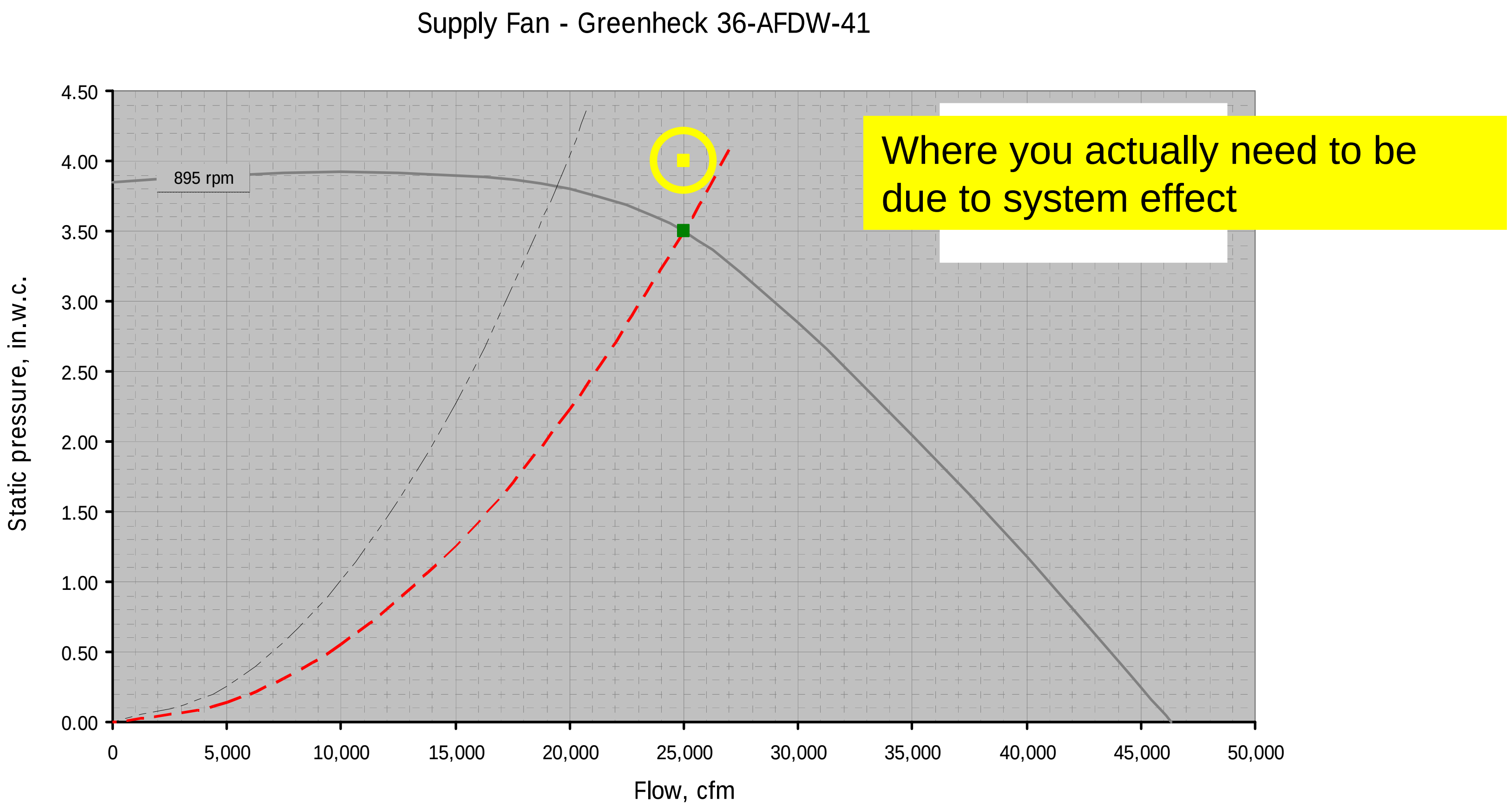

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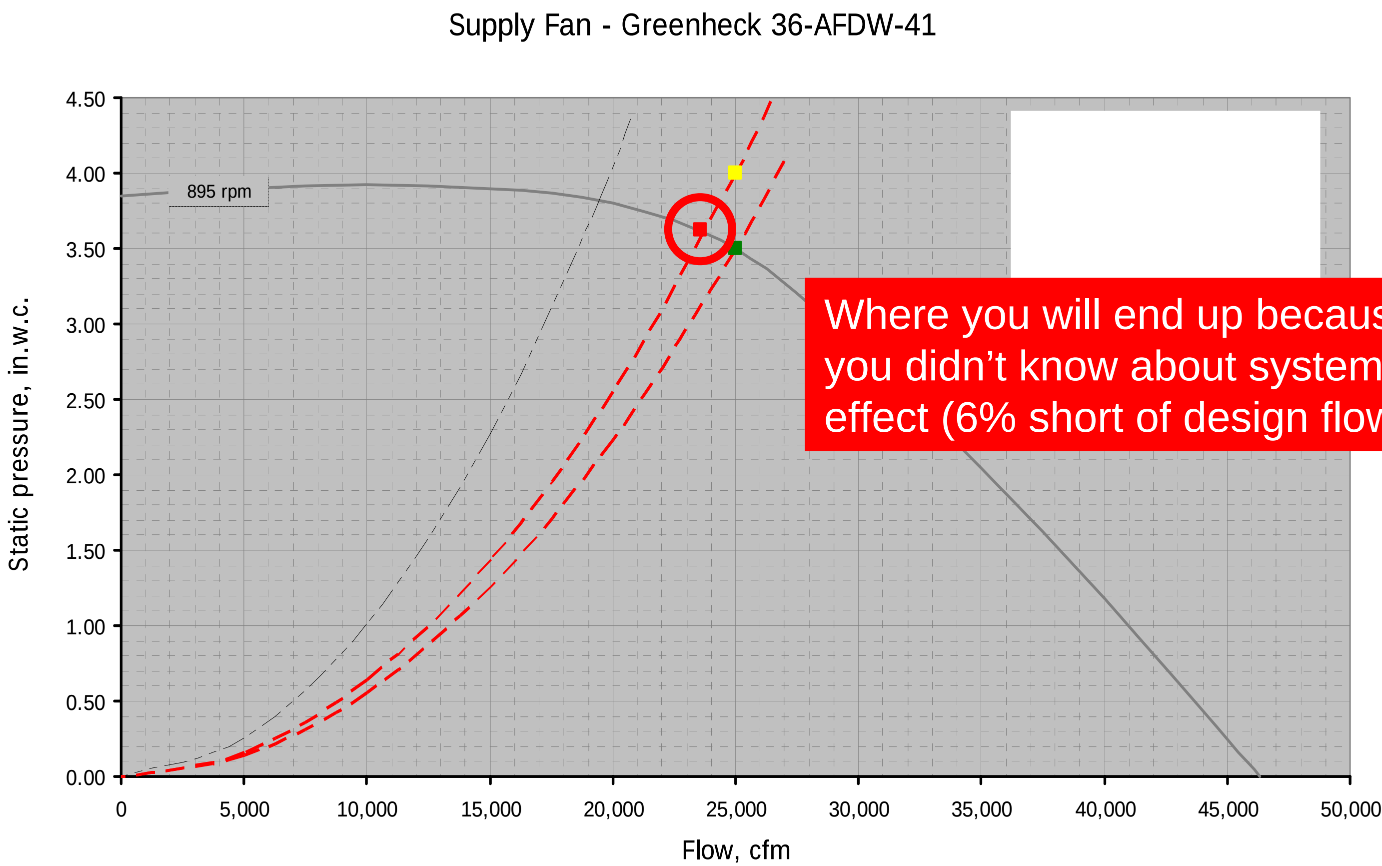
Performance Implications



Where you will end up because you didn't know about system effect (6% short of design flow)

This Problem is Often Solved by Throwing Energy at It

- Fan brake horsepower requirement is typically less than the incremental motor horsepower supplied
- Motor service factor provides some margin for error
  - For our example:
    - Brake horsepower at design is approximately 18 bhp
    - Brake horsepower required if system effect is accommodated is approximately 21 bhp
    - Horsepower available from a 20 hp motor with a service factor of 1.15 is 23 hp

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- For our example:
  - Speed the fan up and everyone wins!

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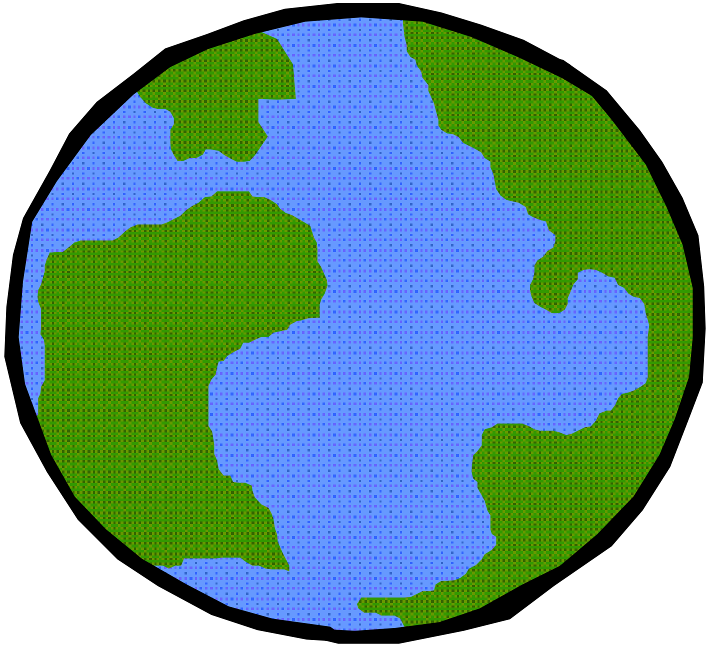


(Except the planet)

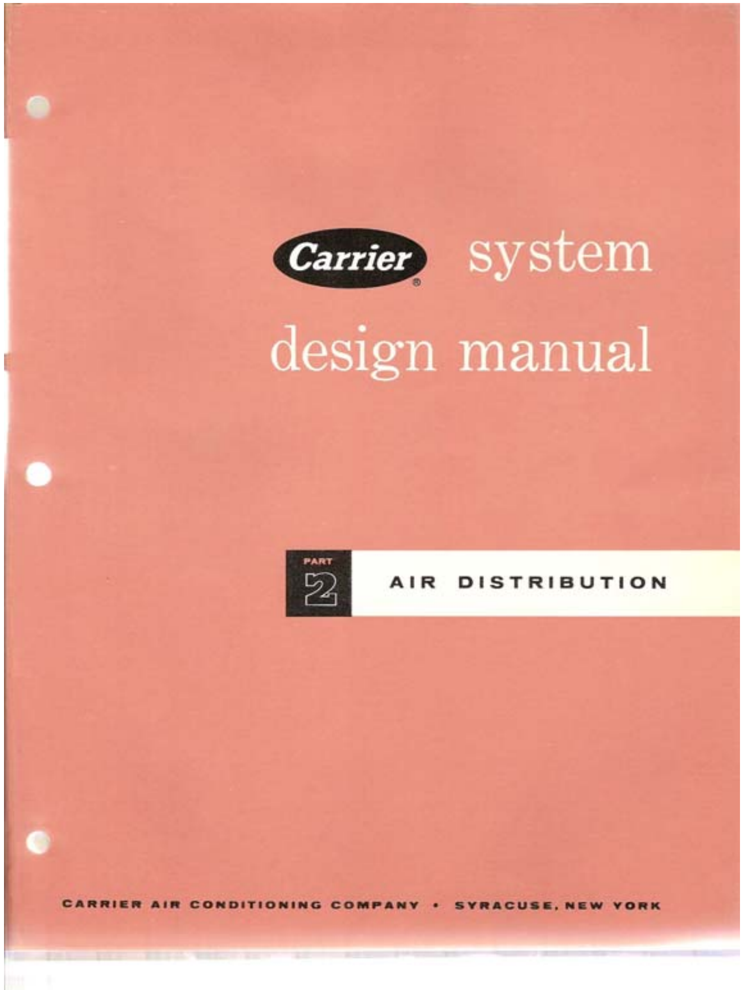
We don't inherit the world

from our ancestors;

We borrow it from our children

Unknown

A Known Phenomenon



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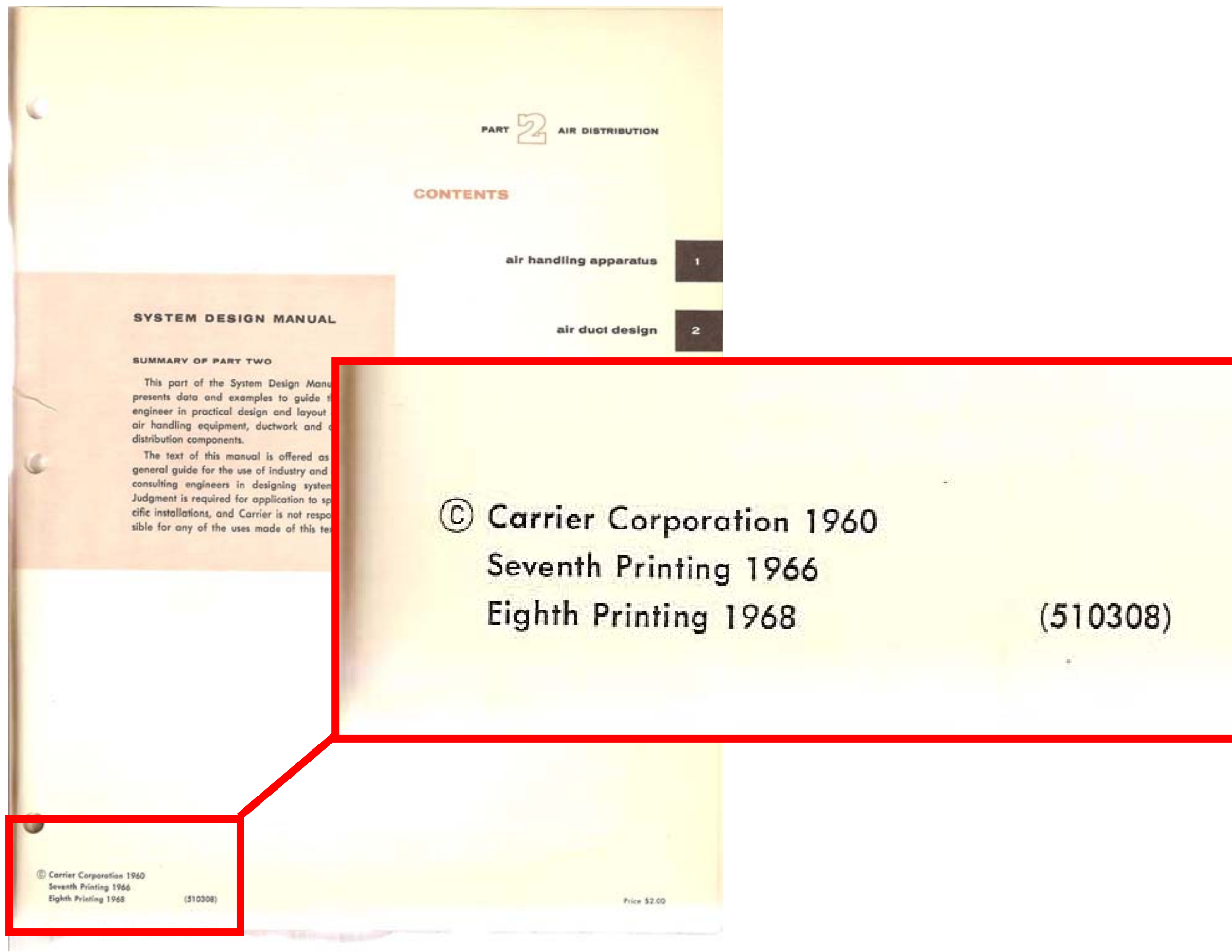
A Known Phenomenon



