# Chillers, Refrigerant Compressors, and Heating Systems

Course# CV802

# Energy Consumption Characteristics of Commercial Building HVAC Systems

# Volume I:

# Chillers, Refrigerant Compressors, and Heating Systems

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# 1 EXECUTIVE SUMMARY

This report is the first volume of a three-volume set of reports on energy consumption in commercial building HVAC systems in the U.S. This first volume focuses on energy use for generation of heating and cooling, i.e. in equipment such as boilers and furnaces for `heating and chillers and packaged air-conditioning units for cooling. The second volume, already in print, focused on "*parasitic*" energy use or the energy required to distribute heating and cooling within a building, reject to the environment the heat discharged by cooling systems, and move air for ventilation purposes. The third volume in the set will address opportunities for energy savings in commercial building HVAC systems.

As mentioned above, this study focuses on the equipment and equipment components used to generate heating and cooling. It does not include fans and pumps, which are the topic of the Volume 2 report. This distinction is clear for most equipment types, such as unit heaters, boilers, and chillers. However, for packaged air-conditioning (AC) equipment the distinction can be subtle. Most packaged AC equipment is treated as a unit by performance rating procedures. Hence, separation of the fans is difficult. For this study, only the refrigerant compressors of packaged equipment are considered, due to arbitrary division of topics of the Volume 1 and Volume 2 studies. In some cases in this report, however, the fans of packaged equipment are included in order to allow comparison to other studies. This is pointed out in the text where necessary. The study was a bottom-up conservative estimate of commercial building HVAC energy use. According to this study, the total cooling energy use in commercial building HVAC systems, including the refrigerant compressors and chillers, accounts for about 1.4 quads of primary energy[1] use annually, while the total heating energy use in commercial building HVAC systems, including furnaces and boilers, accounts for about 1.7 quads of primary energy.

## 1.1 Study Objectives

The objectives of this study were:

- To provide an accurate estimate of the energy used by primary cooling and heating equipment in the US commercial building sector.
- To provide a physical understanding of the factors which contribute to energy use by the equipment.
- To provide a baseline estimate of current national energy use which can be used for calculation of the national energy savings impact of various options for reducing energy usage. The estimate is based on calendar year 1995.

[1] Conversion of site electricity use to primary energy is based on 11,005 Btu per kWh heat rate, which includes transmission and distribution losses.

## 1.2 Summary of Findings

The energy use estimates presented in this report have been developed using a rigorous bottom-up approach, which has not previously been used to estimate national primary equipment energy consumption. Distribution of the commercial building floorspace among building type, system type, and region was based largely on the 1995 Commercial Building Energy Consumption Survey (CBECS95, Reference 3). Models for cooling and heating loads were obtained from Lawrence Berkeley National Laboratory (LBNL) and were based on building models initially presented in Reference 7. Models of HVAC equipment design loads and operating characteristics were developed based on engineering calculations and product literature. Energy use estimates, for both heating and cooling, were developed representing the different building types, regions, system types, and equipment considered in the study. The results are considered to be conservative, because of insufficient available quantitative information regarding excess energy use associated with poor installation, operation, and/or maintenance of HVAC systems. Details regarding the calculation methodology are presented in Section 5. The results of the study are summarized below.

Figure 1-1 below shows the breakdown of cooling and heating energy use by equipment type. About half of the cooling energy is associated with Packaged AC (mostly Rooftop units). Packaged AC units consume an estimated 0.74 quads for cooling. The heating systems of these units consume 0.44 quads for heating (they are referred to as "Packaged Units" in the heating chart). In addition, 0.46 quads is associated with the supply and condenser fans of these units (Reference 9). These units contribute so much to national HVAC energy use primarily because they are used in a majority of the building types comprising a significant amount of floorspace (about 48% of 36 billion sqft cooled commercial floorspace.) The efficiencies of this equipment type are lower on average than those of other equipment types, particularly water-cooled chiller systems.

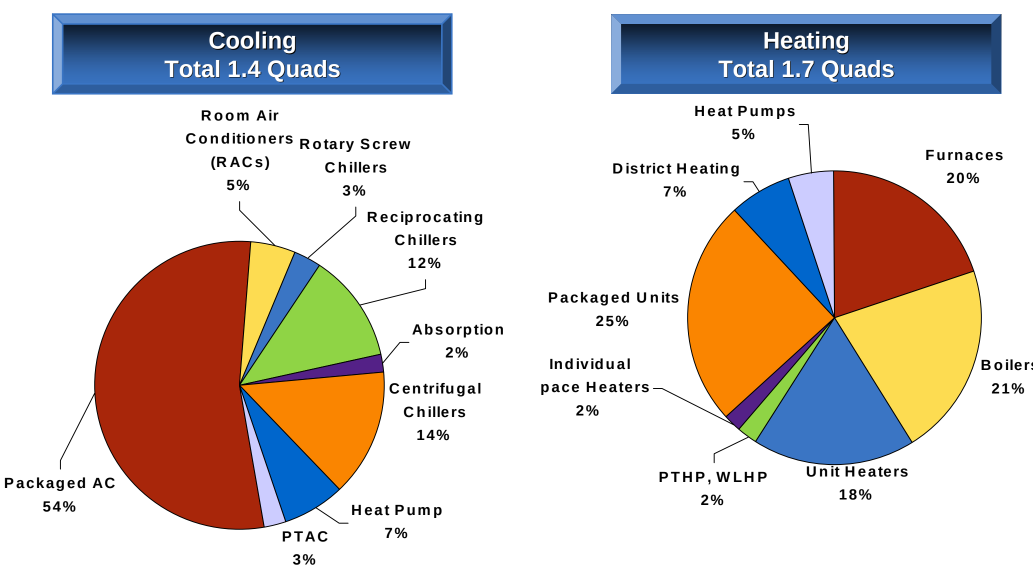



Figure 1-1: Primary Energy Use — Equipment Breakdown

The other cooling equipment types representing high energy use are centrifugal and reciprocating chillers. It is noteworthy that the energy use of centrifugal chillers, which have received much interest in recent years, is only about 14% of the total. Reciprocating chillers, which are typically smaller in size, are generally less efficient, in part because most of them are air-cooled (rather than water-cooled, which is typical for centrifugal chillers, and which allows condensing temperatures to approach ambient wet bulb temperatures). Floorspace for heating and cooling equipment is shown in Figure 1-2 below.

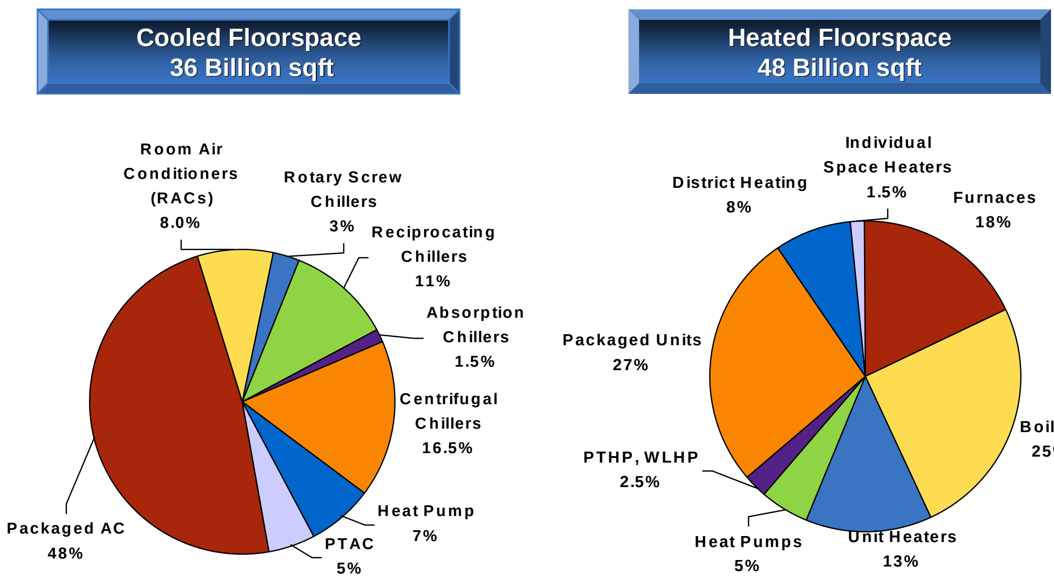
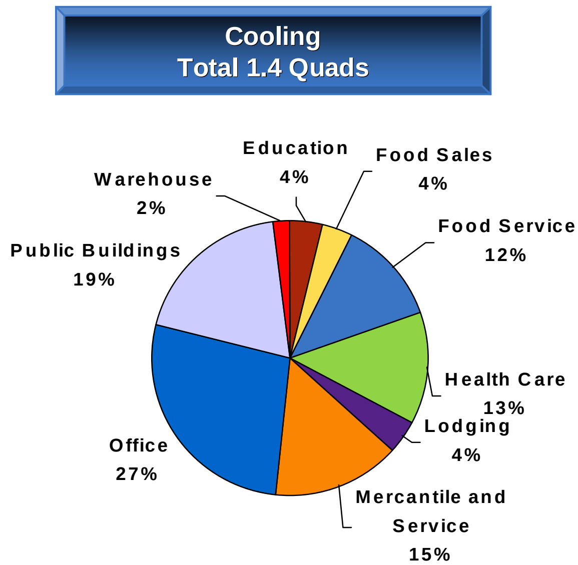



**Figure 1-2: HVAC Equipment Distribution**

The heating equipment types representing high energy use other than packaged units are furnaces, boilers, and unit heaters, representing 0.34, 0.36, and 0.31 quads respectively in commercial buildings.

The distribution of heating and cooling energy use by building type is shown in Figure 1-3 below. The building categories are identical to those used in the 1995 Commercial Building Energy Consumption Survey (CBECS95-Reference 3)[2]. The most energy use is in the Office, Mercantile & Service, and Public Building categories. These categories are large energy users due to their large floorspace in the commercial sector (they each represent at least 7 billion sq. ft.), and they each account for roughly 0.6 quads of heating and cooling energy use. The education category is noteworthy in that it has large floorspace but relatively modest combined cooling and heating energy use. The high energy use intensity of the food service and health care categories make these building types very important, particularly for cooling. Commercial building floorspace distribution by building is shown in Figure 1-4 for reference.

[2] The Building Category "Public Buildings" includes CBECS95 categories "Public Assembly", "Public Order and Safety", and "Religious Worship".



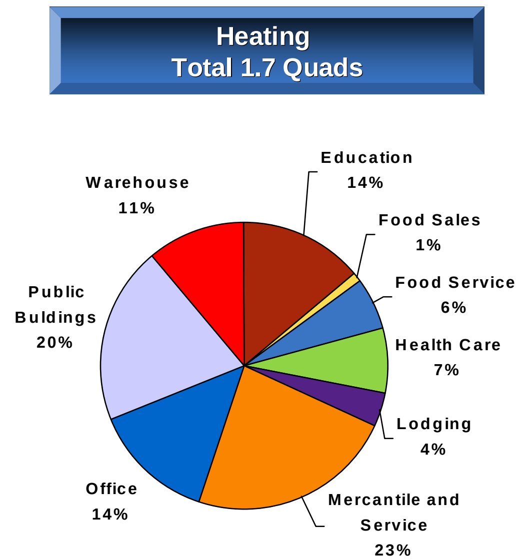




**Figure 1-3: Primary Energy Use - Building Type Breakdown**

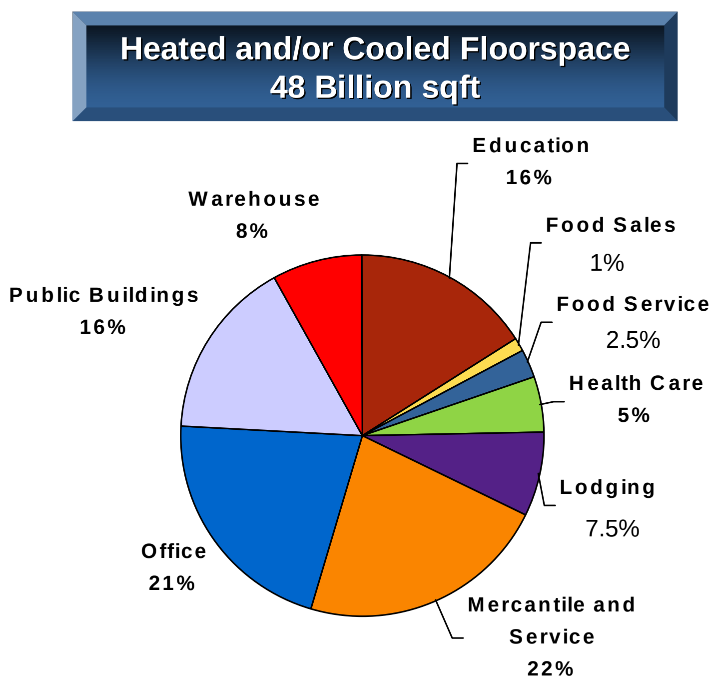



**Figure 1-4: Heated and Cooled Commercial Building Floorspace**

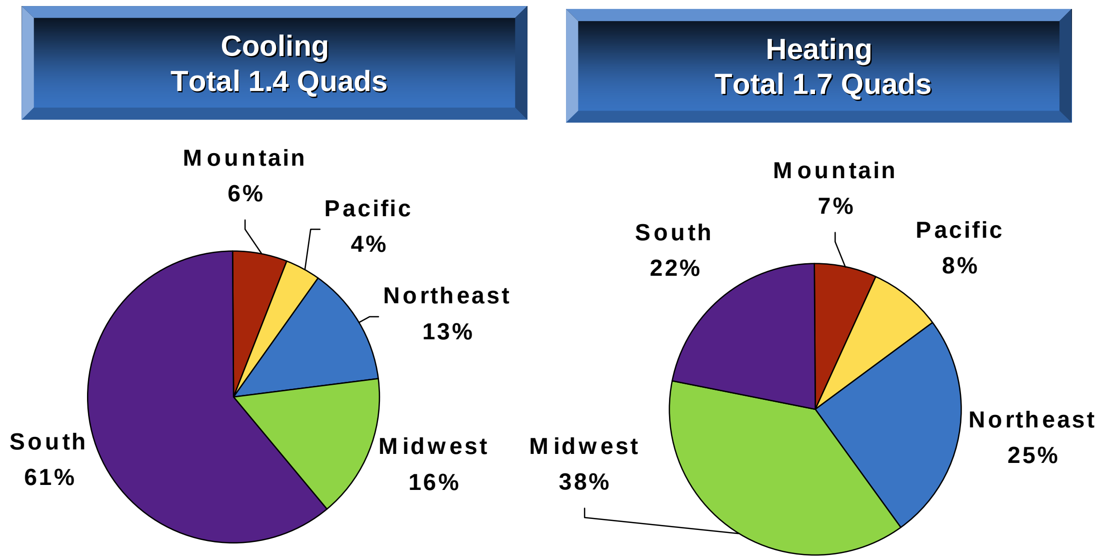



**Figure 1-5: Primary Energy Use -- Regional Breakdown**

The distribution of HVAC primary equipment energy use by geographic region strongly reflects climate as well as commercial building floorspace breakdown. The energy use distributions by region for both heating and cooling are shown in Figure 1-5. As expected, the South represents the highest energy usage for cooling. The Pacific region is notable in that it has low heating and low cooling energy use. The floorspace distribution by region is shown in Figure 1-6.

