International Institute for Sustainable Laboratories®

Best Practices Guide: Manifolding Laboratory Exhaust Systems

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Introduction: Why Manifold?

Manifolding laboratory exhaust in laboratory buildings provides substantial energy and first-cost savings opportunities, compared with separately ducted systems with multiple exhaust fans. A manifolded system offers several additional benefits, including:

- Increased fume dilution.
- Enhanced personnel safety.
- Reduced cost of redundancy.
- Improved design flexibility for future revisions.
- Reduced cost of energy recovery.
- Reduced congestion in ceilings.
- Reduced cost of installation and operation.

Experience has shown that during laboratory retrofit projects, manifolded exhaust systems reduce construction costs and help avoid operational disruptions. These outcomes are especially likely when fume hood exhaust can be combined with general room exhaust. This guide is intended to provide relevant background for practical considerations when designing and operating laboratory exhaust systems. Locally applicable code and existing system configurations must always be considered in the design process.

This best practice guide is one in a series created by the International Institute of Sustainable Laboratories (I^{2}SL). Geared toward architects, engineers, and facilities managers, these guides provide information about technologies and practices to use in the design, construction, and operation of safe, sustainable, high-performance laboratories.

This guide has been updated to include further technological advances, case studies, and changes in applicable codes and standards since the original guide was published in 2007.

Energy Efficiency and Manifolded Exhaust

A basic, manifolded exhaust system, with one or more primary fan(s) and a backup fan in a common duct system, has higher energy efficiency than multiple, dedicated fans working independently. A manifolded exhaust system saves energy in the following ways:

1. Reduces fan power, in part due to larger, more efficient fans.
2. Provides an adjustable airflow system that can modulate airflow needs in response to varying requirements (exhaust diversity).
3. Requires less energy to disperse exhaust plumes due to increased dilution and momentum of effluent.
4. Increases energy recovery opportunities.

Even greater efficiency can be realized compared with a basic manifolded arrangement when combined with other design best practices, including variable air volume fume hoods, multiple fans, and variable speed drives, which will be covered later in this guide and in referenced case studies. Variable speed drives and variable volume fume hoods have increasingly become a design standard and should be assumed to be part of a typical approach unless there are specific criteria preventing their use for a specific lab facility.

Fan Power Reduction

Manifolded exhaust systems reduce the number of fans compared with individual fume hood exhaust systems, and larger fans and fan motors are inherently more efficient. For example, a small fan system might have a fan efficiency of 50% and a motor efficiency of 89%, while a larger fan system can have a fan efficiency of 70% and a 94% motor efficiency. Large ductwork can also have lower pressure drop where duct velocity limits (typically used to limit noise generation) are reached, resulting in lower friction rates compared with smaller ductwork (Varley, 2020).

Adjustable Airflow

A manifolded exhaust system can be designed to accommodate varying fume hood airflow. Since it is unlikely that all of a facility's hoods will be fully operational simultaneously, the inherent flexibility of a manifolded exhaust system allows it to adjust its airflow rate accordingly to save energy. This concept, also known as "diversity," can also be applied to sizing the manifolded exhaust system, to reduce manifold size and initial costs. However, caution is advised when considering a diversity factor; multiple issues, including future laboratory "growth," must inform the decision.

Exhaust Plume Dispersion

Manifolded exhaust systems have increased dilution, making exhaust streams less hazardous. In addition, combining numerous hood exhausts increases the momentum of this more dilute stream.

Consequently, a manifolded exhaust stack disperses a less hazardous stream into a plume more effectively than a single-fan-per-hood arrangement (Petersen et al., 2011).

Energy Recovery Opportunities

A manifolded exhaust system increases the opportunity to recover energy contained in the conditioned air stream that is being exhausted from the laboratories because the exhaust is centralized, so energy recovery is possible at lower costs. Numerous design and operational challenges are involved, including device corrosion, added air-system pressure drops, increased maintenance costs, operational durability, and control complexity, to name a few. Still, depending on the geographical location, exhaust-stream energy recovery, in the form of both heating and cooling energy, can be worth the design challenges and maintenance issues.

Chapter 514 of the International Mechanical Code prohibits the use of "energy recovery ventilation systems," defined as air-to-air heat exchangers, in hazardous exhaust systems. However, air-to-water systems, such as a run-around coil system, are allowed because supply and exhaust air streams are separated (Reilly et al., 2012).

With a centralized manifold exhaust system, run-around heat recovery can be implemented at much lower cost than with decentralized exhaust systems. In fact, heat recovery from decentralized systems is almost never cost-effective because of the need for additional coils, controls, piping, and so on.

Basic Manifold Design

Initial Considerations

Despite the considerable benefits laboratory exhaust manifolds can provide, lab design parameters will determine whether manifolds are appropriate. For example, individual exhaust systems are usually more applicable in single-story buildings that have a small number of widely separated standard fume hoods. In this scenario, an extended ductwork system connected to a manifolded exhaust system may not be economically justifiable. The use of individual fume hood exhaust systems is also recommended, and often required by codes and regulations, for special processes such as perchloric acid fume hoods.

When contemplating a manifolded exhaust system, consider exhaust compatibility, fume hood number and location, required flexibility, and codes and standards.

Exhaust Compatibility

A risk assessment, led by the laboratory chemical hygiene or chemical safety officer, should be conducted to identify potential hazards of combining exhaust streams. The purpose is to identify specific hoods that should not be connected to a manifold system. The first step is a detailed understanding of the chemicals and agents to be handled within fume hoods. Specific hazards have prescriptive approaches based on industry experience and loss history, including:

- Perchloric acid hoods, which require one hood per dedicated set of fans.
- Radioisotope hoods, which require one type of hood per dedicated set of fans.
- High-hazard biological safety cabinets (BSL-4 and BSL-3) dealing with highly infectious or toxic agents, which cannot be manifolded with non-containment lab fume hood exhaust systems. (However, low-hazard biological safety cabinets [BSL-2 and BSL-1] or cabinets dedicated to tissue culture work may be manifolded with chemical fume hoods.)
- Specific high-pressure-drop devices (e.g. Class II type B2 biosafety cabinets). These should remain on a separate system to avoid increasing overall exhaust system-controlling static pressure, which would result in significant wasted fan energy.

Other hazards may only be identified through the risk assessment, such as certain incompatible chemistries. Lab fume hoods using incompatible chemicals or other agents must not be manifolded without careful consideration of the quantity, types, and concentrations of agents that may be present. In all cases, see ANSI Z9.5, Section 5.3.2.1, for further discussion (ANSI/AIHA, 2012).

Fume Hood Number and Location

The larger the number of fume hoods, the greater the operating and installation economy that can be realized from a manifolded system.

Required Flexibility

If more hoods may be added or relocated in the future, then an appropriately sized manifold system will provide the greatest degree of flexibility. See Sidebar 1, "Advantages of Manifolding Lab Exhaust," for more information (page 5).

Codes and Standards

A manifolded fume hood exhaust system based on best-practice safety and engineering principles needs to be specified by the designer. Therefore, applicable codes and relevant standards and best practices should be reviewed, and designs should be compliant with them.

