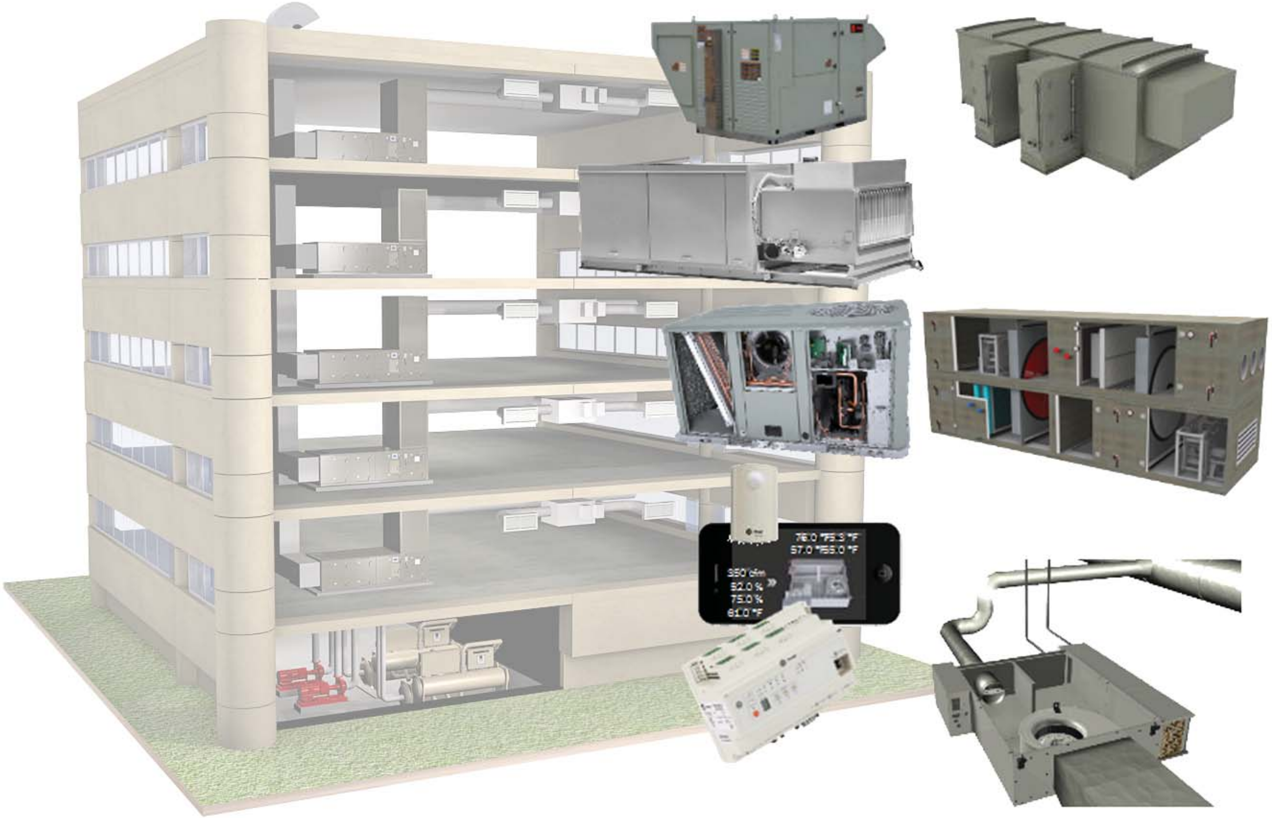
Trane Engineers Newsletter Live

High-Performance Air Systems

with Systems Engineers Dustin Meredith, Ronnie Moffitt and Jeanne Harshaw (host)



Trane program number: APP-CMC063-EN

Agenda

Trane *Engineers Newsletter Live* Series

High-Performance Air Systems

Abstract

This program will discuss the properties of high-performance air systems and provide guidance on their design. Air handling equipment design best practices like right-sizing and proper component selection will be discussed in detail. Duct design guidelines including velocity and fitting placement will complete the air distribution system. System control strategies and damper control strategies will be briefly reviewed. Also included: selection for part-load operation and part-load efficiency requirements, economics of oversizing, and comparisons to traditional air-handling systems.

Presenters: Trane systems engineers Dustin Meredith, Ronnie Moffitt and Jeanne Harshaw (host)

After viewing attendees will be able to:

1. Identify the major components of an air system
2. Summarize how right sizing and proper component selection impact air system performance
3. Identify several opportunities to improve performance and save energy in air systems
4. Summarize best practices for fan configuration, operation and selection

Agenda

- Overview of air system components
- Optimization opportunities (internal and external)
- System layout
- Properties of a high-performance system
- Summary (energy analysis)

TRANE

Presenter biographies

High-Performance Air Systems

Dustin Meredith | systems engineer | Trane
Dustin joined Trane in 2000 and has spent most of his career in applications engineering. In his current role as a systems engineer, he develops and optimizes next-generation systems. His expertise includes fans, acoustics, air system design and overall system optimization. He holds multiple patents and has been instrumental in advancing cutting-edge fan and motor applications to industry. Dustin has authored a variety of technical engineering bulletins, white papers, Trane *Engineers Newsletter* articles and Trane *Engineers Newsletter LIVE* programs.

Dustin is a registered professional engineer and earned his mechanical engineering, computer science, and MBA degrees from the University of Kentucky. He is an ASHRAE Section Head and serves on the “Fans” and “Sound and Vibration” technical committees, including as past Chair of the latter. He is Trane’s voting member for Air Movement and Control Association International, Inc. (AMCA) and serves on a number of AMCA committees.

Ronnie Moffitt | systems engineer | Trane
Ronnie joined Trane in 1996 and currently is a systems engineer focused on developing and optimizing commercial HVAC systems and control strategies. His primary focus has been dehumidification, air-to-air energy recovery and DOAS design. He has several patents related to these subjects and serves on related AHRI and ASHRAE engineering committees.

Ronnie is the current chairman of the AHRI dehumidification engineering section and past chairman of ASHRAE’s “Energy Recovery” technical committee. He led the development of the Trane CDQ™ system, a winner of the R&D 100 Award for *The Most Technologically Significant New Products* of 2005. He received his B.S. in Aerospace Engineering from Syracuse University and is a licensed professional engineer and a certified Energy Manager (CEM) by Association of Energy Engineers.

Ingersoll Rand

High-Performance Air Systems

Trane Engineers Newsletter Live Series

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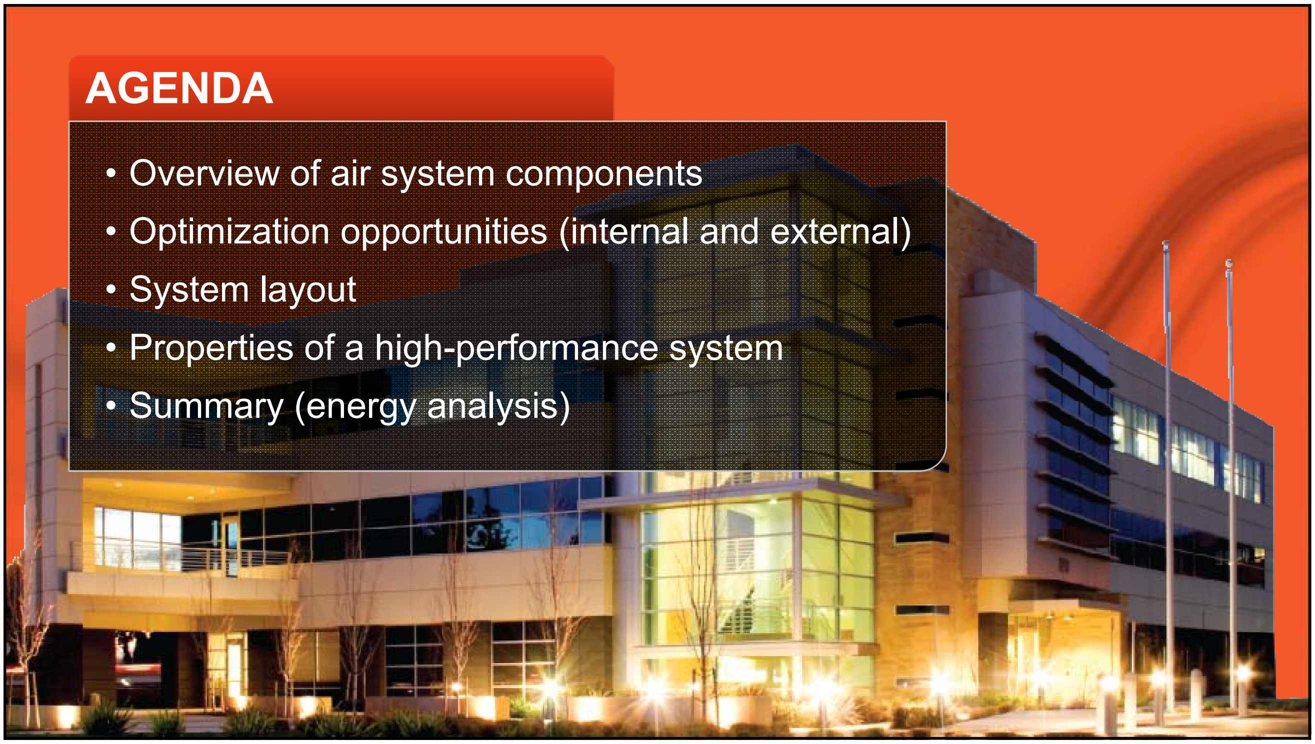
Learning objectives

- Identify the major components of an air system
- Summarize how right sizing and proper component selection impact air system performance
- Identify several opportunities to improve performance and save energy in air systems
- Summarize best practices for fan configuration, operation and selection



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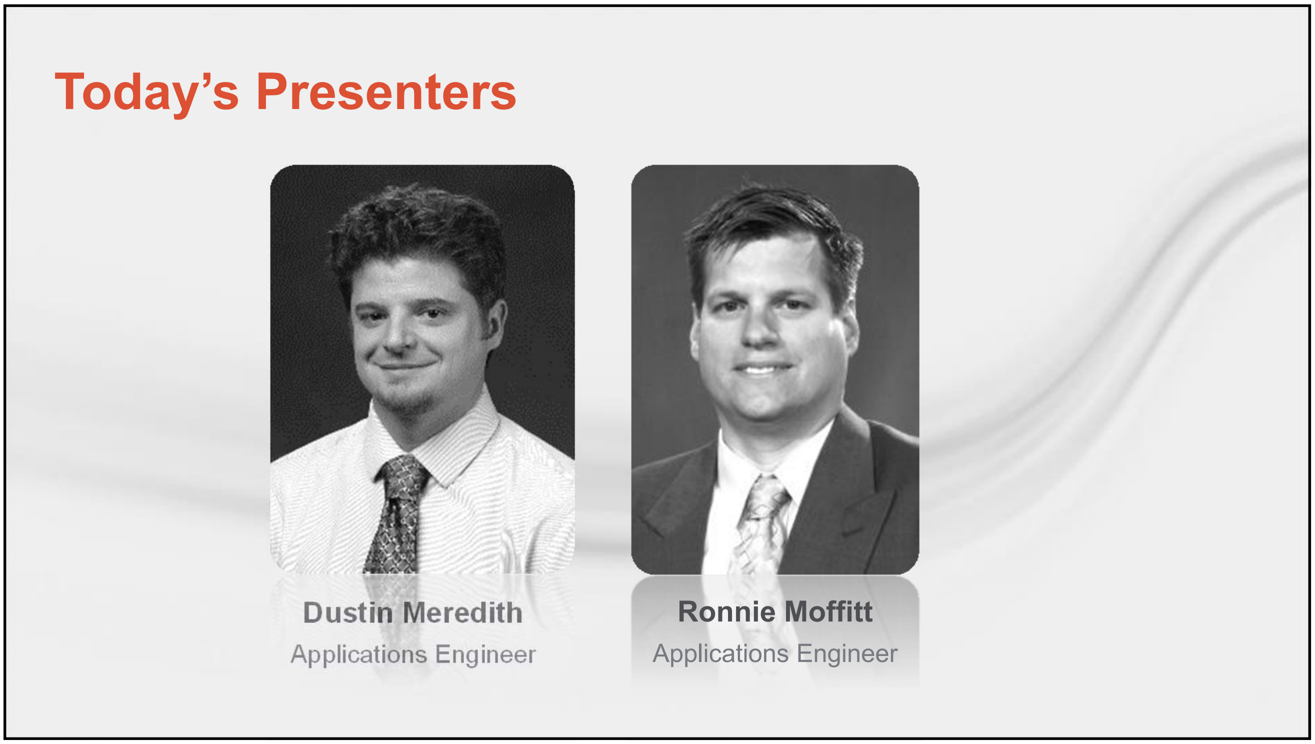
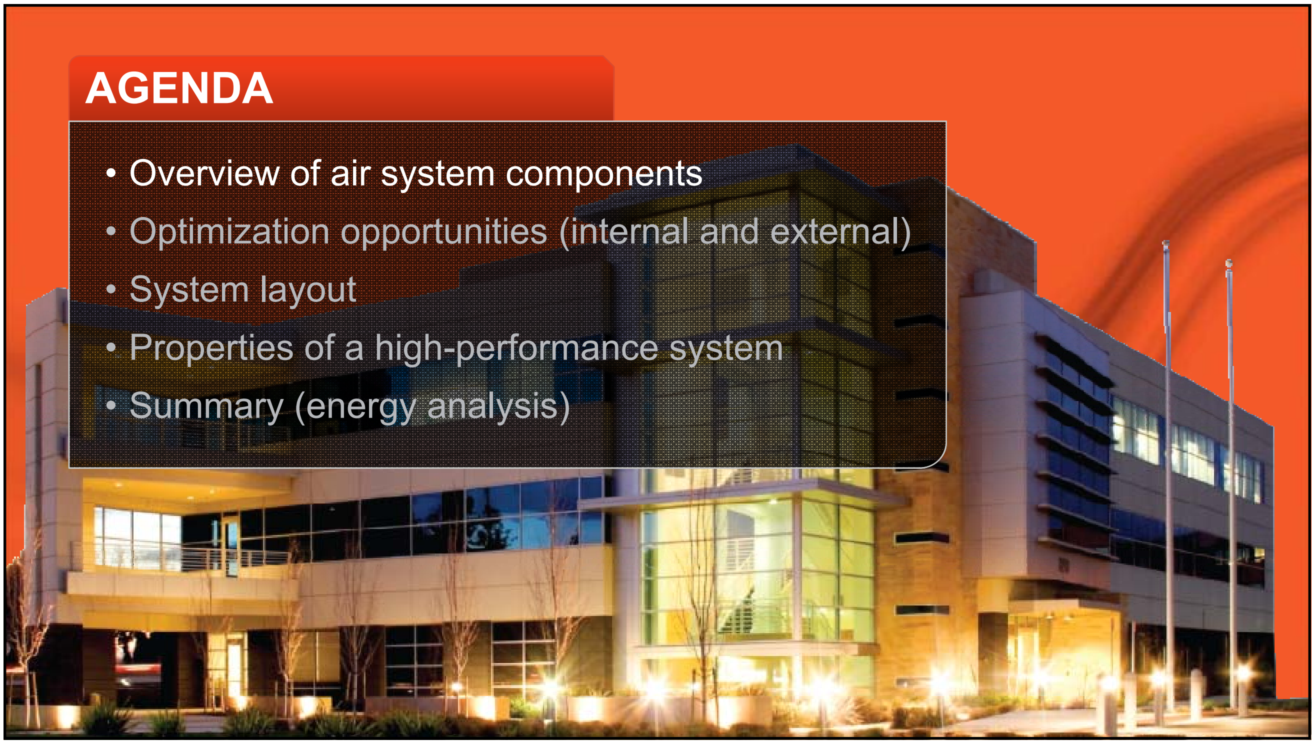


Today's Presenters

Dustin Meredith
Applications Engineer

Ronnie Moffitt
Applications Engineer



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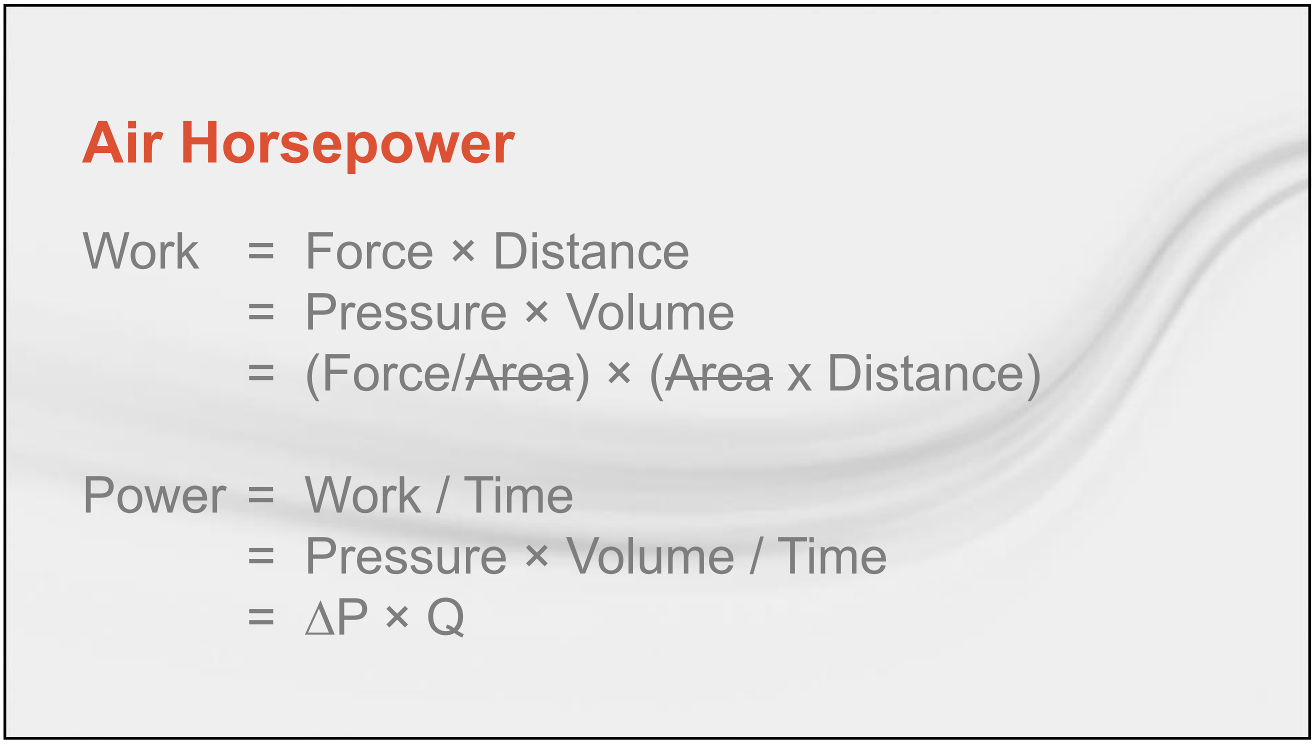
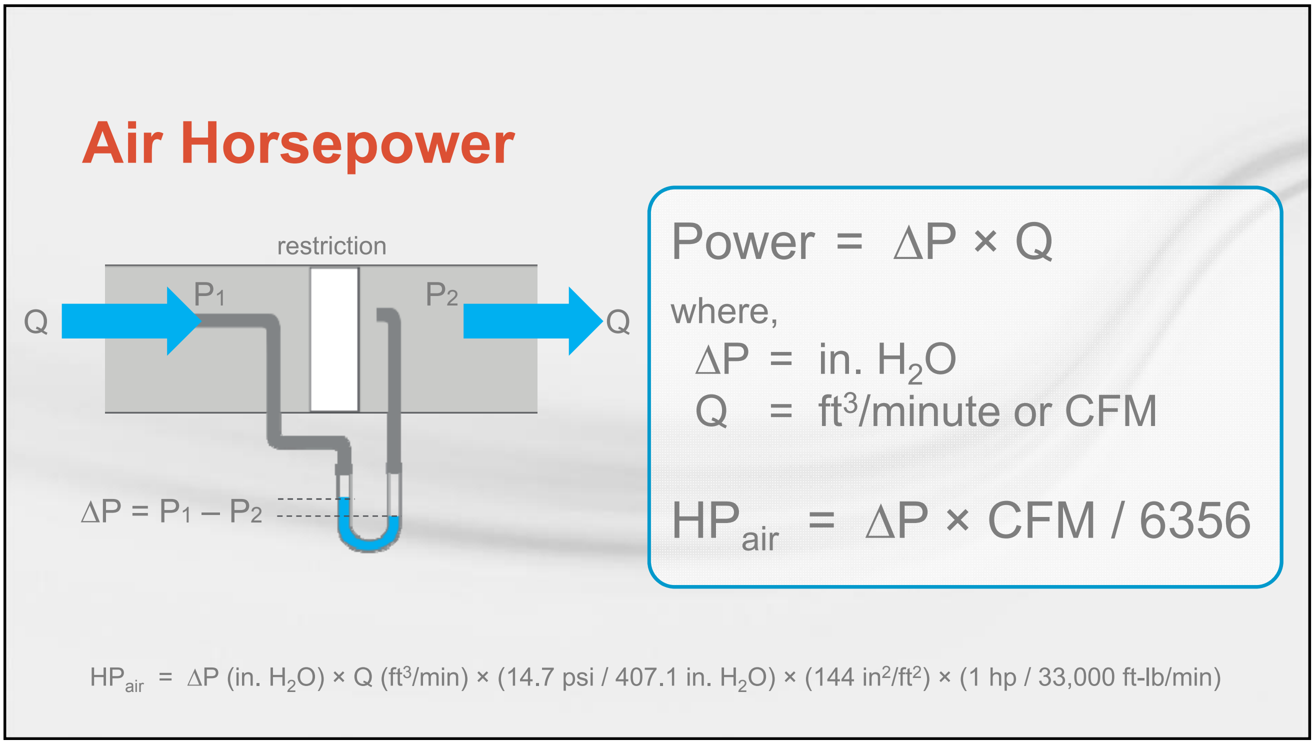
Air System



Air Horsepower

Work = Force × Distance
= Pressure × Volume
= (Force/~~Area~~) × (~~Area~~ x Distance)

Power = Work / Time
= Pressure × Volume / Time
= ΔP × Q



Air Horsepower

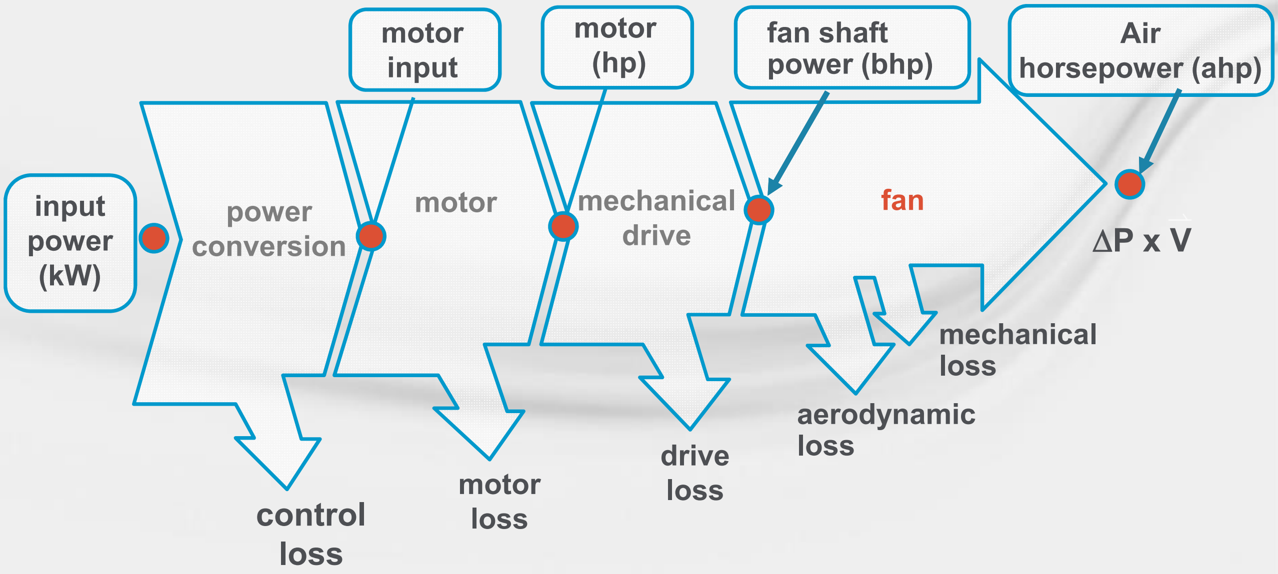
Power = ΔP × Q

where,
ΔP = in. H_2O
Q = ft^3/minute or CFM

$HP_{air} = \Delta P \times CFM / 6356$

$HP_{air} = \Delta P \text{ (in. } H_2O) \times Q \text{ (}ft^3/min) \times (14.7 \text{ psi} / 407.1 \text{ in. } H_2O) \times (144 \text{ in}^2/ft^2) \times (1 \text{ hp} / 33{,}000 \text{ ft-lb/min})$

Power Input vs. Air Horsepower



motor input

motor (hp)

fan shaft power (bhp)

Air horsepower (ahp)

input power (kW)

power conversion

motor

mechanical drive

fan

ΔP x V

mechanical loss

aerodynamic loss

drive loss

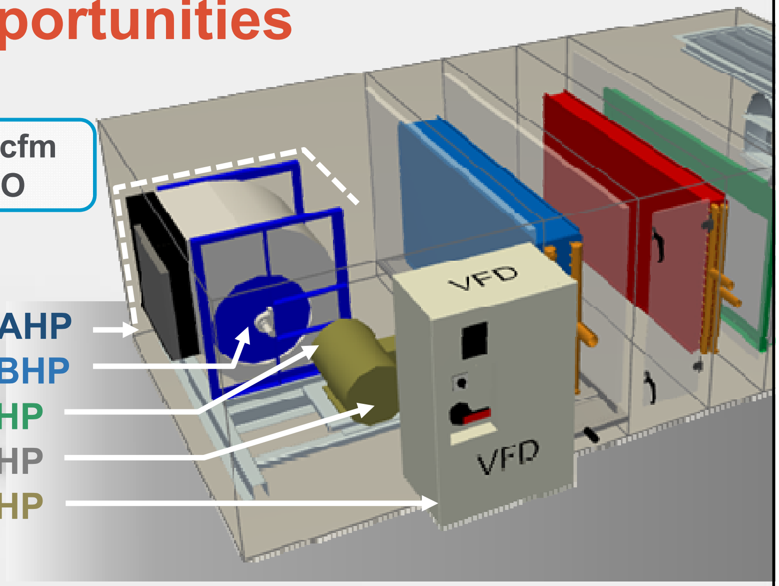
motor loss

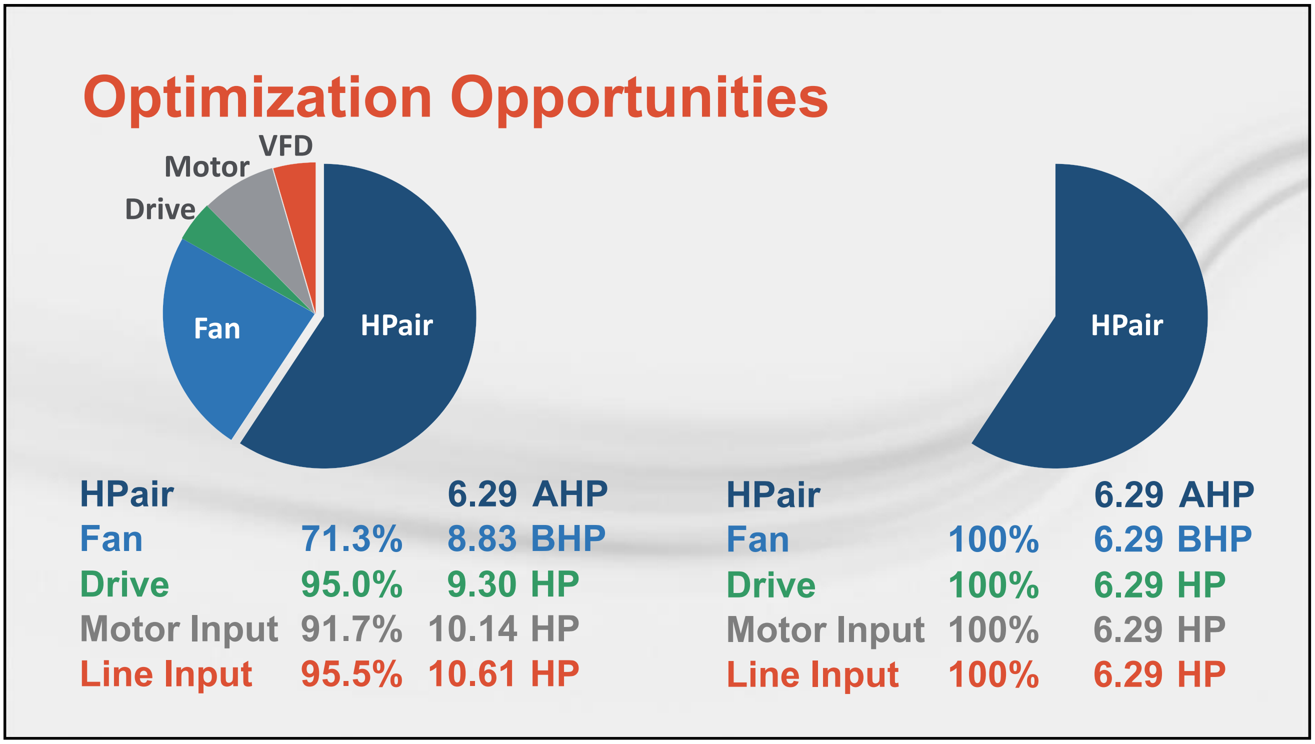
control loss

Optimization Opportunities

Q = 10,000 cfm
ΔP = 4 in. H_2O

HPair		6.29 AHP
Fan	71.3%	8.83 BHP
Drive	95.0%	9.30 HP
Motor Input	91.7%	10.14 HP
Line Input	95.5%	10.61 HP



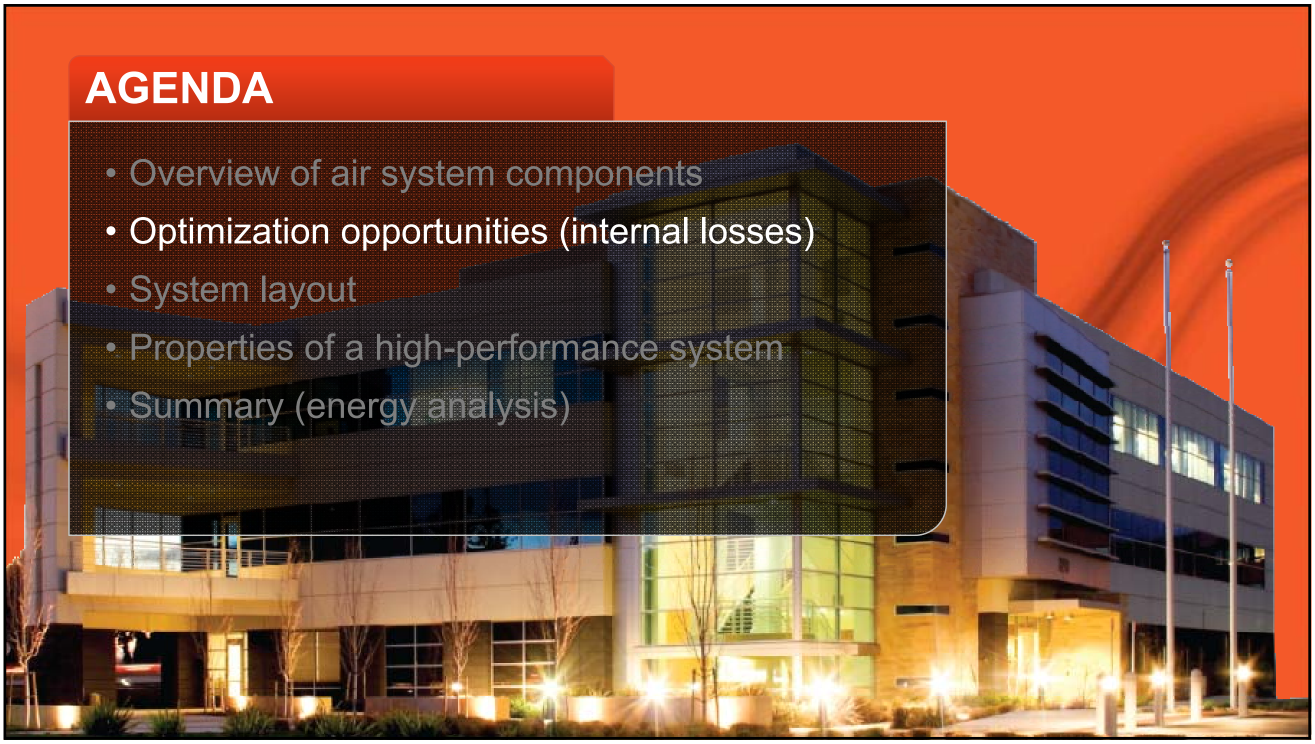


Optimization Opportunities

HPair		6.29 AHP	HPair		6.29 AHP
Fan	71.3%	8.83 BHP	Fan	100%	6.29 BHP
Drive	95.0%	9.30 HP	Drive	100%	6.29 HP
Motor Input	91.7%	10.14 HP	Motor Input	100%	6.29 HP
Line Input	95.5%	10.61 HP	Line Input	100%	6.29 HP

Components of an Air System

- DOAS dedicated outdoor air handler
- Make-up air unit (MUA)
- Air-handling unit (AHU)
- Rooftop unit (RTU)
- Energy recovery ventilator (ERV
- Heat Recovery Unit (HRU)
- Relief or exhaust fans
- Terminal equipment
- Ductwork
- Controls



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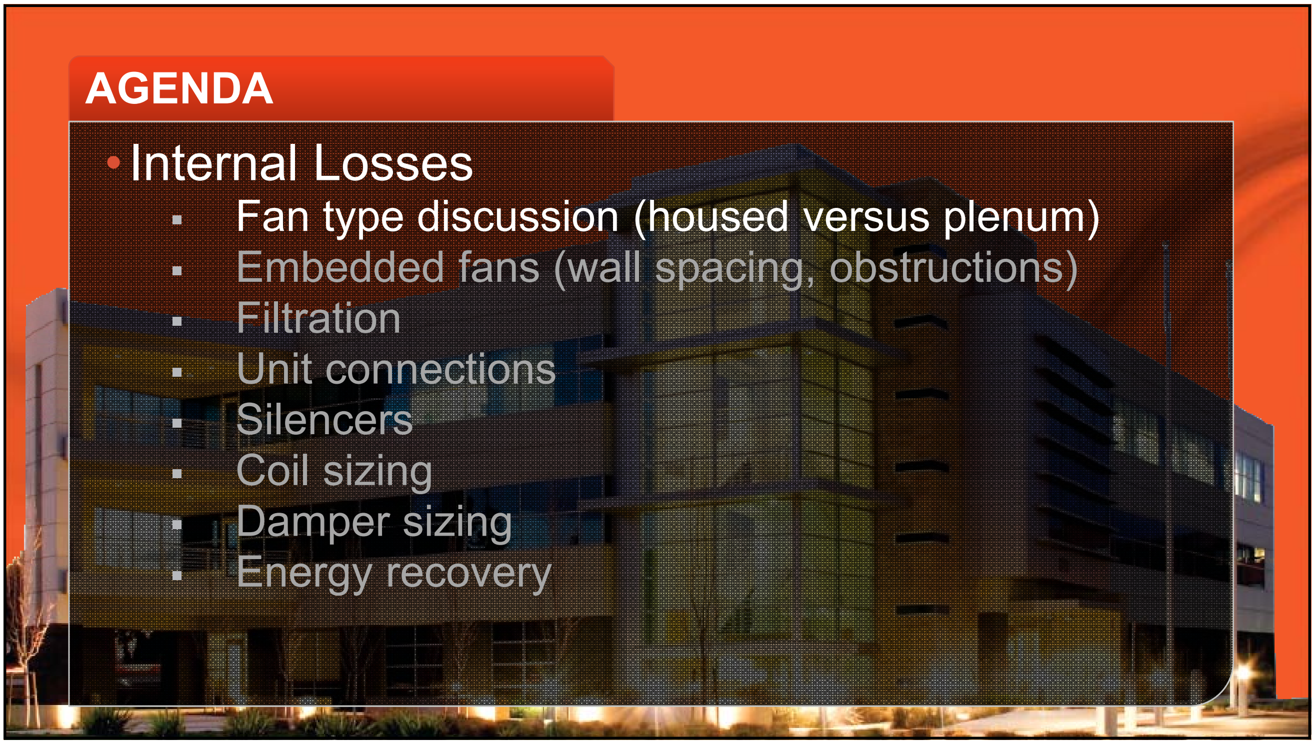
- Overview of air system components
- Optimization opportunities (internal losses)
- System layout
- Properties of a high-performance system
- Summary (energy analysis)