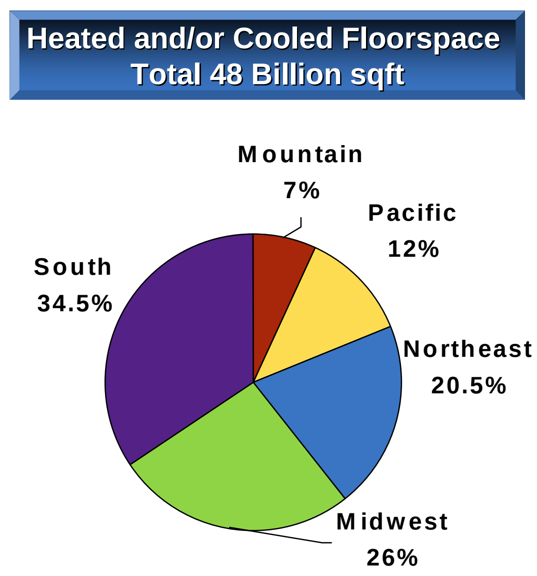



**Figure 1-6: Commercial Building Floorspace — Regional Breakdown**

Total HVAC Primary energy use is shown in Figure 1-7 distributed by building type and by region. These data include the heating and cooling energy of this study and also the HVAC parasitics energy of the Volume 2 Study (Reference 9). These results essentially reflect the results presented earlier.  In particular:

- The major energy-using building categories are Office, Mercantile and Service, and Public Buildings
- The South region represents the largest geographical energy use, in part because of large floorspace, but also because of high energy use for cooling. In addition, the more prevalent use of electric heat in this region as compared to other regions increases the impact of the South's heating energy use.

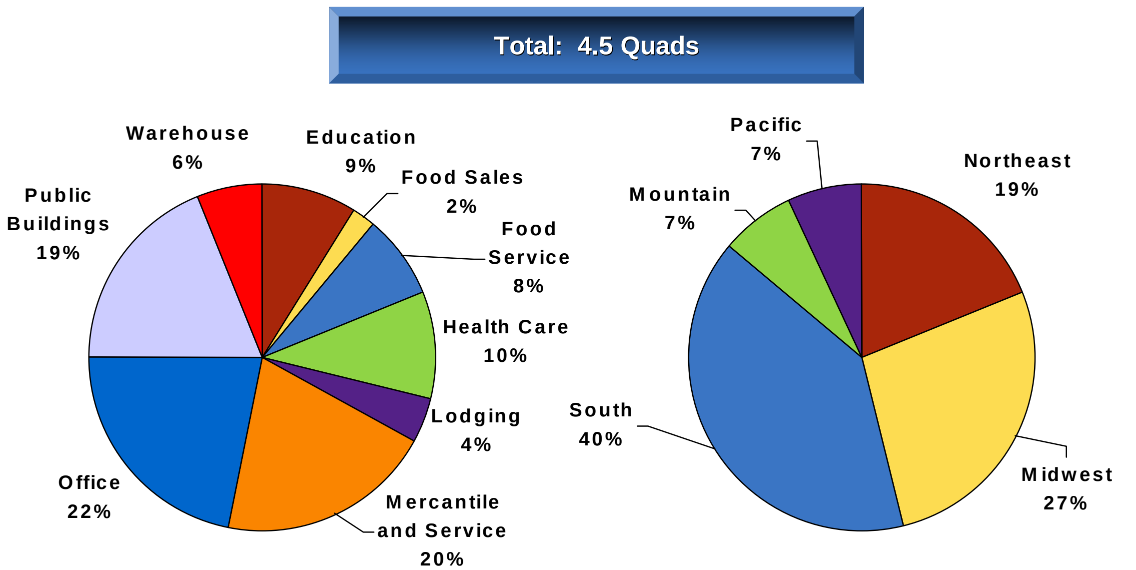



**Figure 1-7: Total HVAC Primary Energy Use**

# 2 INTRODUCTION

## 2.1 Background

Energy use for heating and air-conditioning accounts for more than 25% of the primary energy consumed in commercial buildings in the U.S. (EIA, Annual Energy Outlook 1998, Reference 1). Of the roughly 59 billion square feet of total commercial floorspace, about 82% is heated and 61% is cooled. Energy use for heating and cooling has long been a target for reduction efforts. In fact, significant efficiency improvements have been achieved over the years in these efforts. For example, the efficiency of a typical centrifugal chiller has increased 34% over the past 20 years (HVAC&R News, November 10, 1997, Reference 2). Energy use reductions have been achieved by the efforts of a wide range of players in the market, including manufacturers, contractors, specifying engineers, utilities, and government laboratories and agencies. In spite of these efforts, energy use for space conditioning remains a very large portion of the total national energy use picture and still provides significant opportunity for energy use reduction.

## 2.2 Study Approach and Scope

This report is the first of three volumes characterizing commercial HVAC energy use:

- Volume 1: Chillers, Refrigerant Compressors, Heating Systems – baseline equipment and current energy use.
- Volume 2: Thermal Distribution, Auxiliary Equipment, and Ventilation – baseline equipment and current energy use. This equipment consists primarily of fans and pumps.
- Volume 3: Assessment of energy savings options, identification of barriers to implementation, and development of programmatic options.

Work on these studies started with Volume 2 rather than Volume 1. Much of the background information regarding HVAC system types, market characterization, etc. is covered in more detail in Volume 2 for this reason. The calculation methodology of Volume 2 was also used as the basis for much of the estimates in this Volume 1. The reader is encouraged to refer to Volume 2 as required to supplement this report.

The work of these studies is a detailed examination of cooling and heating equipment in commercial buildings: system configurations; estimates of energy use; market characterizations; trends in system and equipment designs.

We examined a large range of commercial building types, including all of the building categories in the Department of Energy's Commercial Building Energy Consumption Survey (Reference 3). The building stock was further segmented by equipment type, by fuel type, and by geographic region. The tasks comprising the study were as follows:

### Equipment Characterization

Pertinent information about typical heating and cooling equipment for prototypical commercial buildings was obtained. This information was focused primarily on data required to estimate national HVAC energy use: equipment efficiency, sales numbers, percentage of buildings and floorspace served by particular equipment types, etc.

### Baseline Estimate of HVAC Cooling and Heating Equipment Energy Consumption

Annual site and primary energy use associated with the cooling and heating equipment for prototypical commercial buildings were estimated. Total US commercial sector primary energy use for HVAC cooling and heating equipment was estimated for the examined prototypical buildings and compared with estimates prepared by other investigators.

### Identification of Trends and Market Characterization

Issues and trends affecting cooling and heating equipment energy use were identified, along with drivers for these trends (i.e. IAQ, equipment costs, energy costs, controllability, etc.). The HVAC equipment design and selection process was described. The key decision makers have been identified, the equipment supply chain was described, and the most important purchase criteria were discussed. Much of this information is presented in detail in Volume 2.

### Industry Review

The draft final report was reviewed by eight HVAC industry representatives, including equipment manufacturers, A&E's, and ESCO's/utilities, and their comments have been taken into consideration in completing the final report.

## 2.3 Report Organization

This report is organized as follows:

Section 3 provides description of the cooling and heating systems and equipment which are the focus of this report.

Section 4 discusses trends in the HVAC equipment market which are affecting or could affect HVAC energy use in commercial buildings. Additional discussion of the HVAC market and trends is provided in the Volume 2 report (Reference 9).

Section 5 lays out the estimate of HVAC equipment energy use which was the major task of this study, discussing calculation methodology, underlying assumptions, and results. Some of the results of the Volume 2 study (Reference 9) are also presented in this section to give the full picture of HVAC energy use including fan and pump energy.

Section 6 gives our conclusions and recommendations.

Two appendices are included in this report.

Appendix 1 gives the commercial building floorspace segmentation which was used as a basis for national energy use estimates.

Appendix 2 provides data which were used as input for this study.

Additional detailed information which may be of interest is provided in the appendices of Volume 2 (Reference 9). In particular, these appendices include summaries of (a) the XenCAP™ data, which was used as input for the study, (b) the system modeling methodology, and (c) a series of interviews with HVAC industry representatives, which were used as input and background for these studies.

# 3 DESCRIPTIONS OF 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

## 3.1 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.

### *3.1.1 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 in Figure 3-1 below. The space which is conditioned by the system is in the lower right part of the figure. The system is broken down into three major subsystems: the air-handling unit, the chilled water plant, and the boiler plant.

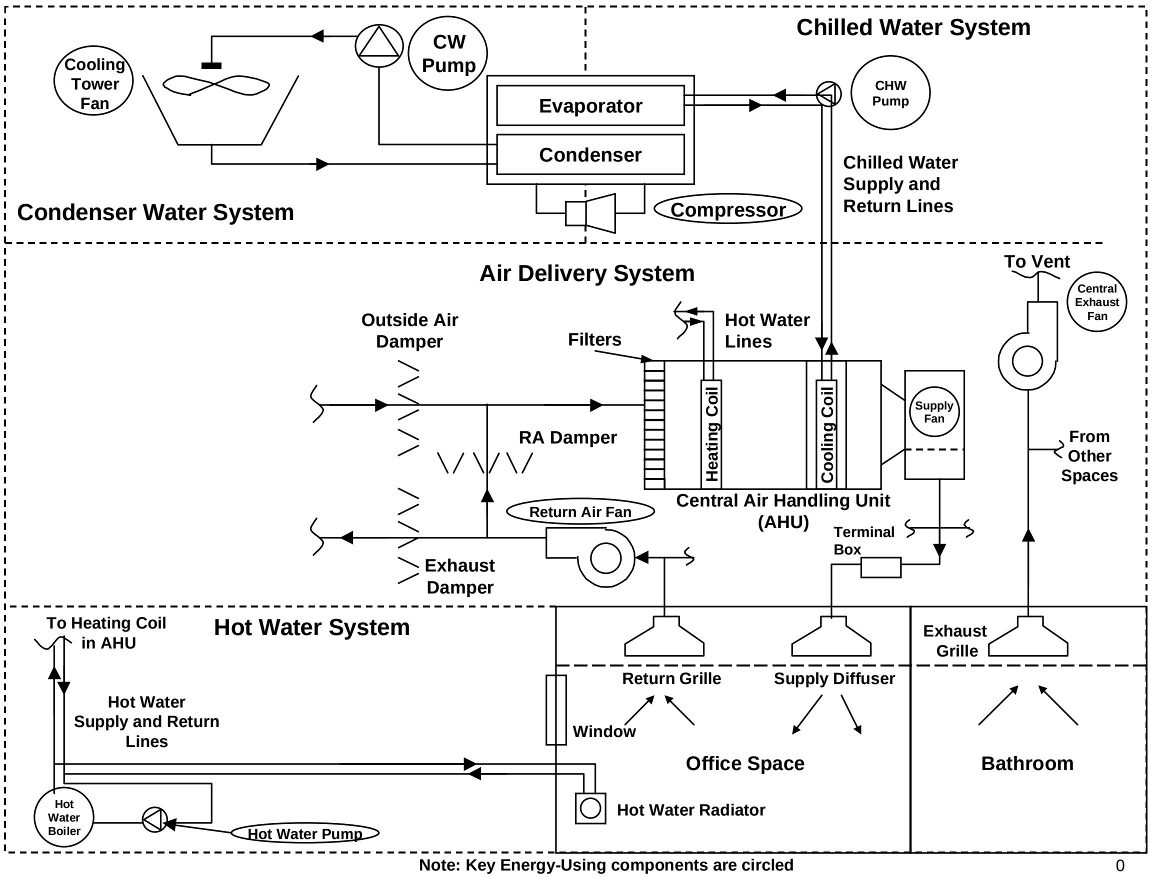



**Figure 3-1: Schematic of a Central System with a Water-Cooled Chiller**

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.  It also may have a fan (see further discussion in Section 5).  Constant air volume (CAV) systems, which are not allowed by energy codes in many applications, do not reduce air delivery rates and are dependent on reheat coils to control the delivered cooling.

