Laboratory Low-Pressure Drop Design

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A laboratory ventilation system isolates and protects occupants from hazardous fumes and provides the minimum outside air at a comfortable temperature. A significantly greater volume of conditioned makeup air is needed for fume removal than is required for conditioning the space. A once-through system usually is used due to the high exhaust quantity and the desire to isolate laboratories from adjacent spaces. The high costs of high airflow systems are magnified by the constant operation found in laboratories. Unfortunately, the common design approach often does not recognize these unique aspects of laboratories.

Figure 1 shows a breakdown of a typical laboratory building's electricity use (based on a DOE-2 model of a baseline laboratory building using Billings, Mont., hourly weather data). In this example, the ventilation system uses slightly more than 50% of the building's total energy. Thus, a 15% reduction in the electricity consumption of the ventilation system saves more electricity than eliminating all lighting. This article discusses saving energy by reducing the ventilation system air pressure drop.

Ventilation Energy Use in Detail

The ventilation system's power requirements in *Figure 1* represent the combined supply and exhaust fan power (the natural gas heating is not represented). This fan power can be estimated by *Equation 1*:

$$\frac{Q \times \Delta P}{6{,}345 \times \eta_{fan} \times \eta_{motor} \times \eta_{drive}} = p_f$$

where

Q = airflow in cfm
ΔP = system total air pressure drop, in. w.g.
6,345 = constants factor
p_f = fan power, bhp

Changing one or more of the three variables in the equation (fan system efficiency, airflow, or system pressure drop) reduces the amount of energy consumed by the ventilation system. *Table 1* compares opportunities for reducing lab ventilation system power requirements.

Standard design practice usually results in a fan system efficiency (motor, drive and fan) of around 62% or less. Careful selection of a direct drive fan and using high efficiency motors can push that efficiency up to 70% to 75%, resulting in a power reduction of about 15% at best. Conventional design methods already optimize the fan efficiency. Little opportunity exists for further energy reduction.

The single design decision with the largest potential energy savings is minimizing the exhaust volume. Typically, a variable volume hood and exhaust system are used, although low face velocity, constant volume hoods can offer the same benefits. A 25% reduction in average exhaust airflow (using a variable air volume system) results in about a 58% reduction in the fan power required. This is based on the fan laws' cube relationship (assuming similar fans of the same diameter).[1] Actual fan energy savings are slightly lower, but the savings suggested by the fan law are a reasonable first estimate of potential energy reduction. Significant additional energy savings are realized by a 25% reduction in the air that is conditioned.

An often-overlooked system parameter that offers the greatest potential for energy savings is the system air pressure drop. It is common for laboratory buildings to have a supply and exhaust system combined total air pressure drop of 10 in. w.g. (2488 Pa) or more. As indicated by the fan power equation, this high-pressure drop consumes a lot of power. Implementing creative low-pressure drop design through the system can

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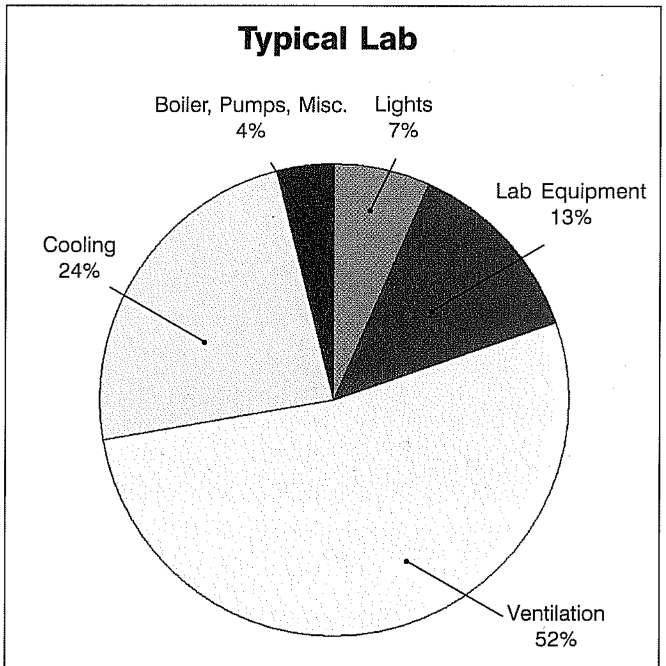
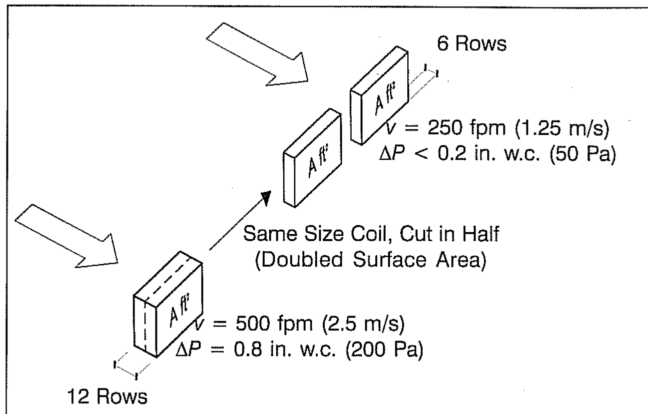


Figure 1: Laboratory building electricity use.



Low Face Velocity Cooling Coil for AHU

1. Standard coil design is 500 fpm (2.5 m/s).
2. Cutting coil in half gives double the face area, half the velocity, and a quarter of the ΔP.
3. Filters, dampers, dehumidifiers similarly reduce ΔP by four times. This increases filter life, decreases by-pass leakage through filter frames and media, and improves aerodynamics through all elements.
4. Fans are much lower ΔP, less horsepower, less vibration and noise, and lower rpm; hence, better bearing life; smaller, cheaper VFD; cheaper casing; and reduced leakage.

Figure 2: Low face velocity coils.

reduce the ventilation energy by 30% to 65%. Several laboratory ventilation system design considerations that are important to reducing pressure drop, energy use and cost are discussed next.

Air Handlers — Low Face Velocity Design Benefits

Traditional office building design often sizes the air handler based on a face velocity of 500 fpm (2.5 m/s). Originally, this approach may have been intended to achieve low first cost and acceptable lifetime energy cost in systems that operate for less than 4,300 hours a year. For laboratory units that operate 8,760 hours per year, this convenient rule of thumb results in unnecessarily large energy costs.

Selecting a lower design face velocity reduces the pressure drop of the air-handling unit and the proportional energy consumption. As shown in *Figure 2,* reducing face velocity decreases the power requirement to the square of the velocity reduction. For example, reducing face velocity to 50% decreases the fan power requirement to about 25%, a 75% reduction. Using a lower row-count, lower pressure drop coil can achieve additional pressure drop savings.

Standard arguments against reducing face velocity include that the first cost of a "bigger" air-handling unit is too high and that the unit requires too much floor space or additional ceiling height. These arguments are often invalid.

First cost. The 500 fpm (2.5 m/s) "standard" is a carryover from the sub-5,000 hour per year operation of a typical office air handler. The lifetime energy consumption costs of a laboratory system are *double* those of an office air handler based on hours of operation alone (not even considering the higher pressure drop). Also, a lower face velocity unit uses less energy and adds little, if any, first cost to a properly designed laboratory makeup air unit.

Although lowering the face velocity requires a larger, and therefore, more expensive enclosure, the reduced energy requirement decreases the cost of most of the other components. The coil has double the surface area, but only half the rows, resulting in a minimal cost increase. The fan motor size in a typical system can be reduced by 25% to 50% due to the lower pressure drop in the air handler. Often, the fan wheel rpm and specification can be dropped down by one class rating to a lighter construction, lower cost wheel. A lower horsepower fan motor saves money, as does a smaller variable frequency drive, and smaller wiring and circuits required to supply the motor.

The larger face area coil allows for a closer approach, permitting a higher chilled water temperature. A 5°F (2.7°C) increase in the chilled water temperature usually improves chiller efficiency by more than 5%. This often lowers the chiller's first cost and always lowers operating costs. More filters are required to cover the greater face area, but the filter change interval can be extended by a proportional amount, resulting in no additional filter cost on an annual basis. Longer intervals between filter changes reduce maintenance costs. When these effects are considered, the first cost increase of an "oversized" low face velocity air handler versus a standard unit can be negligible, if not a savings, and the operating cost reductions are substantial.

Floor space. The additional floor space required by a lower face velocity air handler is typically small. The air handler represents a significant amount of the system pressure drop in a single, relatively compact component. The air handler, with the internal filtration and coils, represents more than 25% of the total supply and exhaust system pressure drop, or about half of the supply

Parameter	Typical Potential for Ventilation Energy Savings Versus Traditional Design	Comment
Fan System Efficiency	5% to 15%	Minor Potential, Traditional Design Often Does OK
Airflow	0% to 60%	VAV Supply and Exhaust Systems Offer Big Fan and Conditioning Energy Savings Over Constant Flow; Dependent on Facility Usage (Diversity)
System Air Pressure Drop	30% to 65%	Traditional Design Results in Poor Laboratory Systems; Large Reductions Are Possible in Many Areas

Table 1: Opportunity ranges for reducing ventilation energy requirements.

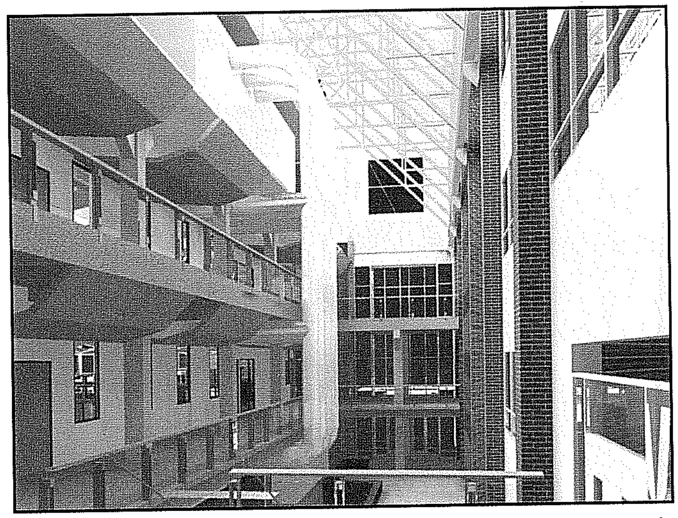


Figure 3: Low cost, low-pressure drop laboratory supply ducting integrated with atrium space.[2]

system pressure drop. Reducing the face velocity in a typical 6 ft 8 in. (2 m) height, 20,000 cfm (9400 L/s) air-handling unit by 25% increases the width of the unit by only about 2 ft (0.6 m), requiring perhaps an additional 50 ft² (5 m²) of mechanical floor space (assuming that the height cannot be increased at all). The architectural impact of a larger face area air handler can be negligible when incorporated from the initial design stages.

Each laboratory design requires careful evaluation to minimize the air handler face velocity and floor space. In some designs, the interstitial space for utilities and maintenance access can provide additional space for air handlers. Angled coils and filter racks can maximize the use of available space to reduce air handler face velocities. If clear space is allowed for coil pull or replacement, the use of split coils can allow for a 50% increase in face area.

Heat Recovery Device Selection

A heat recovery system is often an attractive option in all but the most moderate climates, due to the once-through operation of laboratory ventilation systems. A properly operating heat recovery system uses the exhaust airflow to preheat the supply air in the winter and precool it in the summer. Four commonly used heat recovery systems are heat recovery wheel, flat plate air-to-air heat recovery device, heat pipes or a runaround coil. Any thorough evaluation of cost savings from heat recovery must consider the additional fan costs associated with the pressure drop through the device. While the focus here is the pressure drop cost aspect of an energy recovery system, other design issues such as corrosion and crossover contamination also require evaluation.

A heat recovery system was analyzed in some detail at the request of the architect[2] for the recent EPICenter project, a high-efficiency laboratory building designed for Montana State University. With a design exhaust quantity of 44,000 cfm (20 760 L/s) and a design outside air temperature of –20°F (–29°C), heat recovery was an important part of the design. The savings from a flat plate heat exchanger were compared to a runaround coil, using a typical year of hourly weather data.

After accounting for the relative fan energy and pumping energy costs, the glycol-based runaround coil offered slightly better energy savings, despite having a lower peak heat recovery effectiveness. The runaround coil offered a peak effectiveness of about 60%, compared to a flat plate system with a peak

Component	Standard	Good	Better
Air Handler Face Velocity	500	400	300
Air Handler Pressure Drop	2.5 in. w.g.	1.5 in. w.g.	0.75 in.w.g.
Heat Recovery Device Pressure Drop	1 in. w.g.	0.6 in. w.g.	0.35 in. w.g.
VAV Control Devices Pressure Drop	Constant Volume, N/A	Volumetric Tracking, 0.6 – 0.3 in. w.g.	Presure Differential/Flow Measurement, 0.1 in. w.g.
Zone Temperature Control Coils Pressure Drop	0.5 in. w.g.	0.3 in. w.g.	0.05 in. w.g.
Total Supply and Return Ductwork Pressure Drop	4 in. w.g.	2.25 in. w.g.	1.2 in. w.g.
Exhaust Stack cfm and Pressure Drop	0.7 in. w.g. *Full Design Flow Through Entire Exhaust System,* Constant Volume	0.7 in. w.g. *Full Design Flow Through Fan and Stack Only,* VAV System with Bypass	0.75 in. w.g. *Averaging Half the Design Flow,* VAV System with Multiple Stacks
Noise Control (Silencers)	1 in. w.g.	0.25 in. w.g.	0 in. w.g.
Total	**9.7 in. w.g.**	**6.2 in. w.g.**	**3.2 in. w.g.**

*Table 2: Summary of typical, good and better air pressure drop ranges on a component basis.**

* in. w.g. × 248.8 = Pa

effectiveness of 80%. In this case, the superior effectiveness of the flat plate system could not overcome the fan energy cost associated with the flat plate system. The mechanical space available in this particular design did not permit a low-pressure drop implementation of a flat plate system, which requires crossing the supply and exhaust ductwork.

VAV Control Device Options

As discussed earlier, as a variable flow supply and exhaust system reduces the airflow, the fan power required is reduced by approximately the cube of the flow reduction. The large energy cost of constant volume systems in a 100% outside air laboratory application has made laboratories a good market for variable flow exhaust systems.

When selecting a variable flow system, the energy cost impact in the form of supply and exhaust air pressure drop should be among the factors evaluated. The airflow control valves or dampers used in variable flow systems vary in their air pressure drop from about 0.60 in. w.g. to about 0.05 in. w.g. (149 Pa to 12 Pa). Based on the fan power equation discussed earlier, a 0.25 in. w.g. (62 Pa) pressure difference on the supply and exhaust side, a total pressure drop of 0.5 in w.g. (124 Pa), equates to roughly 580 kWh per year per 6 ft (1.8 m) hood. Over an entire lab facility, the extra energy usage adds up quickly.

Zone Temperature Control Issues

Since the airflow to a laboratory space is dictated by the exhaust or pressurization requirements of the space, variable airflow cannot be used for temperature control. The typical method to provide zone temperature control is to provide a zone reheat coil and a zone cooling coil. The disadvantage of this configuration is the pressure drop incurred by the zone coil(s) 8,760 hours a year.

Several ways exist to minimize the air pressure drop cost of zone coils. A good approach is to lower the coils' pressure drop, for the same general reasons as discussed for air handlers. The better approach is to remove the zone coils from the primary supply. Several design options allow this, including radiant floors and ceilings, baseboard radiators, fan coils in the space and/or providing a low-pressure drop coil bypass.

There are a number of design issues to watch when implementing these strategies. The controls system and algorithms, including supply air temperature reset and variable speed fan control, are important aspects of efficient operation. For example, if the supply air temperature is not reset, the reheat load may exceed the capacity of a radiant system during low load periods. Another example would be a zone coil bypass that would have no savings if the supply fan is controlled to a constant static setpoint, causing the zone flow control damper to add back the pressure drop of the bypassed zone coil.

Ductwork Pressure Drop

One simple measure to reduce the ductwork pressure drop, and cost, is to manifold fume hoods. Combined with a variable air volume fume hood system, connecting all the hoods to a common exhaust duct allows for significant energy savings by taking advantage of diversity. Manifolding exhaust is also essentially a prerequisite for both a heat recovery system and the most efficient exhaust fan and stack options. A manifold system is also typically cheaper to construct and maintain than a configuration with a separate fan for every hood.

Another simple measure, often discarded due to assumed cost, is to specify larger, more direct, lower pressure drop ductwork. The incremental cost of larger ductwork is often exaggerated. A small increase in duct diameter has a large impact on the pressure drop. The pressure drop decrease is approximately proportional to the inverse of the duct diameter to the fifth power, so substituting an 18 in. (457 mm) duct for a 16 in. (406 mm) duct decreases the pressure drop by more than 40%.

