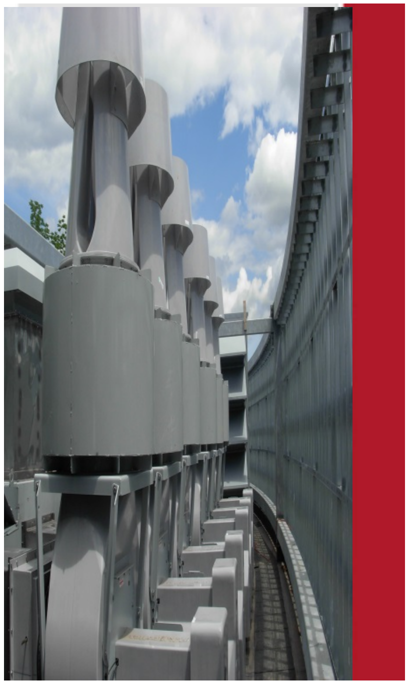
Controlling Variable Volume Critical Exhaust Systems to Optimize Performance and Minimize Energy Costs

The intent of this presentation is to help us

1. Understand the importance of turndown range and associated time distribution when designing VAV critical space exhaust systems.

2. Identify techniques to optimize fan equipment selection based on system operating (turndown) range and fundamental design considerations.

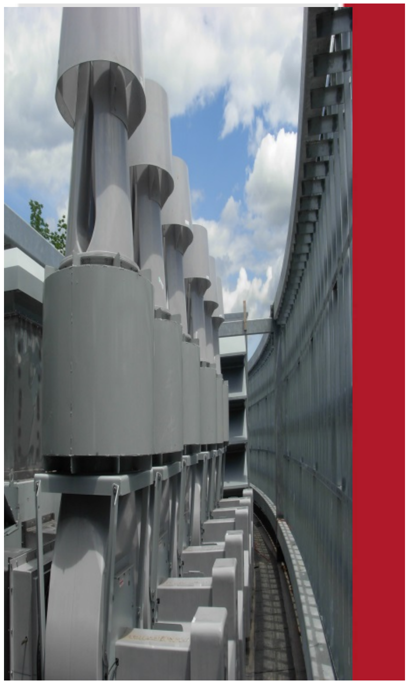
3. Identify control sequence design approaches to properly manage and report the critical parameters, respond to external inputs (i.e., air quality, meteorological conditions, etc.), and operate continuously, safely, and with minimal energy consumption.



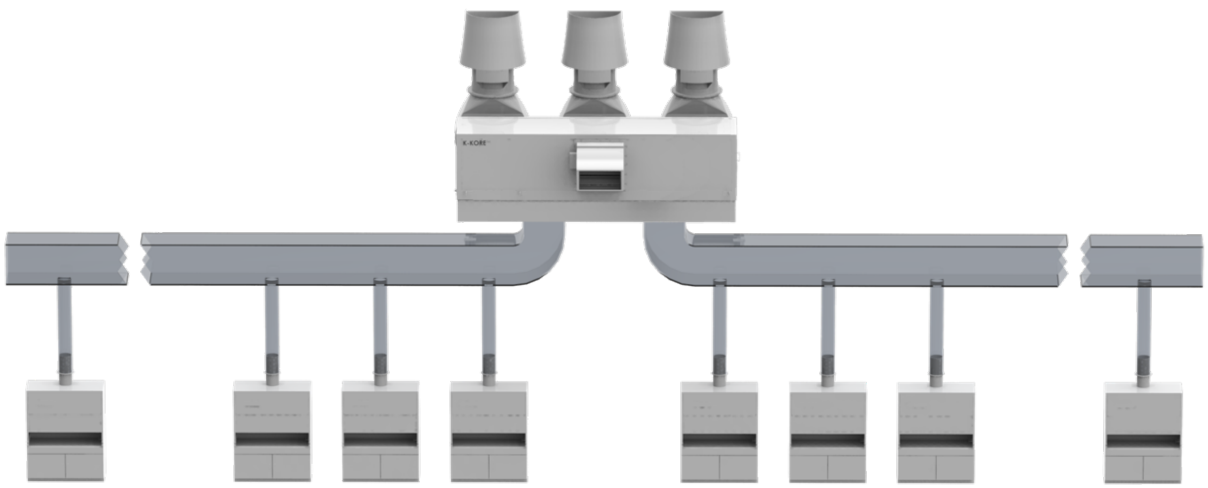
By definition

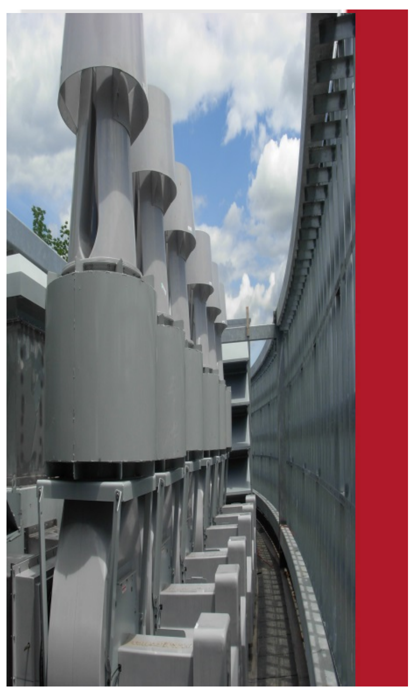
A variable air volume (VAV) exhaust system is used to save energy in a laboratory, accommodating a range of flow rates to control system function, air quality, and temperature in the building, and maintain design specific performance requirements as the air leaves the building.

Turndown is the expression defining the range of exhaust flow, minimum to maximum conditions.



VAV exhaust system





Keep in mind

Good system design:

Define the exhaust flow turndown range (not just the maximum flow).

Keep in mind

Better system design:

Associate a time distribution to the exhaust flow turndown range.

Assumptions for our fan selections

1. 3000 FPM minimum discharge velocity. (This is recommended in ANSI Z 9.5. Required discharge velocities, dilution rates, and plume heights vary with the application and affect the fan selections.)

2. Fans will be controlled with VFDs. (Incremental fan sequencing and bypass control dampers could also be used.)

Scenario #1, VAV Exhaust, Constant SP

1. Constant duct pressure maintenance. (Other control technologies are available.)

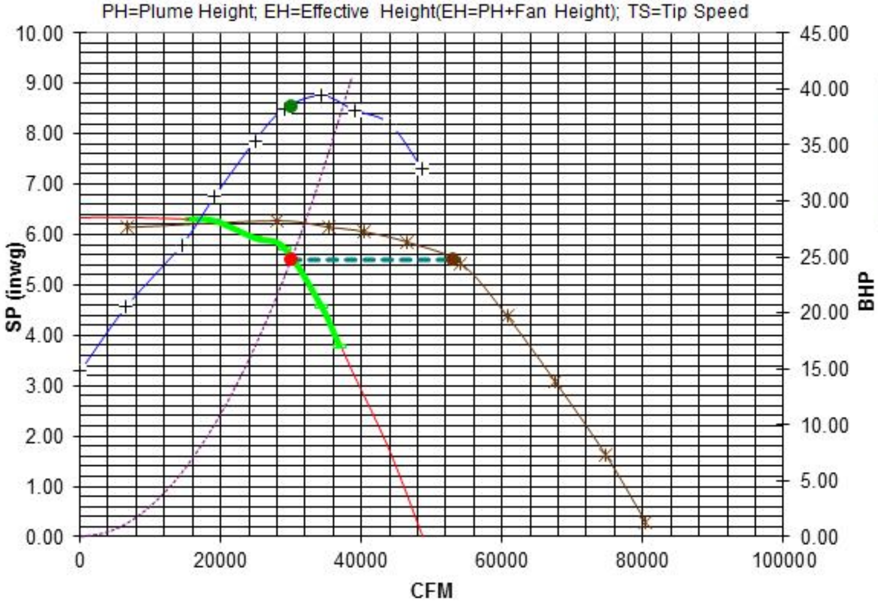
2. 3 fans. 2 running + 1 standby.

