Exhaust Fan Control Systems for Laboratories

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- Joined AMCA in February 2019
- Responsible for development of AMCA's education programs; staff liaison for the Education & Training Subcommittee
- Projects include webinars, online education modules, presentations at trade shows, AMCA Speakers Network and other duties as assigned.

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Doug Ross

Business Development Manager, AMCA Member Company

- Automation & Control Engineer from Auckland Technical Institute in New Zealand; moved to Canada in 2000
- Working in the Air Movement industry since 2005
- Focus on laboratory exhaust system design, especially in critical environment applications

Exhaust Fan Control Systems for Laboratories

Purpose and Learning Objectives

The purpose of this presentation is to provide participants with an understanding of laboratory ventilation systems and the effect of negative pressure controls in that environment.

At the end of this presentation participants will be able to:

1. Identify the main control points of a laboratory ventilation system.
2. Compare N+1 and N-1 configurations.
3. Explain exhaust fan scenarios involving constant volume and variable volume systems.
4. Explain exhaust control scenarios involving constant status pressure and variable static pressure, as well as dynamic vs. demand based static pressure control.

Question:

I am designing a lab ventilation system which uses negative pressure control by modulating exhaust volume from the laboratory areas. The total airflow for the laboratory area is 60,000 CFM with 4.5” w.c. TSP. The exhaust is discharged through a high plume dilution exhaust fan to maintain a discharge velocity of 3000 fpm. Please note that the fan exhaust volume needs to be kept constant to maintain the discharge velocity of 3000 fpm. There is a by-pass damper at the fan inlet to maintain the discharge velocity when the room exhaust volume varies due to operational requirements and night-time setbacks.

What is the best way to control the system?

Response:

1. **Review of the major control points in the system and how they interact with the Building Automation System**
2. **Selection process of laboratory exhaust fan for this application**
    a. Understanding N+1 and N-1 configuration
3. **Various laboratory exhaust fan operation scenarios explained**
    a. Constant Volume exhaust system
    b. Variable Volume exhaust system
4. **Various laboratory exhaust fan control scenarios explained**
    a. Constant Static Pressure Control
    b. Variable Static Pressure Control
    c. Dynamic Static Pressure Control or Demand based Static Pressure Control

Designing Laboratory exhaust control is complex due to the number of variables

- Temperature
- Humidity
- Occupant comfort
- Air change rates (air changes per hour, ACH)
- Redundancy and emergency backup requirements
- Modes of operation: normal, emergency, setback
- Equipment and space criteria monitoring and alarms
- Room airflow direction and speed
- Pressure relationship between spaces
- Filtration: supply and exhaust
- Hood HVAC requirements
- Fire and life safety requirements
- Energy efficiency
- Energy/utility metering

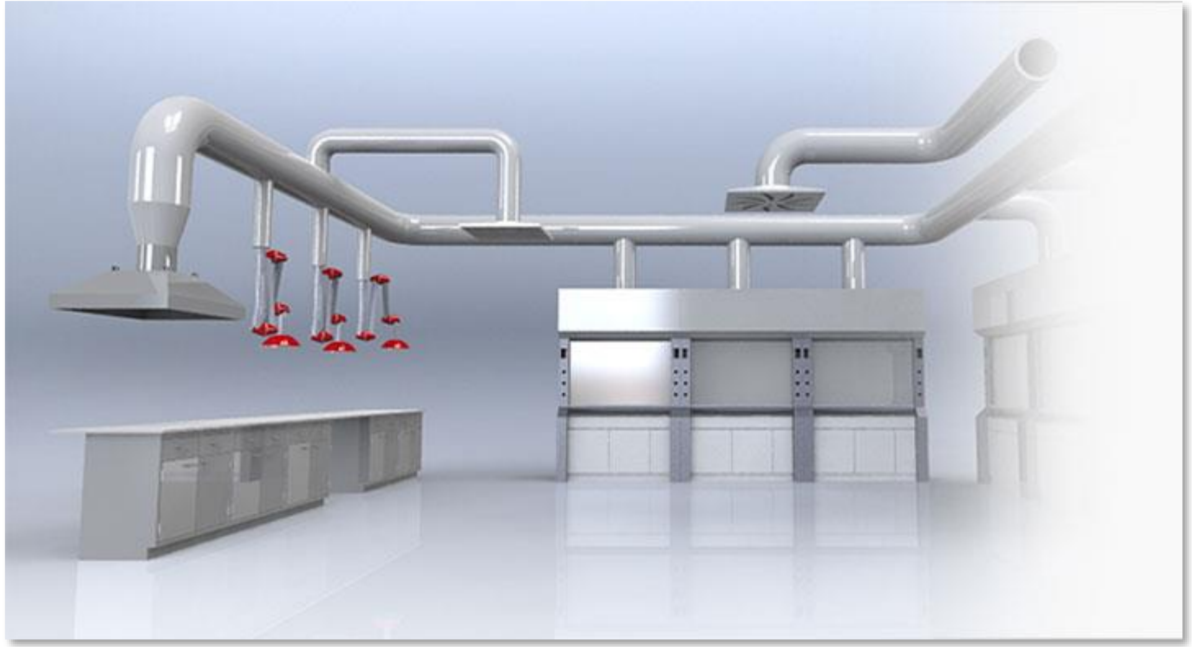
Control Strategies - Overview

- Direct Equipment Exhaust
- General Laboratory Exhaust
- Constant volume versus variable air volume fume hood control
- Variable air volume of laboratory occupied space
- Room pressurization control
  - Direct pressure control
  - Volumetric offset control
  - Cascade control
- Demand control (DCV) - air control devises
- Centralized demand control (CDCV) - source containment, room air changes and exhaust device controls
  - Unoccupied setback control of minimum ventilation rates
- Plume height – wind direction and strength variance
- Room temperature Control
- Emergency modes of operation

General Laboratory Exhaust

General Laboratory Exhaust serves two purposes:

- Removal of odors and contaminants
- Higher air flows to assist cooling



Constant volume versus variable air volume fume hood control

Constant-volume fume hoods, or bypass hoods, are typically vertical sash hoods with a bypass section located above the sash opening.

Constant-volume fume hoods without additional controls do not provide a constant face velocity because the bypass is typically smaller area than the potential sash opening.

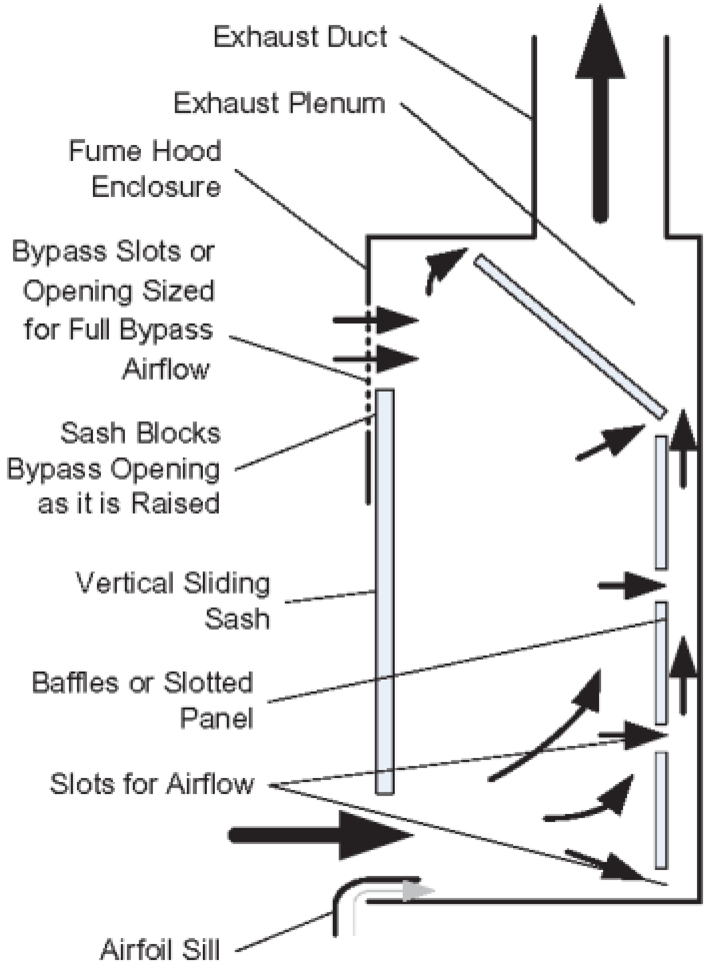


Diagram courtesy of ASHRAE Laboratory Design Guide

Constant volume versus variable air volume fume hood control

Control system for constant-volume fume hood connected to a VAV exhaust system.

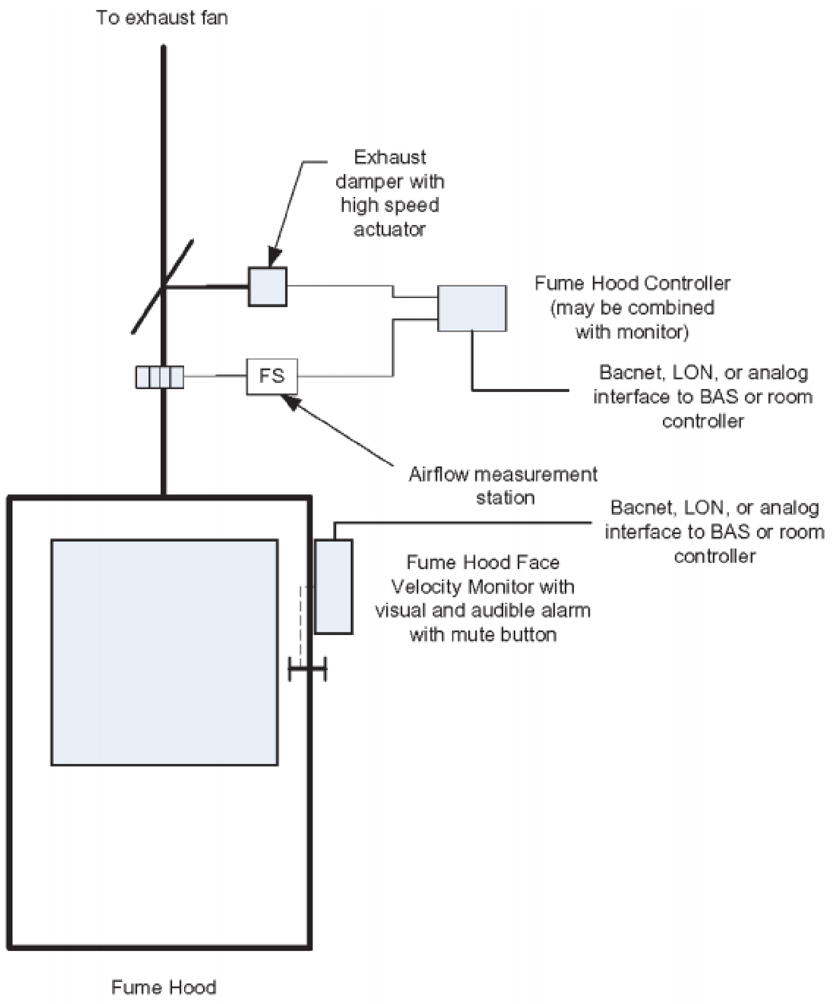
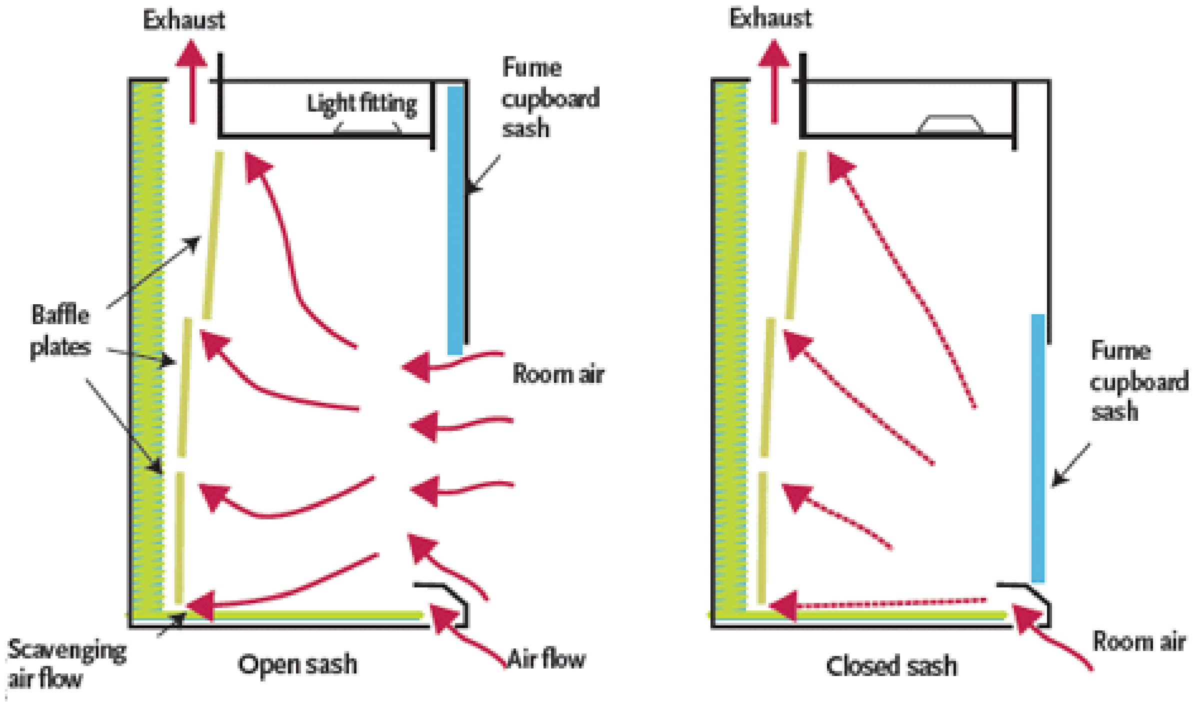


