A Design Guidelines Sourcebook
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High Performance Laboratories

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Introduction

Laboratories typically consume 5 to 10 times more energy per square foot than typical office buildings. Some specialty laboratories, such as those with clean rooms and large process loads, can consume as much as 100 times the energy of a similarly sized institutional or commercial structure. This guide describes several energy efficiency strategies for designing and equipping laboratories. Due to the vast array of laboratory uses, no single recommendation is necessarily appropriate for every laboratory. The list of recommendations given in this guide, however, is meant to be broad enough so that they will be appropriate for considering under any particular laboratory design. This document is intended to provide guidance for PG&E customers to reach higher levels of energy efficiency than the standard practices described in PG&E laboratories baselines documents. This document does not supersede any city, state or federal mandates for buildings or the operation of laboratories. PG&E makes no warranty and assumes no liability or responsibility for the information disclosed in this document.

The content of this guide draws heavily from two sources:

- The best practice guides and technical bulletins prepared for Laboratories for the 21st Century (Labs 21), sponsored by U.S. Environmental Protection Agency and U.S. Department of Energy. The original guides and bulletins can be found at: www.labs21century.gov/toolkit/bp_guide.htm

- Design Guide for Energy-Efficient Research Laboratories posted by E.O. Lawrence Berkeley National Laboratory, which can be found at: ateam.lbl.gov/Design-Guide/index.htm

1. Optimizing Ventilation and Air Change Rates

Introduction

While a typical office building requires less than 1 air volume change per hour (ACH) of outside air, laboratories are frequently designed and operated to support 6 – 10 ACH and sometimes upwards of 15 ACH. As a result, high outdoor air flow rates typically drive energy use in lab HVAC systems. Roughly half of the electrical use in a laboratory can be attributed to fan power for ventilation, as seen in Figure 1.01. Outside air frequently requires conditioning (e.g. cooling, humidity control or heating) which further compounds the impact of the air change rate in contributing to a laboratory's energy usage.

Standard laboratory design practices often derive ventilation rates from the highest values of ranges listed in guidelines. This practice neglects that design guidelines are generalized recommendations and are not meant to address specific ventilation needs for every building. Blindly adopting a ventilation rate without investigating its reasoning often leads to excessive energy usage and can even cause a more dangerous environment. Pinpointing opportunities to optimize outdoor air flow rates while maintaining occupant safety at all times is a key lever to reduce first and operational costs as well as energy use and carbon footprint of laboratories. This chapter highlights best-practice strategies for reducing energy use but does not attempt to specify how to set the most appropriate ventilation rate for particular laboratory uses. Some simulation strategies are described at the end of this chapter which can help determine an optimal air change rate.

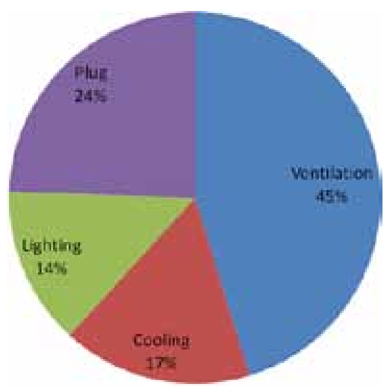


Figure 1.01
Breakdown of Average Energy Use for Measured Lab Buildings in the USA. Labs 21 Benchmarking Tool, 2010.

Principles

To optimize ventilation systems in laboratories, key principles to consider include:

- **Ventilation rates drive the majority of first and operating costs of a laboratory. Optimizing the outside air flow rate can allow for the downsizing of air-side systems as well as cooling and heating plants.**

- **More ventilation is not necessarily better–ventilation guidelines should be scrutinized and adapted to the specific lab in question and varied based on operational parameters.**

- **Advanced laboratory modeling techniques, such as computational fluid dynamics (CFD) simulations, can help determine the laboratory's airflow characteristics to optimize the ventilation rate.**

- **Use centralized or standard demand controlled ventilation systems as well as unoccupied setback to reduce air quantities when possible.**

- **Opportunities to cascade return airflow from other spaces into lab spaces can be used to reduce outside air requirements for labs.**

- **Isolate specific uses (e.g. animal cages, cage washers) which require potentially higher air change rates than the general lab space.**

Approach

Ventilation Rate Codes, Standards and Guidelines

Appropriate ventilation rates and controls will vary widely depending on the physical properties of the hazardous and malodorous materials used in laboratories. Understanding the uses of the lab and the research needs of the occupants is the first step in determining the most appropriate quantity of outside air. Labs often fall into one or more of the following categories:

- **Chemical Laboratories: Labs used for organic, inorganic, physical, and analytical chemistry. They are typically fume hood intensive.**

- **Biological Laboratories: Labs used for biological and life sciences. These have fume hoods as well as bio-safety cabinets. They also tend to have thermal environments (e.g., cold rooms, warm rooms, containment).**

- **Physical Laboratories: Physical labs are typically "dry" labs. They tend to have high plug loads due to an abundance and variety of electrically powered instruments.**

Based upon a solid understanding of the intended program, the laboratory's occupancy classification should be determined (typically by the project architect). The only industrial lab related code ventilation rates mandated in the California Building Code, 2007, beyond those adopted from ASHRAE Standard 62.1, are 1 CFM/sf for Group H-5 occupancies and the greater of 1 CFM/sf or 6 ACH for associated hazardous production material storage rooms (2007 CBC sections 415.8.2.6 and 415.8.5.7). Group H-5 occupancies are defined as, *"Semiconductor fabrication facilities and comparable research and development areas in which hazardous production materials (HPM) are used and the aggregate quantity of materials is in excess of those listed in Tables 307.1(1) and 307.1(2)."*

It is also important to ensure that the difference between codes and standards/guidelines is clearly understood.

- Codes:
  - Have "force of law."
  - Require compliance.

- Standards:
  - Are open to interpretation.
  - Have a wide span of acceptable values.
  - Are subject to manipulation.

- Adopted guidelines:
  - May be based on sound judgment.
  - Could be biased or reflect entrenched doctrine.
  - Could be archaic and not reflect latest technology or practices.

Commonly referenced codes, standards, and guidelines can be found in Table 1.01.

Table 1.01:
Applicable Ventilation Codes, Standards, and Guidelines
(Source: Integral Group.)

Type	Name	Requirements or Recommendations	ACH equivalent (assume 10' ceiling) and Applicability
Code	2007 California Building Code	Comply with California Mechanical code and H-5 occupancy special provisions (Sections 415.8.2.6, 415.8.4.3, and 415.8.5.7)	6 ACH min IF H-5 occupancy, else see Mechanical Code.
Code	2007 California Mechanical Code	Adopted ASHRAE Standard 62.1, see below.	No guidance for commercial or industrial labs – instead it states to use "the requirements for the listed occupancy category that is most similar ..."For educational labs, the max ACH depends upon the occupant density and method of air delivery. The science lab classroom exhaust requirement equates to 6 ACH.
Standard	ANSI/AIHA Z9.5-2003 Laboratory Ventilation	The special room ventilation rate shall be established or agreed upon by the owner and his/her designee	
Standard	ASHRAE 62.1-2010	There are ventilation requirements "in the breathing zone" for educational science labs (10 CFM/person and 0.18 CFM/sf) and for university and college laboratories (7.5 CFM/person and 0.18 CFM/sf). There are exhaust requirements for science lab classrooms (1 CFM/sf).	Again, no specific guidance for commercial or industrial labs. For educational labs, the max ACH depends upon the occupant density and the method of air delivery. The educational science lab exhaust requirement equates to 6 ACH.

Type	Name	Requirements or Recommendations	ACH equivalent (assume 10' ceiling) and Applicability
Standard	NFPA-45-2004 - Standard on Fire Protection for Laboratories Using Chemicals, 2004 Edition (next version due in 2011)	Minimum 4 ACH unoccupied; occupied "typically greater than 8 ACH."	4 – 8 ACH for chemical laboratories
Standard	Occupational Safety and Health Administration: OSHA 29 CFR Part 1910-1450 Appendix A	4-12 room air changes/ hour is normally adequate general ventilation if local exhaust systems such as hoods are used as the primary method of control	4-12 ACH. No specific lab type noted, though lab is defined as: a facility where the "laboratory use of hazardous chemicals" occurs. It is a workplace where relatively small quantities of hazardous chemicals are used on a non-production basis.
Manual	ACGIH – Industrial Ventilation: A Manual of Recommended Practice, 27th Edition, 2001 (2010 version now released)	The required ventilation depends on the generation rate and toxicity of the contaminant – not on the size of the room in which it occurs.	
Guideline	ASHRAE Laboratory Design Guide, 2002	Suggestions given for: Minimum supply air changes Minimum exhaust air changes Minimum outdoor air changes Recirculation considerations	4-12 ACH
Guideline	PG&E Energy Efficiency Baselines for Laboratories, October 1, 2010 (revised annually)	Baseline Air Changes / Hour for Ventilation: General Lab Space: Hazardous Minimally Hazardous Vivariums:	10 ACH 0.15 cfm/sf 15 ACH

Ventilation Rates & Safety

The variation in minimum ventilation rates provided in Table 1.01 underscores the lack of scientific consensus behind recommended values. When using a guideline to determine a ventilation rate for a laboratory, the highest value from the range is often chosen because the guidelines are highly generalized; however, designers should be cautious when using these wide-ranging recommendations. Designing by only referencing past efforts or policy limits energy efficiency and may even compromise safety.

In some instances, increasing ventilation after a spill can increase evaporation of the hazardous material into the air and rapidly decrease air quality as was the case in spill tests at the University of California, Irvine (Bell, 2010). As stated in an EHS guideline for Harvard University, "It is not prudent to specify an air change rate for a building by policy or guideline. Instead, this decision must be based on site-specific information about the various spaces and intended uses of the areas" (Harvard EHS, 2008).

Studies of laboratory facilities have demonstrated that the room air change rate has less effect than a room air diffusing system or other ventilation characteristic on environmental conditions. Designers need specifications that are tailored to a laboratory's air circulation arrangement, because many conventional design parameters and recommendations should not be universally applied; for example, they may not relate to micro environmental (e.g., cage) conditions in a laboratory (Zhang et al., 1992; McDiarmid, 1988).

Other studies show that air dilution or replacement does not protect personnel from exposure to concentrated bursts of aerosols in biological laboratories. For example, Crane (1994) quotes Chatigny and West (1976), who say that "increasing ventilation rates from 6 to 30 air changes per hour (ACH) has a minimal effect on aerosol concentration of microorganisms in the first few minutes after release."

Adjusting ventilation is not the only way to control environmental conditions. For instance, Memarzadeh (1999) has shown that controlling the humidity in animal rooms is more effective than using high air change rates in managing the production of ammonia from animal urine. This has allowed users to decrease "the air change rate from 15 to as low as 5, while improving the welfare of the animals."

To summarize, the goal is to limit occupant exposure to hazardous materials. Increasing the ventilation rate may or may not be an effective way to accomplish this.

Sidebar:

Question: Our university campus standard is 10 ACH ventilation rate for laboratories. How do I address safety concerns when lowering the required minimum ventilation rate to 8 ACH or even 6 ACH?

Answer: Ask your EHS professional for the scenario when 10 air changes are safe and 6 air changes are not. Generally the concern is a major release such as a spill. In such a situation, neither air change rates are safe - the occupants should leave. So if they have the opportunity to push a panic switch, five benefits can arise:

1. **The control system can increase the airflow significantly (say to 20+ air changes).**
2. **An alarm can signal your EHS staff that there is a problem.**
3. **An alarm can signal people outside the lab not to enter.**
4. **Huge amounts of energy and capital costs are saved.**
5. **Lower quantities of air supply reduce the negative effects supply air can have on fume hoods.**

This option with lower capital and operating cost may actually significantly improve safety. Many labs are not classified as hazardous (most university labs). H-6 occupancy (a hazardous classification) only requires six air changes. Note that standards are not codes, and judgment is required in their application. For example, ASHRAE's recommendation of 6 to 12 air changes does not mean 6 is marginal and 12 is better. There are many examples when more air is not better (e.g. fume hood face velocity).

It is when a systems approach is not used that air change rates may be driven up. Poor design may lead to more airflow. For example, if the room airflow patterns are not well designed, undesirable dead air spaces may occur. Increasing airflow and turbulence solves that design problem, but can significantly undermine the safety of the fume hoods. A systems approach optimizes all aspects (no dead air, and safe hoods) and is a win-win approach.

If a 200,000 square foot lab saves 4 air changes per hour that would be in the ball park of $800K per year (perhaps more in colder/warmer climates). That could pay for a full time energy manager and a full time EHS manager to optimize and assure long term performance while still putting hundreds of thousands of dollars back into research or teaching. (Labs21, FAQ, 2010)

Determining Ventilation Rates

After reviewing the lab programming and relevant codes, standards, and guidelines, consider these steps to determine the optimal ventilation rate:

1. **Investigate occupancy classification and code requirements**

2. **Identify energy saving goals of the project**

3. **Garner team support to optimize laboratory ventilation rate during a design charrette**

4. **Identify lab design goals and issues from a variety of perspectives with appropriate constraints (owner's scope, schedule, budget, etc)**

5. **Determine the impact of the ventilation rate on:**
   a. **Continuous safety performance**
   b. **Immediate HVAC first-cost**
   c. **Long-term energy use**
   d. **Life cycle cost (LCC) or total cost of ownership (TCO)**

6. **Create simulation and physical models to test design and optimization strategies that optimize ventilation and safety**

Also, be sure to consider additional scenarios beyond typical lab operation including how the ACH will change and be controlled when:

- **Some or all fume hoods are in the sash-closed position**

- **The lab is not occupied**

- **There is a spill**

Outside Air Reduction Strategies

Reducing the amount of outside air used in a lab area is very important for ensuring an energy efficient design. Conditioning outside air can be very costly, both in the heating or cooling energy required and the fan energy necessary to move it around. While there will always be a minimum ventilation rate requirement depending upon the lab type, there are still opportunities to reduce the use of outside air. One strategy, cascading airflow, involves "reusing" return air from non-lab spaces in lab areas. Other strategies in this section focus on reducing occurrences where the outside air rate - dictated by specific, localized uses - may exceed the minimum required ventilation rate for general lab spaces. These strategies include minimizing cage washer exhaust expulsion into lab areas and using "mini-environments" to isolate higher ACH activities from the general lab area.

Cascading Airflows

Recirculation of air is often prohibited in laboratories. As a result, lab designs often specify 100% outside air. "Cascading" ventilation air from non-lab spaces to labs is an option for reducing the amount of outside air used for 'once through' lab ventilation air. The cascading of airflow simply means that return air from non-lab areas is mixed with additional outside air and then delivered to lab areas. This strategy provides for the reuse of the office air in lab spaces thereby reducing the total quantity of outside air that must be brought into the building. This approach can help to significantly reduce annual cooling and heating energy as the total volume of outside air is reduced. One challenge in implementing this strategy is to maintain the desired pressure differential between lab spaces and adjoining spaces.

Cage Washer Cool Down

Cage washers generally operate through a pre-wash, wash, rinse, and final rinse cycle. The final rinse reaches a temperature of 160 – 180°F. Following the final rinse, there is an exhaust phase whereby the exhaust damper is opened. Following this exhaust phase, the user can open the cabinet and the residual vapor in the cabinet is often released into the space before being vented to the air handling system serving that space. This results in increased space humidity that is typically addressed by increasing the air change rate in the space up to 40 ACH.

There are a variety of ventilation systems that can remove the heated vapor from the cabinet before it is exhausted to the space. By connecting to the existing HVAC system with a vent damper and fan, the vapor can be exhausted directly outside. Alternatively, a self-contained vapor loop removal system can be installed in areas where additional duct connections are not feasible.

Control Banding

Control banding is a strategy for classifying and handling chemicals and hazards according to their associated health risks. A control band score is calculated by weighing a chemical's level of toxicity, scale of use, and ability to become airborne under certain conditions. The control band score directs the user to appropriate control strategies.

Control banding can be applied to laboratory chemical operations. For a specific process and associated chemicals, the control band can specify what activities are permissible at a room air change rate, require local ventilation, and must be conducted in a fume hood at a particular flow rate. Chemicals with the highest risk are handled at hood flows set for optimum containment, or performed in a glove box. A laboratory might optimize airflows for work up to a prescribed control band, or designate specific hoods, based on airflow and contaminant containment, for work within a certain control band.

This new approach to classifying chemical hazards is being increasingly applied worldwide. For example, the United Kingdom has incorporated control banding into its recommended tools for compliance with regulations by the Control of Substances Hazardous to Health Regulations.

During the design of a new lab building and retrofit of an existing one, the University of Rochester (UR) recently used control banding to identify a hazard level for each of its labs. After performing a detailed review and analysis of hazards being used in the university's labs, the UR Health and Safety Officer used control banding to create a new air change rate standard. Based on this approach, an "A" lab has 8 ACH when it is occupied, and 6 ACH when unoccupied (8/6 ACH); a "B" lab has 6/4 ACH, and a "C" lab has 4/2 ACH. Control banding can also be done on a basis of CFM/ft^2.

In the example of the University of Rochester, the use of control banding is a step in the right direction, but it still reinforces the conventional wisdom that "more is better."

Task Ventilation Control

Special-purpose laboratories provide an opportunity for designers to apply localized ventilation devices suited for a lab's particular use. Examples include animal labs using cage ventilation as a task-specific ventilation or local exhaust ventilation (LEV) strategy, electronic clean rooms using mini-environments, or biomedical labs using biological safety cabinets (BSCs).

In the case of animal labs, studies such as those by Memarzadeh (1999) have shown that increasing a room's ventilation rate does not have a significant effect on cage ventilation. In addition, Riskowski et al. (1996) identified cage type as an important factor in determining the ventilation rate in an animal facility, and Zhang et al. (1992) found that providing a quality environment for animal studies "was more dependent on cage design, room ventilation system design, and animal management practices than on room air exchanges."

Good practice therefore involves tailoring ventilation to a specific "task," and to a location within a laboratory equipped with LEV. When this is done, general ventilation rates may be relaxed without compromising safety or comfort at the location of the task. Note that LEV systems can increase energy use if improperly designed, installed, or operated due to high ventilation system pressure drop requirements, leaking devices, and "open" unused LEV devices.

Ventilation Rate Control Strategies

Unoccupied Airflow Setback

The differences in ventilation requirements between occupied and unoccupied modes should be considered. The ASHRAE Laboratory Design Guide suggests that setback control strategies can be used in laboratories to reduce air changes during unoccupied periods, e.g., at night and on weekends. The 2007 ASHRAE Handbook

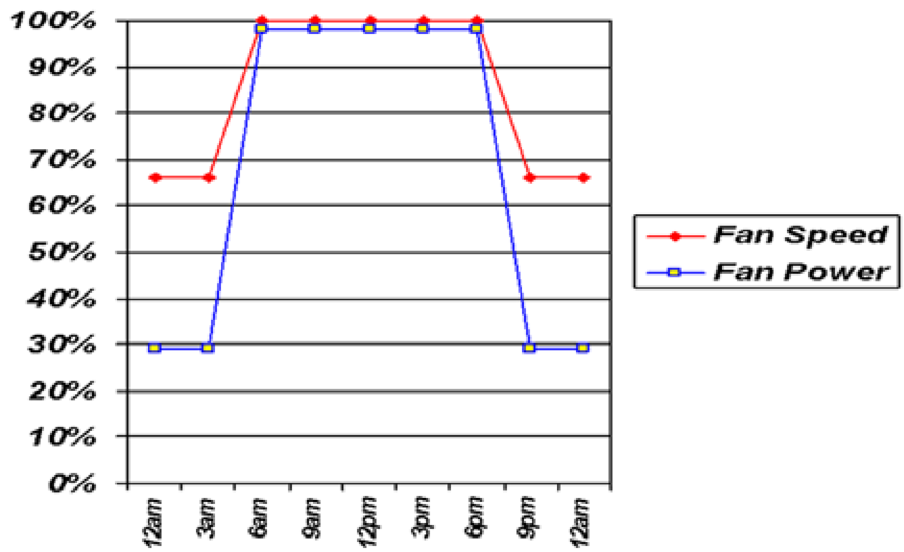


Figure 1.02
Setback of air flow (fan speed) during unoccupied hours results in (approximately) cubic fan power savings.
(Source: Created by Integral Group)

HVAC Applications chapter on laboratories suggests that if appropriate and approved by the lab safety manager, night setback controls can reduce the exhaust volume from one-quarter to one-half the minimum occupied value. The NFPA 45 Standard recommends a minimum ventilation rate of 4 ACH for unoccupied laboratories; some labs are designing for even lower rates.**Centralized Demand**

Controlled Ventilation

Laboratory ventilation rates can also be reduced by using a demand-controlled ventilation (DCV) system that incorporates sensors to monitor real-time lab pollutants. Centralized demand-controlled ventilation (CDCV) is a technological approach that uses a centralized suite of pollutant sensors to provide DCV. A CDCV system is intended to minimize DCV complexity and cost of installing multiple, dedicated pollutant sensors in every lab in the facility. With CDCV, a sample of each lab's exhaust air is retrieved from each lab, in turn, and brought to a centralized sensor-device for analyses. The central device includes multiple sensors for the pollutants expected to be encountered in the facility. If a pollutant detected in a lab exceeds a pre-determined threshold, then the lab ventilation rate is increased to a much higher rate until the spill is cleared from the lab. Spill clearing time is monitored by the CDCV and reported to the building management system (BMS).

A notable benefit of DCV—in addition to energy savings—is the introduction of monitoring equipment that can detect hazards and provide alarms and reporting. In addition to monitoring for spills and other accidents, DCV can also help identify malfunctioning fume hoods or poor lab practice (e.g., chemicals left out of fume hoods) that could otherwise go undetected.

Simulation Strategies

In an effort to optimize ventilation system layouts and laboratory designs, better-practice strategies apply real or virtual laboratory models that permit airflow pattern simulations. These performance-based approaches evaluate a simulated environment's hazards, e.g., they determine a chemical's clearing time by calculating the lab space's "mixing factors" for a given spill scenario rather than simply applying a universal, prescriptive air change rate.
This is an iterative process that accounts for facility design features that influence one another. The following simulation methods may be applicable.

CFD Simulation

A geometric representation of the lab space is "built" within a computer. Then, the airflow patterns inside the lab are modeled using a three-dimensional computer simulation program. Results from the model help designers determine a lab's airflow characteristics by:

- **Developing "answers" to spill scenarios**
- **Estimating residence time of a hazard**
- **Evaluating the placement of major design elements such as hoods, benches, and registers**
- **Eliminating stagnant dead zones in which air recirculates or there are "lazy" airflow patterns**
- **Examining numerous "What if?" scenarios**

Tracer Gas Simulation

Once a scaled or full-size mockup is built, a lab's ventilation system can be determined by using a tracer gas test, according to the ASHRAE Laboratory Design Guide. The tracer gas is evenly distributed throughout the laboratory, and the rate of decay in the tracer gas concentration is used to calculate air changes per hour (ACH). To implement this strategy, sensors are installed in the room, a tracer gas is introduced, and ventilation rates are increased until the desired rate of decay is obtained. (EH&S specialists typically determine the appropriate rate of decay.)

Neutrally Buoyant Helium Bubble Simulation

Using neutrally buoyant helium bubbles to study airflow patterns in a laboratory space is a relatively new method. Tiny helium-filled bubbles about one-eighth of an inch (2 mm) in diameter are generated at the rate of approximately 400 bubbles per minute. These bubbles quickly reach room temperature and follow the slightest air current in the room. They persist for up to two minutes, providing designers an opportunity to study a lab's ventilation system. Helium bubbles are also useful for evaluating the efficacy and placement of supply diffusers and return air grilles; their positions can be varied during the test in order to mitigate areas of stagnant air.

Case Study: Laboratory ACH Reduction

Biotech Case Study – Biotech Startup Revance Drives Energy Management with PG&E Incentives

One of the energy saving measures implemented at the Revance Therapeutics Inc. (a biopharmaceutical company in Newark, California) was a reduction in the laboratory air change rate. In the labs, where proper ventilation requires 8 ACH when occupied, the system reduces the rate to 4 ACH when the labs are empty – not just overnight or on weekends, but during regular business hours. Occupancy sensors determine whether a lab is occupied and adjusts the air flow accordingly.