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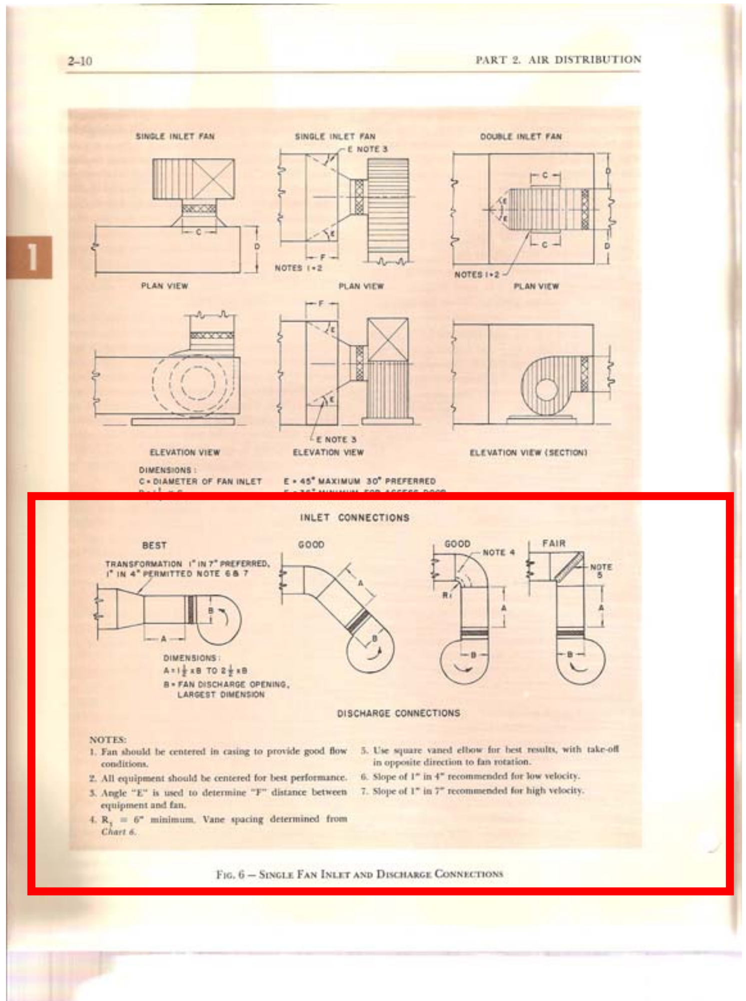
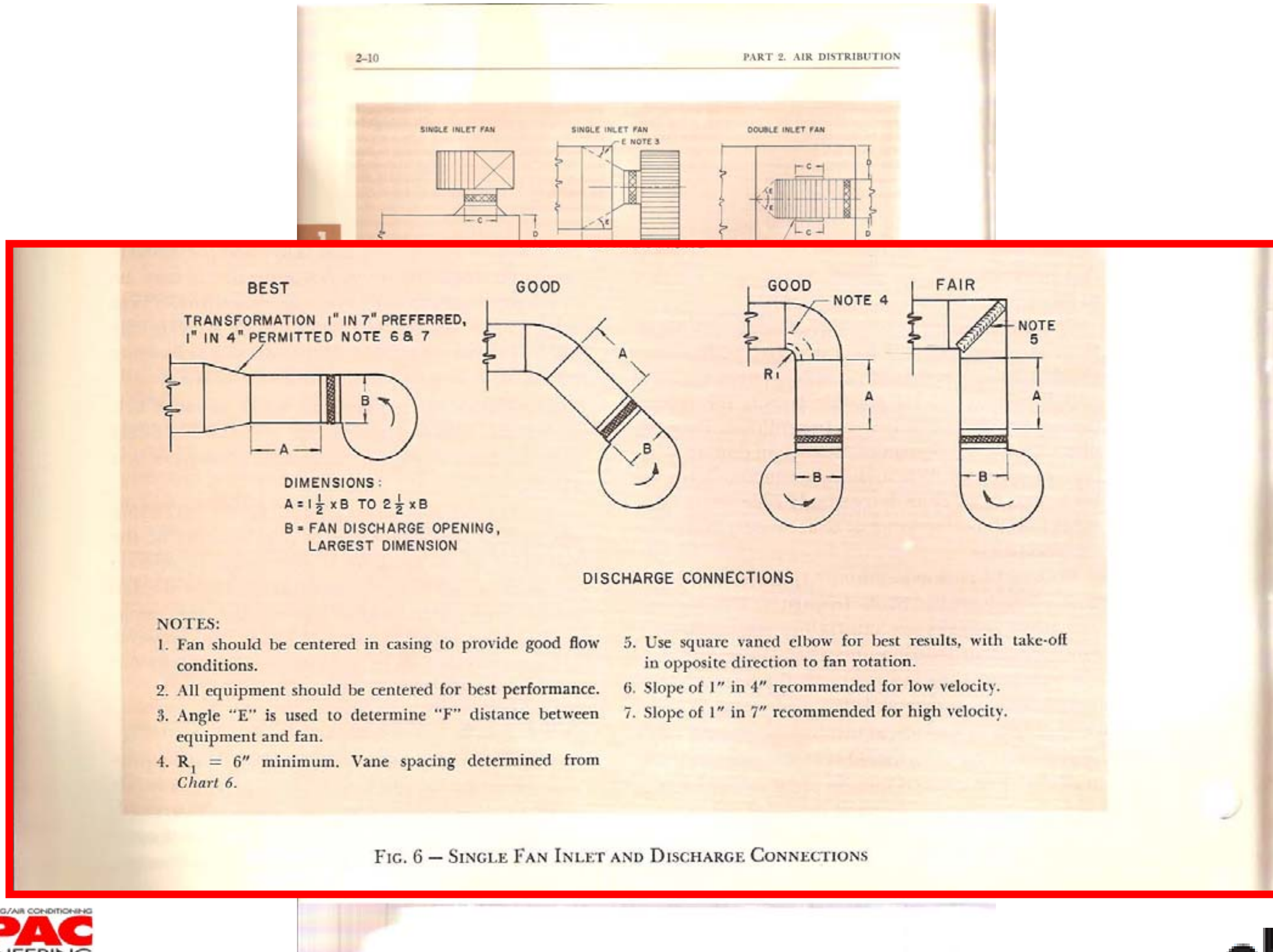


NOTES:

1. Fan should be centered in casing to provide good flow conditions.
2. All equipment should be centered for best performance.
3. Angle "E" is used to determine "F" distance between equipment and fan.
4. R_1 = 6" minimum. Vane spacing determined from *Chart 6.*
5. Use square vaned elbow for best results, with take-off in opposite direction to fan rotation.
6. Slope of 1" in 4" recommended for low velocity.
7. Slope of 1" in 7" recommended for high velocity.

Fig. 6 – Single Fan Inlet and Discharge Connections

A Known Phenomenon



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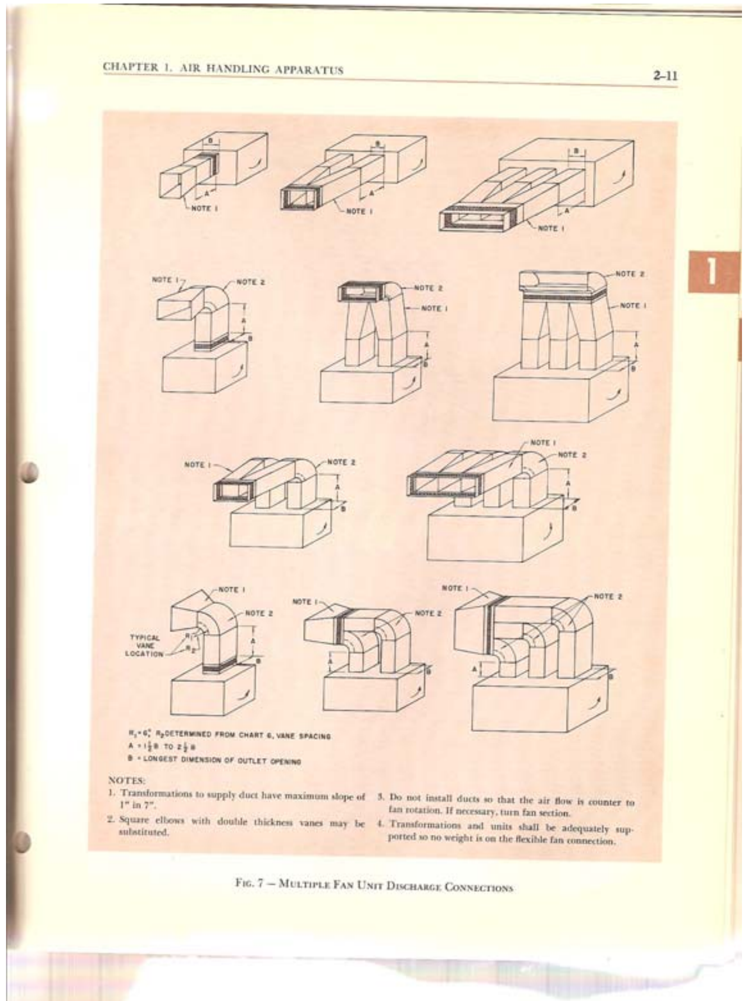
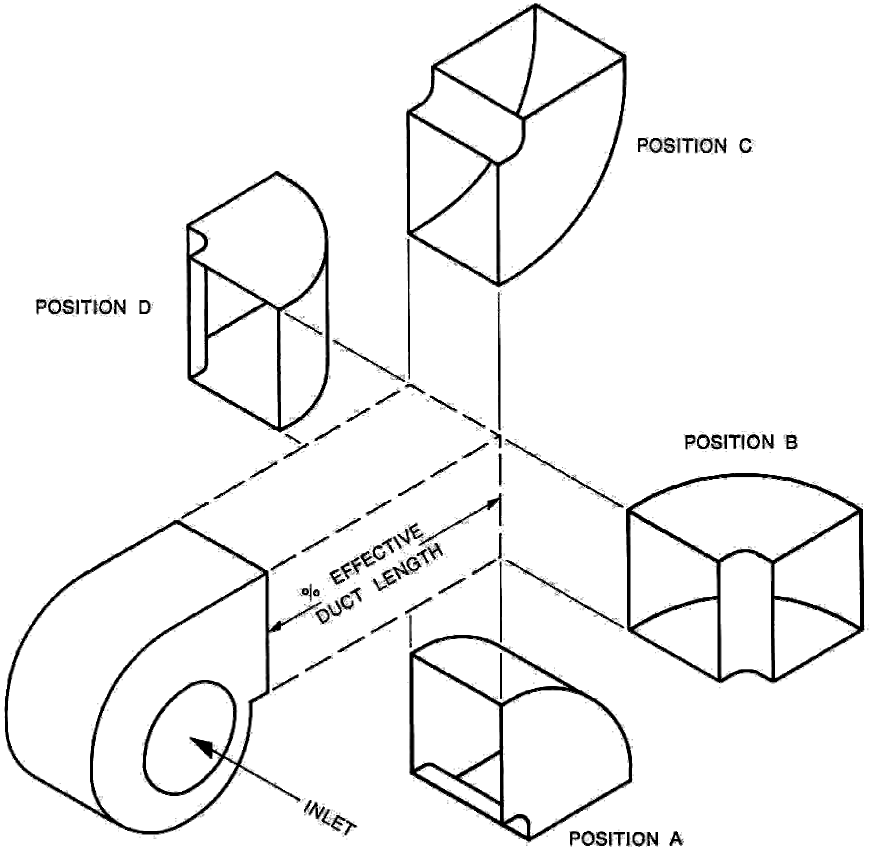


NOTES:

1. Transformations to supply duct have maximum slope of 1" in 7".
2. Square elbows with double thickness vanes may be substituted.
3. Do not install ducts so that the air flow is counter to fan rotation. If necessary, turn fan section.
4. Transformations and units shall be adequately supported so no weight is on the flexible fan connection.

Fig. 7 – Multiple Fan Unit Discharge Connections

AMCA Data Becomes Available in the Late 1970's/Early 1980's



SWSI Centrifugal Fan Shown

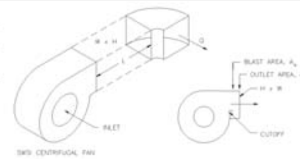
Note: Fan Inlet and Elbow Positions Must be Oriented as shown for Proper Application of System Effect Factors (Figure 22).

OUTLET DUCT ELBOWS

Current ASHRAE Handbooks and Fitting Database

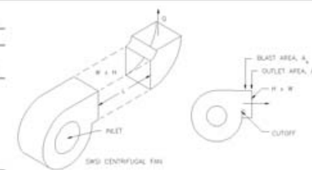
SR7-6 Fan Outlet, Centrifugal, SWSI, with Elbow (Position B)

	C_o Values					
	L/L_e					
A_b/A_o	0.00	0.12	0.25	0.50	1.00	10.00
0.4	3.80	3.20	2.20	1.00	0.00	0.00
0.5	2.90	2.20	1.60	0.67	0.00	0.00
0.6	2.00	1.60	1.20	0.53	0.00	0.00
0.7	1.40	1.00	0.67	0.33	0.00	0.00
0.8	1.00	0.80	0.53	0.26	0.00	0.00
0.9	0.80	0.67	0.47	0.18	0.00	0.00
1.0	0.67	0.53	0.40	0.18	0.00	0.00



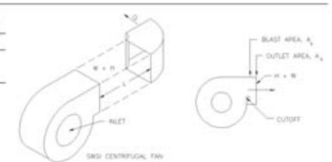
SR7-7 Fan Outlet, Centrifugal, SWSI, with Elbow (Position C)

	C_o Values					
	L/L_e					
A_b/A_o	0.00	0.12	0.25	0.50	1.00	10.00
0.4	5.50	4.50	3.20	1.60	0.00	0.00
0.5	3.80	3.20	2.20	1.00	0.00	0.00
0.6	2.90	2.50	1.60	0.80	0.00	0.00
0.7	2.00	1.60	1.00	0.53	0.00	0.00
0.8	1.40	1.20	0.80	0.33	0.00	0.00
0.9	1.20	0.80	0.67	0.26	0.00	0.00
1.0	1.00	0.80	0.53	0.26	0.00	0.00



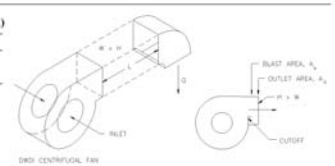
SR7-8 Fan Outlet, Centrifugal, SWSI, with Elbow (Position D)

	C_o Values					
	L/L_e					
A_b/A_o	0.00	0.12	0.25	0.50	1.00	10.00
0.4	5.50	4.50	3.20	1.60	0.00	0.00
0.5	3.80	3.20	2.20	1.00	0.00	0.00
0.6	2.90	2.50	1.60	0.80	0.00	0.00
0.7	2.00	1.60	1.00	0.53	0.00	0.00
0.8	1.40	1.20	0.80	0.33	0.00	0.00
0.9	1.20	0.80	0.67	0.26	0.00	0.00
1.0	1.00	0.80	0.53	0.26	0.00	0.00



SR7-9 Fan Outlet, Centrifugal, DWDI, with Elbow (Position A)

	C_o					
	L/L_e					
A_b/A_o	0.00	0.12	0.25	0.50	1.00	10.00
0.4	3.20	2.50	1.80	0.80	0.00	0.00
0.5	2.20	1.80	1.20	0.53	0.00	0.00
0.6	1.60	1.40	0.80	0.40	0.00	0.00
0.7	1.00	0.80	0.53	0.26	0.00	0.00
0.8	0.80	0.67	0.47	0.18	0.00	0.00
0.9	0.53	0.47	0.33	0.18	0.00	0.00
1.0	0.53	0.47	0.33	0.18	0.00	0.00



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Field Experience Indicates Some Room for Improvement

Left image courtesy of HPAC Editorial Advisory Board Member Ron Wilkinson

Why Does This Matter?

http://www.energy.ca.gov/pier/final_project_reports/500-03-082.html

Recent PIER (California's Public Interest Energy Research program) found that:

- For small commercial buildings (30,000 – 50,000 sq.ft.)
  - Installed fan power exceeds ARI assumptions
    - Fan scheduling and control
    - Fan sizing and distribution system issues
  - Best practices savings potential – 10-15% over current approaches

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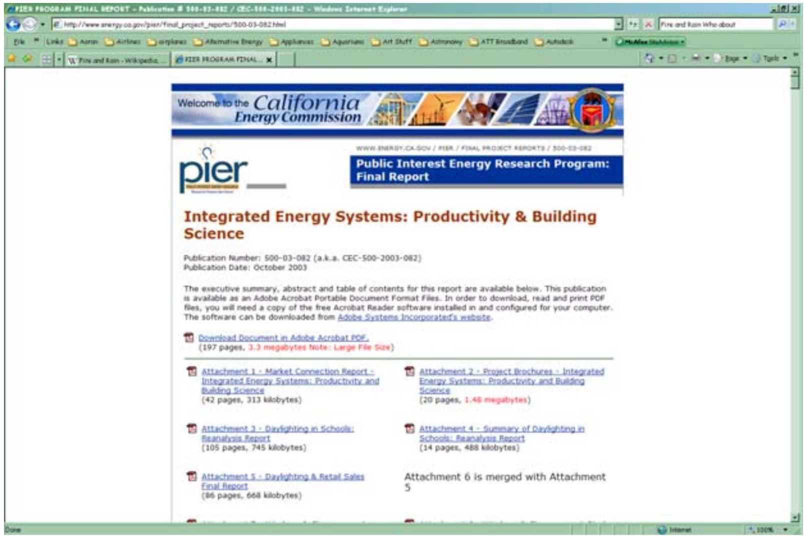

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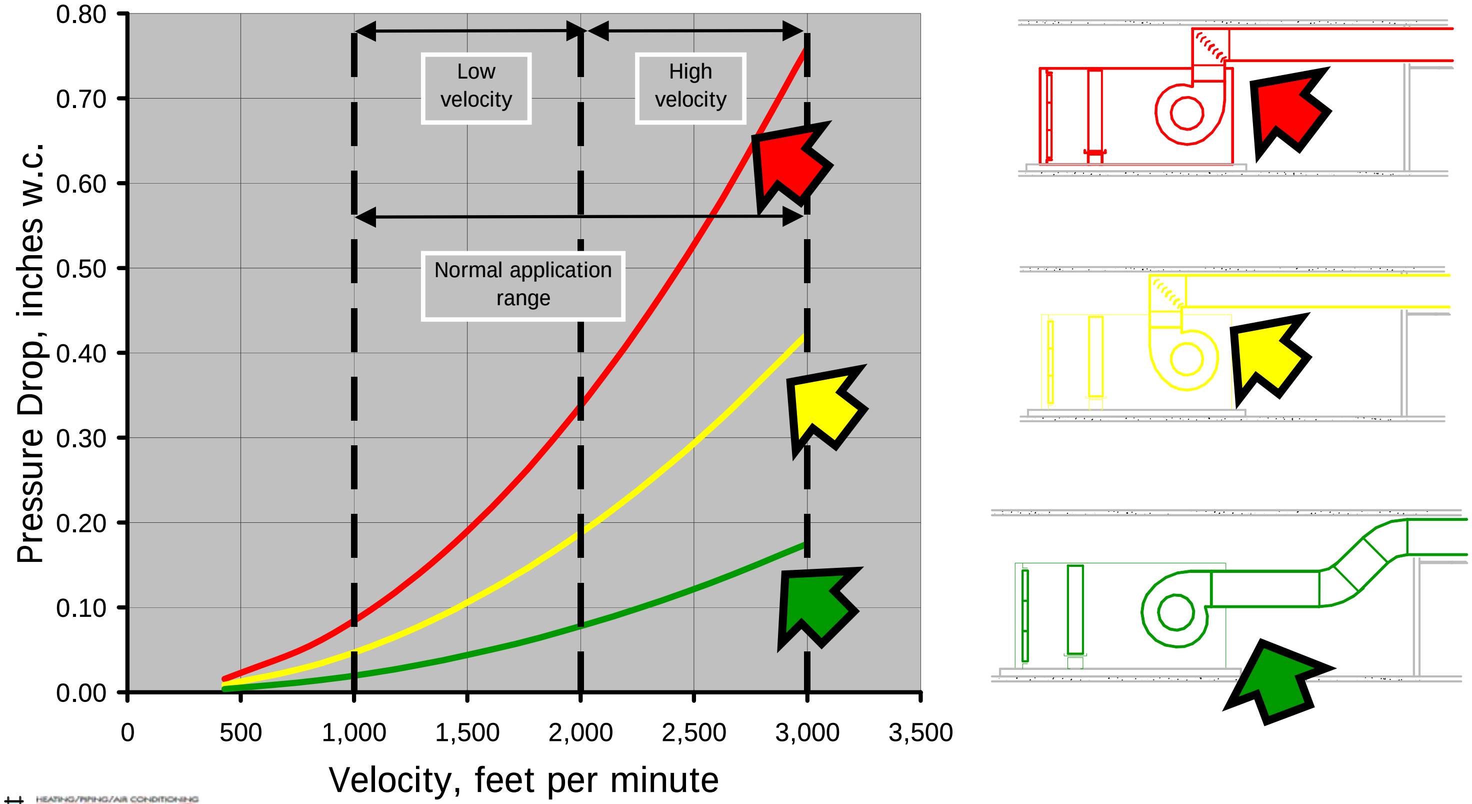
Recent PIER (California's Public Interest Energy Research program) found that:

- For large commercial buildings
  - Best design practices could save $0.12 per square foot in fan energy
  - Fan selection and duct sizing are significant contributors

Design Phase Issue with Life Cycle Cost Implications



Savings Summary

Air handling unit discharge configuration	Static pressure savings at design flow compared to the base case, inches water column	Annual energy cost savings at 2,600 operating hours/year (typical office building)	Annual energy cost savings at 8,760 operating hours/year (typical hospital)
Top, reversed turn	0.00	Base Case	
Top, forward turn	0.17	$69	$234
Front with offset	0.30	$120	$406

Savings based on $.09/kWh electricity and a 10,000 cfm system

For More Information on Why and How Design Details Matter

Energy Design Resources

- Design Details

www.energydesignresources.com

energydesignresources

design brief

DESIGN DETAILS

Summary

Building owners are spending more money on complex building systems than ever before and yet many find they have building system problems. Providing design details on construction documents can reduce these problems and save money. Design details increase the likelihood that designs will be correctly implemented in the field, reducing change orders and saving first costs. Using design details to specify an optimized system can also save energy and other operating costs.

