# CHAPTER 3

# CENTRAL COOLING AND HEATING



CENTRAL cooling and/or heating plants generate cooling and/or heating in one location for distribution to multiple locations in one building or an entire campus or neighborhood, and represent approximately 25% of HVAC system applications. Central cooling and heating systems are used in almost all classes of buildings, but particularly in very large buildings and complexes or where there is a high density of energy use. They are especially suited to applications where maximizing equipment service life and using energy and operational workforce efficiently are important.

The following facility types are good candidates for central cooling and/or heating systems:

- Campus environments with distribution to several buildings
- High-rise facilities
- Large office buildings
- Large public assembly facilities, entertainment complexes, stadiums, arenas, and convention and exhibition centers
- Urban centers (e.g., city centers/districts)
- Shopping malls
- Large condominiums, hotels, and apartment complexes
- Educational facilities
- Hospitals and other health care facilities
- Industrial facilities (e.g., pharmaceutical, manufacturing)
- Large museums and similar institutions
- Locations where waste heat is readily available (result of power generation or industrial processes)

This chapter addresses design alternatives that should be considered when centralizing a facility's cooling and heating sources. Distribution system options and equipment are discussed when they relate to the central equipment, but more information on distribution systems can be found in Chapters 10 to 14.

## SYSTEM CHARACTERISTICS

Central systems are characterized by large chilling and/or heating equipment located in one facility or multiple smaller installations interconnected to operate as one. Equipment configuration and ancillary equipment vary significantly, depending on the facility's use. See Chapter 1 for information on selecting a central cooling or heating plant.

Equipment can be located adjacent to the facility, or in remote stand-alone plants. Also, different combinations of centralized and decentralized systems (e.g., a central cooling plant and decentralized heating and ventilating systems) can be used.

Primary equipment (i.e., chillers and boilers) is available in different sizes, capacities, and configurations to serve a variety of building applications. Operating a few pieces of primary equipment (often with back-up equipment) gives central plants different benefits from decentralized systems (see Chapter 2).

The preparation of this chapter is assigned to TC 9.1, Large Building Air-Conditioning Systems.

Multiple types of equipment and fuel sources may be combined in one plant. The heating and cooling energy may be a combination of electricity, natural gas, oil, coal, solar, geothermal, etc. This energy is converted into chilled water, hot water, or steam that is distributed through the facility for air conditioning, heating, and processes. The operating, maintenance, and first costs of all these options should be discussed with the owner before final selection. When combining heating generation systems, it is important to note the presence of direct-firing combustion systems or chilled-water production systems using HFC or HCFC refrigerants, because the safety requirements in ASHRAE *Standard* 15 must be met.

A central plant can be customized without sacrificing the standardization, flexibility, and performance required to support the primary cooling and heating equipment through careful selection of ancillary equipment, automatic control, and facility management. Plant design varies widely based on building use, life-cycle costs, operating economies, and the need to maintain reliable building HVAC, process, and electrical systems. These systems can require more extensive engineering, equipment, and financial analysis than decentralized systems do.

In large buildings with interior areas that require cooling while perimeter areas require heating, one of several types of centralized heat reclaim units can meet both these requirements efficiently. Chapter 8 describes these combinations, and Chapters 12 to 14 give design details for central plants.

Central plants can be designed to accommodate both occupied/unoccupied and constant, year-round operation. Maintenance can be performed with traditional one-shift operating crews, but usually requires 24 h coverage. Higher-pressure steam boiler plants (usually greater than 15 psig) or combined cogeneration and steam heating plants require multiple-operator, 24 h shift coverage.

### Advantages

- Primary cooling and heating can be provided at all times, independent of the operation mode of equipment and systems outside the central plant.
- Using larger but fewer pieces of equipment generally reduces the facility's overall operation and maintenance cost. It also allows wider operating ranges and more flexible operating sequences.
- A centralized location minimizes restrictions on servicing accessibility.
- Energy-efficient design strategies, energy recovery, thermal storage, and energy management can be simpler and more cost-effective to implement.
- Multiple energy sources can be applied to the central plant, providing flexibility and leverage when purchasing fuel.
- Standardizing equipment can be beneficial for redundancy and stocking replacement parts. However, strategically selecting different-sized equipment for a central plant can provide better part-load capability and efficiency.
- Standby capabilities (for firm capacity/redundancy) and back-up fuel sources can easily be added to equipment and plant when planned in advance.

- Equipment operation can be staged to match load profile and taken offline for maintenance.
- District cooling and heating can be provided.
- A central plant and its distribution can be economically expanded to accommodate future growth (e.g., adding new buildings to the service group).
- Load diversity can substantially reduce the total equipment capacity requirement.
- Submetering secondary distribution can allow individual billing of cooling and heating users outside the central plant.
- Major vibration and noise-producing equipment can be grouped away from occupied spaces, making acoustic and vibration controls simpler. Acoustical treatment can be applied in a single location instead of many separate locations.
- Issues such as cooling tower plume and plant emissions are centralized, allowing a more economic solution.

### Disadvantages

- Equipment may not be readily available, resulting in long lead-time for production and delivery.
- Equipment may be more complicated than decentralized equipment, and thus require a more knowledgeable equipment operator.
- A central location within or adjacent to the building is needed.
- Additional equipment room height may be needed.
- Depending on the fuel source, large underground or surface storage tanks may be required on site. If coal is used, space for storage bunker(s) will be needed.
- Access may be needed for large deliveries of fuel (oil or coal).
- Heating plants require a chimney and possibly emission permits, monitoring, and treatments.
- Multiple equipment manufacturers are required when combining primary and ancillary equipment.
- System control logic may be complex.
- First costs can be higher.
- Special permitting may be required.
- Safety requirements are increased.
- A large pipe distribution system may be necessary (which may actually be an advantage for some applications).



## DESIGN CONSIDERATIONS

### Cooling and Heating Loads

Design cooling and heating loads are determined by considering individual and simultaneous loads. The simultaneous peak or instantaneous load for the entire portion or block of the building served by the HVAC and/or process load is less than the sum of the individual cooling and heating loads (e.g., buildings do not receive peak solar load on the east and west exposures at the same time). This difference between design load and peak load, called the **central equipment diversity factor**, can be as little as 5% less than the sum of individual loads (e.g., 95% diversity factor) or represent a more significant portion of the load (e.g., 45% diversity factor), as is common in academic campus applications. The peak central plant load can be based on this diversity factor, reducing the total installed equipment capacity needed to serve larger building cooling and heating loads. It is important for the design engineer to evaluate the full point-of-use load requirements of each facility served by the central system. Opportunities for improving energy efficiency include

- **Staging** multiple chillers or boilers for part-load operation. Using correctly sized equipment is imperative to accurately provide the most flexible and economical sequencing of equipment.
- For central chiller plants, consider incorporating **variable-frequency drives (VFDs)** onto at least one base-loaded primary chiller. Multiple VFD installations on chillers allow more flexibility in energy control of chiller plant operation.