Related Chapters

- Chapter 3: Eliminating Reheat
- Chapter 5: Fume Hood Optimization
- Chapter 8: Metrics and Benchmarks for Energy Efficiency in Labs

References

- 2007 California Building Code, California Code of Regulations, Title 24, Part 2, California Building Standards Commission. Based on 2006 International Building Code. June 2007.
- 2007 California Mechanical Code, California Code of Regulations, Title 24, Part 4, California Building Standards Commission. Based on 2006 Uniform Mechanical Code. May 2007.
- American Conference of Governmental Industrial Hygienists, "Industrial Ventilation: A Manual of Recommended Practice," 27th Edition, 2001.
- American National Standards Institute, American Industrial Hygiene Association, "ANSI/AIHA A9.5-2003 Standard for Laboratory Ventilation," 2003.

- American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc, Handbook, HVAC Applications, Chapter 14, Laboratories, 2007.

- American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. "Standard 62.1-2010: Ventilation for Acceptable Indoor Air Quality," 2010.

- American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. "ASHRAE Laboratory Design Guide," 2001.

- Bell, G.C. "Optimizing Laboratory Ventilation Rates," Laboratories for the 21st Century, Best Practice Guide, Lawrence Berkeley National Laboratory, September 2008. Available at: http://www.epa.gov/lab21gov/pdf/bp_opt_vent_508.pdf

- Bell, G.C. "Laboratory Centralized Demand Controlled Ventilation System Increases Energy Efficiency in Pilot Study," Laboratories for the 21st Century, Technical Bulletin, Lawrence Berkeley National Laboratory, April 2010. Available at: http://www.epa.gov/lab21gov/pdf/bulletin_demandvent_508.pdf
  Crane J.T. "Biological Laboratory Ventilation and Architectural and Mechanical Implications of Biological Safety Cabinet Selection, Location, and Venting," ASHRAE Transactions, 100(1):1257–1265, 1994.

- Chatigny and West. "Laboratory Ventilation Rates: Theoretical and Practical Considerations Proceedings of the Symposium of Laboratory Ventilation for Hazard Control," 1976.

- Lab Ventilation – Air Changes in Laboratories. Harvard University Environmental Health & Safety Operations, 2008. Accessed August 2010. Available at: http://www.uos.harvard.edu/ehs/ih/Air_Changes_in_Laboratories.pdf

- Labs21, FAQ, 2010. "Frequently Asked Questions," U.S. Environmental Protection Agency and U.S. Department of Energy. Accessed August 2010. Available at: http://labs21.lbl.gov/DPM/bestpractices/FAQlist.htm#ACHuniv

- McDiarmid, M.D. "A Quantitative Evaluation of Air Distribution in Full Scale Mock-Ups of Animal Holding Rooms." ASHRAE Transactions, 94(1): 685–693, 1988. (This article also appears in Laboratory HVAC, 1995, 89–94, ISBN 1-883413-25-7.)

- Memarzadeh, F. "Of Mice, Men, & Research." Engineered Systems, 16(4), April 1999.

- National Fire Protection Association, "NFPA 45: Standard on Fire Protection for Laboratories Using Chemicals," 2004.

- Occupational Safety and Health Administration, OSHA 29 CFR Part 1910-1450 Appendix A.

- Zhang, Y., L.L. Christianson, G.L. Riskowski, B. Zhang, G. Taylor, H.W. Gonyou, P.C. Harrison. "A Survey of Laboratory Rat Environments." ASHRAE Transactions, 98(2): 247–253, 1992

- PG&E Biotech Case Study, Revance Therapeutics, Inc., "Biotech Startup Revance Drives Energy Management with PG&E Incentives."

Resources

- 2007 ASHRAE Handbook: HVAC Applications

- Labs for the 21st Century Best Practice Guides (http://www.epa.gov/lab21gov/toolkit/bp_guide.htm)

- Labs for the 21st Century Benchmarking Database (http://labs21benchmarking.lbl.gov/)

2. Low Pressure Drop Design

Introduction

A laboratory ventilation system can be the largest and easiest target for energy use reductions. Implementing low-pressure-drop design strategies, established in the early stages of the design process, will result in much lower energy costs throughout the system's life.

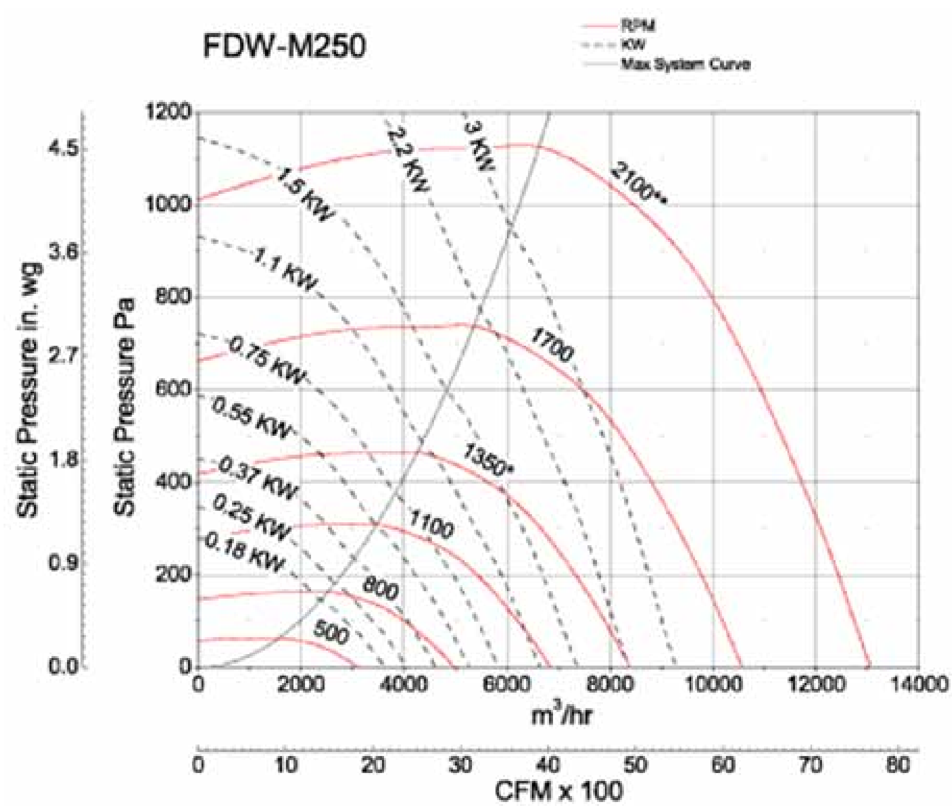


Figure 2.01:
Sample fan curve showing relationships between flow rate, pressure drop, and fan power.
Source: Greenheck fan Double Width Centrifugal Fans Models FDW-M and BDW-M.

Principles

To reduce pressure drop in laboratory ventilation systems:

- **Set targets for low pressure drop air systems early in the design process**
- **Design and select air handling units with low face velocity**
- **Size AHU components (fans, filters) based on reduced face velocity, not standard rules of thumb**
- **Include pressure drop as a criterion in selecting an energy recovery device and VAV dampers. In most cases within mild climate zones, the energy savings due to energy recovery devices may not justify the additional first cost when added fan power is taken into account**
- **Consider removing zone coils from primary air supply. (e.g. radiant floors and ceilings, fan coils, baseboard radiators)**
- **Specify larger, more direct, low-pressure-drop ductwork**

Approach

The electrical power requirements of the ventilation system are represented by the combined supply and exhaust fan power. Fan input power can be estimated by the following fan power equation (where airflow is in units of cubic feet per minute [cfm], pressure drop is in units of inches water gauge [in. w.g.], power is in units of horsepower [hp], and η is efficiency):

$$\frac{\text{Airflow (cfm)} \times \text{System air pressure drop (in. w.g.)}}{6345 \times \text{Fan system efficiency}} = \text{Fan input power (hp)}$$

Where: Fan system efficiency = $\eta_{fan} \times \eta_{motor} \times \eta_{drive}$

Reducing the energy consumed by a laboratory's ventilation system requires changing one or more of the three variables in the equation above: fan system efficiency, airflow, or system pressure drop.

While fan system efficiency is an important aspect of design, the relative potential for energy savings, when compared to low pressure drop design, can be minimal. But when energy efficiency is emphasized as an important design criterion, conventional design methods can result in efficiency improvements on the order of 10 – 15% over typical fan systems.

The airflow through the system is typically set by the requirements of the facility. The design decision with the greatest impact on ventilation energy use is whether to use a variable-flow exhaust system rather than a constant-flow or constant-volume (CV) system. Varying supply and exhaust flows based on actual usage immediately captures the significant savings possible from reducing the flow; a 25% reduction in airflow results in about a 58% reduction in the fan power required.

Despite the significant impact of the ventilation system on yearly energy consumption, it is not uncommon to see laboratory buildings with a supply and exhaust system combined total pressure drop of 12 in. w.g. or higher. This very high pressure drop directly results in a ventilation system with high power consumption. Reducing pressure drop provides some of the largest opportunities for significantly improving the efficiency of a laboratory ventilation system; therefore, it is the focus of this chapter.

The following sections discuss the implications and impacts of pressure drop in various HVAC components. These include air handler coils, energy recovery devices, VAV control devices, zone temperature control devices, ductwork, and exhaust stacks.

Air Handling Unit (AHU) Face Velocity

Traditional AHU design for office buildings bases the size of the air handler on a face velocity of 500 feet per minute (fpm) at the coil face. Originally based on a balance between the first cost and the lifetime energy cost of the equipment, this decades-old rule of thumb for face velocity was never intended for sizing a unit that operates 8,760 hours per year. Selecting a lower face velocity reduces the pressure drop of the AHU and thus its energy consumption.

Lowering the face velocity requires a larger and thus more expensive enclosure due to increasing the cross sectional area of the air handler. But any analysis of the added cost should not end with the enclosure cost, because the lower energy requirement reduces the cost of most other components. The fan motor size in a typical system can be reduced by 25%–50% because of the lower pressure drop in the air handler alone.

Table 2.01:
AHU Face Velocity and Pressure Drop Benchmarking
(Source: Labs 21)

Component	Standard	Good	Better
Air handler face velocity	500 fpm	400 fpm	300 fpm
Air handler pressure drop*	2.7 in. w.g.	1.7 in. w.g.	1.0 in. w.g.

* The pressure drop includes coils, clean 30% and 85% filters, humidifier, and intake damper.

Energy Recovery Devices

Four commonly-used energy recovery systems are often considered for laboratories: energy recovery wheels, flat-plate air-to-air heat exchangers, heat pipes, and run-around coils. The following sections consider the additional pressure drops associated with various types of energy recovery devices. The added fan power due to the additional pressure drop should be carefully weighed against the potential energy savings from the heat recovery device.

Enthalpy wheels

For small applications, an enthalpy wheel can easily be sized for a reasonably low pressure drop. In larger applications, the first cost of many low-pressure-drop wheel selections can be a concern. The need for protection from crossover contamination typically requires a significant purge section; this results in a higher total ventilation rate (cfm) and increases the total fan energy required. An enthalpy wheel also requires the main supply and exhaust ducts to be adjacent to each other. This requirement has the potential to result in more convoluted duct runs, resulting in higher pressure drops than if the supply and exhaust ducts were not adjacent. However, with careful architectural design and configuration of the ducting system, it is possible that duct layout requirements can be fulfilled with an efficient, low-pressure-drop layout.

Flat-plate heat exchanger systems

A flat-plate heat exchanger system can be a very effective heat recovery device, assuming any cross-contamination issues are adequately addressed. It can be specified for a low pressure drop provided two key issues are addressed. The first is that, as with the energy recovery wheel, the supply and exhaust ductwork must be adjacent to each other. The second issue is the specification of the heat exchanger itself. Achieving the best possible performance requires a pressure drop of 0.25 in. w.g. on the supply side, and an equal or lower pressure drop on the exhaust side. This often requires the specification of very large units.

Heat pipe systems

Restrictions on the supply and exhaust duct layout related to heat pipes can be even more stringent than those of a flat-plate heat exchanger. The additional restrictions increase the design challenge of laying-out a clean, low-pressure-drop ducting system.

Run-around coil systems

These systems can require significant effort to properly specify and optimize, but they offer great flexibility in minimizing pressure drop, because the supply and exhaust ducts do not have to be adjacent to each other. When combined with a low-face-velocity air handler, a run-around coil system can provide good energy recovery performance and very low pressure drop.

Table 2.02:
Energy Recovery Device Pressure Drop Benchmarking
(Source: Labs 21)

Component	Standard	Good	Better
Energy recovery device pressure drop (per airstream)*	1.00 in. w.g. (when present)	0.60 in. w.g.	0.35 in. w.g.

* Upstream filters would increase the pressure drop. For a standard 30% efficient clean filter, the associated pressure drops are 0.27 in. w.g. at 500 fpm, 0.18 in. w.g. at 400 fpm, and 0.10 in. w.g. at 300 fpm.

VAV Control Devices

The greatest challenge in applying VAV systems in laboratories is ensuring that the balance between supply and exhaust is maintained properly. Numerous systems can maintain the precise airflow control required for effective variable supply and exhaust systems. Typically, they make use of one of two general methods: direct pressure-independent measurement of air flows, or through-the-wall airflow or pressure measurement in the fume hood.

While these methods are radically different, the results are comparable. The primary difference is that the pressure drop associated with pressure-independent flow measurement valves is about 0.60–0.30 in. w.g., in comparison to about 0.05 in. w.g. pressure drop across a typical butterfly control damper. When designing a low pressure drop system, a 0.25 in. w.g. difference between these two designs can show significant energy impacts when considering the entire laboratory facility's airflow.

Table 2.03:
VAV Control Device Pressure Drop Benchmarking
(Source: Labs 21)

Component	Standard	Good	Better*
VAV control devices pressure drop	Constant Volume (NA)	0.30–0.60 in. w.g. per device	0.10 in. w.g.

* The relative merits of these flow control methods are not judged, only the relative pressure drops (and associated efficiency potential). Other design requirements can also affect the best choice per application.

Zone Temperature Control Devices

If the airflow to a laboratory space is dictated by the minimum ventilation requirements of the space, variable airflow cannot be utilized for temperature control. When these conditions occur, the typical temperature control method is to provide zone reheat coils. The disadvantage of this system is the pressure drop incurred by the zone coil whenever the system is operating, which can be all 8,760 hours in a year in most laboratories. Consequently, the energy cost associated with zone coil pressure drop quickly adds up. There are a number of ways to minimize the pressure drop of zone reheat systems. A good first step is to use the high-volume, high-operating-hours nature of the system to justify the cost of a coil with lower face velocity. Such an approach recognizes the cost of pressure drop and results in a fairly low-pressure-drop solution.

A better approach is to eliminate the zone coil from the primary supply airflow. Several design options will allow this. Reheat coils can be eliminated by utilizing radiant heating in the laboratory space. A radiant heating system offers additional savings by reducing the heating of the air, which is rapidly exhausted from the space. A fan-coil unit with heating and cooling coils can be added to each zone. The fan coil should operate only when there is a need for additional heating or cooling in the zone. One way to reduce pressure drop in four-pipe fan-coil systems is to use a single coil with automatic isolation valves (provided that some mixing of the cooling water and heating water is acceptable).

Table 2.04:

Zone Temperature Control Device Pressure Drop Benchmarking

(Source: Labs 21)

Component	Standard	Good	Better
Zone coil pressure drop	0.42 in. w.g.	0.20 in. w.g.	0.00 in. w.g. (i.e., no reheat coils)

Ductwork

Requiring little change in traditional design methods, reducing the ductwork pressure drop is perhaps the easiest design change that can be made to improve the efficiency of a laboratory's mechanical system. Larger, lower pressure ductwork also provides flexibility in case flow requirements increase in the future. Like the air handler, supply ductwork is usually designed to a rule of thumb target pressure drop using the constant-pressure-drop method carried over from office conditioning design, or it is designed to stay within maximum noise levels.

A common pressure drop rule of thumb used for duct sizing in office buildings is 0.1 in. w.g. per 100 ft of ductwork, but sometimes higher. For a laboratory building operating 8,760 hours per year, it is often reasonable to design to half this pressure drop. Decreasing this design parameter to 0.05 in. w.g. per 100 ft is a simple step and is often defensible because it would halve the fan energy consumption attributable to the ducting system.

The incremental cost of larger ductwork is often overemphasized. Lower pressure drop design can reduce the complexity of ductwork, requiring fewer contraction fittings and shorter, more direct layout. The labor and fitting costs associated with numerous duct contractions versus longer runs of a single, larger diameter duct may help offset the additional material cost. Construction management efficiencies may also be gained from using fewer different sizes of ductwork in a project, for example, when only round ductwork and fittings 24 in. and 18 in. in diameter are used for the distribution ducting.

Figure 2.02:
Larger ductwork results in lower pressure drop and lower fan power.
Source: EHDD Architects.

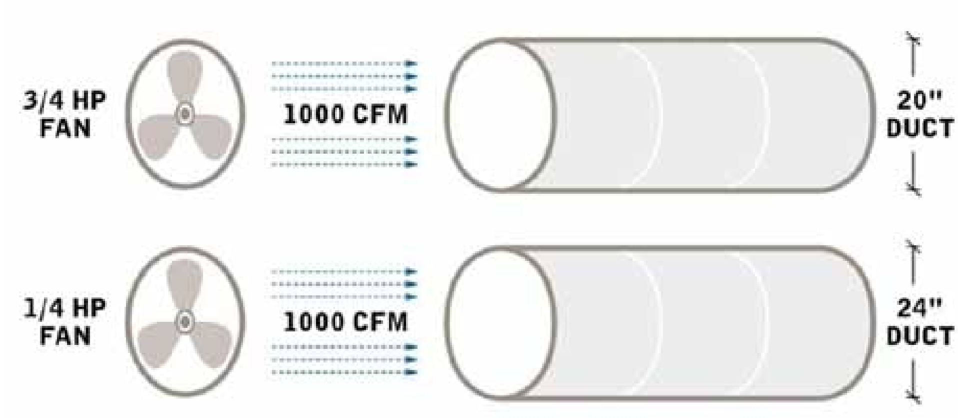


Table 2.05:
Ductwork Pressure Drop Benchmarking
(Source: Labs 21)

Component	Standard	Good	Better
Ductwork pressure drop	4.5 in. w.g.	2.25 in. w.g.	1.1 in. w.g.

Exhaust Stacks

Safe expulsion of exhaust air that may contain toxic contaminants is a requirement for laboratory buildings. To ensure adequate dilution of the exhaust, it must be ejected from either a significant height or at a high velocity. ASHRAE and American Industrial Hygiene Association (AIHA) guidelines require exit velocities of 2,000 to 3,000 fpm, even when a tall exhaust stack is used. In a CAV system, the stack pressure drop can be minimized using conventional duct design techniques. Minimizing the pressure drop in a VAV exhaust system is made more difficult by the varying exhaust flow. Sometimes laboratory owners may allow for a lower minimum exit velocity based on wind tunnel modeling results but still require that the system be designed for a higher minimum exit velocity. In these cases, variable-frequency drives may be used to modulate exhaust flow between the minimum and the design exit velocity, allowing for lower discharge velocities during periods of reduced exhaust flows. Adjustable-diameter exhaust stacks can also be employed to maintain minimum exit velocity when volumetric flow of exhaust air is reduced. However, these can present additional maintenance issues.

Another approach to a variable-flow exhaust system is to maintain a constant volume through the stack itself by drawing in dilution air immediately before exhaust air reaches the exhaust fan. The dilution air allows the stack to operate safely even when the laboratory exhaust volume has dropped to the point where the stack exit velocity would be too low to ensure proper dispersion. Dilution air incurs a fan power penalty because more airflow than is required for the laboratory process must be pushed through and out the stack by the exhaust fan. When the velocity pressure is included, the use of this approach typically results in a pressure drop greater than 0.5 in w.g.

This fan power penalty still makes a VAV system far superior to a CV system, however, in which, at low exhaust load conditions, dilution air is essentially drawn from the conditioned laboratory space.

Another alternative approach is to have multiple fans, each with a dedicated stack, draw from a common exhaust plenum. As the required exhaust volume drops, fans and 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 a safe exit velocity to be maintained without having to maintain a constant, high-volume flow through the exhaust system. Note that the number of fans affects the ability to stage the fans, and the design stack velocity may need to be increased (e.g., peak at 4000 fpm, stage off at 3000 fpm).

Table 2.06:
Exhaust Stack Peak Pressure Drop Benchmarking
(Source: Labs 21)

Component	Standard	Good	Better
Exhaust stack peak 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

Table 2.07:
Summary of Impacts of Designing Ventilation Systems with Low Pressure Drop
(Source: Labs 21)

Component	Standard	Good	Better
Air handler face velocity	500	400	300
Air handler pressure drop	2.7 in. w.g.	1.7 in. w.g.	1.00 in. w.g.
Energy recovery device pressure drop	1.00 in. w.g.	0.60 in. w.g.	0.35 in. w.g.
VAV control devices pressure drop	Constant Volume, N/A	0.60 – 0.30 in. w.g.	0.10 in. w.g.
Zone temperature control coils pressure drop	0.42 in. w.g.	0.20 in. w.g.	0.00 in. w.g. ***
Total supply and exhaust ductwork pressure drop	4.5 in. w.g.	2.25 in. w.g.	1.1 in. w.g.
Exhaust stack pressure drop	0.7 in. w.g. full design flow through entire exhaust system, CV	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)*	1.0 in. w.g.	0.25 in. w.g.	0.0 in. w.g.
Total	10.32 in. w.g.	6.15 in. w.g.	3.3 in. w.g.
Approximate fan power requirement (W/cfm)**	2	1.2	0.6

* Good practice corresponds to the use of low-pressure-drop sound attenuators. Better practice corresponds to eliminating the need for sound attenuators by appropriate duct design and layout.

** To convert pressure drop values into the commonly used metric of W/cfm, these assumptions were used in the fan power equation: 0.62 fan system efficiency (70% efficient fan, 90% efficient motor, 98% efficient drive).

*** Use of radiant system to provide heating and cooling will increase pumping energy slightly. The heat capacity of water is about 4x that of air, requiring less water by unit volume.

Case Study: Laboratory Heat Recovery

Medical Devices and Diagnostics Case Study – LifeScan Powers Energy-Efficiency Measures with PG&E Rebates

In 2007, the LifeScan building in Milpitas, California installed a run-around loop to recover the heat from two large laboratory exhaust fans. Coils were placed in the supply and exhaust air streams to capture waste heat from the exhaust and re-use it to pre-heat labs in the building. The project has saved more than 121,000 kilowatt hours and nearly 25,000 therms annually.

Related Chapters

- Chapter 1: Optimizing Ventilation and Air Change Rates
- Chapter 5: Fume Hood Optimization
- Chapter 8: Metrics and Benchmarks for Energy Efficiency in Labs
- Chapter 9: Optimize Exhaust Systems

References

- Labs 21 Best Practices, "Low-Pressure-Drop HVAC Design for Laboratories," http://www.labs21century.gov/pdf/bp_lowpressure_508.pdf
- Lawrence Berkeley National Laboratory, "How Low Can You Go? Low Pressure Drop Laboratory Design," 2001
- PG&E Medical Devices and Diagnostics Case Study, "PG&E Helps Drive LifeScan's Sustainability Campaign: LifeScan Powers Energy-Efficiency Measures with PG&E Rebates."

Resources

- American society of Heating, Refrigerating, and Air Conditioning Engineers. ASHRAE Handbook – HVAC Systems and Equipment.
- ASHRAE/IESNA Standard 90.1. Energy Standard for Buildings Except Low-Rise Residential Buildings.

3. Eliminating Reheat

Introduction

HVAC systems that are designed without properly accounting for equipment load variation across laboratory spaces in a facility can significantly increase simultaneous heating and cooling, particularly for systems that use zone reheat for temperature control. This chapter describes the problem of simultaneous heating and cooling resulting from load variations, and presents several technological and design process strategies to minimize it.

