16th NATIONAL CONFERENCE ON BUILDING COMMISSIONING

Design Phase Commissioning and the Rest of Life

The Impact of Design Phase Issues on Construction and On-going Operation and Maintenance

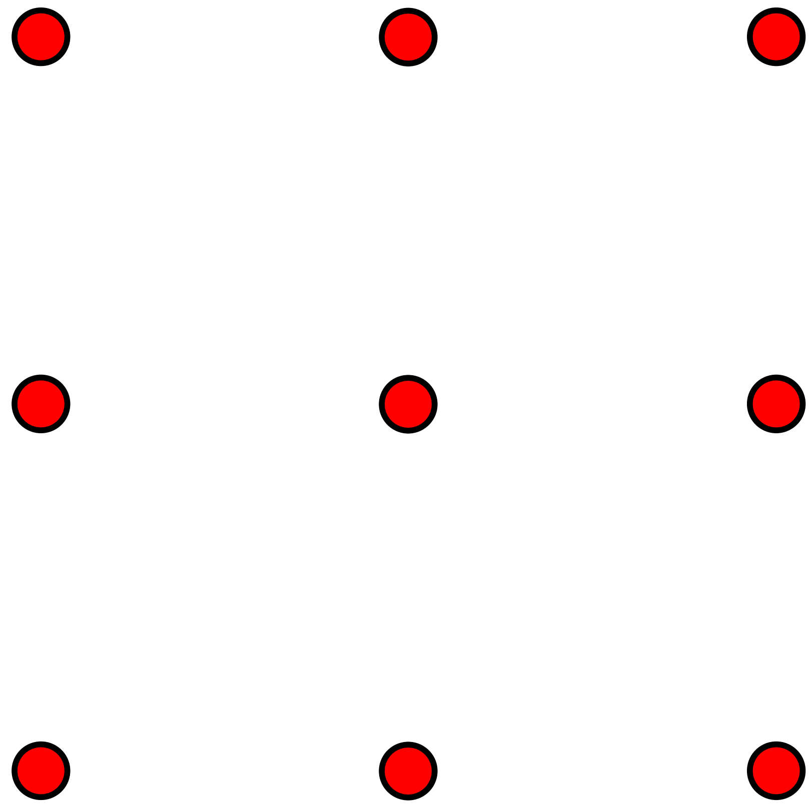
Presented By:
David Sellers, Senior Engineer
Facility Dynamics Engineering

Design Phase Commissioning; Implications Beyond Design Phase

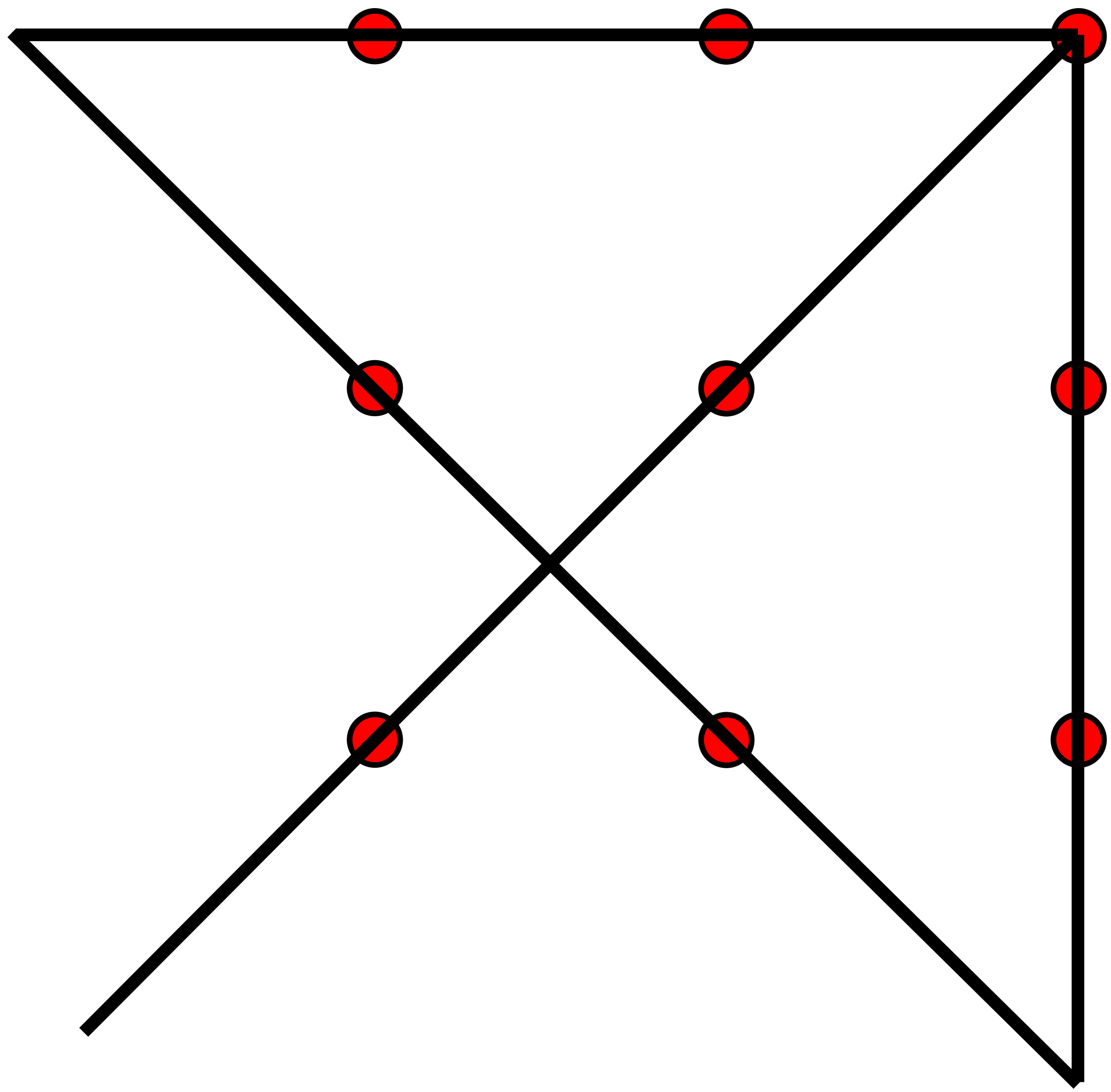
- If somebody doesn't pay attention to the details the first time around, then Mother Nature will bring them to your attention later
- Lessons learned make your future projects better, no matter how you learned them

Innovation and Design Phase Commissioning Go Hand-in-Hand

Connect all of the dots with 4 straight lines with out lifting your pencil and with out retracing a line

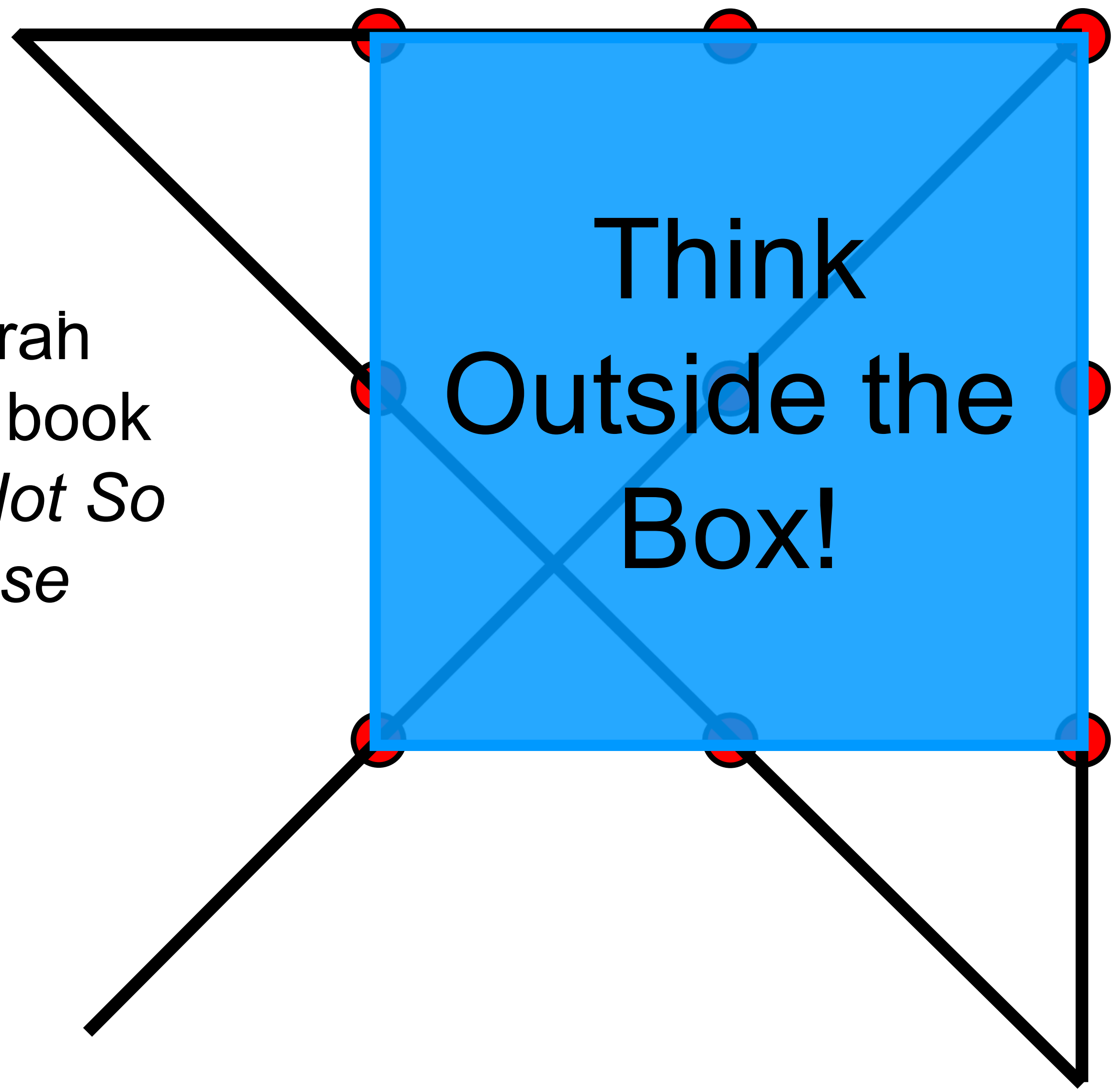


Innovation and Design Phase Commissioning Go Hand in Hand



Innovation and Design Phase Commissioning Go Hand in Hand

From Sarah Susanka's book titled *The Not So Big House*

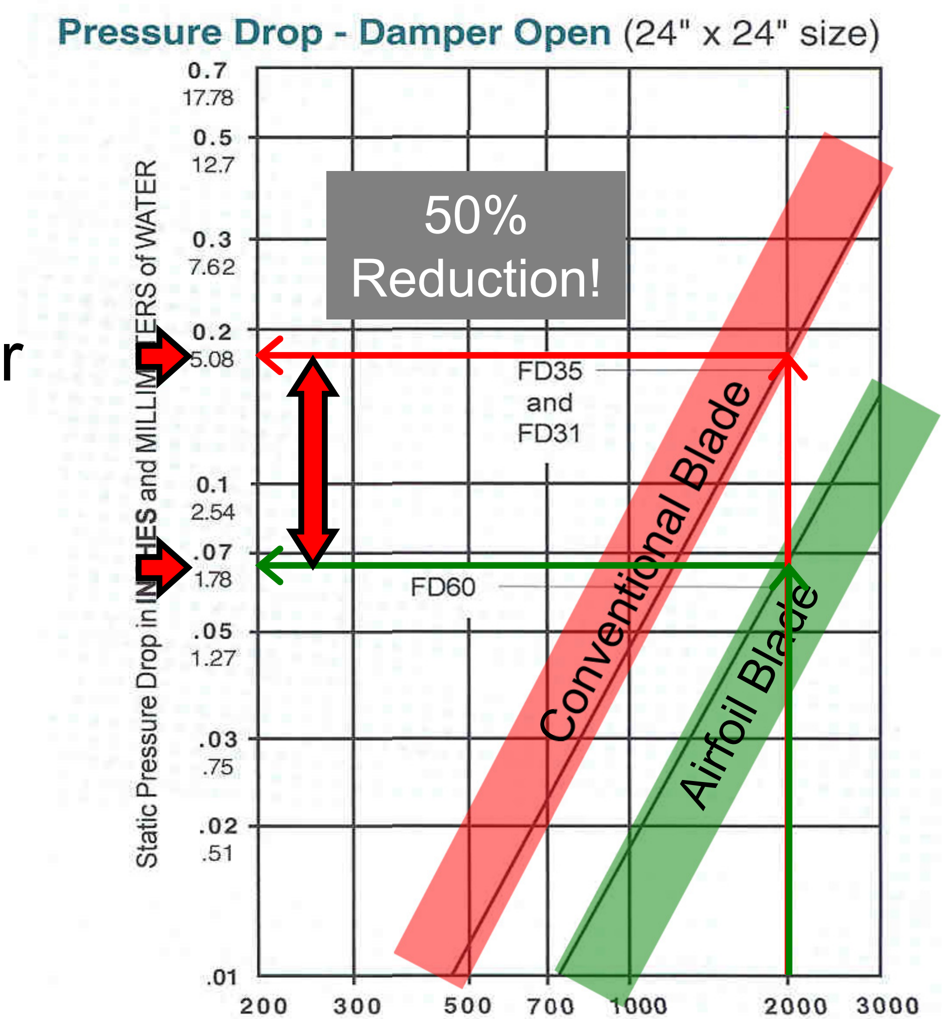


Design is the Time to Capture Savings

- Design time well spent leads to:
  - Project capital expenditures that are optimized
  - Operating costs that are optimized
  - Equipment life cycles that are maximized

Minimizing Pressure Drop to Capture Savings

- Upgrade smoke dampers to airfoil blade design
- Savings potential = 50%+ reduction in pressure drop for every hour of operation



Savings via a blade design change

Horse power = (Flow in cfm) x (Fan static pressure in in.w.c.)/(Coversion constant x Fan efficiency x Motor efficiency)

Flow rate = 46,687 cfm

Static pressure eliminated = 0.23in.w.c. (Ruskin data for an FD60 at 3,000 fpm)

Assumed fan efficiency = 80%

Assumed motor efficiency = 85%

Fan horse power = 2.43hp.

Kw = 1.81

Operating hours per year = 2,600

Annual kWh savings potential = 4,714 kWh per year

Assumed electrical cost = $0.0750 $/kWh

Annual savings potential for AHU9 = $354 per year

The Simple Payback at Design

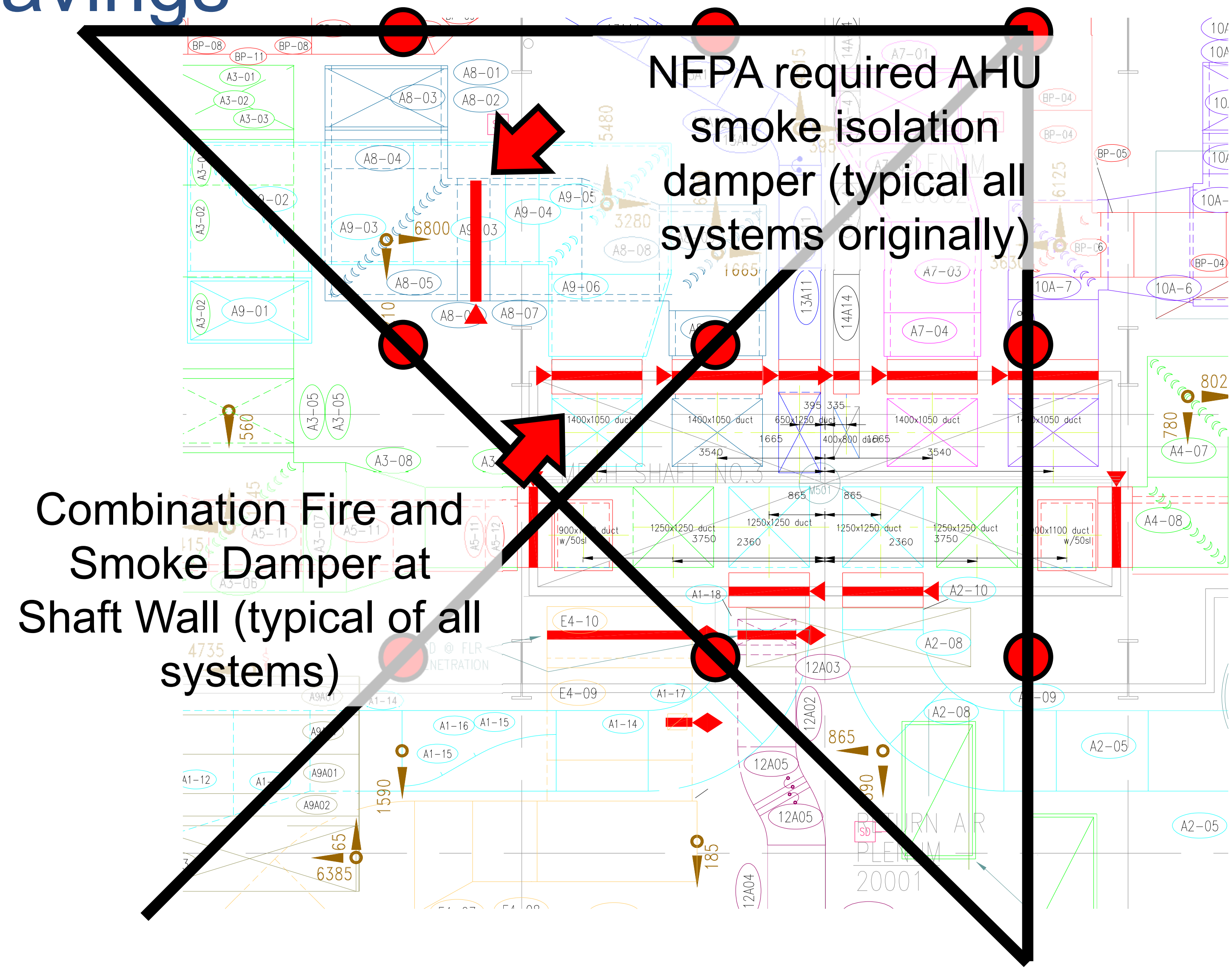
Damper area =	15.82	sq.ft.
Conventional blade cost per square foot =	$88	
Airfoil blade cost per square foot =	$104	
Cost difference for this damper =	$257	
Simple payback =	0.73	years

- The payback decays rapidly if the change is not made until after the damper is purchased or installed!

Thinking Outside the Box to Capture Savings

- Coordinating code and life safety requirements eliminates dampers
  - Operating cost savings
  - First cost savings

Thinking Outside the Box to Capture Savings



Operating Cost Savings

Horse power = (Flow in cfm) x (Fan static pressure in in.w.c.)/(Coversion constant x Fan efficiency x Motor efficiency)

Flow rate = 46,687 cfm

Static pressure eliminated = 0.18in.w.c. (Ruskin data for an FD60 at 3,000 fpm)

Assumed fan efficiency = 80%

Assumed motor efficiency = 85%

Fan horse power = 1.89 hp.

Kw = 1.41

Operating hours per year = 2,600

Annual kWh savings potential = 3,666 kWh per year

Assumed electrical cost = $0.0750 $/kWh

Annual savings potential for AHU9 = $275 per year

For 16 air handling units = $4,400 per year

First Cost Savings

Supply damper area =	15.82	sq.ft.
Damper first cost =	$104	$/sq.ft.

	One Unit	All Units
Supply damper savings	$1,642	$26,266
Return damper savings	$3,283	$52,532
Total savings	$4,925	$78,798

- This does not include the installation costs and wiring, so the actual savings could easily be twice this much!

