Critical Environments

Laboratory Design Handbook

TSI®

Laboratory Design Handbook

This handbook is not intended to be a comprehensive guide to all accepted practices relating to the design of laboratories, their HVAC systems and controls. No handbook can instill that level of expertise. Instead, this handbook focuses on concepts needed to gain a basic understanding of the goals of a laboratory and how controls can help meet those goals.

Contents

Introduction

The use of chemicals and other potentially hazardous compounds separates laboratories from other types of building spaces. Protecting the health and safety of laboratory and building occupants must be the primary concern. Comfort and energy-efficiency are also of considerable importance. The space temperature must remain comfortable for occupants while maintaining an appropriate temperature for chemical processes. At the same time, facilities are under pressure to minimize operating costs.

Even including the general criterion of safety, not all laboratories are alike. Different laboratories contain different hazard levels and uses. As an extreme example, it would be inappropriate to design a high-containment biological laboratory as if it were a general chemistry laboratory due to the high consequences should a biological laboratory's containment be breached. A host of criteria, including safety, comfort and energy efficiency, must be considered when a laboratory is planned or renovated in order to determine the optimal design.

General Goals of Laboratory

Safety

Laboratories are designed to maintain the health and well-being of occupants. Potentially hazardous substances used in different laboratories include chemicals, radioactive materials and infectious biological agents. These materials can be manipulated daily as part of experiments, research or production. Safety must remain the primary goal of a laboratory.

Regulations, guidelines and standards to ensure laboratory safety have been published by many industry groups, many of which can be found in Appendix A. Complying with those requirements is a primary step in achieving laboratory safety objectives.

Comfort

Laboratory safety has to be balanced with worker comfort. Comfort primarily is concerned with maintaining appropriate temperatures and air velocities. Worker productivity will suffer if the space is too warm or too cool. Similarly, spaces with high air currents are perceived as drafty and cool. Air currents also impact safety by limiting containment in fume hoods and other protective equipment.

Ease of use of the laboratory equipment is also a factor in worker comfort. Laboratories employing highly specialized equipment, like glove boxes, may be safest. However, this equipment carries an ease of use penalty inappropriate for the hazards encountered in most chemical laboratories. Laboratory equipment and layout must allow staff to perform necessary tasks with minimal additional effort.

Energy Efficiency

Laboratories are normally designed as once-through systems, without recirculation[1]. Conditioning, supplying and exhausting the large volumes of air used in laboratories consumes sizeable quantities of energy. Reducing these energy costs has a direct impact on a company's bottom line. Laboratories must be designed so that energy efficiency gains do not reduce safety and comfort.

[1] National Fire Protection Association, Standard NFPA 45-2000. Section 6.3.1, p. 12.

Laboratory Ventilation

The key concept of laboratory ventilation is that air entering the laboratory must exit the laboratory. The inflowing air volume, normally composed of supply air and infiltration, will exactly equal the outgoing air volume, or air exhausted through room exhaust, fume hoods, canopy hoods, biological safety cabinets and exfiltration. All airflows must be accounted for when designing a building with laboratories.

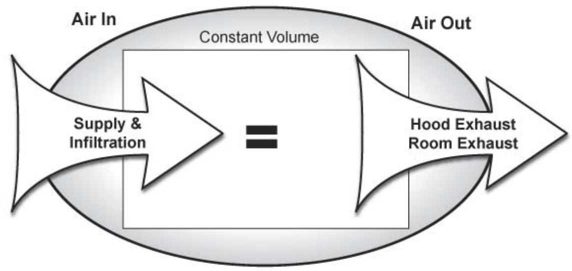


Figure 1. All air exhausted from a lab must enter through either the building HVAC system or infiltration.

In practice, the volume of air supplied into a laboratory is less than the amount of air exhausted, creating negative pressure. The additional air exhausted creates a low-pressure vacuum, pulling air in from adjacent spaces through cracks in the wall, the door undercut, unsealed duct and piping openings or other wall penetrations.

Determining Supply Air Needed

Three drivers determine the required volume of supply air in a laboratory: temperature, exhaust, and ventilation.

Temperature-driven laboratories hold a lot of equipment to perform chemical analysis or ovens and heating elements to speed up chemical processes. Without an adequate supply of cool air, the laboratory housing this equipment will become uncomfortably warm. Lights, laboratory personnel, and even heat transmitted through the building also contribute to the cooling load of a laboratory. Determining the necessary supply air volume for cooling involves summing up all of these loads. However, loads other than the building envelope should be determined according to expected usage. For example, engineers revise supply air volume downward if all of a laboratory’s equipment will not be used simultaneously.

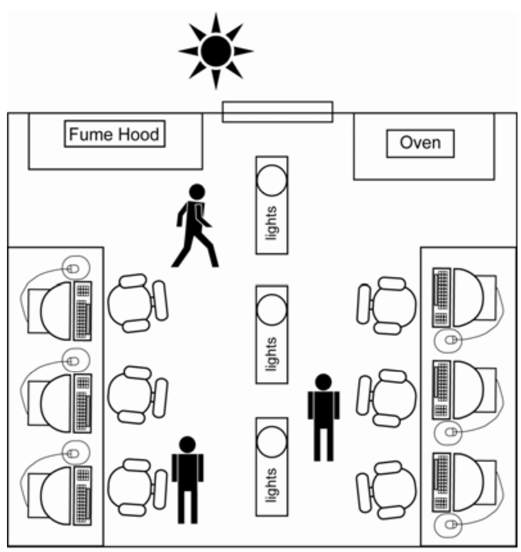


Figure 2. Supply air volume in laboratories with high heat loads, such as computers, ovens and other electrical equipment, is driven by cooling requirements.

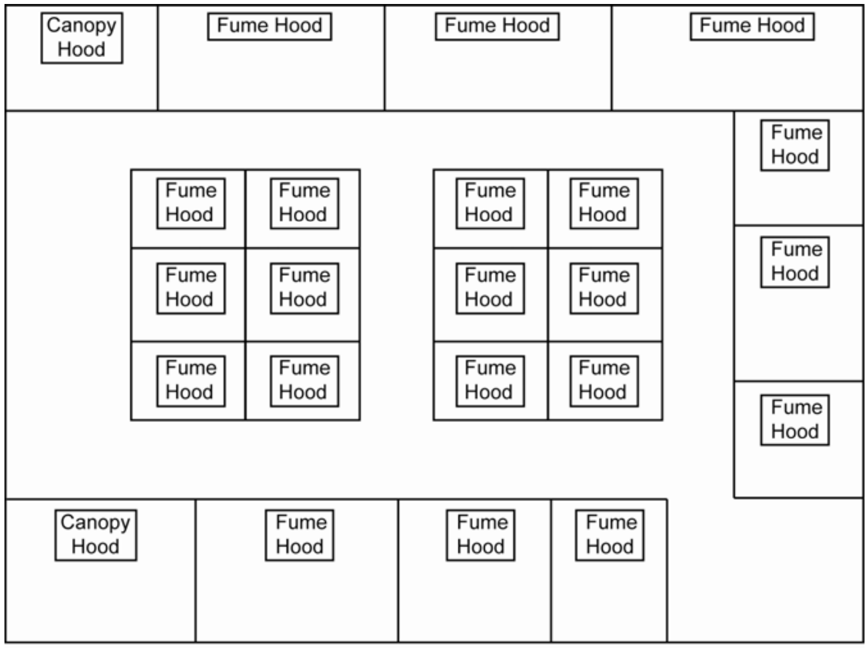


Figure 3. High volumes of air exhausted from fume hoods, canopy hoods and other exhausts require a correspondingly large volume of air to be supplied to a laboratory.

Figure 4. Room ventilation requirements drive the supply air volume in laboratories without high cooling or exhaust loads.

Exhaust-driven laboratories, such as teaching laboratories, are virtually filled with fume hoods and canopy hoods. Fume hoods exhaust large quantities of air in order to contain gasses, vapors, particles and other contaminants. All air exhausted from the laboratory, including fume hood exhaust, must be replaced to prevent excessively negative room pressures within the laboratory and possibly the building.

Finally, some laboratories have low cooling loads and few, if any, fume hoods and other exhaust equipment. These ventilation-driven laboratories still require high supply air volumes to dilute contaminants. The ventilation rate is normally expressed in units of Air Changes per Hour (ACH), calculated as the total air volume supplied in one hour divided by the room volume. Occupied laboratories often have ventilation rates on the order of 8 to 10 ACH, although it could be as low as 4 ACH when unoccupied[2]. In comparison, offices usually see a much lower ventilation rate, often on the order of 4 ACH.[3]

[2] National Fire Protection Association, Standard NFPA 45-2000. Section 6.3.3, p. 12.
[3] ASHRAE 2003 Applications Handbook. Chapter 3, Commercial and Public Buildings, p. 3.2.

Lab Control Type

Constant Volume

The first laboratories with mechanical ventilation, and many laboratories today, were designed as CV systems. As the name implies, the air volume supplied and exhausted from a CV laboratory does not change. Time of day, day of the week, holidays and building usage have no impact on operation of the HVAC system.

