High-Performance HVAC

Source: wbdg.org

Published: November 7, 2016

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Introduction

Heating, ventilating, and air-conditioning (HVAC systems) account for 39% of the energy used in commercial buildings in the United States. Consequently, almost any business or government agency has the potential to realize significant savings by improving its control of HVAC operations and improving the efficiency of the system it uses.

The use of high performance HVAC equipment can result in considerable energy, emissions, and cost savings (10%–40%). Whole building design coupled with an "extended comfort zone" can produce much greater savings (40%–70%). Extended comfort includes employing concepts such as providing warmer, but drier air using desiccant dehumidification in summer, or cooler air with warmer windows and warmer walls in winter. In addition, high-performance HVAC can provide increased user thermal comfort, and contribute to improved indoor environmental quality (IEQ).

Given the range and complexity of the subject, this information should be viewed as only a starting point to access information from the many trade associations, agencies, and manufacturers linked throughout the text.

Description

Heating, Ventilating, and Air-Conditioning (HVAC)

The term HVAC refers to the three disciplines of *Heating*, *Ventilating*, and *Air-Conditioning*. A fourth discipline, *Controls*, pervades the entire HVAC field. Controls determine how HVAC systems operate to meet the design goals of comfort, safety, and cost-effective operation.

- Heating can be accomplished by heating the air within a space (e.g. supply air systems, perimeter fin-tube "radiators"), or by heating the occupants directly by radiation (e.g. floor/ceiling/wall radiation or radiant panels).
- Ventilating maintains an adequate mixture of gases in the air we breath (e.g. not too much CO_2), controls odors, and removes contaminants from occupied spaces. "Clean" air helps keep occupants healthy and productive. Ventilation can be accomplished passively through natural ventilation, or actively through mechanical distribution systems powered by fans.
- Air-conditioning refers to the sensible and latent cooling of air. Sensible cooling involves the control of air temperature while latent cooling involves the control of air humidity. Room air is cooled by transferring heat between spaces, such as with a water loop heat pump system, or by rejecting it to the outside air via air-cooled or water-cooled equipment. Heat can also be rejected to the ground using geothermal exchange. Cool air is not comfortable if it is too humid. Air is dehumidified by condensing its moisture on a cold surface, such as part of mechanical cooling), or by removing the moisture through absorption (desiccant dehumidification). In dry climates, humidification may be required for comfort instead of dehumidification. Evaporative humidification also cools the air. Further, in such climates it is possible to use radiant cooling systems, similar to the radiant heating systems mentioned above.
- Controls ensure occupant comfort, provide safe operation of the equipment, and in a modern HVAC control system enable judicious use of energy resources. HVAC systems are sized to meet heating and cooling loads that historically occur only 1% to 2.5% of the time. It is the function of the controls to ensure that the HVAC systems perform properly, reliably, and efficiently during those conditions that occur 97.5% to 99% of the time.

Each HVAC discipline has specific design requirements and each has opportunities for energy savings. It must be understood, however, that energy savings in one area may augment or diminish savings in another. This applies to interactions between components of an HVAC system, as well as between the HVAC system and the lighting and envelope systems. See WBDG Ensure Appropriate Product/Systems Integration. Therefore, understanding how one system or subsystem affects another is essential to making the most of the available opportunities for energy savings. This design approach is known as *whole building design*.

Impact on Building Energy Performance Goals

Employing high-performance HVAC equipment in conjunction with whole building design can result in significant energy savings. Typically, a 30% reduction in annual energy costs can be achieved with a simple payback period of about three to five years. And, if the payback threshold is extended to seven years, the savings can be about 40%. These figures apply to buildings that offer conventional comfort (e.g., 70°F in winter, 76°F in summer). (For more information on cost-effectiveness, see WBDG Cost-Effective Branch).

If the comfort zone is extended through natural ventilation and air movement in summer, and through lower air temperatures in winter (made possible by highly-insulated and, therefore, warmer wall and window surfaces), even higher savings can be achieved. For example, a typical office building minimally complying with the ASHRAE Standard 90.1 might use 75,000 Btu/sq.ft./yr. The goal for many federal buildings is 50,000 Btu/sq.ft./yr. A highly energy-efficient building using conventional comfort could have an energy use of 40,000 Btu/sq.ft./yr. or even less. A building designed and operated with extended comfort strategies might only use 20,000 to 30,000 Btu/sq.ft./yr.

However, note that highly energy-efficient design utilizing high-performance HVAC equipment often requires more effort and more collaboration from the design team than a conventional, sequential approach.