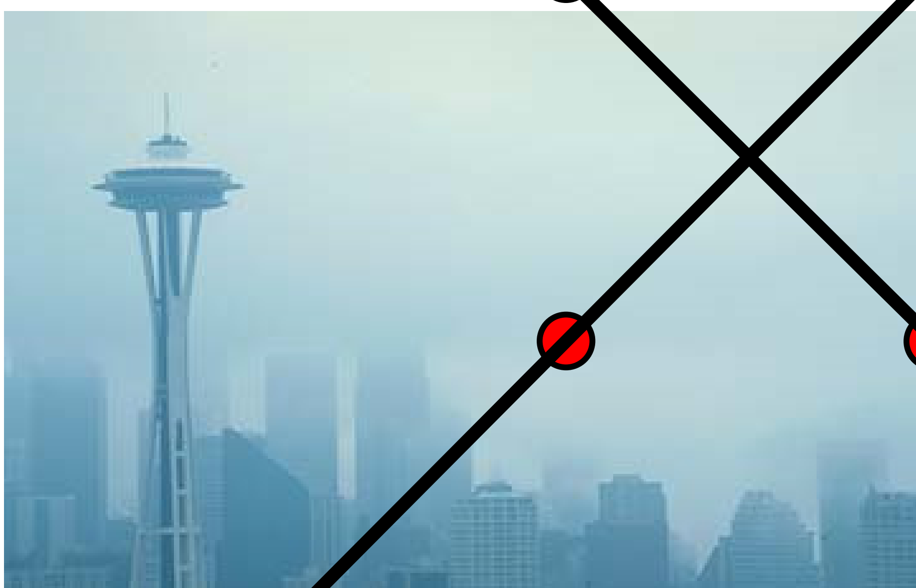
Design is the Time to Capture Intent

- *Design Intent* is integral to the commissioning process
  - Defines functional testing requirements
  - Defines acceptance requirements
  - Defines on-going operating parameters

Thinking Outside the Box in Seattle

The Owners intent to provide a high quality internal environment leads the commissioning provider to ask a question during a design review meeting

Do we really need to humidify in Seattle?



Hmmmm, lets think about that for a minute ….

Looking Humidification in the Bigger Picture

- Lost
  - Absolute assurance that indoor humidity will not be below 30% for 100 hours per year
- Gained
  - $100,000 savings in first cost
  - $6,000 savings in annual operating cost

Design Details and Excellence Go Hand in Hand

The magic behind every outstanding performance is always found in the smallest of details

Gary Ryan Blair

http://ezinearticles.com/?Pay-Attention-to-Details&id=245279

What Kind of Details Matter in HVAC?

- Application – Is there a match?

2000 ASHRAE Systems and Equipment Handbook

To get here

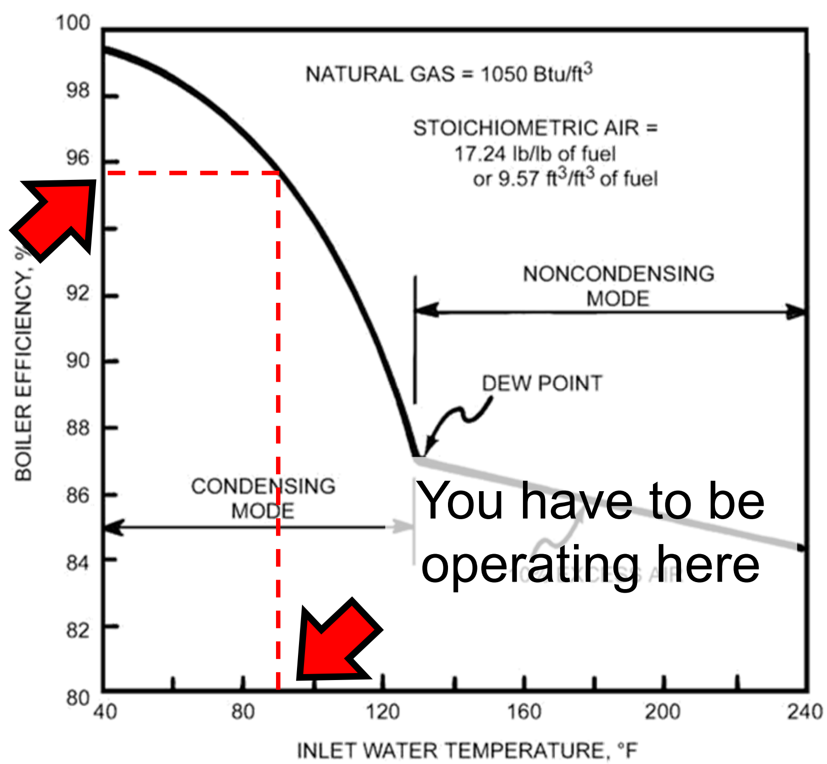
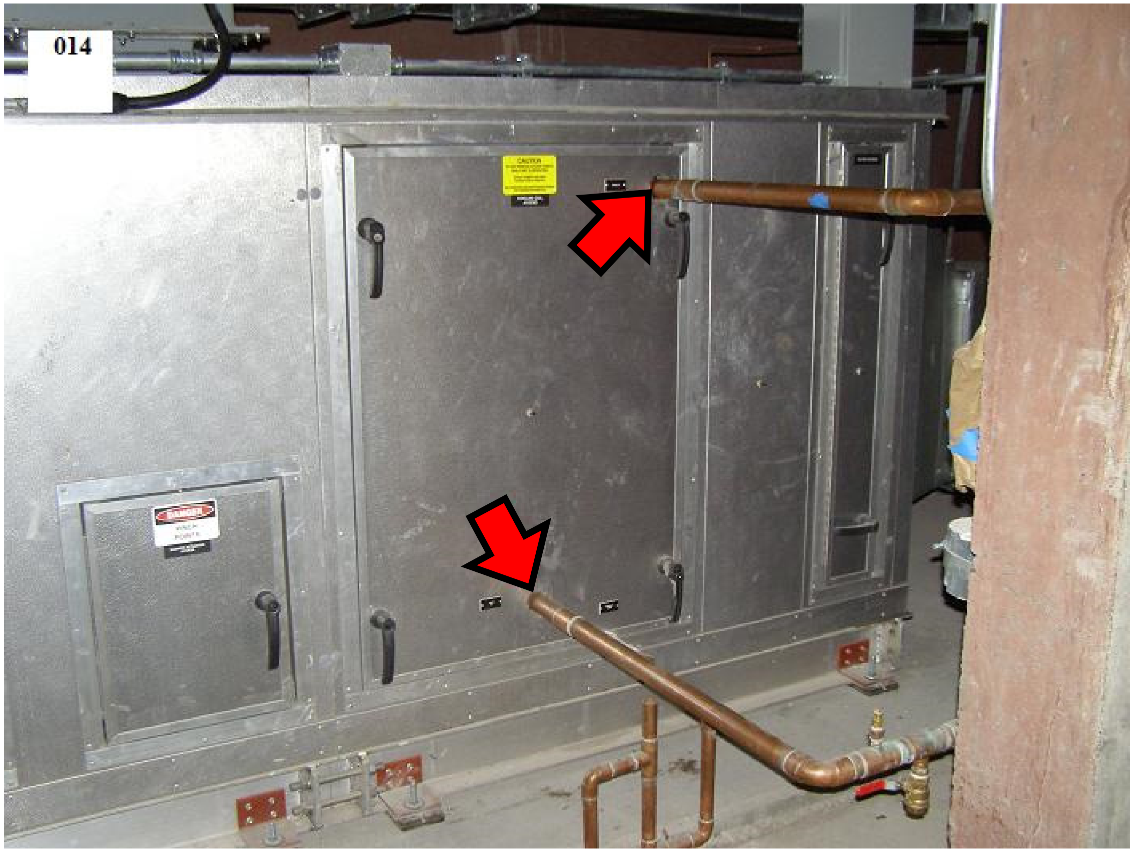


Fig. 5 Effect of Inlet Water Temperature on Efficiency of Condensing Boilers

What Kind of Details Matter in HVAC?

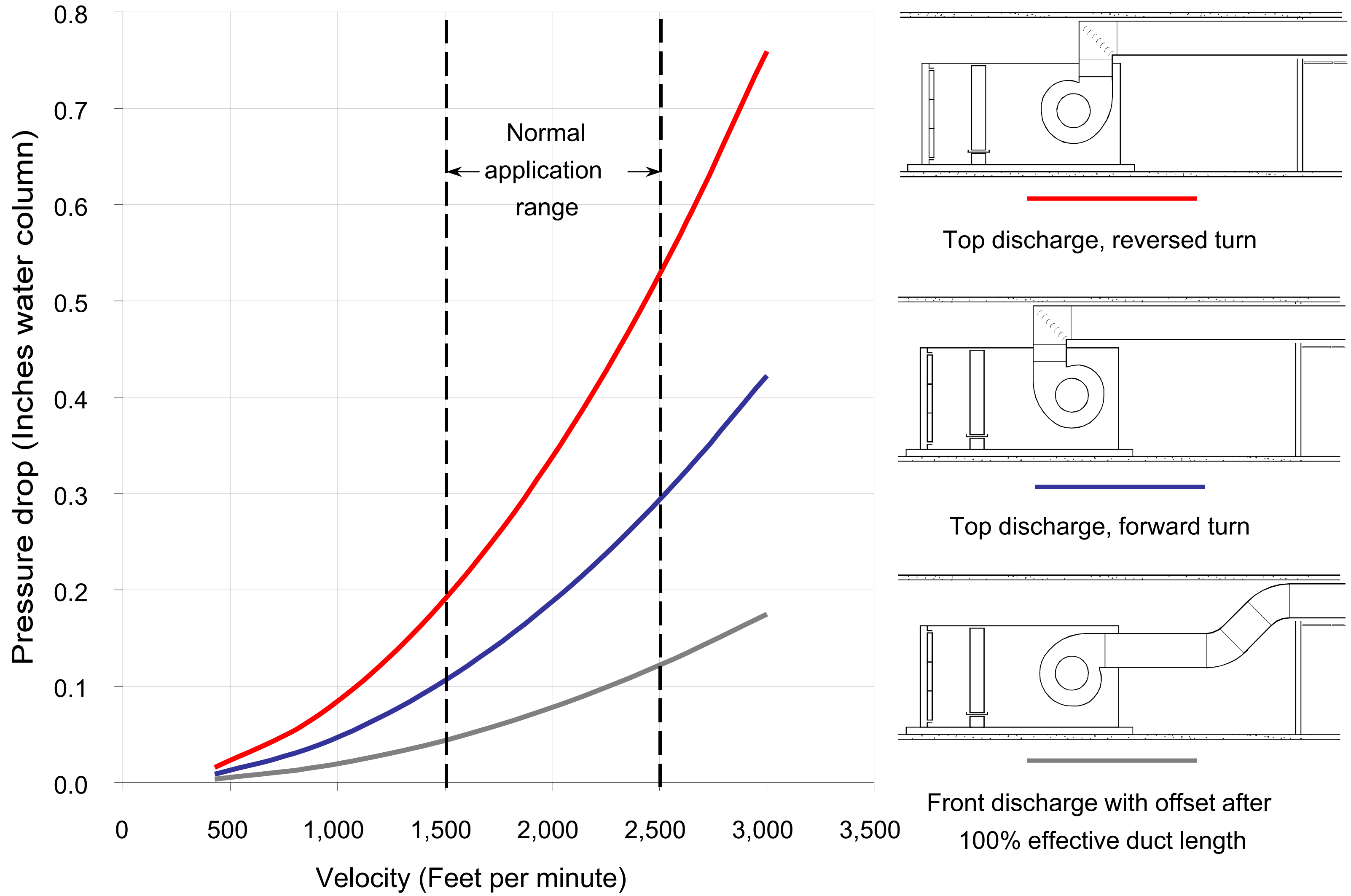
- Application – Can it work as intended?



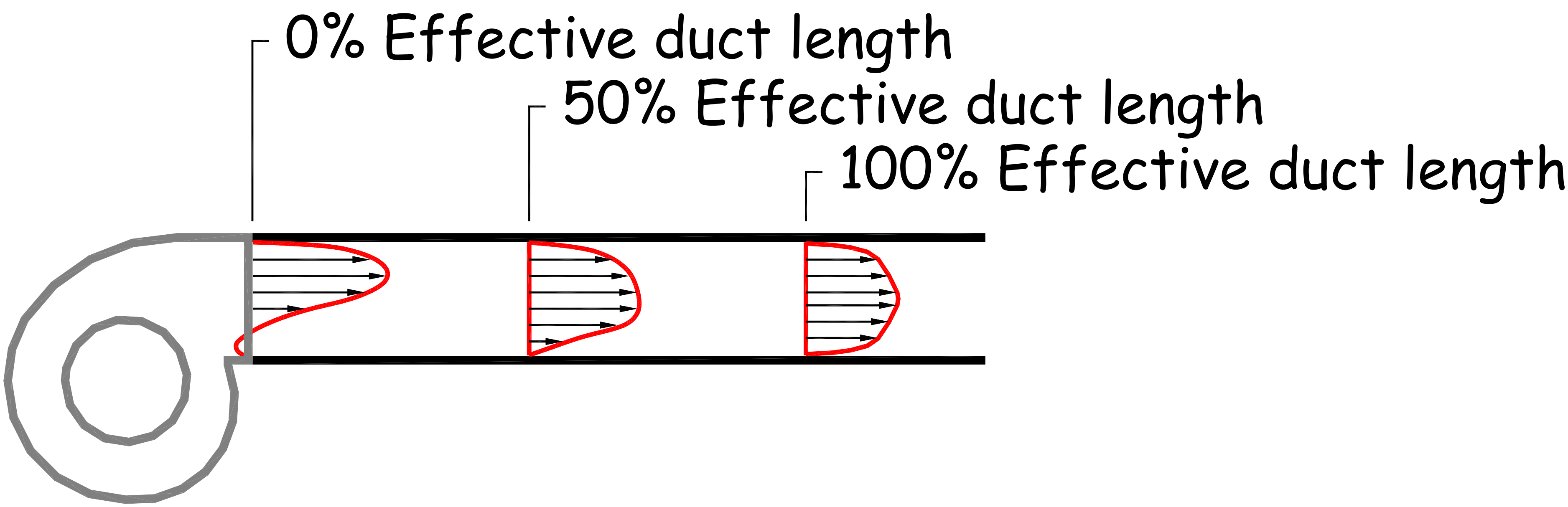
What Kind of Details Matter in HVAC?

- Configuration
  - Will it fit?
  - Is it shaped right?
  - Is it appropriately positioned relative to the system?