CV laboratories are the best option for ventilation driven laboratories, where the air changes per hour rate determines the required supply air volume. In ventilation-driven laboratories, the air changes per hour ventilation rate provides enough air to ensure the expected cooling loads and the exhaust make-up air needs are met. Therefore, there is no need to supply more air to the space.

Some facilities choose to use CV control even for spaces driven by temperature or hood make-up air. In order to maintain the simplicity of CV controls, these facilities always supply and exhaust air volumes to meet the maximum cooling and exhaust loads.

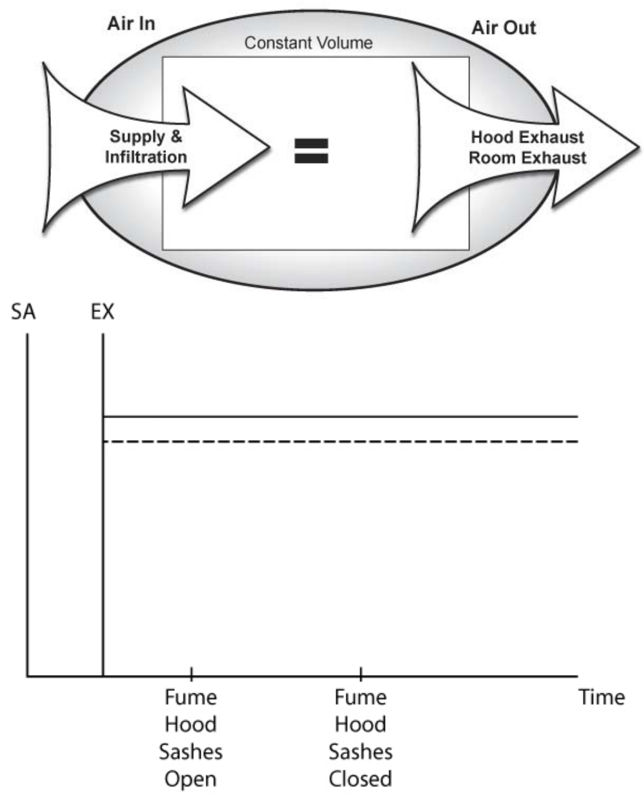


Figure 5. Airflows in constant volume laboratories remain at consistently high levels at all times. Note that the supply volume remains less than the exhaust, maintaining a negative balance.

The CV control sequence has a number of advantages, even when used with laboratories driven by exhaust or cooling. These include:

- Easy to design.
- Minimizes cost of controls.
- Few controls to maintain.

The CV sequence of operations has a number of potential disadvantages, including:

- Mechanical equipment must be sized for full-flows, increasing first and operating costs of the fans, chillers and other capital equipment.
- Difficulties relocating equipment. Moving equipment within a building may change the HVAC system pressure distribution, resulting in a requirement to rebalance systems without pressure-independent controls.
- Limited future expansion, because there may not be sufficient system capacity to allow additional equipment.

- Limited opportunities to warn users of unsafe system operations. Monitors and controllers are not inherent to CV systems. Adding monitors to comply with recent standards[4] adds cost. Older systems without monitors cannot warn users of unsafe conditions, potentially risking exposure.

2-Position

Initial efforts to reduce the operating expenses associated with the high continuous operations of constant volume control focused on reducing airflow in unoccupied laboratories. Under this scenario, full airflows are present only when laboratory users are present. Reduced airflows are possible when the laboratory is unoccupied because users are not present to create airflow obstructions at fume hoods.

As with constant volume laboratories, use the 2-Position control sequence for ventilation-driven laboratories do ***not*** use 2-Position control if exhaust or cooling loads require more supply air.

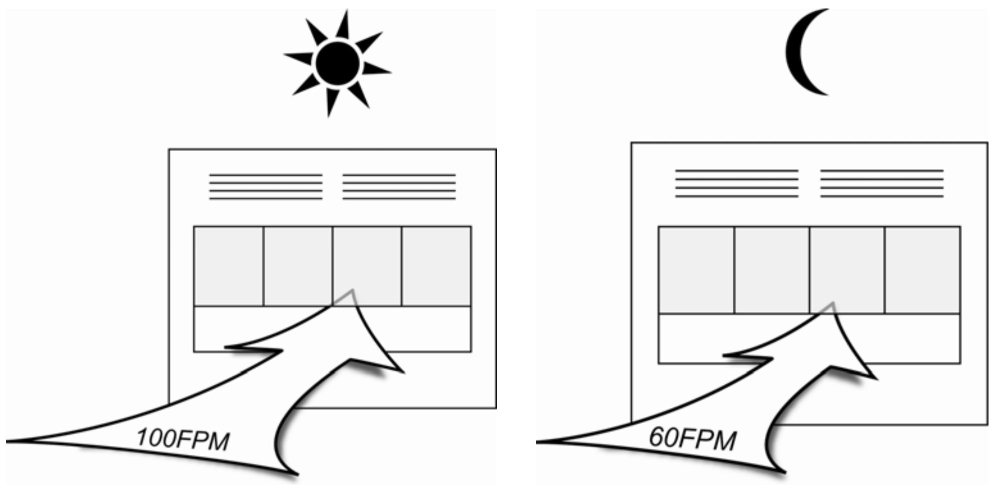


Figure 6. 2-Position controls reduce airflows and therefore operating expenses when the space is unoccupied.

The 2-Position control sequence offers similar advantages and disadvantages as the constant volume control sequence. Benefits include:

- Easy to design.
- Low cost of controls when compared to a variable air volume system.
- Decreased flows during unoccupied hours can reduce operating costs when compared to a constant volume system.

Weaknesses of the 2-Position control system mirror those of the constant volume control system:

- Mechanical equipment must be sized for full-flows, increasing first and operating costs of the fans, chillers and other capital equipment.
- Difficulties relocating equipment. Moving equipment within a building may change the HVAC system pressure distribution, resulting in a requirement to rebalance systems without pressure-independent controls.
- Limited future expansion, because there may not be sufficient system capacity to allow additional equipment.
- Limited opportunities to warn users of unsafe system operations. Monitors and controllers are not inherent to 2-Position systems. Adding monitors to comply with recent standards[5] adds cost. Older systems without monitors cannot warn users of unsafe conditions, potentially risking exposure.

[4] ANSI Z9.5-2003, NFPA 45-2000 and SEFA 1.2-2002.

When dealing with a 2-Position system, the laboratory designer has an additional issue to consider: how to determine if occupied or unoccupied flows should be used. One method to change building mode is to use a time clock to change the state of the entire building. This method requires the least amount of additional equipment, but also offers the least flexibility. Under this scenario, virtually all the HVAC equipment in the building can be controlled to two-position. However, the entire building must return to full airflow should an employee work outside of normal building hours.

Otherwise, occupancy sensors can be used to set each laboratory back to unoccupied mode. This way, should an employee decide to work after hours, only that laboratory will return to full airflow. In addition, if a laboratory should be unoccupied during the day, its airflows could be reduced to save additional energy. The disadvantages of controlling occupancy within individual laboratories primarily consist of the additional control equipment required. Capital equipment such as air handlers and fans will require VAV controls. Individual laboratories will also require pressure-independent controls, or changing airflows in one laboratory will cascade to surrounding laboratories.

Warning

Some control systems are designed to put individual fume hoods within a laboratory into unoccupied mode while the laboratory itself is occupied. This practice has the potential to increase chemical exposures when fume hoods go from the unoccupied to occupied state. No control system can instantaneously increase airflow. Someone walking past an open hood with a reduced face velocity can pull vapors out before the controls can completely react, risking exposure.

Variable Air Volume (VAV)

VAV laboratories reduce supply and air volumes to the minimum required to maintain temperature, ventilation and safe fume hood face velocities. When fume hood sashes are lowered, VAV fume hood controls reduce the air exhausted to maintain constant velocity of air through the sash opening while VAV laboratory controls correspondingly reduce supply air to balance the space. Similarly, VAV room controls increase general exhaust volume to balance the laboratory when increasing the supply air volume to cool the space.

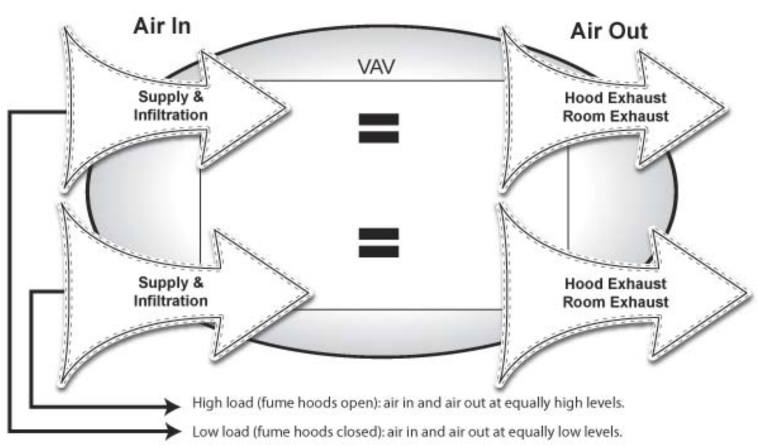


Figure 7. Supply and exhaust flows in VAV laboratories are correspondingly high or low to maintain room pressure or balance.

