EFFICIENT USE OF HEATING, VENTILATING, AND AIR CONDITIONING SYSTEMS IN BUILDINGS

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Summary

Space heating and cooling comprise the majority of energy end-use consumption in buildings. This article describes the main energy-consuming systems used for heating, ventilating, and air conditioning (HVAC) in both residential and commercial buildings; namely chillers, chilled-water systems, cooling towers, air conditioning units, heat pumps, packaged terminal air conditioners, boilers, and furnaces. The primary energy-efficiency opportunities for each family of equipment are then highlighted. Typical opportunities related to improved operation and maintenance practices include better insulation of systems, pipes, and ducts, careful monitoring of equipment settings and outlet conditions, and cleaning of heat transfer surfaces. Equipment retrofit and replacement measures include the installation of high efficiency units, variable speed drives, improved controls, thermal energy storage equipment, and heat recovery equipment.

1. Introduction

Space conditioning of buildings, particularly in industrialized countries, accounts for a large portion of building energy use. The breakdown of energy use for heating, ventilation, and cooling vary considerably with season, climate, building characteristics and use, and economic conditions. For example, northern areas have higher heating demands, while southern areas require more cooling. In addition, while well-insulated buildings may need minimal heating and cooling, they may require a larger portion of forced ventilation. For residential buildings, the space conditioning needs typically arises from the exterior environment; in contrast, internal loads (e.g., lights, people, computers) usually dictate space cooling requirements in commercial buildings. In poorer areas of the world, active space cooling may be an unattainable luxury. Therefore, heating is often accomplished by burning wood, and cooling and ventilation occur naturally. Buildings designed to optimize passive space conditioning can go a long way toward reducing worldwide energy use.

According to the US Office of Technology Assessment, in 1989 space conditioning comprised 55% of building primary energy use in the residential sector, and 48% in the commercial sector. For residential buildings, 84% of the space conditioning energy was consumed by heating systems, and 16% by cooling systems. Commercial buildings had a smaller share of energy consumed by heating systems, with 67% for heating and 33% for cooling. Data from the mid-1990s indicate that space heating accounted for a larger portion of energy use: more than 90% in the residential sector, and about three-quarters in the commercial sector. As mentioned earlier, climate, seasonal weather conditions, and other factors influence end-use values substantially.

This article addresses the main types of energy-consuming equipment for heating, ventilating, and air conditioning (HVAC), with the exception of electric resistance heaters. Though electric resistance heaters have high first-law efficiencies, they have very low second-law efficiencies, and are generally not considered to be efficient for space heating (see *Efficient Use and Conservation of Energy*, which contains detailed explanations of first- and second-law efficiencies.) The types of equipment treated here are chillers and chilled-water systems, cooling towers, air conditioning units, heat pumps, packaged terminal air conditioners, boilers, and furnaces. The primary energy-efficiency opportunities associated with each type of space conditioning equipment are presented.

2. Chillers and Chilled-Water Systems

Chillers are used for space cooling, and are typically applied to larger buildings. In commercial buildings the space conditioning requirements are often driven by the internal loads, such as lights, equipment, and people, rather than by the external environment alone. In the residential sector, external conditions usually dictate the space conditioning requirements. As a result, space cooling accounts for a larger share of HVAC energy use in the commercial sector than in the residential sector. For example, as mentioned earlier, cooling represented about one-third of HVAC energy in the commercial sector and about 16% in the residential sector, in the United States in 1989. Because of its importance to commercial buildings, space-cooling technology (particularly chillers and chilled-water systems) has undergone considerable advancements in energy efficiency. The purpose of this section is to discuss current chiller systems, and energy-efficiency advancements and opportunities. This is accomplished in two parts: the first part describes basic chiller and chilled-water system operation, and the second part provides a summary of the main energy-efficiency opportunities associated with chillers and their corresponding systems.

2.1. Description of Equipment

A chilled-water system provides cooling by extracting energy (i.e., heat) from a building and transferring this energy to the outside environmental, generally through a cooling tower. A diagram of a basic chilled-water system with a single chiller is shown in Figure 1. The chilled-water system comprises three main elements:

- chiller
- chilled-water loop
- condenser-water loop.

The chiller is typically packaged and supplied by the manufacturer as a single skid-mounted unit. The chiller contains the condenser and evaporator components that are connected in the field to the condenser- and chilled-water loops, respectively. The chilled-water loop connects the chiller to the building and includes a chilled-water pump, miscellaneous piping, and an air-handling unit. The condenser-water loop connects the chiller to the cooling tower, and includes a condenser pump and miscellaneous piping.

A variety of energy sources can be used to drive the chiller cycle (e.g., electricity, natural gas, diesel fuel, or steam). Electric, gas, steam, and other types of chiller all represent alternative methods of producing the chilled water. Each type may be used as the chiller element in Figure 1. Regardless of chiller type, the components and functions of the chilled-water loop and condenser cooling-water loop remain the same.