Diagram courtesy of ASHRAE Laboratory Design Guide

Constant volume versus Variable Air Volume fume hood control

Variable-volume fume hoods maintain a specific face velocity at the hood opening as the sash position changes.



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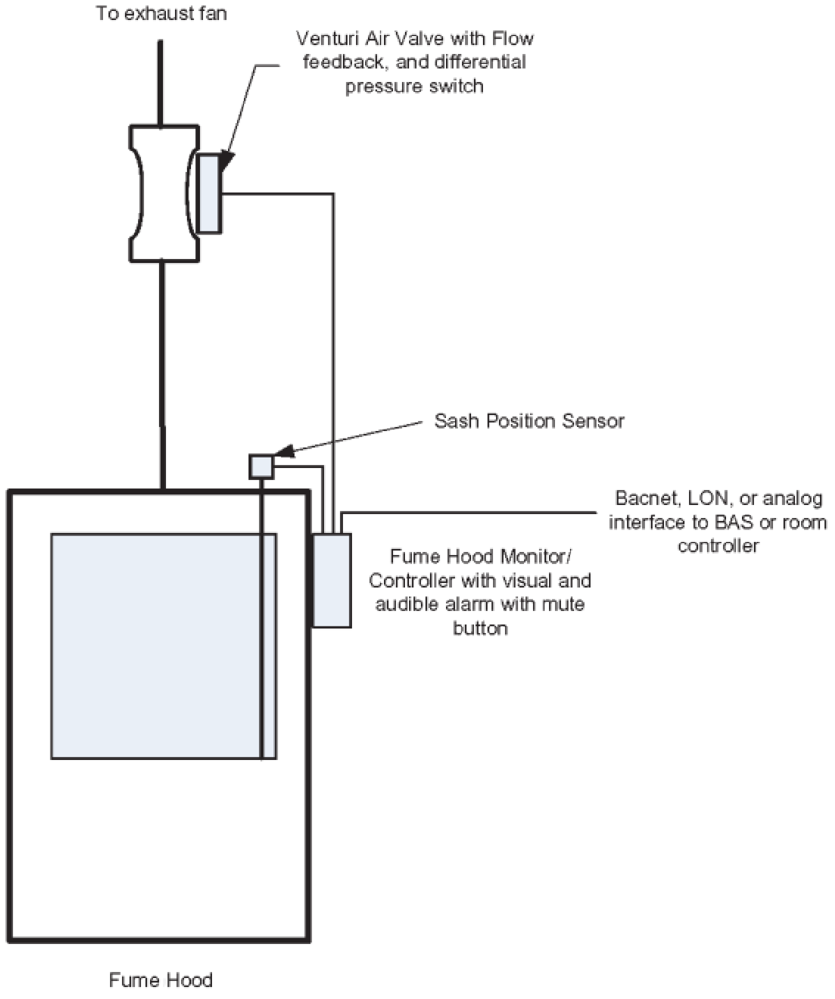


Diagram courtesy of ASHRAE Laboratory Design Guide

Variable Air Volume of laboratory occupied space

The standard system configuration using the Supply and Exhaust Control Concept is one that uses variable air volume (VAV) dampers for both supply and general room exhaust.

In this configuration:

- the room airflow rate difference (ΔQ) is controlled by the supply VAV damper (master), which maintains a constant under/overpressure inside the laboratory
- the air exchange rate is controlled by the general exhaust VAV damper (slave), which ensures a minimum room exchange air rate when the exhaust equipment airflow is insufficient to maintain the room air exchange rate

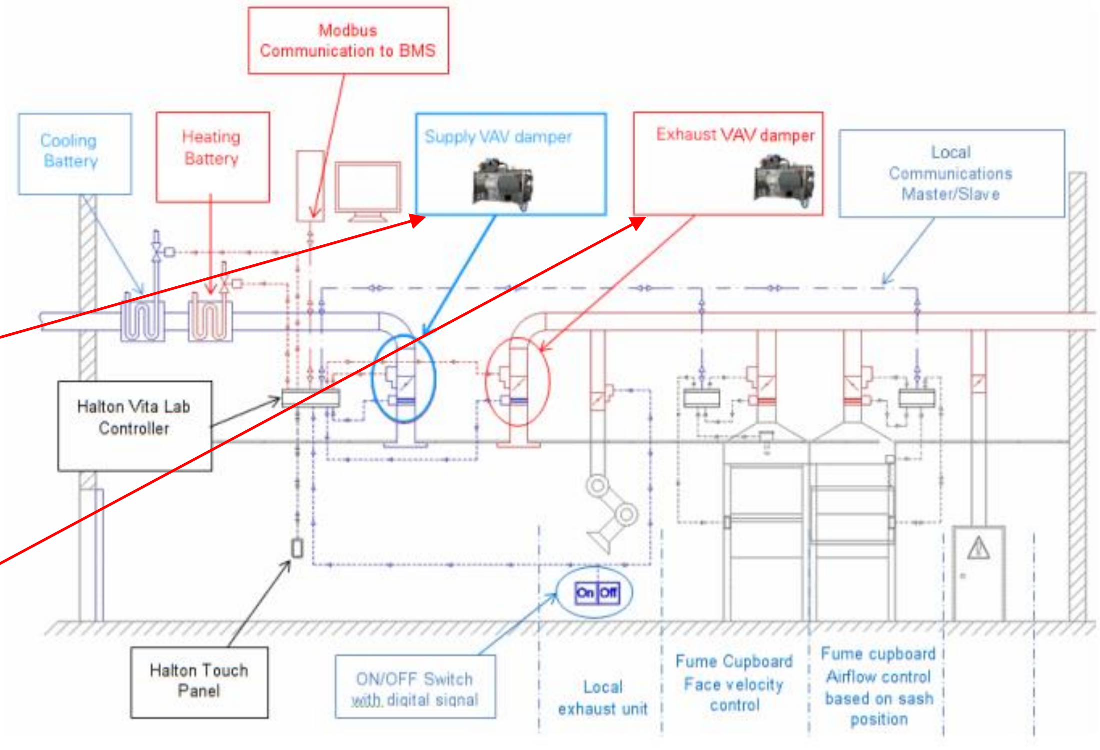


Figure: Room Airflow Control - Supply and Exhaust Control configuration

Image courtesy of Halton Vita Lab Room Design Guide v1.2 en

Room Pressurization Control

Room Pressurization is controlled in a laboratory to ensure the safety of the occupants, protect the environment, and protect the research that is being conducted.

Differential pressure should not exceed 0.30 in w.g (75 Pa).

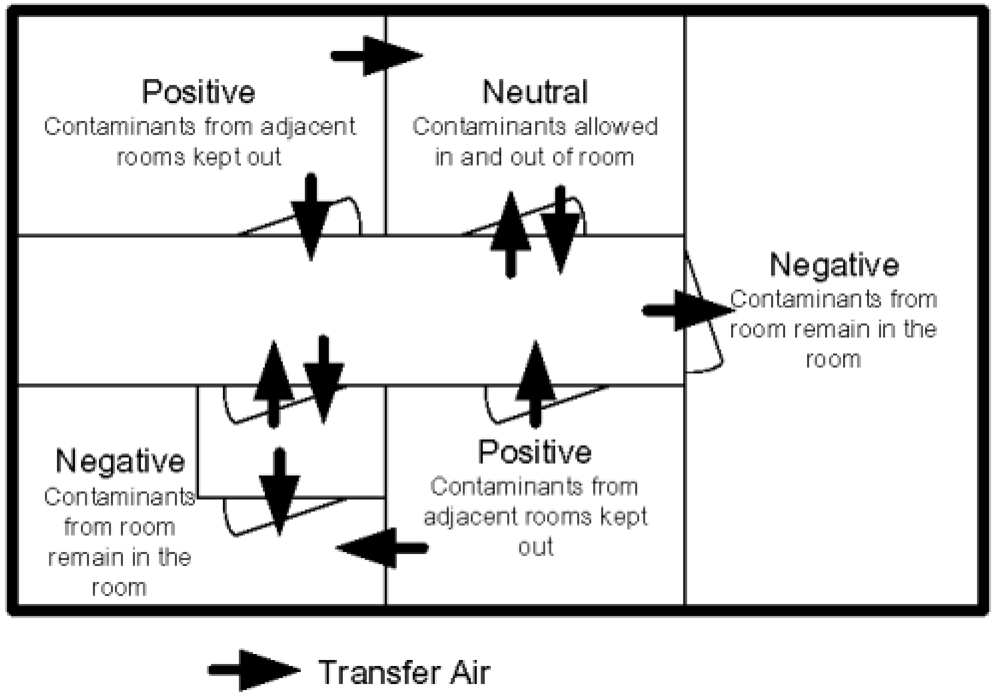


Diagram courtesy of ASHRAE Laboratory Design Guide

Room Pressurization Control

As per the ASHRAE Handbook – HVAC Applications (2015) Chapter 53, using the following equation to determine the room differential pressure:

$$V= 776CA\sqrt{2\Delta P/\rho}$$

Where:
V = Volume flow rate, cfm
C = flow coefficient (typically 0.65)
A = Flow area (leakage area) ft^2
ΔP = Pressure difference across flow path in.w.g.
ρ = density of air entering flow path (0.075 lbm/ft^3)

Differential pressure should not exceed 0.30 in w.g (75 Pa).

Direct Pressure Control

Direct pressure control is accomplished by measuring the differential pressure between the room and the reference space, controlling the exhaust or supply flow to maintain the differential setpoint.

Advantage: No need to measure and track all the exhaust and supply flows.

Disadvantage: Pressure control is subject to disturbances such as door opening or room leakage area.

