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Green for green's sake:

Energy-efficient design can help reduce laboratory operating costs

Companies that want to incorporate sustainable design and energy efficiency into their buildings will find it harder to achieve in their laboratories than in their office spaces—but well-conceived, well-executed plan can result in rewards that make the additional effort worthwhile.

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From curbside recycling to Energy Star appliance ratings to hybrid automobiles, awareness of the need to improve environmental performance continues to gain momentum—and not just on the consumer front. Businesses are beginning to recognize that the benefits of a "greener" orientation can extend beyond better compliance with environmental regulations. Energy efficient facilities often cost less to operate, and some environmental initiatives can bring the company positive recognition. Unfortunately, laboratories face an uphill battle, primarily due to extensive airflow requirements, as well as lighting demands and, sometimes, water use. A close look, however, at laboratory design criteria and system design, and equipment system design, can often reveal ways to reduce energy consumption significantly.

In most laboratories, energy costs are four to six times higher than they are in an office building and two to three times higher than they are in a typical oral solid dosage manufacturing suite. One of the biggest cost drivers is the high volume of outside air that is cooled and/or heated and then vented back out to the environment in order to protect personnel against exposure to hazardous and/or highly potent chemical and biological agents. Often, 100 percent of the air in a lab passes through the facility only once. In contrast, up to 85 percent of the air in an office building is recirculated, so heating and air conditioning costs are lower. Considering that over the life of a lab, its operating costs (including both energy and maintenance) are three to four times higher than the capital cost of the facility, the financial incentive to reduce operating costs is high. With responsible, smart, sustainable design, companies can expect to reduce energy costs 30 percent to 50 percent. Utility company incentives are also often available. In

addition to reducing energy consumption, companies may also be able to reduce air and water emissions at the same time.

Two programs of note address energy efficiency and sustainable design in laboratories. One is Labs21, a joint program of the Environmental Protection Agency (EPA) and the Department of Energy (DOE) to improve the environmental performance of laboratories in the United States. The other is the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) certification program, which recognizes companies for their efforts to conserve resources. The council is currently developing a LEED for Labs program using the Labs21 environmental performance criteria (EPC) as a starting point. These programs offer a good roadmap for investigating means to save energy on new and existing laboratories.

This article focuses on safely reducing airflow and on the corresponding supply and exhaust fan, heating, cooling, dehumidification, humidification energy savings that can be realized. The key is to review each laboratory's operations and design methodically to determine what is truly needed. As a rule of thumb, some of these simple design criteria changes can result in savings in the ballpark of $3–$5/cubic feet per minute (cfm)/year, depending on geographic location, system and utility costs. Take, for example, a 1,000-square-foot laboratory designed for 2,000–2,500 cfm. Reducing the airflow by 30 percent (600-750 cfm) would generate savings of $1,800 to $3,750 annually. When these results are applied throughout a building or research site, the savings become significant—and do not require a large investment to achieve.

Primary containment drives costs

Most of a laboratory's air handling costs revolve around the need to protect personnel from materials that may be hazardous and to prevent contamination. Although these goals remain paramount, and safety cannot be compromised, it may be worth examining science- and risk-based alternatives to the traditional design approach. One of the first things to look at is primary containment, including fume hoods, biological safety cabinets, and local exhaust ventilation. When applied properly, this equipment can actually reduce total laboratory airflow and save energy by using the best technology to contain the hazard. However, these devices are typically not selected or utilized properly, and so they are often associated with increased laboratory energy costs.

A key question to ask is "How much containment is sufficient, based on the level of risk and actual operations?" Ultimately, the decision-making team should include representatives from all impacted functions, including a research representative, a facilities representative, an industrial hygiene or safety officer, and a lab design consultant. This helps ensure that all stakeholders' needs are met.

Fume hoods: Typically, fume hoods are the first line of defense to minimize chemical exposure to research workers. A properly functioning fume hood protects the worker from inhaling hazardous vapors by drawing air away from the face. According to Lawrence Berkeley National Laboratory, 750,000 fume hoods were in use in the United States in 2003, representing a peak electrical demand of 5,000 megawatts and a cost of approximately $3.2 billion annually. A number of steps might be taken to reduce that cost, beginning with the simple initiative of inspecting fume hoods annually to ensure that they are functioning properly.