Peak equipment usage for lab spaces is typically between 6 – 10 W/sf. High-intensity labs can have loads upwards of 15 – 20 W/sf. The reheat problem arises when labs with very different peak equipment loads are served by a single air delivery system and have zone reheat coils as the primary method of temperature control. The high-intensity labs then drive the supply air temperatures and flows to handle high equipment loads, and, as a result, all the other labs have to use reheat to maintain desired temperatures. This issue usually does not come up during design, because designers assume uniform equipment load intensity for all laboratory spaces served by an air delivery system and assume no variation between those spaces. Energy simulation conducted during the design phase that reflects this assumption will not show the increased reheat energy use that is due to load variation.

Principles

To eliminate or minimize reheat in labs, key principles to consider include:

- **Study thermal loads in zones and serve similar zones with separate air delivery systems – watch out for "rogue" zones that may end up driving the entire system**

- **Separate ventilation requirements from cooling or heating requirements**

Table 3.01:
Air Changes per Hour (ACH) Requirement Comparison
(Source: Integral Group.)

Total cooling load including lights, people, building envelope and equipment	Required air change rate for safety (air changes per hour)	air change rate for cooling (assume 55 F supply air and 75 F Exhaust air)	Air Change Rate driven by:
10 W/ft^2	6 ACH	9.4 ACH	Cooling
15 W/ft^2	6 ACH	14.1 ACH	Cooling
20 W/ft^2	6 ACH	18.8 ACH	Cooling
10 W/ft^2	8 ACH	9.4 ACH	Cooling
15 W/ft^2	8 ACH	14.1 ACH	Cooling
20 W/ft^2	8 ACH	18.8 ACH	Cooling
10 W/ft^2	10 ACH	9.4 ACH	Safety
15 W/ft^2	10 ACH	14.1 ACH	Cooling
20 W/ft^2	10 ACH	18.8 ACH	Cooling
10 W/ft^2	12 ACH	9.4 ACH	Safety
15 W/ft^2	12 ACH	14.1 ACH	Cooling
20 W/ft^2	12 ACH	18.8 ACH	Cooling

Approach

There are many HVAC design strategies that can be used in lieu of zone reheat coils as a means to minimize or eliminate reheat energy. All of these strategies involve separating the ventilation air requirements from the heating and cooling systems. By applying these approaches, the energy intensive reheating of over-cooled air can be dramatically reduced or avoided.

In decoupling ventilation requirements from heating and cooling requirements to minimize reheat, air delivery systems and their corresponding ductwork can also be downsized, which can result in capital cost savings. Ventilation requirements for safety in labs are usually in the range of 6 – 10 air changes per hour (ACH). However, many labs are designed for higher air change rates to accommodate high fume hood counts and/or high cooling loads. Typical lab equipment cooling loads range between 5 to 15 W/ft^2. When cooling loads from people, lights and the building shell are factored in, the typical range is 10 to 20 W/ ft^2. As seen in Table 3.01, the maximum air change rate is most commonly determined by the cooling load requirement. In some labs with extremely high fume hood counts, (more than four hoods per 1,000 ft^2 lab or 14 air changes per hour assuming a 10 ft ceiling), air change rates can be dominated by fume hood flow. Other forms of point exhaust, such as gas cabinets, vented balance safety enclosures, snorkels, or bio safety cabinets can also drive the ventilation requirement. If ventilation and cooling requirements are separated in laboratories where duct sizing and air handler sizing are driven by cooling requirements, significant savings are possible: in many cases, ducting can be downsized to handle less than half of the typical air volume. The savings realized from this design strategy can be used to pay for the piping and zone level units, resulting in little, if any, first cost increase.

HVAC design strategies to consider for separating ventilation requirements from thermal requirements include fan coil units, chilled beams, and radiant heating and cooling.

Fan Coil Units

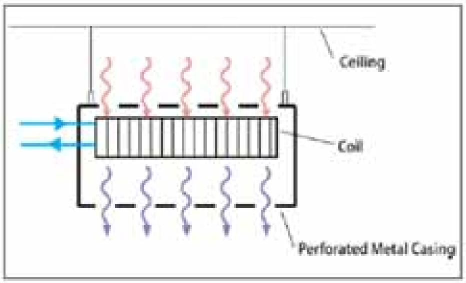
Using fan coil units in lieu of zone reheat coils is a common approach to minimizing reheat. To implement a fan coil system, a ventilation air stream tempered by a dedicated outside air system is first provided to the space. The fan coil unit is linked to a local thermostat and provides supplemental heating or cooling to the space based on the loads and setpoint. Fan coil units are simply a heating and/or cooling coil with an internal fan. The heating and cooling coils are supplied with hot water or chilled water typically from a central plant. The fan draws air over the coils and then recirculates the conditioned air into the space. The unit is typically located overhead and requires minimal or no ductwork. This approach is more energy efficient than a VAV reheat box as the "rogue" zone that would otherwise be driving the supply air temperature for all zones is now able to accomplish the needed heating and cooling with its own fan coil unit. This approach helps to isolate the high intensity zone from the rest of the system.

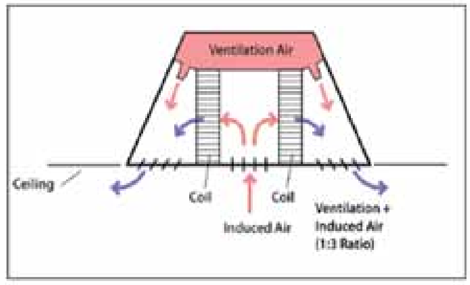
Note that implementing a fan coil in a space may require coordination with and education of local authorities if there are any prohibitions in the local codes pertaining to air recirculation in a laboratory space. A properly implemented fan coil system will not mix air between any zones and will have no impact on space pressurization. While it does not violate the intent of most code regulations, this approach may be unfamiliar and may require educating and gaining the approval of inspectors.

Chilled Beams

Chilled beams provide another approach to separate ventilation air from thermal loads and reduce or eliminate reheat energy. In this scenario, tempered ventilation air is similarly provided to the zone, and space cooling is provided by active or passive chilled beams. Space heating is provided by zone heating coils located in the supply air stream.

As mentioned above, there are two types of chilled beams currently in use: passive and active. Passive chilled beams usually consist of a small coil in a box that is recessed in the ceiling or hung from the ceiling. They are used for cooling and depend on natural convection. Chilled water flows through the coil and the air around the coil is cooled and falls into the room, driven by convection (Figure 3.01). As with passive chilled beams, active chilled beams have coils in ceiling-mounted boxes. However, active chilled beams use ventilation air that flows through the diffuser. The ventilation air is introduced into the diffuser box through small air jets, which induce room air to flow through the coils (Figure 3.02). Because the active introduction of ventilation air magnifies the natural induction effect, active chilled beams are also commonly referred to as induction diffusers. This induction effect gives active chilled beams much higher cooling or heating capacities than passive chilled beams.





Left to Right
Figure 3.01
Passive Chilled Beam
(Source: Created by Integral Group)

Figure 3.02
Active Chilled Beam
(Source: Created by Integral Group)

Active chilled beams allow for ventilation air to be supplied at 65°F or 70°F. When air is supplied at 70°F and all of the cooling is accomplished in the chilled beam's cooling coil, reheat is completely eliminated. In the case where 65°F air is needed to increase the cooling capacity of the chilled beams, small amounts of reheat are needed in labs where cooling loads are small.

In addition to reducing reheat energy, chilled beams have other advantages including:

- **Reduced fan energy: Cooling is accomplished with pumped chilled water instead of blown cold air. Water has a volumetric heat capacity 3,500 times that of air. In typical pump and fan arrangements, this translates into a reduction in fan energy by a factor of seven.**

- **Higher temperature chilled water: Chilled beams require higher chilled water temperatures to avoid condensation. In most cases, chilled water temperatures are in the 55°F to 60°F (13°C to 16°C) range. These warmer temperatures enable water-side economizer or free cooling applications for significantly more hours of the year.**

A major concern with chilled beams is avoiding condensation. If standard temperature chilled water (45°F) is used in the chilled beam, there is a risk of condensing water on the coil. To prevent such condensation, the chilled beam water temperature must be actively maintained above the room air dew point. In addition, designers should recognize the limitations of chilled beams in terms of maximum cooling capability. In labs where equipment loads are in the 20 W/ft2 or higher range, their application can become impractical because too many chilled beams would be required. These more cooling-intensive rooms frequently require different design solutions, such as the use of fan coils.

Radiant Heating and Cooling

Similar to the chilled beams configuration described above, another method to provide heating and cooling independently from the ventilation air is to design for radiant systems. This could consist of ceiling-mounted radiant panels (with chilled water and/or hot water circulated through the panels), or "in-slab" radiant, which entails the installation of a network of cross-linked polyethylene (PEX) tubing into the structural slab while it is being poured. The PEX tubing conveys chilled or hot water within the concrete slab depending upon whether the space requires heating or cooling. Ventilation air is still provided by a dedicated outside air system, sized only for ventilation requirements and supplying tempered air at a neutral temperature.

Radiant heating and cooling have the same advantages as the chilled beams system, in that heating and cooling are accomplished much more efficiently by water instead of air, and the need for higher chilled water temperatures to avoid condensation not only saves energy at the chiller(s), but also allows for more hours in a typical year in which water-side economization is viable. Some disadvantages of radiant systems include:

- **Slow response time: for labs with highly variable loads and irregular occupancy profiles, radiant systems are generally not able to respond sufficiently to abrupt changes in load. Radiant systems are better suited for relatively constant/continuous load characteristics. Similarly, labs that need to switch from heating to cooling quickly would not be able to do so easily with radiant systems.**

- **Limited cooling capacity: For labs with high cooling loads, the number of radiant panels required, or the limitation of in-slab cooling capacity may make radiant an unattractive design choice. To mitigate this, some labs have installed in-slab radiant to serve typical loads, with supplemental fan coils, etc, to pick up any needed cooling capacity during peak loads.**

Case Study: Decoupling Ventilation in Laboratories

Tahoe Center for Environmental Sciences

The Tahoe Center for Environmental Sciences (TCES) is located in Incline Village, Nevada on Sierra Nevada College's Lake Campus. The building is comprised of lab and non-lab space. The laboratory areas require mechanical ventilation for pressurization control, life safety and air quality (filtration) reasons. Ventilation air is supplied to the laboratories via an overhead ducted VAV system. Additional cooling and heating is supplied by active chilled/heated beams. This approach divorces the supply airflow requirements from the space cooling and heating load requirements. The airflows are not driven by the space cooling or heating requirements. The induction diffusers provide additional cooling and heating as required, similar to a fan coil but with no fan electrical requirements.

By decoupling the ventilation from the heating and cooling system, energy consumption was greatly reduced. Energy cost savings over the first year were 45% better than ASHRAE 90.1 baseline and 70% better than a Labs 21 comparable building.

Related Chapters

- Chapter 1: Optimizing Ventilation and Air Change Rates
- Chapter 8: Metrics and Benchmarks for Energy Efficiency in Labs

References

1. Labs 21 Best Practices, "Minimizing Reheat Energy Use in Laboratories,"http://www.labs21century.gov/pdf/bp_reheat_508.pdf
2. ASHRAE Journal, "Chilled Beams in Labs, Eliminating Reheat & Saving Energy on a Budget,"http://www.integralgroup.com/pdf/ASHRAE_chilled_beams.pdf
3. Labs 21 Best Practices, "Chilled Beams in Laboratories: Key Strategies to Ensure Effective Design, Construction, and Operation," http://www.labs21century.gov/pdf/bp_chilled-beam_508.pdf
4. Energy Design Resources, "Innovative Mechanical Designs in the Sierras," http://www.energydesignresources.com/Resources/Publications/CaseStudies/tabid/75/articleType/ArticleView/articleId/400/Default.aspx
5. Labs for the 21st Century, "Tahoe Center for Environmental Sciences at Sierra Nevada College," http://labs21century.gov/community/partnership/partners/snu.htm

Resources

- ASHRAE Journal, "Chilled Beams for Labs, Using Dual Energy Recovery," www.ashrae.org/members/doc/barnet_8090903.pdf
- GreenSource, "Global Ecology Center – Planetary Perspectives: Design for labs and offices for a team of climate researchers mimics natural systems to drive down energy use and carbon emissions," http://greensource.construction.com/projects/0701_planetary.asp

4. Humidity Control

Introduction

Laboratory spaces often include rooms that require humidity control. Examples of such spaces include research animal facilities, rooms with sensitive scientific equipment and pharmaceutical research and development and manufacturing facilities. Maintaining a tight humidity control range usually requires large amounts of energy. Humidity sensor drift combined with a tight humidity control range often lead to control problems unless the sensors are regularly recalibrated. Humidity tolerances tighter than those recommended for human comfort, animal well being or equipment requirements should be carefully evaluated and explicitly justified.

Lower energy alternatives to electric steam generating humidifiers include those that use an adiabatic process to humidify the air. This process involves using the heat present in the air to evaporate the fog, mist or spray of water provided by the humidifier. A result of this evaporation process is a free cooling effect on the air which is especially advantageous in hot, dry climates. Ultrasonic humidifiers, wetted media and micro droplet spray are some examples of adiabatic humidifiers.

Principles

- **Humidity control requires large amounts of energy. Avoid specifying overly tight humidity tolerances. Wider humidity control ranges allow for lower humidity control energy usage.**

- **Spaces requiring humidity control should be served by a dedicated HVAC system to avoid wasteful humidity control of supply air to other spaces.**

- **In vivaria, minimizing spilled water and evaporation of fecal water will help reduce the latent load on the HVAC system.**

- **Dehumidification is an energy intensive process whenever the air needs to be cooled below the supply air temperature setpoint, to condense water out, and then reheated.**

- **Use adiabatic humidifiers and evaporative cooling for humidification whenever possible.**

Approach

Humidity control is very energy intensive and should be minimized whenever possible. Therefore, any specified room humidity level tolerance should be carefully evaluated to avoid excessive energy expenditures. Lab equipment requiring tight environmental requirements (including tight humidity range control) should be grouped in a common space served by an HVAC system dedicated to providing the required environmental control. For the same reason, spaces used for housing and handling animals that require humidity range control should be served by a dedicated HVAC system. This approach avoids unnecessary humidity control of other spaces in the facility.

Research animal facilities require relatively precise temperature and humidity control because variations in the animal's environment can affect experimental results. The Institute of Laboratory Animal Resources (ILAR) suggests the acceptable range of relative humidity is 30 to 70%. This relative humidity range applies to temperature setpoints ranging from 64 to 85 °F that are controlled to ± 2 °F, depending on housed animal species. A relative humidity range between 40% and 75% also reduces the viability of pathogens in the air (ILAR). Additional factors determining humidity requirements include control of animal generated gaseous contaminants and proper ventilation of cage washer equipment. A high humidity environment encourages ammonia production and controlling the humidity level in animal rooms is more effective than using high air change rates in managing ammonia production (ILAR). Raising the supply air temperature will reduce the relative humidity of the air since hotter air has a higher potential capacity for moisture. Thus, control of relative humidity involves temperature control in addition to controlling the moisture content of the air.

In pharmaceutical manufacturing facilities, high humidity causes fine powders to adsorb moisture, clogging the powder feed to the tableting press. Powder inconsistency caused by moisture adsorption results in crumbling tablets and clogged tablet dies. Variations in humidity mean difficult adjustments in bed temperature and spraying rates, resulting in heat damage and moisture intrusion. Humidity in air ductwork creates moist places for bacterial colonies to grow and cause process contamination.

Dehumidification requires that the air be cooled to such low temperatures that reheat is commonly used to maintain a supply temperature setpoint. For instance, if the relative humidity of a space is specified not to exceed 50% RH at 70 °F, then ventilation air must be cooled to 50 °F or colder to dehumidify. If the ventilation air or exhaust air requirements of the space exceed the cooling load, this air must be reheated to avoid overcooling. In addition to the large energy cost of removing moisture from the air stream (about 1,000 Btus for every pint of moisture condensed), using energy to simultaneously heat and cool air is an inefficient but common part of the dehumidification process. Finally, in a chilled water plant system, dehumidification can reduce the efficiency of the entire plant by requiring a lower chilled water temperature.

If a space justifiably requires frequent dehumidification of ventilation air, a "wrap-around" loop can be installed as an energy efficient option for reheating. This device pre-cools and reheats using a pair of coils – one upstream of the cooling coil and one downstream – so that the energy extracted from the air by the pre-cooling coil is mostly returned to the air stream via the reheat coil. The wrap around loop adds significant air-side pressure drop and therefore increases fan energy, so its energy recovery benefits need to be carefully weighed against the additional fan energy.

Barring high infiltration, most cooling systems will automatically control the maximum humidity to about 60% to 70% RH due to the fundamental nature of their operation. Supply air at 60°F saturated with as much moisture as it can possibly carry has a relative humidity of only 66% at 72°F (room temperature). Over-humidity problems are more likely to indicate excessive infiltration (i.e., a broken outside air damper) or malfunctioning humidifiers than a dehumidification control or capacity problem.

Humidity sensors are possibly the least stable sensor technologies in common HVAC use. Even with a control band such as 30-60% RH, humidity sensors should be regularly calibrated. Humidity control consumes a large amount of energy and requires costly equipment to achieve; if the first cost was justified, then calibrating the humidity sensors should be considered as much an operating cost as the electric bill in order to ensure the first-cost investment is actually providing the desired space condition. The Iowa Energy Center sponsored a study of the accuracy of several humidity sensors and concluded that some products performed significantly better than others. See the Resources section at the end of this chapter for links to the Iowa Energy Center reports.

Energy-efficient humidification techniques replace electric steam generators with ultrasonic humidifiers, micro droplet spray, and other low-energy technologies. This adiabatic humidification approach provides evaporative cooling on the way to reaching the humidity set-point. Most importantly, this eliminates the parasitic heat gain of generating steam to humidify the space while providing "free cooling" in the process of reaching the humidity setpoint and is especially advantageous in climates with hot, dry summers.

Related Chapters

- Chapter 1: Optimizing Ventilation and Air Change Rates
- Chapter 3: Eliminating Reheat
- Chapter 10: Chilled Water Plant Optimization

References

- ASHRAE Handbook – HVAC Applications, 2007 Chapter 14 Laboratories
- ASHRAE Handbook – HVAC Applications, 2007 Chapter 22 Environmental Control for Animals and Plants
- Institute of Laboratory Animal Resources (ILAR), "1996 Guide for the Care and Use of Laboratory Animals, National Academy of Sciences," National Academy Press, Washington D.C., http://www.nap.edu/openbook.php?record_id=5140

Resources

- ASHRAE Handbook – HVAC Fundamentals, 2009 Chapter 6 Psychrometrics
- ASHRAE Handbook – HVAC Systems and Equipment, 2008 Chapter 20 Humidifiers
- Lawrence Berkeley National Laboratory, "A Design Guide for Energy-Efficient Research Laboratories," http://ateam.lbl.gov/Design-Guide/DGHtm/humiditycontrol.htm
- Iowa Energy Center, National Building Controls Information Program, "Product Testing Report, Duct-Mounted Relative Humidity Transmitters," April 2004, http://www.energy.iastate.edu/Efficiency/Commercial/download_nbcip/PTR_Humidity_Rev.pdf
- Iowa Energy Center, National Building Controls Information Program, "Product Testing Report Supplement, Duct-Mounted Relative Humidity Transmitters," July 2005, http://www.energy.iastate.edu/Efficiency/Commercial/download_nbcip/NBCIP_S.pdf

5. Fume Hood Optimization

Figure 5.01
Example of horizontal sash chemical fume hoods
(Source: Provided by Integral Group)

Introduction

Exhaust hoods include canopy hoods, equipment hoods, biological safety cabinets, and chemical fume hoods. To protect worker safety and contamination, laboratory facilities generally use chemical fume hoods and biological safety cabinets to contain and/or safely exhaust airborne toxic and hazardous substances. Air enters the hood through the face of the unit to contain the hazardous substances within the hood, and safely exhaust the contaminants through the fume hood exhaust system.

Maintaining a sufficient face velocity through the hood is paramount. Most hoods operate effectively with face velocities ranging from 60 – 100 feet per minute (fpm). Face velocities above 125 fpm have been shown to induce turbulence at the hood opening, causing fumes to spill out of the hood, endangering laboratory personnel.

The California Division of Occupational Safety and Health (Cal/OSHA) requires a face velocity of 100 fpm for typical fume hoods and 150 fpm for radioisotope and perchloric hoods.

Depending upon the specific end-use and required function, chemical fume hoods are available in a wide variety of types and sizes. Types include constant air volume (CAV) hoods, CAV hoods with bypass air, auxiliary-air hoods, two-position hoods, variable air volume (VAV) hoods, walk-in hoods, radioisotope hoods, distillation hoods, and perchloric acid hoods. Fume hood widths range from four to twelve feet.

The typically continuous operation of chemical fume hoods make them attractive targets for energy efficiency in new construction and retrofits. Implementing best practices in the optimization of fume hood operation for a laboratory operating 8,760 hours per year is almost always a cost-effective pursuit.

Principles

To optimize fume hoods and related exhaust systems:

- **Consider Variable Air Volume (VAV) instead of Constant Air Volume (CAV) hoods**
- **Maintain optimum fume hood face velocity**
- **Factors to consider in locating fume hoods**
- **Manifolding fume hood exhausts**
- **High performance fume hoods**
- **Biological safety cabinets (BSC) using recirculating air where possible**
- **Fume hood and biological safety cabinet operator/user education**

Approach

Perhaps the most significant design decision impacting fan energy in a laboratory is to implement a variable air volume (VAV) exhaust system, as opposed to a constant air volume (CAV) system. While CAV systems are simpler to design and control, and may be the most cost-effective control method for facilities driven by high ventilation loads, the significant fan energy savings from VAV supply and exhaust systems generally outweigh any increased design or control complexity.

CAV Fume Hoods

Fume hoods have traditionally been designed as CAV devices. This means the design (maximum) air volume flows through the supply and exhaust systems every hour of the year. This control scheme not only results in much higher fan energy than a VAV system, but much higher heating and cooling energy to condition the high volumes of outdoor air. Implementing a VAV system immediately captures the significant fan, heating, humidity control and cooling energy savings for laboratories not driven by high ventilation rates. Air flows can be matched to the exact volumes needed for ventilation (minimum ACH), heating, and cooling, as opposed to the maximum air volume at all times. In addition, capital cost savings can be realized by the ability to implement a diversity factor and optimally size systems for expected use patterns instead of assuming all hoods will be used at all times.

One concern with CAV hoods is maintaining the proper hood face velocity. With the hood sash in the full open position, the design face velocity (generally on the order of 100 fpm) is maintained. But as the hood sash is lowered by the user, this face velocity will increase, often to levels that are unsafe for the user. To mitigate this, CAV hoods are generally equipped with bypass air openings (drawn from the area immediately outside the hood) to help maintain the proper face velocity through the hood. Still another method is to duct bypass air directly to the hood. These are known as auxiliary air hoods. While these methods help somewhat in maintaining a safe face velocity through the hoods, the ability to dynamically vary the air volume using a VAV system allows the volume to be matched to the sash height and maintain a relatively constant, safe face velocity through the hood regardless of sash position.

For laboratory facilities with air flow rates driven by high ventilation loads (i.e. air changes per hour), VAV fume hoods may not be cost effective since the ability to turn down the air flow may be limited by the high volumes of outside air for ventilation. For these facilities, CAV hoods may still be the best choice from a life-cycle cost perspective, but the high ventilation rates should be evaluated for necessity before the decision is made to design a CAV exhaust system.