Configuration and Fan Applications



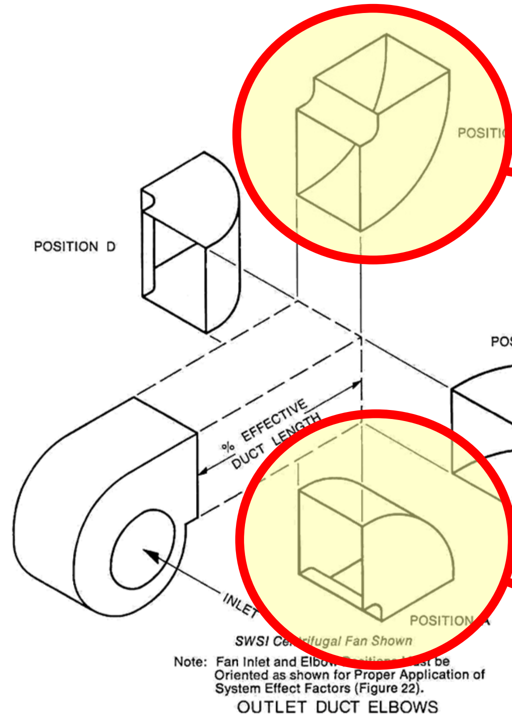
Fan Tests are Based on Ideal Conditions



System Effect

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 fan*

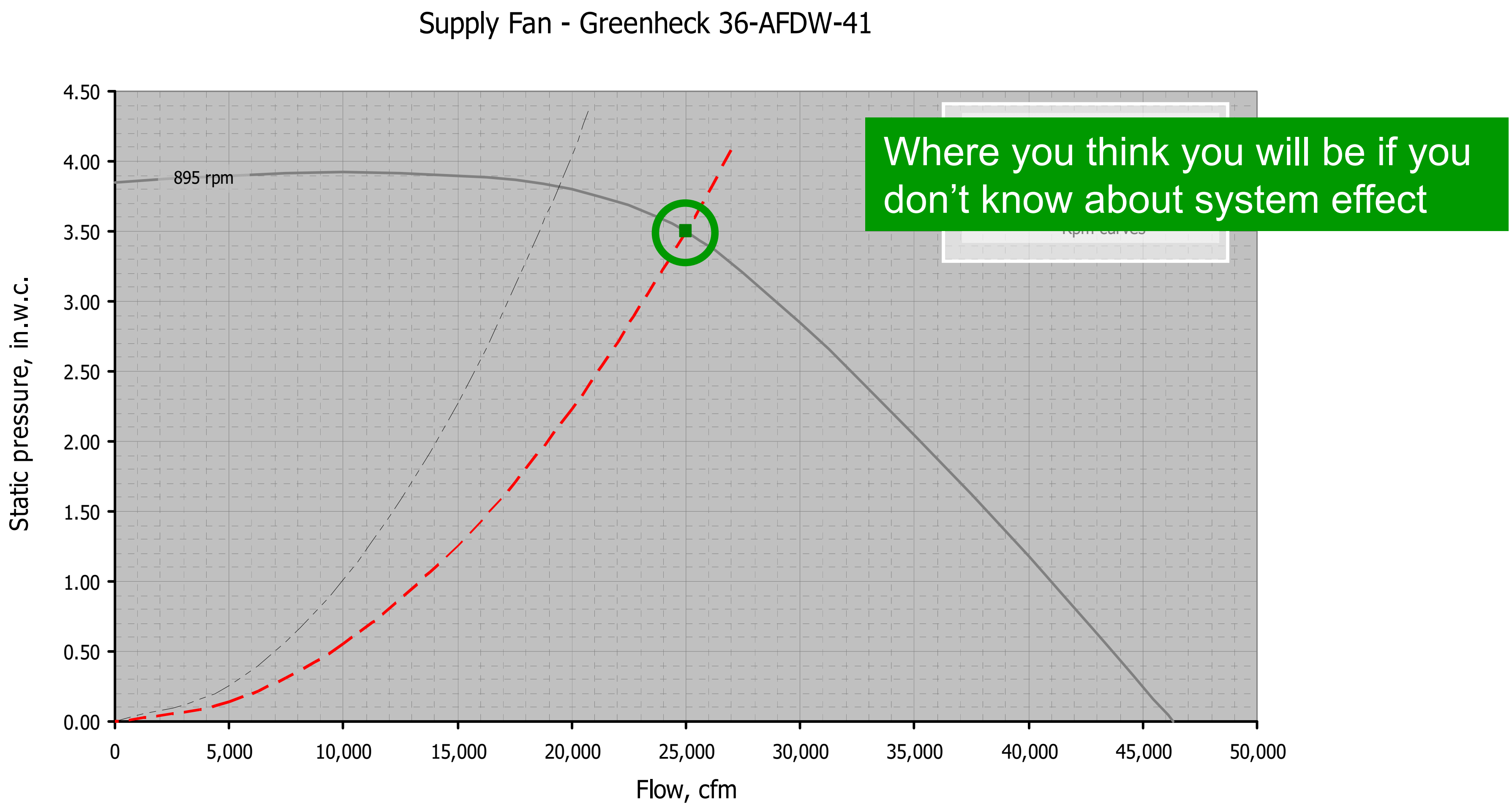


- .55 in.w.c. at 0% effective duct length

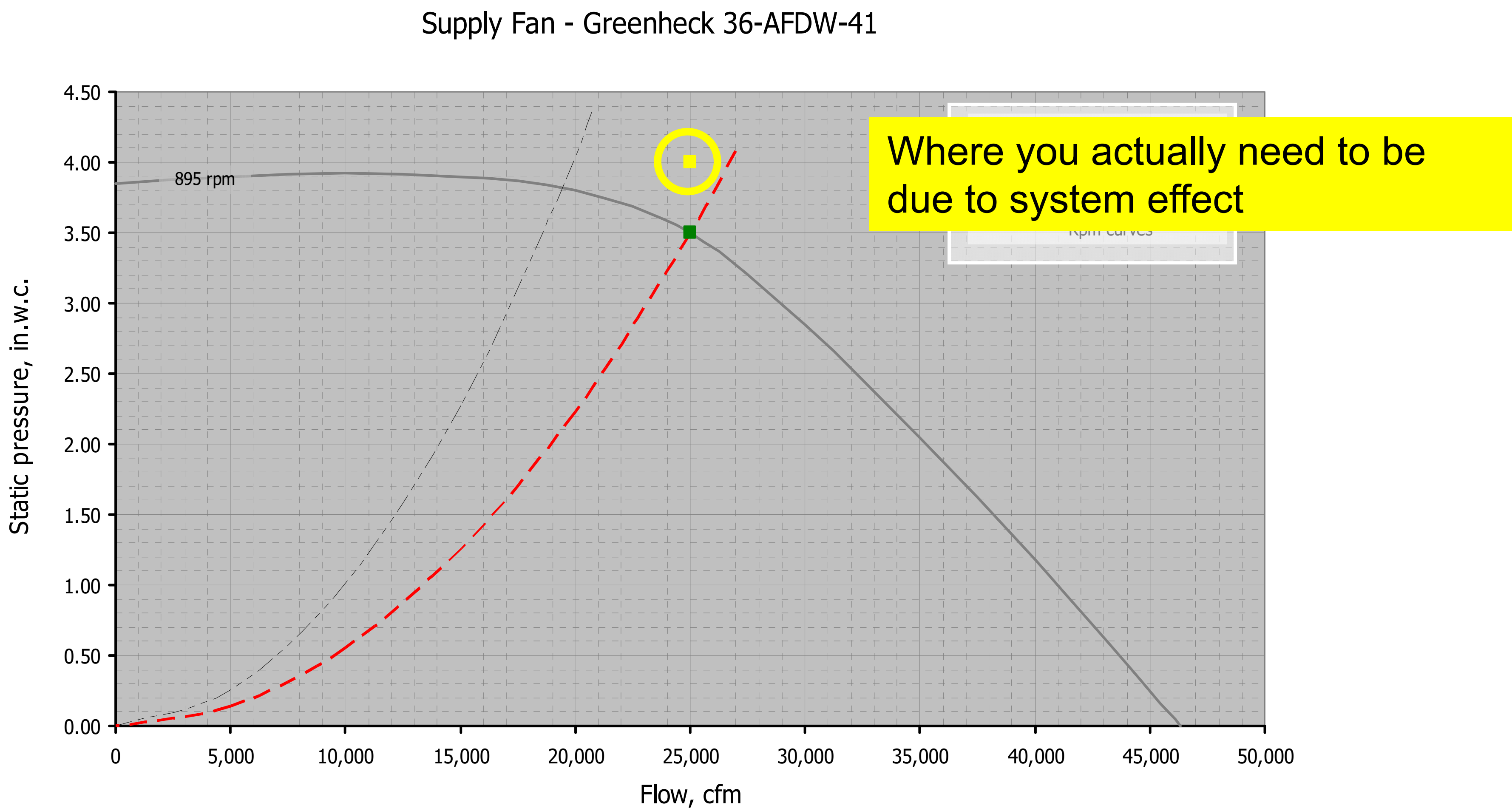
- .20 in.w.c. at 0% effective duct length

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

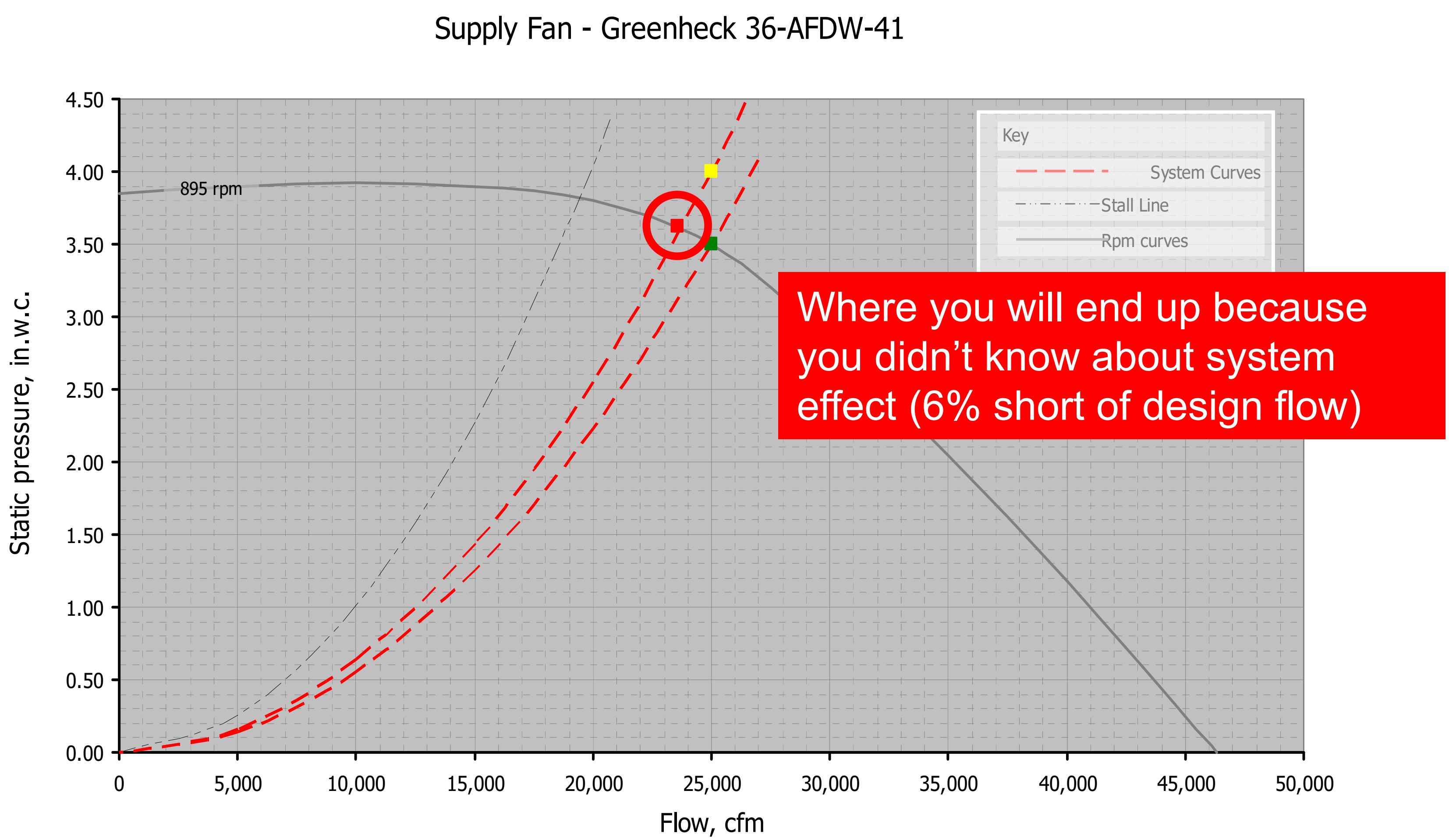
Performance Implications



Performance Implications



Performance Implications



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.

– 72%

sed – 1.4 bhp

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

This Problem is Often Solved by Throwing Energy at It

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

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  - Speed the fan up and everyone wins!

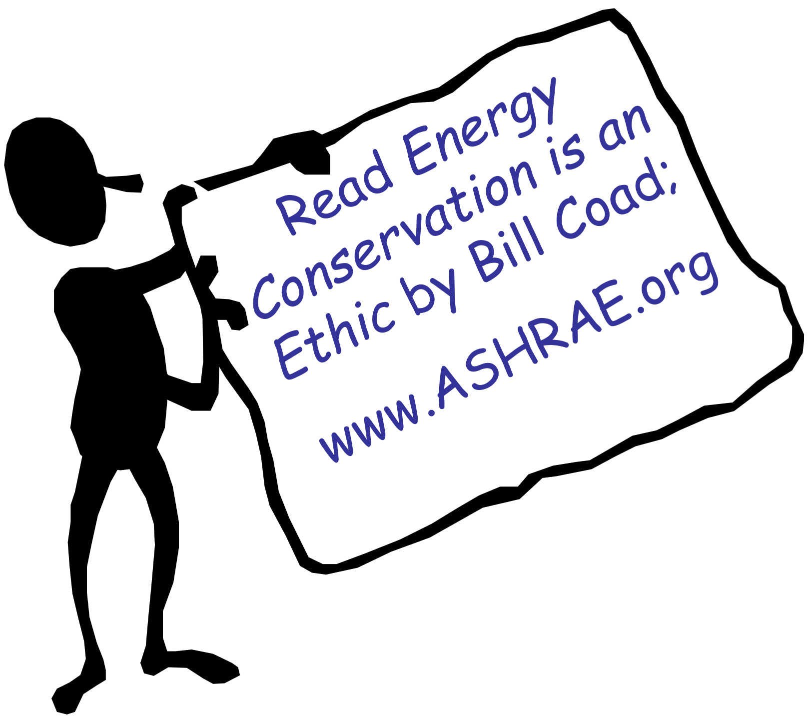
(Except the planet)

We don't inherit the world
from our ancestors;
We borrow it from our children
Unknown

Image Science and Analysis Laboratory, NASA-Johnson Space Center. "The Gateway to Astronaut Photography of Earth."

This Problem is Often Solved by Throwing Energy at It

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



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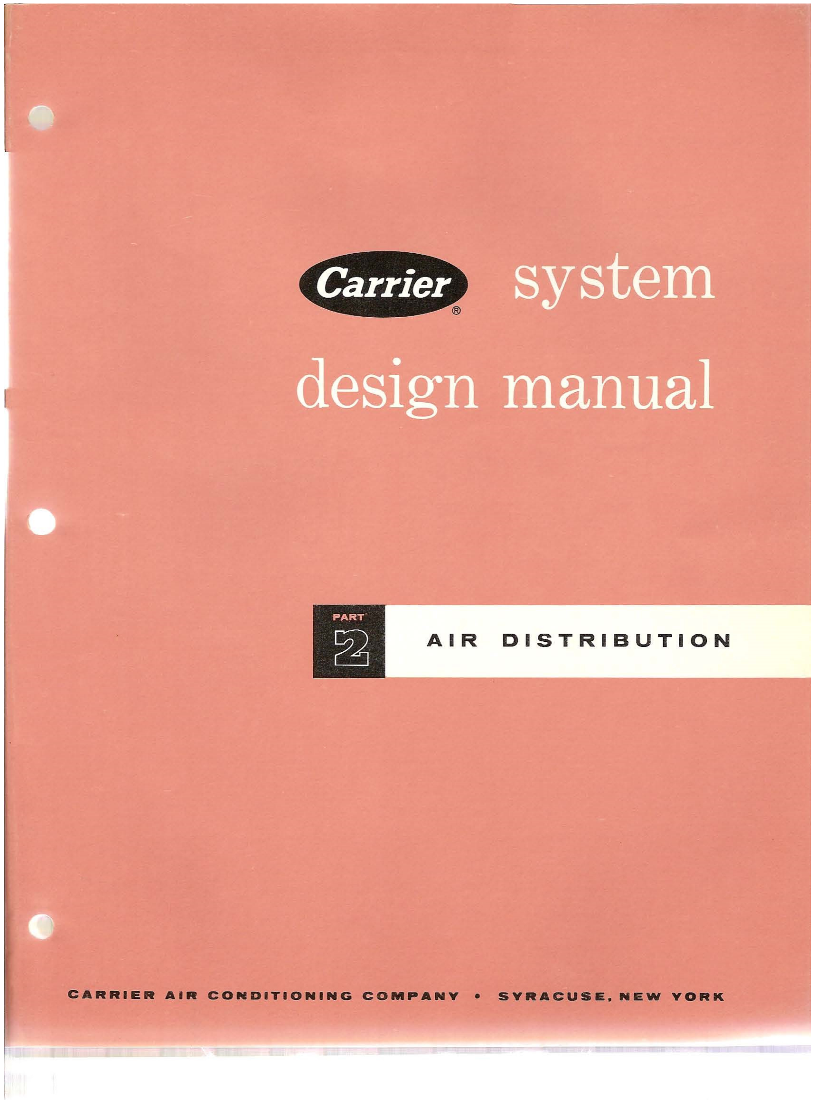
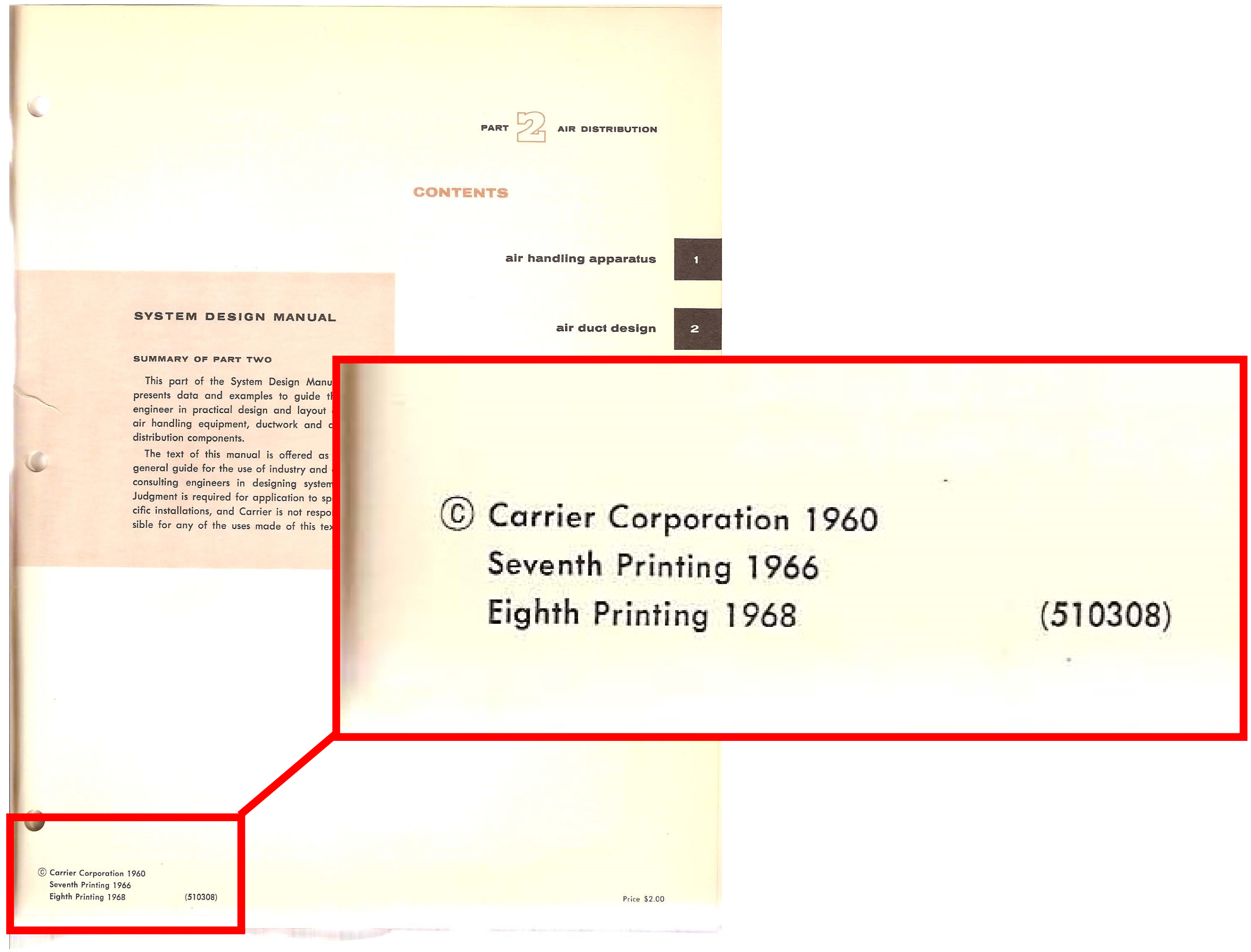
A Known Phenomenon