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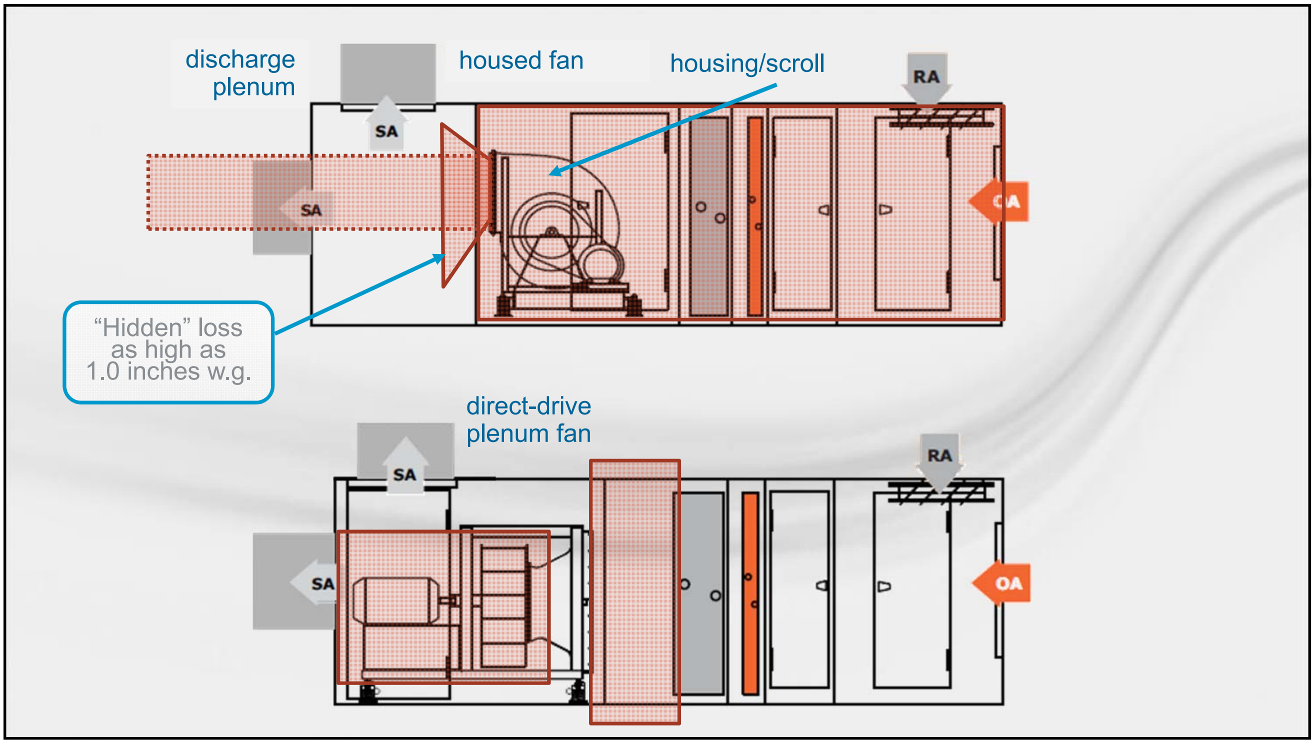
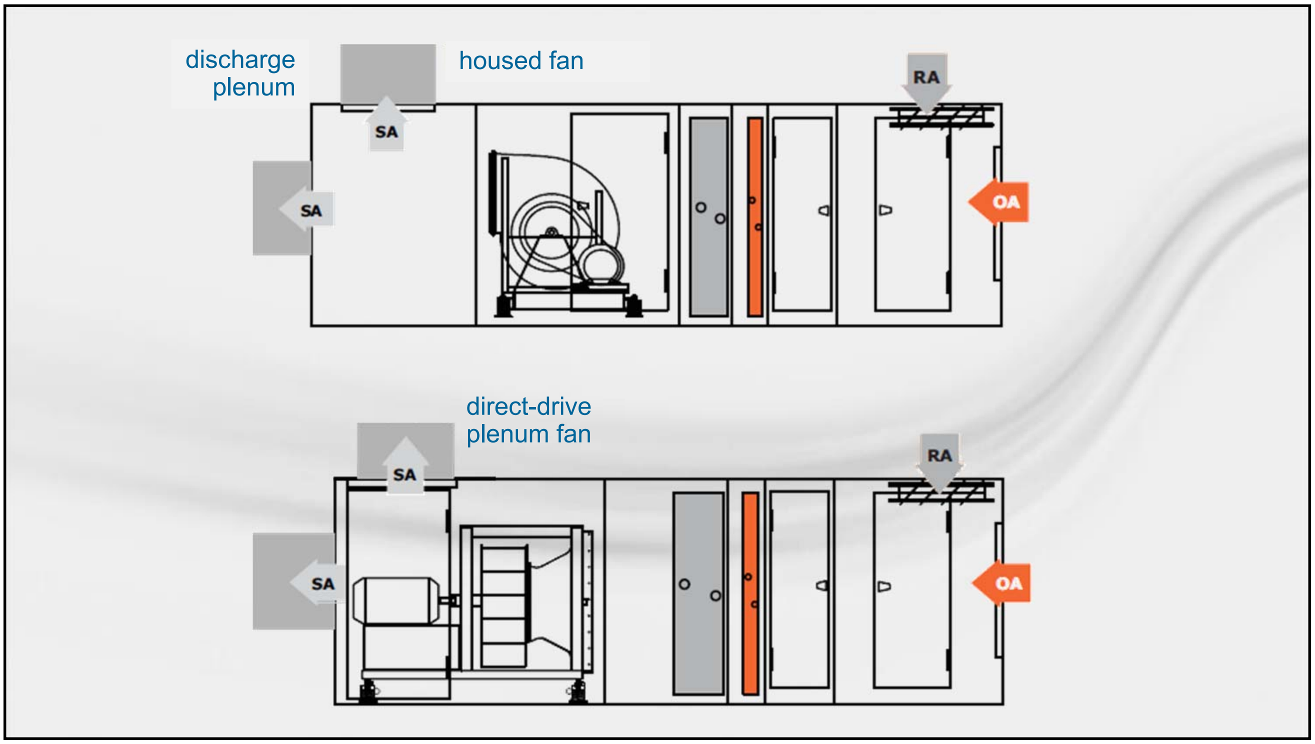
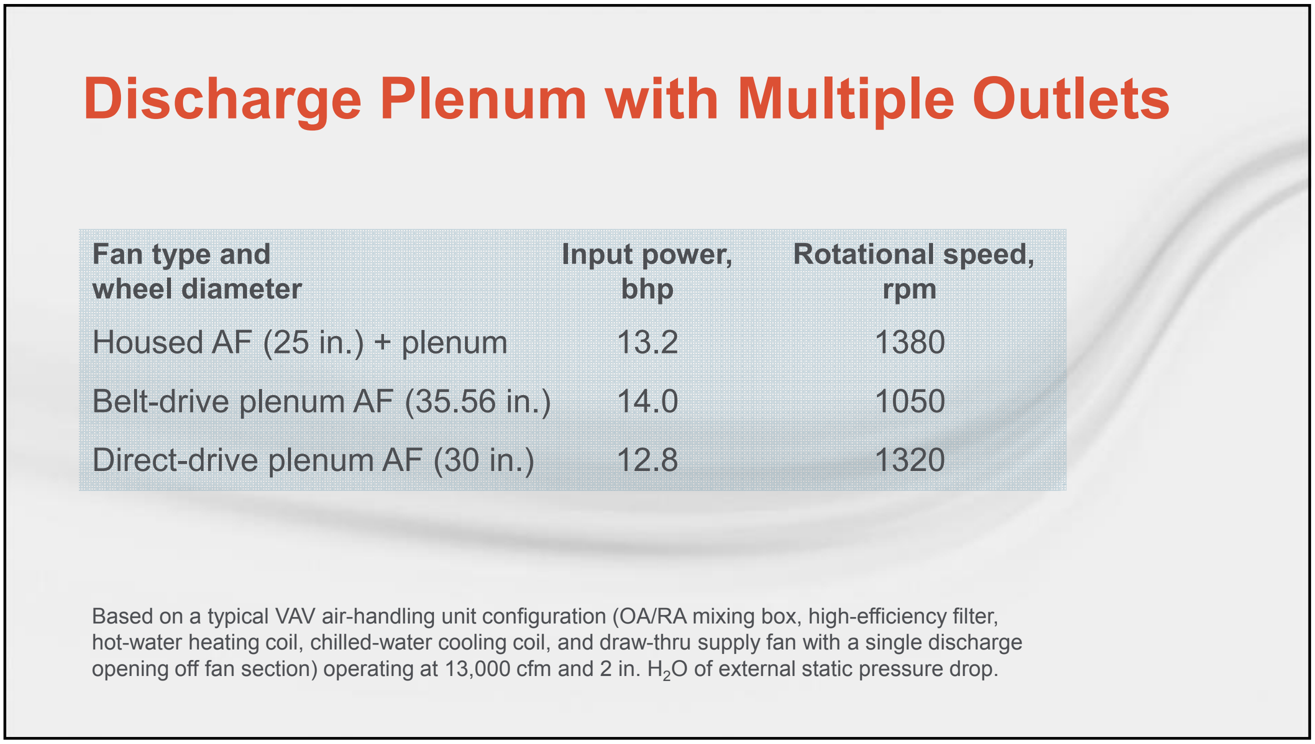
- Internal Losses
  - Fan type discussion (housed versus plenum)
  - Embedded fans (wall spacing, obstructions)
  - Filtration
  - Unit connections
  - Silencers
  - Coil sizing
  - Damper sizing
  - Energy recovery


discharge plenum
housed fan
housing/scroll
SA
SA
RA
OA
"Hidden" loss as high as 1.0 inches w.g.
direct-drive plenum fan
SA
SA
RA
OA

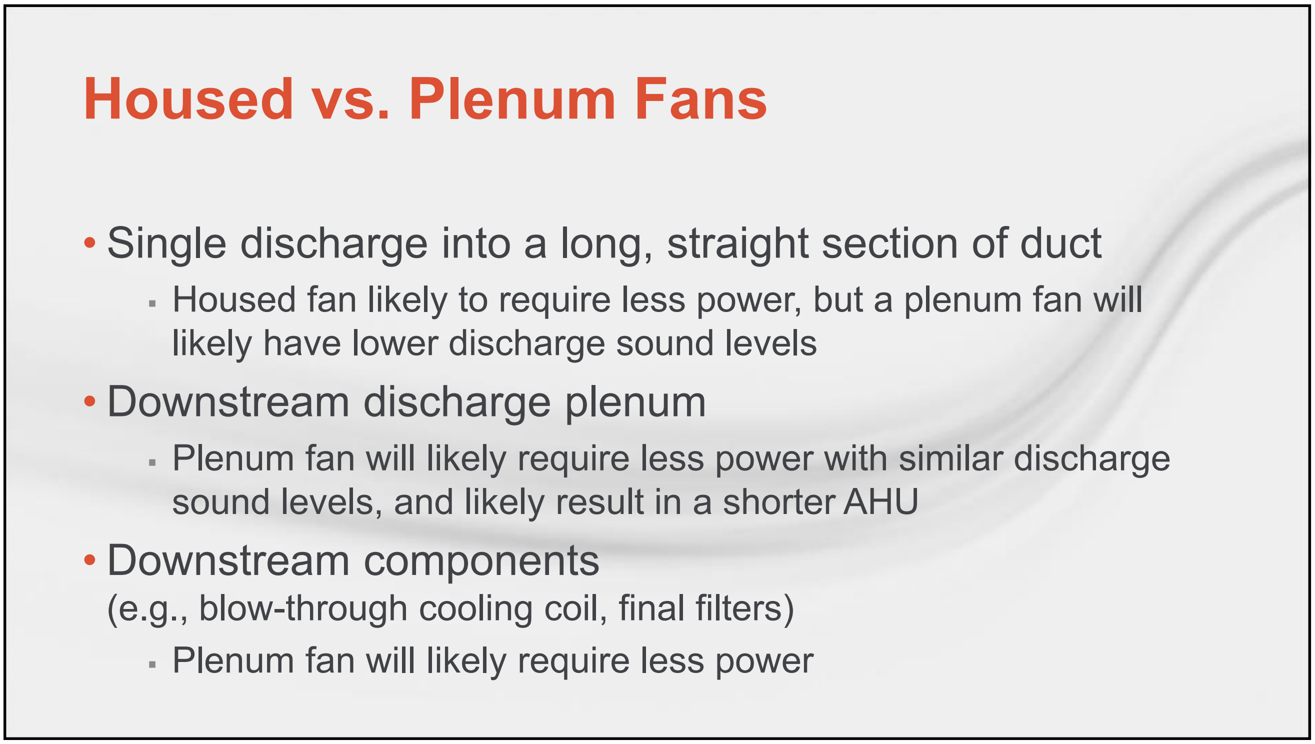

discharge plenum
housed fan
SA
SA
RA
OA
direct-drive plenum fan
SA
SA
RA
OA



Discharge Plenum with Multiple Outlets

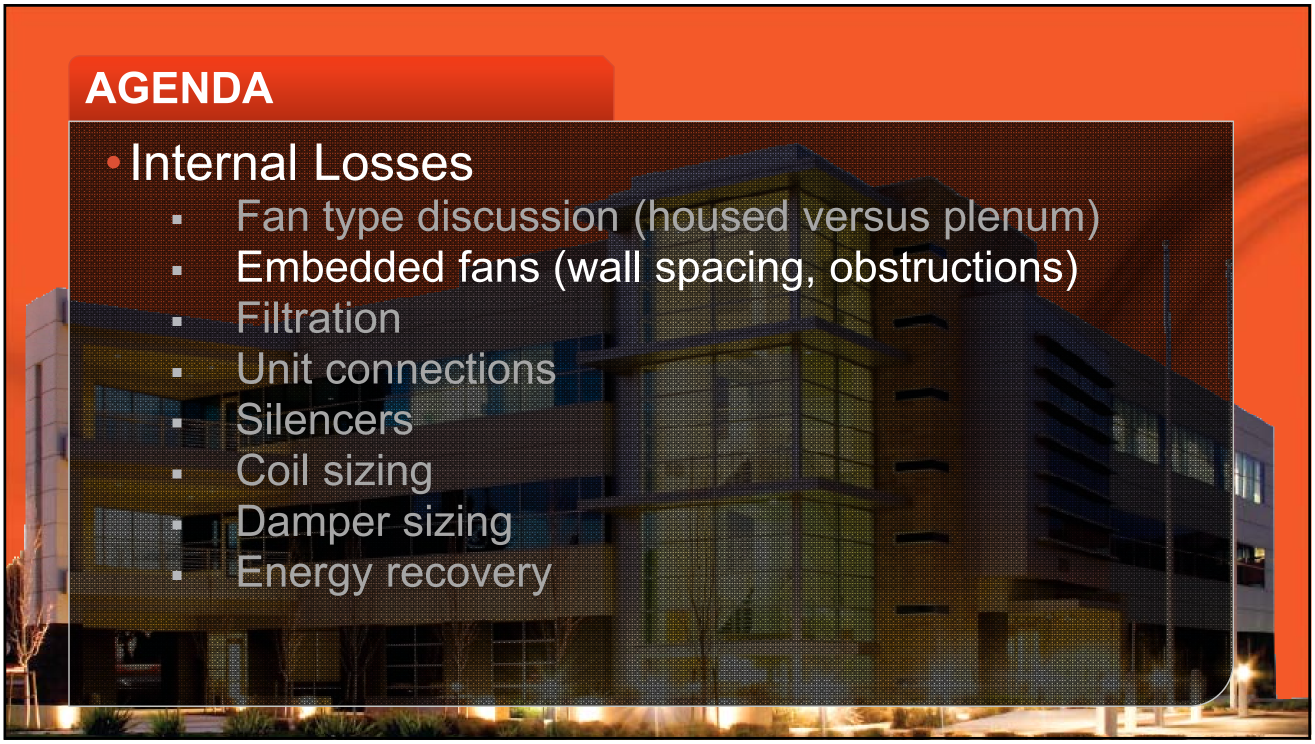
Fan type and wheel diameter	**Input power, bhp**	**Rotational speed, rpm**
Housed AF (25 in.) + plenum	13.2	1380
Belt-drive plenum AF (35.56 in.)	14.0	1050
Direct-drive plenum AF (30 in.)	12.8	1320

Based on a typical VAV air-handling unit configuration (OA/RA mixing box, high-efficiency filter, hot-water heating coil, chilled-water cooling coil, and draw-thru supply fan with a single discharge opening off fan section) operating at 13,000 cfm and 2 in. H_2O of external static pressure drop.



Housed vs. Plenum Fans

- Single discharge into a long, straight section of duct
  - Housed fan likely to require less power, but a plenum fan will likely have lower discharge sound levels
- Downstream discharge plenum
  - Plenum fan will likely require less power with similar discharge sound levels, and likely result in a shorter AHU
- Downstream components (e.g., blow-through cooling coil, final filters)
  - Plenum fan will likely require less power



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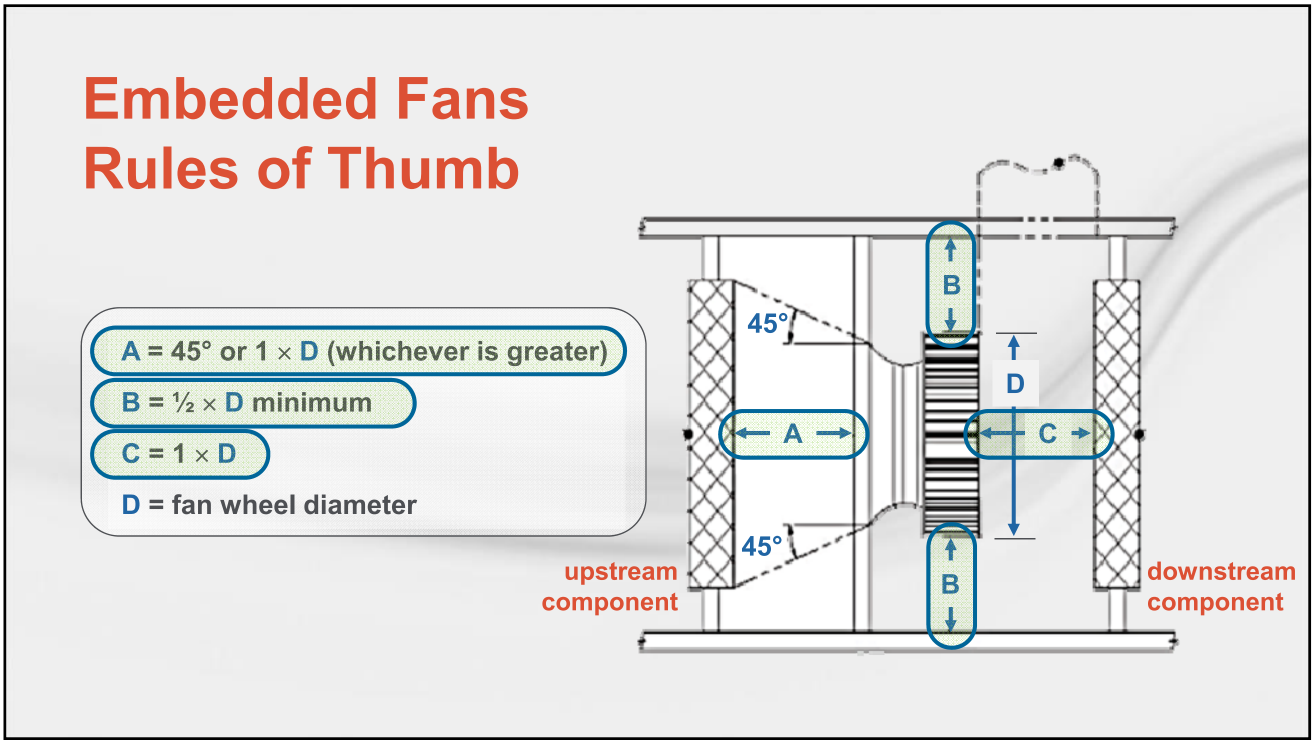
  - Damper sizing
  - Energy recovery



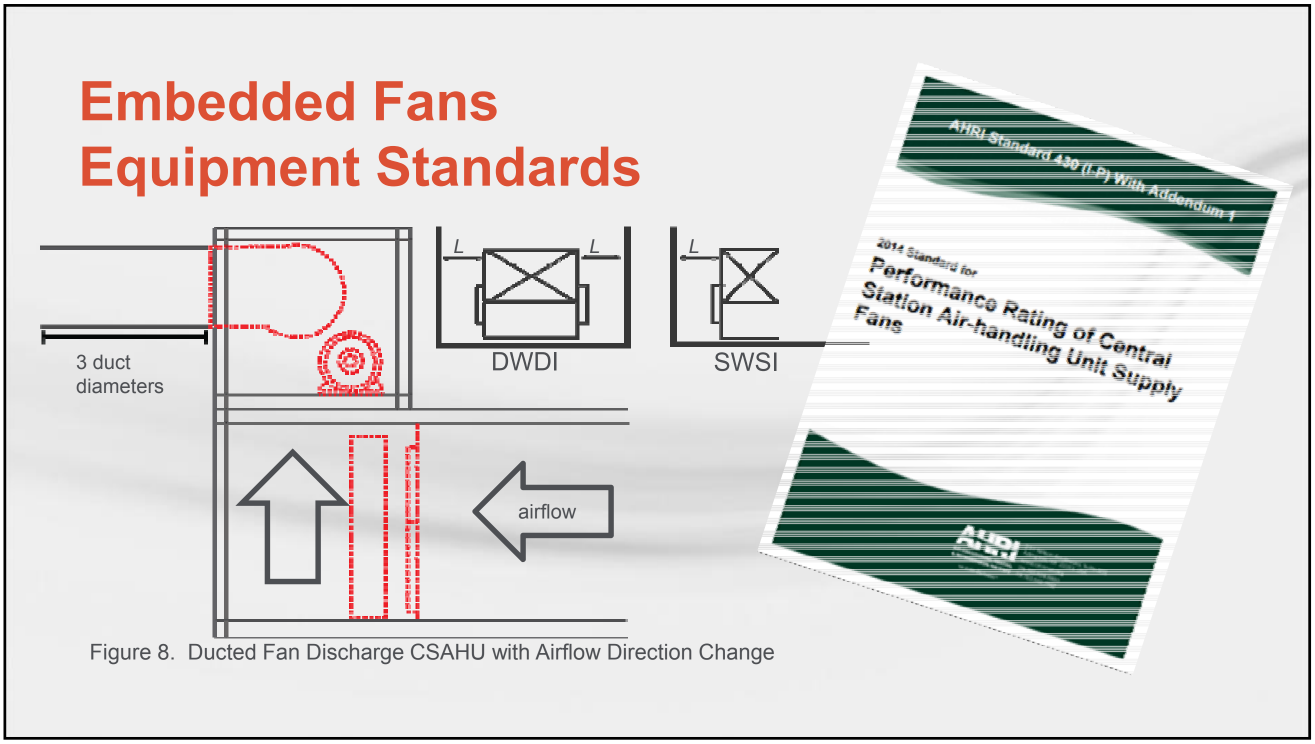
Embedded Fans Rules of Thumb

A = 45° or 1 × D (whichever is greater)

B = ½ × D minimum

C = 1 × D

D = fan wheel diameter

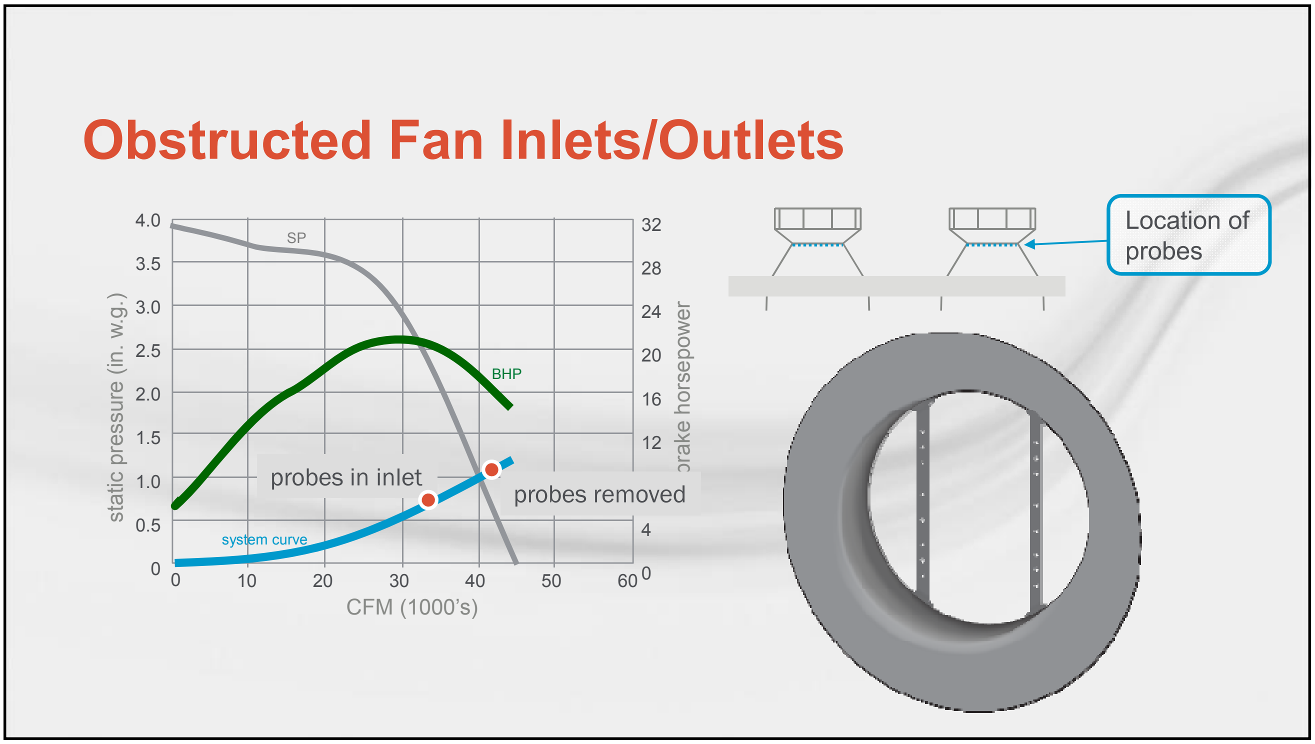


Embedded Fans Equipment Standards

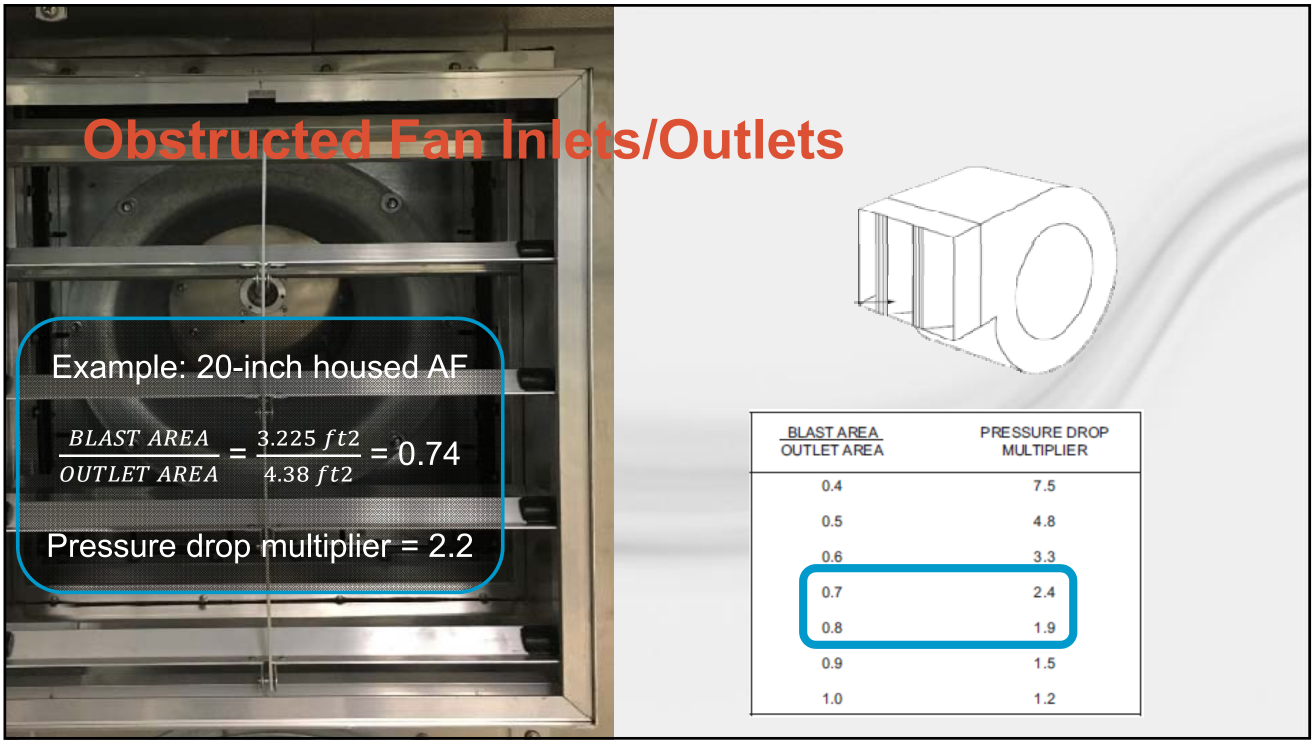
Figure 8. Ducted Fan Discharge CSAHU with Airflow Direction Change

AHRI Standard 430 (I-P) With Addendum 1

2014 Standard for Performance Rating of Central Station Air-handling Unit Supply Fans



Obstructed Fan Inlets/Outlets



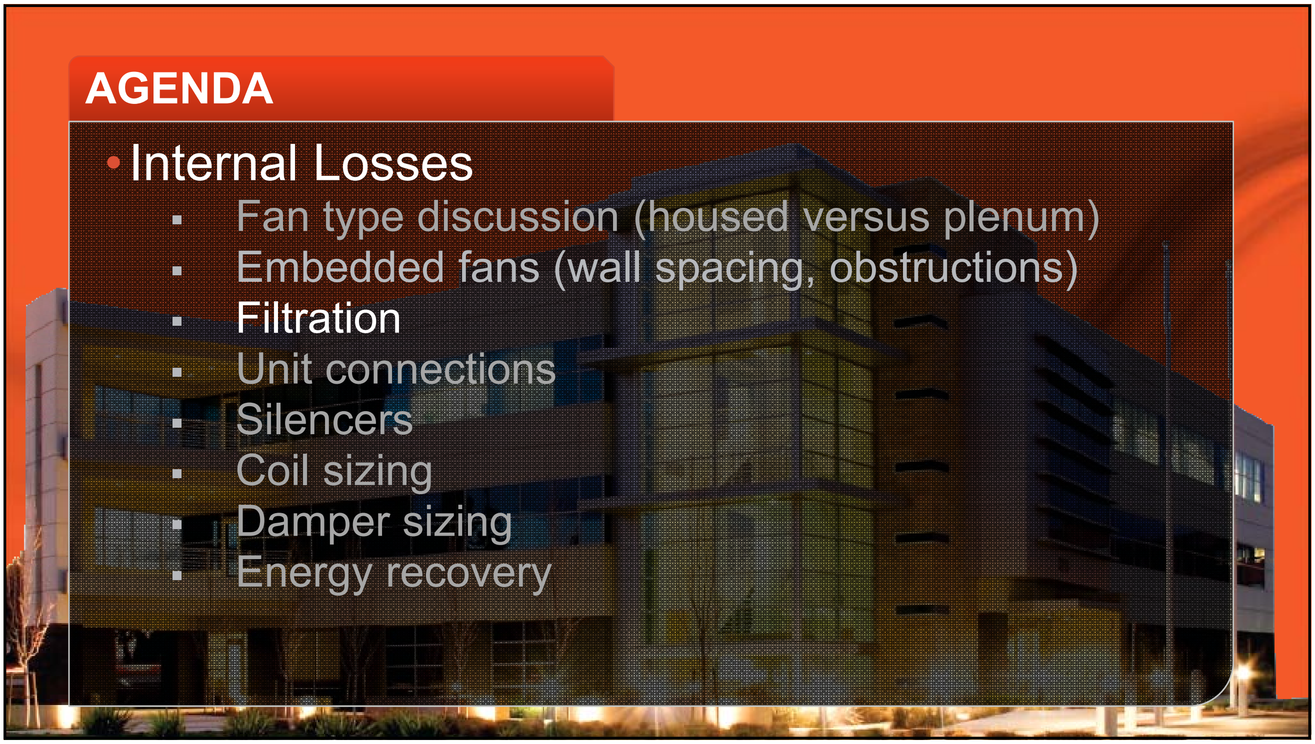
Obstructed Fan Inlets/Outlets

Example: 20-inch housed AF

$$\frac{BLAST\ AREA}{OUTLET\ AREA} = \frac{3.225\ ft2}{4.38\ ft2} = 0.74$$

Pressure drop multiplier = 2.2

BLAST AREA / OUTLET AREA	PRESSURE DROP MULTIPLIER
0.4	7.5
0.5	4.8
0.6	3.3
0.7	2.4
0.8	1.9
0.9	1.5
1.0	1.2



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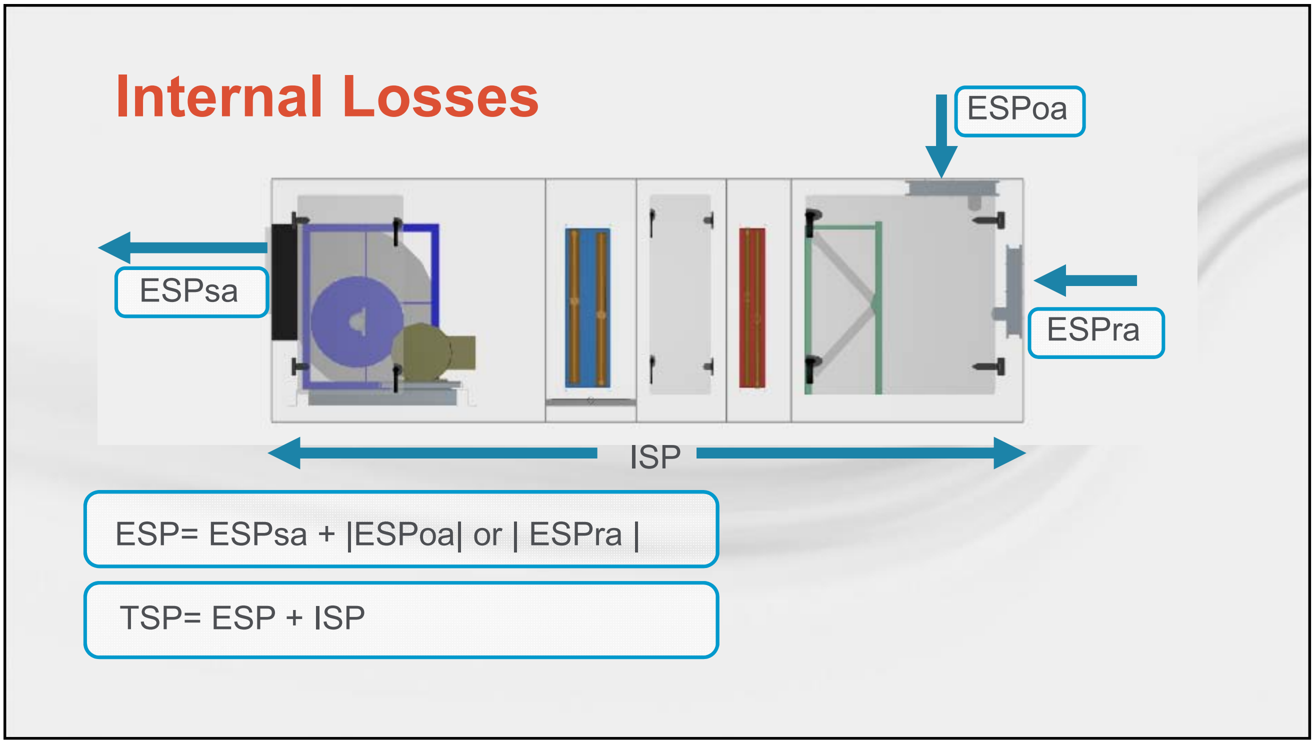


Internal Losses

ESPoa

ESPsa

ESPra

ISP

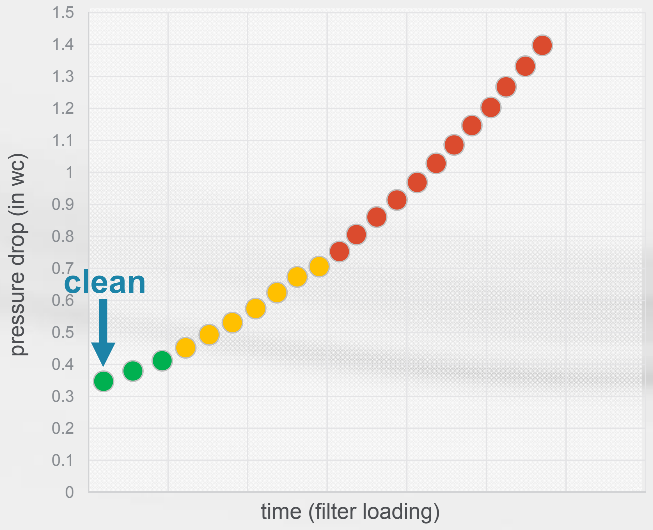
ESP= ESPsa + |ESPoa| or | ESPra |

TSP= ESP + ISP

Specify Filtration Design Requirements

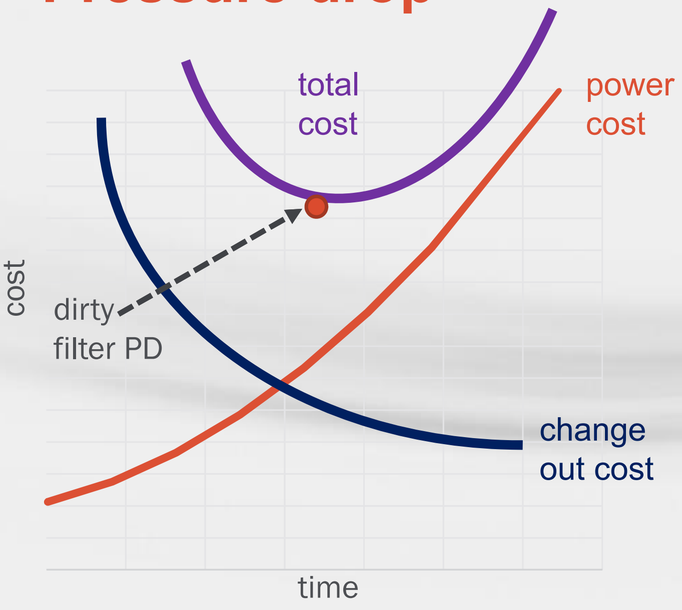
- Type of filter
- MERV rating
- Depth
- Size
- Pressure drop

