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HVAC DESIGN - BUILDING RETROCOMMISSIONING ENERGY SAVINGS

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Course #:	HVC-111
Course Content:	71 pgs
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HVC-111 EXAM PREVIEW

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Exam Preview:

1. Retrocommissioning is the first stage in the building upgrade process. The staged approach accounts for the interactions among all the energy flows in a building and produces a systematic method for planning upgrades that increases energy savings.
    a. True
    b. False
2. A recent study of retrocommissioning revealed a wide variety of problems—those related to the overall HVAC system were the most common type. Energy and non-energy benefits: Retrocommissioning provided both energy and non-energy benefits—the most common of these, noted in one-third of the buildings surveyed, was the extension of _____.
    a. Labor savings
    b. Liability reduction
    c. Thermal confront
    d. Equipment life
3. Diagnostic monitoring of energy systems, which can help determine where particular problems lie. Data are typically gathered using a building's existing energy management system (EMS) along with _____ to obtain any data not available through the EMS.
    a. portable data loggers
    b. variable frequency drives
    c. equipment throttled discharges
    d. economizers

4. As part of the retrocommissioning process, only some elements of a building and its energy-using equipment and systems will be examined. Specifically, the commissioning agents will look only at supplemental loads, HVAC distribution systems, and heating and cooling plants to identify tune-up opportunities.
    a. True
    b. False
5. For the building envelope, air infiltration is often a major energy drain that can be addressed during retrocommissioning. Outside air can penetrate a building through a variety of places, most commonly the windows, doors, walls, and roof. In general, a building envelope should meet recommended infiltration standards.
    a. True
    b. False
6. A TAB analysis usually includes a complete review of a building's design documentation. Typical HVAC system components and parameters to investigate include Air system flow rates, including supply, return, exhaust, and outside airflow (flows go through main ducts, branches, and supply diffusers that lead to specific spaces in a building)
    a. True
    b. False
7. There are two types of air-handling systems: constant volume (CV) and variable air volume (VAV). In a CV system, a constant amount of air flows through the system whenever it is on. A VAV system changes the amount of airflow in response to changes in the heating and cooling load. VAV systems offer substantial energy savings and are becoming more widespread.
    a. True
    b. False
8. A CV system that adjusts or resets the temperature of the supply air is a ____system. As cooling loads decrease, chilled water flow is reduced (or "reset" in control system parlance) to create warmer supply air.
    a. CSV
    b. CVVT
    c. CVVS
    d. CXT
9. An optimum start-and-stop procedure is a common-sense control philosophy that can result in significant energy savings. Normally, a system is set to automatically turn itself on and off based upon the expected occupant working hours.
    a. True
    b. False

10. Although furnaces in the existing buildings stock have an average AFUE of only 76 percent, new gas-fired commercial furnaces have an average AFUE of 80 percent, and high efficiency furnaces built with condensing heat exchangers have AFUEs as high as ___ percent.

    a. 90
    b. 91
    c. 92
    d. 93

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Chapter 5
Retrocommissioning




5. Retrocommissioning

Revised October 2007

5.1 Overview

Retrocommissioning is the first stage in the building upgrade process. The staged approach accounts for the interactions among all the energy flows in a building (**Figure 5.1**) and produces a systematic method for planning upgrades that increases energy savings. When the staged approach is adopted and performed sequentially, each stage includes changes that will affect the upgrades performed in subsequent stages, thus setting up the overall process for the greatest possible energy and cost savings. In this staged approach, retrocommissioning comes first because it provides an understanding of how closely the building comes to operating as intended. It also helps to identify improper equipment performance, what equipment or systems need to be replaced, opportunities for saving energy and money, and strategies for improving performance of the various building systems.

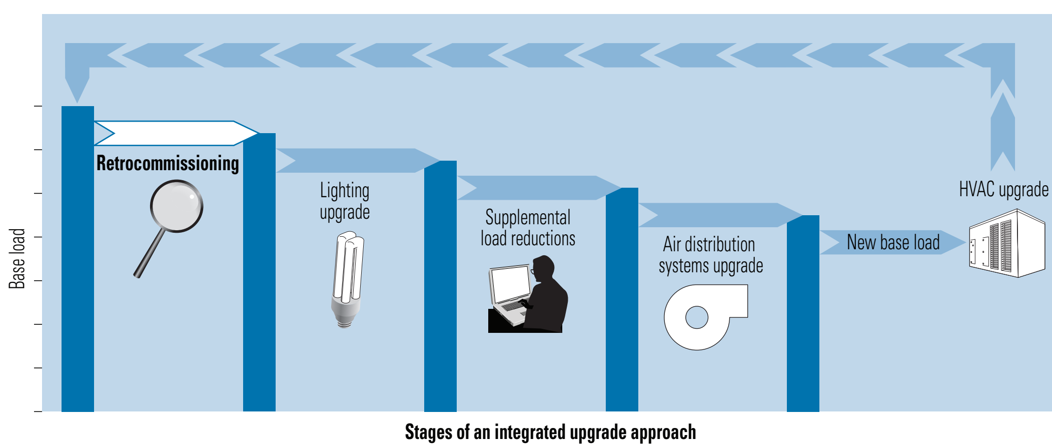
Specifically, retrocommissioning is a form of commissioning. Commissioning is the process of ensuring that systems are designed, installed, functionally tested, and capable of being operated and maintained according to the owner's operational needs. *Retrocommissioning* is the same systematic process applied to existing buildings that have never been commissioned to ensure that their systems can be operated and maintained according to the owner's needs. For buildings that have already been commissioned or retrocommissioned, it is recommended that the practices of recommissioning or ongoing commissioning be applied.

Recommissioning (see Section 5.3) is the term for applying the commissioning process to a building that has been commissioned previously (either during construction or as an existing building); it is normally done every three to five years to maintain top levels of building performance and/or after other stages of the upgrade process to identify new opportunities for improvement.

In *ongoing commissioning*, monitoring equipment is left in place to allow for ongoing diagnostics. Ongoing commissioning is effective when building staff have the time and budget

Figure 5.1: The staged approach to building upgrades

The staged approach to building upgrades accounts for the interactions among all the energy flows in a building. Each stage includes changes that will affect the upgrades performed in subsequent stages, thus setting up the overall process for the greatest possible energy and cost savings. Retrocommissioning begins the process because it provides an understanding of how a facility is currently operating and helps to identify specific opportunities for improvement.



Courtesy: E SOURCE

not only to gather and analyze the data but also to implement the solutions that come out of the analysis.

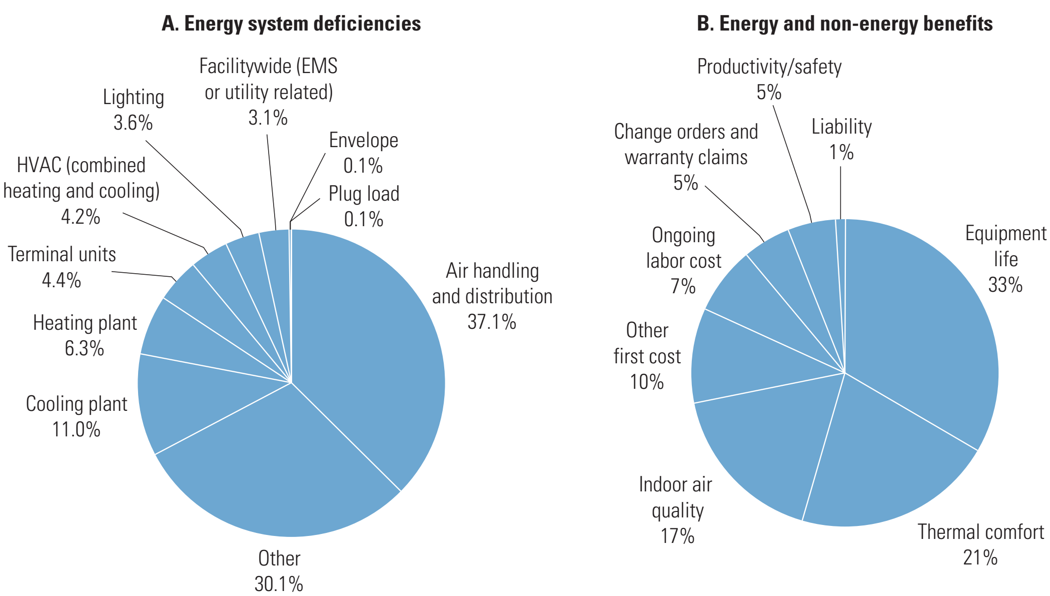
Building owners, managers, staff, and tenants all stand to gain from the retrocommissioning process. It can lower building operating costs by reducing demand, energy consumption, and time spent by management or staff responding to complaints. It can also increase equipment life and improve tenant satisfaction by increasing the comfort and safety of occupants.

Energy and Non-energy Benefits

Researchers at three of the foremost building-commissioning think tanks in the U.S.—Lawrence Berkeley National Laboratory (LBNL), Portland Energy Conservation Inc., and the Energy Systems Laboratory at Texas A&M University—concluded in a study published in December 2004 that retrocommissioning is one of the most cost-effective means of improving energy efficiency in commercial buildings. The researchers statistically analyzed more than 224 new and existing buildings that had been commissioned, totaling over 30 million square feet (ft^2) of commissioned floorspace (73 percent existing buildings and 27 percent new construction). The results revealed the most common problem areas and showed that both energy and non-energy benefits were achieved (**Figure 5.2**). Analysis of commissioning projects for existing buildings showed a median commissioning cost of US$0.27 per ft^2, energy savings of 15 percent, and a simple payback period of 0.7 years. The most cost-effective commissioning projects are typically in energy-intensive buildings such as hospitals and laboratories, whereas the least cost-effective projects are in buildings that are small in comparison with the size of the average commercial building.

Figure 5.2: Retrocommissioning results

Building energy system deficiencies: A recent study of retrocommissioning revealed a wide variety of problems—those related to the overall HVAC system were the most common type (A). Energy and non-energy benefits: Retrocommissioning provided both energy and non-energy benefits—the most common of these, noted in one-third of the buildings surveyed, was the extension of equipment life (B).



Note: EMS = energy management system.

Courtesy: E SOURCE; data from Lawrence Berkeley National Laboratory, Portland Energy Conservation Inc., and Energy Systems Laboratory, Texas A&M University

Target Stores underwent a retrocommissioning project that realized both energy and non-energy benefits. The project was conducted in several SuperTarget® stores where the company identified adjustments to its refrigeration systems, leading to $5,000 to $10,000 in annual energy savings. In addition, according to a study titled "Owner's Strategies for in-House Commissioning," presented at the 2005 National Conference on Building Commissioning, Target funded this effort not only as an energy savings measure but also as a risk-minimization strategy. Optimization of refrigeration equipment reduces risks associated with food quality, which is sensitive to temperature and storage conditions.

Dozens of companies have retrocommissioned their buildings to start their building energy-efficiency upgrade efforts as part of their efforts to earn the ENERGY STAR® Building label (see sidebar). To see descriptions of buildings that have taken this step as part of an ongoing building upgrade process, visit www.energystar.gov/index.cfm?fuseaction=labeled_buildings.showUpgradeSearch&building_type_id=ALL&s_code=ALL&profiles=0&also_search_id=UPGRADE, click on Stage 1, and submit.

The retrocommissioning process described in Sections 5.2 and 5.3 of this chapter follows the recommendations of the "Advanced Retrocommissioning Workbook: A Guide for Building Owners," developed by Portland Energy Conservation Inc. with funding from the U.S. Environmental Protection Agency ENERGY STAR Program. A number of tune-up opportunities may be discovered through this process, as discussed in Section 5.4.

CASE STUDY: The Hatfield Courthouse

Most of the retrocommissioning steps recommended here were carried out when the U.S. General Services Administration (GSA) initiated a full retrocommissioning study of the Hatfield Courthouse, a U.S. federal courthouse located in Portland, Oregon. Built in 1997, the Hatfield Courthouse features 21 floors and a gross square footage of 589,000. The GSA's retrocommissioning goals, as reported by Portland Energy Conservation Inc., were to:

- Improve occupant comfort
- Identify operations and maintenance and energy-efficiency improvements
- Train the building operators on how to help improvements persist
- Review and enhance building documentation

Investigation involved reviewing the building's documentation and utility bills, inspecting building equipment, interviewing building operators, testing selected equipment and systems, and extensive trending of the HVAC control system. The investigation process identified 29 findings that addressed GSA's retrocommissioning goals.

The implementation process involved coordinating efforts among the commissioning provider, facility staff, and building services contractors. The retrocommissioning process resulted in a 10 percent reduction in energy use and significant improvements in building comfort and system operations. Retrocommissioning also increased the building's ENERGY STAR rating from 65 to 75, allowing the building to receive an ENERGY STAR label.

Overall, the project cut annual utility costs by about 10 percent, or $56,000. The project cost (including investigation and implementation, and project oversight costs) was $180,554. Incentives and tax credits brought that number down to $154,772, or about $0.29 per square foot.

5.2 Project Planning

Initial planning activities are critical to the success of any retrocommissioning project because they set the objectives and lay the foundation for the effort. The planning phase begins with the selection of a project, based in part on the generation of an initial benchmark score using the ENERGY STAR national energy performance rating system; selecting and hiring a retrocommissioning service provider and assembling the team that will see the project through to completion; and developing a scope of work.

Selecting a Project

Retrocommissioning is appropriate for most buildings, but there are indicators that can help determine the buildings for which it will be most cost-effective. Owners and property management firms that have building portfolios can look across their holdings to find those properties that should be prioritized for retrocommissioning. Factors to consider are the age and condition of a building and its equipment, existing comfort problems, utility costs, opportunities to share costs with tenants, and the availability of utility and state incentive programs.

The top candidates for retrocommissioning are those buildings with:

- A low ENERGY STAR performance rating or a high energy use index (Btu per ft^2, Btu per patient, and so forth) that cannot be explained, or unexplained increases in energy consumption
- Persistent failure of building equipment, control systems, or both
- Excessive occupant complaints about temperature, airflow, and comfort

Benchmarking

Owners of multiple buildings (private building owners, investment trusts, and property management firms) can evaluate the potential for energy improvement across a portfolio of buildings and select those with the most potential benefit. Owners may choose to have a commissioning provider conduct a study of all their facilities to support development of a multiyear retrocommissioning plan. At a minimum, owners considering retrocommissioning should develop a spreadsheet to understand, compare, and prioritize their building stock to determine which sites present the most opportunity for retrocommissioning. The ENERGY STAR Portfolio Manager benchmarking tool is an effective resource that owners can use for building selection. This tool, including a detailed description of its capabilities, can be accessed by visiting www.energystar.gov/index.cfm?c=evaluate_performance.bus_portfoliomanager.

Portfolio Manager is the most widely used building benchmarking tool in the United States—roughly 17 percent of the eligible commercial space (on a square-footage basis) in the U.S. has been benchmarked using this tool. The building information needed is minimal and can be easily entered online in a private account that owners can create and manage for their buildings.

The tool uses the national energy performance rating system, which was built using statistical algorithms based on an analysis of national survey data conducted by the Department of Energy's Energy Information Administration. This national survey, known as the Commercial Building Energy Consumption Survey (CBECS), is conducted every four years and gathers data on building characteristics and energy use from thousands of buildings across the United States. A specific building's peer group of comparison is defined by those buildings in the CBECS survey that have similar building and operating characteristics. A building is not compared to the other buildings entered into Portfolio Manager to determine the ENERGY STAR rating. For a given building, energy bill data and building characteristics are used to rank the facility on a scale of 1 to 100. The tool accounts for factors that affect energy use but are not the result of inefficient energy use, including climate, occupancy level, hours of operation, and hours of space use. The ranking received by a building reflects how its performance compares to that of similar buildings. A score of 75, for example, means a particular building outperforms approximately 75 percent of its peers. Buildings with a rating of 75 or higher are eligible to receive the ENERGY STAR label, signifying their outstanding level of performance. In general, the lower the rating, the greater the opportunity to improve energy performance levels.

Selecting a Provider and Team

Retrocommissioning projects are often led by a third-party commissioning provider, with varying degrees of involvement by the building owner and staff. When reviewing a commissioning provider's qualifications, it is important to consider the provider's certification (see sidebar), technical knowledge, relevant experience, availability, and communication skills. The building owner should ask if the agent has been involved with ENERGY STAR buildings and benchmarking through Portfolio Manager. If the building does not currently have a rating, this would be a good opportunity to benchmark and get one.

The selection of the commissioning provider is done either by competitive bid or by selection by qualification. A competitive bid requires the owner to issue a request for proposal (RFP). This can be time consuming and expensive but may be the most appropriate method if the project is complex. One word of caution—when comparing bids, be sure to account for any differences in the proposed scope of work from different bidders. Not every bidder responds to the full scope of the RFP.

Many public agencies are required to go with the lowest qualified bidder and should, if using an RFP process, carefully define the minimum qualifications. Selection by qualification is

RESOURCES: Commissioning Certification

The following five organizations currently certify commissioning providers. Visit the organizations' web sites for more information on their certification programs and to obtain lists of certified commissioning providers:

- "Certified Commissioning Professional (CCP)": Building Commissioning Association (BCA), www.bcxa.org/certification/index.htm
- "Certified Commissioning Provider": Associated Air Balancing Council Commissioning Group (ACG), www.acgcommissioning.com/membershipcertification
- "Accredited Commissioning Process Provider": University of Wisconsin at Madison (UWM), http://epdweb.engr.wisc.edu/courses/index.lasso (use link to Building Systems and Construction to find certification training)
- "Systems Commissioning Administrator": National Environmental Balancing Bureau (NEBB), www.nebb.org/bsccertif.htm
- "Certified Building Commissioning Professional (CBCP®)": Association of Energy Engineers (AEE), www.aeecenter.org/certification

often simpler but requires that the owner carefully evaluate the providers' qualifications and interview past clients and references. The process also allows the owner to select the most qualified provider regardless of cost. A sample template and a checklist of factors is included in the "Advanced Retrocommissioning Workbook: A Guide for Building Owners."

Developing a Scope of Work

To develop a scope of work, the commissioning provider visits the site, talks with operations and maintenance staff, and reviews current operating conditions. The commissioning provider then identifies areas of opportunity in the building for energy savings. The following items are indicators of retrocommissioning opportunities commonly found during a building walk-through. Their presence indicates potential problems that can be identified and fixed through a retrocommissioning project:

- Systems that simultaneously heat and cool, such as constant and variable air volume reheat
- Economizers, which often need repair or adjustment—potential problems include frozen dampers, broken or disconnected linkages, malfunctioning actuators and sensors, and improper control settings
- Pumps with throttled discharges
- Equipment or lighting that is on when it may not need to be
- Improper building pressurization (either negative or positive), that is, doors that stand open or are difficult to get open
- Equipment or piping that is hot or cold when it should not be; unusual flow noises at valves or mechanical noises
- Short cycling of equipment
- Variable-frequency drives that operate at unnecessarily high speeds
- Variable-frequency drives that operate at a constant speed even though the load being served should vary

The next step is to define the scope of work—a proposal for work negotiated between the commissioning provider and the owner that outlines the processes and procedures to be undertaken, provides a schedule of activities, identifies the roles of team members, and includes sample forms and templates that the commissioning provider will use to document the retrocommissioning activities.

5.3 Project Execution

The execution phase of retrocommissioning begins with an investigation phase that leads to an understanding of how and why building systems are currently operated and maintained, the identification of issues and potential improvements, and the selection of the most cost-effective measures for implementation. The tasks required to fulfill these goals include:

- A review of facility documentation, which covers operating requirements; original design documents; equipment lists; drawings of the building's main energy-using systems; controls documentation; operations and maintenance manuals; and testing, adjusting, and balancing reports.

- Diagnostic monitoring of energy systems, which can help determine where particular problems lie. Data are typically gathered using a building's existing energy management system (EMS) along with portable data loggers to obtain any data not available through the EMS. Variables typically monitored include whole-building energy consumption (including electricity, gas, steam, or chilled water), end-use energy consumption, operating parameters (such as temperatures, flow rates, and pressures), weather data, equipment status and run times, actuator positions, and setpoints.

- Functional testing, which takes a system or piece of equipment through its paces while personnel observe, measure, and record its performance in all key operating modes. Functional testing also may be used to help verify whether a particular improvement is really needed and is cost-effective. For example, the commissioning provider may observe that the throttling valve on a pump is not fully open. This may indicate that energy savings could be achieved by trimming the impeller so the valve can be fully open. A functional pump test will determine the value of this possible improvement.

Implementing the Recommendations

The recommendations from the investigation are typically implemented according to one of three basic approaches:

- Turnkey implementation is usually applied to projects in which the retrocommissioning provider is capable of providing the service and the in-house staff is either not available to implement any of the measures or does not have the necessary skills. The main advantage of this approach is that only one contract is held by the owner, and any subcontracts are held and managed by the commissioning provider.

- Recommendations can be implemented with the assistance of the retrocommissioning provider, in which case the provider oversees the implementation process but does not directly complete the majority of the work. This strategy works best when a highly skilled in-house staff is available and can carry out much of the work or when the specialized skills of contractors (controls contractors, design professionals, and testing specialists) are required. Working with a commissioning provider to implement the retrocommissioning findings can build in-house skills among facility staff so that they are better able to maintain performance of systems over time.

- Owner-led implementation may be attractive to owners who have strong, established relationships with a service contractor or a highly capable in-house engineer who can implement and verify the retrocommissioning measures.

Whichever approach is used, the recommendations of the investigation phase can be adopted in a staged fashion to accommodate budgeting constraints or implemented in one overall project. Implementing all or most of the measures immediately maintains project momentum and staff involvement and maximizes cost savings. Another key factor is the continued involvement of the commissioning provider, which can be more difficult to maintain if too much time passes without the project moving forward.