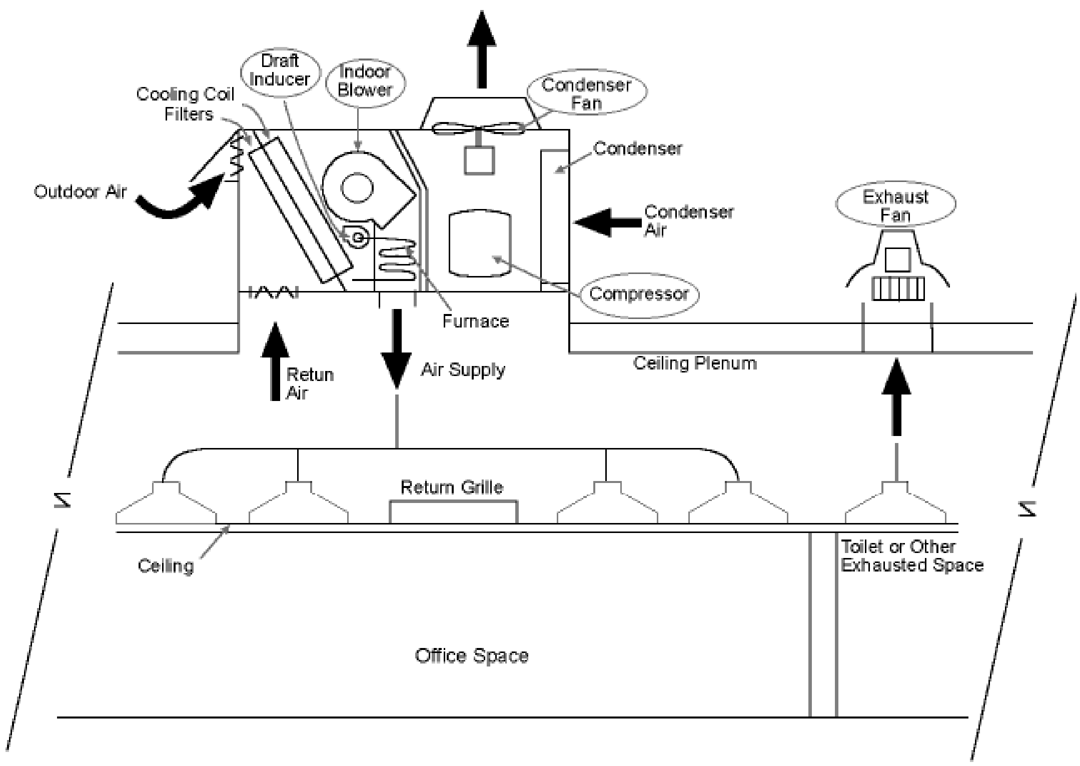
Air leaves the conditioned space either through the return system, or through the exhaust system.  In many installations, the ceiling plenum space is used as part of the return ducting in order to save the cost of return ductwork.

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 as shown in the figure) 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.

### *3.1.2 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.

A packaged system serving office space is depicted in Figure 3-2 below.




**Note: Power-using components are circled.**

**Figure 3-2: Schematic of a Packaged System**

The figure 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. The figure shows air being returned through the ceiling plenum. 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.

In a split system, the two sides of the unit shown in the figure are separated, with refrigerant piped between them. 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.

### *3.1.3 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.

## 3.2 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 system indicated in Figure 3-1 includes a boiler and a pump for circulating the heating water. 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. The same is true for packaged heat pumps. Heating for the rooftop unit in Figure 3-2 is provided with a furnace. 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.

### 3.3 Further System and Equipment Description and Definition

Relationships between the system types of the Volume 2 study (Reference 9) and the heating and cooling equipment types is illustrated in Table 3-1 below. 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.

**Table 3-1: 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) |

[1] According to the Volume 2 study (Reference 9), which focused on thermal distribution and auxiliary equipment.
[2] Various heating equipment types are used in buildings with these cooling systems and equipment
[3] These heating equipment types are not directly associated with any of the cooling equipment types or system types.

Equipment type definitions are provided below. The equipment type definitions are to a large extent adopted from the 1995 Commercial Building Energy Consumption Survey (Reference 3).

**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.

**Swamp Cooler:** See Evaporative Cooler (Swamp Cooler).

**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.

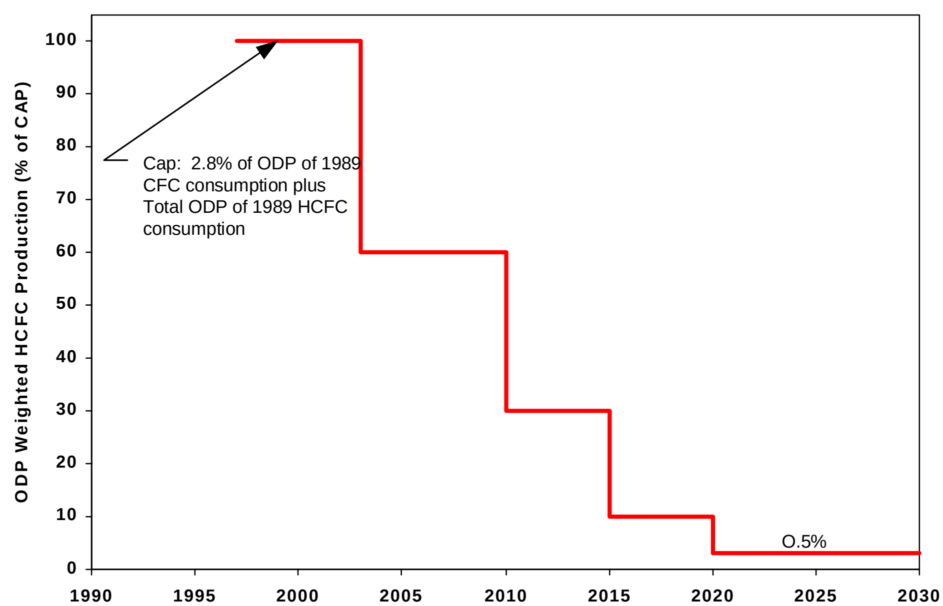
**Water Loop Heat Pump (WLHP):** A packaged heat pump which uses a water coil for condenser cooling during air-conditioning operation and for evaporator heat input during heat pump operation. Water is piped to the heat pump, allowing it to be located in internal spaces. The water circulated in the building's 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 MARKET TRENDS

A general discussion about the HVAC industry and associated trends is presented in the Volume 2 accompanying report (Reference 9). This section presents additional information which applies specifically to the equipment which is the focus of this report: chillers, the vapor compression systems of packaged and individual cooling equipment, and heating equipment.

## 4.1 Refrigerant Trends

The chlorofluorocarbons (CFC's) and hydrochlorofluorocarbons (HCFC's) used traditionally as the refrigerants in all types of air-conditioning equipment have been or will be phased out according to the Montreal Protocol. CFC's such as CFC-11, which was traditionally used in many centrifugal chillers, are no longer produced as of 12/31/95. Old CFC chillers have been replaced at an accelerated rate as a result. The phaseout schedule for HCFC's for developed countries is shown in Figure 4-1. The EPA has established a phaseout schedule for specific refrigerants to meet the overall Ozone Depletion Potential (ODP) reduction goals — for instance HCFC-141b will be phased out in 2003. A current list of the most common types of refrigerants used for different equipment types is shown in Table 4-1, as well as planned replacement refrigerants. HCFC-22 is one of the most important refrigerants, particularly for packaged and individual equipment. The newer refrigerants are hydrofluorocarbons (HFC's) or blends of HFC's.




ODP: Ozone Depletion Potential

**Figure 4-1: Montreal Protocol HCFC Phase-out Timetable**

**Table 4-1: Current and Future Refrigerants**

| Equipment Type | Traditional Refrigerant | Replacement Refrigerants |
|---|---|---|
| Rotary Screw- Chiller | HCFC-22 | R407C, HFC-134a |
| Scroll Chiller | HCFC-22 | R407C, R-410A |
| Reciprocating Chiller | HCFC-22 | R-407C, R-410A |
| Absorption Chiller | R-718 (water) | R-718 |
| Centrifugal Chiller | CFC-11, CFC-12 | HFC-134a, HCFC-123 |
| Packaged Air Conditioners | HCFC-22 | R-407C, R-410A |
| Heat Pump | HCFC-22 | R407C, R-410A |
| PTAC, PTHP | HCFC-22 | R-407C, R-410A |
| Room Air Conditioning | HCFC-22 | R-407C, R-410A |

As each refrigerant is changed, equipment performance may also change due to the refrigerants' differing thermal and physical properties. As shown above, most cooling equipment presently manufactured with HCFC-22 is being or will be altered to HFC-134a, R-410A, or R-407C (R-410A and R407C are blends of HFC refrigerants). The new refrigerants help combat the growing ozone depletion in the earth’s atmosphere, since they contain no chlorine. However, some of the newer refrigerants have a high global warming potential (GWP), which causes concern with environmentalists. As shown in Table 4-2 below, R-410A has a slightly higher GWP than its predecessor, HCFC-22. However, GWP impacts must not be evaluated without consideration of a refrigerant's efficiency and potential emissions rate, since most of the global warming generated by an HVAC system will be associated with $CO_2$ generated to supply its power demand rather than with the refrigerant emitted during the system life cycle. The concept of Total Warming Equivalent Impact (TEWI) is intended to reflect the full life cycle global warming impact of a refrigerant.

**Table 4-2: Environmental Impact and Performance of Refrigerants**

| Refrigerant | Global Warming Potential | Ozone Depletion Potential | Heat of Vaporization (Btu/lbm) |
|---|---|---|---|
| CFC-11 | 4000 | 1.0 | 81 |
| CFC-12 | 7100 | 1.0 | 65 |
| HCFC-22 | 1700 | 0.055 | 86 |
| HCFC-123 | 93 | 0.016 | 77 |
| HFC-134a | 1300 | 0 | 83 |
| R-407C | 1600 | 0 | 95 |
| R-410A | 1890 | 0 | 95 |
| R-290 (Propane) | ~20 | 0 | 159 |
| R-600a (Isobutane) | ~20 | 0 | 151 |
| R- 717 (Ammonia) | <1 | 0 | 536 |
| R-744 (Carbon Dioxide) | 1 | 0 | 94 |
| R-718 (Water) | 0 | 0 | 1070 |

In spite of the general trend of the US HVAC industry to adopt HFC's as replacement refrigerants, as described above, other alternatives have been considered, and are being more aggressively pursued in other countries, primarily because of the high direct global warming potential of HFC's. These alternatives are hydrocarbons, ammonia, and carbon dioxide. Hydrocarbons have thermal and physical properties similar to traditional refrigerants, but they are flammable. Debate has been ongoing regarding their use for HVAC applications. However, stationary cooling products are not being offered currently and there is strong opposition to their use, particularly in the U.S., for safety and liability reasons. Ammonia, used extensively for industrial refrigeration applications for many years, is being developed for commercial refrigeration and air-conditioning, mostly in Europe. Ammonia is somewhat flammable and toxic. Further, it corrodes copper-based alloys, so ammonia units must use more expensive steel, or stainless steel tubing (or aluminum for low-temperature components such as the evaporator). Also, ammonia systems must use open-drive compressors (these are compressors with external motors with shafts that penetrate the housing), which can be more expensive, can require maintenance for the shaft seal, and allow some refrigerant leakage. Ammonia's advantages are low refrigerant cost, good efficiency, and good heat transfer characteristics. However, ammonia is not being considered seriously for air-conditioning applications in the U.S. Cooling systems using carbon dioxide are being developed primarily for mobile air-conditioning applications (cars, buses, etc.). This refrigerant must operate with a super-critical cycle for typical ambient conditions, at head pressures up to and above 100 atmospheres. Most of the development is occurring in Europe.

Alternative cycles for air-conditioning have been the subject of much study and development. Currently, the only alternative cycle with significant market share is absorption, a heat-activated cycle used more because of high electricity costs or when a waste heat source is available than because of better efficiency. Absorption and some of the other alternative cycles could be viable in the future depending on a wide range of factors (energy costs, environmental concerns, etc.). However, vapor compression cooling technology using HFC refrigerants will be dominant in the near term. The reader is referred to Not-In-Kind Technologies for Residential and Commercial Unitary Equipment, prepared by Oak Ridge National Laboratory (Reference 15) for more information on alternative cycles.

## 4.2 Equipment Sales Trends

In general, HVAC equipment sales levels have been increasing steadily in recent years. The major drivers of cooling equipment sales are as follows.

- General economic conditions
- Year-to-year weather patterns
- CFC and HCFC phaseout

The strength of the economy and the construction market has an obvious impact on cooling equipment sales. This is true of both new construction and cooling system replacements.
Weather patterns have an affect on year-to-year equipment sales particularly for smaller equipment. For instance, the mild summer of 1997 correlated with slack sales for packaged air conditioning units, room air-conditioners, and centrifugal and absorption chillers. The CFC phaseout has impacted mostly the centrifugal chiller market where sales have been unusually high since 1995, the year in which production of CFC's stopped.

Sales projections for the general air-conditioning equipment market are optimistic. The weather of recent years has continued to be warmer than normal, leading corporations to be confident in projected sales in the near future. The large number of split systems which are due for replacement, the public awareness of HCFC-22 phase-out, and the healthy economy, predicted to continue its strong trend, should greatly increase the air-conditioning market.

### 4.3 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 [Reference 11].

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.

The efficiency gains achieved in centrifugal compressors since the late 1970's was mentioned in Section 2.1. Centrifugal compressors were redesigned in the early 1990's for non-CFC refrigerants (primarily HCFC-123 and HFC-134a). While the lower pressure HCFC-123 has better theoretical efficiency, it is an HCFC, slated to be phased out by the year 2020 for new products, and it is not non-toxic. 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.

As discussed in the Volume 2 report, 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 <u>Desiccant Dehumidification and Cooling Systems: Assessment and Analysis</u>, prepared by Pacific Northwest National Laboratory (Reference 17). 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.

Also mentioned in the Volume 2 report is the increased use of building automation systems, including remote multi-building monitoring and control. 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.

### 4.4 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

Heat pumps were initially commercialized in the 1960's and have undergone significant improvement over the intervening years.  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.  Heat pump sales are now about 1 million annually in the U.S., representing about one-fifth of unitary air-conditioning equipment sales (the unitary category includes single-package and split-system packaged air-conditioning units and heat pumps).  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 900°F 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 1700°F. Electric units are either type, and have a range of 5-30 kW (17,000-103,000 kBtu/hr)[3]. 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% [Reference 12].

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

[3] Conversion Factor: 1 kW=3,412 Btu/hr

resulted in the need for low emissions equipment, particularly low $NO_x$.  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. Results are presented in Section 5.3.

## 5.1 Overview

The objectives of this study were:

- To provide an accurate estimate of the energy used by cooling and heating equipment in the US commercial building sector.
- To establish a baseline of current national energy use which can be used for calculation of the potential national energy savings impact of various research, development, and demonstration (RD&D) options for reducing energy usage. The estimate is based on calendar year 1995.

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 US commercial building stock floorspace by building type and region. The segmentation is based on the 1995 Commercial Building Energy Consumption Survey (CBECS95), [Reference 3] data, and is discussed in Section 5.2 below. Building conditioning load estimates developed by Lawrence Berkeley National Laboratory (LBNL) were used as the basis for the energy use calculations. 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.

The energy use estimation approach is illustrated in Figure 5-1 below. Energy use is calculated on a national basis by multiplying a floorspace segment’s floor area (sqft) by the annual energy use intensity (EUI) of its cooling or heating system. EUI is in units of kWh/sqft/year for electricity and kBtu/sqft/year for gas and fuel oil.

EUI estimates for the studied equipment were developed using a rigorous analysis based on building load data provided by Lawrence Berkeley National Laboratory. HVAC system and equipment loads were calculated using these building load data. HVAC system performance models were developed, using the building load data as input, and using HVAC equipment models reflective of typical equipment installed in commercial buildings. Assumptions regarding equipment characteristics were derived from a number of sources, including the following.

- **XenCap™ building energy use data.** This database of building energy use was developed as part of Demand-Side Management (DSM) work done by Xenergy, Inc. for a range of electric utilities. The database is described in detail in Appendix 1 of the Volume 2 report (Reference 9). XenCap™ data was used as the basis of some of the load estimates, but was primarily used as a check on calculated load estimates.
- **Previous studies, journal, articles, etc.**
- **Product literature.** Equipment load or efficiency data was in some cases taken from product literature.
- **Industry expert review.** Review of selected interim results and final results of the study was provided by a number of active participants in the HVAC field.

More detailed description of the study methodology as well as the results are provided in the following sections.

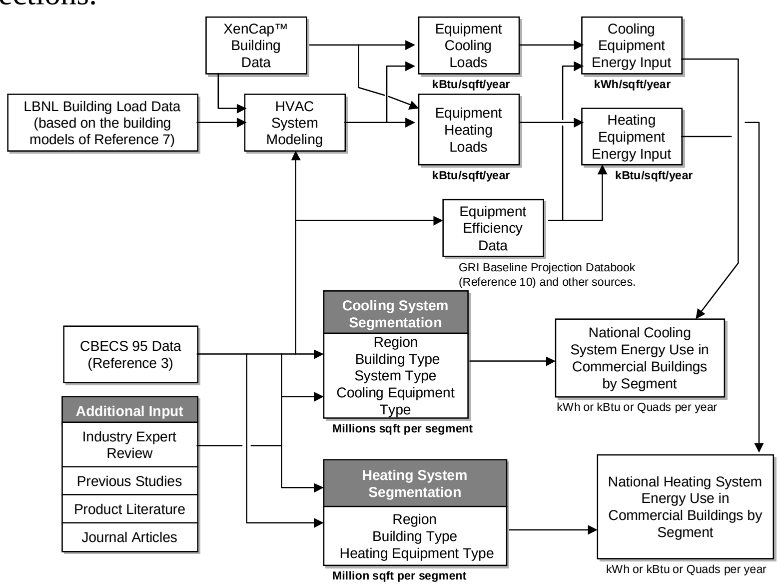



**Figure 5-1: Overview of Energy Use Calculation Methodology**

## 5.2 Building Stock Segmentation

This section describes the segmentation of building floor area, including a description of the segmentation methodology, and presentation of the results. The segmentation is based on floor area. Segmentation by number of buildings was not addressed.

The segmentation variables used in the study were:

- Climate or geographic region
- Building type
- Equipment type (explained in Section 3)

There is no study or survey which gives an adequate breakdown of the U.S. commercial building stock by all of these variables. The CBECS95 data represents the most complete survey that can be used for such segmentation. This database has been used as a basis for the segmentation used in this study.

Segmentation of the building stock for this study is based where possible on segmentation described in the Volume 2 Study (Reference 9). Additional segmentation required for this study was focussed on Cooling Equipment and Heating Equipment. Segmentation for these equipment types was done independently, except for the obvious overlap areas, which are discussed in Table 3-1 in Section 3.3. For instance, building floorspace which is cooled with a heat pump is also heated with same heat pump. Beyond this type of overlap, the study did not address the detail of which heating systems are combined in what quantities with which cooling systems.

The Volume 2 (Reference 9) study provides a segmentation of the commercial building floorspace according to the categories in Table 5-1 below.

**Table 5-1: Segmentation Variables of Reference 9**

| Variable | Categories | Descriptions |
|---|---|---|
| Building Type (CBECS95 categories) | Education | |
| | Food Sales | |
| | Food Service | |
| | Health Care | |
| | Lodging | |
| | Mercantile & Service | |
| | Office | |
| | Public Buildings | Includes CBECS95 Categories Public Assembly, Public Order and Safety, and Religious Worship |
| | Warehouse/Storage | |
| System Type | Individual or Room AC | Window AC, Packaged Terminal AC, Packaged Terminal Heat Pumps |
| | Packaged | Unitary, Split Systems, Residential-Type Central AC, Residential-Type Heat Pumps |
| | Central VAV | Variable Air Volume Systems Served by Central Chillers |
| | Central CAV | Constant Air Volume Systems Served by Central Chillers, Includes Multizone and Dual-Duct Constant Volume |
| | Central FCU's | Fan-Coil Unit Systems Served by Central Chillers |
| | Not Cooled | |
| Region (according to CBECS95) | Northeast | |
| | Midwest | |
| | South | |
| | Mountain | |
| | Pacific | |

The group of building types addressed in this series of studies is nearly identical to the building types of CBECS95 (Reference 3). The Public Order and Safety and Religious Worship categories of CBECS95 are combined with the Public Assembly categories for this study.

The system types listed in Table 5-1 above are descriptive of the cooling system more so than the heating system. However, for this study, the equipment generating either the heating or cooling must be considered. This refinement is discussed below.

As shown in Table 5-1 five regional categories are used in this study. The primary objectives for selection of regions were: (1) sufficient number of regions to give a reasonable representation of US climate variation; (2) the number of regions should not be excessive; (3) consistency with CBECS95 regions; and (4) one city per region for representative weather data. The representative cities for the five regions are listed in Table 5-2 below.

**Table 5-2: Segmentation Regions and Representative Cities**

| Region | City |
|---|---|
| Northeast | New York |
| Midwest | Chicago |
| South | Fort Worth |
| Mountain | Albuquerque |
| Pacific | San Francisco |

The five regions are intended to reflect the range of US climate variations. Further discussion of the selection of the regions and representative cities is provided in Reference 9.

### *5.2.1 Cooling Segmentation Methodology*

This section describes assignment of floorspace to the important categories of cooling equipment.

This segmentation starts with the System segmentation of the Volume 2 study (Reference 9), which is summarized in Figure 5-2 below.

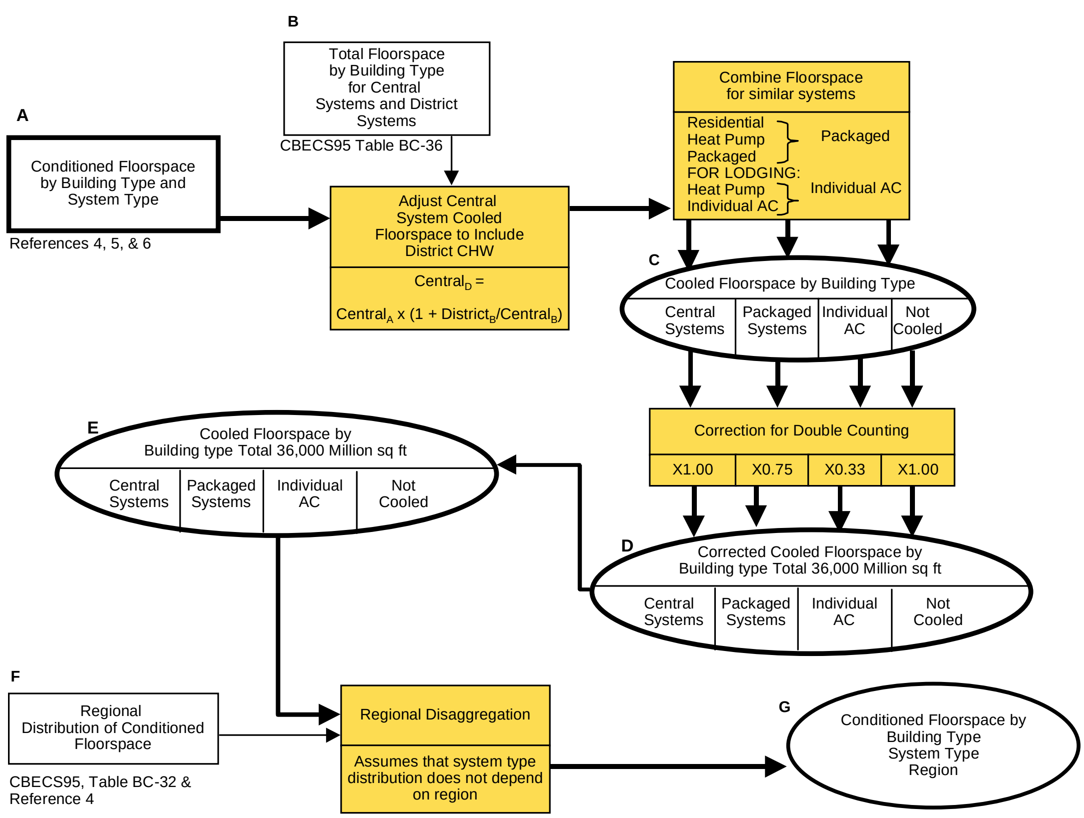



**Figure 5-2: Building Stock Segmentation (Cooling Systems)**

Key points regarding the methodology for the System segmentation are as follows.

- Data sources are CBECS95 (Reference 3) and more detailed summaries of the CBECS95 data provided by Allan Swenson of the DOE Energy Information Administration (References 4, 5, 6).
- The cooling equipment types were separated into the five major system types of interest: Central Systems with VAV air-handling units, CAV air-handling units, or Fan-Coil Units; Packaged Systems; and Individual Air-Conditioners. An additional category was established for uncooled buildings.

- An approach was developed for eliminating excess floorspace due to the double-counting which is inherent in the CBECS95 raw data. Correction factors were used which scaled back floorspace for different system types based on the relative importance of these system types when present in a given building.
- Disaggregation of floorspace to region was done assuming that building and system distributions did not depend significantly on region.

The reader is referred to Reference 9 for additional details regarding the System segmentation.

Segmentation of the system types by cooling equipment categories is summarized in Table 3-1 in Section 3.3. The central system chillers are divided among centrifugal chillers, air-cooled reciprocating chillers, water-cooled reciprocating chillers, air-cooled screw chillers, water-cooled screw chillers, and absorption chillers. District cooling is provided by chillers and is not separately considered. The packaged units are divided among Residential-Type Air-Conditioning Units, Heat Pumps, and Packaged Air-Conditioning Units. The Individual Air Conditioning Units are divided among Room Air-Conditioners, Packaged Terminal Air-Conditioners, Packaged-Terminal Heat Pumps, and Water Loop Heat Pumps. Note that the Heat Pumps and Packaged Air Conditioning Units of the Packaged system type are installed with ductwork to distribute cool air to the conditioned spaces, and the Individual AC Units are designed to cool the rooms in which they are installed. Note that the "Packaged" **equipment** category includes residential AC units, while the "Packaged" **system** category includes ducted heat pumps as well.

The segmentation of System Floorspace to Cooling Equipment was generally based on CBECS95 (Reference 3) Table BC-36 and the 1995 GRI Baseline Projection Databook (Reference 10). A simplifying assumption for this segmentation was that cooling equipment type distribution is not very dependent on geographic region. Figure 5-3 below, based on data from CBECS95 Table BC-36, shows that this assumption, although not unassailable, is reasonable for most equipment types.

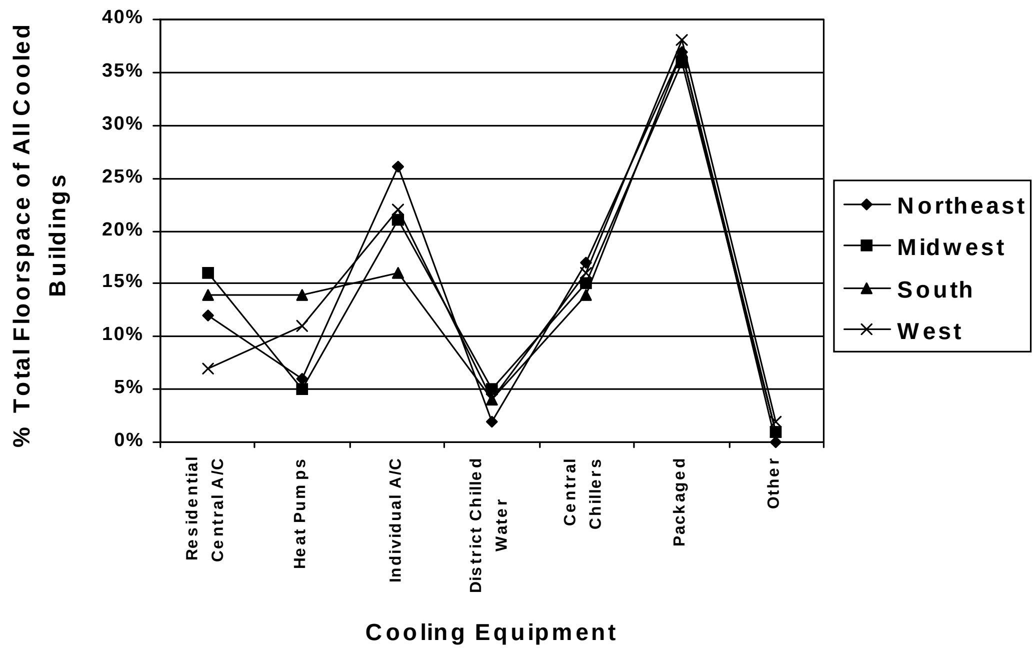



**Figure 5-3: Equipment Type Distribution for Cooling**

**NOTE: Swamp Coolers combined with Individual for this comparison**

Detailed segmentation of electric chillers was based on discussion with vendors. Detailed segmentation of Packaged and Individual Systems was also based on the U.S. Department of Commerce Current Industrial Reports for Refrigeration, Air-Conditioning, and Warm Air Heating Equipment for the year 1994 (Reference 13). Some of the pertinent data of this reference is presented in Appendix 2.

