CHAPTER 8 HVAC (Heating, Ventilation, and Air-Conditioning)

Objectives

- Survey current HVAC system(s), operating procedures, and maintenance schedule.
- Analyze results of energy audit for HVAC system(s) (performed by an HVAC professional) and identify effective energy efficiency improvements.
- Perform due diligence and conduct financial analyses based on the recommendations of energy auditors.

OVERVIEW

Building heating, ventilation, and air-conditioning (HVAC) systems are responsible for controlling temperature and humidity as well as circulating fresh air throughout a building. HVAC systems are relatively energy intensive and consume a significant portion of a building’s energy consumption—51% on average in commercial buildings in the United States, 52% in Spain, 58% in the United Kingdom, 70% in Saudi Arabia, and 71% in Bahrain. Therefore, the HVAC system lends itself to the highest energy savings if properly audited. For illustrative purposes, Figure 8.1 provides a hypothetical energy consumption breakdown in a large office building (>10,000 square meters). The annual breakdown of HVAC energy draw among heating, ventilation, and cooling end-uses can vary widely depending on geographic location. It is not uncommon for larger buildings to require cooling year-round because of hot climatic conditions. Additionally, HVAC systems often operate at high levels during periods of regional peak load (for example, hot summer days) when electricity prices are highest, which can significantly increase a company’s power costs.
HVAC designs vary widely across building types. Standard HVAC systems are considered ‘active’ technologies, which require energy input to drive mechanical equipment. A typical HVAC system involves components including chillers, boilers, air ducts, fans, and heat exchangers. Alternative ‘passive’ cooling technologies are more rare, but typically much more energy efficient. These technologies include natural ventilation, evaporative cooling systems, and radiative heating and cooling systems. Care must be exercised to take a system optimization approach to component design and tuning.

A range of methods can be used to decrease the energy draw of an HVAC system, but one of the easiest is reducing a building’s cooling load by reducing waste heat generated by inefficient lighting systems, office equipment, and water heating systems. These measures are extremely cost effective and should be undertaken before any upgrade to HVAC equipment is considered. If HVAC equipment has recently been upgraded to an efficient model, maintaining system performance at the proper level of efficiency should be a primary consideration.

Like lighting quality, HVAC performance is key to the comfort and productivity of building occupants. In fact, many HVAC efficiency upgrades have the added benefit of improving air quality and comfort.
throughout a space (e.g., precise tuning of thermostat controls or installation of outside air economizers). An HVAC engineer should ensure that efficiency upgrades to an HVAC system do not cause any reduction in the quality of a building environment.

The recommended efficiency improvement strategies for HVAC are presented in the order in which they should be undertaken: 1) ensure that proper maintenance is being performed; 2) investigate possibilities for reducing heating/cooling load; 3) calibrate and tune system controls; and, 4) consider upgrading HVAC equipment. Efficiency improvements can be most cost effectively implemented in conjunction with the regular equipment upgrade schedule.

Note: Costs and energy savings for HVAC efficiency measures vary widely depending on building characteristics. In this section, examples of costs and savings potential are presented through financial case studies.

**INFORMATION GATHERING GUIDE**

A number of key questions are important to consider before addressing improved HVAC system function and efficiency:

- Does the office occupant own or lease the office space?
- Does the tenant pay the utility bill or is it included in the rent?
- Is the landlord (if not the host company) interested in pursuing efficiency improvements?
- What type of HVAC system is installed? Is the system unitary or centralized?
- When was the existing HVAC system installed?
- How do building managers control the HVAC system? Which controls are manual? Which controls are automated?
- Is there a planned preventative maintenance program for HVAC in place? Who conducts maintenance on the HVAC system?
- What data on building temperature and energy consumption does operations staff have access to? How are the data delivered, recorded, and tracked?
- What is the maintenance schedule for the HVAC system?
- Has the HVAC system undergone recent commissioning?
- What has been done to date to improve the efficiency of the HVAC system?
- Is the HVAC system about to undergo a scheduled upgrade or replacement?
- How is the indoor room temperature controlled: by office, zone, or floor?
- Is it possible for office occupants to open any office windows?
- Has feedback been collected about indoor climate comfort?
TACTICS FOR REDUCING HVAC ENERGY USE