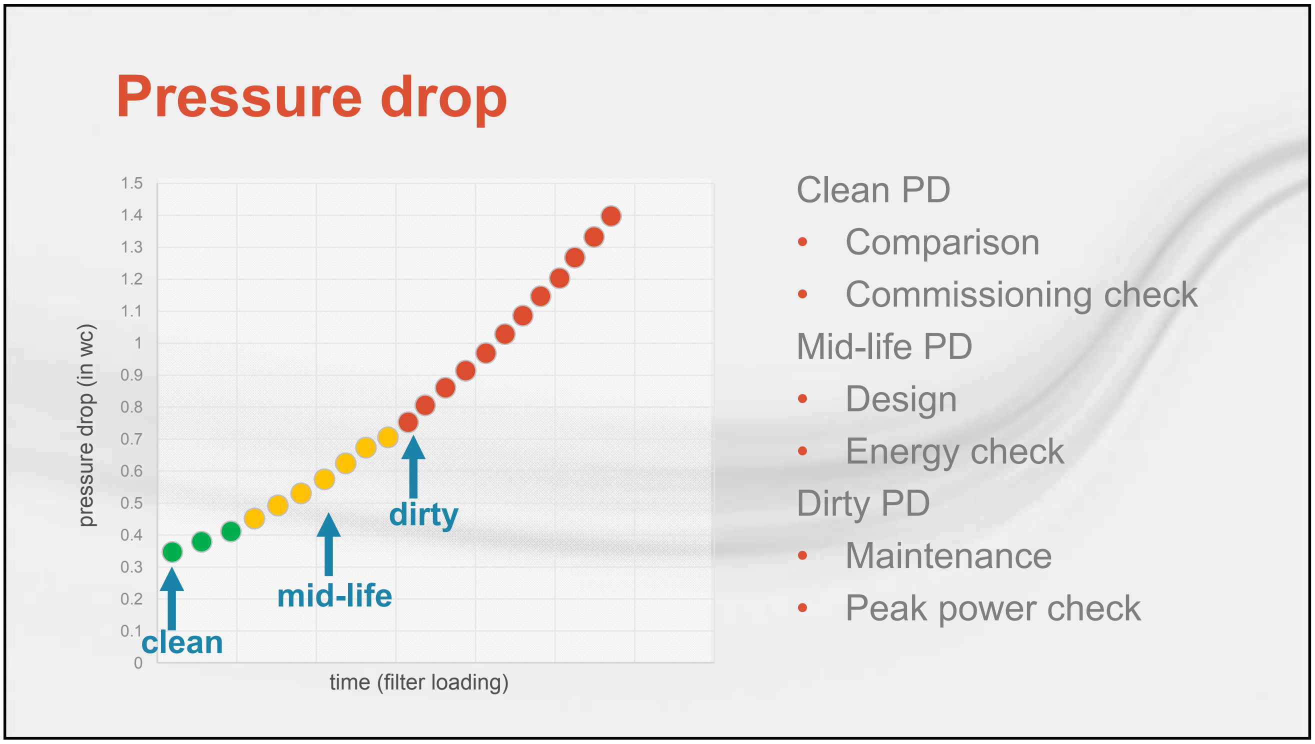
Pressure drop



Pressure drop will increase over time as filter loads up with particulates

Pressure drop



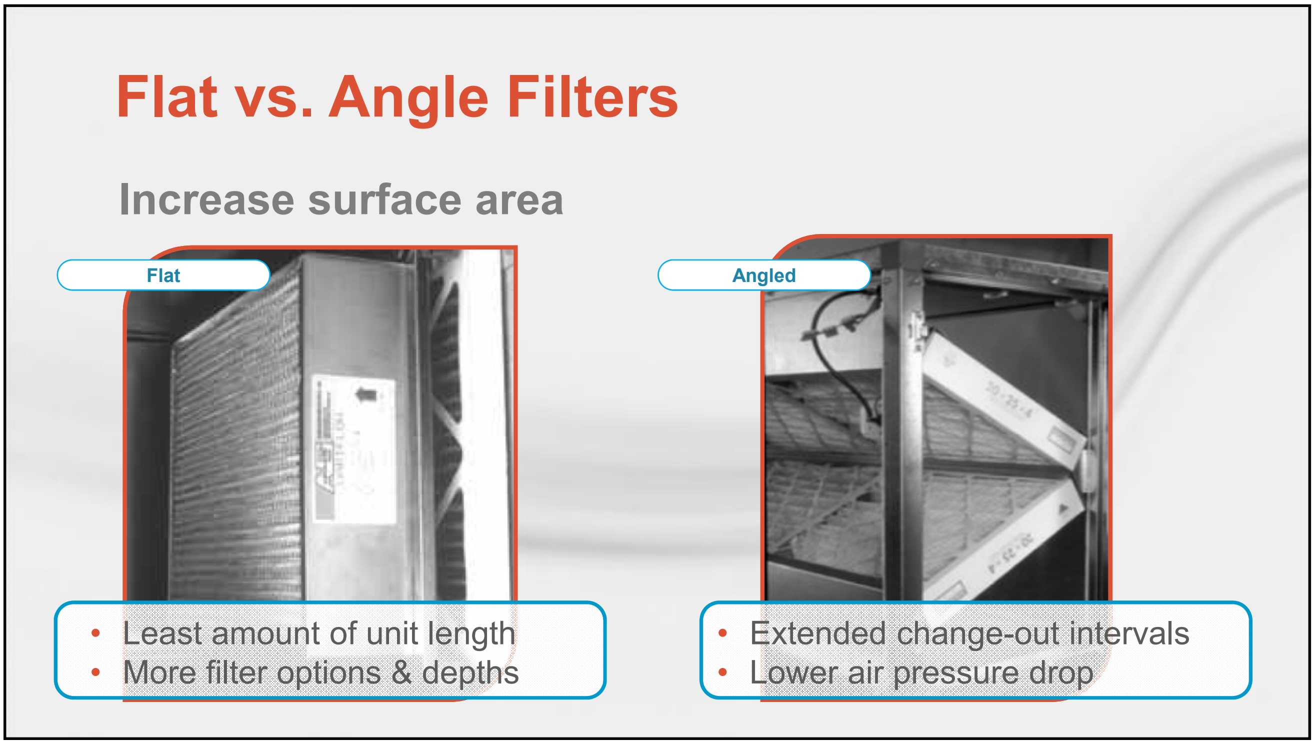


Pressure drop

Clean PD
- Comparison
- Commissioning check

Mid-life PD
- Design
- Energy check

Dirty PD
- Maintenance
- Peak power check



Flat vs. Angle Filters

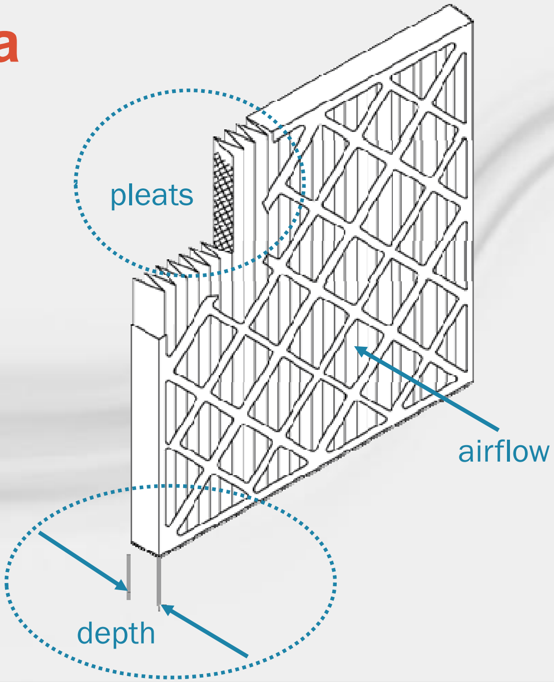
Increase surface area

- Least amount of unit length
- More filter options & depths

- Extended change-out intervals
- Lower air pressure drop

Increase Surface Area

- Better pleat design
- Increase depth
  - Higher dirt holding capacity
  - Lower APD for same efficiency
  - Fewer size options
  - Higher first cost



Loading Direction

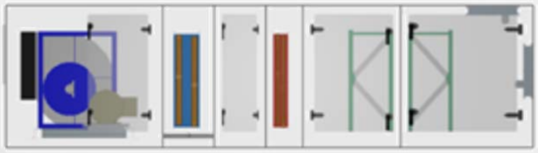
- Side load
  - Shorter length
  - Lower first cost
  - More area
- Front load
  - Less air bypass
  - Servicing wide units
  - Ease of inspection

Example Options

MERV 11 filter depth - pleating	rack type	loading position	face velocity fpm	clean APD in w.c.
4" - standard	flat	side	514	0.34
4“ - premium	flat	side	514	0.25
4“ - standard	angled	side	360	0.28
4" - premium	angled	side	360	0.15
12“ - cartridge	flat	side	577	0.34
12" - cartridge	flat	front	625	0.38

Scheduling

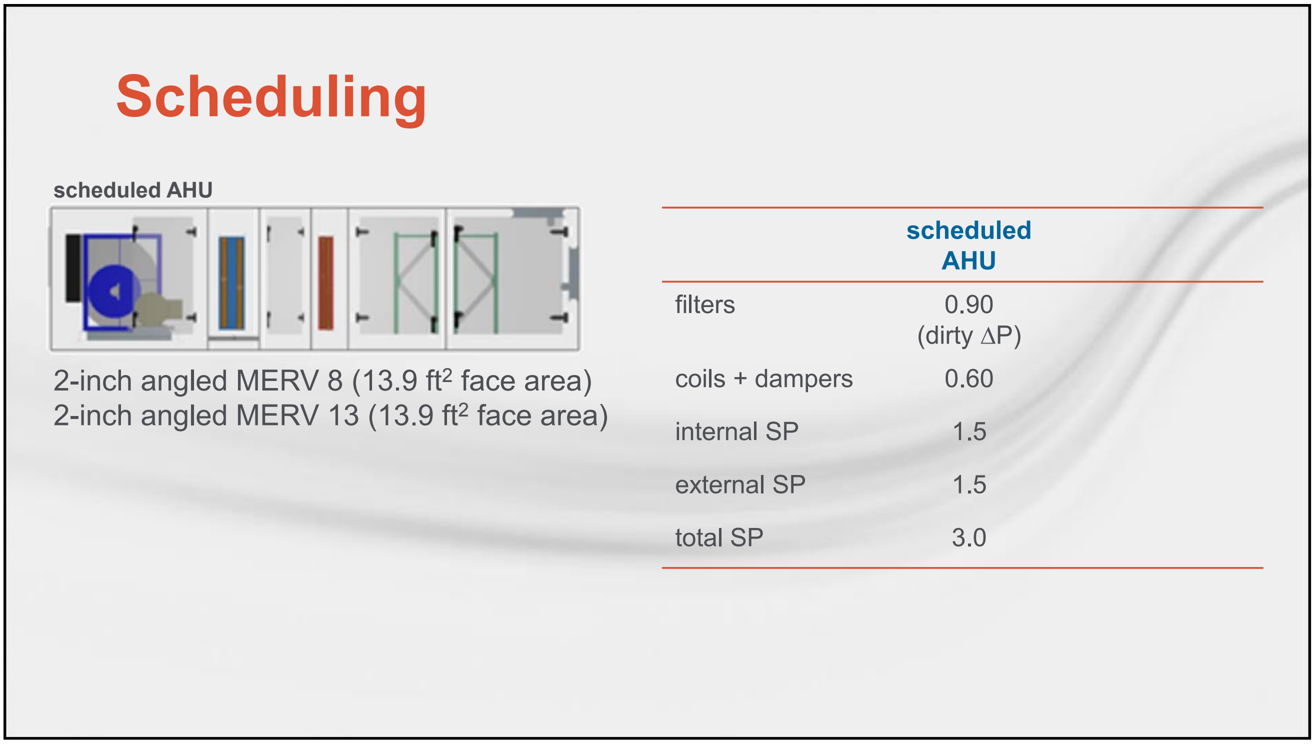
scheduled AHU



2-inch angled MERV 8 (13.9 ft^2 face area)
2-inch angled MERV 13 (13.9 ft^2 face area)

AHU Tag	supply airflow (cfm)	total SP (in w.c.)	external SP (in w.c.)
AHU-1	5000	3.0	1.5

filter ΔP	clean ΔP (in w.c.)	midlife ΔP (in w.c.)	dirty ΔP (in w.c.)
scheduled AHU	0.45	0.67	0.90

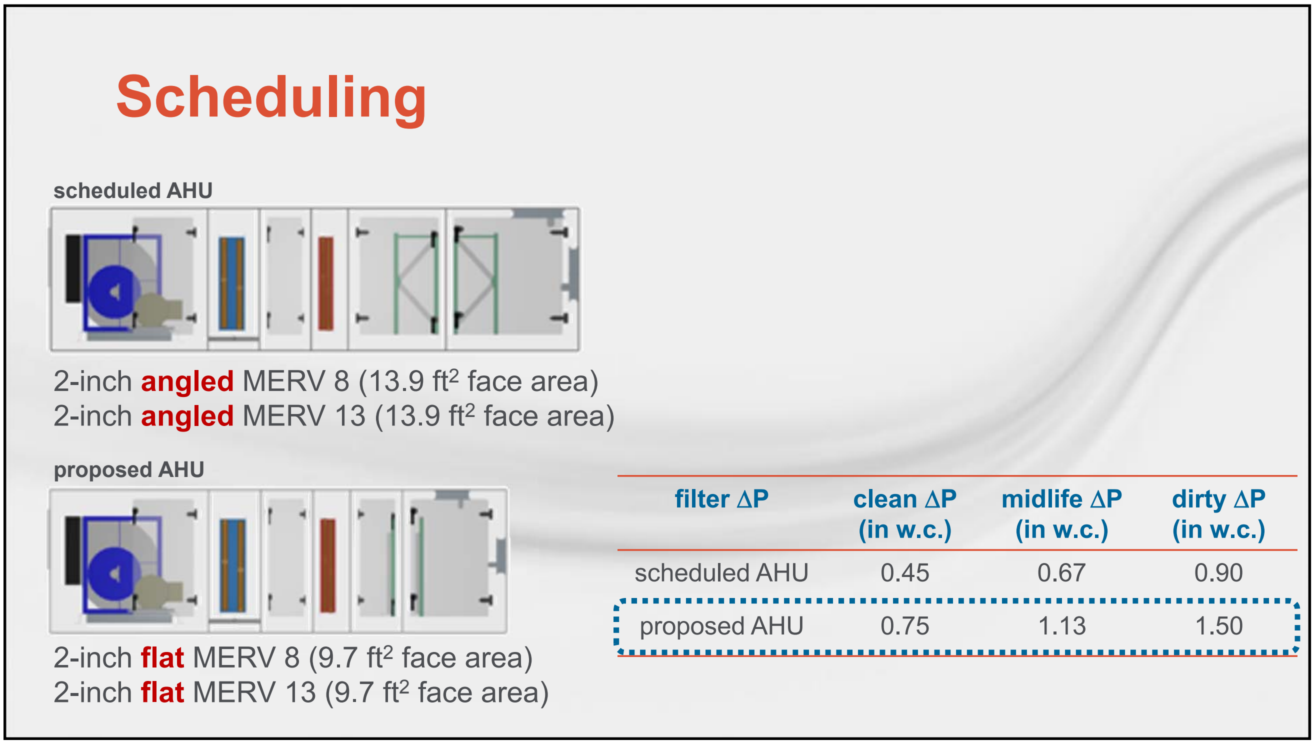


Scheduling

scheduled AHU

2-inch angled MERV 8 (13.9 ft^2 face area)
2-inch angled MERV 13 (13.9 ft^2 face area)

	scheduled AHU
filters	0.90 (dirty ΔP)
coils + dampers	0.60
internal SP	1.5
external SP	1.5
total SP	3.0



Scheduling

scheduled AHU

2-inch **angled** MERV 8 (13.9 ft^2 face area)
2-inch **angled** MERV 13 (13.9 ft^2 face area)

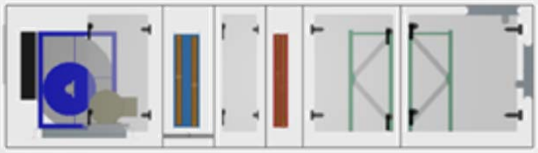
proposed AHU

2-inch **flat** MERV 8 (9.7 ft^2 face area)
2-inch **flat** MERV 13 (9.7 ft^2 face area)

filter ΔP	clean ΔP (in w.c.)	midlife ΔP (in w.c.)	dirty ΔP (in w.c.)
scheduled AHU	0.45	0.67	0.90
proposed AHU	0.75	1.13	1.50

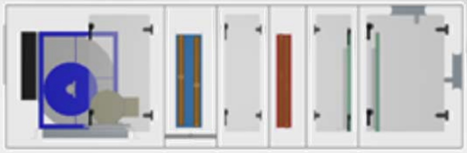
Scheduling

scheduled AHU



2-inch **angled** MERV 8 (13.9 ft² face area)
2-inch **angled** MERV 13 (13.9 ft² face area)

proposed AHU



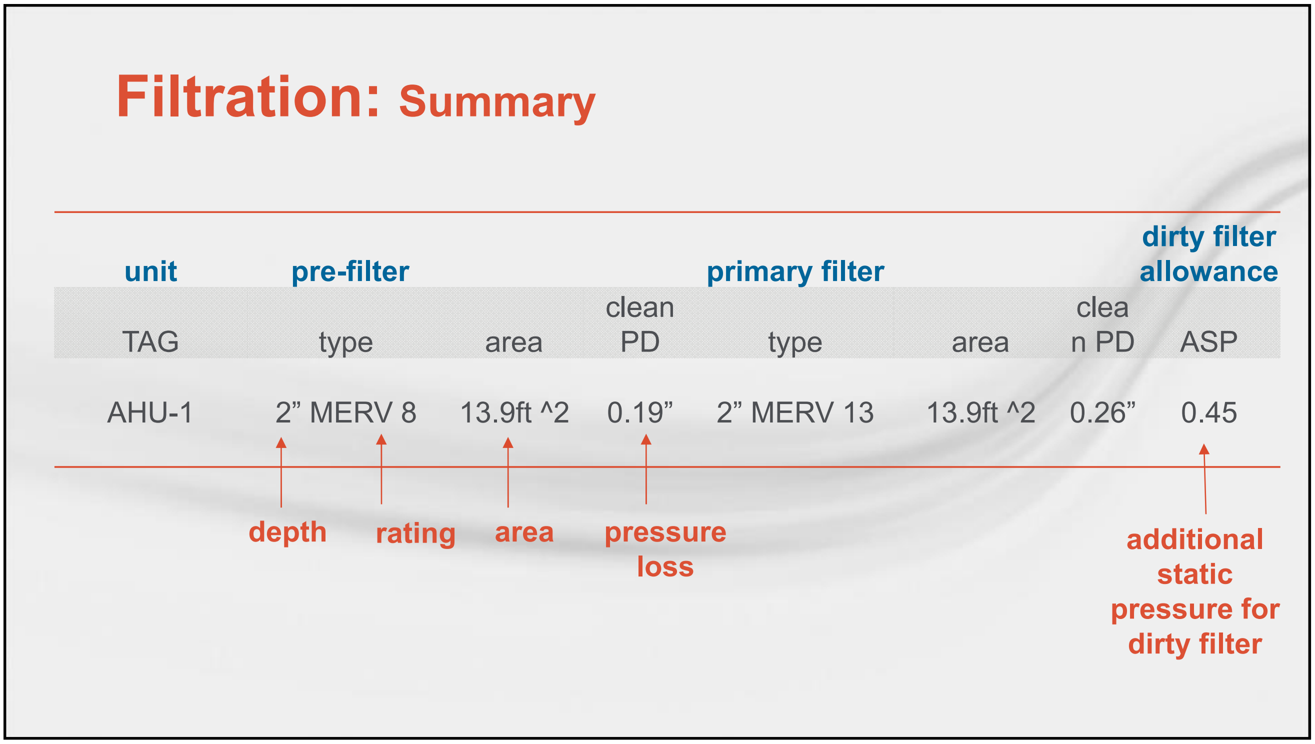
2-inch **flat** MERV 8 (9.7 ft² face area)
2-inch **flat** MERV 13 (9.7 ft² face area)

	scheduled AHU	**proposed AHU**
filters	0.90 (dirty ΔP)	0.75 (clean ΔP)
coils + dampers	0.60	0.75
internal SP	1.5	1.5
external SP	1.5	1.5
total SP	3.0	3.0

Scheduling

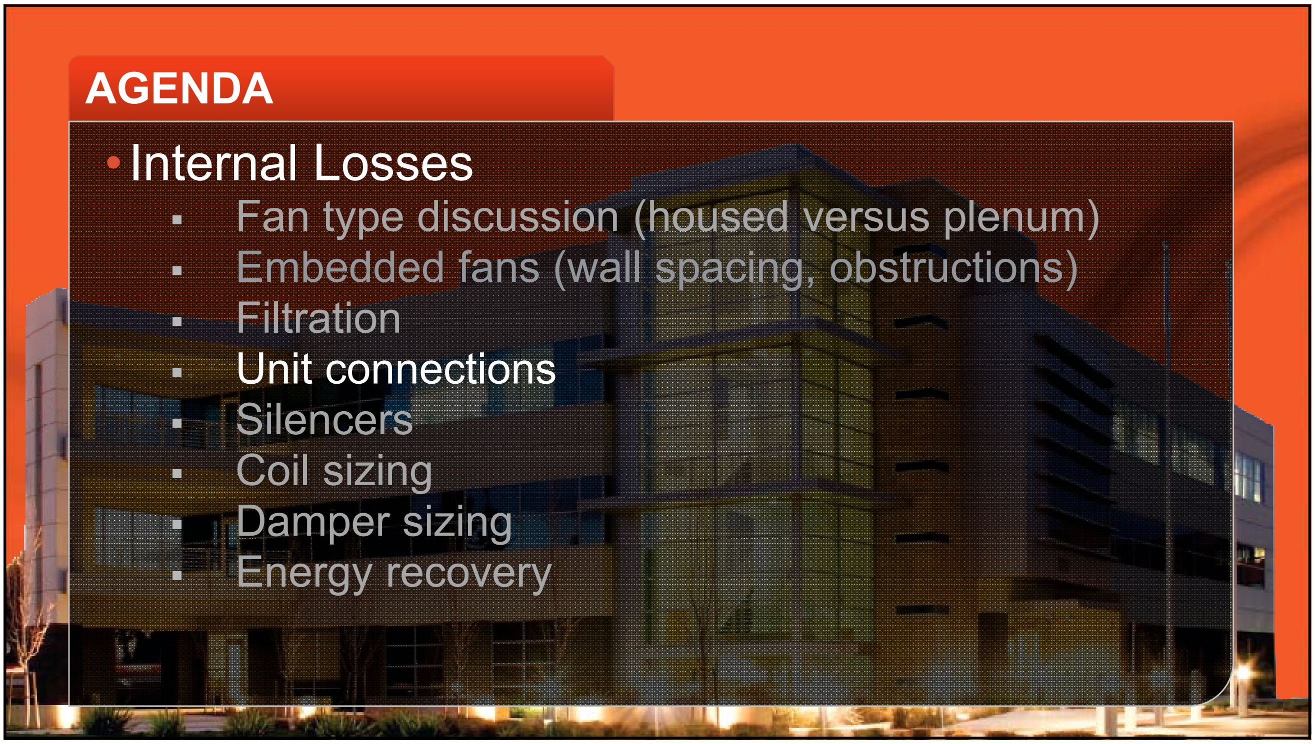
	scheduled AHU (top)		**proposed AHU (bottom)**	
filters	0.90 (dirty ΔP)	0.67 (mid-life ΔP)	0.75 (clean ΔP)	1.14 (mid-life ΔP)
coils + dampers	0.60	0.60	0.75	0.75
internal SP	1.5	1.27	1.5	1.89
external SP	1.5	1.5	1.5	1.5
total SP	3.0	2.77	3.0	3.39

22% more fan power



Filtration: Summary

unit	pre-filter			primary filter			dirty filter allowance
TAG	type	area	clean PD	type	area	clean PD	ASP
AHU-1	2” MERV 8	13.9ft ^2	0.19”	2” MERV 13	13.9ft ^2	0.26”	0.45



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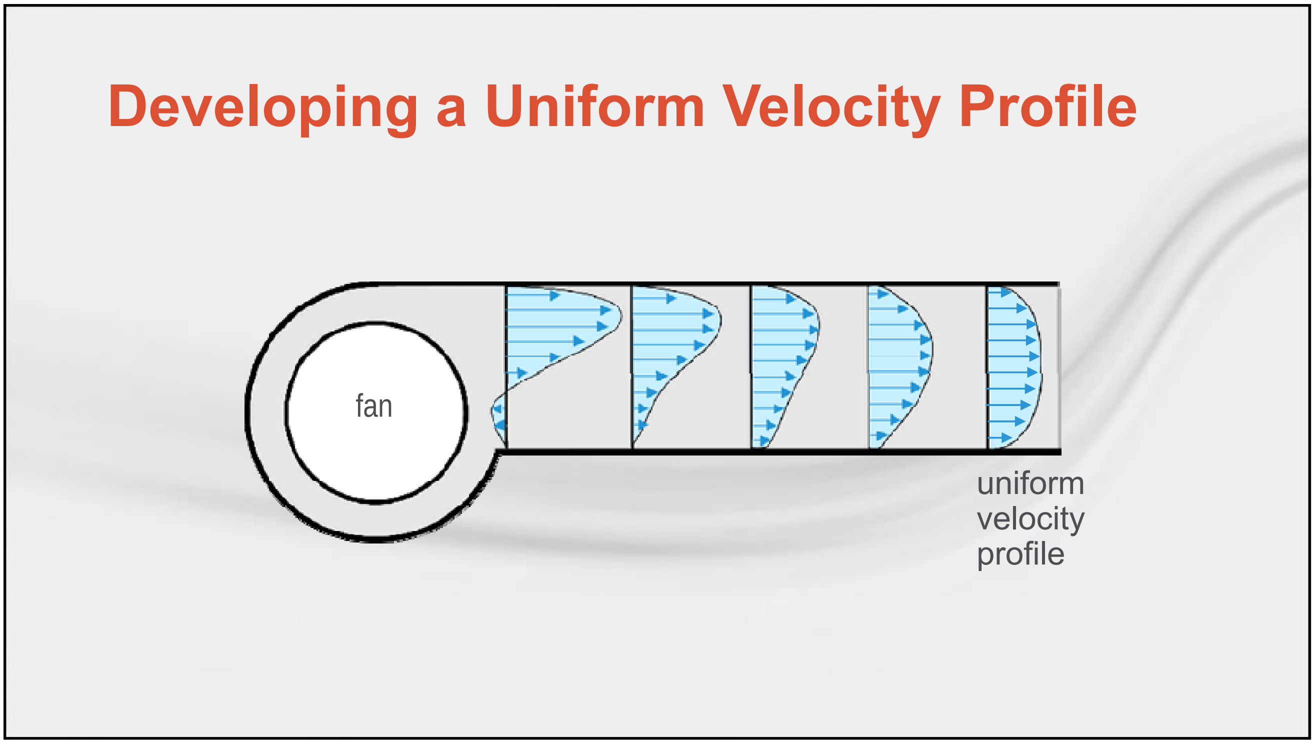
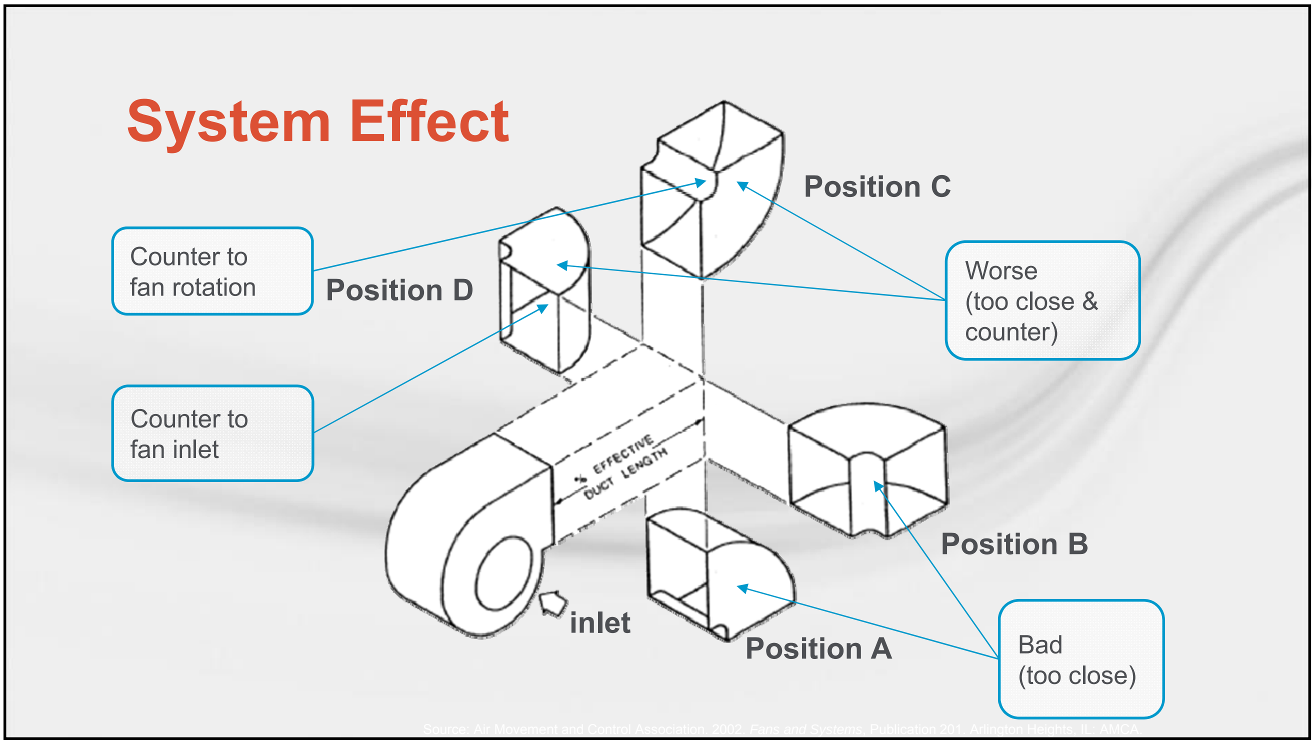


Developing a Uniform Velocity Profile

fan

uniform
velocity
profile



System Effect

Counter to
fan rotation

Position D

Counter to
fan inlet

Position C

Worse
(too close &
counter)

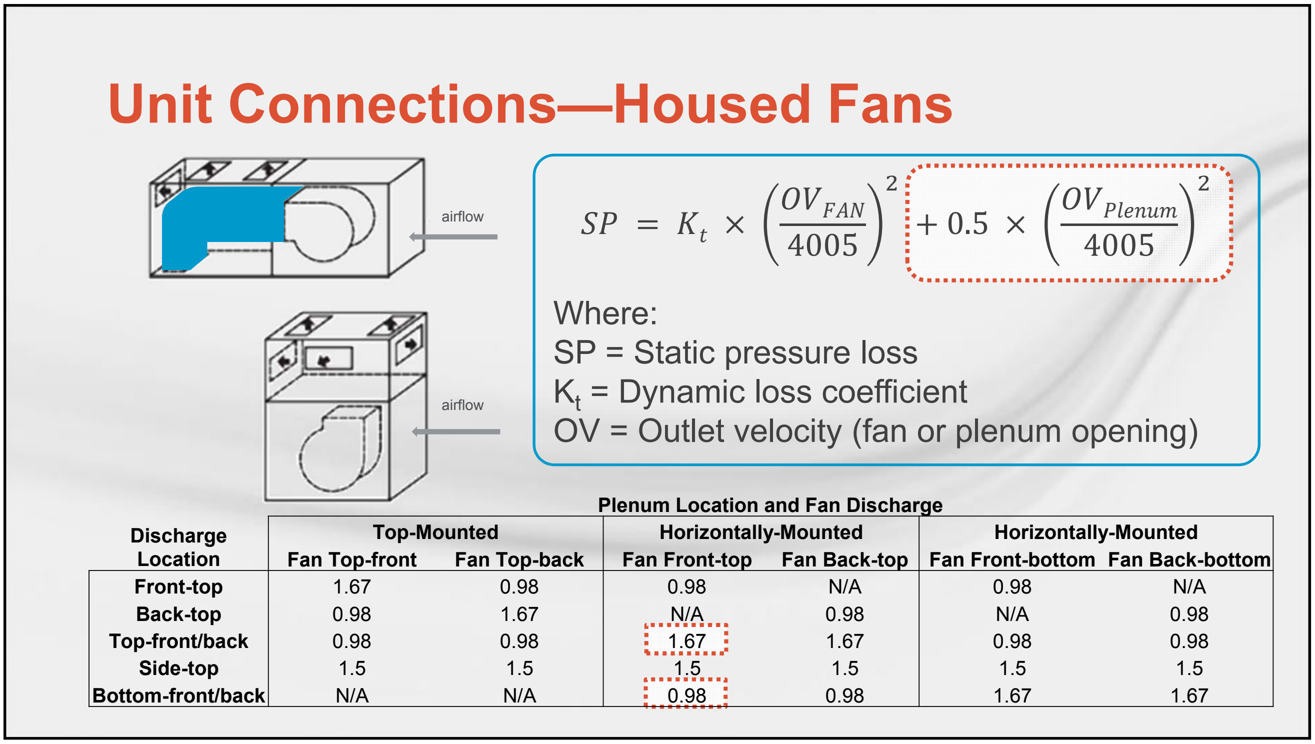
Position B

inlet

Position A

Bad
(too close)

Source: Air Movement and Control Association. 2002. *Fans and Systems*, Publication 201. Arlington Heights, IL: AMCA.



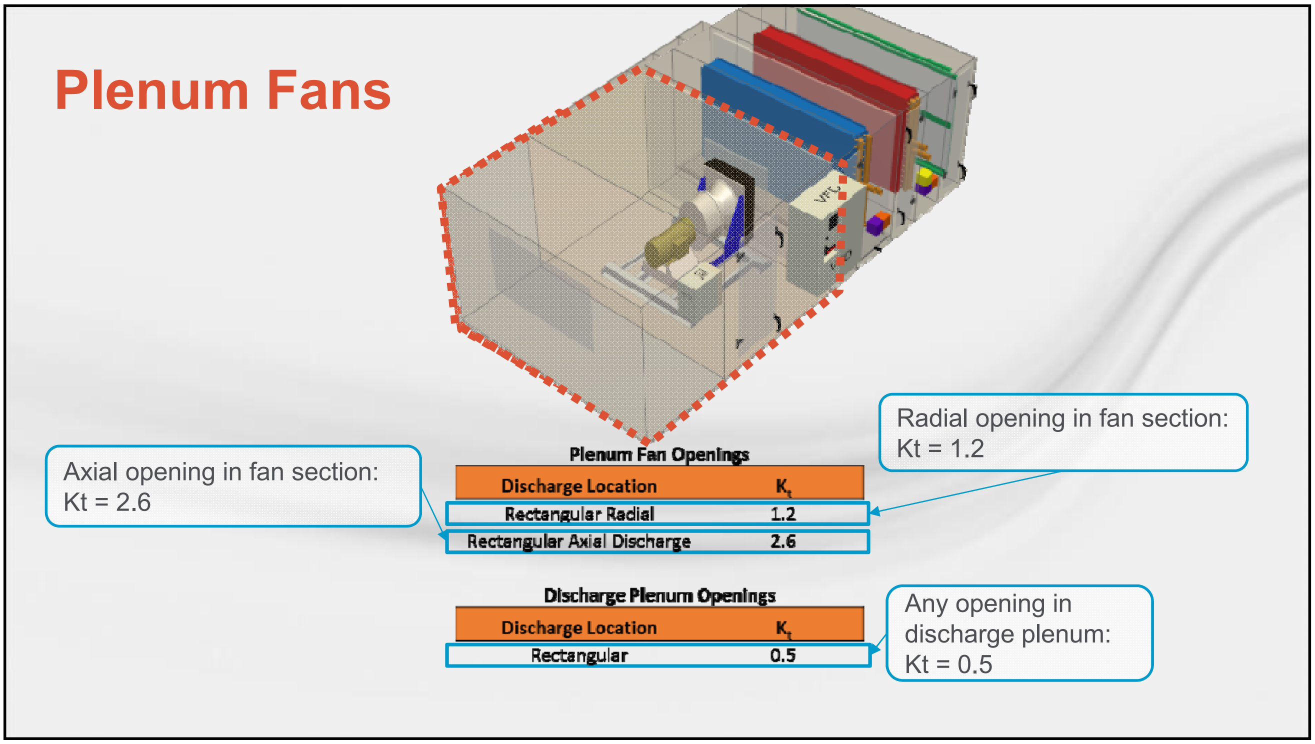
Unit Connections—Housed Fans

$$SP = K_t \times \left(\frac{OV_{FAN}}{4005}\right)^2 + 0.5 \times \left(\frac{OV_{Plenum}}{4005}\right)^2$$

Where:
SP = Static pressure loss
K_t = Dynamic loss coefficient
OV = Outlet velocity (fan or plenum opening)

Plenum Location and Fan Discharge

Discharge Location	**Top-Mounted**		**Horizontally-Mounted**		**Horizontally-Mounted**	
	Fan Top-front	**Fan Top-back**	**Fan Front-top**	**Fan Back-top**	**Fan Front-bottom**	**Fan Back-bottom**
Front-top	1.67	0.98	0.98	N/A	0.98	N/A
Back-top	0.98	1.67	N/A	0.98	N/A	0.98
Top-front/back	0.98	0.98	1.67	1.67	0.98	0.98
Side-top	1.5	1.5	1.5	1.5	1.5	1.5
Bottom-front/back	N/A	N/A	0.98	0.98	1.67	1.67



Plenum Fans

Axial opening in fan section:
Kt = 2.6

Radial opening in fan section:
Kt = 1.2

Plenum Fan Openings

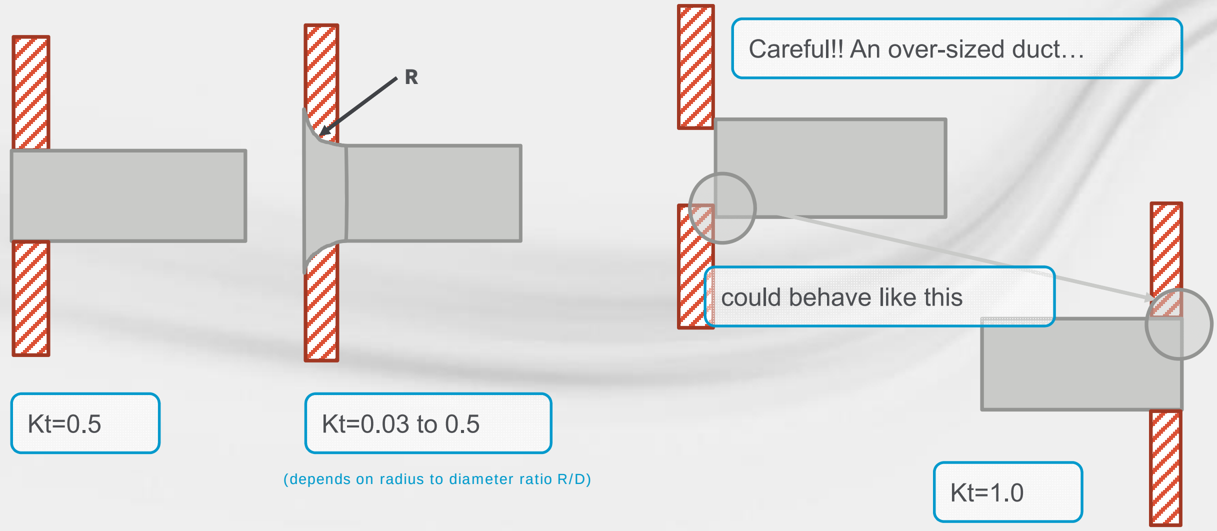
Discharge Location	K_t
Rectangular Radial	1.2
Rectangular Axial Discharge	2.6