Fundamentals of Energy- and Resource-Efficient HVAC Design

Consider all aspects of the building simultaneously	Energy-efficient, climate responsive construction requires a whole building perspective that integrates architectural and engineering concerns early in the design process. For example, the evaluation of a building envelope design must consider its effect on cooling loads and daylighting. An energy-efficient building envelope, coupled with a state-of-the-art lighting system and efficient, properly-sized HVAC equipment will cost less to purchase and operate than a building whose systems are selected in isolation from each other.
Decide on design goals as early as possible	A building that only meets energy code requirements will often have a different HVAC system than one that uses 40% less energy than the code.And the difference is likely to be not only component size, but also basic system type. See WBDG Functional—Meet Performance Objectives.
"Right Size" HVAC systems to ensure efficient operation	Safety factors for HVAC systems allow for uncertainties in the final design, construction and use of the building, but should be used reasonably.Greatly oversized equipment operates less efficiently and costs more than properly sized equipment. For example, oversized cooling systems may not dehumidify the air properly, resulting in cool but "clammy" spaces.It is unreasonable and expensive to assume a simultaneous worst-case scenario for all load components (occupancy, lighting, shading devices, weather) and then to apply the highest safety factors for sizing.
Consider part-load performance when selecting equipment	Part-load performance of equipment is a critical consideration for HVAC sizing.Most heating and cooling equipment only operate at their rated, peak efficiency when fully loaded (that is, working near their maximum output).However, HVAC systems are sized to meet design heating and cooling conditions that historically occur only 1% to 2.5%

	of the time. Thus, HVAC systems are intentionally oversized at least 97.5% to 99% of the time. In addition, most equipment is further oversized to handle pick-up loads and to provide a factor of safety. Therefore, systems almost never operate at full load. In fact, most systems operate at 50% or less of their capacity.
Shift or shave electric loads during peak demand periods	Many electric utilities offer lower rates during off-peak periods that typically occur at night. Whenever possible, design systems to take advantage of this situation. For example, energy management systems can shed non-critical loads at peak periods to prevent short duration electrical demands from affecting energy bills for the entire year. Or, off-peak thermal ice storage systems can be designed to run chillers at night to make ice that can be used for cooling the building during the next afternoon when rates are higher.
Plan for expansion, but don't size for it	A change in building use or the incorporation of new technologies can lead to an increased demand for cooling. But, it is wasteful to provide excess capacity now—the capacity may never be used or the equipment could be obsolete by the time it is needed. It is better to plan equipment and space so that future expansion is possible. For example, adequately size mechanical rooms and consider the use of modular equipment.
Commission the HVAC systems	Commercial HVAC systems do not always work as expected. Problems can be caused by the design of the HVAC system or because equipment and controls are improperly connected or installed.A part of commissioning involves testing the HVAC systems under all aspects of operation, revealing and correcting problems, and ensuring that everything works as intended. A comprehensive commissioning program will also ensure that O&M personnel are properly trained in the functioning of all systems.
Establish an Operations and Maintenance (O&M) Program	Proper performance and energy-efficient operation of HVAC systems can only be ensured through a successful O&M program. The building design team should provide systems that will perform effectively at the level of maintenance that the owner is able to provide. In turn, the owner must understand that different components of the HVAC system will require different degrees of maintenance to perform properly.

Design Recommendations

Consider all aspects of the building simultaneously. The building should incorporate as many features as possible that reduce heating and cooling loads, for example:

1. In skin-load dominated structures, employ passive heating or cooling strategies (e.g., sun control and shading devices, thermal mass).
2. In internal-load dominated structures, include glazing that has a high cooling index.
3. Specify exterior wall constructions that avoid thermal bridging.
4. Detail the exterior wall constructions with air retarder systems.
5. Incorporate the highest R-value wall and roof construction that is cost-effective.

6. Design efficient lighting systems.
7. Use daylight dimming controls whenever possible.
8. Specify efficient office equipment (e.g., EPA Energy Star® Office Equipment).
9. Accept life-cycle horizons of 20 to 25 years for equipment and 50 to 75 years for walls and glazings.

Decide on design goals as early as possible. It is important that the design team knows where it is headed long before the construction documents phase.

a. Emphasize communication between all members of the design team throughout the design process (see WBDG Project Management).
b. Develop a written "Basis of Design" that conveys to all members of the project goals for energy efficiency. For example, such a BOD might highlight the intent to incorporate daylighting and the attendant use of high-performance glazing, suitable lighting controls and interior layout.
c. Establish a quantitative goal for annual energy consumption and annual energy costs.
d. Clarify goals to meet or exceed the minimum requirements of codes or regulations during schematic design.