When upgrading the HVAC system, it would be helpful to be aware of these general principles:

- A clear distinction should be made between energy conservation and energy efficiency: energy conservation should not be made at the expense of building occupants' health and comfort.
- HVAC equipment should be in perfect working order and properly commissioned periodically.
- HVAC equipment capacities should match the load they serve.
- HVAC equipment should not be operated in non-occupied spaces.
- Recover wasted energy as much as practically feasible.
- Avoid using electric resistance heaters.

A) EFFICIENT USE OF HVAC TECHNOLOGIES (LOW COST / NO COST INTERVENTIONS)

Efficient use of HVAC technologies lowers the energy usage of existing equipment, typically by switching equipment to a low-energy state when not in use.

This category includes interventions that typically cost from US$0 to US$2,000 for a medium size office space of around 1,000 m² with paybacks of less than one year. Most of these rely on human interventions at the user and/or the operation & maintenance (O&M) levels, knowing that ultimately the main driver is management commitment towards energy efficiency. Even though at first sight these interventions seem benign and easy to implement, actual execution is not so obvious; results could be quite rewarding if a committed follow up is achieved.

A1) Turn off HVAC equipment when rooms are not occupied. This measure is most applicable when some kind of HVAC equipment such as a fan coil unit, a radiator, or an air handler is dedicated to a space. Another
alternative would be to set the equipment on low operating mode if one knows that space will be occupied after a while. This measure underlines the importance of introducing system flexibility and modularity at the design stage. In many instances, a deficient design results in the necessity to keep a whole floor air conditioned because only one room is occupied.

The client role at the design stage is vital to ensure an integrated design approach is taken, where all stakeholders provide their input to make sure the resulting system fits perfectly the intended application. The rewards that could be reaped surpass by far the time and efforts invested in such an activity.

**A2) Keep windows and external doors shut when HVAC equipment is operating.** This may seem a trivial issue but surprisingly enough, is of quite common occurrence. Often doors and windows are left open as a result of a number of dysfunctional practices including in-office smoking, overcooling or overheating, and faulty ventilation. Overcooling or overheating can be caused by faulty zoning, faulty thermostat settings, or faulty system regulation and balancing. Often times, office occupants have different cooling or heating requirements. Faulty designs will be addressed below. To assist towards keeping windows and external doors shut, it is suggested to:

- Maximize staff cooperation through awareness campaigns.
- Post signs in each room.

**A3) Increase summer space temperature settings and decrease winter settings.** In many Arab countries, especially where the weather is uncompromisingly hot, people tend to favor extremely low space temperatures nearing 20°C or even lower. Apart from being a cause of illness, such practices are a waste of energy especially for thermostat settings below 21°C. Ideally, suggested office temperatures of 23-24°C in the summer and 20°C in the winter are easily achievable without any undue physiological discomfort especially when relative humidity is properly regulated. It is estimated that each 1°C decrease in evaporator temperature may lead to 1-2% increase in energy consumption especially at low operating temperatures. It is a good practice to enclose the thermostat in a locked box.

**A4) Make sure heat rejection equipment is properly aerated.** Sometimes mechanical rooms and building roofs where HVAC equipment is located are used as storage spaces blocking the airways of condensers thus drastically decreasing their performance. It is estimated that on average each 1°C in condenser temperature increase leads to approximately 1.5% decrease in equipment operating efficiency especially at high ambient temperatures as is the case in the Arab world.

**A5) Keep radiators and fan coil units unobstructed.** Do not use floor standing radiators and fan coil units as shelves to place books, files, or
other items. Also do not place these units inside decorative casements that restrict air flow; such consoles could reduce the output capacity of radiators by up to 30%.