Discharge Plenum Openings

Discharge Location	K_t
Rectangular	0.5

Any opening in discharge plenum:
Kt = 0.5

Plenum Outlets



Careful!! An over-sized duct…

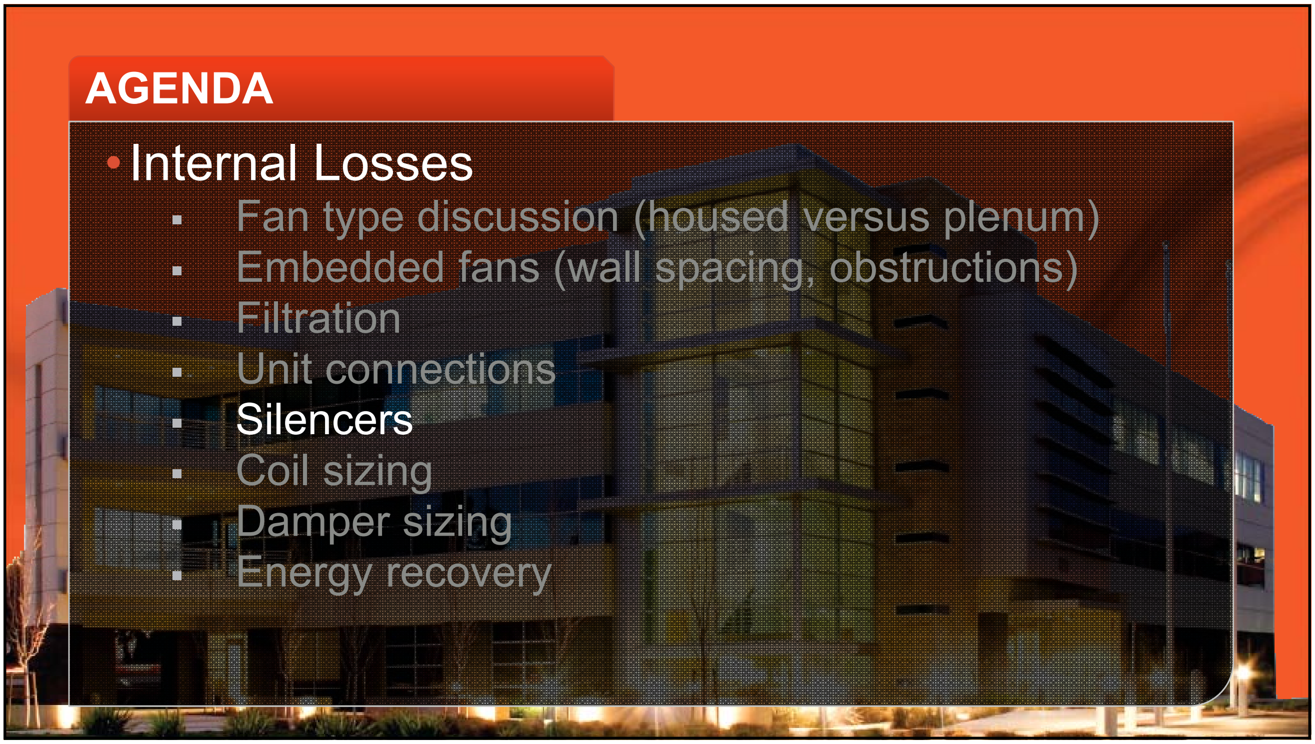
could behave like this

Kt=0.5

Kt=0.03 to 0.5

(depends on radius to diameter ratio R/D)

Kt=1.0

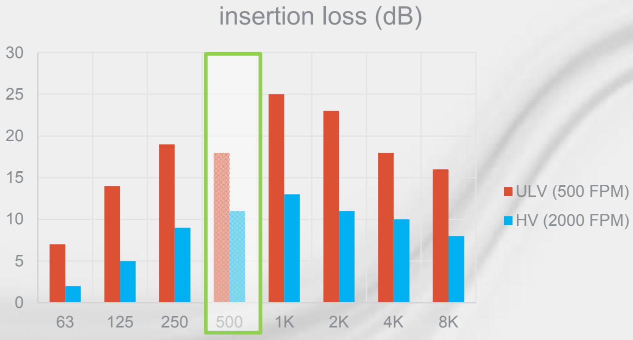


AGENDA

- Internal Losses
  - Fan type discussion (housed versus plenum)
  - Embedded fans (wall spacing, obstructions)
  - Filtration
  - Unit connections
  - Silencers
  - Coil sizing
  - Damper sizing
  - Energy recovery

Silencers (location)

- Insertion loss:
  - 11 vs. 18 dB @ 500 Hz
- Regenerated noise:
  - 48 vs. 29 dB @500 Hz
- Pressure drop:
  - 0.16 vs. 0.12 in. w.g.
- 3 duct diameters min. required both upstream and downstream for a duct-mounted silencer

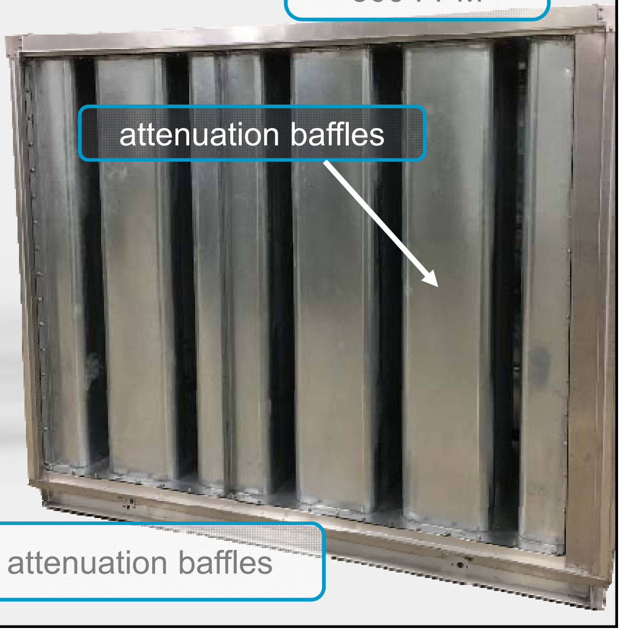


Unit-mounted silencer >> duct-mounted silencer

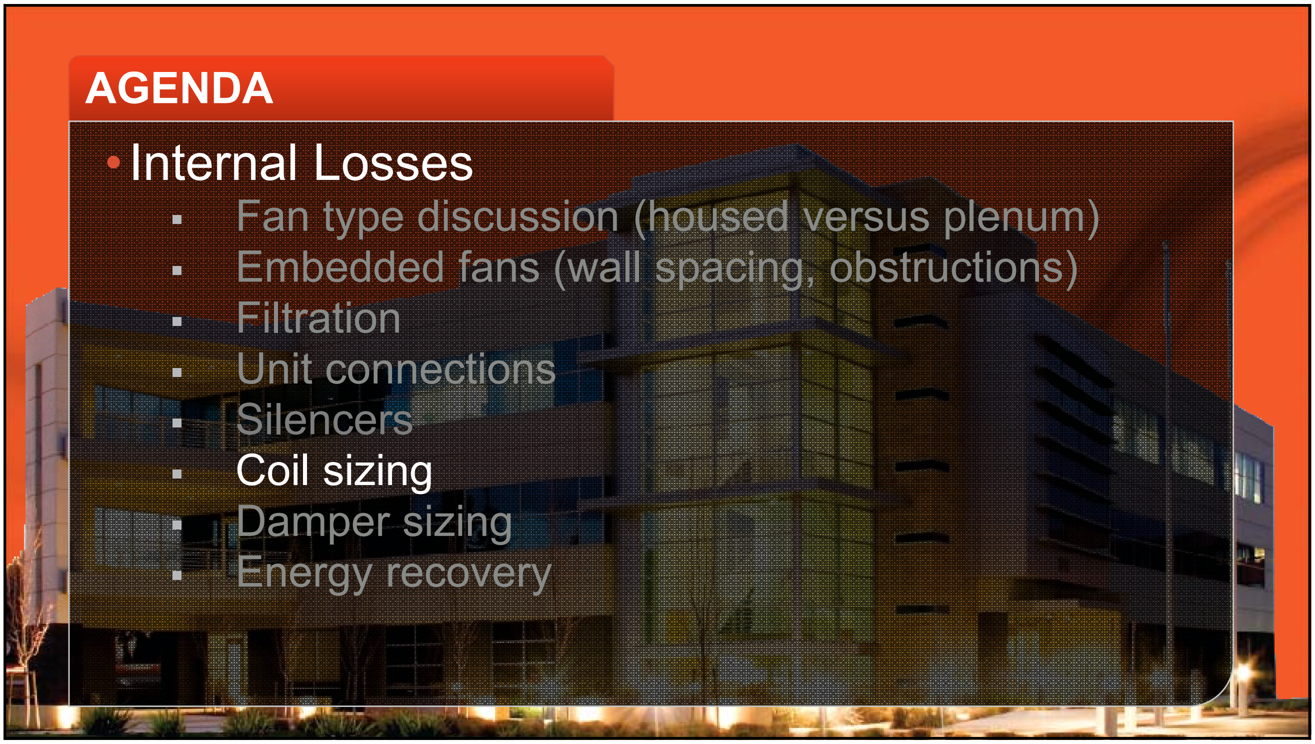
Silencers (location)

duct-mounted
2000 FPM

unit-mounted
500 FPM



Larger silencer size results in closer attenuation baffles



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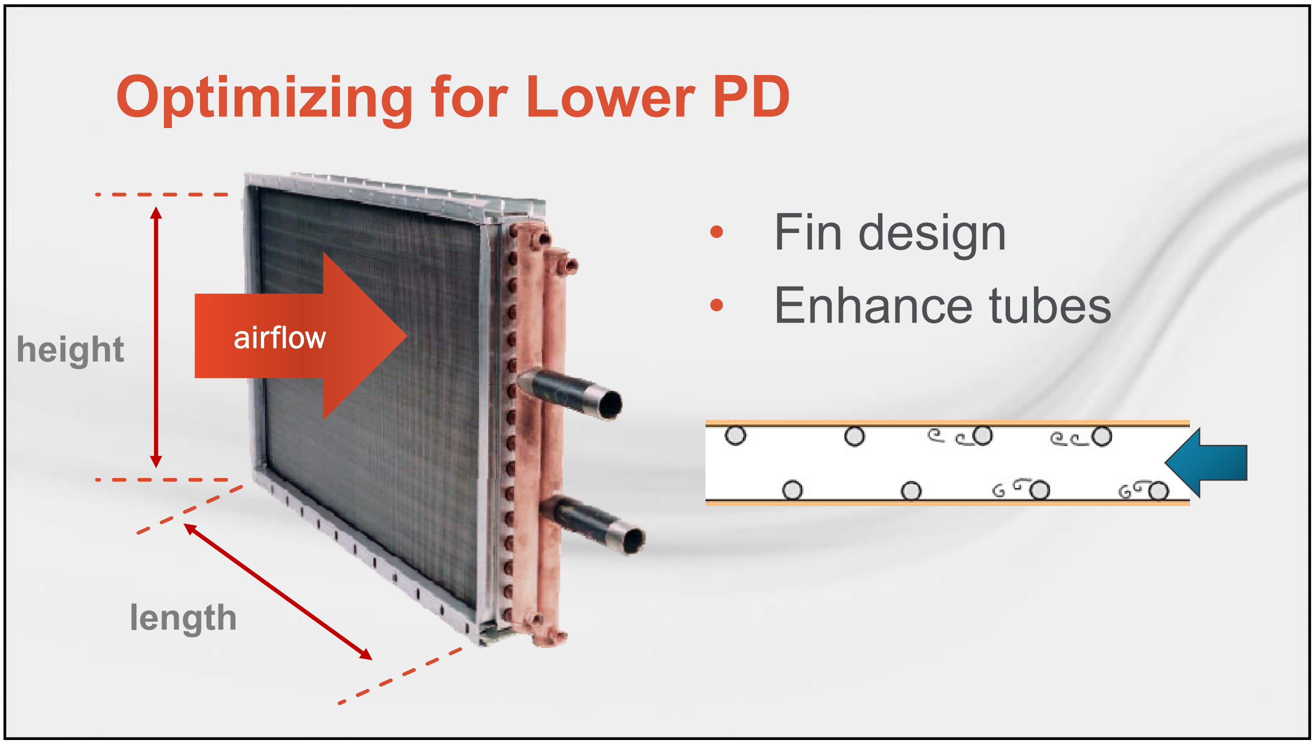
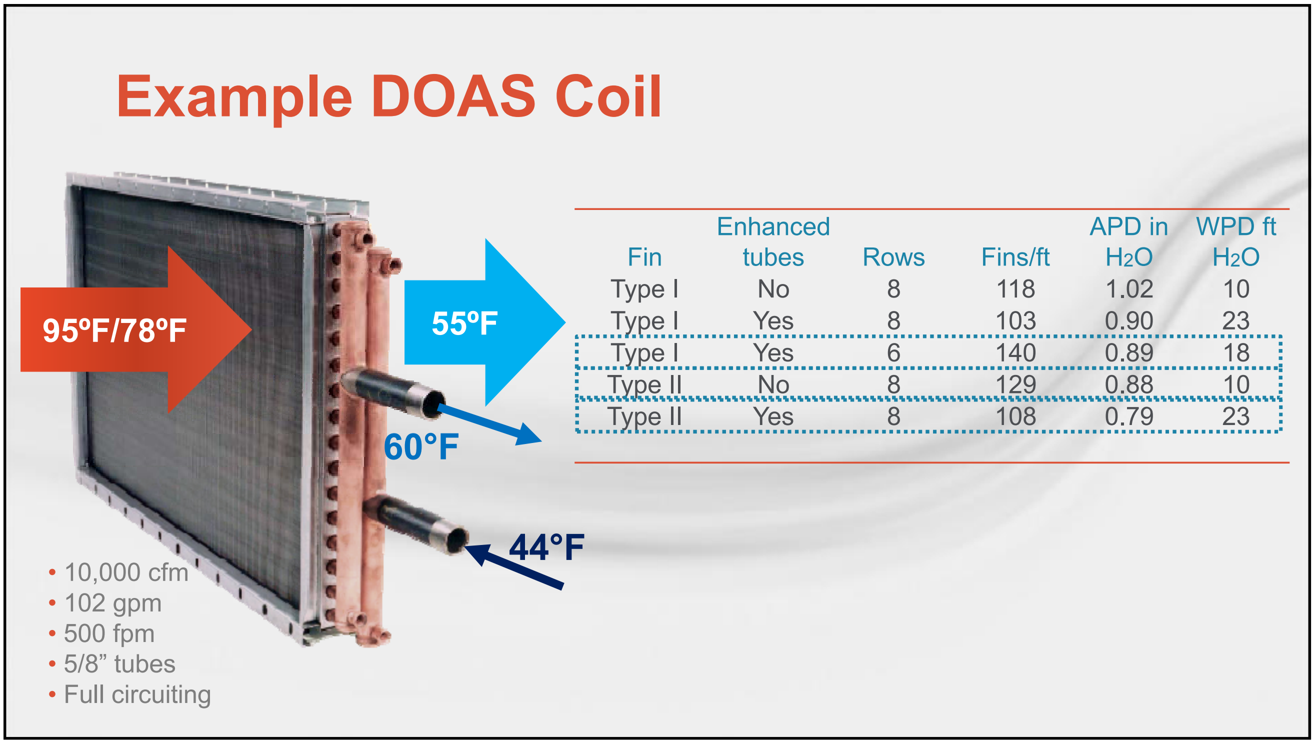


Optimizing for Lower PD

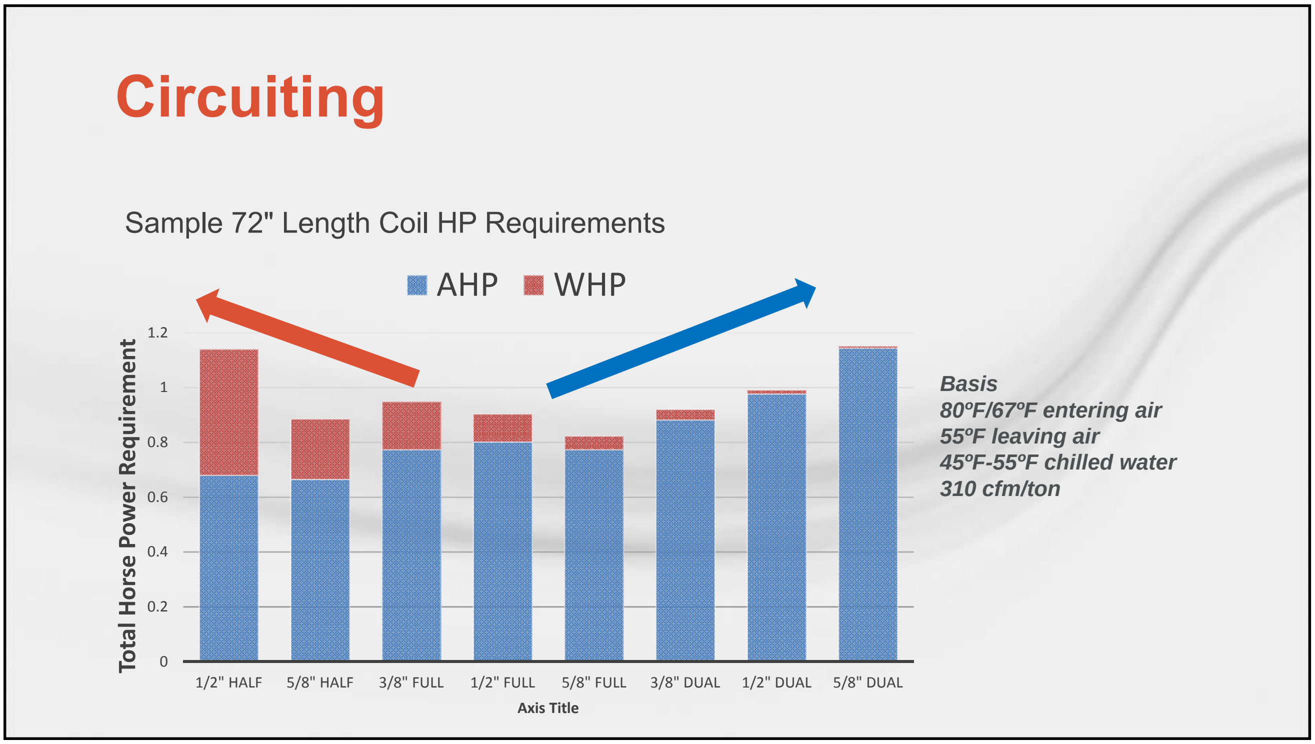
- Fin design
- Enhance tubes



Example DOAS Coil

Fin	Enhanced tubes	Rows	Fins/ft	APD in H_2O	WPD ft H_2O
Type I	No	8	118	1.02	10
Type I	Yes	8	103	0.90	23
Type I	Yes	6	140	0.89	18
Type II	No	8	129	0.88	10
Type II	Yes	8	108	0.79	23

- 10,000 cfm
- 102 gpm
- 500 fpm
- 5/8” tubes
- Full circuiting



Circuiting

Sample 72" Length Coil HP Requirements

Basis
80ºF/67ºF entering air
55ºF leaving air
45ºF-55ºF chilled water
310 cfm/ton

Coil Summary

- Coil size
- Fin design
- Turbulent flow
- Circuiting
- Tube size

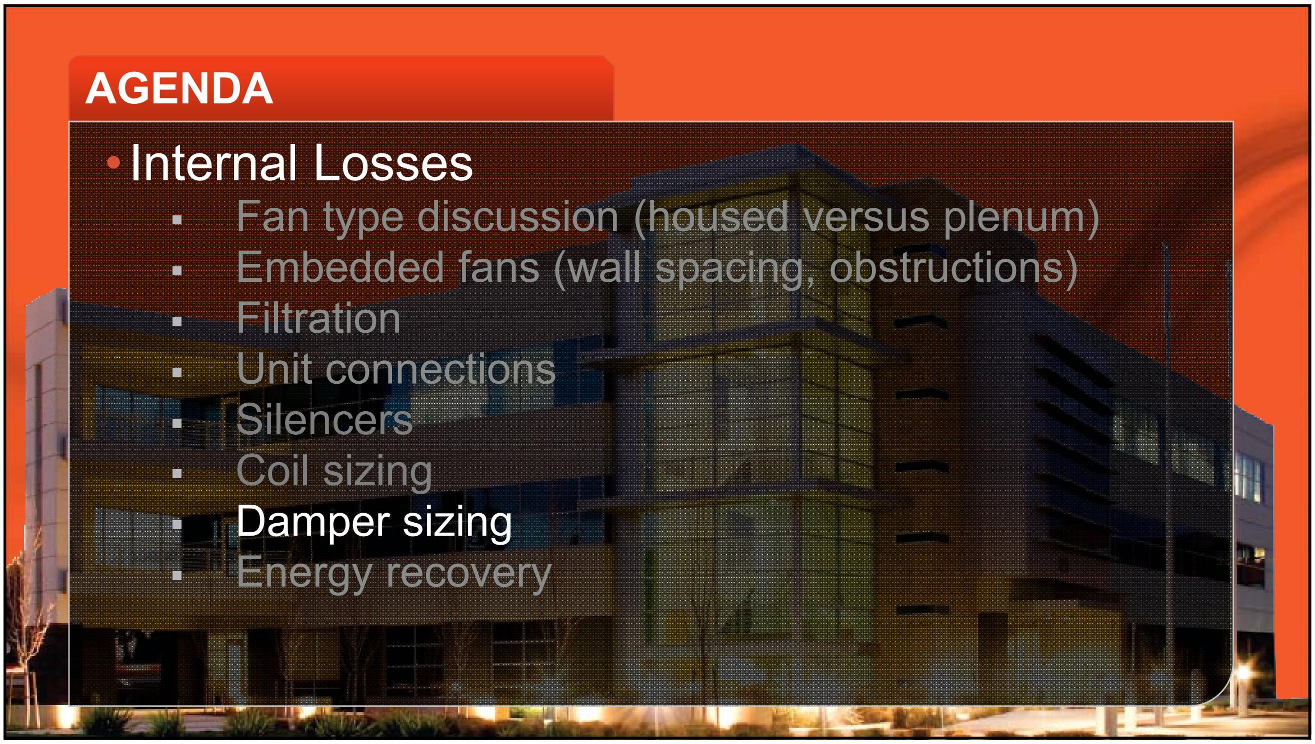
TRANE

Coil Selection and Optimization

Trane Engineers Newsletter Live Series

Trane.com/ENL

APP-CMC054-EN



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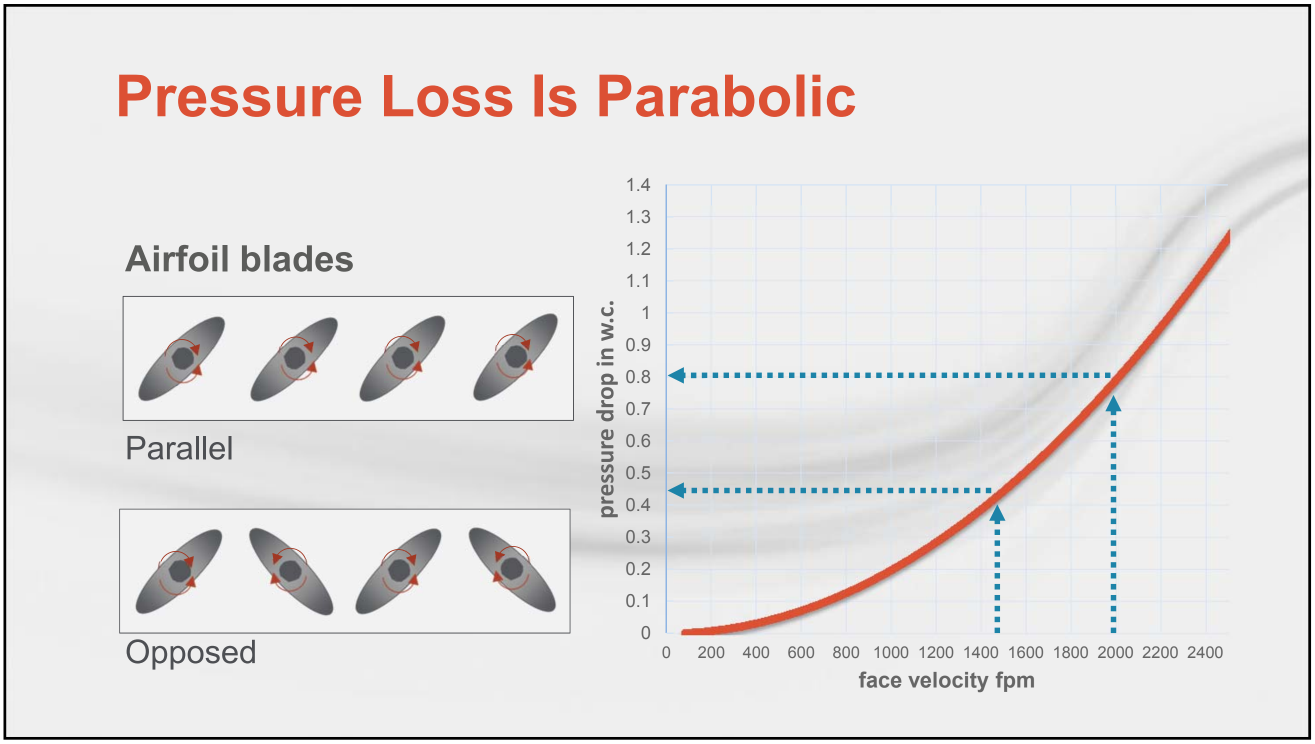
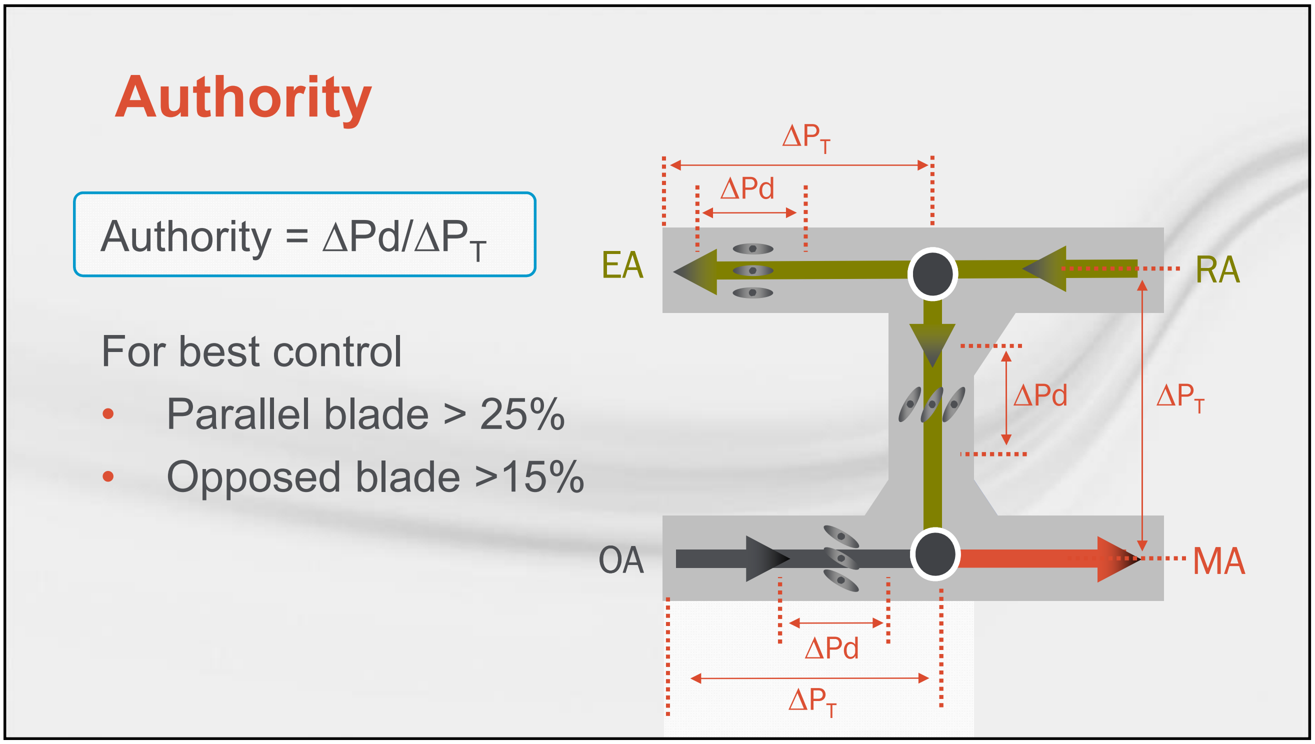


Pressure Loss Is Parabolic

Airfoil blades

Parallel

Opposed

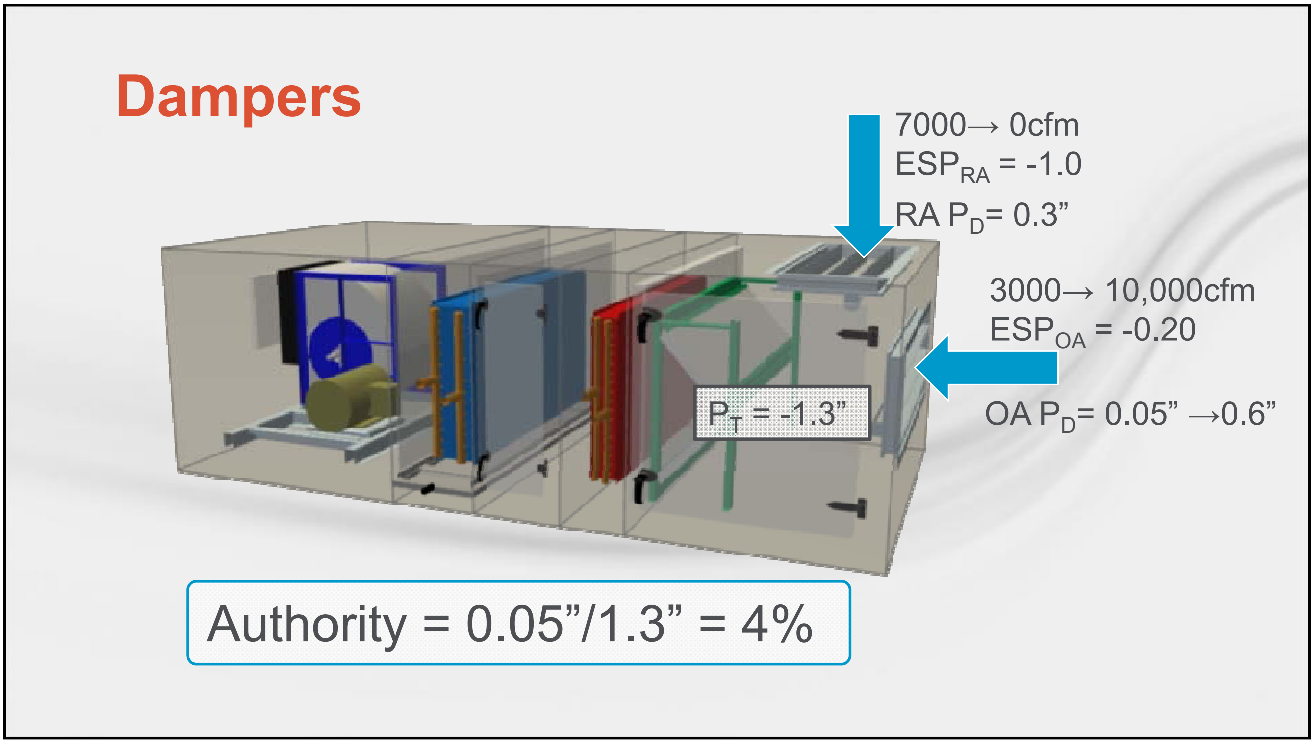


Authority

Authority = $\Delta Pd/\Delta P_T$

For best control

- Parallel blade > 25%
- Opposed blade >15%



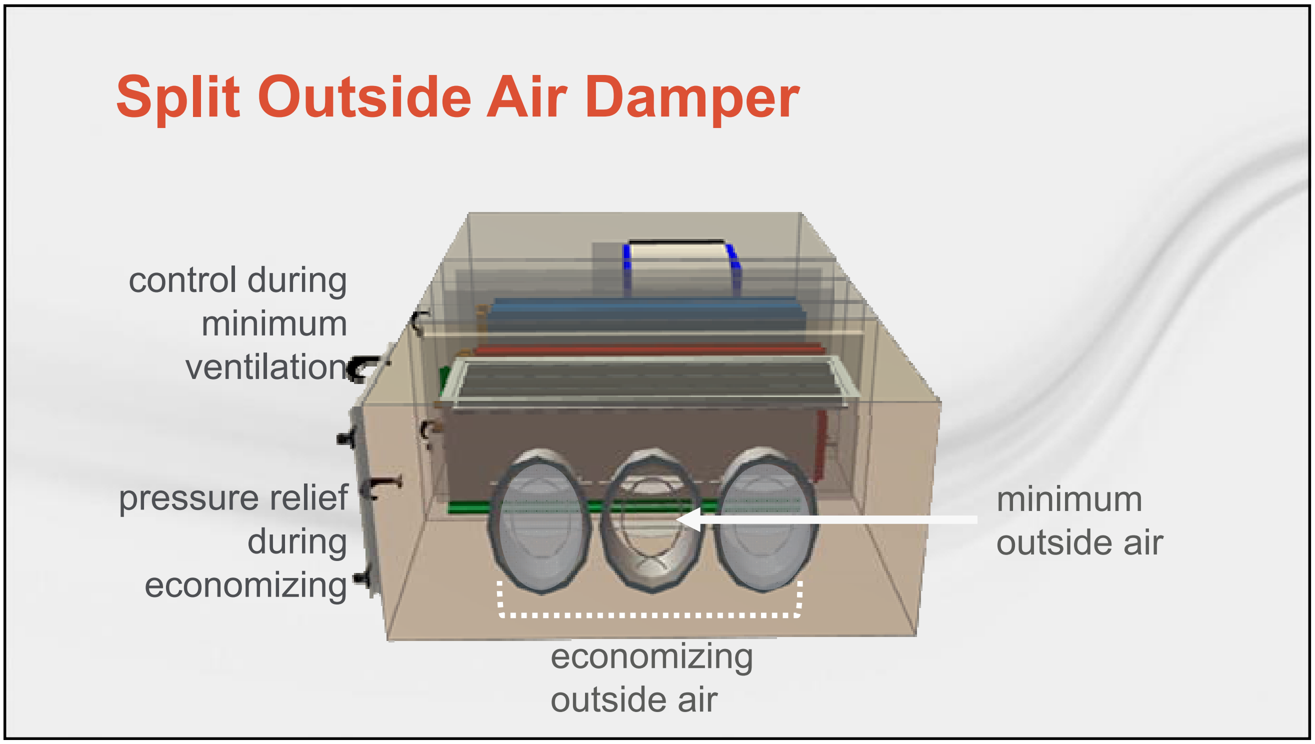
Dampers

7000→ 0cfm
ESP_{RA} = -1.0
RA P_D= 0.3”

3000→ 10,000cfm
ESP_{OA} = -0.20
OA P_D= 0.05” →0.6”

P_T = -1.3”