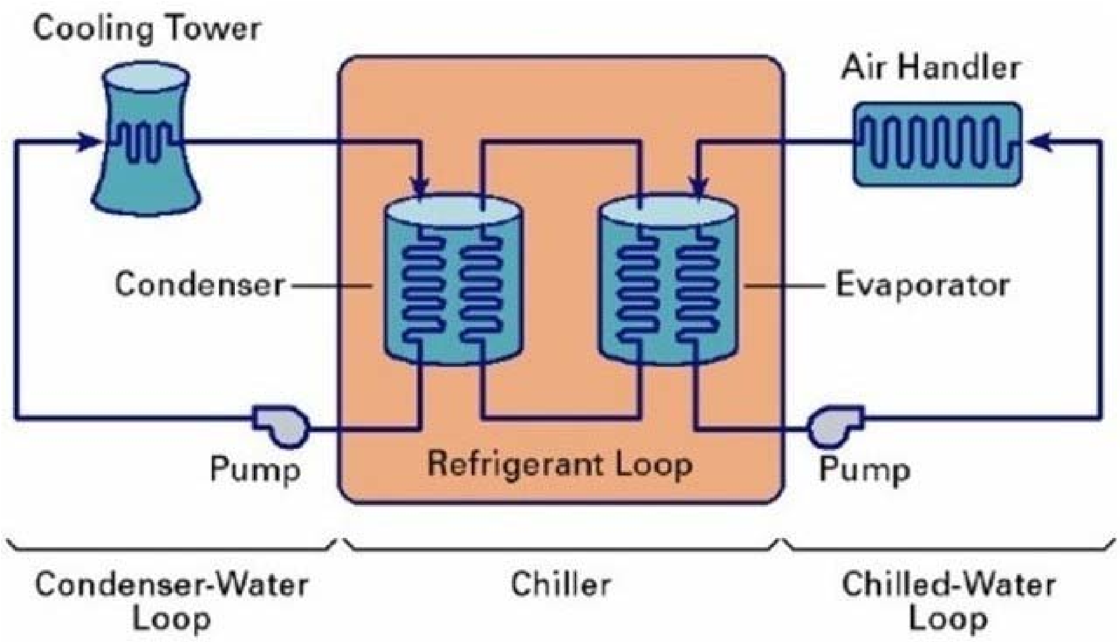

Figure 1. Chilled-water system

2.1.1. Chillers

Electric chillers: Electric chillers use a vapor compression refrigeration cycle, also known as a two-phase mechanical refrigeration cycle, for transferring heat. A diagram for a typical water-cooled electric chiller is shown in Figure 2. The chiller includes an electric motor, a refrigeration compressor, a condenser, an evaporator, an expansion valve, and controls.

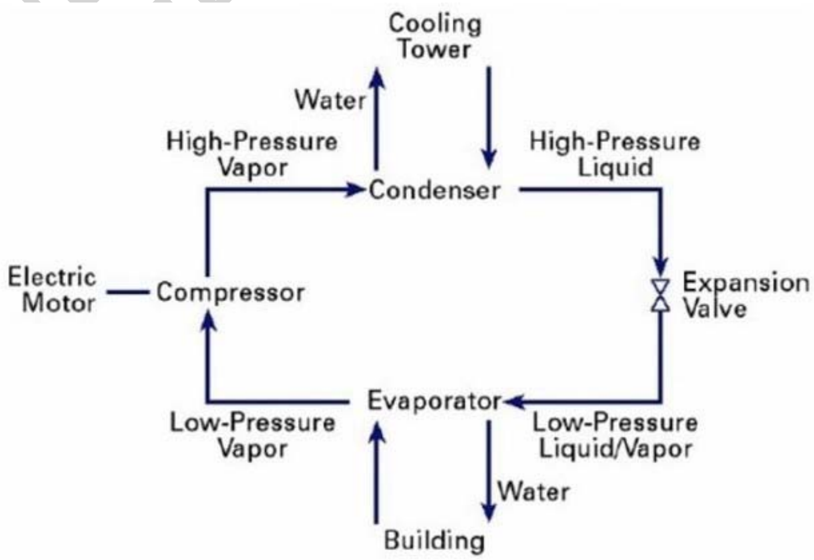

Figure 2. Electric chiller diagram

For smaller chillers (up to 250 tons), an air-cooled condenser is often used rather than a water-cooled arrangement as shown in Figure 2. (Note: 1.0 ton of cooling is equivalent to 12 000 Btu per hour, or 3.517 kW.) Air-cooled condensers use one or more fans, instead of a cooling tower, to cool the hot refrigerant vapor. For an air-cooled system, the condenser and fan(s) are typically supplied as a single unit and located remotely from the chiller. Similarly, evaporative condensers can replace the cooling tower and condenser-water loop.