As measures are implemented, it is important to verify the results. This verification ensures that the work is completed correctly; it also establishes a new baseline for performance and updates cost savings estimates. The new baseline can be used to establish criteria or parameters for tracking whether or not the improvements are performing properly throughout the life of the equipment or systems and can serve as the baseline for the next round of upgrades on the road of continuous improvement.

RESOURCES: Operator Training

An example of training that is available in many locations across the country is Building Operator Certification (BOC) courses. This series is designed specifically for building operators to improve their ability to operate and maintain comfortable, efficient facilities. There are two skill levels for the courses, and both address multiple topics, including electrical, HVAC, and lighting systems; indoor air quality; environmental health and safety; and energy conservation. More information on locations, schedules, and descriptions is available on the BOC web site at www.theboc.info.

Maintaining the Benefits

Implementation is not the end of the project. Without training for facility staff and an operations and maintenance program, the benefits that accrue will not last. The building owner should request that the commissioning provider develop and conduct additional training for facility staff at the end of the project (see sidebar). A training session usually involves a classroom workshop with some hands-on demonstrations on the building equipment. Owners should consider videotaping the training session for later use and as a resource for training new facility staff. Suggested topics for training sessions include:

- Energy usage analysis
- Operating schedules and requirements
- Methods for identifying problems and deficiencies
- A description of project findings and measures that were implemented
- Improvements expected as a result of the project (show before and after trends if available)
- Operations and maintenance procedures needed to ensure that benefits are maintained
- Staff role in helping to maintain the persistence of savings

A typical preventive maintenance plan consists of a checklist of maintenance tasks and a schedule for performing them. The checklists are kept for each piece of equipment and are updated after maintenance tasks are performed. Incorporating operations into the current maintenance plan entails similar rigor for recording setpoints, settings, and parameters for the control strategies. It also means that operators regularly review and update the owner's operating requirements as occupancy or operational changes are made. A good preventive operation and maintenance plan encourages building operators to continuously ask questions such as:

- Have occupancy patterns or space layouts changed?
- Have temporary occupancy schedules been returned to original settings?
- Have altered equipment schedules or lockouts been returned to original settings?
- Is equipment short-cycling?
- Are time-clocks checked monthly to ensure proper operation?
- Have any changes in room furniture or equipment adversely affected thermostat functions?

- Have occupancy patterns or space layouts changed?
- Are new tenants educated in the proper use and function of thermostats and lighting controls?
- Are the building's sequences of operation performing as intended?

Planning for Recommissioning

From the start, the retrocommissioning project includes steps that ensure that the benefits gained will persist and even be improved upon. That is one reason why good documentation, ongoing training, and the performance of preventive operations and maintenance should be included. In addition, planning for recommissioning or ongoing commissioning will help keep a building operating at optimal levels.

The timing of a recommissioning effort will vary depending on the timing of changes in the facility's use, the quality and schedule of preventive maintenance activities, and the frequency of operational problems (see sidebar). Factors that indicate the need for recommissioning include:

- An unjustified increase in energy use or a lower ENERGY STAR score
- An increase in the number of comfort complaints
- An increase in nighttime energy use

CASE STUDY: Recommissioning Provides Rapid Payback

The University of Montana in Missoula, Montana, found that even for a relatively new building, the recommissioning process can be cost-effective. The Gallagher School of Business Administration building was partially commissioned after it was built in 1997. After several years of operation, however, performance problems and complaints began to appear. To address the problems, the university decided to recommission the building.

Working with the Montana Department of Environmental Quality (MDEQ), with funding from the Northwest Energy Efficiency Alliance and support from the U.S. Department of Energy's Rebuild America Program, the university hired a commissioning provider who completed the process by the fall of 2002. The analysis revealed and suggested fixes for 346 problems in the building, including dampers that could not fully open or close, valves that leaked or could not close, and equipment controls that were out of calibration. Implementing many of these measures produced an estimated annual energy cost savings of approximately $19,500. The simple payback for the commissioning provider fee of $24,380 was 1.25 years (the university used its own building staff to implement the corrective measures).

The recommissioning effort delivered several lessons. A big factor in the building's declining performance was that its occupancy load had changed. As enrollment in the business school increased, the number of new people and computers added loads that the heating and cooling systems had not been designed to handle. Periodic recommissioning can help a building to meet such changing needs. In addition, periodic recommissioning is required for complex HVAC control systems to maintain their efficiency and performance. Based on the commissioning findings and a payback analysis, the MDEQ recommended that the university recommission the Gallagher building every three to five years to keep it operating efficiently.

- An awareness of problems but lack of time or expertise to fix them
- Overriding of control logic or setpoints by staff or occupants to quickly "fix" problems
- Frequent equipment or component failures
- Significant tenant build-out projects
- Replacement of major systems or controls since the last commissioning or retrocommissioning effort

The recommissioning process is similar to that followed for retrocommissioning, although it can be less expensive because it can build on the data collection and documentation that will have already been completed. Recommissioning typically involves minor system improvements but in some projects may require more significant design, scheduling, and budgeting issues.

In some cases, ongoing commissioning can be cost-effective. In these cases, monitoring equipment is installed or left in place to allow for ongoing diagnostics and corrective actions. This approach works best in buildings with modern EMSs, Class A buildings (the most prestigious buildings in a particular market), and any site where there is an individual or champion committed to the process. A modern EMS makes more control strategies available and typically has most of the data needed to do diagnostics. Class A buildings often have dedicated energy managers concerned with both saving energy and keeping occupants comfortable.

5.4 Tune-up Opportunities

As part of the retrocommissioning process, all elements of a building and its energy-using equipment and systems will be examined. Specifically, the commissioning agents will look at lighting, supplemental loads, HVAC distribution systems, and heating and cooling plants to identify tune-up opportunities. The order in which the various measures will be implemented is determined after all the potential improvements have been identified and the most cost-effective measures have been selected for implementation. However, making simple repairs as the need is identified is usually the most effective strategy. Small adjustments, such as a sensor calibration, not only improve current operations but also increase the effectiveness of diagnostic monitoring and testing.

Lighting

The lighting systems within a building are an integral part of a comfortable working environment (see Chapter 6). Over time, all lighting systems become gradually less efficient. Certain efficiency losses are unavoidable, such as reductions in light output due to the aging of lighting equipment. However, other efficiency losses, such as improperly functioning controls, dirt accumulation on fixture lenses and housings, and lumen depreciation can be avoided by regularly scheduled lighting maintenance.

A lighting system tune-up should be performed in the following order:

- Follow a strategic lighting maintenance plan of scheduled group relamping and fixture cleaning
- Measure and ensure proper light levels
- Calibrate lighting controls

Periodically cleaning the existing fixtures and replacing burned-out lamps and ballasts can considerably increase fixture light output (see the section on building in an operations and maintenance plan in Chapter 6, "Lighting"). This simple and cost-effective tune-up item can often restore light levels in a building to close to their initial design specifications.

After cleaning and relamping have been accomplished, measure existing light levels to determine whether or not illuminance levels are appropriate for the tasks being performed in the space (see Chapter 6, "Lighting"). Because space use and furnishings may change over time, it is important to match the lighting level to the current occupant requirements. The Illuminating Engineering Society of North America issues recommended illuminance levels depending on the job or activity performed. Overlit or underlit areas should be corrected. Lighting uniformity should also be assessed, as relocation of furniture and even walls may have altered lighting distribution.

Once the proper light levels and uniformity have been achieved in the space, examine the automatic lighting controls. Many buildings use a variety of automatic controls for time-based, occupancy-based, and lighting level–based strategies (see the section on automatically controlling lighting in Chapter 6, "Lighting"). These controls may have never been properly calibrated during installation, or occupants may have tampered with them. Adjusting these controls and associated sensors will reduce occupant complaints, maintain safety, and ensure maximum energy savings.

Many buildings use EMSs, time-clocks, and electronic wall-box timers to control lighting automatically based on a predictable time schedule. These systems need to be programmed correctly to ensure that lights are operating only when the building is occupied and that overrides are operational where required. Exterior lighting schedules must also be changed throughout the year according to the season.

The performance of occupancy or motion sensors depends on customizing the sensitivity and time-delay settings to the requirements of each individual space. The sensor's installed position should also be checked to ensure adequate coverage of the occupied area. Also, keep furnishings from obstructing the sensor's line of sight. Any indoor and outdoor photocell controls should also be checked to ensure the desired daylight dimming or daylight switching response. Setpoints should be adjusted so that the desired light levels are maintained.

The savings associated with performing a lighting tune-up will vary depending on the quality and performance of the current lighting system. For example, cleaning alone may boost fixture light output from 10 percent in enclosed fixtures in clean environments to more than 60 percent in open fixtures located in dirty areas. Simple calibration of occupancy sensors and photocells can restore correct operation, reducing the energy used by the lighting system in those areas by 50 percent or more.

Supplemental Loads

Supplemental load sources are secondary load contributors to energy consumption in buildings. In the retrocommissioning process, loads can be cut by reducing equipment energy use and sealing the building envelope.

In many facilities, energy is wasted running office equipment that is left on when not in use throughout the workday, at night, and on weekends. Electrical loads from office equipment can be reduced by encouraging occupants to shut off equipment when it is not in use, using ENERGY STAR–labeled office equipment, and enabling power management features (see Chapter 7). Energy-efficient equipment not only uses energy efficiently but typically features a low-power sleep mode for inactive equipment. ENERGY STAR–labeled equipment often costs the same as comparable nonlabeled equipment, but these products typically use about half as much electricity as conventional equipment.

For the building envelope, air infiltration is often a major energy drain that can be addressed during retrocommissioning. Outside air can penetrate a building through a variety of places, most commonly the windows, doors, walls, and roof. In general, a building envelope should meet recommended infiltration standards. A frequent result of infiltration problems is an increase in building heating, cooling, and/or electrical loads (when, for example, occupants may bring in space heaters or fans). In addition, the escape of conditioned air forces the air-handling system to work longer and harder to provide the required space temperature.

To reduce air infiltration, take the following steps:

- Tighten the existing building by locating all air leaks in the windows, doors, walls, and roofs.
- Seal with appropriate materials and techniques such as weather stripping on doors; sealing and caulking on windows; and proper insulation distribution in walls, ceilings, and roofing.
- Encourage the use of revolving doors in buildings so equipped. Revolving doors significantly reduce drafts and the loss of conditioned air.
- Calibrate automatic doors to minimize air loss from the building envelope.

Reducing infiltration will result in a reduction in heating and cooling loads. Typical savings for a large office building range up to 5 percent of heating and cooling costs.

Distribution Systems

The systems that distribute air and water for space conditioning throughout a facility may need to be balanced and cleaned as part of the retrocommissioning effort. In a process known as testing, adjusting, and balancing (TAB), HVAC system components are adjusted so that air and water flows match load requirements. The process begins with testing to evaluate the performance of the equipment in its current state and making recommendations for improvements. Adjustments to flow rates of air or water are then made for the purpose of balancing the system and matching the loads throughout a building. Indications that TAB is needed include frequent complaints from occupants about hot or cold spots in a building, the renovation of spaces for different uses and occupancy, and the need for frequent adjustments of HVAC components to maintain comfort.

A TAB analysis usually includes a complete review of a building's design documentation. Typical HVAC system components and parameters to investigate include:

- Air system flow rates, including supply, return, exhaust, and outside airflow (flows go through main ducts, branches, and supply diffusers that lead to specific spaces in a building)
- Water system flow rates for chillers, condensers, boilers, and primary and secondary heating and cooling coils
- Temperatures of heating and cooling delivery systems (air side and water side)
- Positions and functioning of flow-control devices for air and water delivery systems

- Control settings and operation
- Fan and pump speeds and pressures

The savings associated with TAB come from the reductions in the energy used by the heating and cooling system and can range up to 10 percent of heating and cooling costs.

The heat exchange equipment that cools and heats the air that ultimately reaches building spaces should also be inspected and cleaned if necessary. This equipment usually consists of heating and cooling coils installed in air handlers, fan coil terminal units, or baseboard radiators. These units are typically supplied with chilled water and hot water from a central plant. The heating and cooling coils can also be part of a packaged unit such as a rooftop air-conditioning unit or central station air-handling unit.

All surfaces and filters should be clean—dirty surfaces reduce heat transfer and increase pressure loss, which serves to increase energy use. The cleaning technique depends on the type of equipment:

- For air-side heating and cooling coils, whether in an air handler or in a rooftop unit, the methods for cleaning include compressed air, dust rags or brushes, and power washes. Any of these techniques will reduce deposit buildup. In addition, check baseboard heating systems for dust buildup, and clean them if necessary.
- The water side of heating and cooling systems is generally inaccessible for mechanical cleaning. Chemical treatments are often the best solution for cleaning these surfaces. Ongoing water treatment and filtering of the water side are recommended to reduce dirt, biological, and mineral-scale buildup. Filters for both air-side and water-side systems should be cleaned and replaced as necessary.

In addition, make sure that terminal fan coil units and baseboards are not blocked or covered with books, boxes, or file cabinets. Besides creating a fire hazard (in the case of radiators), blocking the units prevents proper air circulation and renders heating and cooling inefficient.

In general, the cleaner the heat transfer surfaces, the greater the savings. In addition, cleaning coils and filters may reduce the pressure drop across the coil and reduce fan or pump energy consumption. Savings can range up to 10 percent.

Heating and Cooling Systems

Both controls and components of the heating and cooling systems present savings opportunities during the retrocommissioning process. The EMS and controls within a building play a crucial role in providing a comfortable building environment. Over time, temperature sensors or thermostats may drift out of tune. Wall thermostats are frequently adjusted by occupants, throwing off controls and causing unintended energy consumption within a building. Poorly calibrated sensors can increase heating and cooling loads and lead to occupant discomfort. Occupants are likely to take matters into their own hands if they consistently experience heating or cooling problems. To tune up the heating and cooling controls, take the following steps:

- *Calibrate the indoor and outdoor building sensors.* Calibration of room thermostats, duct thermostats, humidistats, and pressure and temperature sensors should be in accordance with the original design specifications. Calibrating these controls may require specialized skills or equipment and may call for outside expertise.

- *Inspect damper and valve controls to make sure they are functioning properly.* Check pneumatically controlled dampers for leaks in the compressed-air hoses. Also examine dampers to ensure that they open and close properly. Stiff dampers can cause improper modulation of the amount of outside air being used in the supply airstream. In some cases, dampers may actually be wired in a single position or disconnected, violating minimum outside air requirements.

- *Review building operating schedules.* HVAC controls must be adjusted to heat and cool the building properly during occupied hours. Occupancy schedules can change frequently over the life of a building, and control schedules should be adjusted accordingly. Operating schedules should also be adjusted to reflect daylight saving time. When the building is unoccupied, set the temperature back to save some heating or cooling energy, but keep in mind that some minimum heating and cooling may be required when the building is unoccupied. In cold climates, for example, heating may be needed to keep water pipes from freezing.

- *Review the utility rate schedule.* Utilities typically charge on-peak and off-peak times within a rate, which can dramatically affect the amount of electric bills. If possible, equipment should run during the less expensive off-peak hours. For certain buildings, precooling and/or preheating strategies may be called for (see Chapter 9, Additional Strategies).

Savings from these control tune-up measures can range up to 30 percent of annual heating and cooling costs. The elements of both heating and cooling systems can also benefit from a tune-up as part of the retrocommissioning process. On the cooling side, the following measures can be effective:

- *Chilled-water and condenser-water reset.* In facilities with a central chiller system, the operating efficiency can be increased through a practice known as chilled-water reset—modifying the chilled-water temperature and/or condenser-water temperature in order to reduce chiller energy consumption. (For more information on chilled water reset and specific types of chiller equipment, see Chapter 9.)

- *Chiller tube cleaning and water treatment.* Cleaning chiller tubes and improving water treatment can also improve performance of a chiller system by providing cleaner surfaces for heat transfer on both the refrigerant and water sides of the chiller tubes (see Chapter 9).

- *Reciprocating compressor unloading.* For smaller chiller systems that use reciprocating compressors with multiple pistons, part-load performance can be improved by making sure that the control system properly unloads pistons as the load decreases. If the controls fail to unload, then the system may cycle unnecessarily during low cooling loads. Because starting and stopping are inherently inefficient, cycling decreases the efficiency of the cooling system. Additionally, increased cycling can lead to compressor and/or electrical failures. Unloading is typically controlled by a pressure sensor that is set for a specific evaporator pressure. This sensor, and the controls dependent upon it, can fall out of calibration or fail.

- *Chiller tube cleaning and water treatment.* Cleaning chiller tubes and improving water treatment can also improve performance of a chiller system by providing cleaner surfaces for heat transfer on both the refrigerant and water sides of the chiller tubes (see Chapter 9).

On the heating side, boiler performance can often be improved by a tune-up. For safety reasons, it is a good idea to obtain specialized expertise for boiler tune-up items. The following measures can be effective:

- *Maintaining boiler steam traps.* Boiler system steam traps, which remove condensate and air from the system, commonly need maintenance. They frequently become stuck in the open or closed position. When a trap is stuck open, steam can escape through the condensate return lines to the atmosphere, and the resulting energy loss can be significant. Check steam traps frequently for leaks, and make repairs as needed.
- *Adjusting combustion airflow.* For fossil-fuel-powered boilers, adjusting the combustion airflow usually improves system performance. More air is typically supplied for combustion than is needed. Excess air helps prevent incomplete combustion, and that action helps eliminate hazards such as smoke and carbon monoxide buildup. However, if too much air is introduced, some of the fuel is wasted in heating this excess air. A tune-up of combustion air consists of adjusting combustion air intake until measured oxygen levels in the flue gas reach a safe minimum.
- *Boiler tube cleaning and water treatment.* As with chillers, these measures improve heat transfer in the system. Both the fire side and water side of the boiler tubes can be cleaned by physically scrubbing the surfaces and sometimes by applying a chemical treatment. Treating the heating water may also be a good option to improve efficiency.

When all retrocommissioning steps are taken together, heating and cooling cost savings can reach upwards of 15 percent.

5.5 Summary

The goal of the retrocommissioning stage in a building upgrade effort is to ensure that the building operates as intended and meets current operational needs. Doing so can be very cost-effective, with field experience showing typical costs of about US$0.27/ ft^2, energy savings of about 15 percent, and a simple payback period of 0.7 years.

A well-planned and -executed retrocommissioning project generally consists of planning and execution phases. In addition, the effort includes plans to ensure that benefits persist and can be added to through such measures as training, preventive operations and maintenance, and performance tracking. Plans should also be made for periodic recommissioning or ongoing commissioning of the building. Recommissioning follows the same process as retrocommissioning, but where *retrocommissioning* applies to buildings that have never been commissioned, *recommissioning* is the term used for buildings that have already been commissioned at least once. In *ongoing commissioning,* monitoring equipment is left in place to allow for ongoing diagnostics.

As part of the retrocommissioning effort, adjustments and fine-tuning may be made to all building systems, including lighting, supplemental loads, building envelope, controls, and all aspects of heating and cooling systems.

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Chapter 8
Air Distribution Systems




8. Air Distribution Systems

Revised April 2008

8.1 Overview

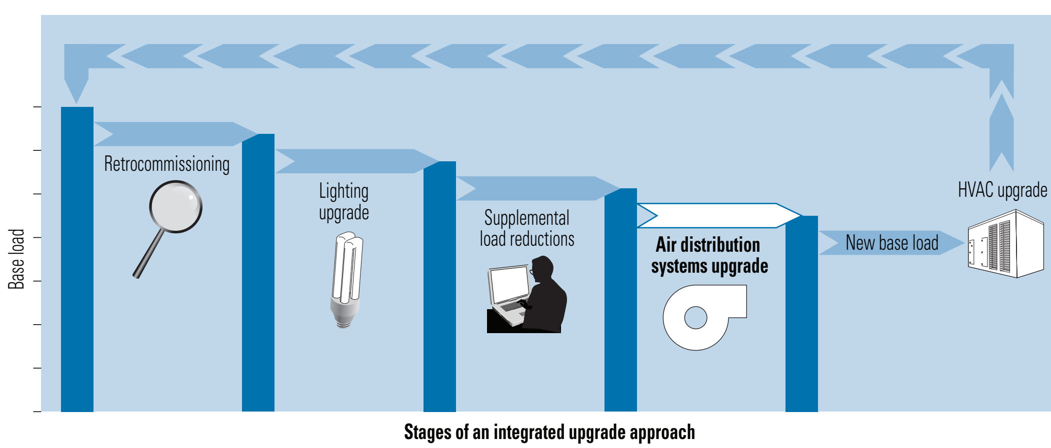
Air distribution systems bring conditioned (heated and cooled) air to people occupying a building, and therefore directly affect occupant comfort. Over the last several decades, significant improvements have been made to the design of air distribution systems as well as to the way in which these systems are controlled. These improved designs and controls can result in dramatic energy savings, yet many buildings continue to rely on obsolete, inefficient systems for this critical function.

The energy savings achieved in the Retrocommissioning, Lighting, and Supplemental Load Reductions stages (**Figure 8.1**) are likely to have reduced the load on the building's HVAC system, sometimes considerably. But before evaluating the potential to replace the existing heating and/or cooling equipment with smaller and more-efficient equipment, optimize the efficiency of the air distribution system itself. Doing so may well enable even greater savings and a reduction in required heating and cooling equipment capacity.