Typical Control Schematic for Direct Pressure Control

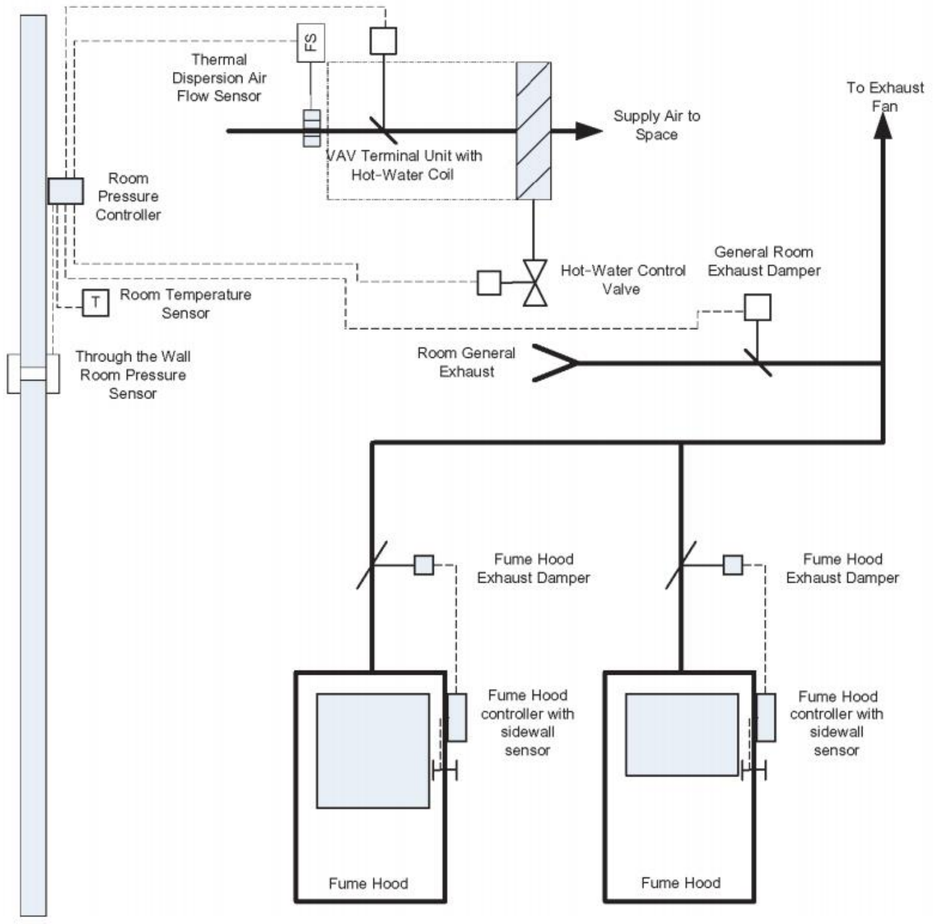


Diagram courtesy of ASHRAE Laboratory Design Guide

Volumetric Offset Control

Volumetric offset control is accomplished by measuring all the supply and exhaust flows in the space and maintaining a set differential flow rate.

Advantage: Ability to calculate and adjust airflow direction based on desired pressure relationship.

Disadvantage: Control system does not recognize changes in pressure of adjacent spaces.

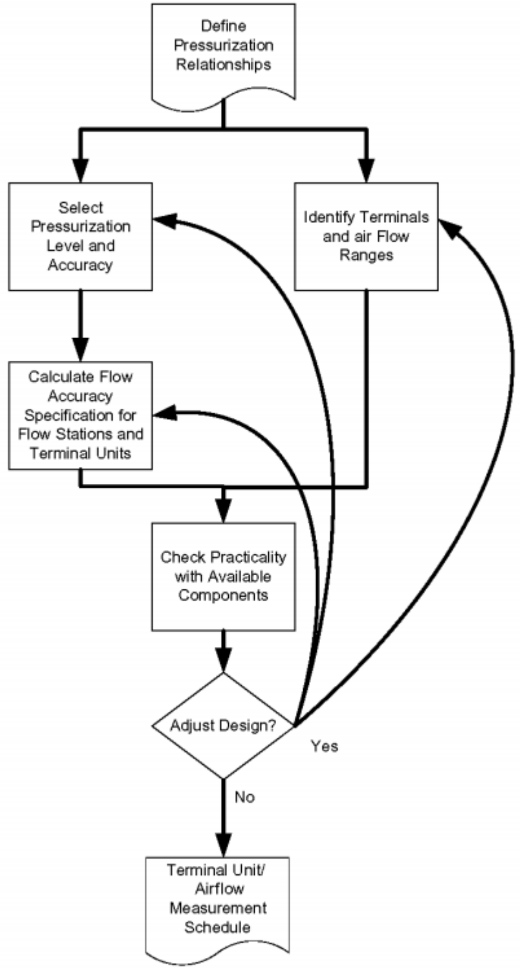


Diagram courtesy of ASHRAE Laboratory Design Guide

Cascade Control

Cascade control system is accomplished by combining volumetric offset control and direct pressure control.

For tightly constructed rooms where the leakage can be very small volumetric offset.

The differential pressure sensor is used to reset the off set over time ensuring proper differential pressure.

Typical Control Schematic for Cascade Control

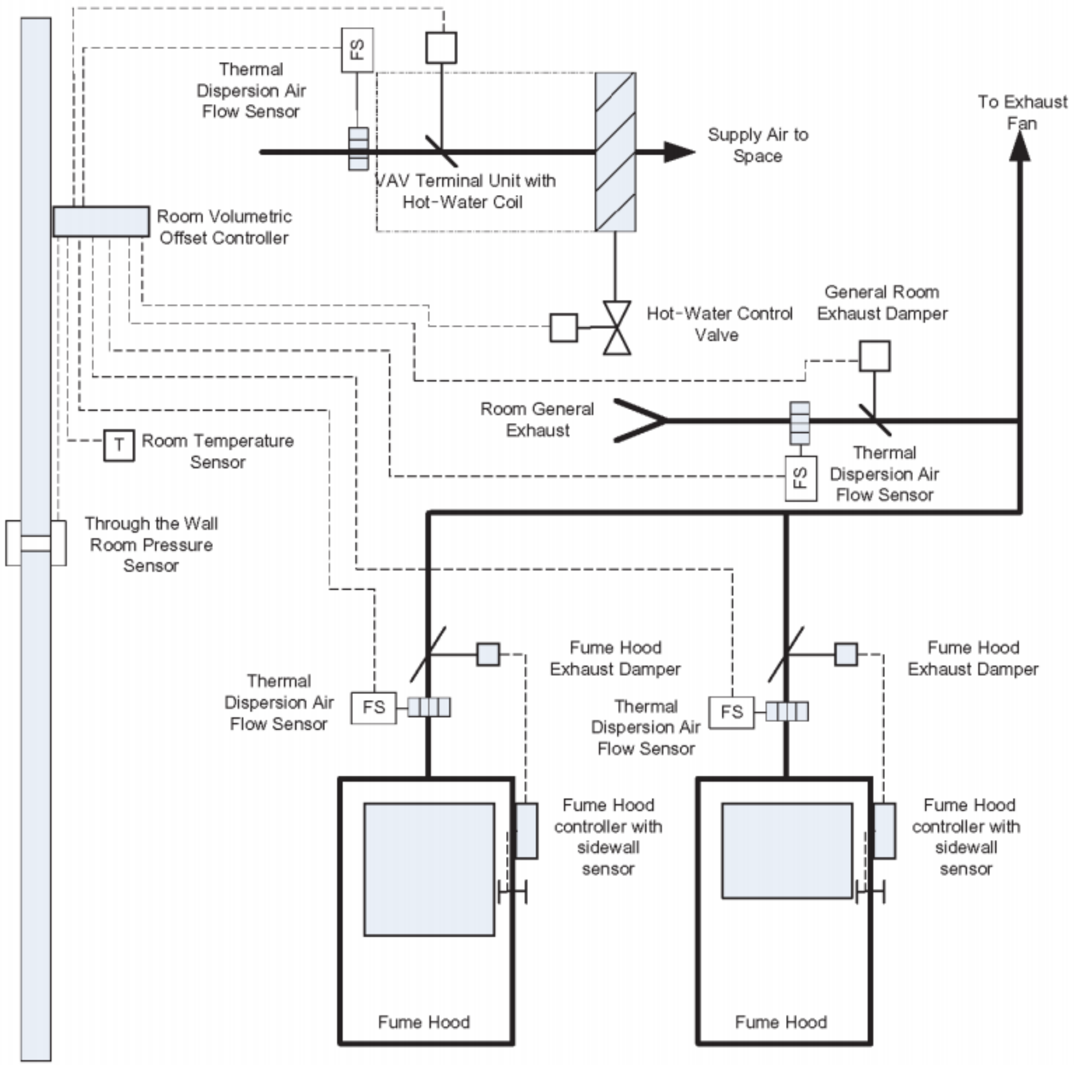


Diagram courtesy of ASHRAE Laboratory Design Guide

Demand control (DCV) - Air control devices

What devices are to used to control airflow, at room level and in the exhaust duct?

Each device should be evaluated for it's function and operating parameters as a component in the laboratory control system.

- **Points for consideration**
  - speed of response
  - accuracy (at maximum and minimum flow)
  - turn down
  - material compatibility
  - operating range
  - pressure independence
  - pressure drop
  - maintenance requirements
  - long-term durability

Demand control (DCV) - Air control devices

What devices are to used to measure airflow, at room level and in the exhaust duct?

Airflow can be measured with **velocity pressure**, thermal dispersion or vortex shedding devices. Each device offers advantages and disadvantages in measuring airflow.

Accuracy of the velocity pressure sensing system depends on the characteristics of the velocity pressure device and the pressure transducer.

Component errors will be addressed through product qualification, balancing and commissioning process.

Demand control (DCV) - Air control devices

What devices are to used to measure airflow, at room level and in the exhaust duct?

Airflow can be measured with velocity pressure, **thermal dispersion** or vortex shedding devices. Each device offers advantages and disadvantages in measuring airflow.

From the power being dissipated to the airstream, the air velocity can be calculated. Check manufacturer’s accuracy and speed of response to changes in airflow. Some have sensor-to-output errors around 2% of reading.

Demand control (DCV) - Air control devices

What devices are to used to measure airflow, at room level and in the exhaust duct?

Airflow can be measured with velocity pressure, thermal dispersion or **vortex shedding** devices. Each device offers advantages and disadvantages in measuring airflow.

Measuring the pressure pulses or vortices formed on the leeward side of an obstruction, airflow is calculated based on these pulses. Response time for Vortex shedders is typically slower than velocity pressure sensors.

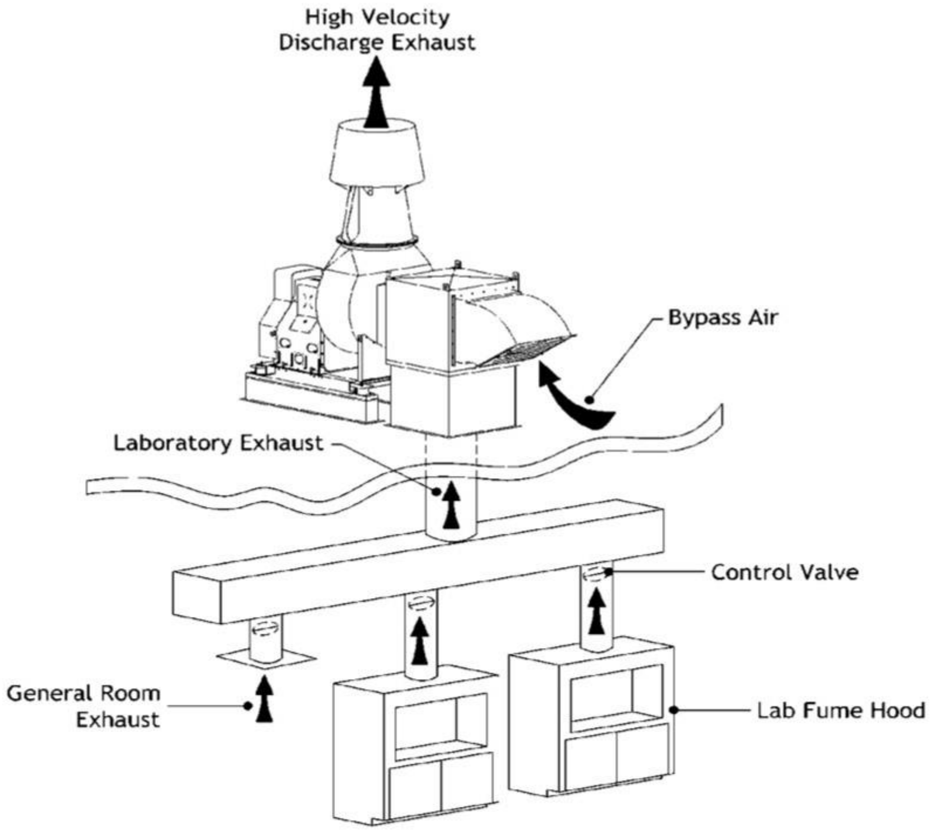
Source Containment and Exhaust Device Controls

The purpose of the exhaust equipment is to maintain containment of chemical, biological and particulate contaminants, therefore the development of a laboratory airflow control system typically starts with these exhaust devices.