Early in the project design, the laboratory user or research group needs to identify the chemicals to be used. The design team, in conjunction with the chemical hygiene or chemical safety officer, can then coordinate appropriate fume hood and exhaust system materials compatible with chemicals or agents to be used (and anticipated for future use), and specialty fume hood requirements for the labs. Without knowing the proposed use

Advantages of Manifolding Lab Exhaust

Fume Dilution

Increased internal dilution, with respect to the building's ductwork system, and enhanced external dilution, with respect to the building's envelope, are advantages of manifolded fume hood systems. A chemical spill or odor generated in one hood is diluted by the combined flow of all the hoods, reducing concentration before reaching the exhaust fan outlet. Additionally, when multiple fume hood exhausts are mixed with general room exhaust, increased internal dilution of the exhaust stream is achieved. Combining contaminated exhaust air from each floor of a multistory building in a header duct serving multiple labs will increase dilution even further.

The reduction in dilution can also lead to less stringent requirements regarding minimum airflow velocity in the exhaust outlet nozzle based on monitoring of the dilution level in the exhaust. Reductions in nozzle velocity can allow the fans to be run at lower speed, which in turn reduces the energy consumption. These options are subject to approval with the local Environmental Health and Safety (EH&S) team and will depend on the quantity and type of chemicals used.

Personnel Safety

Safety of laboratory personnel can be increased when laboratory exhausts are manifolded. A manifolded design can more readily include built-in fan redundancy, automatically providing backup to maintain exhaust flow during system failures or maintenance. Redundancy is also possible with individual hood exhaust fans but at much higher cost, so it is often not provided. By eliminating multiple laboratory exhaust systems, maintenance personnel will spend less time on a laboratory roof or mechanical space, minimizing exposure to hazardous chemicals from the serviced system and adjacent systems.

First-Cost Savings

Manifolded exhaust systems can be less costly than individual systems due to less material and installation labor, and fewer fans and associated installation costs. Fewer fans, ducts, roof penetrations, electrical connections, and exhaust terminals typically yield a smaller first-cost capital investment. There are generally fewer ducts in the ceiling space, which reduces congestion and indirect costs associated with coordination with other trades and possibly raising floor-to-floor height.

Individual, non-manifolded systems require a larger "footprint" for the same hood count and airflow volume. Increased shaft space for ductwork will require a tradeoff in lab square footage. Since a laboratory building exhaust system must be continuously operational, a connection to an emergency power source is usually provided. It's less costly to connect a manifolded exhaust system to an emergency power source than numerous individual exhaust fans. In addition, fewer fans lead to a simpler Building Automation System (BAS), fire alarm system, and smoke control systems, with resulting cost savings.

The increase in dilution can also allow greater flexibility in the type of material used for the duct system in some cases. The level of dilution may allow standard galvanized ductwork to be used for the main riser ducts instead of welded stainless steel or other non-metal corrosion-resistant materials, depending on the chemicals used and function of the laboratory.

continued on page 5

Advantages of Manifolding Lab Exhaust, Continued

Flexibility

Modern laboratory facilities should have the ability to respond to changes in research, technology, and personnel needs. Manifolded fume hood exhaust systems, with their inherent flexibility, can help modern labs accommodate these changes. Many possibilities exist for adjusting and expanding manifolded systems without affecting a building structure. For example, hoods can usually be moved or added with only minor changes of the HVAC system.

When modifying a laboratory space, the building footprint may not accommodate new shafts or new ducts in existing shafts; tapping into the manifolded exhaust duct or plenum causes fewer disruptions and uses significantly less energy than a dedicated exhaust fan. Redundant fans allow maintenance operations to proceed without impacting laboratory operations, so maintenance costs are reduced. The fan system capacity may be increased without disrupting laboratory operations.

of the labs, the designer must make conservative assumptions about future use, potentially restricting flexibility and adding cost to the project and operating budgets.

Codes

- International Code Council (ICC), International Mechanical Code (IMC) 2021 Edition, Section 510, determines whether exhaust should be considered “hazardous” and stipulates appropriate protection provisions. Because the IMC makes this determination based on expected concentrations of chemicals under normal operating conditions in the absence of exhaust, generally lab exhaust will be considered “hazardous” due to the potential for toxic or flammable fumes if such an exhaust system were not present. See the Dampers section below for further discussion.
    - IMC 510 permits manifolding laboratory fume hoods originating in the same fire compartment.
    - Combining hazardous fume hood exhaust and non-hazardous room exhaust, in most circumstances, results in a safer and more efficient system design because room exhaust provides a dilutive effect. This configuration was explicitly allowed in laboratories following the 2012 IMC (Section 510.4 Exception). A code change in the 2015 IMC removed this allowance and required hazardous exhaust systems to remain independent from nonhazardous exhaust (Section 510.4). A further change in the 2021 IMC specifically classified room exhaust as environmental air that must remain independent from non-environmental air systems (Section 501.2). Therefore, in jurisdictions adopting 2015 and newer editions of the IMC, in order to benefit from the safer and more efficient design effects of combining room exhaust and hazardous fume hood exhaust, special consideration and approval from the authority having jurisdiction (AHJ) is required. The technical professionals responsible for developing and reviewing this guide plan to propose modifications to align IMC code requirements with best practices in future editions.
    - IMC 510 permits manifolding of compatible exhaust streams originating in

different fire compartments within a shaft, so long as measures are taken to continue the fire and smoke separations (subducts or rated duct runs in lieu of fire dampers; redundant exhaust fans on legally required standby power in lieu of fire/smoke dampers).

  - IMC 510 does not explicitly permit manifolding of production-scale (non-laboratory) exhaust, and exhaust originating in Group H, High Hazard occupancies.
  - A manifold outside the building (e.g., on the roof) requires special consideration and approval from the AHJ.

Standards & Best Practices

The primary standards and best practices documents are listed below. See the References list at the end of the guide for additional information.

- OSHA 29 CFR 1910.1450, Occupational Exposure to Hazardous Chemicals in Laboratories.
- NFPA 45-2019, Chapter 7, Laboratory Ventilating Systems and Hood Requirements.
- NFPA 91-2020, Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists, Particulate Solids.
- ANSI/AIHA Z9.5, American National Standard for Laboratory Ventilation, American National Standards Institute, Inc./ American Industrial Hygiene Association, 2012.
- Industrial Ventilation: A Manual of Recommended Practice — 28th Edition. The American Conference of Governmental Industrial Hygienists, Inc. (ACGIH), eds. Cincinnati, OH. ISBN: 1-882417-42-9, 2013.
- ANSI/ASHRAE 90.1, Energy Standard for Buildings. American Society of Heating, Refrigeration and Air Conditioning Engineers, 2019.
- Centers for Disease Control, Biosafety in Microbiological and Biomedical Laboratories, 5th Edition, 2009.

Basic Manifold Configuration

Figure 1 (page 7) shows a “basic” manifold configuration that connects constant volume (CV) fume hoods into a common duct. A CV hood system provides a constant exhaust airflow rate to the hood, selected to provide the maximum required face velocity at the sash opening regardless of sash position. When the sash is lowered, the excess air is exhausted, via a bypass opening in the hood face, directly from the space to avoid excessive noise and draft at the sash opening.