Authority = 0.05”/1.3” = 4%



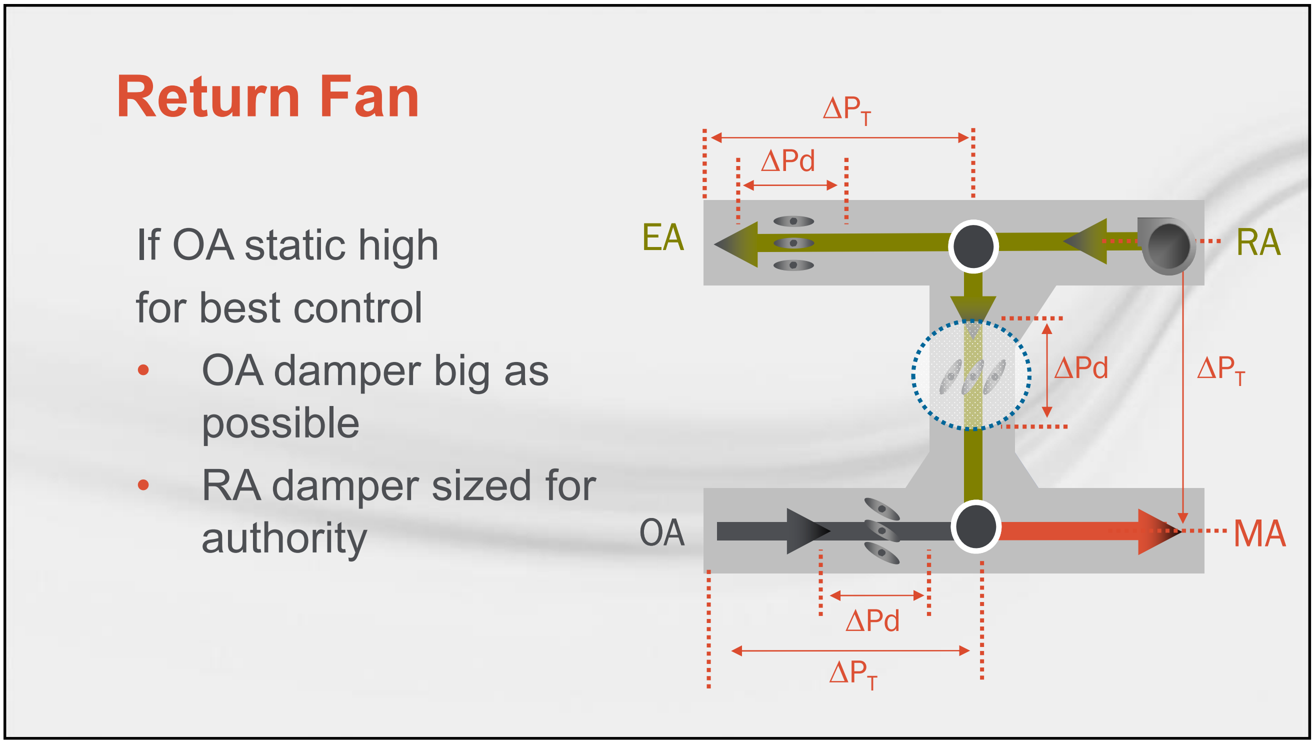
Split Outside Air Damper

control during minimum ventilation

pressure relief during economizing

minimum outside air

economizing outside air

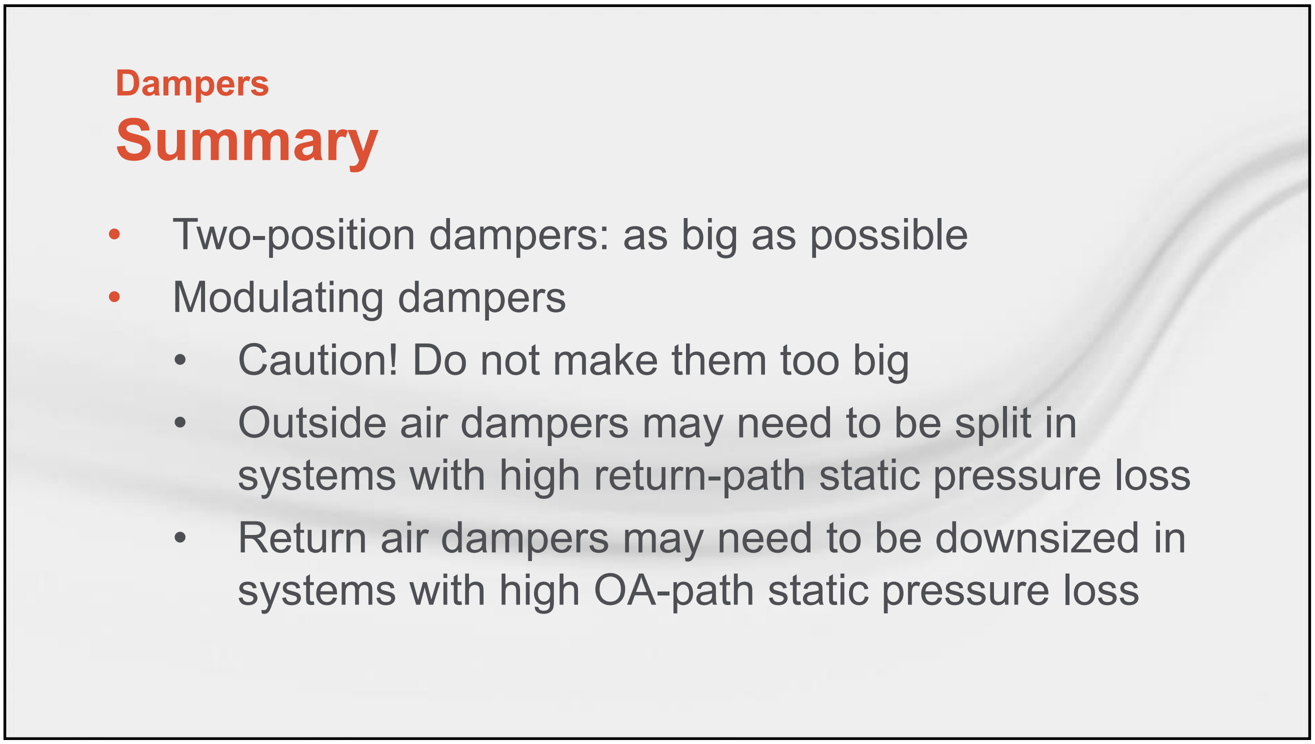


Return Fan

If OA static high

for best control

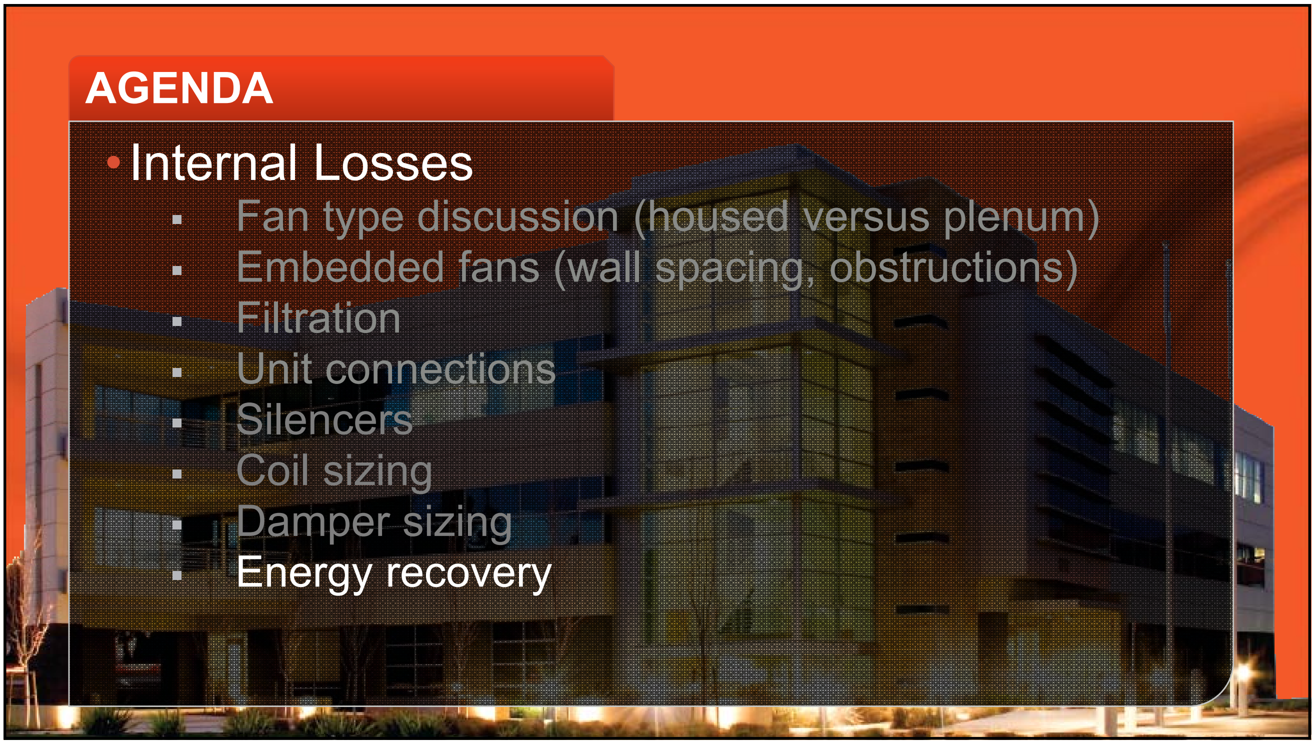
- OA damper big as possible
- RA damper sized for authority



Dampers

Summary

- Two-position dampers: as big as possible
- Modulating dampers
  - Caution! Do not make them too big
  - Outside air dampers may need to be split in systems with high return-path static pressure loss
  - Return air dampers may need to be downsized in systems with high OA-path static pressure loss



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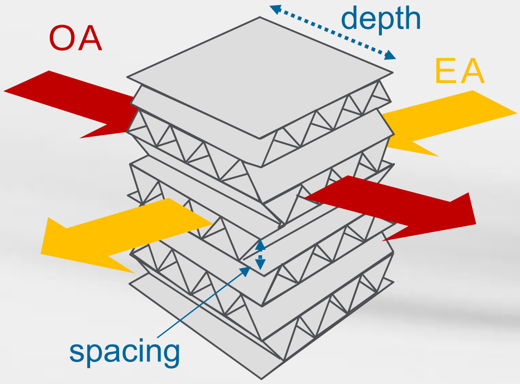
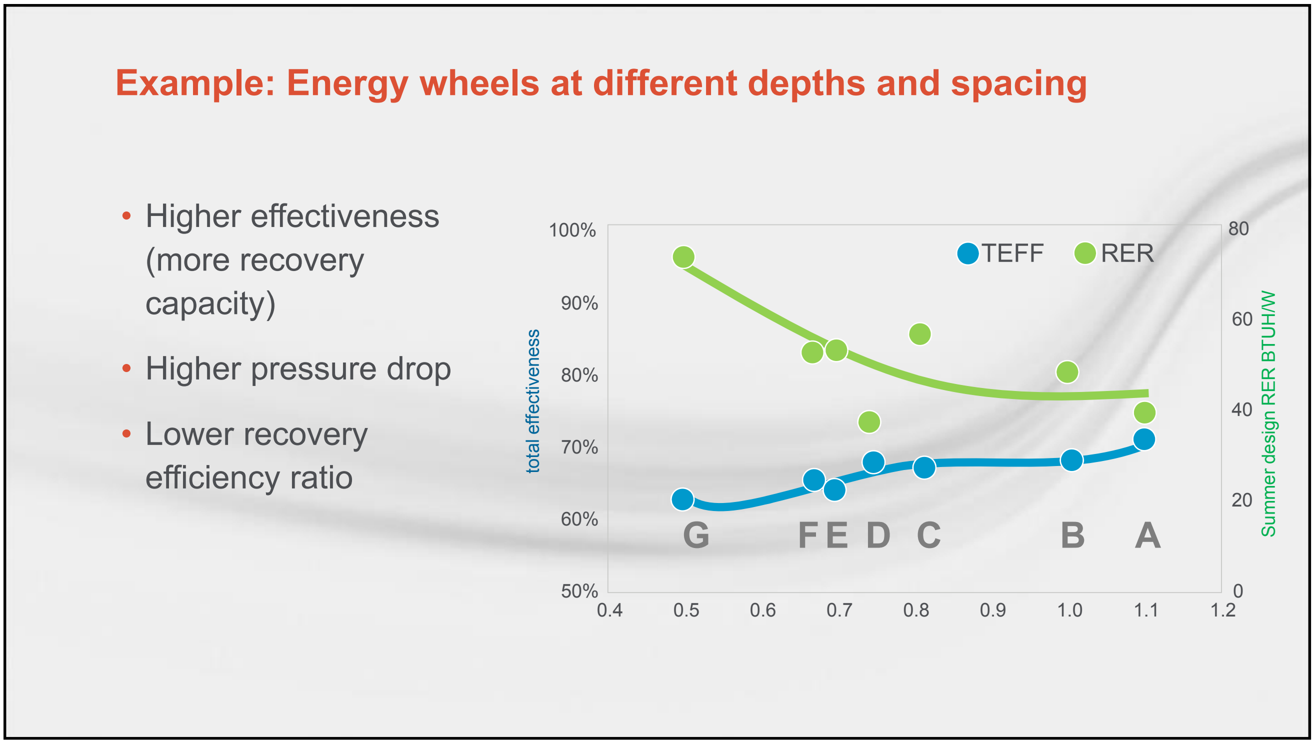
Exhaust Energy Recovery



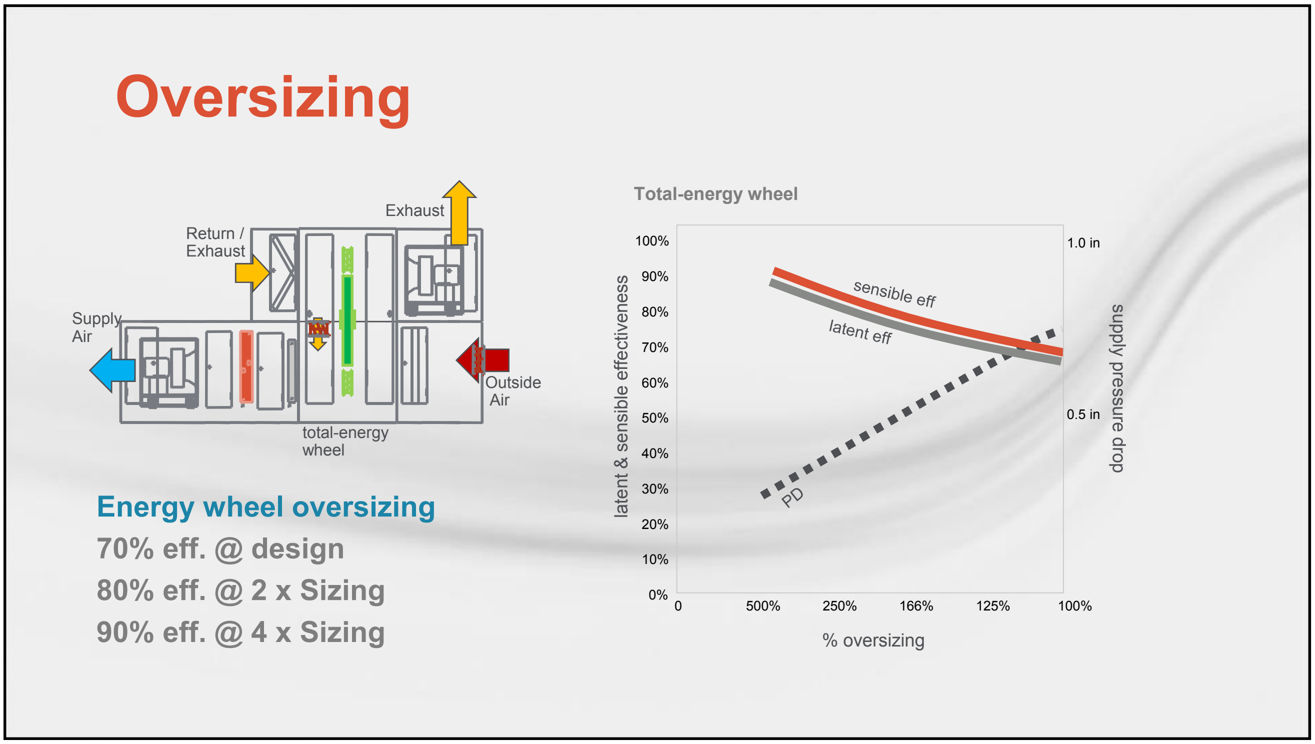
Example: Cross Flow Exchanger

- Tighter spacing ***or longer***
- Higher recovery
- Higher pressure drop
- Wider spacing ***or shorter***
- Lower recovery
- Lower pressure drop



Example: Energy wheels at different depths and spacing

- Higher effectiveness (more recovery capacity)
- Higher pressure drop
- Lower recovery efficiency ratio



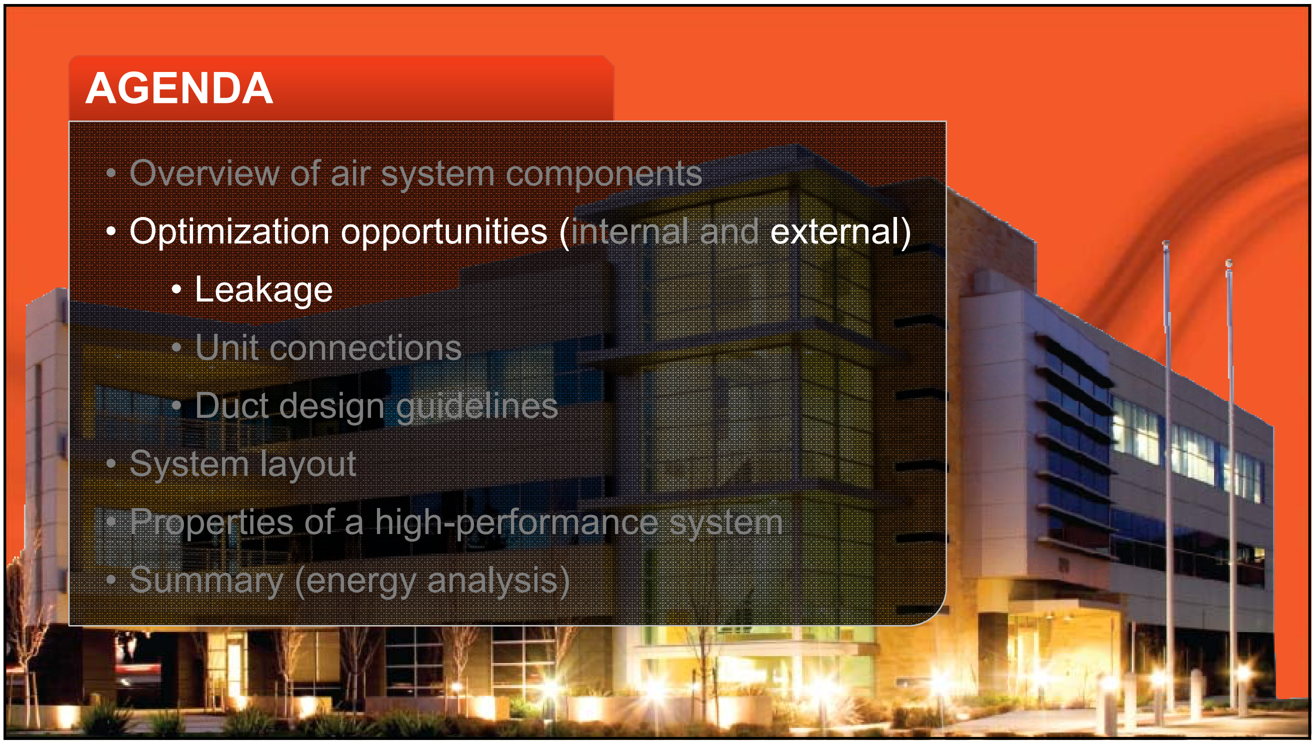
Oversizing

Energy wheel oversizing

70% eff. @ design

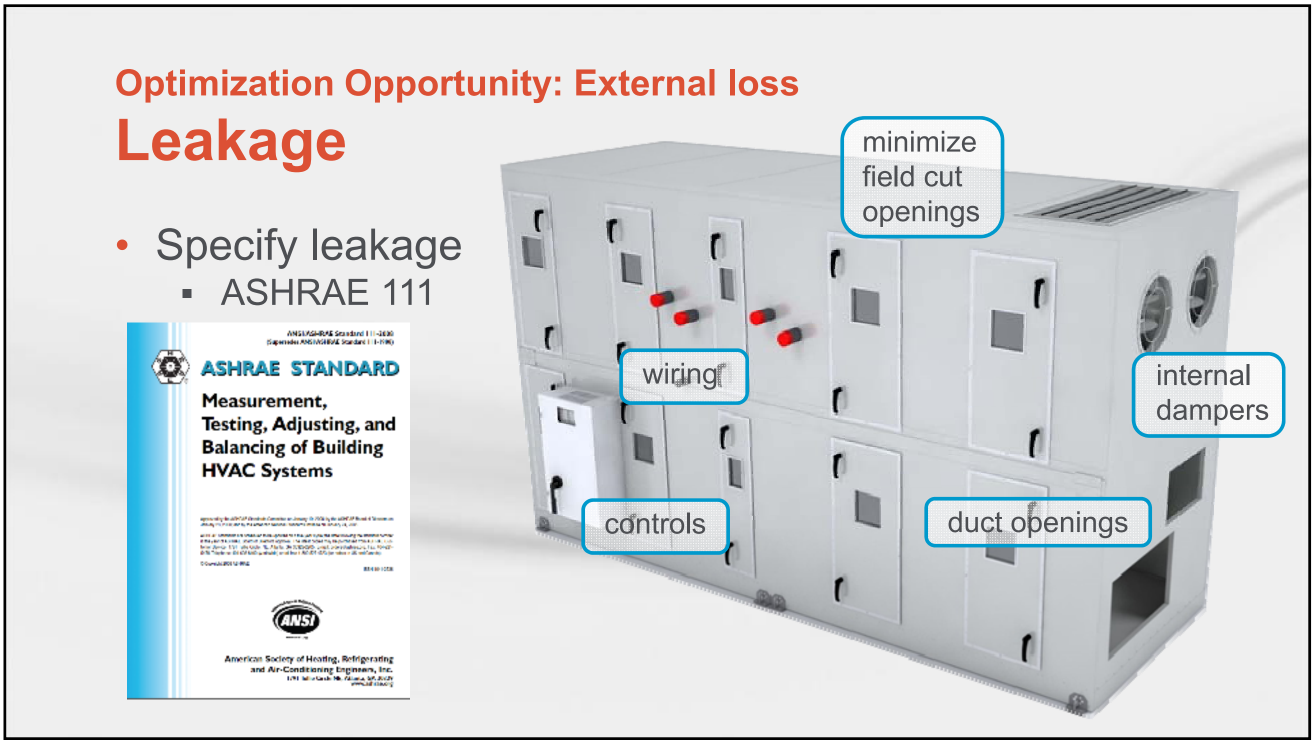
80% eff. @ 2 x Sizing

90% eff. @ 4 x Sizing



AGENDA

- Overview of air system components
- Optimization opportunities (internal and external)
  - Leakage
  - Unit connections
  - Duct design guidelines
- System layout
- Properties of a high-performance system
- Summary (energy analysis)



Optimization Opportunity: External loss

Leakage

- Specify leakage
  - ASHRAE 111

ASHRAE STANDARD

Measurement, Testing, Adjusting, and Balancing of Building HVAC Systems

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

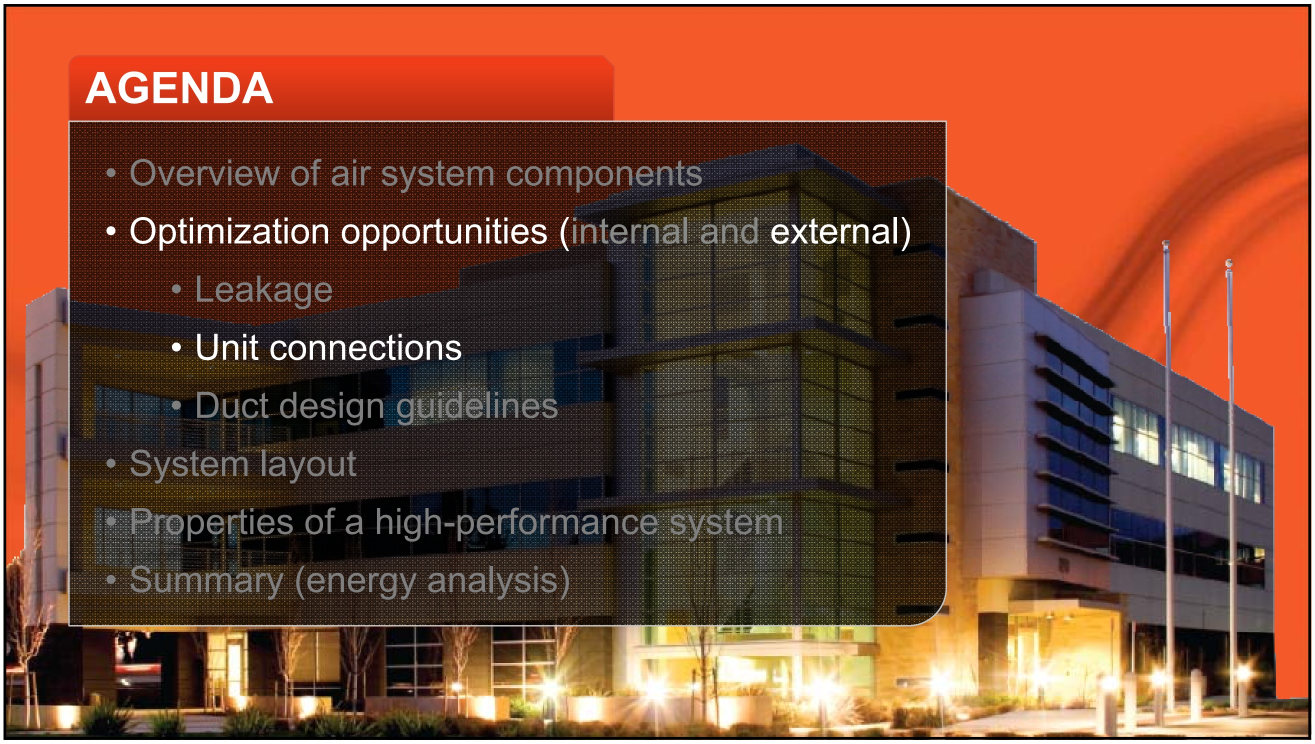
minimize field cut openings

wiring

internal dampers

controls

duct openings



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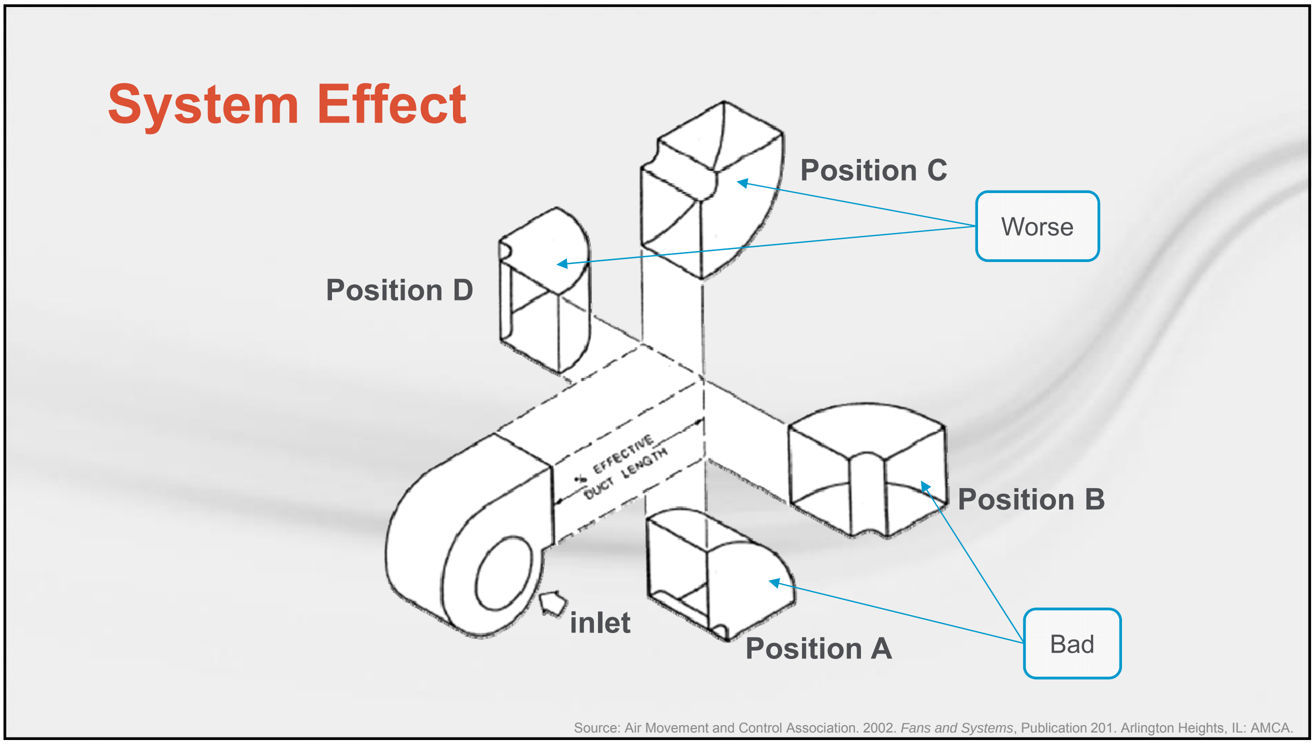
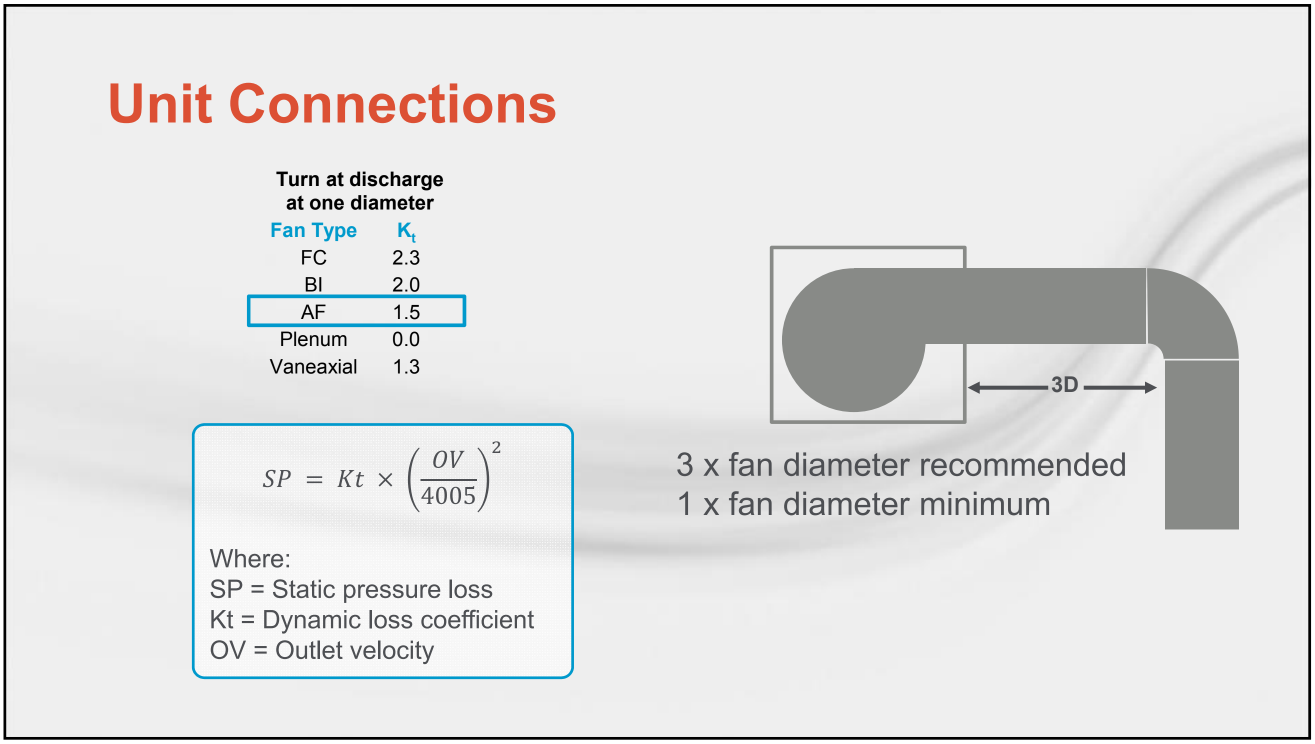


System Effect

Source: Air Movement and Control Association. 2002. *Fans and Systems*, Publication 201. Arlington Heights, IL: AMCA.



Unit Connections

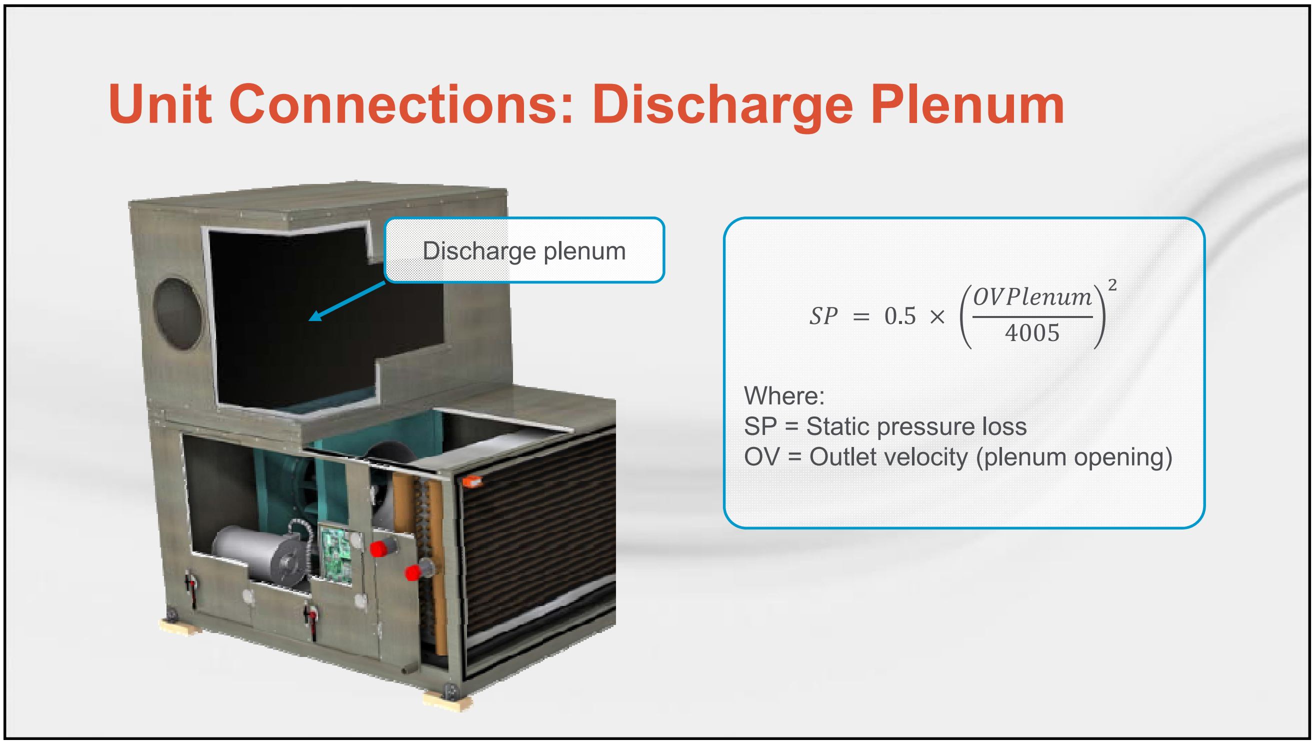
Turn at discharge
at one diameter

Fan Type	K_t
FC	2.3
BI	2.0
AF	1.5
Plenum	0.0
Vaneaxial	1.3

$$SP = Kt \times \left(\frac{OV}{4005}\right)^2$$

Where:
SP = Static pressure loss
Kt = Dynamic loss coefficient
OV = Outlet velocity

3 x fan diameter recommended
1 x fan diameter minimum

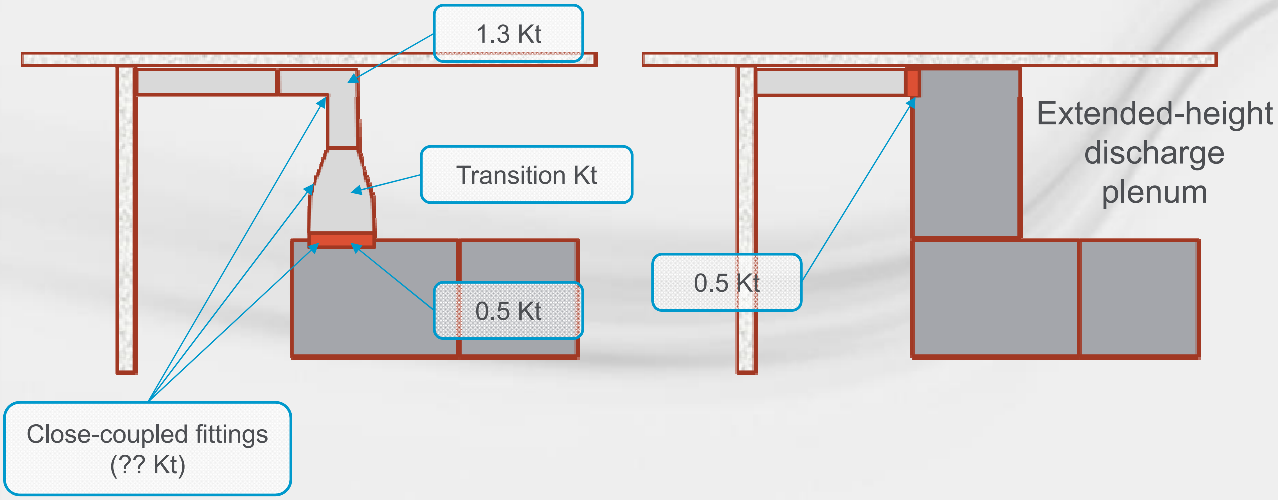


Unit Connections: Discharge Plenum

$$SP = 0.5 \times \left(\frac{OV Plenum}{4005}\right)^2$$

Where:
SP = Static pressure loss
OV = Outlet velocity (plenum opening)

Unit Connections: Discharge Plenum



1.3 Kt

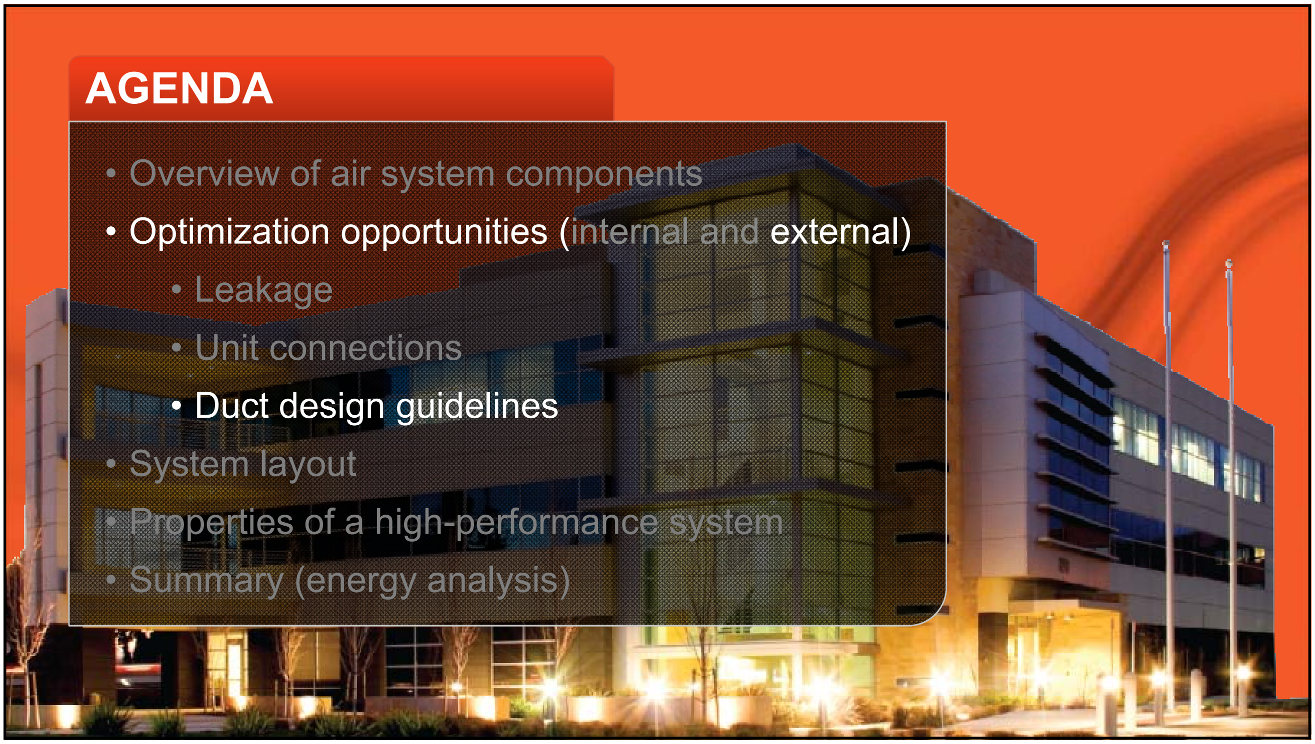
Transition Kt

0.5 Kt

Close-coupled fittings
(?? Kt)