A Known Phenomenon



A Known Phenomenon

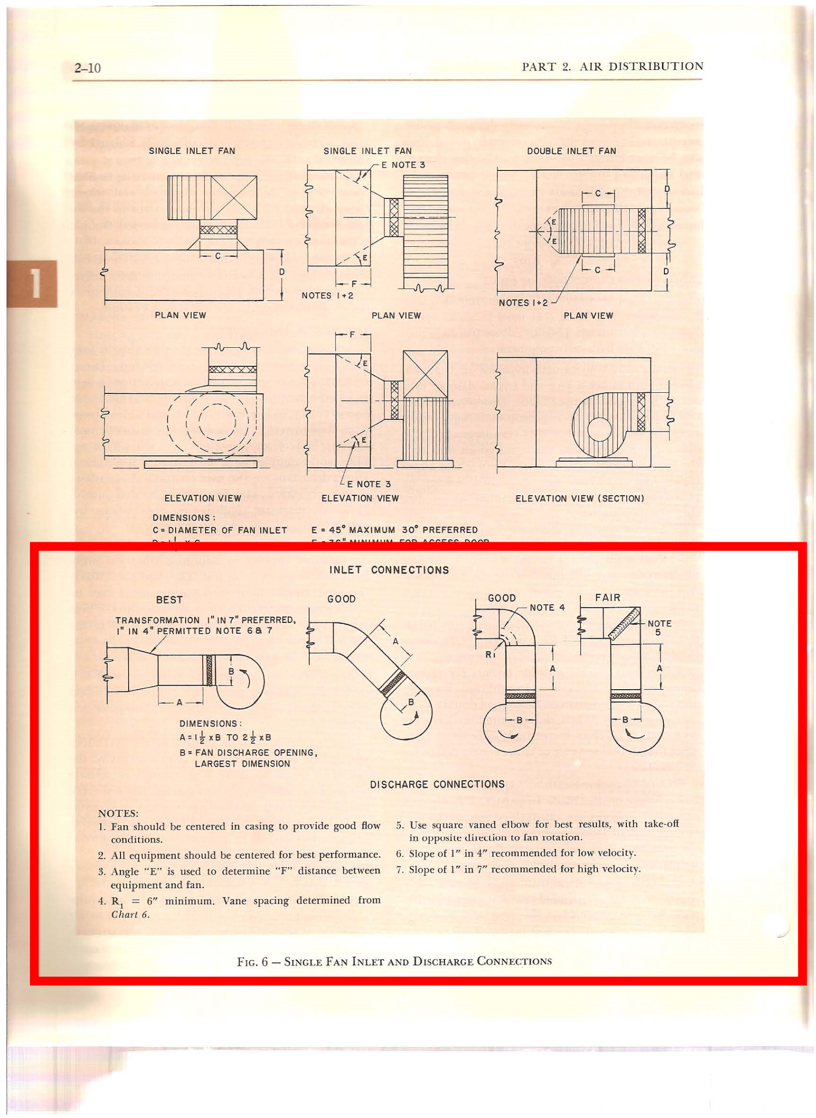
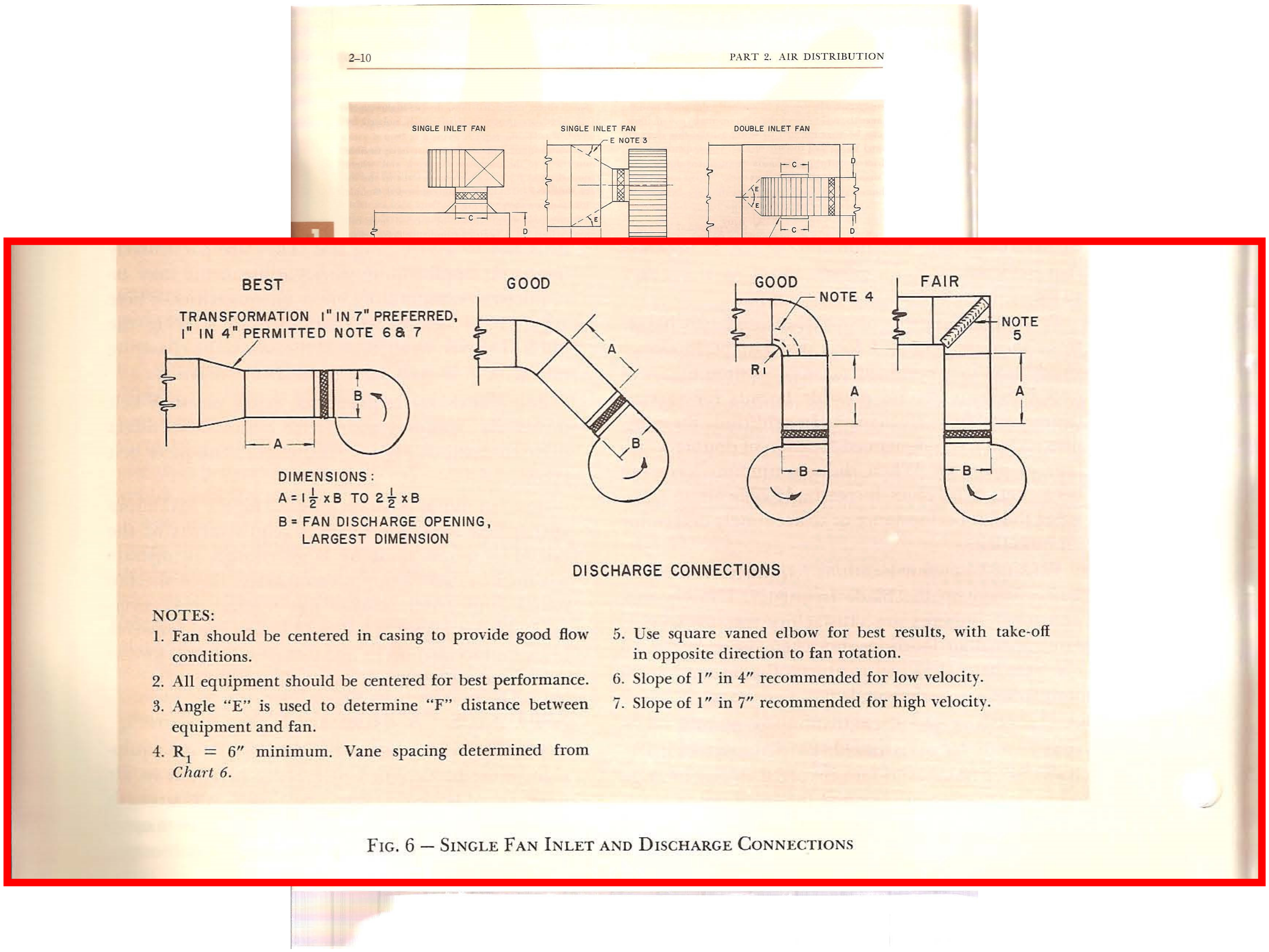


Fig. 6 — Single Fan Inlet and Discharge Connections

A Known Phenomenon



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.

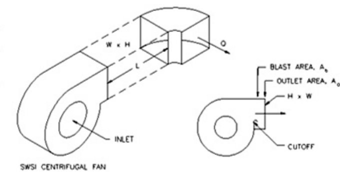
FIG. 6 — SINGLE FAN INLET AND DISCHARGE CONNECTIONS

Current ASHRAE Handbooks and Fitting Database

Duct Design 34.67

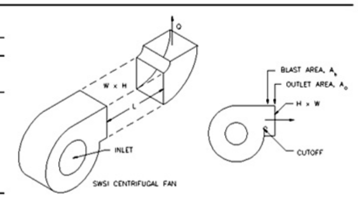
SR7-6 Fan Outlet, Centrifugal, SWSI, with Elbow (Position B)

	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



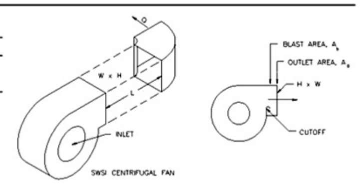
SR7-7 Fan Outlet, Centrifugal, SWSI, with Elbow (Position C)

	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



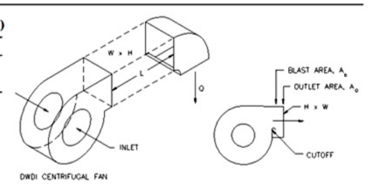
SR7-8 Fan Outlet, Centrifugal, SWSI, with Elbow (Position D)

	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

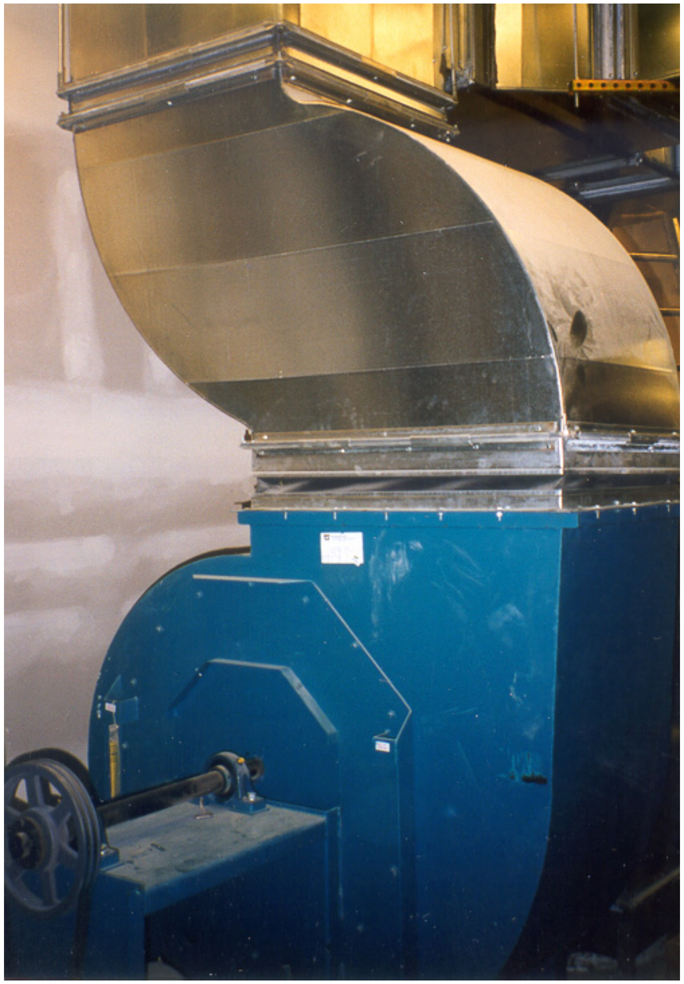


SR7-9 Fan Outlet, Centrifugal, DWDI, with Elbow (Position A)

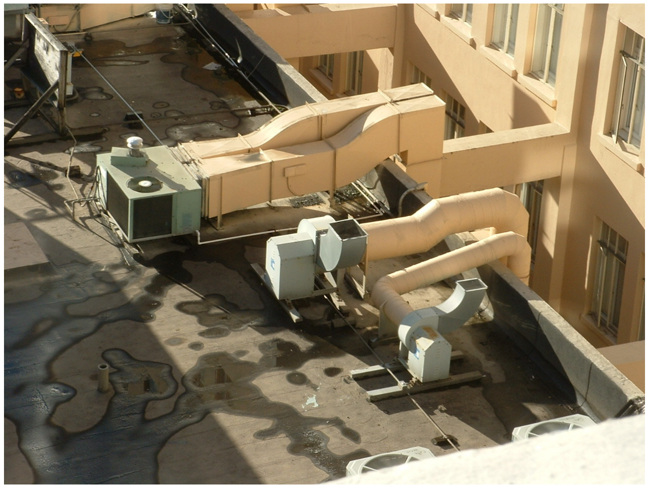
	C_o					
	L/L_e					
A_b/A_o	0.00	0.12	0.25	0.50	1.00	10.00
0.4	3.20	2.50	1.80	0.80	0.00	0.00
0.5	2.20	1.80	1.20	0.53	0.00	0.00
0.6	1.60	1.40	0.80	0.40	0.00	0.00
0.7	1.00	0.80	0.53	0.26	0.00	0.00
0.8	0.80	0.67	0.47	0.18	0.00	0.00
0.9	0.53	0.47	0.33	0.18	0.00	0.00
1.0	0.53	0.47	0.33	0.18	0.00	0.00



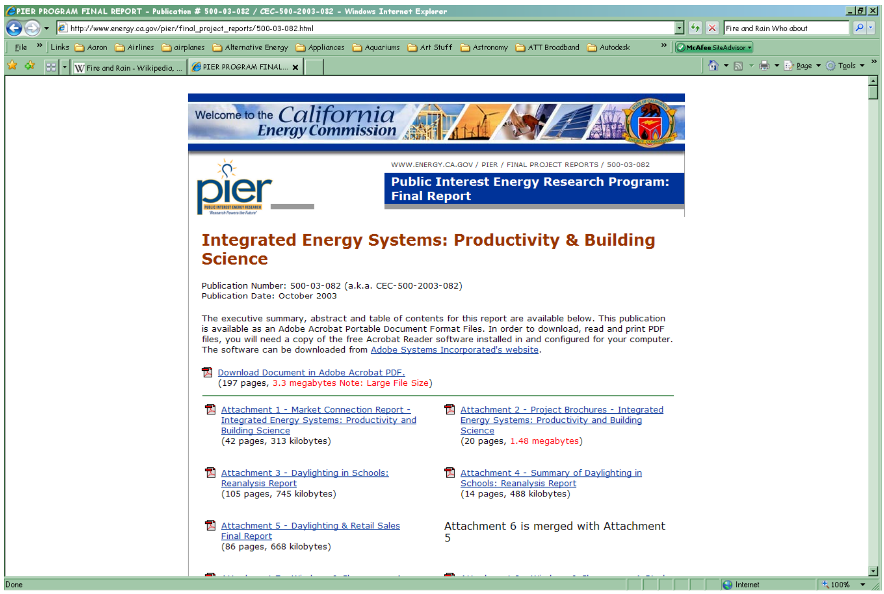
Field Experience Indicates Some Room for Improvement



Left image courtesy of HPAC Editorial Advisory Board Member Ron Wilkinson



Why Does This Matter?

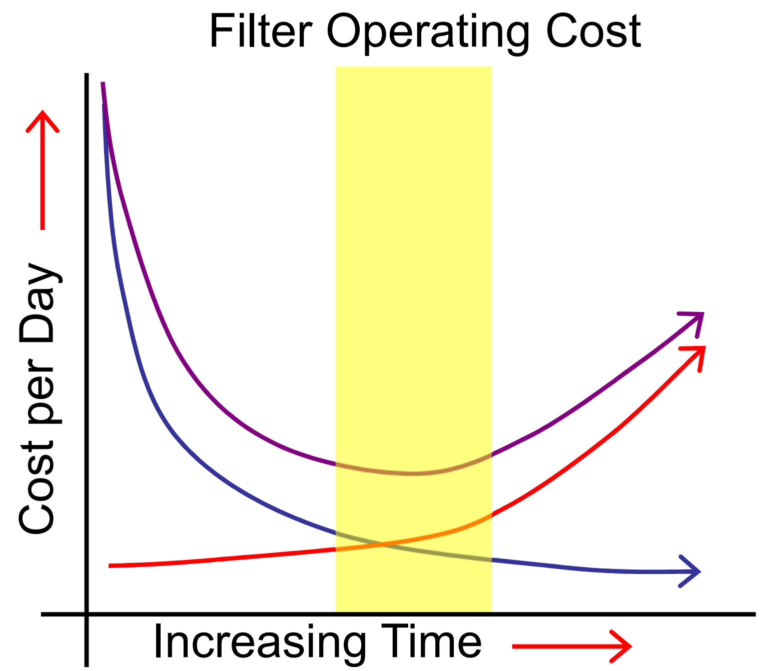


http://www.energy.ca.gov/pier/final_project_reports/500-03-082.html

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
- Similar conclusion for large commercial buildings

Do You Know What you Need to Know for Optimum Operation?

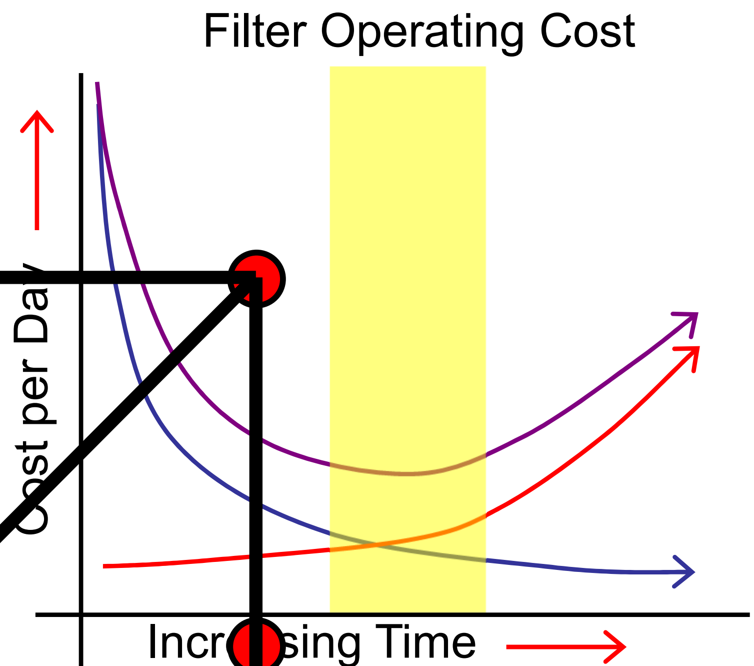


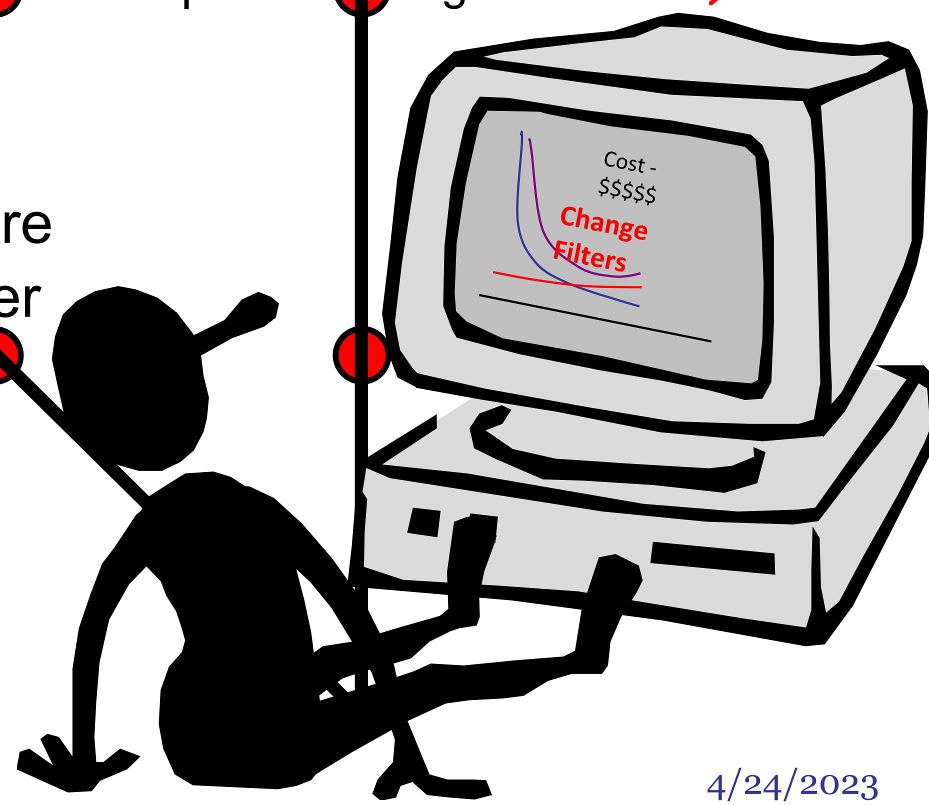
- First cost component
  - Decreases over time
  - Non-linear
    - Day 1 – Cost per day = Cost of filter set
    - Day X – Cost per day = (Cost of filter set)/X Days
- Energy cost component
  - Increases over time
  - Non-linear
- Total cost component
  - Decreases then increases over time
  - Change filters at inflection point for best life cycle cost

Do You Know What you Need to Know for Optimum Operation?