Two important aspects of the segmentation are described further below.

**Chillers: Water Cooled vs. Air Cooled:** Water-cooled chillers require condenser water (CW) pumps and cooling towers to reject heat. Air-cooled chillers reject heat in air-cooled condensers, which use significant fan power. Approximate distribution of these chiller types by building type is shown in Table 5-4 below.

**Water Loop (California) heat pumps:** These heat pumps reject and take heat from a water loop. The water is circulated throughout the building, allowing heat to be moved from areas that do not require it to those that do. Excess heat can be rejected in a cooling tower and needed heat can be added with a boiler. Table 5-3 below indicates the floorspace assigned to this equipment.

**Table 5-3: Water Loop Heat Pumps**

| Segments Affected | Distribution<br>(by floor area) |
|---|---|
| Lodging and Office (Individual System Category) | Percentages of total building type floorspace:<br>Office: 10% WLHP<br>Lodging: 44% PTAC&PTHP<br>15% WLPH |

**Table 5-4: Chiller Distribution**

| | Percent of Floorspace Served by Chiller Type | |
|---|---|---|
| **Building Type** | **Water-Cooled** | **Air-Cooled** |
| Education | 40% | 60% |
| Health Care | 45% | 55% |
| Lodging | 70% | 30% |
| Mercantile and Service | 70% | 30% |
| Office | 50% | 50% |
| Public Buildings | 55% | 45% |
| Warehouse/Storage | 0% | 100% |

Source: Discussion with a representative of a major manufacturer of chillers.

### *5.2.2 Heating Segmentation Methodology*

This section describes assignment of floorspace to the important categories of heating equipment.

The segmentation is based initially on estimates of conditioned floorspace provided in the 1995 Commercial Building Energy Consumption Survey (CBECS95-Reference 3). This reference provides a breakdown of floorspace in heated buildings by building type and heating equipment (Heat Pump, Furnaces, Individual Space Heaters, District Heat, Boilers, and Packaged Heating Units). The CBECS95 data includes significant overcounting of commercial building floorspace (the floorspace sums to 81.5 billion sqft, rather than the 48 billion sqft heated floorspace) because all of a building's floorspace, including unheated areas, are counted towards an equipment category, if the equipment type is present in the building. The adjustment of the data described below both remedies this overcounting, enhances the segmentation to include consideration of additional factors such as region and fuel type, makes the heating equipment segmentation consistent with the cooling equipment segmentation (for heating/cooling equipment), and eliminates the unclear building and equipment categories such as "other." The detailed approach to the segmentation is as follows.

1. Floorspace for "Other" and "Vacant" buildings is redistributed to the main building categories weighted according to the floorspace distribution for these categories. For instance, of the 707 million sqft of "Other" and "Vacant" floorspace associated with boilers, 30% is allocated to Education buildings which represent this same percentage of boiler system floorspace amongst the main building categories.

2. Floor space associated with "Other" Heating Equipment types is redistributed to the main heating equipment categories weighted according to the floorspace distribution for these categories.

3. Floorspace for heating/cooling equipment was set equal to the segmentation values developed for the cooling equipment. This assignment is illustrated in Table 5-5 below. Reduction of the floorspace of some of the affected categories is necessary to reflect the fact that not all of the equipment provides heating. For instance, areas cooled with a cooling-only packaged rooftop air-conditioning unit may be heated by a boiler. These reductions, illustrated in Table 5-5, are based on equipment shipment data provided in U.S. Commerce Department Current Industrial Reports (Reference 13).

**Table 5-5: Correlation of Heating/Cooling Equipment Categories**

| Cooling Equipment | | Heating Equipment | |
|---|---|---|---|
| **Category** | **Floorspace (million sqft)** | **Category** | **Floorspace (million sqft)** |
| PTAC, PTHP, WLHP | 1,881 | PTHP,WLHP | 1,254 |
| Heat Pump | 2,549 | Heat Pump | 2,549 |
| Packaged | 17,217 | Packaged | 12,912 |

4. Reduction of overcounting for the other heating equipment types is done with weighting factors associated with both equipment and building type. This is done to preserve consistency of the results with CBECS95 distribution of heated floorspace by building type. The reduction is represented by the following equation.

   FS (Building, Htg Equipment) = F(Building) x F(Htg Equipment) x CBECS95FS (Building, Htg Equipment).

   In this equation, FS is the floorspace associated with a combination of Building and Heating Equipment types, the F's are correction factors, and CBECS95FS is the overcounted floorspace of CBECS95. The building and equipment factors are shown in Table 5-6 below.

**Table 5-6: Correction Factors for Double Counting**

| Building | Building Factor | Heating Equipment | Heating Equipment Factor |
|---|---|---|---|
| Education | 1.09 | Packaged[1] | 0.71 |
| Food Sales | 0.68 | Boilers | 0.65 |
| Food Service | 1.17 | District | 0.65 |
| Health Care | 1.13 | Furnaces | 0.55 |
| Lodging | 1.08 | Individual | 0.4 |
| Mercantile and Service | 1.04 | Heat Pump, PTHP, WLHP[1] | 0.64[2] |
| Office | 1.01 | | |
| Public Building | 0.95 | | |
| Warehouse | 0.76 | | |

[1]Correction factors for these equipment types are set in order to match the floorspace determined in Step 3
[2]The CBECS95 category "Heat Pumps" includes all types of heat pumps

5. The individual space heating category is separated into three categories with floorspace percentages as follows:
   - 90% Unit Heaters
   - 5% Radiant Heaters
   - 5% Electric Baseboard.

6. Floorspace in each Building/Equipment segment is distributed to the five geographic regions. The distribution is based on the CBECS95 (Reference 3) data for regional distribution of heating equipment types. The distribution among the regions is not assumed to depend on building type for this disaggregation.

7. Floorspace for multi-fuel equipment types is distributed among fuel types based on the 1995 GRI Baseline Projection Databook (Reference 10). The overall fuel distribution for an equipment type is consistent with the reference. Some regional variation of this distribution is incorporated to reflect regional fuel use patterns. The distribution patterns are illustrated in Table 5-7 below.

**Table 5-7: Distribution of Floorspace by Heating Fuel**

| | Region | | | | | Total |
|---|---|---|---|---|---|---|
| | Northeast | Midwest | South | Pacific | Mountain | |
| **Packaged** | | | | | | |
| Gas | 97.5% | 97.5% | 85% | 90% | 90% | 90% |
| Electric | 2.5% | 2.5% | 15% | 10% | 10% | 10% |
| **Furnace** | | | | | | |
| Gas | 50% | 85% | 57.5% | 75% | 70% | 68% |
| Oil | 42.5% | 10% | 17.5% | 10% | 10% | 18% |
| Electric | 7.5% | 5% | 25% | 15% | 20% | 14% |
| **Unit Heaters** | | | | | | |
| Gas | 70% | 75% | 55% | 60% | 70% | 65% |
| Electric | 30% | 25% | 45% | 40% | 30% | 35% |
| **Boilers** | | | | | | |
| Gas | 55% | 75% | 60% | 63% | 63% | 63% |
| Oil | 45% | 25% | 40% | 37% | 37% | 37% |

The detailed heating equipment segmentation by building and equipment type is presented in Appendix 1.

## 5.3 Equipment Energy Use

### *5.3.1 Building Thermal Loads*

The thermal loads used to estimate the equipment energy use within commercial buildings were developed as part of the Volume 2 companion study (Reference 9). The methodology for calculation of these loads is described in detail in Reference 9. The calculations start with building internal space conditioning requirements developed by LBNL.

System models were developed to determine annual heating and cooling load delivered by the equipment. These loads differ from the building requirements due to (1) heating or cooling of outdoor ventilation air, (2) cooling contribution of minimum ventilation air or economizing air quantities, (3) heat input of fans and pumps, and (4) inefficiencies resulting from the limitations of typical control strategies. The system models are discussed in more detail in Reference 9.

The segmentation of Reference 9 was focused on system types (see Table 5-1 above in Section 5.2). For this study, the system loads were assigned to heating and cooling equipment types as indicated in Table 5-8 below.

**Table 5-8: Load Mapping from System to Equipment**

| | Equipment Type | System Types |
|---|---|---|
| Cooling Loads | Chillers | Central CAV, Central VAV, Central FCU |
| | Heat Pump | Packaged |
| | PTAC, PTHP | Individual |
| | Packaged AC Unit | Packaged |
| | WLHP | Individual |
| | Room AC | Individual |
| Heating Loads | Heat Pump | Packaged |
| | Packaged AC Unit | Packaged |
| | PTHP | Individual |
| | WLHP | Individual |
| | Unit Heater | Packaged, Individual, Not Cooled |
| | Boiler | Central CAV, Central VAV, Central FCU, Packaged, Individual, Not Cooled |
| | District Heating | Central CAV, Central VAV, Central FCU, Packaged, Individual, Not Cooled |
| | Furnace | Central CAV, Central VAV, Central FCU, Individual, Not Cooled |
| | Individual Space Heater | Packaged, Individual, Not Cooled |

Note that loads from multiple system models are used to provide an average load for some of the equipment types. This is because these equipment types can be found in more than one of the system types. This averaging of loads is weighted by floorspace associated with the system type for the given building type. For instance, of the 3,967 million sqft of office floorspace with central systems, 59% represents VAV, 12% FCU, and 29% CAV. These floorspace percentages are used as the weighting factors to estimate average office cooling load for chiller systems.

### *5.3.2 Extrapolation of Calculation Results*

The equipment modeling analysis was carried out rigorously for 84 building/region/system combinations: (1) all regions and systems for office buildings and (2) all building types and systems for the Northeast region. Load estimates for the remaining building/region/system combinations were developed by extrapolation according to the relations below.

*EUI (Building, Region, System) = EUI(Building, Northeast, System)* RATIO*

$$\text{RATIO} = \frac{\text{EUI(Office, Region, System)}}{\text{EUI(Office, Northeast, System)}}$$

EUI (Energy Use Intensity) is the equipment annual energy use divided by the floorspace served by the equipment.

To demonstrate the accuracy of the extrapolation ratios, various "spot-check" calculations were conducted for different building and system types as listed below in Table 5-9.

**Table 5-9: EUI Extrapolation Data Comparison Choices**

| Region | City | Building Type | System Type |
|---|---|---|---|
| **South** | Fort Worth | Education | VAV |
| | | Warehouse | Packaged |
| **Midwest** | Chicago | Health Care | FCU |
| | | Large Retail | CAV |
| **Mountain** | Albuquerque | Food Service | Packaged |
| | | Small Retail | Packaged |
| **Pacific** | San Francisco | Food Sales | Not Cooled |
| | | Small Hotel | Individual |

The direct calculations of the heating and cooling equipment annual loads for each of the building and system types were then compared, graphically, to the extrapolated values as shown in Figure 5-4. The solid line in the figure represents an exact match between the extrapolated value and the direct calculated value.

As can be seen from the graph, the extrapolation method used to estimate the remaining values for all the building and system types outside the Northeast was relatively accurate. Figure 5-4 does show a greater tendency for data points to be above the target line, showing that the extrapolation approach has resulted in a conservative estimate of energy use.

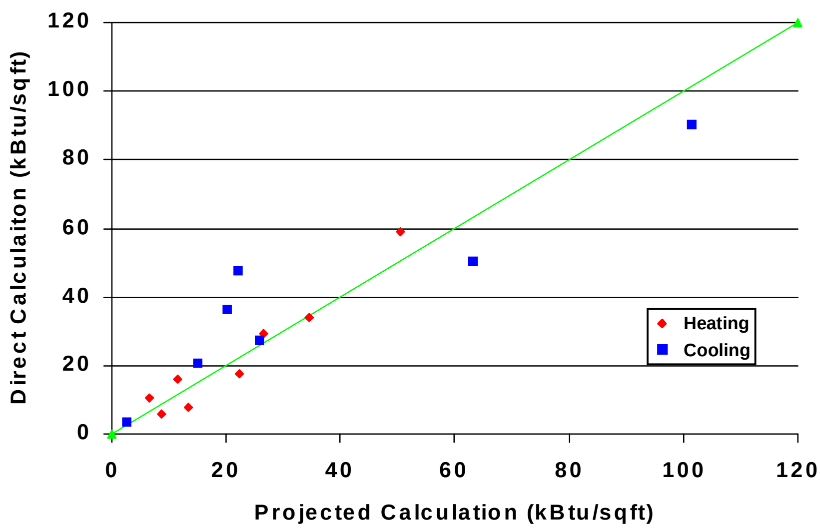



**Figure 5-4: Annual Equipment Load Extrapolation Data Comparison**

### 5.3.3 Equipment Seasonal Efficiencies

Annual equipment loads were converted to equipment energy use based on typical equipment seasonal efficiencies. These efficiencies are tabulated in Table 5-10 below. Sources for these data are References 10 and 18.

**Table 5-10: Equipment Seasonal Efficiencies**

| Cooling (kW/ton) | | Heating (% Efficiency or Seasonal COP) | |
|---|---|---|---|
| Packaged AC* | 1.65 | Gas Furnace | 72% |
| PTAC, PTHP* | 1.41 | Oil Furnace | 74% |
| Heat Pump* | 1.65 | Electric Furnace | 98% |
| Centrifugal Chiller | 0.80 | Gas Boiler | 72% |
| Absorption Chiller | COP 0.96 | Oil Boiler | 74% |
| Air-Cooled Recip. Chiller ** | 1.30 | Gas Unit Heater | 72% |
| Water-Cooled Recip. Chiller | 0.90 | Electric Unit Heater | 98% |
| Air-Cooled Screw Chiller** | 1.11 | Heat Pump | 2.04 |
| Water-Cooled Screw Chiller | 0.85 | PTHP | 2.04 |
| Room AC* | 1.50 | Radiant Heater | 78% |
| | | Electric Baseboard Heater | 98% |
| | | Gas packaged Unit | 72% |
| | | Electric Packaged Unit | 98% |
| | | District Heating | 80% |

*Efficiency includes impact of condenser and evaporator fan
**Efficiency includes impact of condenser fan

Energy use calculated for some of the equipment includes evaporator and condenser fan power, which was estimated separately for the Volume 2 study (Reference 9). The efficiency for the equipment indicated with asterisks includes evaporator and/or condenser fan power. The total energy use estimates for these equipment types was reduced accordingly, so as to include only compressor power.