Depending on the number of hoods in a lab space and the desired air change rate per hour (ACH), sufficient air may be exhausted through the CV hoods to satisfy the ACH required. If not, a “general” exhaust would also need to be tapped into the manifold ductwork. Note that IMC Section 510 requires volume-control devices on each fume hood branch where a manifold system is to be used.

If possible, avoid installing CV hoods in a new facility. Variable air volume (VAV) hoods, which reduce airflow when the sash is closed, are preferred. A VAV hood uses an air valve that varies the amount of exhaust to the hood between a predetermined maximum and minimum volume, depending on the sash height. As the sash is lowered and raised, the air valve opens and closes to maintain the required face velocity at the sash opening.

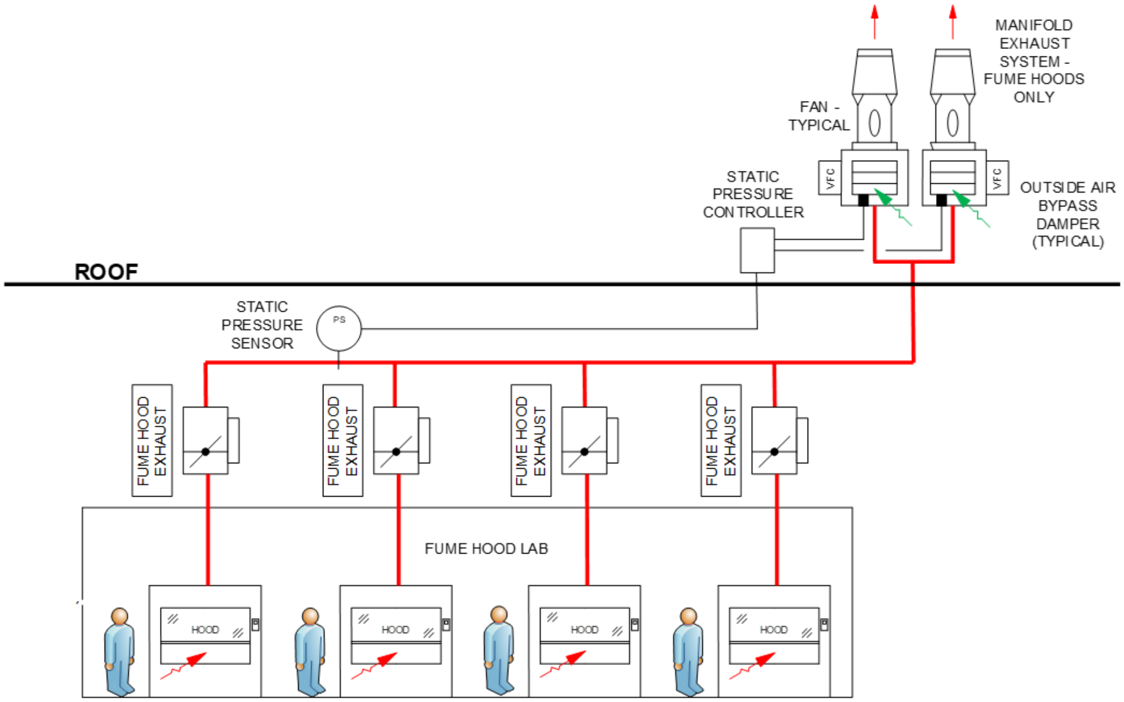

Figure 1: Simple centralized exhaust system. Source: M. Walsh, R.G. Vanderweil Engineers

VAV hoods should be standard practice. CV hoods should be considered only where fume hood exhaust is less than the minimum unoccupied room ventilation rate, for specific operations within the hood, or where specific containment requirements exist.

Two or More Fans

In a basic manifolded exhaust system configuration, a minimum of two fans are connected to a common plenum to provide exhaust capacity. One fan is the primary or "lead" fan, and another is the backup or "lag" fan to the primary. In this basic design, each fan's capacity is equal to the maximum total exhaust requirement of the connected labs, with all hoods and equipment in use. For VAV systems, diversity of loads and hood use may be considered to reduce fan size. (Load diversity is a complex issue that requires coordination with the registered design professionals and laboratory stakeholders.)

The active fan operates at a constant full speed to provide both required exhaust flow and a resulting stack exit velocity. Thus, a manifolded exhaust system mitigates the problem of a single fan-per-hood failure since backup capacity is readily available for the connected hoods. In addition, fan inspection and critical maintenance can be accomplished without shutting down the entire system.

Fan Types and Location

Centrifugal fans have efficient flow and pressure characteristics that are most often used in a manifolded exhaust system. Specialized mixed-flow and axial-type exhaust fans are available for constant or variable air volume manifolded exhaust systems (discussed below). These fans are designed to move large amounts of ambient air into the exhaust plume as it is discharged from their stacks at a high upward velocity. The induced ambient air provides additional dilution. The high plume velocity reduces the tendency for wind to push the exhaust back down toward the building.

Regardless of the fan type used, it is best practice to located fans outside on the roof or within a dedicated penthouse so that most of the ductwork is situated before the fan and, therefore, negatively pressurized. Any ductwork after the fan should be well-sealed to prevent leakage; usually, this means welding. If fume hood exhaust fans are installed in a penthouse, ANSI Z9.5 and NFPA both require the penthouse to be mechanically ventilated.

Ductwork and Stack

Manifold ductwork can be arranged to serve all of a facility's labs, or specific groupings of laboratories and their fume hoods, typically on a particular floor or in a wing of a building. One large centralized exhaust backbone plenum serving the total exhaust needs of a laboratory building helps maximize the energy benefit of a manifolded exhaust system. Manifolded exhaust systems may use horizontal or vertical exhaust headers, or a combination of the two.

When designing the ductwork layout, attention should be given to potential "system effects" that unnecessarily increase turbulence and pressure drop, resulting in higher fan energy use. Ductwork should be as straight as possible, with minimal elbows. As a matter of due diligence, the manifold exhaust ductwork system should be tested for its overall leakage rate, and the responsible engineer should document these test results in the building's permanent records.

Usually, a manifolded system's stack can be more conveniently located away from laboratory intakes to minimize potential re-entrainment. To the extent possible afforded by the facility's layout, it is advised to cluster or group the exhaust stacks to enhance plume dispersion.

Dampers

Dampers must be used in manifolded exhaust systems to provide fan isolation. Manifolds with outlet gravity-style backdraft dampers are a minimum-design necessity to prevent reverse-flow short circuits through idle (lag) manifolded fans. Damper configuration, material, actuator type, end switches, and seals are some of the necessary design considerations. Monitoring the manifold's damper positions with the laboratory facility's building automation system (BAS) is recommended.

Note that fire and smoke dampers are prohibited in hazardous exhaust ducts, due to the risk that closing the dampers in a fire condition could expose users in the room of origin to toxic fumes. As a result, hazardous exhaust ducts are generally more robust than other ducts in the building as they must maintain continuity of fire and smoke compartments.