Constant air volume fume hoods: Conventional constant-volume fume hoods draw air in and away from the face, then up and out an exhaust. For containment, the average “face velocity” is typically 90 to 100 feet per minute (fpm). A movable sash can cover the hood opening; when the sash is fully open, the face velocity is at the desired rate. The sash is typically designed for use with an opening from 18 inches high to fully open—typically 30-32 inches. As the sash is closed, the face velocity increases because the volume of air remains constant. The lower the sash, the higher the face velocity. Velocities greater than 125 fpm can create turbulence that can cause contaminants to flow out of the hood and into the breathing zone. Therefore, it is common to design these devices with an exhaust airflow based on an 18-inch sash height and to place stops at or just above the height where the face velocity drops below a safe minimum (80 fpm). This not only reduces the energy and airflow, translating to energy savings, but also results in a safer operation when the sash is in the lower two-thirds of the opening. Any hoods that are designed for 100 fpm with the sash wide open should be rebalanced to a lower airflow. This results in an immediate impact on laboratory energy consumption. Remember that exhaust fan energy is only a small part of the overall laboratory energy, as air that is exhausted is replaced with conditioned outside air, which is often reheated at the laboratory level.

Another means of saving energy on constant volume fume hoods is in sash selection. Sashes may be vertical, horizontal or a combination of both. Reducing the amount of open area reduces airflow requirements. For example, a 6-foot fume hood with a vertical sash requires 1,250 cubic feet per minute (cfm) with a 30-inch sash height and only 750 cfm at 18 inches. A horizontal sash fume hood of the same size requires only 850 cfm when it is fully open, and airflow requirements can be reduced through sash stops and balancing, but it raises ergonomic issues. Often a combination sash offers both the energy efficiency of a horizontal sash and the ergonomics of a vertical sash during setup. The key is to find the configuration that achieves the optimal balance of containment, ergonomics and energy efficiency. Once that is determined, the sash management plan should include signage and personnel awareness training.

Another means of reducing the amount of conditioned room air that is vented through the constant air volume hood is to incorporate an auxiliary air supply, or makeup air fume hood, that provides unconditioned or partially conditioned outside air. This approach is designed to save heating and cooling energy costs, but the additional ductwork, fans and air tempering facilities it requires actually

increase the mechanical and operational costs. Additionally, auxiliary air hoods can be uncomfortable workstations, and the potential for unconditioned air to contaminate the experiment make this approach unacceptable in most cases.

Control schemes for constant volume laboratories range from simple but energy-inefficient hard-balanced systems to two- or three-position terminally controlled systems, which are designed for better lifecycle costs. A hard-balanced system has no local or terminal controls other than a reheat coil for temperature control in each laboratory. Supply and exhaust air to and from each laboratory is hard-balanced via a duct-mounted balancing damper. This approach may be attractive from a first-cost perspective, the payback of local airflow control is often less than five years, so hard-balanced systems are not recommended for facilities that will be in operation for more than five years. Two-position constant volume control schemes use terminal boxes or similar devices that modulate a damper or cone to maintain a constant volume of supply and exhaust airflow to and from the laboratory. When the laboratory is unoccupied, the supply and exhaust airflow are set back to a reduced volume. This saves energy while maintaining safe conditions in a laboratory without active research. The three-position constant volume system adds the ability to set back fume hood exhaust flow to a reduced volume when the laboratory is occupied and the sash is fully closed. A microswitch in the sash mechanism indicates to the building automation system that the sash is closed and sets the fume hood terminal device to a reduced volume. In hood-intensive laboratories where airflow is driven by fume hood exhaust, and with proper scientist sash management, the three-position constant volume system has a similar energy profile of variable air volume systems with a less complicated control scheme.

Variable air volume fume hoods: The industry is trending away from constant volume systems toward variable air volume (VAV) fume hoods. In fact ASHRAE 90.1, which is incorporated into portions of the 2006 International Energy Conservation Code, now requires the use of VAV fume hoods in systems greater than 15,000 cfm unless a heat recovery system is applied. VAV fume hoods maintain a constant face velocity regardless of sash position by continuously measuring and adjusting the amount of air being exhausted based on the face velocity or sash position. This significantly increases the hood's ability to protect against exposure to chemical vapors. It also reduces the volume of air that the facility uses, so less air must be heated or cooled. When properly used, the VAV fume hood system offers the lowest energy costs, as it reduces the fume hood exhaust volume to a minimum flow when the sashes are closed—which should be at all times except at setup. This system also allows the flexibility necessary for operations such as medicinal chemistry, which requires large size and high quantities of fume hoods while maintaining energy efficiency. Although VAV laboratory systems support flexible and energy efficient laboratories because they use only the air necessary for actual operation of the laboratory, the controls associated with these systems can be expensive and complicated.

