Selection and Management of Exposure Control Devices in Laboratories

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Without the knowledge, expertise and diligence of these dedicated professionals, this document would not have been realized.

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Acronyms

AHU	Air Handling Unit
ANSI	American National Standards Institute
AIHA	American Industrial Hygiene Association
ASHRAE	American Society of Heating Refrigeration and Air Conditioning Engineers
ASSE	American Society of Safety Engineers
BAS	Building Automation System
BSL	Biosafety Level
BSC	Biological Safety Cabinet
CAV	Constant Air Volume
CFD	Computational fluid dynamics
CFM	Cubic Feet of Air Per Minute
Cx	Commissioning
DP	Difference in pressure between two adjacent spaces
ECD	Exposure Control Device
ECTI	Exposure Control Technologies, Inc.
EH&S	Environmental Health and Safety
EXF	Exhaust Fan
FHPT	Fume Hood Performance Test
FPM	Feet Per Minute
Gex	General Exhaust
HEPA	High-Efficiency Particulate Arrestor
HES	Hazard Emission Scenario
HVAC	Heating, Ventilation and Air Conditioning
IDLH	Immediately Dangerous to Life and Health
LET	Laboratory Environment Test
LVMP	Laboratory Ventilation Management Program
O&M	Operations and Maintenance
Qex, Qs, and Qt	Exhaust Flow, Air Supply Flow, Transfer Airflow
Riser	Vertical length of duct from lower floors to penthouse
SEFA	Scientific Equipment and Furniture Associations
VAV	Variable Air Volume
VFD	Variable Frequency Drive
VBE	Ventilated Balance Enclosure
VEE	Ventilated Equipment Enclosure
VSE	Ventilated Safety Enclosure
VVE	Variable Volume Exhaust

2 INTRODUCTION

The Scientific Equipment & Furniture Association ("SEFA") is a global, not-for-profit trade association whose Executive Members are among the world's largest manufacturers of laboratory furniture and equipment. SEFA was formed in 1988 and currently has 165 members in 22 countries. SEFA's essential purpose is to promote the use of "Laboratory Grade" furniture, fixtures and equipment. To insure that laboratory grade equipment is used it is important that industry representatives refer to SEFA's Recommended Practices (Standards) for laboratory grade furniture and fixtures.

Exposure control devices (ECDs) provide the main engineering control for preventing overexposure of personnel to airborne hazards generated within laboratories. ECDs can be ventilated as a part of a laboratory ventilation system or operate independently with internal fans that return filtered air back to the lab environment. In either case, proper performance means preventing overexposure through control, capture and removal of airborne hazards at or near the source. The chemical fume hood (sometimes call fume cupboard) is the primary and predominant ECD used in labs, but other types are also used including biological safety cabinets (BSCs), ventilated safety enclosures (VSEs), snorkel exhaust, slot hoods, gloveboxes, and many other special purpose devices. Each type of ECD is different in design to accommodate the application and can offer different levels of protection for users. Ensuring adequate protection requires: understanding the functional requirements of the users; understanding the characteristics of the physical process; selecting the appropriate ECD; ensuring proper design of the laboratory and the ventilation systems; and, maintaining operation within specifications verified or validated to provide satisfactory performance.

The performance of an ECD can be affected by four primary factors including its design, how it is operating, how it is used and the operating environment. The ECD must be appropriate for the intended application and utilized by people trained in proper work practices. All ECDs must be tested and maintained to ensure they perform properly and provide adequate protection for people working in the lab. The evaluation of performance and procedures used to verify proper operation must be appropriate for each device. In addition, the lab environment and supporting ventilation systems must be properly designed, tested and maintained to ensure proper performance at all possible operating modes. For the purposes of this document, the ECDs together with the components of the exhaust and air supply systems that affect ECD performance are referred to collectively as the ECD System. See Figure 1 for a diagram depicting different ECDs in a laboratory and other ECD System components that may affect performance.

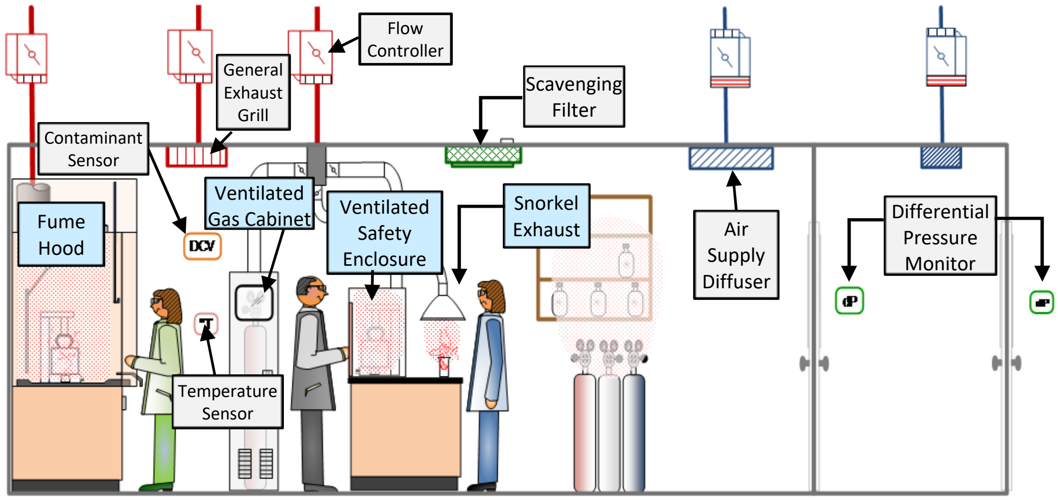


Figure 1 Side view of lab depicting various ECDs and Lab Ventilation Components

In addition to providing the primary means of protecting people working in labs, the ECD Systems can also be the greatest consumer of energy in laboratory buildings. The operation of ECD Systems is typically attributed to 50% to 85% of annual energy consumption depending on the volume of airflow, efficiency of the systems and need to condition the supply/replacement air. Poor selection, improper design, component malfunction and/or failures of ECD Systems increase the probability and/or severity of unacceptable impact to the health of people, harm to the environment, loss of property, increased liability, wasted energy and inefficient utilization of resources. The ANSI/AIHA Z9.5 *American National Standard for Laboratory Ventilation* requires laboratory management to establish a Laboratory Ventilation Management Plan (LVMP) to ensure proper selection, operation, use, and maintenance of laboratory ventilation equipment used to control airborne hazards generated during laboratory scale procedures.

2.1 Purpose

The primary purpose of this Manual is to help select and manage performance of ECDs used to control exposure to airborne hazards generated in laboratories. This Guide compliments SEFA guidelines (i.e. SEFA-1, SEFA-9, SEFA-11) for fume hoods and other exposure control devices (ECDs). This document is not intended to duplicate other standards and guidelines but instead expand the available information to help users better provide safe, efficient and sustainable laboratory environments. This Guide intends to help stakeholders increase the probability of: providing adequate protection for lab occupants; meeting the demand for ventilation; minimizing energy consumption and; reducing expenditures.

2.2 Scope

There any many types of ECDs commonly available for laboratories. These ECDs are applied to help control overexposure to airborne hazards generated during "laboratory-scale" activities. Many different types and sources of airborne hazards exist in laboratories and the selection and use of the appropriate ECD can be critical to achieving adequate safety performance. This Guide describes different types of ECDS, their intended use, and methods for managing performance. General laboratory safety practices are not included except where they may relate to the ECD System's proper function or effectiveness to control airborne hazards. This guide does not apply to comfort and air conditioning unless there are possible effects on control of airborne hazards and ECD performance.

2.3 Regulatory Basis and References

Laboratory facilities are required to ensure proper functioning and performance of ECDs used to protect people working in labs. This Guide provides information to support selection and use of different types of ECDs commonly found in laboratories. The information contained herein is meant to compliment the Scientific Equipment and Furniture Association, 5th Edition, Desk Reference, the ANSI/ASSE Z9.5-2012 "*American National Standard for Laboratory Ventilation*", the ANSI/ASHRAE 110-2016 *Method of Testing Performance of Laboratory Fume Hoods*, the Public Works and Government Services of Canada, PWGSC Standard MD15128 Laboratory Fume Hoods, the European Standard EN14175 *Fume Cupboards*. Additional resources include OSHA regulatory documents such as the OSHA 1910.1450 Laboratory Standard, the NSF International (The National Sanitation Foundation) NSF/ANSI 49 - 2008, Biosafety Cabinetry: Design, Construction, Performance, and Field Certification and ECD product guides from SEFA member manufacturers.

In all cases, facility management and environmental health and safety personnel should be consulted with questions or for guidance on risk assessment, ECD application, performance criteria and regulations regarding health, safety and the environment. *Where national, state, or local laws require a higher (specific or additional) requirements than mentioned herein, these requirements must be followed first and foremost. However, where national, state, or local laws are less stringent or less comprehensive, SEFA recommends consideration and application of the most appropriate engineering controls and measures available.*

3 ECD Types and Application

ECDs are manufactured, installed and operated to meet the functional requirements of the users and provide the primary engineering control for mitigating the risk of personnel exposure to airborne hazards in laboratories. Selection and use of appropriate ECDs requires consultation with stakeholders including researchers, lab managers, health and safety personnel, ventilation engineers and facilities maintenance personnel. Considerations during selection should include:

- The hazards and processes
  - Airborne Effluent Properties
  - Exposure Limits and Concentration Levels of Concern
  - Characteristics of Generation

    - Quantities
- User-specific needs;
- Type, size and construction of the ECD;
- Required performance capabilities;
- Ventilation system and airflow control requirements;
- Operating modes, and
- Potential impact of changing environmental conditions.

There are many different types, models and sizes of ECDs. In addition, ECDs include many different features, components and sub-systems. Some ECDs are designed exclusively to provide personnel protection, whereas other designs incorporate special filtration and/or isolation features to provide both personnel and product protection. In addition, certain ECDs are equipped to handle a wide variety of effluent including gases, vapors and aerosols, but other ECDs may only be suitable for handling particulates. In general, the major types of ECDs include:

- Chemical Fume Hoods;
- Biological Safety Cabinets (BSCs);
- Ventilated Safety Enclosures (VSE);
- Snorkels (Spot Exhaust);
- Downdraft Tables;
- Slot Hoods,
- Canopy Hoods, and
- Glovebox/Isolators.

Other types of devices may include ductless enclosures, special purpose devices and custom equipment enclosures. SEFA 9-2010 provides guidance on ductless enclosure. Regardless of the type, any ECD utilized in labs to control exposure must be included in the LVMP. Figure 2a and 2b list major types and models of ECDs and recommended application. Additional information about suggested application of each device can be found in subsequent sections of this document.

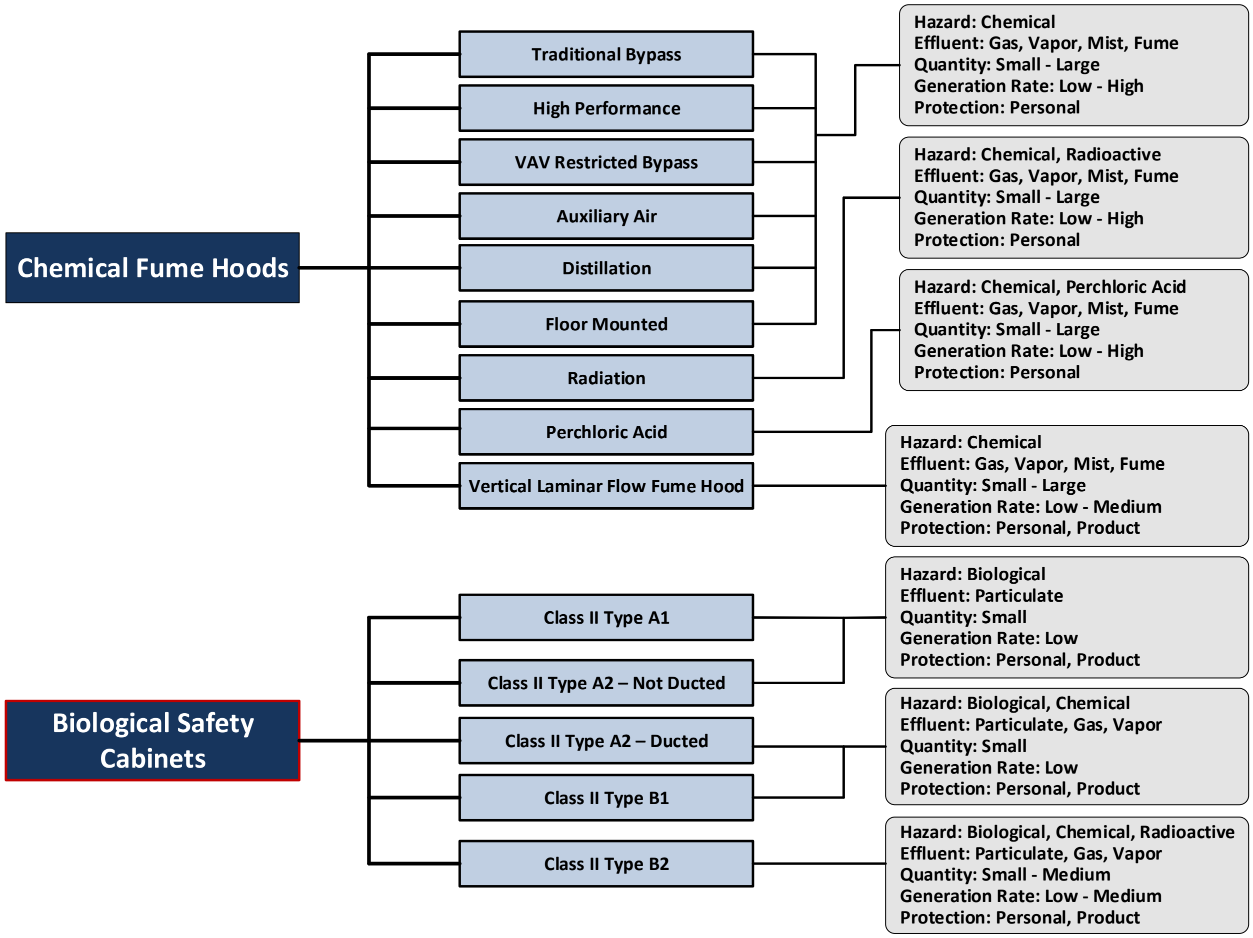


Figure 2a - Major Types of ECDs and Typical Application.

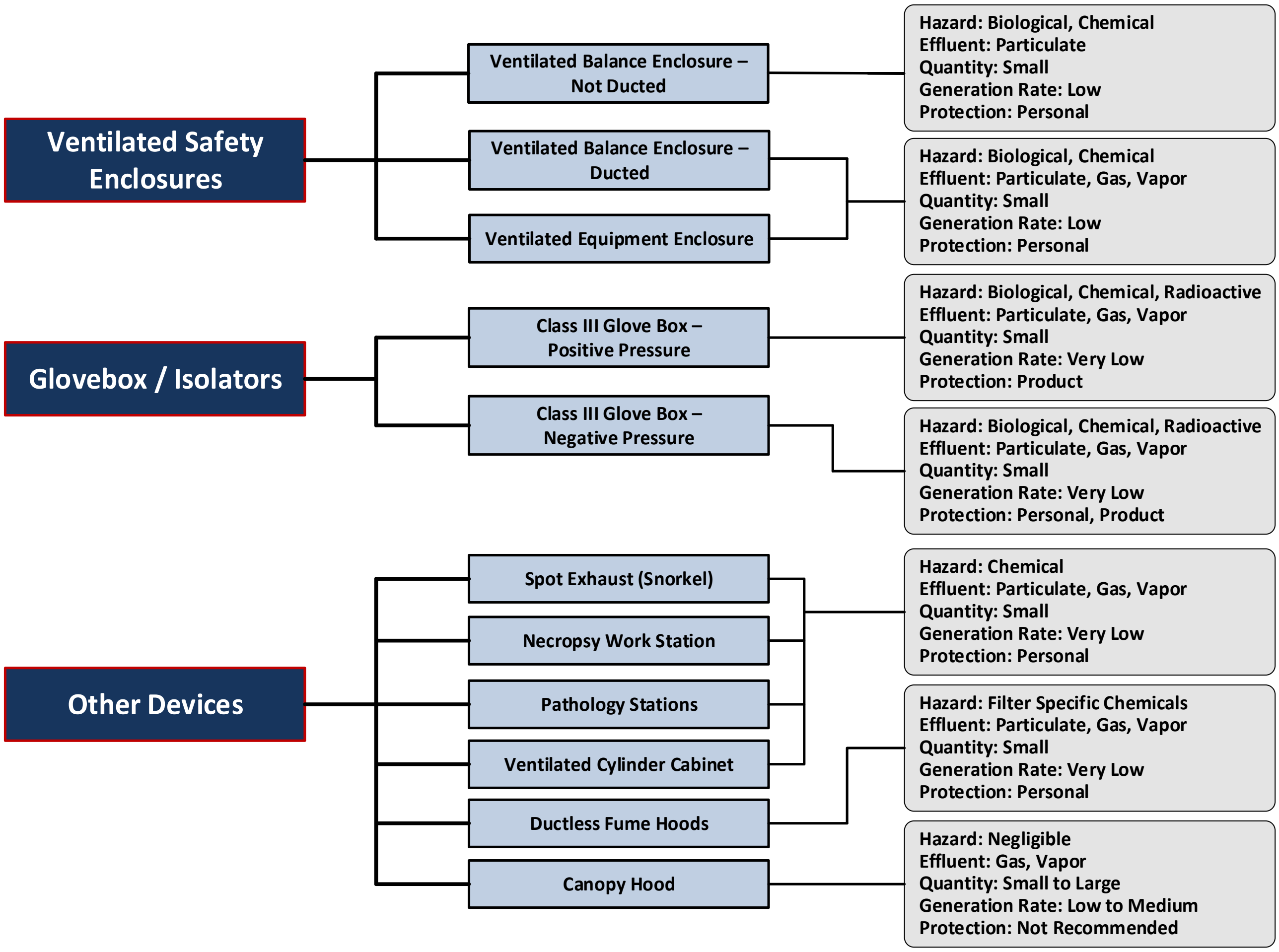


Figure 2b - Major Types of ECDs and Typical Application.