3. Maximum flow is 60,000 CFM, 5.5" SP.

Scenario #1, VAV Exhaust, Constant SP

Date		Model	AXIJET		10 [mph]
		Fan Size	4900	EH =	59.6 [feet]
Sys. No.		Dia.[in]	49.00	PH =	41.4 [feet]
		CFM	30000	NV =	4615 [fpm]
		SP	5.5	WV =	2187 [fpm]
Drawing	A	BHP	38.47	TF =	52893 [cfm]
Revision		RPM	879	TS =	11276 [fpm]
		Recommended Motor HP :	50.00	T =	70 [°F]
Air performance		(For Belt Drive only)	Calculate	ALT =	0 [feet]

TF=Total Flow; NV=Nozzle Velocity; WV=Windband Velocity
PH=Plume Height; EH=Effective Height(EH=PH+Fan Height); TS=Tip Speed



CLASS II WHEEL

Density : 0.075 lb/ft^3

CFM-SP
System Curve
CFM-BHP
Total Flow-SP
10% Peak Eff.

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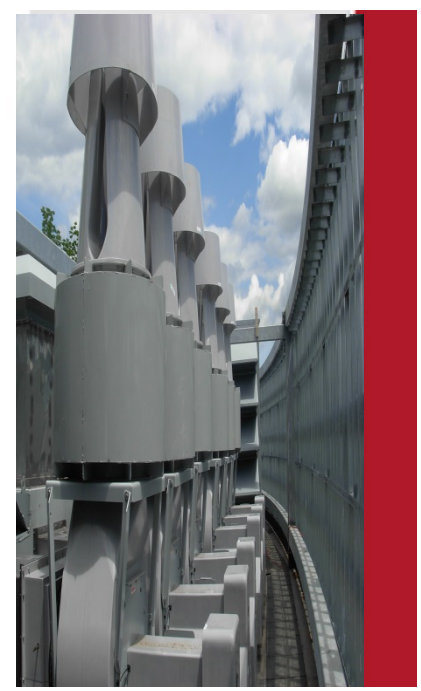
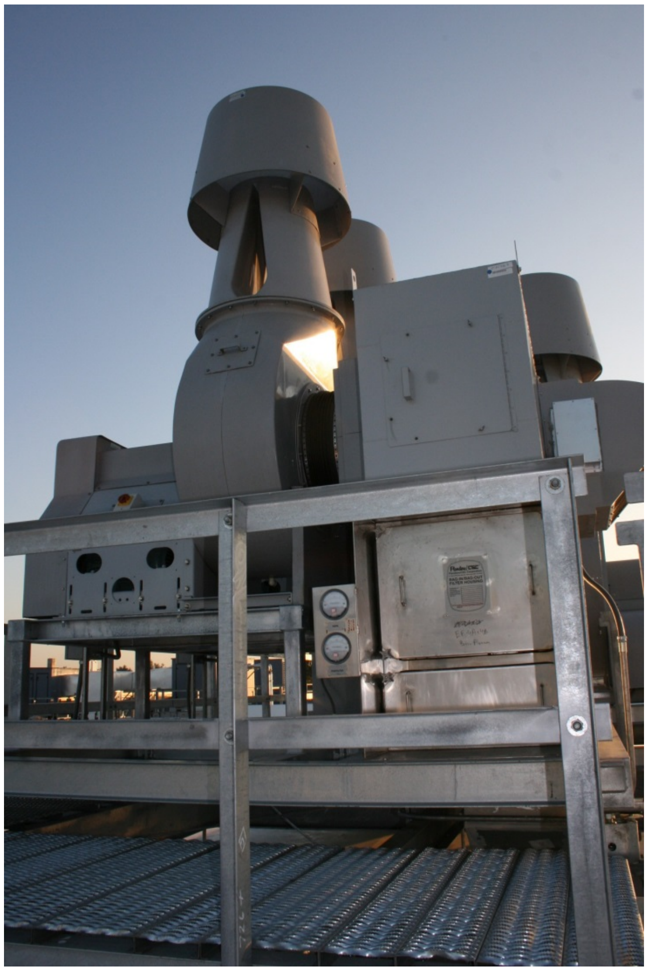
Performance certified is for installation type C: Ducted inlet, Free outlet. Power rating (BHP) does not include transmission losses. Performance ratings do not include the effects of appurtenances (accessories). Performance ratings do not include the effects of crosswinds.

Three 50 HP size ***49"*** fans are the most efficient selection. 150 connected HP.



Scenario #1, VAV Exhaust, Constant SP



- Now, let's add that the system will turn down to a minimum flow of 36,000 CFM. 5.5" SP maintained.

Scenario #1, VAV Exhaust, Constant SP

Date	.
Sys. No.	.
Drawing	. A
Revision	.

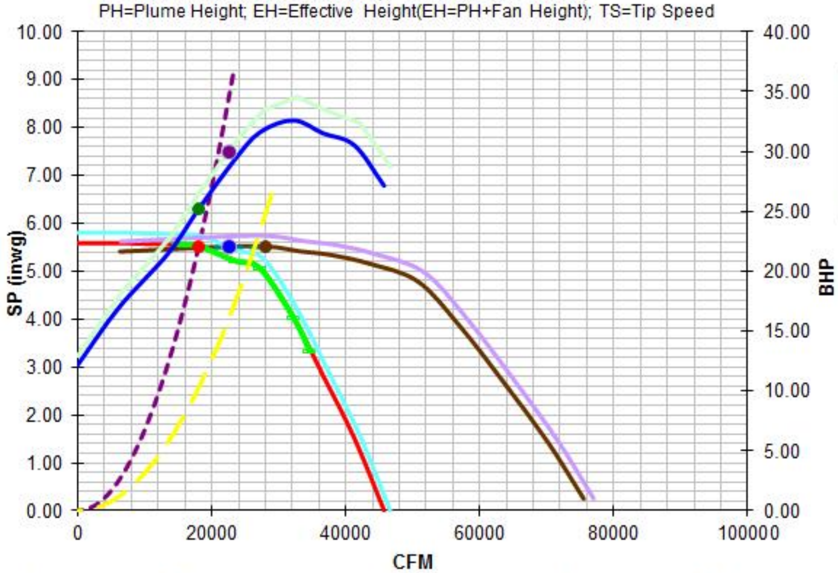
Model	AXIJET		10	[mph]
Fan Size	4900	EH =	40.1	[feet]
Dia.[in]	49.00	PH =	21.9	[feet]
CFM	18000	NV =	2769	[fpm]
SP	5.5	WV =	1158	[fpm]
BHP	25.18	TF =	28012	[cfm]
RPM	825	TS =	10583	[fpm]
Recommended Motor HP :	50.00	T =	70	[°F]
(For Belt Drive only)	Calculate	ALT =	0	[feet]

Air performance

TF=Total Flow; NV=Nozzle Velocity; WV=Windband Velocity
PH=Plume Height; EH=Effective Height(EH=PH+Fan Height); TS=Tip Speed