Various laboratory exhaust fan operation scenarios

Constant Volume exhaust

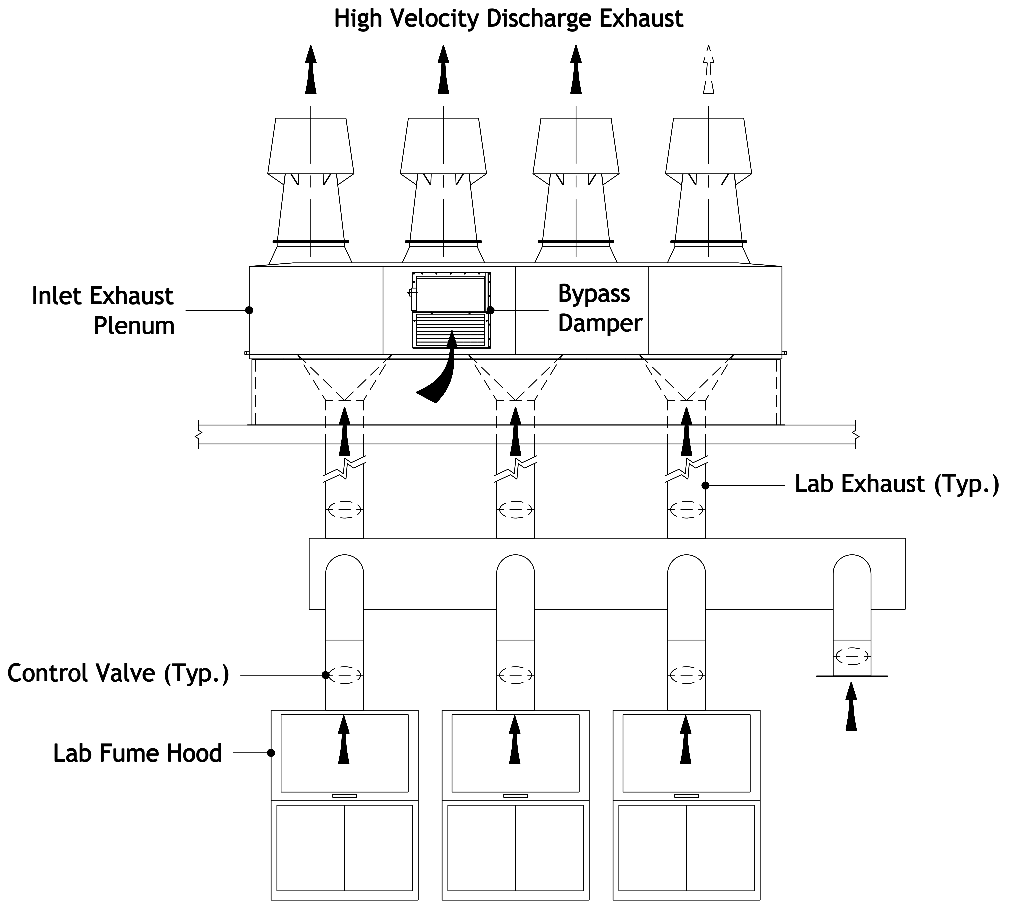
Fan operates at a constant speed while pressure is monitored by pressure transducer, mounted on plenum, proportional control of the by-pass damper maintains either exhaust static pressure and/or plume height.



Various laboratory exhaust fan operation scenarios

Variable Volume exhaust

Fan operates with VFD control while static pressure monitored.
Control system will vary motor RPM or by-pass damper position to maintain static pressure through the many operating points demanded by the equipment used in the laboratory.



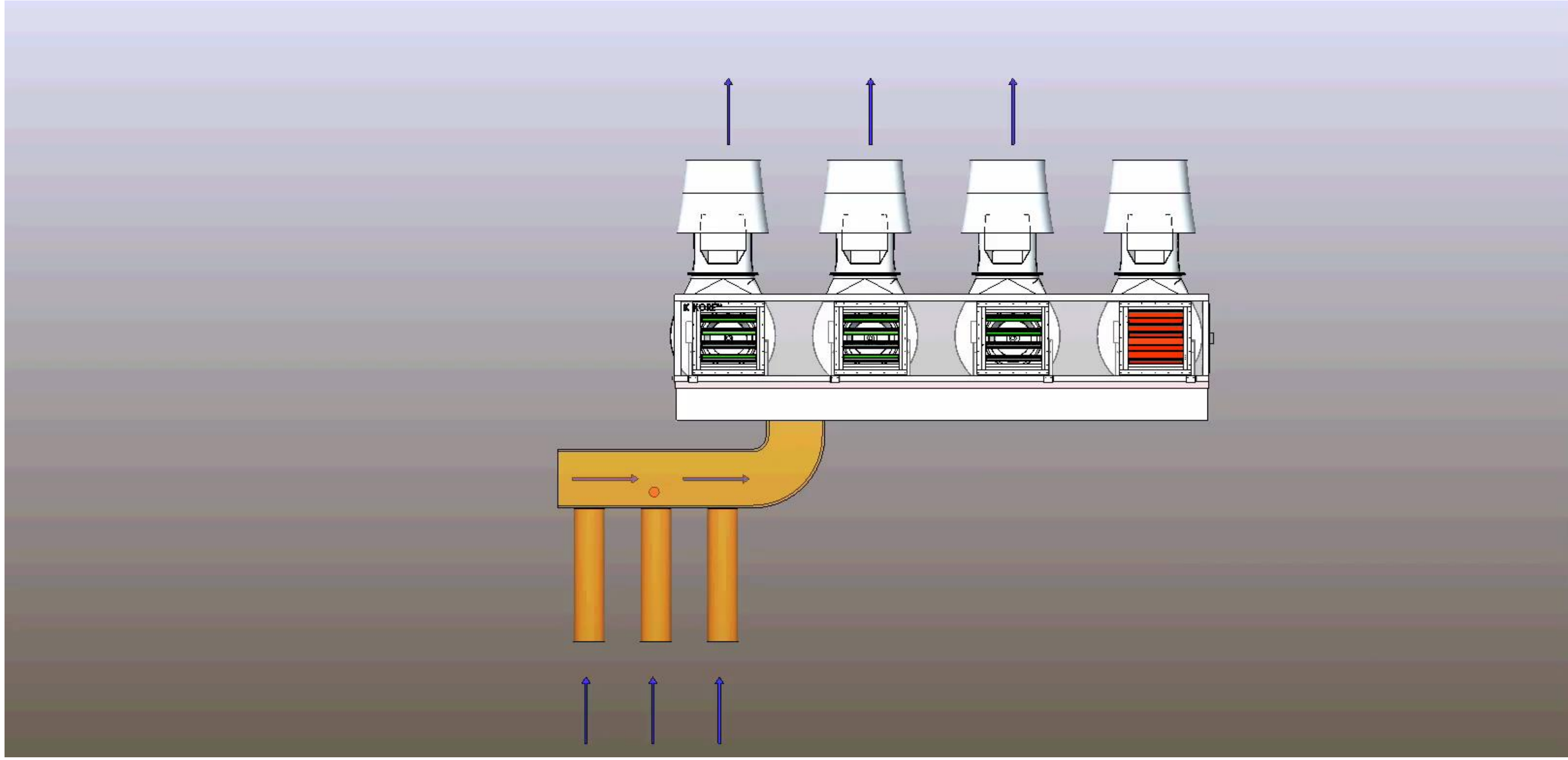
Exhaust Fans – High Plume Dilution Fans

As the airflow is controlled at the space level, the exhaust fan is typically controlled to maintain a constant negative pressure in the exhaust ductwork.

Understanding N+1 Configuration

N+1, fans 1, 2, & 3 operating, #4 idle

The N+1 concept has been traditionally employed wherein there is an idle back-up fan which can be brought online in the event that an operating fan fails or goes offline.



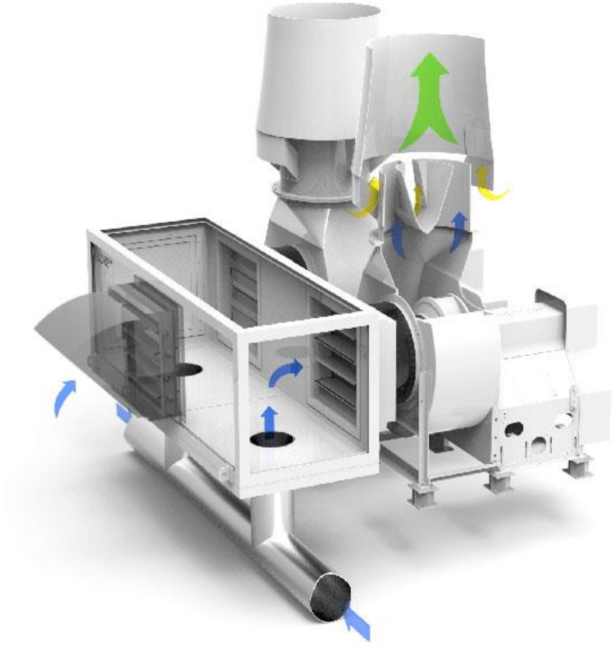
Understanding N+1 Configuration

N+1, fans 1 operating, #2 idle

Starting an idle fan takes time (the larger the fan the more time).

Offline fan isolation damper closes
Back-up fan isolation damper opens.

Back-up fan energizes, overcomes starting moment, and ramps up to operating speed.