For example, it is not uncommon for the connection between a duct and a supply plenum to be shown as a square (representing the plenum) with a line connected to it (representing the duct). A literal interpretation of this connection may result in a fitting with significant pressure loss. However, a simple expansion of the duct at the connection point by a bellmouth fitting can cut this pressure loss by 50% or more. This can translate into hundreds of dollars in annual energy savings for numerous fittings in a large air handling system.

Attention to design details can improve performance and efficiency in almost all aspects of a design. Design details are particularly important for:

- Piping and duct arrangements that minimize the number of fittings and bends.
- Pipe and duct fittings that minimize frictional losses.
- Fan and pump discharge conditions that minimize losses.

Although the energy savings for each detail may be small, the combined effects in a commercial building are significant. In a typical building, providing design details can save an owner approximately 5 to 15% in energy costs.

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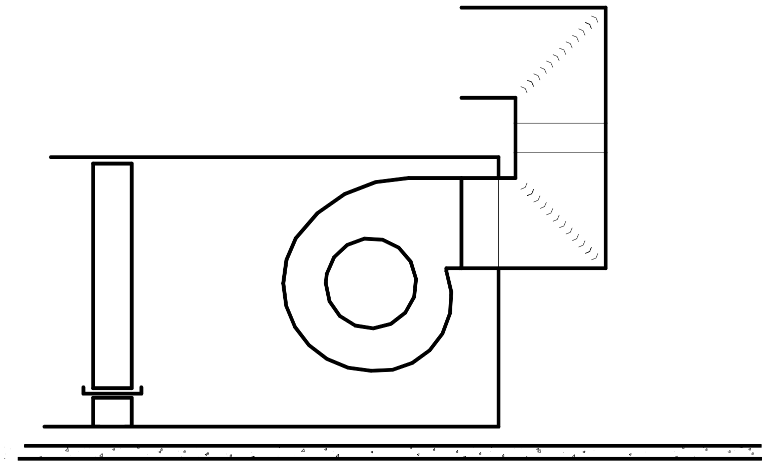
CONTENTS

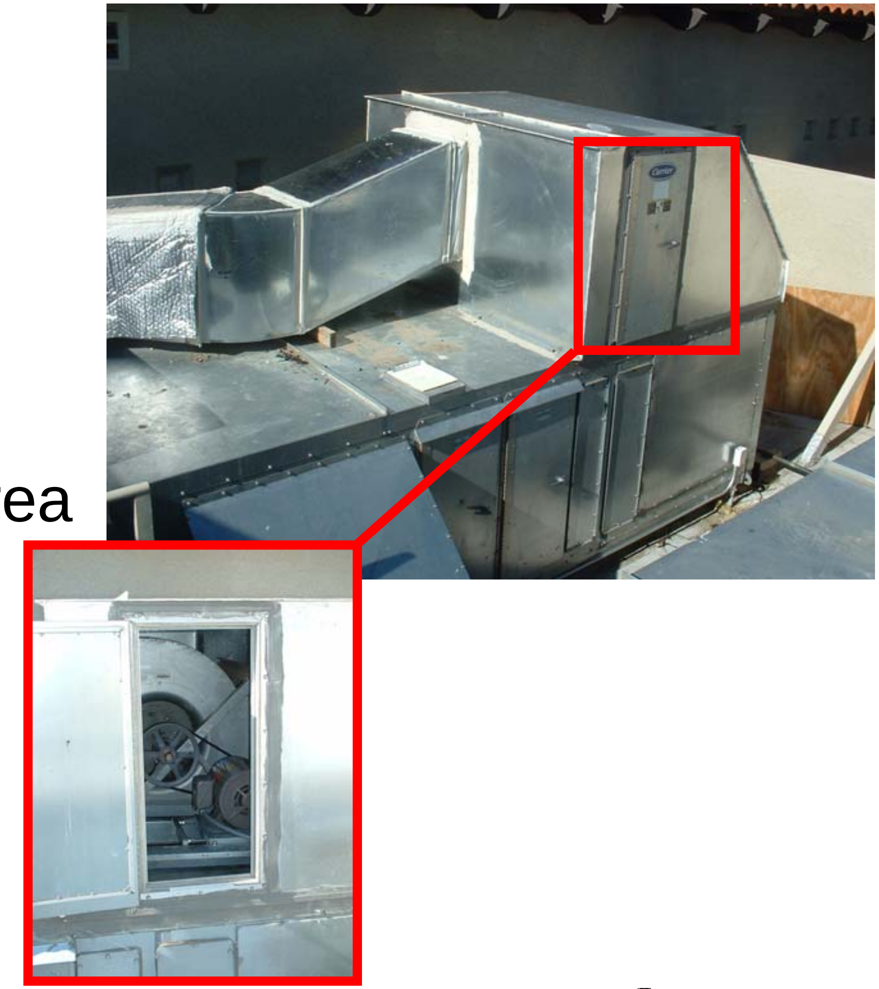
A Common Commissioning Problem

- Resort Spa = High profile, High revenue, High client expectation area
- Poor "As Built" Spa AHU discharge condition resulted in poor performance
  - Fan ran at full speed all of the time
  - Operating staff juggled set points to maintain comfort



Innovative Improvement By The Staff

- Founded on fundamentals
- Implemented directly with contractors
- Fan runs at 50% speed or less most of the time
- Comfort through-out the area served



The Good News:

- The Modifications:
  - Save 11,508 kWh and $1,150 in electricity annually

    Savings based on $0.10 per kWh electrical costs
  - Improved Spa client satisfaction …

… Priceless!

The Bad News:

- These benefits and others could have been realized by right sizing during design
  - Spa reputation for quality established from the start
  - Modification costs avoided

Fan Energy is Directly Related to Flow and Fan Static Pressure

$$bhp = \left(\frac{cfm \times static}{6{,}356 \times \eta_{fan_{static}}} \right)$$

Where :

$bhp =$ Brake horse power into the fan drive shaft

$cfm =$ Flow rate in cubic feet per minute

$static =$ Fan static pressure

$6{,}356 =$ A units conversion constant

$\eta_{fan_{static}} =$ Fan static efficiency; .40 = .60 for small fans,

.68 - .78 for large fans

Divide by motor efficiency and multiply by .746 kW per horse power to get killoWatts

Fan Energy is Directly Related to Flow and Fan Static Pressure

- Flow rate – 25,000 cfm
- Unnecessary static pressure burden – 0.25 in.w.c.
- Fan static efficiency – 72%
- Brake horsepower used - 1.4 bhp

A Powerful Relationship Out in the Field

- The Issue
  - Resolve a balancing problem
    - AHU flow below design
    - Fan motor run into service factor
- The design approach
  - Estimate static required based on past experience
  - Use one line duct drawings to convey requirements
- The situation
  - “Tense”
- The Cx provider’s goals
  - Achieve design flow
  - Focus on the problem
  - Minimize
    - Cost of correction
    - Operating costs

The Insight

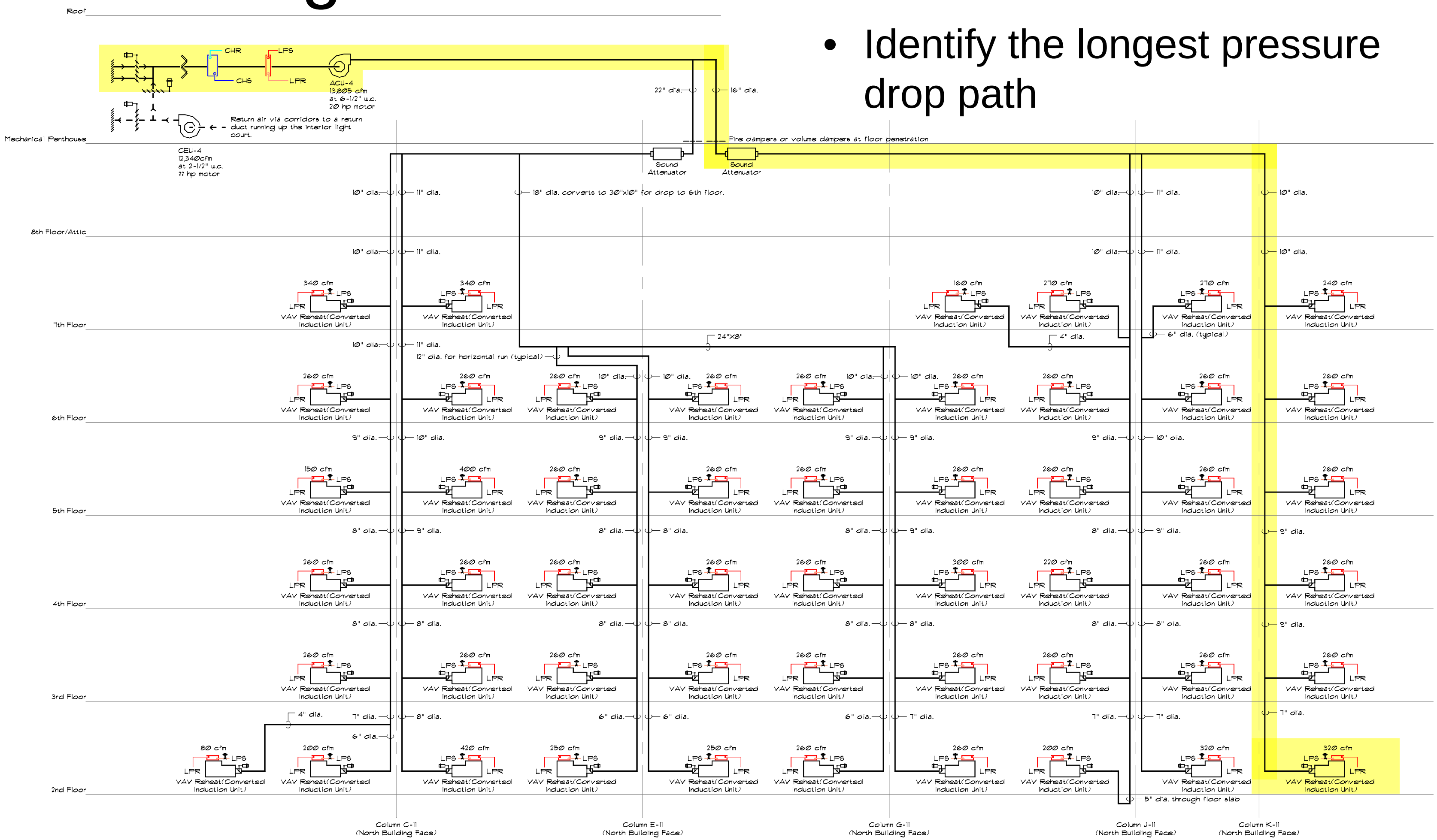
- Eliminating less than 0.25 in.w.c of static from the system would solve the problem with out a larger motor
  - Revise filter change-out pressure drop
  - Improve poor fittings

Resolving the Problem

- Estimate anticipated static pressure at various points in the system at a given flow rate
- Measure actual static pressure in the system at the same points and flow rate
  - Reference pressure may be important
- Investigate any differences encountered

Collecting the Data

- Start with the system diagram
- Identify the longest pressure drop path



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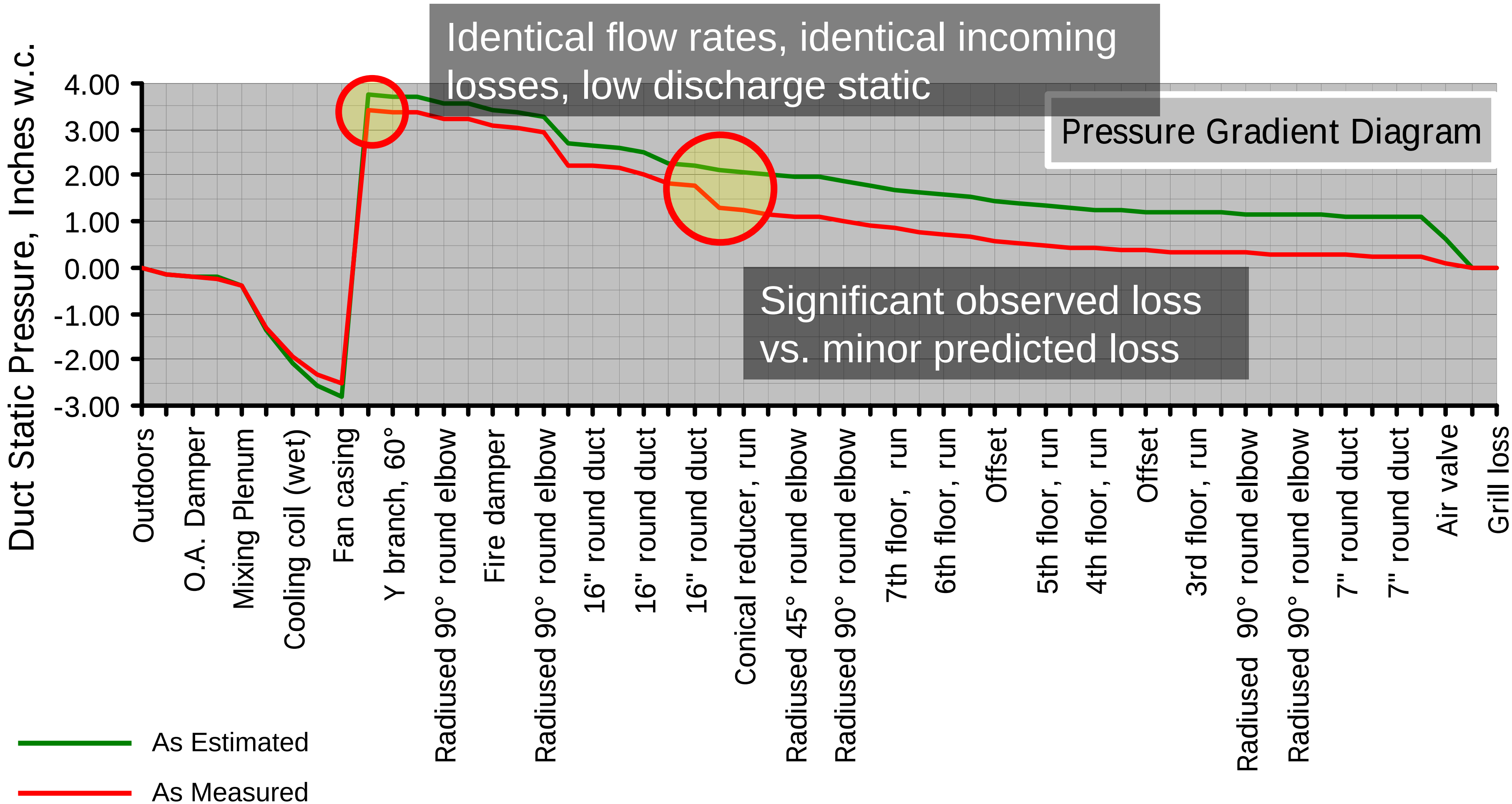
Analyzing the Data