0.5 Kt

Extended-height
discharge
plenum



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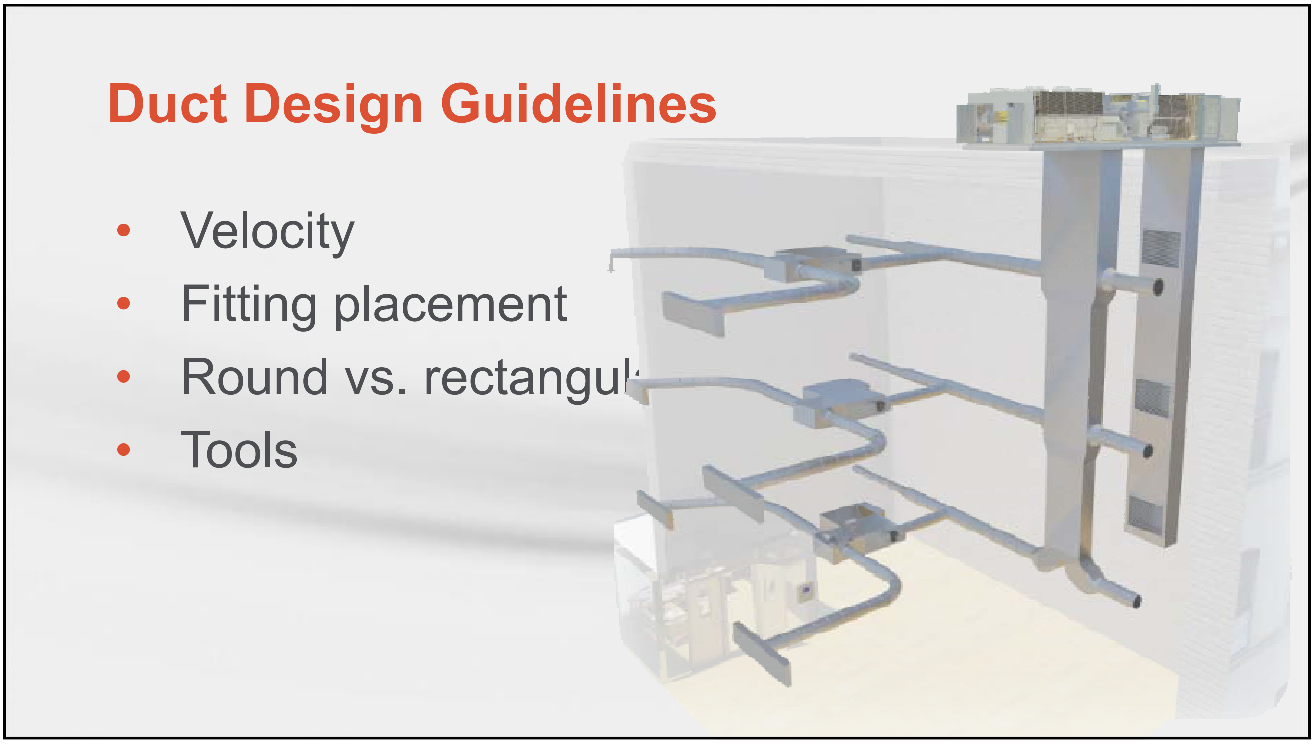
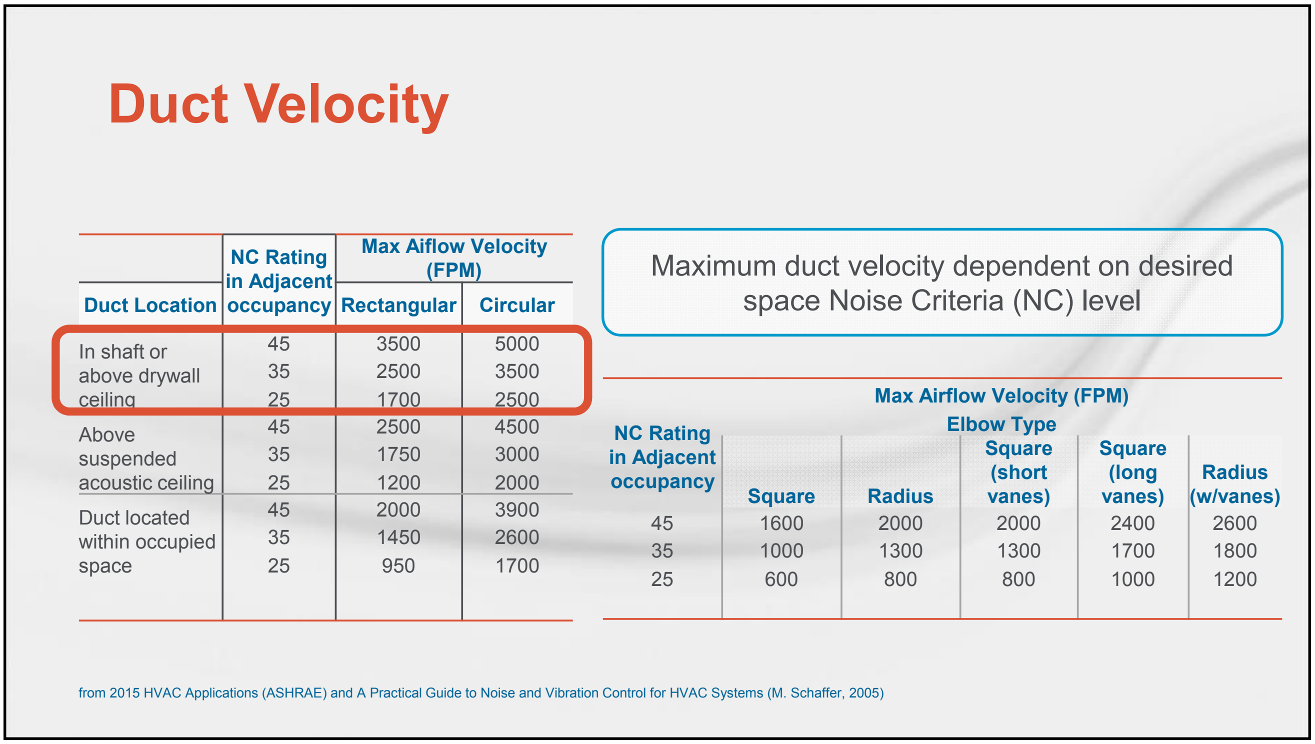


Duct Design Guidelines

- Velocity
- Fitting placement
- Round vs. rectangul
- Tools



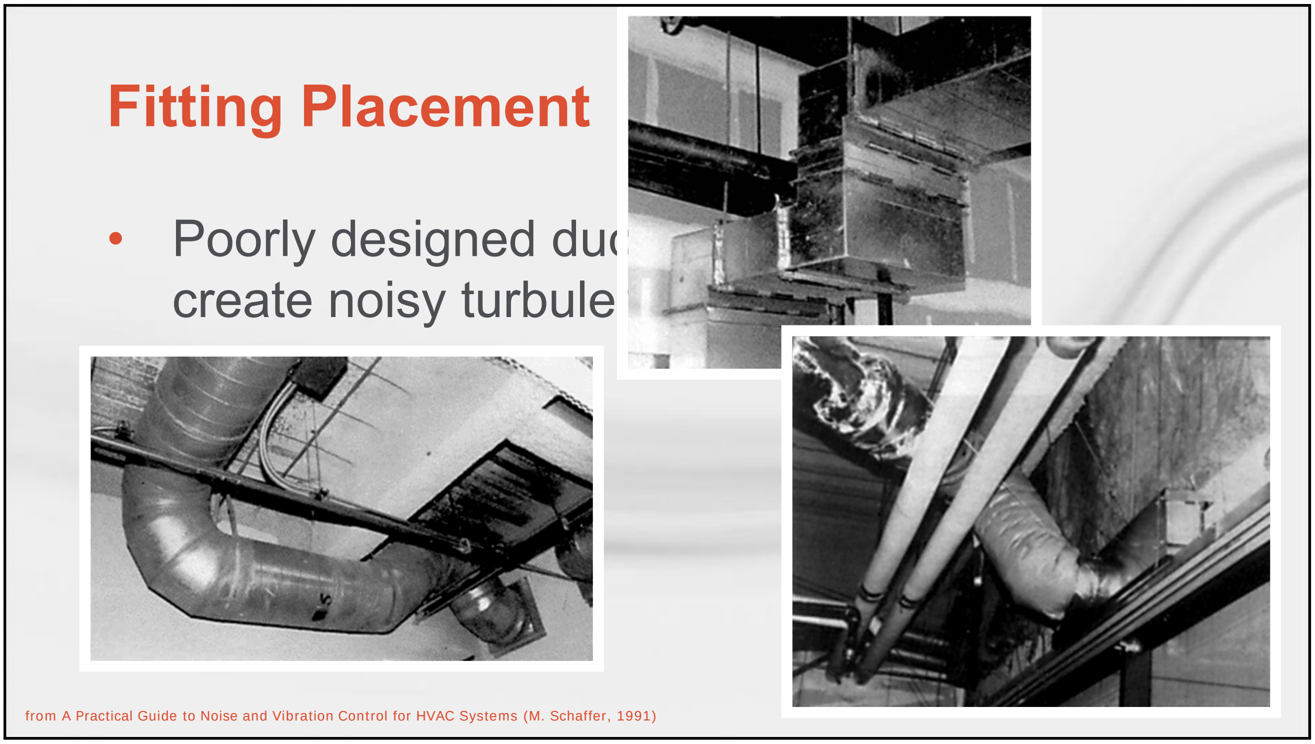
Duct Velocity

	NC Rating in Adjacent	Max Aiflow Velocity (FPM)	
Duct Location	**occupancy**	**Rectangular**	**Circular**
In shaft or above drywall ceiling	45	3500	5000
	35	2500	3500
	25	1700	2500
Above suspended acoustic ceiling	45	2500	4500
	35	1750	3000
	25	1200	2000
Duct located within occupied space	45	2000	3900
	35	1450	2600
	25	950	1700

Maximum duct velocity dependent on desired space Noise Criteria (NC) level

	Max Airflow Velocity (FPM) Elbow Type				
NC Rating in Adjacent occupancy	**Square**	**Radius**	**Square (short vanes)**	**Square (long vanes)**	**Radius (w/vanes)**
45	1600	2000	2000	2400	2600
35	1000	1300	1300	1700	1800
25	600	800	800	1000	1200

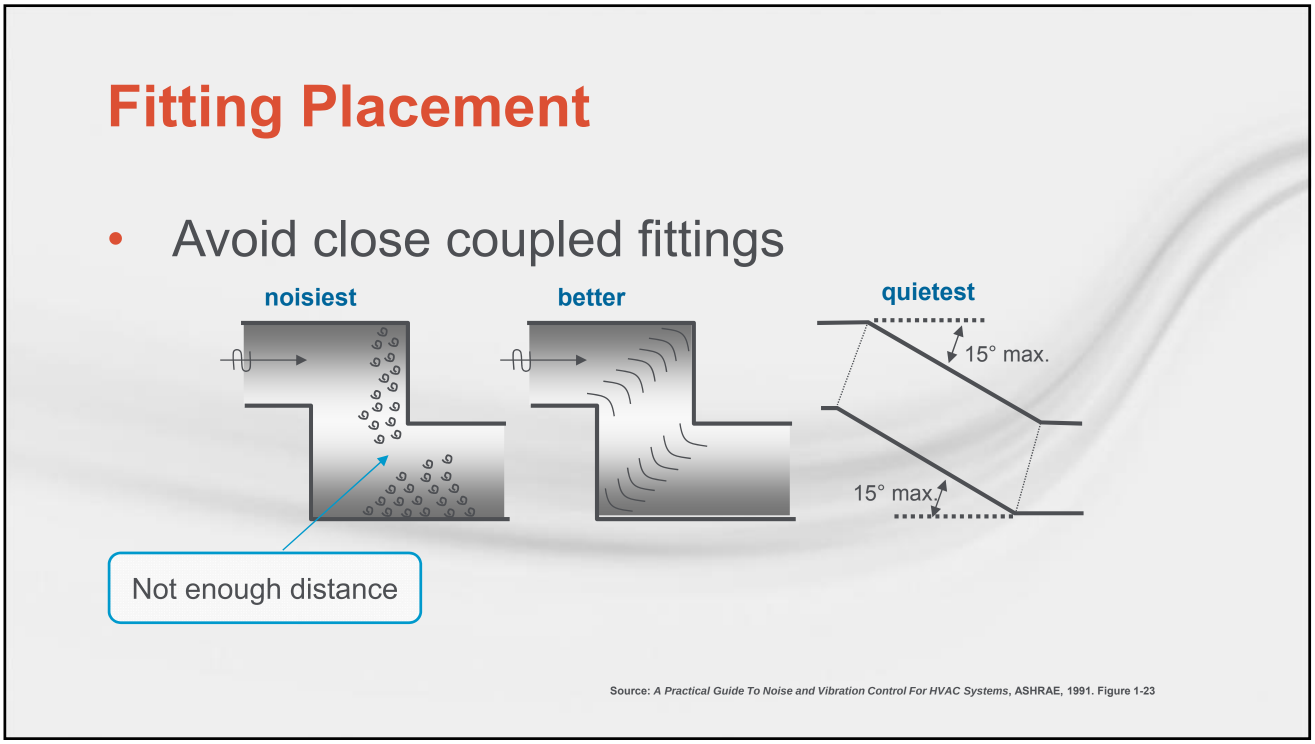
from 2015 HVAC Applications (ASHRAE) and A Practical Guide to Noise and Vibration Control for HVAC Systems (M. Schaffer, 2005)



Fitting Placement

- Poorly designed duc create noisy turbule

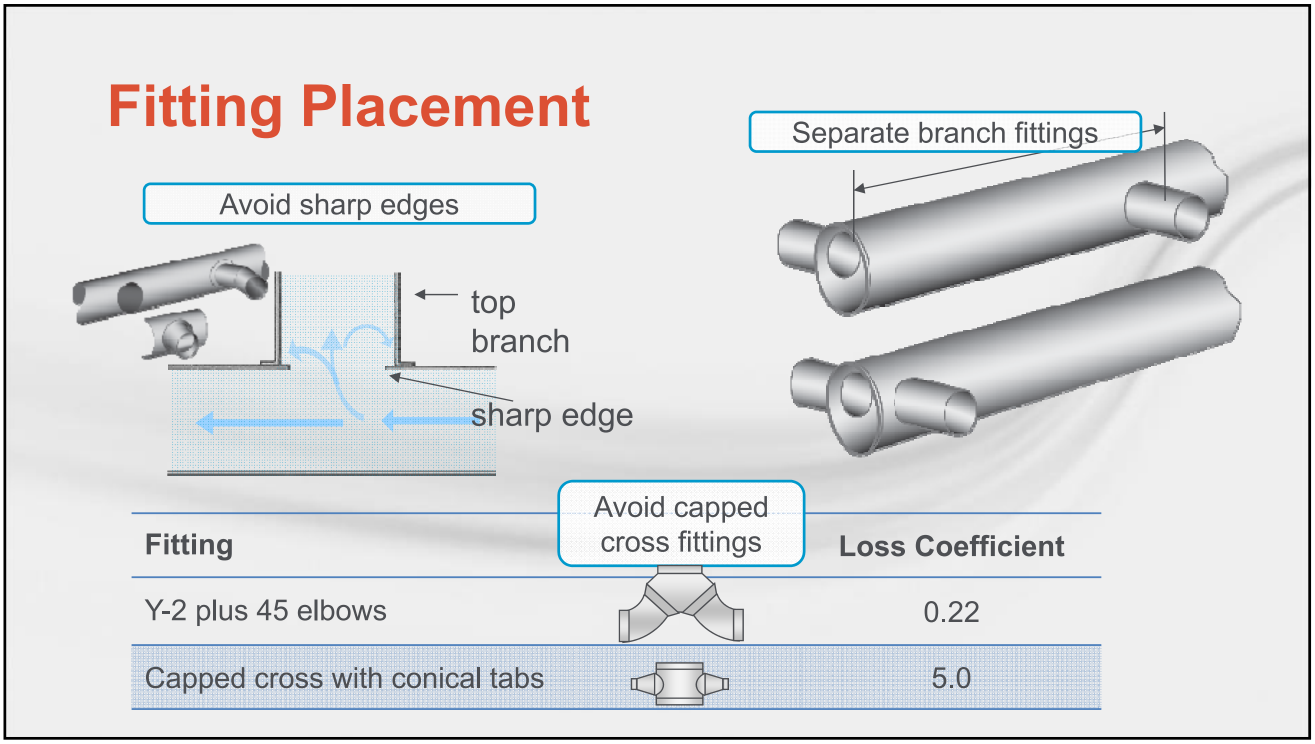
from A Practical Guide to Noise and Vibration Control for HVAC Systems (M. Schaffer, 1991)



Fitting Placement

- Avoid close coupled fittings

Source: *A Practical Guide To Noise and Vibration Control For HVAC Systems*, ASHRAE, 1991. Figure 1-23



Fitting Placement

Avoid sharp edges

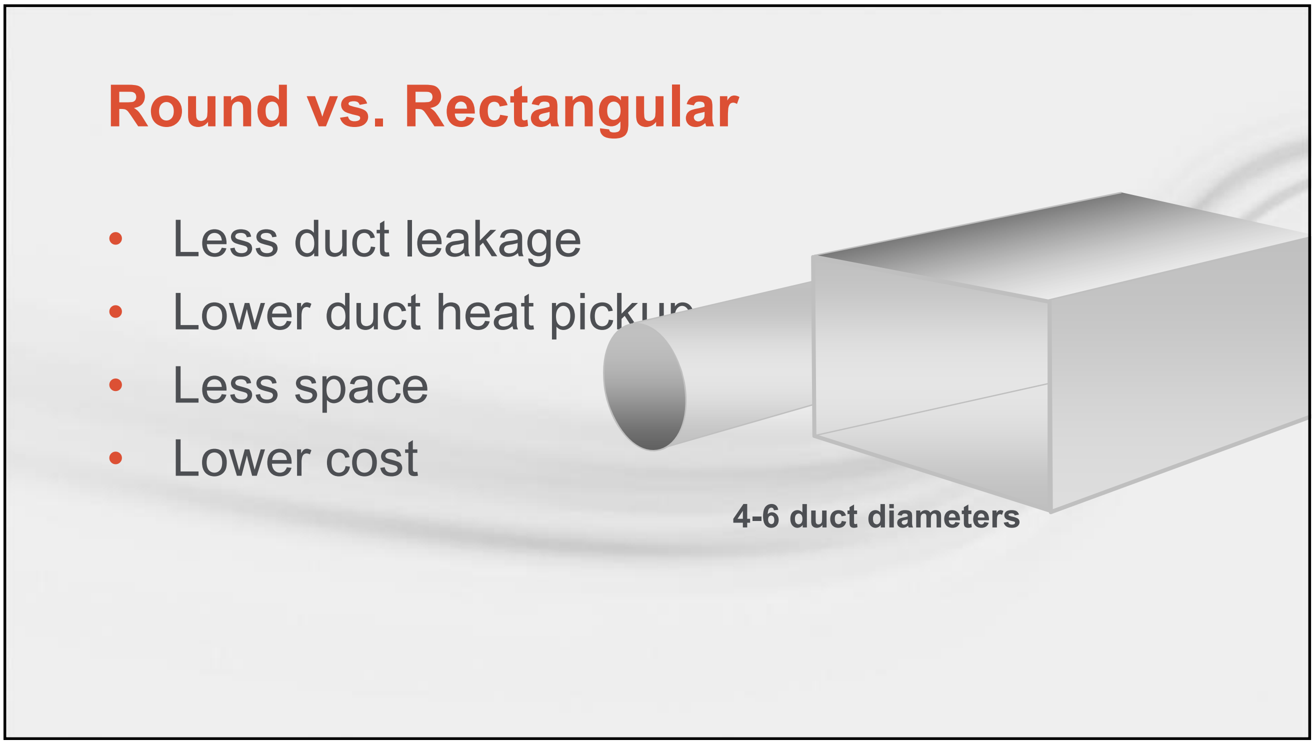
top branch

sharp edge

Separate branch fittings

Avoid capped cross fittings

Fitting	Loss Coefficient
Y-2 plus 45 elbows	0.22
Capped cross with conical tabs	5.0

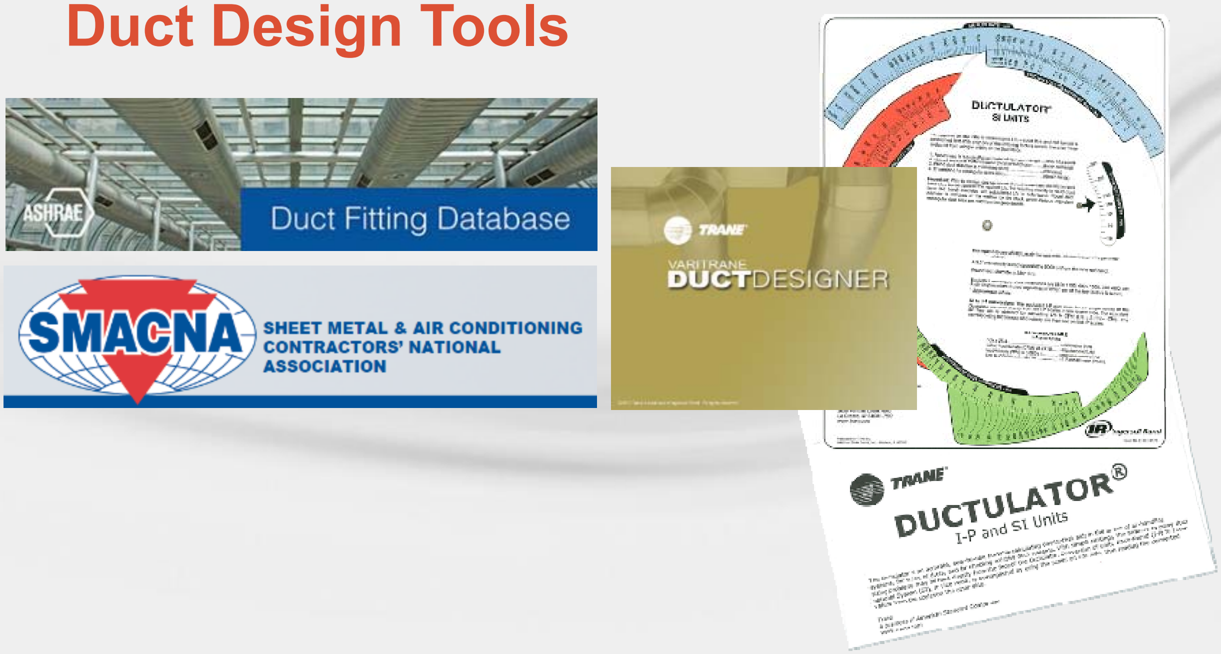


Round vs. Rectangular

- Less duct leakage
- Lower duct heat pickup
- Less space
- Lower cost

4-6 duct diameters

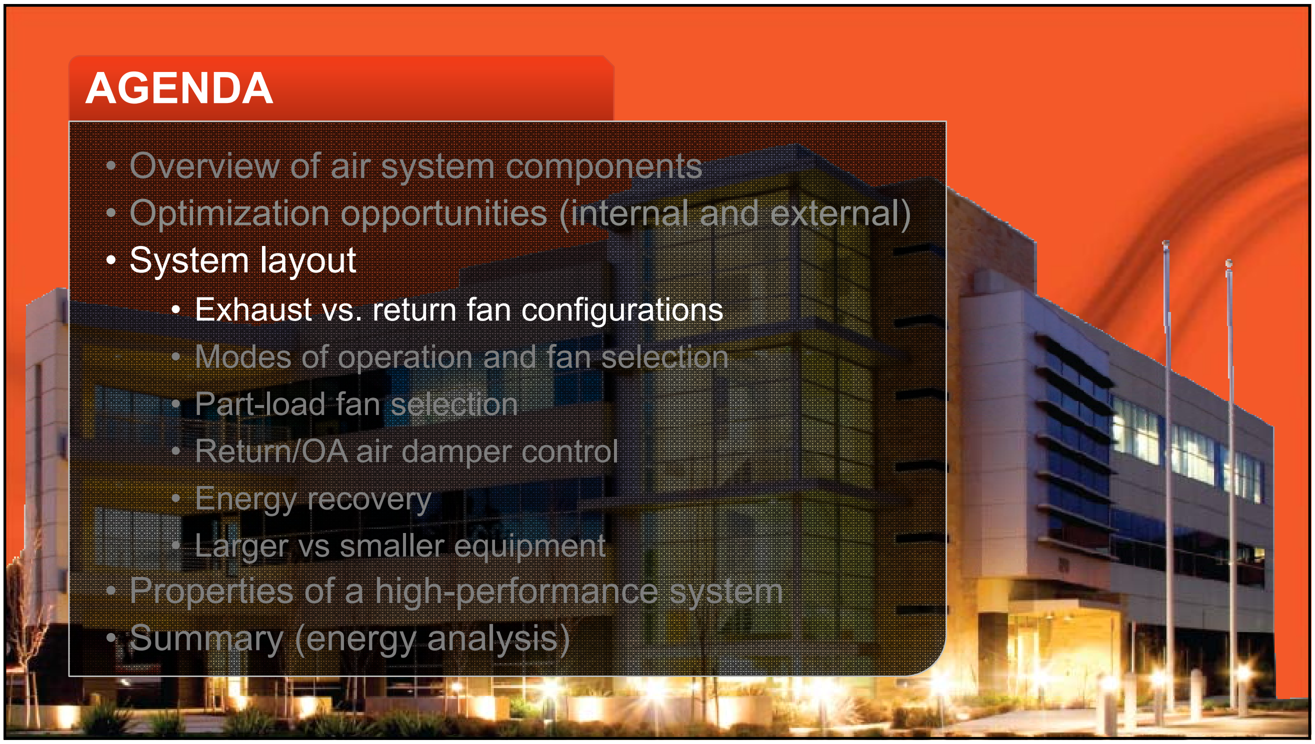
Duct Design Tools



Summary

External Losses

- Leakage
- Unit connections
  - Plenums
- Duct design guidelines



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  - Modes of operation and fan selection
  - Part-load fan selection
  - Return/OA air damper control
  - Energy recovery
  - Larger vs smaller equipment
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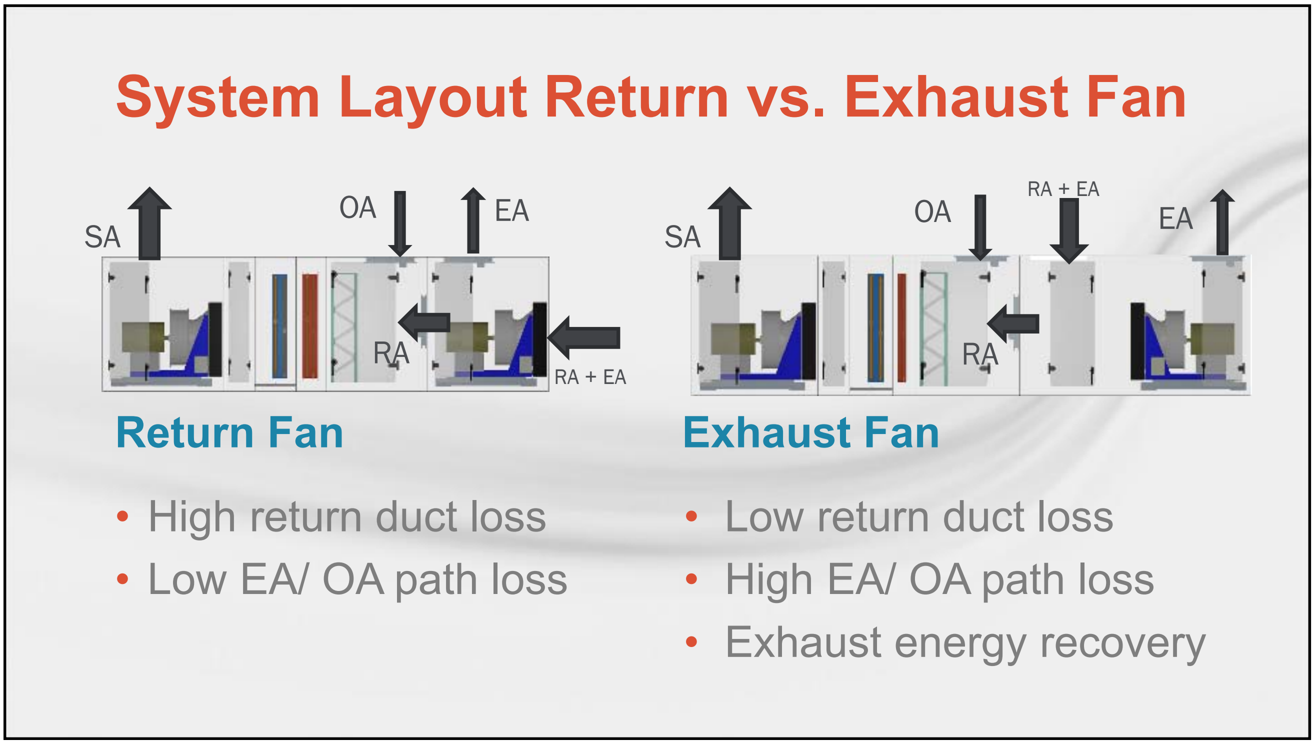


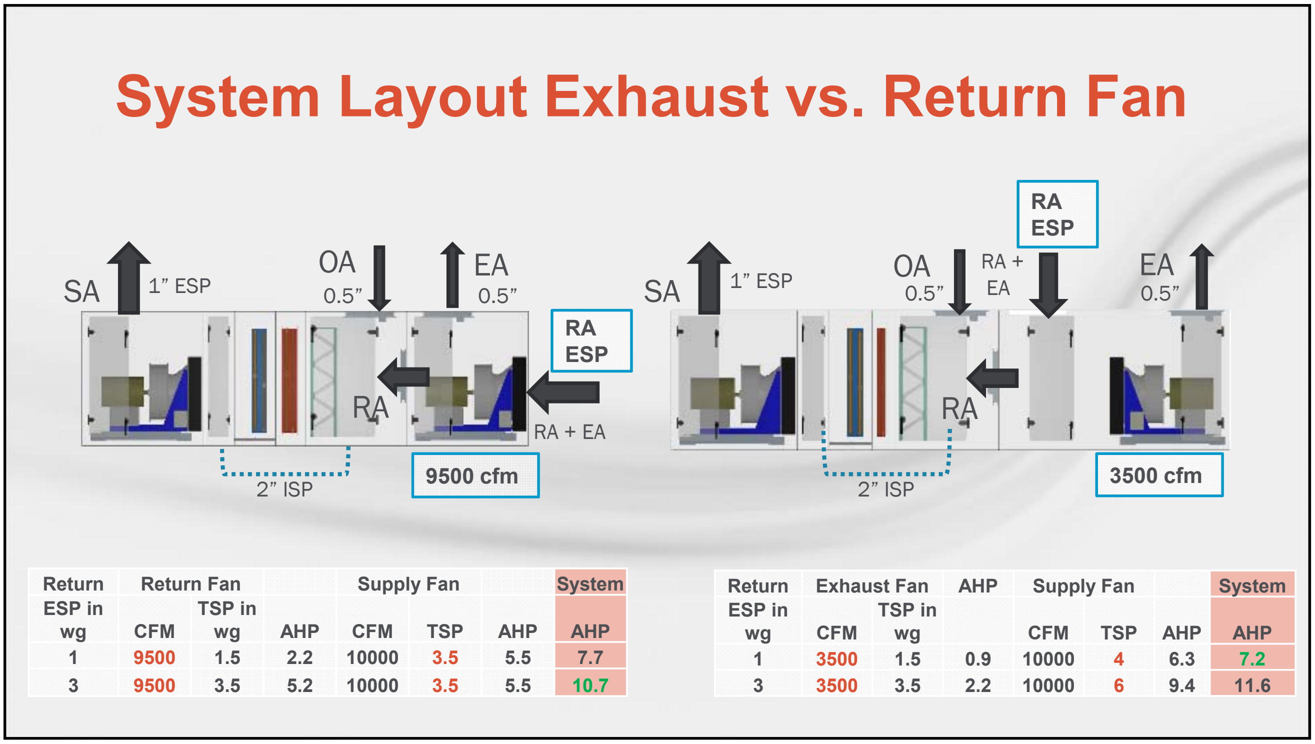
System Layout Return vs. Exhaust Fan

Return Fan

- High return duct loss
- Low EA/ OA path loss

Exhaust Fan

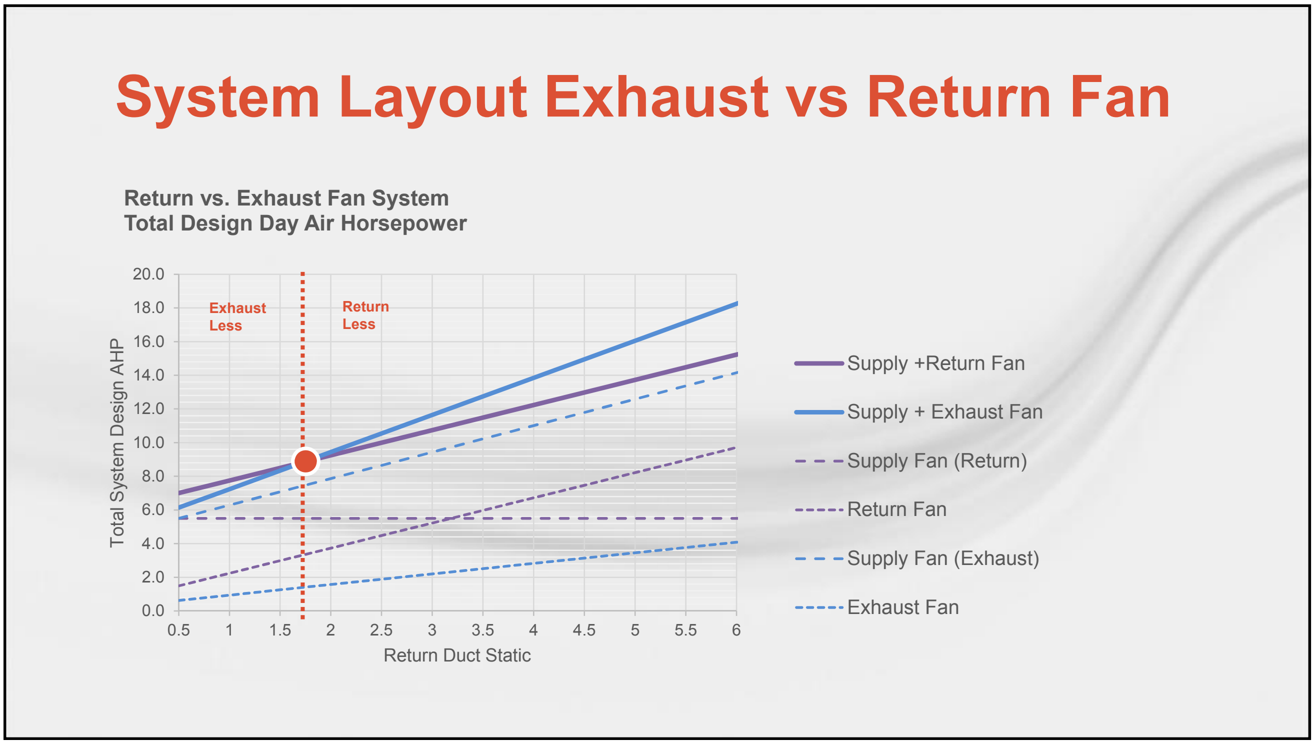
- Low return duct loss
- High EA/ OA path loss
- Exhaust energy recovery



System Layout Exhaust vs. Return Fan

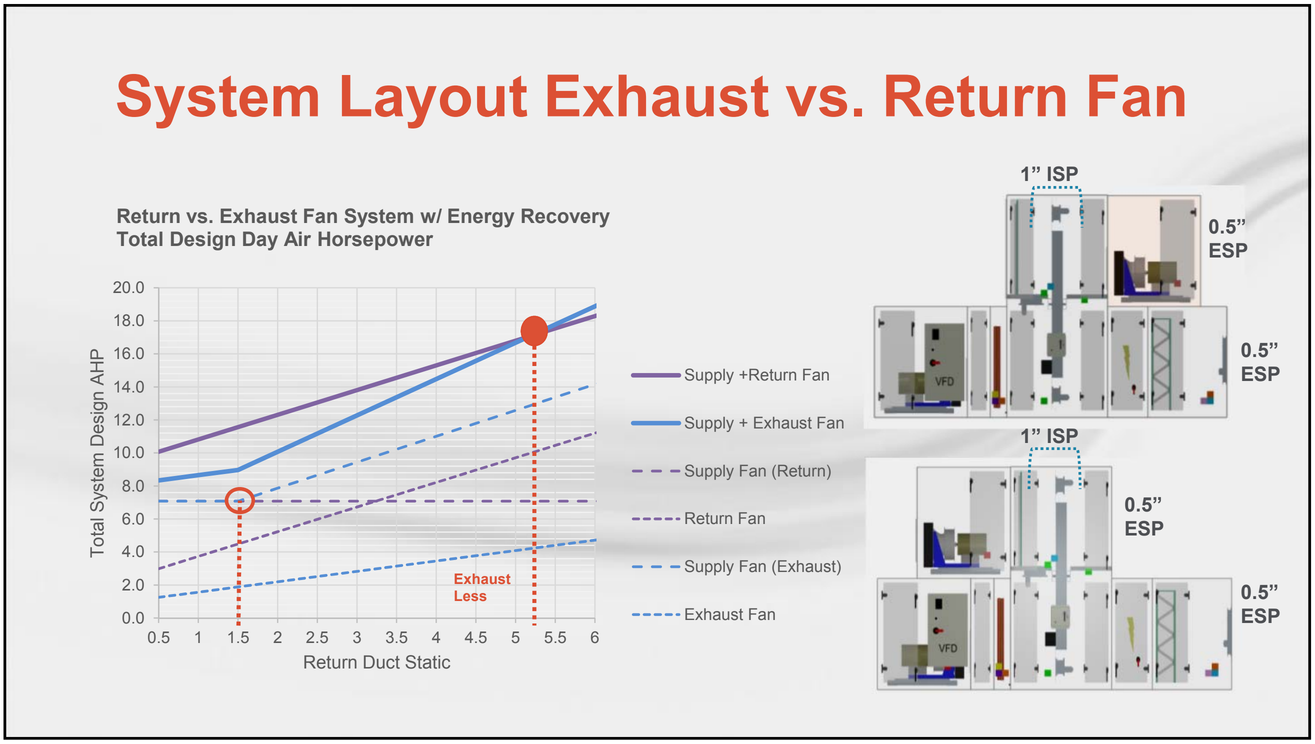
Return ESP in wg	Return Fan			Supply Fan			System
	CFM	TSP in wg	AHP	CFM	TSP	AHP	AHP
1	9500	1.5	2.2	10000	3.5	5.5	7.7
3	9500	3.5	5.2	10000	3.5	5.5	10.7