**B) MAINTENANCE AND COMMISSIONING**

The efficiency of existing HVAC systems can be maximized through a combination of regular in-house maintenance and periodic commissioning. In-house maintenance typically involves cleaning and replacing worn-out parts. Commissioning is a process by which equipment is tested to make sure it is performing according to design intent. Testing, adjusting, and balancing (TAB) are examples of commissioning tasks. Most commissioning services should be completed by professional technicians specialized in particular building systems.

**B1) Regular maintenance of heat exchange equipment.** This should involve:

i. Removal of deposit buildup from heating coils/chiller tubes.
ii. Cleaning and replacement of HVAC air and water filters: Clogged filters of air handlers cause a decrease in air flow which impact system performance and energy consumption. Moreover, dirty filters may be a breeding ground for bacteria.
iii. Boiler tune-ups.
iv. Checking steam traps for leaks.

**B2) Commissioning.** This should be performed by a specialized commissioning technician. A commissioning technician should:

i. Verify that HVAC system components are functioning correctly.
ii. Identify and correct any problems with the system controls.
iii. Ensure that the HVAC system is providing proper indoor air quality.
iv. Calibrate temperature sensors and controls to align with original design specifications.

Additional maintenance and commissioning activities are included in **APPENDIX C: HVAC background information.**
Financial case study: HVAC maintenance performed for a tower complex in San Jose, California, has resulted in tune-ups including modified boiler control programming, which cost $600 in labor and saved $41,779 in annual energy costs. An additional correction to the chilled-water pump controls cost $1,200 and netted $43,000 in annual energy savings.

C) Efficiency tune-ups

C1) Complete envelope upgrades. An energy efficiency engineer can evaluate whether upgrades to the building envelope can reduce heating/cooling load. Envelope upgrades include:

- Locating and sealing air leaks in windows, doors, roofs and walls. Eliminating infiltration due to air leaks in a large office building typically saves up to 5% of heating/cooling energy.

- Installing window films/shading. Window coverings block solar radiation from entering the building and reduce internal heat loss through windows by improving insulation. The typical cost for specialized high-grade window films that block heat and allow transmission of light is around US$3.00 per square foot. Window films have a typical lifetime of more than seven years.

Additional passive design practices and more detailed building envelope upgrades, including installing double-glazed windows and insulation, are discussed in Appendix D.

Financial case study: A property owner of a 1.4-million square-foot office complex installed 140,000 square feet of window film on floor to ceiling windows in San Francisco, California. The project qualified for efficiency incentives from the local electric power utility and reduced heating and cooling costs significantly. Taking the utility rebate into account, the project had a payback time of less than two years.

C2) Tune/install thermostat controls. An HVAC engineer should compare the host company building’s heating/cooling patterns with its occupancy schedule to determine whether controls should be adjusted to reflect occupancy. Additional savings can be accomplished through the installation of combined automated control systems for HVAC and lighting (see Chapter 10, Energy Management Systems). HVAC and lighting can then be continuously monitored and adjusted based on occupancy and environment. An HVAC engineer should evaluate the feasibility of preheating or pre-cooling the building at night using off-peak electricity.

Financial case study: A property owner performed a modification of temperature and runtime settings of boilers in an office building costing
$400. The adjustments reduced the boilers’ natural gas use by 20% for an annual savings of $42,960, representing an immediate payback on investment.

D) EQUIPMENT REPLACEMENT/PURCHASING

Full replacement of up-to-date HVAC systems is unlikely to be cost effective if undertaken solely to increase energy efficiency. However, many modern buildings are operating with outdated and inefficient HVAC systems. Upgrading an older system to a higher efficiency system should be considered, particularly if the building in question has experienced HVAC performance problems. In general, the property portfolio of an organization should be managed based on a life cycle approach and a capital plan. The office manager must be alert to take energy efficiency into account, when a capital project is planned for the HVAC system.

The principle objectives of HVAC upgrades are:

- Improved year-round occupant comfort and convenience.
- Higher energy efficiency with lower operational costs.

D1) Install outside air economizers. Air-side economizers use a damper to control intake of outside air. When outside air is cooler than return air, the damper adjusts to maximize air intake; when outside air is warmer, the damper reduces outside air intake to the minimum required in building codes. Air-side economizers can also be used to pre-cool buildings at night.