- Measure/monitor filter pressure drop
- Measure air flow
- Calculate filter fan power

- Create a graphic that projects what your filter operating costs are based on a manually entered filter cost and alarms when you hit the inflection point





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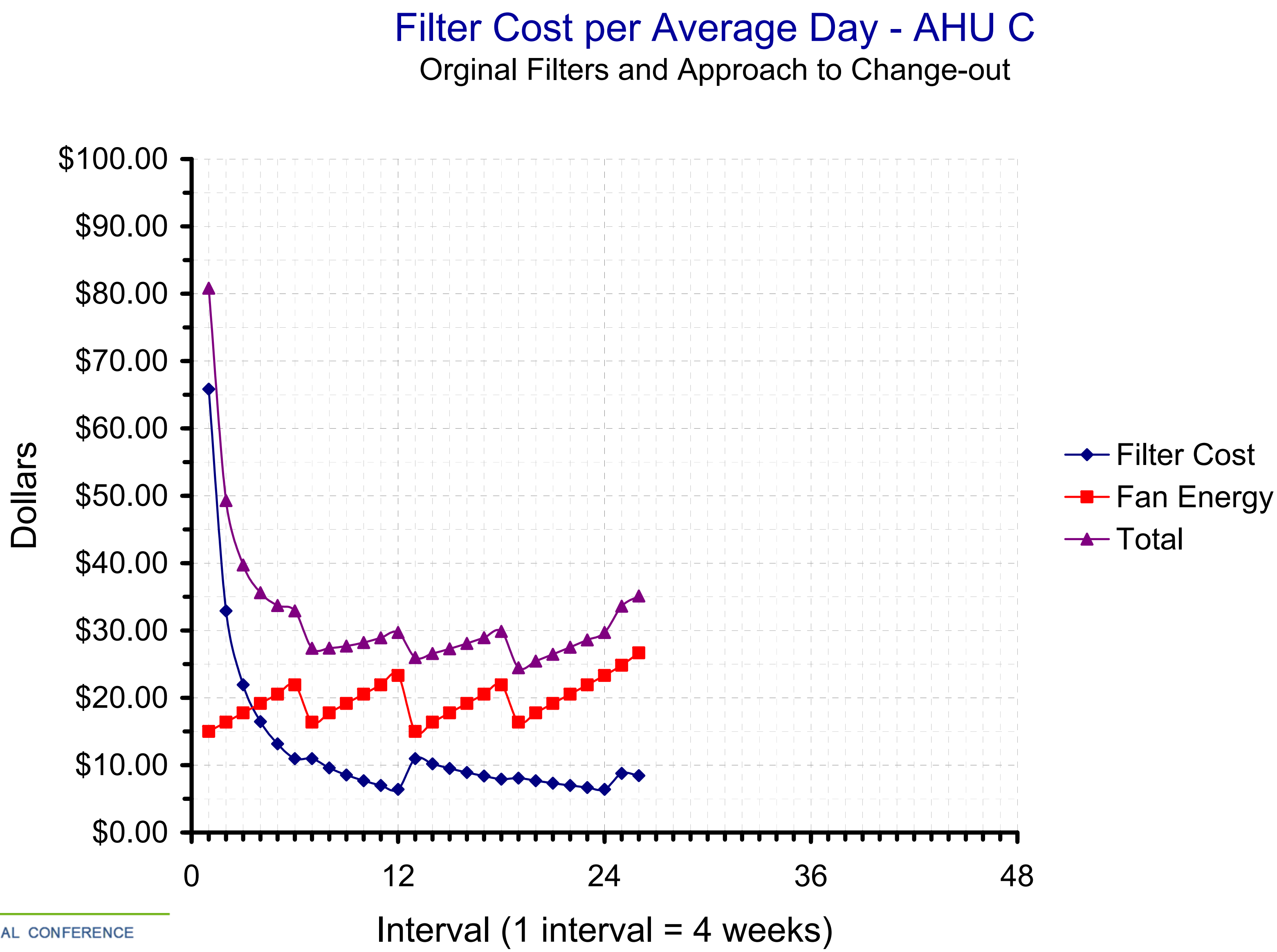

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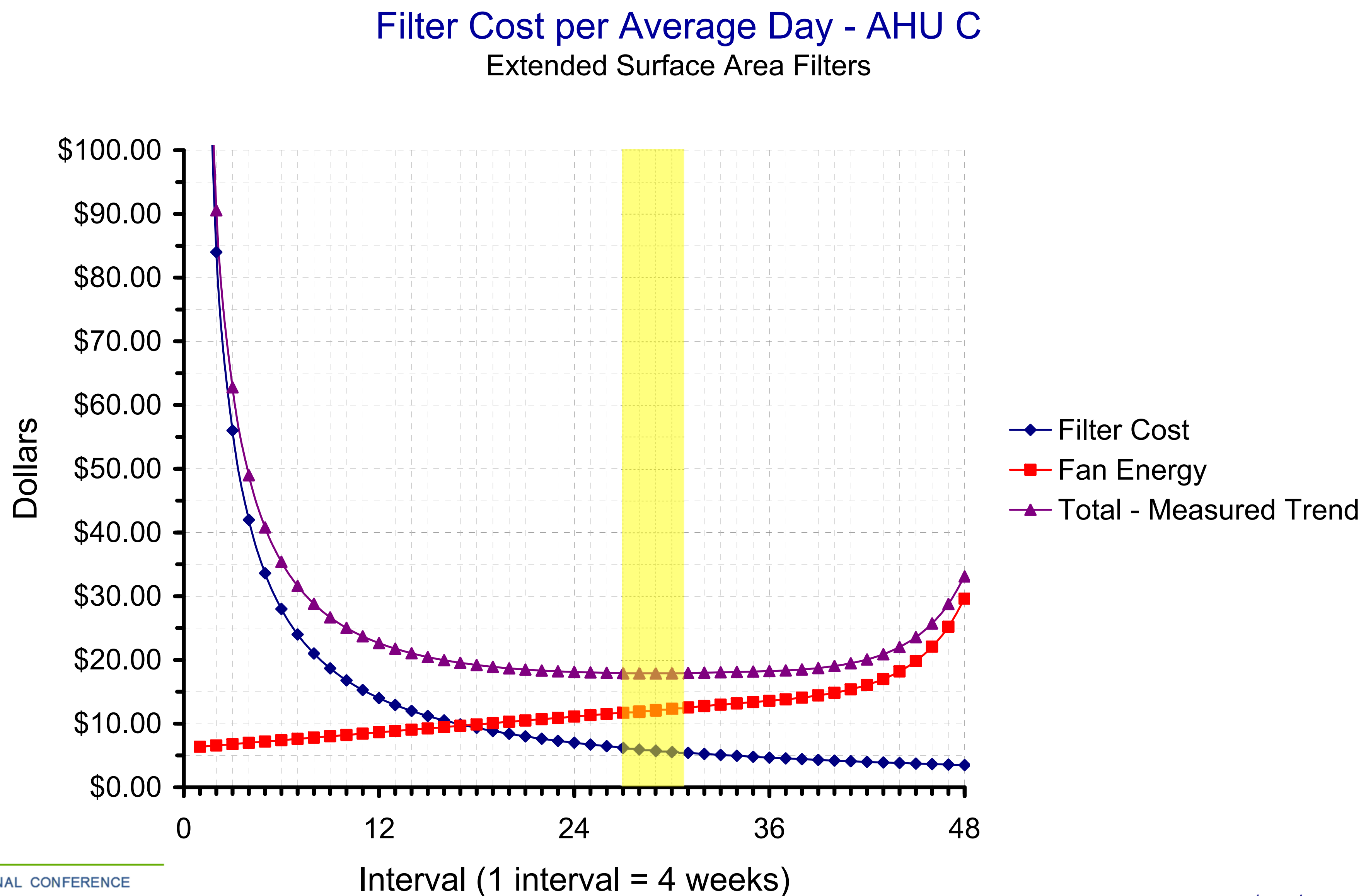

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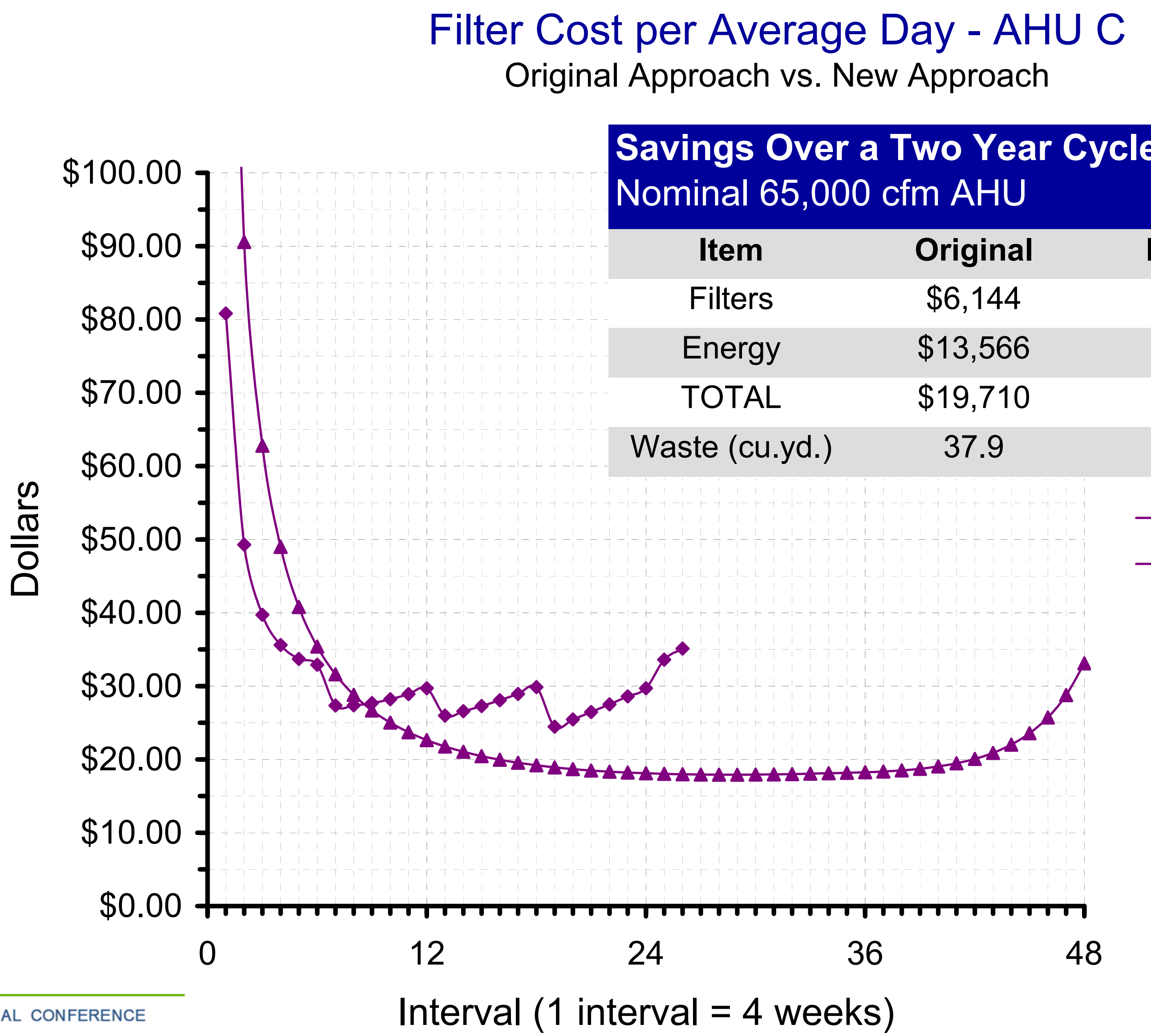
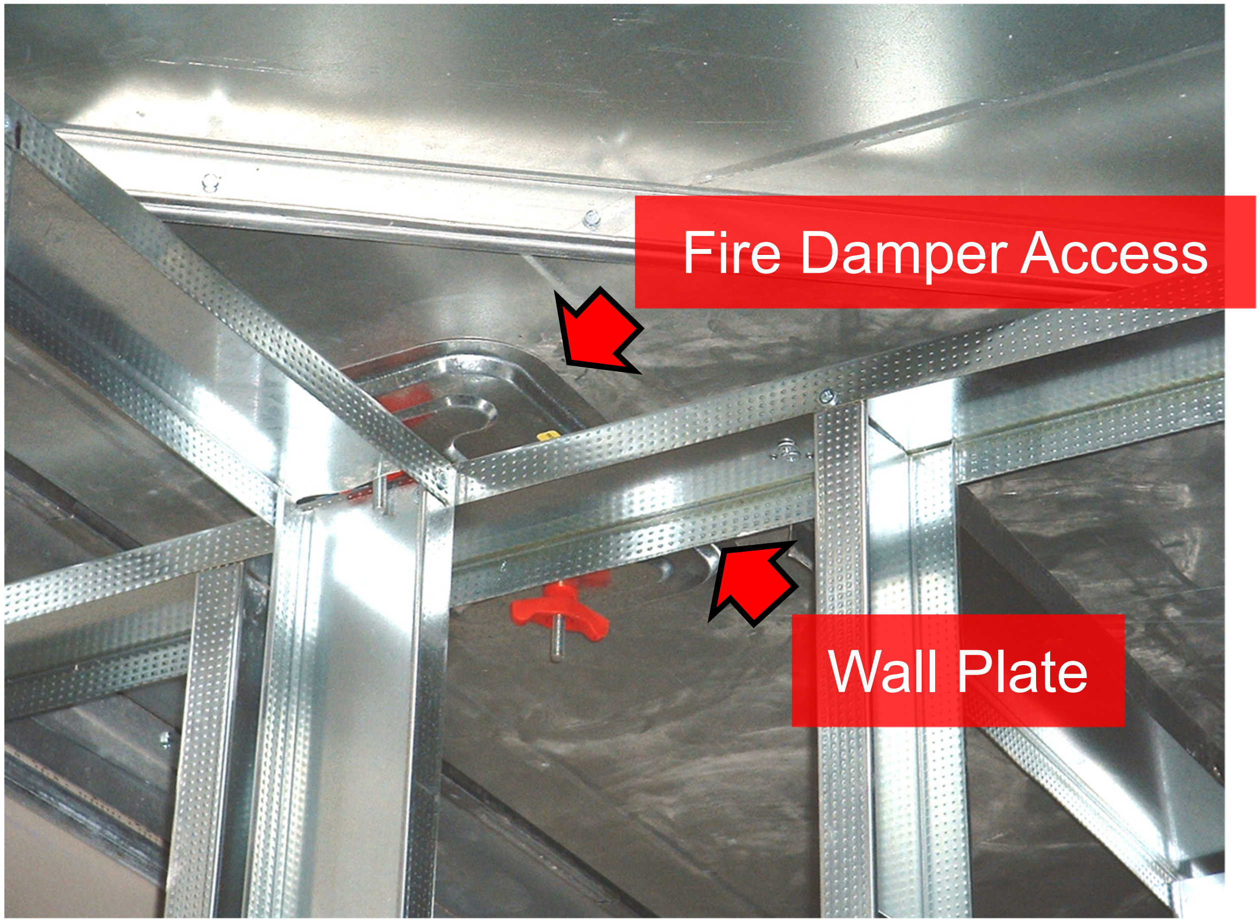


Savings Over a Two Year Cycle
Nominal 65,000 cfm AHU

Item	Original	Improved	Savings
Filters	$6,144	$4,704	$1,440
Energy	$13,566	$6,186	$7,380
TOTAL	$19,710	$10,890	$8,820
Waste (cu.yd.)	37.9	10.7	27.3

Construction Observation

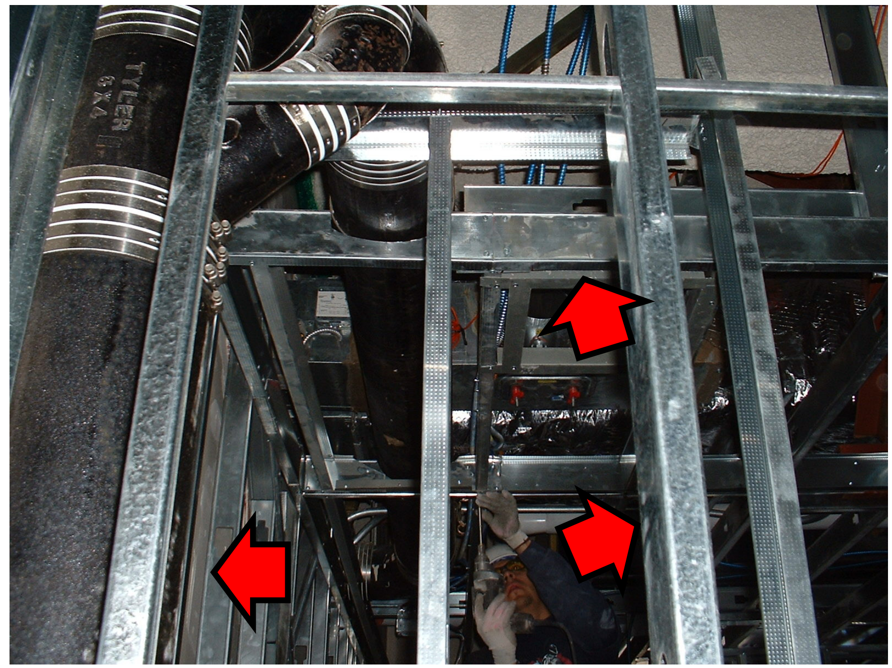


Because inspecting and servicing a combination fire and smoke damper should not involve removing a wall.

An Architect, an Engineer, and a Commissioning Provider Go to Inspect a Fire Damper ….

What the Architect sees:

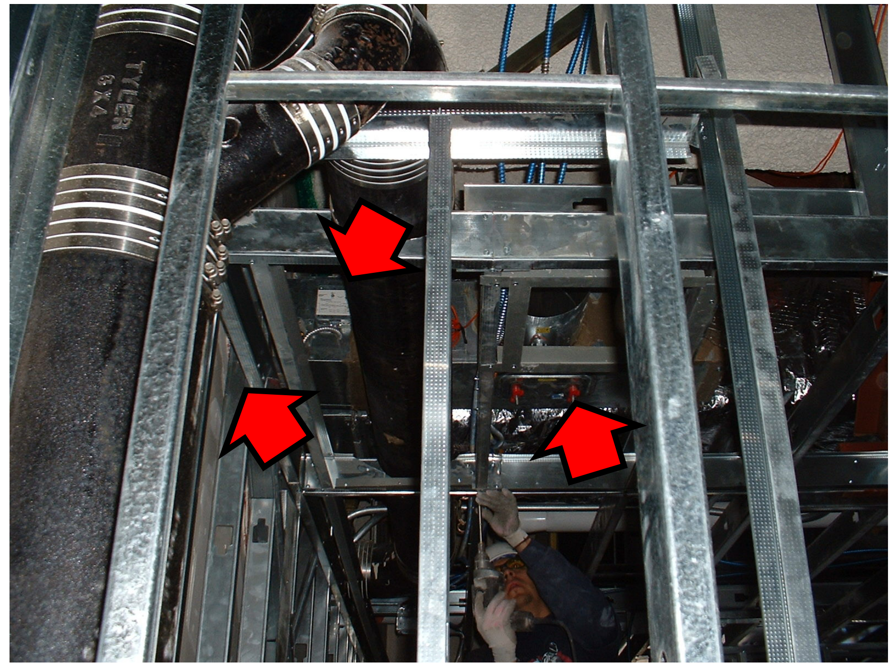
- Properly rated shaft wall
- Properly framed partitions
- Ceiling heights look about right based on the framing



An Architect, an Engineer, and a Commissioning Provider Go to Inspect a Fire Damper ….

What the Engineer sees:

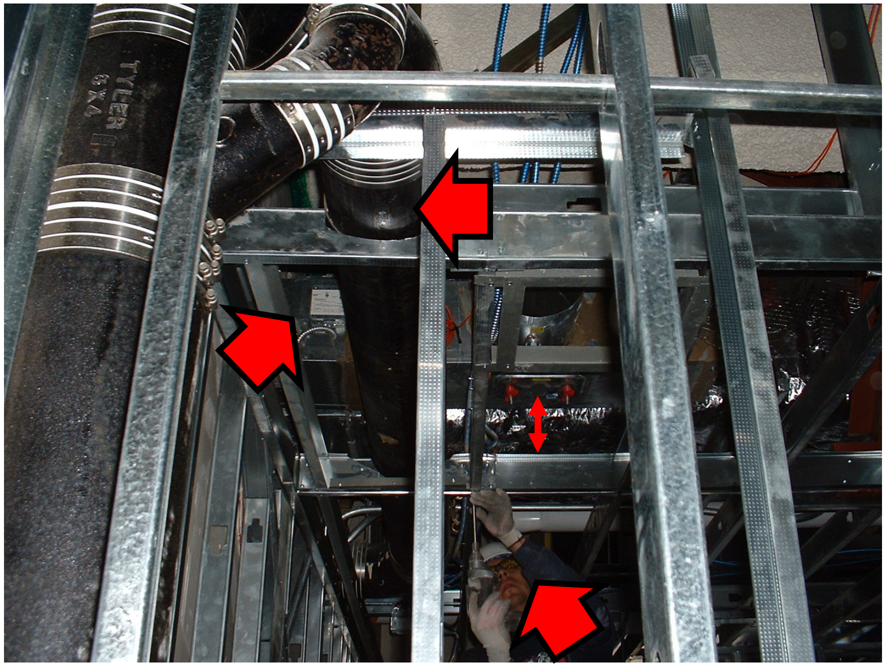
- Fire damper properly installed in the rated partition
- Duct inspection access provided
- Test/manual reset switch provided



An Architect, an Engineer, and a Commissioning Provider Go to Inspect a Fire Damper ….