### 5.3.4 Results - Cooling

Total 1995 national commercial building HVAC cooling equipment energy use is estimated to be 1.4 quads of primary energy[4]. The breakdown of this energy by equipment, building type, geographic region, and system type are shown in the figures of this section. As can be seen from Figure 5-5, the equipment type using the most energy is Packaged AC. This equipment alone comprises more than half of the total cooling equipment energy use. Another 6% of the energy use is associated with heat pumps. Chillers combined represent about 35% of the energy use, while the individual equipment categories represent about 8% of the energy. Differences in distribution of energy use and floorspace of the cooling equipment reflects differences in energy use intensity resulting mostly from corresponding differences in the load intensities of the building types typically using the equipment, and differences in the equipment efficiencies.

[4] A heat rate including generation, transmission, and distribution losses of 11,005 Btu/kWh has been assumed in conversion to primary energy

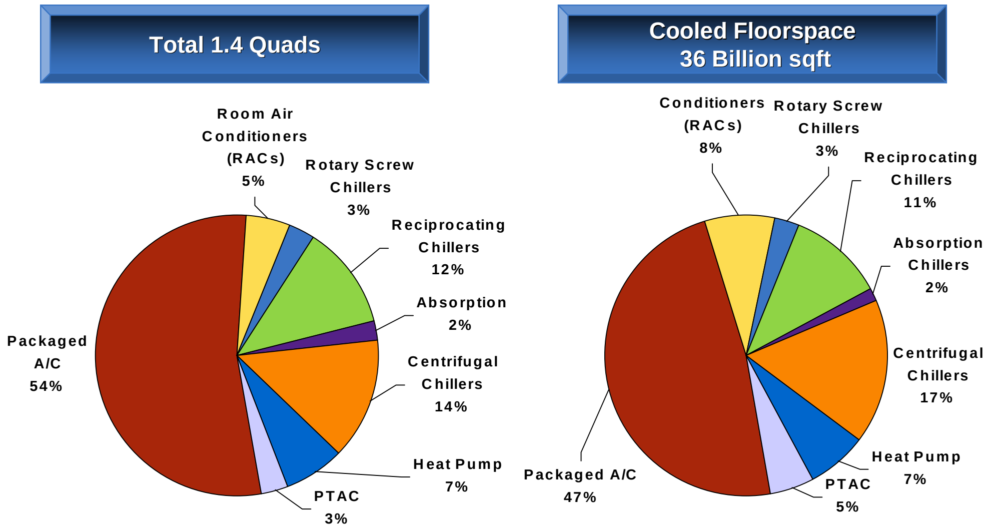



**Figure 5-5: Cooling Primary Energy Use-Equipment Breakdown**

Efficiency of central and packaged systems is compared in Figure 5-6 below for the small office building type. This comparison of prototypical systems in prototypical buildings shows that the central system with VAV using a water-cooled centrifugal chiller has better efficiency than a packaged system. The differences are primarily due to:

- Heat rejection in the centrifugal-based central system using a cooling tower, which enhances heat rejection through evaporation of condenser water
- Use of larger more-efficient refrigerant compressors for the centrifugal chiller systems.
- Constant-volume operation of the packaged unit and the Central CAV supply fans in spite of varying cooling loads. This accounts for the fact that supply fan energy use is higher for these two systems, even though design fan input power is higher for the VAV system.
- Chiller water pump energy is higher for the CAV than the VAV system due to the higher annual cooling.

Note that the air-cooled reciprocating chiller energy use is very close to that of the packaged system, which shows the impact of the first two factors. These factors more than make up for the central system disadvantages of additional heat exchangers and additional power for thermal distribution. However, it should be noted that packaged systems can be designed for variable-volume operation, be fitted with higher-efficiency components, and utilize evaporative condensers, which would practically eliminate the efficiency advantage of a central system. It should also be noted that these performance models are based on 1995 building stock average efficiencies. New equipment today will have better efficiency.

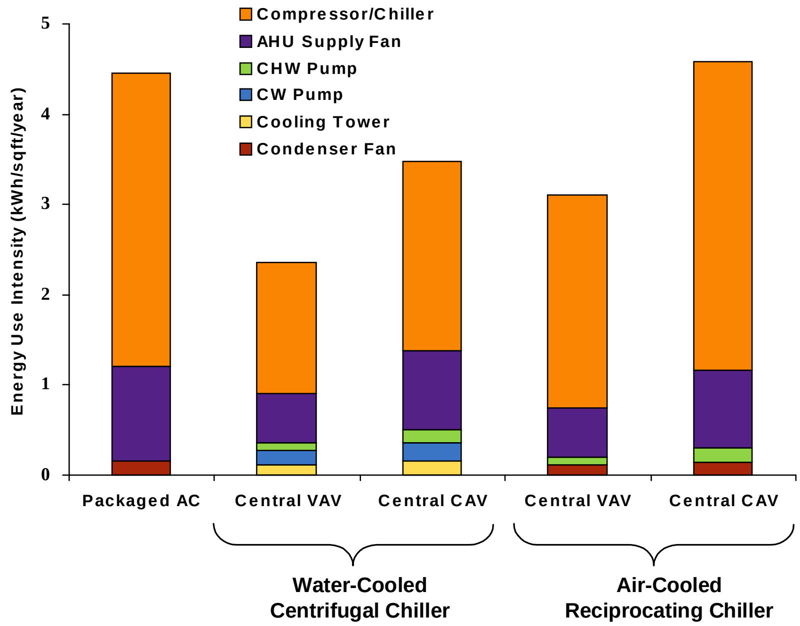



**Figure 5-6: Energy Use Comparisons of Packaged and Central Systems (New York City Small Office Building)**

As observed in Figure 5-7 below, the building type that consumes the most cooling energy is Office comprising about 27% of the total cooling energy. The other large energy use buildings are Public Buildings, Mercantile and Service, Health Care, and Food Service. Average Site Energy Use Intensity for electric cooling equipment is shown for the building categories in Figure 5-8 below. The figure compares estimates of this study with those of CBECS95 (Reference 3). To preserve consistency with the CBECS95 data, energy use for supply fans and condenser fans are included for packaged and individual systems. The estimates of this study are higher than those of CBECS95 for many of the building categories. [5]

The importance of different building categories to the overall cooling energy use depends on floorspace and energy use intensity. The energy use intensity is primarily dependent on internal loads and required ventilation rates. The high-intensity buildings are Food Service, Food Sales, and Health Care.

[5] The CBECS95 Energy Use Intensities are calculated using total cooling electricity data reported in CBECS95 Table EU-3 and dividing by estimates of cooled floorspace in buildings using electricity for cooling. The latter estimates were derived from the CBECS95 microdata.

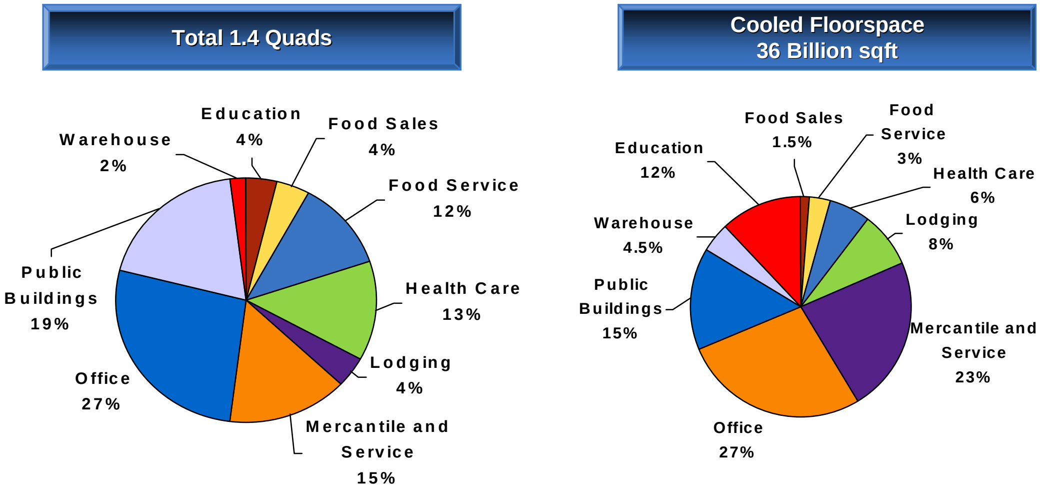



**Figure 5-7: Cooling Primary Energy Use and Floorspace - Building Type Breakdown**

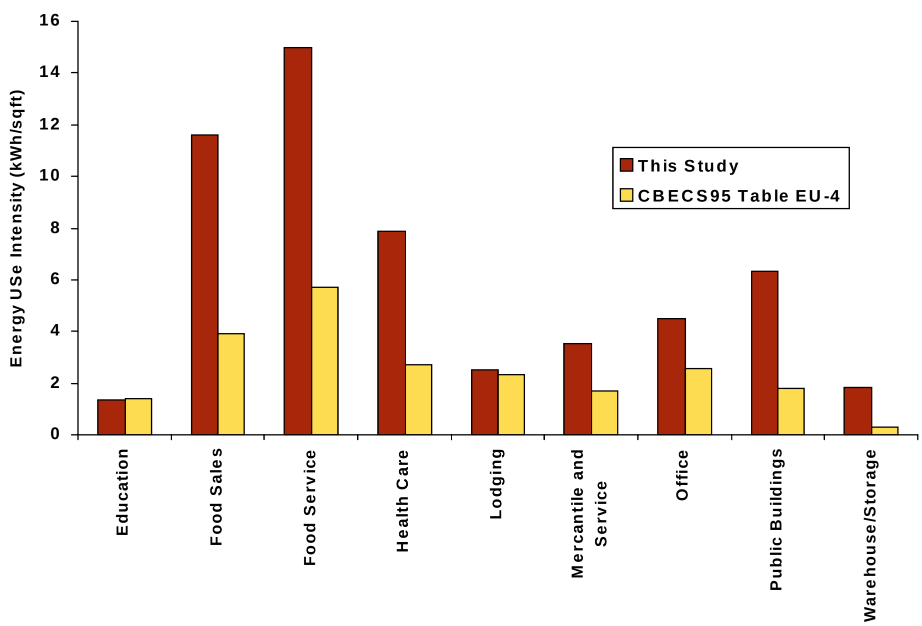



**Figure 5-8: Cooling Site Energy Use Intensity by Building Type**

The education category has very low energy use intensity because these buildings do not typically require cooling throughout the year, especially during the hottest months of summer when they are not occupied. Internal loads are also very low for this building category.

Energy use intensities estimated in this study are somewhat higher than the CBECS95 estimates. Different approaches used in derivation of the two sets of estimates account for the discrepancies. The bottom-up estimates of this study more rigorously take into account the additional cooling loads associated with fan and pump heat and ventilation air for the different building types.

The distribution of cooling energy use by geographic region strongly reflects the geographic weather differences. The energy use and floorspace distributions by region are shown in Figure 5-9 below. The differences in the two distributions are due to the expected differences in energy use intensity resulting from higher cooling loads in warmer regions.

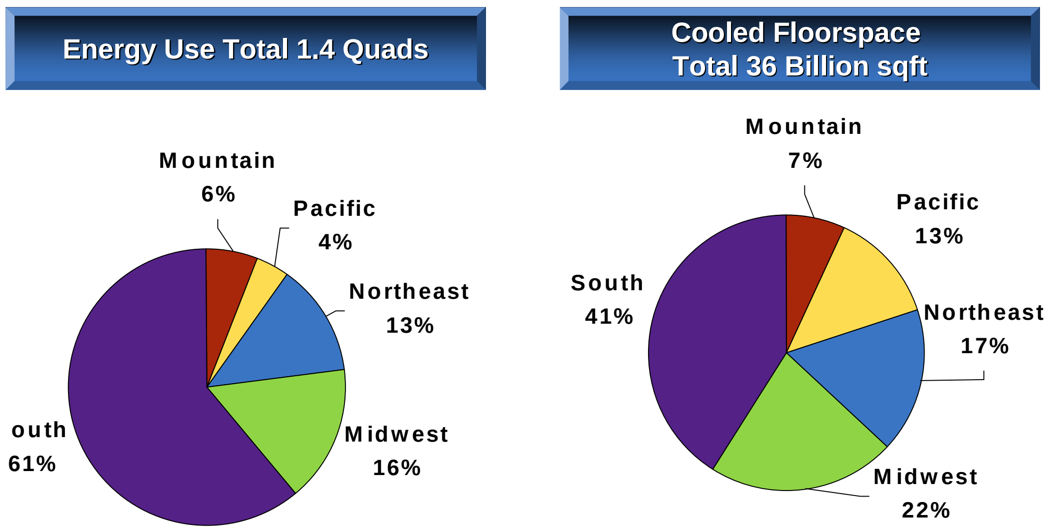



**Figure 5-9: Cooling Primary Energy Use - Geographic Region Breakdown**

### *5.3.5 Results - Heating*

Total 1995 national commercial building HVAC heating equipment energy use is estimated to be 1.7 quads of primary energy[6]. The breakdown of this energy by equipment, building type, geographic region, and system type are shown in the figures of this section. As can be seen from Figure 5-10, the equipment type representing the most heating energy use is Packaged Units. Packaged Units represent a lesser portion of heating energy use than cooling energy use because of the importance to heating of the uncooled buildings, which represent 25% of the total conditioned floorspace, and which use other heating system types.