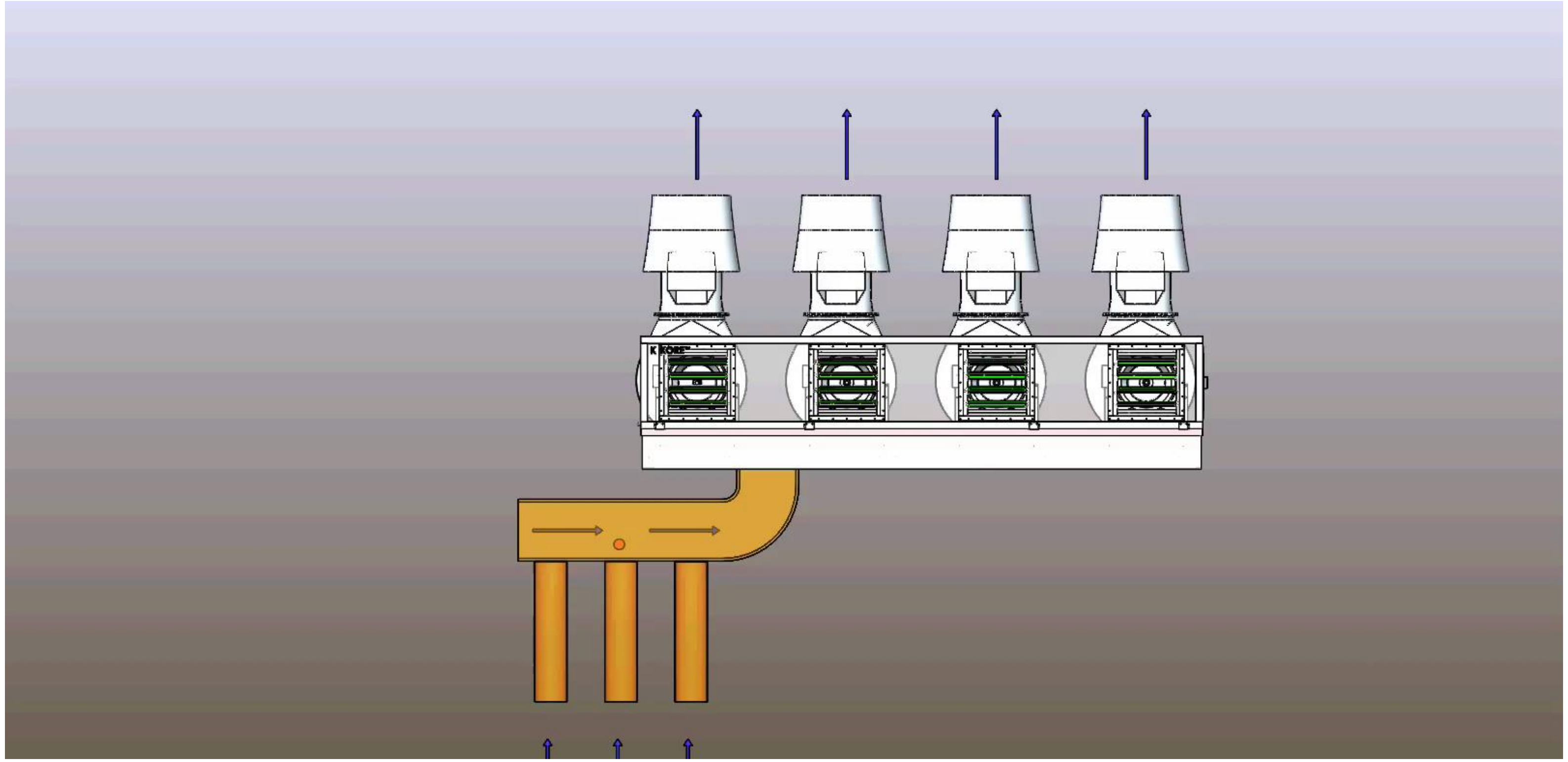


Understanding N-1 Configuration

N-1, all fans operating

In N-1, backup fan remains active while the other fans are active (operating).

In N-1, when an operating fan goes offline, the other fans increase speed on VFDs to carry the system load.



Understanding N+1 and N-1 Configuration

Benefits associated with N-1 vs. N+1:

- Faster system response to fan failure
- Greater system stability
- Lower energy consumption/cost
- Better airflow/energy transfer over ERU coil

And often ….

- Smaller system size (footprint)
- Reduced weight
- Lower first cost

Question - revisited

I am designing a lab ventilation system which uses negative pressure control by modulating exhaust volume from the laboratory areas. The total airflow for the laboratory area is 60,000 CFM with 4.5” w.c. TSP. The exhaust is discharged through a high plume dilution exhaust fan to maintain a discharge velocity of 3000 fpm. Please note that the fan exhaust volume needs to be kept constant to maintain the discharge velocity of 3000 fpm. There is a by-pass damper at the fan inlet to maintain the discharge velocity when the room exhaust volume varies due to operational requirements and night-time setbacks.

What is the best way to control the system?

Selecting a suitable High plume Dilution fan

Known Parameters

- Total Max Flow = 60,000 CFM
- Total Static Pressure = 4.5” w.c.
- Nozzle Velocity ≥ 3000 fpm
- Design Guide ANSI/AIHA/ASSE Z9.5 2012
- FEG > 67 (ASHRAE 90.1 2015)
- FEI > 1.00(ASHRAE 90.1 2019)

Assumed Parameters

- Minimum Flow = 36,000 CFM
- Available Roof space - TBA
- Sound Requirements ≤ 75dB(A) @ 100ft
- Exhaust gases – Wet Chemistry Labs
- Dilution and Dispersion Requirements - TBA

Selecting a suitable High plume Dilution fan

3 Fans operating in N + 1 operation

Date .

Sys. No. .

Drawing . A

Revision .

Model	AXIJET		10	[mph]
Fan Size	4450	EH =	61.5	[feet]
Dia.[in]	44.50	PH =	44.9	[feet]
CFM	30000	NV =	5597	[fpm]
SP	4.5	WV =	2612	[fpm]
BHP	35.18	TF =	52119	[cfm]
RPM	996	TS =	11603	[fpm]
		T =	70	[°F]
		ALT =	0	[feet]

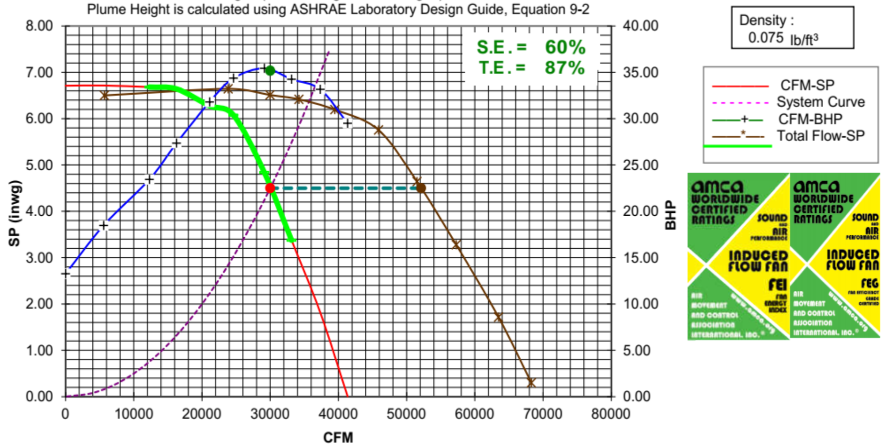
FEI_T Based on Default Motor Efficiencies

Regulated Motor Efficiencies

Air performance FEI_T = 1.40

CLASS II WHEEL

TF=Total Flow; NV=Nozzle Velocity; WV=Windband Velocity; TS=Tip Speed
EH: Effective Plume Height. (Plume Height + Fan Height)
Plume Height is calculated using ASHRAE Laboratory Design Guide, Equation 9-2



Performance shown 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. FEI values are calculated in accordance with AMCA 208 and are based on default motor efficiencies. FEI values for fans with specific motors will vary slightly from those shown.

4 Fans operating in N - 1 operation

Date .

Sys. No. .

Drawing . A

Revision .

Model	AXIJET		10	[mph]
Fan Size	3000	EH =	44.2	[feet]
Dia.[in]	30.00	PH =	33.4	[feet]
CFM	15000	NV =	6173	[fpm]
SP	4.5	WV =	2886	[fpm]
BHP	20.57	TF =	26138	[cfm]
RPM	1588	TS =	12472	[fpm]
		T =	70	[°F]
		ALT =	0	[feet]

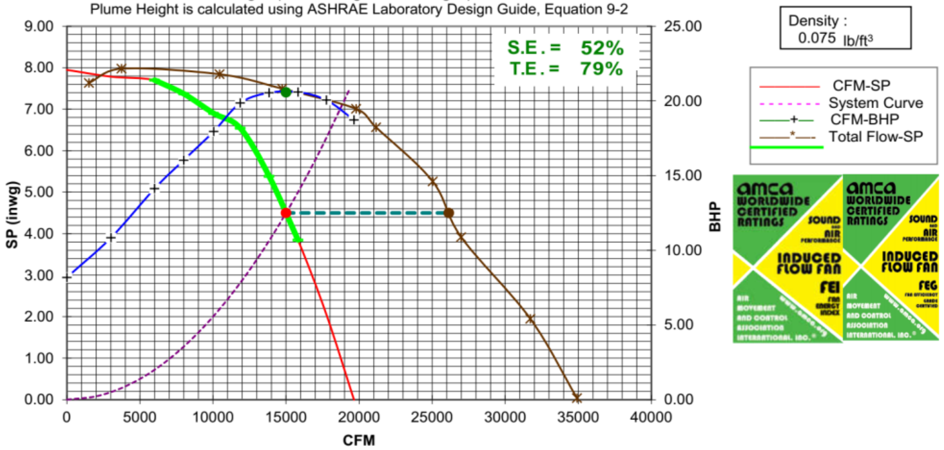
FEI_T Based on Default Motor Efficiencies

Regulated Motor Efficiencies

Air performance FEI_T = 1.28

CLASS II WHEEL

TF=Total Flow; NV=Nozzle Velocity; WV=Windband Velocity; TS=Tip Speed
EH: Effective Plume Height. (Plume Height + Fan Height)
Plume Height is calculated using ASHRAE Laboratory Design Guide, Equation 9-2



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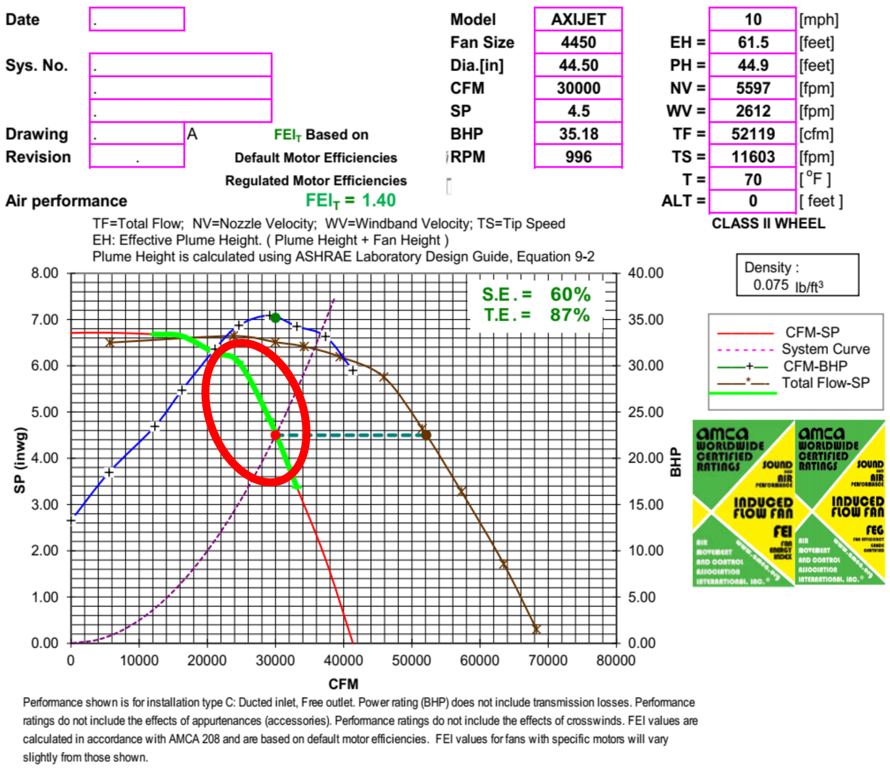
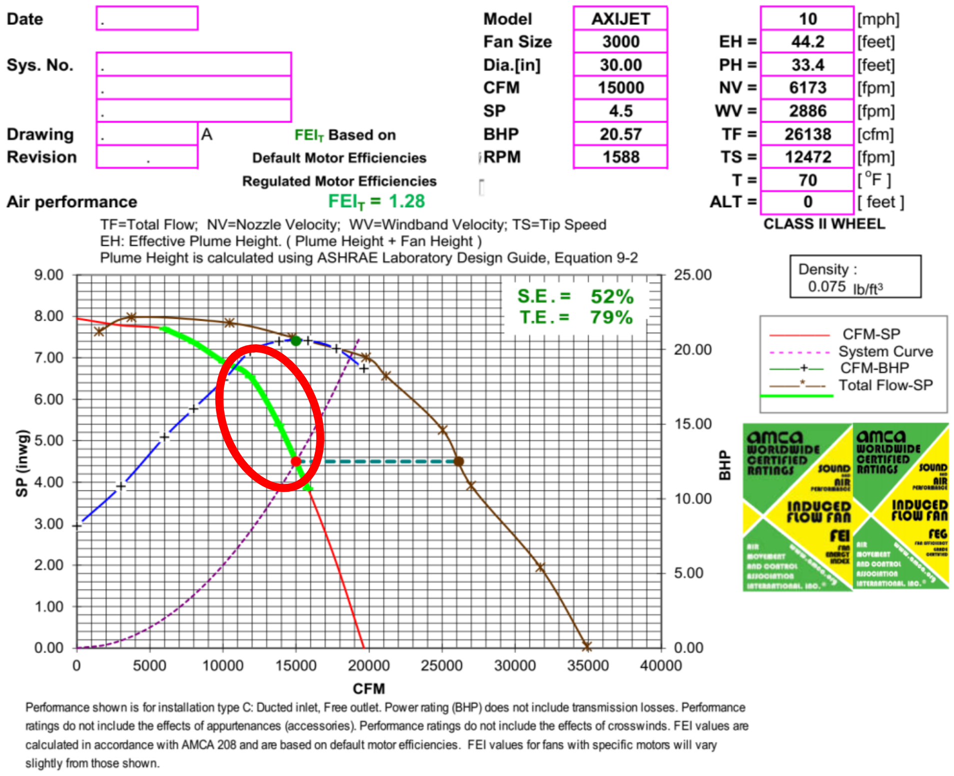
Selecting a suitable High plume Dilution fan