"Right Size" HVAC systems to ensure efficient operation.

a. Accept the HVAC safety factors and pick-up load allowance stated in ANSI/ASHRAE/IES 90.1 as an upper limit.
b. Apply safety factors to a reasonable baseline. It is unreasonable to assume that on the hottest clear day if no shades are drawn and all lights are on that each room is occupied by the maximum number of people allowed by fire codes (thus, far in excess of the maximum number of people that can be expected in the building), and then apply safety factors. Safety factors should be applied to a baseline that was created using reasonable assumptions.
c. Take advantage of the new generation of dependable computerized analysis tools, such as DOE 2.1E, to reduce uncertainty and eliminate excess oversizing. Hour-by-hour computer simulations can anticipate how building design and operation affect peak loads. Issues such as diversity, pick-up requirements, and self-shading due to building geometry can be quantified. As uncertainties are reduced, oversizing factors can also be reduced or at least can be applied to a more realistic baseline.

Consider part-load performance when selecting equipment.

a. Select systems that can operate efficiently at part-load. For example:
    - Variable volume fan systems and variable speed drive controls for fan motors;
    - Variable capacity boiler plants (e.g., step-fired (hi/lo) boilers, modular boiler plants, modulating flame boilers);
    - Condensing boilers operate more efficiently (95%–96%) as the part-load decreases to the minimum turn-down ratio;
    - Variable capacity cooling plants (e.g., modular chiller plants, multiple compressor equipment, and variable speed chillers);

  - Variable capacity cooling towers (e.g., multiple cell towers with variable speed or two speed fans, reset controls);
  - Variable capacity pump systems (e.g., primary/secondary pump loops, variable speed pump motors); and,
  - Temperature reset controls for hot water, chilled water, and supply air.

Shift or shave the load.

a. Investigate the utility company's rate structure; negotiate for a favorable rate structure.
b. Take advantage of the on-peak and off-peak rate differences.
c. Use energy management controls systems to avoid unnecessary peak demand charges (peak shaving and demand limiting).
d. Explore thermal storage systems (e.g., thermal ice storage).
e. Examine alternate fuel sources for heating and cooling systems (e.g., district steam vs. natural gas vs. fuel oil; steam or natural gas chillers; dual fuel boilers).

Plan for future expansion instead of greatly oversizing the equipment. "Right sizing" the systems means avoiding systems that have more capacity than currently required.This concept extends to accommodating for planned expansion.Don't provide excess capacity today for a future load that may never exist, instead:

a. Provide the physical space required for additional equipment: boilers, chillers, pumps, cooling towers.
b. Design distribution systems that can easily accept additional equipment, and can be expanded to provide for the requirements of the future expansion.

The result is savings in first cost and operating cost, and savings in construction cost and down time when making expansion alterations. See WBDG Productive—Design for the Changing Workplace.

Commission the HVAC systems. ASHRAE Guideline 1.1 presently recommends a comprehensive commissioning protocol for HVAC equipment. Many advocates of high-performance buildings are urging that more general, Total Building Commissioning (TBC) be implemented. More information on commissioning can be found at:

- Building Commissioning Association
- National Institute of Building Sciences—Total Building Commissioning Program
- Portland Energy Conservation, Inc.
- WBDG Building Commissioning

Establish an Operations and Maintenance Program.

a. Specify systems that can be properly maintained by the owner, based on the owner's stated resources. See WBDG Functional/Operational.
b. Provide as part of construction, contract system interfaces to allow personnel to easily monitor and adjust system parameters.

c. Make systems control, operation, and maintenance training part of the construction contract.
d. Include complete documentation regarding operation and maintenance of all equipment and controls systems as part of the construction contract.
e. Establish a written, comprehensive operation and maintenance program, based on the requirements of the facility, equipment, and systems installed. See WBDG Sustainable O&M Practices.

Types of HVAC Systems

Heating Systems

1. Boilers are used to generate steam or hot water and can be fired by natural gas, fuel oil, or coal.
   a. The following boilers have combustion efficiencies between 78% and 86%.
      - *Firetube steel boilers* are constructed so that hot gases from the combustion chamber pass through tubes that are surrounded by water.Typically, firetube boilers do not exceed 25 million Btu/hr (MMBtu/hr), but capacities up to 70 MMBtu/hr are available.
      - *Watertube steel boilers* pass hot combustion gases over water-filled tubes.Sizes for packaged watertube boilers range from small, low pressure units (e.g., around 10 MMBtu/hr) to very large, high-pressure units with steam outputs of about 300 MMBtu/hr.
      - *Cast iron boilers* are used in small installations (0.35 to 10 MMBtu/hr) where long service life is important.Since these boilers are composed of precast sections, they can be more readily field-assembled than watertube or firetube boilers.At similar capacities, cast-iron boilers are more expensive than firetube or watertube boilers.