Low-flow fume hoods: New low-flow hoods have challenged the conventional thinking of fume hood design. The new hoods are designed to reduce hood airflow while maintaining a safe environment by reinventing the way a fume hood captures chemical vapors. The Air Sentry hood from Lab Crafters was one of the first low-flow fume hoods. It maintains operator safety by controlling the vortex that forms in the upper region of all vertical sash fume hoods. Using proprietary sensors and controls, the Air Sentry adjusts baffles inside the hood to maintain the strength and speed of the vortex, thereby maintaining containment at lower face velocities. In contrast, the Protector XStream from Labconco is designed to diminish or defeat the vortex and create laminar flow to the rear of the fume hood. Fisher Hamilton offers two low-flow options, a fan downdraft and a downdraft bypass model. These hoods typically cost significantly more than conventional fume hoods but do not require terminal controls. As a result, they can deliver an attractive payback for most facilities that desire a hard-balanced system or facilities that do not have a sophisticated building automation system. However, when low-flow hoods are coupled with terminal controls for two-position constant volume control, the laboratory can realized even more savings when unoccupied.

Biosafety cabinets: Biosafety cabinets are used to protect personnel and the environment from harmful biological agents inside the cabinet. They also protect the product inside from contamination. Several classes and types of biosafety cabinets are available. Generally, the more protection they provide, the higher the exhausted airflow. The challenge is to select the class and type that provides adequate protection without overprotecting. Once again, the input of Environmental Health and Safety group is key. For example, a Class II, Type B2 cabinet provides the greatest protection of the Class II biosafety cabinets. The building exhaust system must pull all of required exhaust air through the cabinet and associated exhaust HEPA filter. Therefore, in addition to exhausting 1,100 cfm of air from the lab at all times, the exhaust system must have approximately 2 inches of negative pressure available at the connection to the Class II, Type B2 cabinet. Any other connections to the system—such as fume hoods and general exhaust grilles, which have a much lower pressure drop, typically 0.25 inches or less—will be subject to the same pressure and will require a balancing damper or terminal device to induce about 1.75 inches of pressure drop at the point of connection to these devices. This is not only a tremendous waste of fan energy, but it is likely to be a source of nuisance noise complaints in the laboratory and will require noise attenuation. On the other hand, a Class II, B1 cabinet, which recirculates 30 to 50 percent of the cabinet air, might be sufficient—and it exhausts only 430 cfm.

Type B cabinets can be used for Biological Safety Level 3 and below. Most pharmaceutical development applications, even those involving HIV antigens, fall into Safety Level 2. A Class II, Type A2 (formerly A/B3) cabinets exhaust even less air and often are not connected to the building exhaust system, as they discharge their HEPA-filtered exhaust airflow directly into the laboratory. This cabinet can be used for Biological Safety Level 2 applications and is often adequate protection for most applications. It should be noted that when Class II,

Type A2 biosafety cabinets exhaust to the room, they do add heat load to the laboratory; this heat load still requires supply air energy to condition. With the range of cabinets available, from Class I weigh booths to Class III glove boxes, and the options in between, it takes careful consideration to weigh the relative benefits of cabinet cost, operating cost, decontamination procedures required, highest level of use and other factors and then to make a selection that provides the optimal cost/benefit ratio and meets all stakeholders' needs.

Local exhaust ventilation: Elephant trunks or snorkel arms and canopy or slot hoods can also impact HVAC operating costs. Although point exhausts add flexibility, they also draw air from the building at all times and often do not get utilized as anticipated when designed. Identifying unused point exhausts and closing them off has an almost instant payback. Depending on how point exhausts are used, it may be necessary to evaluate main duct velocity to assure that vapors are still conveyed when branches are capped. In addition, the design of the point exhaust end connection should be considered. Rigid articulating arms, which are sometimes used, come with a large pressure drop. Often a plastic hose or flex duct connected to an acrylic enclosure will accomplish the same or better containment with less resistance and more flexible ergonomics. Similar to the Class II, Type B2 cabinet described above, any end device with an excessive pressure drop creates a pressure drop requirement, which the entire system must meet.

Canopy or slot hoods are typically designed to provide 100 to 150 fpm face velocity. If the application does not require such velocities, more efficient designs are available. For example canopy hoods are often used at autoclave doors to capture steam emissions when the doors are opened. However, most autoclaves have cycles to cool and ventilate steam vapors, and they emit minimal, if any, moisture and heat to the laboratory when the doors are opened. In contrast, the canopy hood constantly pulls air out of the room regardless of whether the autoclave is in use or if the doors are open or closed.