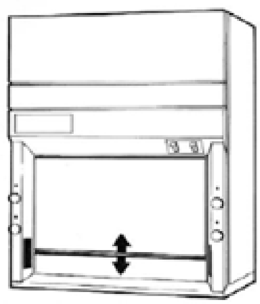
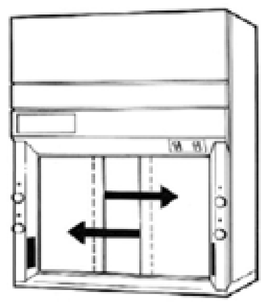
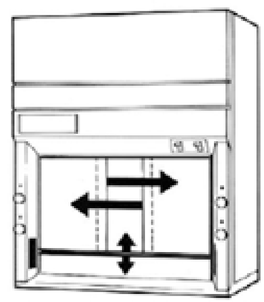
Two-Position Control

One method to reduce air volume at certain times (generally when the laboratory is unoccupied) is to use two-position control. This allows a high air flow during times when the lab is occupied and a reduced, but still safe, air flow when the space is unoccupied. When the lab is occupied, two-position fume hoods function essentially the same as CAV hoods in that they move the maximum (design) air flow at all occupied times. But during times when the lab is unoccupied, a reduced air volume can be used to maintain a lower-than-occupied face velocity, resulting in energy savings. Implementing two-position control also requires the HVAC system to have the ability, either using two-speed fan motors or a variable frequency drive (VFD), to reduce the flow to the lower volume. Implementing a two-speed fan motor control requires submitting a variance request to Cal/OSHA unless the system is controlled to the active sash position.

VAV Fume Hoods

Fume hoods employing variable air volume (VAV) have many advantages in laboratory facilities not driven by high ventilation air volumes. VAV control is appropriate in labs with supply air volumes driven by fume hood makeup air or cooling loads. Besides the inherent energy savings resulting from moving and conditioning lower volumes of air, VAV hoods are also able to maintain a safe hood face velocity regardless of sash position. This prevents potentially dangerous turbulence at the hood that can result from significant deviation from the proper face velocity set point.

Realizing the savings from VAV fume hoods requires proper user education to lower the sash to a minimum position when the hood is not in use. If users leave sash heights at maximum even when the hood is not in use, the hood will function essentially as a CAV system. Only when the sash is lowered can the exhaust volume be reduced and energy savings realized. In response to poor sash management, several laboratories have introduced automated sash closure systems. The installation of an automatic sash closure system on a VAV hood that is controlled by an occupancy sensor has the potential to reduce airflow through fume hoods by 75%. In an effort to maintain 100 fpm face velocity, fume hood designs have been developed to simply reduce/restrict the sash opening and thus save air/energy. The two most popular techniques are horizontal sliding sashes and sash stops.

From Left to Right
Figure 5.02
Hood with vertical-rising sash

Figure 5.03
Hood with horizontal-sliding sashes

Figure 5.04
Hood with combination "A-style" sash
(Source: PG&E Emerging Technologies Program)

Horizontal sliding sashes are used to restrict the fume hood opening and protect the user. In theory these sliding sashes cannot be opened all the way but two (or more) can overlap, creating an opening. Some users feel the sashes get in the way and remove them (not a safe or efficient option). Some horizontal sashes offer another spill protection setup using three pieces of horizontal glass. In this arrangement, one pane of glass remains in-front of the lab operators body at all times with arm access on either side of this middle pane. Some laboratories, with strong sash management cultures, have successfully used this technique.

Figure 5.05
Hood with combination "A-style" sash.
(Source: PG&E Emerging Technologies Program)

Sash stops prevent the sash from opening all the way. Usually the stops are placed at 18" thus blocking the top two fifths of the opening. In most cases the stops are designed for easy override to lift the sash out of the way during setup. Systems designed for the 18" opening violate Cal/OSHA standards when the sash stops are bypassed. A laboratory culture that assures bypass only when hazards are not present is needed. Sash stops "encourage" diversity in VAV hoods (at least the hood is partially closed – 2/5ths or more – most of the time).

Manifolding Fume Hood Exhaust

One simple measure that can reduce ductwork pressure drop (and costs) is to manifold fume hoods. Combined with the use of a VAV fume hood system, connecting the hoods to a common exhaust duct results in significant energy savings by taking advantage of operational diversity. Manifolding exhaust is also essentially a prerequisite for both an energy recovery system and the most efficient exhaust fan and stack options. When designing an exhaust stack, one of the main goals is to ensure the right dilution factor down-wind of the building. This is a function of ensuring the right exit velocity of the air and the amount of contaminants in the exhaust stream. By manifolding fume hoods, the system can reduce the amount of total exhaust air required at any one moment since fume hood spills typically occur independent of one another and by the time the air reaches the stack, the dilution is well within safety requirements. A manifold system is also typically less expensive to construct and maintain than a configuration with a separate fan for every hood.

Design Considerations

Reducing fume hood face velocities must be considered in the context of factors such as: the hood's location in the laboratory, the location of work inside of the hood, and throw velocity of the supply air diffusers.

Supply grilles, opening doors, and traffic paths within the laboratory present a "Room Air Challenge" that must be considered by the engineer who wishes to apply recommended face velocity values of 100 fpm (or less when unoccupied). Normally, the engineer specifically selects supply air diffusers to cause mixing in the room that will establish adequate temperature distribution. However, in laboratories this mixing action interferes with the fume hood exhaust air flow, negatively affecting the hood performance. Supply diffusers must not blow directly at the fume hood face unless they have a throw velocity of only one-half to
two-thirds of the hood's face velocity. Even lower throw velocities are advisable to maximize fume hood performance.

Increased hood face velocity has a more beneficial effect for a "poor" supply system than for a "good" supply system. Consequently, for equal hood working space and equal protection, a well-designed supply system permits lower hood face velocities and hence lower energy consumption. In California, to operate a fume hood below 100 fpm, the building must apply for a Cal-OSHA Variance to prove safety requirements are met at the lower speeds.

Perforated ceiling panels provide better supply system than grilles or ceiling diffusers in that the system design criteria are simpler and easier to apply and precise adjustment of fixtures is not required. Ceiling panels also permit a greater concentration of hoods than do wall grilles or ceiling diffusers.

Several high performance fume hoods (safe and low flow) are on the market (outside of California). They offer advantage (over VAV) of simplicity (generally constant volume), lower peak requirements, safety, and the ability to downsize the mechanical/electrical systems (no diversity assumptions required). There is a major institutional barrier to high performance hoods in California where Cal/OSHA requires hoods to have 100 fpm face velocity. First generation hoods have achieved a 20 to 40% savings, whereas second generation hoods have reached 40 to 75% savings. Second generation high performance fume hoods are similar to the first generation, but with lower flow requirements to provide the same level of safety. The "Berkeley Hood" is the only known second generation high performance hood under development. While it may be possible to reach the 75% savings solely with a second generation high performance hood, it may be easier (technically and from a cost standpoint) to achieve this result with a hybrid hood system (combining high performance with control options).

The new Santa Clara County District Attorney's Crime Laboratory installed approximately 50 variable air volume fume hoods. This efficiency measure takes advantage of the building's cascading air pressure system to direct airflow. This measure alone has saved the crime lab nearly 80,000 kilowatt hours and more than 50,000 therms of heat annually, reducing energy costs by more than $50,000 a year.

Biological Safety Cabinets

Biological safety cabinets (BSCs) require different considerations than fume hoods. BSCs are constant-volume devices, and must be set and operated within close tolerances. For some cabinets this may represent an airflow tolerance of as little as 15 cfm. Biological safety cabinets reduce hazards by three methods: isolation of the biohazard to an identifiable area, containment of the biohazard, and removal of the biohazard from the exhaust air stream.

BSCs vary in requirements for product and people protection. At one end, BSCs are designed to only protect the products they store. At the other end of the spectrum are BSCs that protect both the product and the people tending to them.

- **Class I BSCs utilize airflow to protect the user from hazards in the cabinets. Class I BSCs supply the product with HEPA-filtered air and either exhaust the air into the space or out through the exhaust.**

- **Class II BSCs use tightly balanced airflow to protect the user and environment, and product by means of a physical barrier, i.e., an enclosed box where the product inside is manipulated with attached "rubber" gloves. Class II biological safety cabinets are most frequently utilized in biomedical laboratories. Class II BSCs recirculate 70% of the air inside them. The remaining 30% is either exhausted through HEPA back into the room or outside through a thimble unit.**

- **Class III BSCs supply "once-through" air that is exhausted through a hard-duct exhaust. This system provides for protection of the user and the products it stores. However, this system results in a much higher pressure drop than the other BSCs, adding 1 inch w.g. in some situations.**

From an energy efficiency standpoint, it takes significantly less fan energy to operate a recirculating biological safety cabinet (RBSC) than a "once-through" system. In the "once-through" system, air flows into the BSC from the surrounding lab space, to be immediately exhausted from the building. In the recirculating case, air is passed over a HEPA filter (or other appropriate filter depending upon the hazardous substances contained in the BSC), to either be recirculated within the cabinet, or returned back into the lab space.

Recirculating BSCs reduce the amount of outdoor makeup air required to supply the BSC, which translates directly into heating and cooling energy savings. A small fan power penalty may be incurred to compensate for the HEPA filter, but this is almost always outweighed by the energy savings resulting from the need to condition considerably less ventilation air.

Benchmarking Findings/Case Studies

Biotech Case Study – PG&E Incentives Support Construction of Efficient Biotech Research Facility

A laboratory building on the Elan Corporation (a biotechnology research and development company) campus in South San Francisco, California has incorporated into their system, a unique ventilation system. Elan has dramatically reduced its energy requirements by deploying a customized Phoenix air valve system for its laboratory hoods. When the hood sash is closed and less air is being drawn, the Phoenix valve automatically reduces the exhaust fan speed to a lower rate. Elan has customized dual-direction sashes that can be opened and closed horizontally as well as vertically. Lab researchers are trained to maintain the smallest possible opening which is an issue emphasized in the facility's annual lab safety meetings. It has been estimated that the facility has reduced its laboratory energy use by a remarkable 50% with this measure alone.

Related Chapters

- Chapter 1: Optimizing Ventilation and Air Change Rates
- Chapter 2: Low Pressure Drop Design
- Chapter 6: Right-Sizing for Equipment Loads
- Chapter 8: Metrics and Benchmarks for Energy Efficiency in Labs
- Chapter 9: Optimize Exhaust Systems

References

- Labs 21 Best Practices, "Low-Pressure-Drop HVAC Design for Laboratories," http://www.labs21century.gov/pdf/bp_lowpressure_508.pdf
- Labs 21, "A Design Guide for Energy-Efficient Research Laboratories," http://www.labs21century.gov/toolkit/design_guide.htm
- Lawrence Berkeley National Laboratory, "A Design Guide for Energy-Efficient Research Laboratories – Room Air Challenge," http://ateam.lbl.gov/Design-Guide/DGHtm/roomairchallenge.htm
- Lawrence Berkeley National Laboratory, "A Design Guide for Energy-Efficient Research Laboratories – Room Airflow Recommendations," http://ateam.lbl.gov/Design-Guide/DGHtm/roomairflowrecommendations.htm
- Lawrence Berkeley National Laboratory, "A Design Guide for Energy-Efficient Research Laboratories – Biological Safety Cabinets," http://ateam.lbl.gov/Design-Guide/DGHtm/biologicalsafetycabinets.htm
- Pacific Gas and Electric Company Emerging Technologies Program Application Assessment Report 0607, "Automatic Fume Hood Sash Closure"
- PG&E Biotech Case Study, "Elan: Designing Energy Conservation – PG&E Incentives Support Construction of Efficient Biotech Research Facility."
- PG&E Biotech Case Study, "Santa Clara County Crime Lab: PG&E Helps Crime Lab Clue in on Energy Savings."

Resources

- ASHRAE Journal, September 2008, "HVAC Design for Sustainable Lab,"http://www.ashrae.org/members/doc/ASHRAEDAJ08Sep0120080828_8090903.pdf
- Labs 21 Case Studies: http://www.labs21century.gov/toolkit/case_studies.htm

6. Right-Sizing for Equipment Loads

Introduction

Laboratory equipment such as autoclaves, glass washers, refrigerators, and computers account for a significant portion of the energy use in laboratories. However, because of the general lack of measured equipment load data for laboratories, designers often use estimates based on "nameplate" rated data, or design assumptions from prior projects. Consequently, peak equipment loads are frequently overestimated. This overestimate results in oversized HVAC systems, increased initial construction costs, and increased energy use due to inefficiencies at low part-load operation. This chapter first presents the problem of over-sizing in typical practice, and then describes how best-practice strategies obtain better estimates of equipment loads and right-size HVAC systems, saving initial construction costs as well as life-cycle energy costs.

Principles

- **Equipment load measurements from various laboratories showed that peak equipment loads are significantly overestimated. Evidence from laboratory designers and planners suggests this is not unusual and occurs widely in laboratory design practice.**

- **When designing a laboratory HVAC system, the use of measured equipment load data from a comparable laboratory can effectively support right-sizing HVAC systems, saving initial construction costs as well as life-cycle energy costs.**

- **Probability-based analysis provides a structured and logical way to derive diversity factors for equipment loads.**

- **The most common argument against right-sizing is the risk of under-sizing and determining who carries that risk.**

- **Right-sizing requires that owners and designers come to agreement on the basis for right-sizing and the associated risk management.**

Approach

HVAC systems are sized based on a peak condition that takes into account climate-related loads and internal loads from occupants, lighting, and equipment. For some of these parameters, there are well-established criteria for peak conditions (e.g., design days for climate), while for others, the designer has to use context-specific information (e.g., load diversity) and engineering judgment to determine a peak load. This is especially the case with equipment loads, for which there is uncertainty about several factors:

- **Quantity and type of equipment: While this is analyzed and documented by laboratory planners during the programming phase of design, the actual quantity and type of equipment installed will vary over the life cycle of the laboratory.**

- **Rated vs. actual power: For most equipment, the rated ("nameplate") power is much higher than the actual power, even when the equipment is in full operating mode.**

- **Schedule of use: Even if the designer has good estimates of the first two parameters, the schedule of use is very difficult to derive deterministically because it is largely driven by user behavior, and the complete inventory of installed equipment is typically not used simultaneously.**

The ASHRAE HVAC Applications Handbook 1999 recommends that the designer "...should evaluate equipment nameplate ratings, applicable use and usage factors, and overall diversity." However, due to the lack of data on these parameters, it is often difficult to analytically derive the equipment loads. ASHRAE indicates that heat gains in laboratories range from 5 W/ft^2 to 25 W/ft^2, but there is no additional data that would narrow this range for use in the design of a specific laboratory. As a result, designers typically assume the worst case for each of these parameters, thereby grossly overestimating actual equipment loads. Furthermore, designers assume that the worst-case equipment load will be simultaneous with the worst-case climate loads. In short, conventional engineering methods chronically over-size HVAC systems. Brown [2002] cites several examples including one where even after the size of the cooling plant was halved the as-installed plant still had twice the capacity needed to meet the actual loads of the fully occupied building. An analysis of 26 laboratory projects by Martin [2004] showed that the over-sizing of cooling systems in these projects ranged from 40% to 300%, with an average of about 80%.

Data from the Labs21 benchmarking database provides further insight. The database contains data on energy use and demand for about 70 laboratory facilities. Figure

6.01 shows the total electrical demand for the facilities for which measured peak demand data were available. The facilities include various types of laboratories in several different climate zones. The data show that none of the facilities have total peak electrical loads of more than 15 W/ft^2. Note that this metric includes all electric end uses, i.e., HVAC, lighting, and equipment. Yet, it is common for designers to assume equipment loads alone at 10 - 12 W/ft^2 or more. While this assumption may be appropriate for a few high-intensity lab spaces in a building, it would be unreasonable to assume such high loads building-wide.

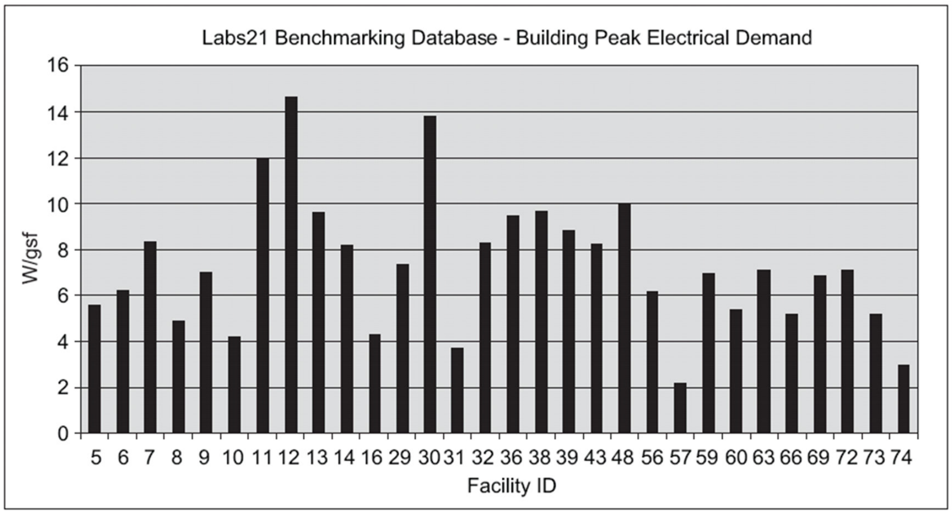


Figure 6.01
Total electrical demand (W/ft^2) for various laboratory facilities recorded in the Labs21 energy benchmarking database.
(Source: Labs 21)

Best Practice Strategies

1. Measure equipment loads in a comparable lab

The Labs21 Environmental Performance Criteria has a credit for right-sizing that recommends the following approach:
"...For each comparable laboratory space, obtain one week (7 days) of continuous power metering at a distribution panel level of all laboratory equipment, including plug loads and hard-wired equipment....metering data should be obtained while the spaces are fully occupied. Continuous metering data should be time averaged over 15 minute time periods. Design heat load criteria for each typical laboratory space in the facility should then be based on the maximum load indicated over the metering period...."

It should be noted that this approach represents a minimum requirement, and longer periods of measurement, or more detailed measurements may be required for specialized situations.

Measurements can be made easily with commercially available data loggers. PG&E offers loan of data loggers to its customers through its Pacific Energy Center Tool Lending Library. The usual configuration has the current transformers (CTs) and voltage connections inside the panel, and the actual logger outside the panel. This requires the wires to run out through a partially closed door. Most authorities allow this configuration for temporary connections, and typically no special provision needs to be made for it (the CTs and voltage connections coexist with what is already in the panels).

In the design for the new Molecular Foundry laboratory at Lawrence Berkeley National Laboratory (LBNL), measured loads were used to right-size HVAC and process cooling equipment, resulting in reductions in mechanical system sizing of over 30%, electrical transformer and distribution sizing of over 35%, and standby generator sizing of 20% (reductions are relative to the base case, which used estimated loads).

2. Use a probability-based approach to assess load diversity

This approach uses a probability analysis to derive design loads based on the probability of simultaneous peak use of equipment. It is essentially a "bottom-up" approach to calculating diversity. While the depth and rigor of the analysis can vary, the approach essentially involves the following steps:

- **For each type of heat source in a space, determine the number of sources and their peak outputs. This could be based on actual pieces of equipment, or the number and type of electrical and other outlets (as a proxy for equipment heat output). This information is often available from the programming documents.**

- **For each type of heat source in a space, determine the likelihood that it will be used. These data are typically obtained empirically through measurements or surveys.**

- **Use probability formulae or other statistical techniques to calculate the peak simultaneous load for the space, using the parameters described above for each heat source.**

A major benefit of this bottom-up approach is that it provides a structured and logical way to calculate diversity factors for different levels of aggregation; i.e., as the number of pieces of equipment increases, a greater diversity can be assumed. For example, a building with 200 fume hoods can assume much more diversity than one with 20 fume hoods.

A more detailed description of this approach is provided by Martin [2004], who estimates the cost of probability analysis to be about $0.50/ft². This is easily offset by the savings from right-sizing, which are conservatively estimated at about $7.50/ft² for HVAC and piped utilities in laboratories.

Figure 6.02
LBNL replaced two boilers with 11 modular boilers to maximize part-load efficiency.
(Source: LBNL)

3. Allow for flexibility and growth, especially in the distribution systems

HVAC systems should be right-sized and configured to allow flexibility and growth. In the "plant", this will require provision of access and space for new equipment. For example, the initial design may call for three chillers with the potential to add two more. In the distribution systems, shaft and ceiling space should allow for future expansion at a minimum. Additionally, passive components such as ducts, pipe, and wiring, should be sized for the maximum potential loads. Increasing the capacity of these systems as a retrofit is extremely costly and often inefficient. On the other hand, the incremental cost for extra carrying capacity in new construction is minimal, and provides significant flexibility in the future. Furthermore, if the load does not materialize, the reduced pressure drops and resistances result in improved energy efficiency. There are also first-cost savings in the active components (pumps, fans, and their motors; starters or variable-speed drives; and the electrical distribution system).

4. Compare design loads with most-likely maximum (MLM) loads

Traditional design loads are chronically overestimated because designers assume that the worst-case equipment load will be simultaneous with the worst-case climate loads, while allowing large margins of safety and little consideration of diversity. One way to assess the potential for right-sizing is to compare the design loads to the "most likely maximum" (MLM) loads. This approach was developed and used in right-sizing the central plant at the new University of California, Merced campus.

To avoid over-sizing the central plant for the new campus, the owner used measured benchmark data from other campuses to right-size the plant. Instead of just using design values that assume a worst-case estimate, a "most likely maximum" (MLM) load was also determined, based on the actual measured maximum loads in comparable buildings. Design for efficient operation at MLM load can be mandated, and the difference between the MLM and the design loads can be value-engineered to reach a reasonable margin of safety for each subsystem.

During the early design phase of the Li Ka-Shing Center for Biomedical and Health Sciences on the UC Berkeley campus, an estimate was developed of actual cooling loads that would be required in the labs. Careful study of the current energy usage in existing lab facilities established a realistic baseline for the internal loads of new labs that was considerably lower than conventional lab design standards. LBNL's "right-sizing" policies and studies of safe ventilation rates in lab spaces established credibility for this decision. This step in the design process contributed to a projected 33.7% less energy than the California Energy Code (Title 24) baseline.

5. Configure equipment for high part-load efficiency

Plant equipment, including fans, pumps, chillers, and boilers, should be configured for high efficiency even at very low part-loads. Even if the equipment has been right-sized for the peak load, the load fluctuates widely, and the equipment operates at low part-loads many if not most hours of the year. Therefore, it is advisable to design the system for high efficiency at low loads. One solution is a modular plant design,

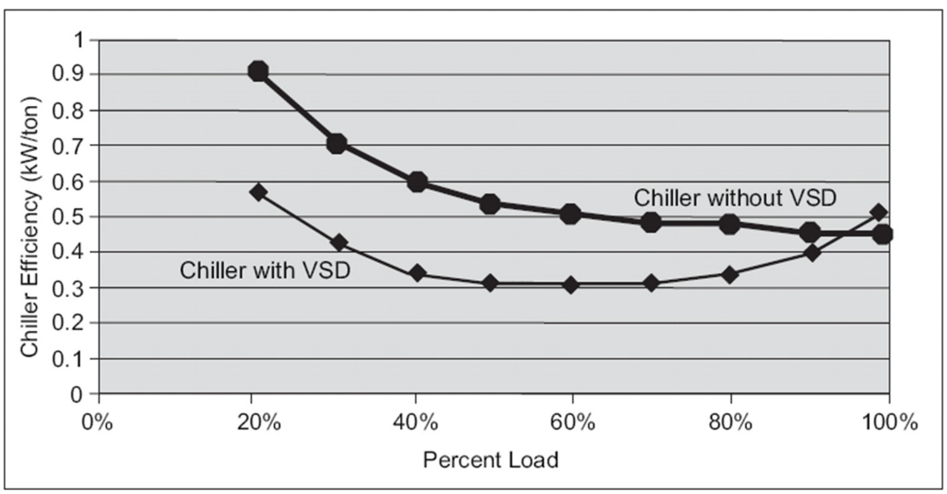


Figure 6.03
Data provided by York International Corp. for chillers running at 42°F chilled water supply and 65°F condenser water supply
(Source: Created by Integral Group using York Data.)

where only the number of units that are needed, run. The design can accommodate increases in the load by adding modules. For example, at LBNL, two large, aging boilers with high mass and high standby loss were replaced by eleven modular low-mass boilers (Figure 6.02). Thus far, no more than seven of these have been required to meet peak loads. Plant designs with multiple modular primary components and optimized lead-lag logic programs will increase run-time hours at or near the peak efficiency of each primary component as compared with plant designs with one or two primary components for each major system, thereby increasing the average plant efficiency.