   b. Condensing boilers achieve higher system efficiencies by extracting so much heat from the flue gases that the moisture in the gas condenses. The gases that remain can often be vented directly to the outside, simplifying and reducing the cost of breeching.They are typically fired with natural gas and operate between 95% and 96% combustion efficiencies. Theyalso operate more efficiently than non-condensing boilers at part-load.Condensing boilers are available in capacities between 0.3 and 2 MMBtu/hr, and can be connected in modular installations.
2. Furnaces can be used for residential and small commercial heating systems. Furnaces use natural gas, fuel oil, and electricity for the heat source.Natural gas furnaces are available in condensing and non-condensing models. The cooling can be packaged within the system, or a cooling coil can be added. When direct expansion systems with coils are used, the condenser can be part of the package or remote.
3. Heat pumps are devices that add heat to or extract heat from a conditioned space. Both refrigerators and air conditioners are types of heat pumps that extract heat from a cooler, conditioned space and reject it to a warmer space (i.e., the outdoors). Heating can be obtained if this cycle is reversed: heat is moved from the outdoors to the conditioned space indoors. Heat pumps are available in two major types: conventional packaged (air-source) and water-source (conventional or geothermal).

Geothermal heat pump system on the Georgia Institute of Technology Campus
Courtesy of U.S. DOE, Craig Miller Productions

More information on heat pumps can be found at:

- Energy Star—Air-Source Heat Pumps
- Energy Star—Geothermal Heat Pumps
- The Geothermal Exchange Organization
- International Energy Agency (IEA) Heat Pumping Technologies
- International Ground Source Heat Pump Association (IGSHPA)
- U.S. Department of Energy (DOE)—Geothermal Energy Program

Heating Controls

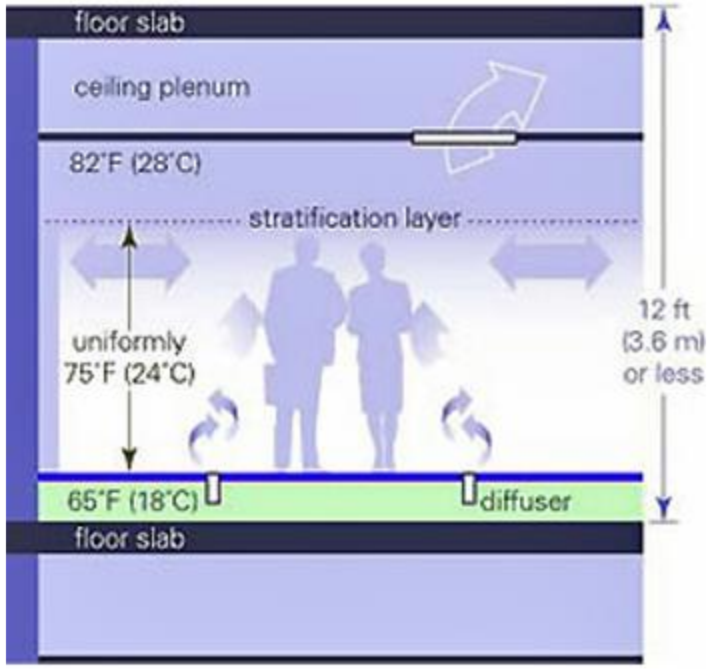
The first three controls increase energy efficiency by reducing on/off cycling of boilers. The fourth improves the efficiency during operation.

1. **Modulating flame**—The heat input to the boiler can be adjusted continually (modulated) up or down to match the heating load required.Modulating flame boilers have a minimum turn-down ratio, below which the boiler cycles off.This ratio is 25% for most boilers, but some can be turned down to as low as 10%.
2. **Step-fired**—The heat input to the boiler changes in steps, usually high/low/off.Compared to steady-state units, the capacity of the boiler can come closer to the required heating load.
3. **Modular boilers**—Another energy-efficient measure is to assemble groups of smaller boilers into modular plants.As the heating load increases, a new boiler enters on-line, augmenting the capacity of the heating system in a gradual manner.As the heating load decreases, the boilers are taken off-line one by one.
4. **Oxygen trim** systems continuously adjust the amount of combustion air to achieve high combustion efficiency. They are usually cost-effective for large boilers that have modulating flame controls.