3.1 Ventilation and Energy Consumption

ECDs and laboratories utilize airflow to contain and capture contaminants, dilute and remove contaminants, isolate the laboratory from adjacent areas and control space temperatures. The volume of airflow required to provide adequate protection depends on the risk, the design of the ECD employed and the operating modes. ECDs, such as chemical fume hoods, typically require greater exhaust flow than ventilated balance enclosures or snorkel exhaust devices. Furthermore, variable air volume (VAV) fume hoods and other types of ECDs can vary the exhaust flow depending on their utilization and available modes of operation. Modulation of flow through fume hoods and other devices affects the volume of airflow through the laboratory resulting in variable air change rates and varying airflow patterns with potential adverse effects on ECD performance and lab air balance. Energy consumption is a function of numerous factors including flow and system static pressure. Minimizing the volume of airflow and system resistance when and where possible is desirable, but never at the expense of safety. Safety is an inviolable constraint and the performance requirements can dictate the minimum airflow and operating specifications for ECDs and laboratories.

Figure 3A and 3B depict an example lab showing the plan and elevation diagrams indicating the location and type of ventilation devices located therein. Proper performance requires specification of the minimum and maximum flow for each exhaust and supply device for the range of possible operation.

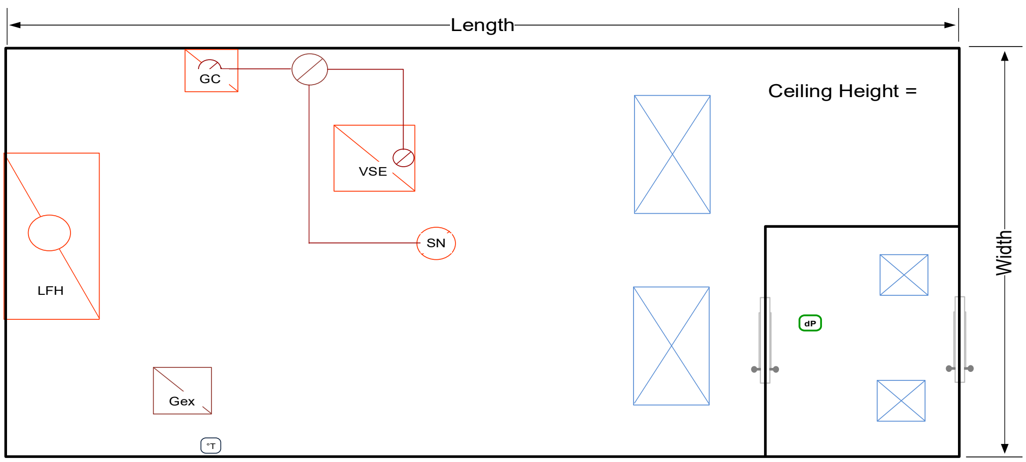


Figure 3A Top view or plan view of lab showing location of major ventilation components

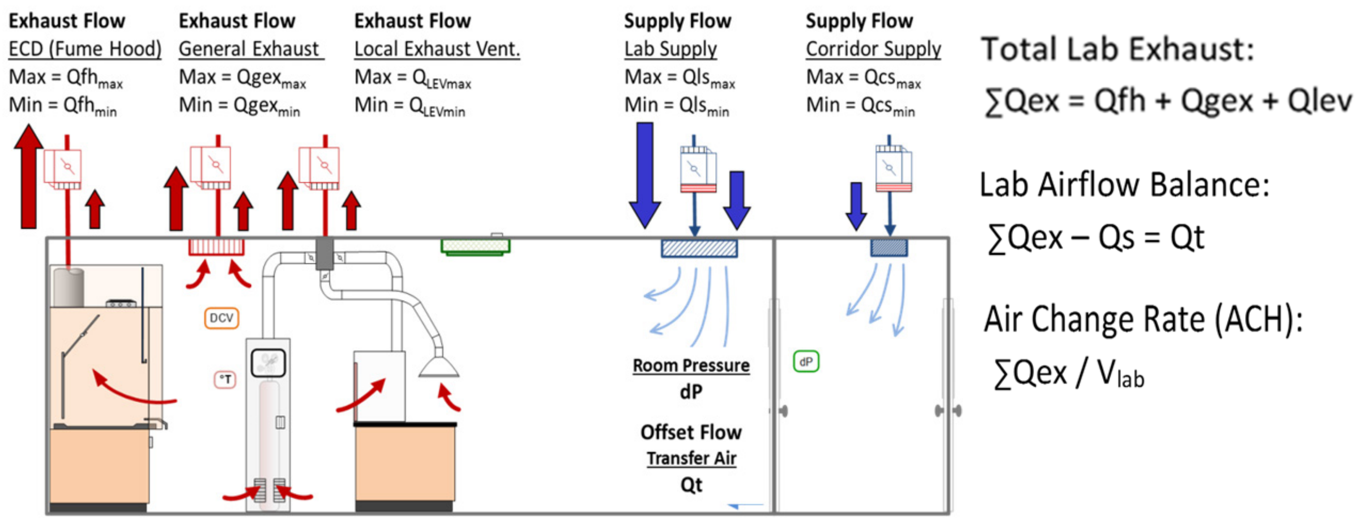


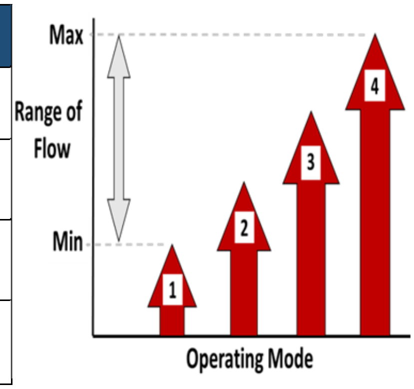
Figure 3B Side view of laboratory showing exhaust and air supply flow

Airflow specifications are required for all ECDs, the general exhaust, the air supply and the offset volume (transfer air) required to maintain space pressurization. Negative pressurization may be critical to provide isolation to prevent contaminant escape or to minimize contaminant infiltration. The flow specifications for ECDs and the lab environment depend on numerous factors including the risk of exposure and the overall demand for ventilation. Improper airflow specifications can lead to poor performance of ECDs and deleterious operating conditions.

Modulation of exhaust flow must be balanced with mechanically supplied, properly conditioned, replacement air plus or minus the transfer air required for the desired lab pressurization. Changes in the exhaust for any device requires an immediate and commensurate change in supply flow to compensate and maintain balance. It is usually preferable to maintain a constant offset volume to maintain space pressure relationships regardless of changes in operating modes. For a laboratory containing a VAV fume hood that also modulates general exhaust and air supply flow to control room temperature, there can be a variety of operating modes, sequences of operation and a significant range of flow. The total flow through the lab can vary from low when unoccupied to maximum with the fume hood in use and where high conditioning loads requires extra supply. Table 1 describes four common operating modes that demonstrate the impact on total airflow for a lab with a VAV fume hood and VAV terminal reheat, air supply systems.

Table 1 Operating modes and impact on total airflow through lab

Mode	Operating Condition
1	Unoccupied Lab – Sashes Closed – Min. Conditioning Required
2	Occupied Lab – Sashes Closed – Max. Conditioning Required
3	Occupied Lab – Sashes Open – Min. Conditioning Required
4	Occupied Lab – Sashes Open – Max. Conditioning Required



Theoretically, the ECD Systems are operating properly when the change in flow through an ECD and the laboratory translate to an equivalent change in flow at the exhaust fan units and air supply units serving the laboratory. The total airflow through the systems can vary depending on the aggregate operating mode for all spaces where minimum flow corresponds to all spaces operating at the lowest flow mode and the highest airflow results when all spaces are operating at the mode corresponding to the highest flow. The energy consumption is a function of the total flow through the systems and energy can generally be reduced by decreasing the average flow over time. The diagram in Figure 4 depicts an ECD System where the range of flow modulation can be related to energy consumption. The average operation over a period of time should correlate closely with the demand for ventilation.

For effective management of both safety and energy consumption, the criteria for ECD selection and establishment of airflow specifications should focus on mitigating risk and satisfying the demand for ventilation without excess or unnecessary ventilation. The safest and most efficient operation results when the ECD Systems modulate flow to meet and track changes in the demand for ventilation. Unfortunately, many systems suffer due to improper or inadequate evaluation of risk, improper specification of airflow and failure of the controls to properly modulate air supply and exhaust fans over the range of flow dictated by the demand for ventilation. Failure to properly modulate flow can compromise both safety and energy efficiency. This understanding is key to achieving safe, energy efficient and sustainable labs. The following section describes risk and methods to evaluate the demand for ventilation.

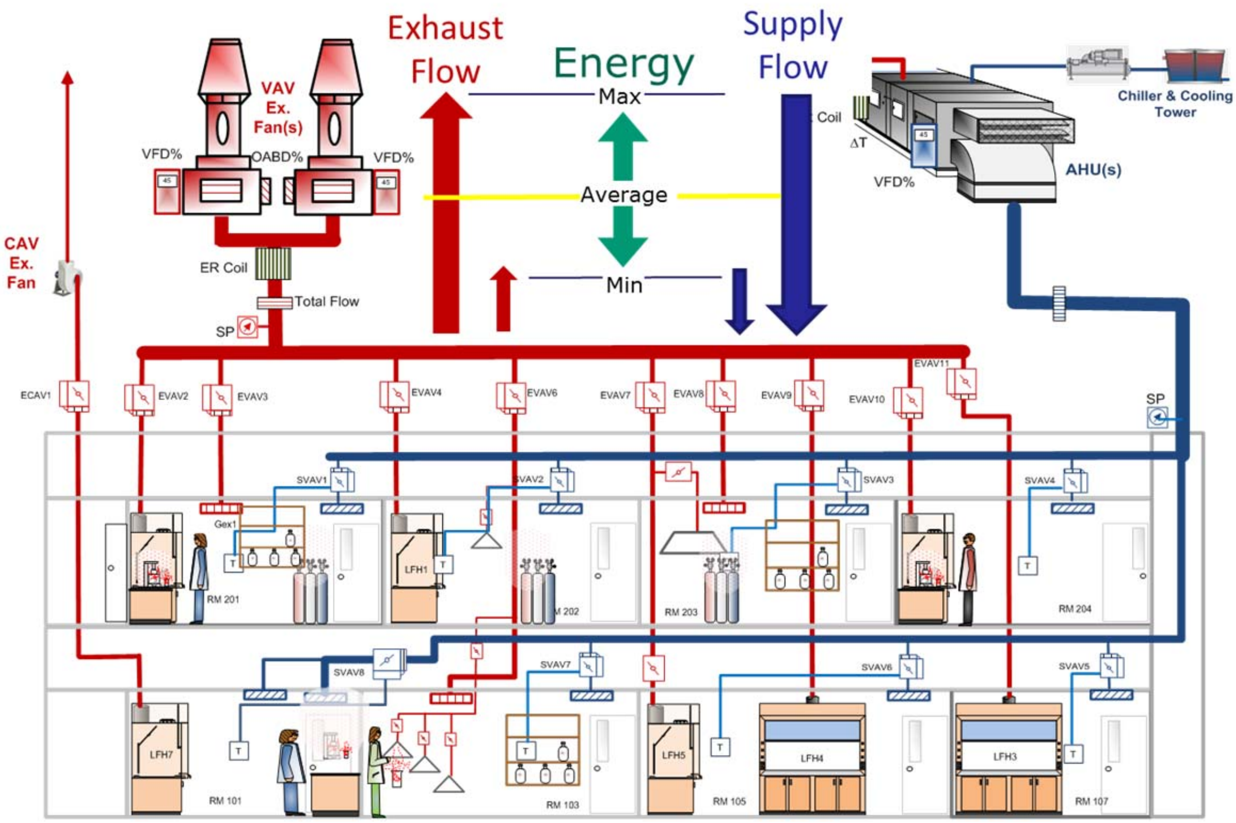


Figure 4 Diagram depicting ECD Systems and energy use corresponding to the range of airflow modulation.

3.2 Ventilation for Protection of Personnel

ECDs are designed and operated for different purposes and they offer varying levels of protection depending on their design, use, operation, and the impact of environmental conditions such as room air turbulence, temperature gradients and pressurization. The location of air supply fixtures, ECDs and general exhaust together with the resulting airflow patterns are critical to support ECD performance, provide adequate dilution and facilitate contaminant removal from the lab environment. Sources of extraneous concentrations in the lab environment may include escape from ECDs, poorly sealed storage containers, leaking gas cylinders, and analytical equipment operating outside ECDs. Where the ECDs provide primary protection through source capture, the airflow through the lab environment provides secondary protection through dilution and removal of extraneous contaminants. Figure 5 depicts a laboratory with a fume hood to provide capture, containment and removal of hazards generated therein and relies on dilution and removal of contaminants concentrations in the lab exterior to the fume hood.

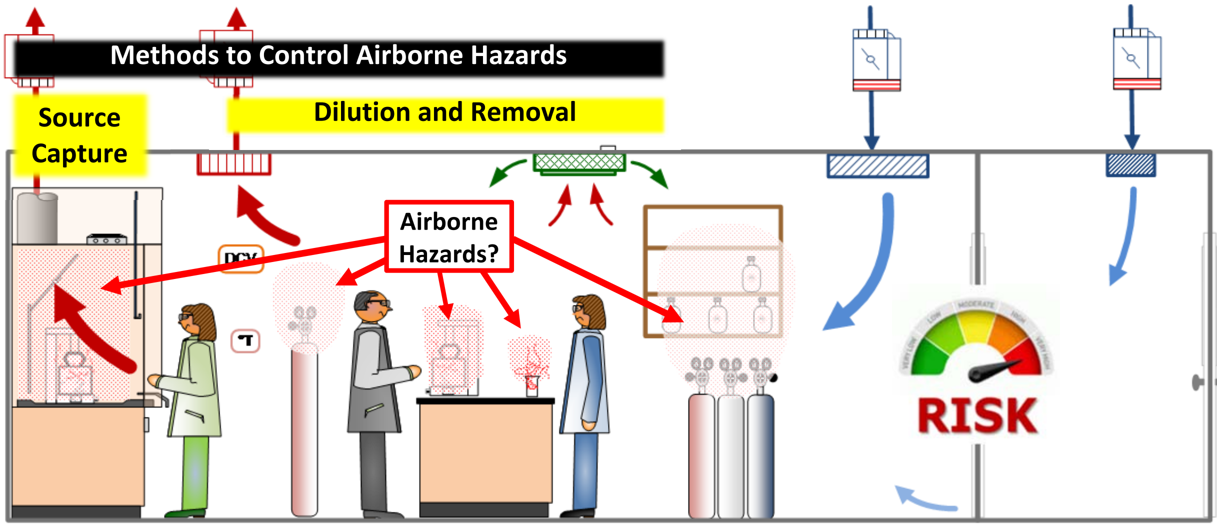


Figure 5 Diagram of laboratory with various types of ECDs and potential sources of airborne contaminants.

Some of the issues to consider when evaluating potential sources of airborne hazards in labs include:

- The risk of exposure posed by the generation of airborne hazards. For example, some materials can cause acute adverse effects at very low concentrations whereas other airborne hazards can have more chronic effects after prolonged exposure.
- The effectiveness of available methods to mitigate unacceptable risk.
- The volume of airflow required for dilution and the effectiveness of removal from the lab environment.
- The appropriate type of ECD and airflow specifications necessary to provide adequate protection.
- The capabilities and limitations of the ECDs. For example, a canopy hood may offer very little protection for the operator whereas a glovebox may be required to provide total isolation and maximum protection.
- The factors that influence when an ECD, such as a fume hood, is not appropriate or the level of performance may not provide adequate protection.
- The methods required to validate performance and factors that affect performance over time. In many instances, measurement of air velocities alone may be inadequate to evaluate potential for exposure. More sophisticated tracer gas tests or even exposure monitoring may be required to assure proper safety performance.
- The impact of changes in hazardous materials, processes or potential for generating airborne contaminants.