Return ESP in wg	Exhaust Fan		AHP	Supply Fan			System
	CFM	TSP in wg		CFM	TSP	AHP	AHP
1	3500	1.5	0.9	10000	4	6.3	7.2
3	3500	3.5	2.2	10000	6	9.4	11.6



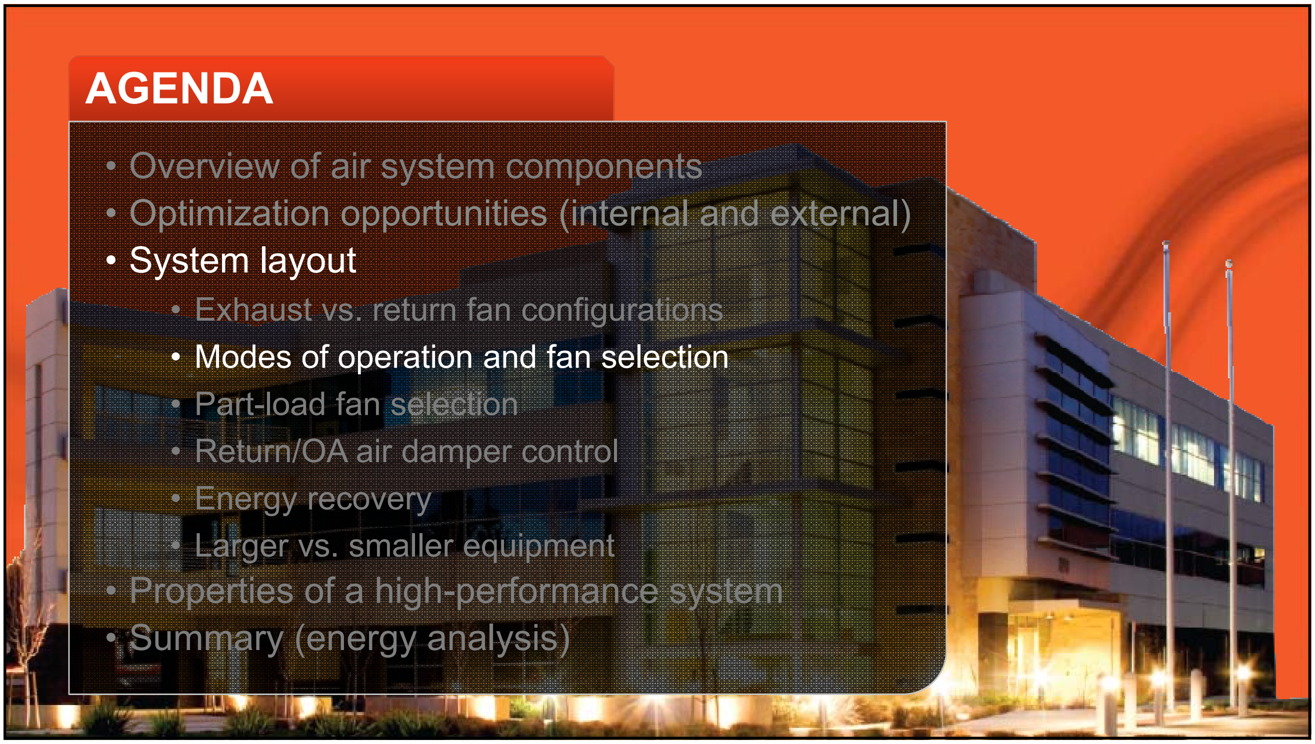
System Layout Exhaust vs Return Fan

Return vs. Exhaust Fan System
Total Design Day Air Horsepower



System Layout Exhaust vs. Return Fan

Return vs. Exhaust Fan System w/ Energy Recovery
Total Design Day Air Horsepower



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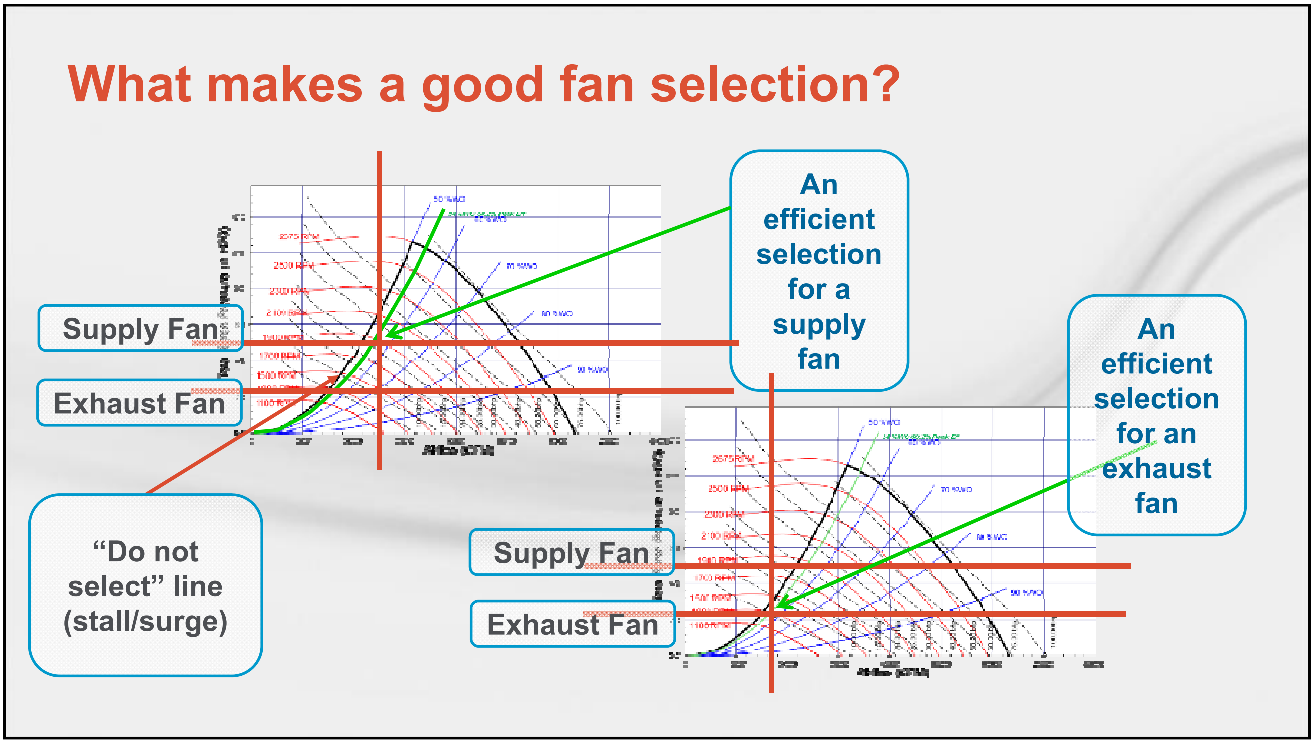


What makes a good fan selection?

Supply Fan

Exhaust Fan

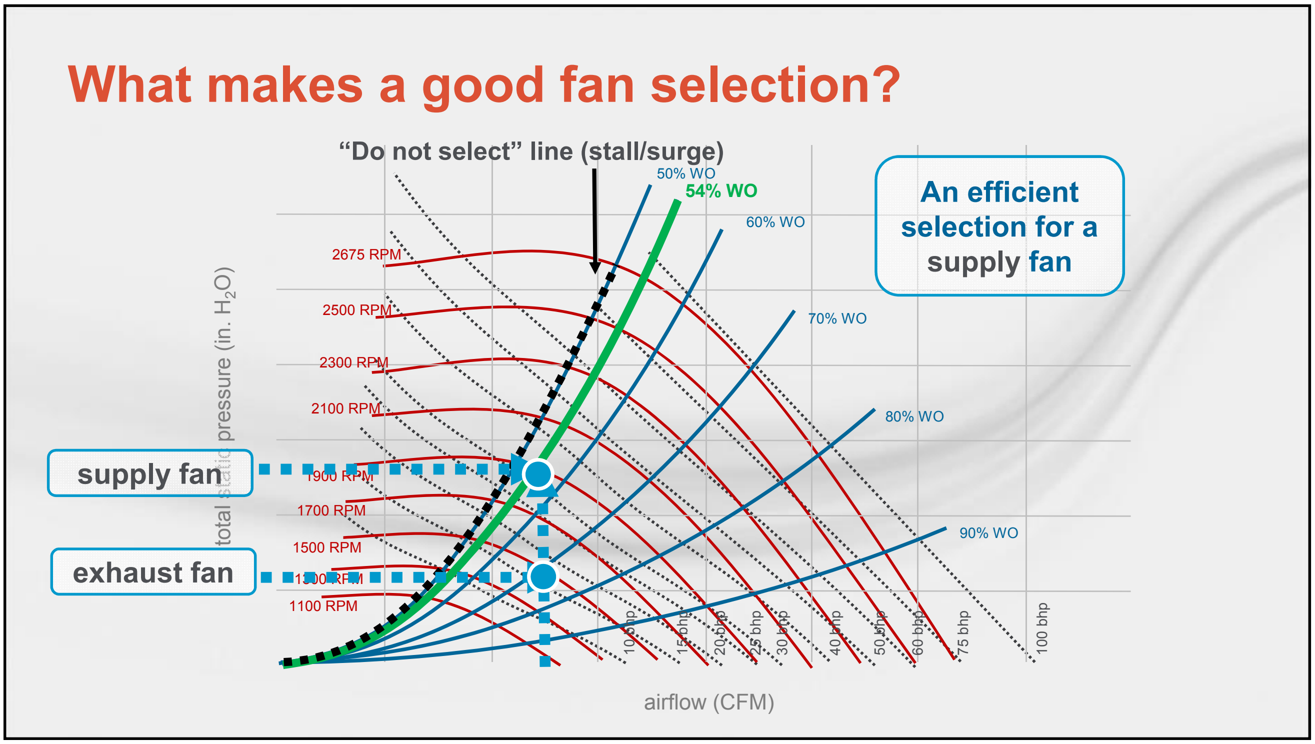
An efficient selection for a supply fan

"Do not select" line (stall/surge)

Supply Fan

Exhaust Fan

An efficient selection for an exhaust fan



What makes a good fan selection?

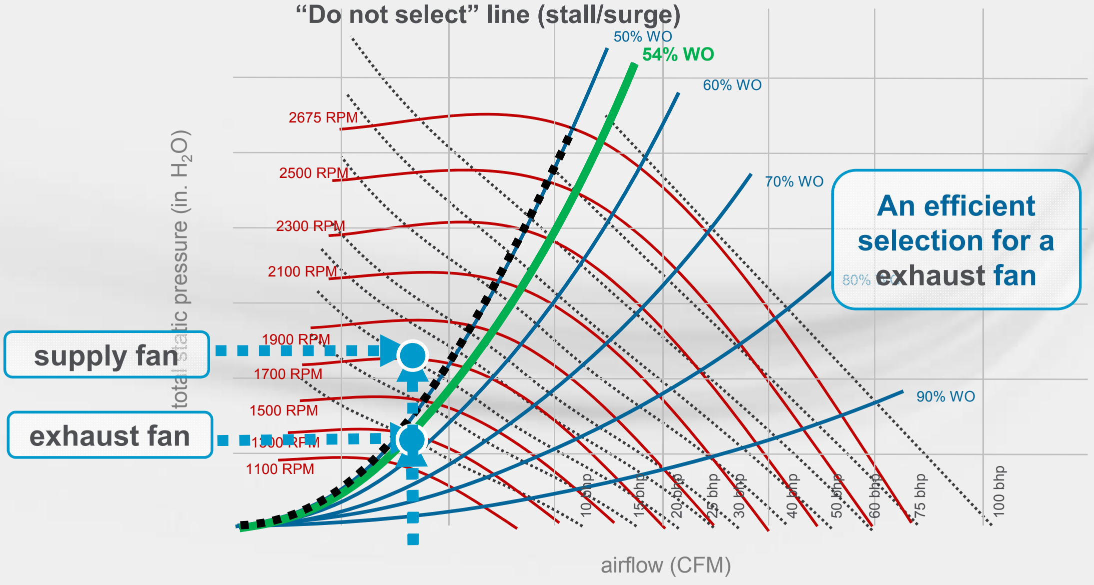
"Do not select" line (stall/surge)

An efficient selection for a supply fan

supply fan

exhaust fan

What makes a good fan selection?

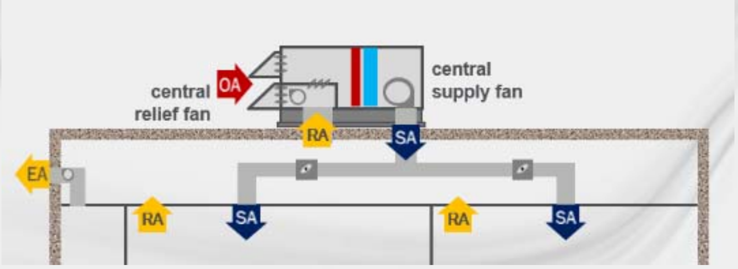


An efficient selection for a exhaust fan

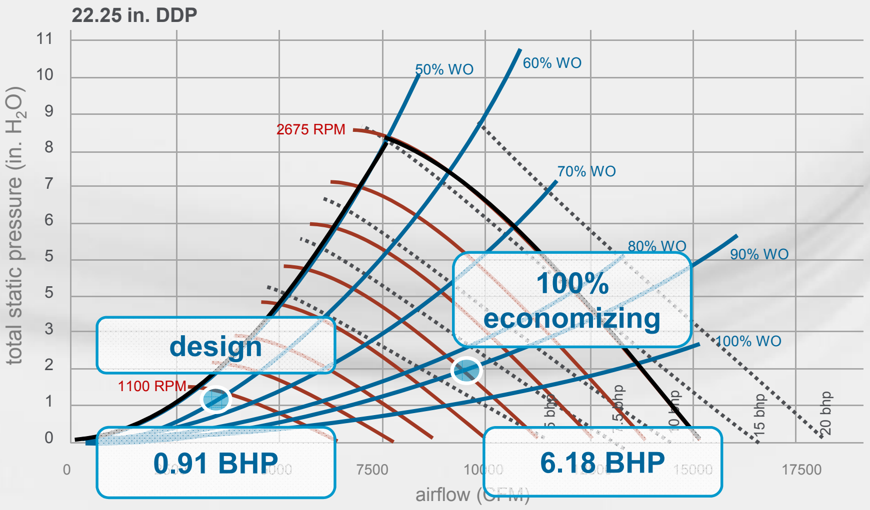
Two Modes of Operation

Example:

- Supply fan airflow: 10,000 CFM
- Relief airflow @ cooling design: 3500 CFM
- Maximum relief airflow (economizer mode): 9500 CFM



Dual Purpose Exhaust Fan



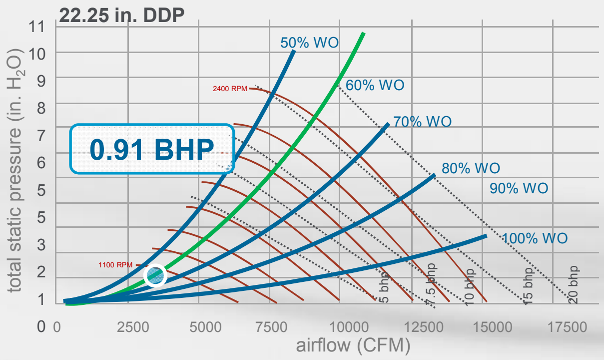
design

0.91 BHP

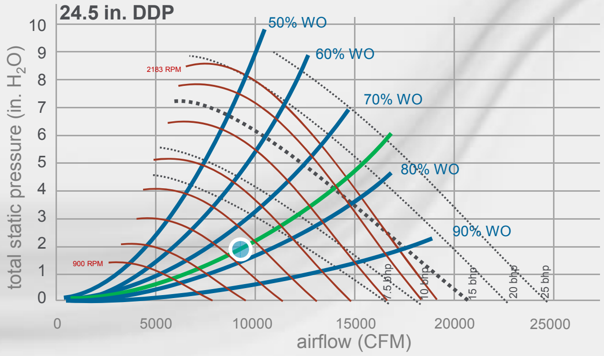
100% economizing

6.18 BHP

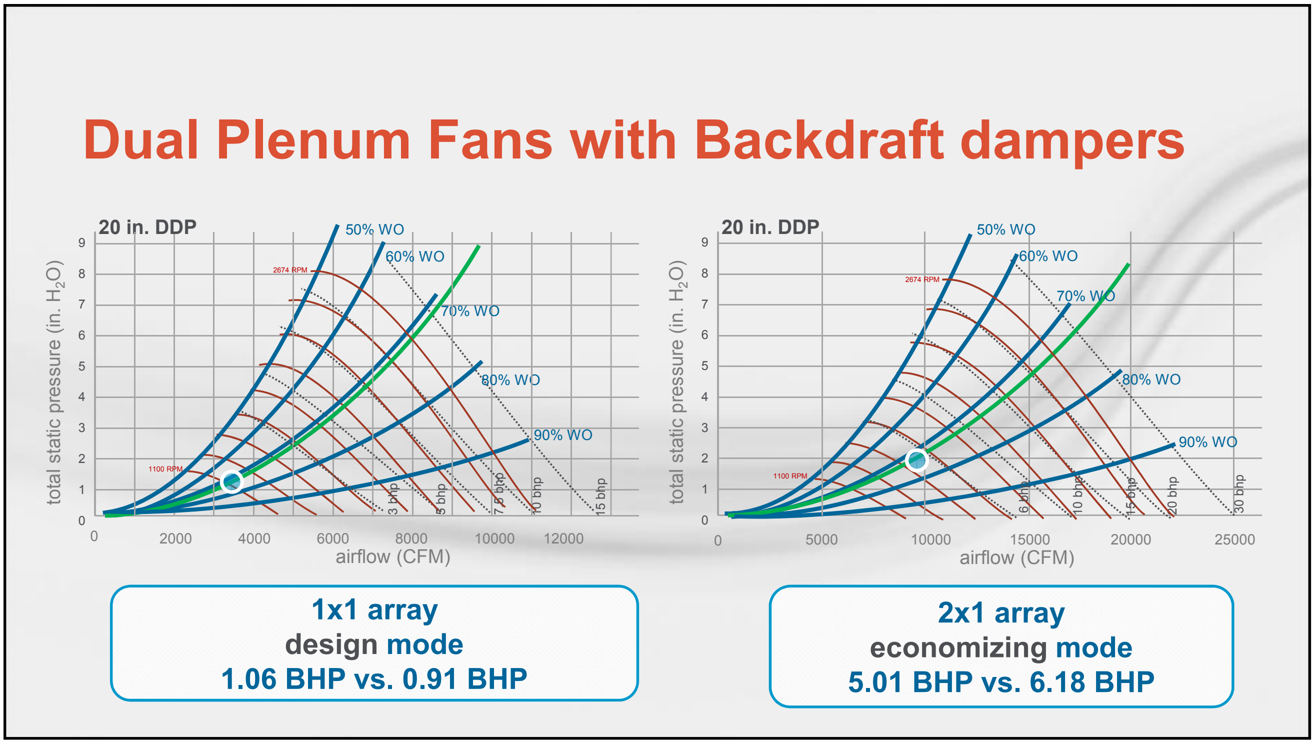
Secondary, Remote Relief Fan



0.91 BHP



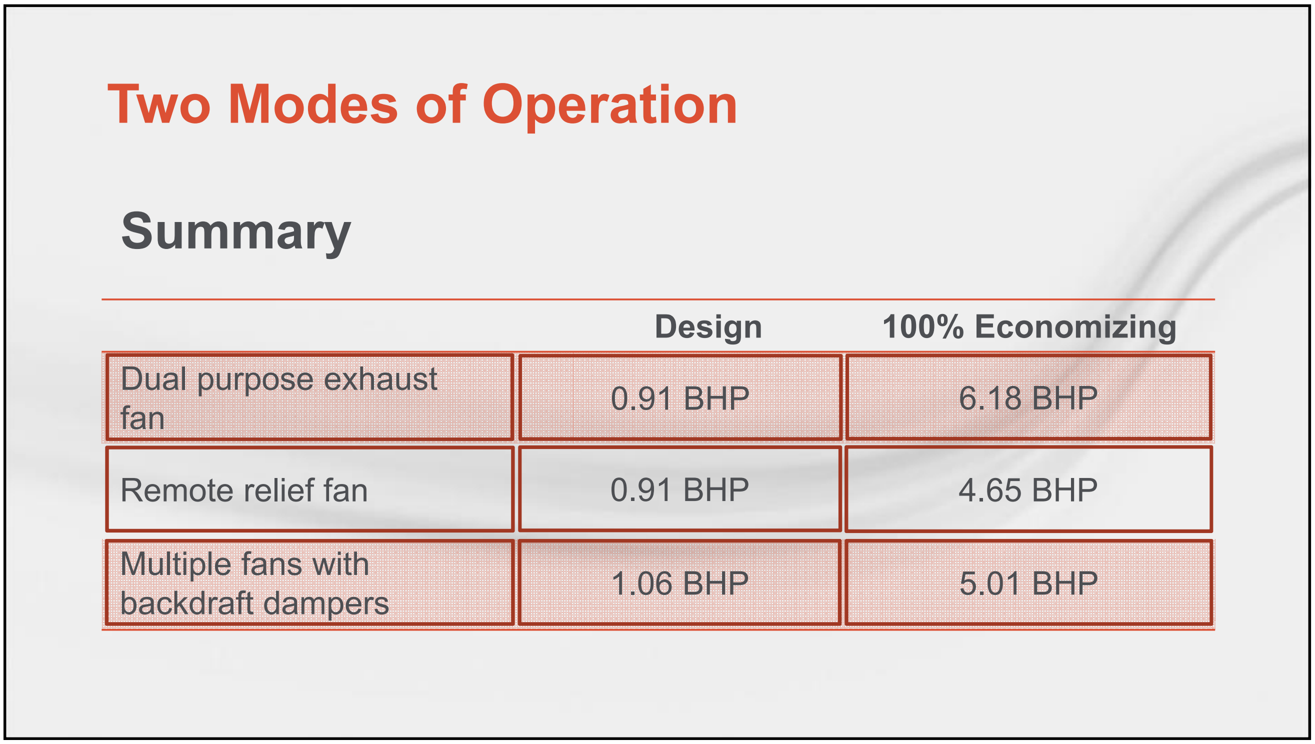
100% economizing
4.65 BHP vs. 6.18 BHP



Dual Plenum Fans with Backdraft dampers

1x1 array
design mode
1.06 BHP vs. 0.91 BHP

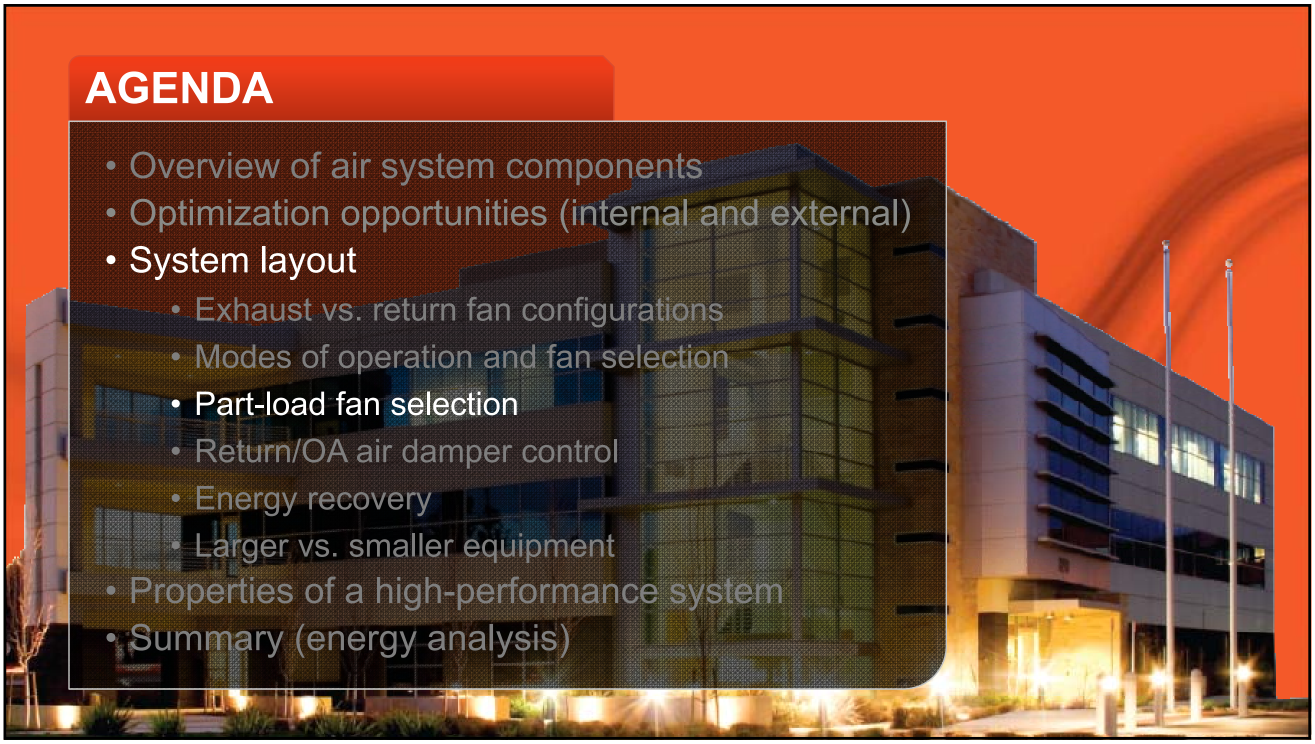
2x1 array
economizing mode
5.01 BHP vs. 6.18 BHP



Two Modes of Operation

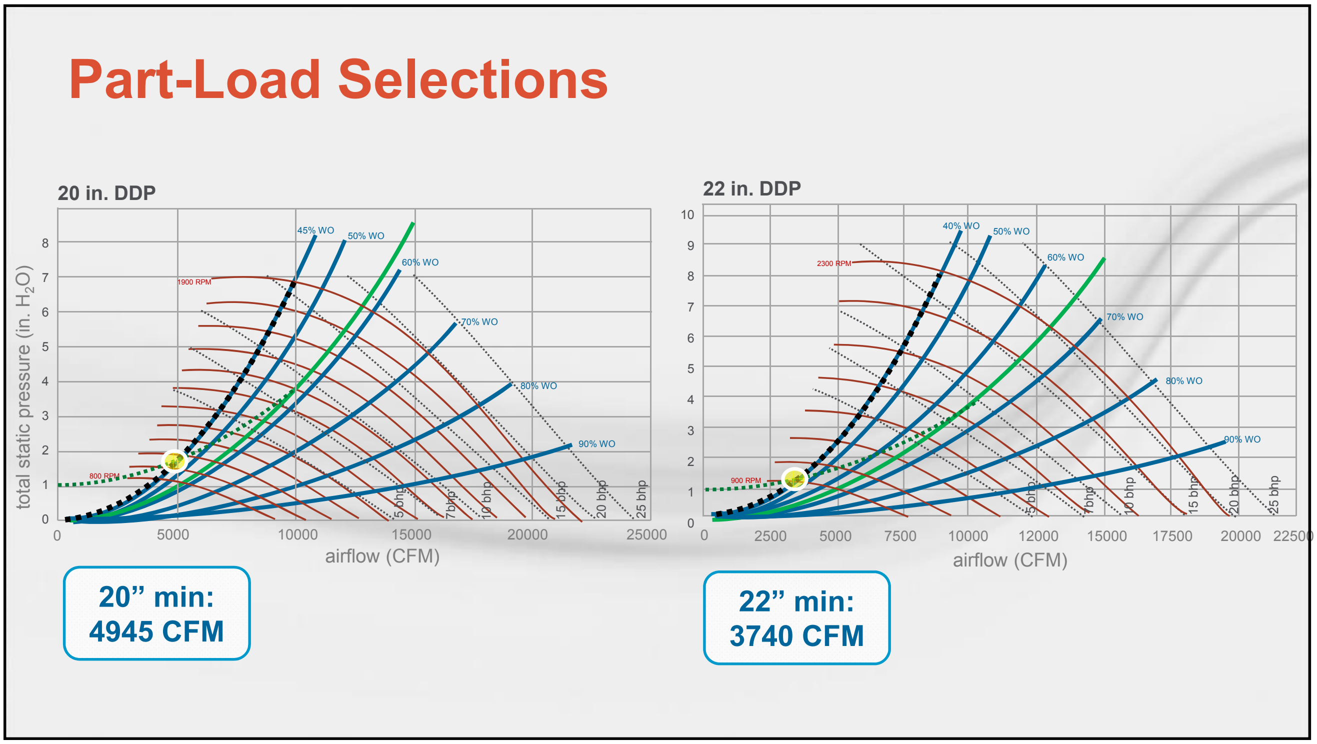
Summary

	Design	100% Economizing
Dual purpose exhaust fan	0.91 BHP	6.18 BHP
Remote relief fan	0.91 BHP	4.65 BHP
Multiple fans with backdraft dampers	1.06 BHP	5.01 BHP



AGENDA

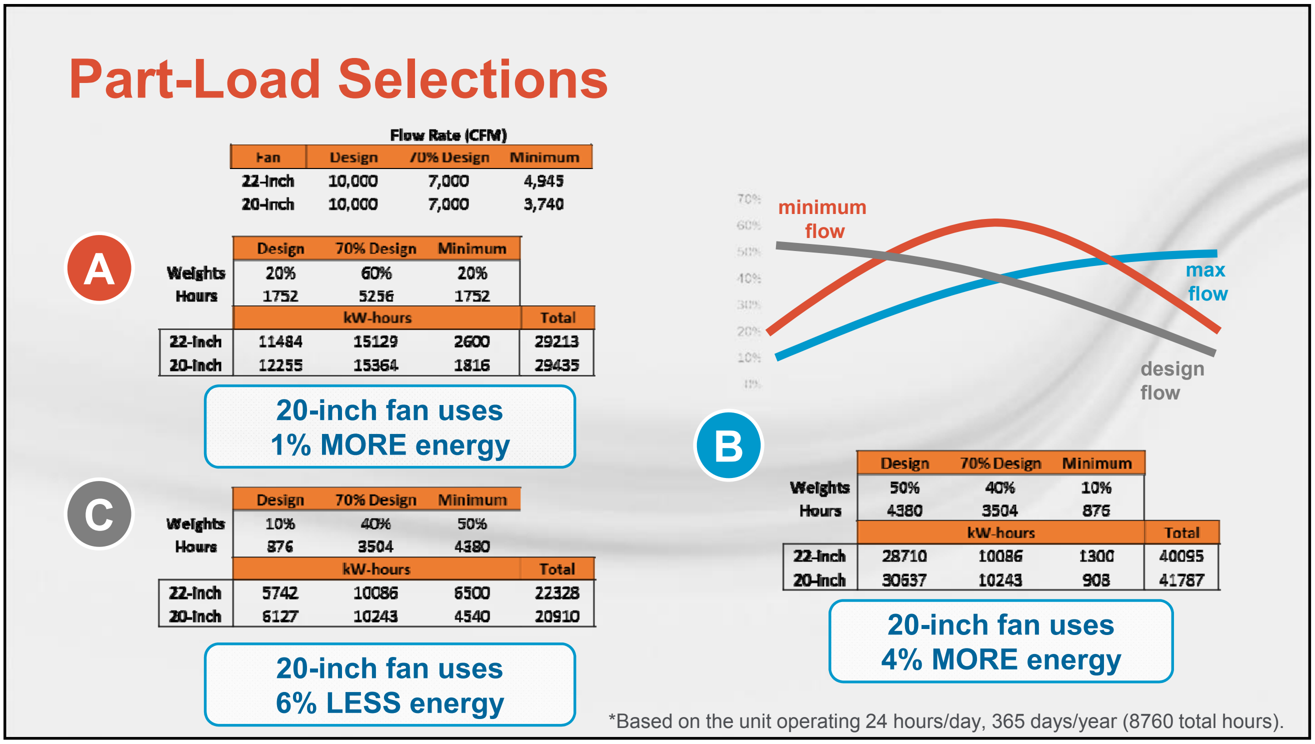
- Overview of air system components
- Optimization opportunities (internal and external)
- System layout
  - Exhaust vs. return fan configurations
  - Modes of operation and fan selection
  - Part-load fan selection
  - Return/OA air damper control
  - Energy recovery
  - Larger vs. smaller equipment
- Properties of a high-performance system
- Summary (energy analysis)



Part-Load Selections

**20” min:
4945 CFM**

**22” min:
3740 CFM**



Part-Load Selections

Flow Rate (CFM)

Fan	Design	70% Design	Minimum
22-Inch	10,000	7,000	4,945
20-Inch	10,000	7,000	3,740

A

	Design	70% Design	Minimum	
Weights	20%	60%	20%	
Hours	1752	5256	1752	
	kW-hours			Total
22-Inch	11484	15129	2600	29213
20-Inch	12255	15364	1816	29435

20-inch fan uses 1% MORE energy

B

	Design	70% Design	Minimum	
Weights	50%	40%	10%	
Hours	4380	3504	876	
	kW-hours			Total
22-Inch	28710	10086	1300	40095
20-Inch	30537	10243	908	41787

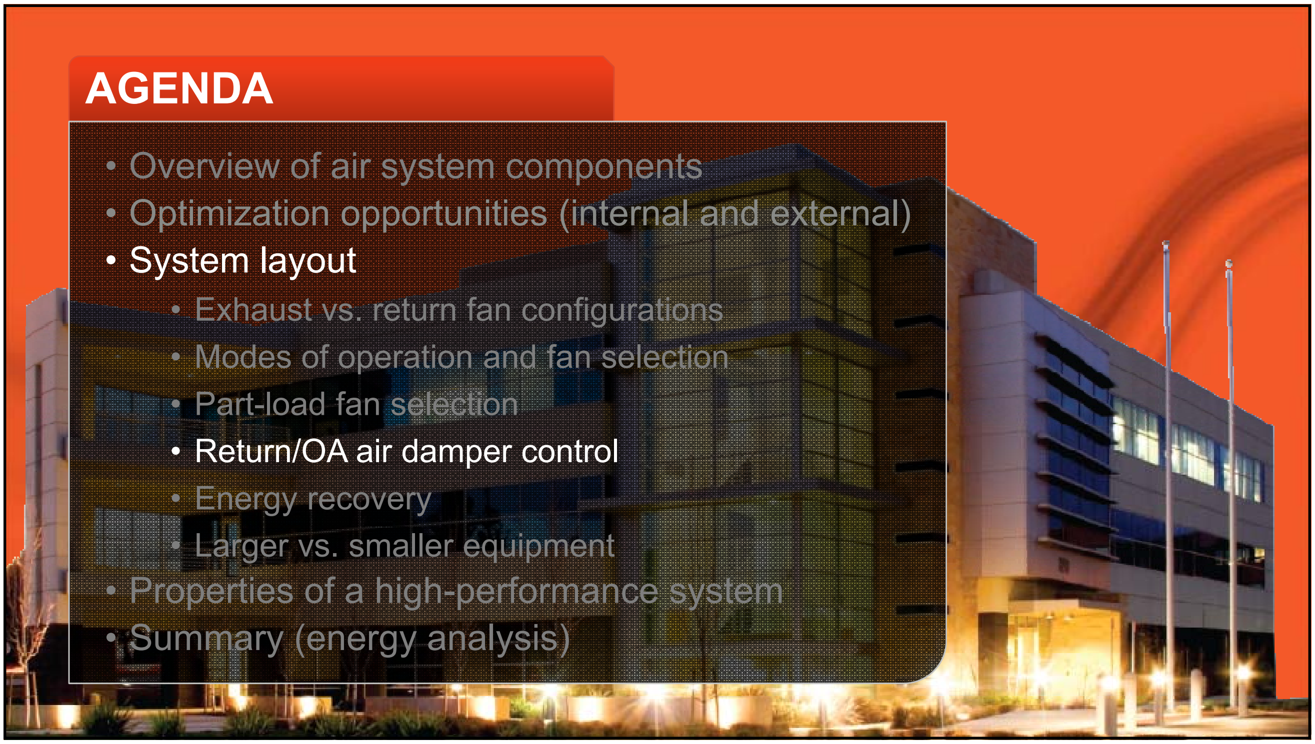
20-inch fan uses 4% MORE energy

C

	Design	70% Design	Minimum	
Weights	10%	40%	50%	
Hours	876	3504	4380	
	kW-hours			Total
22-Inch	5742	10086	6500	22328
20-Inch	6127	10243	4540	20910

20-inch fan uses 6% LESS energy

*Based on the unit operating 24 hours/day, 365 days/year (8760 total hours).