Area of turn down on the performance curve

3 Fans operating in N + 1 operation



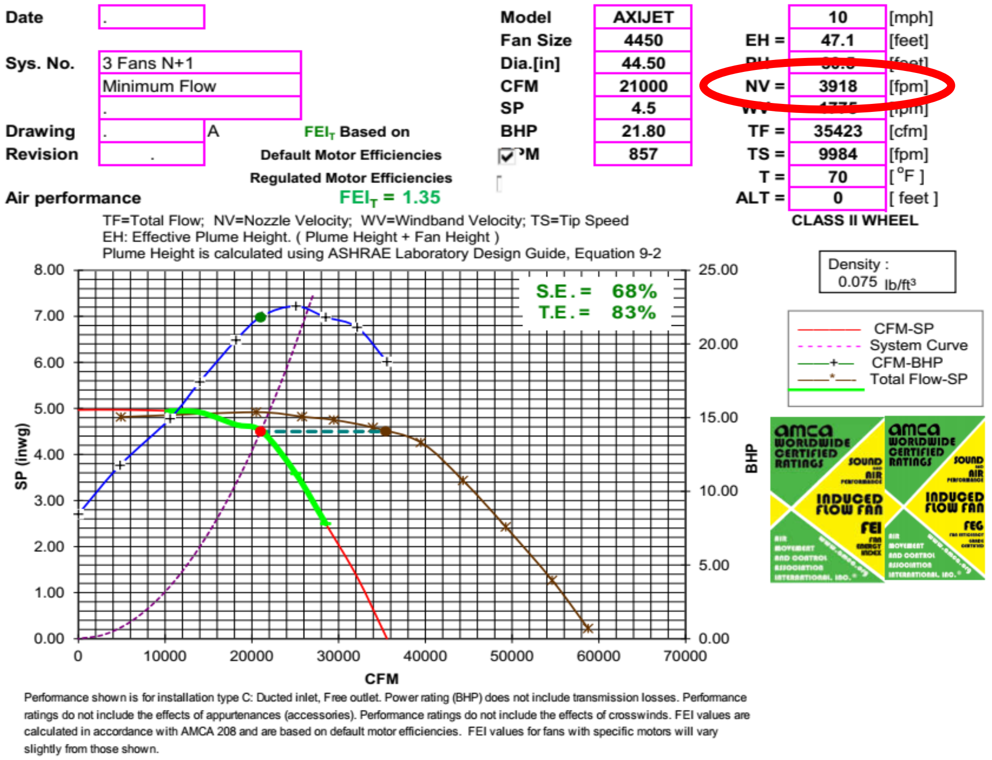
4 Fans operating in N - 1 operation



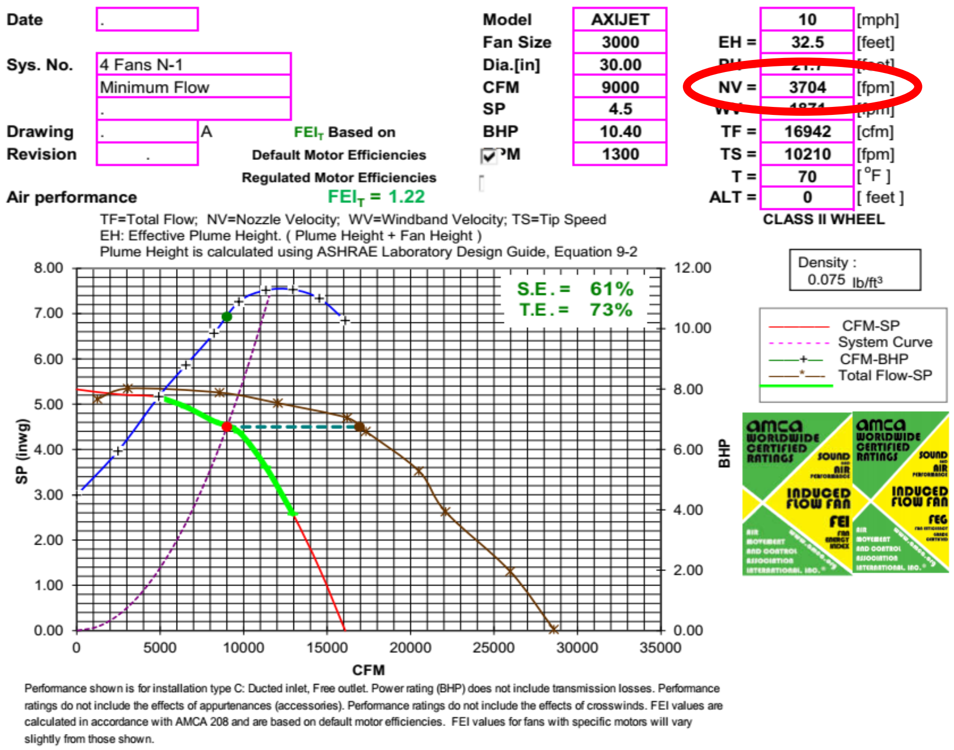
Selecting a suitable High plume Dilution fan

Minimum volume or turn down performance

3 Fans operating in N + 1 operation



4 Fans operating in N - 1 operation



Selecting a suitable High plume Dilution fan

100% volume operation Sound Power & Relevant Sound Pressure levels

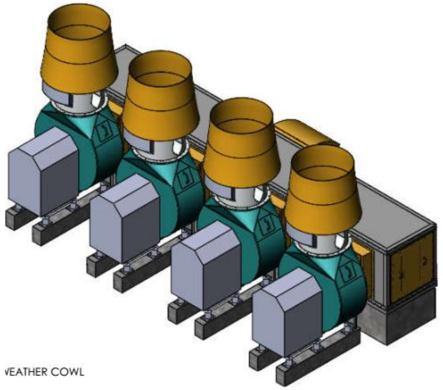
3 Fans operating in N + 1 operation

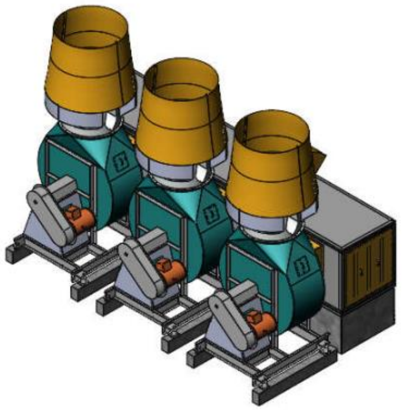
Sound power level The sound power level ratings shown are in decibles, referred to 10^{-12} wattes calculated per AMCA standard 301. Values shown are for (outlet Lwo and LwoA) sound power levels for installation type C :Ducted inlet, Free outlet. Ratings do not include the effects of duct end correction. The A-weighted sound ratings have been calculated per AMCA Standard 301.

RPM				Hz					LwA
	63	125	250	500	1000	2000	4000	8000	
996	96	95	89	86	87	86	79	69	92

Sound pressure level variation Values shown are calculated based on a free-field over a reflecting plane conditions. (ASHRAE Fundamentals Handbook). dBA levels are not licensed by AMCA international.

Feet	1	3	5	10	15	50	100	150
dB(A)	94	85	80	74	71	60	54	51





4 Fans operating in N - 1 operation

Sound power level The sound power level ratings shown are in decibles, referred to 10^{-12} wattes calculated per AMCA standard 301. Values shown are for (outlet Lwo and LwoA) sound power levels for installation type C :Ducted inlet, Free outlet. Ratings do not include the effects of duct end correction. The A-weighted sound ratings have been calculated per AMCA Standard 301.

RPM				Hz					LwA
	63	125	250	500	1000	2000	4000	8000	
1588	92	93	94	87	86	85	82	74	92

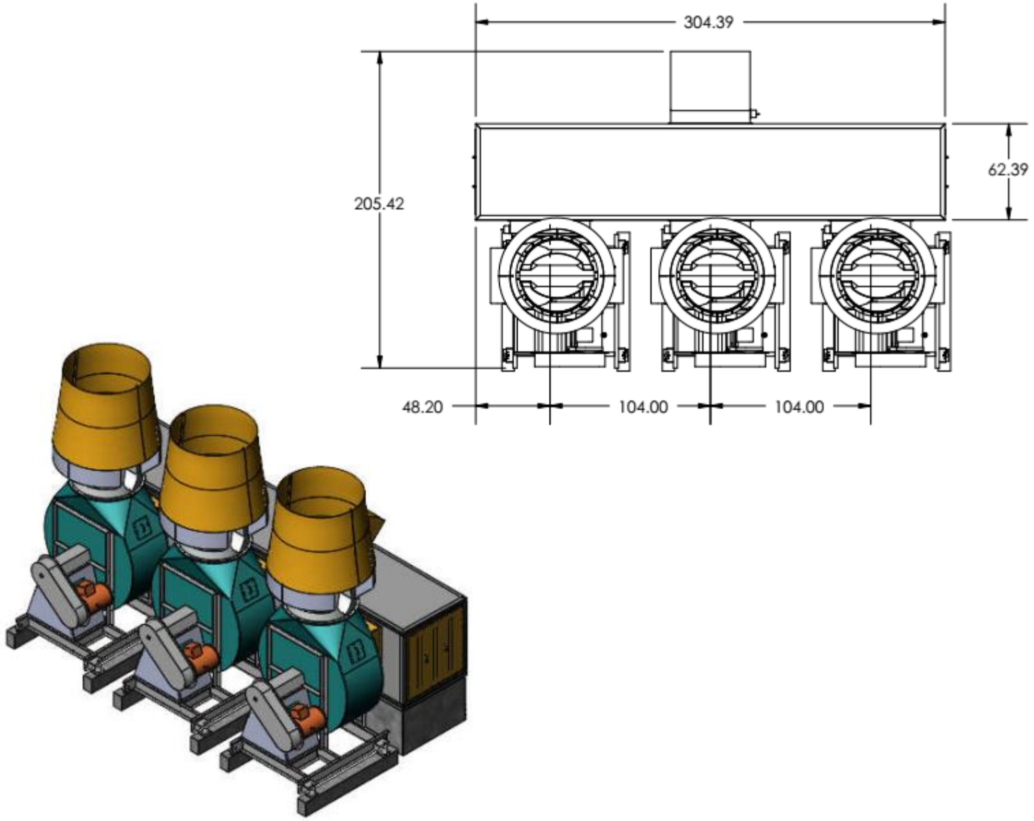
Sound pressure level variation Values shown are calculated based on a free-field over a reflecting plane conditions. (ASHRAE Fundamentals Handbook). dBA levels are not licensed by AMCA international.