Discrete loads (e.g., server rooms) are best served independently; a small, independent system designed for the discrete load may be the most cost-effective approach. Central plants sized for minimum part-load operation may not be able to reliably serve a discrete load. For example, a 2000 ton chiller plant serving multiple facilities could be selected with four 500 ton chillers. In a remote facility connected to the central distribution system, an independent computer room server has a year-round 5 ton load. Operating one 500 ton chiller at less than 100 tons reliably may be extremely inefficient and possibly detrimental to the chiller plant operation. Serving the constant remote load independently allows the designer the flexibility to evaluate the chiller plant as a whole and individual subsystems independently, so as to not adversely affect both systems.

Peak cooling load time is affected by outside ventilation, outside dry- and wet-bulb temperatures, period of occupancy, interior equipment heat gain, and relative amounts of north, east, south, and west exposures. For buildings with a balanced distribution of solar exposures, the peak usually occurs on a midsummer afternoon when the west solar load and outside wet-bulb temperature are at or near concurrent maximums. However, for buildings with much more solar exposure on one side than on another, the peak cooling period can change significantly with time of day and month.

The diversity of building occupancies served can significantly affect the peak cooling load diversity factor. For example, in a system serving an entire college campus, the peak cooling period for a classroom is different from that for a dormitory or an administration building. Special consideration for planning load profiles at academic facilities should be identified. Unlike office and residential applications, universities and colleges typically have peak cooling loads during late summer and fall.

Peak heating load has less opportunity to accommodate a diversity factor, so equipment is most likely to be selected on the sum of individual heating loads. This load may occur when the building must be warmed back up to a higher occupied space temperature after an unoccupied weekend setback period. Peak demand may also occur during unoccupied periods when the ambient environment is harshest and there is little internal heat gain to assist the heating system, or during occupied times if significant outside air must be preconditioned or some other process (e.g., process heating) requires significant heat. To accommodate part-load conditions and energy efficiency, variable-flow may be the best economical choice. It is important for the designer to evaluate plant operation and system use.

### System Flow Design

The configuration of a central system is based on use and application. Two types of energy-efficient designs used today are primary variable flow and primary/secondary variable flow.

**Primary variable flow** uses variable flow through the production energy equipment (chiller or heating-water generator) and directly pumps the medium, usually water, to the point of use. Variable-flow can be achieved using two-way automatic control valves at terminal equipment and either variable-frequency drive (VFD) pumping (Figure 1) or distribution pressure control with bypass valve (Figure 2). Both concepts function based on maintaining system pressure, usually at the farthest point (last control valve and terminal unit) in the water system.

**Primary/secondary variable flow** hydraulically decouples the primary production system (chilled- or heating-water source), which is commonly constant flow. A variable-flow secondary piping system distributes the chilled or heating medium to the point of use (Figures 3 and 4).

Another design is a straight **constant-volume primary** system. Hydronic pumps distribute water through the energy equipment

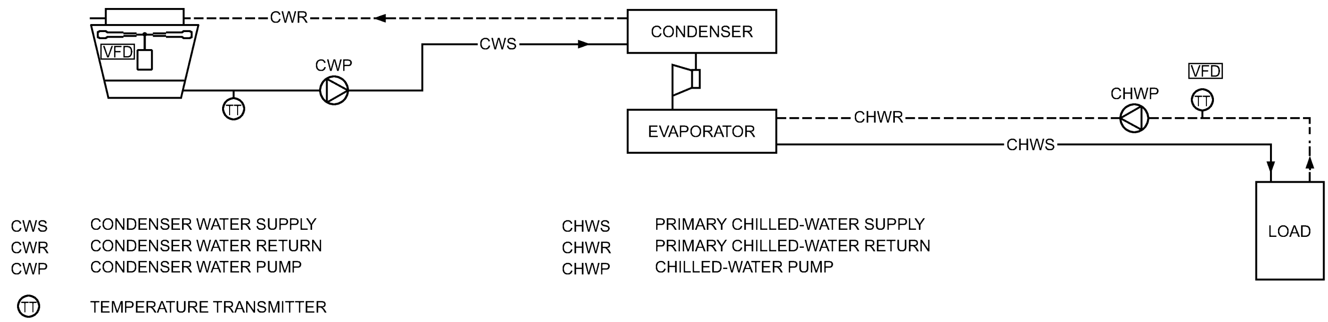


**Fig. 1 Primary Variable-Flow System**
(Courtesy RDK Engineers)

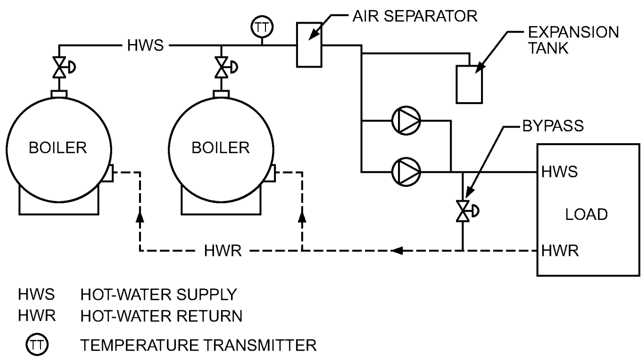


**Fig. 2 Primary (Limited) Variable-Flow System Using Distribution Pressure Control**
(Courtesy RDK Engineers)

straight to the point of use. Pumping energy is constant, as is the distribution flow, which generally requires a means to maintain the design flow rate through the system while in operation. Thus, these systems are generally more expensive to operate and less attractive in central system designs.