CLASS II WHEEL

Density : 0.075 lb/ft³



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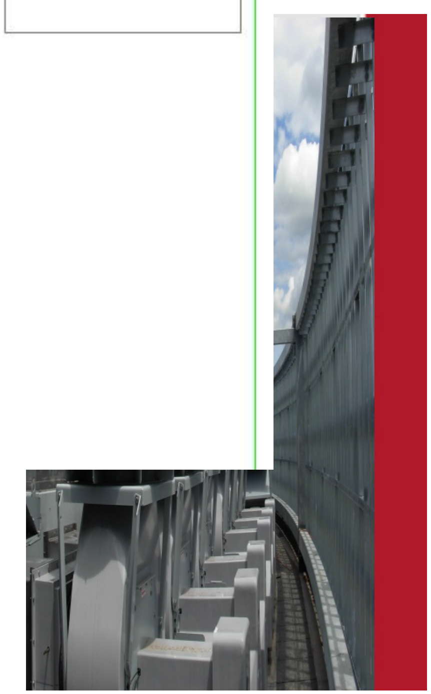
Model	AXIJET		10	[mph]
Fan Size	4900	EH =	49.5	[feet]
Dia.[in]	49.00	PH =	31.3	[feet]
CFM	22500	NV =	3462	[fpm]
SP	5.5	WV =	1655	[fpm]
BHP	29.97	TF =	40031	[cfm]
RPM	841	TS =	10788	[fpm]
	Calculate	T =	70	[°F]
		ALT =	0	[feet]

Density : 0.075 lb/ft³

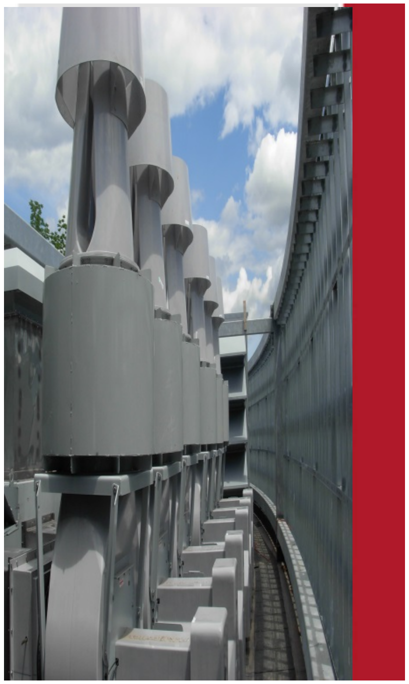
CFM-SP
System Curve
CFM-BHP
Total Flow-SP

Notice that the size ***49"*** is unstable at lower flows, constant SP.



Scenario #1, VAV Exhaust, Constant SP

- Now, let's add that the system will operate at 45,000 CFM 65% of the time (day mode), 36,000 CFM 30% of the time (night mode), and 60,000 CFM 5% of the time, probably only during test and balance.



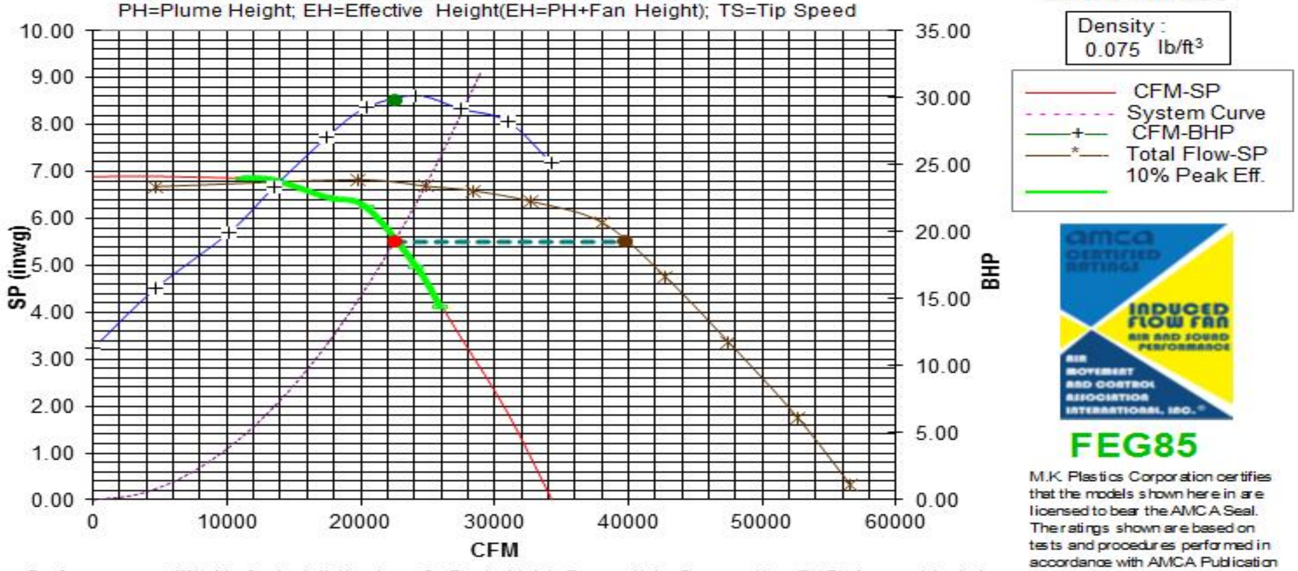
Scenario #1, VAV Exhaust, Constant SP

Date	.	Model	AXIJET		10	[mph]
		Fan Size	4025	EH =	52.8	[feet]
Sys. No.	.	Dia.[in]	40.25	PH =	37.9	[feet]
	.	CFM	22500	NV =	5125	[fpm]
	.	SP	5.5	WV =	2438	[fpm]
Drawing	. A	BHP	29.78	TF =	39806	[cfm]
Revision	.	RPM	1116	TS =	11760	[fpm]
		Recommended Motor HP :	50.00	T =	70	[°F]
Air performance		(For Belt Drive only)	Calculate	ALT =	0	[feet]

TF=Total Flow; NV=Nozzle Velocity; WV=Windband Velocity
PH=Plume Height; EH=Effective Height(EH=PH+Fan Height); TS=Tip Speed

CLASS II WHEEL

Density : 0.075 lb/ft³



Performance certified is for installation type C: Ducted inlet, Free outlet. Power rating (BHP) does not include transmission losses. Performance ratings do not include the effects of appurtenances (accessories). Performance ratings do not include the effects of crosswinds.

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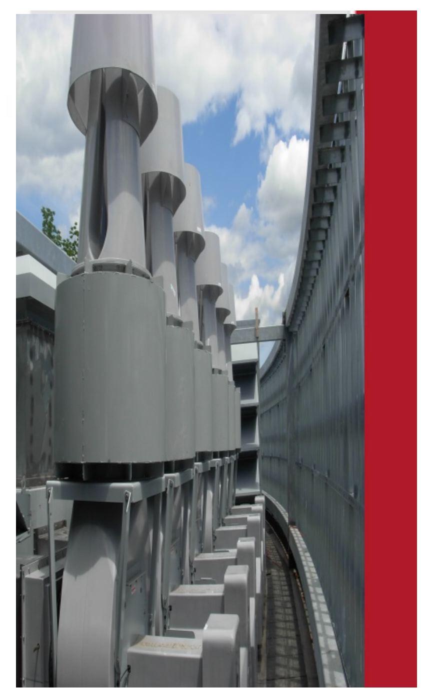


Three 50 HP size ***40"*** fans are the most efficient selection.