Another common strategy to maximize efficiency is to use variable-speed drives on equipment that operates at part-loads. Figure 6.03 shows the energy use impact of variable-speed drives on chiller operation for various part-loads. Fan and pump applications typically show even greater savings.

6. Negotiate risk management between owner and designers

The most common argument against right-sizing is the risk of under-sizing and the question of who carries that risk. As many design engineers have observed, the legal and contractual basis for design services rarely rewards right-sizing, and almost certainly will penalize under-sizing. Right-sizing requires that owners and designers come to an agreement on the basis for right-sizing and the associated need for risk management. This requires a shared understanding and agreement on parameters such as peak occupancy characteristics, laboratory equipment loads, and load diversity assumptions. Designers should provide owners with information on the first-cost and operating-cost penalties for different degrees of over-sizing so that owners can make an informed decision on the tradeoffs.

7. Include energy efficiency in the procurement process

By incorporating energy efficiency criteria into the equipment procurement process, owners can reduce equipment loads and obtain better estimates of actual equipment energy use. Furthermore, they, and especially high-volume purchasers, can create a market "pull" to develop more energy-efficient laboratory equipment. For example:

- **Where available, specify EnergyStar™ equipment. Many of the refrigerators and computers used in laboratories are standard commercial products for which EnergyStar™ choices are available. EnergyStar™ also provides energy use information that can be used to estimate total loads.**

- **For equipment types that do not have a rating system such as EnergyStar™, request energy use information from manufacturers. At a minimum, this should include energy use for three operating modes: peak mode, typical (nominal) mode, and dormant ("sleep") mode. This information can be used to compare the energy use of functionally equivalent options, as well as to estimate total loads.**

Stanford University conducted a survey of their laboratory refrigerators and found a significant opportunity to reduce energy use and peak demand. Stanford then decided to include energy efficiency as a criterion in procuring laboratory refrigerators, and required suppliers to provide energy use data in their bids.

Case Study: Measured vs. Estimated Loads

The University of California, Davis (UC Davis) initiated a project to measure equipment loads at two of its laboratory buildings in order to use the measured data as a basis for sizing the HVAC systems in the design of new, comparable facilities. In each building, measurements were made for several laboratory spaces, representing a range of different uses within that building. Clamp-on meters were used to take continuous measurements of equipment electrical loads for each lab space. Each measurement period was typically about two weeks long. The measurements were taken when the labs were nominally fully occupied and used. Three quantities were measured, as follows:

- **Apparent instantaneous power: The product of the voltage and the current at any given instant. This number is important because it informs the sizing of the electrical distribution system.**
- **Actual instantaneous power: This is the actual instantaneous power draw, which becomes a thermal load to the space.**
- **Average interval power: This is obtained by averaging the actual instantaneous power over each 15-minute interval. This quantity is typically measured by utility interval meters to determine demand charges.**

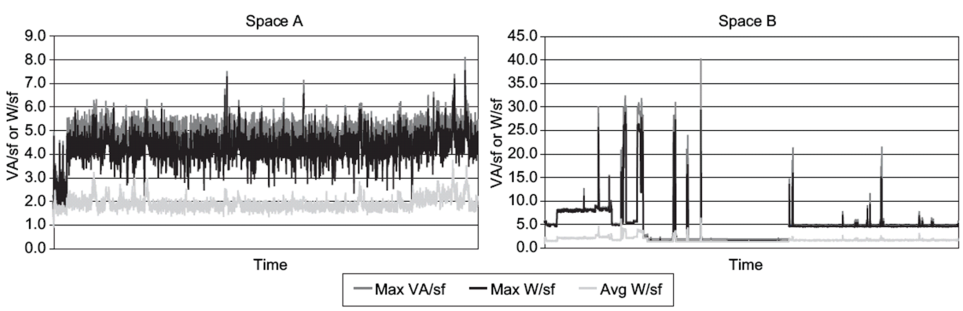
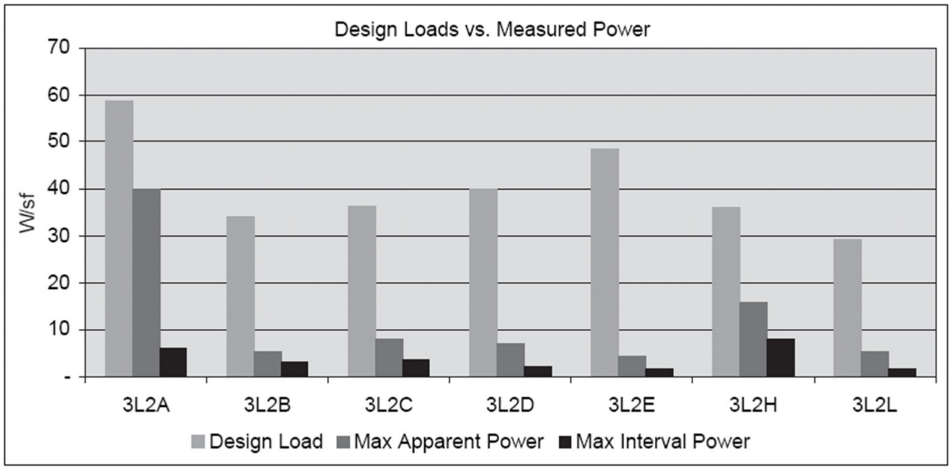


Figure 6.04
Equipment load measurements for two UC Davis laboratories
(Source: Labs 21)

Figure 6.04 shows the 15-minute-interval measured data for two laboratory spaces, each of which was measured twice (about four weeks total for each space). The figure shows the peak apparent instantaneous power (VA/ft^2), peak actual instantaneous power (W/ft^2) and the average interval power for each 15-minute interval (W/ft^2). As expected, in each interval the peak apparent power is always equal to or higher than the peak actual power, which in turn is always higher than the average interval power. The ratio of actual power to apparent power is the power factor, which is always less than or equal to 1. In space A, the overall peak apparent power is about 8 VA/ft^2, and the overall peak actual power is about 7.5 W/ft^2. The maximum interval power is only about 3.75 W/ft^2, which is less than half the overall peak apparent power. In space B, the overall peak apparent power is about 40 VA/ft^2, and the overall peak actual power is about 29 W/ft2, while the maximum interval power is about 6 W/ft2, which is only 15% of the overall peak apparent power.

Figure 6.05
Comparison of equipment power for various UC Davis laboratory spaces



Generally, space temperatures are not sensitive to instantaneous peaks of a few seconds; therefore, it is unnecessary to size HVAC systems to peak instantaneous power. The only exception to this would be in highly specialized labs with equipment, processes, or instrument calibration requirements that require space temperatures to be very tightly controlled. In most situations, it is more appropriate to size HVAC systems to the maximum interval power. However, it is not uncommon for designers to assume equipment loads that even exceed the peak instantaneous power. Figure 6.05 compares the measured loads to the assumed design loads for several different laboratory spaces in one of the buildings at UC Davis. This shows that the design assumptions were 2 to 5 times the peak instantaneous power, and were a whole order of magnitude above the maximum interval power. Evidence from laboratory designers and planners suggests this is not unusual and occurs widely in laboratory design practice. It is important to note that the sizing approach for electrical systems is different from HVAC systems. The electrical designer is more constrained by the National Electrical Code, and other code and safety constraints. HVAC designers have much greater latitude in their approach to sizing. HVAC constraints are largely self-imposed, consisting primarily of the "code of common sense" and the risk of liability.

Related Chapters

- Chapter 8: Metrics and Benchmarking for Energy Efficiency in Labs
- Chapter 11: Power Supply and Plug Load Efficiency

References

- ASHRAE [1999]. HVAC Applications Handbook 1999. American Society of Heating, Refrigerating and Air-conditioning Engineers. Atlanta, Georgia.
- Brown, K. [2002], "Setting Enhanced Performance Targets for a New University Campus: Benchmarks vs. Energy Standards as a Reference? Proceedings of the 2002 ACEEE Summer Study of Energy Efficiency in Buildings." ACEEE, Washington, DC.
- Enermodal and NREL [2003], "Laboratories for the 21st Century Energy Analysis," accessed October 2010 at: http://www.labs21century.gov/toolkit/case_studies.htm
- Labs21 [2005], "Labs21 Environmental Performance Criteria version 2.1," accessed October 2010 at: http://www.labs21century.gov/toolkit/epc.htm
- Martin, J. [2004], "Filling a Scientific Void in Laboratory Planning and Design. A Case for Probability Based Analysis," Syska Hennessy Group, San Diego, CA.
- Mathew, P., D. Sartor, O. Van Geet, S. Reilly [2004], "Rating energy efficiency and sustainability in laboratories: Results and lessons from the Labs21 program, Proceedings of the 2004 ACEEE Summer Study of Energy Efficiency in Buildings." ACEEE, Washington, DC.
- Wilkins, C.K. [1998], "Electronic Equipment Heat Gains in Buildings. ASHRAE Transactions." 1998, V. 104, Pt. 1. Atlanta, Georgia: American Society of Heating, Refrigerating and Air-conditioning Engineers.
- Wilkins, C.K., M.H. Hosni [2000], "Heat Gain from Office Equipment, ASHRAE Journal." 42:6:33-44.
- PG&E Tech Brief, "Energy Efficient Laboratory Design." http://www.pge.com/includes/docs/pdfs/mybusiness/energysavingsrebates/incentivesbyindustry/biotech/ucberkeley_li_ka_shing.pdf

Resources

- Coogan, Jim [2008], "Constant Flow, Variable Flow, and All the Space Between," http://www.i2sl.org/elibrary/coogan2008.html

7. Commissioning

Introduction

Commissioning is the process of ensuring that systems are designed, installed, functionally tested, and capable of being operated and maintained according to the owner's operational and economic needs. Not to be confused with the typical equipment/system start-up procedures that are a matter of course for any construction project, commissioning as described in this chapter is intended to add a higher level of rigor and accountability to ensure that the systems are not just installed and started-up properly, but also to ensure that the building(s) and systems(s) are able to be properly calibrated, operated, and maintained well after construction is complete.

Commissioning principles can be applied to new construction and retrofits of existing buildings, but can also be applied to buildings and systems that have been in operation for years, whether or not they were originally commissioned. Often the commissioning of an existing building (or subsystem of a building) that was originally commissioned during design and construction is referred to as "re-commissioning", and the retroactive commissioning of an existing building (or subsystem of the building) that was never originally (or thoroughly) commissioned is referred to as "retro-commissioning." Finally, the most conscientious of facilities managers choose to engage in ongoing commissioning or "continuous commissioning" as it is generally called, which involves ongoing collection of system data to continually troubleshoot and ensure optimal operation and energy performance of the building and its systems.

Commissioning is also a prerequisite for any facilities applying for Leadership in Energy and Environmental Design (LEED) certification from the United States Green Building Council (USGBC). USGBC has a specific set of commissioning criteria, and even those facilities not attempting LEED certification tend to rely on this same framework.

Principles

- Setting commissioning goals and operational/performance requirements is most valuable in the earliest phases of the design process
- Pre-functional checklists assess a system's initial start-up, and help ensure equipment installation is completed as specified
- Functional testing ensures a system's operational control sequences are implemented properly
- Control system data trends can show areas where operational sequences can be improved
- Sensors and actuators should be regularly calibrated to help ensure that the controls system is operating as intended
- Diagnostic monitoring can help pinpoint particular performance issues, minimize energy use and maximize efficiency
- Commissioning processes can be applied to new construction, retrofits of existing buildings, and as a tool to troubleshoot operational and energy performance for existing systems
- Facilities dedicated to ongoing optimization of building systems apply commissioning processes and techniques on a continuous basis

Approach

Commissioning Overview

To ensure accountability and avoid conflicts of interest, a third-party commissioning agent is generally contracted, usually by the building owner or architect. This commissioning agent should have expertise in the design and analysis of energy-using building systems and controls. It is generally best to contract the services of the commissioning agent as early in the design as possible to ensure a valuable commissioning process. In general, the process involves:

- An initial commissioning plan
- Documenting the building owner's functional and performance requirements
- Review of the basis of design
- Review of design documents to ensure the owner's functional and performance requirements will be met

- Scoping and commissioning meetings throughout the design process
- Revision of the commissioning plan as needed throughout the design process
- Review of equipment submittals and operations/maintenance documentation
- Pre-functional checklists and testing
- Functional performance testing
- Operations and maintenance training of facilities personnel
- A commissioning report and systems manual for re-commissioning and continuous commissioning
- Seasonal testing
- Post-occupancy warranty review (approx. 1 year after occupancy)
- Ongoing/continuous and re-commissioning

A commissioning plan that begins in the earliest stages of a project can lead to a more orderly and effective succession of events. A detailed design document, the commissioning plan reflects agreements among all parties as to the valid requirements of the project that will shape later commissioning: equipment choices, such as the design opening of hoods, and performance criteria, such as average face velocity, speed of response, stability, and containment. User needs, safety / risk assessments, and environmental and energy performance requirements all fit into the mix, expressed in a set of construction drawings, a bidding package, and a well-defined commissioning plan.

Design and equipment/system documentation review is of paramount importance to a thorough commissioning process. These reviews, generally undertaken by the commissioning agent, are intended to identify system functional and performance deficiencies during the design phase while there is still time to make necessary revisions. This begins with documenting the basis of design in the pre-design/programming phase, and continues throughout the design and construction process to include review of design documents, equipment submittals, sequences of operation and control, and operations, maintenance, and training documentation.

Pre-functional checklists are generally written by the commissioning agent and carried-out by the installing contractors. The primary value of the pre-functional checklists is to ensure that the systems are prepared for functional performance testing, meaning equipment has been installed properly, sensors and actuators are calibrated, and control algorithms are programmed and ready to be functionally tested.

Functional tests are also generally written by the commissioning agent, carried-out by the controls contractor and installing contractors, and witnessed by the commissioning agent. These functional tests are designed to take the systems and equipment "through its paces," testing operational sequences under the range of expected loading and weather conditions. Deficiencies in operation or performance are noted, and the commissioning agent documents the testing process, noted deficiencies, and their resolution.

The functional testing, while it seeks to ensure proper operation, can also uncover energy performance issues that may be missed without a rigorous review of the operation and controls. Some typical causes of energy waste in labs include, but are not limited to:

- **Underutilized fume hoods**
- **Inappropriate hoods or exhaust devices**
- **Unnecessary reheat; either in the lab space or at the central heating/cooling plant**
- **Positive pressure in hazardous containment labs**
- **Pressure tracking for lab space isolation: offset is too great, or is not monitored or controlled**
- **Excessive duct static pressure**
- **Over-ventilated lab spaces**
- **Response time of flow tracking/modulating device for fume hood or supply and general exhaust system that leads to over- or under-shooting set points**
- **Supply air temperature overshoot or undershoot: can upset fume hood containment. Can cause surges in airflow volume that sends system into an unstable, "hunting mode."**

- **Lack of load management within lab space. Determine profile of use by apparatus in lab space to determine potential to shift operations to more even loading**

- **Poorly functioning energy recovery system**

- **No unoccupied setback of temperature or airflow**

- **Fans operating in override position, i.e., in "hand" rather than "auto" position.**

- **Dampers in fixed positions**

- **Fume hoods with large bypass openings**

Re-/Retro-Commissioning of Existing Buildings and Systems

Unless a building (or subsystem of a building) is continuously commissioned through the use of ongoing control system trend review and analysis, it is highly recommended that re-commissioning/retro-commissioning be undertaken on a regular basis, such as every few years. For laboratory buildings, the need for regular review by environmental health and safety (EH&S) personnel, and energy managers, can complement this regular re-commissioning. In addition, personnel changes, lost documentation and "quick fixes" of system components and operation by busy facilities personnel can all contribute to degradation of system performance over time. For buildings and systems that were properly commissioned during construction, many of the same causes of energy waste in labs listed above can resurface in systems and buildings years after construction, even if they were properly commissioned at initial start-up.

Continuous Commissioning

It is difficult to effectively manage the operation and maintenance of a building and its systems, as well as the energy consumed by them, without continuous measurement, monitoring, and analysis. The concept of continuous commissioning ensures that, even if systems were shown to be operating optimally during initial construction, or after a comprehensive re-/retro-commissioning effort, they will continue to do so throughout the life of the building. Maintaining control system (and/or stand-alone measuring device) data trends of system parameters, implementing a regular program of sensor and actuator calibration, conducting surveys of building users, and periodically re-evaluating building loads and occupancy profiles are all integral parts of the continuous commissioning process. With the safety risks and high energy use associated with most laboratory facilities, continuous commissioning can serve to ensure on an ongoing basis that environmental, economic, and performance criteria are properly maintained throughout the life of the facility.

Benchmarking Findings/Case Studies

- California Commissioning Collaborative. "Sacramento County Coroner and Crime Laboratory."http://www.cacx.org/database/data/Sacramento_County_Coroner.pdf
- Federal Energy Management Program. (2004). "A Case Study on In-House Retrocommissioning at a DOE National Laboratory. "http://www1.eere.energy.gov/femp/pdfs/om_retrocx.pdf

Related Chapters

- Chapter 1: Optimizing Ventilation and Air Change Rates
- Chapter 3: Eliminating Reheat
- Chapter 4: Humidity Control
- Chapter 5: Fume Hood Optimization
- Chapter 8: Metrics and Benchmarks for Energy Efficiency in Labs
- Chapter 9: Optimize Exhaust Systems
- Chapter 10: Chilled Water Plant Optimization

References

- Labs21, U.S. DOE, U.S. EPA [2008],"Commissioning Ventilated Containment in the Laboratory"
- Labs21, U.S. DOE, U.S. EPA [2007], "Retro-Commissioning Laboratories for Energy Efficiency"
- LBNL, Rumsey Engineers [2009], "Commissioning: Data Center Energy Practitioner"

Resources

- Portland Energy Conservation, Inc. (PECI) - http://www.peci.org/
- United States Green Building Council (USGBC) - http://www.usgbc.org/
- California Commissioning Collaborative (CACX) – http://www.cacx.org/

8. Metrics and Benchmarks for Energy Efficiency in Labs

Introduction

Using metrics and benchmarks to 1) establish targets, 2) to monitor on-going performance (or progress towards achieving the targets), and 3) to verify performance is one of the most powerful means to optimizing building performance. The likelihood of a new or existing laboratory optimizing energy efficiency is dramatically improved if metrics, benchmarks, targets, & ratings are established and then continually referenced throughout the design, construction, and operations process.

Many federal, state, academic, and industry organizations use building level metrics to define a targeted level of energy efficient building performance. For example, Executive Order 13514 requires that all federal buildings entering the design phase after 2020 are designed to achieve net zero energy by 2030 (FEMP, 2010). Or, the United States Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) denotes that to earn all 19 Energy & Atmosphere Credit 1 points, a building must be designed to exceed ASHRAE Standard 90.1-2007 by 48 percent (USGBC, 2010). While regulators and third party certifiers rely mostly on building level metrics, building operators or design team members are more likely to use specific system level metrics. Granular system level metrics such as ventilation system fan power or plug load intensity are much more useful in identifying specific areas for design or operational improvement than are whole building metrics.

Benchmarks are defined as a particular value of a metric. A benchmark is often a function of lab type (e.g. chemical versus physical), lab area ratio (what percentage of the building is lab), and climate. Definitions for metric, benchmark, target, and label are provided here:

- **Metric: a unit of measure that can be used to assess a facility, system, or component; e.g., W/sf lighting power density (LPD).**

- **Benchmark: a particular value of a metric that denotes a level of performance; e.g., California Title 24 allows 1.3 W/sf for lighting in laboratory spaces.**

- **Target: a performance goal that may incorporate metrics or benchmarks; e.g. this project is targeting a lighting power reduction of 50% below California Title 24.**

- **Label: a third-party design or performance assessment that incorporates metrics and benchmarks to verify achievement of target(s); e.g. this project has achieved a LEED-NC v2.2. Gold rating or an Energy Star score of 92.**

Metrics, benchmarks, targets, and labels are a simple way to quickly understand and convey performance from both a whole-building perspective and a system perspective. This chapter focuses on different laboratory appropriate metrics and how to compute them. It also provides resources for how to implement the benchmarking process.

Principles

Key principles to consider when establishing or using metrics include:

- **Consider what metrics are most applicable to the project at hand.**

- **Determine what data is available and appropriate for benchmarking.**

- **Use metrics and benchmarks to set aggressive design and/or operational targets.**

- **Ensure the lab incorporates a building management system (BMS) and the correct metering hardware to enable long-term trending and to track progress towards achieving targets.**

Metrics & Benchmarks

Whole Building

Whole building energy metrics relate to the performance of the entire building. Commonly used metrics employ either numeric values (e.g. 342 kBtu/sf/yr) or are established relative to a baseline value (e.g. a 45% reduction from a baseline building energy model created using ASHRAE 90.1-2007 Appendix G). These metrics are useful in comparing laboratories with similar programming, and in similar climate zones. These metrics are not overly useful in identifying operational deficiencies or specific energy efficiency measures for individual buildings. Whole building metrics typically also determine the level or score for earning a building energy label or rating.

Building Site Annual Energy Use Intensity

This metric is the sum of the total site annual energy use per unit of gross building area. This metric is one of the most commonly used whole-building performance metrics, because the data required are usually easy to obtain from utility bills. However, it can be misleading because it does not account for the source energy for each energy stream.

Table 8.01:
Site Energy Use Intensity
(Source: Integra Group, Labs 21)

$$Site\ Energy\ Use\ Intensity = \frac{Site\ Annual\ Energy\ Use\ (kBtu)}{Square\ Footage\ (sf)}$$

PG&E Territory		
Standard	Good	Better
550	400	250

Building Source Annual Energy Use Intensity

This metric is the sum of the total source annual energy use per unit of gross building area. It is highly dependent upon the energy source factor for resources used in the building including electricity, natural gas, fuel oil, district steam, district hot water, and district chilled water.

Table 8.02:
Source Energy Use Intensity
(Source: Integra Group, Labs 21)

$$Source\ Energy\ Use\ Intensity = \frac{Source\ Annual\ Energy\ Use\ (kBtu)}{Square\ Footage\ (sf)}$$

PG&E Territory		
Standard	Good	Better
900	700	600

Building Annual Energy Cost Intensity

This metric is the sum of all energy costs use per unit of gross building area. Note that energy cost is a function of energy use, unit cost of energy, demand charges, and other utility charges that may not be directly related to energy use. Therefore, this metric is not a good indicator of energy efficiency potential i.e. a low-energy use building may have high energy costs because of high unit costs of energy.

Table 8.03:
Energy Cost Intensity
(Source: Integra Group, Labs 21)

$$Energy\ Cost\ Intensity = \frac{Annual\ Energy\ Cost\ (\$)}{Square\ Footage\ (sf)}$$

PG&E Territory		
Standard	Good	Better
8	6	4

Building Peak Electrical Demand Intensity

This metric is the peak electrical power demand per unit of gross building area. Note that depending on whether the facility is served by district utilities, the peak demand may or may not include demand due to electric chillers, etc. Therefore, this metric is only a coarse screen for overall demand reduction potential.

Table 8.04:
Peak Demand Intensity
(Source: Integra Group, Labs 21)

$$Peak\ Demand\ Intensity = \frac{Peak\ Demand\ (W)}{Square\ Footage\ (sf)}$$

PG&E Territory		
Standard	Good	Better
12.0	10.0	8.0

Sidebar –ASHRAE 90.1-2007 Lab Modeling Guidelines

Whole building metrics can be stated in absolute terms or as a percent reduction from a baseline value. Baseline values originate from either an energy model or a public or internal benchmarking database. ASHRAE Standard 90.1-2007 Appendix G is increasingly being used to create baseline energy models. Comparison or "proposed" models that reflect the actual building design are also created and the two models are then compared to generate the percent savings presented in any of the four whole building metrics described above.