[6] A heat rate for electricity including generation, transmission, and distribution losses of 11,005 Btu/kWh has been assumed in conversion to primary energy

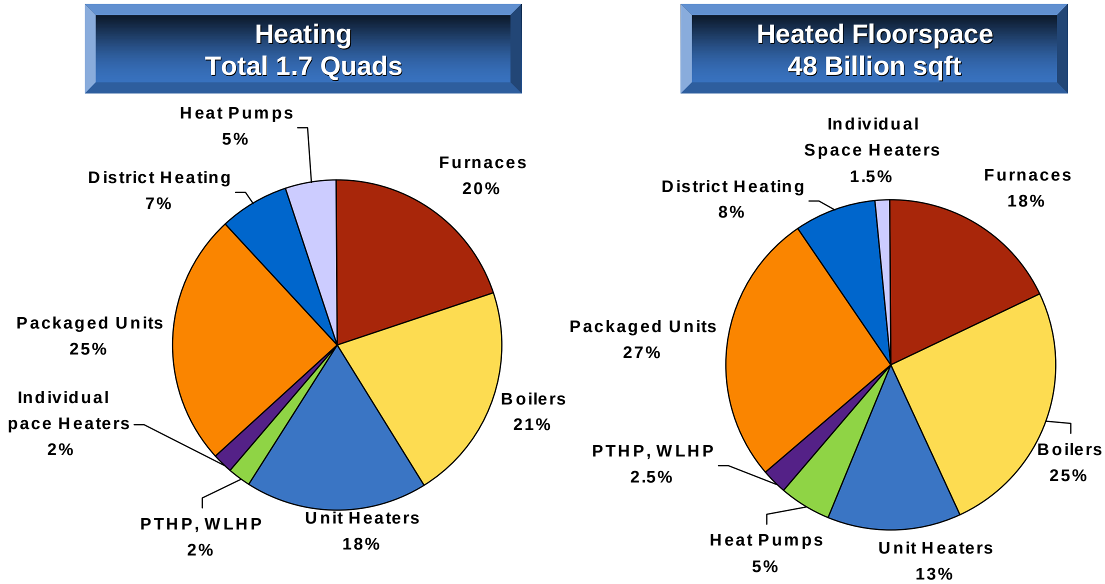



**Figure 5-10: Heating Primary Energy Use and Floor Space - Equipment Breakdown**

As observed in Figure 5-11 below, the building type that consumes the most heating energy is Mercantile & Service (comprising about 24% of the total heating load) with Office and Public Buildings following very closely. Average heating site Energy Use Intensity is shown for the building categories in Figures 5-12 and 5-13 below. The EUI's of this study for electric and non-electric heating are compared to data from CBECS95[7]. As with cooling energy use, the estimates of this study are generally higher than those of CBECS95. The most noteworthy building type is Food Service, which has high energy use, primarily due to high ventilation rates. The high energy use of warehouse buildings is somewhat surprising. This high usage is due to high space heating load, which results from the absence of significant internal load from lighting, equipment, and occupants. The pattern of heating energy use intensity by building is very similar for the electric and non-electric equipment. However, when converted to primary energy, the electric-heat energy use intensity is higher. For example the 4 kWh/sqft energy use intensity for electrically-heated education buildings represents 44 kBtu/sqft of primary energy, which is significantly higher than the 29 kBtu/sqft for non-electric education buildings. A heat rate of 11,005 Btu/kWh is used – this heat rate incorporates losses associated with generation, transmission, and distribution.

[7] Note that the CBECS95 Energy Use Intensities are not derived from CBECS95 Tables EU-4 and EU-6. Instead, the end-use energy reported in Tables EU-3 and EU-5 are normalized by building floorspace using electricity and natural gas as the primary heating fuel. For natural gas, actual heated floorspace of buildings using natural gas for heating was derived from the CBECS95 microdata. For electricity, the floorspace in Table BC-24 was used.

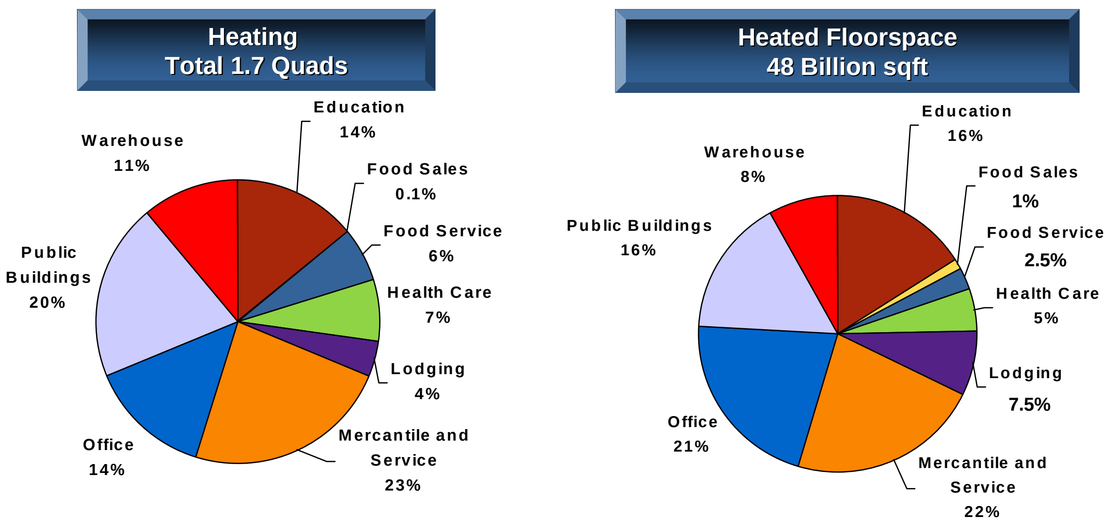



**Figure 5-11: Heating Primary Energy Use and Floorspace - Building Type Breakdown**

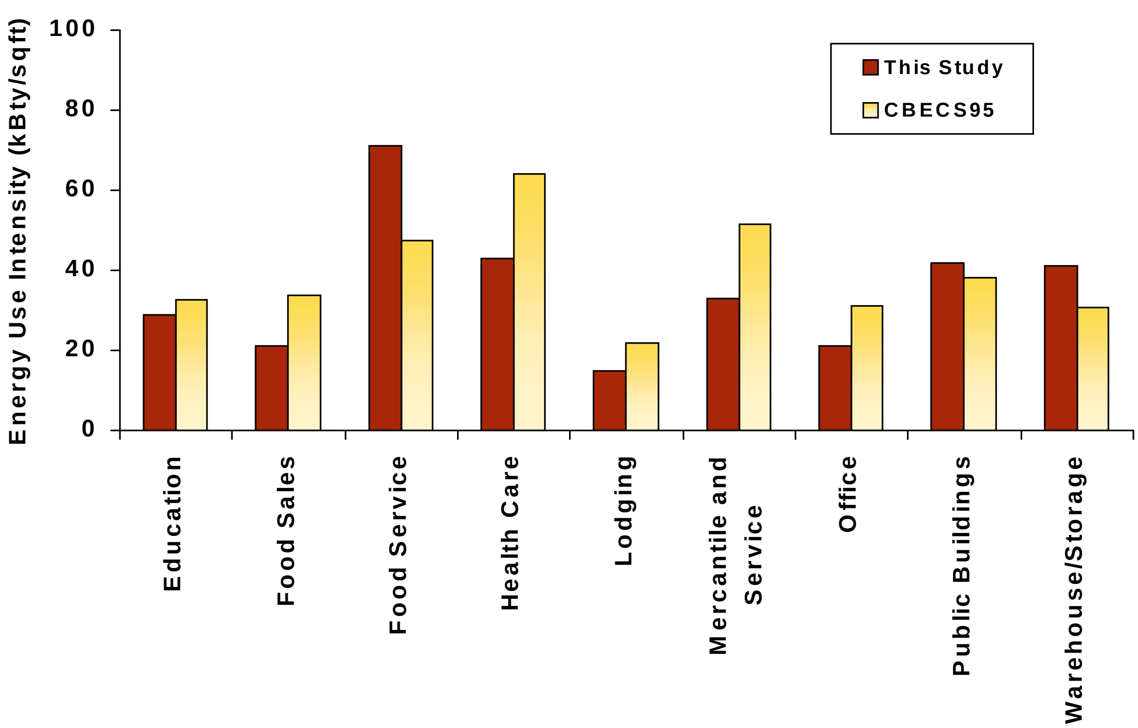



**Figure 5-12: Heating Site Energy Use Intensity by Building Type (Non-Electric Fuels)**

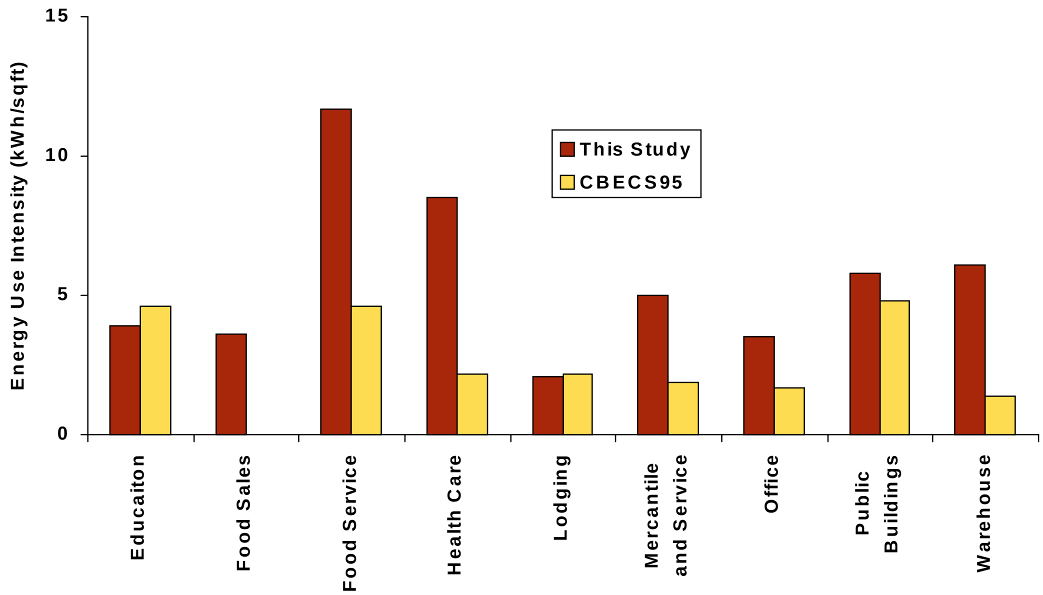



**Figure 5-13: Heating Site Energy Use Intensity (Electricity)**

The distributions of HVAC heating energy use and floorspace by geographic region are show in Figure 5-14 below. The differences between energy use and floorspace distributions reflect the higher heating loads in cooler regions. The Pacific region is noteworthy in that it has both low cooling and heating energy use.

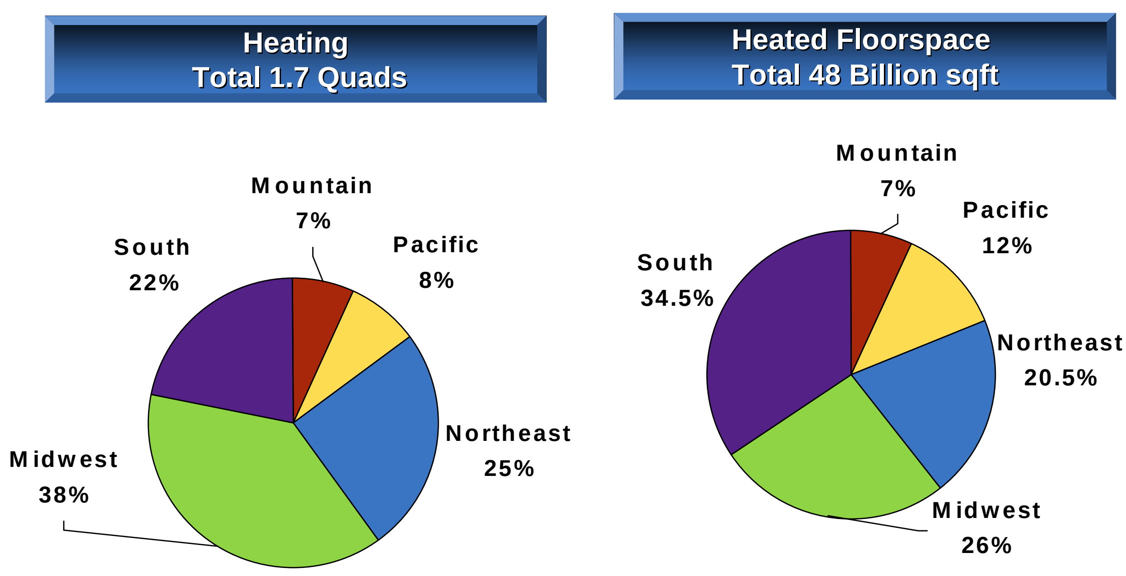



**Figure 5-14: Heating Primary Energy Use - Geographic Region Breakdown**

### *5.3.6 Total HVAC Energy Use*

Total national HVAC energy use in the Commercial Sector, including the estimates of this study and those of the Volume 2 study (Reference 9) is 4.5 quads. The distribution of this energy use by building type is shown in Figure 5-15 below. From this figure it is clear that the most important building categories are Office, Mercantile and Service, and Public Buildings.

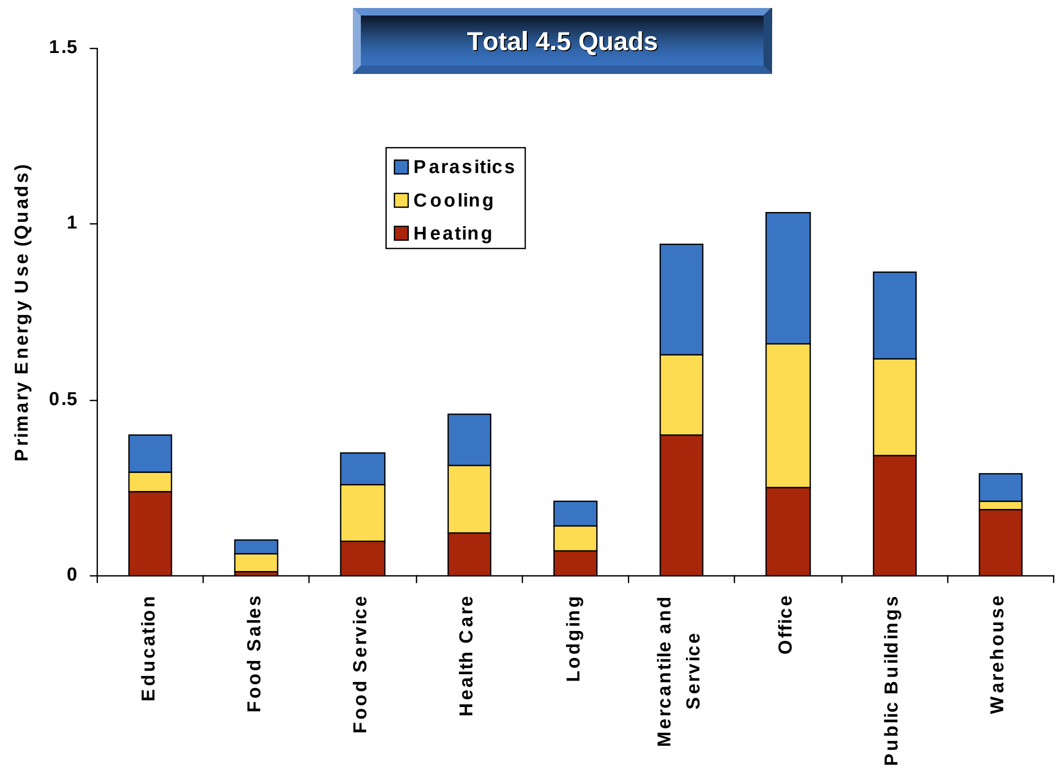



**Figure 5-15: Total HVAC Primary Energy Use by Building Type**

These three building types have moderate energy use but large floorspace. The energy use intensity in the building types is shown in Figure 5-16 below.