Ventilation Systems

Ventilation systems deliver conditioned air to occupied spaces. Depending on the building type, ventilation air may be comprised of 100% outside air, such as in a laboratory building, or some mixture of re-circulated interior air and outside air. In commercial and institutional buildings, there are a number of different types of systems for delivering this air:

1. **Constant air volume (CAV)** systems deliver a constant rate of air while varying the temperature of the supply air. If more than one zone is served by a CAV system, the supply air is cooled at a central location to meet the need of the zone with highest demand. The other zones get overcooled or, if comfort is to be maintained, the air is reheated at the terminal units. CAV systems with reheat are inefficient because they expend energy to cool air that will be heated again. CAV systems with reheat, however, provide superior comfort in any zone. Constant airflow reduces pockets of "dead" air, and reheat provides close control of the space temperature.
2. **Variable air volume (VAV)** systems vary the amount of air supplied to a zone while holding the supply air temperature constant. This strategy saves fan energy and uses less reheat than in a CAV system. VAV systems, however, can have problems assuring uniform space temperature at low airflow rates. At times, the minimum airflow required for ventilation or for proper temperature control may be higher than is required to meet the space load. When this occurs reheat may be required.
3. **Low-flow air diffusers** in VAV systems help maintain uniform air distribution in a space at low airflows. These devices can be passive or active. Passive low flow diffusers are designed to mix the supply air with the room air efficiently at low flow. Active diffusers actually move the outlet vanes of the diffuser to maintain good mixing at low flow. Active diffusers can also be used as VAV terminal units.
4. **Fan-powered VAV** terminal units provide another method to improve air distribution at low load conditions. These units combine the benefits of a VAV system, by reducing central fan energy and reheat energy, with the benefits of a CAV system, by maintaining good airflow. There are two major types, series and parallel: Series fan-powered units maintain constant airflow to the zone at all times; parallel fan-powered units allow the airflow to the zone to vary somewhat, but do not allow the airflow in the zone to drop below a desired level. Both, however, allow the central fan to throttle down to the minimum airflow required for ventilation.
5. **Raised floor air distribution** delivers air low in the space, at low velocity and relatively high temperature compared to traditional plenum mounted distribution systems. Delivering air through a series of adjustable floor-mounted registers permits room air to be stratified with lower temperatures in the bottom portion of the room where people are located and high temperatures towards the ceiling. This system type is attracting increasing interest because it has the potential to save energy and to provide a high degree of individual comfort control. These systems have historically used constant-volume air delivery. Manufacturers arenow beginning to offer VAV systems that are more easily designed, installed, and operated with raised floor plenum systems.



Underfloor air distribution.

Ventilation System Controls

In recent years, ventilation control systems have become more complex and, if installed and maintained properly, more dependable. Among the advancements are:

1. **Direct digital control (DDC)** systems using digital-logic controllers and electrically-operated actuators are replacing traditional pneumatic controls. Pneumatic systems use analog-logic controllers and air-pressure actuators. DDC systems are repeatable and reliable,provide accurate system responses, and can be monitored from a central computer station. DDC systems also require less maintenance than pneumatic systems. However, pneumatic controllers can be less expensive than electric actuators. Hybrid systems use a combination of digital logic controllers and pneumatic actuators.
2. **CAV systems** should have controls to reset the supply air temperature at the cooling coil to provide the warmest air possible to the space with the highest cooling load. This reduces reheat throughout the system. However, the temperature should be no higher than is necessary to properly dehumidify the air. Another option to reduce reheat is to use a bypass system. Bypass systems work like variable volume systems at the zones, but have constant airflow across the central fan.
3. **VAV systems** can now be designed to serve areas with as little as six tons of cooling load.Inlet vanes or, better yet, variable speed fans should be used to control air volume. In systems that have supply and return fans, airflow monitoring stations should be used to maintain the balance between supply and return airflow.
4. **CO_2**-based control systems control the amount of outside air required for ventilation. These systems monitor the CO_2 in the return air and modulate the outside air damper to provide only the amount of outside air required to maintain desired levels. Since CO_2 does not account for contaminants released by the building materials (e.g., carpets,

furniture), there must be a minimum amount of outside air even when the spaces are unoccupied. Alternately, detectors of volatile organic compounds (VOC) can supplement the CO_2 monitoring system.