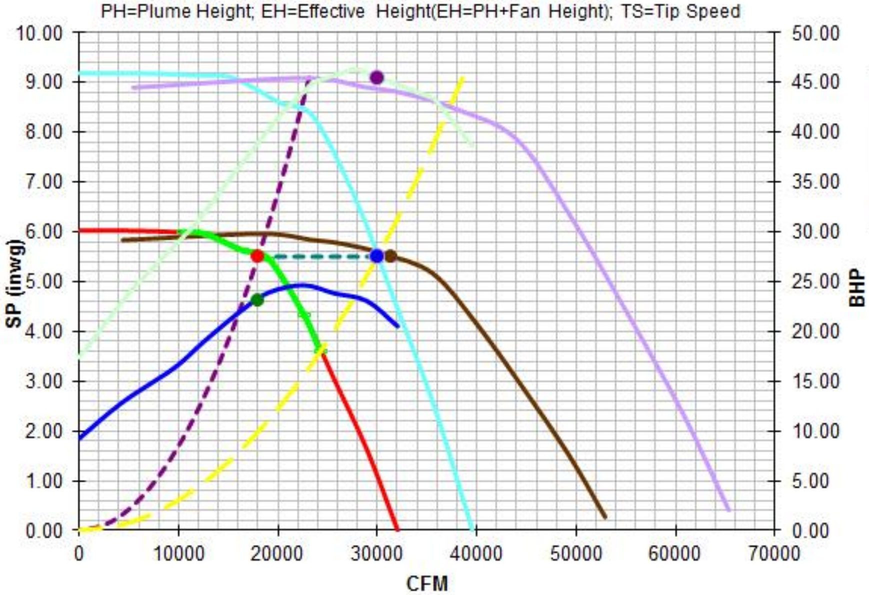
Two operating at 22500 CFM each, 65% of time. 150 connected HP

Scenario #1, VAV Exhaust, Constant SP

Date	.	Model	AXIJET		10	[mph]
Sys. No.	.	Fan Size	4025	EH =	44.8	[feet]
	.	Dia.[in]	40.25	PH =	29.8	[feet]
	.	CFM	18000	NV =	4100	[fpm]
		SP	5.5	WV =	1918	[fpm]
Drawing	. A	BHP	23.19	TF =	31306	[cfm]
Revision	.	RPM	1043	TS =	10991	[fpm]
		Recommended Motor HP :	50.00	T =	70	[°F]
Air performance		(For Belt Drive only)	Calculate	ALT =	0	[feet]

CLASS II WHEEL

TF=Total Flow; NV=Nozzle Velocity; WV=Windband Velocity
PH=Plume Height; EH=Effective Height(EH=PH+Fan Height); TS=Tip Speed



Density : 0.075 lb/ft³

CFM-SP
System Curve
CFM-BHP
Total Flow-SP
10% Peak Eff.

FEG85

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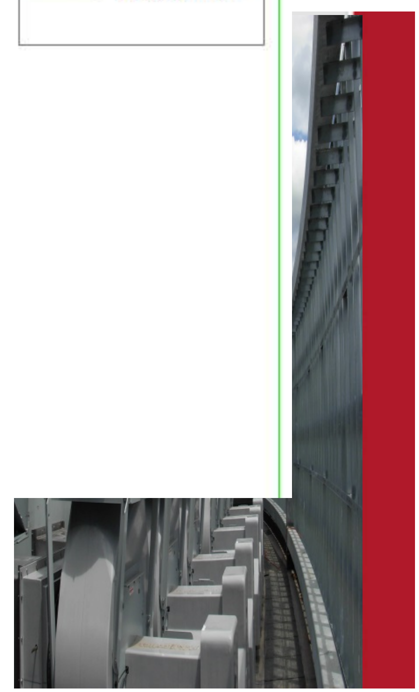
Performance certified is for installation type C: Ducted inlet, Free outlet. Power rating (BHP) does not include transmission losses. Performance ratings do not include the effects of appurtenances (accessories). Performance ratings do not include the effects of crosswinds.

Model	AXIJET		10	[mph]
Fan Size	4025	EH =	64.3	[feet]
Dia.[in]	40.25	PH =	49.3	[feet]
CFM	30000	NV =	6834	[fpm]
SP	5.5	WV =	3173	[fpm]
BHP	45.53	TF =	51807	[cfm]
RPM	1288	TS =	13572	[fpm]
	Calculate	T =	70	[°F]
		ALT =	0	[feet]

Density : 0.075 lb/ft³

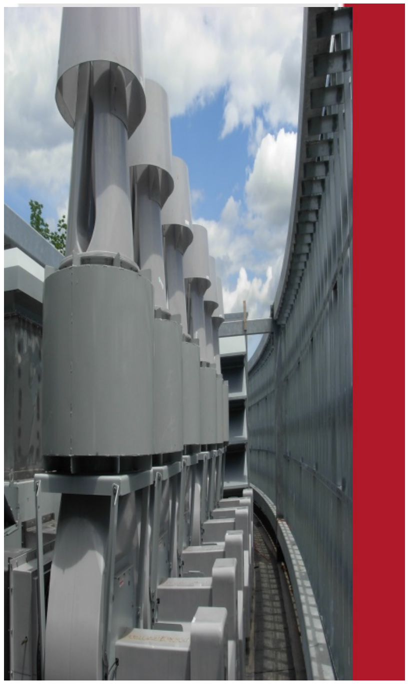
CFM-SP
System Curve
CFM-BHP
Total Flow-SP



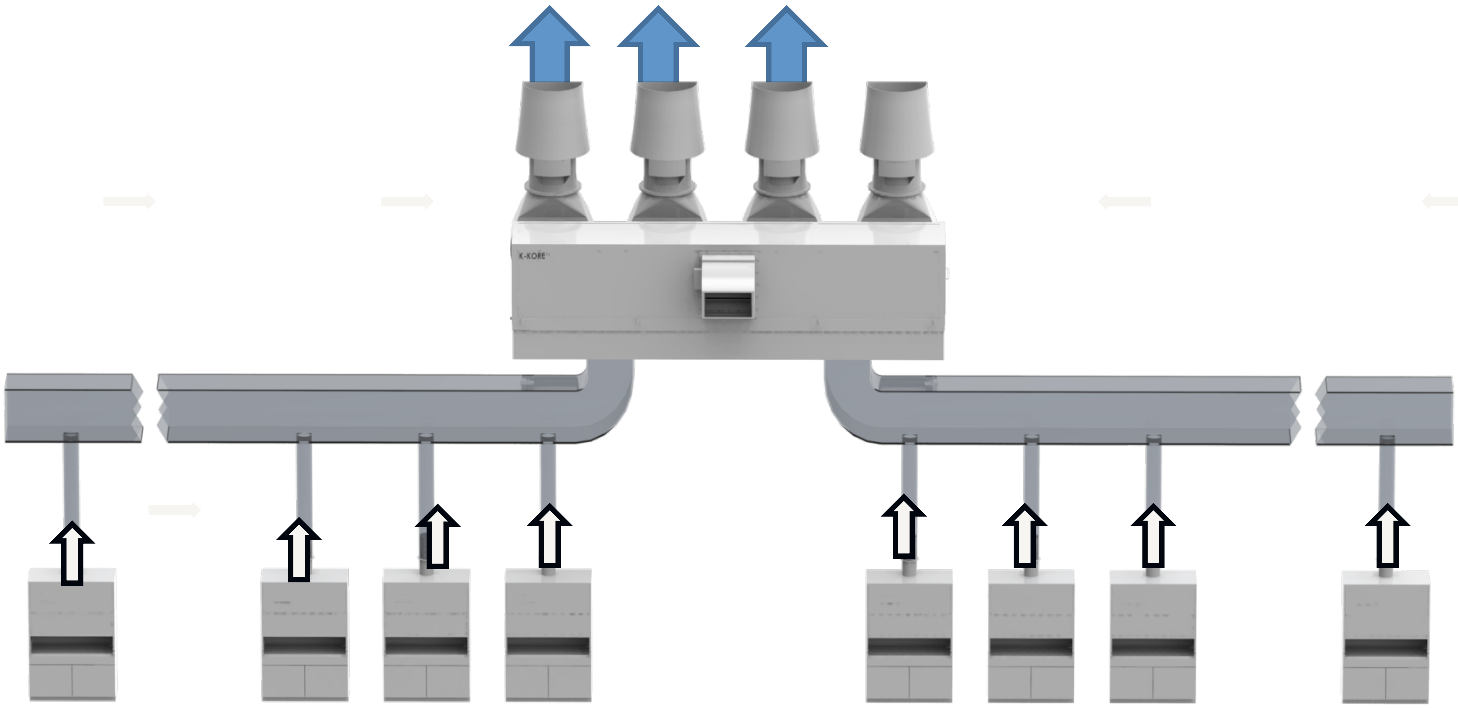
A size ***40"*** fan is efficient at the 65% operating condition but less efficient at the max condition (5%). It operates stable throughout the range, and is lower first cost.