VAV laboratories offer a number of advantages and disadvantages when compared to constant volume and 2-position labs. Advantages include:

- Reduced energy costs because less air will be conditioned, supplied and exhausted when loads decrease.
- Use unoccupied mode to decrease supply and exhaust airflows to further save energy expenses.

[5] ANSI Z9.5-2003, NFPA 45-2000 and SEFA 1.2-2002.

- Applying diversity (see Appendix B) decreases maximum design airflows, resulting in smaller capital equipment such as fans, ductwork, and air handlers.
- Pressure-independent VAV controls adapt to system changes when equipment is moved or added, requiring rebalancing only in areas directly affected by the change as opposed to the entire building.
- VAV controls alarm if fume hood face velocity and room pressure differential or balance reach potentially unsafe levels.

Disadvantages of the VAV system include:

- Reduced airflows are dependent on users closing fume hood sashes to reduce airflows. VAV system will not reduce airflows if sashes remain open.
- Increased HVAC system complexity, including requirements for VAV controls on fans, air handlers and other capital equipment.

Diversity

For a laboratory HVAC system to operate to its full potential, equipment must be sized properly for the expected loads and airflows. A VAV laboratory can be expected to have lower airflows than other laboratory types. Taking diversity into account simply means sizing building equipment for expected airflows instead of the maximum possible airflows.

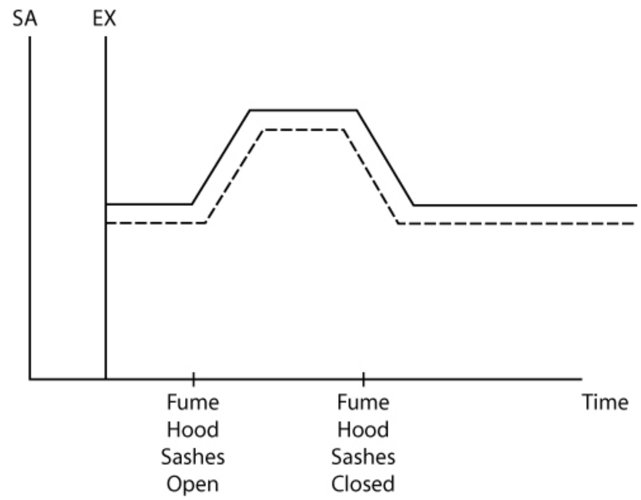


Figure 8. Airflows in VAV systems change, yet supply consistently remains less than exhaust to maintain a negative balance.

This does entail a level of risk however, for the needed airflow will not be available should all devices require it. When predicting VAV airflows in a laboratory building, diversity levels must be decided on a case-by-case basis. No two laboratories will experience exactly the same usage patterns. Industrial Hygiene professionals must be consulted to determine the level of hazard to be present in a laboratory. Only after these steps have been performed can a realistic estimate of the building airflows be determined. Appendix B details the use of statistics to predict building airflows once the expected hood usage and safety factor have been determined.

Diversity is used on buildings using manifolded exhaust systems; there must be a large number of variable volume devices in the system for diversity to be effectively applied. If each fume hood has its own fan, then downsizing the fan will cause insufficient airflow when the hood requires its maximum exhaust. Similarly, when sizing ductwork and other equipment, it must be assumed that any individual laboratory could require its full airflow.

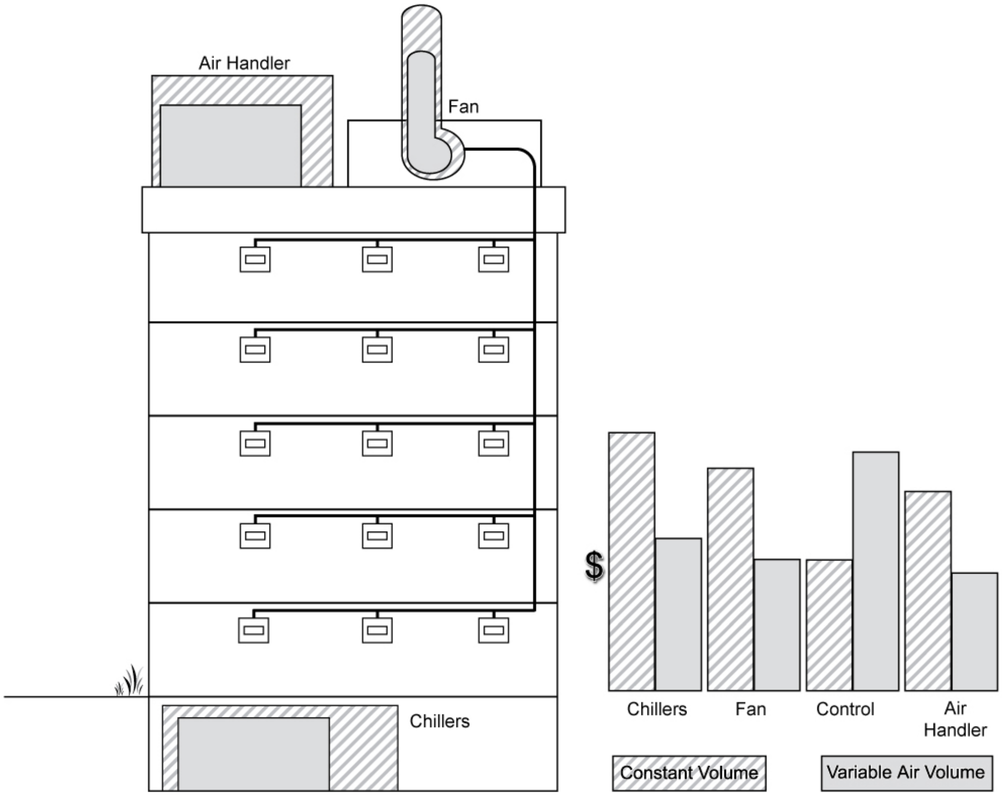


Figure 9. Applying diversity reduces maximum airflows, shrinking capital equipment and off-setting the additional cost of controls.

The savings from diversity result from the assumption that not all laboratories will require full airflow at the same time. These savings take the form of downsizing capital equipment. Much of the cost of a buildings HVAC system is in the chillers, fans, air handlers, and other large equipment. Sizing this equipment for expected loads instead of maximum possible loads can cover much of the cost premium of VAV controls. Operating expenses may also decrease, because HVAC equipment is most efficient at full-flow operation—equipment sized for expected airflows will run at close to peak capacity instead of part-load.

Laboratory Room Controls

Laboratories are maintained at a lower pressure than surrounding areas, called negative pressure, to prevent contaminants from spreading through a building. In constant volume laboratories, the supply and exhaust airflows are balanced to always maintain a given airflow. In constant volume 2-position laboratories, the supply and exhaust airflows are controlled to maintain either full or reduced airflows. For either of these types of laboratories, either venturi valves or standard HVAC controls are normally used. Room monitors also may be used to warn facilities maintenance staff and laboratory users if room airflows or pressure differentials are not maintained.

In a VAV laboratory, airflows almost constantly change since fume hood sashes move and space temperature loads vary. Some sort of control system is needed to modulate supply and room exhaust volumes in order to maintain room pressure. Engineers choose direct pressure, flow tracking or flow tracking with pressure feedback controls. In order to determine which method is best for each situation, an understanding of each system's limitations is needed. Appendix C illustrates how each control type responds to common disturbances.

Direct Pressure Controls

Direct pressure controls may be the simplest style of VAV room controls. With this control style, the room controls modulate the supply and exhaust dampers to maintain room pressure differential between the laboratory and its reference space. If the direct pressure changes for any reason, the controls take appropriate action. Direct pressure controls can therefore hold the room pressure differential closest to setpoint, which is important for rooms housing highly hazardous substances.

Like any control system, direct pressure controls have limitations. Direct pressure controls will modulate supply and general exhaust dampers to any change in room pressure differential, whether the reaction is wanted or unwanted. Effectively applying direct pressure controls requires designing the building to keep the reference pressure stable. Key requirements include:

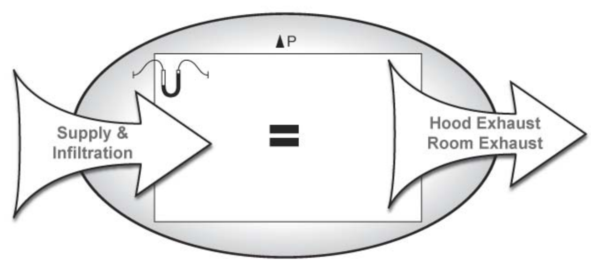


Figure 10. Direct Pressure Controls maintain an actual pressure differential. They are best used in small labs, lab with closed doors and labs with low traffic.

- Maintain stable pressure in the reference space. Pressure fluctuations in the reference space cause corresponding disturbances to the room pressure differential.
- Keep laboratory doors closed. When the door is closed, the open area comprised of the cracks around the sides and top of the door plus any undercut is very small. When the door opens, the open area could increase by a factor of 20 or more. The room pressures of the reference and laboratory spaces will almost immediately equalize, causing the direct pressure controller to minimize the room supply and maximize the room exhaust in order to return the room pressure differential to setpoint. This large difference between exhaust and supply flow rates could cause problems with room pressure differentials for adjacent spaces or even the building pressure. Door switches, used to lock the supply and exhaust airflows or change to a reduced room pressure setpoint, can reduce this problem.
- Avoid elevators opening directly to the reference space without a vestibule. As the elevator moves between floors, it pumps air into or out of the shaft, altering the pressure of adjacent spaces.

- Avoid doors opening directly to the outdoors. Gusts of wind impacting or blowing past the building can influence the reference pressure even when the door is closed. Should this door open, then the reference pressure will quickly equal the pressure outside, forcing the direct pressure controller to compensate.

Flow Tracking Controls

Flow tracking controls are designed to maintain larger exhaust flows than supply flows. Because more air is exhausted than supplied, the laboratory balance is negative. The extra air exhausted, commonly referred to as the “offset” air, is actually supplied to adjacent spaces, entering the laboratory through doors and other penetrations. Flow tracking controls modulate the supply and exhaust volumes to maintain a constant offset.

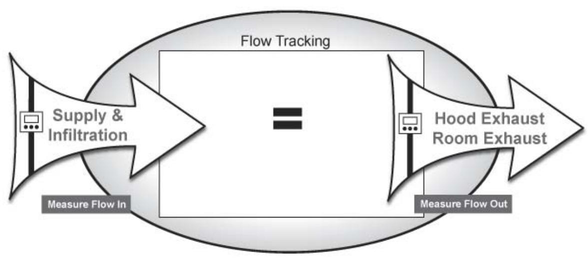


Figure 11. Flow Tracking Controls exhaust more air than is supplied to maintain laboratory balance, not pressure differential. They are best in high-traffic laboratories, open laboratories without doors and laboratories of low to medium hazard.

To work correctly, room controls using flow tracking must measure all ducted supply and exhaust airflows. Room pressure is not part of flow tracking controls—room pressure changes will go undetected. Open doors, which can cause challenges for direct pressure controls, are ignored by flow tracking controls. While an open door causes the room pressure differential to drop to zero, it does not directly affect the supply or exhaust airflow so the room controller will not take action. Flow tracking controls can therefore be used with open architecture laboratories, designed and constructed without doors.

Some engineers prefer flow tracking controls because supply and exhaust airflows are easy to predict, simplifying the sizing of fans, air handlers, ductwork and other capital equipment. In practice when designing a laboratory with flow tracking controls, the offset is calculated based on the number of doors and other penetrations into the space. Once the laboratory is constructed, the actual offset is adjusted until the space is sufficiently negative. The room controls are then configured to maintain this offset, working on the assumption that the building dynamics will not change.

Flow tracking controls should not be used in laboratories housing highly toxic substances, because they can only assume that the room pressure differential is maintained.

Flow Tracking with Pressure Feedback Controls

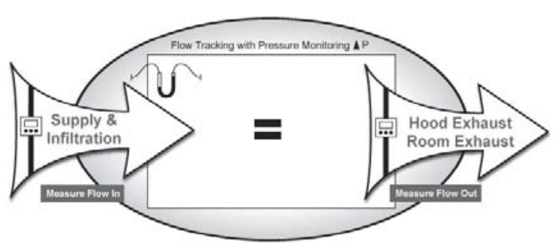


Figure 12. Flow Tracking with Pressure Feedback Controls combines the safety of Direct Pressure and the stability of Flow Tracking Control Systems.

Flow tracking with pressure feedback combines flow tracking control with a measurement of room pressure differential. This control combines benefits of both flow tracking and direct pressure control systems, although it has some of the limitations of both systems.

In a room using the flow tracking with pressure feedback control system, all ducted supply and exhaust airflows are measured like with any flow tracking system. Supply and exhaust flows are modulated to maintain a specific offset, maintaining negative laboratory balance. However, the hybrid control system also measures the room pressure differential.

The room controls use the room pressure measurement to slowly adjust the offset, correcting long-term changes in room dynamics. Should the room pressure differential change too quickly, the room controls can alert facilities maintenance and laboratory personnel of the potentially unsafe conditions.

The measure of room pressure differential introduces many of the limitations of direct pressure controls to flow tracking with pressure feedback controls. These controls require the reference space pressure to be relatively stable. While quick fluctuations in the room pressure differential will be ignored by the control system, they can cause alarms if room pressure differential undergoes sufficient changes.

Doors, therefore, do not cause the same level of challenge with flow tracking with pressure reset controls as they do with direct pressure controls. When a door is opened, it almost immediately causes the room pressure differential to drop to zero. The pressure feedback component of this control system can only slowly adjust the offset to maintain room pressure setpoint. In the short time that a door is typically opened, flow tracking with pressure feedback controls will not significantly adjust the offset so the supply and exhaust airflows will remain nearly constant. Should the door be propped open, however, flow tracking with pressure feedback controls will eventually increase the exhaust and decrease the supply, within field-configured limits, similar to direct pressure controls.

Temperature Control

Maintaining laboratory balance and pressure is not sufficient. The room controller must maintain the temperature at levels appropriate for laboratory personnel and processes. Standard VAV temperature control sequences are effective at maintaining laboratory space temperature.

In the standard VAV temperature control sequence, hot water in the reheat coil warms cool supply air. The warm supply air then enters the space. If the space is too cool, the temperature control system reduces the volume of supply air to its minimum setpoint and then uses more hot water to heat the air. If the space is too warm, the temperature control system decreases the amount of hot water heating the supply air, and then increases the volume of cool air delivered to the room.

Space temperature control therefore changes the volume of supply air delivered to a laboratory. Similarly, room controls must adjust supply air volume in response to changing exhaust volumes from fume hoods and other VAV equipment. These changing supply air volumes will affect space temperature.

Effective control of laboratory temperature therefore requires integrating temperature control functions into the room controller. Bolting a temperature control system to a room control system adds needless complexity and the potential for unfavorable interactions when compared to a laboratory system combining airflow and temperature controls.

Fume Hoods

Fume hoods are safety devices, used to contain chemicals with long-term exposure hazards. Fume hoods are not appropriate for protection from substances causing significant health consequences with only isolated, short-term exposures.

It is important to note that the technical term for a fume hood is a laboratory chemical hood. However, industry convention remains to call them fume hoods. This primer will therefore call them fume hoods.

The exhaust system draws air through all openings in a fume hood, including the face. These entering airstreams prevent chemicals inside the air from escaping. Air in the fume hood is then exhausted, drawing vapors, gasses and particulates in the hood out.

Figure 13. Benchtop fume hood. Photo courtesy of Fisher Hamilton LLC.

Fume hoods come in different sizes and configurations. There are two basic configurations of fume hood. Benchtop hoods, as the name suggests, are physically placed on the laboratory bench. Floor-mounted hoods, commonly called walk-in hoods, are therefore mounted on the floor. A floor-mounted hood cannot offer any protection to a user who actually enters the hood.

Architectural Issues

A fume hood commonly draws room air into it at a face velocity, or sash opening, of 100 fpm, which is approximately 1 mile per hour. Room air currents have a large impact on a hood’s ability to contain. Practices to eliminate the effect of room air currents, called competing airflows, on fume hoods are:

- Choosing and placing supply diffusers to keep competing airflows less than 30% of the face velocity. For a 100 fpm face velocity, room air currents at the hood must be limited to a 30 fpm maximum. This may also require ensuring that each hood has sufficient space around it.
- Placing fume hoods away from walkways within the lab. People commonly walk at a speed of 2–3 miles per hour, creating a “wake” that can draw air out of a hood.
- Locating fume hoods away from doors. Laboratories are normally held at a lower pressure than surrounding areas. When the door is open, air will enter the laboratory, potentially upsetting the fume hood. Additionally, it may not be safe to force people to pass by the fume hood to exit the laboratory should there be a spill or other accident in the fume hood.

Figure 14. Diffusers blowing air at fume hoods can cause turbulence, hindering containment.

Fume Hood Testing

It can be difficult for users to verify proper operation of the hood. Users cannot accurately gauge a hood's face velocity to determine if it has dropped to unsafe levels. The concentration of chemicals in a hood is low enough to render them invisible. Odor is not a sufficient indicator, because the level of chemical required to be hazardous is independent of our ability to smell the chemical. Suppliers of laboratory equipment and services have therefore developed testing procedures, such as ASHRAE 110, to help ensure user safety.

Initially certifying fume hoods involves three different tests: flow visualization, face velocity and containment. After acceptance, annual face velocity tests are sufficient absent renovations to the HVAC system, laboratory or hood[6].

Test 1—Flow Visualization

The first test to measure a fume hood's performance is to perform a flow visualization, or smoke, test. In this test, a smoke generator is moved around the open face of the fume hood. How the smoke enters the hood should be observed. Any areas where smoke does not enter the hood or even comes out should be noted and corrected before continuing with other tests.

Test 2—Face Velocity

Once the flow visualization test has qualitatively determined that the airflow into the hood is uniform, quantitative testing is performed. In this testing, the open area of the face is divided into sections of approximately 1 square foot. Air velocity is measured at the center of each of these sections. The face velocity at each of these points should be within 20% of the measurement average. Any points falling outside of this range should be corrected before continuing.

Face velocity is sometimes recommended to be between 80–120 fpm. However, hood design, HVAC system design and competing airflows will all affect a hood's ability to contain. Consequently no face velocity will ensure containment. Face velocity is only considered to be an indicator of containment if a containment test has been performed and there have not been significant changes to the laboratory or fume hoods.

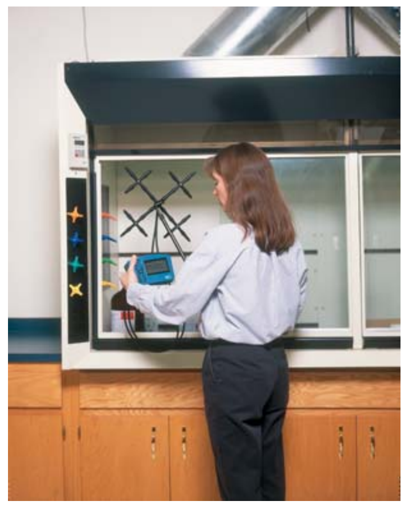


Figure 15. Face velocity is the primary method of evaluating fume hood performance after initial set-up.

Monitors are now required to ensure the long-term performance of fume hoods. These monitors measure face velocity, alarming if it should drop to potentially unsafe levels.

Test 3—Containment

The third test to measure a fume hood's performance is to measure the containment itself. Most industry organizations, such as ASHRAE[7], AIHA[8] and SEFA[9], recommend actually testing the hood's ability to contain a chemical under controlled conditions, recognizing that face velocity alone cannot ascertain a hood's ability to control exposures.

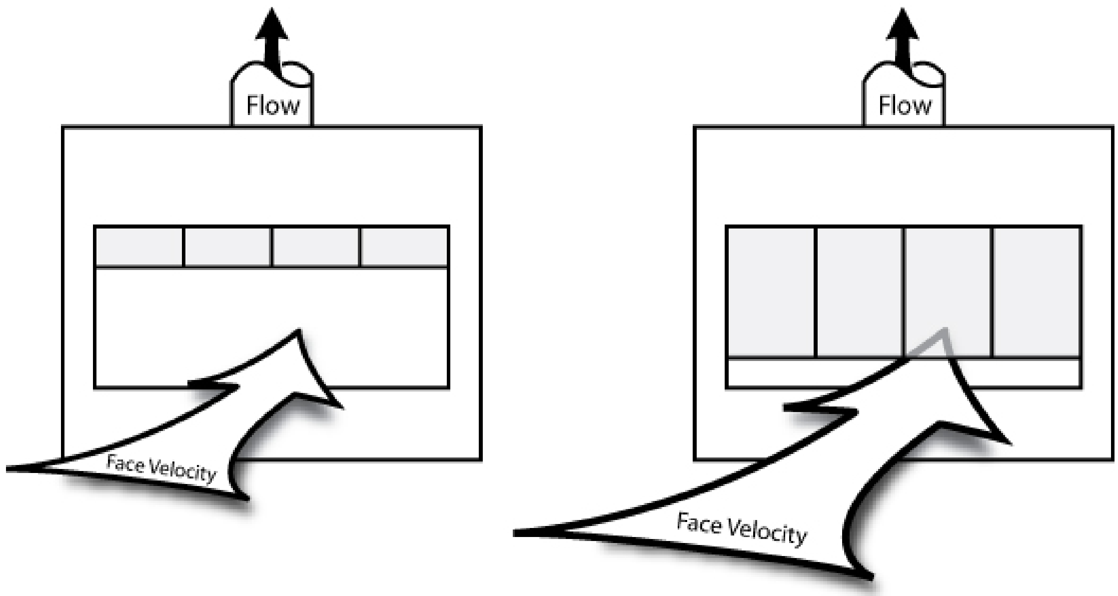
6 ANSI Z9.5-2003. Section 3.3.2.
7 American Society of Heating, Refrigerating and Air Conditioning Engineers
8 American Industrial Hygiene Association
9 Scientific Equipment and Furniture Association

Containment testing typically is based around releasing a known flow rate of a tracer gas inside a fume hood. A mannequin is positioned in front of the hood to disturb airflow and the concentration of the tracer gas at the mannequin's mouth measured. These containment tests cannot guarantee safety either, because test conditions may differ from as-used conditions. A facility's industrial health and safety staff must determine the validity of a containment test and interpret the results.

Fume Hood Control Type

Constant Volume Fume Hoods

Just as the first laboratories were designed with constant volume ventilation systems, so too were the first fume hoods. As the name implies, the air volume exhausted from these fume hoods should not change. Time of day, day of the week, holidays and hood usage should have no effect the air volume passing through the hood.



Constant volume fume hoods may be the best choice in laboratories driven by ventilation and other labs with a constant volume supply. In these laboratories, any air not exhausted through the hoods must be exhausted through the room exhaust to maintain laboratory air balance. Constant volume hood controls have other advantages, including:

- Easy to design HVAC system
- Minimizes cost of controls

Because the exhausted air volume does not change, the velocity of air entering the hood will change when the sash is moved or the hood is loaded with equipment. On fume hoods with bypass, the face velocity can rise as high as three times the design face velocity when the sash is closed. The face velocity will rise even higher on hoods without a bypass. In addition, face velocities decrease when the sash is raised, possibly to unsafe levels.

- Face velocities greater than 150 fpm can create eddy currents in front of the user, pulling contaminants into the user's breathing zone.
- High velocities can entrain dusts and evaporate chemicals, potentially affecting experiments and processes in the hood.
- High energy costs to condition large quantities of exhaust air.

Airflow with Constant Volume Hoods

For a group of laboratories with 30 hoods driven by hood exhaust air, the airflow rate will be:

30 hoods * 1,000 cfm/hood = 30,000 cfm

at all times.

Other challenges with constant volume controls include:

- Precludes downsizing of capital equipment in laboratories driven by hood make-up air.
- Moving equipment within a building may change the HVAC system pressure distribution, resulting in a requirement to rebalance systems without pressure independent controls.
- High supply air volumes create potential for competing airflows affecting hood containment.

Fume hood manufacturers have developed new hoods designed for appropriate containment of pollutants at face velocities of 60 or even 40 fpm. These manufacturers claim to gain the energy-saving opportunities of a VAV hood can be gained while maintaining the simplicity of a constant volume HVAC system by using a fume hood with a low exhaust volume. While low flow hoods can be an effective solution for some laboratories, they do not fit all applications. Challenges facing low-flow fume hoods include:

- Many local codes require fume hood face velocities of 100 fpm. Low flow hoods may require obtaining a variance to operate at lower face velocities.
- Low flow hoods cannot reduce the volume of laboratory air exhausted below that needed for ventilation, resulting in less dilution of chemicals in the laboratory air. Some manufacturers have touted laboratory systems with fewer air changes per hour to increase the apparent energy savings from their hoods at the expense of safety.
- VAV hoods will exhaust less air when the sash is closed than a low flow hood. For facilities with good sash management, VAV hoods have the potential to reduce energy costs even further.

2-Position Fume Hoods

When disturbances to the airstreams entering a hood are eliminated, a hood can adequately contain at reduced flow rates. 2-Position hoods are therefore designed to maintain a high safe face velocity when the laboratory is occupied and a reduced, safe face velocity when the laboratory is unoccupied. Fume hoods and the laboratory should use the same method of determining occupancy.

In an occupied laboratory, 2-Position fume hoods function as constant volume hoods. The airflow exhausted is not affected by sash position or equipment loading. These hoods are therefore used in the same type of laboratories as constant volume hoods, namely ventilation-driven laboratories and other laboratories with a constant supply volume. Using 2-Position hoods in a laboratory confers advantages including:

- Relatively easy to design, although the HVAC system is no longer constant
- Simple, inexpensive controls
- Lower operating costs than constant volume controls, because less air is conditioned, supplied and exhausted during unoccupied hours

Airflow with 2-Position Hoods

For a group of laboratories with 30 hoods driven by hood exhaust air, the airflow rate will be:

Day: 30 hoods * 1,000 cfm/hood = 30,000 cfm
Night: 30 hoods * 600 cfm/hood = 18,000 cfm

This is a reduction of 12,000 cfm during Night hours.

When considering 2-Position hoods, it is important to remember that they have the same disadvantages as constant volume hoods because the air volume exhausted does not change during occupied hours. Therefore, fume hood face velocities will vary with sash position and equipment loading.

For fume hoods designed for a face velocity of 100 fpm when the sash is open, this means that the face velocity can rise to 300 fpm on fume hoods with bypass and even higher on fume hoods without bypass. These high face velocities can cause challenges including:

- Face velocities greater than 150 fpm have the potential to create eddy currents in front of the user. pulling contaminants into the user’s breathing zone.

- High velocities can entrain dusts and evaporate chemicals, potentially affecting experiments and processes in the hood.
- High energy costs to condition large quantities of exhaust air in laboratories not driven by ventilation.

Other challenges associated with 2-position controls include:

- Precludes downsizing of capital equipment in laboratories driven by hood exhaust air, because airflow is not reduced during occupied hours.
- Moving equipment within a building may change the HVAC system pressure distribution, resulting in a requirement to rebalance systems without pressure independent controls.
- High supply air volumes create potential for competing airflows affecting hood containment.
- Requires 2-position or VAV controls for the HVAC system.

VAV Fume Hoods

VAV fume hoods are designed to always exhaust only the air required to maintain face velocity at the desired setpoint. With a VAV fume hood, only the amount of air required to maintain an appropriate face velocity is exhausted. This commonly means that the air exhausted will increase directly with the sash height. When fume hoods users follow proper practices, meaning that hood sashes are only raised when the equipment in a hood is manipulated, VAV controls can dramatically reduce the air exhausted from a hood. Use VAV controls in labs with supply air volume driven by hood make-up air or cooling loads.

Airflow with VAV Hoods

For a group of laboratories with 30 hoods driven by hood exhaust air, the airflow rate will be:

5 hoods in use	* 1,000 cfm/hood	=	5,000	cfm
5 hoods with sash open	* 1,000 cfm/hood	=	5,000	cfm
20 hoods with sash closed	* 200 cfm/hood	=	4,000	cfm
Total		=	14,000	cfm

This is a reduction of 16,000 cfm from Constant Volume.

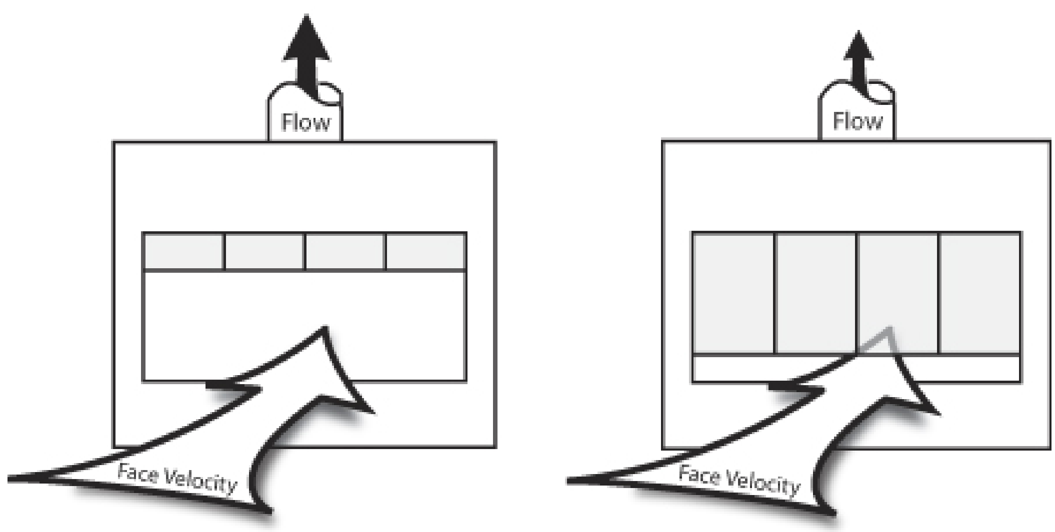


Figure 17. By reducing flow with open sash area to maintain a constant face velocity, VAV hoods can reduce operating expenses while enhancing safety.

VAV fume hoods prevent turbulence associated with high face velocities by maintaining face velocity at setpoint. VAV fume hoods may therefore increase the safety of a fume hood. To take advantage of this, some facilities use VAV fume hoods even in constant volume laboratories.

VAV fume hoods offer a number of other advantages and disadvantages when compared to constant volume and 2-position hoods, including:

- Reduced energy costs because less air will be conditioned, supplied and exhausted when loads decrease.
- Reduced airflows may allow for capital equipment, such as fans and air handlers, to be downsized.
- Easier to add or move equipment because VAV controls can adapt to system changes.
- Alarms to warn of potentially unsafe conditions are included with VAV controls.

Disadvantages of the VAV system include:

- Reduced airflows are dependent on users closing fume hood sashes to reduce airflows. VAV system will not reduce airflows if sashes remain open.
- Increased HVAC system complexity, including requirements for VAV controls on fans, air handlers and other capital equipment.

VAV Hood Controls

VAV hood controls are designed to maintain a constant face velocity, so the hood only exhausts the air necessary. There are two styles of VAV hood controls—those using sash position and those using sidewall sensing.

Sash Position Controls

This method of controlling fume hood face velocity is to divide the volume of air exhausted from the hood by the fume hood open area. Sash position-based control systems measure exhaust air volume and sash position, which are easier measurements to make than face velocity. The exhaust volume measurement from sash position systems also is used in flow tracking systems, allowing the room controls to react to changes in fume hood exhaust volume.

However, these sash position controls assume that face velocity can only change if the exhaust volume or the open area changes. Under certain common conditions, safety may be jeopardized:

- Equipment in a hood, splash shields, and users working in a hood can all effectively block off part of the open sash area. Since none of these incidents move the sash or change the exhaust volume, face velocity will change. Undetected changes to face velocity have the potential to result in loss of hood containment.
- Cross-currents and other competing airflows often are the cause when a fume hood cannot contain. Sash position systems cannot detect these conditions to alert users of the potential hazard, instead instilling a false sense of security by indicating normal, safe conditions.

Sidewall Sensing Controls

Fume hood controls based on sidewall sensors actually measure the average fume hood face velocity. They can therefore detect face velocity changes caused by equipment in a hood, competing airflows and sash movements. VAV fume hood controls based on sidewall sensors therefore maximize safety by detecting virtually any change to face velocity.

Competing airflows present a challenge for sidewall sensing VAV hood controls, just as they present a challenge for the fume hood itself. Competing airflows have the potential to actually pull contaminants out of the hood by overpowering the face velocity. Sidewall sensing VAV controls will often see competing airflows as an overly-fluctuating face velocity. In response, the controls will modulate the damper or other control device in an attempt to return face velocity to setpoint. Since the competing airflow is seen as a constantly fluctuating face velocity, sidewall sensing controls may appear to hunt and never maintain stable control. In reality, the controls simply indicate challenges affecting fume hood containment.

Control Components

There is more to outfitting a laboratory HVAC system than choosing appropriate control strategies. The components used can have a profound effect on system operation, and, therefore, must be chosen appropriately. In a manifolded system, control components are usually venturi valves or dampers with flow stations. Dampers and flow stations could be mounted either together in a VAV box or as individual pieces.

Dampers

Dampers are a common control device in almost any HVAC system. When using dampers for laboratory control systems, choose high-quality dampers constructed from appropriate materials to ensure long-term, successful operation. Blade and frame dampers have a number of features making them suitable for use in laboratory control systems, including:

Figure 18. Blade-and-frame dampers can be an excellent choice when cost and pressure drop are primary considerations.

- Low pressure drop results in lower-pressure system. Full flow pressure drops are on the order of 0.1 inches H_2O, meaning that fan sizes and the use of welded ductwork can be minimized. Low pressure drops generate less unwanted noise that could be transmitted to the laboratory space. Finally, low pressure drops save fan energy and operating costs. Using dampers in high-pressure systems typical of venturi valves may result in controllability and noise issues.
- Dampers are available constructed from virtually any material. While galvanized dampers are common in supply and room exhaust locations, fume hood exhausts can contain corrosive vapors. Dampers are readily available with protective coatings or constructed from stainless steel and other materials to resist attack.
- When used with a fume hood or laboratory control system, a system with pressure dependent dampers becomes pressure independent. As duct static pressure changes, measured airflows, face velocities and pressure differentials will also change. The control system senses the effects of these airflow changes and modulates the damper appropriately.

Flow Stations

When dampers are used in flow tracking laboratory control systems, airflow measurements are needed for proper room control. Flow stations are used in conjunction with dampers to measure airflow through a duct. Flow stations are well-accepted control components. Like dampers, they are available in a variety of materials, although anodized aluminum and stainless steel are most common. Flow stations do have characteristics to be considered as part of the laboratory control system, including:

Figure 19. Flow stations are used in conjunction with dampers to measure volumetric airflow.

- Duct velocities must be considered when installing flow stations. Pressure-based flow stations normally require a duct velocity greater than 400 fpm to maintain acceptable accuracy. Linear flow stations, based on thermal anemometry, offer the ability to measure down to nearly no-flow conditions. Linear flow stations are not normally used in corrosive exhausts, like that of fume hoods.

- Accuracy of a pressure-based flow station varies with the flow rate. These flow stations are most accurate at high flow rates and less accurate at low flow rates. Determining expected error in the control system is therefore more difficult than with systems utilizing venturi valves.
- Flow stations may require sections of straight ductwork to give accurate readings. Laboratories often are characterized by large airflows from many devices, making it a challenge for the HVAC designer to fit all the necessary ductwork into the space given. Providing additional straight sections of ductwork to allow for accurate measurements can be a difficult task.

For systems using dampers and flow stations, many designers chose to use VAV boxes, or factory-assembled dampers with flow stations, instead of separate components. For supply airflows, VAV boxes can be ordered with integral heating coils and insulation, further reducing field assembly. By minimizing field installation labor requirements, VAV boxes can reduce installation costs.