While Appendix G is quite clear and stringent regarding some model inputs, it provides much less guidance on other topics, especially those critical to accurately modeling lab performance. Many challenges were addressed between the 2004 and 2007 versions of the 90.1 Standard, most notably those related to baseline HVAC system types and baseline fan power allowances. Two critical issues are not yet addressed in the 2007 version. Guidance on these two issues is provided from the Labs 21 "Laboratory Modeling Guidelines using ASHRAE 90.1-2007 Appendix G" document:

- **Modeling reheat and load diversity (Table G.3.1 No.4 Schedules): Accurately model the equipment load in each laboratory space instead of using an average across all spaces. See Appendix A of the Labs 21 guideline document for sample schedules.**

- **Supply-air-to-room air temperature difference (G3.1.2.8 Design Airflow Rates): For systems serving laboratory spaces, use a supply-air-to-room-air temperature difference of 17 deg F.**

While metrics based on ASHRAE 90.1 are useful for exploring design alternatives, many owners and designers are uncomfortable with the wide variability in modeling results. Some projects are now looking to define an explicit energy use target that the design should meet— which also serves as a reality check for the modeled results. In the case of office buildings, for example, owners can specify that they should be designed to earn an Energy Star label. However, Energy Star does not have a comparable rating system for laboratories. For labs, there are two non-energy modeling options for setting a target:

- **For organizations that have energy use data on a portfolio of laboratory buildings, targets could be set based on the range of energy use intensity across the portfolio.**

- **Based on the Labs21 energy benchmarking database.**

In both cases, the comparison set of buildings should have similar climatic context and lab-area ratio (ratio of net lab area to gross building area), or otherwise correct for these factors.

System Metrics

Ventilation – Minimum Required Ventilation Rate

Ventilation dominates energy use in most laboratories, especially chemical and biological laboratories. One of the key drivers of ventilation energy use is the minimum ventilation rate required for health and safety. The only exceptions to this are laboratories where the air-change rates are driven by thermal loads (and hence always exceed minimum ventilation rates for health and safety) or where very high fume hood density, typically greater than 1 square foot of hood work surface per 25 gross square feet of laboratory, drives the minimum flow.

Air-change rates should be benchmarked with the two metrics shown below.

Table 8.05:
Minimum laboratory ventilation rate: volume-based
(Source: Integra Group, Labs 21)

$$Air\ Changes\ Per\ Hour = \frac{Supply\ CFM * 60\ min}{Room\ Volume\ (cubic\ feet)}$$

PG&E Territory		
Standard	Good	Better
12	6	4

Table 8.06:
Minimum laboratory ventilation rate: area-based
(Source: Integra Group, Labs 21)

$$CFM\ per\ Square\ Foot = \frac{Supply\ CFM}{Square\ Foot\ (sf)}$$

PG&E Territory		
Standard	Good	Better
2	1	0.5

Table 8.07:
Number of fume hoods per unit of net laboratory area
(Source: Integra Group, Labs 21)

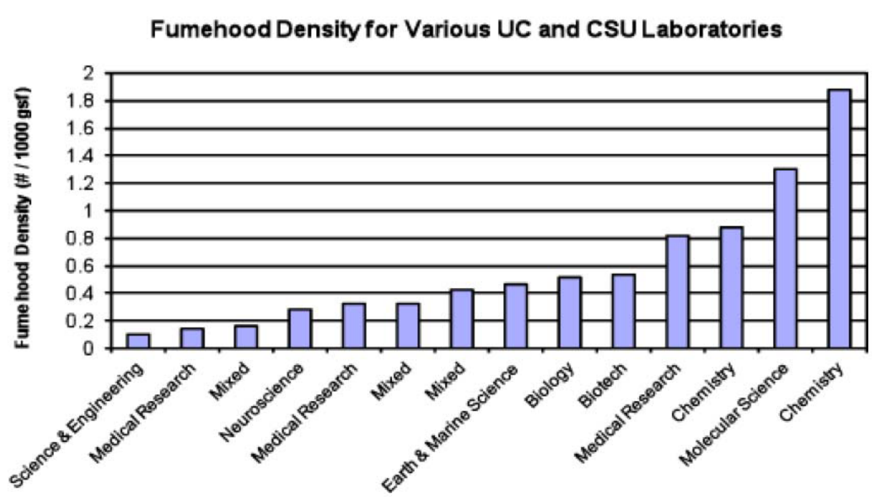
$$Fume\ Hood\ Density = \frac{\#\ of\ Fume\ Hoods}{1{,}000\ Square\ Feet\ (sf)}$$

PG&E Territory		
Standard	Good	Better
1.0	0.6	0.2

Ventilation – Hood Density

Fume hoods are prodigious consumers of energy and lab planners should work with owners to carefully avoid installing more and larger hoods than are necessary for programmatic requirements. Specifically, fume hoods should not be used for purposes that can be effectively met with lower-energy alternatives such as snorkels,

Figure 8.01
Fume hood density (#/1000 gross sf) for selected academic laboratories.
(Source: Integral Group, Labs 21)



balance hoods, and chemical storage cabinets. It is recommended that fume-hood density should be benchmarked with other labs that have similar programmatic requirements. For example, Figure 8.01 shows the range of fume-hood density (expressed as number of hoods/1000 gross square feet) in various laboratories in the University of California (UC) or the California State University (CSU) systems. Based on this chart, values higher than about 3 hoods/1000 gsf may present opportunities for optimizing the number of fume hoods.

Ventilation – Fume Hood Sash Management

Once the number and size of fume hoods has been optimized, the next major opportunity is to reduce fume hood energy use by reducing airflow through low-volume fume hoods and VAV hoods with effective sash management (a major retro-commissioning opportunity).

The fume hood sash management metric is the ratio of the average flow to the minimum flow, i.e., the flow through the fume hood when the sash is closed. Note that this metric is not applicable to constant volume fume hoods (which do not vary the airflow with sash position).

Figure 8.02 shows the impact of sash management training on airflow management ratios for a laboratory at Duke University, indicating a significant improvement in sash management as a result of the training and awareness campaign. The airflow with sash open was 650 cfm, and with sash closed was 340 cfm. Therefore, the airflow ratio if sashes were never closed would have been 1.91.

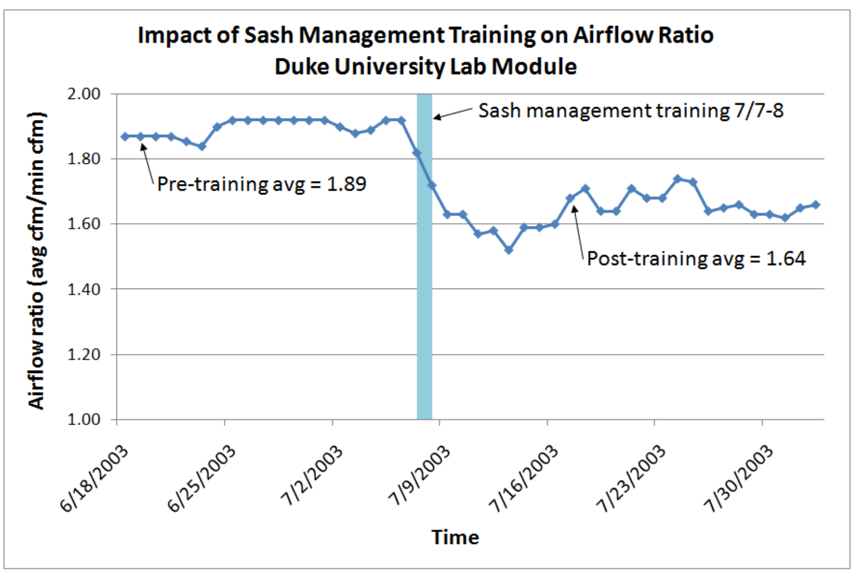


Figure 8.02
Impact of sash management.
(Source: Integral Group, Labs 21)

Table 8.08:
Fume hood airflow management
(Source: Integra Group, Labs 21)

$$Fume\ Hood\ Sash\ Management = \frac{Fume\ Hood\ Average\ Airflow\ (CFM)}{Fume\ Hood\ Minimum\ Airflow\ (CFM)}$$

PG&E Territory		
Standard	Good	Better
2.0	1.5	1.0

Ventilation – Airflow Efficiency

Ventilation airflow efficiency is typically the most significant way that HVAC design engineers can influence overall lab efficiency (besides reducing air flow rates). Each component in the supply and exhaust system can be optimized for low pressure drop. In addition to reducing the system pressure drop, the system fan efficiency can be improved by selecting efficient motors and fans.

Table 8.09:

Total system pressure drop

(Source: Integra Group, Labs 21)

$$Pressure\ Drop\ (in\ w.g.) = Supply\ (in\ w.g.) + Exhaust\ (in\ w.g.)$$

PG&E Territory		
Standard	Good	Better
8.0	4.0	2.0

Table 8.10:

Overall airflow efficiency

(Source: Integra Group, Labs 21)

$$Airflow\ Efficiency = \frac{Supply\ Fan\ Peak\ Power\ (W) + Exhaust\ Fan\ Peak\ Power\ (W)}{Supply\ Peak\ Airflow\ (CFM) + Exhaust\ Peak\ Airflow\ (CFM)}$$

PG&E Territory		
Standard	Good	Better
1.5	1.0	0.6

Cooling & Heating – Temperature & Humidity Set Points

Temperature and humidity set points in laboratory spaces are driven by human comfort and laboratory function (experimentation/equipment requirements). Laboratory users and planners sometimes call for tight tolerances based on laboratory function, without evaluating whether these are actually required. Tight tolerances can increase energy use due to reheat and humidification. It is recommended that tolerances tighter than those required for human comfort (e.g., based on ASHRAE Standard 55), be carefully evaluated and explicitly justified.

At the Global Ecology Center at Stanford, equipment requiring tight tolerances (70F +/- 1F) was grouped into a dedicated area so that other areas of the lab could be controlled to wider tolerances (73F +/- 5F) with some rarely accessed freezers and growth chambers actually relocated to a minimally conditioned adjacent structure controlled to 55F–95F.

Table 8.11:

Benchmarks for laboratory temperature setpoints

(Source: Integra Group, Labs 21)

$$Lab\ Temp\ Setpoint\ Range = Cooling\ SP\ (F) - Heating\ SP\ (F)$$

PG&E Territory		
Standard	Good	Better
2	5	10

Table 8.12:

Benchmarks for laboratory relative humidity setpoints

(Source: Integra Group, Labs 21)

$$Lab\ Humidity\ Setpoint\ Range = Max\ RH\ SP\ (\%) - Min\ RH\ SP\ (\%)$$

PG&E Territory		
Standard	Good	Better
10	30	50

Cooling & Heating – System Efficiency

The key metrics and benchmarks to evaluate the efficiency of chiller and boiler systems in labs are no different than those typically used in other commercial buildings. These include chiller plant efficiency (kW/ ton), cooling load (tons/ gsf), boiler efficiency (%), pumping efficiency (hp/gpm), etc. Since these are well-documented elsewhere, they are not discussed here and the reader is referred to other publications, such as ASHRAE Standard 90.1. However, two additional metrics have special impact on lab efficiency, and bear further discussion.

Laboratory systems are often oversized due to reliability/redundancy requirements, over-estimated process loads, or other factors. Even when systems are "right-sized", there are many hours when loads are much lower than peak. Therefore, chiller systems in labs should be designed for low minimum-turndown ratios, defined as the ratio of minimum load (with continuous compressor operation without hot gas bypass or other false loading methods) to design load. Standard practice would be about 15 percent. Good and better practice benchmarks would be 5 percent and less than 5 percent respectively. In the Molecular Foundry at Lawrence Berkeley National Laboratory (LBNL), the chiller system is capable of a 5 percent turndown ratio. In labs with tight humidity control, even lower ratios are warranted, unless alternative dehumidification strategies are adopted.

Table 8.13:

Benchmarks for chiller system minimum turndown ratio

(Source: Integra Group, Labs 21)

$$Chiller\ System\ Min\ Turndown\ Ratio = \frac{Minimum\ Load}{Design\ Load}$$

PG&E Territory		
Standard	Good	Better
0.15	0.05	<0.05

Another lab-specific metric related to cooling and heating efficiency is the reheat energy use factor. Reheat energy use can be significant in labs. This can be due to tight temperature and humidity requirements, wide variation in loads served by given air handling system (Labs21 Reheat, 2005) or poorly calibrated controls. While there is no well-established metric for assessing reheat energy use, we suggest a metric such as reheat energy-use factor, defined as the ratio of the reheat energy use to the total space heating energy use. The best practice benchmark for this would be 0 percent (i.e., complete elimination of reheat energy use for temperature control). The Koshland Integrated Natural Science Center at Haverford College achieves this by using dual heat wheels and separation of thermal and ventilation systems (Bartholomew, P, 2004 and Labs21, Koshland, 2005).

Table 8.14:

Benchmarks for reheat energy use factor

(Source: Integra Group, Labs 21)

$$Reheat\ Energy\ Use\ Factor = \frac{Reheat\ Annual\ Energy\ Load\ (MMBtu)}{Heating\ Plant\ Annual\ Load\ Served\ (MMBtu)}$$

PG&E Territory		
Standard	Good	Better
0.25	0.1	<0.1

Plug Load Metrics

Equipment loads in laboratories are frequently overestimated because designers often use estimates based on "nameplate" data, and design assumptions of high demand. There can be a large difference between the plug load assumed in the design (lab plug load design peak) and the actual realized peak load (lab plug load actual design peak). The latter not only depends on the lower actual power draw of equipment compared to nameplate data but also due to diversity factors in equipment use. This disparity in peak load assumed for design vs. actual peak loads usually results in oversized HVAC systems, increased initial construction costs, and increased energy use due to inefficiencies at low part-load operation (Labs21, Plug Loads, 2005).

Table 8.15:

Benchmarks for laboratory design plug load intensity

$$Lab\ Design\ Plug\ Load\ Intensity = \frac{Lab\ Plug\ Load\ Design\ Peak\ (kW)}{Lab\ Net\ Area\ (sf) * 1000}$$

PG&E Territory		
Standard	Good	Better
10.0	5.0	3.0

Table 8.16:

Benchmarks for laboratory actual plug load intensity

(Source: Integra Group, Labs 21)

$$Lab\ Actual\ Plug\ Load\ Intensity = \frac{Lab\ Plug\ Actual\ Design\ Peak\ (kW)}{Lab\ Net\ Area\ (sf) * 1000}$$

PG&E Territory		
Standard	Good	Better
8.0	4.0	<2.0

Table 8.17:

Benchmarks for laboratory plug load sizing factor

(Source: Integra Group, Labs 21)

$$Lab\ Plug\ Load\ Sizing\ Factor = \frac{Lab\ Plug\ Load\ Design\ Peak\ (kW)}{Lab\ Plug\ Load\ Actual\ Peak\ (kW)}$$

PG&E Territory		
Standard	Good	Better
3.0	2.0	<2.0

Table 8.18:

Benchmarks for laboratory annual plug load intensity

(Source: Integra Group, Labs 21)

$$Plug\ Load\ Energy\ Intensity = \frac{Plug\ Load\ Annual\ Energy\ Use\ (kWh)}{Building\ Gross\ Area\ (sf)}$$

PG&E Territory		
Standard	Good	Better
20.0	10.0	6.0

Lighting Metrics

The key metrics and benchmarks to evaluate the efficiency of lighting systems in laboratories are not fundamentally different from those typically used in other commercial buildings. These include daylight factors, luminance levels, lamp and ballast efficacy, lighting power density, etc. There are two key metrics for which the benchmarks in laboratories are different from other commercial buildings:

Task luminance in laboratory spaces foot candles (fc): The 9th edition of the IESNA Handbook (IESNA, 2000) has revised its luminance recommendations for laboratories downward from the previous edition. The current recommendations are:

- **Specimen collecting: 50 fc (horizontal), 10 fc (vertical)**

- **Science laboratory: 50 fc (horizontal), 30 fc (vertical)**

Values higher than 50 fc should be carefully reviewed and justified by special functional requirements and should be restricted to the areas where the task is being performed. Furthermore, it is important to recognize that luminance in and of itself is not an adequate measure of visual acuity, which is a function of several other factors, such as contrast ratios, color rendition, etc.

- **Installed lighting power density (W/nsf): This refers to the lighting power density in the laboratory spaces.**

ASHRAE 90.1-2004 allows a maximum of 1.4 W/sf. The California Title 24-2008 energy code allows a maximum of 1.3 W/sf. At the Tahoe Center for Environmental Studies, the laboratory spaces were designed to 0.80 W/sf.

Benchmarking Process

There are many excellent resources available that explain processes for benchmarking laboratories. For more detail please see the Lawrence Berkeley National Lab self-benchmarking document available at:
http://hightech.lbl.gov/benchmarking-guides/lab-process.html

Key considerations are also available in the Labs 21 Best Practices benchmarking guide including:

1. **<u>Identify metrics and set targets with stakeholder team.</u> Metrics and targets are, in effect, key performance indicators for the quality of design and operation, and therefore should have the buy-in of all the key stakeholders (owners, designers, and operators). This could be done at project conception, and then refined during the early stages of the project. In the design for a new laboratory at LBNL, for example, a goal-setting meeting was held prior to conceptual design, in which the designers and owners considered a wide range of metrics, selected key metrics, and set targets for them.**

2. **<u>Incorporate key metrics and targets in programming documents.</u> Designers and operators are much more likely to ensure that targets are met if they are officially incorporated into the programming documents.**

3. **<u>Identify individual(s) responsible for tracking metrics.</u> Ideally, the commissioning authority would have overall responsibility, since metrics are integral to the performance tracking and assurance process. However, various design professionals may have responsibility for computing individual metrics and providing these to the commissioning authority (e.g., lab planner for hoods/nsf, HVAC engineer for W/cfm, etc.)**

4. **<u>Determine process and format for tracking and documenting metrics.</u> The Labs21 Design Intent Tool can be used to track metrics and generate formatted reports in a consistent manner over the course of a project.**

Related Chapters

- Chapter 1: Optimize Ventilation and Air Change Rates
- Chapter 2: Low Pressure Drop Design
- Chapter 3: Eliminating Reheat
- Chapter 4: Humidity Control
- Chapter 5: Fume Hood Optimization
- Chapter 6: Right Sizing for Equipment Loads
- Chapter 9: Optimize Exhaust Systems
- Chapter 10: Chilled Water Plant Optimization
- Chapter 11: Power Supply and Plug Load Efficiency

References

- Bartholomew, P. "Saving Energy in Labs," ASHRAE Journal, February 2004. P.35-40.
- VanGeet, O. et al. "Laboratory Modeling Guideline using ASHRAE 90.1-2007 Appendix G." Labs for the 21st Century, National Renewable Energy Lab, August 2008. Accessed October 2010 at: http://www.labs21century.gov/pdf/ashrae_appg_2007_508.pdf
- Mathew, P. "Metrics and Benchmarks for Energy Efficiency in Laboratories." Labs for the 21st Century, Best Practice Guide, Lawrence Berkeley National Laboratory, October 2007. Accessed October 2010 at: http://www.labs21century.gov/pdf/bp_metrics_508.pdf
- U.S. Department of Energy Federal Energy Management Program, Laws & Regulations, New Facility Construction and Major Renovations. Accessed July 2010 at: http://www1.eere.energy.gov/femp/regulations/requirements_by_subject.html
- U.S. Green Building Council. LEED 2009 for New Construction and Major Renovations Rating System. Accessed July 2010 at: http://www.usgbc.org/ShowFile.aspx?DocumentID=5546

- Mathew, P. et al. "Self-Benchmarking Guide for Laboratory Buildings: Metrics, Benchmarks, Actions," Lawrence Berkeley National Laboratory, July 2009. Accessed October 2010 at: http://hightech.lbl.gov/benchmarking-guides/docs/lab-benchmarking-guide.pdf

- Labs21 Reheat, 2005. "Minimizing Reheat Energy Use in Laboratories", Labs for the 21st Century, Best Practice Guide, Lawrence Berkeley National Laboratory, August 2005. Accessed October 2010 at: http://www.labs21century.gov/pdf/bp_reheat_508.pdf

- Labs21 Koshland, 2005. "Marian E. Koshland Integrated Natural Science Center," Labs for the 21st Century, Best Practice Guide, Lawrence Berkeley National Laboratory, June 2005. Accessed October 2010 at: http://www.labs21century.gov/toolkit/case_studies.htm

- Labs for the 21st Century Benchmarking Database Tool. Lawrence Berkeley National Laboratory. Accessed August 2010 at: http://labs21benchmarking.lbl.gov/Labs21Intro.php

- Labs21, Plug Loads, 2005. "Right-sizing Laboratory Equipment Loads," Labs for the 21st Century, Best Practice Guide, Lawrence Berkeley National Laboratory, August 2005. Accessed October 2010 at: http://www.labs21century.gov/pdf/bp_rightsizing_508.pdf

- IESNA Lighting Handbook, Reference and Application. 9th Edition. Rea, M. (ed). Illuminating Engineering Society of North America. 2000.

Resources

- Energy Star, Laboratory Energy Benchmarking Initiative, http://www.energystar.gov/index.cfm?c=industry.bus_labs_benchmark

9. Optimize Exhaust Systems

Introduction

Manifolding laboratory exhaust in laboratory buildings provides substantial energy and first-cost savings opportunities when compared to separately ducted, multiple exhaust fans. A manifolded system also offers a number of benefits, including:

- **Increased fume dilution**
- **Enhanced personnel safety**
- **Augmented redundancy**
- **Improved design flexibility**
- **Probable energy recovery**

Experience has shown that during laboratory retrofit projects, manifolded exhaust systems reduce construction costs and help avoid operational disruptions.

Principles

- **Use multiple fans and stacks connected to common plenum.**
- **Provide necessary stack exit velocity.**
- **Use less fan energy and less ductwork.**
- **Require isolation dampers, controls, and programming to start/stop multiple, stepped fans.**
- **Add VFDs to each exhaust fan (a minimum of three VFDs).**
- **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.**

- **Evaluate stack exit velocity to a lower energy use that ensures safe and effective operation.**

- **Wind-tunnel modeling is often the preferred method for predicting maximum concentrations for stack designs and locations of interest, and is recommended because it gives the most accurate estimates of concentration levels in complex building environments.**

Approach

A basic, manifolded exhaust system with a primary fan and a backup unit in a common duct system has higher energy efficiency than multiple, dedicated fans working independently. Manifolded exhaust systems save energy in four ways:

1. **Reduces fan power: Less pressure drop in duct work.**

2. **Adjustable airflow system: Can modulate energy needs in response to a varying requirement.**

3. **Requires less energy to disperse exhaust plumes: Increased dilution and momentum of effluent.**

4. **Increases energy recovery opportunities.**

Even greater efficiency can be realized over a basic manifolded arrangement when advanced design practices are used, including variable air volume fume hoods, multiple fans, and variable speed drives.

Fan Power Reduction

Manifolded exhaust systems reduce the number of fans and the ductwork needed when compared to individual fume hood exhaust systems. Therefore, less energy is used to move the exhaust air due to consolidation of numerous small fans into a larger and more efficient fan, and the reduction of ductwork pressure drop with larger dimension ductwork.

Adjustable Airflow

A manifolded exhaust system can be designed to accommodate varying fume hood airflow. Since it is unlikely that all hoods will be fully operational at one time, 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, since a variety of issues needs to be considered, including future laboratory growth.

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.

Energy Recovery Opportunities

A manifolded exhaust system maximizes the opportunity to recover energy contained in the conditioned air stream that is being exhausted from the laboratories. There are numerous design and operational challenges with recovering this energy including: device corrosion, added air-system pressure drops, increased maintenance costs, operational durability, and control complexity. Still, depending on the lab's geographical location, exhaust-stream energy recovery, in the form of both heating and cooling energy, can be worth the design challenges and maintenance issues.

Basic Manifold Design

Initial Considerations

Despite the considerable benefits laboratory exhaust manifolding can provide, a lab's design parameters will determine whether manifolding is appropriate. For example, while multiple exhaust fans effectively dilute hazardous fume hood exhaust, individual exhaust systems are usually more applicable in single-story buildings that have a small number of widely separated standard fume hoods. In the latter scenario, an extended ductwork to a manifolded exhaust system may not be economically justifiable. Otherwise, the use of individual fume hood exhaust systems should be limited to special processes and hoods with pertinent, restrictive codes and regulations, e.g., perchloric acid fume hoods. When contemplating a manifolded exhaust system, consider the following three topics:

Exhaust Compatibility

Perchloric acid, radioisotope hoods, and biological safety cabinets are segregated from general chemical exhaust due to incompatibility or special operating conditions, which may necessitate one hood per dedicated set of fans (standard for perchloric acid), or one type of hood per dedicated set of fans (e.g., all radioisotope hoods manifolded together). Biological safety cabinets (BSCs) used in Biosafety Level 1 (BL1) or Level 2 (BL2) work or just tissue-culture work can be manifolded with chemical fume hoods and lab general exhausts. Biosafety Level 3 and 4 (BL3 and BL4) labs and select "agent" labs that work with highly infectious or toxic agents are prohibited from manifolding.