Feet	1	3	5	10	15	50	100	150
dB(A)	95	85	81	75	71	61	55	51

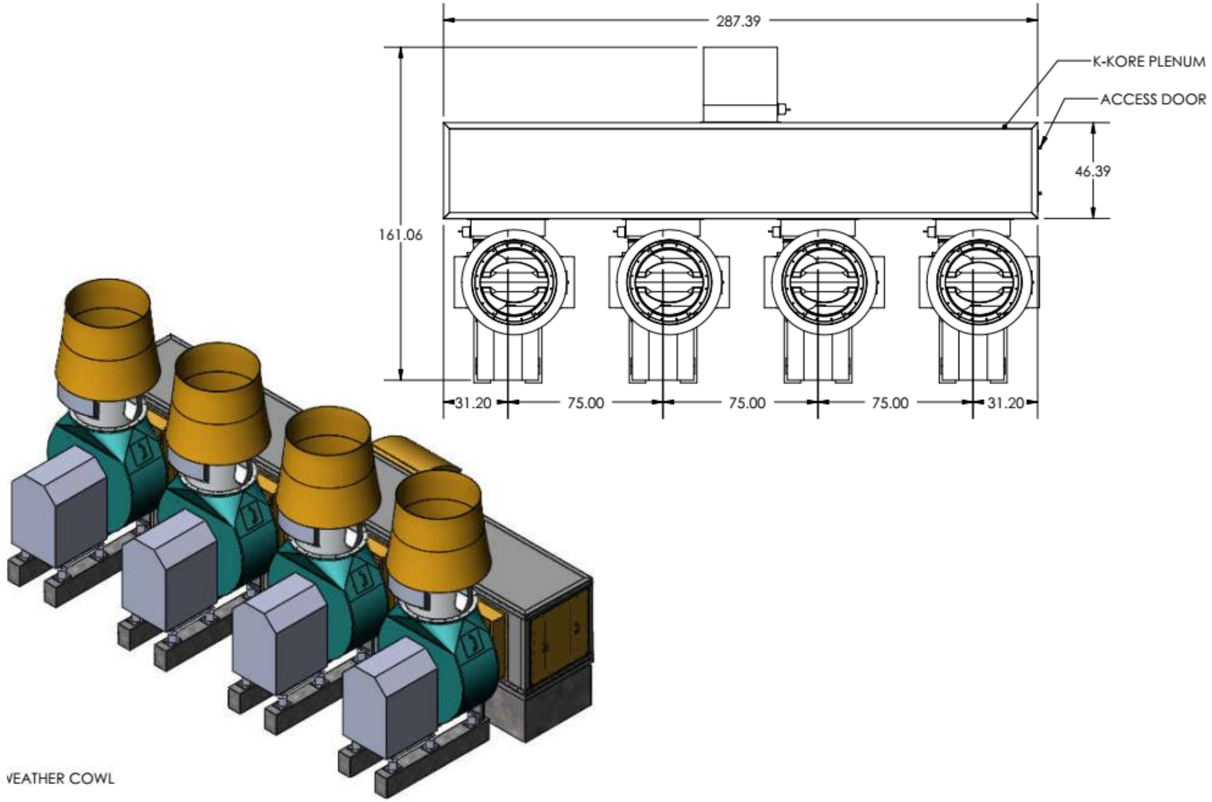
Selecting a suitable High plume Dilution fan

Minimum volume or turn down performance

3 Fans operating in N + 1 operation

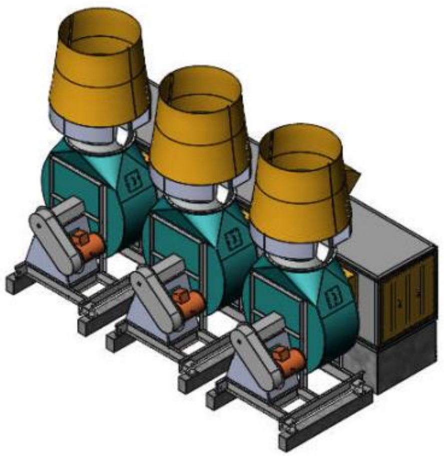


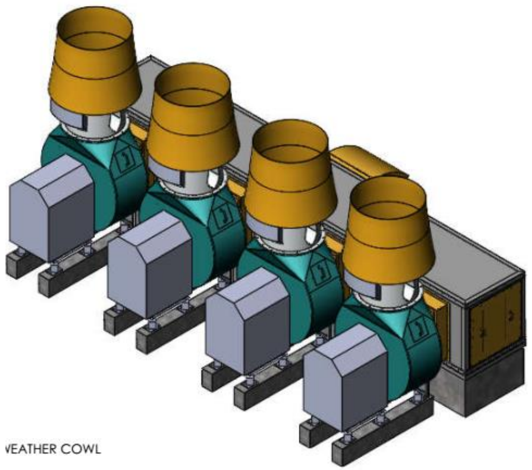
4 Fans operating in N - 1 operation



Selecting a suitable High plume Dilution fan

	3 Fans operating N + 1	4 Fans operating N - 1
Weight (lbs)	3 x 3167+2273= **11,774**	4 x 1320+1630 = **6910**
Sound @ 100Ft dB(A)	54+3 = 57	55+6 = 61
Foot Print Area (in²)	L= 304x W=205 = 62,320	L=288 x W= 161 = 46,368



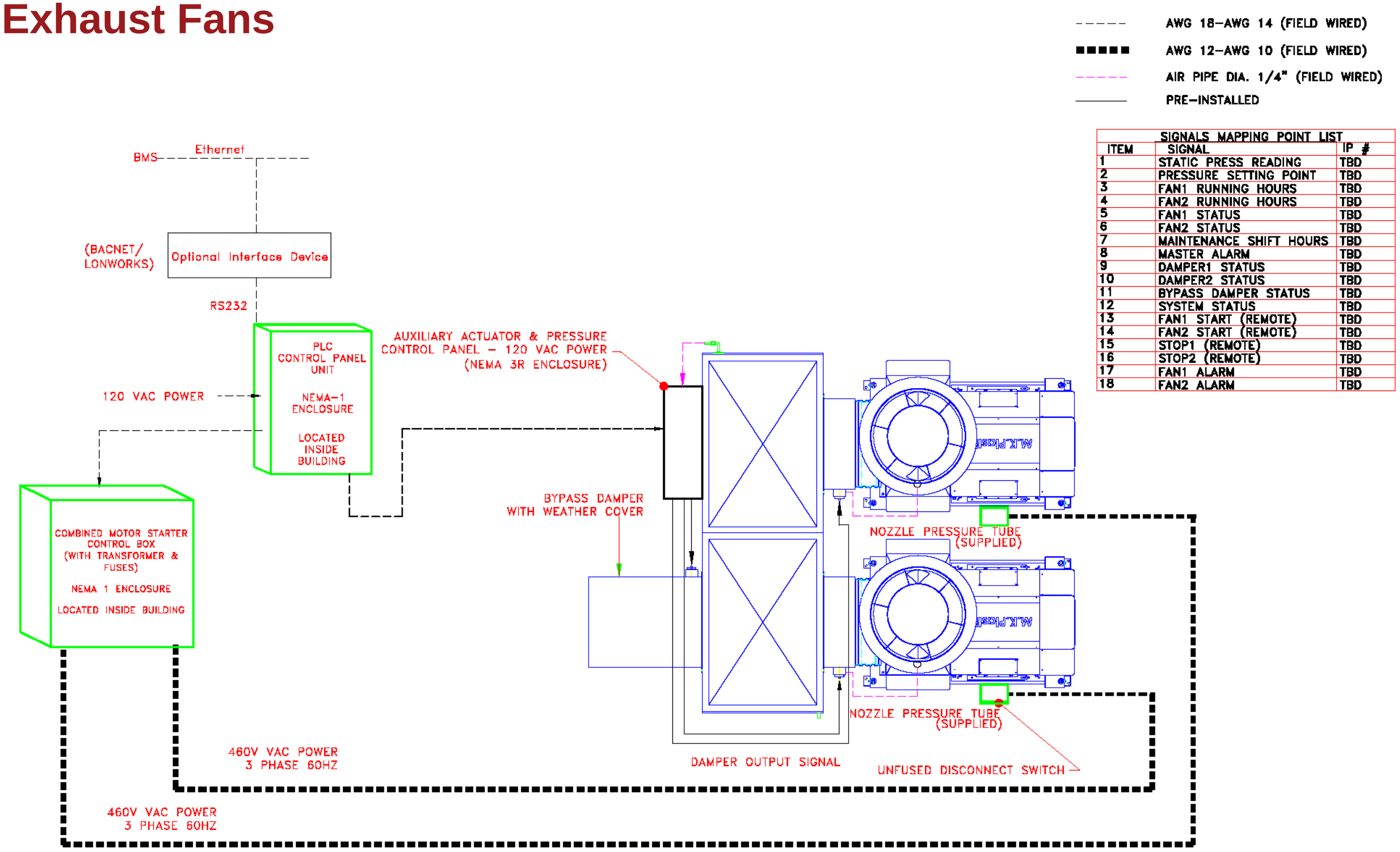


Controls for Laboratory Exhaust Fans

A Plc controlled system for Exhaust Fans

Feedback points to accurately control the exhaust fans:

- Pressure Transducer
- Piezometer Ring
- VFD Motor Control
- Proportional Actuator
- Two position actuator
- Communication to BAS



SIGNALS MAPPING POINT LIST

ITEM	SIGNAL	IP #
1	STATIC PRESS READING	TBD
2	PRESSURE SETTING POINT	TBD
3	FAN1 RUNNING HOURS	TBD
4	FAN2 RUNNING HOURS	TBD
5	FAN1 STATUS	TBD
6	FAN2 STATUS	TBD
7	MAINTENANCE SHIFT HOURS	TBD
8	MASTER ALARM	TBD
9	DAMPER1 STATUS	TBD
10	DAMPER2 STATUS	TBD
11	BYPASS DAMPER STATUS	TBD
12	SYSTEM STATUS	TBD
13	FAN1 START (REMOTE)	TBD
14	FAN2 START (REMOTE)	TBD
15	STOP1 (REMOTE)	TBD
16	STOP2 (REMOTE)	TBD
17	FAN1 ALARM	TBD
18	FAN2 ALARM	TBD