On average, the fans that move conditioned air through commercial office buildings account for about 7 percent of the total energy consumed by these buildings (**Figure 8.2**), so reductions in fan consumption can result in significant energy savings. A U.S. Environmental Protection Agency (EPA) study found that almost 60 percent of building fan systems were oversized by at least 10 percent, with an average oversizing of 60 percent. "Rightsizing" a fan system, or better matching fan capacity to the requirements of the load, is an excellent way to save energy in air distribution systems. There are also opportunities for energy-saving improvements to the air distribution system in four other categories: adjusting ventilation to conform with code requirements or occupant needs, implementing energy-saving controls, taking advantage of free cooling where possible, and optimizing the efficiency of distribution system components. This chapter will describe the opportunities in each of these areas, but first, it is important to gain an understanding of the types of systems that are commonly encountered and the various components of air distribution systems.

Figure 8.1 The staged approach to building upgrades

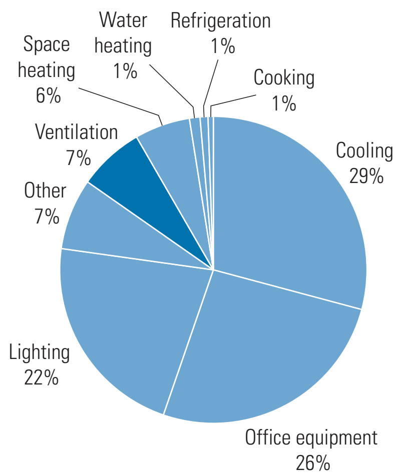
The staged approach to building upgrades accounts for the interactions among all the energy flows in a building. Each stage includes changes that will affect the upgrades performed in subsequent stages, thus setting the overall process up for the greatest energy and cost savings possible. The air distribution systems stage takes advantage of the load reductions achieved in earlier stages.



Courtesy: E SOURCE

Figure 8.2: Typical electricity consumption in commercial office buildings

The power used to circulate conditioned air accounts for approximately 7 percent of commercial office building electricity consumption.



Source: U.S. Department of Energy

8.2 Air-Handling System Types

There are two types of air-handling systems: constant volume (CV) and variable air volume (VAV). In a CV system, a constant amount of air flows through the system whenever it is on. A VAV system changes the amount of airflow in response to changes in the heating and cooling load. VAV systems offer substantial energy savings and are becoming more widespread.

Constant-Volume Systems

Constant-volume systems are the simplest type of air distribution system and are installed in a large percentage of existing commercial buildings. In a CV system, when the supply fan is on, a constant amount of air flows through; there is no modulation of the fan power, no discharge dampering at the fan, and no dampering at the terminal ends of the duct runs. In its simplest configuration, a CV system serves a single space (also called a zone). A thermostat is located in the zone that senses space temperature and sends signals to the air-handling unit to provide heating or cooling based on the thermostat setting.

Reheat systems. In larger buildings, CV systems serve multiple zones with varying heating or cooling requirements. For example, a perimeter office with a vast expanse of south-facing glass may require cooling in the middle of December when the rest of the building requires heating. Constant-volume systems that serve multiple zones are typically designed with some way to vary the temperature of air delivered to each zone. To meet differing cooling loads with a CV system, *terminal reheat* or *zone reheat* is frequently added: an electric resistance element, hot water coil, or other heat source that reheats the cooled air just before it enters the room. The system is sized to provide cooling to the zone with the peak load, and all zones with less cooling load have their air reheated as it enters the zone. In humid climates, reheat systems not only provide terminal control but also strip moisture out of the supply airstream by allowing deep cooling of the primary air.

Reheat systems are as inefficient as they sound: energy is used first to cool and then to reheat the air. The thermostat in a CV-supplied zone only controls the amount of reheat applied to that zone's air. If reheat is not applied, zones will be overcooled, possibly to uncomfortable levels. CV systems without temperature reset (thermostatic control of the supply-air temperature) are now prohibited by many energy codes.

Constant-volume, variable-temperature (CVVT) systems. A CV system that adjusts or resets the temperature of the supply air is a CVVT system. As cooling loads decrease, chilled water flow is reduced (or "reset" in control system parlance) to create warmer supply air. This reset can be controlled by monitoring either the outside air temperature (outside-air reset) or the cooling needs of the warmest zone (warmest-zone reset). Although outside-air reset has simpler controls and thus may be more reliable, it bases its strategy on the frequently incorrect assumption that cooling load varies linearly with the temperature of the outside air. Solar gain through the windows and internal heat gain from people, lights, and equipment all impact the cooling load independently of the outside temperature. Warmest-zone reset, which directly monitors the indoor air temperature of interest, is more accurate: the supply-air temperature is set just low enough to cool the zone with the highest cooling load.

Because CVVT systems respond to changes in cooling load by reducing the load on the chiller, they use less cooling energy than simple CV systems do. In reheat systems, less energy is used to reheat the air because the supply air is already warmer due to the temperature reset. However, the system only responds to the peak load in each zone; large load differences among zones can still cause substantial overcooling or reheating. This is why reduction of building-skin loads with shading or window films is important: it can reduce that peak load, raise the supply-air temperature, and enable all other zones served by that air handler to use warmer supply air, use less chiller energy, and require less reheat energy. Also, for hot water reheat systems, the temperature of the hot water can be reduced based on the outside air temperature or a "coldest-zone reset" to further reduce the energy waste associated with mixing heated and cooled air.

Dual-duct systems. Often found in buildings constructed during the 1960s and 1970s, dual-duct systems are a relatively effective means of maintaining comfort, yet an extremely inefficient method of conditioning air. Dual-duct systems consist of two independent systems, one warm and one cool, that circulate air through all sections of the building via a parallel sets of ducts. Hot and cold air are mixed in local mixing boxes (also called zone dampers or, sometimes, "pair of pants" dampers) in each zone and then fed into that area. Depending on the temperature needs of the zone, the mixture of hot and cold air is adjusted until the desired temperature is reached. Unfortunately, with a dual-duct system, a volume of air that is typically much larger than the actual volume required by the building must be cooled, heated, and circulated.

In addition, the dampers in dual-duct mixing boxes frequently leak, even when they are supposed to be fully closed. During cooling operation, warm duct leakage increases the energy necessary to condition the space. The leakage is a function of construction quality and of the static pressure in the duct. Leakage ratios vary from about 3 percent to about 20 percent, with 5 percent often used as an estimate for well-built systems.

Multizone systems. Multizone systems are similar to dual-duct systems in that two streams of air, hot and cold, are mixed to produce a desired temperature. But whereas dual-duct systems mix the air in individual boxes located at each area or room, multizone systems mix air with dampers near the fans. This conditioned air is then fed to each zone so that each zone receives air at a different temperature based on its load.

There are several advantages to the multizone design. These systems require less ductwork and dampering, and therefore occupy less space, than a dual-duct system. Furthermore, the location of the mixing dampers facilitates their inspection and repair. Also, these systems tend to be quieter because the noise and vibration associated with air passing over the mixing dampers is not directly above the conditioned space. On the other hand, the disadvantages of multizone systems are the wasted energy to supply simultaneous heating and cooling and the high capital cost for the multizone dampering unit. In addition, the placement of the mixing dampers directly downstream of the main supply fan means that the air velocity will be high as it passes through them, creating significant pressure loss. The supply fan must compensate for this pressure loss to ensure adequate airflow to each zone. Finally, the dampers on the hot and cold supply streams may leak, requiring additional energy to achieve the desired temperature setpoint.

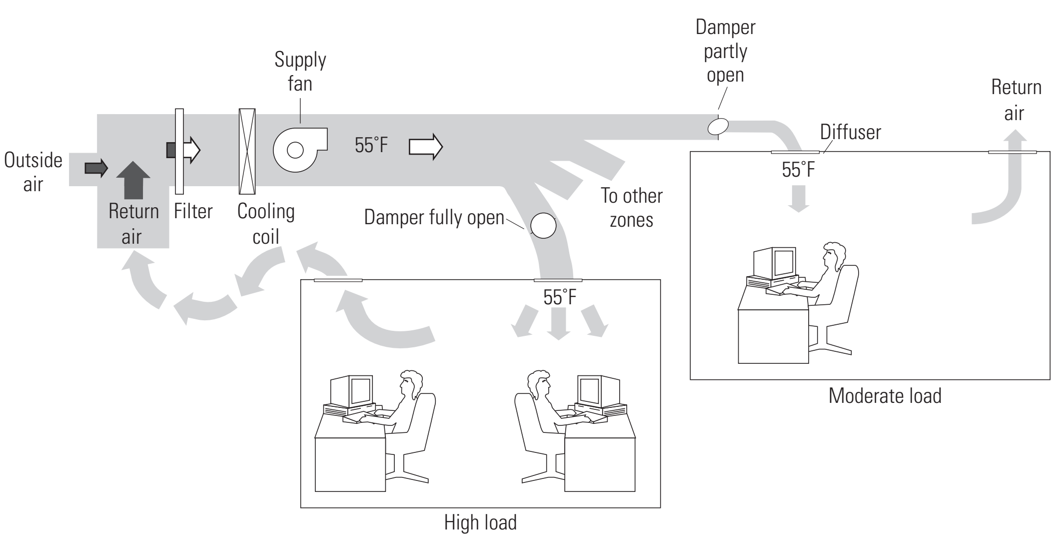
Variable Air Volume Systems

Currently available air distribution components, controls, and design strategies offer much more efficient designs than those installed and operating in many existing buildings. Today's VAV systems can handle changing load requirements by varying the amount of heated or cooled air circulated to the conditioned space in response to varying heating or cooling loads. This reduces fan power requirements, which saves energy and costs.

VAV systems work either by opening or closing dampers or by modulating the airflow through mixing boxes powered by VAV fans as loads in various zones of the building change (**Figure 8.3**). If, for example, more cooling in an area is required, the damper to that area is opened wider, increasing the flow of cold air until the desired temperature is reached. As the damper opens, static pressure in the duct drops, signaling the fan to increase air delivery. Conversely in this same example, if an area is too cool, the damper is slowly closed, reducing the flow of cold air. Used in combination with variable-speed drives (VSDs), this reduction in flow results in a reduction in the fan power needed, saving energy. Converting an existing constant-volume system to a VAV system is a popular option for many building owners, because it allows the system to turn itself down in response to changing demand.

Figure 8.3: Variable air volume system

In a VAV system, dampers control the flow of chilled air to respond to changes in cooling load.



Note: F = Fahrenheit.

Courtesy: E SOURCE

A proper conversion to a VAV system includes changing constant-volume dampers to operate in variable-volume fashion, which typically reduces fan horsepower requirements by 40 to 60 percent. Conversion from constant to variable volume can be complicated in certain circumstances due to nonmechanical factors such as:

- If the existing zone dampers are located in difficult-to-access spaces;
- If the space has a hard ceiling (typically with undersized metal access panels used to reach the mixing dampers for service);
- If the spaces to be converted have a "concealed spline" ceiling tile system (where nearly the entire ceiling must be disassembled to get at one particular spot because all of the ceiling tiles interlock); or
- If asbestos is present in the ceiling space.

It is also possible to convert an existing constant-volume, single-zone system to variable volume without modifying the zone dampers, though careful planning and testing are required for a successful project. In this type of conversion, a VSD is installed to control supply-fan speed. The VSD is controlled by either the return air temperature or the outside air temperature. Typically, to maintain comfort, the airflow reduction range is limited in such systems to 30 to 40 percent of design flow. However, even this modest reduction in airflow can reduce fan power by more than 50 percent. An additional benefit is that, under mild temperature conditions, reheat energy will be reduced along with airflow.

As with constant-volume systems, VAV supply air temperature can be reset (raised) if loads drop enough, thus reducing chiller load as well as fan power. Such a variable-volume, variable-temperature (VVVT) system changes both the temperature and the volume of supply air as needed to achieve maximum load responsiveness while minimizing reheat. A fully loaded VVVT system moves fully chilled air, usually at 55° Fahrenheit (F), at maximum fan capacity with all terminal dampers wide open. As cooling loads drop, the terminal dampers close as necessary and the supply fan slows down. When dampers reach their minimum position, zone reheat is applied (if available). Finally, when all zones are at their minimum stops, the supply air temperature is reset (raised) so that the warmest zone will need no reheat. This has the double effect of reducing the load on the chiller and decreasing the reheat energy throughout the system. The trade-off between resetting supply-air temperature and lowering supply-air volume can be optimized for a given system, perhaps reversing the order of volume reduction and temperature reset. Due to the complexity of the control system, a high degree of expertise is required to successfully commission VVVT systems.

8.3 Air-Handling Components

The major components in an air-handling system are its fans, filters, ducts, and dampers. Each component performs a task critical to the proper operation of the system: Fans circulate the air and provide the pressure required to push it through filters, coils, ducts, transitions, fittings, dampers, and diffusers. Filters clean the air, protecting occupant health, inhibiting bacteria and mold growth, and keeping coil surfaces clean. Ducts convey the conditioned air throughout the building, distributing the air to occupants and then returning it to be conditioned and circulated again. Dampers control the flow and mix of returned and outside air through the ducts to the various parts of the building. All of these components must function well both individually and together to ensure efficient system operation and occupant comfort.

Fans

Fans are the heart of a building's air-handling system. Like a heart that pumps blood through a body, they distribute the conditioned (heated or cooled) air throughout the building. There are two main types of fans: centrifugal and axial (**Figure 8.4**).

Centrifugal fans. Centrifugal fans are by far the most prevalent type of fan used in the HVAC industry today. They are usually cheaper than axial fans and simpler in construction, but they generally do not achieve the same efficiency. Centrifugal fans consist of a rotating wheel, or impeller, mounted inside a round housing. The impeller is driven by a motor, which is usually connected via a belt drive.

Axial fans. Axial fans consist of a cylindrical housing with the impeller mounted inside along the axis of the housing. In an axial fan, the impeller consists of blades mounted around a central hub similar to an airplane propeller. As with an airplane, the spinning blades force the air through the fan. Axial fans are typically used for higher-pressure applications (over 5 inches total static pressure) and are more efficient than centrifugal fans.

The motor of an axial fan can be mounted externally and connected to the fan by a belt. However, axial fans are often driven by a motor that is directly coupled to the impeller that is mounted within the central hub. As a result, all heat due to motor electrical losses is added to the airstream and must be removed by the cooling system.

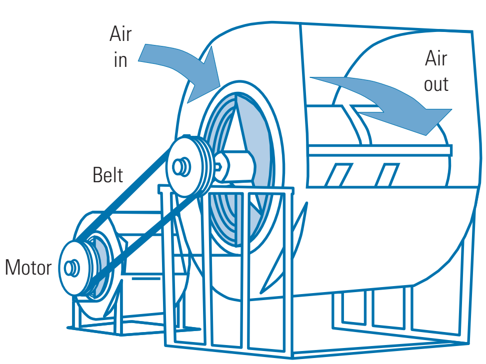
Filters

Air filtration occupies an increasingly important role in the building environment. The high profile of ASHRAE's (the American Society of Heating, Refrigerating, and Air-Conditioning Engineers') indoor air quality standard (Standard 62.1-2007) and recent actions by the Occupational Safety and Health Administration (OSHA) have combined to give air filtration new prominence. Filtration also has a substantial impact on energy efficiency. With static pressure drops of up to 0.072 pounds per square inch (psi), filters can consume an enormous amount of fan power. As with other air-handling components, the key to efficient filtration is to consider the details, especially face velocity (airflow per unit area of filter media).

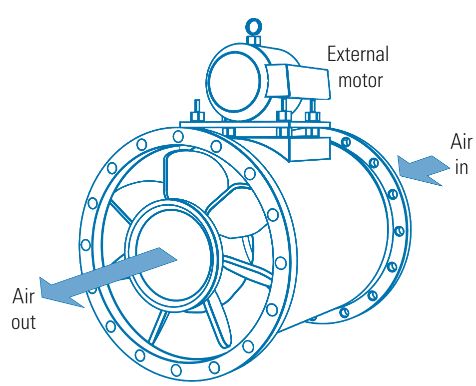
Figure 8.4: Centrifugal and axial fans

Centrifugal fans (A) are the most common fans used in HVAC applications. They are often cheaper but usually less efficient than axial fans (B).

A. Centrifugal fan



B. Axial fan



Courtesy: E SOURCE

Filters work by capturing particles through gravity or through centrifugal collection, screening, adhesion, impingement, and/or adsorption. The *efficiency* of a filter refers not to energy efficiency, but to how well it removes particles from the airstream. *Pressure drop* is the measure that determines how much fan power is required to move air through the filter, and it varies by the square of the air speed through it. For typical HVAC-duty filters (30 percent ASHRAE dust-spot efficiency) a reasonable target pressure drop is 0.0036 psi. Dirty, thick, or poorly designed filters can have pressure drops as high as 0.072 psi—as much as the entire frictional drag of the duct system. Higher pressure also increases fan noise and vibration, duct leakage, wear and tear on the fan and other mechanical components, and a host of other air-handling ills that add real costs to fan operation. Filter performance and longevity are improved with uniform airflow, which is found upstream of the supply fan rather than downstream. Upstream filter placement also cleans the air before it moves through the cooling coils and the fan, helping to maintain their efficiency as well.

Regular filter maintenance is essential to keeping ductwork and coils clean. Dirt accumulation in ductwork can facilitate the growth of bacteria and mold, particularly if condensation occurs within the ducts. Dirt accumulation on coils impedes heat transfer, reducing system efficiency and increasing HVAC costs. Dirty filters will also reduce airflow, and may therefore reduce occupant comfort.

Visual inspection is not always an adequate way to determine whether filter cleaning or replacement is necessary. A sure-fire way to determine when filter maintenance is necessary is to install a device that measures pressure drop across the filter bank. A signal from such a device can be an input to a building automation system to alert operators when filter maintenance is required.

Commonly found filter types in commercial buildings include dry filters, bag filters, high-efficiency particulate air (HEPA) filters, electrostatic precipitators, and carbon filters.

Dry filters. Dry filters have fine strands of fabric or fiber that intercept smaller particles of about 0.5 to 5.0 micrometers. The pleats in these filters give them greater surface area, but the additional surface also lowers their face velocity. The media is contained in a cardboard frame that is generally thrown away with the fabric when it becomes dirty. These are often used as pre-filters for bag or HEPA filters.

Bag filters. Bag filters use dry media that is arranged in a long stocking shape to extend their surface area or to allow recovery of the collected material. Although commonly used in HVAC systems, bag filters are generally being replaced by rigid dry filters.

HEPA filters. HEPA filters use thin, dry media (such as paper or glass-fiber mats) with very small pores that trap superfine particulates down to 0.01 micrometer in diameter. They are heavily pleated to reduce face velocity but still contribute pressure drops of up to 0.072 psi. HEPA filters are used mostly for the demanding applications of electronics and pharmaceutical production facilities, hospital operating rooms, and facilities that generate radioactive particles. HEPA filters should be coupled with a coarser pre-filter to extend their lifetime.

Electrostatic precipitators. Electrostatic precipitators use a high voltage to ionize particles suspended in the air, then pass the airstream between charged plates that attract and accrete the charged particles. Because there is no physical impediment to the air, these filters have very low pressure drops. However, the power equipment used to create the voltage differences continuously consumes about 20 to 40 watts per 1,000 cubic feet per minute (cfm) of airflow. An efficient fan uses about 140 watts per inch of pressure drop (water gauge) for each 1,000 cfm, so the precipitator energy is about the fan-energy equivalent of 0.004 to 0.007 psi of pressure drop. Electrostatic precipitators are usually used together with low-efficiency dry media filters that capture the largest particles and minimize the need to clean the charged plates.

This dual filter use means that electrostatic precipitator systems typically require more energy consumption and maintenance than a system with conventional filters would. One engineer estimates that electronic filters "double or triple" filter maintenance costs. The effectiveness of electronic air cleaners decreases with heavily dust-laden plates, with high-speed air, and with nonuniform air velocity. The plates that collect the charged particles must periodically be taken out of the duct and washed off, adding a maintenance step more complex than simple filter replacement. However, they do decrease the use of nonrecyclable filter components, and avoid the increasingly difficult problem of filter disposal. For overall HVAC efficiency, electronic filters usually do not make sense unless they can fulfill a specific need, such as local air cleaning in a smoking lounge.

Carbon filters. Carbon filters clean the air of gases and vapors at the chemical or molecular level. The porosity of activated, granulated carbon media is such that large, odor-causing molecules become adsorbed as they seep through the filter. The carbon can adsorb up to half its own weight in gases, which can then be driven off by heating, allowing the carbon to be reused. Carbon filters are not common in typical commercial buildings, unless there is a need to remove persistent sources of odor, such as from local industry.

A common metric for filter performance is the minimum efficiency reporting value (MERV), a rating derived from a test method developed by ASHRAE. The MERV rating indicates a filter's ability to capture particles between 0.3 and 10.0 microns in diameter. A higher MERV value translates to better filtration, so a MERV-13 filter works better than a MERV-8 filter.

Ducts

Like the arteries and veins in the human body, ducts convey the conditioned air from the air-handling unit out through the building and return it back to be conditioned again (or exhausted from the building). They are usually constructed of sheet metal and are insulated.

Ductwork can either be round or rectangular. Rectangular duct material used to be cheaper and more common than round, but the trend these days is to use a spiral version that is fabricated at local manufacturing facilities to the sizes and lengths required for each job. Spiral duct construction is similar to that of a paper drinking straw; a long strip of metal is wrapped around itself in an overlapping, continuous pattern. Spiral ductwork can be fabricated in round or oval cross-section designs. Spiral ducts tend to be less expensive than rectangular and are characterized by lower pressure drop, reduced heat gain or loss (due to the reduced surface area), and reduced weight. Spiral ducts can be manufactured in long lengths, and the spiral-lock seams make the ductwork more rigid. From an architectural standpoint, more new buildings are leaving the ductwork exposed as opposed to concealing it behind a T-bar ceiling, and spiral ductwork has an attractive shape and surface pattern that lends itself to this sort of installation.