When using either primary/secondary or primary variable-flow designs, the engineer should understand the design differences between two- and three-way modulating valves. Variable-flow designs vary the flow of chilled or heating water through the distribution loop. As terminal units satisfy demand, the valve modulates toward the closed position. In the distribution system, the pump, if at design operating conditions, increases system pressure above the design point. To compensate, a VFD is typically installed on the distribution pump. This VFD is usually controlled by a pressure differential sensor, which may be located approximately two-thirds of the way down the piping loop, at the critical, farthest point in the system, to maintain the minimum pressure needed to provide design flow through the last terminal device and associated control valve. As the pressure differential increases, the sensor sends a signal to the VFD to reduce speed. The affinity laws then allow flow to reduce in direct proportion to the change in flow. As system demand requires increased flow, the control valve modulates open, reducing system differential pressure. The reduction in pressure difference measured causes a corresponding increase in pump speed (and therefore flow) to meet the plant demand. With a primary/secondary design, minimum system flow for the chiller or heating plant is accomplished by using a decoupler bypass across the primary and secondary systems. Because the primary system is constant volume (i.e., the system maintains design flow during operation as designed when production flow exceeds distribution flow), water recirculates within the plant to maintain the minimum design flow required by the production plant. Care should be taken during design to ensure minimum flow is achieved under part-load operation throughout the system. When selecting the distribution system pump, ensure distribution flow does not exceed production flow, which could cause a temperature drop if flow exceeds demand (**low Δ*T* syndrome**). The engineer should evaluate operational conditions at part load to minimize the potential for this to occur.

With primary variable-flow designs, the primary chilled- or heating-water pumps are of a variable-flow design, again using a VFD. Primary variable-flow systems use modulating two-way control valves to reduce water flow across each heat transfer device (as in the primary/secondary system). At minimum flow conditions, as required by the equipment and plant design, a way is needed to prevent flow from becoming laminar; typically, this is done with a minimum flow bypass around the plant.

With a straight constant-volume system, flow is constant at the design requirement. These systems commonly use three-way control valves, and throttle closed (as in a two-way valve) as terminal unit demand is satisfied. However, the three-way valve also has a bypass port to allow up to design flow to flow around the terminal heat transfer device and return to the central plant. With constant-volume designs, temperature swings typically occur across the plant and terminal heat exchange devices, because design flow does not change.

## Energy Recovery and Thermal Storage

Depending on the operations schedule of the building(s) served, energy recovery and thermal storage strategies can be applied to a central cooling and heating plant. Water-to-water energy recovery systems are common and readily available. Thermal water or ice storage also can be very adaptable to central plants. See Chapter 25 in this volume and to Chapters 32 to 35 and 40 in the 2007 *ASHRAE Handbook—HVAC Applications* for more information on energy-related opportunities. Thermal energy storage (TES) systems may offer multiple strategies for both part-load and peak-load efficiency control. Examples such as base-loading plant operation for a more flat-line energy consumption profile may help in negotiating energy costs with a utility company supplier. Thermal energy storage of chilled water, ice, or heating water offers a medium for redundant capacity, with potential reductions in both heating and cooling infrastructure equipment sizing.

# EQUIPMENT

## Primary Refrigeration Equipment

Central cooling plant refrigeration equipment falls into two major categories: (1) vapor-compression refrigeration cycle (compressorized) chillers, and (2) absorption-cycle chillers. In some cases, the chiller plant may be a combination of these machines, all installed in the same plant. Cooling towers, air-cooled condensers, evaporative condensers, or some combination are also needed to reject heat from this equipment. The energy for the prime driver of