Controls for Laboratory Exhaust Fans

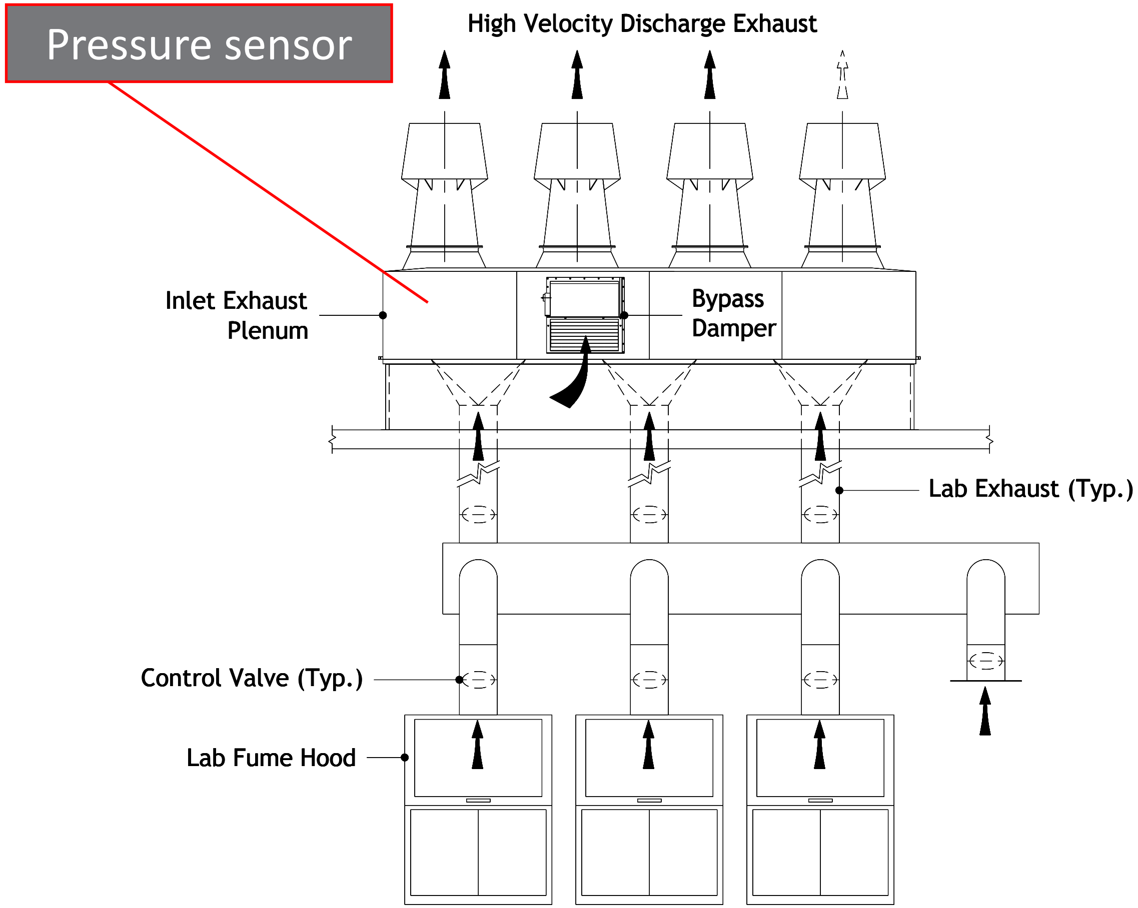
Different Control Points for Exhaust Fans

Constant Duct Pressure

Constant Duct Pressure control:

- Operating variable air volume laboratory ventilation, via control of the system static pressure.

- Using a pressure switch mounted on the plenum directly adjacent to the exhaust fans indicating the static pressure.



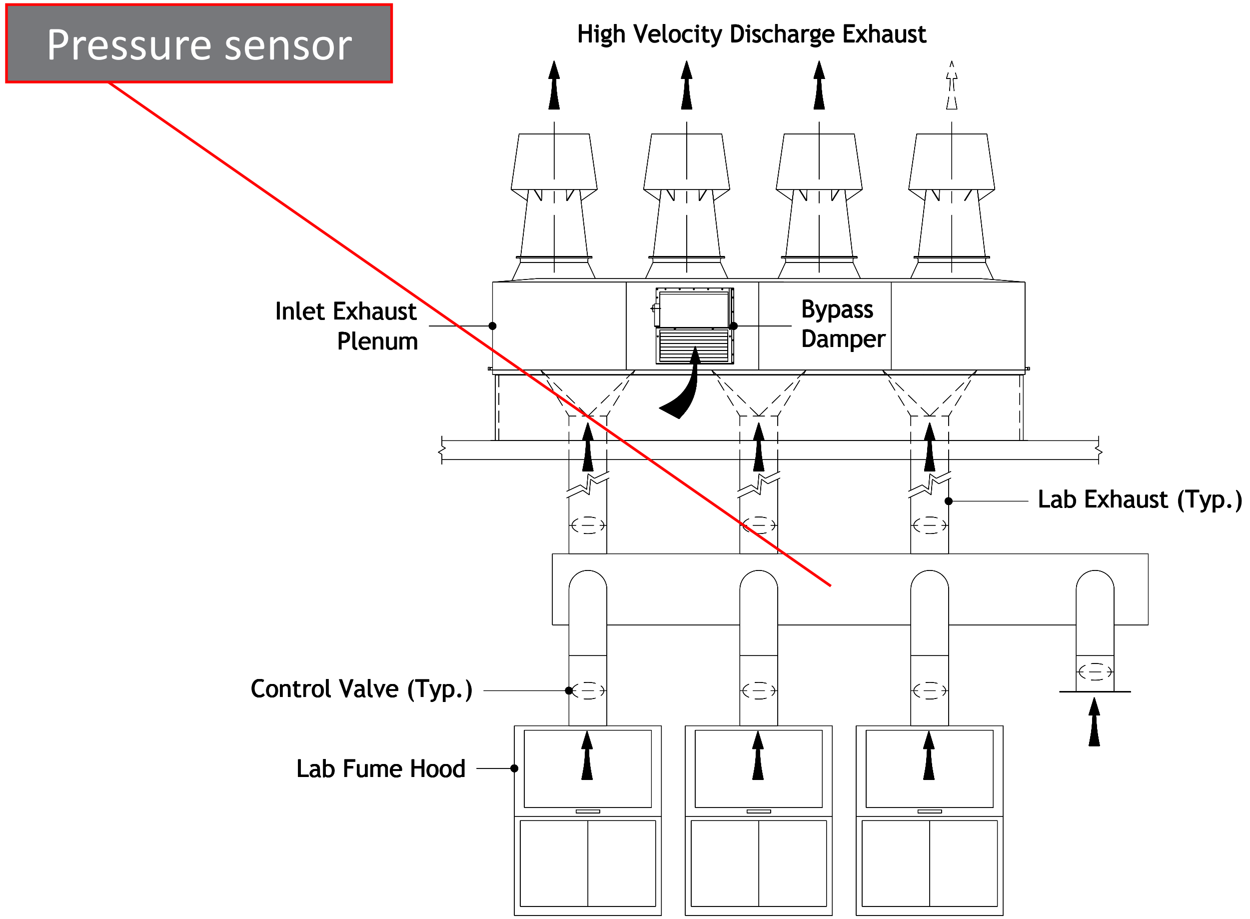
Controls for Laboratory Exhaust Fans

Different Control Points for Exhaust Fans

Variable Duct Pressure

Variable Duct Pressure control:

- Limited use of the out-side air by-pass damper
- Providing the static pressure of the system closer to the lab control valves.
- The laboratory exhaust fan is controlled using a Variable Frequency Drive (VFD) to vary the RPM to maintain the predetermined static pressure of the exhaust.



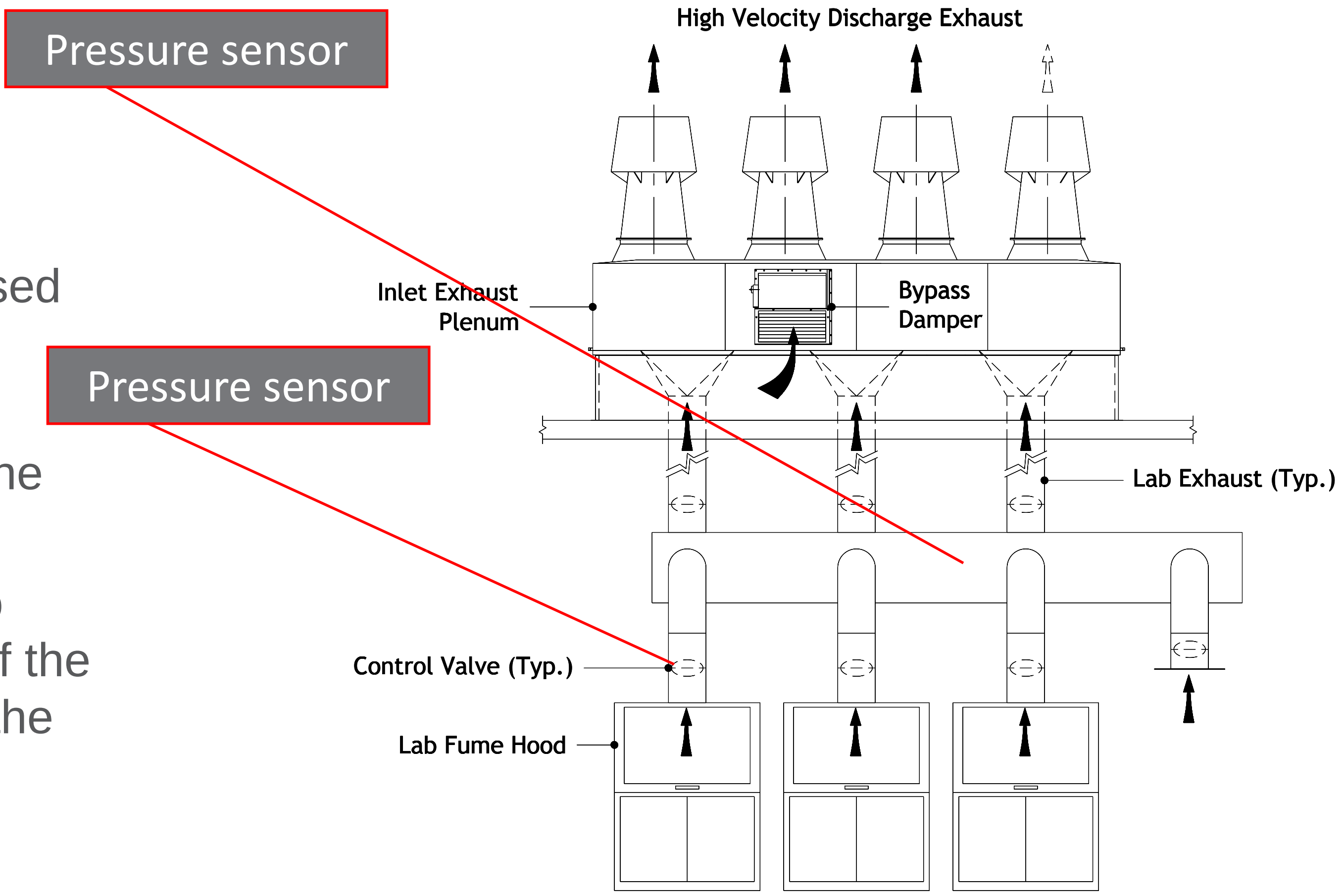
Controls for Laboratory Exhaust Fans

Different Control Points for Exhaust Fans

Dynamic Duct Pressure

Obtaining dynamic static exhaust pressure reset:

- Provide exhaust duct static pressure based on actual operational pressure set point.
- Establishing the static pressure of the system, between the exhaust fans and the lab control valve, in real time.
- The laboratory exhaust fan modulates to maintain the measured static pressure of the exhaust system and therefore, ensures the fume hoods and laboratory space are operating within design criteria range.



Response to question:

Based on what we have learned, the Laboratory fan system would consist of the following:

- 4 Fans operating on an N-1 configuration
- Dynamic duct pressure Laboratory exhaust fan control
- Closed loop with feedback to BAS
- Variable Volume Fume Hoods
- Variable Air Volume space control
- Volume Off Set Control for space

Resources

- **AMCA International**: www.amca.org

- **ANSI/AMCA Standards**

  > 208-18: Calculation of the Fan Energy Index ***(FREE PDF download)***: www.amca.org/store

  > 260-20: Laboratory Methods of Testing Induced Flow Fans for Rating *(Available for purchase)*: www.amca.org/store

  > 301-14: Methods for Calculating Fan Sound Ratings from Laboratory Test Data *(Available for purchase)*: www.amca.org/store

Thank you for your time!

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Questions?

NEXT PROGRAM

Join us for our next AMCA *insite*™ Webinar:

- Wednesday, February 10
- 12:00-1:00pm CT
- ***TOPIC: Understanding & Reducing Air System Noise***
- Presenter: Kristen Neath, Canadian National Sales Manager, AMCA Member Company

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