- The range of airflow through the ECD laboratory and potential impact of varying flow on dilution, contaminant removal effectiveness, and ECD containment performance.
- The impact of the airborne hazards on the ECD System. Some materials like acids may degrade the duct and components leading to premature degradation and inadequate performance. The materials of construction can be critical to long-term performance.
- The need for training and enforcing use of proper work practices.

The level of required protection typically depends on the process, the severity of the airborne hazards, the exposure limits, the quantities of materials used in the process and the characteristics of generation including the rate and type of effluent. These characteristics define a hazard emission scenario that can be used to specify an ECD and determine appropriate operating specifications for the laboratory and ECD System. The hazard emission scenario must stay within the boundaries dictated by "laboratory scale" work (i.e. substances in containers used for reactions, transfers and other applications that are designed to be easily handled by one person). The ECD must be appropriate for the application, operate properly and provide adequate performance over the range of possible operating conditions. The level of protection afforded by an ECD system is ultimately based upon the ability to control and limit concentrations of airborne contaminants where people could be exposed. The rate of contaminant accumulation equals the rate of generation minus the rate of removal. The following section describes risk factors and information to help specify appropriate ECDs.

4 Risk and ECD Performance Requirements

4.1 Spectrum of Risk

There are many possible hazards in laboratories particularly where activities involve chemical, biological and/or radioactive materials. People can be exposed to airborne hazards through inhalation, contact with the skin or ingestion of food or drinks contaminated through contact. The risk or potential for exposure to an airborne contaminant is a function of many factors that depend largely on the how the contaminants are generated, the magnitude of the resulting concentration, and the duration of the concentration in the occupied space. The potential for exposure and risk of suffering adverse effects (health or otherwise) is subject to an even more complex interaction of variables that include not only the type of hazard and the dose (concentration times duration), but also the susceptibility of the exposed individual.

The spectrum of risk of exposure to airborne hazards in labs can range from negligible to extreme. ECD Systems are employed to reduce the risk to people, property and the environment by controlling airborne hazards, limiting accumulation of unsafe concentrations and minimizing the duration of unsafe concentrations. Some ECDs are also used to minimize potential and effects of explosions and high-pressure gas release. As shown in Figure 6, the range of risk can be associated with the design and operating requirements of the ECD System and other factors including energy consumption, stakeholder effort, operating costs and potential liability.

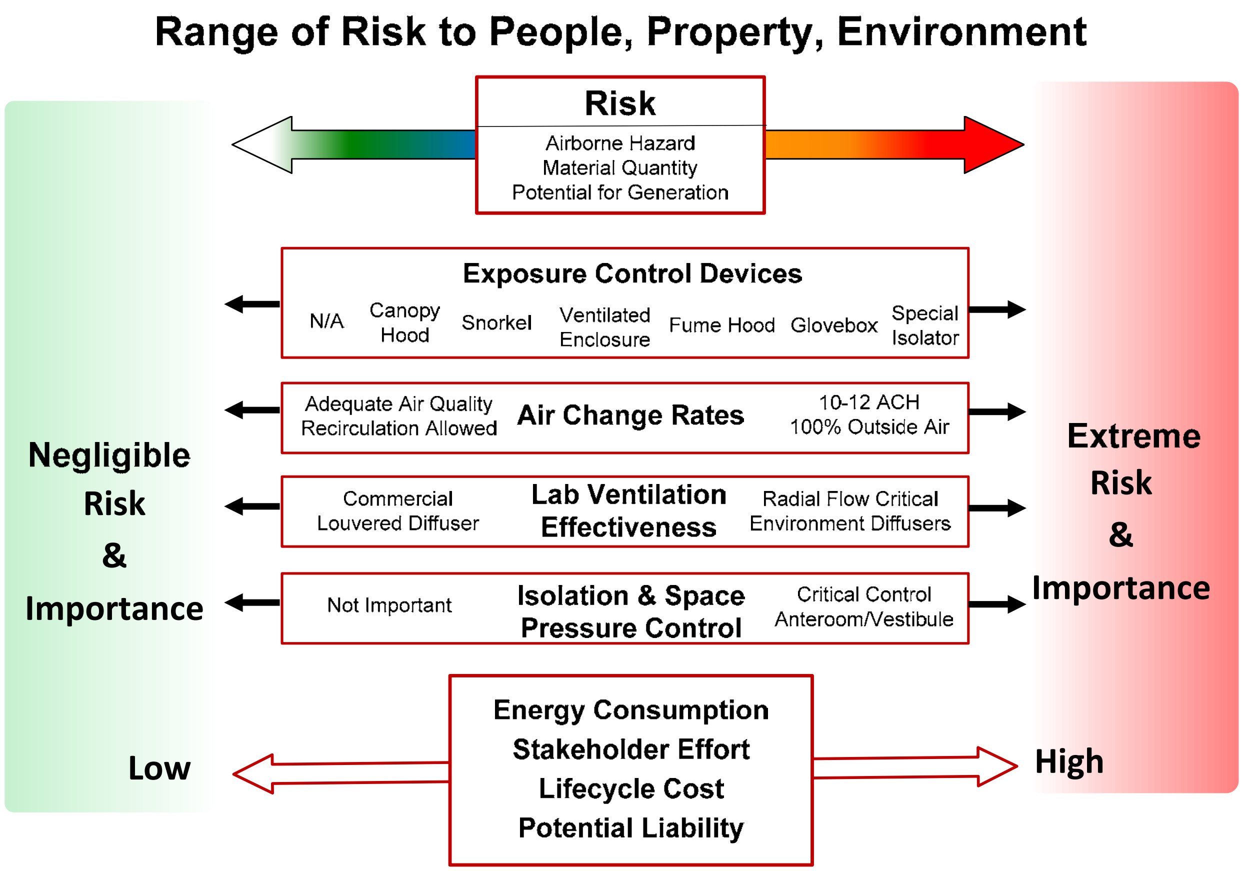


Figure 6 Relationships that correlate with the spectrum of risk from airborne hazards in labs.

The risk can be characterized as a function of the type and quantity of airborne hazards, the rate of generation, the duration of generation and the severity of exposure. Characterization enables better selection and design of the ECDs, establishment of airflow specifications and configuration of the lab supply and exhaust devices to maximize effectiveness of ECD Systems. Exposure and the risk of adverse health effects can be based on the potential magnitude of the airborne concentration, the potential residence time of the concentration, the severity of the hazard and the duration of exposure. As such, risk factors include the severity of the hazards, the quantities of materials, the rate of generation, the duration of generation and effectiveness of the ECD system to capture, dilute and remove the airborne contaminants. The severity of the hazard indicates the maximum allowable concentration, the potential for generation indicates the rate of generation and the quantity of material indicates the potential duration of generation. Figure 7 shows the risk as a function of the hazard, the potential for generation and quantity of the material available to sustain generation.

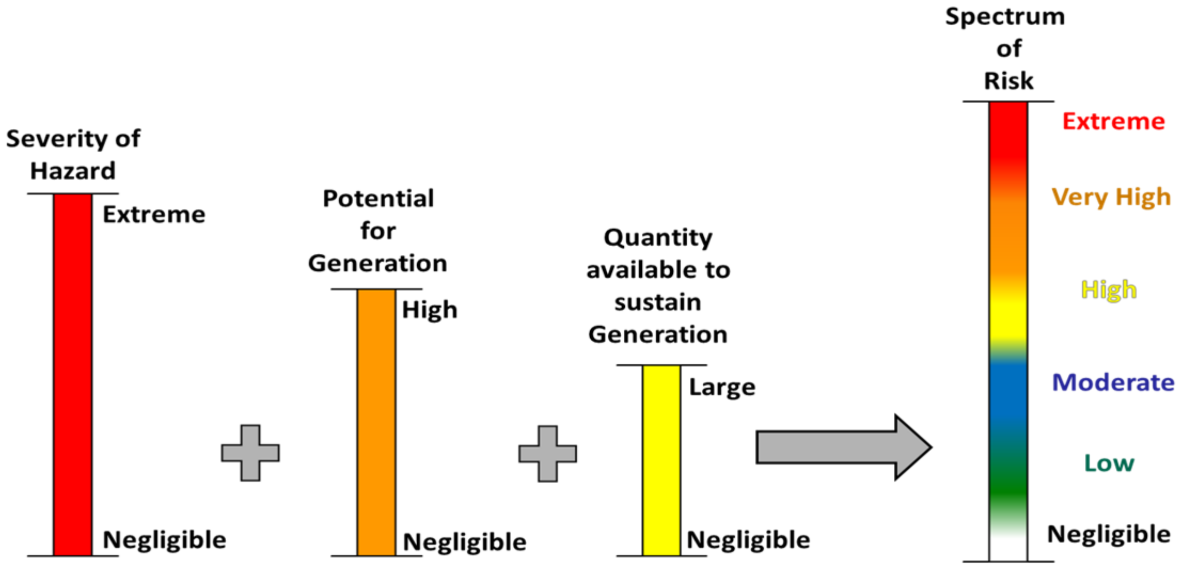


Figure 7 Risk factors that indicate the risk of a hazardous airborne concentration.

In this context, risk is an estimate of the probability that unsafe concentrations of airborne hazards may exist. The range of risk is always greater than zero and less than 100%. Risk can't be 100% because it would then be a certainty and it can't be zero as it would then cease to be a risk. No algorithm may accurately calculate risk, but there is value in understanding and characterizing the factors influencing the level of risk.

4.1.1 Airborne Hazard and Severity

The characteristics of airborne hazards and the concentration levels of concern are critical to evaluating risk and ensuring appropriate design and operation of an ECD System. Airborne hazards (effluent) are present in concentrations of gases, vapors, particulates and other types of aerosols typically composed of chemical, biological and/or radioactive materials. The characteristics of the effluent can affect the type of ECD, need for filtration, materials of construction, capture velocities and duct transport velocities. The following categories can be used to help characterize the hazardous effluent.

- **Gas** – A substance that exists in the gaseous state and lacks inherent volume and shape at normal atmospheric conditions. Examples: oxygen or helium.
- **Vapor** - A substance in the gaseous state that is a liquid at standard temperature and pressure, exerting a partial pressure that can be condensed into the liquid form. Examples: formaldehyde, xylene and acetone.
- **Fume** - Condensed solid particles produced by physicochemical reactions such as combustion, sublimation, or distillation. Examples: fumes from spectroscopy samples and laser surgical procedures.
- **Mist** - Airborne liquid droplets associated with the disruption of a liquid. Examples include sonication, spraying, mixing, and violent chemical reactions.

- **Particulate** - Solid particles (Silica gel, Aluminum oxide) or nanoparticle products that are temporarily suspended in a volume of air. Deposition of suspended particulates is dependent on particle size and turbulence.

The hazardous materials can be further classified by type, physical properties, negative effect of exposure and exposure limits. There are many different types of materials and methods to classify the hazard associated with the materials of concern. Some examples of type and effect include:

- **Carcinogen –** Materials that are known cancer causing agents.
- **Flammable** – Materials with a higher risk of catching fire.
- **Reactive** – Materials that violently react with certain substances such as water or oxygen.
- **Corrosive** – Materials that can easily destroy or damage materials of construction or surface materials the contaminants contacts such as metal, plastic or skin.
- **Explosive** – Materials that may explode when subject to high heat, sparks or other ignition sources.

The concentration level of concern that may lead to adverse health effects may be associated with exposure limits published by organizations such as the United States Occupational Safety and Health Administration (OSHA), the American Conference of Governmental Industrial Hygienist (ACGIH) and other groups including material producers. Hazards can be described as acute or chronic where acute hazards have more immediate effects from exposure and where chronic hazards may exhibit effects after repeated exposure or after some prolonged latency period.

The severity of the hazard is based on the potential effects from overexposure and range from negligible to immediately dangerous to life and health (IDLH). Exposure limits are typically reported as concentration in mass per unit volume (i.e mg/m^3) and parts per million (ppm). Negligible health hazards may have concentrations with a level of concern greater than 1000 ppm (< 1 g/m3) whereas extreme hazards may be associated with concentrations of concern less than 1 ppm (1 mg/m3). However, these definitions for the hazard level may vary and be subject to the authority having jurisdiction, the prevailing standard (regulatory and institutional) or referenced source.

As the application and protective capability of ECDs can vary, understanding the risk can be critical to selecting the appropriate ECD and establishing operating specifications that enable the required control and performance. In the absence of the requisite information, the choice of ECD and operating specifications can be based on a worst-case scenario and account for the ability of the user to safely conduct the hazardous procedure. Most labs will operate within a definable range hazard where a concentration levels of concern (LOC) can be associated with a level of risk from negligible to extreme. The LOC then defines the criterion for performance.

For example, a concentration LOC of 0.1 ppm indicates that the ECD must be capable of preventing escape greater that 0.1 ppm.

4.1.2 Quantities of Materials

The quantity of material is important to consider as large amounts of materials can potentially contribute to a long duration of generation. Local regulations, national fire codes, and mechanical building codes often set limits on the maximum quantities of materials that can be stored and/or used in laboratories. Refer to table 2 for example classifications of material quantities that might represent a range anticipated for a small lab. Note that all things may be relative as a minute quantity per Table 3 may represent a very large quantity of a highly hazardous material. It is important to understand the hazards when establishing the volume or mass of material associated with rather arbitrary descriptions such as minute, small, moderate, large or extra-large.

Table 2 Range and quantity of materials used in laboratory scale procedures

Description/Quantity	Volume	Mass
Minute	< 1 mL	< 1 mg
Small	< 10 mL	< 1 g
Moderate	< 1 L	< 10 g
Large	< 10 L	< 100 g
Extra Large	< 50 L	< 500 g

4.1.3 Airborne Hazard Generation

Health and safety staff should consult with laboratory managers, Principal Investigators (PIs) and other stakeholders to characterize procedures, evaluate means of generation, estimate the potential rates of generation and consider future changes in activities. Airborne hazards can be generated during a variety of activities where the rate may be subject to the process and the mechanism affecting generation. The following categories can be helpful for characterizing hazardous procedures:

- **Storage:** Emissions may occur from improperly sealed or degraded storage containers. The rate and quantity of generation may be small, but not negligible. Complaints of odors may indicate escape of small concentrations from inadequately sealed containers. Note that some chemicals may pose hazards below the odor threshold.
- **Closed Process**: Materials are contained in process apparatus, which may include beakers, flasks, tubing, equipment, etc. The volume of material that could be released during a catastrophic incident such as accidental over pressurization, damage to the system or leaks should be estimated.

- **Normal Process**: A normal process typically involves procedures that result in low volume generation and where little energy is added to the process. Pouring and weighing of materials and pipetting are examples of a normal process where generation of materials is typically through diffusion and/or evaporation.
- **Complex Process**: A complex process generally involves procedures that apply significant energy and produce a larger volume of airborne contaminants. Such processes might involve volatile reactions, stirring and mixing, heating and boiling, bulk material transfers and weighing. The application of energy complicates the determination of contaminant generation rates.
- **Leaks to Catastrophic Failure**: Partial or total sudden release of material resulting from a physical defect such as worn gaskets, rupture in connective tubing, pinhole in a structural weld, etc.

There are no standardized categories that relate to the generation rates associated with the range of laboratory procedures. Research conducted by Exposure Control Technologies, Inc., now known as 3Flow™ indicates the generation rates shown in Table 3 lists different types of processes and associated generation rates. In the absence of information about generation rates, the worst-case rates for normal operating conditions should be used to determine the hazard emission scenario.

Table 3 Typical ranges for laboratory scale generation rate

Category	Generation Rate (lpm)	Possible Source
Storage and Closed Process*	<0.1	Fugitive emissions from leaky containment vessels
Normal Process	0.1 - 1	Open containers, evaporation
Complex Process	1 - 10	Boiling/mixing/stirring
Leaks to Catastrophic Failure*	<0.1 to >1400	Leaking or Failed Compressed Gas Cylinders

* Note: Worst case release from catastrophic failure should be estimated.

4.2 Hazard Emission Scenario

As described above, the appropriate ECD and the required level of performance depend on the types of hazards, exposure limits, quantities of materials used in the processes and estimates of the rates of generation. These combined characteristics define the hazard emission scenario that can be used to select the ECD. A hazard emission scenario can also be used to test and validate ECDs and establish the required operating specifications. Hazard emission scenarios can and should be used to further aid the ECD specification process.

4.3 ECD Performance Criteria

After considering the risk factors, the performance criteria define the required level of containment or protection afforded the user. The hazard emission scenario together with the performance criteria are used to select the ECD and determine appropriate tests to challenge the device and validate adequate performance under the prevailing operating conditions.

5 Selection and Specification of ECDs

5.1 ECD Performance Capabilities

Figure 8 shows a diagram representing increasing hazard levels on the y axis and increasing generation potential (as a function of both the rate and quantity of material) on the x axis. The different types of ECDs are shown on the diagram to simply represent their application according to the hazard level and generation potential. The diagram provides only a representation of typical areas of application and determining thresholds would be subject to the process and capabilities of the ECDs.

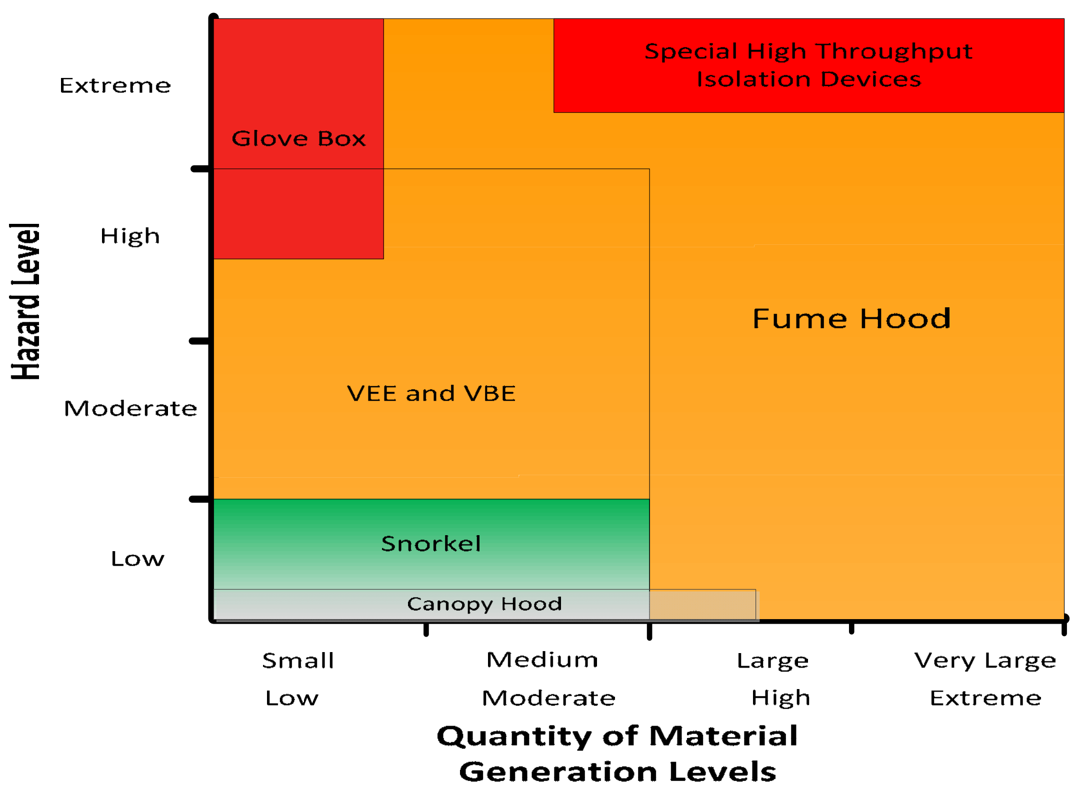


Figure 8 ECD applications as a function of hazard level and generation potential.

Fume hoods provide the widest range of protection for hazard emission scenarios that include small to very large quantities of low to extremely hazardous materials generated at rates from less than 0.1 liter of gas per minute (lpm) to as much as 10 lpm. Snorkel exhaust devices are used for negligible to low hazards with correspondingly low generation rates. Un-ducted BSCs and VSEs equipped with HEPA filtration are only appropriate for protecting people from exposure to small quantities of low to highly hazardous particulates at up to moderate rates of generation. Ventilated Safety Enclosures (VSE) can be used for low to high hazards with low to moderate rates of generation. Gloveboxes provide the greatest protection for airborne materials of high to extreme hazards, but only for small quantities with very low rates of generation. Finally, special isolators combine the throughput of fume hoods and protection of a glovebox are used for high to extreme generation rates of high to extreme hazards.

5.2 ECD Application Risk Matrix

ECD Application Risk Matrices shown in the following tables 4, 5 and 6 can be used to match the ECD to the hazard emission scenario. The risk factors consider the type of material, the characteristics of the hazard, quantities and the potential for generation. Please note that it is important to consider that the user must understand the capabilities of limitations of the devices and how application of proper work practices can impact the effectiveness and ability to provide adequate protection. Refer to the Risk Matrices provided below for chemical fume hoods, BSCs and other types of ECDs.

Table 4 ECD Application Risk Matrix for different types of fume hoods

Fume Hood Risk Matrix																		
ECDs	Hazard Level	Quantity	Generation	Chemical	Biological	Radioactive	Radioisotopes	Product Protection	Gas/Vapor	Particulate/Powder	Nanoparticle	Acute	Carcinogen	Flammable	Reactive	Corrosive	Explosive	Heated Process
Chemical Fume Hood	High	Very Large	Very Large	✓	(1)	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Radioisotope Fume Hood	High	Very Large	Very Large	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Perchloric Fume Hood	High	Very Large	Large	✓					✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Laminar Flow Fume Hood	High	Very Large	Very Large	✓				✓	✓	✓	✓	✓	✓			✓		✓
Filtered Fume Hood	Medium	Medium	Low	✓					✓	✓								
Auxiliary Fume Hood	High	Very Large	Very Large	✓					✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Distillation Fume Hood	High	Very Large	Very Large	✓		✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Floor Mounted Fume Hood	High	Very Large	Very Large	✓		✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Educational Hood	Medium	Large	Large	✓					✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Notes: (1) See Table 5 for application with Biological Materials

Table 5 ECD Application Risk Matrix for different types of BSCs

Biological Safety Cabinet Risk Matrix																	
ECDs	Bio Hazard Level	Generation	Chemical	Biological	Radioactive	Radioisotopes	Product Protection	Gas/Vapor	Particulate/Powder	Nanoparticle	Acute	Carcinogen	Flammable	Reactive	Corrosive	Explosive	Heated
Class I	1-3	Very Low	✓	✓					✓	✓	✓	✓					
Class II Type A1	1-3	Low		✓			✓		✓	✓	✓	✓					
Class II Type A2	1-3	Low		✓			✓		✓	✓	✓	✓					
Class II Type A2 Ducted	1-3	Low	✓	✓			✓	✓	✓	✓	✓	✓					✓
Class II Type B1	1-3	Low	✓	✓	✓		✓	✓	✓	✓	✓	✓					✓
Class II Type B2	1-3	Medium	✓	✓	✓		✓	✓	✓	✓	✓	✓	(1)				✓
Class III	1-4	Very Low	✓	✓	✓		✓	✓	✓	✓	✓	✓	(1)				

Notes (1) Potential for use with very small quantities of flammable materials such as ETOH.

Table 6 ECD Application Risk Matrix for other types of ECDs (1)

ECDs	Other ECD Risk Matrix																	
	Hazard	Quantity	Generation	Chemical	Biological	Radioactive	Radioisotopes	Product Protection	Gas/Vapor	Particulate/Powder	Nanoparticle	Acute	Carcinogen	Flammable	Reactive	Corrosive	Explosive	Heated
Glove Box	High	Medium	Very Low	✓		✓		✓	✓	✓	✓	✓	✓					
Ventilated Enclosure	Low	Medium	Low	✓		✓		✓	✓	✓				✓	✓	✓	✓	✓
Ventilated Balance Enclosure	High	Low	Very Low	✓		✓		✓	✓	✓	✓	✓	✓					
Canopy Hood	Very Low	Low	Low	✓					✓									✓
Flexible Spot Exhaust	Low	Low	Low	✓					✓	✓				✓		✓		✓
Slot Hood	Low	Low	Low	✓					✓	✓				✓				✓
Downdraft Necropsy Table	Low	Medium	Low	✓					✓					✓				
Histology Station	Low	Medium	Low	✓				✓	✓					✓				
Ventilated Wet Bench	Mediu m	Medium	Medium	✓				✓	✓	✓		✓	✓	✓				✓
Gas Cabinet	Very High	Medium	Very Low	✓					✓	✓	✓	✓	✓	✓	✓	✓	✓	
Special Isolator	Very High	Very High	Very High	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Notes: (1) Please note that there are can be exceptions to this guidance based on professional guidance and application

ECD Types, Design, Construction and Operation

ECDs serve as the primary means of protecting personnel and should be considered an integral part of the building HVAC system. ECDs must be manufactured, installed and operated per specific requirements and for specific applications. Selection of the appropriate ECD requires input and consultation with a variety of stakeholders including health and safety personnel, mechanical engineers, researchers, operations/maintenance and others. Considerations during the design process should include:

- User-specific needs identified during the Laboratory Demand Ventilation Assessment;
- The type of ECD needed to perform a specific operation;
- Specific containment and ECD size requirements; and
- Satisfactory performance testing of potential ECD/control-system configurations.
- Change Management

The following describes ECDs and potential applications.

5.3 Standard Laboratory Fume Hood

Description - Laboratory fume hoods are 4-sided enclosures designed to protect users from hazardous chemical substances. Fume hoods are accessed using a moveable sash at the front opening in which the user inserts his/her hands and arms. Safe fume hood operation is obtained through proper aerodynamic design, adequate face velocity and in the case of a variable air volume (VAV) hood; appropriate minimum flow with the sash closed and the impact of the lab environment. Fume hoods come in various sizes and configurations depending on the need of the user and the processes occurring within the hood. See Figure 8 for a diagram of a standard fume hood.

Applications - A fume hood's primary objective is to protect users from exposure to toxic fumes, vapors and gases. When used correctly, the sash can provide additional protection against splashes, fires or minor explosions that may occur within the hood. Specialized fume hoods are necessary when working with radioisotopes and perchloric acid.

Limitations - Fume hoods should not be used for biohazard containment; refer to the section on Bio-Safety Cabinets when using hazardous or infectious biological agents. Also, fume hoods are not appropriate for the most highly hazardous airborne materials. Consider using a glove box or specialized containment enclosure where any exposure cannot be tolerated.

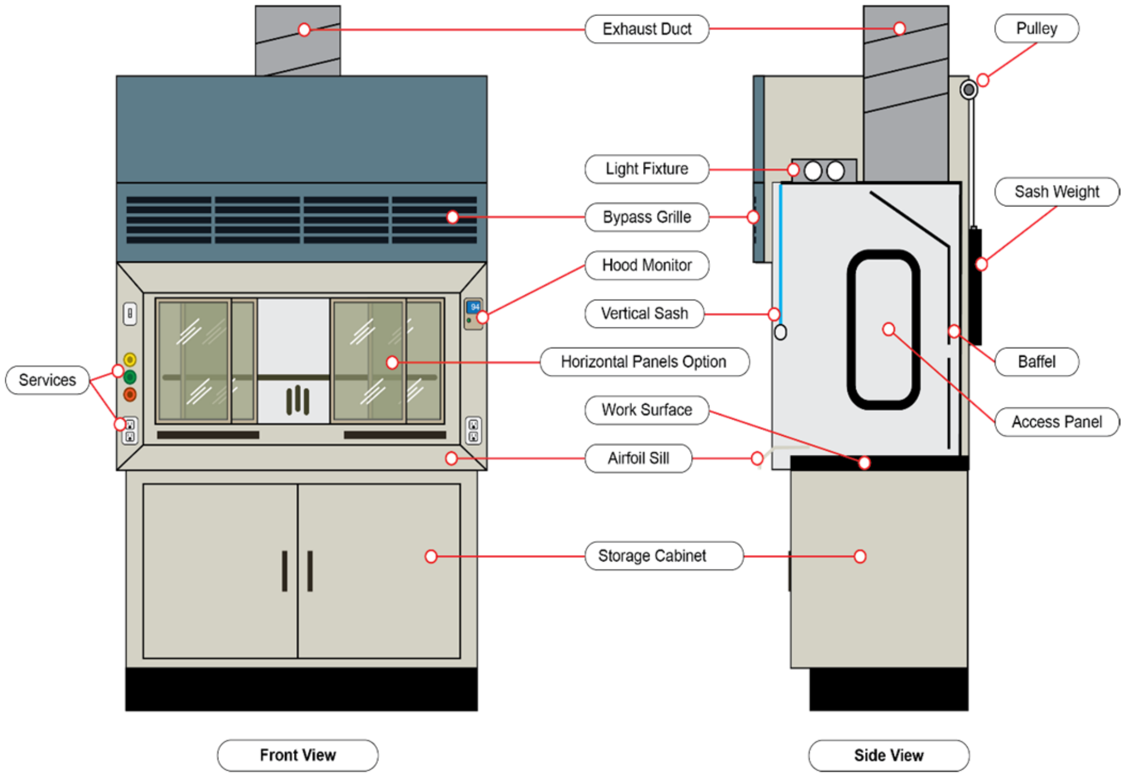


Figure 9 – Standard Laboratory Fume Hood Components

5.3.1 High Performance Fume Hood

Description - A high performance (HP) fume hood is a bypass fume hood operated at face velocities 30% to 40% less than traditional fume hoods. High performance fume hoods incorporate enhanced aerodynamic design features, particularly the airfoil sill, sash handle, side posts and baffles, that enable equivalent containment at reduced face velocities (as low as 60 fpm). The primary benefit of a HP fume hood is the reduction in total hood exhaust flow at the design opening and potential for reduced energy use while maintaining containment.

Applications - High performance fume hoods can be used in the same manner as a standard laboratory fume hood.

Limitations - The same limitations for standard fume hoods apply to high performance fume hoods.

5.3.2 Auxiliary Air Fume Hood

Description - An auxiliary air hood equipped with an air supply plenum mounted over the sash opening (See Figure 10). The auxiliary air supply is designed to direct either unconditioned, or in some cases conditioned or tempered outside air to the outside plane of the hood sash. The objective is to reduce fume hood energy consumption by reducing the volume of conditioned laboratory make-up air necessary for the hood to operate.

Applications - The commentary section in ANSI/AIHA Z9.5-2012 states, "Auxiliary supplied air hoods are not recommended unless special energy conditions or design circumstances exist."

Limitations – Same limitations as standard fume hoods with a greater possible risk of exposure due to the auxiliary air creating excessive turbulence in the breathing zone. Careful balance between exhaust flow and the auxiliary air flow is critical to maintain performance.

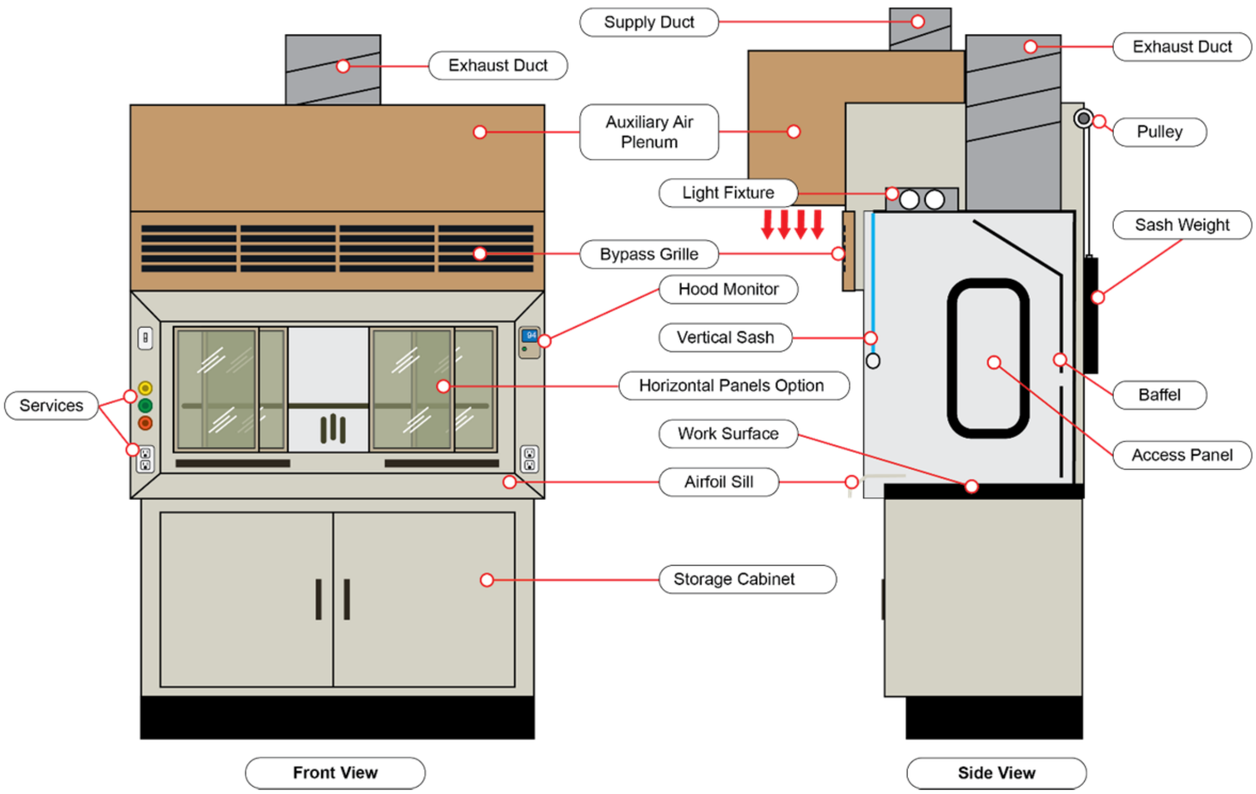


Figure 10 Auxiliary Air Fume Hood

5.3.3 Distillation Fume Hood

Description - Distillation hoods have many of the same components as a standard bench top hood but are constructed with a greater interior height for use with larger equipment and apparatus (See Figure 11). The hoods can be equipped with vertical rising sashes or horizontal sliding panels. Generally, if equipped with a vertical sash then more than one sash panel is used. The vertical sash design generally enables a larger opening than horizontal sash configurations.

Applications - Typically used for large distillation processes or large equipment and processes that won't fit inside of a standard fume hood.

Limitations - The same limitations for standard fume hoods apply to distillation fume hoods.

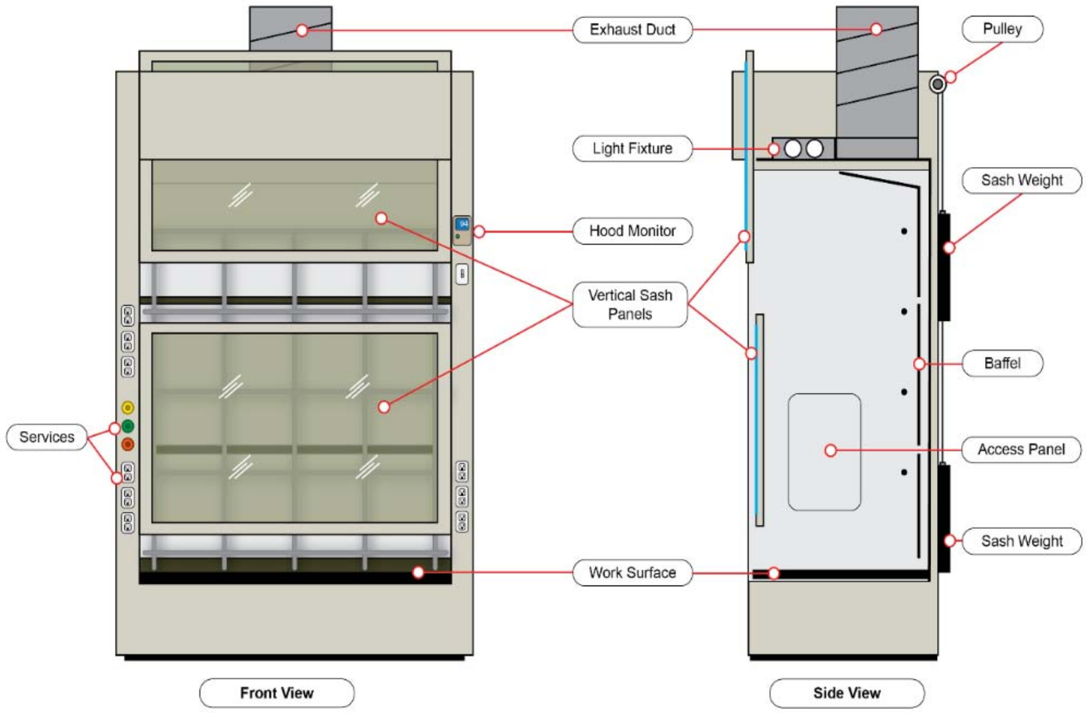


Figure 11 Distillation Hood

5.3.4 Floor Mounted Fume Hood

Description - Floor mounted hoods, often inappropriately described as “walk - in” hoods, are used to accommodate large apparatus that cannot fit inside of a standard size fume hood. A floor mounted hood is designed so that large equipment can be “wheeled” into the hood if necessary. See Figure 12 for an example of a floor mounted fume hood.

Applications – Floor mounted fume hoods can be used in the same manner as a standard laboratory fume hood.

Limitations - The same limitations for standard fume hoods apply to floor mounted fume hoods.

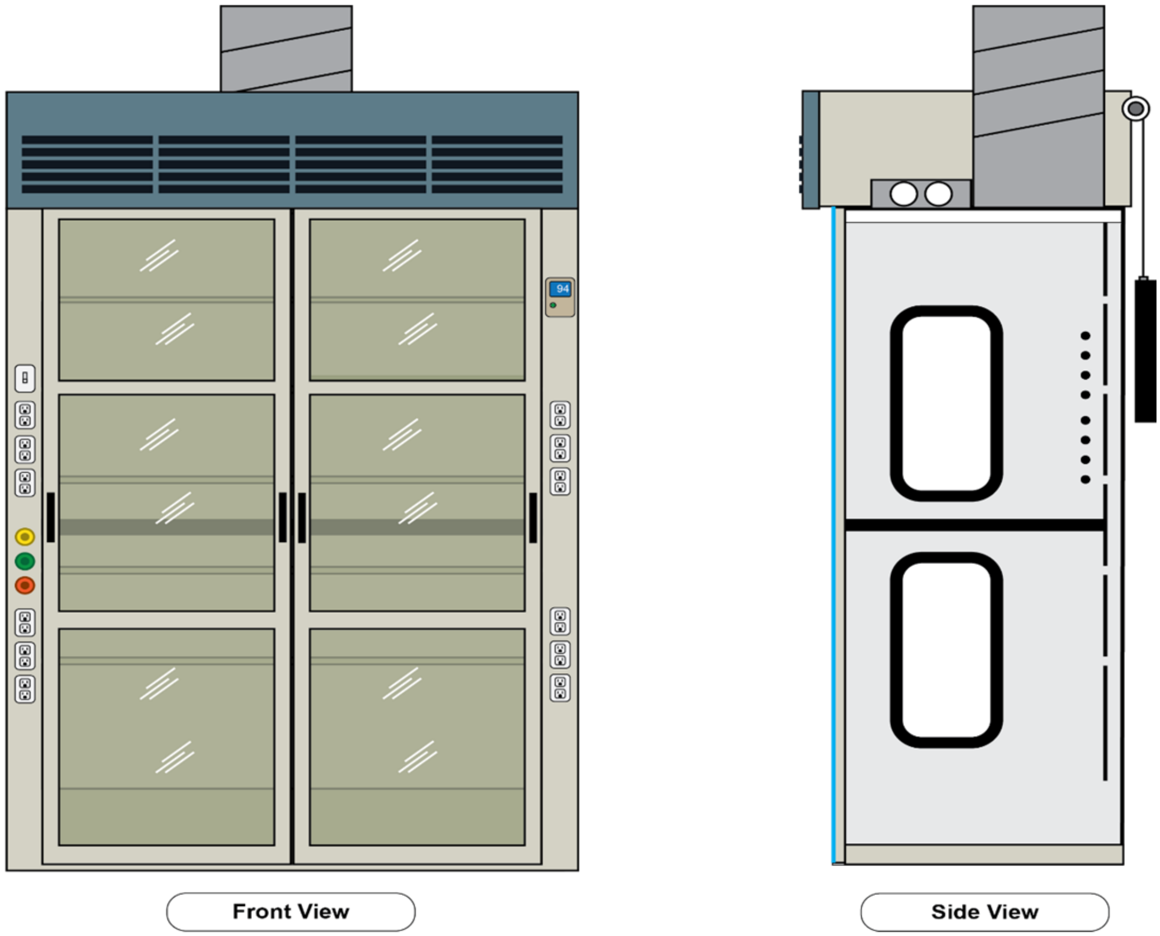


Figure 12 Floor Mounted Hood

5.3.5 Perchloric Acid Laboratory Fume Hood

Description - Perchloric acid fume hoods and their exhaust systems are specifically designed for perchloric acid applications and should not be used for other procedures (See Figure 13). Often made using 316 stainless steel, or type 1 PVC, perchloric hoods are equipped with water wash down systems to prevent accumulation of perchlorate salt deposits. A trough along the back of the work surface collects the water from the wash down system and is connected to an approved drainage system.

Applications - Used in laboratory processes that require perchloric acid to be heated or aerosolized.

Limitations - Should not be used in applications other than those requiring perchloric acid or with materials that may be reactive with perchlorates and potential residue.

5.3.5.1 Acid Digestion Laboratory Fume Hood

Description – Same as PVC Perchloric Acid Fume Hood in construction, except the sash material has been changed to Lexan in lieu of safety glass.

Applications - Used for non-perchloric acid digestions with mineral acids.

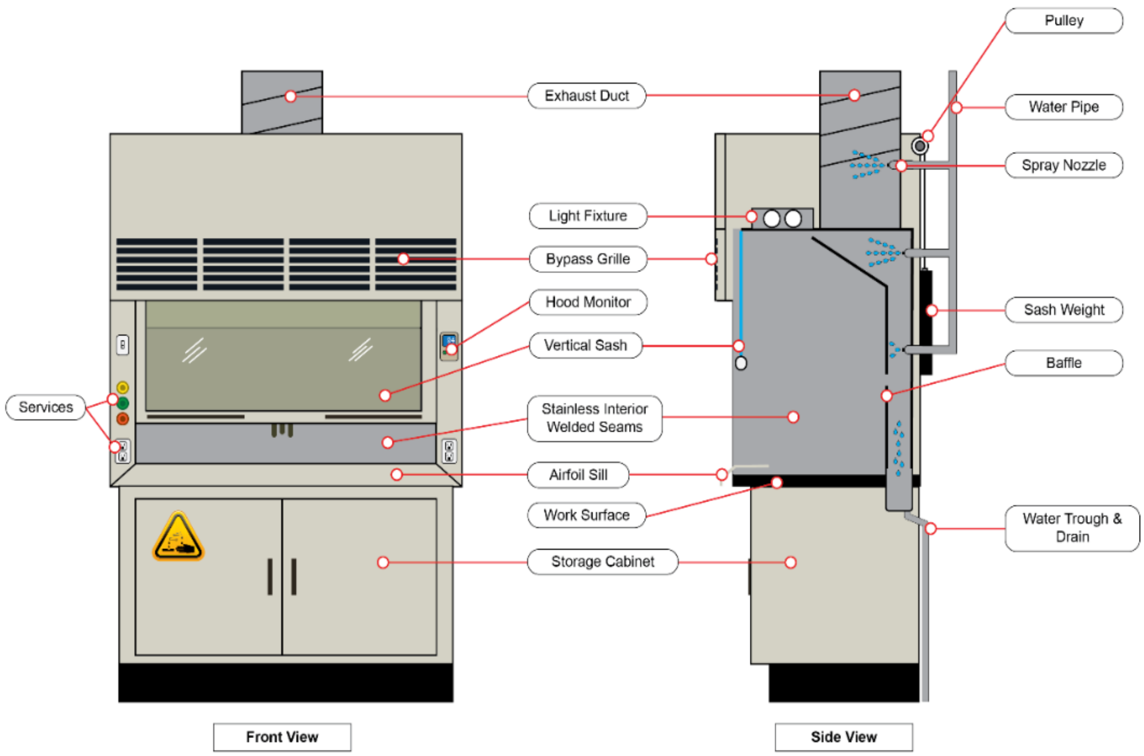


Figure 13 Perchloric Acid Fume Hood

5.3.6 Radioisotope Fume Hood

Description - Radioisotope hoods are constructed of solid, resistant materials to chemical agents and coved corners for easier decontamination. Normally, the external and internal surfaces are made of stainless steel or plastic resins (epoxy). The surfaces exposed to the radioactive material should be smooth and sealed at the essential junctions to prevent accumulation of radioactive particles and allow for easy cleaning and decontamination. See Figure 14 for an example of a radioisotope fume hood.

Applications - Radioisotope fume hoods are used to avoid radiation exposures of workers or researchers manipulating radioactive substances. Typical radioactive hoods should meet all requirements for constant volume bypass-type or VAV fume hoods and may or may not be equipped with HEPA filter systems.

Limitations - A radioisotope fume hood can be operated similarly to standard fume hoods, with special precautions for high radioactive concentrations.

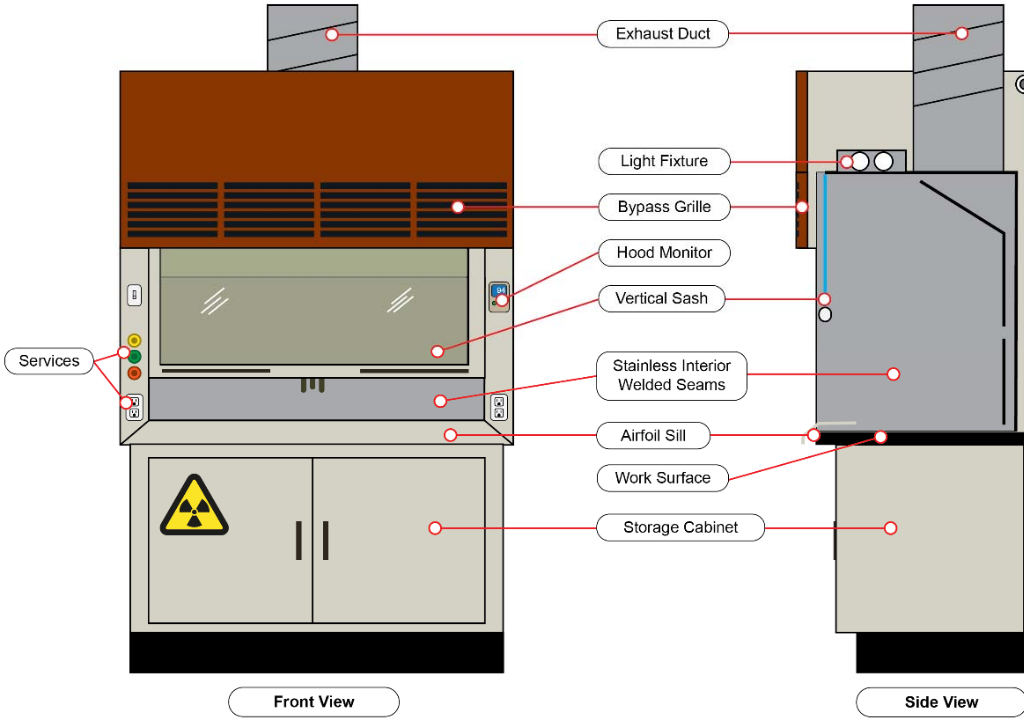


Figure 14 Radioisotope Fume Hood

5.4 Ductless "Filtered" Fume Hood

Description - A filtered fume hood is an enclosure equipped with filtrating technology that feature filters specific to the types of chemicals being utilized (See Figure 15). Air that enters through the opening of the device creates a barrier between the personnel and the chemicals. The integral ventilation system draws the particles and molecules towards the filtration system, preventing hazardous material from being released into the laboratory space. This filtration and release of the air into the lab space in some cases may help to refresh the ambient air in the lab.

Applications – Generally, filtered fume hoods can be used for specific processes that match up with the hood's filter type. Chemical process volumes are typically limited to 500 ml/s or less per chemical. Some hoods have the ability to monitor filter effectiveness or filter life.

Limitations – Filtered fume hoods require routine filter replacement dependent upon the type of filter and volume of chemical use in the hood. No extreme heating processes should be conducted within the hood. Hood use is restricted by type of filtration. Note that some materials cannot be adequately filtered and may even poison some filter media rendering it useless for other applications. Take careful note of the manufacturers installation, application and instruction for use and maintenance manuals.

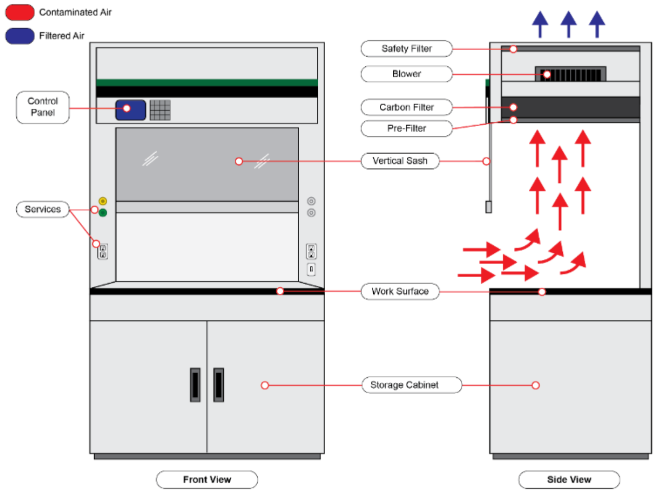


Figure 15 Ductless "Filtered" Fume Hood

5.5 Laminar Flow Clean Bench

Description - Also called clean benches, laminar flow hoods use HEPA filtered air to provide a sterile, contamination free environment for working with critical processes or products. Laminar flow hoods can provide either horizontal or vertical airflow depending on the design configuration. See Figure 16 for an example.