Rough-surfaced duct material makes a fan work harder than smooth duct materials do. In engineering terms, the pressure loss of a duct is proportional to the friction factor of its inside skin and to the square of the air speed. The friction factor depends on surface roughness (the average height of protrusions from the surface) and, to a much lesser extent, on duct diameter, air speed, and air density. Smooth sheet metal, usually steel or aluminum, is the best material for ductwork: Rigid fiberglass ductwork suffers nearly 30 percent more pressure drop than sheet metal. The acoustic fiber lining used in many supply ducts (especially just downstream of the fan) has 40 percent more frictional resistance than smooth sheet metal.

Ducts must be properly insulated to prevent excessive energy loss. Duct insulation helps prevent the warming of chilled air and the cooling of heated air as it passes through the ducts. ASHRAE standard 90.1, the energy code governing design of new commercial buildings in many jurisdictions in the U.S., specifies duct insulation with a heat flow resistance level of as much as R-8 in some locations for ducts carrying hot or cold air. This requirement varies by jurisdiction; local energy and/or mechanical codes must be consulted. Proper choice of insulation can also help reduce the transmission of fan and motor noise from the HVAC system to the working spaces inside buildings.

Proper installation of the duct insulation is important as well. Because soft insulation is frequently used, it must be kept from compressing under duct hangers, against the floor or roof structure above, or against the suspended ceiling below. This requires adequate vertical clearance. Some brands of ductwork come complete with an insulation layer.

Dampers

Dampers modulate the flow of air through the ducts to the various parts of the building, reducing or increasing the airflow depending upon conditions. Dampers also regulate the quantity of outside air that is allowed to enter the air-handling unit and mix with return air for ventilation purposes. Dampers can be difficult to maintain and can affect occupant comfort as the space requirements change and as the air-handling system ages.

A typical commercial HVAC system has numerous dampers that alter the flow of outside air, return air, exhaust air, and supply air. An efficient air-handling system minimizes the number of dampers necessary overall and eliminates dampers or uses low-loss dampers at branch takeoffs, reducing the fan power needed to blow air past them but maintaining the capability for minor balancing adjustments. Using variable-speed drives for fan regulation can eliminate the need for fan inlet or discharge dampers.

8.4 Best Opportunities

When considering options for improving the performance of an air distribution system, it is important to remember that the purpose of having an HVAC system in the first place is to regulate the temperature, humidity, freshness, and movement of air in buildings. Accordingly, energy-efficiency retrofit projects should not undermine the system's capability to provide thermal comfort and air quality. The goal of energy retrofit projects should be to improve system efficiency while maintaining or enhancing comfort.

Although there are different ways to address air-handling system efficiency opportunities, one effective approach is to start at the conditioned space and work back to the air-handling unit. Looking at the opportunities in this order enables building operators to take advantage of downstream savings when addressing upstream opportunities. For example, repairing corroded zone mixing dampers that are stuck in the full-cooling position in a dual-duct system will provide better comfort to the occupants while also reducing the amount of cool air that the air-handling unit must provide. Fixing the zone dampers may unearth upstream opportunities to take advantage of the reduced cooling load with system control reset strategies or the installation of rightsized equipment.

Optimize Zone-Level Performance

The zone-level equipment consists of zone mixing dampers (such as dual-duct mixing dampers or VAV mixing boxes), reheat coils (hot water or electric), and the thermostats that control this equipment in response to user preferences. As facilities age, zone-level equipment often falls out of calibration or into disrepair, impairing its ability to provide comfort and undermining overall system performance. Fixing zone-level problems can lead to more comfortable occupants as well as upstream energy savings.

Some of the most common opportunities to consider at the zone level are:

- *Recalibrate thermostats.* In systems with pneumatic controls, the thermostats periodically require recalibration (typically, every 6 to 12 months) in order to regulate space temperature more accurately. Though thermostat calibration should be checked if a comfort complaint exists, it is preferable to evaluate the thermostats on a regular basis as a proactive maintenance measure.

- *Inspect dampers.* For systems with zone dampers, periodically inspect the damper, linkage, and actuator for proper operation. In older buildings where maintenance has not been rigorous, it is likely that some of the zone dampers are frozen in position, rendering them ineffective at regulating comfort. Because evaluating and repairing nonfunctional zone dampers can be time-consuming and costly (especially in large buildings that may have hundreds or even thousands of zones), consider allocating a portion of the annual maintenance budget for this purpose to address a certain quantity or percentage of zones. For example, in a 100,000-square-foot, 10-story office building with 150 VAV zones, the maintenance budget might include time and money to evaluate 50 VAV zones per year.

- *Prevent overcooling.* In zone-level reheat systems, performance should be evaluated to keep cooling levels as low as possible. For hot water reheat systems, verify operation of the hot water reheat valve to ensure that it opens and closes in response to control system commands. Check the coil itself to confirm that water is flowing through when it is supposed to and that the coil is not clogged. Confirm the sequence of operation to make sure the reheat coil only operates when it is supposed to. For a single-duct VAV system, the reheat coil typically operates after the VAV damper has reached its minimum airflow position while the zone is calling for heat. If the reheat system is electric, verify proper operation of the coil in response to system commands. Verify the capacity of the electric coil by measuring its input power with an amp probe or true RMS (root-mean-square) power meter. Compare the calculated value with the nameplate value. If the calculated value is much lower than the nameplate value, the coil may have burned-out elements and may require replacement.

- *Disable reheat systems in summer months.* For CV reheat systems, consider whether the zone-level reheat systems can be disabled during the summer. Some facilities with electric reheat systems have successfully shut off the reheat coils at the breaker during the cooling season, leading to significant energy savings. In conjunction with this change, it may be necessary to adjust the supply-air temperature to avoid overcooling certain spaces, and it may be necessary to leave the reheat coil breakers active in certain spaces (such as interior zones) in order to maintain comfort.

- *Regulate static pressure.* Dual-duct systems typically include static balancing dampers for the hot and cold ducts (also called hot and cold “decks”). The purpose of static balancing dampers is to regulate the static pressure in the hot and cold decks in response to zone demands. Over time, these systems (consisting of a static pressure sensor, damper, actuator, and linkage) can fall into disrepair. Failure of the static balancing dampers can cause significant energy waste and discomfort. For example, if the static balancing damper for the cold deck is stuck in a nearly closed position, none of the zones will have an adequate source of cold air, leading to overheating.

Convert CV Systems to VAV

Retrofits involving conversion from CV to VAV are perhaps the most widely employed energy-saving retrofit to commercial HVAC systems, because typical airflow requirements for VAV systems are only about 60 percent that of CV systems. VAV systems also cool only the air volume required to meet demand, rather than meeting demand by simultaneously heating and cooling large volumes of air. **Table 8.1** presents cost and savings data from several large VAV retrofits.

To determine whether the existing system is VAV or CV, review the original design drawings for the HVAC system. If there is a schedule of VAV terminals in the equipment list that includes a minimum and maximum airflow (cfm) for each zone, it is a VAV system.

The conversion of an older constant-volume reheat, multizone, or dual-duct system to a modern, energy-efficient variable air volume system is a task to be undertaken with serious consideration and expert analysis. Unless the facility's management possesses expertise in the

Table 8.1: Installation cost and energy savings from variable air volume retrofits

The cost and savings of VAV retrofits vary widely, though most retrofits cost between $1 and $4 per square foot.

	AT&T Bell Laboratories, Indian Hills Complex, Naperville, IL	Lamonts Apparel Inc. (Factoria Square), Bellevue, WA	One Bellevue Center, Bellevue, WA	Fanny Allen Hospital, Colchester, VT	General American Life Insurance Co., St. Louis, MO	St. Louis Children's Hospital, St. Louis, MO	100 Market Building,[a] Portland, OR
Building size (ft^2)	1,200,000	50,000	344,715	114,000	450,000	560,000	120,000
Nominal fanpower (hp)	3,300	40	400	85	750	1,470	150
Peak flow (cfm)	600,000	44,000	n/a	58,800	n/a	n/a	132,000
Project cost							
VAV retrofit cost ($)	3,500,000	33,620	965,104	810,838	1,013,000	405,000	575,000
Utility rebate ($)	0	26,167	814,793	552,666	0	0	0
Net cost ($)	3,500,000	7,453	150,311	258,172	1,013,000	405,000	575,000
Cost per square foot ($/$ft^2$)	2.90	0.67	2.80	7.10	2.30	0.70	4.80
Cost per nominal fan hp ($/hp)	1,060	840	2,412	9,539	1,350	275	3,833
Cost per peak cfm ($/cfm)	5.80	0.80	n/a	13.80	n/a	n/a	4.40
Project savings							
Fan energy savings (kWh/year)	15,000,000	97,456	2,052,391	1,336,592	7,146,974	2,416,160	2,000,000
Fan power savings (kW peak)	900	n/a	234	255	n/a	n/a	200
Energy savings ($/year)	1,200,000	9,211	79,111	129,086	248,000	138,000	80,000
Payback with rebate (years)	2.9	0.8	1.9	2.0	4.1	2.9	7.2
Payback without rebate (years)	2.9	3.6	12.2	6.3	4.1	2.9	7.2

Note: cfm = cubic feet per minute; ft^2 = square foot; hp = horsepower; kWh = kilowatt-hour; n/a = not available; VAV = variable air volume.

a: In this project, TRAV control logic by Microgrid/Hartman was utilized to control the VAV systems. The cost for this project includes fees for design, project management, contractor management, and commissioning.

Courtesy: E SOURCE

conversion of CV systems, this would require the services of an engineering firm or an HVAC controls contractor. In some cases, the local energy utility may be able to provide technical assistance and incentives to help evaluate and implement the project.

The three factors that affect the feasibility of implementing a VAV retrofit are the implementation cost, the annual energy cost savings, and the building owner's minimum attractive rate of return. Surprisingly, in the case of VAV retrofit projects, the most volatile term in the cost-effectiveness equation is the implementation cost, because of the number of factors that influence the effort required to complete the retrofit. The difference between high and low energy cost savings, even when estimated using the simplest of methods, will not typically vary by more than a factor of two. On the other hand, the implementation cost can vary by a factor of ten or more depending on the characteristics of the HVAC system to be converted and the installation conditions. In certain circumstances, it will not be cost-effective to convert to a VAV system. The following factors provide an indication of whether a specific conversion project is likely to be straightforward (and therefore relatively low cost) or to present challenges that will make it more expensive.

Building-level factors

- Consider what type of access the contractor will have to the zone dampers. For example, will the contractor have to work in cramped or inaccessible spaces to access a multizone system? Check the equipment accessibility of dual-duct systems where the zone dampers are located out in the conditioned space: Is the ceiling a T-bar system that facilitates access for equipment installed above the ceiling, or is it a "hard-lid" system that makes it more challenging to access the dampers?
- If the building includes asbestos-containing materials, they may either have to be removed or contained during the retrofit process, which can add significantly to project cost.

System-level factors

- In an existing CV system, check the age and condition of the existing zone dampers and actuators. If they are in good condition, it will make the conversion easier than if the contractor also has to repair components along the way. It would not make sense to make costly changes to a system that has maintenance issues that would prevent it from functioning properly.
- For a dual-duct or multizone system, see whether the existing hot and cold dampers are controlled by one or two actuators. Converting these systems to VAV usually requires two actuators so that the hot and cold air supply can be regulated independently. Having two actuators already installed usually leads to a simpler, less expensive conversion. It is possible to add a second actuator if there is only one, but it will add cost and complexity to the project.
- If the existing system is in poor condition, a major portion of the total project cost for a VAV conversion can be attributed to system maintenance and replacement as opposed to an energy retrofit project. The energy savings are a benefit of such a conversion, but the focus ought to be how to make the HVAC system meet the occupants' thermal comfort requirements.

When soliciting bids from contractors, it can be helpful to look for nearby buildings that are similar in age and design to the building in question and determine whether VAV conversion has been implemented. Often, several similar buildings that used the same design and construction team would have been built in a city during the same era. As a result, the energy retrofit solutions that worked (or did not work) at one building might be applied to another. And a contractor who has already converted similar HVAC systems in previous projects will likely be able to provide a more competitive price than ones who will need to figure it out as they go.

Once the conversion is complete, have the new system commissioned by an independent contractor as part of the retrofit project to ensure that everything operates according to plan.

Rightsize Fans

If HVAC fans are oversized, replacing them with ones that are correctly sized—"rightsizing" them—can be cost-effective. Rightsizing can be implemented separately or in combination with the installation of premium-efficiency motors and VSDs. In general, rightsizing with a premium-efficiency motor, energy-efficient belts, and a VSD is the best alternative. A rightsized system saves energy costs, but there are other advantages as well:

- *Lower first costs.* Because the capacity required from the fan system is reduced, the system can be more accurately tailored to the new airflow requirements. By installing smaller, more energy-efficient equipment that meets these requirements, first costs are also reduced.
- *Comfort.* If the fan system supplies too much air to occupants, energy is wasted and comfort can be compromised. Too much air can result in disturbing drafts, increased humidity, and noise.
- *Longer equipment life.* Prolonged operation at very low speed of an oversized motor with a VSD can reduce the useful life of the motor and associated equipment. Properly sized equipment will be more suited to operation at reduced capacities.

As a first step, the opportunity for rightsizing an air distribution system can usually be determined by building maintenance staff. Once an opportunity has been identified, however, it is usually necessary to hire an HVAC engineer to verify it, to conduct a more detailed analysis, and to make recommendations for optimizing the system.

The approach to assessing the potential for rightsizing varies depending upon whether the existing system is constant or variable volume. Either way, though, it is critical that the proper amount of outside air is maintained to ensure occupant health and comfort. Consult local building codes for information about required outside-air quantities.

Diagnosing oversized fans in VAV systems. Although VAV systems are more energy efficient than CV systems, the potential for rightsizing may still exist. Building maintenance staff may be able to determine whether the VAV fans are oversized by using one of three methods: measuring fan-system static pressure, measuring the fan-motor current draw (amperage), or checking the fan-control vanes and dampers.

The first method is to measure the static pressure of the main supply fan system. It is best to get a baseline measurement on a hot, humid day. Make sure that all fan vanes and dampers and all VAV boxes are fully open. Compare the static pressure reading with the static pressure setpoint. If the reading is less than the setpoint and building occupants are comfortable, the setpoint can be adjusted to the lower static pressure.

Static pressure measurements must be taken at the same location in the distribution system as the pressure sensor that regulates system operation, usually about two-thirds of the way down the main supply duct. If such a measurement is not possible or practical, the desired setpoint can be found by gradually reducing the fan speed each day until the pressure is as low as possible but occupant space is still comfortable. This change will significantly reduce fan power requirements. Be sure to survey occupants periodically to assess comfort. It may also be necessary to restore the old setpoint on extremely hot days. In those cases, consider having the control system programmed to automatically reset the static pressure setpoint (for more on pressure reset, see the Modify Controls section).

Next, measure the fan-motor power draw using a true RMS power meter. For a VAV system, make this measurement when the cooling system is operating under a peak load (for example, on a hot, humid day). Next, read the full-load power rating off the motor's nameplate or from the operating manual. Compare these two numbers. If the measured power is less than 75 percent of the motor's rating, the motor is oversized.

Comparisons of measured to rated current can be misleading because a motor's power factor drops when it is lightly loaded. Therefore, measuring only current does not provide an accurate estimate of motor loading. Better accuracy will be achieved by using an RMS power meter that measures voltage and current simultaneously and displays true power. Also, when comparing measured input power to nameplate power, keep in mind that 1 kilowatt = 0.746 horsepower (hp). Power meters typically display results in kilowatts, but motor nameplates in the U.S. are labeled in horsepower.

Last, check the position of the fan control vanes or dampers when the cooling system is operating under a peak load. If the vanes or dampers are closed more than 20 percent, the fan may be oversized.

Diagnosing oversized fans in CV systems. If it is not economically feasible to retrofit to a VAV system, rightsizing a CV system is generally a profitable choice. However, building maintenance staff is typically limited to just one method of determining the potential for rightsizing: measuring fan-system static pressure.

Measure the main supply fan system static pressure on a hot, humid day. Make sure that all fan vanes and dampers are fully open. If the measured static pressure is greater than the design pressure (found in building mechanical drawings), the fan is probably supplying too much air and is a good candidate for rightsizing.

Three ways to rightsize. If analysis indicates that a supply fan is oversized, considerable energy can be saved by rightsizing the fan in one of three ways:

- *Larger pulleys.* Replacing an existing belt-driven pulley with a larger one will reduce its speed, and since fan power is proportional to the cube of speed, even small speed reductions can reduce energy costs appreciably. The new pulley should operate the fan at a reduced speed that still matches peak load requirements.

- *Static pressure adjustment (VAV systems only).* Reducing static pressure in a VAV system reduces the fan horsepower consumption. By gradually reducing the static pressure setpoint to a level low enough to keep occupants comfortable, fan speed will be reduced, thereby reducing energy consumption.

- *Smaller, premium-efficiency motors.* Once the fan flow rate has been properly adjusted, the existing motor will probably be larger than necessary. Replace the existing, oversized motor with a smaller, premium-efficiency motor that matches the load. For example, rightsizing a 75-hp standard-efficiency motor to a 50-hp premium-efficiency motor could reduce motor energy consumption by about 33 percent. Some premium-efficiency motors operate at slightly higher speeds than the motors they replace. Because a fan's power consumption increases in proportion to the cube of its speed, it is important to compare the nameplate speed of the existing motor with its premium-efficiency replacement. See the Pick Premium-Efficiency Motors section.

Estimating potential savings. The expected benefits of rightsizing can be estimated using a commercially available fan analysis software program. The U.S. Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy has collected information about several such packages (www.eere.energy.gov/buildings/tools_directory/subjects.cfm/pagename=subjects/pagename_menu=materials_components/pagename_submenu=hvac_systems). This software generally requires information about the existing fan system such as:

- Operating schedule
- Type of flow control
- Duty cycle
- Motor horsepower and efficiency
- Peak flow rate
- Peak cooling coil load

Install Variable-Speed Drives

Variable-speed drives are an efficient and economical retrofit option that should be considered for all VAV systems. VSDs allow the motor speed to vary depending on actual operating conditions, rather than operating continuously at full speed. Varying a fan's speed allows it to match changing load requirements more closely, and because fan power draw is proportional to the cube of its speed, reducing speed can save a lot of energy. For example, reducing a fan's speed by 20 percent can reduce its energy requirements by nearly 50 percent (**Figure 8.5**). Installing a VSD on the fan motor allows the fan to automatically match this reduced capacity, slowing down in response to reduced demand, thereby saving energy.

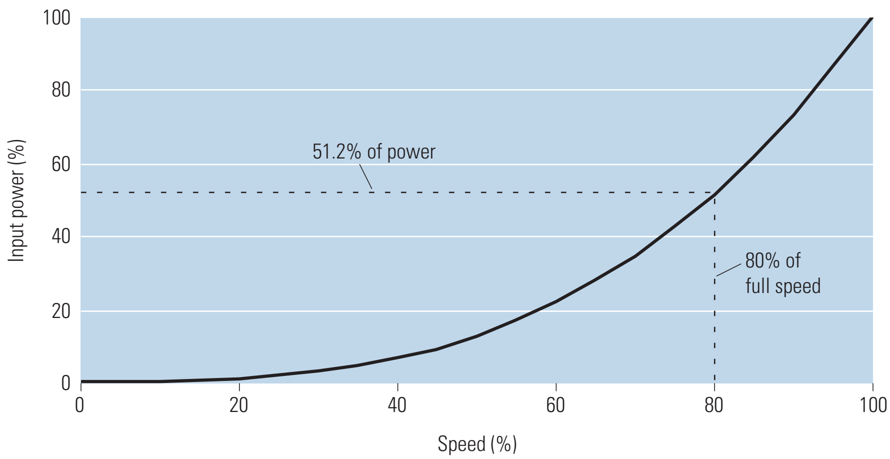
CASE STUDY: Big Savings from a VAV System Retrofit

A retrofit to the 12-story City Hall in Phoenix, Arizona, demonstrates the savings achievable by matching fan power to cooling and heating load. The building originally had a constant-volume, dual-duct system with cold deck temperature reset, supplied by four 60-hp supply-air fans and two 50-hp return-air fans. Pre-retrofit, the fan energy consumption was over 2.2 million kilowatt-hours per year. Analysis of the building's loads showed that the fans were considerably oversized, moving a constant 220,000 cubic feet per minute when the peak load actually called for only 130,000 cfm. On this basis, two of the supply fans and both return fans were disconnected, resulting in an immediate savings of over 50 percent. A bypass duct was installed around each of the disabled return fans, eliminating substantial friction losses.

The remaining two fans were converted to variable air volume by installing variable-speed drives controlled by static pressure sensors in the ducts. The interior zone dual-duct boxes were converted to VAV boxes by sealing off the connection from the hot deck and connecting a new pneumatic actuator to the cold deck damper that was operated by a zone thermostat. The new system registered average savings of 70 percent compared to constant-volume operation, with a maximum demand reduction of 78 percent. Complaints of discomfort also decreased. Based on a conservative estimate of 50 percent average annual VAV savings, the $90,000 project saved 1.7 million kWh, worth over $135,000 per year, resulting in a payback of about eight months.

Figure 8.5: Fan power input versus speed

The load on a fan motor increases as the cube of its speed. Therefore, using a variable-speed drive (VSD) to reduce speed to 80 percent of full speed reduces power consumption to just $(0.8)^3$, or 51.2 percent of its original load level. The VSD itself does consume some power, so careful assessment is necessary for any application where average fan speed will exceed 90 percent of full speed.