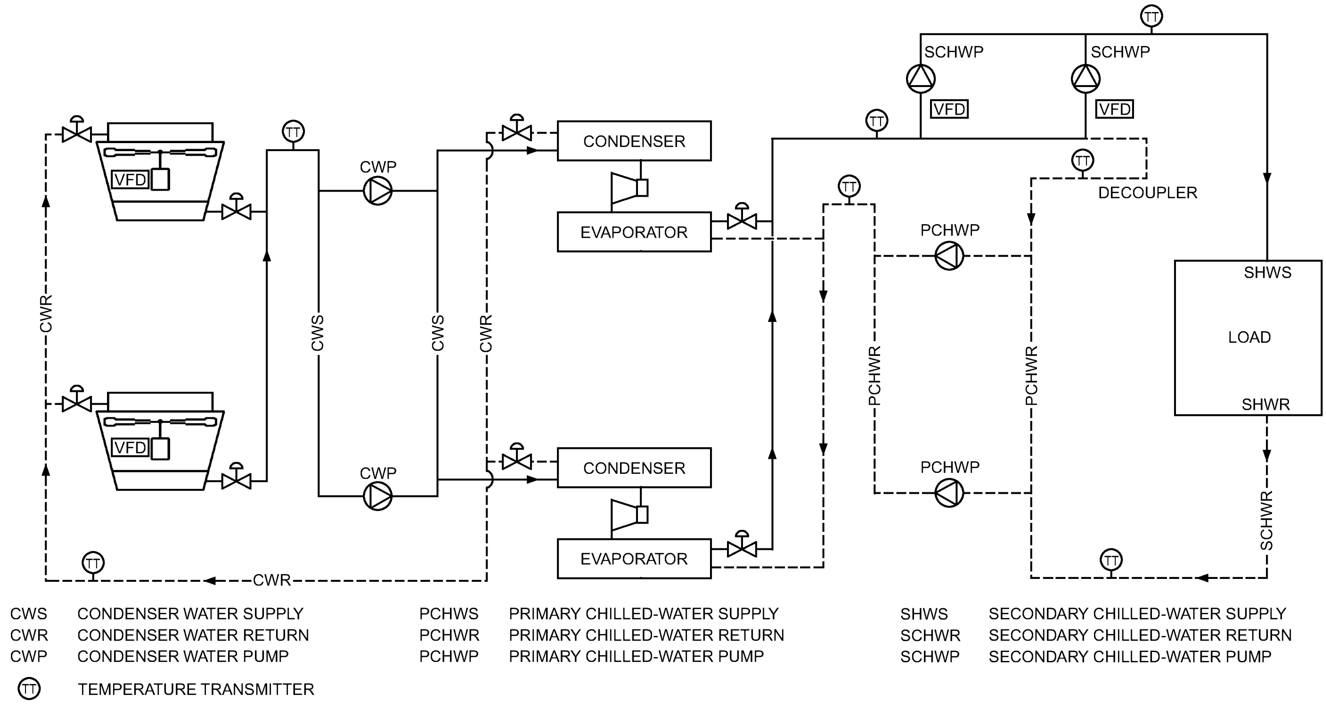


**Fig. 3 Primary/Secondary Pumping Chilled-Water System**
(Courtesy RDK Engineers)

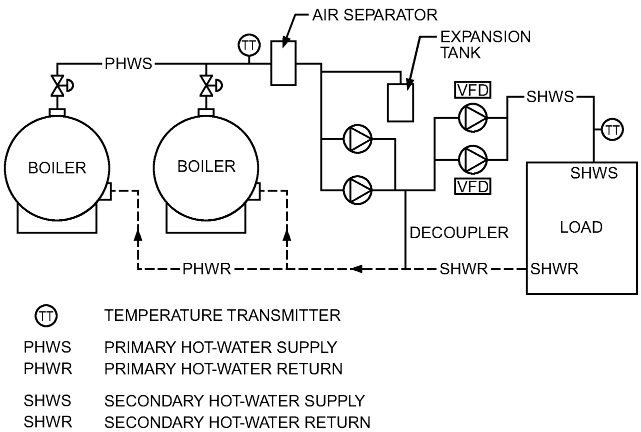


**Fig. 4 Primary/Secondary Pumping Hot-Water System**
(Courtesy RDK Engineers)

cooling equipment may also come from waste heat from a combined heat and power (CHP) system. Typically, electricity production efficiency is improved when waste heat can be reclaimed and transferred to a heat source. A heat recovery generator supplying either steam or hot water to a driver (e.g., a steam turbine or absorption-cycle chiller) allows a facility to track a thermal load from the heat rejection of electric generation, which can be an attractive economic model.

Chapter 42 of this volume and Chapters 41 and 43 of the 2006 *ASHRAE Handbook—Refrigeration* discuss refrigeration equipment, including the size ranges of typical equipment.

**Compressorized chillers** feature reciprocating, helical rotary (screw), and centrifugal compressors, which may be driven by electric motors; natural gas-, diesel-, or oil-fired internal combustion engines; combustion turbines; or steam turbines.

**Compressors** may be purchased as part of a refrigeration chiller that also includes the drive, evaporator, condenser, and necessary safety and operating controls. Reciprocating and helical rotary compressor units can be field-assembled and include air- or water-cooled (evaporative) condensers arranged for remote installation. Centrifugal compressors are usually included in packaged chillers, although they can be very large and sometimes require field erection. These types of chillers also require remote air- or water-cooled ancillary equipment. Chapter 37 has information about compressors.

**Absorption chillers** may be single- or double-effect, fired by steam or direct-fired by gas, oil, or waste heat. Like centrifugal chillers, absorption chillers are built to perform with remote water-cooled ancillary heat rejection equipment (e.g., cooling towers). These absorption chillers use a lithium bromide/water cycle in which water is the refrigerant, and are generally available in the following configurations: (1) natural gas direct-fired, (2) indirect-generated by low-pressure steam or high-temperature water, (3) indirect-generated by high-pressure steam or hot water, and (4) indirect-generated by hot exhaust gas. Chapter 41 of the 2006 *ASHRAE Handbook—Refrigeration* discusses absorption air-conditioning and refrigeration equipment in more detail.

## Ancillary Refrigeration Equipment

Ancillary equipment for central cooling plants consists primarily of heat-rejection equipment (air-cooled condensers, evaporative condensers, and cooling towers), pumps (primary, secondary, and tertiary), and heat exchangers (water-to-water), as well as water pumps and possibly heat exchanger(s). For more detailed information on this additional equipment, see Chapters 25, 38, 39, and 41 to 46.

**Air-cooled condensers** pass outside air over a dry coil to condense the refrigerant. This results in a higher condensing temperature and thus a larger power input at peak condition (although peak time may be relatively short over 24 h). Air-cooled condensers are popular in small reciprocating and helical rotary compressor units because of their low maintenance requirements.

**Evaporative condensers** pass outside air over coils sprayed with water, thus taking advantage of adiabatic saturation to lower the condensing temperature. As with cooling towers, freeze prevention and close control of water treatment are required for successful operation. The lower power consumption of the refrigeration system and much smaller footprint of the evaporative condenser are gained at the expense of the cost of water and water treatment used and increased maintenance cost.

**Cooling towers** provide the same means of heat rejection as evaporative condensers but pass outside air through an open condenser return water spray to achieve similar adiabatic cooling performance. Either natural or mechanical-draft cooling towers or spray ponds can be used; the mechanical-draft tower (forced-draft, induced-draft, or ejector) can be most easily designed for most conditions because it does not depend on wind. Cooling tower types and sizes range from packaged units to field-erected towers with multiple cells in unlimited sizes. Location of heat rejection equipment should consider issues such as reingestion or short-circuiting of discharge heat rejection air because of location in a confined area, tower plume, and the effect of drift on adjacent roadways, buildings, and parking lots.

**Makeup water subtraction meters** should be evaluated for both evaporative condensers and cooling towers by the design engineer or owner. In many areas, sewage costs are part of the overall water bill, and most domestic water supplied to a typical facility goes into the sewage system. However, evaporated condenser water is not drained to sewer, and if a utility grade meter is used, potential savings in plant operating costs can be made available to the owner. Metering should be evaluated with chilled-water plants, especially those in operation year-round. Consult with the water supplier to identify compliance requirements. Consider piping cooling tower water blowdown and drainage (e.g., to remove dissolved solids or allow maintenance when installing subtraction meters) to the storm drainage system, but note that the environmental effects of the water chemistry must be evaluated. Where chemical treatment conditions do not meet environmental outfall requirements, drainage to the sanitary system may still be required unless prefiltration can be incorporated.

**Water pumps** move both chilled and condenser water to and from the refrigeration equipment and associated ancillary equipment. See Chapter 43 for additional information on centrifugal pumps, and Chapters 11 to 13 for system design.

**Heat exchangers** provide operational and energy recovery opportunities for central cooling plants. Operational opportunities generally involve heat transfer between building systems that must be kept separated because of different pressures, media, or other characteristics. For example, heat exchangers can thermally link a low-pressure, low-rise building system with a high-pressure, high-rise building system. Heat exchangers can also transfer heat between chemically treated or open, contaminated water systems and closed, clean water systems (e.g., between a central cooling plant chilled-water system and a high-purified, process cooling water system, or between potentially dirty pond water and a closed-loop condenser water system).

To conserve energy, water-to-water heat exchangers can provide water-side economizer opportunities. When outside conditions allow, condenser water can cool chilled water through a heat exchanger, using the cooling tower and pumps rather than a compressor. This approach should be considered when year-round chilled water is needed to satisfy a process load, or when an air-side economizer is not applicable to the air distribution systems of connected facilities in a central system distribution loop.

**Plant Controls.** Direct digital control (DDC) systems should be considered for control accuracy and reliability. Temperature, flow, and energy use are best measured and controlled with modern DDC technology. Pneumatic control should be considered where torque or rapid response of power actuation is required; medium pressure (typically 30 to 60 psig) is best. Programmable logic controllers (PLCs) should be considered for larger central plants or where future expansion/growth is possible.