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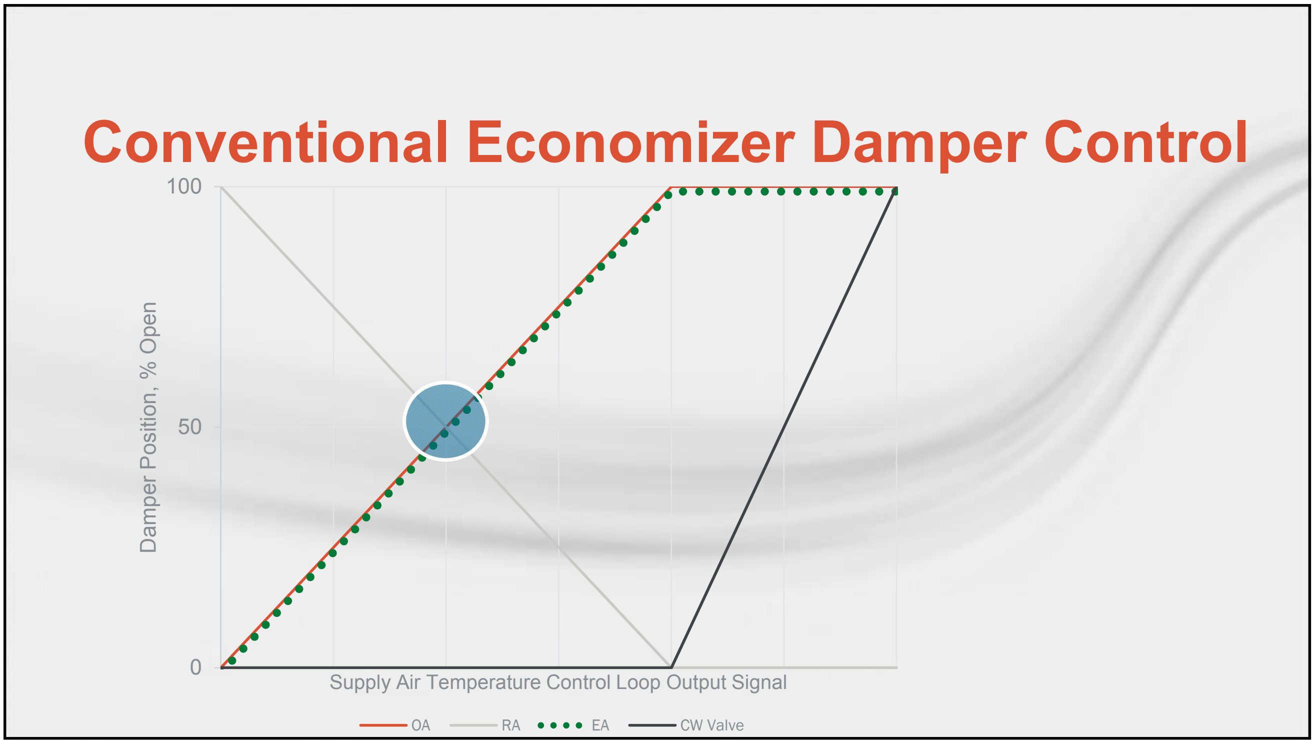
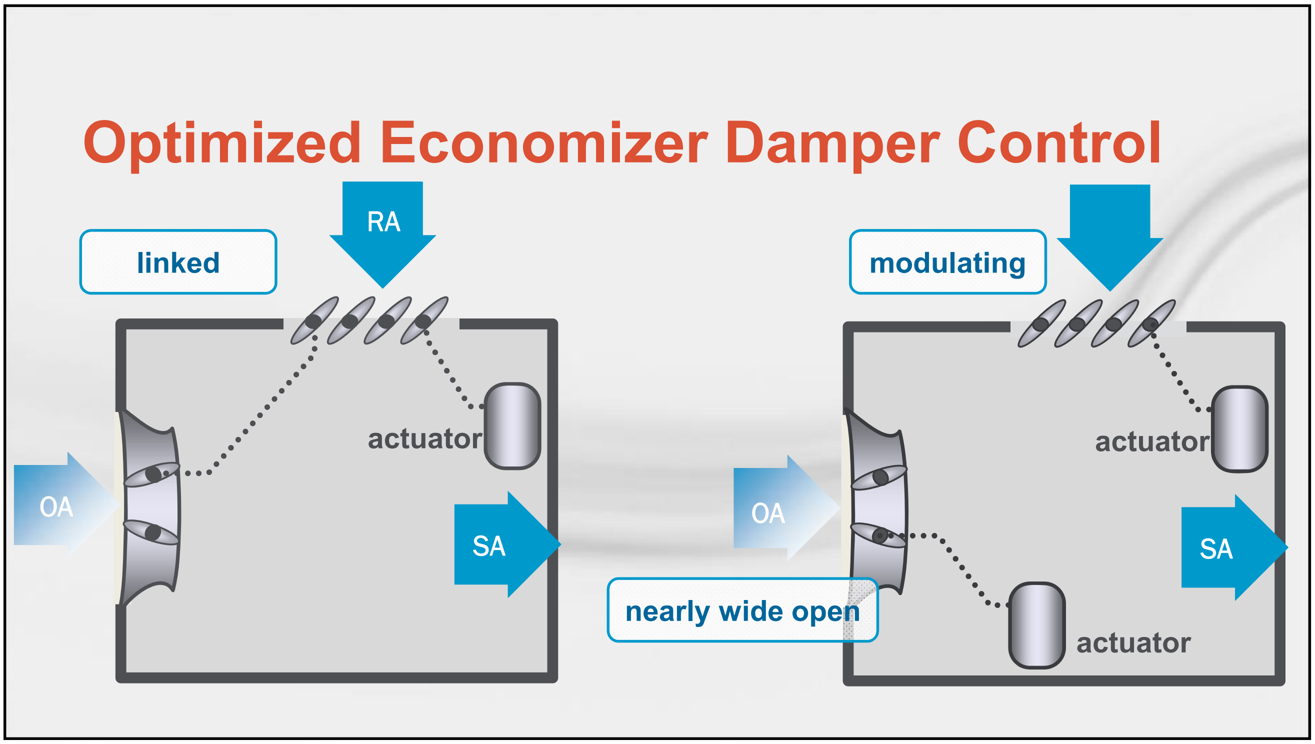
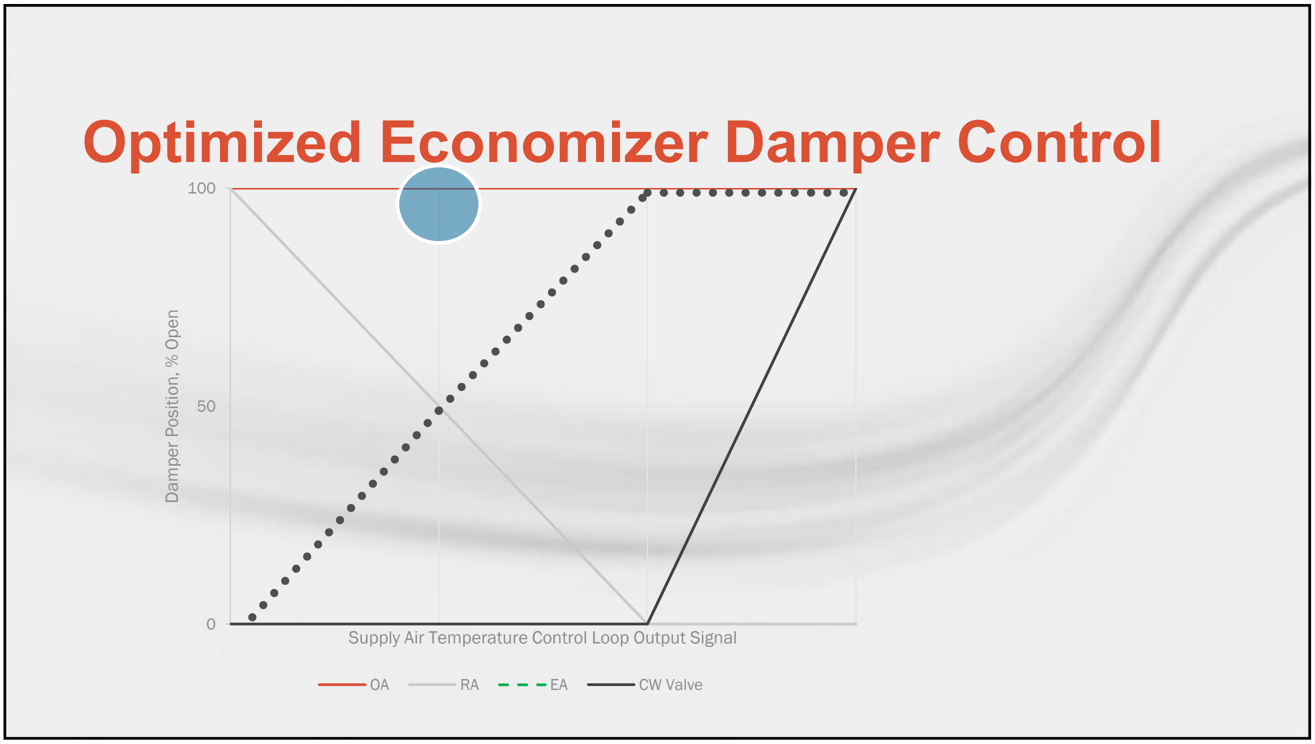


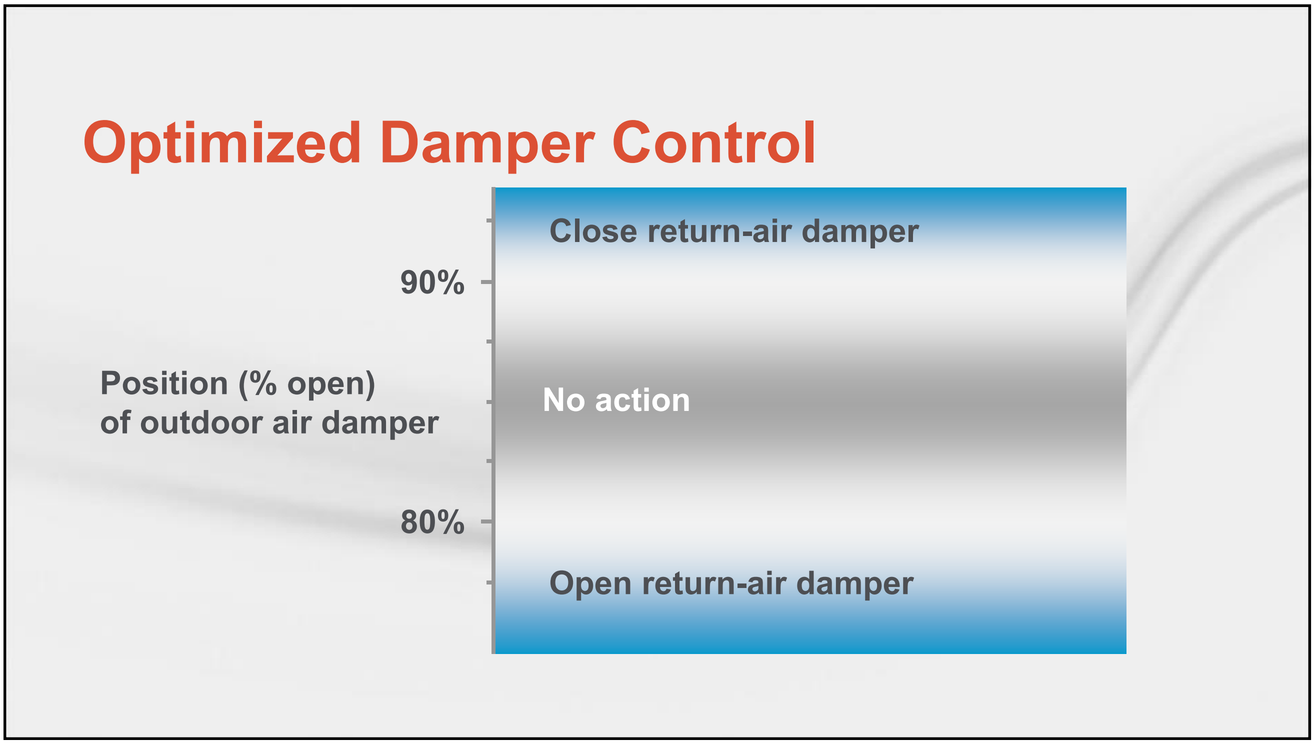
Conventional Economizer Damper Control



Optimized Economizer Damper Control



Optimized Economizer Damper Control



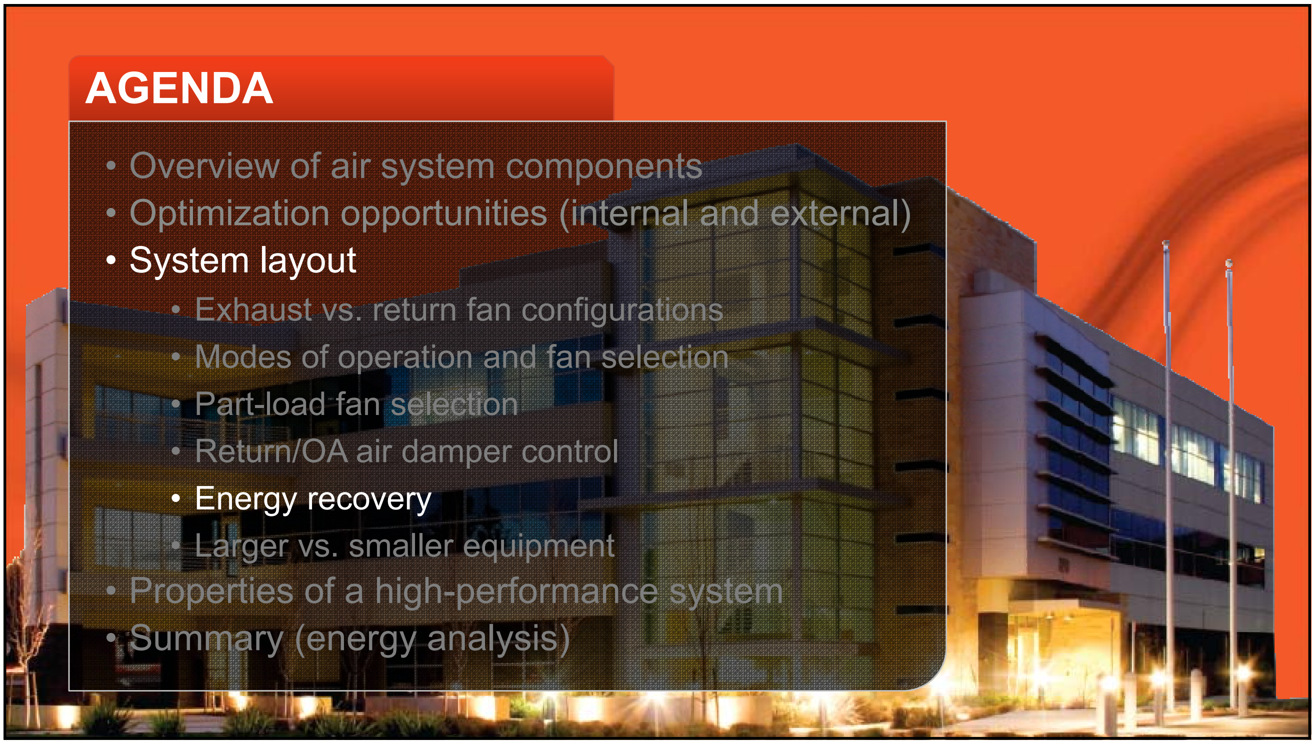
Optimized Damper Control

Position (% open) of outdoor air damper

Close return-air damper

No action

Open return-air damper



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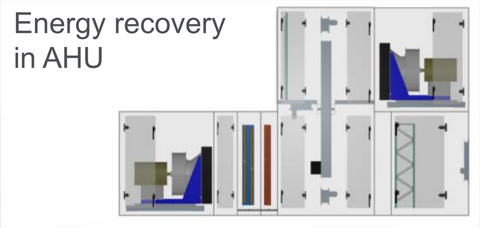
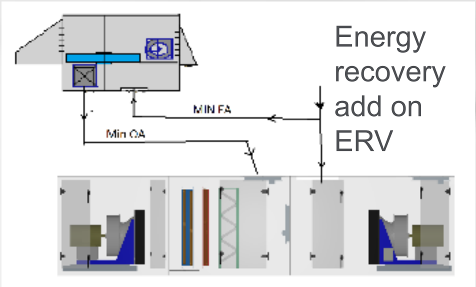
System Layout Energy Recovery



Energy recovery in AHU

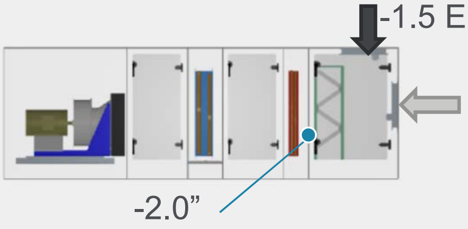


Energy recovery add on ERV

Benefits of incorporating in AHU vs. ERV

- Oversized economizing EA outlet
- Oversized economizing OA inlet
- Oversized filters

System Layout Energy Recovery



-1.5 ESP

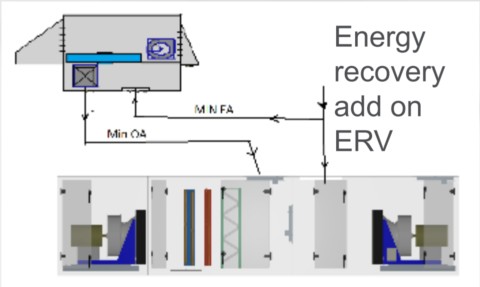
-0.75 ESP economizing
-0.15 ESP Min ventilation

-2.0”

Adding exhaust energy recovery to this system will not increase supply fan power requirement

System Layout Energy Recovery

Energy recovery in AHU

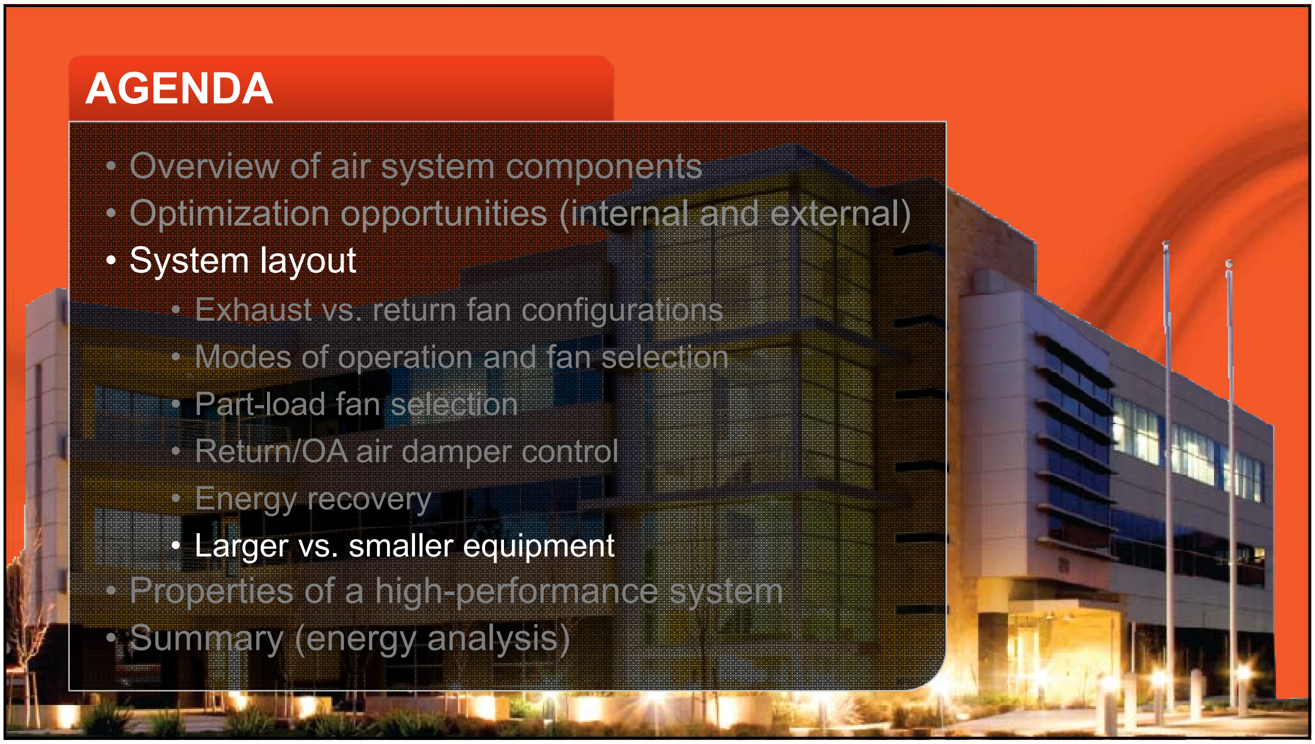


Energy recovery add on ERV

	Energy Recovery in AHU	Add on ERV
Design Supply Fan Air Flow (CFM)	10,000	10,000
Supply Fan TSP (in wg)	4.3	4.3
Supply Fan Static Efficiency	66%	66%
Supply Fan Power (BHP)	10.3	10.3
Design Exhaust Air Flow (CFM)	4,500	0
Exhaust/Return Fan TSP (in wg)	2.8	N/A
Exhaust/Return Fan Static Efficiency	63%	N/A
Exhaust/Return Fan Power (BHP)	3.2	N/A
ERV Ventilation Fan (BHP)	N/A	2.8
ERV Exhaust Fan (BHP)	N/A	4.5
System Total Fan Power(BHP)	13.5	17.6

System Layout Energy Recovery

- Use economizing inlet and outlets during recovery when possible
- Avoid using a stand alone ERV if high return duct static is present



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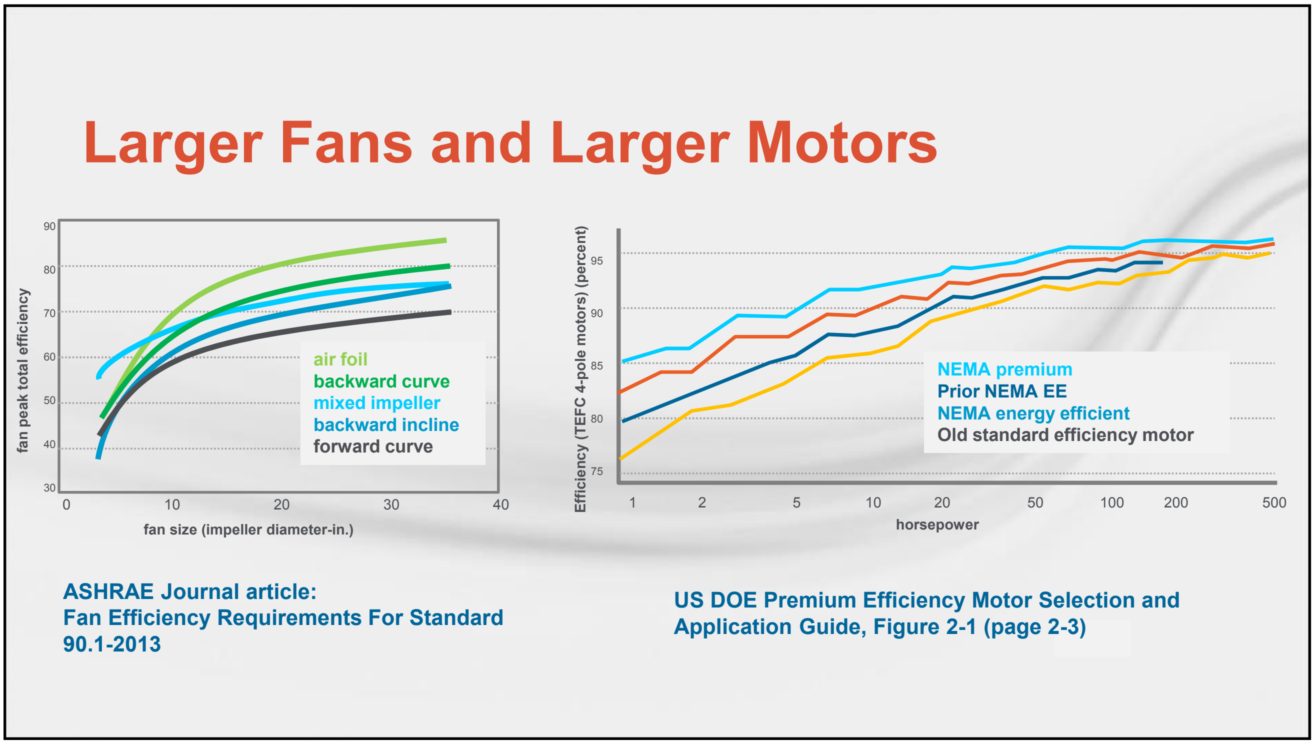
Larger vs. Smaller Equipment



Larger Fans and Larger Motors

ASHRAE Journal article:
Fan Efficiency Requirements For Standard 90.1-2013

US DOE Premium Efficiency Motor Selection and Application Guide, Figure 2-1 (page 2-3)

Larger Fans and Larger Motors

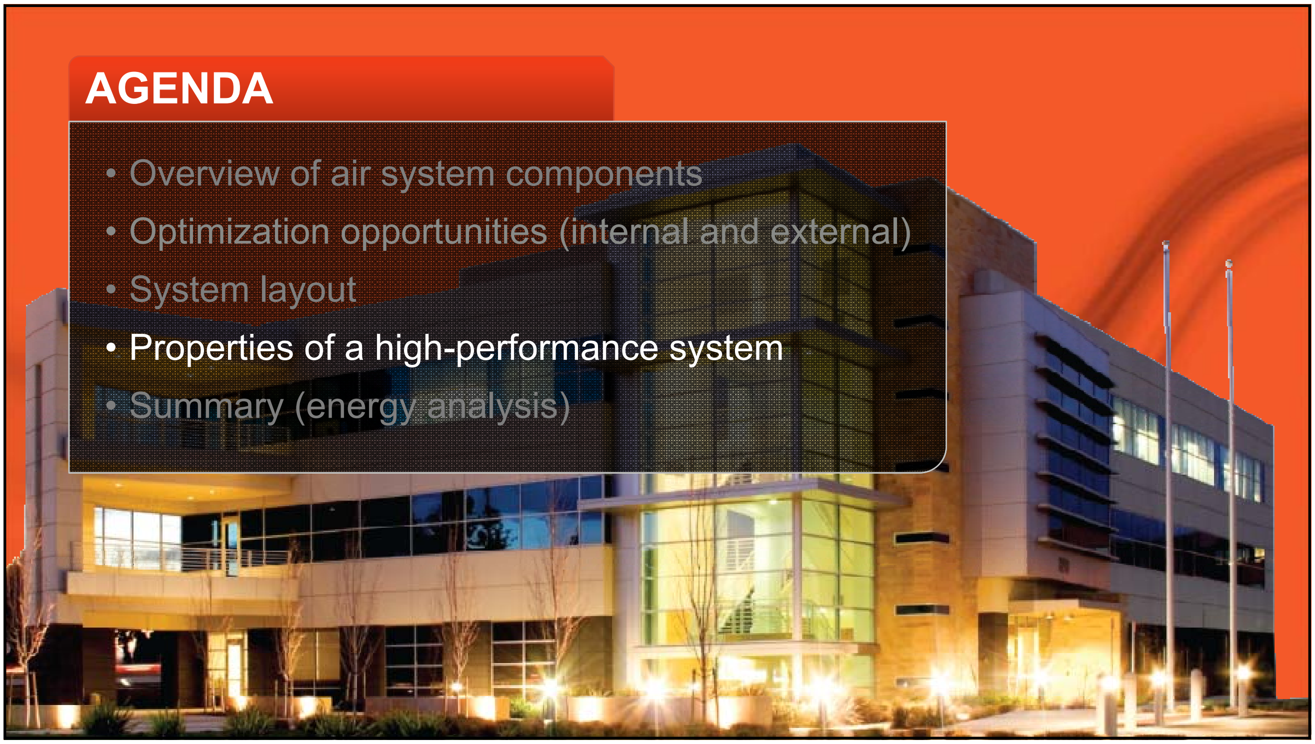
Fan Qty	Fan Size	CFM (each)	BHP (each)	BHP (total)	Motor HP	Efficiency (Fan)	Efficiency (Motor)	Efficiency (Total)
1	33"	15000	13.22	13.22	15	71.34%	90.2%	64.3%
2	24.5"	7500	6.55	13.1	7.5	72.05%	88.5%	63.8%
3	20"	5000	4.68	14.04	7.5	67.23%	88.5%	59.5%
4	18.25"	3750	3.53	14.12	5	66.79%	87.5%	58.4%

Notes:

Duty point: 15,000 CFM @ 4.0 inches H_2O

Flexible motor speed selections

Diameters chosen to maximize efficiency at a reasonable (90% of peak pressure, +/- 5%) selection point



AGENDA

- Overview of air system components
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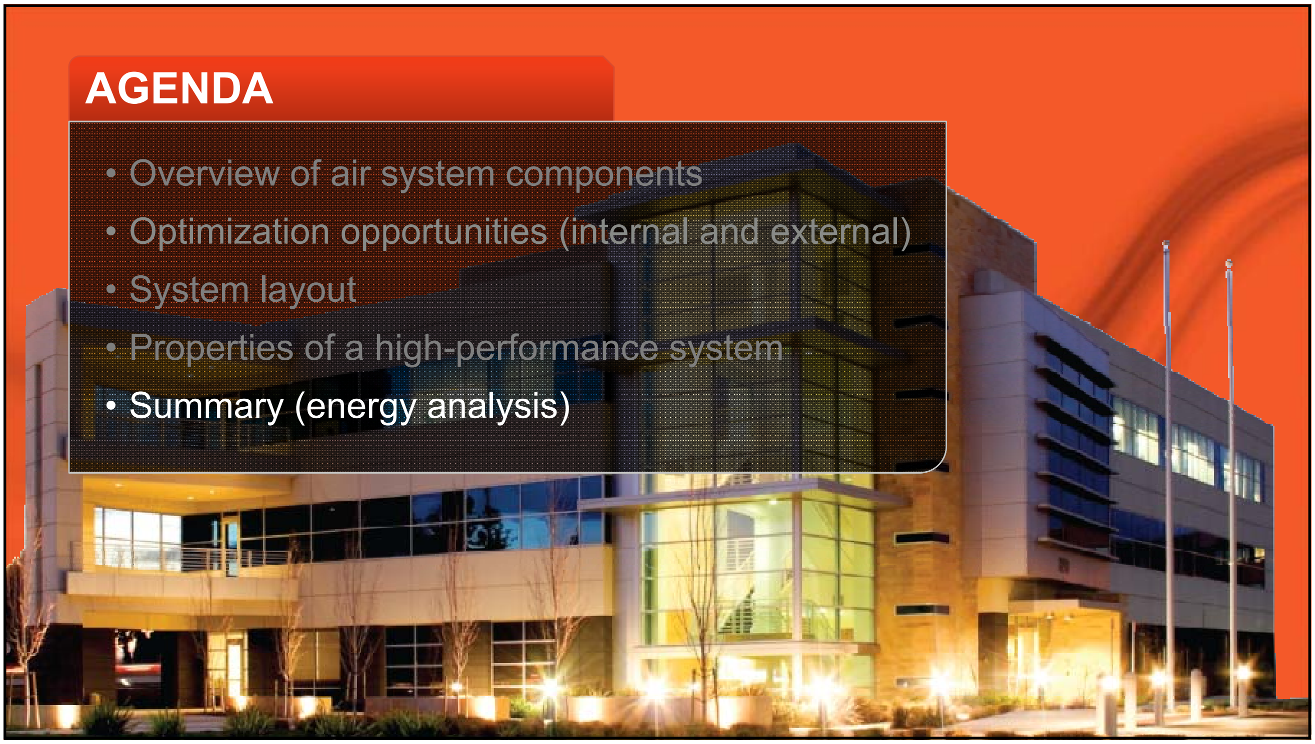
High Performance Air Systems

Properties of a high performance air system:

- Optimization opportunities (internal & external)
- Leakage, duct design, & noise attenuation
- System layout
- Economics of oversizing & control strategies



AGENDA

- Overview of air system components
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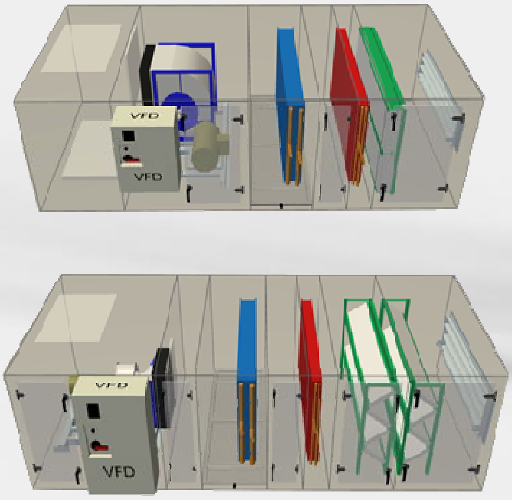
High Performance Air System



	DP in wc	DP in wc	
Damper	0.66	0.15	
MERV 8+11 Filters	1.14	0.54	
HC	0.07	0.06	
CC	1.02	0.79	
Fan	0.367	0.06	
Disch	0.02	-	
ISP Total	3.277	1.6	51%
ESP	1.9	1.9	
TSP	5.2	3.5	33%
BHP	12.12	8.47	30%

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Bibliography

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Industry Resources

Air-Conditioning, Heating, and Refrigeration Institute. 2011. *AHRI Standard 1210-2011: Performance Rating of Variable Frequency Drives*. Arlington, VA: AHRI.

Air-Conditioning, Heating, and Refrigeration Institute. 2014. *AHRI Standard 430-2014: Performance Rating of Central Station Air-handling Unit Supply Fans*. Arlington, VA: AHRI.

Air-Conditioning, Heating, and Refrigeration Institute. 2008. *AHRI Standard 440-2008: Performance Rating of Room Fan Coils*. Arlington, VA: AHRI.

Air-Conditioning, Heating, and Refrigeration Institute. 2012. *AHRI Standard 260-2012: Sound Rating of Ducted Air Moving and Conditioning Equipment*. Arlington, VA: AHRI.

Air Movement and Control Association International, Inc. 2015. *Fan System Efficiency and Fan System Input Power Calculation*. Publication 207 DRAFT as of 2/17/2015. Arlington Heights, IL: AMCA.

Air Movement and Control Association International, Inc. 2012. *Energy Efficiency Classification for Fans*. Publication 205-2012. Arlington Heights, IL: AMCA.

ANSI/ASHRAE 2016 Handbook: HVAC Systems and Equipment. Available from www.ashrae.org/bookstore

ANSI/ASHRAE/IES Standard 62.1-2013*: Ventilation for Acceptable Indoor Air Quality*. Atlanta, GA: ASHRAE.

ANSI/ASHRAE/IES Standard 90.1-2013: *Energy Standard for Buildings Except Low-Rise Residential Buildings*. Atlanta, GA: ASHRAE.

ANSI/ASHRAE Standard 90.1-2013 *User's Manual*. Atlanta, GA: ASHRAE.

ANSI/ASHRAE 2015. Research Project 1420, "Inlet and Discharge Installation Effects on Airfoil Centrifugal Plenum/Plug Fans for Air and Sound Performance." Atlanta, GA: ASHRAE.

ANSI/ASHRAE Standard 111-2008 Practices for Measurement, Testing, Adjusting, and Balancing of Building HVAC and Refrigeration Systems. Atlanta, GA: ASHRAE.

ASHRAE 1991. *Practical Guide to Noise and Vibration Control for HVAC Systems*. Atlanta, GA: ASHRAE

ASHRAE Duct Fitting Database. Available through the ASHRAE bookstore. ASHRAE.org/bookstore.

Arnold, B. Dean and D. Matela, A. Veeck. "Life-cycle Costing of Air Filtration." ASHRAE Journal pp. 30-32. November 2005.

Cermak, J. and M. Ivanovich: "Fan Efficiency Requirements For Standard 90.1-2013." ASHRAE Journal. April 2013

Moffitt, R. "Adding More Fan Power Can Be a Good Thing." ASHRAE Journal, pp. 44-54. May 2014.

U.S. Department of Energy. Premium Efficiency Motor Selection and Application Guide, Figure 2-1 (page 2-3). DOE/GO-102014-4107, February 2014

Trane Resources (visit http://www.trane.com/bookstore)

Meredith, D. and J. Harshaw. "A Closer Look at Fan Efficiency Metrics." *Engineers Newsletter* 43-3 (2014).

Meredith, D. and J. Murphy. "Direct-Drive Plenum Fans and Fan Arrays." *Engineers Newsletter* 39-1 (2010).

Guckelberger, D., Meredith, D., Murphy, J., Stanke, D., and J. Harshaw, "Fans in Air-Handling Systems," *Engineers Newsletter Live* program (2010) APP-CMC038-EN (DVD). (Available on-demand at www.trane.com/continuingeducation)

Murphy, J., B. Hafendorfer, T. Michael and J. Harshaw. "Coil Selection and Optimization," *Engineers Newsletter Live* program (2015) APP-CMC054-EN (DVD). (Available on-demand in Trane Continuing Education)

Trane, “Direct-Drive Plenum Fans for Trane Climate Changer™ Air Handlers” engineering bulletin, CLCH-PRB021-EN. La Crosse, Wisconsin: Trane, 2009.

Trane, “Motorized Impellers – Advanced DDP Fans” white paper, CLCH-PRB054A-EN. La Crosse, Wisconsin: Trane, 2015.

Trane, “So What Are Motorized Impellers” white paper, CLCH-PRB051A-EN. La Crosse, Wisconsin: Trane, 2015.

Trane, “Precision Motor Update” white paper, CLCH-PRB049A-EN. La Crosse, Wisconsin: Trane, 2015.

Trane, “Precision Motor™ Option” white paper, CLCH-PRB043A-EN. La Crosse, Wisconsin: Trane, 2014.

Trane, “Direct-Drive Fan Selection” white paper, CLCH-PRB029A-EN. La Crosse, Wisconsin: Trane, 2013.

Trane *Engineers Newsletter LIVE:* High-Performance Air Systems
APP-CMC063-EN QUIZ

1. The external static pressure is the sum of the intake and discharge duct pressures?
   a. True
   b. False

2. By angling filters, more filters can be placed in the airstream, thus angle filters will lower pressure drop and extend the change out interval required.
   a. True
   b. False

3. Which of the following statements regarding dampers are true?
   a. There is a benefit to making two-position dampers as big as possible.
   b. Caution is needed to not make the modulating dampers too big or you might sacrifice controllability.
   c. Outside air dampers may need to be split for systems with a high return static pressure loss.
   d. Return air dampers may need to be downsized for systems with a high outside air path pressure loss.

4. Which of the following are common ways to select fans to handle two modes of operation in this example: A rooftop exhaust fan economizer system with a central supply fan and a central relief fan. Where 10,000 CFM is required to condition the space and the ventilation requirements are about 4000 CFM. During design, 3500 CFM is exhausted from the building to maintain proper building pressurization but during full economizing, 9500 CFM is exhausted:
   a. Size the central relief fan to handle both modes.
   b. Size the central relief fan for one mode and size a remote relief fan for the other mode.
   c. Use multiple fans for one mode and a different fan quantity for the other model
   d. Size both fans the same to handle both modes

5. Based on the program example the following guidance is true or false?
   In general use economizing inlet and outlets during recovery whenever possible and avoid using a standalone ERV if high return duct static is present.
   a. True
   b. False

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High-Performance Air Systems

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