Courtesy: E SOURCE

A VSD is not a motor; it is an electronic device that varies the speed of a motor by changing the frequency of the electrical power between 0 and 60 Hertz. The EPA study "Variable Air Volume Systems Maximize Energy Efficiency and Profits" showed that VSDs can greatly reduce the energy used by the same fan operating under similar airflow volumes and static pressure conditions. Overall, the study indicated that VSDs provided an average energy savings of 52 percent.

VSDs make economic sense when installed on motors that operate many hours per year at fluctuating loads, and especially on larger motors. **Table 8.2** presents representative installed costs for VSDs of various sizes.

Modify Controls

Modifying the way the distribution system operates, not just the system itself or its components, can also save energy.

Optimized scheduling. An optimum start-and-stop procedure is a common-sense control philosophy that can result in significant energy savings. Normally, a system is set to automatically turn itself on and off based upon the expected occupant working hours. For example, a building's cooling system might come on at 6:00 a.m. and shut off at 7:00 p.m. Adjusting these times for varying seasons will reduce energy costs. In the spring and fall seasons, when cooling is required but the peak temperatures are typically lower than the summer peak temperatures, the system can be set to come on later in the morning and shut off earlier in the day. Of course, the system can also be shut down if the building is unoccupied.

Supply-air temperature reset. Most cooling coils are designed to deliver 53° to 55°F air to satisfy cooling requirements on the hottest day of the year. During periods of milder weather, this temperature can be automatically reset upward to improve system efficiency by reducing wasteful reheating of already cooled air. Supply-air temperature reset can be accomplished in a few different ways.

Table 8.2: Installed costs of VSDs for various size motors

Installed costs for variable-speed drives range from approximately $2,500 for a 5-horsepower (hp) drive to $16,000 for a 100-hp drive. Note that the price per horsepower declines dramatically as power capacity increases.

Motor hp	Installed cost ($)	Price per hp ($)
5.0	2,475	495
7.5	2,950	393
10.0	2,950	295
15.0	3,675	245
20.0	4,900	245
25.0	5,875	235
30.0	6,825	228
40.0	9,275	232
50.0	10,400	208
60.0	11,800	197
75.0	15,200	203
100.0	15,800	158

Courtesy: E SOURCE; data from R.S. Means Electrical Cost Data, 2007 edition

The most common reset strategy is to implement a simple proportional reset based on the outside air temperature; on a hot day, the supply-air temperature (SAT) is set to its design (or original) value, and when the weather is cooler, the SAT is increased. This is usually specified in a table that lists two outside temperatures and the corresponding SAT. For example, at 95°F outside temperature, the SAT is set to 53°F; at 65°F outside temperature the SAT is set at 68°F. The SAT is then reset proportionally between these two points. With a proportional reset system, building operating staff will often provide better comfort if they "tune" the reset parameters based on observed performance. Some buildings will require a colder SAT on mild days due to higher internal loads (people, lights, office equipment) or due to higher solar gain through windows. Conversely, buildings with efficient lighting systems and high-performance glazing may achieve good comfort with a warmer SAT at the same outside conditions.

For HVAC systems that include digital controls at the zone level, it is also possible to reset the SAT based on the "worst-case zone" approach. Under this scenario, the SAT setpoint is reset so that the zone with the greatest cooling requirement has its zone damper fully opened to provide 100 percent flow. All other zones, which have lower cooling requirements, will automatically adjust the VAV damper to maintain comfort.

For VAV systems, particularly those with VSDs installed, it is important to consider the impact of SAT reset on fan power; if the SAT is reset too high, then the energy saved due to reduced reheat will be overshadowed by increased fan power requirements.

Pressure reset. Pressure reset is a method that can yield additional energy savings in systems that have VSDs installed. Pressure and flow are related. Reducing the pressure supplied by fans also reduces the flow supplied, which in turn reduces the power required. By reducing the duct pressure by 30 percent when less air is required, almost instantaneous fan energy savings of more than 50 percent can be achieved above and beyond the application of a VSD. The desired setpoint can be found by gradually reducing the fan speed each day until the pressure is as low as possible but occupant space is still comfortable. It is possible to have two or more pressure settings; for example, one for daytime and one for evening or one for summer and one for winter. With HVAC systems that include digital zone controls, it is also possible to implement a static pressure reset based on the worst-case zone approach described above for supply-air temperature reset. The strategy is the same: The static pressure setpoint is reset so that the zone damper in the worst-case zone is fully open. Keep in mind that, if both temperature and pressure resets are to be implemented simultaneously, some thought must be given to how these savings measures will interact.

CASE STUDY: Air Distribution System Upgrade Saves Energy, Boosts Comfort

The building known as 600 B Street is a 24-story, 334,000-square-foot, Class A commercial office facility located in San Diego. The 25-year-old high-rise facility had unreliable cooling equipment, high operating and maintenance costs, and substantial numbers of tenant complaints.

Prior to the energy-efficiency implementation, the fan systems could not provide adequate comfort on hot, humid days. The variable air volume dampers would open fully in an attempt to satisfy the space-conditioning requirements. But as the chiller plant and air-handling systems reached their capacity limits, the supply-air temperature would climb too high and the system static pressure would be too low, blowing large quantities of air that was too warm and humid to provide the required cooling effect. As a result of these problems with static pressure control, the system was drafty on hot days and noisy on cold days. Variable-speed drives were installed on the supply fans to gain energy savings and quiet the system during low-load operation, reducing tenant complaints.

To allow faster resetting of the HVAC system variables and to maximize the potential for savings, 25 percent of the VAV terminal controllers in the building were switched from pneumatic control to digital (electronic) zone-terminal control and the information from the zones was used to reset the static pressure setpoint for the air-handling units and the supply-air temperature setpoint. Ideally, all of the VAV terminal controllers would have been replaced, but the cost of doing so would have been high. The digital system is configured to reset static pressure and supply-air temperature continually based on the loads being served.

After a two-year period of measurement and verification, it was determined that fan energy was reduced by 73 percent. The 800,000 kilowatt-hours per year in electrical savings equates to about $120,000 per year in energy cost savings, resulting in a very cost-effective retrofit. Including the incentives offered by the local utility, the energy retrofit project (which included chiller plant measures in addition to the modifications to the air system) paid for itself within about three months. The indoor air quality has also improved dramatically, resulting in an 85 percent drop in tenant complaints.

As a result of the project's documented level of energy efficiency and its positive effect on occupant thermal comfort, the project was honored by ASHRAE for both the San Diego Chapter and the Western Region.

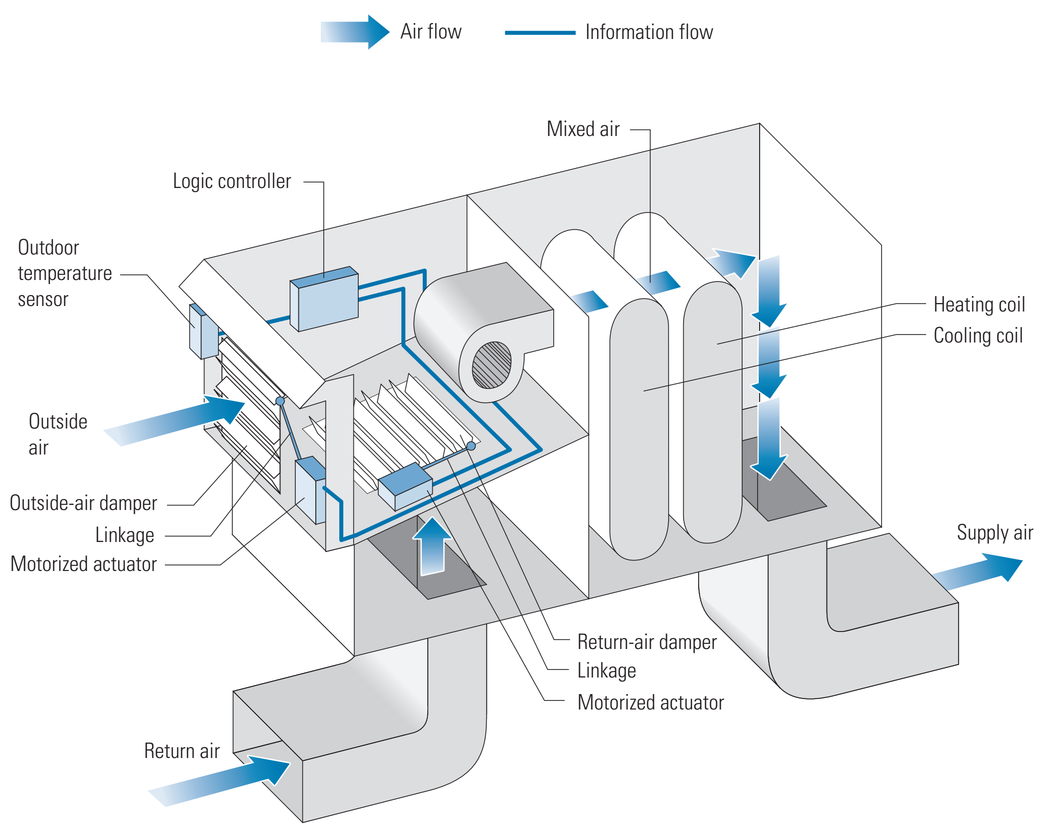
Economizer cooling. Air-side economizers consist of a collection of dampers, sensors, actuators, and logic devices on the supply-air side of the air-handling system (**Figure 8.6**). The outside-air damper is controlled so that when the outside air temperature is below a predefined setpoint, the outside-air damper opens, allowing more air to be drawn into the building. On hot days, the economizer damper closes to its lowest setting, which is the minimum amount of fresh air required by the local building code.

All economizers are not created equal. The simplest and most common type is the basic dry-bulb economizer that controls the outside-air damper based on a specified temperature setpoint. An enhancement to this approach is an enthalpy (or total energy content) economizer, which accounts for both the temperature and the humidity of the outside air and can improve the energy savings associated with the economizer by not cooling with outside air under high-humidity conditions. One of the most advanced economizer control strategies available today is a differential enthalpy system, in which two enthalpy sensors are installed (one for the outside air and the other for the return air). Under the differential control strategy, the system preferentially uses whichever air source (outside or return) has lower enthalpy when there is a need for cooling.

When the outside temperature and humidity are mild, economizers save energy by cooling buildings with outside air rather than using refrigeration equipment to cool recirculated air. A properly operating economizer can cut energy costs by as much as 10 percent of a building's

Figure 8.6: The components of an economizer

When the air outside is cooler than the return air and sufficiently dry, economizers cool buildings by bringing in outside air, thereby reducing the load on the compressor.



Courtesy: E SOURCE

total energy consumption (up to 20 percent in mild, coastal climates), depending mostly on local climate and internal cooling loads.

Economizer commissioning and maintenance are vital to proper operation and energy savings. A large number of newly installed economizers do not work properly, and their problems increase as they age. To make matters worse, malfunctioning economizers often waste much more energy than they were intended to save. If an economizer breaks down when its damper is wide open, peak loads can shoot up as cooling or heating systems try to compensate for the excess air entering the building. A computer simulation of an office building in arid Phoenix, Arizona, shows that a damper permanently stuck in the wide-open position could add as much as 80 percent to that building's summer peak load, assuming the building had enough cooling capacity to meet the much higher load resulting from cooling excessive outside air.

Demand-controlled ventilation. Many building codes in the United States base their ventilation requirements on a standard written by ASHRAE that requires that commercial buildings bring in a specified minimum amount of fresh air to ensure adequate indoor air quality. To adhere to this standard, the choice made in most buildings is to ventilate at the fixed minimum rate per person based on the building type and the assumed occupancy, which is usually the building's design occupancy. But because the number of people occupying the space at any given time can vary widely, the ASHRAE standard offers another way to ventilate based on actual occupancy numbers. This is called demand-controlled ventilation (DCV).

Because the average amount of carbon dioxide (CO_2) exhaled by a person in a fixed time period at a given activity level is well known, the concentration of CO_2 in the air inside a building is a good indicator of the number of people in a space and the rate at which the air in the space is being diluted with outside air. The more occupants a building has at any given time, the higher the level of CO_2 in the air. The ASHRAE standard allows building operators to use DCV to bring in and condition only the air necessary for the actual occupancy. In a DCV system, sensors monitor the CO_2 levels inside and send a signal to the HVAC controls, which regulate the amount of outside ventilation air that is drawn into the building. Though ASHRAE does not set a maximum allowable CO_2 concentration, the most recent version of the standard recommends that the indoor CO_2 level be no more than 700 parts per million (ppm) above the outside level, which is typically about 350 ppm.

CASE STUDY: Power Exhausts Cut Cooling Costs

The majority of conventional air-handling units are able to provide 100 percent outside air. However, at one 200,000-square-foot office building in a Boston suburb, it was noticed that air-conditioning compressors in the rooftop units operated on all sunny days, even when outside air temperature was as low as 35° Fahrenheit. The reason was that solar-heated interior air had no way to escape from the building, so even with outside air dampers wide open, the rooftop units could not provide enough outside air to cool the building without the aid of mechanical refrigeration.

The solution was to install power exhausts in the rooftop units that exhausted all indoor air when the building was in economizer cooling mode. Roughly 1,000 hours per year were found to have proper conditions for free cooling. After the installation of the power exhausts, cooling compressors only operated when the outside air temperature was above 55°F. The installation cost $75,000 and paid for itself in under four years.

DCV systems save energy by reducing the need to heat or cool outside air. The only system change is the ratio of recirculated air to outside air; fan power is usually unaffected. DCV systems can save from $0.05 to $1.00 per square foot, depending on the occupancy schedule and climate (see sidebar).

The overall cost for implementing DCV has dropped substantially in recent years, opening up new opportunities for savings and spurring changes in some building codes. Also, several HVAC equipment manufacturers now offer DCV-ready rooftop units and variable air volume (VAV) boxes. This equipment is shipped with terminals for the CO_2 sensor wires and controls that are preprogrammed to implement a DCV strategy. By limiting installation costs to the cost of mounting the sensor and running wires to the rooftop unit or VAV box (wireless models are also available), DCV-ready HVAC equipment substantially reduces the cost of implementing DCV.

Facilities that would likely reap energy savings with the use of DCV tend to have long operating hours, widely varying and largely unpredictable occupancy levels, and at least moderate annual heating or cooling loads. A large number of facilities meet this description, including grocery stores, supermarkets, big-box stores, theaters and other performance spaces, lecture halls, places of worship, sports arenas, restaurants and bars of all types, and department stores. In fact, the majority of commercial facilities that are not now using DCV are at least potential targets for the technology.

Care must be applied when planning a DCV retrofit to ensure that adequate air quality is maintained. Of paramount concern are the location and quantity of CO_2 sensors. Although it might be tempting to install a single CO_2 sensor in the return-air duct for the entire building, this could lead to situations where the average CO_2 level is acceptable but the level in specific, highly occupied spaces (such as a packed conference room) is too high. For this reason, it is typically more effective to install CO_2 sensors in each high-occupant-density or high-diversity space and use them to command the minimum position of the VAV box.

Many energy codes that permit DCV also have required minimum ventilation and airflow rates (such as 0.15 cfm per square foot). Be sure to confirm local requirements before committing to a project.

A study conducted in 2003 at Purdue University shows favorable paybacks for DCV in a variety of buildings. The study investigated four types of buildings—a restaurant, a retail store, a

RESOURCES: Demand-Controlled Ventilation Design Tools

Several free tools are available to evaluate potential energy savings from demand-controlled ventilation:

- Carrier provides the Hourly Analysis Program (www.commercial.carrier.com/commercial/hvac/general/1,,CLI1_DIV12_ETI496,00.html?SMSESSION=NO).
- Honeywell has the Savings Estimator (http://customer.honeywell.com/Business/Cultures/en-US/Products/Applications+and+Downloads/Economizer+Logic+Module+(W7212)+Simulator+and+Demand+Control+Ventilation+Savings-Estimator.htm).
- AirTest offers a spreadsheet-based demand-controlled ventilation savings analyzer (https://www.airtesttechnologies.com/support/software/index.html).

school, and an office—in each of two cities in California and three cities outside the state. Total energy savings ranged from 6.4 to over 50 percent, and payback periods ranged from 0.25 to 6.8 years, though paybacks were well under two years for most of the modeled facilities.

Keep in mind that CO_2 concentration rates do not indicate the levels of other potential air contaminants contained within the space. If a facility contains significant nonhuman sources of contaminants (such as materials or products containing volatile organic compounds), additional ventilation may be required to provide acceptable indoor air quality. This makes warehouses, kitchens, dry cleaners, and many types of industrial facilities poor candidates for DCV. Consult local building codes for proper ventilation rates.

Pick Premium-Efficiency Motors

All new motors installed in HVAC applications have been required to meet minimum federal energy-efficiency standards since October 1997. The motors that drive older HVAC systems are likely to be inefficient by today's standards, and even newer systems that meet the current federal motor efficiency standards can be made more efficient. Motors that perform to the National Electrical Manufacturers Association's NEMA Premium (NP) specification (see **Table 8.3**) can yield highly cost-effective energy savings in HVAC applications because these applications tend to have long running hours.

Table 8.3: Premium versus standard efficiencies of totally enclosed, fan-cooled motors

NEMA Premium motors often exceed the efficiencies of standard-efficiency motors by 1.5 to 2 percent. Although that may not seem like much, given their very long running hours in HVAC applications, it is often quite easy to justify the higher cost of premium-efficiency motors based on energy savings alone, particularly if the local utility offers a rebate.

	Efficiency (%)					
	3,600 rpm		1,800 rpm		1,200 rpm	
Motor horsepower	Standard	NEMA Premium	Standard	NEMA Premium	Standard	NEMA Premium
1.0	75.5	77.0	82.5	85.5	80.0	82.5
1.5	82.5	84.0	84.0	86.5	85.5	87.5
2.0	84.0	85.5	84.0	86.5	86.5	88.5
3.0	85.5	86.5	87.5	89.5	87.5	89.5
5.0	87.5	88.5	87.5	89.5	87.5	89.5
7.5	88.5	89.5	89.5	91.7	89.5	91.0
10.0	89.5	90.2	89.5	91.7	89.5	91.0
15.0	90.2	91.0	91.0	92.4	90.2	91.7
20.0	90.2	91.0	91.0	93.0	90.2	91.7
25.0	91.0	91.7	92.4	93.6	91.7	93.0
30.0	91.0	91.7	92.4	93.6	91.7	93.0
40.0	91.7	92.4	93.0	94.1	93.0	94.1
50.0	92.4	93.0	93.0	94.5	93.0	94.1
60.0	93.0	93.6	93.6	95.0	93.6	94.5
75.0	93.0	93.6	94.1	95.4	93.6	94.5
100.0	93.6	94.1	94.5	95.4	94.1	95.0

Courtesy: E SOURCE; data from NEMA and U.S. Department of Energy

After completing the building upgrade stages described earlier in this manual, building heating and cooling loads are likely to have been reduced, allowing for the installation of smaller motors that better match the reduced power requirements. Although NP motors also often come with a price premium, the cost of a smaller, premium-efficiency motor will often be less than that of a standard-efficiency motor of the same size as the existing motor, making the premium-efficiency motor an easy choice. Also, many utilities offer rebates on the purchase of NP motors that are designed to cover all or a portion of the price premium.

The DOE offers a free software application called MotorMaster that is an excellent tool for evaluating the economics of alternative motor choices. The software comes with a frequently updated database of commercially available motors and allows the user to compare the initial and lifecycle cost implications of replacing an existing motor with a standard- or premium-efficiency motor. MotorMaster can be downloaded from www1.eere.energy.gov/industry/bestpractices/software.html#mm.

Here are a few additional issues to consider when evaluating HVAC motors.

Motor speed. Some premium-efficiency motors operate at higher speeds. All induction motors have a synchronous speed (the speed at which the magnetic field within the motor is rotating) and a full-load speed (the speed at which the motor shaft rotates when the motor is providing full-load torque or power). A motor's full-load speed will always be less than its synchronous speed by a few percent. The difference between synchronous and full-load speed is called slip.

The exact amount of slip a motor has depends on its design, construction, and loading. Be aware that premium-efficiency motors tend to have lower slip, which means that their full-load speed tends to be higher than that of less-efficient models. As noted earlier, the power a fan requires to move air varies by the cube of its speed, so power draw and energy consumption are very sensitive to motor speed. In air-circulation systems that are not controlled by a VSD, it is therefore conceivable that replacing an existing motor with a NP motor could actually result in greater energy consumption, even though the new motor operates at higher efficiency. Therefore, when selecting a premium-efficiency motor, it is important to compare its rated full-load speed to that of the motor it will replace. If necessary, the fan's speed can be reduced by increasing the diameter of its pulley.

Voltage balance. Three-phase induction motors (that is, motors that draw power from three phase conductors) are designed, specified, and rated by their manufacturers on the assumption that exactly the same voltage will be fed to each phase and that equal current will therefore flow through the coils connected to each phase, generating a uniform magnetic field from each pole pair. When this voltage is not balanced, however, significant harm can come to the motor, including reduced performance, increased heat, shortened life, and dramatically reduced efficiency. Phase unbalance dramatically increases the heat generated within a motor. That increase then feeds upon itself, because hotter windings have higher resistance, pushing up losses further. Just a 3.5 percent unbalance can increase total motor losses by 20 to 25 percent, which is equivalent to bringing the efficiency of a 90 percent efficient motor down to 87.5 to 88 percent.

Unbalance is defined by NEMA as 100 times the maximum deviation from the average of the voltages on the three phases, divided by that average voltage. For example, if the phase voltages measured at a motor's terminals are 465, 470, and 473 volts, the average voltage is 469.3 and the maximum deviation is 4.3 volts. The unbalance, then, is 4.3/469.3 = 0.9 percent. A well-balanced system should have voltage unbalance of less than 1 percent. If voltage unbalance is greater than 1 percent, evaluate the loading on each phase. The unbalanced phase may be carrying significantly more or less load than the others, in which case rebalancing the loads across the phases will also rebalance phase voltages.