ITEM	DESCRIPTION	FLOW RATE cfm	SECTION LENGTH Feet	DUCT HTH. In.	DUCT WTH. In.	DUCT DIA. In.	DUCT VEL. Fpm	VEL. PRESS. In.w.c	LOSS COEFF. Co	CAT. LOSS In.w.c.	FRIC. RATE In.w.c per 100 ft.	SECTION OR ITEM LOSS in.w.c	PERCENT OF TOTAL	RUNNING TOTAL Clean filters In.w.c.	RUNNING TOTAL Dirty filters In.w.c.
0	Outdoors													0.00	0.00
1	Intake louver	13,680					#DIV/0!	#DIV/0!	N/A	0.15	N/A	0.15	2.2%	-0.15	-0.15
2	O.A. Damper	13,680		20.00	72.00		1,368	0.1167	0.52	N/A	N/A	0.06	0.9%	-0.21	-0.21
3	O.A. Duct	13,680	52	20.00	72.00		1,368	0.1167	N/A	N/A	0.05	0.03	0.4%	-0.24	-0.24
4	Mixing Plenum	13,680					#DIV/0!	#DIV/0!	N/A	0.20	N/A	0.20	3.0%	-0.44	-0.44
5	Filters	13,680					#DIV/0!	#DIV/0!	N/A	0.90	N/A	0.90	13.4%	-0.69	-1.34
6	Cooling coil (wet)	13,680					#DIV/0!	#DIV/0!	N/A	0.71	N/A	0.71	10.5%	-1.40	-2.05
7	Reheat coil	13,680					#DIV/0!	#DIV/0!	N/A	0.42	N/A	0.42	6.2%	-1.82	-2.47
8	Fan casing	13,680					#DIV/0!	#DIV/0!	N/A	0.20	N/A	0.20	3.0%	-2.02	-2.67
9	System effect - fan discharge	13,680		27.00	33.00		2,211	0.3047	1.00	N/A	N/A	0.30	4.5%	3.77	3.77
10	Y branch, 60°, with conversion to round	13,680		27.00	33.00		2,211	0.3047	0.21	NA	NA	0.06	0.9%	3.70	3.70
11	16" round duct	4,970	2			16.00	3,560	0.7899	NA	NA	0.95	0.02	0.3%	3.68	3.68
12	Radiused 90° round elbow	4,970				16.00	3,560	0.7899	0.15	N/A	N/A	0.12	1.8%	3.56	3.56
13	16" round duct	4,970	2			16.00	3,560	0.7899	NA	NA	0.95	0.02	0.3%	3.55	3.55
14	Fire damper	4,970				16.00	3,560	0.7899	0.19	NA	NA	0.15	2.2%	3.40	3.40
15	16" round duct	4,970	2			16.00	3,560	0.7899	NA	NA	0.95	0.02	0.3%	3.38	3.38
16	Radiused 90° round elbow	4,970				16.00	3,560	0.7899	0.15	N/A	N/A	0.12	1.8%	3.26	3.26
17	Sound attenutator	4,970				16.00	3,560	0.7899	0.81	NA	NA	0.64	9.5%	2.62	2.62
18	16" round duct	4,970	4			16.00	3,560	0.7899	NA	NA	0.95	0.04	0.6%	2.58	2.58
19	Radiused 45° round elbow	4,970				16.00	3,560	0.7899	0.07	NA	NA	0.06	0.8%	2.52	2.52
20	16" round duct	4,970	14			16.00	3,560	0.7899	NA	NA	0.95	0.13	2.0%	2.39	2.39
21	Offset down	4,970				16.00	3,560	0.7899	0.25	N/A	N/A	0.19	2.9%	2.20	2.20
22	16" round duct	4,970	5			16.00	3,560	0.7899	NA	NA	0.95	0.05	0.7%	2.15	2.15
23	Y branch, flow through run	4,970				16.00	3,560	0.7899	0.13	NA	NA	0.10	1.5%	2.05	2.05
24	Conical reducer with branch, flow	3,500				16.00	2,507	0.3917	0.13	NA	NA	0.05	0.8%	2.00	2.00
25	10" round duct	1,600	12			10.00	2,934	0.5365	NA	NA	0.73	0.09	1.3%	1.91	1.91
26	Radiused 45° round elbow	1,600				10.00	2,934	0.5365	0.07	NA	NA	0.04	0.6%	1.87	1.87
27	10" round duct	1,600	2			10.00	2,934	0.5365	NA	NA	0.73	0.01	0.2%	1.86	1.86
28	Radiused 90° round elbow	1,600				10.00	2,934	0.5365	0.15	N/A	N/A	0.08	1.2%	1.78	1.78
29	10" round duct	1,600	14			10.00	2,934	0.5365	NA	NA	0.73	0.10	1.5%	1.68	1.68
30	7th floor connection, flow through run	1,600				10.00	2,934	0.5365	0.14	NA	NA	0.08	1.1%	1.60	1.60
31	10" round duct	1,360	12			10.00	2,494	0.3876	NA	NA	0.60	0.07	1.0%	1.53	1.53
32	6th floor connection, flow through run	1,360				10.00	2,494	0.3876	0.13	NA	NA	0.05	0.7%	1.48	1.48
33	9" round duct	1,100	6			9.00	2,490	0.3865	NA	NA	0.80	0.05	0.7%	1.44	1.44
34	Offset	1,100				9.00	2,490	0.3865	0.25	N/A	N/A	0.09	1.4%	1.34	1.34
35	9" round duct	1,100	6			9.00	2,490	0.3865	NA	NA	0.80	0.05	0.7%	1.30	1.30
36	5th floor connection, flow through run	1,100				9.00	2,490	0.3865	0.13	N/A	N/A	0.05	0.7%	1.25	1.25
37	9" round duct	840	12			9.00	1,901	0.2254	N/A	N/A	0.55	0.06	0.9%	1.18	1.18
38	4th floor connection, flow through run	840				9.00	1,901	0.2254	0.13	N/A	N/A	0.03	0.4%	1.15	1.15
39	9" round duct	580	6			9.00	1,313	0.1075	N/A	N/A	0.30	0.02	0.3%	1.14	1.14
40	Offset	580				9.00	1,313	0.1075	0.25	N/A	N/A	0.03	0.4%	1.11	1.11
41	9" round duct	580	6			9.00	1,313	0.1075	N/A	N/A	0.30	0.02	0.3%	1.09	1.09
42	3rd floor connection, flow through run	580				9.00	1,313	0.1075	0.14	N/A	N/A	0.01	0.2%	1.08	1.08
43	7" round duct	320	3			7.00	1,197	0.0894	N/A	N/A	0.32	0.01	0.1%	1.07	1.07
44	Radiused 90° round elbow	320				7.00	1,197	0.0894	0.15	N/A	N/A	0.01	0.2%	1.06	1.06
45	7" round duct	320	2			7.00	1,197	0.0894	N/A	N/A	0.32	0.01	0.1%	1.05	1.05
46	Radiused 90° round elbow	320				7.00	1,197	0.0894	0.15	N/A	N/A	0.01	0.2%	1.04	1.04
47	Close fitting interation	320				7.00	1,197	0.0894	N/A	N/A	N/A	0.00	0.1%	1.03	1.03
48	7" round duct	320	8			7.00	1,197	0.0894	N/A	N/A	0.32	0.03	0.4%	1.01	1.01
49	Radiused 90° round elbow	320				7.00	1,197	0.0894	0.15	N/A	N/A	0.01	0.2%	0.99	0.99
48	7" round duct	320	3			7.00	1,197	0.0894	N/A	N/A	0.32	0.01	0.1%	0.98	0.98
49	7" flex duct	320	1			7.00	1,197	0.0894	N/A	N/A	0.64	0.01	0.1%	0.98	0.98
50	Air valve	320		4.00	4.00		2,880	0.5171	N/A	N/A	N/A	0.43	6.3%	0.55	0.55
51	Plenum loss	320		4.00	4.00		2,880	0.5171	1.00	N/A	N/A	0.52	7.7%	0.03	0.03
52	Grill loss	320		4.00	16.00		720	0.0323	1.00	N/A	N/A	0.03	0.5%	0.00	0.00
53							#DIV/0!	#DIV/0!	N/A	N/A	N/A	0.00			
54							#DIV/0!	#DIV/0!	N/A	N/A	N/A	0.00			
55							#DIV/0!	#DIV/0!	N/A	N/A	N/A	0.00			
											TOTAL	6.74			
								TOTAL with lower loss attenuator				6.31			

- Estimate the losses on an item by item basis
- Depict the results graphically – a pressure gradient diagram
- Measure the real pressure drop under similar conditions as calculated

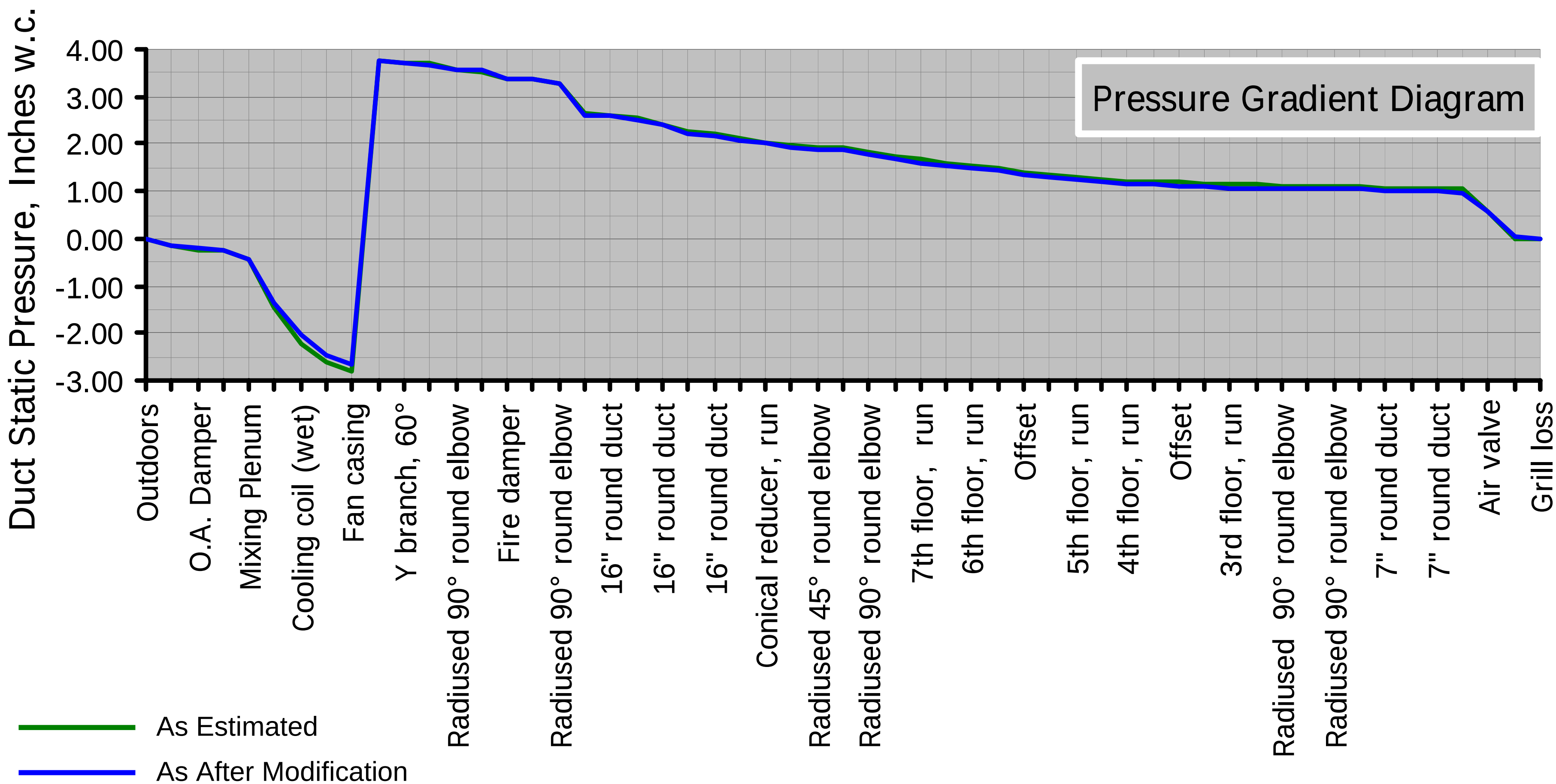
Conclusions



Solutions

- Improve fitting design at areas with higher than anticipated losses;
  - Improved plenum connection at the AHU discharge
  - Improved fitting design at a branch connection in the main run
- Much more palatable to the sheet metal contractor than the new motor, drive and wiring service required to go to a larger motor
- Much more palatable to the Owner who will see reduced operating cost for the building's life

The Results



Duct Static Pressure, Inches w.c.
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
Pressure Gradient Diagram
Outdoors
O.A. Damper
Mixing Plenum
Cooling coil (wet)
Fan casing
Y branch, 60°
Radiused 90° round elbow
Fire damper
Radiused 90° round elbow
16" round duct
16" round duct
16" round duct
Conical reducer, run
Radiused 45° round elbow
Radiused 90° round elbow
7th floor, run
6th floor, run
Offset
5th floor, run
4th floor, run
Offset
3rd floor, run
Radiused 90° round elbow
Radiused 90° round elbow
7" round duct
7" round duct
Air valve
Grill loss
As Estimated
As After Modification

The Bottom Line; Everyone Wins

Planet

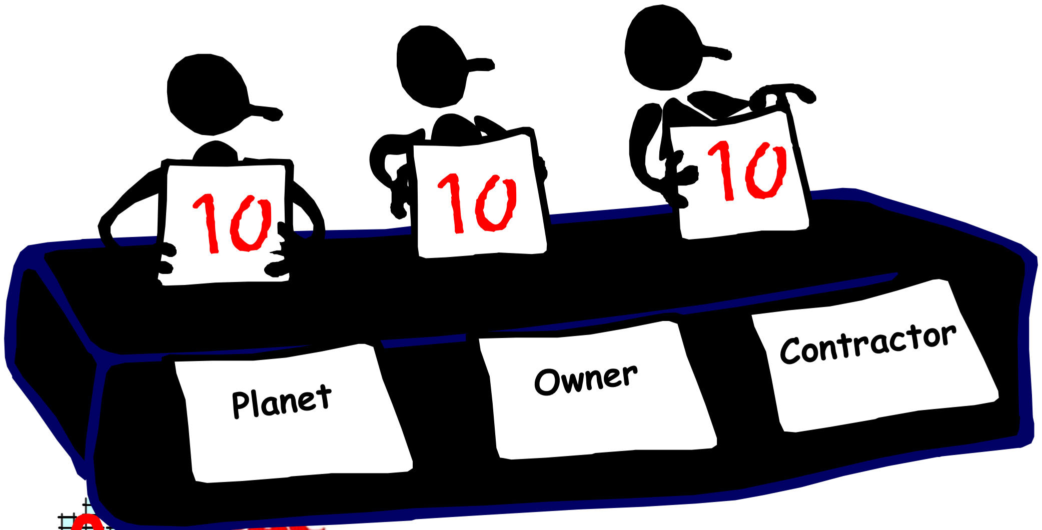
- Performance improved with brain power, not electric power

Owner

- Lower operating costs for the life of the system

Contractor

- Improved profit margin



The Bottom Line; Everyone Wins

Planet

- Performance improved with brain power, not electric power

Owner

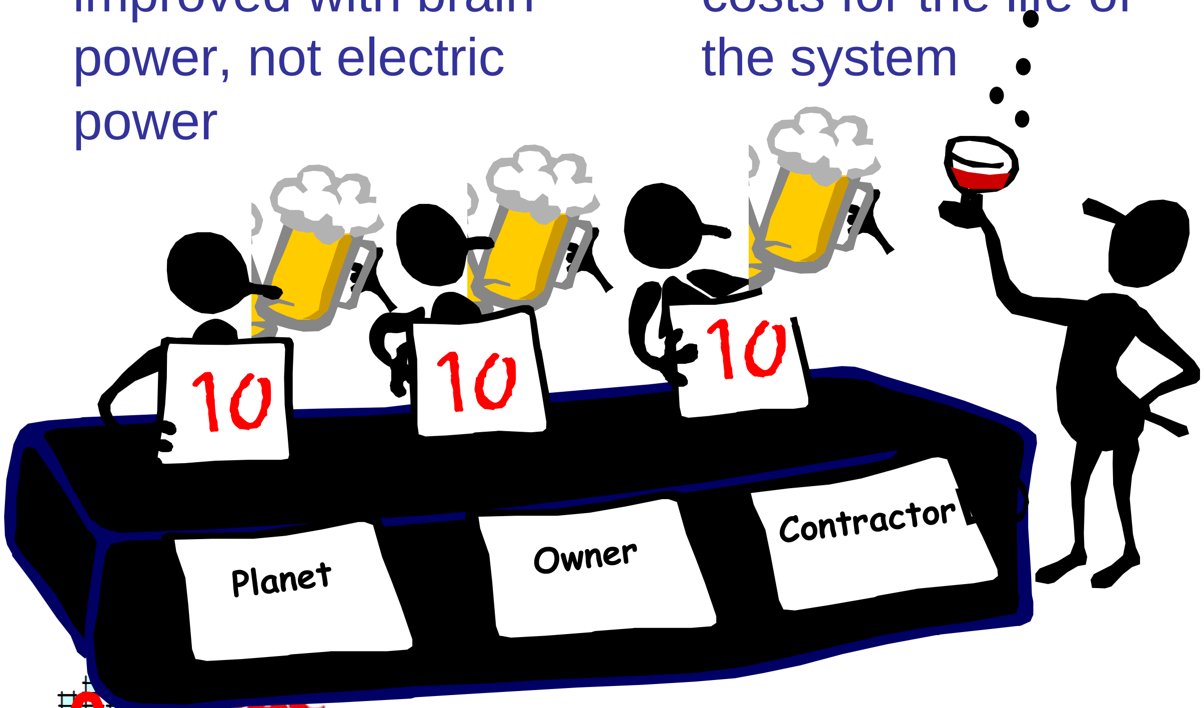
- Lower operating costs for the life of the system

Contractor

- Improved profit margin

Cx Provider

- Job satisfaction
- Beer (or a nice Cabernet)
- New relationships



Plug Fans Solve Space Problems …

… but they may raise efficiency and sustainability issues

- Comparing a plug fan and a house airfoil fan
  - Identical requirements
  - Best efficiency selection

Fan Style	Model	Volume (CFM)	SP (in. wg)	TS (ft./min)	OV (ft./min)	FRPM	Max Class FRPM	Operating Power (hp.)	SE %
Housed Airfoil	33-AFDW-21	23,052	5.09	10,169	2,045	1,177	1,225	25.4	75
Backward Inclined Plug	44-PLG-II	23,052	5.09	10,205	2,024	876	1,105	28.6	67

Plug Fans Solve Space Problems …

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- Comparing a plug fan and a house airfoil fan
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Housed Airfoil	33-AFDW-21	23,052	5.09	10,169	2,045	1,177	1,225	25.4	75
Backward Inclined Plug	44-PLG-II	23,052	5.09	10,205	2,024	876	1,105	28.6	67

- Ripple effects
  - Larger drive
  - Larger electrical service
  - Capturing benefits now – Easy
  - Capturing benefits later - Hard

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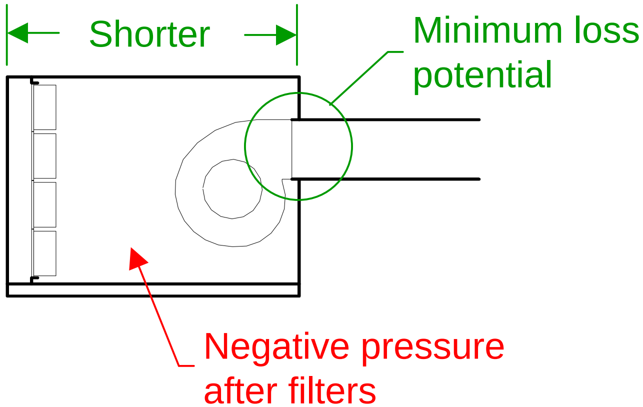
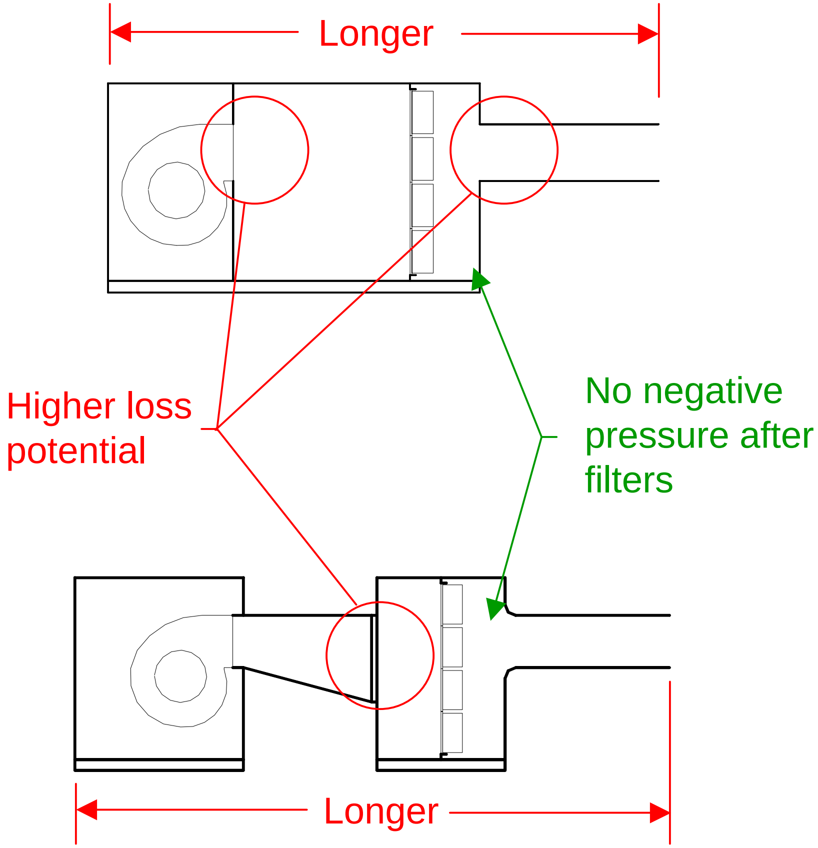
Filter Location Impacts Fan Energy