The electric chiller vapor compression cycle operates in the following manner (items in Figure 2 correspond to the following explanations):

1. The compressor is used to compress the low-pressure refrigerant vapor to a high-pressure vapor. An electric motor powers the refrigeration compressor.
2. The high-pressure refrigerant vapor is cooled and condensed to a high-pressure liquid in the condenser. The condenser removes heat from the refrigerant and rejects it through a condenser cooling-water loop to the cooling tower.
3. An expansion valve or pressure reducer is used to lower the pressure of the liquid refrigerant that passes into the evaporator.
4. In the evaporator, the low-pressure liquid refrigerant vaporizes, removing heat from the chilled water. The low-pressure refrigerant vapor then returns to the compressor inlet.

Gas-fired absorption chillers: Absorption chillers are based on an absorption, or heat-activated, thermodynamic cycle. A two-component fluid is circulated in the absorption cycle. One component, the refrigerant, is alternately absorbed and desorbed from the second component, the absorbent. Two common fluid pairs are water (refrigerant) with lithium bromide (absorbent) and ammonia (refrigerant) with water (absorbent).

The absorption process occurs in a section of the chiller referred to as the absorber, and the desorption step occurs in a section referred to as the generator. Absorption chillers include condenser and evaporator sections much like electric chillers (see Figure 2). However, absorption chillers can include additional condenser sections that are combined with additional generator sections. Each set of generators and condensers is referred to as an effect. In general, chiller efficiencies improve with additional effects. Single-effect and double-effect absorption chillers are in common use, and triple-effect and quadruple-effect absorption chillers are also now available. These machines are expected to have significantly higher efficiencies than existing single-and double-effect chillers. For comparison, triple-effect machines are anticipated to have efficiencies, as expressed in terms of coefficient of performance (COP), of 1.5 or greater. This efficiency indicates that these machines will be on the order of three times more efficient than single-effect machines (typical COP near 0.5) and approximately 50% more efficient than double-effect chillers (typical COP near 1.0).

Heat is added, either directly or indirectly, to the generator to desorb the refrigerant. Direct-fired chillers use a natural gas-fired burner to provide heat, and indirect-fired units use hot water, steam, or waste heat.

Gas engine chillers: Gas engine-driven chillers are based on vapor compression refrigeration cycles. A natural gas-fired internal combustion engine is used to power the compressor. With the exception of the gas engine and its ancillary components and controls, gas engine-driven chillers are similar in design and operation to electric chillers. The description of the vapor compression presented in Figure 2 is also applicable to gas engine-driven chillers, with substitution of a gas engine for the electric motor. In addition, the basic components of a gas engine-driven chiller are similar and include refrigerant, compressor, gas engine drive, condenser, pressure reducer, evaporator, and controls. The engine and compressor components are generally mounted on a single skid, although for large chillers the engine components may be mounted on a separate skid.

Gas engine-driven chillers typically use natural gas-fired, spark-ignited, internal combustion engines. Both naturally aspirated and turbo-assisted models are in use. Natural gas-fired engines are available from a variety of manufacturers in sizes from 50 hp to 2000 hp (where 1 hp is equivalent to 0.746 kW). Both automotive-derivative gas engines and industrial gas engines are in use.

Gas engine-driven chillers are usually larger and heavier than electric chillers of the same capacity. Weight, size, noise, and vibration considerations may limit installation options. Ventilation must be provided to control radiated heat from the engine and exhaust systems. The engine jacket cooling water must be cooled; this is generally accomplished using an air-cooled radiator. In some cases, energy may be recovered from the cooling water and used for other purposes.

Exhaust silencers or mufflers are required, and sound-dampening enclosures may be necessary. Depending on local air-quality regulations, lean-burn engines or catalytic converters may be required to meet emission levels for carbon monoxide, nitrogen oxides, and hydrocarbons. When speed-control packages are used, the installation of automatic air-to-fuel ratio control packages may be necessary to maintain low emission levels over the entire range of loads and engine speeds.

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Biographical Sketch

Clark W. Gellings's 30-year career in energy spans from hands-on wiring in factories and homes to the design of lighting and energy systems to his invention of "demand-side management" (DSM). He coined the term DSM and developed the accompanying DSM framework, guidebooks, and models now in use throughout the world. He provides leadership in EPRI, an organization that is second in the world only to the US Department of Energy (in US dollars) in the development of energy-efficiency technologies. He has demonstrated a unique ability to understand what energy customers want and need, and then implement systems to develop and deliver a set of R&D programs to meet the challenge. Among his most significant accomplishments is his success in leading a team with an outstanding track record in forging tailored collaborations—alliances among utilities, industry associations, government agencies, and academia—to leverage R&D dollars for the maximum benefit. He has published 10 books, more than 400 articles, and has presented papers at numerous conferences. Some of his many honors include seven awards in lighting design and the Bernard Price Memorial Lecture Award of the South African Institute of Electrical Engineers. He has been elected a fellow in the Institute of Electrical and Electronics Engineers and the Illuminating Engineering Society of North America. He won the 1992 DSM Achiever of the Year Award of the Association of Energy Engineers for having invented DSM. He has served as an advisor to the US Congress Office of Technical Assessment panel on energy efficiency, and currently serves as a member of the Board of Directors for the California Institute for Energy Efficiency.