Shaft alignment. In typical fan-system configurations, the motor and the fan each have shafts that are connected with a belt or belts and two pulleys. If the pulley faces are not square with each other, then the belt and shafts are not in alignment. Improperly aligned shafts can not only result in poor efficiency and higher operating costs, but also can lead to premature failure and increased maintenance costs. Whenever a motor is replaced or rewound, be sure to pay close attention to the shaft alignment.

Use Energy-Efficient Belt Drives

Belts are often used to transfer power from the motor to the fan system being driven. Standard V-belt drives can be found in the majority of belt applications. They are the lowest-cost option of the belt family. The trade-off, as usual, is reduced energy efficiency. New V-belts typically achieve efficiencies in the 90 to 95 percent range. A worn belt, however, can considerably reduce the efficiency by slippage caused by slackening and worn grip surfaces. Cogged V-belts are similar to standard V-belts, except that the normally flat underside has longitudinal grooves in it, allowing better grip and less slip than standard V-belts. They typically offer a 2 to 5 percent efficiency bonus.

Less commonly found synchronous belts combine toothed belts with grooved sprockets. The belts are called “synchronous” because both sprockets rotate in exact synchrony, eliminating losses from slippage and creep and significantly reducing maintenance because the nonstretch belt does not need retensioning. These belts transmit power by engaging teeth rather than tension-induced friction, so they operate much more efficiently than V-belts, achieving efficiencies in the range of 97 percent to 99 percent.

A potential downside to synchronous belts is that by reducing slippage, they will actually increase the speed of the fan, which will result in more airflow, but it will also require more power from the motor. For example, reducing belt slip on a constant-volume centrifugal fan by 3 percent will result in a corresponding 3 percent increase in rotational speed for the fan wheel and an increase in the volume of air that is delivered. Because such a fan has a cubic relationship between airflow and horsepower, however, the horsepower required to drive the fan will increase by $(1.03)^3$, or 1.093—a 9.3 percent increase from the previous requirements. So the building owner who wants energy savings may instead be getting increased airflow and increased energy use (and possibly an overheated fan motor) if the proper precautions are not taken. Retrofits from V-belts to synchronous belts should be coordinated with the replacement of standard-efficiency motors with properly sized premium-efficiency motors. Doing both retrofits together reduces total labor costs and offers an opportunity to correct for any changes in speed from the new motor or belts at zero marginal cost. Additionally, when selecting synchronous belts it is important to follow manufacturer guidelines for sizing and tensioning the belts to ensure quiet, trouble-free operation.

V-belts should be a standard replacement part in every building’s maintenance program, requiring replacement every few months. Energy-efficient synchronous belts can easily be incorporated into a standard maintenance program, and the savings generated greatly outweigh the slight increase in cost per belt.

Consider a Testing, Adjusting, and Balancing Contractor

The modifications outlined above are likely to alter the operating characteristics of a building's HVAC system. Normally, the engineer or contractor who performed the work will be responsible for what is called the testing, adjusting, and balancing (TAB) of the modified or new system. TAB involves measuring and analyzing the various flows of air, chilled water, hot water, steam, etc., and ensuring that distribution of heating and cooling throughout the building meets the required specifications as outlined in the contract documents. Independent TAB contractors serve as an unbiased third party to ensure accuracy of the TAB measurements and are worth retaining if further oversight is desired. To find a qualified TAB firm, look for a firm that is certified by a recognized national professional society such as the Associated Air Balance Council. In addition, confirm that the TAB firm has experience with balancing systems in the type of facility in question (such as office, university building, or laboratory). Finally, ask for references.

8.5 Summary

This chapter illustrates the many options that are available to optimize constant-volume and variable air volume air distribution systems. Some of the strategies to remember are:

- Address zone-level opportunities first.
- Consider converting a CV system to VAV.
- Rightsize fan system to match actual loads.
- Install VSDs where practical.
- Consider improved controls to optimize scheduling and to implement temperature or pressure reset, economizer cooling, and demand-controlled ventilation.
- Install rightsized, premium-efficiency motors where possible.
- Install energy-efficient belts.

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Chapter 9
Heating and Cooling




9. Heating and Cooling

Revised January 2008

9.1 Overview

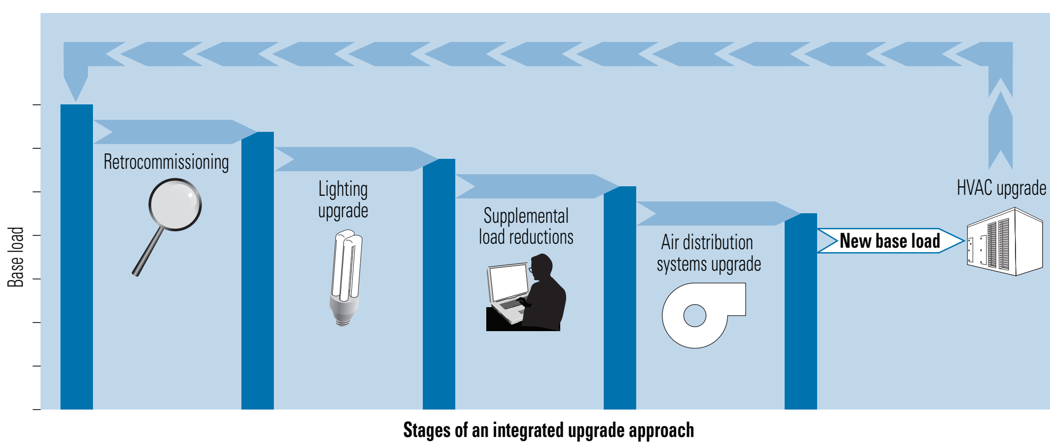
Although heating and cooling systems provide a useful service by keeping occupants comfortable, they also account for a significant portion of a building's energy use—typically about a quarter. However, it is possible to lessen this impact in both central and unitary systems by increasing their efficiency.

This chapter identifies opportunities for improving the performance of heating and cooling systems. Cooling systems generally have higher space-conditioning capacities than heating systems because waste heat from people, lighting, and office equipment supplies a large portion of a building's heating requirement. Although their higher capacities often translate into more opportunities for savings from cooling systems, significant savings can still be had from heating systems.

Following the steps outlined in previous stages of this manual should have reduced cooling and heating loads (**Figure 9.1**). Many existing systems are oversized to begin with, so it may now be possible to justify replacing the current system with a properly sized one—or retrofitting it to operate more efficiently. When replacing system components, it is extremely important to size the equipment properly to meet current loads. Besides saving energy, proper sizing will likely reduce noise, lower first costs for equipment, and optimize equipment operation, which in turn reduces maintenance costs and extends equipment lifetime. For example, a 1 watt per square foot (W/ft^2) reduction in lighting load in a 100,000-ft^2 building would allow a chiller capacity reduction of about 23 tons (assuming 80 percent of the waste heat reaches the conditioned space). If a typical chiller costs $450 per ton, then a 23-ton reduction would reduce the first cost of a new chiller by more than $10,000. Other load reductions would further reduce the required chiller size. To determine new heating and cooling loads accurately, it may be necessary consult an energy engineer or other expert.

Figure 9.1: The staged approach to building upgrades

The staged approach to building upgrades accounts for interactions among all the energy flows in a building. Each stage affects the upgrades performed in subsequent stages, thus ensuring the greatest energy and cost savings possible. The heating and cooling stage takes advantage of all the load reductions achieved in earlier stages.



Courtesy: E SOURCE

The conventional approach to upgrading a heating and cooling system is to address each component of the system individually. However, addressing the interactions among components using an integrated-system approach ultimately results in superior efficiency, particularly with central systems.

An annual maintenance program is also essential for keeping any heating or cooling system operating efficiently. Clean or replace air filters regularly, verify proper refrigerant levels and airflow, and inspect equipment for obvious malfunctions like stuck dampers.

Although heating and cooling upgrades represent the last stage of building upgrades, they do not signal the end of the process. It is important to make sure the changes implemented continue to provide the intended benefits throughout their useful lifetimes—through periodic recommissioning and further upgrades as needed. See the EPA's Guidelines for Energy Management Overview at www.energystar.gov/index.cfm?c=guidelines.guidelines_index.

9.2 Central Cooling Systems

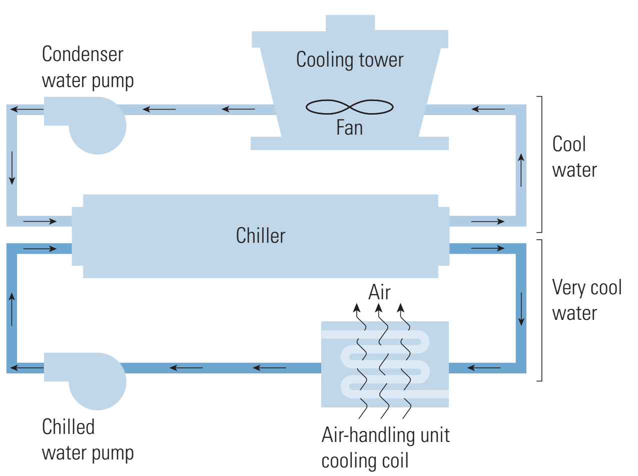
Chilled-water systems, found mainly in large buildings, feature separate central chillers and air handlers, with a network of pipes and pumps to connect them (**Figure 9.2**). Although only 18 percent of all U.S. commercial building floor space is cooled by chillers, about 39 percent of all buildings larger than 100,000 ft^2 contain chilled-water systems.

Chillers use one of four types of compressor: reciprocating, scroll, screw, and centrifugal. Reciprocating chillers are the least efficient. Screw and scroll compressors are typically used in applications needing up to 300 tons of cooling capacity. Centrifugal compressors traditionally provide larger capacities, although a new type of centrifugal compressor that employs magnetic bearings breaks this mold to serve the under-300-ton market.

There are no federal minimum efficiency standards for chillers. However, ASHRAE (the American Society of Heating, Refrigerating, and Air-Conditioning Engineers) does provide

Figure 9.2: Typical water-cooled chiller system

The air-handling unit captures heat inside the building and the cooling tower expels it.



Courtesy: E SOURCE; adapted from EPA

efficiency specifications in its 90.1 standard, "Energy Standard for Buildings Except Low-Rise Residential Buildings," which is used in many local building codes (**Table 9.1**).

As counterintuitive as it may sound, focusing on just the efficiency of the chiller will not necessarily lead to the most cost-effective savings. Chiller efficiencies do not account for pumps and fans in the cooling system and they apply only to single chillers (80 percent of plants use multiple chillers). Full-load efficiency data is also of little value because chillers rarely run at full load, and integrated part-load data is provided at too few operating points to give an accurate indication of performance. The best way to produce energy and demand savings is to consider the operation of the entire chiller plant using an integrated approach. Energy and demand savings are achievable through improved operation and maintenance of the plant as well as through efficiency retrofits. Note that many chillers that used the now-banned chlorofluorocarbon (CFC) refrigerants have already been either replaced or upgraded to use compliant refrigerants. When a remaining CFC system is finally replaced or upgraded, this presents an opportunity to evaluate other chiller plant modifications that could yield substantial energy savings.

Chiller Plant Operations and Maintenance

The efficiency of a chiller plant can be improved through both operations and maintenance adjustments.

Use controls to properly sequence chillers. Monitor the capacity of all chillers in the plant and turn chillers on or off so that each one is loaded enough to keep it in its most efficient zone (see sidebar, "Sequencing Chillers Yields Savings").

Monitor outdoor conditions and reset the chilled-water temperature accordingly. This strategy can help match chiller output to the actual load. Note however that this strategy is often disabled by chiller plant operators trying to rectify unrelated plant problems. To help prevent this, show plant operators how to apply and maintain this strategy and explain why it is valuable.

Monitor outdoor conditions and reset the condenser-water temperature accordingly. Higher condenser-water temperatures decrease cooling tower fan power but increase chiller power. The optimum operating temperature occurs at the point where these two opposing trends combine to produce the lowest total power use. However, this point changes with outdoor conditions, so it needs to be adjusted periodically to maintain efficiency.

Table 9.1: ASHRAE 90.1-2001 and 2004 minimum required efficiencies for water-cooled chillers

Many local building codes directly reference ASHRAE 90.1 or require using the International Energy Conservation Code, which has adopted 90.1.

	Capacity range					
	< 150 tons		150 to 300 tons		> 300 tons	
Chiller type	Full load	IPLV	Full load	IPLV	Full load	IPLV
Centrifugal	0.703	0.670	0.634	0.596	0.576	0.549
Screw and scroll	0.790	0.676	0.718	0.628	0.639	0.572
Reciprocating	0.837	0.696	0.837	0.696	0.837	0.696

Note: IPLV = integrated part-load value.

Courtesy: E SOURCE; data from ASHRAE

CASE STUDY: Sequencing Chillers Yields Savings

A chiller plant monitored in a loading and performance study by San Diego Gas & Electric demonstrates the savings potential of better chiller sequencing. The plant includes two 200-ton centrifugal chillers serving a 162,930-square-foot office building. The study revealed that many hours were spent with both chillers operating simultaneously at less than 45 percent capacity each. Calculations showed that savings of about 5 percent could be achieved by operating a single chiller at 90 percent load instead of both at 45 percent load. Annual energy savings would be about 34,500 kilowatt-hours (kWh), or about $2,800 per year at $0.08 per kWh.

Further study revealed additional savings. By shutting down one chiller, the auxiliary chilled-water and condenser-water pumps that served it could also be shut down. This would yield additional savings of about 14,100 kWh or $1,100 annually, bringing the overall savings from improved chiller sequencing to about $3,900 per year.

Take full advantage of available cooling towers. Most chilled-water plants have excess capacity, with one or more cooling towers not operating during low-load periods. To make the most of existing cooling towers, simply run condenser water over as many towers as possible, at the lowest possible fan speed, and as often as possible. This strategy is feasible only for chilled-water systems that include multiple chillers and towers plumbed in parallel—and the ability to vary the speed of the fans. For such systems, open all the condenser-water isolation valves at the cooling towers and leave them open. To avoid additional pumping power costs, run only enough condenser-water pumps to maintain adequate flow through the chillers. This retrofit strategy does have one drawback for two-speed fans: It causes additional fan cycling (between half speed and off, and between half speed and full speed). This in turn leads to additional wear and tear on motors and gears.

Inspect tubes annually and clean as needed, or use automatic tube-cleaning equipment. As a chiller runs, water may leave behind scale, algae, or slime on the inside of the condenser tubes (buildup is typically not a problem in the evaporator tubes because that is a closed system). These deposits can decrease both the efficiency and the capacity of the chiller by reducing heat-transfer efficiency. Periodic chemical or ozone treatments can help keep condenser tubes clear. Another option is automatic cleaning equipment that inserts thumb-sized nylon brushes into each condenser tube—catch baskets epoxied to the ends of the tubes collect the brushes. These brushes are slightly larger than the inside diameter of the tubes, so they brush the whole length of the tube as they are propelled by the water flow.

Energy and maintenance savings depend on the chemical or manual treatment that would otherwise have been used—the more deposits that would have built up, the greater the savings. A condenser fouled to the point that the temperature increases 5 degrees results in a 5 percent decrease in capacity and a 5 percent increase in power requirements. In some older machines, refrigerant tubes in the evaporator can become fouled by oil in the refrigerant—oil separators address this problem and are standard equipment on newer systems.

Prevent scale formation in cooling towers. Scaling, corrosion, and biological growth all impede tower efficiency and increase maintenance costs from the resultant condenser fouling and loss of heat transfer. Chemical treatments typically mitigate these problems, but nonchemical treatment technologies, such as ozone generators and ultraviolet irradiation, are also available.

Chiller Plant Retrofits

Chilled-water plants are complex and thus present many retrofit efficiency opportunities. As a general approach, thinking upstream through possible retrofit opportunities—starting at the valves and ending at the cooling tower fan—can yield upstream capital cost savings and energy savings. For example, by reducing resistance in the piping system, a designer might be able to reduce capital costs by specifying a smaller pump and a smaller chiller. However, to improve the overall efficiency of a chiller plant, an integrated system approach must be used. This is important for two reasons. First, it is difficult to make generalizations about specific opportunities—creating the most cost-effective chiller plant for a particular building often requires a designer to consider energy and demand prices, building load characteristics, local climate, building design, operating schedules, and the part-load operating characteristics of the available chillers. Second, modifying the design or operation of one set of components often affects the performance of other components of the system. For example, increasing the chilled-water flow can improve chiller efficiency, but the extra pumping power required can result in an overall *reduction* in system efficiency.

To illustrate the challenge of improving a chiller plant's overall efficiency, consider the case of a designer who switched a chiller condenser-tube bundle from two-pass flow to four-pass flow in order to improve chiller efficiency. That change indeed improved chiller efficiency from 0.62 kilowatts (kW) per ton to 0.60 kW per ton, but it also added 28 feet of pressure drop to the chilled-water flow stream—and thus increased the required pumping power. As shown in **Table 9.2**, this produced a net chiller plant energy savings at full load. However, because this particular building featured a constant-flow system, at the typical 75-percent load condition there was a net plant energy-use increase. The net effect was even worse at lower loads. Although the designer had intended to reduce energy consumption by improving chiller efficiency, the "improvement" wound up increasing overall building energy consumption.

Accounting for all the variables in a chiller plant can be a daunting task, so one of the best options for producing an optimal chilled-water system is to use a building energy performance simulation package. These computer programs (see sidebar, "Resources: Chillers") perform the numerous and complex calculations needed to evaluate how buildings use energy. The most sophisticated programs can calculate building energy consumption hour by hour for an entire year. That allows designers to see how modifications to any of the building's systems—including the chilled-water system—will affect the building's annual energy consumption. These packages also account for interactions among building components, which allows building designers to experiment with a variety of combinations of efficiency strategies and determine which ones produce the most cost-effective building. Designers and their clients may seek to amortize the cost of

Table 9.2: The perils of piecemeal chiller improvements

By not considering the interaction of all chiller components, this conversion to a two-pass flow condenser-tube bundle resulted in a net energy use increase at the more typical load factor of 75 percent.

	Post-conversion power consumption	
Component	Full load (kW)	75% load (kW)
Chiller	-8.80	-6.60
Pumps	8.60	8.60
Chiller + pumps	**-0.20**	**2.00**

Note: kW = kilowatt.

Courtesy: E SOURCE

simulating building performance by using simulations after the building is occupied—to verify savings, optimize HVAC system control, and identify malfunctions in building systems. Several HVAC equipment manufacturers also offer energy simulation software.

The following list presents efficiency opportunities to consider for chilled-water systems.

Replace standard valves with low-friction units to reduce flow resistance for the chilled water. This measure reduces pump energy use and returns less heat to the chiller. Where valves control flow by inducing pressure drop, consider converting to variable-speed controls, trimming the impeller, or staging pumps instead. Then eliminate or completely open the valves.

Insulate chilled-water pipes. Insulation helps ensure that the chilled water only absorbs heat from the spaces where it is intended to do so.

Replace standard-efficiency or oversized pumps with highly efficient units sized for the newly reduced loads. Most induction motors that drive pumps reach peak efficiency when about 75 percent loaded, and are less efficient when fully loaded. Thus, wherever possible, size pumps so that much of their operating time is spent at or close to their most efficient part-load factor. If a pump is oversized, then it likely operates at an inefficient loading factor.

RESOURCES: Chillers

DOE-2

www.doe2.com

This hourly building energy performance simulation software was developed by the Simulation Research Group at Lawrence Berkeley National Laboratory. It takes some practice to become adept at this software and running a variety of scenarios can be quite time-consuming, so consider hiring consultants who specialize in performing these evaluations.

eQUEST

www.doe2.com/equest

Developed as part of the Saving by Design incentive program offered by California utilities, eQUEST is a free software package that provides a "window- and wizard-driven" front end to DOE-2. Although easier to use than DOE-2, it allows users to access DOE-2's full capabilities to model many variables that affect a chiller's performance. It can also be used to assess and help minimize building cooling loads. Savings achieved from proposed systems are compared with a modeled baseline chiller plant set to conform with local building codes.

CoolTools Chilled Water Plant Design and Specification Guide

www.taylor-engineering.com/publications/design_guides.shtml

This free guide sponsored by Pacific Gas & Electric Co. is written for technical designers and offers direction on many of the options available in designing a chilled-water plant.

Danfoss Turbocor

www.turbocor.com

This is the only magnetic-bearing chiller compressor. Turbocor manufactures and supplies the compressor direct to end users for retrofits and to chiller manufacturers who incorporate the compressor into new chillers and offer them for retrofits.

Control chilled-water pumps with variable-speed drives (VSDs). VSDs can ensure that pumps are performing at maximum efficiency at part-load conditions. As with fan systems, the power required to operate a pump motor is proportional to the cube of its speed. For example, in a pump system with a VSD, a load reduction that results in a 10 percent reduction in motor speed reduces energy consumption by 27 percent: $1 - (0.9)^3 = 0.27$. However, it is necessary to ensure that flow rates through chillers are maintained at safe levels. With sophisticated controls, lower chilled-water flow rates enabled by VSD pumps can also be coordinated with a chilled-water temperature reset strategy to meet loads accurately and efficiently. For example, low loads might be most efficiently met by creating colder chilled water and reducing the flow rate to save pump energy.

Upgrade the chiller compressor. For a centrifugal compressor, install a VSD. This will allow the chiller to run at lower speeds under part-load conditions, thereby yielding a higher efficiency than is typically achieved by ordinary centrifugal chillers that control part-load operation with inlet vanes. However, a VSD may not be cost-effective in applications where there are extended periods with very low loads (10 percent of full load). In these cases, consider installing a separate small chiller just for these loads.