- Different configurations
- Different dimensions
- Different fan static requirements

Early Discovery = Better

Detail improved fitting at design

- May lower first cost
  - Less sheet metal
- Capture life time savings with a wiser and/or lower first cost expenditure
  - Less static = Smaller fan

    Smaller drive

    Smaller wire

    Smaller service

Early Discovery = Better

Discover a problem during installation

- May take money to correct
  - Reconfigure
  - Design issue vs. contractor issue
- Capture operational savings
- Loose first cost savings

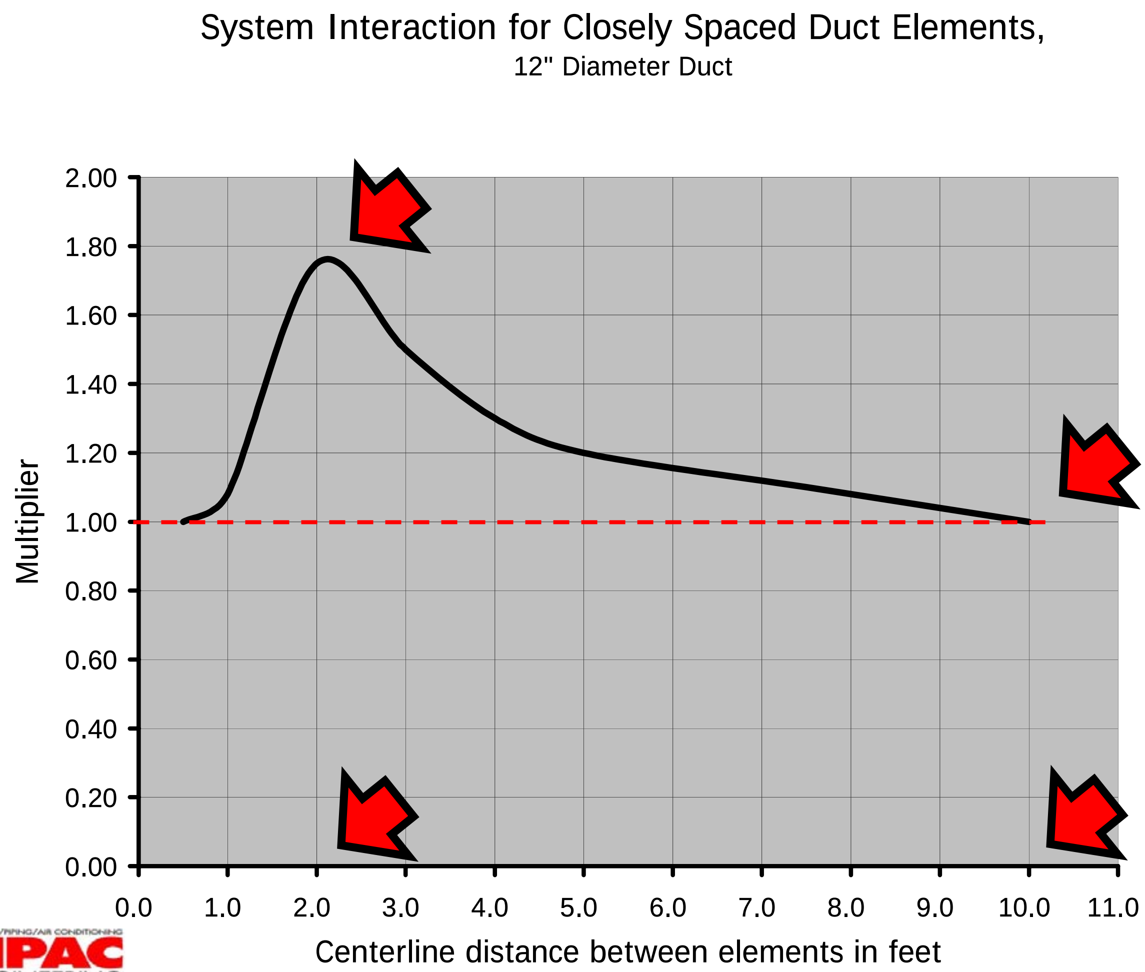
Early Discovery = Better

Discover a problem after installation

- Correction may be financially unviable unless driven by a performance requirement
- Operational penalty for the life of the system
- First cost savings opportunity lost

System Effect and Duct Fittings

(Fittings Interact!)



Total pressure drop for the closely space fittings is calculated by adding the losses calculated for the fittings as individual elements and then multiplying them by the system effect multiplier shown in the curves.

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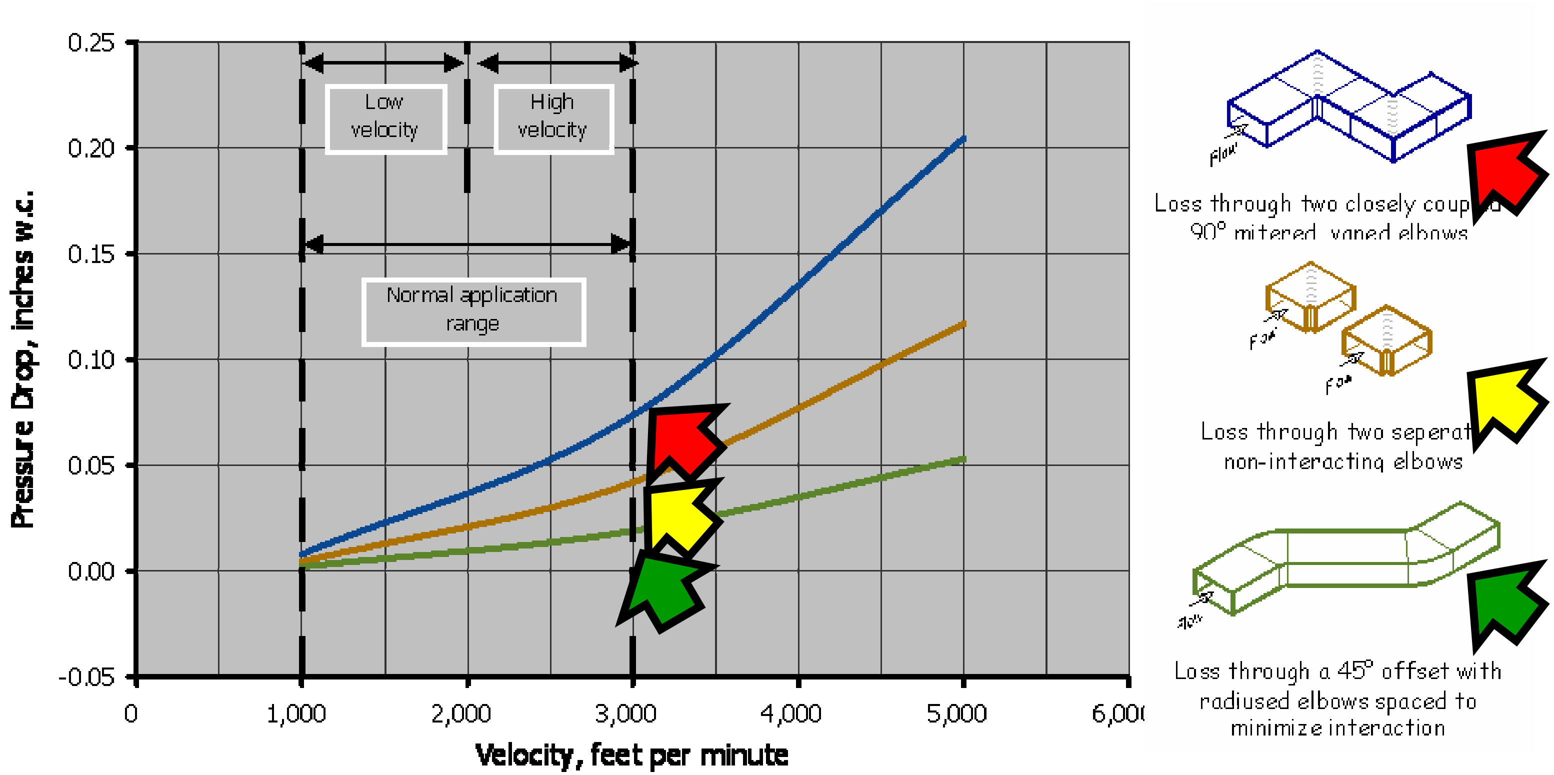
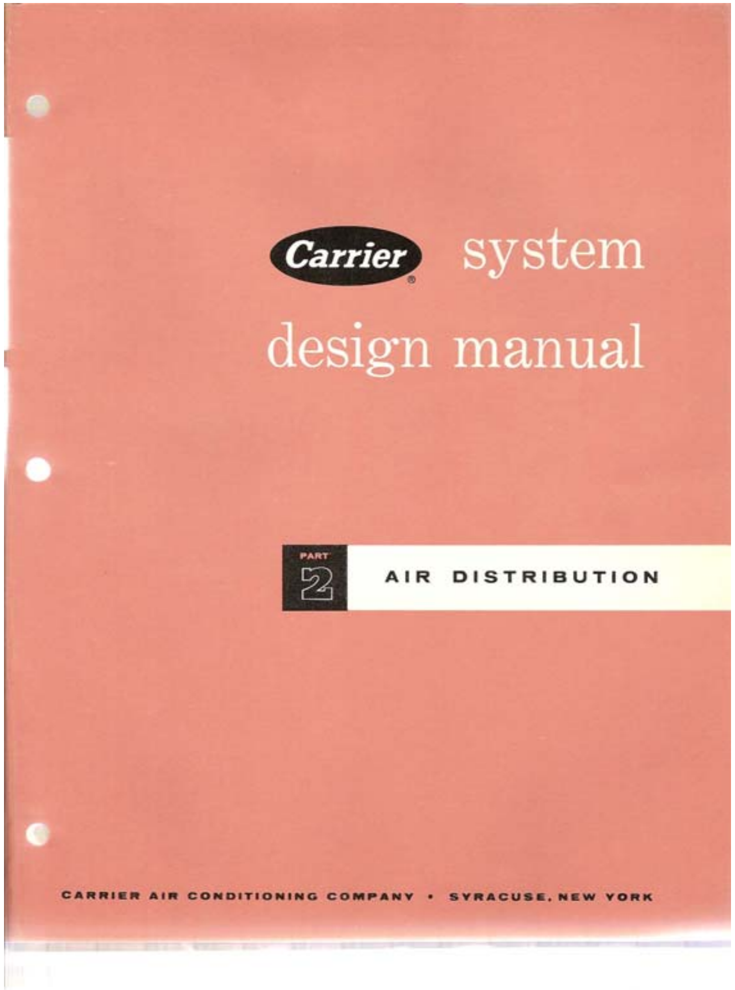
Fitting to Fitting Interactions = Big Difference

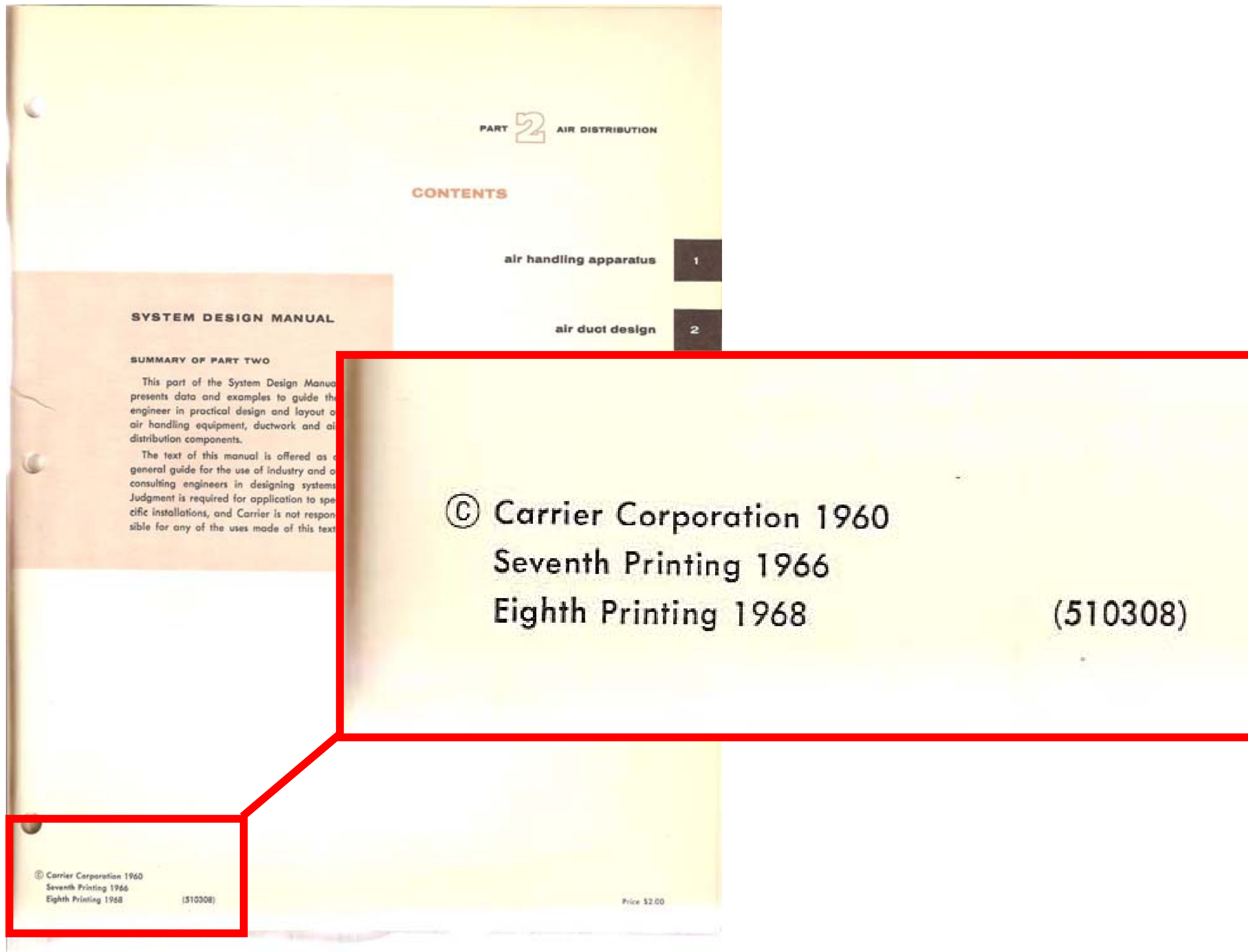
Close Coupled Elbows



Techniques For Addressing Fitting Losses Have Been Around for a While



Techniques For Addressing Fitting Losses Have Been Around for a While



Techniques For Addressing Fitting Losses Have Been Around for a While

TABLE 12—FRICTION OF RECTANGULAR ELBOWS

Duct Dimensions (in.) W	D	Radius Elbow No Vanes: Radius Ratio† R/D = 1.25	Radius Elbow—With Vanes‡: R_i = 6" (Recommended)	Vanes	Radius Elbow—With Vanes‡: R_i = 3" (Acceptable)	Vanes	Square Elbows‡: Double Thickness Turning Vanes	Square Elbows‡: Single Thickness Turning Vanes
		ADDITIONAL EQUIVALENT LENGTH OF STRAIGHT DUCT (FT)						
96	48	31	45	2	43	3	40	60
	36	25	36	2	31	3	30	45
	30	22	31	2	38	2	25	37
	24	19	33	1	29	2	20	30
	20	16	28	1	25	2	17	25
72	48	28	44	2	41	3	35	60
	36	23	33	2	29	3	29	45
	30	21	28	2	33	2	25	37
	24	17	29	1	25	2	21	30
	20	15	23	1	19	2	18	25
	16	13	18	1	16	2	15	20
	12	12			15	1	11	15
60	48	27	41	2	39	3	33	60
	36	22	31	2	27	3	27	45
	30	19	25	2	31	2	23	37
	24	16	27	1	26	2	20	30
	20	14	22	1	21	2	17	25
	16	12	16	1	15	2	13	20
	[illegible]	[illegible]						
48	96*	45	35	3				
	48	26	35	2	34	3	29	60
	36	20	26	2	22	3	23	45
	30	18	23	2	28	2	21	37
	24	15	24	1	21	2	18	30
	20	14	19	1	17	2	15	25
	16	11	15	1	14	2	12	20
	12	9			13	1	10	15
	10	8			11	1	8	12
	8	8			9	1	7	10
42	42	23	28	2	26	3	24	53
	36	20	24	2	21	3	22	45
	30	17	21	2	26	2	20	37
	24	15	21	1	19	2	16	30
	20	13	18	1	16	2	14	25
	16	11	14	1	13	2	12	20
	12	9			13	1	9	15
	10	8			10	1	8	12
	8	7			8	1	6	10
36	72*	34	27	3				
	36	19	22	2	19	3	20	45
	30	16	19	2	22	2	18	37
	24	14	20	1	22	2	15	30
	20	12	17	1	15	2	13	25
	16	10	13	1	12	2	11	20
	12	9			12	1	9	15
	10	8			9	1	8	12
	8	7			8	1	6	10
32	32	17	19	2	16	3	17	40
	30	16	18	2	21	2	17	37
	24	14	19	1	17	2	15	30
	20	12	16	1	14	2	12	25
	16	10	12	1	12	2	11	20
	12	8			12	1	8	15
	10	7			9	1	7	12
	8	6			8	1	6	10

2

Techniques For Addressing Fitting Losses Have Been Around for a While

TABLE 12—FRICTION OF RECTANGULAR ELBOWS

DUCT DIMENSIONS (in.)		RADIUS ELBOW NO VANES	RADIUS ELBOW—WITH VANES‡				SQUARE ELBOWS‡	
W	D	Radius Ratio† R/D = 1.25	R_t = 6″ (Recommended)		R_t = 3″ (Acceptable)		Double Thickness Turning Vanes	Single Thickness Turning Vanes
ADDITIONAL EQUIVALENT LENGTH OF STRAIGHT DUCT (FT)								
				Vanes		Vanes		
96	48	31	45	2	43	3	40	60
	36	25	36	2	31	3	30	45
	30	22	31	2	38	2	25	37
	24	19	33	1	29	2	20	30
	20	16	28	1	25	2	17	25
72	48	28	44	2	41	3	35	60
	36	23	33	2	29	3	29	45
	30	21	28	2	33	2	25	37
	24	17	29	1	25	2	21	30
	20	15	23	1	19	2	18	25
	16	13	18	1	16	2	15	20
	12	12			15	1	11	15
60	48	27	41	2	39	3	33	60
	36	22	31	2	27	3	27	45
	30	19	25	2	31	2	23	37
	24	16	27	1	26	2	20	30
	20	14	22	1	21	2	17	25
	16	12	16	1	15	2	13	20
	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]

The Effects of Multiple Fittings Were Recognized

2

TABLE 10—FRICTION OF RECTANGULAR DUCT SYSTEM ELEMENTS

ELEMENT	CONDITIONS	L/D RATIO †
Rectangular Radius Elbow	(see sub-table A)	
Rectangular Vaned Radius Elbow	(see sub-table B)	
X° Elbow	Vaned or Unvaned Radius Elbow	X/90 times value for similar 90° elbow
Rectangular Square Elbow	No Vanes	60
	Single Thickness Turning Vanes	15
	Double Thickness Turning Vanes	10
Double Elbow	S = O	15
W/D = 1, R/D = 1.25*	S = D	10
Double Elbow	S = O	20
W/D = 1, R/D = 1.25*	S = D	22
Double Elbow	S = O	15
W/D = 1, R/D = 1.25* For Both	S = D	16
Double Elbow	Direction of Arrow	45
W/D = 2, R_1/D = 1.25*, R_2/D = .5	Reverse Direction	40
Double Elbow	Direction of Arrow	17
[illegible]	Reverse Direction	[illegible]

Sub-table A — Rectangular Radius Elbow:

W/D	R/D .5	R/D .75	R/D 1.00	R/D 1.25*	R/D 1.50
	L/D Ratio				
.5	33	14	9	5	4
1	45	18	11	7	4
3	80	30	14	8	5
6	125	40	18	12	7

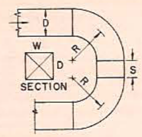
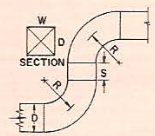
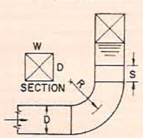
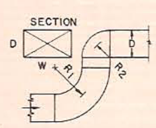
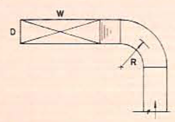
Sub-table B — Rectangular Vaned Radius Elbow:

Number of Vanes	R/D .50	R/D .75	R/D 1.00	R/D 1.50
	L/D Ratio			
1	18	10	8	7
2	12	8	7	7
3	10	7	7	6

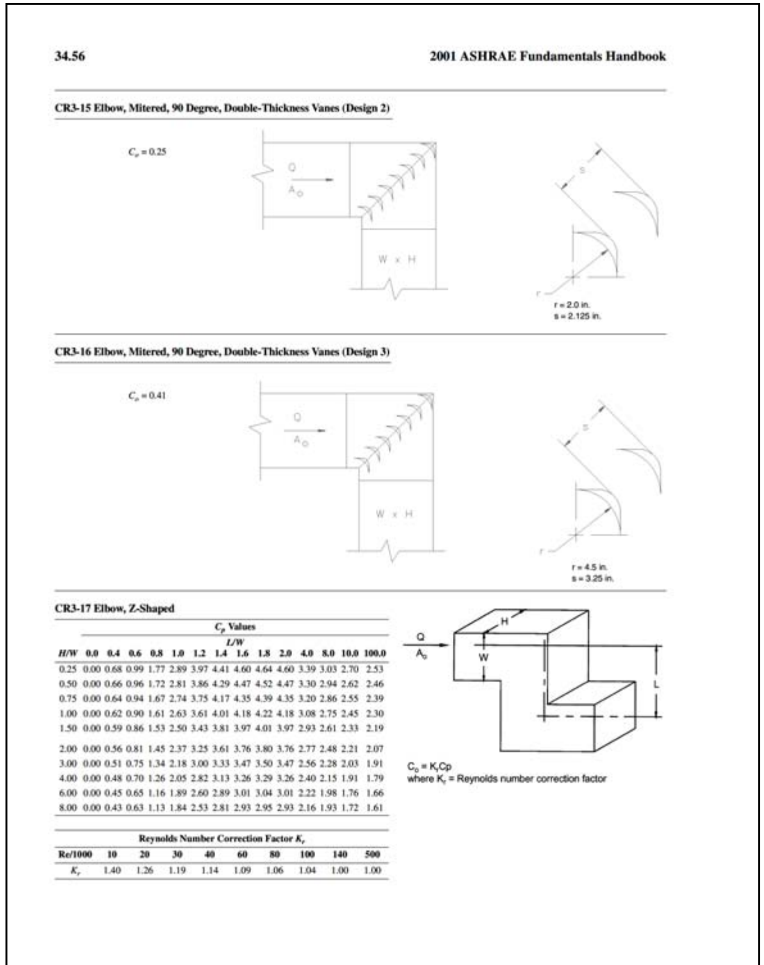
The Effects of Multiple Fittings Were Recognized

TABLE 12—FRICTION OF RECTANGULAR ELBOWS

DUCT	RADIUS ELBOW NO VANES	RADIUS ELBOW—WITH VANES‡	SQUARE ELBOWS‡

Double Elbow  W/D = 1, R/D = 1.25*	S = O S = D	15 10
Double Elbow  W/D = 1, R/D = 1.25*	S = O S = D	20 22
Double Elbow  W/D = 1, R/D = 1.25* For Both	S = O S = D	15 16
Double Elbow  W/D = 2, R_1/D = 1.25*, R_2/D = .5	Direction of Arrow Reverse Direction	45 40
Double Elbow 	Direction of Arrow	17

The Current ASHRAE Handbooks and Fitting Database Expand What we Know



CR3-15 Elbow, Mitered, 90 Degree, Double-Thickness Vanes (Design 2)

$C_o = 0.25$

CR3-16 Elbow, Mitered, 90 Degree, Double-Thickness Vanes (Design 3)

$C_o = 0.41$

CR3-17 Elbow, Z-Shaped

	C_p Values													
	L/W													
H/W	**0.0**	**0.4**	**0.6**	**0.8**	**1.0**	**1.2**	**1.4**	**1.6**	**1.8**	**2.0**	**4.0**	**8.0**	**10.0**	**100.0**
0.25	0.00	0.68	0.99	1.77	2.89	3.97	4.41	4.60	4.64	4.60	3.39	3.03	2.70	2.53
0.50	0.00	0.66	0.96	1.72	2.81	3.86	4.29	4.47	4.52	4.47	3.30	2.94	2.62	2.46
0.75	0.00	0.64	0.94	1.67	2.74	3.75	4.17	4.35	4.39	4.35	3.20	2.86	2.55	2.39
1.00	0.00	0.62	0.90	1.61	2.63	3.61	4.01	4.18	4.22	4.18	3.08	2.75	2.45	2.30
1.50	0.00	0.59	0.86	1.53	2.50	3.43	3.81	3.97	4.01	3.97	2.93	2.61	2.33	2.19
2.00	0.00	0.56	0.81	1.45	2.37	3.25	3.61	3.76	3.80	3.76	2.77	2.48	2.21	2.07
3.00	0.00	0.51	0.75	1.34	2.18	3.00	3.33	3.47	3.50	3.47	2.56	2.28	2.03	1.91
4.00	0.00	0.48	0.70	1.26	2.05	2.82	3.13	3.26	3.29	3.26	2.40	2.15	1.91	1.79
6.00	0.00	0.45	0.65	1.16	1.89	2.60	2.89	3.01	3.04	3.01	2.22	1.98	1.76	1.66
8.00	0.00	0.43	0.63	1.13	1.84	2.53	2.81	2.93	2.95	2.93	2.16	1.93	1.72	1.61

Reynolds Number Correction Factor K_r									
Re/1000	**10**	**20**	**30**	**40**	**60**	**80**	**100**	**140**	**500**
K_r	1.40	1.26	1.19	1.14	1.09	1.06	1.04	1.00	1.00

$C_o = K_r C_p$
where K_r = Reynolds number correction factor

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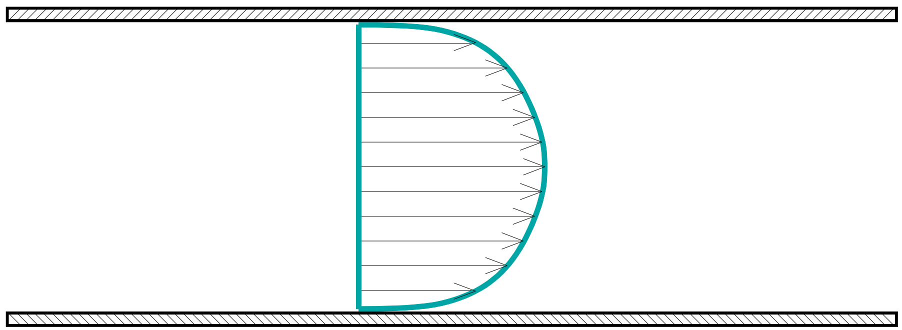
FLOW Relationships



From the Darcy - Weisbach Equation

$$H_L \propto V^2$$

Where :

H_L = **Friction loss for fully developed conduit flow**

V = **Fluid velocity**

Velocity Relationships

For fittings:

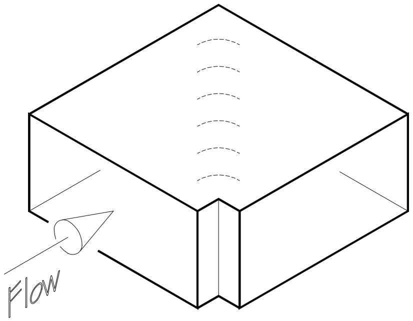
$$\Delta p_{fitting} = C_o \, p_{velocity}$$

Where:

$\Delta p_{fitting}$ = **Fitting pressure loss**

C_o = **Local loss coefficient**

$p_{velocity}$ = **Velocity pressure**



Velocity pressure is VERY significant:

$$V = 4{,}005\sqrt{p_{velocity}}$$

Therefore:

$$p_{velocity} = \left(\frac{V}{4{,}005}\right)^2$$

As with Most Relationships …

There are games to be played!

- Low aspect ratio or round ducts may be more sustainable
  - Square shafts vs. long thin shafts
  - Accommodate deeper ceiling space requirements with:
    - Soffits for main ducts
    - Exposed ductwork

As with Most Relationships …

… there are games to be played!

Looking at Different Options for Moving 10,000 cfm at a Nominal .2 in.w.c./100 ft., 2 inch Pressure Class Duct

Duct Size - inches			Aspect Ratio	Cross Sectonal Area - sq.ft.	Perimeter - ft.	Ratio of Cross Sectional Area to Perimeter	Gauge	Pounds of Sheetmetal per lineal foot of duct	Velocity - fpm
Height	Width	Diameter							
N/A	N/A	29.0	N/A	4.59	7.59	0.60	24	9.10	2,180
26.5	26.5	N/A	1.0	4.88	8.83	0.55	26	8.00	2,051
18.0	41.0	N/A	2.3	5.13	9.83	0.52	24	11.37	1,951
14.0	56.0	N/A	4.0	5.44	11.67	0.47	24	13.49	1,837
12.0	70.0	N/A	5.8	5.83	13.67	0.43	24	15.80	1,714

Round duct weight information based on spiral construction.

But, Sometimes you Win …

… and some times, you loose.

Velocities and Velocity Pressures in Small vs. Large Ducts at Equal Friction Rates

Duct Size - inches			Aspect Ratio	Cross Sectional Area - sq.ft.	Perimeter - ft.	Ratio of Cross Sectional Area to Perimeter	CFM Capcity at a Friction Rate of .15 in.w.c. per 100 ft.	Velocity - fpm	Velocity Pressure - in.w.c.
Height	Width	Diameter							
N/A	N/A	6.0	N/A	0.20	1.57	0.13	130	662	0.03
N/A	N/A	48.0	N/A	12.57	12.57	1.00	32,000	2,5[illegible]	0.40
6.0	12.0	N/A	2.0	0.50	3.00	0.17	420	840	0.04
24.0	48.0	N/A	2.0	8.00	12.00	0.67	16,500	2,063	0.27

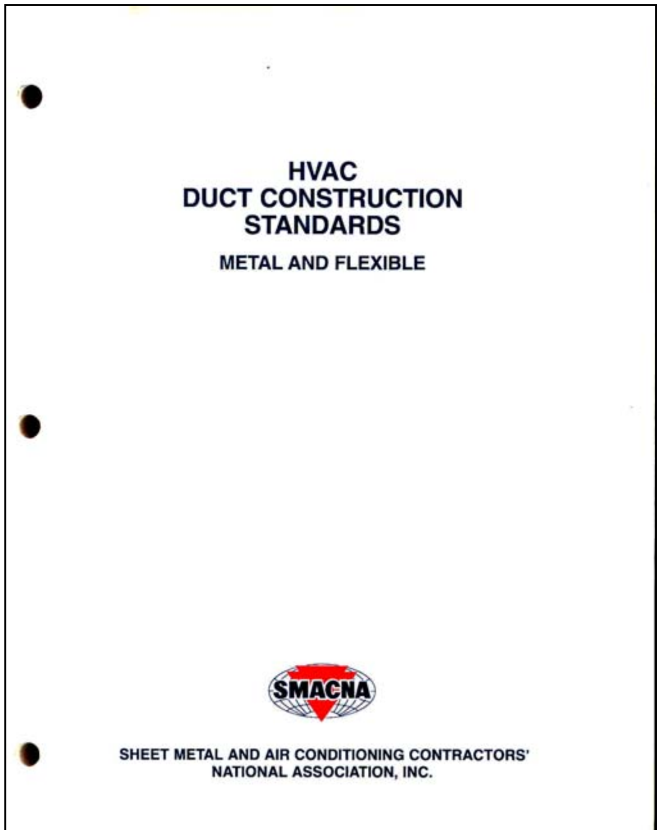
But, Sometimes you Win …

… and some times, you loose.

Velocities and Velocity Pressures in Small vs. Large Ducts at Equal Friction Rates

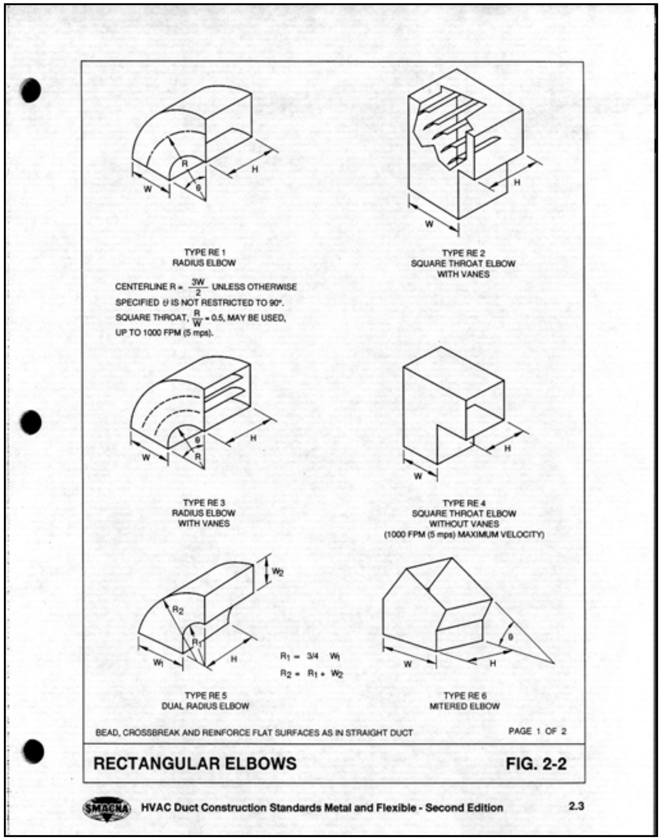
Duct Size - inches			Aspect Ratio	Cross Sectonal Area - sq.ft.	Perimeter - ft.	Ratio of Cross Sectional Area to Perimeter	CFM Capcity at a Friction Rate of .15 in.w.c. per 100 ft.	Velocity - fpm	Velocity Pressure - in.w.c.
Height	Width	Diameter							
N/A	N/A	6.0	N/A	0.20	1.57	0.13	130	66[illegible]	0.03
N/A	N/A	48.0	N/A	12.57	12.57	1.00	32,000	2,546	0.40
6.0	12.0	N/A	2.0	0.50	3.00	0.17	420	8[illegible]	0.04
24.0	48.0	N/A	2.0	8.00	12.00	0.67	16,500	2,063	0.27

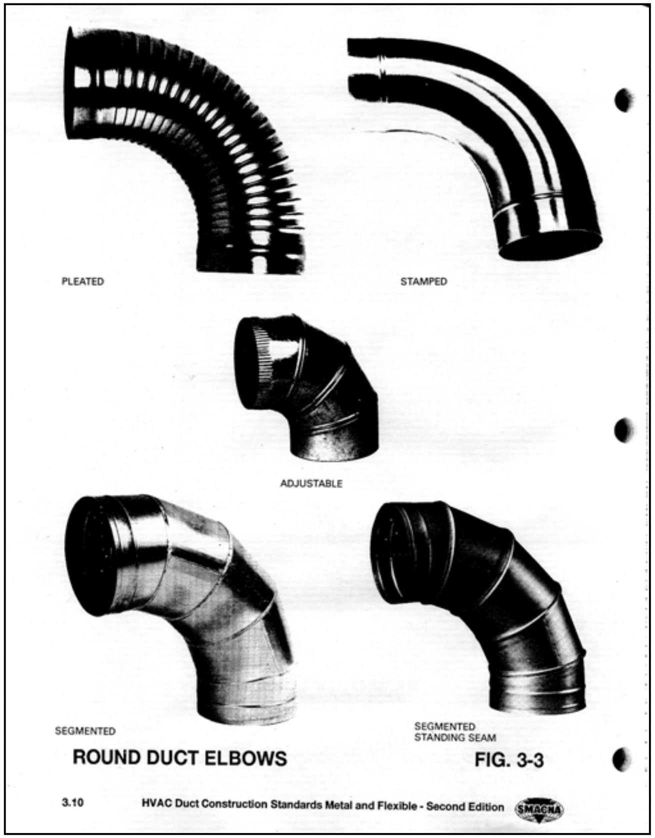
Specifying SMACNA is a Good Start



… but it's not a design solution!

SMACNA Elbow Standards





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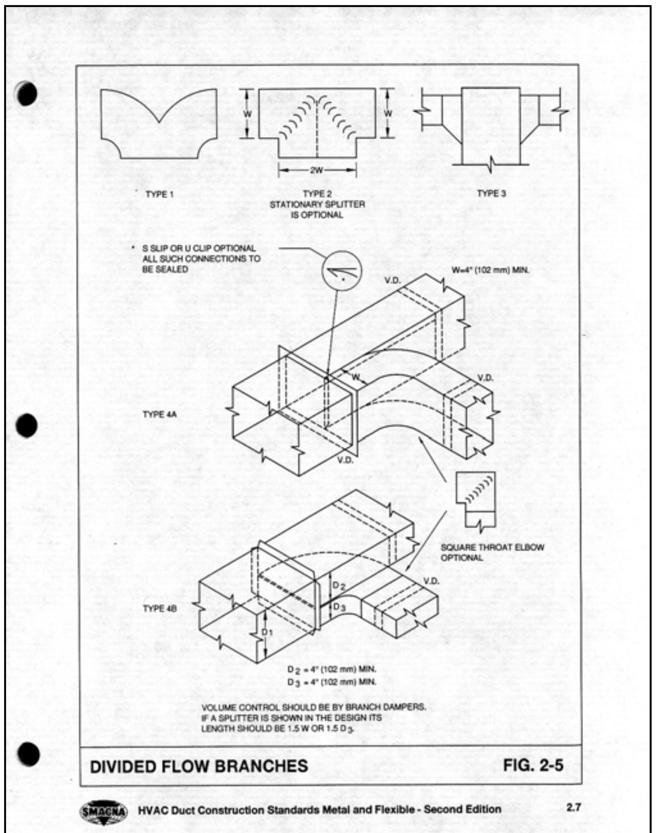
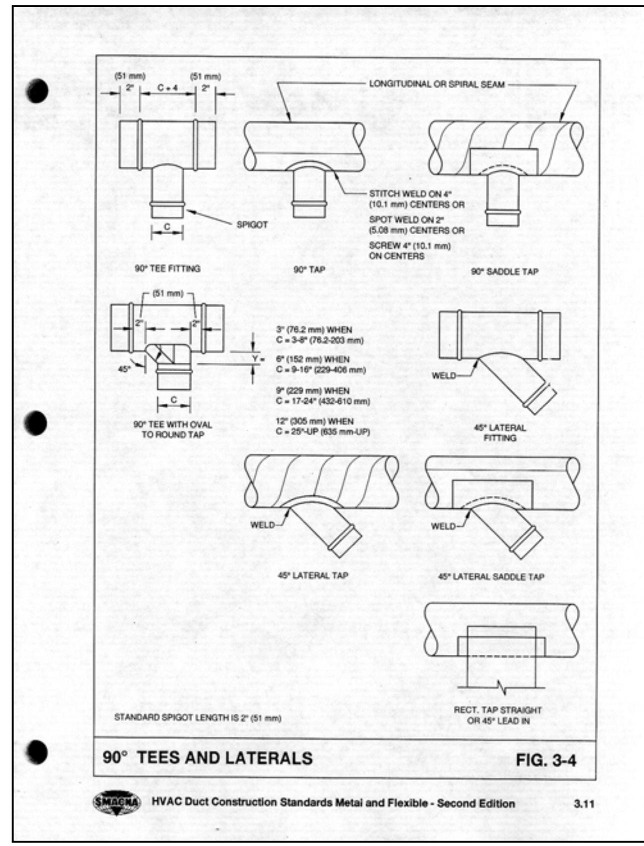
SMACNA Flow Division Standards





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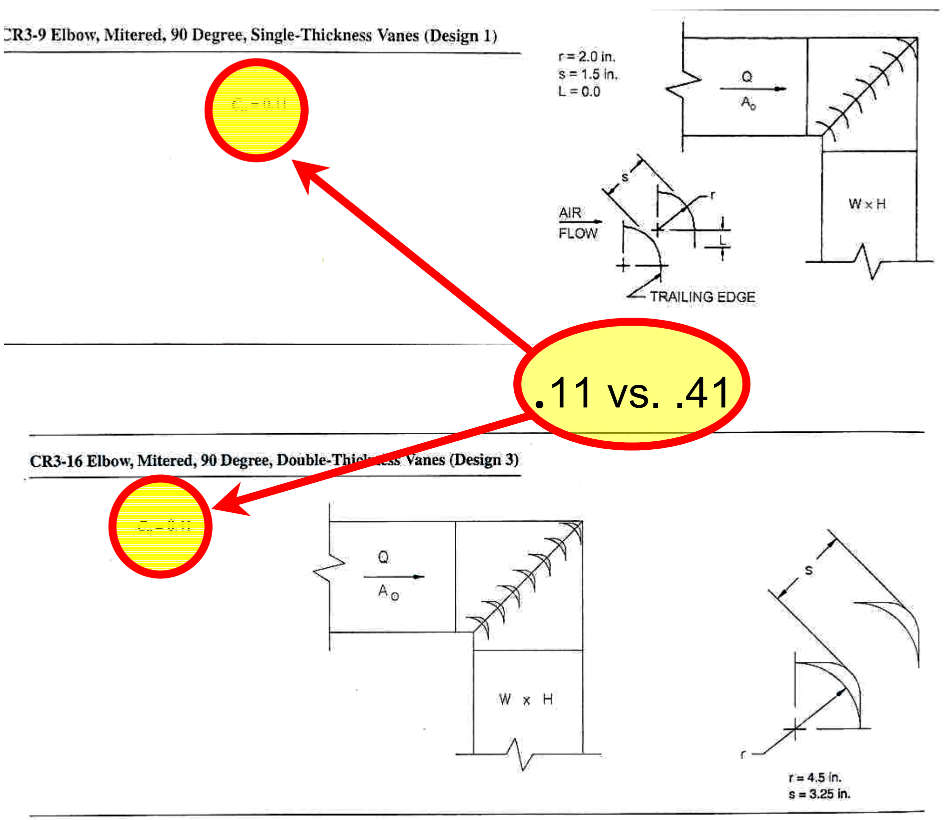
Duct Elbows

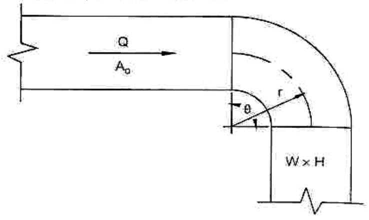


Turning vane design significantly impacts mitered elbow performance!

Duct Elbow Losses

CR3-1 Elbow, Smooth Radius, Without Vanes

$C_o = KC_p$ where K = angle factor



1.53 vs .15

C_p Values

r/W	[illegible]	[illegible]	0.75	1.00	1.50	2.00	3.00	4.00	5.00	6.00	8.00
					H/W						
0.50	1.53	[illegible]	1.29	1.18	1.06	1.00	1.00	1.06	[illegible]	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	[illegible]	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	[illegible]	0.15

Angle Factor K

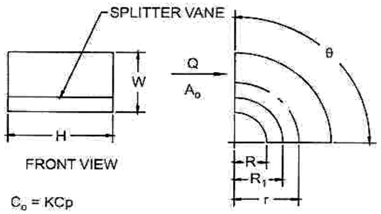
θ	0	20	30	45	60	75	90	110	130	150	180
K	0.00	0.31	0.45	0.60	0.78	0.90	1.00	1.13	1.20	1.28	1.40

CR3-3 Elbow, Smooth Radius, One Splitter Vane

.52 vs.05

C_p Values

r/W	0.25	[illegible]	1.00	1.50	2.00	3.00	4.00	5.00	6.00	7.00	8.00
					H/W						
[illegible]	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	[illegible]	0.30	0.32
0.70	0.22	0.16	0.14	0.14	0.15	0.16	0.17	0.18	[illegible]	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	[illegible]	0.12
0.85	0.13	0.09	0.08	0.07	0.07	0.08	0.08	0.08	0.08	[illegible]	0.09
0.90	0.11	0.08	0.07	0.06	0.06	0.06	0.06	0.07	0.07	[illegible]	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



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

Angle Factor K

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

Curve Ratio CR

r/W	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00
CR	0.218	0.302	0.361	0.408	0.447	0.480	0.509	0.535	0.557	0.577

Throat Radius/Width Ratio (R/W)

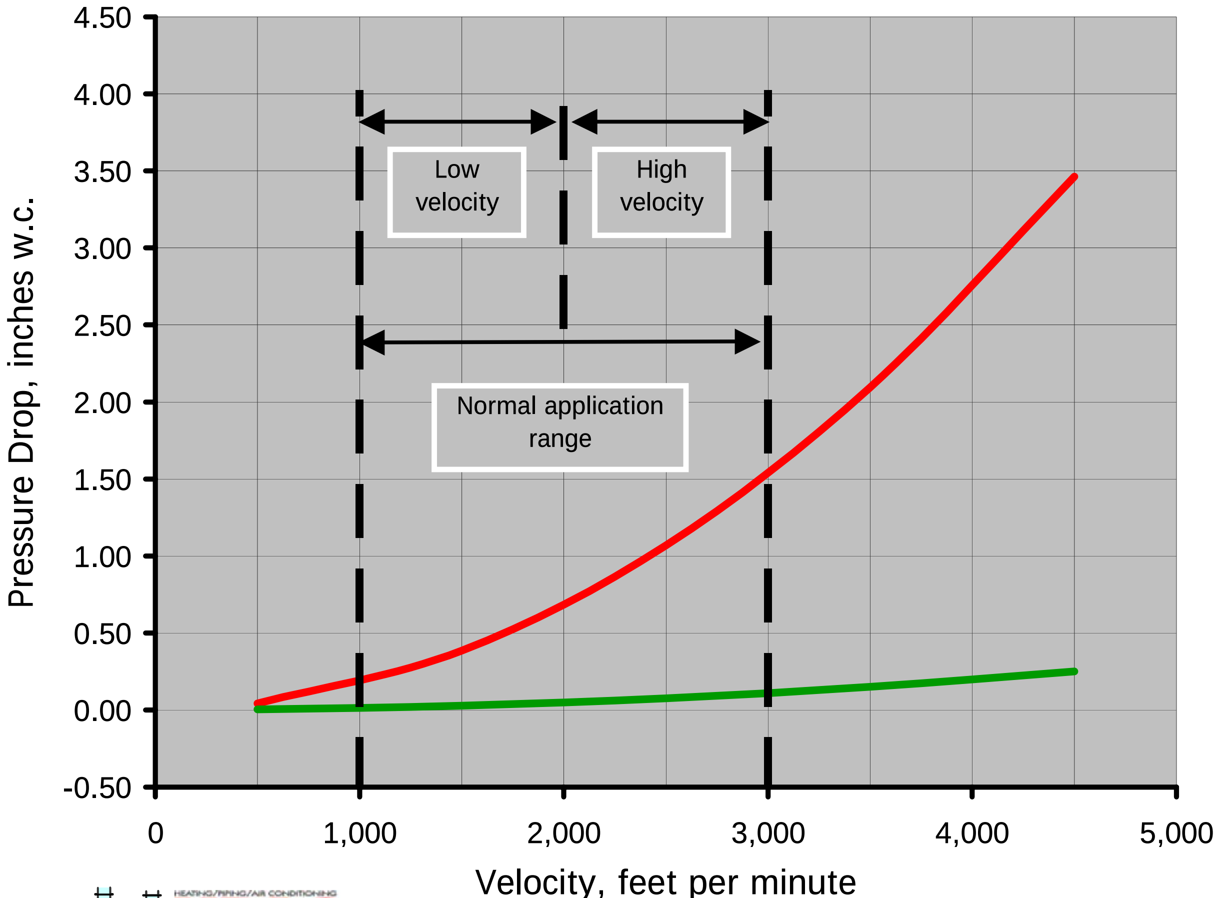
r/W	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00
R/W	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50

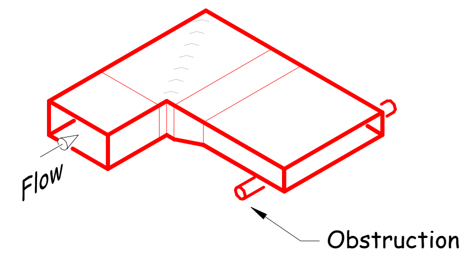
Minor design differences

=

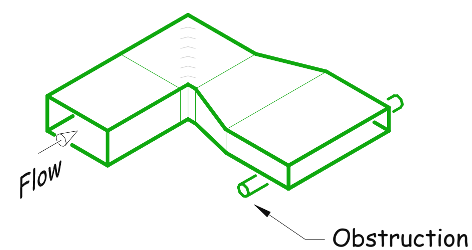
Major loss differences!

How I Learned About This





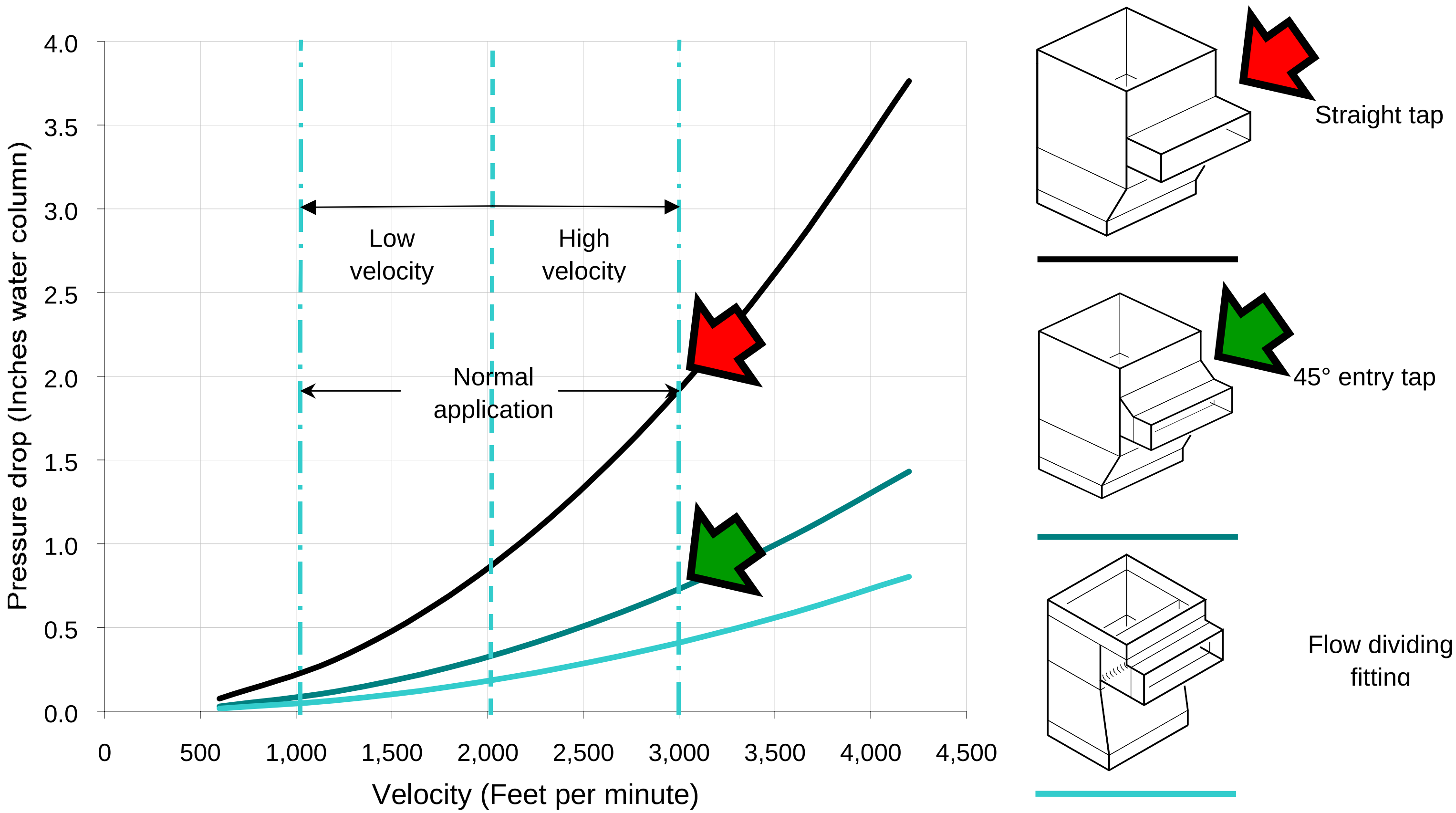
Dimension change made in a turn with an expanding elbow