Applications - Often used for working with non-hazardous materials which require a clean, particle-free work area. These laminar flow clean benches are different than laminar flow fume hoods in that they only offer product protection where as a laminar flow fume hood can provide product protection and personnel protection by also capturing and exhausting airborne hazards.

Limitations - Laminar flow hoods do not offer personnel protection and are not designed for working with biological hazards, aerosols, or toxic chemicals.

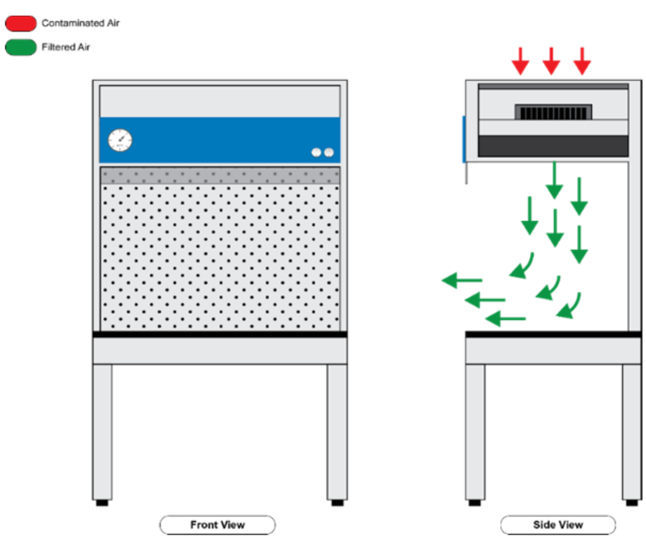


Figure 16 Laminar Flow Clean Bench

5.6 Biological Safety Cabinet (BSC)

BSC's are used to provide effective primary containment for work with pathogens. There are three classes of BSC: Class I, Class II and Class III. Selection of the proper class of BSC requires careful evaluation of the activities to be conducted in the device.

Biological safety cabinets shall meet minimum standards for cabinet classifications in NSF/ANSI STD 49: 2016 for personnel, environmental, and product safety and shall be listed and identified by a distinctive NSF seal. Field re-certification, performed by an NSF 49 accredited technician and conducted per the procedures outlined in NSF 49, will be required once the cabinet is installed. Cabinet classification shall be determined in consultation with the laboratory managers. These types of cabinets have special design requirements depending on their intended use including:

- Protecting personnel from harmful agents inside the cabinet.
- Protecting the product, experiment, or procedure from contamination by the laboratory environment, leading to invalidated test results.
- Protecting the laboratory environment from contaminants inside the cabinet.

5.6.1 Class I

Description - Class I cabinets have un-recirculated airflow away from the operator that is discharged to the atmosphere after filtration through a HEPA filter.

Applications - For use with BSL 1-3 agents. Provides operator protection but does not protect the material within the cabinet from contamination.

Limitations - Class I BSC's, provide environmental and personnel protection only. They do not provide product protection. Routine testing and replacement of HEPA filters is required. Flammable or explosive materials should not be used within biological safety cabinets.

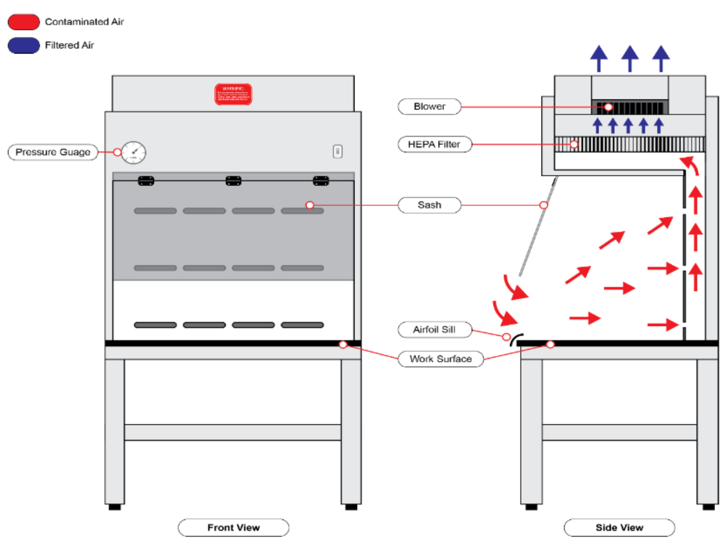


Figure 17 Class I Bio - Safety Cabinet

5.6.2 Class II, Type A1

Description – Approximately 70% of air is recirculated after passing through a HEPA filter; Approximately 30% is exhausted to the room after filtration.

Applications - Typically used for biosafety levels 1 – 3.

Limitations - Not suitable for low levels of volatile toxic chemicals. Routine testing and replacement of HEPA filters is required. Flammable or explosive materials should not be used within biological safety cabinets.

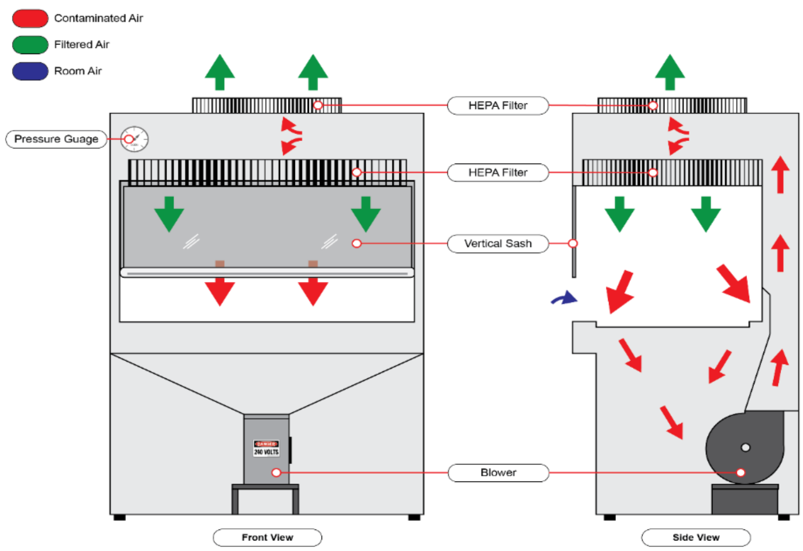


Figure 18 BSC Class II, Type A1

5.6.3 Class II, Type A2

Description – Approximately 70% of air is recirculated after passing through a HEPA filter; Approximately 30% is either exhausted to the room or building exhaust system after filtration (See Figure 19).

Applications - For use with low to moderate risk biological agents (biosafety levels 1 – 3). Type A2 can be used for work with small amounts of chemicals if vapors are non-hazardous, won't affect work due to recirculation, and cabinet is exhausted via building exhaust system.

Limitations - Routine testing and replacement of HEPA filters is required. Flammable or explosive materials should not be used within biological safety cabinets.

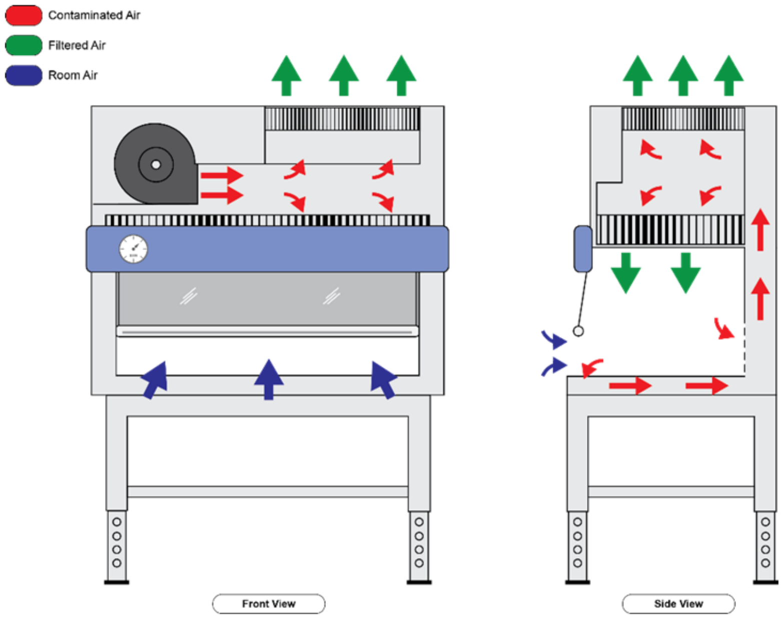


Figure 19 Class II, Type A2

5.6.4 Class II, Type B1

Description – Approximately 40% of air is recirculated after passing through a HEPA filter; Approximately 60% is exhausted into building exhaust system after filtration (See Figure 20).

Applications - For use with low to moderate risk biological agents (biosafety levels 1 – 3).

Limitations - Routine testing and replacement of HEPA filters is required. Flammable or explosive materials should not be used within biological safety cabinets.

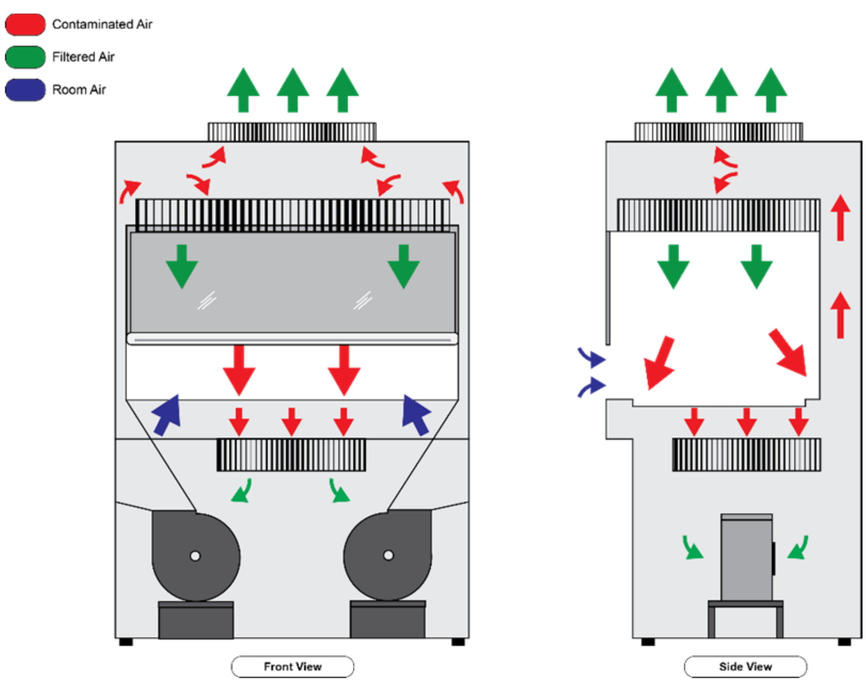


Figure 20 Class II, Type B1

5.6.5 Class II, Type B2

Description - 0% of air is recirculated; 100% is exhausted into building exhaust system. See Figure 21 for an example of the airflow patterns for a B2 Cabinet

Applications - For use with low to high risk biological agents (biosafety levels 1 – 3) and volatile chemicals.

Limitations - Routine testing (at least annual) and replacement of HEPA filters is required when necessary. Flammable or explosive materials should not be used within biological safety cabinets.

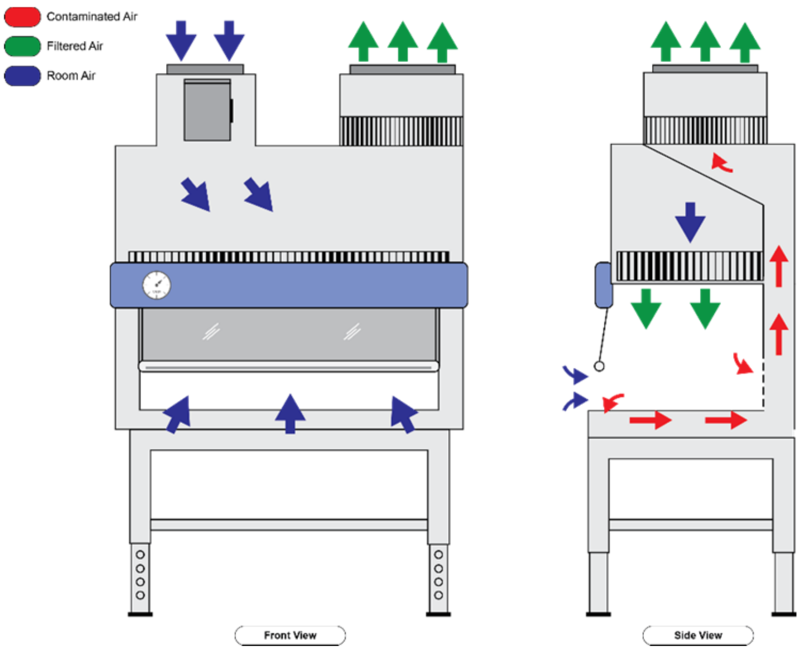


Figure 21 Class II, Type B2

5.6.6 Class II Type C1 BSCs

Description - Class II Type C1 BSCs have the following characteristics:

- They typically maintain an average minimum inflow velocity of 100 fpm through the work access opening, but the inflow velocity can vary depending on the risk and performance requirements;
- They have HEPA/ULPA filtered downflow air composed largely of uncontaminated recirculated inflow air;
- They exhaust contaminated downflow air from a region of the work area via an internal dedicated exhaust plenum and blower, and then through HEPA/ULPA filters(s);
- Have all biologically contaminate ducts and plenums under negative pressure or surrounded by negative pressure ducts and plenums; and
- May exhaust HEPA/ULPA filter air either back into the lab or via a canopy connection to an external system that exhausts to the atmosphere.

Applications - For working with low to high risk biological agents (biosafety levels 1 – 3) and volatile chemicals when connected to an external exhaust system.

5.6.7 Class III

Description - Class III biosafety cabinets are gas tight glove boxes designed for working with a variety of high risk materials/agents. The exhaust air must be double HEPA-filtered or HEPA-filtered and incinerated. The supply air can also be HEPA filtered as well.

Applications - For working with chemical carcinogens, high concentrations of low to moderate risk agents, highly infectious or hazardous materials.

Limitations - Often need to be custom built to meet exact use specifications. Require strict monitoring and filtering capabilities.

5.7 Glove Box

Description - Glove boxes are tightly sealed, fully enclosed systems often required to ensure total containment of chemical and biological contaminants where a separate atmosphere is desired. Built into the sides of the glovebox are gloves that the user can place their hands into the gloves and perform functions inside the box without breaking containment. See Figures 22 and 23 for examples of different glovebox configurations.

Applications - Two types of gloveboxes exist; one allows a person to work with hazardous substances and the other allows manipulation of substances that must be contained within a high purity inert atmosphere (such as argon or nitrogen). It is also possible to use a glovebox for manipulation of items in a vacuum chamber.

Limitations - Glove boxes have several parameters and performance criteria that must be set and monitored to ensure containment. These parameters include pressure, alarm set points for oxygen and moisture, filter leak tests, evacuation time for the antechamber and regeneration intervals.

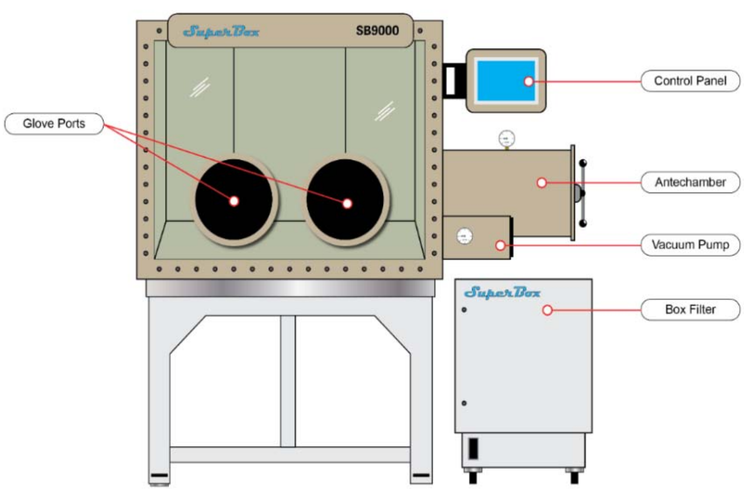


Figure 22 Glove Box

Figure 23 Photograph of Glove Boxes

5.8 Teaching Hood (Educational Hood)

Description - A teaching hood sometimes called a California hood, demonstration hood, or pass-through hood, are special fume hoods with viewing glass or sashes on multiple sides. The purpose of this hood is to allow full visibility of the processes being conducted in the hood. The hoods often are not equipped with baffles to keep the flow of air into the hood uniform across the sash opening.

Applications - Designed to allow students to view demonstrations as well as allowing teachers to supervise student use. Can be used to transfer chemicals from one room to another without leaving the fume hood.

Limitations - The same limitations for standard fume hoods apply to teaching fume hoods. Use with only one of the two sashes open at one time.