For reciprocating and screw chillers, replace the existing compressor with one that uses new magnetic bearing technology. These achieve much better efficiency than any other compressor type in the under-300-ton capacity range. Chillers using magnetic bearing compressors can achieve an integrated part-load value (IPLV) of 0.3699 kW/ton, as compared with an IPLV of 0.6000 kW/ton for standard screw- and scroll-based chillers, producing significant savings.

For example, at the San Diego East County Family Resource Center, a single 80-ton magnetic-bearing compressor replaced two reciprocating compressors on an existing 88-ton air-cooled chiller after one of the reciprocating compressors failed. Before-and-after monitoring showed an efficiency gain of 0.41 kW/ton. Because cooling loads were relatively low—1,347 equivalent full-load cooling hours (a metric used to estimate annual energy use for cooling in a building)—the chiller was oversized by about 30 tons. The compressor replacement produced an estimated payback period of 4.7 years (or 2.8 years with incentives from the San Diego Regional Energy Office) and an ongoing energy savings of about $8,000 per year.

For chillers without a VSD, use low-voltage soft starters. The motor windings of constant-speed compressors experience great stress when the chiller is first started due to the high inrush of current. Over time this can lead to motor failure. Soft starting gradually raises the voltage and current to avoid the high inrush. Soft starting itself does not save energy, but it does enable shutting off chillers that are otherwise left running because operators are concerned about wear and tear from frequent starts.

Replace an old or oversized standard-efficiency chiller with a properly sized high-efficiency water-cooled unit. If the existing chiller is nearing the end of its life or is in need of substantial maintenance, consider retiring it early to capitalize on the savings that a new high-efficiency model can provide. The annual energy cost for operating a chiller can be as much as one-third of its purchase price, so even a modest improvement in efficiency can yield substantial savings and attractive paybacks. For example, paying an extra $6 per ton for each 0.01 kW/ton improvement to raise the efficiency of a 500-ton chiller from 0.60 kW/ton to 0.56 kW/ton would increase that machine's first cost by $12,000. But it would also reduce operating costs by $3,000 per year, yielding a four-year simple payback. This can be particularly fruitful if the existing chiller is already oversized or if load reductions achieved through other stages in the building upgrade process allow the chiller to be downsized.

When replacing an existing chiller, select one that will be most efficient under the conditions it is likely to experience. Even though chiller performance can vary dramatically depending on loading and other conditions, designers frequently select chillers based on full-load, standard-condition efficiency. However, chillers spend most of their operating time at 40 to 70 percent load under conditions that are often considerably different from standard conditions. For example, when San Diego Gas & Electric reviewed the performance of 21 chiller plants, it found that at 11 of the sites more than one chiller was running at less than 50 percent of design load most of the time. To select the chiller that will have the lowest operating costs, determine what the actual operating conditions are likely to be and then consider how efficiently the unit will operate under those conditions. In many cases, VSD chillers along with VSD pumps and fans are highly cost-effective.

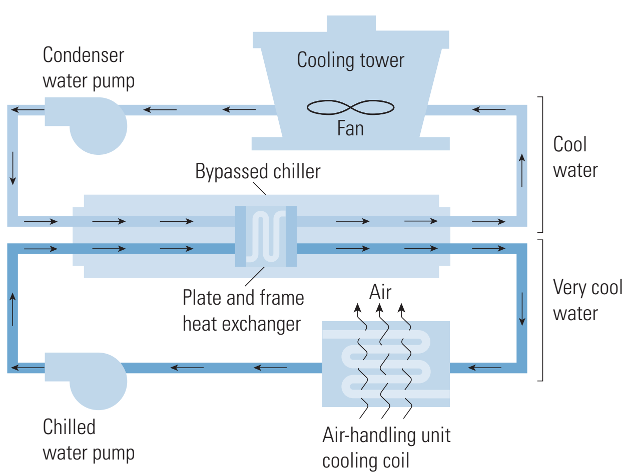
Install plumbing to connect multiple cooling towers or multicell towers in parallel and VSDs to control cooling tower fans. This step allows the chiller plant to use excess cooling tower capacity at part-load conditions and save on fan energy, as described in the Chiller Plant Operations and Maintenance section.

Install water-side economizers to allow cooling towers to produce chilled water when weather conditions permit. Under the right conditions, water-side economizers can save a lot of energy. In cool, dry climates, they can provide more than 75 percent of the cooling requirements; in warm climates they may provide only 20 percent. The most common type is an *indirect* economizer that uses a separate heat exchanger, typically of the plate-and-frame type (**Figure 9.3**). It allows for a total bypass of the chiller, transferring heat directly from the chilled-water circuit to the condenser-water loop. When the wet-bulb temperature is low enough, the chiller can be shut off and the cooling load may be served exclusively by the cooling tower.

Again, before pursuing any of the opportunities listed above, it is important to evaluate the performance of the chiller plant as an integrated system. Although an integrated approach requires more effort than simply picking measures independently, it can produce significant savings (see sidebar). Note that for the opportunities listed here that involve adding VSD

Figure 9.3: Indirect water-side economizer

Inserting a heat exchanger between the cooling tower and air-handling unit enables the controls to bypass the chiller when outdoor temperatures are low enough.



Courtesy: E SOURCE; adapted from EPA

CASE STUDY: A Chiller Plant Overhaul

The cooling plant at the San Diego Crime Lab was in need of an upgrade. The chiller plant was 18 years old, used two outdated 130-ton air-cooled reciprocating chillers, and was wasting energy and increasing demand charges. On top of these problems, more cooling capacity was required for a planned laboratory expansion. One option was to replace the reciprocating compressors with air-cooled screw compressors. Based on a whole-plant analysis, this retrofit would supply the needed capacity—but with only moderate energy and demand savings. After further evaluation of the existing equipment and the facility's needs, the crime lab opted instead to install an all-variable-speed water-cooled chiller plant. This included variable-speed cooling tower fans and pumps on both the chilled- and condenser-water side, as well as a magnetic-bearing compressor that could operate at variable speeds.

The new chiller plant, including the pumps and fans, performed at an average efficiency of 0.538 kilowatts (kW) per ton. Traditionally, a plant efficiency of 0.7 to 0.8 kW/ton is considered good in the under-300-ton size range, and most plants operate at 1.0 kW/ton or above. The old air-cooled chiller plant was measured as using around 1.48 kW/ton. The incremental cost and savings between a new standard chiller plant (using air-cooled screw compressors without variable-speed equipment) and the all-variable plant produced a payback of five years based on energy and demand savings alone. Incentives provided by San Diego Gas & Electric further reduced the incremental payback to two years. The ongoing estimated annual energy and demand savings amount to about $65,000.

components, control upgrades may also be required. VSD pumps, fans, and compressors provide greater operations flexibility and efficiency, but the control system must coordinate their operations with the rest of the system—existing controls may not be able to provide the advanced functions necessary for efficient operation.

9.3 Central Heating Systems

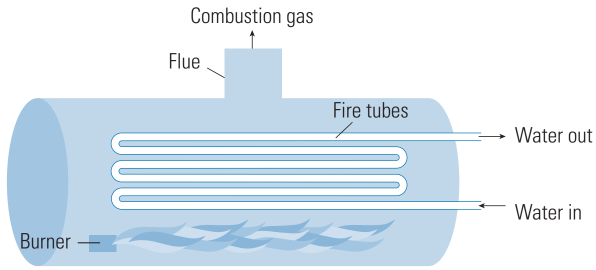
Two types of equipment are used to provide central heat for buildings: boilers and furnaces. Boilers, which produce hot water or steam that is then distributed throughout a building, heat about 32 percent of all U.S. commercial floor space (**Figure 9.4**). Typically there are more opportunities to improve the efficiency of boiler systems due to their more complicated nature, as compared to furnaces.

Furnaces heat air (instead of water) and distribute it to occupied spaces. Note that in commercial applications, the term "furnace" applies to several types of equipment, which together heat about 30 percent of the floor space in U.S. commercial buildings. Central furnaces, though they serve a relatively small percentage of heated commercial space, offer the greatest savings opportunities amongst furnaces because they are the only type that heats an entire building. Other types, such as duct furnaces and vertical-air-turnover furnaces, supply heat to only a limited area of the building.

Other heating systems, such as those contained in packaged rooftop units (see section 9.4), typically do not offer savings opportunities.

Figure 9.4: A typical boiler

In this water-tube boiler, feedwater flows through tubes where hot gases from the combustion process heat the water. Exhaust gases leave through the flue.



Courtesy: E SOURCE; adapted from EPA

Boiler System Operations and Maintenance

The following list of operation and maintenance measures are important parts of the overall boiler system upgrade strategy and can provide significant energy savings:

- *Establish a total-system water treatment program.* This will help prevent the formation of deposits that degrade heat transfer and increase friction.
- *Periodically check the air-fuel ratio.* If it is not cost-effective to install a boiler combustion monitoring system, periodically check and calibrate the stack temperature, excess air, CO, CO_2, opacity, and NO_x using portable monitoring equipment. The data will reveal inefficiencies in the combustion process.
- *Periodically reset the boiler pressure.* If temperature/pressure reset controls are not used, periodically assess the temperatures required and reset boilers to the minimum necessary pressure.
- *Assess feedwater and blowdown rates.* Where it is not feasible or economical to install an automatic blowdown control system (see “Boiler System Retrofits”), establish the feedwater and blowdown rates described in the *Boiler and Pressure Vessel Code* developed by the American Society of Mechanical Engineers (see www.asme.org). This will help remove dissolved solids that might otherwise damage equipment and waste energy.
- *Identify and repair steam leaks.* Leaks waste energy and can damage surrounding spaces.
- *Establish a program for systematically inspecting, testing, and repairing steam traps.* Leaking steam traps waste energy by allowing steam to escape into the condensate return line, thus preventing the steam from delivering heat where intended.
- *Remove scale from boiler heat-exchange surfaces.* Scale decreases the heat transfer capability of heat exchangers.

Boiler System Retrofits

Consider replacing an existing boiler with a new, energy-efficient unit sized to reflect loads reduced through other stages of the building upgrade process. While the average gas boiler in the commercial stock has a combustion efficiency (100 percent minus flue losses) of 76 percent, new gas-fired commercial boilers have an average combustion efficiency of 80 percent, and high-efficiency boilers built with condensing heat exchangers have combustion efficiencies as high as 90 percent.

The current federal minimum efficiency standards for commercial boilers took effect on January 1, 1994. For boilers with a rated maximum input capacity of at least 300,000 Btu per hour, the combustion efficiency at the maximum rated capacity must be at least 80 percent for gas-fired equipment and 83 percent for oil-fired equipment.

Although the federal standards use combustion efficiency to measure the efficiency of boilers, the EPA qualifies boilers for the ENERGY STAR program based on their annual fuel utilization efficiency (AFUE). AFUE estimates energy use more accurately than combustion efficiency because it includes flue losses, off-cycle losses, and equipment-jacket losses. Qualified boilers must have an AFUE of at least 85 percent (see www.energystar.gov/index.cfm?c=boilers.pr_boilers).

Because efficient models require corrosion-resistant materials and sophisticated controls, they cost up to three times as much as conventional boilers. However, a properly sized condensing boiler system will generally beat out a less efficient boiler system in terms of life-cycle cost (boilers have an average life of 25 years). To determine whether to replace a boiler system, calculate the expected energy savings by comparing rated energy consumption at various loads for the old and new boiler systems. These calculations can be complicated, so it may be useful to consult an engineering firm or boiler manufacturer for assistance.

Several small boilers can also be grouped together in parallel to provide staged heating capacity. This approach is usually more economical and efficient than using a single large boiler because:

- The boilers can be staged to operate at or near their highest efficiency points.
- Small boilers are more efficient than large commercial boilers.
- Multiple boilers provide redundancy, which can reduce system downtime.
- Small boilers can reduce installation costs because each boiler is small enough to be handled without a crane.

The multiple-boiler approach can also be used as a retrofit measure to improve the seasonal efficiency of large, inefficient, aging boilers. A small high-efficiency “front-end” boiler can be installed in tandem with the old one—the small boiler serves the base heating load and the large boiler only fires up when needed to meet high demand.

Where boiler replacement is not feasible, there are many retrofit options that will improve the efficiency of an existing boiler system:

- *Insulate hot-water distribution lines.* Insulation reduces heat loss to unconditioned spaces, thereby optimizing the delivery of heat to the intended portions of the building.
- *Install VSD controls on hot-water distribution pump motors.* This measure is most effective in large buildings where pumping energy is significant and when used in conjunction with condensing boilers. Be careful with noncondensing boilers because low flow rates can cause flue gas condensation and corrosion in the boiler.
- *Install a combustion monitoring and control system.* Use the monitoring data to trim boiler excess air and/or install automatic oxygen trim controls. To learn more about flue gas monitoring and burning tuning, see the U.S. Department of Energy (DOE) Industrial Technologies Program Steam Tip Sheet #4 at www1.eere.energy.gov/industry/bestpractices/pdfs/steam4_boiler_efficiency.pdf.
- *Install temperature/pressure reset controls.* These provide significant energy savings by matching the supply of steam or hot water with the demand for heat—by resetting the system

temperature or pressure based on outdoor temperature. If outdoor temperature increases, the system water temperature or steam pressure is lowered.

- *Install controls to set back supply temperature during unoccupied hours.* This saves energy by reducing heating when maintaining occupant comfort is not required.
- *Install an automatic blowdown control system.* This helps remove dissolved solids that can damage equipment and lead to energy waste, depending on the concentrations present. See the DOE Steam Tip Sheet #23 at www1.eere.energy.gov/industry/bestpractices/pdfs/steam23_control_system.pdf. When using continuous blowdown instead, install a heat exchanger to warm feedwater with heat recovered from blowdown.
- *Install a stack economizer.* A stack economizer captures waste heat in the exhaust flue gases and uses it to preheat the boiler feedwater. This measure is typically only cost-effective for very large (more than 2 million Btu per hour capacity) systems. When natural gas fuels the boiler, maintain the stack temperature at at least 250° Fahrenheit to avoid water condensation in the flue gases.
- *Install baffle inserts.* These induce combustion gases to flow in a turbulent spiral pattern, which increases heat-transfer efficiency.
- *Install outside-air intake vents for the boiler.* This reduces or eliminates building air infiltration caused by boiler operation.
- *For steam systems, use the DOE Steam System Scoping Tool.* This software, available at www1.eere.energy.gov/industry/bestpractices/software.html, quickly evaluates the entire steam system operation and suggests a range of ways to save steam energy and boost productivity. It also compares an existing system to identified best practices and evaluations of similar facilities. Also see the DOE's collection of Steam Tip Sheets at www1.eere.energy.gov/industry/bestpractices/tip_sheets_steam.html for other improvement ideas.
- *Insulate steam distribution and condensate return lines.* Insulation will prevent heat loss through the system. The DOE provides the 3E Plus software tool at www1.eere.energy.gov/industry/bestpractices/software.html to calculate how much insulation is needed to conserve energy and avoid the expense of overinsulation.
- *Install wide-deadband thermostats for unbalanced single-pipe steam systems.* Conventional thermostats with shorter deadbands may not cycle on the boiler long enough for steam to fill the entire distribution line, resulting in insufficient heating at the end. But increasing the thermostat setting to compensate causes overheating near the start of the line. Wide-deadband thermostats will produce longer on and off cycles and provide more even heating.

Improving Furnace Efficiency

Furnaces are usually fueled by gas or oil; electric furnaces are rare and generally more expensive to operate. Although furnaces in the existing buildings stock have an average AFUE of only 76 percent, new gas-fired commercial furnaces have an average AFUE of 80 percent, and high-efficiency furnaces built with condensing heat exchangers have AFUEs as high as 92 percent.

The current federal minimum efficiency standards for commercial furnaces took effect on January 1, 1994. For furnaces of 225,000 Btu per hour capacity or greater, the standards specify a steady-state or thermal efficiency (100 percent minus flue losses) of at least 80 percent for gas-fired equipment and at least 81 percent for oil-fired equipment at their maximum rated input capacity. Note that these efficiency ratings do not account for cycling losses, losses through the central heater's cabinet, or distribution losses. Although the standards only specify thermal efficiency, manufacturers can also include AFUE, which accounts for cycling and cabinet losses.

Residential warm-air gas furnaces are sometimes used in small commercial applications. The current federal standard for these units became effective on January 1, 1992, and establishes a minimum efficiency of 78 percent AFUE for units with an input rating of less than 225,000 Btu per hour. A new standard was set in November 2007—to become effective in 2015—raising the minimum efficiency to 80 percent AFUE. For more information on this change, see the DOE's Residential Furnaces and Boilers web page at www.eere.energy.gov/buildings/appliance_standards/residential/furnaces_boilers.html.

To improve furnace system efficiency:

- *Consider replacing the existing furnace with a new, energy-efficient model.* It may be possible to downsize the furnace based on load reductions achieved through other stages of the building upgrade process.
- *Install controls to set back supply temperature during unoccupied hours.* This saves energy by reducing heating when maintaining occupant comfort is not required.
- *For electric furnaces, install two-stage setback controls.* In spaces where the temperature is reduced during unoccupied periods, the electric demand needed to bring the space back to its original temperature can be significant. In this case, if the local electric rate structure includes demand charges, install a two-stage setback thermostat with staged supplemental heat and a programmable demand limiter to prevent demand peaks in the morning. Also consider alternatives to resistance heating to reduce heating costs and environmental impact.

9.4 Unitary Systems

Unitary equipment cools about 70 percent of air-conditioned commercial buildings in the U.S. Unitary equipment is factory assembled, available as single-packaged or split-system units, and may take the form of a heat pump (providing both heating and cooling) or an air conditioner. Unitary systems include an evaporator, blower, compressor, and condenser. Some unitary air conditioners also include an electric resistance or gas heater section. The systems are typically cabinet- or skid-mounted for easy installation and range in cooling capacity from about 1.5 to 130 tons.

Compared to central chiller plants, unitary systems do not last as long (median lifetime of 15 years compared to 20 to 23 years for chillers) and are less efficient. Unitary systems are generally used in buildings up to three stories that have small cooling loads, such as retail spaces, small office buildings, and schools.

Generally speaking, it is not feasible to convert a building from a unitary to a central chilling system. However, it is not always necessary to replace an old unit with a new one of the same type. For example, a packaged rooftop air conditioner can be replaced with an air-to-air heat pump.

Commercial buildings typically have unitary systems with cooling capacities greater than 5 tons. These systems are rated by energy-efficiency ratio (EER), which is a measure of full-load efficiency at conditions specified by the Air-Conditioning and Refrigeration Institute. Some buildings use residential-sized unitary systems (under 5 tons, using single-phase power) because of space requirements, physical limitations, or for small additions. Residential-sized systems are rated by seasonal energy-efficiency ratio (SEER), a seasonally-adjusted value. For both EER and

SEER, a higher number indicates a higher efficiency. ENERGY STAR qualified residential air conditioners have a SEER of at least 14 (see www.energystar.gov/index.cfm?c=cac.pr_central_ac for more information).

Three-phase equipment under 5 tons falls into its own category in the federal standards—although designed for the commercial market, these units use the residential SEER rating. ENERGY STAR qualified three-phase equipment under 5 tons must have a SEER of at least 13 (see www.energystar.gov/index.cfm?c=lchvac.pr_lchvac for more information).

The current U.S. federal standard established in 1992 requires manufacturers to produce commercial air-cooled air conditioners and heat pumps at the minimum efficiencies specified in **Table 9.3**. The Energy Policy Act of 2005 set new federal standards for commercial packaged rooftop units with capacities greater than 65,000 Btu per hour that will take effect on January 1, 2010. For smaller three-phase equipment, a rule-making is in progress to determine whether new standards should be set for this size category. Note that federal standards do not cover geothermal heat pumps, although ASHRAE 90.1 requires that those with a cooling capacity below 135,000 Btu per hour have a minimum cooling efficiency of 13.4 EER and a minimum heating coefficient of performance (COP) of 3.1.

Table 9.3: Federal efficiency standards for commercial packaged air-cooled air conditioners and heat pumps

The U.S. Energy Policy Act of 2005 added a "very large" category as part of the update of the standards for commercial packaged air-cooled equipment, in addition to increasing the minimum efficiency levels for existing size categories. All equipment listed here uses three-phase power. ENERGY STAR criteria will likely change for <5-ton equipment when the new minimum standards become effective.

			Federal minimum standards			
Federal size category	Equipment type	System design	Effective January 1, 1994	Effective June 16, 2008	Effective January 1, 2010	ENERGY STAR minimum criteria
< 65 kBtu/h, < 5 tons	Air conditioner	Split system	SEER 10.0	SEER 13.0	—	SEER 13.0[a]
		Single-packaged unit	SEER 9.7	SEER 13.0	—	SEER 13.0[a]
	Heat pump	Split system	SEER 10.0 & HSPF 6.8	SEER 13.0 & HSPF 7.7	—	SEER 13.0 & HSPF 7.7[a]
		Single-packaged unit	SEER 9.7 & HSPF 6.6	SEER 13.0 & HSPF 7.7	—	SEER 13.0 & HSPF 7.7[a]
Small (65 to < 135 kBtu/h; 5 to 11.25 tons)	Air conditioner	Split system and single-packaged unit	EER 8.9	—	EER 11.2	EER 11.0[b]
	Heat pump	Split system and single-packaged unit	EER 8.9 & COP 3.0	—	EER 11.0 & COP 3.3	EER 10.1 & COP 3.2[b]
Large (135 to < 240 kBtu/h; 11.25 to 20 tons)[c]	Air conditioner	Split system and single-packaged unit	EER 8.5	—	EER 11.0	EER 10.80[b]
	Heat pump	Split system and single-packaged unit	EER 8.5 & COP 2.9	—	EER 10.6 & COP 3.2	EER 9.3 & COP 3.2[b]
Very large (240 to < 760 kBtu/h; 20 to 63 tons)	Air conditioner	Split system and single-packaged unit	—	—	EER 10.0	—
	Heat pump	Split system and single-packaged unit	—	—	EER 9.5 & COP 3.2	—

Notes: COP = coefficient of performance; EER = energy-efficiency ratio; HSPF = heating seasonal performance factor; kBtu/h = thousand Btu per hour; SEER = seasonal energy-efficiency ratio; ton = 12,000 Btu/h.
a. Effective January 1, 2004; b. Effective January 1, 2002;
c. Energy Star criteria apply to equipment of capacity up to 250 kBtu/h.