Air-Conditioning Equipment

1. **Chillers.** In large commercial and institutional buildings, devices used to produce cool water are called chillers. The water is pumped to air handling units to cool the air. They use either mechanical refrigeration processes or absorption processes.
    a. **Mechanical refrigeration chillers** may have one or more compressors. These compressors can be powered by electric motors, fossil fuel engines, or turbines. Refrigeration systems achieve variable capacity by bringing compressors on or off line, by unloading stages within the compressors, or by varying the speed of the compressor. The major types of compressors are described below:
        1. Reciprocating compressors are usually found in air-cooled direct expansion (DX) systems for residential and small commercial systems. They can also be found in chillers with capacities of 10 through 200 tons. To better match part-load conditions and achieve higher operating efficiencies, multiple compressors can be employed in a single system.
        2. Scroll compressors are manufactured in the 1 to 15 ton range. Multiple compressors can be found in water chillers with capacities of 20 to 500 tons. Scroll compressors require less maintenance than reciprocating compressors.
        3. Rotary screw compressors are found in chillers with capacities of 70 to 500 tons.
        4. Centrifugal compressors are used in chillers with typical capacities of 100 to 7,000 tons. Centrifugal chillers are the most efficient of the large-capacity chillers.

    b. **Absorption chillers** are heat-operated devices that produce chilled water via an absorption cycle. Absorption chillers can be direct-fired, using natural gas or fuel oil, or indirect-fired. Indirect-fired units may use different sources for heat: hot water or steam from a boiler, steam from district heating, or waste heat in the form of water, air, or other gas. Absorption chillers can be single-effect or double-effect, where one or two vapor generators are used. Double-effect chillers use two generators sequentially to increase efficiency. Several manufacturers offer absorption chiller/heater units, which use the heat produced by firing to provide space heating and service hot water.

    c. **Evaporative coolers**, also called swamp coolers, are packaged units that cool the air by humidifying it and then evaporating the moisture. The equipment is most effective in dry climates. It can significantly reduce the peak electric demand when compared to electric chillers.

    d. **Typical full-load operating efficiencies** for chillers are noted below:
        - Small air-cooled electric chillers have 1.6-1.1 kW/ton (Coefficient of Performance (COP) of 2.2 to 3.2).
        - Large and medium-sized air-cooled electric chillers have 0.95-0.85 kW/ton (COP of 3.7 to 4.1).

- Similar water-cooled electric chillers have 0.8-0.7 kW/ton (COP of 4.4 to 5.0). Lower values such as 0.6-0.5 kW/ton chillers (COP of 5.9 to 7.0) may indicate energy efficient equipment, but part-load performance should also be examined.
- The COP of absorption units is in the range of 0.4-0.6 for single-effect chillers, and 0.8-1.05 for double-effect chillers.
- Engine-driven chillers attain COPs of 1.2 to 2.0.

Cooling tower

2. **Condensers** are heat exchangers that are required for chillers to reject heat that has been removed from the conditioned spaces. Condensers can be either air-cooled or water-cooled. Water-cooled condensers often rely on rooftop cooling towers for rejecting heat into the environment; however, it is possible to reject the heat to the ground or river water.
   a. **Air-cooled condensers** are offered on smaller, packaged systems (typically from less than one ton to 120 tons). They are initially less costly than water-cooled condensers, but do not allow the chiller to operate as efficiently.
   b. **Water-cooled condensers** use water that is cooled directly from the evaporative condenser or indirectly via a cooling tower. The lower temperature achieved by evaporating water allows chillers served by water-cooled condensers to operate more efficiently.
   c. A **waterside economizer** consists of controls and a heat exchanger installed between the cooling tower water loop and the chilled water loop. When the outdoor air temperature is low and/or the air is very dry (i.e., when the wet-bulb temperature is low), the temperature of the cooling tower water may be low enough to directly cool the chilled water loop without use of the chiller, resulting in significant energy savings.

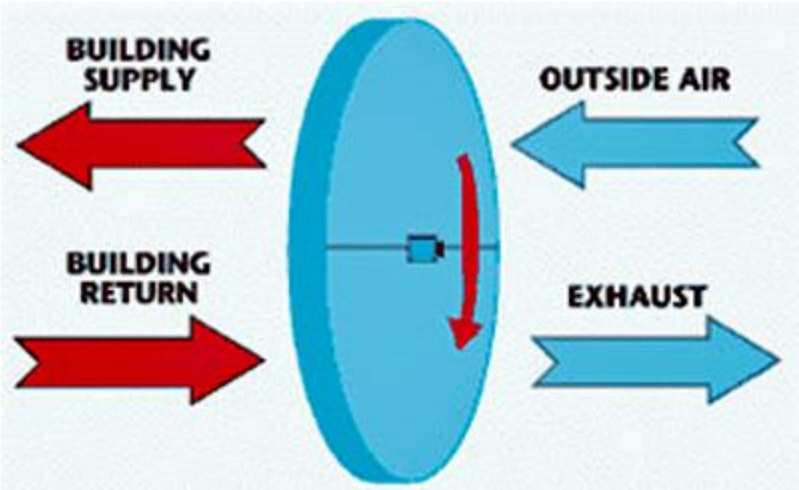
Air-Conditioning Equipment Controls

1. Controls that significantly affect the energy efficiency of chillers include:

   a. Variable speed drives achieve good part-load performance by matching the motor output to the chiller load, and by cycling off at a lower fraction of capacity than constant-speed chillers.
   b. Multiple compressor achieves a closer match of the load than single-compressor chillers by sequencing the compressors as needed.
   c. Water temperature reset controls raise the water temperature as the demand decreases, allowing for more efficient chiller operation.
2. Strategies that significantly affect the energy efficiency of cooling towers include the use of:
   a. Variable-speed or multiple-speed fans
   b. Wet-bulb reset strategies, where the temperature of the cooling water is adjusted according to the temperature and humidity of outside air (instead of maintaining it constant)
   c. Fans and pumps that use variable frequency drive (VFD) controls to reduce energy use at part-load
3. Integrated chiller plant controls use monitoring and computational strategies to yield the minimum combined energy cost for the chillers, cooling towers, fans, and pumps.This approach can be significantly more effective (though more difficult to implement) than optimizing the operation of each piece of equipment independently.

Heat Recovery

Air is blown across copper coils to reject heat from this residential air-cooled condenser. Heat Recovery is an important component of many energy efficient HVAC systems.



Enthalpy recovery wheel.

Types of heat recovery include:

a. Air-to-air heat exchangers transfer heat or "coolth" from one air stream to another. They are usually classified as one of the following:
   - Plate heat exchangers, with 60%–75% efficiencies

    - Glycol loop heat exchangers, with 50%–70% efficiencies (including pump energy use)
    - Heat pipe heat exchangers, with efficiencies as high as 80%

b. Desiccant wheels retrieve both sensible and latent heat, with efficiencies as high as 85%. Desiccant dehumidification of the air is achieved by inserting a rotating wheel in the air stream that needs to be dried. The desiccant extracts moisture from the air stream. The wheel then rotates, exposing the moist part to another air stream that dries (or regenerates) the desiccant material. Two methods of regeneration are typical:
    - Energy (Enthalpy) recovery wheels are located in the outside intake and the exhaust air streams. The exhaust air regenerates the desiccant.
    - Gas-fired desiccant dehumidification packages are located in the outside intake air stream or in the entire supply air stream. Outside air is heated by the gas furnace and is blown over the wheel to regenerate the desiccant.

c. Other forms of heat exchange include:
    - Indirect evaporative cooling (IDEC) uses water-to-air heat exchange to precool air.
    - Electric heat recovery chillers receive up to 50% of rejected heat, usually though split or multiple condensers.
    - Absorption chiller/heaters can use a fraction (typically 50%) of the heat input for cooling and the rest for heating.
    - Gas-fired, engine driven chillers retrieve much of the heat rejected (usually 20% - 50%).

Cogeneration

Cogeneration is a process in which electric power is generated at the facility where the waste heat is recovered to produce service hot water, process heat, or absorption cooling. Currently, packaged cogeneration systems between about 60-600 kW are widely available. Extensive research and marketing efforts are underway for smaller systems (as low as 4 kW).

Fuel Cells

Fuel cells use chemical processes to generate electricity. The heat generated by fuel cells can also be recovered, as in cogeneration. Currently, the minimum size for a fuel cell in building applications is 200 kW. Note that fuel cells need continuous, full-load operation.

Application

The benefits of high performance, energy-efficient HVAC systems are universal. Therefore, high performance HVAC systems can be installed in all different types of buildings, including office buildings, schools, hospitals, and courthouses.

Representative Example

Sam Nunn Atlanta Federal Center, Atlanta, GA
Commercial Buildings, Saving Energy with Energy-Efficient HVAC Systems in Commercial Buildings

Relevant Codes and Standards

- Energy Policy Act of 2005 (EPACT)—The enactment of the Energy Policy Act in 1992 has eased many restrictions of the Public Utility Holding Company Act of 1935 (PUHCA).Forty-six states in the United States have some form of deregulation plan for electric utilities. Under the new framework, facility owners can solicit proposals from utilities, including independent power producers, for their energy services.Thus, contract negotiations at the pre-design phase could result in significantly lower energy cost for the same energy use. While this is good news for consumers, it does suggest that investments in energy efficiency and renewable energy equipment may be harder to justify in the short-term.