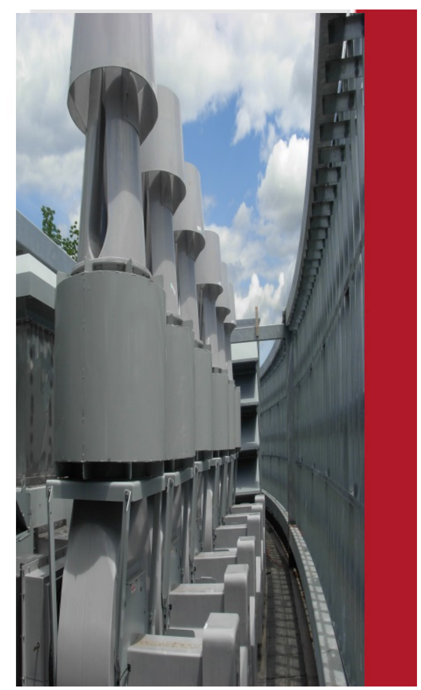
Scenario #1, VAV Exhaust, Constant SP

Fan Size	CFM/Fan	Fan BHP	System BHP	Motor HP	NV
	Full Capacity 5% of operational demand 60,000 CFM 5.5" S.P				
4900	30,000	38.47	76.94	50	4615
4025	30,000	45.53	91.06	50	6834
	60Hz Stable				
	Day Mode 65% of operational demand 45,000 CFM 5.5" S.P.				
	CFM/Fan	Fan BHP	System BHP	Motor HP	NV
4900	22,500	29.97	**Unstable**	50	3462
4025	22,500	29.78	59.56	50	5125
	53Hz Stable				
	Night Mode 30% of operational demand 36,000 CFM 5.5" S.P.				
	CFM/Fan	Fan BHP	System BHP	Motor HP	NV
4900	18,000	25.18	**Unstable**	50	2769
4025	18,000	23.19	46.38	50	4100
	49Hz Stable				



Scenario #1, VAV Exhaust, Constant SP





Day operation

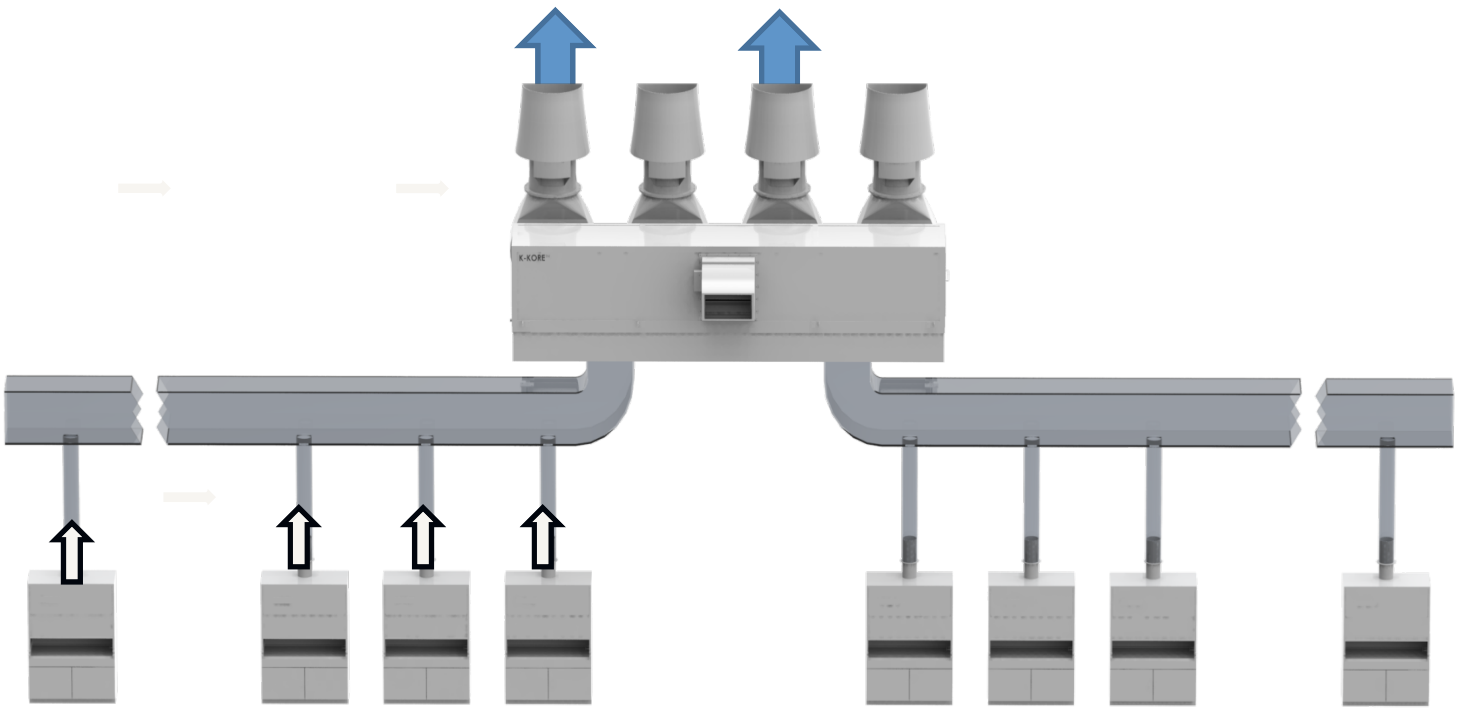
- 60,000 CFM 5% of the time
- 45,000 CFM 65% of the time
- 3 size ***40"*** fan is efficient at the 65% operating condition but less efficient at the max condition (5%). It operates stable throughout the range, and is lower first cost.