**Codes and Standards.** Specific code requirements and standards apply when designing central cooling plants. For cooling equipment, refer to ASHRAE *Standard* 15; Chapter 51 of this volume provides a comprehensive list of codes and standards associated with cooling plant design, installation, and operation. Manufacturers' recommendations and federal, state, and local codes and standards should also be followed.

## Primary Heating Equipment

The major heating equipment used in central heating plants, **boilers** vary in type and application, and include combined heat and power (CHP) and waste heat boilers. Chapter 31 discusses boilers in detail, including the size ranges of typical equipment.

A boiler adds heat to the **working medium**, which is then distributed throughout the building(s) and/or campus. The working medium may be either water or steam, which can further be classified by its temperature and pressure range. Steam, often used to transport energy long distances, is converted to low-temperature hot water in a heat exchanger near the point of use. Although steam is an acceptable medium for heat transfer, low-temperature hot water is the most common and more uniform medium for providing heating and process heat (e.g., heating water to 200°F for domestic hot water). Elevated steam pressures and high-temperature hot-water boilers are also used. Both hot-water and steam boilers have the same type of construction criteria, based on temperature and pressure.

A boiler may be purchased as a package that includes the burner, fire chamber, heat exchanger section, flue gas passage, fuel train, and necessary safety and operating controls. Cast-iron and water-side boilers can be field-assembled, but fire-tube, scotch marine, and waste-heat boilers are usually packaged units.

**Energy Sources.** The energy used by a boiler may be electricity, natural gas, oil, coal, or combustible waste material, though natural gas and fossil-fuel oil (No. 2, 4, or 6 grade) are most common, either alone or in combination. Selecting a fuel source requires detailed analysis of energy prices and availability (e.g., natural gas and primary electrical power). The availability of fuel oil or coal delivery affects road access and storage for deliveries. Security around a central plant must be considered in the design and include standby electrical power generation and production of central cooling and heating for critical applications in times of outages or crisis.

Energy for heating may also come from waste heat from a CHP system. Typically, electricity production efficiency is improved when waste heat can be reclaimed and transferred to a heat source. A heat recovery generator converting the heat byproduct of electric generation to steam or hot water to meet a facility's heating needs when the thermal load meets or exceeds the heat rejection of the electric generation can be a cost-effective plant operation.

Additionally, attention to the design of an efficient and maintainable **condensate return** system for a central steam distribution plant is important. A well-designed condensate return system increases overall efficiencies and reduce both chemical and makeup water use.

**Codes and Standards.** Specific code requirements and standards apply when designing central heating boiler plants. It is important to note that some applications (e.g., high-pressure boilers) require continuous attendance by licensed operators. Operating cost considerations should be included in determining such applications. Numerous codes, standards, and manufacturers' recommendations need to be followed. Refer to Chapter 51 for a comprehensive list of codes and standards associated with this equipment, plant design, installation, and operation.

## Ancillary Heating Equipment

**Steam Plants.** Ancillary equipment associated with central steam heating plants consists primarily of the boiler feed unit, deaerator unit (both with receiver and pumps), chemical feed, and possibly a surge tank and/or heat exchanger(s).

**Boiler feed** equipment, including the receiver(s) and associated pump(s), serve as a reservoir for condensate and makeup water waiting to be used by the steam boiler. The boiler feed pump provides system condensate and water makeup back to the boiler on an as-needed basis.

**Deaerators** help eliminate oxygen and carbon dioxide from the feed water (see Chapter 48 of the 2007 *ASHRAE Handbook—HVAC Applications* for more information).

**Chemicals** can be fed using several methods or a combination of methods, depending on the chemical(s) used (e.g., chelants, amines, oxygen scavengers). Continuous-feed pumps are the preferred and most reliable method for high-pressure steam systems.

**Surge tanks** are also applicable to steam boiler plants to accommodate large quantities of condenser water return and are primarily used where there is a rapid demand for steam (e.g., morning start-up of a central heating plant).

See Chapter 10 for more information on steam systems.

**Hot-Water Plants.** Ancillary equipment associated with central hot-water heating plants consists primarily of pumps and possibly heat exchanger(s). Water pumps move boiler feed water and hot-water supply and return to and from the boiler equipment and associated ancillary equipment. See Chapter 43 for additional information on centrifugal pumps, as well as Chapters 10 to 12 and Chapter 14 for system design.

**Heat Exchangers.** Heat exchangers offer operational and energy recovery opportunities for central heating plants. In addition to the heat exchange and system separation opportunities described in the section on Refrigeration Equipment, the operational opportunities for heat exchangers involve combining steam heating capabilities with hot-water heating capabilities.

Air-to-water and water-to-water heat exchangers provide opportunities for economizing and heat recovery in a central heating plant (e.g., flue gas exhaust heat recovery and boiler blowdown heat recovery).

For more detailed information on ancillary equipment, see Chapters 30 to 32 and Chapter 34.



## DISTRIBUTION SYSTEMS

The major piping in a central cooling plant may include, but is not limited to, chilled-water, condenser water, city water, natural gas, fuel oil, refrigerant, vent, and drainpipe systems. For a central steam heating plant, the major piping includes steam supply, condensate return, pumped condensate, boiler feed, city water, natural gas, fuel oil, vent, and drainpipe systems. For a central hot-water heating plant, it includes hot-water supply and return, city water, natural gas, fuel oil, vent, and drainpipe systems. In the 2005 *ASHRAE Handbook—Fundamentals*, see Chapter 35 for information on sizing pipes, and Chapter 37 for identification, color-coding, abbreviations, and symbols for piping systems.

Design selection of cooling and heating temperature set points (supply and return water) can affect first and operating costs. For water systems with a large temperature difference between supply and return water, the resulting flow can allow smaller pipe sizing and smaller valves, fittings, and insulation, which can lower installation cost. However, these savings maybe offset by the larger coils and heat exchangers at the point of use needed to accomplish the same heat transfer. A similar design strategy can be achieved with steam pressure differential.

Determining the optimum cooling and heating water supply and return temperatures requires design consideration of equipment performance, particularly the energy required to produce the supply water temperature. Although end users set water temperatures, the colder the cooling water, the more energy is needed by the chiller. Similar issues affect hot-water supply temperature and steam operating pressure. When designing for energy management, supply water reset may be considered when peak capacity is not needed, potentially reducing energy consumption. This reduces chiller power input, but those savings may be offset by increased pump power input because of a higher water flow rate with higher supply temperature. Energy implications on the whole system must be considered. The design engineer should consider using higher temperature differences between supply and return to reduce the pump energy required by the distribution system, for both heating and chilled-water systems. Additionally, central plant production systems (e.g., boilers, steam-to-heating-water converters, chillers) operate more efficiently with higher return water temperatures. During conceptual planning and design, or as early in design as possible, the engineer should evaluate the type(s) of existing facilities to which the central system will be connected. When using variable-flow distribution with a constant design temperature split between the supply and return medium, it is critical to avoid low $\Delta T$ syndrome (see the section on System Characteristics). The engineer should attempt to ensure the condition is minimized or avoided, or at minimum perform due diligence to make the owner aware of the potential shortfalls where it is allowed to occur. With existing constant-flow/variable-temperature systems, measures should be taken to avoid a loss of the conceptual design strategy of a variable-flow/ constant-temperature split. Examples of connection strategies less costly than full renovation of a connected facility are (1) return recirculation control, to maintain a design temperature across a facility connection, or (2) separation of primary distribution supply from the secondary facility connection by a plate-and-frame heat exchanger with a control valve on the primary return controlled by the secondary supply to the facility. If the temperature split is allowed to fall, increased flow of the medium through the distribution system will be required to accomplish the same capacity. This increase in flow increases pump horsepower and chiller plant energy, compromising the available capacity and operation of the system.

Hydraulically modeling the cooling and heating media (chilled water, heating water, steam, domestic water, natural gas, etc.) should be considered. With an emphasis on centralizing the source of cooling and heating, a performance template can be created for large plants by computerized profiling of cooling and heating delivery. Hydraulic modeling provides the economic benefits of predesigning the built-out complete system before installing the initial phase of the project. The model also helps troubleshoot existing systems, select pumps, project energy usage, and develop operation strategy.

Energy conservation and management can best be achieved with computerized design and facility management resources to simulate delivery and then monitor and measure the actual distribution performance.

## ACOUSTIC, VIBRATION, AND SEISMIC CONSIDERATIONS

### Sound and Vibration

Proper space planning is a key to sound and vibration control in central plant design. For example, central plants are frequently located at or below grade. This provides a very stable platform for vibration isolation and greatly reduces the likelihood of vibration being transmitted into the occupied structure, where it can be regenerated as noise. Also, locating the central ventilation louvers or other openings well distant from noise- and vibration-sensitive areas greatly reduces the potential for problems in those areas. Louvers should be installed to prevent unwanted ambient air or water from being entrained into a facility. Louvers should be installed high enough to prevent security breaches (above ground level, where possible). As a guide, maintain free area around louvers as specified in ASHRAE *Standard* 15.

Vibration and noise transmitted both into the space served by the plant and to neighboring buildings and areas should be considered in determining how much acoustical treatment is appropriate for the design, especially if the plant is located near sensitive spaces such as conference rooms or sleeping quarters. See the section on Space Considerations for further discussion of space planning.

Acoustical considerations must also be considered for equipment outside the central plant. For example, roof-mounted cooling tower fans sometimes transmit significant vibration to the building structure and generate ambient noise. Many communities limit machinery sound pressure levels at the property line, which affects the design and placement of equipment. See Chapter 47 of the 2007 *ASHRAE Handbook—HVAC Applications* for more detailed information on sound and vibration.

## Seismic Issues

Depending on code requirements and the facility's location with respect to seismic fault lines, seismic bracing may be required for the central plant equipment and distribution. For instance, a hospital located in a seismically active area must be able to remain open and operational to treat casualties in the aftermath of an earthquake. Most building codes require that measures such as anchors and bracing be applied to the HVAC system. Refer to the local authority responsible for requirements, and to Chapter 54 of the 2007 *ASHRAE Handbook—HVAC Applications* for design guidance.

## SPACE CONSIDERATIONS

In the very early phases of building design, architects, owners, and space planners often ask the engineer to estimate how much building space will be needed for mechanical equipment. The type of mechanical system selected, building configuration, and other variables govern the space required, and many experienced engineers have developed rules of thumb to estimate the building space needed. Although few buildings are identical in design and concept, some basic criteria apply to most buildings and help approximate final space allocation requirements. These space requirements are often expressed as a percentage of the total building floor area; the combined mechanical and electrical space requirement of most buildings is 6 to 9%.

A central system reduces mechanical space requirements for each connected building. Where a central plant is remote or standalone, space requirements for equipment and operation are 100% for the plant. In these cases, it may be typical to have space requirements of 2.5 to 3.5 $ft^2$ per ton of refrigeration.

Space for chillers, pumps, and towers should not only include installation footprints but should also account for adequate clearance to perform routine and major maintenance. Generally, 4 ft service clearance (or the equipment manufacturer's minimum required clearance, whichever is greater) around equipment for operator maintenance and service is sufficient. For chillers, one end of the chiller barrels should be provided with free space the length of the evaporator and condenser barrels, to allow for tube pull clearance. In many cases, designers provide service bay roll-up doors or ventilation louvers (if winter conditions do not cause freeze damage issues) to allow tube access. Overhead service height is also required, especially where chillers are installed. Provision for 20 ft ceilings in a central plant is not uncommon, to accommodate piping and service clearance dimensions.

Plant designs incorporating steam supply from a separate central boiler plant may use steam-to-heating-water converters and the heating distribution equipment (e.g., pumps) along with the chilled-water production equipment and distribution infrastructure, increasing the general space to 4 to 6 $ft^2$ per ton. Where a boiler installation as well as heating distribution equipment and appurtenances are required, the plant's physical size increases to account for the type of boiler and required exhaust emissions treatment. Generally, for central heating plants, steam or heating water and chilled-water production systems are separated during design, which may further increase the overall footprint of the plant.

The arrangement and strategic location of the mechanical spaces during planning affects the percentage of space required. For example, the relationship between outside air intakes and loading docks, exhaust, and other contaminating sources should be considered during architectural planning. The final mechanical room size, orientation, and location are established after discussion with the architect and owner. The design engineer should keep the architect, owner, and facility engineer informed, whenever possible, about the HVAC analysis and system selection. Space criteria should satisfy both the architect and the owner or owner's representative, though this often requires some compromise. The design engineer should strive to understand the owner's needs and desires and the architect's vision for the building, while fully explaining the advantages, disadvantages, risks, and rewards of various options for mechanical and electrical room size, orientation, and location. All systems should be coordinated during the space-planning stage to safely and effectively operate and maintain the central cooling and heating plant.