Venturi Valves

A venturi valve consists of a spring-loaded cone inside the valve body. As duct static pressure changes, the spring positions the cone to maintain a constant airflow. Moving the cone’s shaft sets the venturi valve to a new airflow.

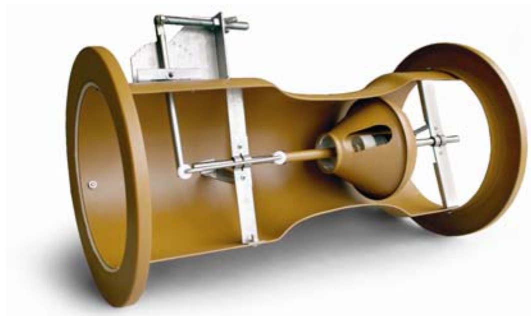


Figure 20. Venturi valves trade pressure drop and initial expense against eliminating straight duct runs.

Venturi valves have a number of features making them well-suited for laboratory HVAC controls, including:

- Venturi valves have a large pressure drop, which serves to condition the airflow and eliminate requirements for upstream and downstream straight duct runs. As long as there is physically room for the venturi valve, it can function effectively.
- Sizing of venturi valves is very inflexible. Venturi valves will only function with the proper range of static pressure drops. Similarly, each size venturi valve is good for predetermined airflows. This lack of flexibility, however, actually makes design easier for the consulting engineer. To size venturi valves, an engineer simply matches the needed flow rates to the catalogued values.
- Venturi valves are accurate to percent of reading, not percent of scale. Venturi valves are therefore most accurate at low flows, with less accuracy at high flows. In other words, a venturi may be accurate to 5 cfm on a 100 cfm exhaust, but only be accurate to 100 cfm on a 2,000 cfm exhaust.

Venturi valves have a number of limitations, as well. These include:

- Venturi valves have a high pressure drop because the mechanical spring must be sufficiently compressed in order to operate properly. Venturi valves therefore are normally designed with a pressure drop of 1.0 inch H_2O at full flow, which is up to 10 times the pressure drop of a damper system. The high pressure drop requires additional fan energy and raises the potential of noise in the space. Many venturi valve systems have additional mufflers installed in the ductwork to reduce the noise.
- Venturi valves must be constructed for their specific orientation. Valves to control vertical upflows, vertical downflows and horizontal flows are different and will not perform properly if installed in another direction.
- The limited flow rates of venturi valves are capable means that high flow rates will require ganging 2, 3, or even 4 venturi valves together, raising the expense of the system.
- Venturi valves are only available constructed from aluminum. Corrosion resistance can be gained through the application of coatings, but field repair of coatings can be very difficult should the valve suffer a scratch or abrasion during installation.

Conclusion

Maximizing a laboratory's functionality requires the design team, building owners and laboratory users to determine the usage and goals of the facility. Building design, laboratory design and laboratory equipment all can affect functionality.

Laboratory HVAC controls also have significant impact on building functionality. No single type of system is appropriate for all laboratories. Each control system has its own usages and limitations. An overall comparison of control strategies is listed below.

Let TSI help you evaluate the goals for your laboratory in order to develop an optimal control strategy.

	Energy Efficiency	First Cost	Future Flexibility	Safety
Constant Volume	☆	☆☆☆	☆	☆☆
2-Position	☆☆	☆☆	☆	☆☆
Variable Air Volume				
Direct Pressure	☆☆☆	☆☆	☆☆☆	☆☆☆
Flow Tracking	☆☆☆	☆☆	☆☆☆	☆☆
Flow Tracking with Pressure Feedback	☆☆☆	☆☆	☆☆☆	☆☆☆

Figure 21. Comparison of Room Control Types.

Appendix A—Other Sources of Information

Many groups have written guidelines and standards relating to laboratory design and work practices. Contact these groups for additional information, or contact TSI for a summary.

American Conference of Governmental Industrial Hygienists, Inc. (ACGIH)
1330 Kemper Meadow Dr., Suite 600
Cincinnati, OH 45240
www.acgih.org

American Industrial Hygiene Association (AIHA)
2700 Prosperity Avenue, Suite 250
Fairfax, VA 22031
www.aiha.org

American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE)
1791 Tullie Circle NE
Atlanta, GA, 30329
www.ashrae.org

American National Standards Institute (ANSI)
11 West 42nd Street, 13th Floor
New York, New York 10036
www.ansi.org

British Standards Institution
389 Chiswick High Road
London W4 4AL
United Kingdom
www.bsi-global.com

Building Officials and Code Administrators International, Inc. (BOCA)
4051 W. Flossmoor Road
Country Club Hills, IL 60478
www.bocai.org

Canadian Standards Association
5060 Spectrumway, Suite 100
Mississauga, Ontario L4W 5N6
www.csa.ca

Controlled Environmental Test Association (CETA)
4110 Lake Boone Trail
Raleigh, NC 27607
www.cetainternational.org

German National Standard
DIN Deutsches Institut füür Normung e. V.
10772 Berlin, Germany
www.din.de

International Conference of Building Officials
5360 Workman Mill Road
Whittier, CA 90601-2298
www.icbo.org

National Institutes of Health (NIH)
Bethesda, MD 20892
www.nih.gov

National Fire Protection Association (NFPA)
1 Batterymarch Park
PO Box 9101
Quincy, MA 02269
www.nfpa.org

National Research Council (NRC)
2101 Constitution Avenue, NW
Washington, DC 20418
www.nas.edu

National Sanitation Foundation International (NSF)
789 Dixboro Road
Ann Arbor, MI 48113
www.nsf.org

Scientific Equipment and Furniture Association (SEFA)
7 Wildbird Lane
Hilton Head Island, SC 29926
www.sefalabfurn.com

US Centers for Disease Control and Prevention (CDC)
1600 Clifton Road NE
Atlanta, GA 30333
www.cdc.gov

US Department of Health and Human Services
200 Independence Avenue, SW
Washington, DC 20201
www.hhs.gov

US Occupational Safety and Health Administration (OSHA)
200 Constitution Avenue
Washington, DC 20210
www.osha.gov

Appendix B—Calculating Airflows with Diversity

The ability to downsize equipment due to reduced airflows is an important economic advantage of using VAV controls. However, reducing the capacity of equipment below full flow levels creates the risk of not having the capacity required should all hoods be used at once.

In most facilities, one hood's usage is independent of other hood's usage. Teaching laboratories are a notable exception: these facilities often have times in class when all hoods in a laboratory will be in use. Understanding how a laboratory will be used is key to ensuring safe, successful operation.

Some studies have shown that many hoods are only in use for less than one hour per day[10]. Assuming a ten hour workday, this one hour of usage means there is a roughly 10% chance that a hood will be in use. Since the harm of underestimating hood usage when sizing the HVAC system is potentially dangerous, some designers choose a safety factor of 3. This raises the odds of a given hood being used to 30%. Statistics can determine the maximum number of fume hoods that will be in use at a given time. The figure below shows that for a system with 100 hoods, less than 45% of the hoods will be open with 99.9% certainty.

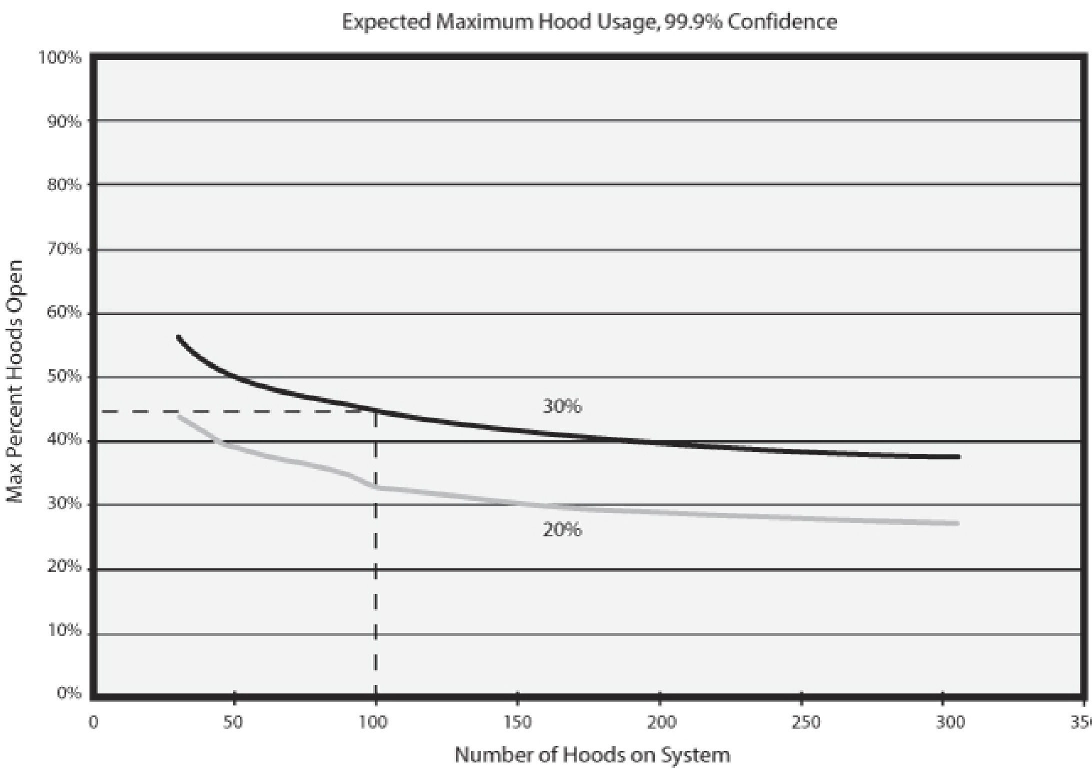


Figure 22. The percentage of hoods in use on a system is expected to decrease as more hoods are added to the system.