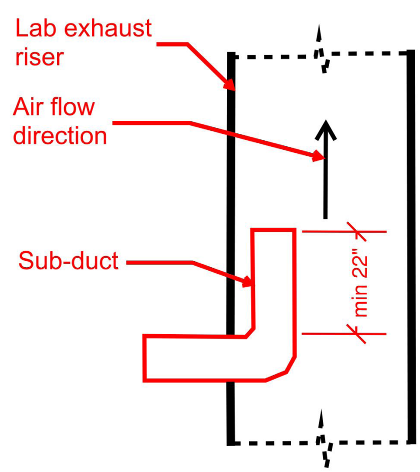

Figure 2: Sub-duct. Source: Arup.

One acceptable method of providing equivalent protection to a fire/smoke damper is to use sub-ducts to prevent smoke transfer from one floor to the next within the riser; these sub-ducts are combined with a continuously running exhaust system that is connected to generator power to ensure operation in a power outage and redundant fans. Code and NFPA require a minimum 22-inch sub-duct height. See the Codes and Standards section above for further discussion.

Control zones

As mentioned in the Codes and Standards discussion above, fume hoods can be manifolded from the same fire compartment or different fire compartments if a suitable method of fire separation can be provided. Therefore, it is important to plan the duct manifold distribution with the fire compartmentation in mind to avoid excessive amounts of rated duct work.

Good Manifold Design Practice

The following three "good practice" enhancements to the basic design approach provide pragmatic energy-use reductions without excessive expenses or design complications (see Figure 3, below):

1. Exhaust less conditioned air. Reduce conditioned air exhausted from a building by using variable air volume (VAV) systems, including VAV fume hoods and a bypass damper.
2. Modulate fan speed. Decrease exhaust fan power by using variable speed drives (VSDs) to modulate exhaust fan speed.
3. Set back duct static pressure. Reduce exhaust fan energy use by lowering manifold duct

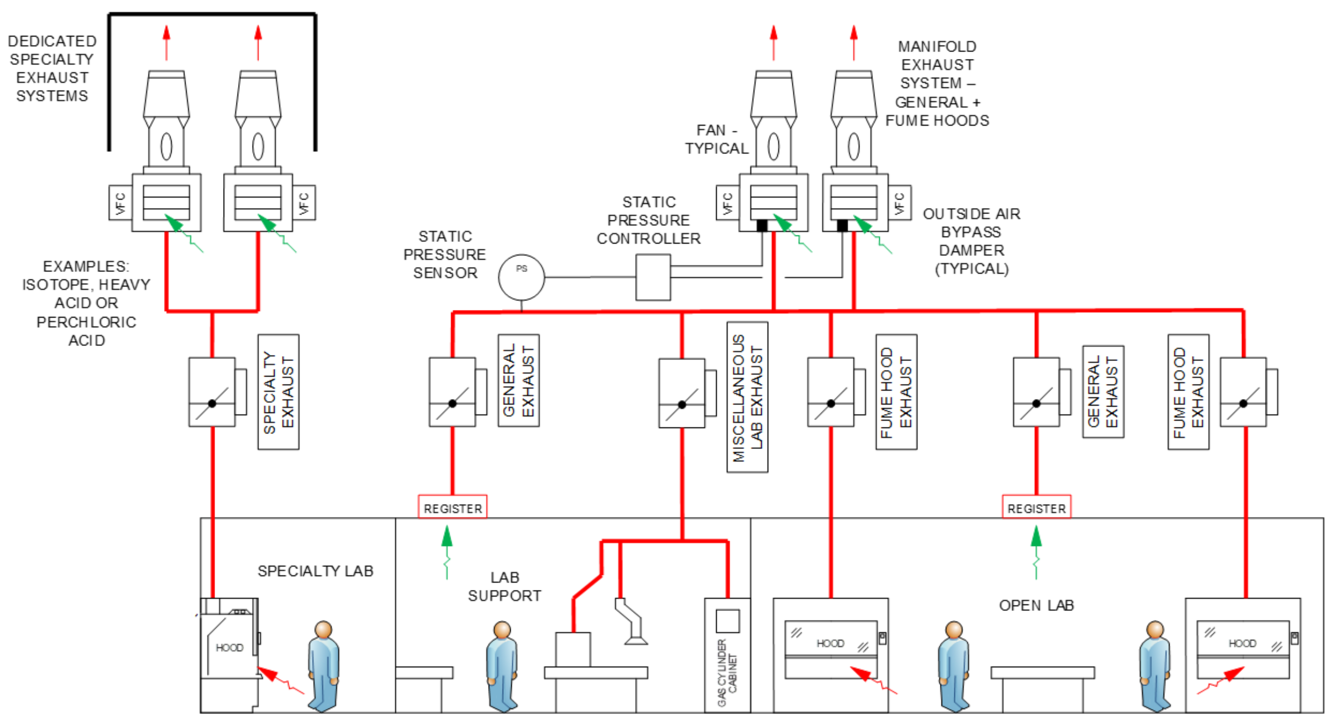

Figure 3. Good manifolding design practice. Source: M. Walsh, R.G. Vanderweil Engineers

static pressure during off-hours operation (static pressure reset).

We consider these three concepts in more detail below.

Exhaust Less Conditioned Air

Summary

- Use VAV lab hoods in “hood-dominated” labs (those where hood exhaust rates exceed those for minimum ACH and cooling loads).
- Track changing VAV hood exhaust volume with a bypass damper as required to maintain minimum stack exit velocity.
- Ensure that lab controls maintain the minimum lab air change rate and desired directional airflow, but no more.

Considerations

When VAV hoods are connected to a manifolded laboratory exhaust system, the manifolded system experiences changing airflow volume caused by varying fume hood sash positions. This good-practice manifold configuration uses an inlet, or bypass damper, located in the exterior central exhaust plenum. Modulating the bypass damper provides a constant exhaust duct static pressure, while the constant fan speed provides a constant stack exit velocity.

This constant pressure control approach does not save exhaust fan energy, but it does reduce the amount of conditioned air exhausted from the facility, while providing the required stack exit velocity. A good manifolded system design also has a motorized or gravity isolation damper at the inlet of each fan connected to the centralized plenum.

Modulate Fan Speed

Summary

- Add variable speed drives (VSDs) to the exhaust fans to further reduce energy use.
- Modulate the bypass damper to maintain sufficient exhaust volume in response to hood operations; as more hoods are opened, the bypass damper modulates to a closed position.
- Operate exhaust fans at a reduced speed, maintaining the minimum required stack velocity until the bypass damper is fully closed.
- Increase exhaust fan speed to provide necessary volume flow when the bypass damper is fully closed, and more hoods are opened.
- Modulate the bypass damper until it is fully open to maintain minimum stack exit velocity when all fume hood sashes are in a “closed” position (e.g., off-hours).

Considerations

The design of a manifold with a bypass damper for tracking changing manifold volume can be enhanced by adding variable speed drives (VSDs) to the exhaust fans. Varying the speed of the primary exhaust fans with VSDs saves more energy than using a bypass damper alone.

First, the design must provide adequate stack discharge velocity for an “absolute minimum” airflow that results when all fume hood sashes are in their closed (minimum) position. This velocity requirement is provided with the manifold bypass damper (noted above) in its fully open position. Second, as increased exhaust capacity is required (due to an increased open sash area), the bypass damper is eventually modulated to a fully closed position by the control system. Typically, this airflow volume is considered a “most-likely minimum” airflow that is predicted by a chosen fume hood “diversity factor.” Third, airflow volume greater than the most-likely minimum is provided by continuously adjusting fan speed with the VSD in response to duct static pressure changes in the manifold plenum caused by more fume hood sashes being opened. Finally, with maximum volume demand on the system, the primary fan operates at maximum speed with all hood sashes open.

When using variable speed drives, it is important to choose a fan type that has flow characteristics well-suited for the airflow volume ranges resulting from fume hood activity. Additionally, these multiple fan arrangements provide redundancy in the system, for safety.

Set Back Duct Static Pressure

Summary

- Reset the static pressure operating point for the manifolded system with the building automation system (BAS).

Considerations

Energy-efficient control of a manifolded exhaust system is accomplished with direct digital control (DDC) that is part of the facility’s BAS using indicators of pressure demand from each exhaust air valve, including both those controlling airflow and those controlling general exhaust. Pressure demand from air valves is most commonly ascertained in two ways:

- Air valve damper position. Damper position is generally known for closed-loop-type air valves that measure airflow and directly control air valve damper position. The static pressure reset strategy, then, is to ensure that at least one air valve damper is close to 100% open.
- Differential pressure (DP) across the air valve. For venturi-type pressure-independent air valves, actual damper position is not known, but pressure demand can be approximately determined by measuring the differential pressure across the air valve. The static pressure reset strategy, then, is to ensure at least one air valve damper is close to the minimum DP required to maintain its maximum airflow.

In both cases, the air valve digital controllers must be integrated with the fan control system. Reset strategies include “trim and respond,” as outlined in ASHRAE Guideline 36.

Note that ASHRAE Standard 90.1 prescriptively requires static pressure setpoint reset for VAV lab systems.

The following DDC input information and output controls are recommended:

Input Information

- Exhaust stack discharge air velocity: Maintain the exhaust stack discharge air velocity above the required minimum.
- Fan speed input: Verify variable speed drive operation.
- Fan failure/status: Automatic/bypass start of standby exhaust fan(s).
- Manifold duct static pressure: Used for controlling fan speed and starting standby fan(s).
- Isolation damper position end switches: Verify full opening or closure of damper.
- Bypass damper position: Verify damper position.

- Air valve damper position or differential pressure: Reset static pressure down to maintain the lowest pressure needed for the valve requiring the most pressure.

Output Control

- Start/stop fan: Initiate fan operation through variable speed drive (VSD).
- Fan speed output: Modulate VSD control of fan speed to maintain the duct static pressure setpoint.
- Isolation damper operation: Initiate opening/closing of damper.
- Bypass damper operation: Continuous positioning of damper to maintain the duct static pressure setpoint in sequence with the fan speed.

Better Manifold Design Practice

The following three good-design-practice enhancements substantively reduce energy use (see Figure 4, below):

1. **Multiple staged variable speed fans.** Decrease exhaust fan power by using multiple fans, each with variable speed drives (VSDs) to modulate exhaust fan speed.
2. **Plume dispersion evaluation.** Diminish energy needed for plume generation by performing dispersion analyses.
3. **Monitoring wind speed and direction** and allowing reduction in plume height, and bypass volumes when conditions are favorable.
4. **Monitoring exhaust plume for chemical concentration levels** to allow reduction in plume height and bypass volume when chemical concentrations are low.

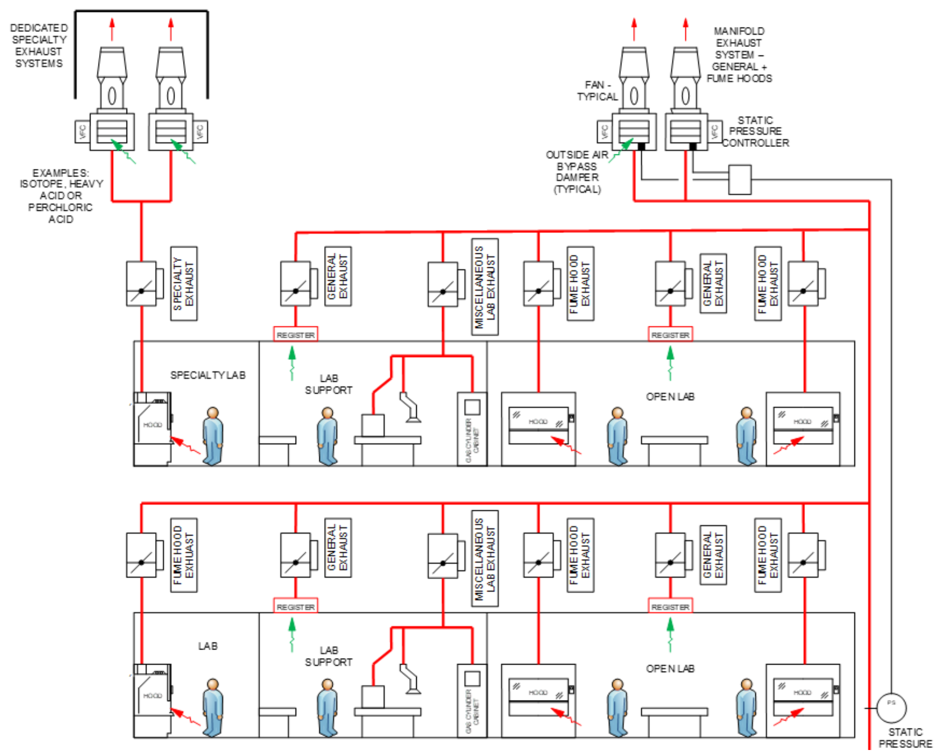

Figure 4. Better manifolding design practice. Source: M. Walsh, R.G. Vanderweil Engineers

Multiple Staged Variable Speed Fans

Summary

- Uses three exhaust fans (each sized for 50%) connected to common plenum.
- Provide VSDs for each exhaust fan.
- Operate two primary fans in parallel to maintain minimum required stack velocity.
- Maintain minimum stack exit velocity with a bypass damper when all fume hood sashes are in a "closed" position (e.g., off-hours operation).

Considerations

Using a set of multiple exhaust fans provides greater operational flexibility and increased redundancy than one primary fan. Combined with this approach, increased efficiency can be realized by modulating each fan's capacity with an associated VSD, thus providing a variable-volume capability.

As in the good-design approach, a modulating bypass damper ensures that the required stack exit velocity is provided below a most-likely minimum airflow condition (see Figure 4). When the most-likely minimum airflow through the manifold system is reached, i.e., when the system "diversity" is reached, the bypass damper will be fully closed. Increased volume flow, above the most-likely minimum, is provided by increasing the speed of the primary fans, in parallel, with their VSDs. In this way, compared with the good-design-practice approach, greater efficiency is achieved by operating two smaller fans with smaller diameter exhaust stacks in parallel than by operating one large fan with a larger diameter stack.