In addition, the mechanical engineer sometimes must represent other engineering disciplines in central plant space planning. If so, it is important for the engineer to understand the basics of electrical and plumbing central plant equipment. The main electrical transformer and switchgear rooms should be located as close to the incoming electrical service as practical. The main electric transformers and switchgear for the plant and the mechanical equipment switchgear panels should be in separate rooms that only authorized electricians can enter. If there is an emergency generator, it should be located considering (1) proximity to emergency electrical loads, (2) sources of combustion and cooling air, (3) fuel sources, (4) ease of properly venting exhaust gases outside, and (5) provisions for noise control.

The main plumbing equipment usually contains gas and domestic water meters, the domestic hot-water system, the fire protection system, and elements such as compressed air, special gases, and vacuum, ejector, and sump pumps. Some water and gas utilities require a remote outside meter location.

The heating and air-conditioning equipment room houses the (1) boiler, pressure-reducing station, or both; (2) refrigeration machines, including chilled-water and condensing-water pumps; (3) converters for furnishing hot or cold water for air conditioning; (4) control air compressors, if any; (5) vacuum and condensate pumps; and (6) miscellaneous equipment. For both chillers and boilers, especially in a centralized application, full access is needed on all sides (including overhead) for extended operation, maintenance, annual inspections of tubes, and tube replacement and repair. Where appropriate, the designer should include overhead structural elements to allow safe rigging of equipment. Ideally, large central facilities should include overhead cranes or gantries. It is critical that local codes and ASHRAE *Standard* 15 are consulted for special equipment room requirements. Many jurisdictions require monitoring, alarms, evacuation procedures, separating refrigeration and fuel-fired equipment, and high rates of purge ventilation.

A proper operating environment for equipment and those maintaining it must also be provided. This may involve heating or cooling the space for freeze protection and to prevent overheating motors and controls. HVAC equipment serving the central plant itself may be housed in its own equipment room and serve the chiller, boiler room, and adjacent rooms (e.g., switchgear room, office space, generator room, pump room, machine shop). Where ventilation and maximum temperature limits are not defined in code requirements, a ventilation rate of 0.5 cfm/$ft^2$ and a maximum temperature rise of 122°F are recommended (ASHRAE 2007). Where refrigeration equipment is installed, follow design requirements in ASHRAE *Standard* 15.

### Location of Central Plant and Equipment

Although large central plants are most often located at or below grade, it is often economical to locate the refrigeration plant at the top of the building, on the roof, or on intermediate floors. For central plants, on-grade should be the first choice, followed by below grade. The designer must always ensure access for maintenance and replacement. Locating major equipment in roof penthouses may pose significant access problems for repair and replacement. For single high-rise central plants, intermediate-floor locations that are closer to the load may allow pumping equipment to operate at a lower pressure. A life-cycle cost analysis (LCCA) should include differences in plant location to identify the most attractive plant sustainability options during the planning stage. The LCCA should consider equipment maintenance access, repair, and replacement during the life of the plant, as determined in the owner's criteria. If not identified, an engineer should suggest to the owner or client that maintenance criteria be included as a component in developing the LCCA (see the section on Operations and Maintenance Considerations). Electrical service and structural costs are greater when intermediate-floor instead of ground-level locations are used, but may be offset by reduced energy consumption and condenser and chilled-water piping costs. The boiler plant may also be placed on the roof, eliminating the need for a chimney through the building.

Benefits of locating the air-cooled or evaporative condenser and/or cooling tower on the ground versus the roof should be evaluated. Personnel safety, security, ambient noise, and contamination from hazardous water vapors are some of the considerations that help determine final equipment location. Also, structural requirements (e.g., steel to support roof-mounted equipment, or a concrete pad and structural steel needed to locate equipment at or near grade) require evaluation. When locating a cooling tower at or near grade, the net positive suction head and overflow of condenser water out of the cooling tower sump should be studied if the tower is below, at, or slightly above the level of the chiller.

Numerous variables should be considered when determining the optimum location of a central cooling or heating plant. When locating the plant, consider the following:

- Operating weight of the equipment and its effect on structural costs
- Vibration from primary and ancillary equipment and its effect on adjacent spaces in any direction
- Noise level from primary and ancillary equipment and its effect on adjacent spaces in any direction
- Location of electrical utilities for the central plant room, including primary electric service and associated switchgear and motor control center, as well as electrical transformer location and its entrance into the building
- Location of city water and fire pump room (it may be desirable to consolidate these systems near the central plant room)
- Accessibility into the area and clearances around equipment for employee access, equipment and material delivery, and major equipment replacement, repair, scheduled teardown, and rigging
- Location of cooling, refrigerant relief piping, heating, vents, and boiler flue and stack distribution out of the central plant and into the building, along with the flow path of possible vented hazardous chemical, steam, or combustion exhaust products
- Need for shafts to provide vertical distribution of cooling and heating services in the building
- Future expansion plans of the central plant (e.g., oversizing the central plant now for adding more primary equipment later, based on master planning of the facility)
- Architectural effect on the site
- Location of boiler chimney
- Loading dock for materials and supplies
- Roadway and parking considerations
- Storage of fuel oil, propane gas, and/or coal
- Electrical transformer location
- Underground and/or overhead utility and central cooling and heating system distribution around the central plant and to the building(s)
- Wind effect on cooling tower plume or other volatile discharges such as refrigerant or boiler emissions.

### Central Plant Security

Restricted access and proper location of exposed intakes and vents must be designed into the central plant layout to protect the facility from attack and protect people from injury. Care must be taken in locating exposed equipment, vents, and intakes, especially at ground level. Above ground and at least 10 to 15 ft from access to intake face is preferred. When this is not possible, fencing around exposed equipment, such as cooling towers and central plant intakes, should be kept locked at all times to prevent unauthorized access. Ensure that fencing is open to airflow so it does not adversely affect equipment performance. Air intakes should be located above street level if possible, and vents should be directed so they cannot discharge directly on passing pedestrians or into an air intake of the same or an adjacent facility.

## AUTOMATIC CONTROLS AND BUILDING MANAGEMENT SYSTEMS

One advantage of central cooling and heating plants is easier implementation of building automation because the major and ancillary equipment is consolidated in one location. Computerized automatic controls can significantly affect system performance. A facility management system to monitor system points and overall system performance should be considered for any large, complex air-conditioning system. This allows a single operator to monitor performance at many points in a building and make adjustments to increase occupant comfort and to free maintenance staff for other duties. Chapter 46 of the 2007 *ASHRAE Handbook—HVAC Applications* describes design and application of controls.