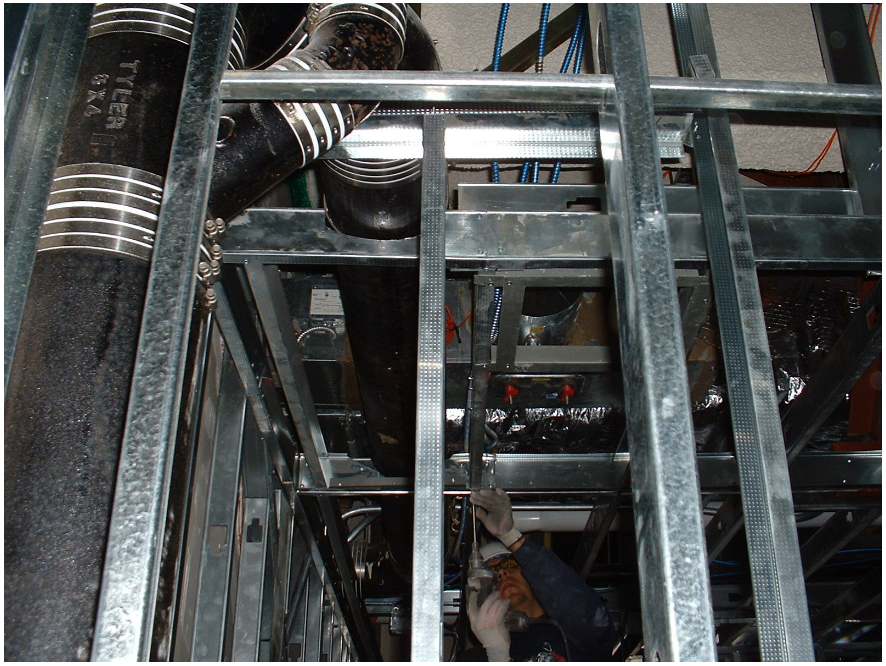
What the Commissioning Provider sees:

– Ceiling access framing that is several feet from the duct access
– 6” of clearance between the top of the ceiling framing and the bottom of the duct access
– An 8” line blocking what little access there is to the test/manual reset switch



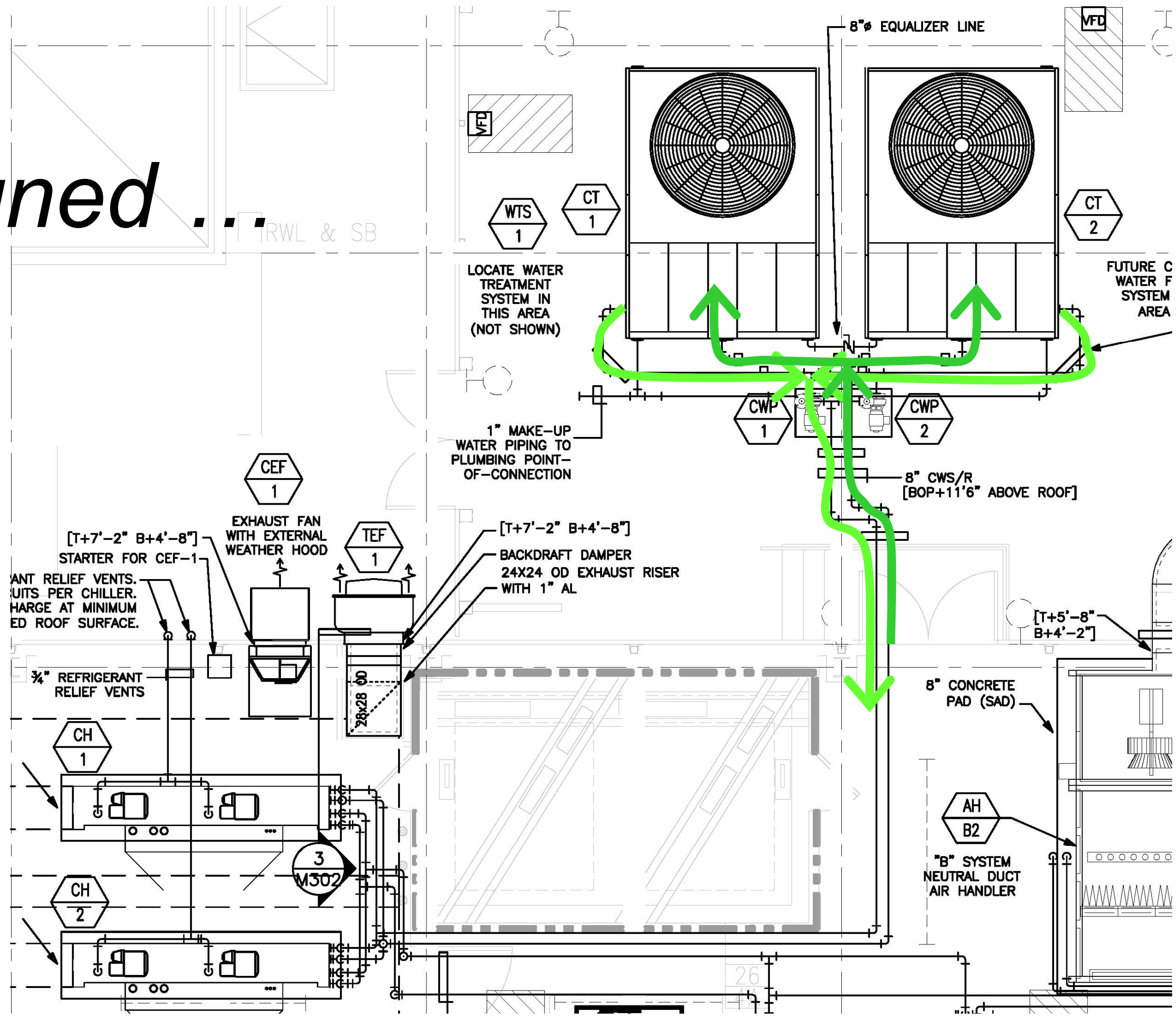
Everyone Did Their Job

- The Design Professionals verified compliance with critical design requirements
- The Commissioning Provider brought additional valuable perspectives
  - Integration
  - Operations and maintenance
- Some of these things are not apparent until you get into construction



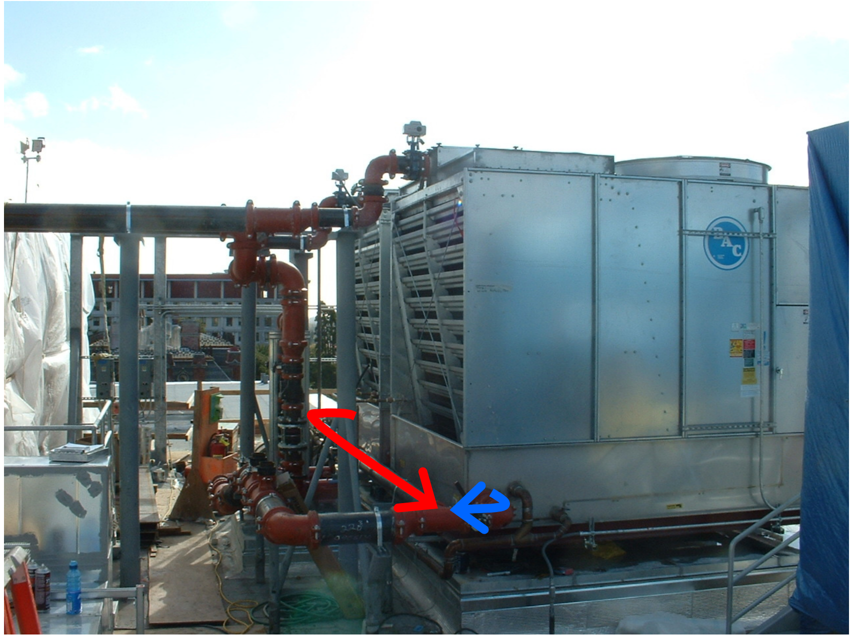
Capturing Design Intent via Construction Observation

As designed ...



As Installed

… not so symmetrical!

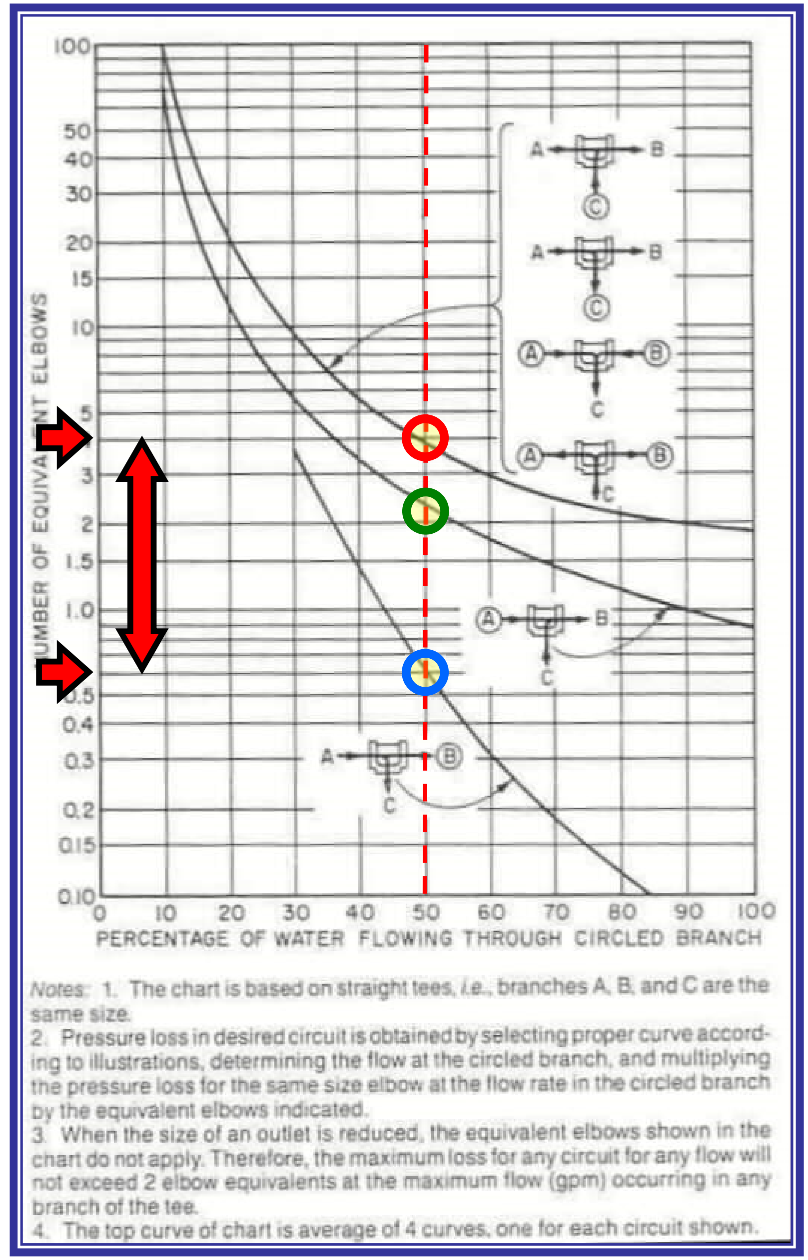


Tee Details

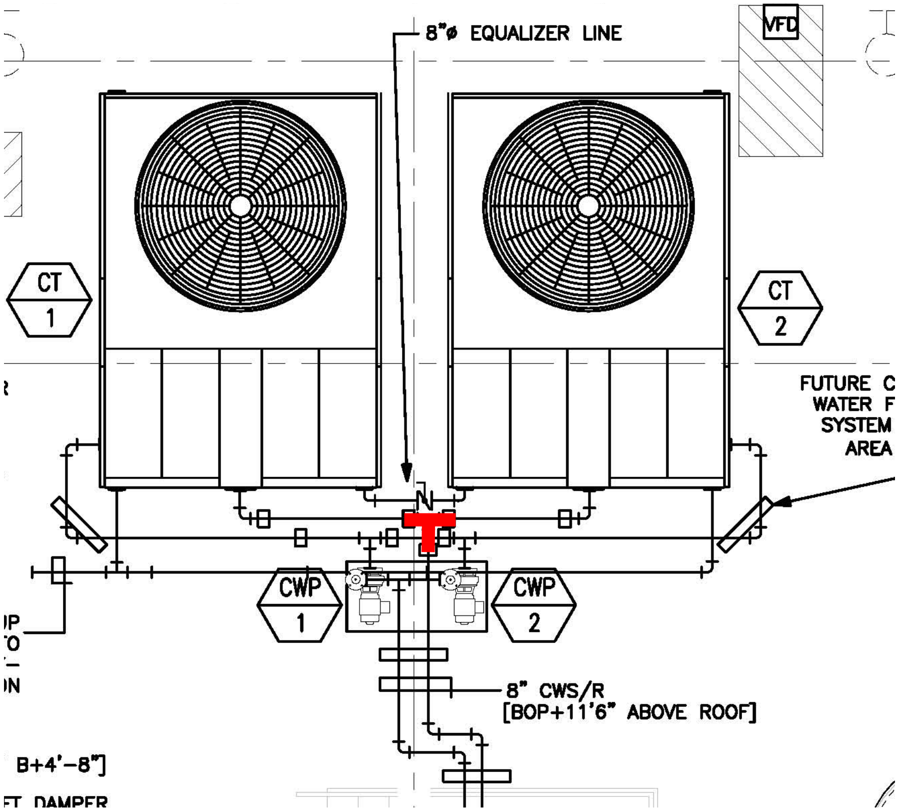
Tee Orientation has a significant impact on pressure drop

Factor of 6.7 Difference!

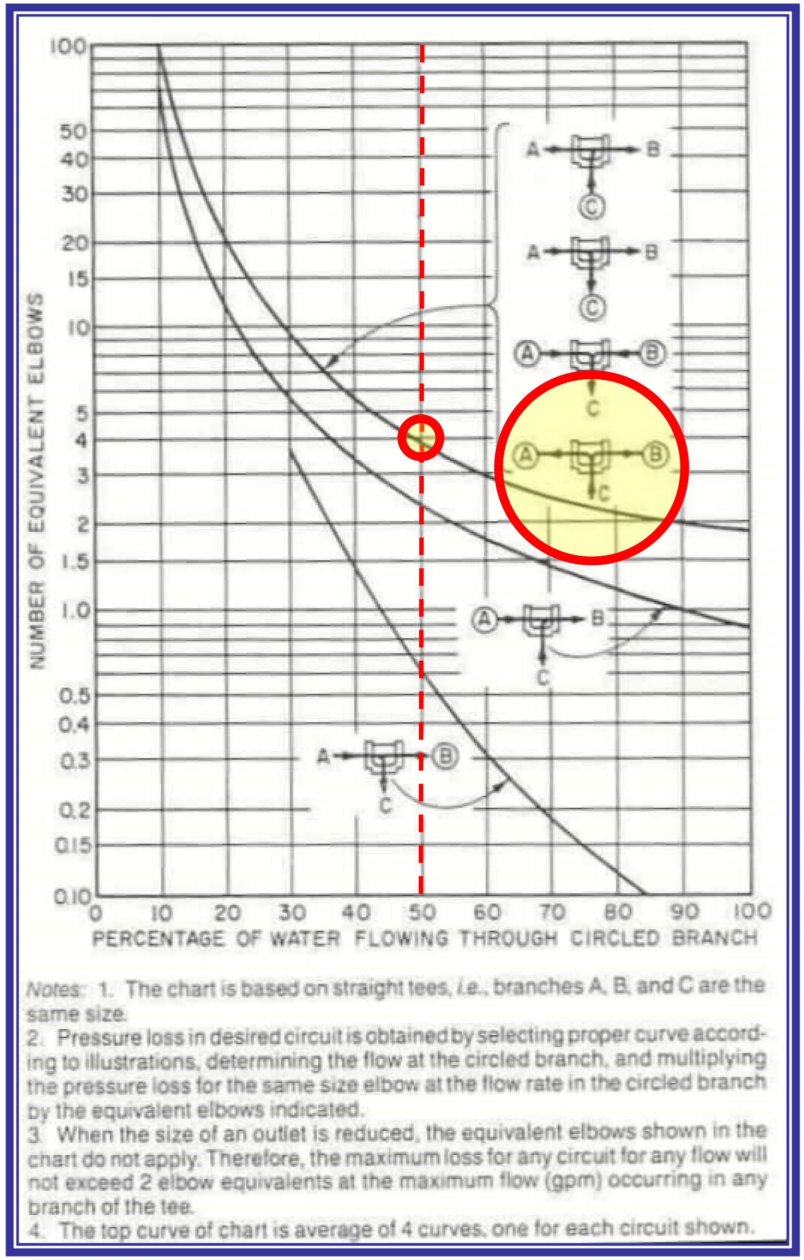
Image from the ASHRAE Handbook of Fundamentals