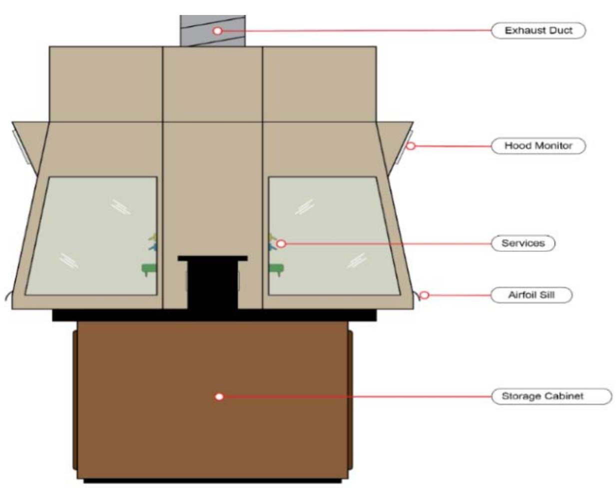


Figure 24 California Hood – Teaching Hood

5.9 Ventilated Safety Enclosure (VSE)

Description - Ventilated enclosures are typically smaller than standard fume hoods and can usually be placed on a countertop or benchtop surface. Ventilated enclosures can be ducted into an existing building exhaust system or in certain applications, non-ducted models exhaust HEPA filtered air back into the lab space.

Applications - A ventilated enclosure is suitable for operations that are largely unattended but will emit small volumes of potentially hazardous materials or excessive heat.

Limitations - The same limitations for standard fume hoods apply to ventilated enclosures. Filtered units require routine filter testing and maintenance.

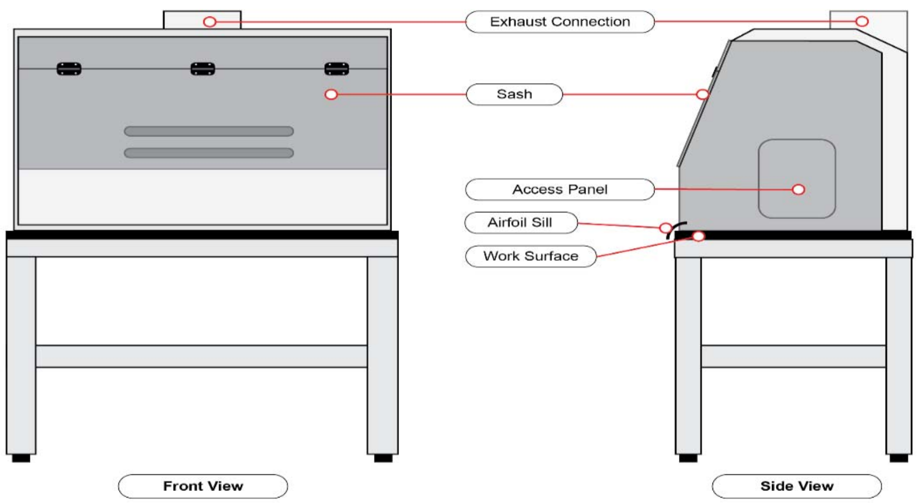


Figure 25 Ventilated Safety Enclosure

Figure 26 Photograph of Ventilated Equipment Enclosure

5.9.1 Ventilated Balance Enclosure (VBE)

Description - While similar in design to standard ventilated enclosures, VBE's provide exceptional containment characteristics along with a turbulence-free environment necessary for weighing of materials and compounds. They are typically transparent and operated at lower face velocities than chemical lab hoods to reduce balance disturbance and loss of material.

Applications - VBE's are specifically designed for providing exposure protection during the weighing and handling of potent materials and compounds.

Limitations - The same limitations for standard fume hoods apply to ventilated balance enclosures. Filtered units require routine filter testing and maintenance.

Figure 27 Ventilated Balance Enclosure

5.10 Canopy Exhaust Hood

Description – Typically built using corrosion resistant materials, canopy hoods are usually wall or ceiling mounted. They are hard ducted into the building's ventilation system and are comprised of a large, typically rectangular metal opening.

Applications - Canopy exhaust hoods are receiving hoods provided for the removal of steam, heat and negligible hazards from specific laboratory apparatus such as furnaces, ovens, and sterilizers.

Limitations - Should not be used for personal protection. Not for removing hazardous fumes or vapors.

Figure 28 Canopy Hoods

5.11 Flexible Spot Exhaust (FSE)

Description - Flexible Spot Exhaust or snorkel ducts, consist of a bell mouth and articulated connection to the building exhaust system.

Applications - Best used to remove fumes or heat from laboratory instrumentation or processes not appropriate for conduction inside a fume hood or other ventilated enclosure such as gas chromatographs and other analytical bench-top instrumentation with potential for low volume discharge of low hazard materials.

Limitations - FSE's have limited capture effectiveness and application must be limited to point source generation. The capture effectiveness is a function of the proximity to the contaminant source and the design of the hood inlet. Successful FSE bench applications are highly specific to the mass of the contaminant and the velocity and angle of emission.

Figure 29 Flexible Spot Exhaust

5.12 Slot Hood

Description - Slot hoods are typically wall mounted, hard ducted exhaust devices constructed of either metal or plastic slots.

Applications – Commonly used in darkrooms and acid dipping operations.

Limitations - Slot hoods provide a limited range of capture. In addition, the orientation of the user with respect to the opening can also influence capture. Locate a slotted hood so that the direction of airflow does not create significant eddy zones or low pressure areas that could bring concentrations into the breathing zone of the operator.

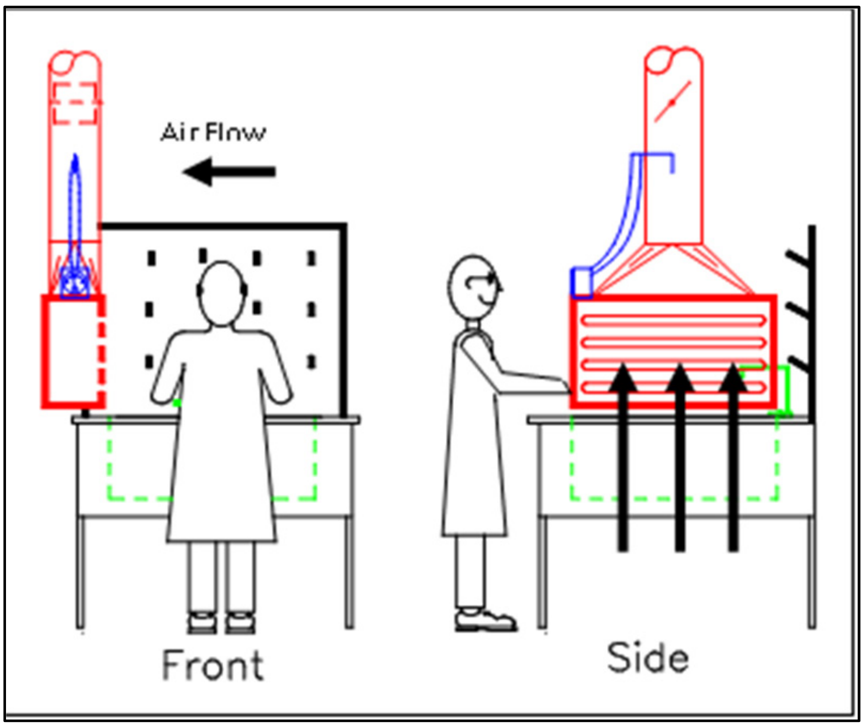


Figure 30 Slot Hoods

5.13 Downdraft Table (Necropsy Table, Histology Station)

Description – Downdraft tables are ventilated tables which allow unobstructed top access while limiting release of chemicals and odors into the lab space. Downdraft tables protect personnel and the working environment by drawing contaminated air away from the work area. The workstation operates under negative pressure to exhaust fumes, aerosols and the other chemical irritants or odors through a properly configured exhaust system.

Applications - Downdraft tables provide protection during animal necropsies, surgeries, specimen dissections, gross dissections/tissue grossing, perfusions and preparation of histological slides as well as other histology work. A histology station, also known as a tissue grossing station, is a ventilated work bench designed for surgical and medical experiments.

These stations are composed of a sink, removable perforated dissecting trays that create downdraft exposure control and a ventilation connection for the station to be hard ducted into the building's ventilation.

Limitations - Limited by low containment capabilities and generally not recommended for use with high hazard chemicals and compounds unless capture effectiveness is tested and confirmed.

Figure 31 Downdraft Necropsy Table

5.14 Ventilated Wet Bench

Description - Ventilated wet benches are typically enclosed and hard ducted to the building's exhaust system and are manufactured from polypropylene or stainless steel. Some benches are equipped with a vertical sash depending on the application and some may also be equipped with sinks. Wet benches operate with a cross flow exhaust system to draw hazards away from the user. See Figure 32 for a photo of a ventilated wet bench.

Applications - A ventilated wet bench can be used for both semiconductor industrial processes as well as medical processes.

Limitations - Containment capabilities may be subject to design and should not be used for work with high hazard chemicals and compounds where performance is not tested and confirmed.

Figure 32 Ventilated Wet Bench

5.15 Wet Process Workstation

Description - WPS provide protection for personnel from large scale acid and solvent usage. Unlike conventional chemical fume hoods, WPS have full-unit-width under-worksurface exhaust plenum/spill containment tubs, allowing for large volumes of heated process chemical baths to be recessed down under work surface, with fumes captured locally and brought down and away under the station work surface, and out rear exhaust. WPS are typically placed in cleanrooms or clean labs due to critical processes performed within, so also provide process protection due to unique station physical design which allows work surface to be 'washed' by HEPA filtered air above. WPS may have vertically or horizontally closing sashes, or hinged eye shields with fixed access openings. WPS often have some degree of automation incorporated into functionality.

Applications - Critical parts processing with acid, base, and solvents, often at elevated temperatures for semiconductor processes, electronics manufacturing, Biomedical, nanotech, medical devices, military, aerospace and other critical processes.

Limitations - Due to larger scale of chemical use in WPS, adequate chemical waste must be planned for. Most WPS have onboard waste systems, each dedicated to particular waste stream used in WPS, with materials of construction carefully selected for compatibility with precise chemistry, concentration, and temperature to be contained. Multi levels of safety interlocks must be included in WPS or otherwise station use should be limited to lower volumes of usage more similar to a chemical fume hood.

Figure 33 Wet Process Workstations

5.16 Hazardous Gas Storage Cabinet

Description - Typically constructed of metal and approximately five-feet tall, the hazardous gas storage cabinets are used to house compressed cylinders. There is often a glass window constructed on the top of the cabinet to view the gas containers inside.

Applications – Storage in these cabinets can include; corrosive solids or liquids, toxic liquids or solids, flammable solids or liquids, organic peroxide formulations, oxidizer solids or liquids, pyrophoric solids or liquids, toxic or highly toxic solids or liquids, unstable solids or liquids, water-reactive solids or liquids. These cabinets can be required by fire codes to increase the maximum allowable quantities, separate incompatible materials, and should be locked to prevent unauthorized access. For further information refer to SEFA 11 – 4.2

Limitations - Leak detectors and low-exhaust flow alarms, as well as a gas purge system, should be required to provide for safe exchange of cylinders.

5.17 Flammable Liquid Storage Cabinet

Design and Construction – Venting of storage cabinets is not required for fire protection purposes, but venting may be required to comply with local codes or authorities having jurisdiction. Non-vented cabinets should be sealed with the bungs supplied with the cabinet or with bungs specified by the manufacturer of the cabinet. If cabinet venting is required, the cabinet should be mechanically vented to the outside and:

- Both metal bungs must be removed and replaced with flash arrestor screens (normally provided with cabinets). The top opening serves as the fresh air inlet.
- The bottom opening must be connected to an exhaust fan by a length of rigid steel tubing that has an inside diameter no smaller than the vent opening.
- The fan should have a non-sparking fan blade and non-sparking shroud.
- The cabinet should exhaust directly to the outside (the cabinet should not be vented through the fume hood).
- The cabinets should be conspicuously marked, "Flammable - Keep Fire Away."

Application - Used to organize and store flammable liquids in approved closed containers. To guard liquids from their auto ignition temperature of the liquids stored in the event of a fire. Flammable Liquids storage cabinets are often used to increase the maximum allowable quantities, to separate incompatible materials, and should be locked to prevent unauthorized access. For further information refer to SEFA 11 – 4.1

Operation - The operating specifications for these cabinets include flow, static pressure and containment.

Figure 34 Ventilated Flammable Gas Cabinets

5.18 Special Purpose Devices

Special purpose hoods are defined as any hood that does not conform to the specific types described above. Special hoods may be used for operations for which other types are not suitable (e.g., robot sampling equipment, liquid nitrogen dewars, ETO sterilizers). Other applications might present opportunities for achieving contamination control with less bench space or less exhaust volume (e.g., using the hoods as special mixing stations, evaporation racks, heat sources, or ventilated worktables).

6 ECD System Management Plan

ECD systems are complex, costly to install, and require diligent efforts to select, operate, maintain and ensure proper use and application. Installation of ECD Systems can be associated with 15% to 30% of the costs to construct a laboratory building and their operation often accounts for as much as 60% to 80% of annual energy consumption and utility costs. Depletion of energy resources and resultant increase in energy costs advocates for efficient energy use as a prominent, but secondary criterion to lab safety. Finally, significant time and effort are required from numerous stakeholders including laboratory personnel, EHS, facilities engineering, facilities maintenance, management, and outside contractors to ensure proper performance and provide safe, productive, energy efficient and sustainable laboratories.

Failure to properly select, design, operate, use and maintain ECD systems may:

- Increase the potential for unacceptable impact to the health of people;
- Increase potential for harm to the environment;
- Increase potential for premature degradation of the ECDs;
- Increase potential for loss of productivity and operational efficiency;
- Increase unnecessary energy consumption and operating costs;

- Increase the risk of non-conformance with regulatory and industry standards; and
- Increase the risk of liability.

6.1 ECD Management Program Description

To help ensure that a framework exists for organizations to provide safe and efficient operation of laboratory ventilation systems, the ANSI/AIHA Z9.5-2012 American National Standard for Laboratory Ventilation requires laboratory facilities to implement a Lab Ventilation Management Plan (LVMP). The LVMP is intended to ensure proper design, operation, and maintenance of lab ventilation systems. In this document, an ECD Management Program serves as the equivalent of an LVMP and should be implemented where hazardous airborne contaminants may be found in laboratory environments. The following elements should be included in a written ECD Management Program:

- Program management and stakeholder coordination;
- Risk assessment process to understand and characterize the airborne hazard, associated risk, and level of protection required;
- ECD selection process;
- ECD system design and operating specifications;
- Performance testing to validate and verify proper performance of the ECD system prior to use with hazards (sometimes referred to as commissioning);
- Maintenance and routine testing program in compliance with THE MAINTENANCE PLAN;
- Training for all stakeholders including users operating ECDs and personnel involved with selection, design, operation, maintenance and testing of ECDs;
- Management of Change process capable of ensuring ECD systems remain appropriate for the hazardous processes and provide proper performance;
- Documentation and recordkeeping; and
- Review and revise annually or as necessary to maintain relevance and use.

The elements of the ECD Management Program are shown in Figure 35 below.

Figure 35 Elements of a comprehensive ECD Systems Management Program

6.2 Program Management and Stakeholder Coordination

Responsibilities for implementation and execution of the ECD Management Program are at the discretion of the facility management. Depending on the number and type of ECDs, risk associated with the applications and complexity of the systems; the responsibilities for execution of the tasks of the ECD Management Program may be assigned to one or more stakeholder groups including Environmental Health and Safety (EHS), Facility Engineering, Facility Managers, Lab Managers and Lab Professionals.

A responsible person or ECD program coordinator should be available for overseeing the ECD Management Program and should review the program regularly (usually annually) and its implementation. Control of frequency, execution, documentation, and records of all tasks and services should be included in the site ECD Management Program.

6.2.1 Hazard Emission Risk Assessment

The risk assessment process should be developed to identify and characterize the hazards and procedures that may lead to the need for an ECD System. This information defines the hazard emission scenario for determining the required performance criteria (acceptable level of control) and selecting an appropriate ECD system. The emission scenario shall indicate the type of airborne contaminant, the characteristics of the airborne contaminant's concentration (e.g.

gas, vapor, particulate, or other aerosol), the quantity of material used in the process, and the potential method and rate of generation.

6.2.2 Selection of ECD's

Where the risk assessment process indicates a need for an ECD due to a hazardous airborne contaminant, the ECD system selected for use must be appropriate for the hazard emission scenario and capable of meeting the required performance criteria under normal and expected operation conditions. This may or may not be effective for a catastrophic event and this should be taken into account when selecting an ECD System.

An inventory and description of the types and application of site specific ECDs should be included as part of the ECD Management Program.

6.2.3 ECD Design and Operating Specifications

The ECD system must be designed and have the attributes appropriate to achieve the required performance criteria when operated in accordance with the established operating specifications. The requirements for design, construction and operation of the ECD systems shall be included in the ECD Management Program and align where applicable with relevant industry standards (e.g. SEFA, ANSI etc). The operating specifications for all commercially manufactured, pre-engineered or custom designed ECD systems must be provided by the manufacturer or determined by the assigned stakeholder.