Using three fans sized at 50% each also allows lower stack exhaust rates (see the following sections for information about improving exhaust turndown), with less risk of fans operating in surge compared with two fans sized at 100%. In addition, if one primary fan fails, the other operating primary fan immediately speeds up to maintain the required volume airflow. The backup (standby) fan is then brought online gradually. Note that more than three fans can be used, but control and maintenance become increasingly complex and costly as more fans are added.

When using multiple fans, there is potential for them to be grouped ("cigarette pack") so that they can behave as a single, larger stack. This can result in a lower minimum stack momentum than individual stacks operating independently.

Evaluate Plume Dispersion

Summary

- Evaluate stack exit height and momentum (airflow rate and velocity) to lower energy use that ensures safe and effective operation.

Considerations

There is an associated energy cost to dispersing an exhaust stack's plume. Within the manifolded exhaust system's ductwork, combining many hood and general exhausts increases effluent dilution. Therefore, a fundamental benefit of a manifolded system is a diluted effluent being expelled from its stack(s). By carefully studying this diluted plume's dispersion, exhaust fan energy use can be reduced. (See Sidebar 2, "Benefits of Manifolding Fume Hood Exhausts — A Dispersion Modeling Perspective." Also see Petersen et al., 2011.)

When considering a stack exit momentum (airflow rate and velocity), it is recommended that plume dispersion calculations or atmospheric modeling be performed to evaluate exhaust entrainment rather than using a "design standard." These evaluation techniques will account for the beneficial dilution

Benefits of Manifolded Fume Hood Exhausts—A Dispersion Modeling Perspective

One of the benefits associated with manifolded exhaust systems is increased momentum, resulting in improved plume rise of the discharged flow.

For example, a 10,000-cfm exhaust will achieve a plume rise about three times greater than a 1,000-cfm exhaust discharged at the same velocity, wind conditions, and stack height. Increasing the distance the plume rises above the emitting building is effective in avoiding recirculation zones and will result in improved overall dispersion.

A second benefit of manifolding is increased internal dilution of the combined exhaust stream. For a typical worst-case scenario where a large release would occur in one fume hood, the exhaust in a manifolded system would be diluted "internally" before being discharged to the atmosphere (i.e., contaminated exhaust is diluted by "clean" air in other fume hoods).

The total dilution achieved by the exhaust stream at a receptor location (e.g., air intake, window) is the product of internal dilution (between the point of contamination and point of discharge) and external dilution (between the stack top and the receptor). As the internal dilution of a system increases, less outdoor stack exhaust dilution will be needed. Therefore, savings in energy costs and stack design requirements can be achieved. In addition, a single stack for a central exhaust system will be easier to position to reduce the impact on building air intakes than multiple individual exhaust stacks.

Source: Simona Besnea/RWDI

and momentum provided by a manifolded system and will likely result in a lower stack exit velocity, saving exhaust fan energy. Additionally, such models can determine potential detrimental effects to neighboring buildings, such as entrainment of exhaust fumes into nearby building air intakes.

Taller stacks will generally reduce requirements for stack exit momentum, and this saves energy, so increasing stack height should be evaluated within architectural and practical construction considerations.

Evaluate Plume Dispersion at Range of Wind Conditions

Summary

- Evaluate stack exit rate and velocity to a lower energy use that ensures safe and effective operation based on wind direction and velocity.

Considerations

The plume dispersion model discussed above will determine the recommended location and nozzle velocity required to achieve safe levels of dilution at a conservative design condition with respect to wind speed and direction. This same model can determine if reductions can be made at lower wind speeds and/or directions. This can them allow the nozzle momentum (cfm and velocity) to be reduced during favorable wind conditions in conjunction with real-time wind speed monitoring. A table of wind speed and direction vs. airflow can be created, such as that shown in Table 1 (page 15).

This measure should only be implemented after a wind tunnel test or similar CFD analysis has been performed to determine the conditions under which the nozzle airflow velocity and, therefore, plume height can be reduced safely. The shape and size of the building and those surrounding it can have an unpredictable effect on the airflow around

Wind Direction		Anemometer Wind Speed*														
Min	Max	< 1	1	2	3	4	5	6	8	10	12	14	16	19	22	25
350	10	43%	50%	79%	99%	100%	100%	100%	100%	100%	100%	100%	86%	61%	47%	91%
10	30	43%	40%	59%	74%	88%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
30	50	43%	40%	41%	55%	67%	78%	88%	100%	100%	100%	92%	79%	72%	100%	100%
50	70	43%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	100%
70	90	43%	40%	43%	52%	62%	70%	76%	83%	82%	78%	74%	73%	66%	97%	100%
90	110	43%	50%	61%	70%	78%	84%	90%	100%	100%	100%	100%	100%	100%	100%	100%
110	130	43%	65%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
130	150	43%	62%	96%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
150	170	43%	52%	90%	100%	100%	100%	100%	100%	100%	92%	86%	86%	87%	66%	100%
170	190	43%	49%	78%	92%	95%	92%	86%	71%	61%	56%	54%	51%	48%	72%	100%
190	210	43%	49%	63%	64%	59%	50%	42%	40%	40%	40%	40%	40%	40%	100%	100%
210	230	43%	40%	49%	52%	51%	48%	44%	40%	40%	40%	40%	40%	40%	94%	100%
230	250	43%	40%	43%	56%	65%	72%	76%	79%	79%	76%	73%	71%	69%	66%	60%
250	270	43%	40%	53%	70%	83%	93%	100%	100%	100%	100%	100%	100%	100%	100%	100%
270	290	43%	40%	66%	85%	99%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
290	310	43%	40%	58%	77%	91%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
310	330	43%	41%	68%	88%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
330	350	43%	46%	75%	96%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

All Values are in % of Full Load Volume Flow
*U = Local anemometer wind speed

Table 1. Example wind speed and direction vs. airflow. Source: S. Taylor, Taylor Engineering.

the exhaust plumes, so it is not recommended to assume that the fans can be turned down based on arbitrary wind speed to nozzle speed relationships.

Monitor Dilution Levels in the Exhaust Plume

Summary

- Monitoring the chemical concentration in the exhaust air before it exits the building allows reduction of the makeup air and fan speed when the dilution levels are already within an acceptable range.

Considerations

Sensors that detect a range of commonly used chemicals can be installed in the exhaust duct to monitor their concentration and increase or decrease the fan speed when required. In many laboratories with known chemical uses, the sensors can be selected and calibrated to monitor the concentrations within the exhaust air stream. If the concentration is below acceptable limits, the airflow is effectively classed as non-hazardous. This reduces the level of dispersion needed and can, in turn, allow the fans to turn down. If the chemical concentration increases due to heavier fume hood use, the sensor will detect this and ramp up the fans to increase the plume height and dilute the exhaust air.

When considering chemical sensing in the exhaust air stream, it is important that the laboratory chemical hygiene or chemical safety officer approve setpoints used for varying exhaust discharge velocities. Since the concentration of chemicals acceptable at air intakes is similar in magnitude to concentrations typically used as acceptance criteria for fume hood leakage, safety officers may want to consider the following guidance from ASHRAE 62.1 and NFPA 45 when considering use of chemical sensing:

- NFPA 45-2019: “Increase ventilation automatically upon detection of any condition within 25% of the level of concern.”
- ASHRAE 62.1-2019: “Contaminants or mixtures of concern for purposes of the design shall be identified. For each contaminant or mixture of concern, indoor sources (occupants, materials, activities, and processes) and outdoor sources shall be identified, and the emission rate for each contaminant of concern from each source shall be determined.”