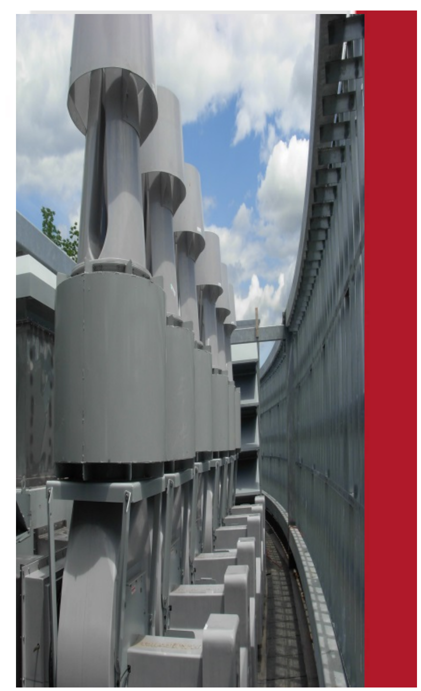
Scenario #1, VAV Exhaust, Constant SP

Change from ***three*** 50 HP ***40"*** fans to ***four*** 30 HP ***36"*** fans. Run three fans day mode; two fans night mode. Reduce connected HP from 150 to 120. Reduce operating power.

Fan Size	CFM/Fan	Fan BHP	System BHP	Motor HP	NV
	Full Capacity 5% of operational demand 60,000 CFM 5.5" S.P.				
	CFM/Fan	Fan BHP	System BHP	Motor HP	NV
4900	30,000	38.47	76.94	50	4615
4025	30,000	45.53	91.06	50	6834
3650	20,000	27.14	81.42	30	5540
	3 Fans Running 60Hz Stable				
	Day Mode 65% of operational demand 45,000 CFM 5.5" S.P.				
	CFM/Fan	Fan BHP	System BHP	Motor HP	NV
4900	22,500	29.97	**Unstable**	50	3462
4025	22,500	29.78	59.56	50	5125
3650	15,000	19.2	57.6	30	4155
	3 Fans Running 53Hz Stable				
	Night Mode 30% of operational demand 36,000 CFM 5.5" S.P				
	CFM/Fan	Fan BHP	System BHP	Motor HP	NV
4900	18,000	25.18	**Unstable**	50	2769
4025	18,000	23.19	46.38	50	4100
3650	18,000	23.56	47.12	30	4986
	2 Fans running 57Hz Stable				

Scenario #1, VAV Exhaust, Constant SP



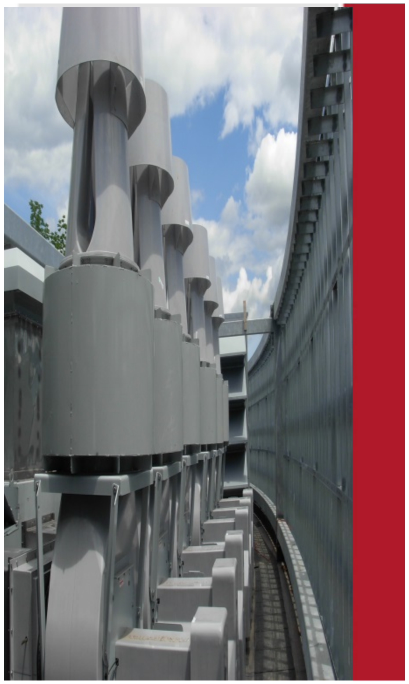


Night operation

- 36,000 CFM 30% of the time
- Running ***four*** 30 HP ***36"*** fans. Run three fans day mode; two fans night mode. Reduce connected HP from 150 to 120. Reduce operating power.

Learning objective #1

So, you can see that understanding and defining the VAV exhaust system turndown range is important to fan selection and scheduling.

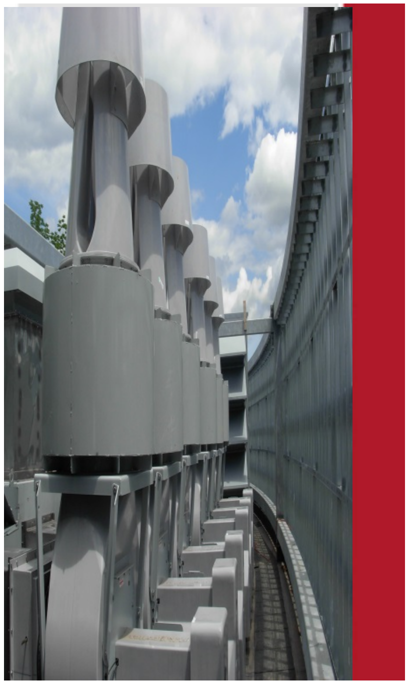


Scenario #2, VAV Exhaust, Variable SP

1. Same three volume conditions as in Scenario #1.

2. Duct SP decreases as flow is reduced. (In this scenario we will maintain a minimum of 2" duct SP at the furthest hydraulic location from the fans.)

3. 3 fans. 2 running + 1 standby.



Scenario #2, VAV Exhaust, Variable SP

Now, at the 65% operating condition, we see a size ***44"*** fan is the most efficient selection while supporting full turn-down, in the variable duct SP scenario.

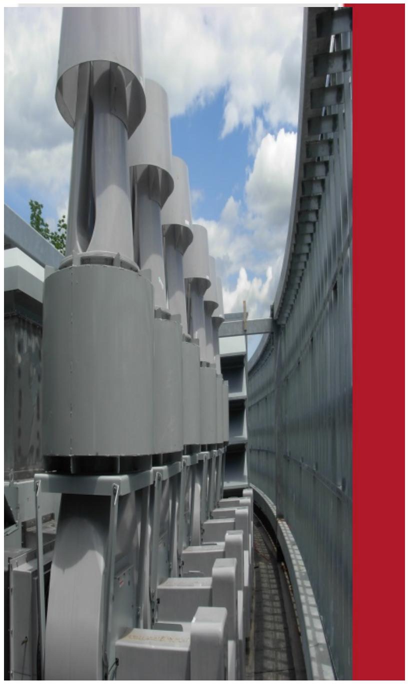
Fan Size	CFM/Fan	Fan BHP	System BHP	Motor HP	NV
	Full Capacity 5% of operational demand 60,000 CFM 5.5" S.P				
	CFM/Fan	Fan BHP	System BHP	Motor HP	NV
4450	30,000	40.67	81.34	50	5597
	2 Fans Running 60Hz Stable				
	Day Mode 65% of operational demand 45,000 CFM 5.5" S.P				
	CFM/Fan	Fan BHP	System BHP	Motor HP	NV
4450	22,500	20.91	41.82	50	4198
	2 Fans running 48Hz Stable				
	Night Mode 30% of operational demand 36,000 CFM 5.5" S.P				
	CFM/Fan	Fan BHP	System BHP	Motor HP	NV
4450	18,000	12.96	25.92	50	3358
	2 Fans running 41 Hz Stable				

Scenario #2, VAV Exhaust, Variable SP

or, as in Scenario #1…

Change from ***three*** 50 HP ***44"*** fans to ***four*** 30 HP ***36"*** fans. Run three fans day mode; two fans night mode. Reduce connected HP from 150 to 120. And ……

Fan Size	CFM/Fan	Fan BHP	System BHP	Motor HP	NV
	Full Capacity 5% of operational demand 60,000 CFM 5.5" S.P				
	CFM/Fan	Fan BHP	System BHP	Motor HP	NV
4450	30,000	40.67	81.34	50	5597
3650	20,000	27.14	81.42	30	5540
	3 Fans size 3650 Running 60Hz Stable				
	Day Mode 65% of operational demand 45,000 CFM 5.5" S.P				
	CFM/Fan	Fan BHP	System BHP	Motor HP	NV
4450	22,500	20.91	41.82	50	4198
3650	15,000	13.77	41.31	30	4155
	3 Fans size 3650 running 48Hz Stable				
	Night Mode 30% of operational demand 36,000 CFM 5.5" S.P				
	CFM/Fan	Fan BHP	System BHP	Motor HP	NV
4450	18,000	12.96	25.92	50	3358
3650	18,000	15.04	30.08	30	4986
	2 Fans size 3650 running 50 Hz Stable				