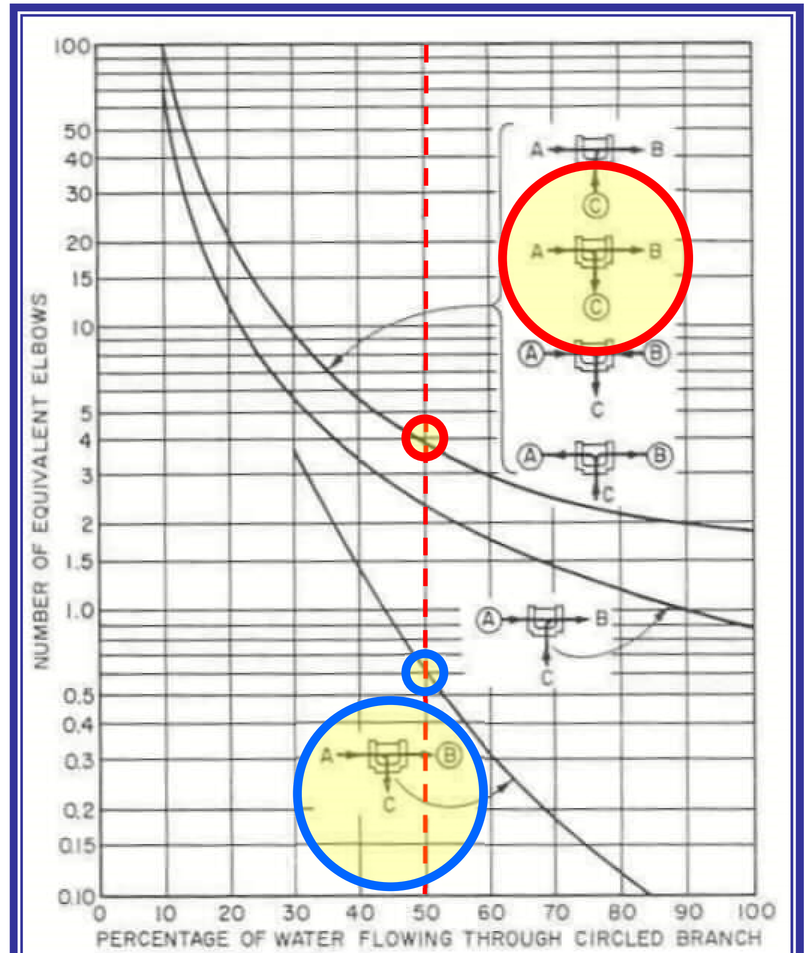
As Designed



…higher, but equal pressure drops



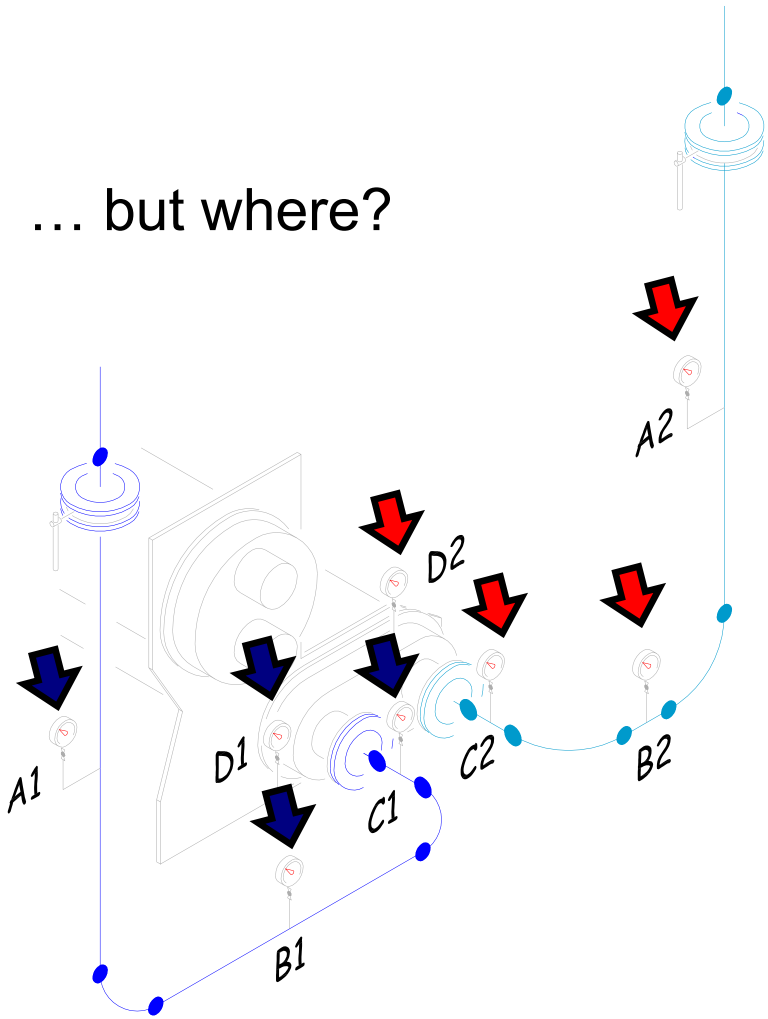
As Installed



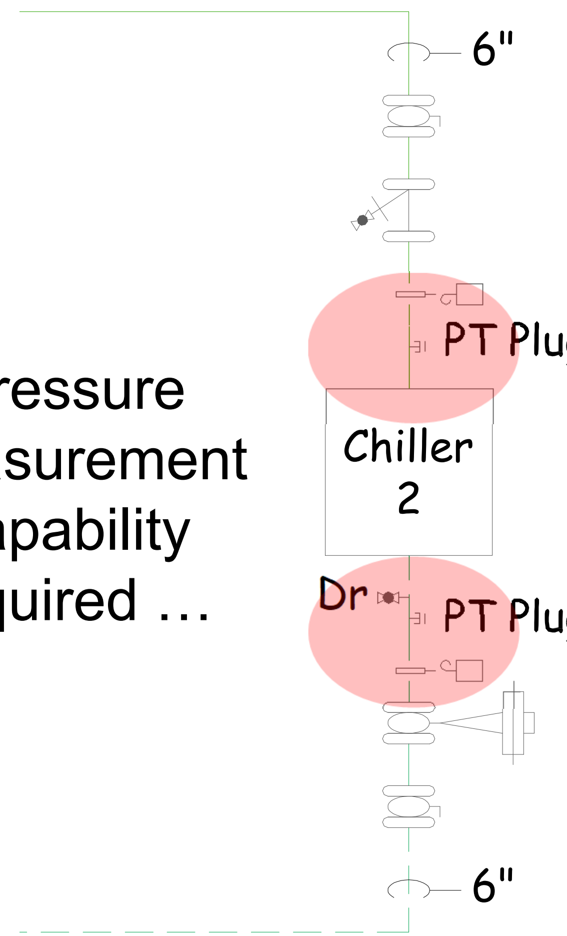
Notes: 1. The chart is based on straight tees, *i.e.*, branches A, B, and C are the same size.
2. Pressure loss in desired circuit is obtained by selecting proper curve according to illustrations, determining the flow at the circled branch, and multiplying the pressure loss for the same size elbow at the flow rate in the circled branch by the equivalent elbows indicated.
3. When the size of an outlet is reduced, the equivalent elbows shown in the chart do not apply. Therefore, the maximum loss for any circuit for any flow will not exceed 2 elbow equivalents at the maximum flow (gpm) occurring in any branch of the tee.
4. The top curve of chart is average of 4 curves, one for each circuit shown.

Another Situation Where Small Details can Make A Big Difference

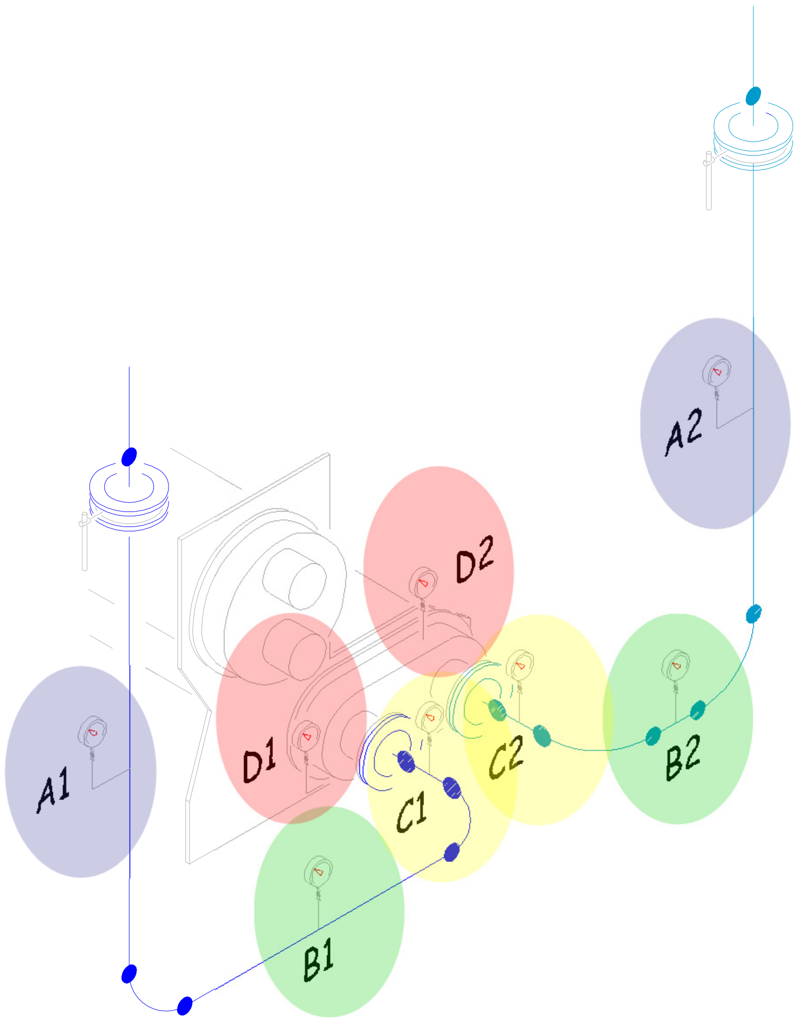
… but where?



Pressure measurement capability required …



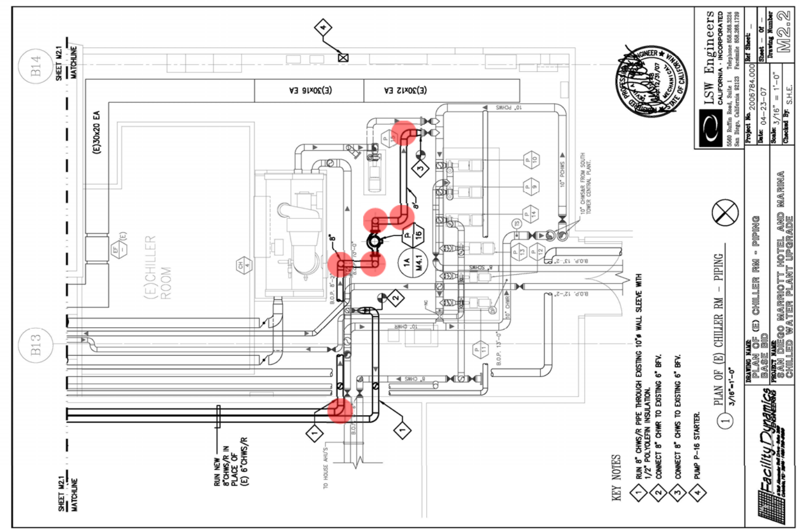
Another Situation Where Small Details can Make A Big Difference

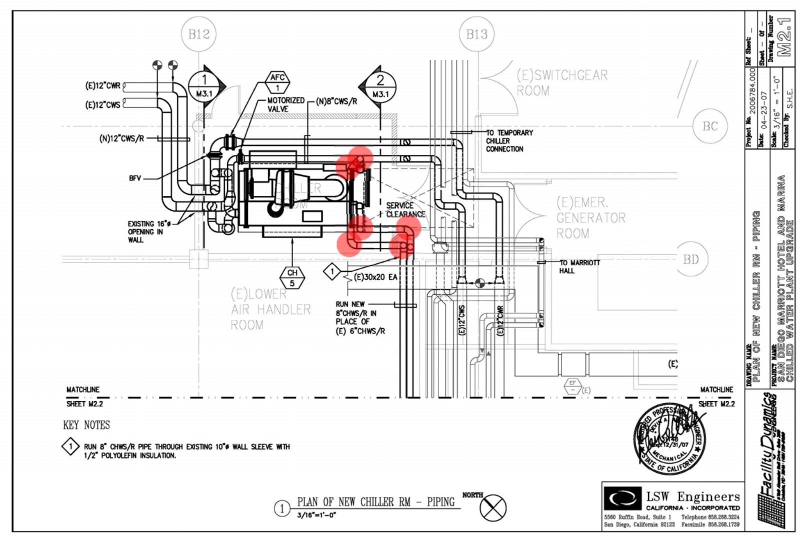


Flow Based on Differential Pressure			
Location	Pressure Difference, ft.w.c.	Flow Based on Pressure Difference	
		gpm	%
D1 - D2	14.48	1,363	85%
C1 - C2	17.00	1,600	100%
B1 - B2	18.26	1,718	107%
A1 - A2	19.78	1,862	116%

Short Radius vs. Long Radius Elbows

- Number of elbows = 26
- Difference in head for the circuit with long radius versus short radius elbows
  - 3+ ft.w.c.
  - 9+% difference in pump head (A.K.A. the safety factor)



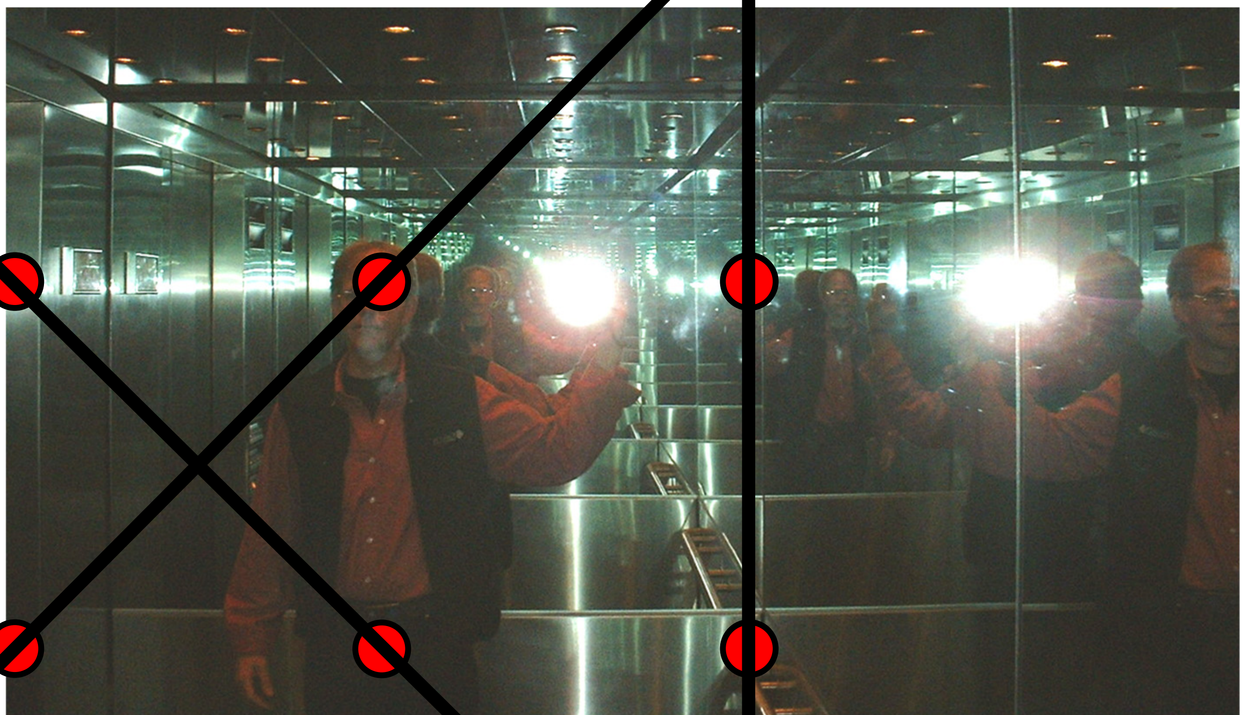


Bottom Lines

- Design phase is the ideal time to hit critical Cx targets
  - Plan and set up the process
  - Capture design intent
  - Optimize efficiency
  - Ensure access and other O&M considerations
- Unresolved design opportunities become field opportunities
- Getting it right on paper does not necessarily mean it will be right in the field

Persistence

Resources



… and you'll discover a key source of innovation and persistence!

Integrated Design and Design Review Resources

Energy Design Resources Design Briefs

- *Design Details*
- *Design Review*
- *Field Review*
- *Improving Mechanical System Energy Efficiency Through Architect and Engineer Coordination*


energydesignresources

design brief

IMPROVING MECHANICAL SYSTEM ENERGY EFFICIENCY THROUGH ARCHITECT AND ENGINEER COORDINATION

Summary

Technological advances and economic pressure frequently join forces to reduce the design and construction time for building projects. Narrowing the design window places intense pressure on the design team to produce construction documents as quickly as possible. As a result, other factors like life cycle cost, distribution efficiency, access, maintainability, and system integration may not receive a thorough evaluation to provide the best overall solution to the design problem.

Failing to take these factors into account during the early stages of design can have long-term negative impacts on the efficiency of a building and its systems. For example, a constricted mechanical space will probably remain constricted for the life of the building, compromising the efficiency and maintainability of the machinery and eroding the building's operating budget for years to come. Correcting such a problem subsequent to construction may be an economic and practical impossibility, while preventing it during early phases of design may have little first cost implication and yield substantial ongoing benefits.

This design brief explores techniques that use the "fuzzy" information available during schematic design as a foundation for establishing a project's design intent and making good long-term mechanical and electrical systems decisions. Properly applied, they allow the mechanical designer to:

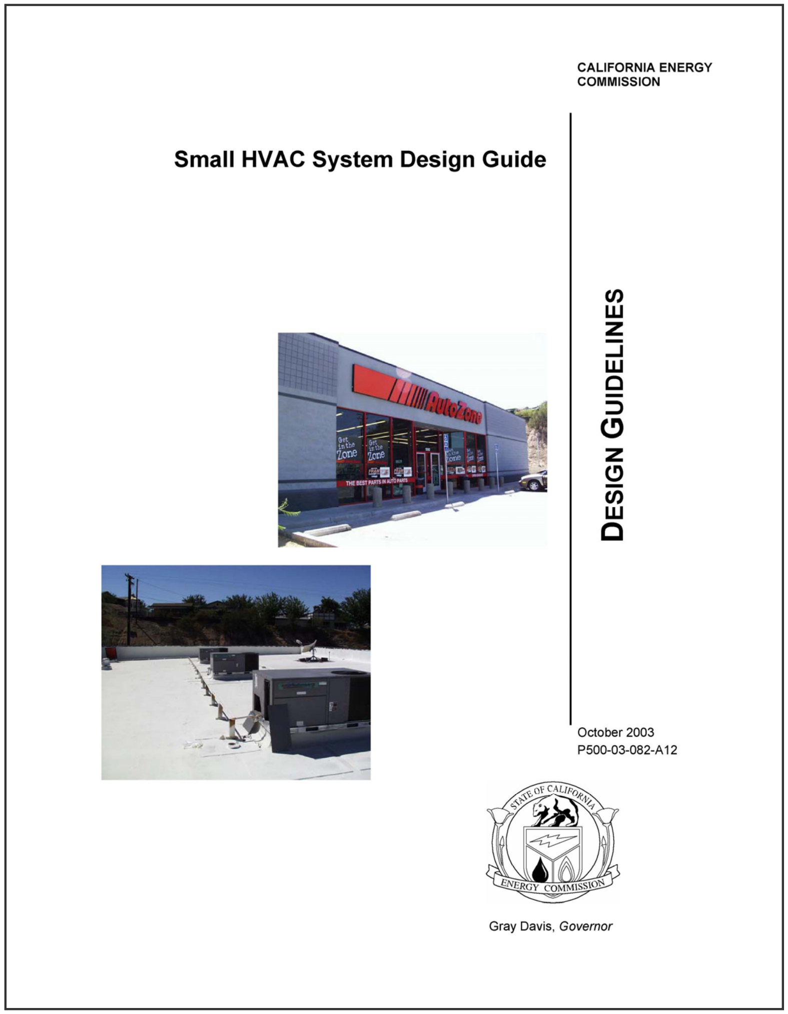
- Suggest more efficient system alternatives with better life cycle cost profiles for consideration.
- Ensure that the architectural elements of the building are configured to promote distribution system efficiency.
- "Right size" building systems from the very start, improving energy efficiency, as well as first cost.
- Coordinate with other team members to capture the additional savings that "ripple out" of these decisions.

Tight design timelines can compromise the design team's ability to consider factors like life cycle cost, distribution efficiency, access, maintainability, and system integration.