Software to consider when designing, managing, and improving central plant performance should include the following:

- Automatic controls that can interface with other control software (e.g., equipment manufacturers' unit-mounted controls)
- Energy management system (EMS) control
- Hydraulic modeling, as well as metering and monitoring of distribution systems
- Using VFDs on equipment (e.g., chillers, pumps, cooling tower fans) to improve system control and to control energy to consume only the energy required to meet the design parameter (e.g., temperature, flow, pressure).
- Computer-aided facility management (CAFM) for integrating other software (e.g., record drawings, operation and maintenance manuals, asset database)
- Computerized maintenance management software (CMMS)
- Automation from other trades (e.g., fire alarm, life safety, medical gases, etc.)
- Regulatory functions (e.g., refrigerant management, federal, state and local agencies, etc.)

Automatic controls for central cooling and/or heating plants may include standard equipment manufacturer's control logic along with optional, enhanced energy-efficiency control logic. These specialized control systems can be based on different architectures such as distributed controls, programmable logic controllers, or microprocessor-based systems. Beyond standard control technology, the following control points and strategies may be needed for primary equipment, ancillary equipment, and the overall system:

- Discharge temperature and/or pressure
- Return distribution medium temperature
- Head pressure for refrigerant and/or distribution medium
- Stack temperature

- Carbon monoxide and/or carbon dioxide level
- Differential pressures
- Flow rate of distribution medium
- Peak and hourly refrigeration output
- Peak and hourly heat energy output
- Peak and hourly steam output
- Flow rate of fuel(s)
- Reset control of temperature and/or pressure
- Night setback
- Economizer cycle
- Variable flow through equipment and/or system control
- Variable-frequency drive control
- Thermal storage control
- Heat recovery cycle

See Chapter 41 of the 2007 *ASHRAE Handbook—HVAC Applications* for more information on control strategies and optimization.

The **coefficient of performance (COP)** for the entire chilled-water plant can be monitored and allows the plant operator to determine the overall operating efficiency of a plant. Central plant COP can be expressed in the following terms:

- Annual heating or refrigeration per unit of building area (Btu per hour per square foot per year)
- Energy used per unit of refrigeration (kilowatt-hours per ton)
- Annual power required per unit of refrigeration per unit of building area (kilowatts per ton per square foot per year)

### Instrumentation

All instrument operations where cooling or heating output are measured should have instrumentation calibration that is traceable to the National Institute of Standards and Technology (NIST).

The importance of local gages and indicating devices, with or without a facility management system, should not be overlooked. All equipment must have adequate pressure gages, thermometers, flow meters, balancing devices, and dampers for effective performance, monitoring, and commissioning. In addition, capped thermometer wells, gage cocks, capped duct openings, and volume dampers should be installed at strategic points for system balancing. Chapter 37 of the 2007 *ASHRAE Handbook—HVAC Applications* indicates the locations and types of fittings required. Chapter 14 of the 2005 *ASHRAE Handbook—Fundamentals* has more information on measurement and instruments.

## MAINTENANCE MANAGEMENT SYSTEMS

A review with the end user (owner) should be done, to understand the owner's requirements for operation (e.g., if an owner has an in-house staff, more frequent access may be required, which may affect the extent to which a designer incorporates access). Reviewing ASHRAE *Guideline* 4 and *Standard* 15 with the owner can provide insight to the development of a maintenance plan. If maintenance is outsourced as required, extensive access may not be as high a priority. In some cases, regulatory and code access may be the only determining factors.

Operations and maintenance considerations include the following:

- Accessibility around equipment, as well as above and below when applicable, with minimum clearances per manufacturers' recommendations and applicable codes
- Clearances for equipment removal
- Minimizing tripping hazards (e.g., drain piping extending along the floor)
- Adequate headroom to avoid injuries
- Trenching in floor, if necessary
- Cable trays, if applicable
- Adequate lighting levels
- Task lighting, when needed
- Eyewash stations for safety
- Exterior access for outside air supply and for exhaust
- Storage of mechanical and electrical parts and materials
- Documentation storage and administrative support rooms
- Proper drainage for system maintenance
- Outlets for service maintenance utilities (e.g., water, electricity) in locations reasonably accessible to equipment operators
- Adequate lines of sight to view thermometers, pressure gages, etc.
- Structural steel elements for major maintenance rigging of equipment

Typical operator maintenance functions include cleaning of condensers, evaporators, and boiler tubes. Motor electrical testing such as annual megohm testing should be considered. Cooling tower catwalk safety railing and ladders should be provided to comply with U.S. Occupational Safety and Health Administration (OSHA) requirements.

## BUILDING SYSTEM COMMISSIONING

Because a central plant consumes a major portion of the annual energy operating budget, building system commissioning is imperative for new construction and expansion of existing installations. During the warranty phase, central-plant performance should be measured, benchmarked, and course-corrected to ensure design intent is achieved. If an energy analysis study is performed as part of the comparison between decentralized and centralized concepts, and/or life-cycle comparison of the study is part of a Leadership in Energy and Environmental Design (LEED®) project, the resulting month-to-month energy data should be a good electronic document to benchmark actual energy consumption using the measurement and verification plan implementation.

Ongoing commissioning or periodic recommissioning further ensures that the design intent is met, and that cooling and heating are reliably delivered after the warranty phase. Many central systems are designed and built with the intent to connect to facilities in a phased program, which also requires commissioning. Retro- or recommissioning should be considered whenever the plant is expanded or an additional connection made to the existing systems, to ensure the original design intent is met.

Initial testing, adjusting, and balancing (TAB) also contribute to sustainable operation and maintenance. The TAB process should be repeated periodically to ensure levels are maintained.

When completing TAB and commissioning, consider posting laminated system flow diagrams at or adjacent to the central cooling and heating equipment, indicating operating instructions, TAB performance, commissioning functional performance tests, and emergency shutoff procedures. These documents also should be filed electronically in the central plant computer server for quick reference.

Original basis of design and design criteria should be posted as a constant reminder of design intent, and to be readily available in case troubleshooting, expansion, or modernization is needed.

As with all HVAC applications, for a maintainable, long-term design success, building commissioning should include the system training requirements necessary for building management staff to efficiently take ownership and operate and maintain the HVAC systems over the useful service life of the installation.

## REFERENCES

ASHRAE. 1993. Preparation of operating and maintenance documentation for building systems. *Guideline* 4-1993.

ASHRAE. 2007. Safety standard for refrigeration systems. ANSI/ASHRAE *Standard* 15-2007.

Related Commercial Resources