For more information on regulations:

- ASHRAE Standards and Guidelines
  - Standard 62.1 *Ventilation for Acceptable Indoor Air Quality*
  - ANSI/ASHRAE/IES Standard 90.1 *Energy Standard for Buildings Except Low-Rise Residential Buildings*
  - Guideline 1.1 *HVAC&R Technical Requirements for the Commissioning Process*
- Energy Information Administration—Electricity
- PBS-P100 *Facilities Standards for the Public Buildings Service*

Additional Resources

Design and Analysis Tools

Building energy simulations allow the system designer to compare different HVAC systems and control strategies. These tools vary in their scope and level of complexity. Some tools analyze individual components of HVAC systems (e.g., motors) under simplified assumptions regarding the component use (e.g., annual hours of operation). Other tools simulate entire buildings, including energy gains/losses through the building envelope, energy gains from internal loads, and energy used by the HVAC systems to maintain user-prescribed space conditions (e.g., temperature, humidity, ventilation rates). The latter tools require expertise and experience to obtain accurate results due to the detailed input required. Some building simulation packages have reduced input requirements. The trade-off is that these tools are typically not as accurate, since the programs use defaults or assumptions to replace the user inputs. However, simplified tools can be used early in the design process to investigate the influence of HVAC system selection on energy efficiency strategies such as daylighting.

More information on a variety of tools, including those listed below, can be found at:

- Building Energy Software Tools (BEST) formerly hosted by the U.S. Department of Energy (DOE)
- WBDG Energy Analysis Tools

Whole Building Annual Energy Simulation Software

- Detailed Input
  - DOE-2
  - EnergyPlus™

Individual Component Energy Analysis

- MotorMaster
- Pumping System Assessment Tool

Government Agencies and Initiatives

- Department of Energy (DOE)
  - Federal Energy Management Program (FEMP)—Information on Energy Technologies
  - Office of Energy Efficiency and Renewable Energy (EERE)
  - Office of Scientific and Technical Information (OSTI)
- Energy Information Administration (EIA)
- Environmental Protection Agency (EPA) Energy Star Program
- National Technical Information Service (NTIS)
- National Institute of Standards and Technology (NIST)
- U.S. Department of Commerce NOTE: This is a repository for all publications by the federal labs and contractors.
- U.S. EPA Atmospheric Pollution
- USA.gov

National Laboratories and Research Centers

- Lawrence Berkeley National Laboratories (LBNL)
- National Renewable Energy Laboratory (NREL)
- Oak Ridge National Laboratory (ORNL)
- Pacific Northwest National Laboratory (PNNL)

Professional and Trade Associations, and Interest Groups

- Air-Conditioning and Refrigeration Institute (ARI)
- American Boiler Manufacturers Association (ABMA)
- American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE)
- Association of Energy Engineers (AEE)
- Cooling Technology Institute
- Electric Power Research Institute (EPRI)
- Geothermal Exchange Organization
- Geothermal Resources Council (GRC)
- International Ground Source Heat Pump Association (IGSHPA)

- International Energy Agency (IEA) Heat Pumping Technologies Centre
- Sheet Metal and Air Conditioning Contractors' National Association (SMACNA)

Trade Publications

- ACHRNEWS—Air-Conditioning, Heating and Refrigeration News
- *American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) Journal*
- *Consulting-Specifying Engineer*
- *Energy User News*
- *Engineered Systems Magazine*
- *Heating/Piping/Air-Conditioning HPAC Engineering Magazine*

Books

- *Building Technology: Mechanical and Electrical Systems, 2nd Edition* by Stein, Benjamin. New York: John Wiley & Sons, Inc., 1997.
- *Energy-Efficient Design and Construction for Commercial Buildings* by Steven Winter Associates, Inc. New York: McGraw-Hill, 1997. ISBN 0-07-071159-3.
- *Energy-Efficient Operation of Commercial Buildings: Redefining the Energy Manager's Job* by Herzog, Peter. New York: McGraw-Hill, 1997. ISBN 0-07-028468-7.
- *Simplified Design of HVAC Systems*, by Bobenhausen, William. New York: John Wiley & Sons, Inc., 1994.

Articles

- *HVAC Characteristics and Occupant Health* by W.K. Sieber, M.R. Petersen, L.T. Stayner, R. Malkin, M.J. Mendell, K.M. Wallingford, T.G. Wilcox, M.S. Crandall, and L. Reed. *ASHRAE Journal*, September 2002.
- *Ventilation Rates and Health* by Olli Seppänen, Fellow ASHRAE, William J. Fisk, P.E., Member ASHRAE, and Mark J. Mendell, Ph.D. *ASHRAE Journal*, August 2002.

Other

- GSA Sustainable Facilities Tool (SFTool)—SFTool's immersive virtual environment addresses all your sustainability planning, designing and procurement needs.