Secondary Containment: Challenge room level criteria such as air changes and heat load

Secondary containment also has an impact on energy consumption. An evaluation of room criteria can often identify "low-hanging fruit"—factors than can be adjusted without significant capital investment. Often it is assumed that these variables are not adjustable; challenging that assumption can pay huge dividends. Minimum ventilation requirements should be based on user needs, health and safety protection, and energy consumption, recognizing that "more" is not necessarily safer. As with primary containment, it is important to develop a realistic assessment of the need versus the standard.

For example, consider how much transfer air for pressurization is actually necessary. Reducing transfer from corridors to laboratories by 100 cfm per door saves $300-$500 per door per year. Typically, 100 cfm is adequate to maintain negative pressurization with doors closed, and corridor supply airflow is usually

based on makeup air for pressurization. In higher hazard laboratories where a minimum differential pressure value is desired, larger transfer quantities will be required.

Determine whether 100-percent outside air is required or whether recirculating air systems can be used in ancillary spaces. Consider using fan coil units or recirculating air systems for equipment rooms that do not have fugitive chemical or biological emissions and for laboratory offices. Doing so can reduce the cost of supply air to $1–$2/cfm/year for systems with code minimum outside air.

What is the minimum air change rate required? If all of the hazards are contained in the primary containment devices, how much ventilation is necessary to assure safe conditions in the laboratory at all times? Air changes can vary from four to 20 per hour. Ultimately, the ventilation required depends on the hazards in the laboratory. Be sure to consult an Environmental, Safety and Health expert.

What temperature and relative humidity are required? It is important to determine exactly how temperature and humidity affect the products, equipment and research in order to identify an acceptable range. Remember that relative humidity is relative to the temperature. A relative humidity of 50 percent at 74 degrees Fahrenheit has more moisture than a relative humidity of 50 percent at 72 degrees and therefore requires less dehumidification energy. Conversely, in the heating and humidification season, a relative humidity of 30 percent at 72 degrees requires more humidification than 30 percent at 70 degrees. If changes are possible, they can have a significant impact. For example, a facility in the Midwest raised its room temperature and relative humidity set points from 68 degrees F at 48 percent relative humidity to 74 degrees F at 50 percent relative humidity and saved more than $50,000 a year.

Probably the greatest source of wasted energy in laboratories is overestimated heat loads. Typically, supply air is cooled and heated simultaneously, frequently to a greater degree than necessary. The problem lies in accurately predicting laboratory heat loads. If heat load estimates are based on calculating lighting and equipment loads and assuming diversity, the diversity assumption is typically very conservative. This is because all equipment is not used simultaneously, equipment is frequently changed in the lab after the researchers move in, etc. For this reason, heat load is usually established as heat load density of 5 to 15 watts per square foot. Even if the peak heat load is estimated to pinpoint accuracy, it varies over time. In a constant volume system, lack of heat load makes it necessary to reheat supply air to maintain space temperature. Variable air volume systems address this issue by reducing the supply air to the laboratory when heat load does not exist and reheating only as necessary when supply air is at the minimum required for ventilation. On constant volume systems, local metering and discharge temperature sensors can provide solid data about how changes to temperature and humidity settings impact the building air. Laboratories that are constantly operating their reheat coil can reduce the supply and exhaust airflow to reduce reheat energy while maintaining minimum air changes per hour.

Lighting can account for up to a significant portion of the cooling loads within a laboratory, and it is common to see lighting power densities of 2.5 watts per square foot in older labs. By verifying a lab's illumination needs, efficiently laying out the lighting fixtures, and using high-efficiency luminaires and lamps, lighting power densities of 1.3 w/sq. ft. or below can be achieved. In addition, incorporating energy management system-based lighting control systems, occupancy sensors and daylight harvesting, as well as other approaches that turn off or vary the lighting levels, can provide a substantial decrease in lighting power costs without diminishing the lab's safety or functionality.

Further reducing energy requirements

At the equipment level, a number of factors can impact energy efficiency. Proper maintenance plays a key role in optimizing performance and, therefore, energy efficiency as follows:

Filter management: A good filter management program helps minimize resistance. This includes filter selection as well as change-out procedures. For example, using filters with more media via V-pleats or other technologies can reduce life-cycle cost significantly. Filter pressure drops often account for 25 to 40 percent of the system pressure drops and therefore should be optimized.