D2) Correctly size and retrofit HVAC fan systems. Fan systems (which distribute heated or chilled air throughout a building) are often more economical to replace than heating/chilling components. Fans are often oversized - a recent EPA study found that 60% of U.S. office buildings had fan systems that were at least 10% oversized, with an average oversizing of 60%. In general, correctly sizing a fan system results in a 50% decrease in energy drawn by the fan system.

Constant volume fan systems, which circulate a set volume of air and regulate temperature by heating or cooling air, are common in commercial buildings, but are relatively inefficient. Variable air volume (VAV) systems, which regulate temperature primarily by varying the volume of circulated air, are typically more efficient. Conversion from a constant volume system to a VAV system can reduce horsepower requirements for fans by 40-60%.

A VAV system can be retrofit to control fan speed using a variable-speed drive (VSD). VSD devices vary fan speed according to need, resulting in energy savings from reduced fan speeds. A recent EPA study found that
installing a VSD to an existing VAV system achieved a mean savings of 52% in fan system energy requirements. (For more information on VSDs see ENERGY STAR Building Upgrade Manual, p.107–108).

Once energy requirements of fans have been reduced, an engineer can determine whether downsizing a fan motor to a more efficient size is appropriate.

**Financial case study:** A 36-story high-rise in San Francisco, California, is undertaking a retrofit conversion of its constant volume system to a variable air volume system. The retrofit project will cost approximately $848,000, but will receive $179,000 in utility incentives and is expected to save $473,000 in annual energy costs, for an adjusted payback period of 1.3 years (see APPENDIX F: Case studies).

Financial case study: A variable frequency drive was added to the fan system in a tower complex in San Jose, California, enabling the system to adjust air volume and fan power to meet cooling load. The retrofit cost $126,960 and received a $63,500 rebate. Estimated annual energy savings are $78,000, representing a ten-month payback period.

**D3) Measure existing heating/cooling loads and correctly size HVAC heating and chilling components.** An HVAC engineer should re-measure heating and cooling loads to capture savings achieved through previous efficiency improvements and assess whether heating/chilling components can be downsized.

Generally, HVAC engineers will apply an “integrated system approach” to evaluating opportunities in heating and cooling systems. If heating systems and cooling systems are assessed separately, the process will be more time consuming and whole system efficiency upgrade opportunities may be missed.

**D4) When feasible, replace outdated or highly inefficient HVAC systems.** “Reheat systems,” which cool and circulate a set amount of air and then reheat the cooled air as necessary to achieve desired temperatures, and “multi-zone systems,” which mix cooled and heated air to produce desired air temperatures, are extremely inefficient. An HVAC engineer can consult on the feasibility of converting these types of systems to more efficient ones.

**Financial case study:** While renovating a 223,000-square-foot (six-story) office building in Encino, California, the property owner replaced an outdated chiller during an HVAC system retrofit. The 375-ton R-12 centrifugal chiller was near the end of its life, so a new chiller was required. The owner selected an energy-efficient Carrier 19XRV as a replacement, which has reduced annual energy costs by $15,500. After the receipt of a $15,750 utility rebate, the net cost of the chiller replacement was $273,884.
In a nutshell …

Tactics for reducing HVAC energy use

1. Maintenance and commissioning
   - Turn off HVAC equipment when rooms are not occupied.
   - Make sure heat rejection equipment is properly aerated.
   - Keep radiators and fan coil units unobstructed.
   - Verify regular maintenance schedule.
   - Determine frequency of HVAC commissioning.

2. Efficiency tune-ups
   - Complete envelope upgrades.
   - Tune/install thermostat controls.

3. Equipment replacement/purchasing
   - Install outside air economizers.
   - Correctly size and retrofit HVAC fan systems.
   - Measure existing heating/cooling loads and correctly size HVAC heating and chilling components.

Additional information

A Checklist for collecting data about the heating status of rooms and windows in office buildings is available at:

An explanation of the checklist is available at: