# Cooling Systems and Equipment

This section gives a brief description of the system and equipment types under consideration in the study. Definition of the equipment types is also provided

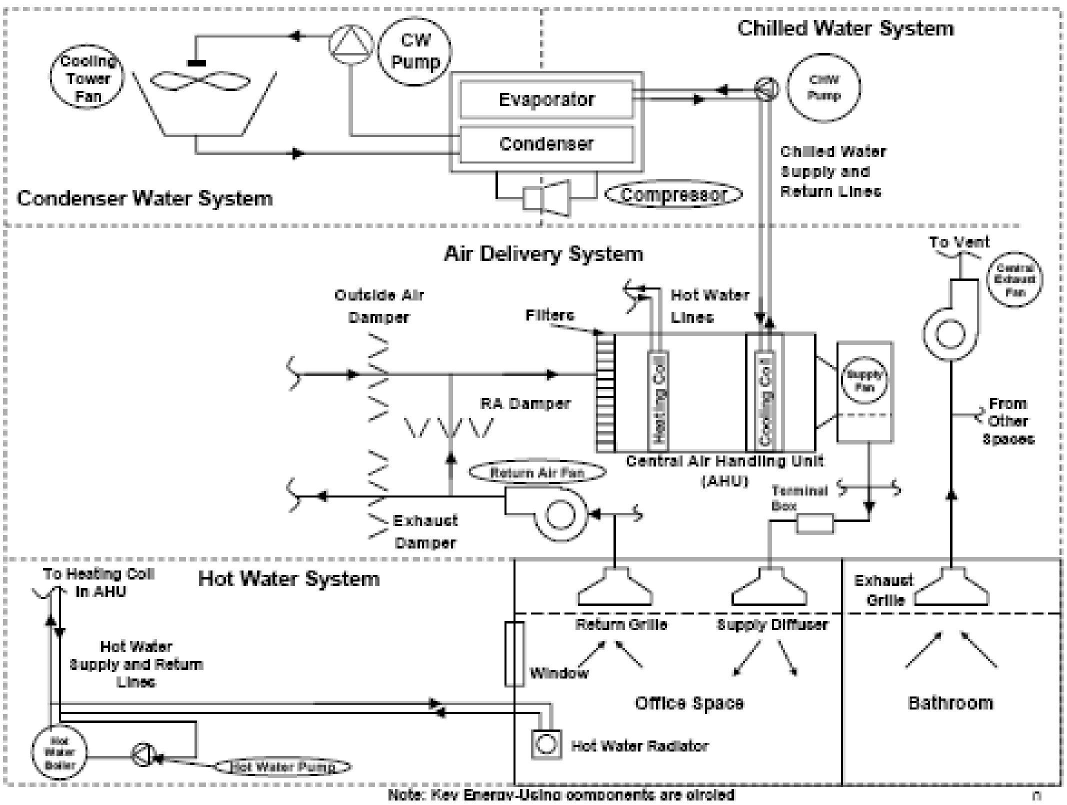
## 1. Cooling System Types

Air-conditioning system types in commercial buildings are broken down into three broad categories for the purposes of this study: central, packaged, individual AC and uncooled. Central systems are defined as those in which the cooling is generated in a chiller and distributed to air-handling units or fan-coil units with a chilled water system. Packaged systems include rooftop units or split systems which have direct-expansion cooling coils, with heat rejection remote from the cooled space. Individual AC systems involve self-contained packaged cooling units, which are mounted in windows or on an external wall such that cooling occurs indoors and heat rejection occurs outdoors. Uncooled buildings of interest are heated but not cooled.

### *1.1 Central Systems*

Central systems are defined as any HVAC systems which use chilled water as a cooling medium. This category includes systems with air-cooled chillers as well as systems with cooling towers for heat rejection. Heating in these systems is often generated in a boiler and is distributed in hot water or steam piping.

A central system serving office space is depicted below. The system is broken down into three major subsystems: the air-handling unit, the chilled water plant, and the boiler plant.



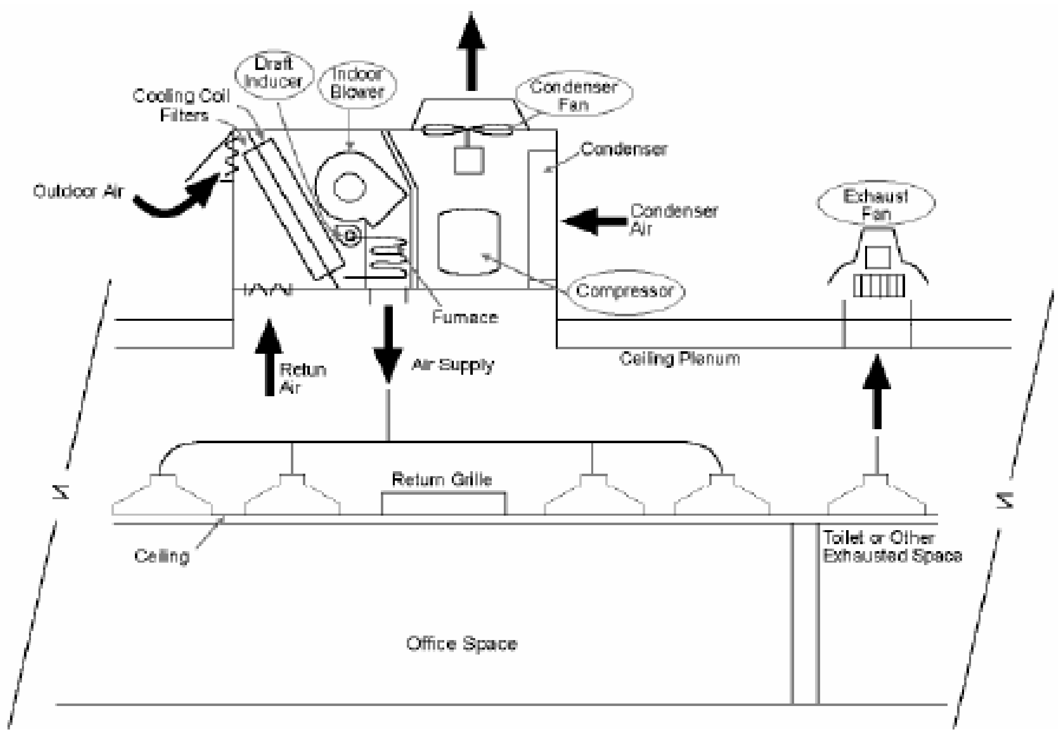

*Schematic of a Central System with a Water-Cooled Chiller*

The air-handling unit conditions and supplies air to the conditioned space. Air is taken by the unit either from outside or from the space itself through a return air system. The three dampers are controlled to mix the air according to the chosen control strategy. When the temperature of outdoor air is lower than that of the return air, it is more economical to use the outdoor air for cooling of the building than to circulate return air (this is called economizing). When the outdoor air is warmer than return air, or when the outdoor temperature is very low, a minimum amount of outdoor air will be mixed with the return air in order to provide fresh air ventilation for removal of indoor contaminants such as carbon dioxide. The air is filtered and conditioned to the desired temperature (the air may require preheating rather than cooling, depending on outdoor conditions).

Preheating and cooling are done with heat exchanger coils which are supplied with a heat exchange medium, typically steam or hot water for heating, and chilled water for cooling. Air flow to the conditioned space may be controlled, as in the case of a variable air volume (VAV) system, with a terminal box containing a valve for modulating air flow. The air is finally delivered to the space through a diffuser, whose purpose is to mix the supply air and the room air. The terminal box may or may not have a reheat coil, which provides additional heat when the space does not need to be cooled or needs less cooling than would be delivered by supply air at the terminal box's minimum air quantity setting. Air leaves the conditioned space either through the return system, or through the exhaust system. In many installations, the ceiling plenum space is used as part of the return ducting in order to save the cost of return ductwork. The chilled water system supplies chilled water for the cooling needs of all the building's air-handling units. The system includes a chilled water pump which circulates the chilled water through the chiller's evaporator section and through the building. The system may have primary and secondary chilled water pumps in order to isolate the chiller(s) from the building: the primary pumps ensure constant chilled water flow through the chiller(s), while the secondary pumps deliver only as much chilled water as is needed by the building. The chiller is essentially a packaged vapor compression cooling system which provides cooling to the chilled water. The chiller rejects heat either to condenser water (in the case of a water-cooled chiller) or to ambient air (in the case of an air-cooled chiller). For a water-cooled chiller, the condenser water pump circulates the condenser water through the chiller's condenser, to the cooling tower, and back. The cooling tower rejects heat to the environment through direct heat exchange between the condenser water and cooling air. Some of the condenser water evaporates, which enhances the cooling effect, allowing the return water temperature to be close to the ambient wet bulb temperature, which is below the ambient dry bulb temperature (except in 100% relative humidity conditions). For an air-cooled chiller, condenser fans move air through a condenser coil.

### 1.2 Packaged Systems

Packaged systems include both unitary systems such as rooftop units, and split systems. It includes cooling-only units as well as heat pumps. These are systems which do not used chilled water as an intermediate cooling medium. The cooling is delivered directly to the supply air in a refrigerant evaporator coil. Packaged units have either a gas furnace or an electric resistive heating coil for heating, or they are designed as heat pumps (in which the refrigeration system pumps heat from the outdoors into the building), or they have no heating.




*Schematic of a Packaged System*

The above shows a rooftop unit used for cooling an office. Again, air is circulated from the conditioned space through the unit and back. Rooftop units can use outdoor air for cooling when outdoor temperature is cool enough, using the outdoor and return dampers to mix the air. The air moves through a filter, through the cooling coil (evaporator), through the indoor blower, through a furnace coil, and is supplied to the space through ductwork and supply diffusers. Some air is pulled from the space through exhaust fans. Cooling for the unit is again provided by a vapor compression cooling circuit. However, cooling is delivered directly to the supply air, and the heat is rejected in a condenser coil directly to the ambient air.

A condensing unit, consisting of the refrigerant compressor, the condensing coil, and the condensing fan, is located externally. The indoor unit, consisting of the evaporator and indoor blower, is located near or in the conditioned space. Inclusion of a furnace or provision for intake of outdoor air will depend on proximity of the indoor unit to the outside.

### *1.3 Individual Room Air Conditioning*

Individual room air conditioning includes window AC units, packaged terminal air-conditioners (PTAC’s), packaged terminal heat pumps (PTHP’s), and water-loop heat pumps (WLHP's). Window AC units similar to those used in residences are frequently used in commercial applications for reduced installation cost. PTAC’s or PTHP’s are used primarily in hotels, motels and offices. The unit is mounted on an external wall, and a hole in the wall provides access to outdoor air, which is used for ventilation, heat rejection, and heat pumping (for the PTHP).

Water loop heat pumps (also called California heat pumps) are similar to PTHP’s except that water piped to the unit takes the place of the outdoor air. This allows more flexibility in placement of the unit, allows pumping of heat from warm to cool parts of the building through the circulated water loop, but requires installation of the water loop system. The water loop requires a cooling tower and a boiler for heat rejection or addition when the building thermal loads do not balance.

## 2. Heating System Types

Heating system types can be classified fairly well by the heating equipment type. The heating equipment used in commercial buildings includes the following types.

- District Heating
- Boilers (Oil and Gas)
- Furnaces (Oil, Gas, and Electric)
- Packaged HVAC Unit Furnaces (Gas and Electric)
- Packaged Heat Pumps
- Unit Heaters
- Packaged Terminal Heat Pumps
- Individual Space Heaters

District heating and boiler-based heating systems have steam and/or water piping to distribute heat. The heating water may serve preheat coils in air-handling units, reheat coils, and local radiators. Additional uses for the heating water are for heating of service water and other process needs, depending on the building type. Some central systems will have steam boilers rather than hot water boilers because of the need for steam for conditioning needs (humidifiers in air-handling units) or process needs (sterilizers in hospitals, direct-injection heating in laundries and dishwashers, etc.) For furnaces, either in heating-only units or in packaged units, the heat is distributed with ductwork. Most rooftop units use draft inducing fans to move combustion products through the furnace coil. Some larger units use forced draft fans which push combustion air into the furnace. Heat can also be provided by resistance electric heat or by the vapor compression circuit (operating as a heat pump). The remaining heating units heat the space directly and require little or no distribution. These include unit heaters, packaged terminal heat pumps, water-loop heat pumps and individual space heaters.

## 3. Further System and Equipment Description and Definition

Some equipment types provide both heating and cooling. This is shown in the table. For instance the heat pumps of the cooling equipment group are the same heat pumps in the heating equipment group. Other equipment types do not have the same heating/cooling relationship. For instance, boilers can be used for heating in buildings with chillers, packaged AC, or room AC for cooling, or in buildings with no cooling.

## Equipment Type Summary

| SPACE CONDITIONING SYSTEM TYPE[1] | COOLING EQUIPMENT | HEATING EQUIPMENT |
|---|---|---|
| Central<br>• Constant Air Volume<br>• Variable Air Volume<br>• Fan-Coil Units | Central Chiller<br>• Rotary Screw<br>• Reciprocating<br>• Absorption<br>• Centrifugal | See Note 2 |
| Packaged | Heat Pump | Heat Pump |
| | Packaged Air-Conditioning Unit | Packaged Unit |
| | Residential-Type Central Air-Conditioner | |
| Individual | Packaged Terminal Heat Pump | Packaged Terminal Heat Pump |
| | Water Loop Heat Pump | Water Loop Heat Pump |
| | Packaged Terminal Air Conditioner | See Note 2 |
| | Room Air-Conditioner | See Note 2 |
| Not Cooled | NONE | See Note 2 |
| | See Note 3 | Unit Heater |
| | | Boiler |
| | | District Heating |
| | | Furnace |
| | | Individual Space Heater<br>• Radiant<br>• Baseboard (electric) |

**Baseboard:** A type of heating distribution equipment in which either electric resistance coils or finned tubes carrying steam or hot water are mounted behind shallow panels along the bottom of a wall. Baseboard heating distribution equipment relies on passive convection to distribute heated air in the space. Electric baseboards are an example of an Individual Space Heater. (See Electric Baseboard and Individual Space Heater.) Finned-tube baseboard heaters require boilers to heat the steam or water used in them. Systems using these heaters are classified under the “Boiler” category.

**Boiler:** A type of space-heating equipment consisting of a vessel or tank where heat produced from the combustion of such fuels as natural gas, fuel oil, or coal is used to generate hot water or steam. Many buildings have their own boilers, while other buildings have steam or hot water piped in from a central plant. For this study, only boilers inside the building (or serving only that particular building) are included in the “Boiler” category. Steam or hot water piped into a building from a central plant is considered district heat.

**Central Chiller:** A type of cooling equipment that is centrally located and that produces chilled water in order to cool air. The chilled water is then distributed throughout the building by use of pipes. These systems are also commonly known as “chillers.” The two major categories of chillers are "water-cooled" and "air-cooled". "Water-cooled" chillers use water to transport away the heat rejected in their condensers. The water (called "condenser water") is cooled in a cooling tower. "Air-cooled" chillers have condensers which are cooled with ambient air.

**Constant Air Volume (CAV):** A classification of HVAC equipment for which the air flow rate is constant. The main system air supply fan operates only at a single speed, thus the delivered air flow rate is constant. This system operation is in contrast to the Variable Air Volume (VAV) system operation, which allows variation in the supply air flow.

**District Chilled Water:** Water chilled outside of a building in a central plant and piped into the building as an energy source for cooling. Chilled water may be purchased from a utility or provided by a central physical plant in a separate building that is part of the same multibuilding facility (for example, a hospital complex or university). For the purposes of this study, buildings with district chilled water are considered part of the “Central Chiller” category.

**District Heat:** Steam or hot water produced outside of a building in a central plant and piped into the building as an energy source for space heating or another end use. The district heat may be purchased from a utility or provided by a central physical plant in a separate building that is part of the same multibuilding facility (for example, a hospital complex or university.) District heat includes district steam and/or district hot water.

**Electric Baseboard:** An individual space heater with electric resistance coils mounted behind shallow panels along the bottom of a wall. Electric baseboards rely on passive convection to distribute heated air to the space.

**Evaporative Cooler (Swamp Cooler):** A type of cooling equipment that turns air into moist, cool air by saturating the air with water vapor. It does not cool air by use of a refrigeration unit. This type of equipment is commonly used in warm, dry climates. This equipment category is not considered separately in this study because of its limited importance on a national basis.

**Fan-Coil Unit:** A type of heating and/or cooling unit consisting of a heating or cooing coil and a fan for air circulation. Fan-coil units have thermostatically controlled built-in fans that draw air from a room and then carry the air across finned tubes containing hot water, steam, or chilled water. The hot water, steam, or chilled water can be produced by equipment within the building or can be piped into the building as part of a district heating or cooling system.

**Furnace:** A type of space-heating equipment with an enclosed chamber where fuel is burned or electrical resistance is used to heat air directly without steam or hot water. The heated air is then distributed throughout a building, typically by air ducts.

**Heat Pump:** A type of heating and/or cooling equipment that draws heat into a building from outside and, during the cooling season, ejects heat from the building to the outside. Heat pumps are vapor-compression refrigeration systems whose indoor/outdoor coils are used reversibly as condensers or evaporators, depending on the need for heating or cooling. Different categories of heat pumps include Single-Package, Split-System, Packaged Terminal Heat Pumps, and Water Loop Heat Pumps (see definitions for these equipment types). For the purposes of this study, the category "Heat Pumps" includes only Single-Package and Split-System heat pumps. A separate category is used for the other two heat pump types.

**Individual Air Conditioner:** A type of cooling equipment installed in either walls or windows (with heat-radiating condensers exposed to the outdoor air). These self-contained units are characterized by a lack of pipes or duct work for distributing the cool air; the units condition only air in the room or areas where they are located. For this study, Packaged Terminal Air Conditioners, Packaged Terminal Heat Pumps, Water Loop Heat Pumps, and Room Air Conditioners are considered part of the "Individual Air Conditioner" Category.

**Individual Space Heater:** A type of space heating equipment that is a free-standing or a self-contained unit that generates and delivers heat to a local zone within the building. The heater may be permanently mounted in a wall or floor or may be portable. Examples of individual space heaters include electric baseboards, electric radiant or quartz heaters, heating panels, gas- or kerosene-fired or electric unit heaters, wood stoves, and infrared radiant heaters. These heaters are characterized by a lack of pipes or duct work for distributing hot water, steam, or warm air through a building.

**Packaged Unit:** A type of heating and/or cooling equipment that is assembled at a factory and installed as a self-contained unit. Packaged units are in contrast to engineer-specified units built up from individual components for use in a given building. This equipment differs from individual air conditioning or heating equipment in that air ducts are used to move the conditioned air to and from the unit. Some types of electric packaged units are also called "Direct Expansion," or DX, units. For this study, the "Packaged Unit" category represents units which provide heating and cooling, including Single-Package Rooftop Units and Split Systems. The category includes Residential-Type Central Air Conditioners, which can be configured either as single-package or split systems. Heating for these units is provided either by an integrated gas furnace or integrated electric resistance heat.

**Packaged Air-Conditioning Unit:** A *packaged unit* used for cooling. The unit may also be used for heating, typically with gas or electric resistance heat. The two main categories of packaged air-conditioning units are Rooftop Units and Split Systems.

**Packaged Terminal Air Conditioner (PTAC):** A single-package air-conditioning unit which requires no thermal distribution ductwork or piping. It is mounted in an external wall to have access to the outside air to provide cooling for the condenser. The unit may also provide heating with integrated electric resistance heat. For the purposes of this study, PTAC's are classified as Individual Air Conditioners, and not as Packaged AC Units.

**Packaged Terminal Heat Pump (PTHP):** An equipment type similar to a PTAC whose vapor compression cooling system serves as a heat pump as well as an air conditioner.

**Radiator:** A type of heating distribution equipment that is usually visibly exposed within the room or space to be heated. It transfers heat from steam or hot water by radiation to objects within visible range and by conduction to the surrounding air, which, in turn, is circulated by natural convection.

**Reheating Coils:** A part of some air-conditioning systems, they are electric coils in air ducts used primarily to raise the temperature of circulated air after it was over cooled to remove moisture.

**Residential-Type Central Air Conditioner:** A type of cooling equipment in which there are four basic parts: (1) a condensing unit, (2) a cooling coil, (3) ductwork, and (4) a control mechanism, such as a thermostat. CBECS95 mentions two basic configurations of residential central systems: (1) a "split system," where the condensing unit is located outside and the other components are inside, and (2) a packaged-terminal air-conditioner (PTAC) that both heats and cools, or only cools. The second system contains all four.components encased in one unit and is usually found in a "utility closet." For this study, the second system is considered part of the "PTAC" category.

**Room Air Conditioner:** A subcategory of "Individual Air Conditioner" which mounts in a window or an exterior wall opening. This type of equipment, also known as Window Air Conditioner, is used mostly in residential applications, but is also present in commercial applications.

**Unit Heater:** A heating unit typically mounted near the ceiling in which air is heated by blowing it across a heating coil. The heated air is directed at the area to be heated, typically with manually adjustable louvers. Unit heaters can be heated with gas, oil, electricity, hot water, or steam. For this study, the "Unit Heater" category does not include equipment heated with steam or hot water, since buildings with such systems have boilers to generate heat and they are included in the "Boilers" category.

**Variable Air-Volume (VAV) System:** An HVAC conservation feature usually referred to as "VAV" that supplies varying quantities of conditioned (heated or cooled) air to different parts of a building according to the heating and cooling needs of those specific areas.

**Water Loop Heat Pump (WLHP):** A packaged heat pump which uses a water coil for condenser cooling during air-conditioning operation and for evaporator heat input during heat pump operation. Water is piped to the heat pump, allowing it to be located in internal spaces. The water circulated in the building's water loop is typically cooled in a cooling tower and heated with a boiler as required depending on the net load. This type of HVAC system allows heat to be transferred from one part of the building to another depending on the need. For instance, during the winter, the heat generated in the interior of a large building can be transferred to the perimeter for heating, thus resulting in minimal net heating load.

## 4. Cooling Equipment and System Design Trends

Major recent trends in cooling equipment design include the following:

- Packaging of equipment and continued pursuit of smaller size
- Refrigerant compressor developments including scroll and screw compressors
- Advances in heat exchanger technology
- Response to IAQ and control technology advances.

There has been a long-term trend towards packaging of HVAC systems. This trend is driven by the need to reduce installed cost and reduce system installation time. Mass-produced packaged designs that perform adequately to well in their range of applications have made central air-conditioning affordable for many establishments which would have used room air-conditioners or no cooling in the past. This trend continues today as large manufacturers strive to design "all-purpose" packaged systems (unitary, packaged terminal AC and heat pumps, packaged chillers, etc.). Recent environmental concerns have enhanced this trend with a push for no-leakage refrigerant circuits. The refrigerant circuits of packaged units can easily be leak-checked at the factory to assure minimal leakage over the product life.

One example of the packaging trend is the move towards air-cooled chillers. Air-cooled chillers are at present surpassing water-cooled chillers in terms of units shipped. They also have some advantages over traditional water-cooled units. They are easier to install and maintain, which means a lower first cost than water-cooled. Water-cooled units require cooling towers, which can breed Legionnaire's Disease if not properly maintained. These advantages in many cases outweigh some of the disadvantages of air-cooled chillers, including larger size and generally higher energy use. It is projected that air-cooled chiller sales will continue to exceed that of water-cooled chillers.

Another manifestation of the push for smaller equipment is the introduction of ductless AC units. These systems, initially developed by Japanese manufacturers, have not yet had much exposure in the US market. With these systems, thermal distribution is done with refrigerant rather than with air, significantly reducing the space taken by the distribution system. Evaporator units similar to conventional fan coil units provide cooling within the building. The systems can be set up with multiple evaporators connected to each outdoor condensing unit, thus making the system suitable for larger buildings. On an energy basis, these systems can provide savings over conventional rooftop AC systems. However, their installed cost is higher in today's market, partly due to currently low demand and unfamiliarity with the concept.

The most significant recent trend in refrigerant compressor technology for air-conditioning applications is the commercialization of the hermetic scroll compressor. This technology, initially patented in 1905 and eventually developed in the 1970's and commercialized in the 1980's, has gained significant market share in small and medium-sized packaged systems and air-cooled chillers. The commercialization of the technology was made possible in part by the advent of Computer-Numerically-Controlled (CNC) machining, which makes finish machining of the scroll economical. The capacity range of these compressors continues to be extended, with vendors developing compressors up to 30 tons capacity. The benefits claimed for scroll technology include superior noise and vibration characteristics, reduced size (especially footprint), improved reliability, lower "applied" cost (the cost of the entire system including the compressors), and improved efficiency. Currently, scroll compressors are offered by most packaged air-conditioning unit manufacturers in high-efficiency units, while most standard-efficiency units in the commercial size range still use reciprocating compressors. In larger-tonnage systems, capacity modulation is provided by use of multiple scroll compressors (semi-hermetic reciprocating compressors used cylinder unloading for modulation). The use of multiple compressors and the development of larger units allows scroll technology to be used over the entire capacity range traditionally dominated by hermetic and semi-hermetic reciprocating compressors. Future development will likely focus on further extension of the capacity range, development of HFC-refrigerant scroll compressors, and development of modulating scroll compressors.

In medium-capacity packaged systems and chillers, (50-100 tons) the rotary screw compressor has established dominance over the past decade, replacing large semi-hermetic reciprocating compressors. Screw compressors also compete with centrifugal compressors in the 150 to 300 ton range. As with the scroll, automated CNC-machining has made this technology economical to manufacture. Many of the same performance benefits have been claimed for screw compressors: lower noise and vibration, smaller size, and improved reliability. Capacity modulation is achieved in screw compressors with various mechanical devices which delay closing of the working volume to the suction port. Over the past five years, some manufacturers have begun to offer hermetic screw compressors with integrated oil separators, which simplifies the integration of the compressor into air-conditioning products, putting the burden of oil-handling on the compressor manufacturer, and also reduces refrigerant leakage potential. Current development is addressing redesign for HFC refrigerants.

Centrifugal compressors were redesigned in the early 1990's for non-CFC refrigerants. The conversion from CFC refrigerants has helped to open the door to screw compressors for chiller applications less than 300 tons in size. Formerly centrifugal chillers using CFC-11 could be sized down to 100 tons. Manufacturers have designed chillers for use with medium and high pressure refrigerants with smaller-diameter higher-speed centrifugal compressors which can be sized down to 200 tons in capacity. Further efficiency gains have been possible through the use of turbines or expanders. These devices replace the throttle used in the conventional refrigerant cycle with an energy recovering device, increasing total cycle efficiency roughly 5%. Manufacturers have put increased focus on part-load efficiency, with the introduction of variable-speed drives, improved inlet-guide vane capacity control and variable-geometry diffusers. Further, the introduction of microprocessor control with advanced sensors has improved the capability of chillers to allow reduced chilled water flow when the load is low, which reduces part-load pumping power. The most significant change in heat exchanger technology for packaged air-conditioning units is the now widespread use of enhanced surfaces on both air-side and refrigerant-side surfaces. Rifled tubes and lanced or wavy fins are now fairly standard. These improvements to the traditional fin-and-tube heat exchanger technology have improved its effectiveness, allowing use of smaller condensers and evaporators, thus reducing equipment size. The potential for further improvement in heat exchanger technology lies in microchannel heat exchangers, such as the Parallel-Flow™ technology, developed initially by Modine for the automotive air-conditioning industry. Microchannel heat exchangers generally have smaller face area and significantly less depth than an equivalent-performance fin-and- tube heat exchanger. However, the traditionally higher cost of microchannel technology, particularly for stationary air-conditioning sizes and production volumes, has prevented their successful introduction for stationary products. In the future, more emphasis will be placed on microchannel heat exchanger technology for this application, as Modine and other manufacturers focus on this market. However, it is too soon to tell whether this technology will take significant market share from conventional fin/tube heat exchanger designs.

Brazed-plate heat exchangers have made significant inroads in applying enhanced surfaces to refrigerant/liquid heat exchanger applications (i.e., in chillers). A brazed plate heat exchanger consists of formed sheet metal plates which are sandwiched together to create a compact heat exchanger core. Alternating cavities of the core are filled with refrigerant and water, the manifolding structure at the edges establishing the internal flow arrangement. Brazed plate heat exchangers can be significantly smaller than conventional shell and tube designs. The same general heat exchanger geometry is used in plate-fin heat exchangers, which are used for liquid/liquid or steam/liquid heat exchange in HVAC systems. These units, which also are replacing shell and tube heat exchangers, are bolted together rather than brazed. This feature allows them to be disassembled for cleaning. Advances in manufacturing capabilities has allowed both of these technologies to become practical.

Increased concern regarding indoor air quality has been affecting HVAC system and product design. The increases in the required outdoor air quantities used for ventilation have led to the development of Energy Recovery Ventilators and increased use of Makeup Air units dedicated to the provision of the ventilation requirements. Energy Recovery ventilators use a passive total energy recovery wheel to exchange heat and moisture between incoming makeup air and conditioned building air which is being vented, thus reducing the energy cost impact of fresh air ventilation. Makeup air units, with or without energy recovery, provide the required fresh air to a space, allowing 100%-recirculation units within the space to provide the needed internal cooling. The benefits of this system approach include easy verification of delivery of the required fresh air, simplified and improved control of space temperatures, and energy savings. An in-depth study of total Energy Recovery and related energy-saving technologies is provided in Desiccant Dehumidification and Cooling Systems. Total energy recovery wheels should continue to gain increased acceptance, as lower-cost designs are developed, equipment and systems are designed to take advantage of their potential, and knowledge of how to install and maintain them properly increases. Other technologies have also been proposed to achieve energy recovery, for instance heat pipes, which have less pressure drop than energy recovery wheels, thus incurring less fan power penalty, but don't transfer latent heat. Another approach to enhancing an air-conditioning unit's ability to treat the make-up air incorporates an additional vapor compression circuit which transfers heat from the make-up air to the exhaust air. This approach also involves less heat exchanger pressure drop than energy recovery wheels and it allows greater transfer of heat than heat pipes. The concerns over IAQ will likely result in more innovative HVAC system and product design concepts, with emphasis on verification of delivery of required air quantities and mitigation of the associated energy costs. The general downward trend in electronics costs has resulted in the introduction of microprocessor control for many HVAC products. This trend will continue, allowing improved control and monitoring capability in all equipment types. Improved low-cost sensors will allow more advanced control schemes to become possible and cost effective, such as enthalpy-based economizer control (use of outdoor air for cooling) or control of excess latent cooling. Wireless controls will be developed which will further decrease the cost of advanced or even basic control functions. For instance, retrofit installation of a variable-capacity packaged AC unit will not require installation of new control wiring if a wireless thermostat can replace the conventional on/off thermostat.

## 5. Heating Equipment Design Trends

Major recent trends in heating equipment include the following:

- Continuing development of heat pumps
- Continued reduction in equipment size and development of modular heating equipment
- Efficiency improvements in combustion equipment leading to development of condensing equipment
- Development of radiant heating equipment
- Modulating and low-input heating equipment
- Improved emissions control

A number of important heat pump equipment categories have established themselves over the years: split-system residential heat pumps, single-package heat pumps, packaged terminal heat pumps, and water-loop heat pumps. While some early heat pumps had significant reliability problems and did not provide adequate heating when outdoor temperature dropped below freezing, significant improvements have been made. Even so, air-source heat pumps still require resistance backup heating for the coldest weather, and the lower air supply temperature (as compared with furnaces for example) still represents a comfort barrier for these units. Heat pumps have gained the most acceptance in southern regions, where the infrastructure for delivery of heating fuels is not as strong, and where the heating season is less demanding. Ground-source heat pumps have also been developed but have not yet established significant market share in the commercial sector due primarily to the high cost of the ground loop. Because of moderate and stable ground temperatures as ambient temperature varies, ground-source heat pumps have the potential for significant energy savings. Efforts have been mounted in recent years to improve the cost of the ground loop. This has been somewhat successful in the development of residential housing, where prefabricated plastic horizontal ground loops can be installed for tract housing projects at a modest cost. The cost of vertical ground loops has also improved recently, as drilling contractors gain more experience in the field. The success of this concept will depend both on reduction of installation cost and the importance of technical issues such as suitability of the ground in typical building locations, possible contamination of ground water, etc.. In addition to the electric-input heat pumps mentioned above, gas-fired heat pumps based on absorption and engine-driven vapor compression technology have also been developed.

These systems have significant potential for energy use reduction, but they are larger and much more expensive than conventional air-conditioners and heat pumps, and they have not gained significant market share. Continued development of these technologies could possibly reduce their costs to an acceptable level in future, but this represents a significant technical challenge.

The development of continually smaller equipment is no surprise to most observers of the HVAC industry. This trend is particularly pronounced in boilers, for which replacement units in commercial buildings can be one-quarter the size of the original boilers. The fire-tube boilers used more frequently in the past are being replaced with cast-iron sectional boilers with enhanced heat transfer surfaces and water-tube boilers. This reduction in size has been possible partly through the development of improved burners, which can fire larger amounts of fuel using less space for the flame. In most boilers, the refractory-lined firebox has been replaced with a firebox surrounded by heat transfer surface, thus saving space. There has been a push for reduction of water volume in the boiler in order to reduce standby losses, but this trend is mostly driven by the cost of the material, the cost of the space required for the equipment, and ease of installation. Similar size reductions have occurred with furnaces through the used of improved-design heat exchangers.

Size reduction has been accompanied also by the development of modular or multiple heating systems. With this concept, a number of small residential-sized boilers are ganged together to provide heating for a large commercial building. The fact that these systems use residential-style boilers has advantages in reduced cost, easier service, and typical higher efficiencies of these boilers. Multiple or modular boilers also have advantages in easier installation, especially in retrofit applications, due to the small size of each component boiler and good adaptability to a range of heating system configurations and design operating conditions. Finally, failure of one of the boilers does not leave the building without heat. In spite of the potential for good energy savings due to the inherently good part load efficiency of a multiple boiler system, many of these systems are installed in a way that results in inferior efficiency. Because these boilers generally use a natural draft combustion system, standby losses can be large. In systems where the boilers are installed without flue dampers or isolation valves or some other means to reduce the standby loss for non-firing boilers, the potential energy benefits are not realized. In addition to reduction of equipment sizes, significant improvements in furnace and boiler efficiency have been made over the past 2 to 3 decades. Again, this is partly the result of improved burner technology and partly the result of improved heat exchanger design. The limits of non-condensing operation have been reached (efficiency percentages in the low 80’s for gas and the high 80’s for oil). Condensing boilers and furnaces have also been developed, with efficiencies up to the low 90’s. These are based primarily on gas rather than oil, due to the corrosive nature of sulfur-based compounds in the flue gas of oil-fired products. The natural extension of the push for higher efficiency is the development of direct-contact boilers, where the flue gas makes direct contact with the boiler water. While heaters of this type have been developed, their practicality must still be proven for commercial building heating. Another extension of the condensing heater is the wet recuperator concept, developed by Dunkirk, and currently available for residential-size boilers. With this technology, the condensed gases are evaporated into the burner makeup air, thus enhancing the ability of the recuperator to cool the flue gases prior to leaving the boiler. The concept is most beneficial for boilers, since dramatic cooldown of flue gases is possible without wet recuperation in furnaces.A new system technology which is worth mentioning, but is more important for residential heating is the combination system, which combines water heating and space heating. A water heater is used for both purposes, and the heated water is distributed in a hydronic heating system which doubles as the hot water distribution piping. This concept has the potential for significant cost reduction in heating/hot water systems. However, it is still fairly new and unproven, and the concept does not provide any clear energy advantages. Infrared or radiant space heaters have the potential for energy savings because they heat people directly, allowing for space temperature reduction without compromising comfort. Infrared space heaters come in three varieties: Low intensity, high intensity, and electric. Low intensity commercial units are gas-fired tube heaters (where the flame is blown down the length of a tube), with a range of 20,000-250,000 MBtuh and 90̄F maximum surface temperature. High intensity units are gas-fired tile heaters (where the flame ignites a ceramic plate), with a similar capacity range as low-intensity units, but with a maximum surface temperature of 170̄F. Electric units are either type, and have a range of 5-30 kW (17,000-103,000 kBtu/hr) Electric units accounted for 9% of the infrared market in 1996. For the past several years, the gas-fired infrared heating market has grown between 11 and 13%, while the electric market has only grown 2.5%. The development of modulating and low-input furnaces and boilers is being pursued by a variety of organizations in an effort to improve comfort as well as efficiency. The on/off firing of furnaces has long been a detriment to occupant comfort. Development of modulating furnaces is an obvious solution, which is under intensive development currently. This concept will be integrated in packaged air-conditioning units, resulting in savings in fan power and gas for heating as well as comfort improvement. The challenge to widespread introduction of the technology will be minimization of the associated cost premium. Low-input boilers and furnaces are a subject more for the residential sector than the commercial sector. Such systems address the need to more closely match heating capacity to building loads. Attempts to develop burner technologies for oil systems which operate reliably under a 0.5 gph (70,000 Btu/hr input) firing rate have not been commercially successful. This technology will have to be successful in residential applications before its potential benefits will be important for the commercial sector.

Much development over the last decade has focused on reduction of emissions from fuel-fired heating equipment. This has been driven by the Federal Clean Air Act, which has Conversion Factor: 1 kW=3,412 Btu/hr. resulted in the need for low emissions equipment, particularly low NOx. In addition, there is a heightened concern regarding carbon monoxide emissions, either during normal equipment operation, or during failure modes resulting from poor installation or maintenance. Deaths resulting from CO poisoning have been well publicized, and a market has been created for CO detectors. Improved burner design and improved controls have contributed significantly to the reduction of emissions and improved robustness to failure modes which could result in CO generation. Continued development of burner technology and reduction in cost of advanced burner controls will help to increase heating system reliability, comfort, and efficiency as these technologies are brought to market.

## 5. Baseline Energy Use Estimates

This section describes the estimates of the HVAC cooling and heating equipment energy use, which were developed during this study. A fairly comprehensive description of the approach to the estimate is presented.

### 5.1 Overview

The energy use estimates developed in this study are "bottom-up" estimates based on building floorspace and per-sqft energy use for typical building systems. The estimates are “as-designed” estimates, which means that equipment is assumed to operate properly according to design intentions. For instance, modeling of chilled water systems does not allow for operation with reduced chilled water temperature to account for inadequate airflow in air handling units. Because the study takes an “as-designed” approach to energy estimates, the estimates are considered a conservative approximation of actual conditions. Unintended operation can result in increase or decrease in energy use. The magnitude of the uncertainty associated with the unintended operation is difficult to predict. It might be as much as 20% of overall estimates, but was not examined rigorously for this study. The baseline estimate starts with a segmentation of the commercial building stock floorspace by building type and region. These loads are the heating and/or cooling requirement for the building interior required to maintain space thermal conditions, not including the impact of fresh air ventilation, which represents an additional load. This set of load estimates, based on building models described in Reference 7, is the best and most complete space conditioning load database anywhere available for the commercial sector.

## Conclusion:

The main recommendations which emerge at this point are as follows.

1) One factor which was not addressed in depth in this study is the common discrepancy between intended and actual HVAC system operation. Quantification of the impact of this discrepancy is important, because it could represent a significant opportunity for improvement which may also be much more cost effective than introduction of new technology.

2) The packaged air-conditioning equipment category is the ripest for future development effort, due to the large importance of this equipment throughout the commercial sector. The low initial cost and ease of installation of systems based on packaged AC equipment make them very popular in today's HVAC market, for which first cost is perhaps the most important consideration. Development of packaged equipment with significant improvements in energy use, but with only modest cost increase and minimal size increase, have the potential to make a huge impact. Consideration of extension of seasonal rating of unitary equipment to the commercial equipment size range would improve awareness among equipment buyers of the actual energy impact of different equipment choices, which would represent one step towards convincing end-users to make the investment to buy more efficient HVAC systems.

3) Further study of potential energy saving options is necessary. Much work has been done in this area, and many of the claims are contradictory. The third study in this set will focus on energy saving opportunities in commercial HVAC systems, and attempt to clarify some of these opportunities.

## Reference:

http://www.eere.energy.gov