CONTENTS

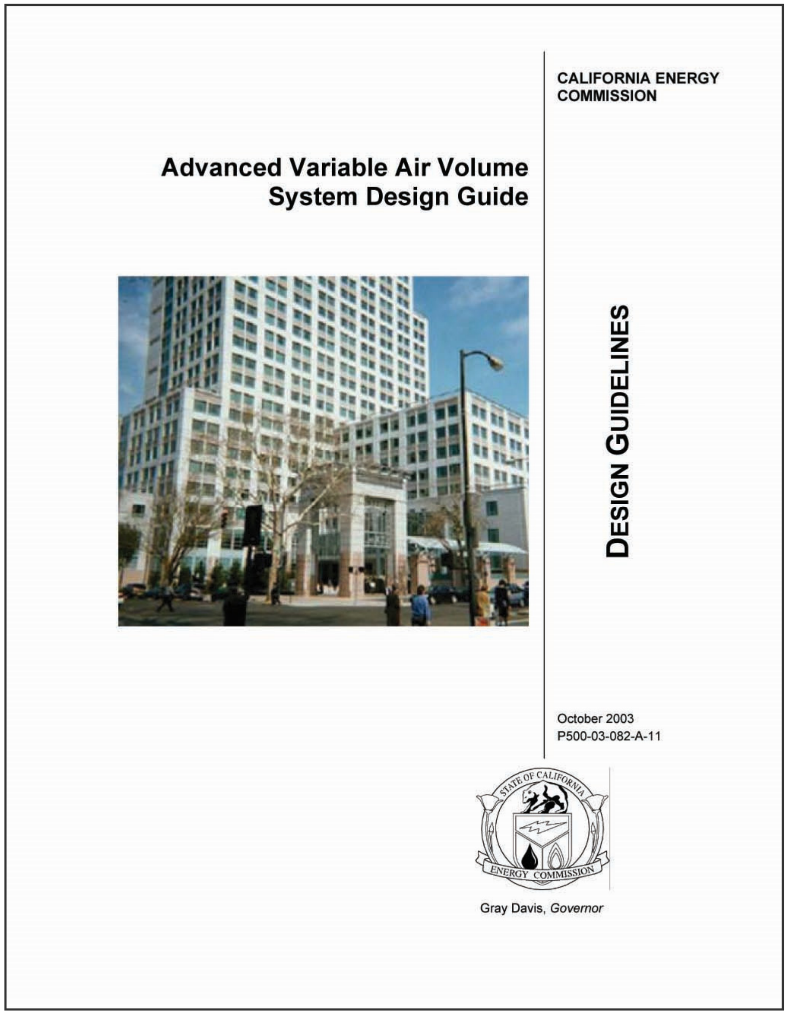
Free Downloads from www.energydesignresources.com

Small Commercial HVAC Design Guideline



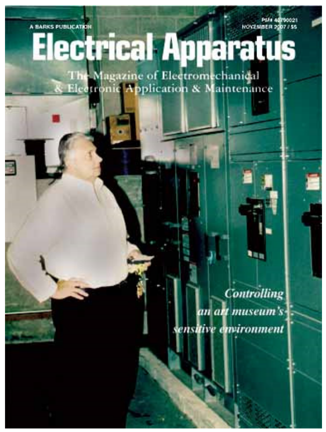
- Good design paves the way for successful Cx
- Design review is an essential component of Cx
- Topics include
  - Integrated design
  - Unit sizing
  - Unit selection
  - Distribution systems
  - Ventilation
  - Thermostats and controls
  - Commissioning
  - Operations and maintenance

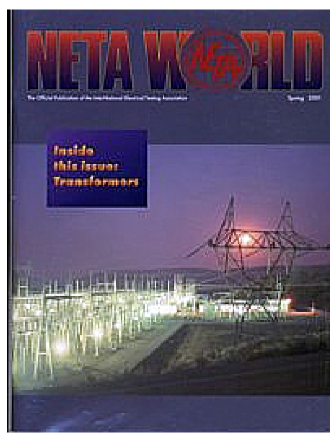
Advanced VAV Design Guideline



- Good design paves the way for successful Cx
- Design review is an essential component of Cx
- Topics include
  - Early design issues
  - Zone issues
  - VAV box selection
  - Duct design
  - Supply air temperature control
  - Fan size, type and control
  - Coils and filters
  - OA, RA, relief and exhaust control

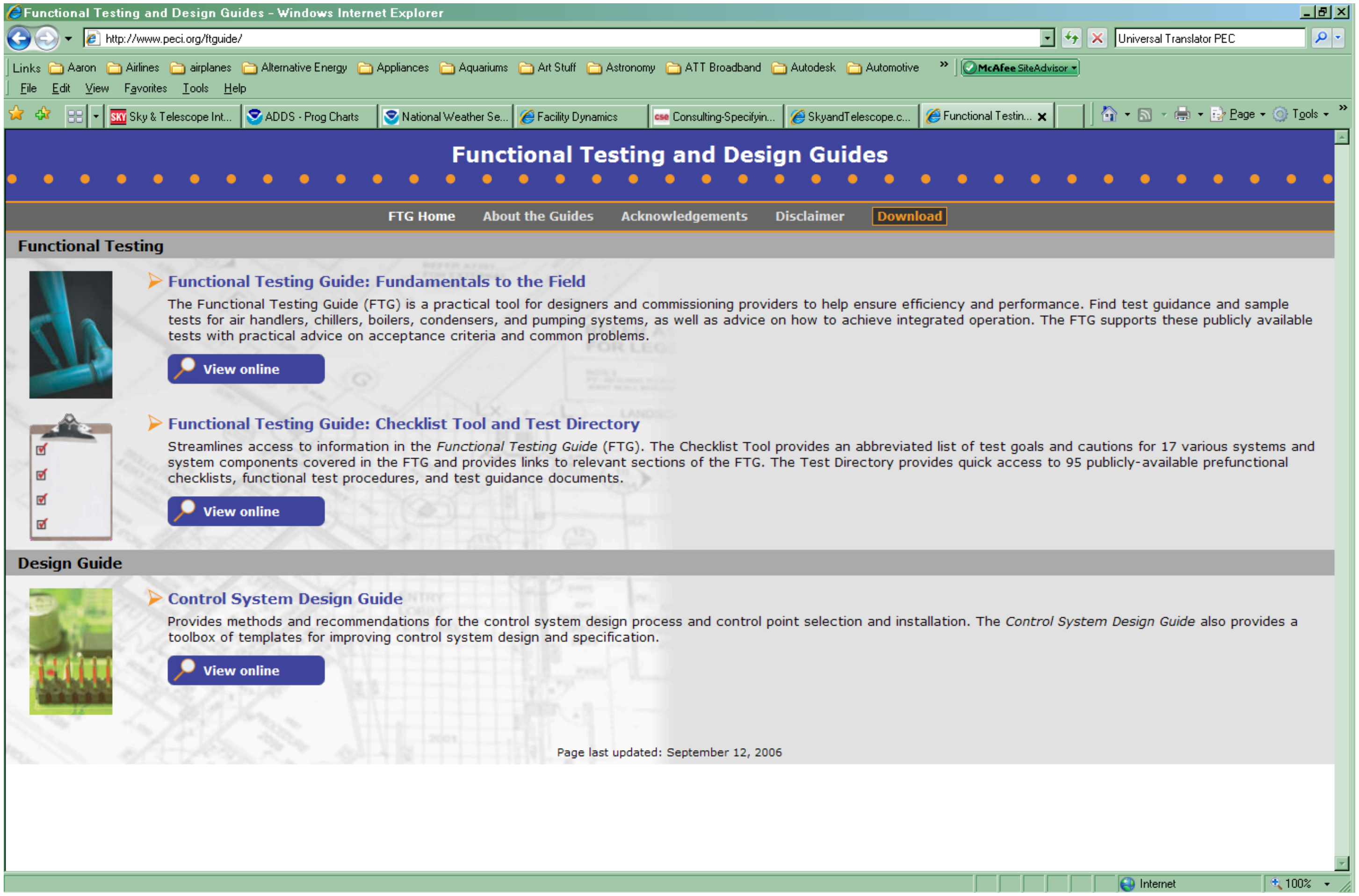
Take Advantage of *Free* Trade Publications





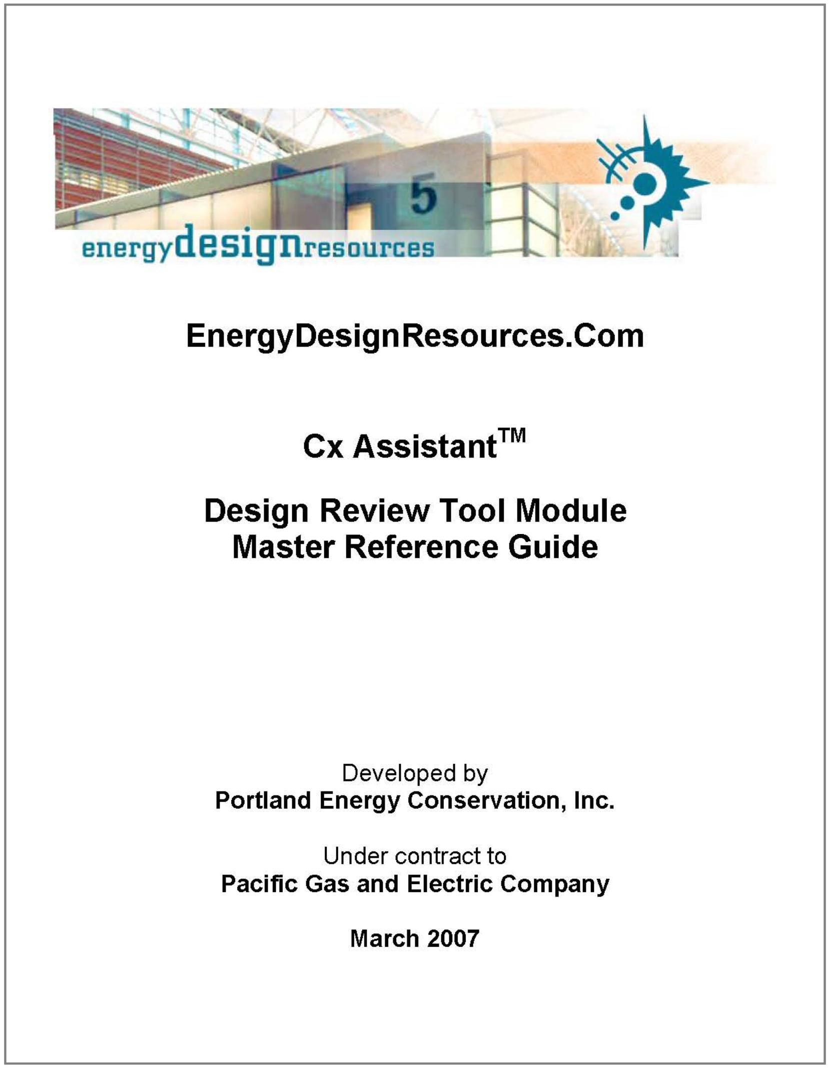
- Consulting Specifying Engineer
  www.csemag.com
- Heating, Piping, and Air Conditioning
  www.hpac.com
- Engineered Systems
  www.esmagazine.com
- Electrical Apparatus
  http://www.barks.com/index.htm
- NETA World
  http://www.netaworld.org/

The Functional Testing Guide Checklist Tool



The Functional Testing and Design Guide; www.peci.org/ftguide

EDR's Design Review Checklist Tool



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EnergyDesignResources.Com

Cx Assistant™

Design Review Tool Module
Master Reference Guide

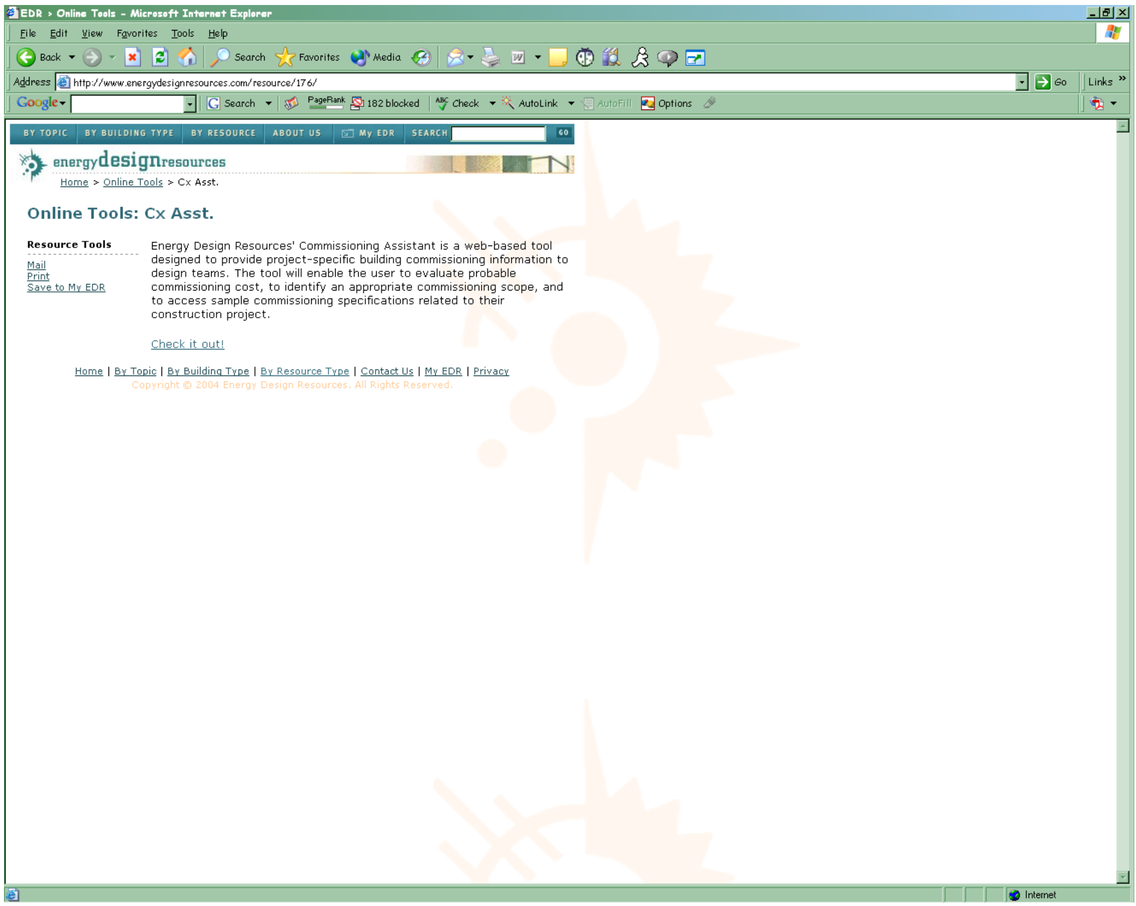
Developed by
Portland Energy Conservation, Inc.

Under contract to
Pacific Gas and Electric Company

March 2007

http://resources.cacx.org/library/,
Search for Design Review Tool

The Commissioning Assistant

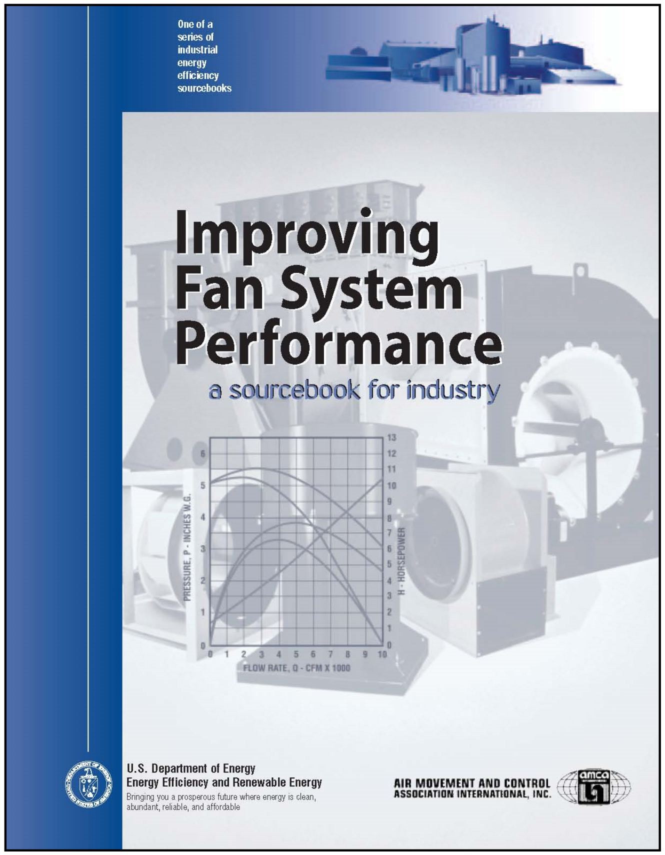


- Develop design intent
- Evaluate probable commissioning cost
- Identify an appropriate commissioning scope
- Access sample commissioning specifications

Watch for Web Based Training Opportunities

http://207.67.203.54/p40007staff/opac/index.asp

Want To Learn More?



Make use of publicly available resources:

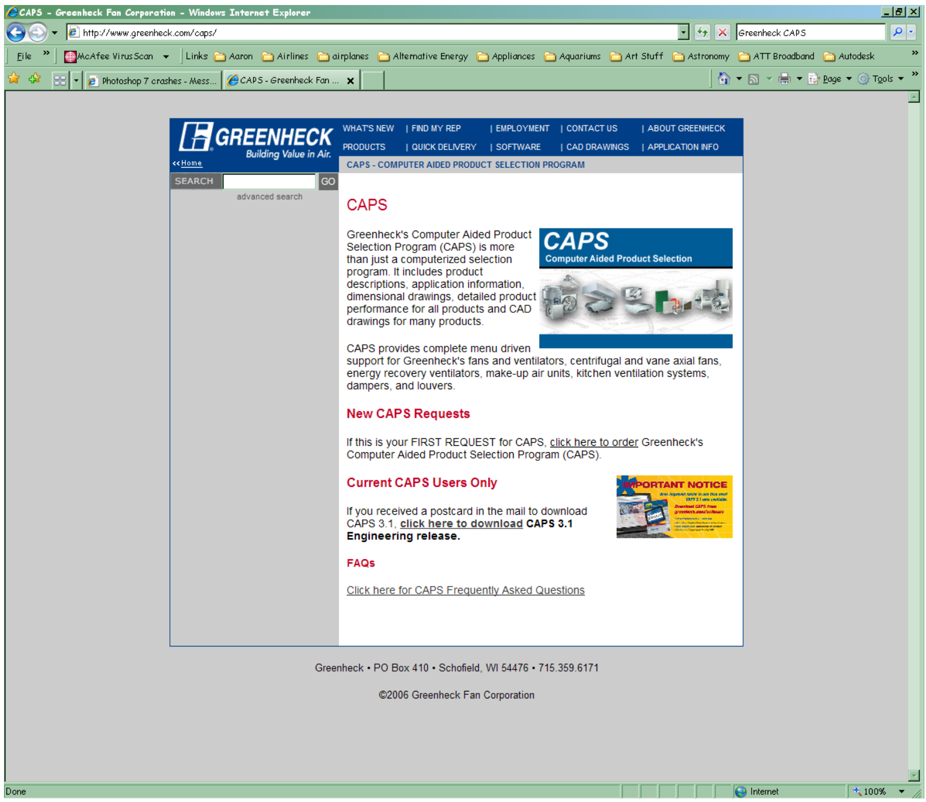
– The DOE/AMCA sourcebook *Improving Fan System Performance* can be downloaded at http://industrial-energy.lbl.gov/node/297

Motor Selection and Comparison Tool

Compare motor purchase and replacement options

www.eere.energy.gov/industry/bestpractices/software.html

Vendor Tools Provide Field Insights

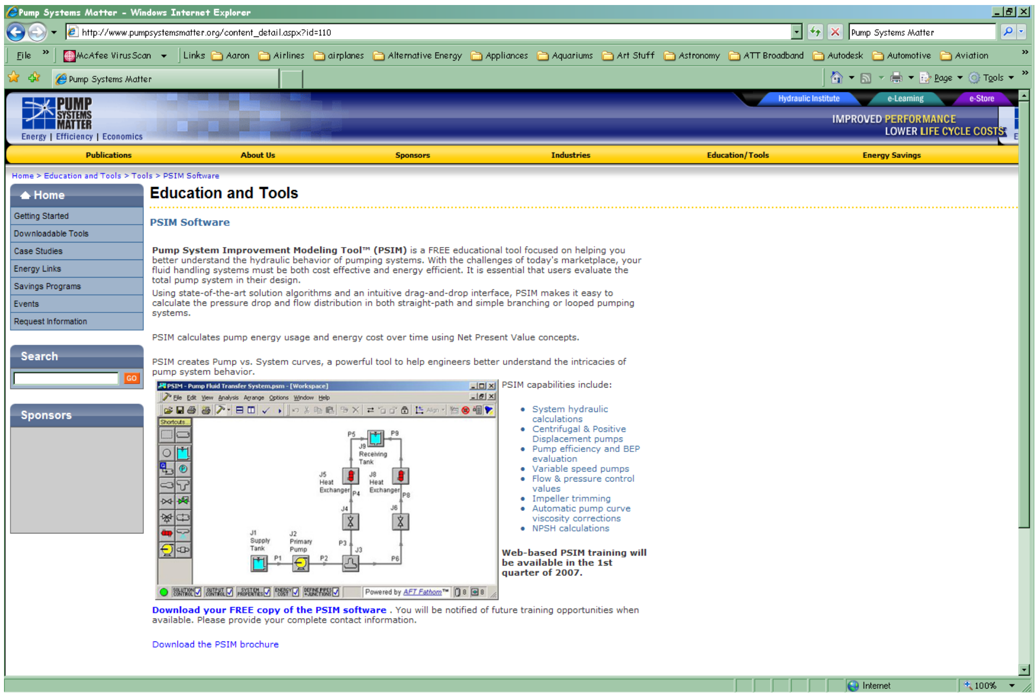


Design and Operations;
Same idea, different direction

What should it do? → What does it look like?

What should it do? ← What does it look like?

Use PSIMT to Assess Pump Head



This tool is a free download at the Pump Systems Matter website at:

[*www.pumpsystemsmatter.org*](http://www.pumpsystemsmatter.org)

Another Free Pump Performance Resource