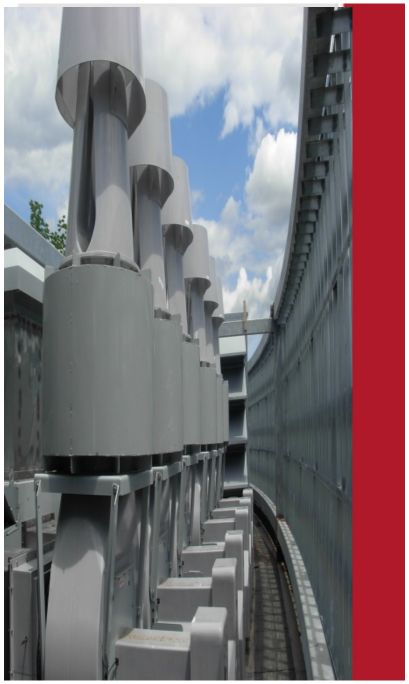


Scenario #2, VAV Exhaust, Variable SP

In a system with a variable SP control, operating power can be significantly reduced.

In daytime operation (4) Size 3650 fans selected on constant 5.5"S.P has a system BHP of 57.6

Fan Size	CFM/Fan	Fan BHP	System BHP	Motor HP	NV
	Full Capacity 5% of operational demand 60,000 CFM 5.5" S.P				
4450	30,000	40.67	81.34	50	5597
3650	20,000	27.14	81.42	30	5540
	Variable S.P Control S.P 5.5"				
3650	20,000	27.14	81.42	30	5540
	3 Fans size 3650 Running 60Hz Stable				
	Day Mode 65% of operational demand 45,000 CFM 5.5" S.P				
	CFM/Fan	Fan BHP	System BHP	Motor HP	NV
4450	22,500	20.91	41.82	50	4198
3650	15,000	13.77	41.31	30	4155
	Variable S.P Control S.P 3.9"				
3650	15,000	13.77	41.31	30	4155
	3 Fans size 3650 running 48Hz Stable				
	Night Mode 30% of operational demand 36,000 CFM 5.5" S.P				
	CFM/Fan	Fan BHP	System BHP	Motor HP	NV
4450	18,000	12.96	25.92	50	3358
3650	18,000	15.04	30.08	30	4986
	Variable S.P Control S.P 3.1"				
3650	18,000	15.04	30.08	30	4986
	2 Fans size 3650 running 50 Hz Stable				

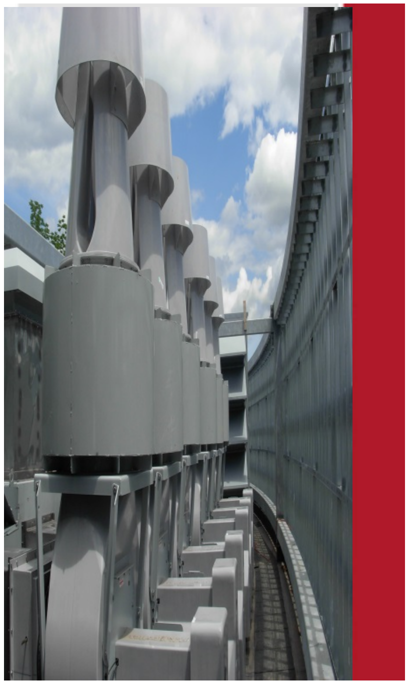


Learning objective #2

The above are examples of techniques you can use to:

1. Approach your design (constant vs. variable SP).

2. Select your exhaust fans optimizing system performance and efficiency.



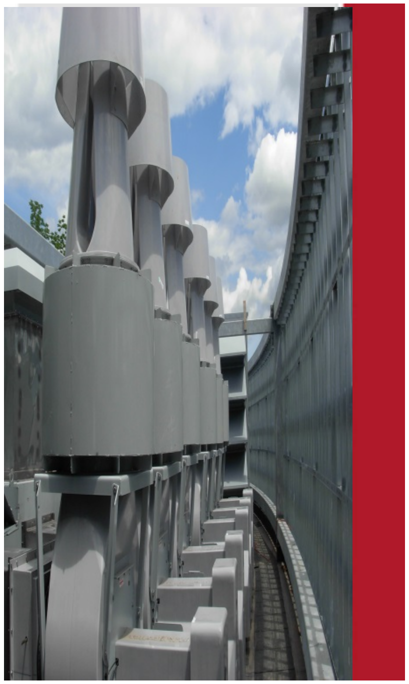
Now let's consider some basics regarding the exhaust system control

Control Approach: *Constant* Duct SP

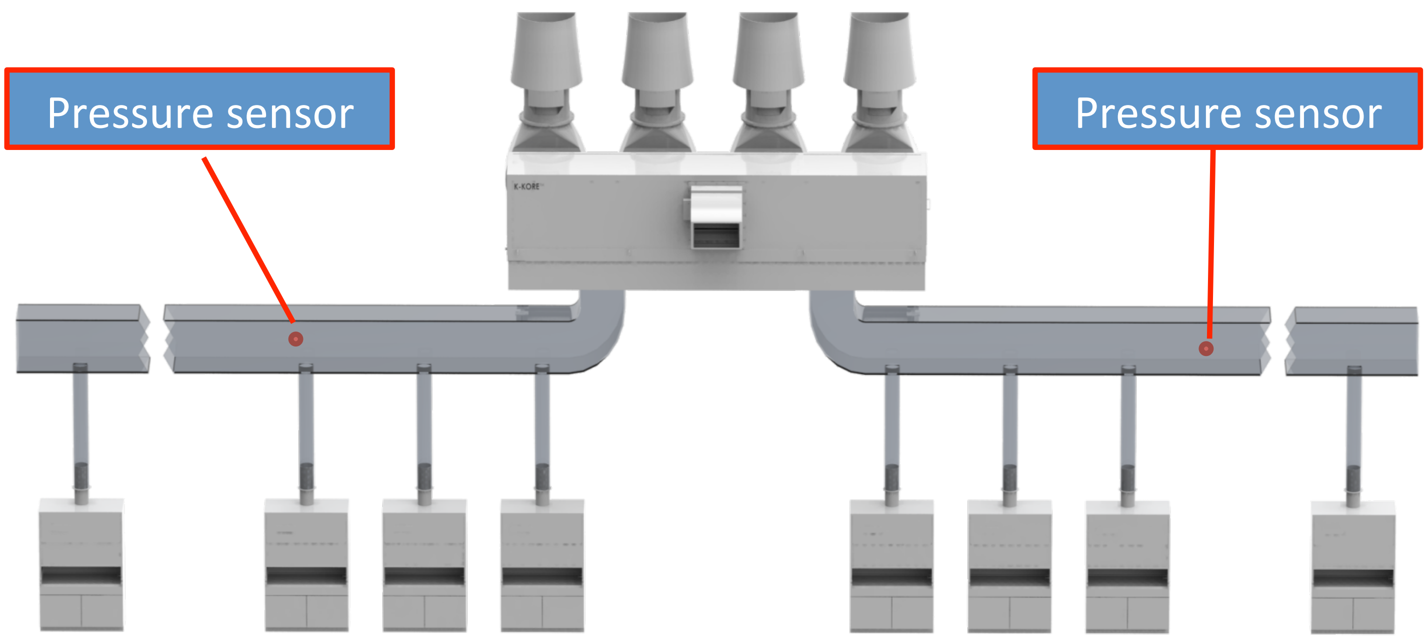
1. A common, basic design is for a system with constant duct SP.