Using contaminant concentrations to reset stack airflow and velocity entails some risk because not all contaminants can be measured, and fast changes in concentration (e.g. due to a spill) may not be detected quickly enough for the fan speed controls to appropriately respond. The system should be approved for use by EH&S staff considering these risks.

Manifold Performance Examples

Case Studies

Northeastern University Interdisciplinary Science and Engineering Complex (ISEC)

This 234,000-gsf research laboratory for Northeastern University in Boston, completed in 2016, was able to utilize manifolding of both fume hood and general exhaust to reduce ductwork and allow for variable speed fan control, plus energy recovery via a run-around coil system (Figure 5, page 17).

Two separate exhaust plenum boxes with three fans connected to each were located at separate ends of the building next to the main exhaust risers. The plenums were connected via an equalizing duct to allow either plenum to be shut down for maintenance and still provide continuous exhaust to all the labs in the building.

The building has approximately 60 fume hoods installed; however, the size and location of these hoods was subject to change. Many of the lab spaces were fitted out after the building opened, and it was important to provide a flexible solution to the university so that new researchers could be accommodated with minimal changes to the building systems, or disruption to the existing occupants.

Each floor has two lab control zones fed from two shafts, and each shaft connects multiple floors, each protected by sub-ducts. At the top of each shaft an exhaust plenum with filters, sound attenuators, and a heat recovery coil transfer energy from the exhaust air to a water/glycol loop. The loop connects to coils in the air-handling units so that the incoming outdoor air is heated or cooled by recovered energy before new energy is used. This style of energy recovery ensures that the laboratory exhaust is completely separate from the supply.

Sub-ducts were used at the connection to the riser to prevent smoke transfer between floors or control zones. The lab exhaust fans were provided with generator-backed power to ensure that fume hood containment was maintained even during a power failure.

Radioactive and flammable waste exhaust was ducted to the roof and exhausted via separate fans. Additionally, the shafts provided for individual hazardous lab exhausts in case of future needs for fume hoods that couldn’t be manifolded with the rest of the lab system. This provision was to allow more flexibility, as the occupants of the building were not known at the time of construction.

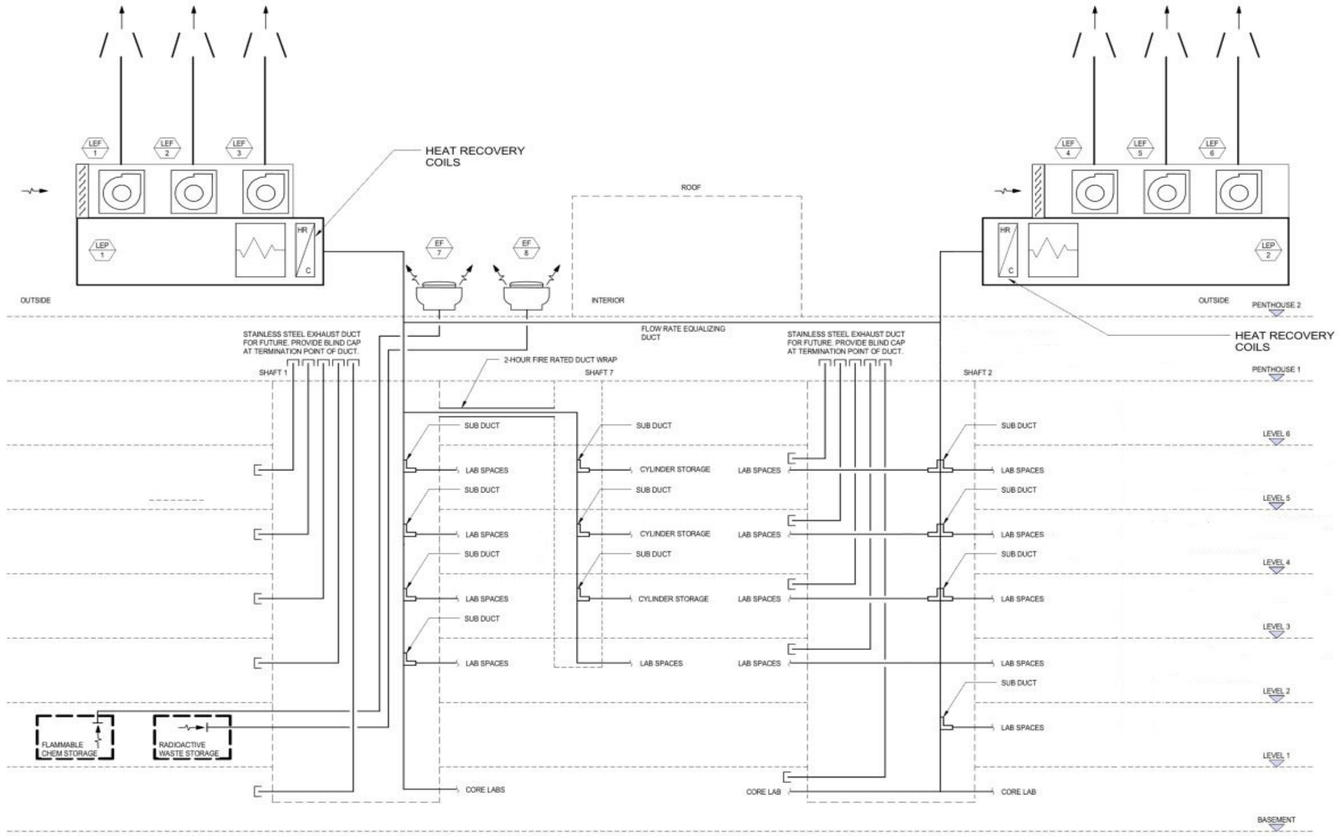

Figure 5. Manifolded lab exhaust single-line diagram for Northeastern University's Integrated Science and Engineering Complex (ISEC). Source: Northeastern University/Arup.