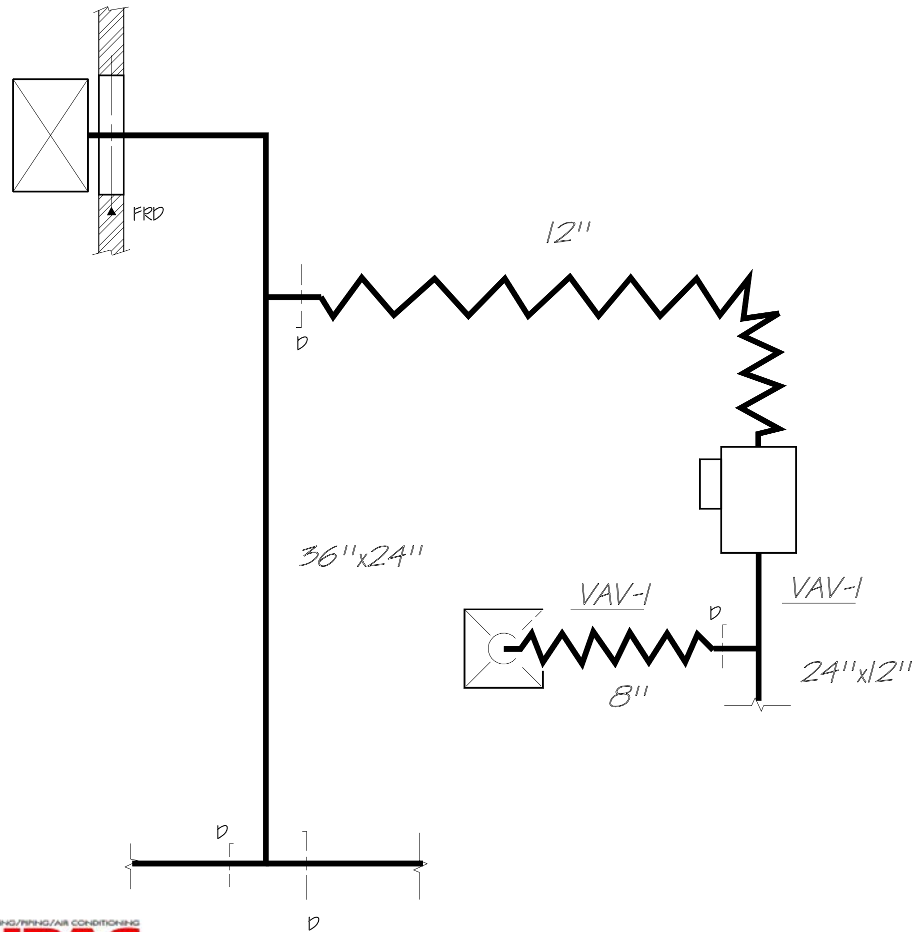
Dimension change made by expanding after the elbow

Details Matter

Minor cost addition = Major energy reduction

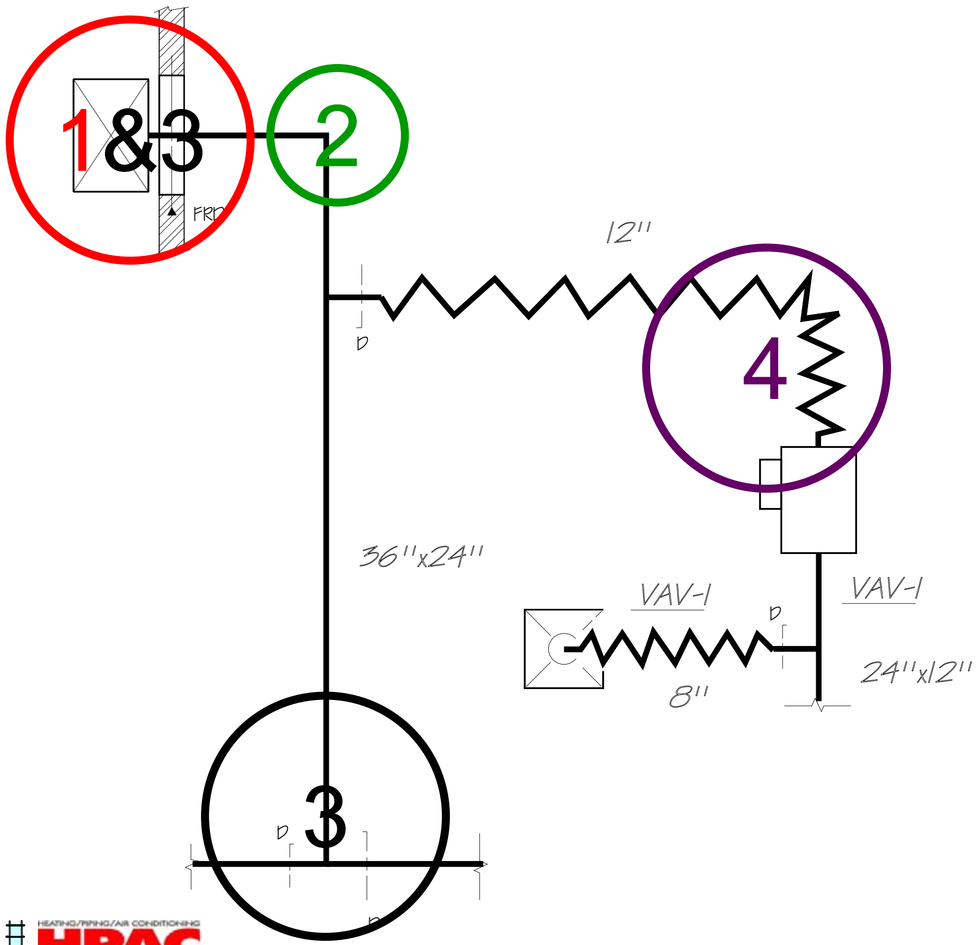


Single Line Drawings



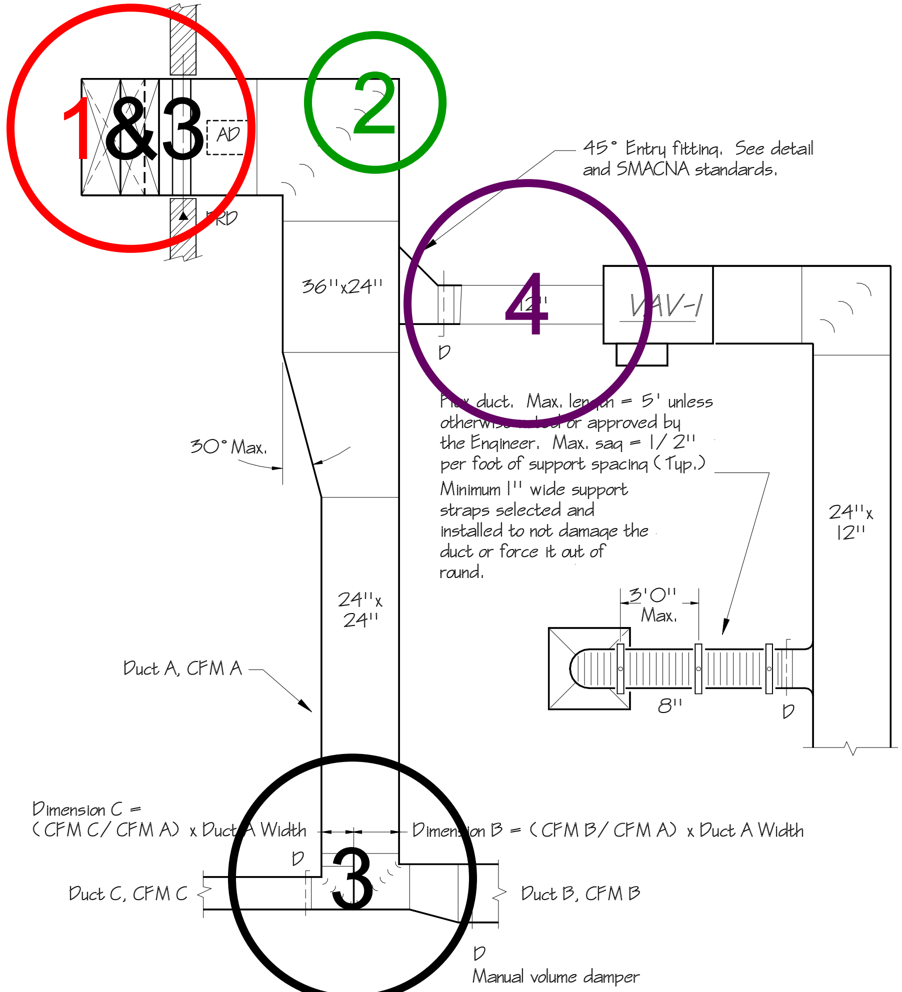
- Single Line Duct Drawings
  - Contain all the basic information
  - Are subject to interpretation
  - May introduce their own problems

Single Line Problems



1. Fire damper issues
2. Turn geometry issues
3. Flow division issues
4. Terminal unit issues

Double Line Solutions



Double line duct drawings clarify many of the issues noted in the previous slide

One Thing Leads to Another

The fan horsepower used in moving air results in heat the becomes part of the room sensible load, provided the fan is on the leaving air side of the conditioner. If the fan is on the entering air side, the fan heat becomes part of the refrigeration load, but not of the room sensible heat.

Dr. Willis Carrier

One Thing Leads to Another

Example:

- Draw through system, motor in the air stream
- 20°F supply air to space temperature differential
- Fan static = 4 inches w.c.
- Fan heat = 10% of the sensible cooling capacity!

One Thing Leads to Another

The power of the chilled water circulating pump is a heat gain similar to that of the fan, but is added to the total heat since it affects only the refrigeration load.

Dr. Willis Carrier

One Thing Leads to Another

Example:

- Chilled water system; 1,000 full load hours per year
- 2 gpm per ton circulated at 75 ft.w.c. head with 70% pump efficiency
- Pump heat accounts for 10% of the total cooling ton hours furnished by the plant!

One Thing Leads to Another …

- The bottom line:
  - Fan static becomes fan power
  - Fan power becomes cooling load leading to:
    - Bigger pumps and refrigeration machines
    - Additional cooling load due to the extra pump heat
    - Cooling tower capacity due to the additional chiller motor efficiency losses associated with the larger chiller
  - Interested in learning more?
    - See Jerry William's Fan Heat Articles Published in HPAC in September and October of 2005

Want To Learn More?

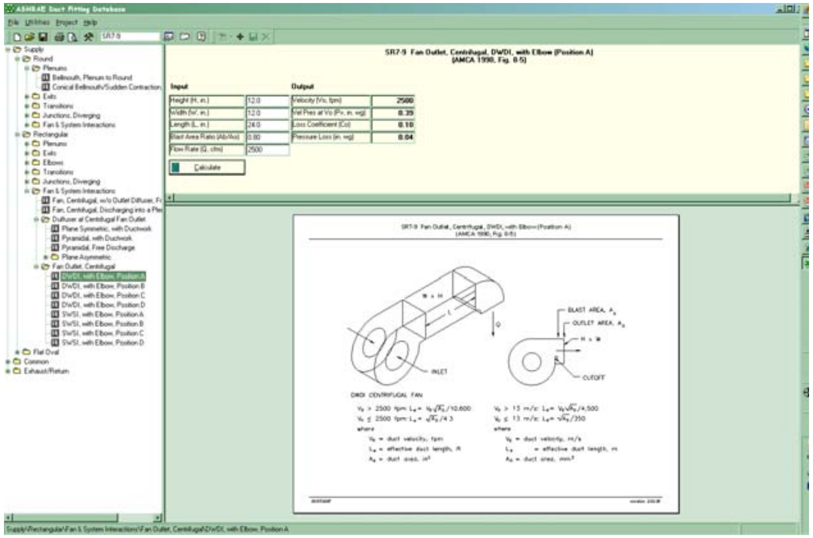
Go to www.HPAC.com

- Subscribe!
- Use the on-line resources

Want To Learn More?

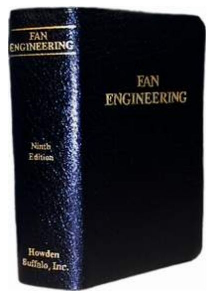
Use the resources available from vendor web sites like our sponsor's at www.ebmpapst.us

Want To Learn More?



Take advantage of resources like the ASHRAE Duct Fitting Database and the ASHRAE Handbooks

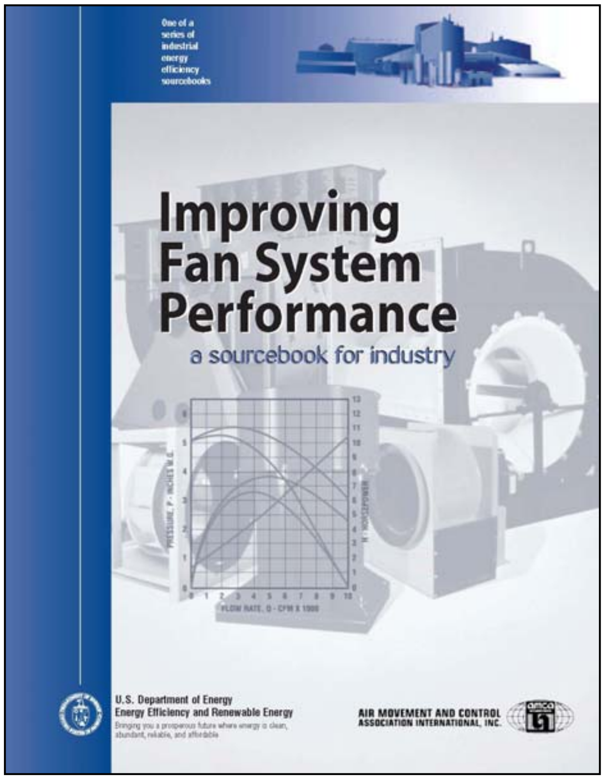
Want To Learn More?



- Purchase the Buffalo Fan Engineering Handbook
  - Order on line from http://www.howdenbuffalo.com/
  - Look in a used book store

- Purchase Air Movement and Control Association International (AMCA) publications
  - 200 – Air Systems
  - 201 – Fans and Systems
  - 202-88 – Troubleshooting
  - 203 – Performance Testing
  - Order on line from http://www.amca.org/

Want To Learn More?



Make use of publicly available resources:

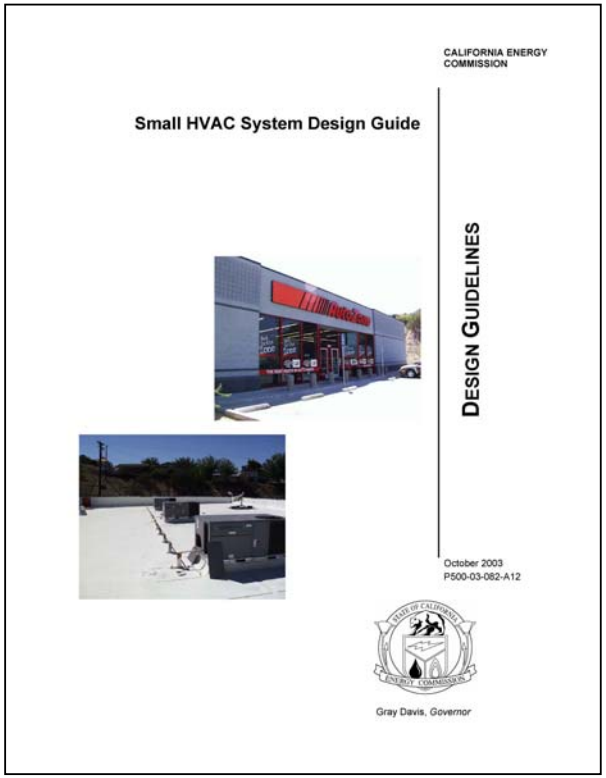
- The DOE/AMCA sourcebook *Improving Fan System Performance* can be downloaded at http://industrial-energy.lbl.gov/node/297

Want To Learn More?

Make use of publicly available resources:

– The *Advanced VAV System Design Guide* can be downloaded at *http://energy.ca.gov/reports/2003-11-17_500-03-082_A-11.PDF*

Want To Learn More?



CALIFORNIA ENERGY COMMISSION

Small HVAC System Design Guide

DESIGN GUIDELINES

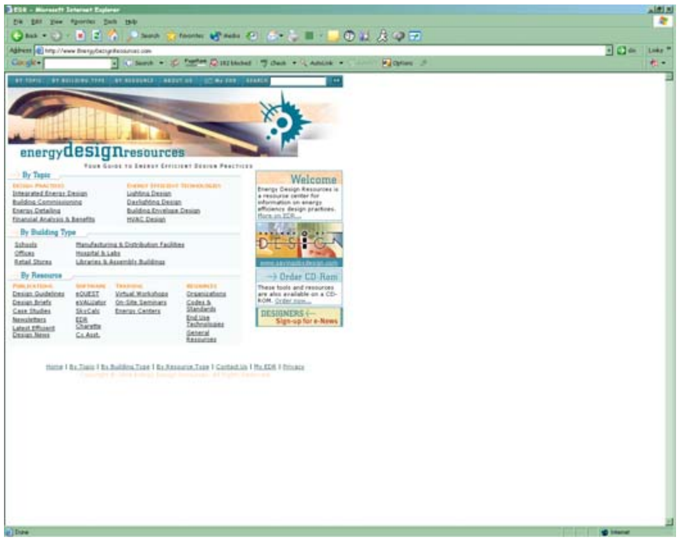
October 2003
P500-03-082-A12

Gray Davis, *Governor*

Make use of publicly available resources:

- The *Small HVAC System Design Guide* can be downloaded at *http://www.energy.ca.gov/reports/2003-11-17_500-03-082_A-12.PDF*

Want To Learn More?



Energy Design Resources offers:

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- Training

Visit them at
www.energydesignresources.com

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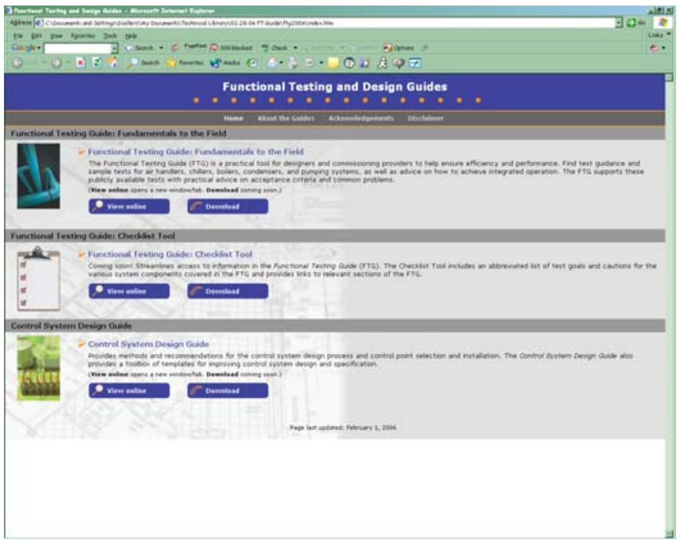

The *Functional Testing and Design Guides* at www.peci.org/ftguide provide field insights into design and operational issues related to fans and the utility systems that support them

Want To Learn More?

The Pacific Energy Center

- Training for Californian's in their service territory.
- Some classes available as web broadcasts

And, they have a tool lending library!

Find out more at www.pge.com/pec/

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Get a Field Perspective on Design!

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  - May 2-4, 2007
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  - The Sheraton Towers
- Learn Techniques
- Meet other Providers, Owners, and Researchers
- Share Ideas
- Attend the Trade Show
- Eat, Drink and Be Merry!
- Go to www.PECI.org for details

Questions?

Thanks for attending!

Go make the world a better place