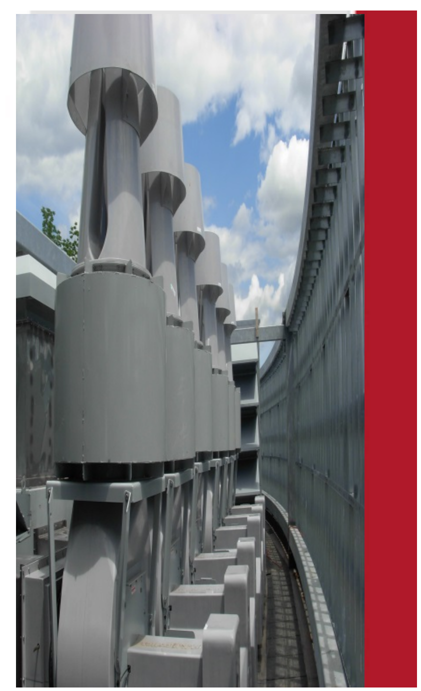
2. A minimum of one duct SP sensor is required.

3. Use VFD to adjust exhaust fan speed and/or modulate bypass damper to maintain SP set-point.



Control Approach: *Constant* Duct SP





Control Approach: *Variable* Duct SP

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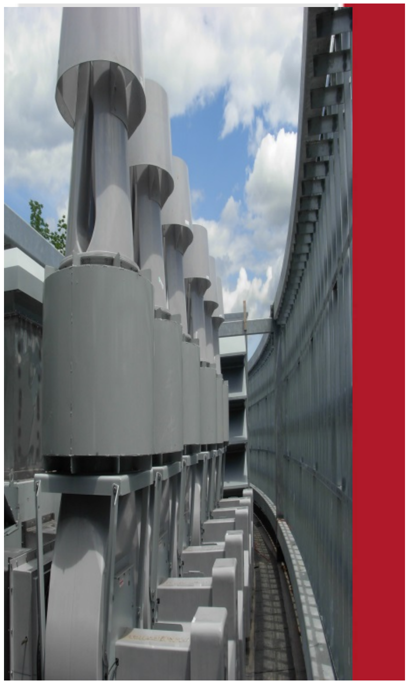
1. Predetermined different duct SP settings are common, such as day, night, weekend, vacation, etc.

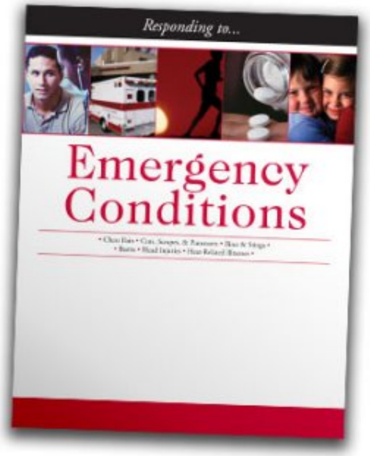
2. The system can also be set up to respond to secondary input.

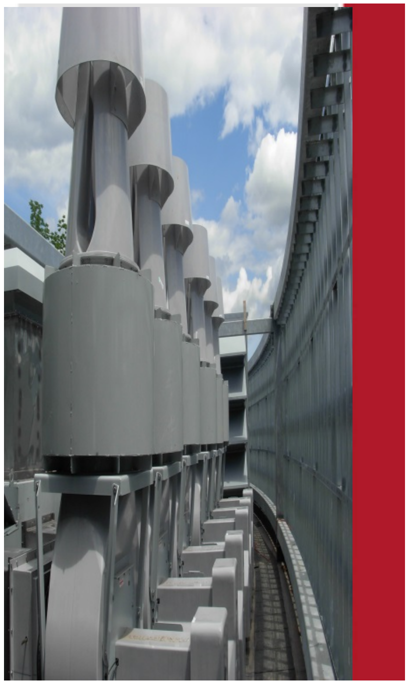


Control Approach: *Variable* Duct SP

Secondary input can include:

- Each Secondary input below, requires a clear command parameter, which will not interfere with any other control point.



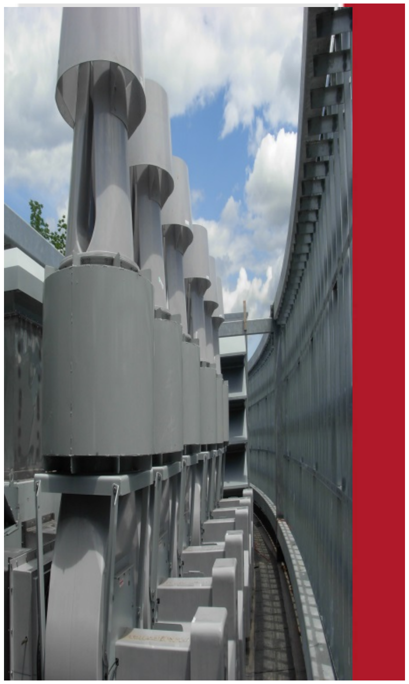


Control Approach: *Dynamic* Duct SP

1. Duct SP can be adjusted by external input (trending, BMS, flow sensors, etc.).

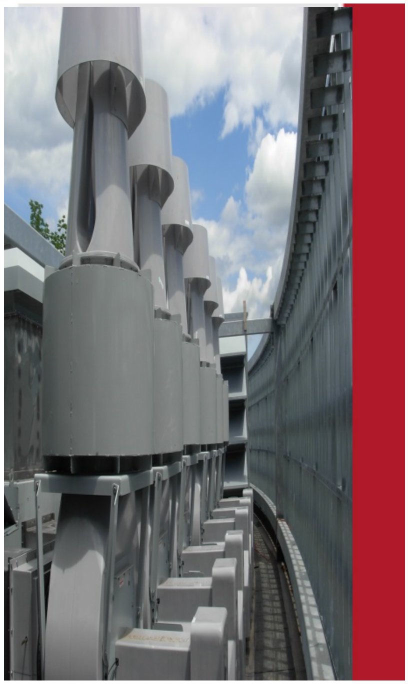
2. Do not change the dynamic SP control point too frequently, in order to avoid hunting.

3. Control point hierarchy is required when using multiple simultaneous input signals.



Learning objective #3

- There are many control sequence design approaches to properly manage and report the critical system parameters and respond to external inputs.



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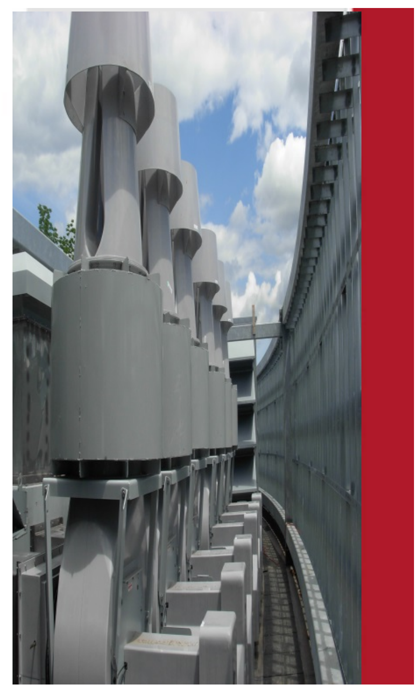

Thank you!