Chilled water: The impact of improperly maintained air systems on chilled water systems is often overlooked. Low delta T syndrome, an inability to maintain the temperature difference between water entering and leaving the chiller plant, is usually the result of air system problems, such as air- and water-side coil fouling, instrumentation that is out of calibration or incorrect discharge air temperature setpoint, leaking control valves, three-way valves, and unbalanced coils. Plants operating with low delta T syndrome often need to run additional chillers, towers and pumps to maintain flow requirements.

Variable frequency drives: Air systems that use variable frequency drive (VFD) motors are more efficient than systems that use inlet guide vanes.

Exhaust fans: Adding a variable geometry discharge damper to an exhaust fan makes it possible to modulate the fan speed to control exhaust duct static pressure and to maintain constant stack velocity.

Static pressure optimization: Resetting the static pressure setpoint as required to satisfy all terminal devices on the system without overpressurizing the system can save up to 15 percent in annual energy costs. Direct digital controls can help optimize the efficiency of the air handling equipment. ASHRAE 90.1 requires this algorithm on all systems with terminal devices.

In addition to the maintenance issues described above, heat recovery systems can reduce energy consumption significantly, especially for facilities that must exhaust 100 percent, by recapturing the energy from exhausted air before it leaves the building and using it to preheat or cool the conditioned makeup air entering the building. Options include run-around loop systems, heat pipes, fixed-plate heat exchangers and enthalpy wheels. Run-around loop systems and heat

pipes can eliminate cross-contamination concerns, because the systems can be designed with non-adjacent exhaust and supply streams. Run-around loop systems, heat pipes and fixed-plate heat exchangers capture sensible energy, that is, heat or cold. Enthalpy wheels capture both sensible energy and latent energy, or humidity. A desiccant absorbs moisture from the exhaust stream and then both moisturizes and preheats the incoming air. Although there is some risk of cross contamination because some lab air is introduced into the air stream, it can be minimized by placing the fume hoods and primary hazards on a separate system. National Institute of Health (NIH) tests on enthalpy wheels quantified that cross-contamination was limited to 0.04 percent. Although heat recovery systems represent added hard and soft costs, in most cases they can pay for themselves quickly. The choice of technology—and the payback period—will be driven by a number of factors, including climate. As energy prices climb, the payback period gets shorter.

Renewable energy systems, such as photovoltaic cells, wind power, geothermal, and combined heat and power systems can also help reduce fossil energy use, depending on the facility's requirements and location.

A green light for energy savings

For cost savings and myriad other reasons, energy efficient design makes sense for pharmaceutical laboratories. New technologies, from low-flow fume hoods to variable air volume ventilation to heat recovery systems and lighting control systems, can help reduce energy consumption. The challenge lies in ensuring that the new technologies meet existing standards designed to protect site personnel and prevent cross contamination, while also avoiding the traditional inclination to overdesign. Nor are all energy conservation tools capital intensive. Simple changes to environmental controls, for example, can also contribute to energy savings, provided that changes are based on data rather than assumptions. So can a sash management program. A number of resources are available (*see sidebar*) to get companies on the right path. The key to a successful project is an interdisciplinary approach based on input from all stakeholders, a thorough assessment of needs and goals, and a design plan that balances costs, risk and benefits.

SIDEBAR

Relevant regulations and resources

A number of resources are available for companies that want to increase the energy efficiency of their laboratories. For example, the Labs 21 Web site features an online Energy Benchmarking tool, as well as Laboratory Modeling Guidelines for all regulated systems serving laboratory areas, including HVAC, service hot water, interior lighting, and laboratory ventilation systems and exhaust devices. Any design for energy efficiency must remain in compliance with applicable regulations. References and resources for laboratory design include:

- ANSI/AIHA Z9.5, “Laboratory Ventilation”
- ASHRAE Technical Committee 9.10, “Laboratory Systems”
- ASHRAE Standard 110, Method of Testing Performance of Laboratory Fume Hoods
- CDC/NIH “Biosafety in Microbiological and Biomedical Laboratories”
- International Building Code
- International Mechanical Code
- NFPA 30
- NPFA 45
- NSF International 49-2002
- OSHA Laboratory Standard 29 CFR 1910.1450
- Scientific Equipment and Furniture Association (SEFA)
- Labs21 EPC 2.1
- Labs21 Toolkit (includes process manual, design intent tool, EPC, best practice guides and other resources)
- LEED NC 2.1
- www.labs21century.gov/index.htm
- www.usgbc.org/LEED/

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