The operation of the ECD system must be monitored and there must be a means to notify ECD users and other stakeholders when the ECD systems fail to operate within the operating specifications and tolerances necessary for proper performance. Where possible, the systems must be designed and operated to minimize energy consumption, but at no time can energy efficient operating modes adversely affect performance and the ability to protect users.

6.2.4 ECD Performance Verification

All ECD systems must be tested following installation and prior to use with hazardous processes. The performance tests shall verify that the ECD systems are operating in accordance with the specifications and meet the required performance criteria. The performance tests must be appropriate for the ECD system and conform to relevant site standards and guidelines. Proper performance of the ECD system must be verified under all possible modes of operation and the prevailing operating conditions, associated specifically with the laboratory environment and the ventilation systems must be determined and documented.

All ECD systems should be subject to re-tests to verify performance following any major change to the configuration of the ECD, physical design of the laboratory, physical design of the ventilation systems or changes in airflow specifications that could impact performance. The extent of the modifications that justify the need for tests to verify performance should be included in the ECD Management Program.

6.2.5 Maintenance and Routine Testing

All ECD Systems should be maintained according to a Maintenance Plan. The Maintenance Plan includes provision for preventative maintenance and tests to verify that all components are in good working order and operating in accordance with specifications that prevailed at the time of the original commissioning. The maintenance procedures should be appropriate for the ECD systems and cover all operating modes. The procedures should be conducted on a defined frequency to identify and rectify operational deficiencies before performance of the ECDs are compromised.

All maintenance activities and routine tests should be conducted and documented in accordance with applicable standards. The individual standards for maintenance and testing of each type of ECD should include requirements for test equipment, calibration, procedures and training of personnel required to execute the maintenance and testing. All systems, components, labs and ECDs should be evaluated at least annually or as frequently as indicated in the maintenance program to maintain performance within acceptable tolerances. Requirements for verifying proper function of all monitors and alarms should also be included in the ECD Maintenance Program.

6.2.6 Training of Personnel

The continuous training of personnel is critical for the successful implementation and operation of an ECD program. All stakeholders involved in the ECD Management Program including safety, facility operators, lab managers and laboratory associates should receive initial and periodic training to ensure the safe and efficient operation of the ECD Systems. Individual stakeholders should also receive training specific to their responsibilities. A training course should be required for all users and cover work practices, operational capabilities and performance limitations of the ECD systems.

Following initial training, the effectiveness of training and need for refresher training should be evaluated annually or as needed to demonstrate conformance with the ECD Management Program. All stakeholders should be alerted to any changes that may have occurred to application or operation of the ECD systems.

Training topics need to be both general in nature to provide an overview of the ECD management process and describe employee responsibilities and more specific with targeted training as required for the sub-groups of stakeholders. Training should be provided for:

- Facility Managers
- HVAC and Controls Engineers
- Building Operators and Maintenance
- Environmental Health and Safety Managers
- Lab Managers

- Researchers.

6.2.7 Management of Change

While systematic implementation of maintenance, testing and reporting is important, the methods by which changes to the systems or changes to the procedures are handled can be even more critical. The ECD Management Program should include or reference relevant Management of Change plans and include a process or processes wherein changes in use of the ECD's systems are considered.

The Management of Change plan should cover modifications to ECD systems, operating specifications and performance requirements. Maintenance, testing and reporting requirements should reflect the implemented changes. The Management of Change plan associated with the ECD Management Program should include a sample structure of personnel, departments and other various interests that are critical to the Management of Change process.

Initiated Change: An initiated change occurs when an individual or department seeks a modification to the laboratory ventilation system. Initiated changes should follow the MOC process and return to risk assessment and evaluation of hazardous procedures.

Reactive Change: A reactive change is in response to an unplanned change, such as equipment or component failure. This type of change may require an expedited approval process due to immediate concerns for safety and possible damage to the ventilation system. Incidents should be well documented as well as evaluated for prevention of future issues.

The MOC program establishes accountability by providing the procedures and a system of checks and balances to fully document changes that may affect the ECD System. MOC procedures can be conducted any number of ways such as: paper forms, electronic forms, online database system, mobile phone application, etc. These procedures can be summarized as follows:

- Assess conditions that have changed
- Request for ECD change or change to operating environment that might impact performance of the ECD
- Informal review
- Detailed evaluation
- Approval
- Planning and updates
- Implementation
- Follow-up

6.2.8 Documentation and Record Keeping

Documentation describing the location and types of ECDs, descriptions of systems, engineering drawings, flow specifications, commissioning results, maintenance efforts and routine test results should be stored, readily accessible and remain up to date. The location of the documents and records should also be specified as part of the ECD Management Plan. Although not an inclusive list, the records and documents should include:

- Basis of Design Documents and As-built drawings;
- Commissioning reports;
- Testing and Air Balance reports;
- Results of "As installed" and Periodic Routine Test reports;
- Maintenance logs; reported problems and corrective actions;
- System modifications including equipment replacement or changes in operational specifications, flow set points or sequences of operation.

6.3 Responsibilities for the ECD Management Program

It is up to a laboratory's management to provide leadership, allocate resources and assign responsibilities for overseeing and executing tasks of the ECD Management Program. The Table below provides a list of responsibilities recommended for assignment to one or more stakeholder groups such as Environmental Health and Safety (EHS), Facility Engineering, Facility Maintenance, Lab Personnel, Purchasing and Space Planning.

Group or Department	Suggested Responsibility
Head of R&D Operations, Lab Managers, Researchers and ECD Users	• Provide information on use of hazardous materials; • Provide information about procedures, work practices, duration of use, changes in hazardous operations and materials etc; • Provide information and participate in ensuring appropriate safety systems are available; • Provide notification of any ECD Systems which are not operating properly; • Utilize ECD Systems in accordance with operating requirements and safety guidelines; • Provide notification of changes in the work activities or to the laboratory which may necessitate a change, repair, modification of, addition to or removal of ventilation equipment; • Follow the guidelines in the Management of Change for any modifications to laboratory equipment, operations or procedures; and • Follow all safety and health procedures associated with the safe operation of ECD Systems; attend all required health and safety trainings assigned relative to job function and activities performed.
Environmental Health and Safety (EHS)	• Assist researchers with recognition and evaluation of hazards; • Establish control objectives, safety requirements and suitable control strategies; • Assist with selection of the appropriate ECD systems to ensure adequate protection for personnel and the environment; • Assist with ensuring testing protocols of ECD systems are being properly performed, and routine testing and certification dates are being enforced; • Review and provide written final acceptance of testing of ECD systems before use and following periodic tests to verify proper operation; • Communicate findings of testing protocols; • Maintain records associated with testing ECD Systems; and • Assist with review of proper work practices and safety training

Group or Department	Suggested Responsibility
Facility Engineering and Facility Maintenance	• Ensure ECD systems have the capability to provide safe, dependable and efficient operation; • Ensure proper design, installation, and commissioning of systems; • Maintain up-to-date system documentation; • Ensure all stakeholders understand the operation, capabilities, limitations and testing requirements of the ECD systems; • Ensure testing protocols of ECD systems are being properly performed and routine testing dates are being enforced; • Provide notification of scheduled testing of ECD systems; • Periodically inspect the entire ECD system; • Perform preventative and repair maintenance as necessary to ensure proper operation of the ECD systems; • Identify, report and document deficiencies and the required repairs / modifications to fix the deficiency. Such inspections should be integrated and documented as part of the maintenance plan; and • Perform, or arrange to be performed, all necessary repairs / modifications to any equipment which affects the ECD system's ability to meet performance requirements.
Purchasing	• Ensure ECD systems are approved prior to purchase; and • Work with stakeholders to establish purchase requirements for ECD systems to promote standardization.
Space Planning	• Ensure safety and engineering issues are considered in any space allocation decisions.

7 References Sources

- ACGIH - Industrial Ventilation: A Manual of Recommended Practice for Design
- ACGIH - Industrial Ventilation: A Manual of Recommended Practice for Operation and Maintenance, 2007
- ANSI/AIHA® Z9.5 – 2012 American National Standard for Laboratory Ventilation
- ANSI/ASHRAE 110 – 2016 – Method of Testing Performance of Laboratory Fume Hoods
- ASTM F 1412-16 (American Society for Testing and Materials) Standard Specification for Polyolefin Pipe and Fittings for Corrosive Waste Drainage Systems
- EN 14175-3 March 2004 - Fume Cupboards Part 3: Type test methods
- EN 14470-1 - Safety Cabinet Standard for Flammable Products
- IBC International Building Code
- IFC International Fire Codes
- National Environmental Balancing Bureau (NEBB) 2009 - Procedural Standards for Fume Hood Performance Testing
- NFPA 30 2015 Flammable & Combustible Liquids Code
- NFPA 91 2015 Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists and Combustible Particulate Solids
- NFPA 45 2015 Standard on Fire Protection for Laboratories Using Chemicals
- NFPA I 2015 Fire Code
- NSF/ANSI 49 – 2016 Biosafety Cabinetry: Design, Construction, Performance, and Field Certification
- OSHA 29 CFR 1910.106 Flammable Liquids
- Prudent Practices in the Laboratory: handling and management of chemical hazards - 2011
- PWGSC 15128 Laboratory Fume Hoods – Guidelines for Building Owners, Design Professionals, and Maintenance Personnel
- PWGSC 15129 Perchloric Acid Fume Hoods and Their Exhaust Systems
- UL 1275 Standard for Flammable Liquid Storage Cabinets
- SEFA Desk Reference 5th Edition

8 Relevant Organizations

SEFA recognizes and acknowledges the importance of government agencies that produce documents concerning laboratory ventilation, laboratory fume hoods and laboratory safety. These agencies include:

AABC Associated Air Balance Council
1000 Vermont Avenue, NW
Washington, DC 20001
www.aabc.com

ACGIH American Conference of Governmental Industrial Hygienists
1 330 Kemper Meadow Drive
Cincinnati, Ohio 45240
www.acgih.org http://www.acgih.org,
(513) 742-2020

ADC Air Diffusion Council
230 North Michigan Avenue
Chicago, IL 60601
www.flexibleduct.org

AGA American Gas Association 1515 Wilson Blvd.
Arlington, VA 22209
www.aga.com

AGC Associated General Contractors of America
1957 E. Street, NW
Washington,DC 20006
www.agc.org

AGS American Glove Box Society
P. O. Box 9099
Santa Rosa, CA 95405
www.gloveboxsociety.org
(800) 530-1022

AHA American Hardboard Association
1210 W. Northwest Highway
Palatine, IL 60067-1897
www.domensino.com/aha/
(847) 934-8800

AIA The American Institute of Architects
1735 New York Ave. NW
Washington, DC 20006
www.aia.org
(202) 626-7300

AIHA American Industrial Hygiene Association
2700 Prosperity Ave.,
Suite 250
Fairfax, VA 22031
www.aiha.org
(703) 849-8888

AMCA Air Movement & Control Association International, Inc.
30 W. University Drive
Arlington Heights, IL 60004-
1893 www.amca.org
(847) 394-0150

ANSI American National Standards
Institute 1 1 West 42nd Street 13th Floor
New York, NY 10036-8002
www.ansi.org
(888) 267-4683

AHRI Air Conditioning, Heating, and Refrigeration Institute
4301 Fairfax Drive, Suite
425 Arlington, VA 22203
www.ari.org
(703) 524-8800

ASCE American Society of Civil Engineers
World Headquarters
1801 Alexander Graham Bell
Drive Reston, VA 20191-4400
www.asce.org
(800) 548-2723

ASCET American Society of Certified
Engineering Technicians
P. O. Box 1348
Flowery Branch, GA 30548
Www.ascet.org
(777) 967-9173

ASHRAE American Society of Heating, Refrigerating and Air Conditioning Engineers
1791 Tullie Circle, NE
Atlanta, GA 30329-2305
www.ashrae.org
(800) 527-4723
(404) 636-8400

ASME American Society of Mech. Eng.
345 East 47th Street
New York, NY 10017-
2392 www.asme.org
(800) 843-2763 (US and Canada)
011-800-843-2763 (Mexico)
(973)822-1 170 (Outside NA)

ASPE American Society of Plumbing Engineers
3617 Thousand Oaks Blvd.,
Suite 210
Westlake Village, CA 91362
www.aspe.org
(805) 495-7120

ASSE American Society of Sanitary Engineering
28901 Clemens Road
Westlake, OH 44145
www.asse-plumbing.org
(440) 835-3040

ASTM American Soc of Testing & Materials
100 Barr Harbor Drive West
Conshohocken, PA 19428-2959
www.astm.org
(610) 832-9500

BSI British Standards Institution
389 Chiswick High Road
London W4 4AL United Kingdom
www.bsi-global.com
+44 -8996 9000

CALOSHA California Division of Occupational Safety and Health
455 Golden Gate Avenue 10th
Floor San Francisco, CA 94102
www.dir.ca.gov/dosh
(800) 963-9424 — (916) 274-5721

CDC Center for Disease Control and Prevention
1600 Clifton Road
Atlanta, GA 30333
www.cdc.gov
(404) 639-3311

CSI Construction Specification Institute
99 Canal Center Plaza, Suite 300
Alexandria, VA 22314
www.csinet.org
(800) 689-2900

CETA Controlled Environmental Testing Association
3801Lake Boone Trail, Suite 1900
Raleigh, NC 27607
www.cetainternational.org
(919) 792-6339

CSA Canadian Standards Association
5060 Spectrum Way,
Suite 100
Mississauga, Ontario L4W 5N6
www.csa.ca
(800) 463-6727

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

EJCDC Engineers' Joint Contract Documents Committee
American Consulting Engineers Council
1015 15th Street, NW
Washington, DC 20005
www.acec.org
(202) 347-7474

EPA Environmental Protection Agency
401 M Street, SW
Washington, DC 20460
www.epa.gov
(202) 260-2090

FM Factory Mutual System
1 1 51 Boston-Providence Turnpike
P. O. Box 9102
Norwood, MA 02062-9102
www.factorymutual.com
(781) 762-4300

Federal Specifications
General Service Administration Specifications and Consumer Information
Distribution Center (WFSIS)
Washington Navy Yard
Building 197
Washington, DC 20407
http://apps.fas.gsa.gov

IBC International Conference of Building Officials
5360 Workman Mill Road
Whittier, CA 90601-2298
www.icbo.org
(800) 423-6587

IEEE Institute of Electrical and Electronics Engineers
345 E. 47th Street
New York, NY 100172394 www.ieee.org
(800) 678-4333
(212) 705-7900

ISA Instrumentation, Systems, and Automation Society
67 Alexander Drive
Research Triangle Park, NC 27709
www.isa.org
(919) 549-841 1

ISO Int'l Organization for Standardization
Case Postal 56 - 1, ch. de la Voie-Creuse,
Case postale 56
CH-121 1 Geneva 20, Switzerland
www.iso.org
+41 22 74901 1 1

MCAA Mechanical Contractors Association of America
1385 Piccard Drive Rockville, MD 20850-4329
www.mcas.org
(301) 869-5800

MSS Manufacturers Standardization Society of the Valve and Fittings Industry
127 Park Street, NE
Vienna, VA 22180-4602
www.mss-hq.com
(703) 281-6613

NEBB National Environmental Balancing Bureau
8575 Grovemont Circle
Gaithersburg, MD 20877
www.nebb.org
301-977-3698

NEC National Electrical Code
One Batterymarch Park - P. O. Box 9101
Quincy, MA 02269-9101
www.nfpa.org

NEMA National Electrical Manufacturers Association
1300 N. 1 7th Street, Suite 1847
Roslyn, VA 22209
www.nema.org
(703) 841-3200

NFPA National Fire Protection Association
One Batterymarch Park
P. O. Box 9101 Quincy, MA 02269-9101
www.nfpa.org

NIH National Institute of Health
Bethesda, Maryland 20892
www.nih.gov

NSPE National Society of Professional Engineers
1420 King Street
Alexandria, VA 22314
(703) 684-2800

NSF NSF International
789 North Dixboro Road
Ann Arbor, Ml 48105
www.nsf.org
(734) 769-8010

OSHA Occupational Safety and Health
Administration
U.S. Department of Labor
200 Constitution Avenue, NW
Washington, DC 20201
www.osha.gov
(202) 219-8148

PDI Plumbing and Drainage Institute
45 Bristol Drive, Suite 101
South Easton, MA 02375
www.pdi-online.org
(800) 589-8956 - (508) 230-3516

SMACNA Sheet Metal & Air Conditioning Contractors' National Association
4201 Lafayette Center Drive
P. O. Box 221230
Chantilly, VA 20151-1209
www.smacna.org
(703) 803-2980

UL Underwriters Laboratories Inc.
333 Pfingsten Road
Northbrook, IL 60062
www.ul.com
(800) 704-4050
(847) 272-8800