Lower pressure drop design can reduce the complexity of ductwork, reduce duct runs and use fewer fittings. With the cooperation of the project architect, shorter, more direct layouts can save both energy and first cost. For the Montana State EPICenter laboratory building design, supply ducts were incorporated into the architecture as vertical elements in the atrium space,[2] as seen in *Figure 3*. This allowed for a short, direct run of large diameter, low-pressure drop ducting to supply the lab spaces. Close cooperation with the architect is crucial to developing a low-pressure drop design in the common situation where shaft and above ceiling space is limited.

Considering the cost impacts of lower pressure drop duct design, construction management efficiencies can be gained from selectively upsizing all small ductwork to a common intermediate size, which reduces pressure drop and results in fewer sizes of ductwork and fittings in a project. The flexibility of a laboratory space is also improved by using low-pressure drop design. If a future space use requires a larger quantity of ventilation air, undersized ductwork is typically more difficult to deal with than adding additional air handler capacity or increasing the heating and cooling equipment capacity.

Exhaust Stack Opportunities

Laboratory exhaust requires a stack or some other measure (such as dilution and/or a high velocity discharge) to eliminate recirculation of potentially toxic contaminants. To ensure adequate dilution of the exhaust before it can re-enter an occupied area, it must be ejected at a significant height and/or at a high velocity. Even when a tall stack is used, a high exit velocity of 2,000 to 3,000 fpm (10 to 15 m/s) (a velocity pressure of 0.25 to 0.56 in. w.g. [62 to 139 Pa]) is usually recommended.[3]

There is little opportunity to minimize the pressure drop in the stack itself; the opportunity to reduce fan energy is in implementing a variable exhaust flow. Varying the exhaust flow through the stack is difficult since a minimum exit velocity and volume must be maintained. Reducing the flow could result in an unacceptably low exit velocity and volume. The common work-around to this problem is reduce flow through the building exhaust system, but introduce dilution air just prior to the exhaust fan as required to maintain a constant flow through the exhaust stack. This allows for a lower flow of conditioned air through the overall building ventilation system, but incurs an energy penalty from increasing the volume of air that must be expelled through the stack and released at 2,000 to 3,000 fpm (10 to 15 m/s).

A simple alternative method is to have multiple fans, each with a dedicated stack, drawing from a common exhaust plenum. As the exhaust volume demand from the space drops, fans with their dedicated stacks are staged off. Motorized or flow actuated backflow dampers are used to minimize leakage through shut-off stacks back into the plenum. Reducing the number of stacks in use allows for a safe exit velocity to be maintained without needing a constant high volume flow through the exhaust system.

A staged exhaust stack approach was successfully used in a retrofit performed at the U.S. Department of Agriculture Salinity Laboratory in Riverside, Calif., where fume hoods were converted in groups of four from individual dedicated fans and exhausts to a common manifold.[4] The pre-existing exhaust fans, one for each of the four hoods per manifold, drew from the common manifold and were staged as required. Each constant volume flow fan had its own dedicated exhaust stack. Therefore, on an individual stack basis, the operating volume flow and exit velocity were constant. Fan staging was used to vary both the airflow and the total operating exhaust stack outlet area (the number of operating stacks) as the exhaust flow varied with hood usage. A pneumatic damper was used to close off stacks that were not in use, while the fan location kept the common plenum under negative pressure, ensuring that any leakage past the stack shutoff damper was outside air *into* the plenum rather than fumes leaking *out* of the stack.

Conclusion

Table 2 sums up the impact that good and better design practices can have on the design of a laboratory ventilation system. The ventilation system is a large consumer of energy in a laboratory building, and opportunities for dramatic and cost-effective improvements are available. The values in *Table 2* offer some guidelines for evaluating the air pressure drop of laboratory ventilation systems. Pressure drop is frequently neglected in ventilation design, to the detriment of economical facility operation.

In many laboratory buildings, the pressure drop of the ventilation system is directly responsible for the majority of the facility's energy usage. Significant pressure drop reductions can be achieved by making pressure drop a priority in the design of the ventilation system and using good design practice. Lower pressure drop systems directly contribute to more efficient and more economical laboratories, with the potential for reductions of 25% or more in overall *building* electricity use. These efficient design techniques can be implemented with no compromises or limitations on the facility operation, offering good energy savings through good design.

Acknowledgments

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