Fume hood usage at any facility may or may not correlate to past studies. Determining an appropriate diversity factor is a task best left to the consulting engineering designing a laboratory HVAC system in conjunction with the facilities management and the health and safety staffs responsible for maintaining the building.

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[10] Varley, John O, "Measuring Fume Hood Diversity in an Industrial Laboratory." ASHRAE Transactions, vol 99, part 2, 1993.

The maximum predicted airflow will be greater than the predicted number of hoods sashes that are open. Even hoods with closed sashes exhaust 20% or 25% of the maximum hood exhaust airflow. The figure below shows the relationship between the percent of hoods with sashes open and the maximum predicted airflow. Continuing the example of 100 hoods, the maximum predicted exhaust flow will be just under 60% of the flow when all sashes are raised.

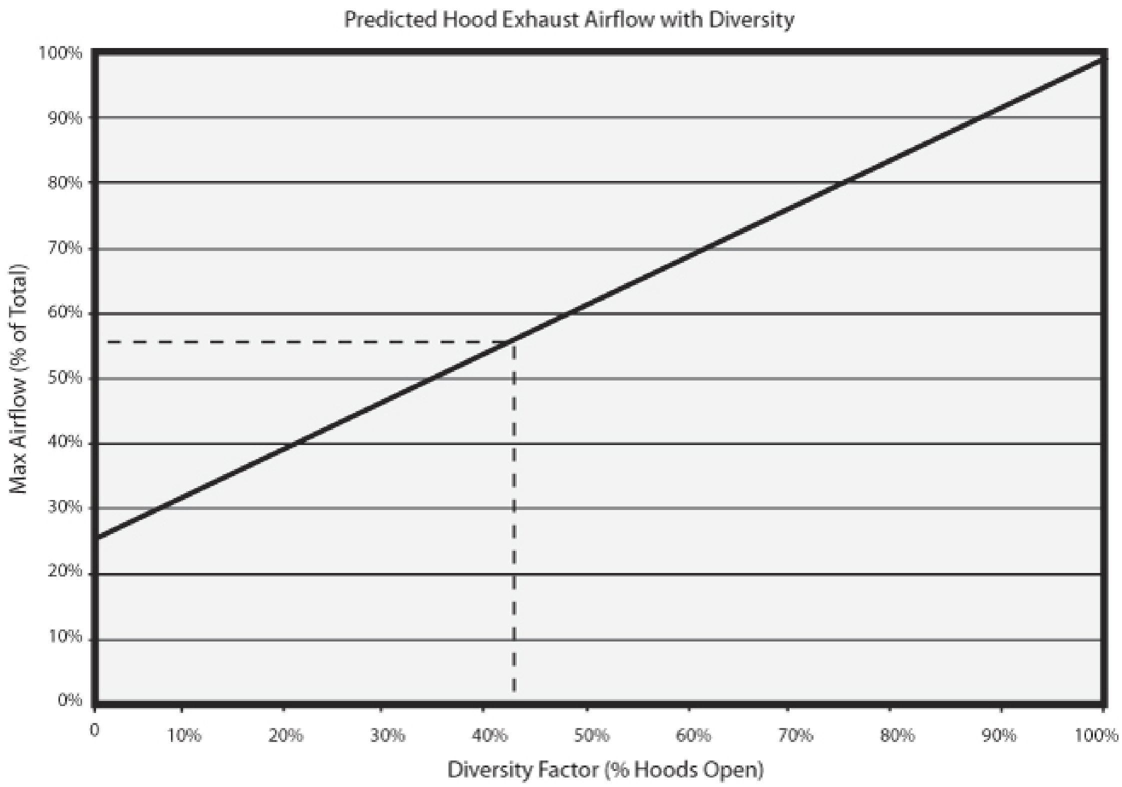

Figure 23. The percentage of hoods open can predict the maximum airflow percent, although they will not be equal because hoods exhaust air even when the sash is closed.

If these 100 fume hoods are all 4-foot benchtop units, with a maximum exhaust of 1,000 cfm per hood, the maximum possible exhaust air volume would be 100,000 cfm. With a VAV system, the expected maximum exhaust airflow is only 60,000 cfm, a reduction of 40%.

Appendix C—Control Sequence

If …	*Direct Pressure Control*
Fume hood sashes are raised. VAV hood controls increase hood exhaust flow to maintain face velocity setpoint.	Room controller sees the laboratory pressure differential become more negative. In response, the room controller closes the general exhaust. If this does not return the space to pressure setpoint, the room controller then increases the supply air volume until pressure setpoint is achieved.
Fume hood sashes are lowered. VAV hood controls decrease hood exhaust flow to maintain face velocity setpoint.	Room controller sees the laboratory pressure differential become less negative. In response, the room controller reduces the supply to its minimum volume. If this does not return the space to pressure setpoint, the room controller then increases the general exhaust volume until pressure setpoint is achieved.
An oven is turned on, heating the laboratory.	Room controller sees the laboratory temperature rise. In response, the room controller closes the reheat valve. If the reheat valve is fully closed and the space is still too warm, the room controller increases the supply air volume to bring more cool air into the space. When the supply air volume increases, the room controller sees the room pressure differential become less negative and increases the general exhaust in response.
An oven is turned off, cooling the laboratory.	Room controller sees the laboratory temperature drop. In response, the room controller decreases the supply air volume to its minimum setpoint, reducing the amount of cool air entering the space. If the space is still too cool, the room controller opens the reheat valve until the temperature returns to setpoint. When the supply air volume decreases, the room controller sees the room pressure differential become more negative and reduces the general exhaust in response.
A door to the laboratory is left open or reference pressure changes.	Room controller sees the laboratory pressure differential become less negative. In response, the room controller quickly decreases the supply airflow to its minimum setpoint and increases the general exhaust to its maximum. If the change was caused by an open door and a door switch is used, the room controller will either hold the supply and exhaust dampers in position or maintain a near neutral pressure differential.

Flow Tracking Control	*Flow Tracking with Pressure Feedback Control*
Room controller sees the increase in exhaust flow. In response, the room controller closes the general exhaust. If this does not return the offset to its setpoint, the room controller increases the supply air volume until the laboratory is balanced. Room pressure differential is unknown.	Room controller sees the increase in exhaust flow. In response, the room controller closes the general exhaust. If this does not return the offset to its setpoint, the room controller increases the supply air volume until the laboratory is balanced. Room controller slowly adjusts offset, within field-configured limits, if room pressure differential strays from setpoint.
Room controller sees the decrease in exhaust flow. In response, the room controller reduces the supply to its minimum volume. If this does not return the offset to its setpoint, the room controller then increases the general exhaust air volume until the offset is achieved and the laboratory balanced. Room pressure differential is unknown.	Room controller sees the decrease in exhaust flow. In response, the room controller reduces the supply to its minimum volume. If this does not return the offset to its setpoint, the room controller then increases the general exhaust air volume until the offset is achieved and the laboratory balanced. Room controller slowly adjusts offset, within field-configured limits, if room pressure differential strays from setpoint.
Room controller sees the laboratory temperature rise. In response, the room controller closes the reheat valve. If the reheat valve is fully closed and the space is still too warm, the room controller increases the supply air volume to bring more cool air into the space. The room controller correspondingly increases the general exhaust air volume to maintain a constant offset. Room pressure differential is unknown.	Room controller sees the laboratory temperature rise. In response, the room controller closes the reheat valve. If the reheat valve is fully closed and the space is still too warm, the room controller increases the supply air volume to bring more cool air into the space. The room controller correspondingly increases the general exhaust air volume to maintain a constant offset. Room controller slowly adjusts offset, within field-configured limits, if room pressure differential strays from setpoint.
Room controller sees the laboratory temperature drop. In response, the room controller decreases the supply air volume to its minimum setpoint, reducing the amount of cool air entering the space. The room controller correspondingly decreases the general exhaust air volume to maintain a constant offset. If the space is still too cool, the room controller opens the reheat valve until the temperature returns to setpoint. Room pressure differential is unknown.	Room controller sees the laboratory temperature drop. In response, the room controller decreases the supply air volume to its minimum setpoint, reducing the amount of cool air entering the space. The room controller correspondingly decreases the general exhaust air volume to maintain a constant offset. If the space is still too cool, the room controller opens the reheat valve until the temperature returns to setpoint. Room controller slowly adjusts offset, within field-configured limits, if room pressure differential strays from setpoint.
Room controller does not see a change in airflow, so it takes no action.	Room controller sees the laboratory pressure differential become less negative. In response, the room controller slowly increases the room offset, within field-configured limits, to return the pressure to setpoint.

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