Courtesy: E SOURCE; data from U.S. Department of Energy and EPA

Regardless of the equipment chosen, it is important to commission the overall system to ensure its proper operation from the onset as well as to maintain it properly over time (see sidebar). Comprehensive testing, adjusting, and balancing the installed unit and its controls will maximize efficiency and comfort. Conducting regular tune-ups, correcting refrigerant charge, cleaning and adjusting the system to correct airflow and improve heat transfer, and verifying economizer operation can yield surprising energy savings at low cost. The Consortium for Energy Efficiency offers installation guidelines for commercial air-conditioning equipment at www.cee1.org/com/hecac/hecac-spec.php3. Testing, adjusting, and balancing contractors; general HVAC service contractors; and those who use specialized diagnostic products to specifically measure refrigerant charge and airflow levels can perform commissioning and maintenance services.

Packaged Rooftop Units

About half of all U.S. commercial floor space is cooled by self-contained, packaged air-conditioning units. Often called single-packaged units or rooftop units (RTUs), most sit on rooftops, but they can also be installed on a concrete pad at ground level. Typical units include a blower section, filter bank, evaporator coil, at least one compressor (larger units often have multiple compressors to improve load matching), and an air-cooled condenser section. Evaporatively cooled condensers are used to achieve higher efficiencies (**Figure 9.5**). They may also come equipped with a natural gas or electric heating section—gas models, depending on local energy prices, are generally more economical. When replacing a packaged unit that uses electric resistance heat, consider using a heat pump instead because it may be more cost-effective.

All newer packaged rooftop units are equipped with factory-installed microprocessor controls. These controls make maintaining equipment easier and improve the energy efficiency of both the unit and the overall HVAC system. Control features include temperature setback and on/off scheduling. Large systems have variable-air-volume capability (see Chapter 8, "Air Distribution"). Also, most units have an optional communication interface for connection to an energy management system or to a demand-controlled ventilation system.

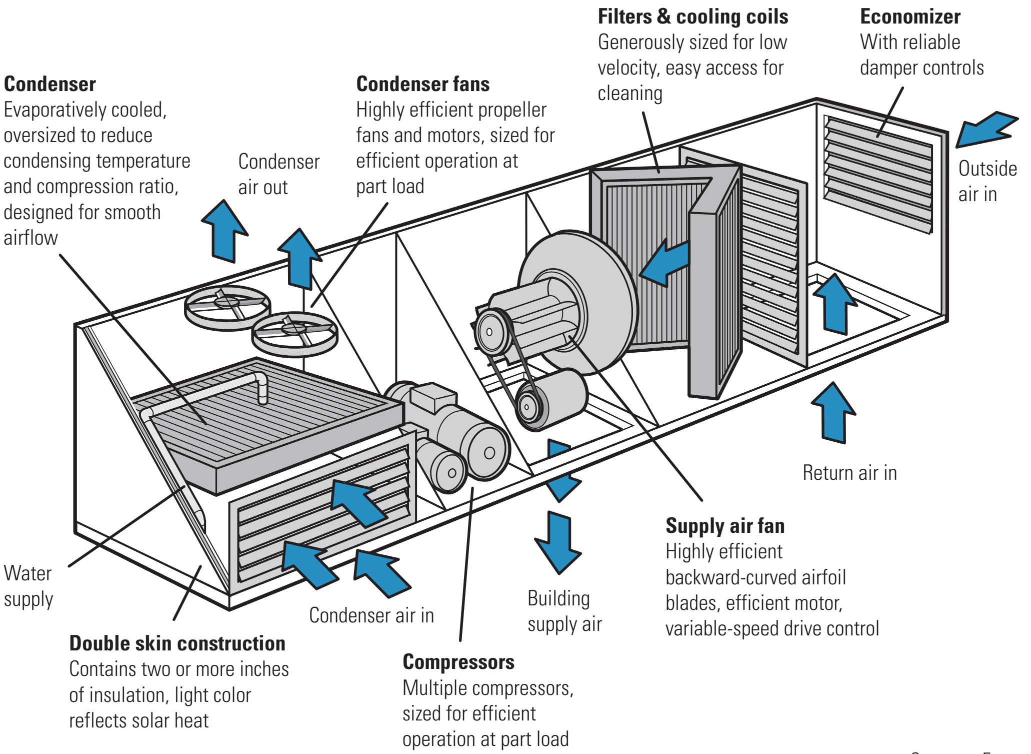
Selecting new high-efficiency models. Efficiency levels for packaged rooftop units have gradually increased over the past 15 years. In the small size range, the number of units with an EER of at least 10.4 has grown from only 14 percent of available models in 1993 to at least 65 percent in 2007. Units in this size range now have EERs as high as 12.7—so upgrading older units to a new high-efficiency model can produce substantial long-term energy savings. For

CASE STUDY: Diagnostic Service Proves Its Value

Air-conditioning tonnage and airflow-delivery systems are not always matched properly. A contractor certified to use a diagnostic tool that measures refrigerant charge and airflow levels received a report from the Poultry Palace and Deli in El Cajon, California, complaining that its air-conditioning system was not working. Two other companies had unsuccessfully attempted to repair the system. The certified contractor arrived on the site and determined that the refrigerant charge was correct, but the new 5-ton air conditioner had been coupled with a duct system capable of delivering only 3 tons of airflow. The service technician said he would not have found the problem had it not been for the diagnostic tool. The technician relayed the information to the customer, who authorized the repairs. Once repairs were made, the system was able to meet the cooling load.

Figure 9.5: Components and features of efficient packaged rooftop unit design

Manufacturers can incorporate several design features to produce high-efficiency units.



Courtesy: E SOURCE

example, a typical office building in Kansas City, Missouri, that has 10 standard 25-ton packaged units with EER ratings of 10 could save almost $30,000 annually by upgrading to units with EERs of 12. Note that since packaged rooftop units are primarily used for cooling, those that also provide heating generally do not offer a high-efficiency option for the heating component.

When replacing broken equipment or evaluating early retirement of working equipment, use the free web-based life-cycle cost estimation tool from the Federal Energy Management Program (www1.eere.energy.gov/femp/procurement/eep_unitary_ac_calc.html) to see how much energy high-efficiency models will save. After entering data for a specific high-efficiency unit and location, the tool estimates life-cycle cost, simple payback, and other metrics as compared to a standard unit that the user selects. Equipment manufacturers or engineering consultants can provide more detailed assistance. The EPA also establishes ENERGY STAR program criteria for high-efficiency commercial air conditioners (Table 9.3) and provides a list of qualified units at www.energystar.gov/index.cfm?c=lchvac.pr_lchvac.

Upgrading existing rooftop units. Upgrading existing packaged rooftop units is typically not feasible due to the cost and complexity of retrofitting components within a unit. However, there is one option that can be retrofitted onto the outside of a unit. Called the EER+, it is a heat-exchange module that can be retrofitted onto both existing air-cooled air conditioners and heat pumps to increase their efficiency. Made by Global Energy Group, a manufacturer of energy-efficient cooling equipment, it works by capturing waste condensate water from the unit and routing it over evaporative cooling pads. Exhaust air or outdoor air is blown across the pads (**Figure 9.6**). The resulting evaporative cooling removes heat from the air conditioner's refrigerant, increasing the efficiency and capacity of the system. When using exhaust air from the building, outdoor humidity does not significantly affect the heat exchangers. But when using outdoor air in humid climates, the efficiency increase may not be as great as it is in dry climates.

Split-System Packaged Units

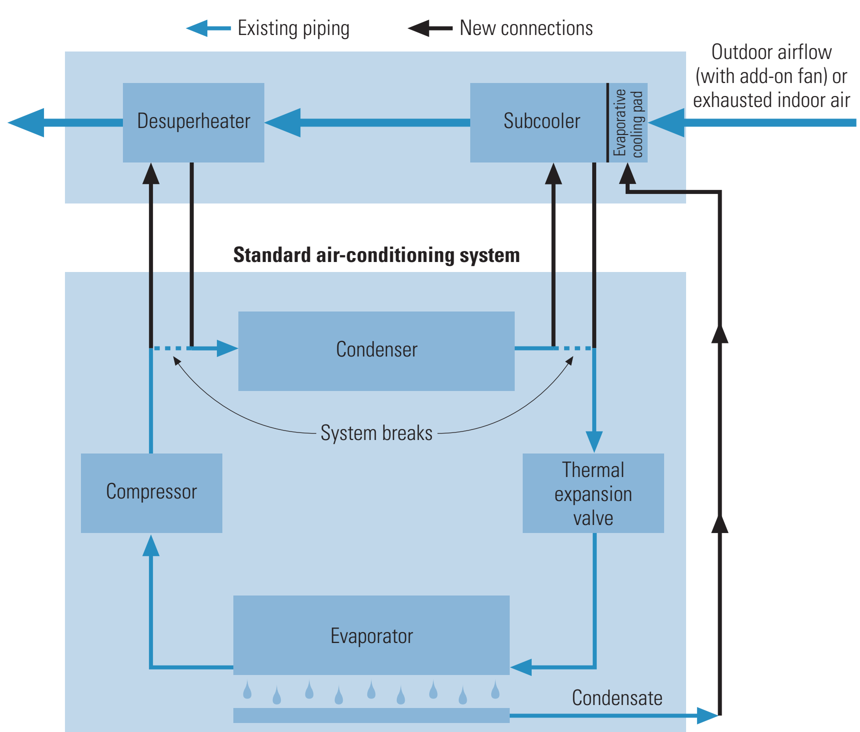
Split-system packaged units have an air-cooled condenser mounted on an outdoor pad or rooftop. Refrigerant piping connects the compressor section to an indoor air-handling unit and evaporator coil (**Figure 9.7**). Unless units include a heat pump, they cannot provide space heating. However, heating coils can be installed in the air-handling section, particularly if there is a central source of heat such as hot water or steam from a boiler. Split systems may be used in retrofit applications for architectural reasons (if a flat roof is not available, for example) or to provide cooling to a specific zone without having to cut a large hole in the roof, which would be required for the ductwork of a single-packaged unit. The same federal standards, ENERGY STAR criteria, and efficiency opportunities that apply to single packaged rooftop units also apply to split-system packaged units.

Air-Source Heat Pumps

Air-source heat pump systems are typically mounted on the roof, packaged either complete or as split systems. In cooling mode, the unit operates like a typical air conditioner. In heating

Figure 9.6: Rooftop unit efficiency upgrade

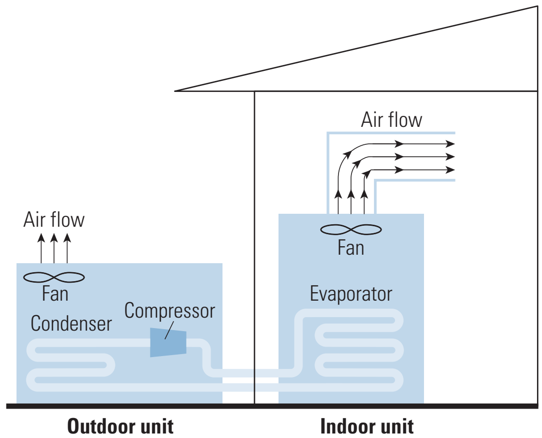
With this retrofit product, an evaporative cooling pad uses condensate water to subcool and desuperheat the refrigerant.



Courtesy: E SOURCE; adapted from Global Energy Group

Figure 9.7: Location of split-system components

The compressor and condenser are in one self-contained outdoor unit and the evaporator and air handler are in another unit inside the building.



Courtesy: E SOURCE; adapted from EPA

mode, the cooling system operates in reverse, extracting heat from the outside air and using it to provide space heating. Air-source heat pump systems range in size from about 1.5 to 25 tons. High-efficiency air-source heat pumps have an EER as high as 11.5 and a COP for heating as high as 3.6.

Air-source heat pumps offer an attractive alternative to rooftop units in cases when one needs to be replaced or a new unit is needed. Compared to packaged rooftop air conditioners that incorporate electric resistance heating coils, heat pumps offer improved year-round energy efficiency; compared to air conditioners that incorporate gas heating, heat pumps can offer cheaper operation where gas prices are high and electric rates are low.

In either case, most heat pumps are best suited to relatively warm climates, such as the southeastern U.S. This is because when temperatures are low, a heat pump's COP falls dramatically: A 7.5-ton rooftop heat pump that has a high-temperature COP of 3.0 can have a low-temperature COP of 2.0 or lower. And at very low temperatures, a heat pump can require supplemental heat, typically in the form of electric resistance—so effective heating efficiencies become even lower. However, dual-fuel heat pumps are available in areas where natural gas can be used as the supplemental heating source.

Ground-Source, Closed-Loop Heat Pumps

Ground-source (geothermal) heat pumps evolved from the family of water-to-air heat pumps used in commercial buildings. These devices pump water or antifreeze through a buried coil of pipe to absorb heat from or reject heat to the ground, depending on whether heating or cooling is needed. Unlike the less common open-loop systems, the heat-exchange fluid stays within a closed loop and does not come into contact with the environment. Ground-source systems offer higher efficiencies than air-source heat pumps—they have EERs as high as 30 and COPs as high as 5. However, these units are also more expensive due to the network of pipes that must be buried. They are most appropriate in cold climates where the ground temperature is significantly warmer and less variable than the air temperature, and where natural gas for heating is unavailable.

ENERGY STAR qualified ground-source closed-loop heat pumps must have at least an EER of 14.1 and a COP of 3.3. Both ENERGY STAR (www.energystar.gov/index.cfm?c=geo_heat.pr_geo_heat_pumps) and the Geothermal Heat Pump Consortium (www.geoexchange.org) offer more information on geothermal heat pump systems.

9.5 Additional Strategies

Depending on a building's size, location, business use, and local utility rate structures, it may be worthwhile to investigate a number of additional technological strategies for saving energy and reducing costs.

Air-Side Economizer

There are times when increasing outside air beyond ASHRAE Standard 62.1, "Ventilation for Acceptable Indoor Air Quality," will lower cooling loads. Economizers can often use outdoor air to partially or totally cool a space. An economizer consists of local controls and dampers capable of delivering up to 100 percent outdoor air. Air-side economizers come in two types: dry-bulb and wet-bulb. A dry-bulb economizer is activated by outdoor air temperature—as temperature varies, the air damper modulates to bring in sufficient outdoor air to satisfy cooling needs. A wet-bulb economizer operates in the same manner, except it also monitors relative humidity. However, wet-bulb economizers should only be used in appropriately humid climates because of their higher maintenance requirements—to maintain accuracy, they must be calibrated frequently.

Note that economizers offer excellent savings opportunities, but their operation is sensitive to temperature setpoints and the condition of system components. If operating incorrectly, they may not save energy. In some cases, if the dampers are stuck in the 100 percent outdoor air position all the time, for example, they could even waste energy. However, it is easy to avoid or minimize malfunctions. Using robust controls and a regular maintenance program can ensure that economizers function as intended. For guidance on proper economizer control, see the Eugene Water and Electric Board's Tech Brief, "Outside Air Economizers: Making Them Work Right for You," available at www.eweb.org/business/energy/energysmart/techbriefs.

Energy Recovery

Heat recovery is one of the most effective ways to optimize energy efficiency during building operations. Exhaust air from HVAC systems is a primary source of useful waste heat. Transferring the energy from the exhaust air to the incoming outdoor air reduces the energy required to condition the incoming air.

Several heat-recovery technologies are available, including rotary heat wheels, plate-and-frame heat exchangers, runaround coils, and heat pipes—each suited to specific applications. Consult vendors and engineers to determine the best match for a given building. Depending on the application and technology type, these systems can recover 50 to 80 percent of the energy used to heat or cool incoming outdoor air.

Desiccant Dehumidification

Desiccants dehumidify the air and can be regenerated through heating to drive out the absorbed moisture. The heat used for desiccant regeneration is generally derived from gas, steam, or waste heat from the building—and the cost of this heat is typically much lower than the cost of electricity used for conventional dehumidification. Traditionally, desiccant systems have been targeted to humid climates or to applications that require tight control over humidity—like hospitals, museums, and supermarkets. But new hybrid air conditioning–desiccant systems are more efficient than previous desiccant technology. The higher efficiencies, coupled with changing building standards, are now making such systems appealing for applications where humidity control is still important but less critical, such as in schools, restaurants, and office buildings.

Changing building standards are making desiccant systems more appealing now for two reasons. First, to meet code, some buildings are admitting more outdoor air than their original design specified, leading to a larger need for humidity control. Second, where increasingly stringent energy-efficiency standards make the sensible (dry-air) cooling load lower than the humidity load, it is more challenging to handle humidity. For example, ASHRAE Standard 90.1, which is often adopted directly or indirectly in local building codes, has increased many efficiency requirements compared with the standards in place before the 1990s. Most of these changes have reduced the sensible cooling load (the portion of a building's heat load unrelated to humidity) but not the latent cooling load (the portion of a building's heat load contained in the moisture in the air). For instance, efficient lighting required by newer standards gives off less heat, but it does not reduce the moisture content of the air. A sensible load that is much lower than the latent load makes it more challenging for conventional air conditioners to condition the air properly without increasing energy use—desiccant systems offer another way to meet these challenges (see sidebar).

Night Precooling

In many climates, night temperatures are cool even when daytime temperatures exceed economizer limits. Taking advantage of this resource, the air handler and economizer can flush the building with night air to cool down the building mass. The cool mass then acts as a heat sink the following day.

Setting controls for night precooling can save a significant amount of energy, depending on location. Studies indicate cost savings range from 5 percent in Phoenix, Arizona, to 18 percent in Denver, Colorado, for a typical office building. Night precooling also reduces peak demand. Simulation analyses show that precooling a 100,000-ft^2 three-story building in Sacramento, California, would reduce energy use by 12.6 percent and cause a peak demand reduction of 31.3 percent.

CASE STUDY: Desiccants Save Energy While Dehumidifying

A November 2005 field study funded in part by the U.S. Department of Energy and conducted by the Georgia Tech Research Institute and Georgia State University showed that a hybrid air conditioner–desiccant system can dehumidify better than a conventional unit while saving energy. One elementary school in Atlanta, Georgia, was suffering from poor indoor air quality and occupant discomfort because the existing conventional packaged rooftop unit was not providing adequate dehumidification. The rooftop unit was replaced with a hybrid unit, which was able to maintain a relative humidity near 50 percent at an average thermostat setting 2.4° higher than the 70.4° Fahrenheit average setpoint the old system used. Based on energy simulations, this higher setpoint reduced cooling energy consumption by about 10 percent.

Cool Storage

Cool storage uses cheaper off-peak power to supply cooling and is generally only cost-effective in retrofits where the local utility offers a critical peak pricing program. The technology cools a storage medium while chiller operating cost is low, and then the medium is discharged when chiller operating cost is high. Cool storage media include water, ice and water, or water circulating around chemical modules that freeze and thaw. Ice systems and freeze-thaw systems take up less space than chilled-water storage because the freezing process can naturally store much more "cold" in a given volume. Most cool storage is custom built for a particular application, but one manufacturer, Ice Energy, produces packaged cool storage equipment.

Evaporative Cooling

Evaporative cooling typically uses less than a quarter the energy of vapor-compression air-conditioning systems. In its basic form, air is blown over a wet surface. Heat in the air evaporates moisture from the surface, thereby lowering the temperature of the air. There are several types of evaporative coolers:

- *Direct.* Also known as "swamp coolers," these units evaporate moisture directly into the supply air stream, increasing its humidity. Although this effect may be desirable in dry climates, it is usually not so in humid ones.
- *Indirect.* These units cool the building supply air through a heat exchanger with a separate air stream cooled by a direct evaporative cooler. The supply air does not come into contact with the wet surface, so no moisture is added.
- *Indirect-direct.* Indirect-direct evaporative coolers, commonly called IDECs, first cool the supply air indirectly and then directly.

Although evaporative cooling systems are most effective in dry climates where the air has a large capacity to absorb evaporating water, they can also be used elsewhere to precool air to reduce the load on a mechanical refrigeration system. Mechanical refrigeration can also increase the evaporative cooling capacity by cooling the water used for evaporation.

9.6 Summary

Many opportunities exist for optimizing a building's heating and cooling system efficiency. Load reductions achieved through other stages of the building upgrade process have likely made these opportunities more attractive than they were initially. When evaluating which heating and cooling upgrades to pursue, remember:

- Determine the building's heating and cooling loads.
- Use current loads to calculate the proper capacity for equipment.
- Consider the interactions among all system components.
- Consider replacing old inefficient equipment with new high-efficiency equipment.
- Evaluate alternative strategies for meeting heating and cooling loads.
- Establish a regular maintenance program for all heating and cooling equipment.

Although heating and cooling improvements represent the final stage in the staged approach to building upgrades, they do not signal the end of the process. Building upgrades continue to provide the intended benefits throughout their useful life only through periodic recommissioning and further upgrades, as needed. An upgrade is not an endpoint but a step along a path of continuous improvement.

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