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. If more hoods may be added or relocated in the future, then an appropriately sized manifold system will provide the greatest degree of flexibility.

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 should be reviewed, and designs should be made in compliance with them. Note that for every facility, "the authority having jurisdiction" can adopt a "standard(s)" as a "code." Therefore, any standard can have "the force of law," when so stipulated by "the authority."

During schematic design, the laboratory user or research group needs to provide the designer with a complete list of chemicals that are currently in use or will be used in the laboratories. This will assist in the selection of appropriate exhaust system materials based on code compliance and compatibility with chemicals or agents to be used (and anticipated for future use) in the labs. If particulates are present in the exhaust, sufficient transport velocities in accordance with codes and adopted standards must be maintained in the ducts at all times.

Good Manifold Design Practice

When compared to a basic constant volume (CAV) manifolded exhaust system, energy-efficiency improvement in the range of 30% can be achieved with "good" design practice. The following three "good practice" enhancements to the basic design approach provide pragmatic energy-use reductions without excessive expenses or design complications:

Exhaust Less Conditioned Air

Summary

- **Use VAV lab hoods.**

- **Track changing VAV hood exhaust volume with a bypass damper.**

- **Ensure that lab general exhaust, plenum bypass damper, static pressure sensor(s), and controls maintain the minimum lab air change rate and desired directional airflow.**

- **Operate exhaust fans at a sufficient speed to meet exit velocity requirements.**

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 exhausted conditioned air from the facility, while providing the required stack exit velocity. A good manifolded system design also has a motorized 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 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 operation.**

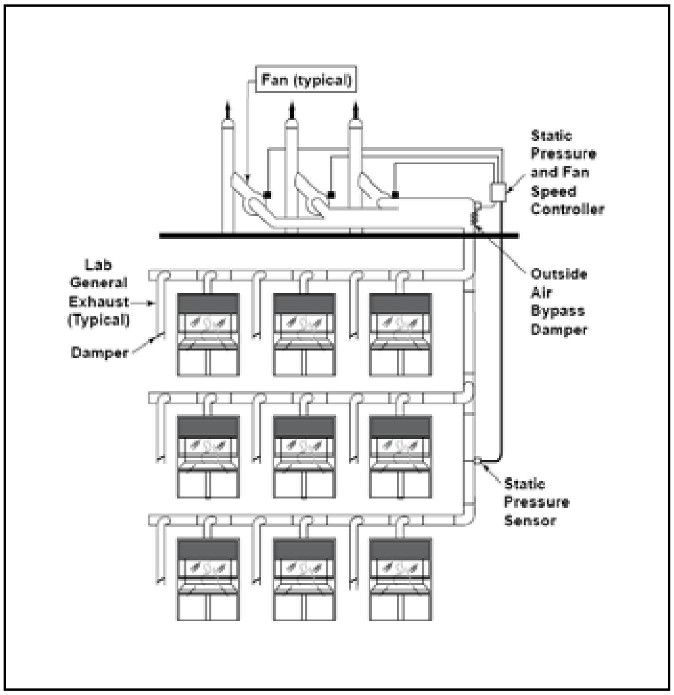


Figure 9.01
Manifold design energy-efficiency improvements.
(Source: Labs 21)

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 only using a bypass damper.

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 full 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. Monitor duct static pressure in at least two locations by placing one static pressure sensor in the exhaust plenum, just after the entry of the main exhaust inlet duct; and placing the other sensor in one of the exhaust system duct branches at the location where the static pressure is anticipated to be at the lowest (the least negative) value. Typically, this will be in the longest exhaust system branch duct, at the farthest end from the exhaust plenum; however, pressure sensor quantity and location(s) are highly system-dependent.

Better Manifold Design Practice

Additional energy-efficiency improvements in the range of a 50% reduction compared to a CV system can be realized when "better" design practice is added to the good-design practice for manifolded exhaust systems, presented above. The following three good-design practice enhancements significantly reduce energy use:

Stepped Fan Operation

Summary

- **Uses multiple fans and stacks connected to common plenum.**
- **Provides necessary stack exit velocity.**
- **Uses less fan energy in smaller diameter stacks.**
- **Require isolation dampers, controls, and programming to start/stop multiple, stepped fans.**

Considerations

Using a set of multiple exhaust fans provides greater operational flexibility and increased redundancy than one primary fan. The number of fans connected to a manifold exhaust system is influenced by a variety of factors, including:

- **Total airflow volume**
- **Diversity, i.e., the ratio of minimum to maximum flow or the percent of theoretical maximum flow**
- **Required stack exit velocity**

- **Hazard analysis**

- **Effluent dispersion needs**

Therefore, a "better" design practice uses multiple fans sized for partial volume so the airflow can be stepped up or down by starting or stopping additional fans. A minimum of three exhaust fans – two primaries and one standby – are used; more fans may be incorporated. In general, exhaust airflow volume is adjusted by individually sequencing the fans connected to the manifold's common plenum. This approach reduces energy by exhausting less air during low hood use. When using three constant-volume fans, each unit is sized to provide 50% of the required maximum volume exhaust airflow. Therefore, with one fan operating, the manifold system can provide up to 50% of the maximum design capacity; with two fans operating, 100% capacity is provided. The third fan provides backup in the event of either primary fan's failure. Each of these constant-volume fans generates the required stack exit velocity.

Better manifolded exhaust systems use high-quality, leakage-rated, motorized isolation dampers, between both the inlet and outlet of each exhaust fan, which do not allow stack exhaust air of an operating fan to be drawn through a non-operating fan.

Modulate Fan Speed

Summary

- **Add VSDs to each exhaust fan (a minimum of three VSDs).**

- **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

As described above, a stepped operation of three exhaust fans, sized at 50% of maximum capacity, improves energy efficiency. However, building on 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. 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 to 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. In addition, in the event 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.

Evaluate Plume Dispersion

Summary

- **Evaluate stack exit velocity to a 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.

When considering a stack exit velocity, it is recommended that plume dispersion calculations or atmospheric modeling be performed to evaluate exhaust re-entrainment rather than to use a "design standard." These evaluation techniques will account for the beneficial dilution and momentum provided by a manifolded system, and will likely result in a lower stack exit velocity, thus saving exhaust fan energy.

Stack Modeling

An accurate assessment of exhaust dispersion can be used to produce exhaust/intake designs optimized for energy consumption. No matter what type of exhaust system is used, the important design parameters are physical stack height, volume flow rate, exit velocity, expected pollutant emission rates, and concentration levels at sensitive locations. Whether conventional or induced-air exhaust systems are used, the overall performance should be evaluated using the appropriate criterion that will ensure acceptable concentrations at sensitive locations.

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.

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 ensure efficient, long-term operation.

Case Studies

Minnesota College Retrofit

A completed renovation project for a lab at Minnesota College, a small private educational institution, provided a net reduction from 30 dedicated exhaust fans to six arranged on three plenums. Each fan, sized for approximately 67% of the full load, provides backup capacity and growth potential. This project demonstrated a manifolded lab exhaust system's improved design flexibility and increased fume dilution while providing a substantial energy reduction.

Genentech, Inc.

The flexibility of manifolded exhaust systems enabled Genentech to promote its science and save energy simultaneously. By using VFD-driven fans in the exhaust manifold system, a quarter-million-sq-ft lab project has saved approximately $100,000 in annual operating costs when compared to a constant volume/air bypass manifolded design. In another instance when even more hoods were needed on another manifolded exhaust system that would not accommodate larger exhaust fan motors, disruptions to research activities were minimized while lab hood sashes were changed sequentially from operating vertically to horizontally. Horizontal hood sashes, sized to fit the science, reduced energy demand from 30 ten-foot hoods by a third.

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.

Related Chapters

- Chapter 2: Low Pressure Drop Design
- Chapter 5: Fume Hood Optimization

References

- Labs21, U.S. DOE, U.S. EPA [2008], "Manifolding Laboratory Exhaust Systems"
- PG&E Biotech Case Study, "Genentech." http://www.pge.com/includes/docs/pdfs/mybusiness/energysavingsrebates/incentivesbyindustry/biotech/genentech_cs.pdf

Resources

- National Renewable Energy Laboratory [NREL], http://www.nrel.gov/

10. Chilled Water Plant Optimization

Introduction

Labs offer a number of opportunities in central chilled water plant optimization, both in design and operation. Chiller efficiency is a function of the chilled water temperatures. All other things equal, higher chilled water temperatures result in improved chiller efficiency. Dual temperature loops can be implemented to increase energy savings: one loop to provide colder chilled water (e.g. 42-44°F water for dehumidification) and a second loop to provide medium temperature (e.g. 50-55°F) for sensible cooling and process chilled water. When outside air temperatures are cool and humidity is low (i.e., no low-temperature water is needed for dehumidification), 100% of the chilled water is for medium temperature loop uses. Further energy savings can be realized during cool, low humidity days by using a water-side economizer: cooling towers to generate the cooling water, rather than chillers. The condenser loop should also be optimized; a 5°F – 7°F approach cooling tower plant with a condenser water temperature reset pairs nicely with a VSD chiller to offer large energy savings.

A primary-only variable volume pumping system is well matched to modern chiller equipment and offers fewer points of failure, lower first cost, and energy savings. Thermal energy storage can be a good option, and is particularly suited for critical facilities where a ready store of cooling can have reliability benefits as well as peak demand savings. Finally, monitoring the efficiency of the chilled water plant is a requirement for optimization and basic reliable energy and load monitoring sensors can quickly pay for themselves in energy savings. If efficiency (or at least cooling power use) is not independently measured, achieving it is almost as much a matter of luck as design.

Adding temperature and pressure resets to the system can increase savings across the entire chilled water plant. Rather than have a constant setpoint, resets can introduce better operating conditions to the system, greatly increasing the efficiency of the equipment. Chiller plant optimization controls software can be implemented to calculate the minimum energy use operating point given several hundred inputs (temperatures, pressures, compressor speeds, chiller loading, etc.). These optimization programs are typically higher in initial cost due to the instrumentation and newer equipment that is needed, but drastically lower the energy use of the plant in the long run.

Principles

- Design for medium temperature chilled water (50°F or higher) in order to lower plant operating costs

- Use aggressive chilled and condenser water temperature resets to maximize plant efficiency. Specify oversized cooling towers to achieve a 5°F – 7°F approach in order to economically improve chiller performance.

- Design hydronic loops to operate chillers near design temperature differential, typically achieved by using a variable flow evaporator design and staging controls.

- Primary-only variable flow pumping systems have fewer single points of failure, have a lower first cost (half as many pumps are required), are more efficient, and are more suitable for modern chillers than primary-secondary configurations.

- Thermal storage can result in peak electrical demand savings and improved chilled water system reliability. Thermal storage can be an economical alternative to additional mechanical cooling capacity.

- Use efficient water-cooled chillers in a central chilled water plant. A high efficiency VSD-equipped chiller with an appropriate condenser water reset is typically the most efficient cooling option for large facilities. The VSD optimizes performance as the load on the compressor varies.

- Monitor chiller efficiency for peak efficiency and to allow for preventive maintenance.

- Modify temperature and pressure setpoints to increase savings on non-design condition days.

- After monitoring instrumentation is installed, a system-wide optimization program can be implemented in the form of software programs. These programs compute the lowest energy use at a given point in time based on mathematical algorithms.

Approach

For large lab facilities, a chilled water system served by a central plant is the most efficient approach to providing mechanical cooling. There are many design decisions that impact the efficiency of a central plant; the issues discussed here are selected due to their prevalence in typical lab operation.

Use Non-Condensing Chilled Water Temperature

Lab facilities usually have a number of medium temperature loops required by lab equipment. Recirculation cooling may be supplied by coils that use mixing stations to supply a non-condensing 55°F water temperature, and a process cooling water loop would utilize a heat-exchanger to create water between 60°F and 70°F. Energy savings are realized not by creating medium temperature demands, but by designing a system that creates medium temperature water directly without wasting energy-intensive low temperature water.

Lab facilities typically need low temperature water only to handle peak outside air and/or dehumidification loads. Peak loads, by definition, occur 2% - 5% of the time in a year. For example, an outdoor air drybulb (DB) temperature of 95°F is used for design conditions, but 24-hour operating conditions may be at an average outside air temperature of 70°F DB. Typically, make up air conditioning accounts for 25% - 30% of the chilled water load, while recirculation air and process cooling loads account for 60% - 70%.

Chiller efficiency depends on the chilled water supply temperature – chillers operate most efficiently when the temperature lift (the difference in temperature between the evaporator and the condenser) is minimized. The magnitude of the lift is proportional to the difference between the chilled water supply temperature and condenser water supply temperature. The lift is reduced if either the condenser water supply temperature is reduced or if the chilled water supply temperature is increased. Therefore, if the medium temperature water loads can be served by a chiller operating at the required medium supply temperature, the chiller energy required will be reduced significantly over a low temperature chiller with mixing loop or heat-exchanger. For example, an increase in chilled water temperature from 44°F to 54°F can be expected to cut chiller power use by 10% - 20%. In some cases by raising the temperature, the initial chiller selection can be altered since a smaller compressor and motor can be used on the chiller to provide the same capacity.

A medium temperature loop also greatly expands the potential for free cooling, which is when the cooling tower is used to produce chilled water. Cooling towers sized for an approach temperature of 5°F to 7°F can be utilized to produce chilled water at 55°F for much of the year, particularly at night in moderate and dry climate zones such as in California and Arizona. There is better system redundancy in a dual temperature chilled water loop system as compared to a low temperature chilled water loop system that provides cooling for sensible and process loads.

In some climates, it is appropriate to reset a central plant's chilled water temperature down only during short periods that require dehumidification. For the remainder of the year when dehumidification is not needed, the chilled water supply temperature can be set higher to improve chiller plant efficiency.

Design and Control Cooling Tower System for Low Condenser Temperatures

Reducing the lift to optimize chiller efficiency involves both a higher chilled water temperature and a lower condenser water temperature. Oversized cooling towers with an approach of 5°F – 7°F should be used and a reset implemented to maintain a cold condenser water temperature that optimizes the chiller plant efficiency. Low air pressure drop cooling towers (typically draw-through) equipped with variable speed fans should be used and the maximum number of towers and/or cells should be operated in parallel at any given time. Minimum water flow requirements for proper tower media wetting typically determine the maximum number of towers and/or cells that can operate. The minimum allowed condenser temperature should be determined by the chiller manufacturer during selection, and usually is around 50°F – 60°F.

Use of a constant condenser water temperature of 70°F, or even higher, is a major cause of wasted energy in electrical chiller plants. Typically, chillers that allow a lower minimum condenser water temperature offer higher efficiency, a factor that should be considered when selecting a chiller; a "more efficient" chiller may actually yield poorer energy performance than a slightly less efficient chiller that is better able to capitalize on low condenser water temperatures available at night or during the winter. The condenser water temperature actually available is determined by the climate, design and control of the cooling tower system.

Figures 10.01 and 10.02 shows the reduction in cooling power, measured in kilowatts of power required to produce a ton of cooling (12,000 Btu/hour), as the condenser water temperature (CWT) is reduced. Lower kW/ton values reflect more efficient operation. The top curve is a baseline chiller operating without a condenser water reset. The curves below the baseline are the performance of an equivalent VSD chiller at various CWT. A VSD tends to allow the greatest utilization of low condenser water temperatures and provides better performance at part loads. Economizer and/or free cooling are other options to be considered that can optimize plant operation during mild outdoor conditions.

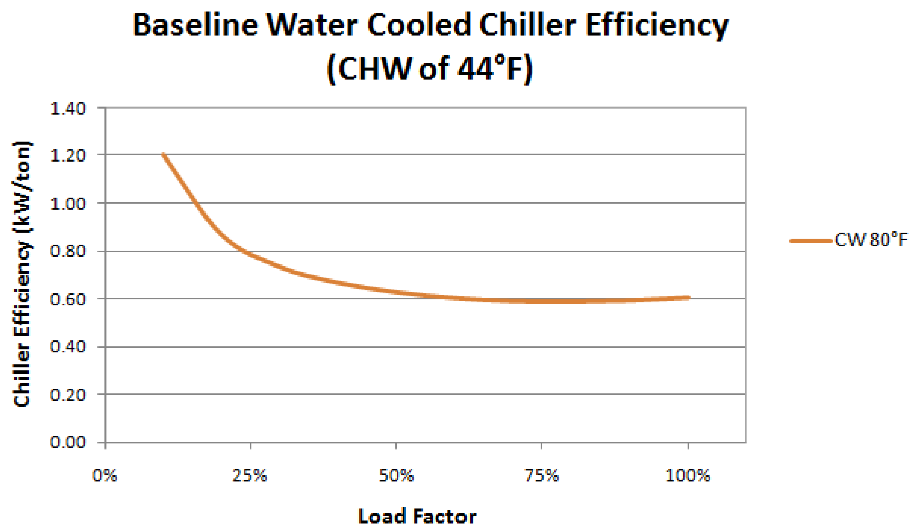


Figure 10.01:
Baseline Constant Speed Chiller Performance Curve.
(Source: Created by Integral Group.)

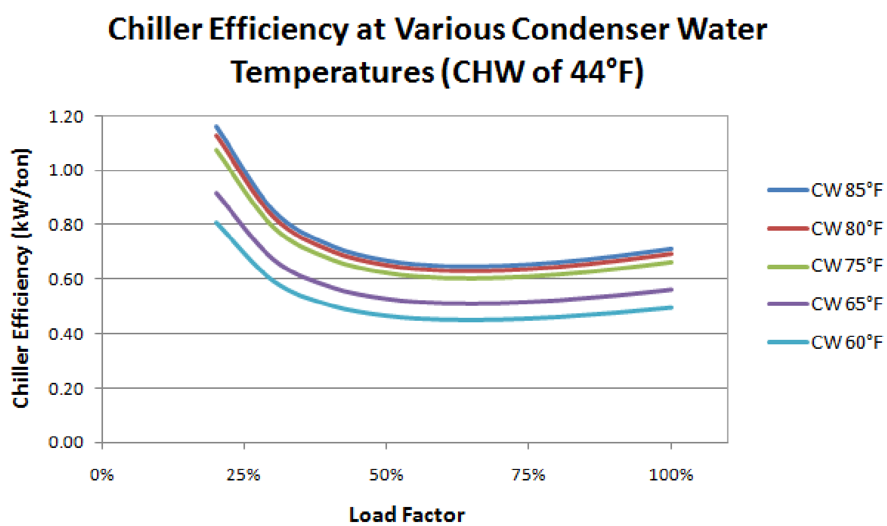


Figure 10.02:
Variable Constant Speed Chiller Performance Curves with CW Reset.
(Source: Created by Integral Group.)

Use Variable Speed Chillers

Variable speed compressor chillers (often referred to as VSD or VFD chillers) currently offer the best performance for moderate to large loads (loads where centrifugal chillers are widely available). In order to capitalize on a VSD chiller's part load performance capabilities, a condenser water reset and low approach cooling tower system, as discussed above, are required. While the internal loads may not vary much, the actual load on the chiller compressor does vary as the weather impacts the condenser water temperature. It is the reduction of condenser water temperature during non-design day conditions (which are 99.9% or more of the year for a critical facility plant) that allow the VSD chiller to offload and run more economically at part load.

Regardless of the chiller type selected, data on chiller efficiency should be requested from manufacturers during chiller selection and the chillers performance, including at part load, should be a required part of equipment submittals. It is very important that the efficiency be compared at the condenser water temperatures and part-load ratios at which the plant is expected to operate. The standard ARI performance rating conditions assume a typical office building load that varies proportionally with the condenser water temperature / outside air conditions. VSD chillers tend to offer the best part load performance when compared to an equivalent (same condenser and evaporator heat exchanger configuration) constant speed chiller. While the chiller is not the only important element in an efficient plant design, it is the largest energy consumer; whole-plant design optimization and life cycle cost analysis should be utilized when selecting a chiller.

Design Cooling Water System to Operate Near Design Chilled Water Delta-T at Part-Load

Chillers are optimized to operate with a specific supply and return temperature difference for example, a return water temperature of 65°F and a supply water temperature of 55°F, which would be referred to as a "10°F delta-T". An efficient chilled water system design will operate the chiller at or near its design delta-T over all the expected load conditions, even at part load conditions. There are several design steps required to achieve a good part-load delta-T system; most include eliminating unnecessary bypasses (particularly three-way coil valves) and using a pumping system that allows the chiller to operate at or near the design delta-T during the expected part load operation.

Variable flow pumping is required in order to allow the chiller to operate at design delta-T during part load conditions. Traditional chiller design maintains a constant flow through the chiller, which inevitably results in the delta T (the difference between the warm water entering the chiller versus the chilled water leaving the chiller) being directly proportional to the load. A 50% load will result in a delta T that is 50% of the design value. This type of operation results in unnecessary pumping power use and often leads to inefficient chiller staging control, with an additional chiller (and condenser water pumps and towers) being staged on before the operating units are fully loaded.

Primary Only Variable Speed Pumping

Primary only variable speed pumping is quickly gaining in popularity. It is more efficient, costs less to build and has fewer points of failure. The figure below shows a standard primary only, variable flow pumping configuration. Often, chilled water pumping costs can be reduced by 30% to 50% with this arrangement compared to the conventional constant primary-variable secondary pumping configuration. The staging and control of a primary-only pumping system is no more complex than the traditional primary-secondary approach, but it is different. ASHRAE publications and white papers from chiller manufacturers are good sources of information on this configuration.

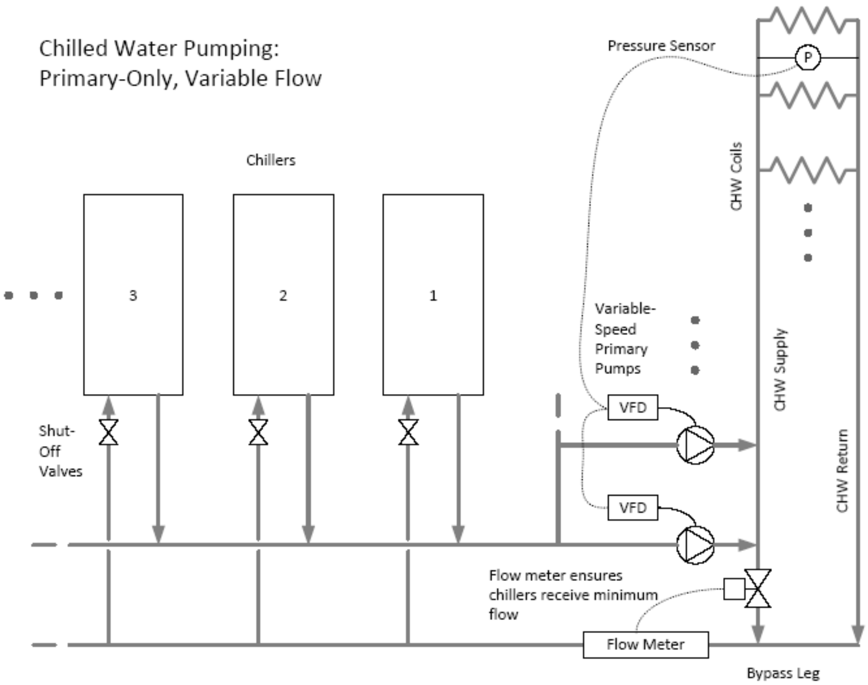


Figure 10.03:
Primary-Only, Variable Flow Chilled Water Piping Diagram
(Source: Integral Group)

Thermal Storage

There are two main types of thermal energy storage for cooling: ice storage, and chilled water storage. With ice storage, the cooling plant must be able to produce chilled water (actually a water/glycol mix) at 25-28°F. This cold fluid is piped through the ice storage tanks to convert the liquid tank water into ice. The ice is stored for future use. Water storage is preferred over ice because water is simpler, cheaper, more efficient, and more reliable – although it requires more space. With chilled water storage, the cooling plant does not have to produce temperatures as low as in the ice-making case. Otherwise the concept is the same. The stored chilled water can then be used for cooling at a future time.