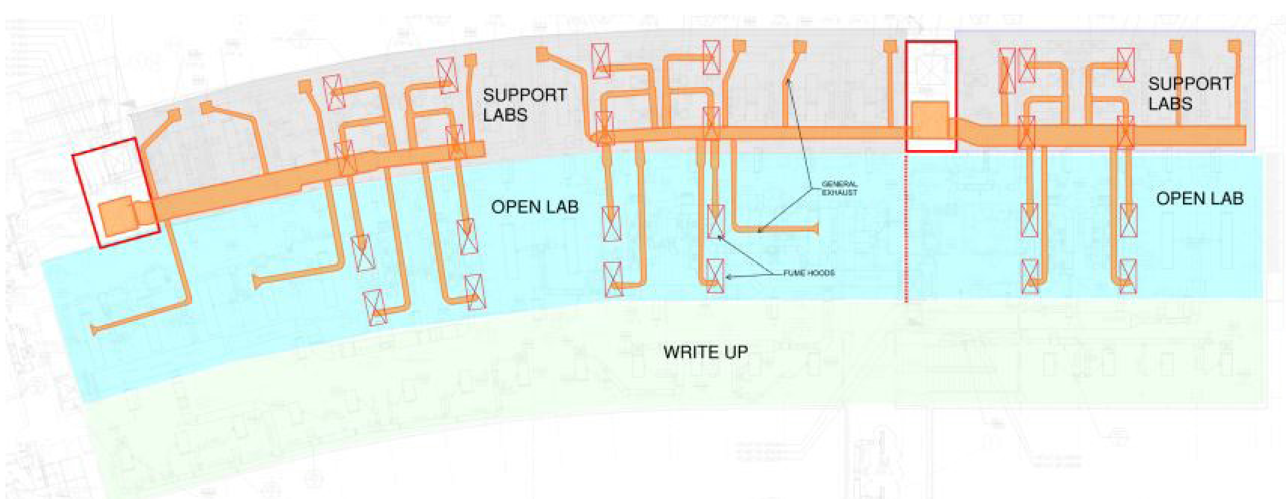

Figure 6. Typical lab floor at ISEC. Source: Northeastern University/Arup.

In each lab area, both fume hoods and general lab exhaust were connected to the same duct mains. The general lab exhaust provided extra dilution to the fume exhaust.

The resulting building energy use reduction over a typical I²SL benchmark research building for this climate zone was 75% overall once this measure was combined with other energy-saving technologies and measures. The energy use intensity, or EUI, was 103 kBtu/sf/yr, and the project was certified LEED Gold.

University Laboratory Building in Texas

The building ventilation system at a university laboratory building in Texas was designed with fume hood exhaust and environmental air ducts co-located within the same fire-resistance-rated shafts. This design approach was contingent on conformance, in part, with NFPA 90A §5.3.4.5 (2), which stipulates that the fume hood exhaust ducts cannot contain flammable vapors inside the common shafts. However, NFPA 90A does not include specific criteria or methods to demonstrate that vapors are not flammable.

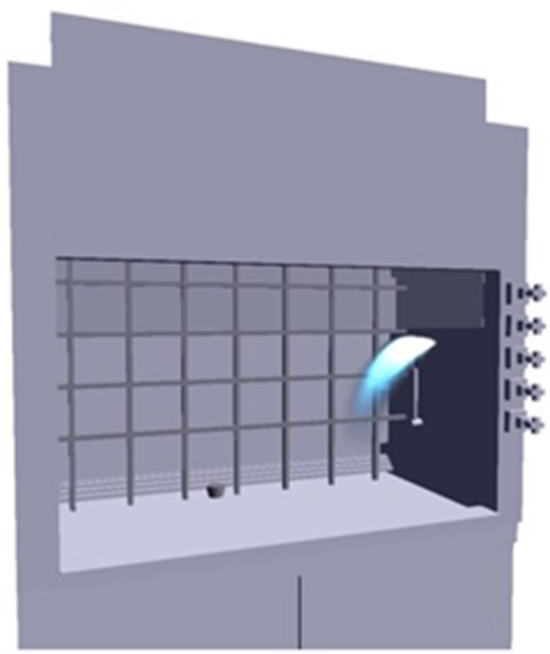

Figure 7. Release of service gas from a supply nozzle. Source: Jensen Hughes.

In accordance with good practice and other NFPA codes and standards, gas concentrations in excess of 25% of their corresponding LFL (lower flammability limit) were established as the threshold for the purposes of considering a vapor “flammable.” A CFD-based analysis using FLACS (Flame Acceleration Simulator) software was performed to study the fume hood exhaust for worst-case release scenarios, to determine gas concentration at the entrance to the local fume hood exhaust ductwork. The gases used in the study were chosen based on the anticipated user requirements.

Further, a system-level analysis of all the fume hood exhaust combined within each duct network was performed to determine the gas concentrations prior to the entrance to the common shafts. Exhaust ducts were modeled to be supplied with minimum anticipated flow rates during operation as well as simulated released flammable gas. Increased internal dilution due to connection of multiple fume hoods to a common fume hood exhaust duct network was evaluated.

The analysis identified the need to install velocity check valves in the gas supply lines to limit the flow rate of flammable gases in an accidental release scenario in order to maintain non-flammable gas concentrations (concentrations less than 25% LFL) in the fume hood exhaust duct network. As a result of the analysis and inclusion of the recommended engineering controls, the feasibility of the design approach was validated and approved.

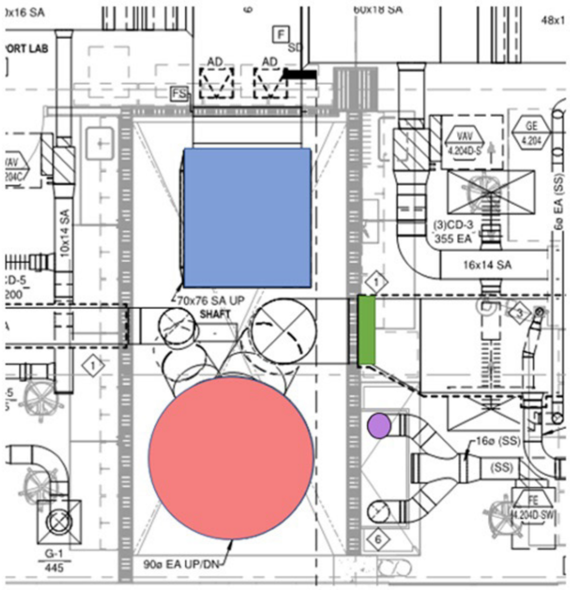

Figure 8. Example schematic of the duct network. Source: University of Texas/Jensen Hughes.

Energy Evaluations

National Renewable Energy Laboratory (NREL)

The NREL Science and Technology Facility (S&TF) exhaust-air system incorporates six (20,000 cfm each) parallel exhaust fans, one of which is always available as backup. The fans in the S&TF are staged according to building exhaust needs, an improvement on the typical lab construction where all exhaust fans run 100% of the time at a constant speed, and pull in bypass air when building exhaust requirements are less than exhaust-fan capacity.

A DOE2 energy analysis comparing the six-fan design to three 50,000-cfm fans (with one always available as a backup), including stacks and dampers, determined that the six-fan design saved approximately $4,700 per year in energy costs, and provided an eight-year simple payback. (The analysis was done more than a decade ago, and energy costs have only risen since then.)

Conclusion

A holistic, team-based approach is important when determining the design and appropriateness of a manifolded exhaust system. Design decisions regarding fan type, stack location, plenum configuration, ductwork details, controls, and screening systems need careful attention to optimize the energy reductions inherently obtainable with a manifolded exhaust system. Clear, unambiguous documentation of the design approach is essential to ensure stakeholder alignment and understanding of the building systems' limitations for future retrofit projects.

Architectural and mechanical designers may need to collaborate with specialized consultants to perform dispersion studies, re-entrainment analyses, and acoustical reviews. Developing the system's control sequence and conducting performance-based commissioning with experienced professionals offer the best likelihood of achieving success. Thorough training of maintenance personnel will help ensure efficient, long-term operation.

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