Thermal storage offers the following benefits:

- **Provide backup and thermal capacitance**
- **Can shift demand to off-peak hours in order to save on peak electrical demand charges**
- **Allow the cooling plant to run at its most efficient load point**

For chilled water storage, night-time production offers the same advantage of more efficient heat rejection. A water-cooled chiller plant equipped with water-side economizing can offer exceptional performance when combined with chilled water storage, providing both significant energy savings and peak demand charge savings over a standard chilled water plant.

Monitor Plant Efficiency

Chilled water plants consume a large amount of energy, yet are rarely monitored in any way in order to verify design and operating efficiency. The small initial expense of installing basic monitoring is usually necessary to achieve and maintain design efficiency. Frequently the efficiency of even a brand new chiller is degraded by minor equipment or installation defect, such as un-calibrated internal sensors, incorrect refrigerant charges, loose wiring harness connections, or non-optimal compressor mapping. Finding and correcting such errors can provide an immediate payback for permanent monitoring equipment. Continuous monitoring can also help to rapidly diagnose operational problems or pending equipment failures.

At a minimum, a monitoring system should be provided that determines and displays the chillers kW/ton performance in real-time. Monitoring of the full plant kW/ton offers additional optimization opportunity and can often be achieved for minimal additional cost. A true-power kW sensor, which incorporates voltage, amperage and power factor measurements, should be selected to monitor chiller power. Plant delta-T should be determined using a matched set of stable temperature sensors that provide an accuracy of ± 0.36°F or better. The delta-T is often in the range of only 4°F – 9°F, so a closely matched and/or high accuracy pair of temperature sensors is required to achieve reasonable accuracy. For whole plant monitoring, VSDs often offer an economical way to monitor power consumption of smaller, lower-priority loads such as pumps and towers.

Flow meters are the traditional weak link in plant monitoring equipment since high quality, high stability flow meters tend to be of higher cost. Insertion-type flow meters with moving parts have been observed to foul unacceptably rapidly even in well managed closed-loop fluid streams. To provide diagnostic value, the flow meter must be reliable enough that 'odd' readings indicating a plant problem are not dismissed as an inaccurate flow meter. A flow meter based on electromagnetic induction or ultrasonic sensing provides the highest accuracy with exceptional long term stability and is recommended for reliable and accurate plant monitoring. A good practice is to ask the chiller manufacturer the type of flow meter used for their factory tests and use the same type for plant monitoring. This approach can eliminate finger pointing if the chiller is found to not be meeting submittal performance requirements as installed.

Implement Chilled Water Pumping Delta-P Setpoint Reset

Standard control system design calls for the chilled water pump serving the chilled water distribution system to maintain a constant pressure at a given location (usually at the most remote cooling coil), regardless of the current cooling load. The pressure setpoint is set to a value that ensures adequate flow through all the coils under the highest possible load condition. Under lower load conditions, the coils require lower flow rates and the pressure needed to supply the flow is also much lower. With constant pressure control, the CHW control valves at the coils are required to throttle closed to prevent overflowing the coil at low loads. Rather than maintaining a constant pressure across the chilled water loop, the pressure setpoint can be lowered during periods of low load.

Software Based Plant Optimization

There are several chiller plant optimization programs available today. These programs require intensive monitoring and full control of every piece of equipment in the plant. To use the full capability of the program, all chillers, cooling tower fans and pumps must be installed with VSD motors. Despite the high cost of implementation, the programs have been shown to reduce the energy use of the plant dramatically, depending on the baseline system. Mathematical algorithms often optimize hundreds of inputs to find a specific operating point that minimizes the load.

Related Chapters

- Chapter 4: Humidity Control
- Chapter 8: Metrics and Benchmarks for Energy Efficiency in Labs

References

- Emerging Technologies, ASHRAE Journal September 2006, "Cool Thermal Energy Storage."

Resources

- Schwedler P.E., Mick, Trane Engineers Newsletter, Volume 31, No. 4, 2002, "Variable-Primary-Flow Systems Revisited."
- TC9. 9 Mission Critical Facilities, ASHRAE, 2004, "Thermal Guidelines for Data Processing Environments."
- Chapter 17, ASHRAE HVAC Applications, 2003, "Data Processing and Electronic Areas."
- Chapter 41, ASHRAE Applications Handbook, 2003, "Supervisory Controls Strategies and Optimization."
- ARI Standard 550/590- 2003, "Water Chilling Packages Using the Vapor Compression Cycle," Air-Conditioning and Refrigeration Institute, 2003

11. Power Supply and Plug Load Efficiency

Introduction

While great effort has been made to improve efficiency in laboratories through the building shell, lighting system, heating, ventilation and air conditioning, the issue of plug loads is usually ignored. In super low energy labs, when building loads have already been reduced considerably, lab equipment plug loads can make up a proportionately larger percentage of the total energy use – up to 50% or more – so savings gained from reducing plug loads have a more significant proportional effect on total energy use.

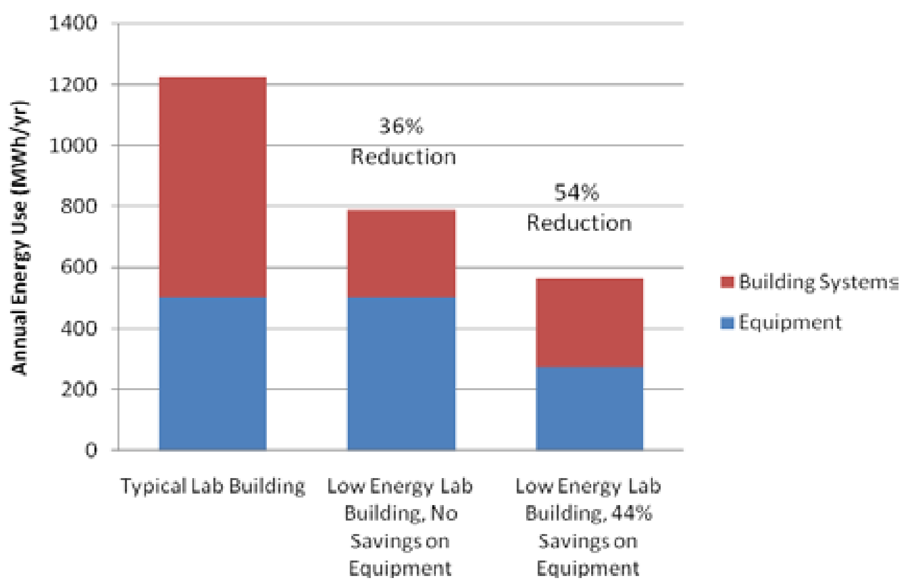


Figure 11.01: Laboratory Annual Energy Use Comparison
(Source: Created by Integral Group)

Substantial reductions in energy use have been implemented in other products in the residential sector long ago, notably with refrigerators, air conditioners, and light bulbs. These reductions came about as a result of a combination of customer demand, government regulation, and the collective voluntary actions of equipment manufacturers. These initiatives point toward an established protocol and methodology for measuring plug load energy use, which will help critical facilities to work with equipment manufacturers to develop more energy efficient products.

Typically inefficiency in lab equipment results from a lackof consideration for energy performance when purchasing, or from the ghost loads that occur when the equipment is not in use. This chapter will discuss how to identify wasted energy from plug loads, typical solutions for reducing this consumption, and a case study illustrating an investigation that achieved 44% savings in annual energy use by reducing laboratory equipment plug loads.

Principles

Laboratories can take the following actions to reduce plug-load inefficiencies:

- Consolidate small pieces of equipment, such as portable chillers, vacuum pumps, etc. to a larger, centralized, more efficient system when possible.

- Ensure all supporting equipment is right-sized for its parent instrument. Often lab users tend to use what is available at the time to get the work done, whether it is oversized for the job or not.

- Consider total cost of ownership (TCO) when purchasing equipment. While high-efficiency systems may come with higher price tags, the future benefits of these systems will justify the upfront cost premium.

- Look for IT and office equipment with the ENERGY STAR label. Though it is not available for all types of equipment, this label signifies that the equipment has met or exceeded a rigorous series of product quality and efficiency standards.

- Use vacancy sensor plug strips for equipment that does not require power when not in use. Vacancy sensor plug strips address ghost loads by fully shutting down power to pieces of equipment that would otherwise draw power unnecessarily.

- Implement power management for IT equipment. Computers and monitors can draw considerable amounts of power even when they are in a suspended state. However, operating system settings or software applications can be configured to fully power down computers when they are not in use.

- Work with lab users and equipment manufacturers to learn more about how the equipment operates, and to implement changes in how the equipment is constructed and operated in order to achieve maximum efficiency.

Approach

Since no one building has the same type of equipment, use schedules, and occupant behavior, a formalized methodology for examining building plug loads on a case-by-case basis must be established:

1. **Survey existing equipment to predict major energy-users.**

2. **Interview occupants to predict typical use schedules of equipment and behavior patterns.**

3. **Power monitoring on a selected sample of major energy-users for a substantial period of time.**

4. **Detailed analysis of power monitoring data.**

5. **Formulate a baseline trend for all equipment based on results of the monitoring data.**

6. **Investigate energy saving alternatives and estimate savings.**

In order to create an accurate baseline by which any energy reductions can be calculated, a thorough itemization and description of all laboratory equipment used in a facility should be conducted. This assessment should include every piece of equipment, their model numbers, nameplate power ratings, cooling requirements, year manufactured and installed, associated supporting equipment, special process fluids or gases needed, and any energy savings features (standby operation, sleep mode, etc).

Interviews with the staff of the laboratory provide an idea of annual equipment use. Keep in mind that it is not always the largest piece of equipment with a high power draw that consumes the most annually. For example a large laser may only be used for several minutes a week, whereas a small vacuum pump may only consume a fraction of the power of a laser, but is required to stay on 24 hours a day, seven days a week. With the use schedule and basic nameplate information for the equipment it is possible to predict the major energy hogs of the laboratory, and then take a sampling of these for power monitoring.

When monitoring power consumption of the equipment, it is recommended to monitor on one-minute intervals for a period of at least seven days of typical use on a true RMS power meter. After compiling data from the monitoring process, the following quantities should be measured to make an accurate assessment of a baseline trend for plug load energy consumption in a laboratory:

- Measured instantaneous power (kW): Obtain this by multiplying the instantaneous voltage, amps, and power factor together for each one-minute interval on each piece of monitored equipment. Calculate a maximum, minimum, and average of all of these values for the entire monitoring period.

- Room plug loads (W/sf): Add the average measured instantaneous power for each piece of equipment (those that were not monitored can be estimated based on the monitored ones) for each room, and divide by the area of each room. This value can help reduce the size of the cooling system needed for a particular room (see chapter 6).

- Typical usage (hr): The number of hours each piece of equipment draws any power during the entire monitoring period. This, along with the typical schedule of use provided by the lab users, can be used to project a baseline of annual plug load energy consumption in the laboratory.

Finding energy saving alternatives may not always be a straightforward task, especially since most lab equipment is designed around performance and precision, and not energy efficiency. When following the principles described above one must realize that it is not mandatory each of the recommendations be carried out, but more importantly to know that there are always possible alternatives worth investigating for saving energy from lab equipment plug loads. Working with the lab users and equipment manufacturers is possibly the most effective way to improve lab equipment efficiency in the long run.

Benchmarking Findings/Case Studies

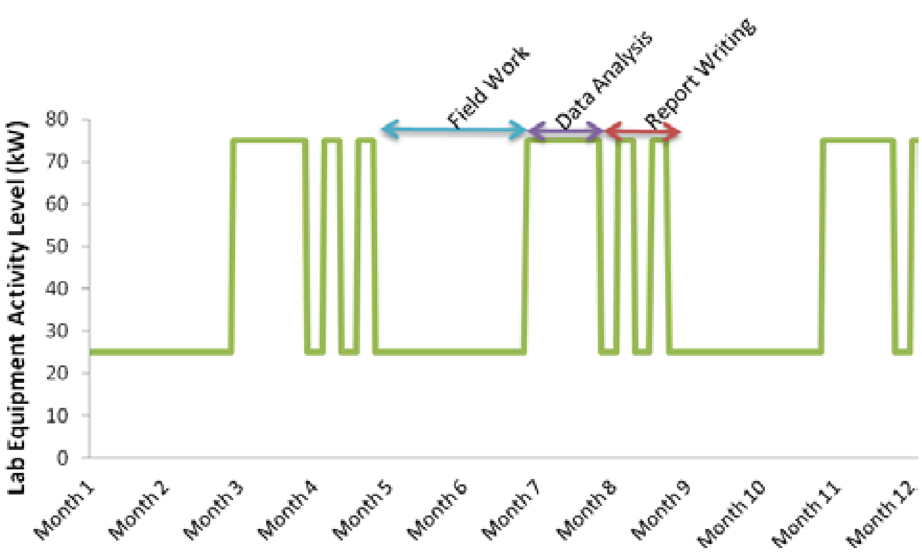


Figure 11.02:
Monthly Laboratory Equipment Activity
(Source: Created by Integral Group)

A thorough investigation of all the lab and office equipment in a small environmental sciences research facility was recently performed by a group of engineers determined to reduce the power consumed by plug loads. By following the procedures described above, a potential annual energy savings of 44% in equipment energy consumption was discovered. A large savings was also realized in downsizing the HVAC system required to cool the more efficient equipment.

The lab consisted of many high-powered lasers, mass spectrometers, supporting vacuum pumps and chillers, and various other types of equipment. The office areas consisted of the basic desktop computers, monitors, printers, task lights, and servers. From observing behavioral patterns among the lab users, it was apparent the lab users demonstrated very responsible behavior by powering down equipment when not in use, ensuring all equipment was cooled properly, and used standby modes when appropriate. Interviews with the staff of the laboratory provided an idea of annual equipment use.

The schedule of use, according to a typical lab occupant, for this particular laboratory is shown in Figure 11.02. During times of "field work" the labs are not occupied, and equipment is not in use; however there are certain types of equipment that are never turned off, which is why the equipment activity level remains at 25 kW during this period. During times of "data analysis" the labs are fully occupied and all equipment is in use. For the time of "report writing" the equipment is used sporadically throughout the period.

From looking at the equipment survey and schedules of use, it was predicted that the mass spectrometers, lasers, and supporting chillers would be the main culprits of energy consumption. Approximately 50 pieces of equipment were monitored on one-minute intervals for a period of seven days of "full use" on a true RMS power meter.

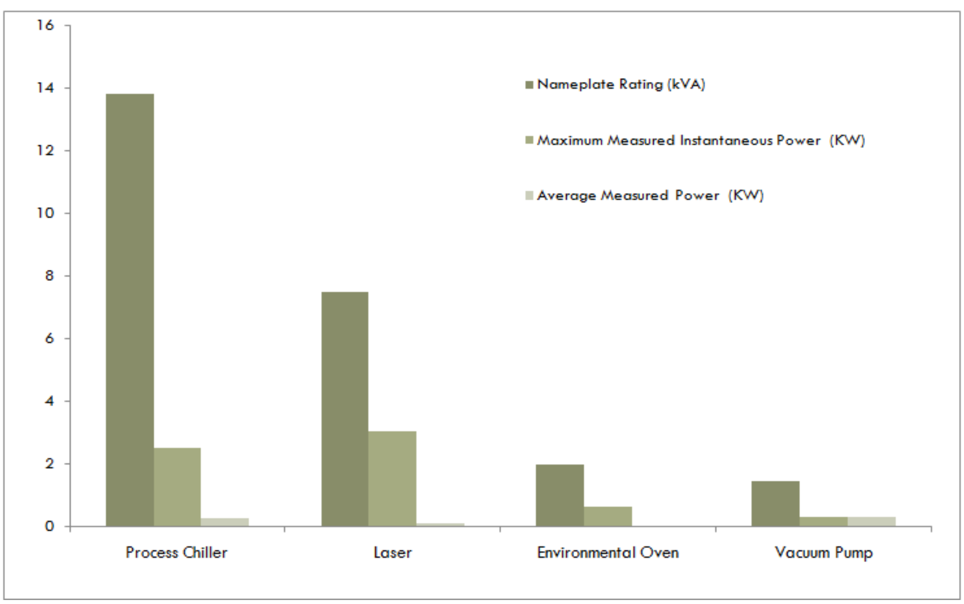


Figure 11.03: Laboratory Equipment Power Comparison (Source: Created by Integral Group)

One important observation made after completing the monitoring process was the staggering difference between the nameplate power rating for a piece of equipment and the actual power it consumed during the monitoring process. In some cases the nameplate rating was as much as four or five times the maximum measured instantaneous power. This is important to note because often lab designers use the nameplate values to estimate the plug load design value, which results in oversized

HVAC systems, increased initial construction costs, and increased energy use due to inefficiencies at low part-load operation.

Upon completion of the data analysis, a baseline value for lab equipment energy use was determined based on the measured energy data. The overall annual equipment energy consumption was 450 MWh/yr, at a cost of $80,000 per year. The majority of this came from the process chillers, vacuum pumps, mass spectrometers, and servers, but not the lasers as originally predicted.

After extensive research and development in coordination with the lab users, equipment manufacturers, and the investigation team a series of recommendations was proposed to improve the efficiency of the lab equipment:

1. **Replace process chillers with heat exchangers connected to the central building chilled water**

2 **Replace general purpose vacuum pumps with high efficient models**

3 **Replace mass spectrometer supporting vacuum pumps with right-sized, high efficient models**

4 **Use efficient office equipment and servers**

5 **Implement upgrades on mass spectrometers**

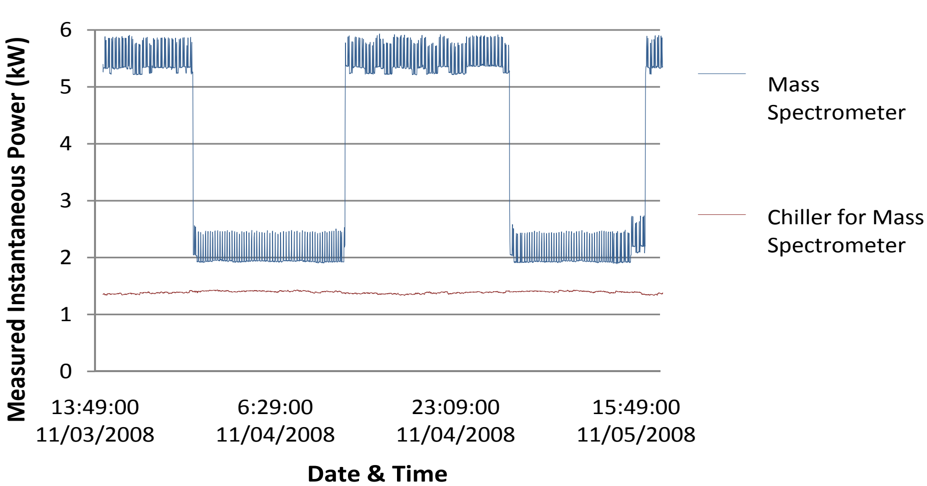


Figure 11.04:
Laboratory Equipment Measured Instaneous Power
(Source: Created by Integral Group)

One mass spectrometer and its supporting equipment are great examples of how collaboration between the lab users, engineers, and equipment manufacturers can lead to significant energy savings. The graphs below show the results found from monitoring the original equipment:

From the monitoring data it was discovered that this instrument alone consumed 29,000 kWh annually. The supporting vacuum pumps and process chillers added in another 18,000 annual kWh. Once this information was shared with the lab users, they were shocked by the amount of energy consumed, and focused on brainstorming for methods of reduction.

It turned out many of the vacuum pumps were outdated and oversized. By replacing with new, more efficient right sized models the vacuum pumps power consumption was reduced by 50%.

Looking at the monitoring data of the chillers it is apparent that they draw a constant amount of power at all times even though the instruments they are cooling can fluctuate between operating and standby modes. This is an unnecessary use of energy and can easily be eliminated. Replacing each unit with a small heat exchanger and pumping system was a much more efficient alternative. These systems must be made accessible to a tap in each lab that will supply chilled water from the building's central chilled water plant. After making this replacement, the only energy consumption for this process will come from that of the pump in each system and the building's chiller plant. This resulted in a 90% reduction in annual power consumption for the chillers.

The mass spectrometer itself had the highest power consumption out of all equipment monitored. This is because it demands large amounts of power to operate and its functionality requires that it stays on at all times. According to manufacturers' measured data, most brands have lower energy consumption than the particular instrument at hand. However none can perform to the same standards, and therefore, it was not recommended to replace this instrument.

In a group effort involving the engineers, lab users, and manufacturer representatives, extensive analysis was performed on this particular mass spectrometer to assess what was causing the high power consumption, and how to reduce it. The manufacturers are looking at creating more efficient inner components of the machine, mainly the power supplies and electromechanical devices. This is estimated to vastly reduce the overall consumption, however could take years to implement into the instrument's design.

This instrument already had a function that shuts down the plasma when not in analysis mode as can be seen in the graph of monitoring data. However, a standby power of 2 kW is still very high. One possible option for reducing this, which was discovered by the lab users, is to modify the software controls so that when a measurement is finished the magnet is set to Lithium, the lowest mass. The exact amount of power savings from this modification has not yet been quantified, but is estimated to reduce the standby power consumption from 2 kW to 1.5 kW.

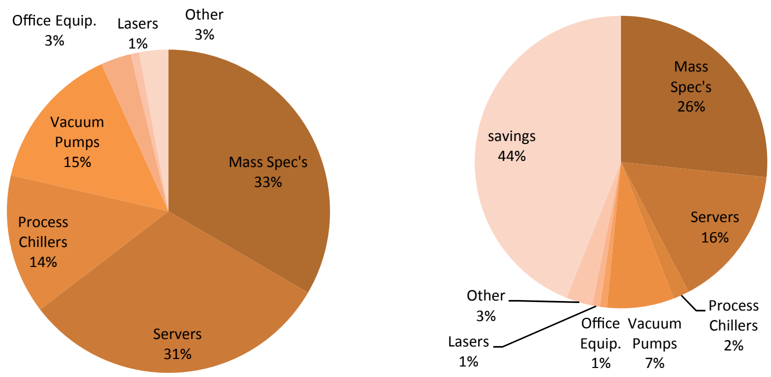


Figure 11.05:
Comparison of traditional lab energy use vs. that of a lab designed for energy efficiency.
(Source: Created by Integral Group)

Execution of all the recommendations for the laboratory resulted in a total of 200 MWh/yr and $36,000 per year that will be saved, which is a 44% reduction of annual energy consumption from that of the current equipment's baseline energy use. Furthermore, implementing these recommendations not only saved the kilowatt-hours the equipment consumes, but also the energy required to cool them.

Related Chapters

- Chapter 6: Right-Sizing for Equipment Loads
- Chapter 8: Metrics and Benchmarks for Energy Efficiency in Labs

References

- Labs for the 21st Century, "A Design Guide for Energy-Efficient Research Laboratories," http://www.labs21century.gov/toolkit/design_guide.htm
- Labs for the 21st Century, "The Energy-Efficient Laboratory Equipment Wiki," http://www.labs21century.gov/toolkit/equip_wiki.htm
- Lab Manager Magazine, "Energy Retrofit," http://www.labmanager.com/articles.asp?ID=528
- Labs for the 21st Century, "Energy Efficient Lab Equipment," http://labs21.lbl.gov/DPM/bestpractices/EAEL-EfficientLabEquip.htm

- Labs for the 21st Century, “Minimize Electrical Distribution Losses,” http://labs21.lbl.gov/DPM/bestpractices/EAEL-EfficientDistribution.htm

- UCSB Sustainability, “LabRATS Programs,” http://sustainability.ucsb.edu/LARS/programs/

- Sustainability at Harvard, “Bacterial Factories Advance Blueprint for Clean Energy,” http://www.greencampus.harvard.edu/labs/best_practices.php

Resources

- Energy Star, www.energystar.gov

- EPEAT, www.epeat.net

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