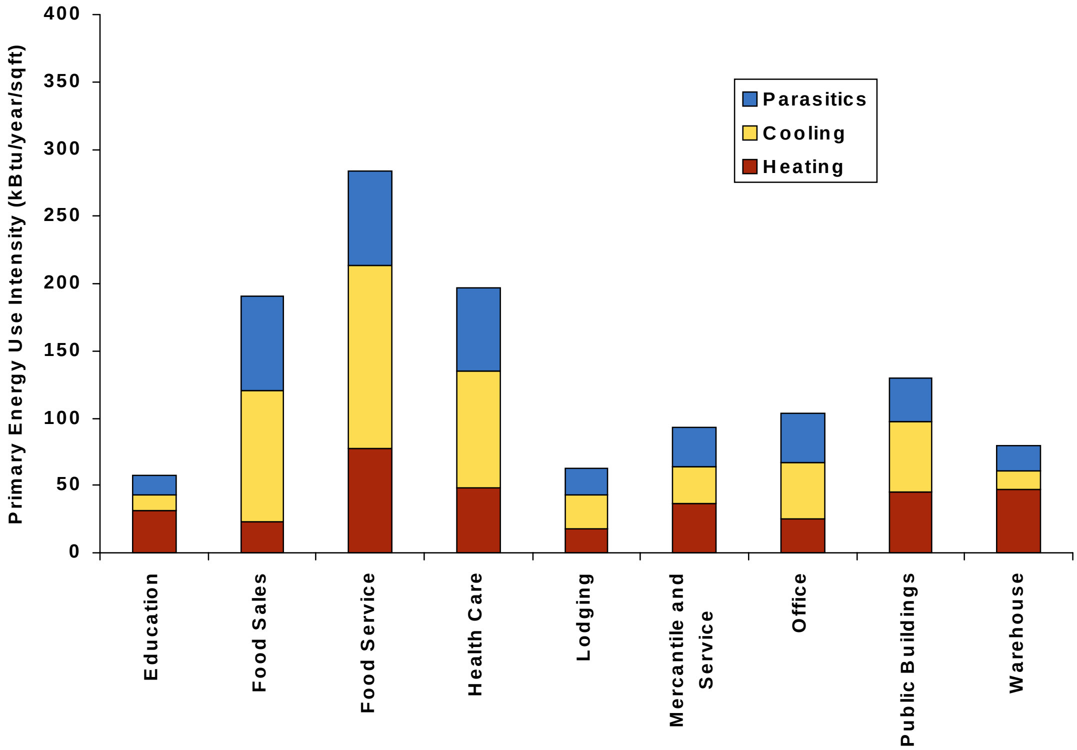



**Figure 5-16: HVAC Primary Energy Use Intensity by Building Type**

The most energy-intensive buildings are Food Service, Food Sales, and Health Care.

Primary Energy Use and Energy Use Intensity is shown in Figures 5-17 and 5-18 by region. The second of those plots is more interesting than the first. It clearly shows the geographic differences in heating and cooling energy according to climate. The total energy use intensities are very similar, except for the Pacific region. In the South, the total is somewhat higher, due to the very large amount of cooling energy. Parasitics energy is very consistent among all the regions but Pacific.

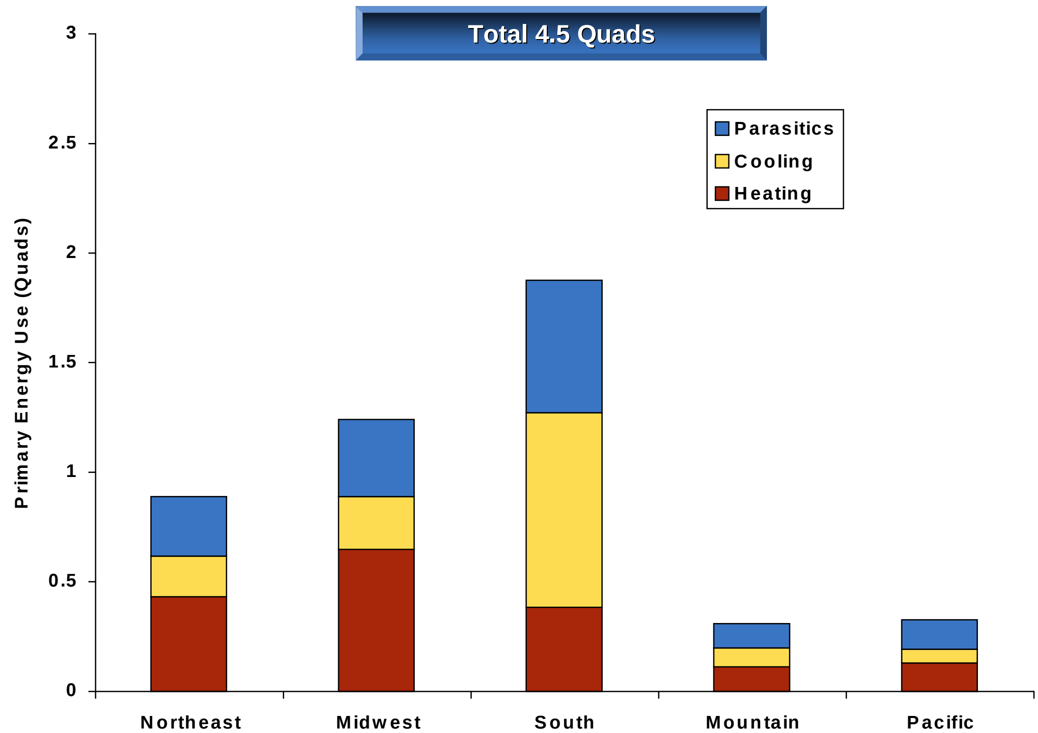



**Figure 5-17: Total HVAC Primary Energy Use by Region**

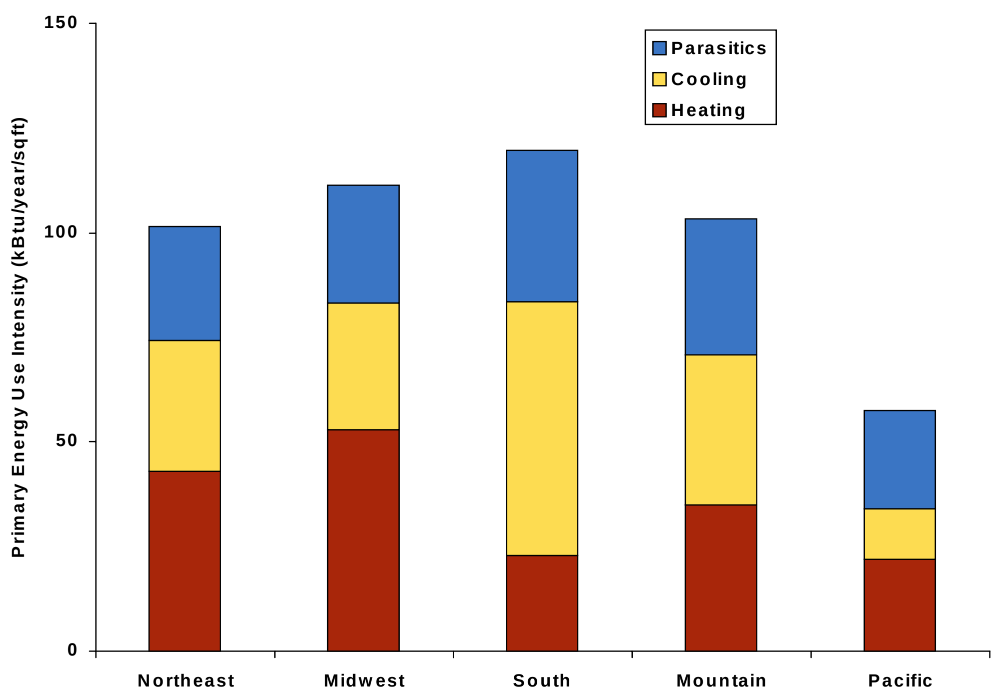



**Figure 5-18: Total HVAC Primary Energy Use Intensity by Region**

## 5.4 Comparison to Other Studies

The overall results of this study are compared to the estimates of other studies in Figure 5-19 below. The estimates are for the year 1995, except for the LBNL data, which do not have association with specific years. Further, while the AEO97 and AEO98 estimates are for the year 1995, they are based on information collected in the 1992 CBECS survey rather than information from CBECS95. For these comparisons, the energy use of the ADL studies is allocated to the energy use categories as follows.

- Heating includes both heating energy of this study and heating water pump energy of Reference 9
- Ventilation includes exhaust fans and one-third of the supply fan energy
- Cooling includes the cooling energy of this study and the remaining "parasitic" energy use, which includes supply fans, condenser fans, cooling towers, chilled water pumps, condenser water pumps, and terminal boxes.

The results of this study show higher energy use than most of the other studies, but they are fairly consistent with the AEO98 estimates.

The cooling energy use estimate of this study is consistent with the other largest estimate of this energy use (AEO97). This study's heating energy use estimate is between the range of other estimates, which range from 1.52 to 2.67 quads. This study's estimate for ventilation energy is somewhat higher than all the other estimates except for the LBNL 1999 estimate. This may be due to the fraction of supply fan energy assigned to this category, which was somewhat arbitrary.

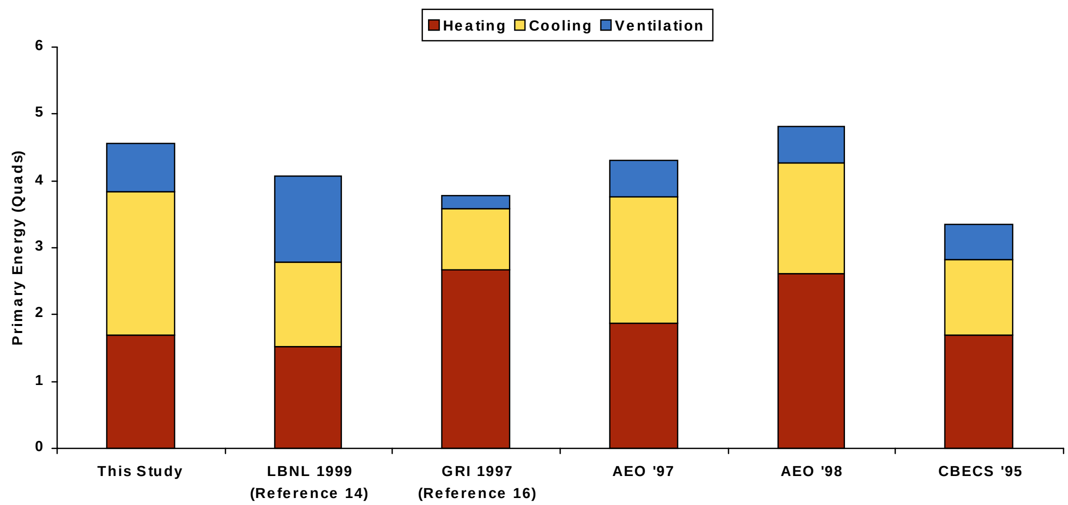



**Figure 5-19: Comparison of This Study's Results to Other Studies**

## 6 CONCLUSIONS AND RECOMMENDATIONS

The bottom-up estimate of national energy consumption for commercial sector HVAC equipment which was described in this report includes 1.4 quads of primary energy for cooling, 1.7 quads for heating, and 1.5 quads for "parasitic" equipment, such as fans and pumps, for a total of 4.5 quads (the sums do not add exactly due to round-off inconsistencies). This division of the energy is based on designation of fans and pumps as parasitic, even though many of them are associated with cooling and heating functions.

For an alternative grouping of the equipment types, in which heating and cooling auxiliary equipment is combined with the heating and cooling categories, and in which all exhaust fan energy and one-third of supply fan energy is termed to be "ventilation" energy, the breakdown is as follows: 2.0 quads for cooling, 1.8 quads for heating, and 0.7 quads for ventilation. This grouping of the energy use is more consistent with groupings typically used in other studies. The energy use estimates of this study are somewhat greater than some other estimates of national commercial sector HVAC energy use, but not inconsistent with the magnitude of most of these estimates. For example, the heating energy use estimate of 1.7 quads of this study compares with other estimates ranging from 1.4 to 2.7. Further, this study's estimate for ventilation energy use of 0.7 quad compares with estimates ranging from 0.18 to 1.29 for ventilation. The cooling energy use estimate of this study is higher than that of other studies: 2.0 quads compared with estimates ranging from 0.42 to 1.91.

The HVAC equipment class which represents the greatest energy use, with strong contributions in cooling, heating, and ventilation (or parasitics) is packaged air-conditioning units. This equipment, sometimes referred to as unitary air-conditioners, includes single-package rooftop units and split-systems. This equipment is used in 17.2 billion sqft of floorspace (about 48% of the cooled floorspace in the commercial sector), and is responsible for about 0.74 quads of cooling energy use and 0.44 quads of heating energy use. In descending order of importance, other types of cooling equipment and their portion of the 1.4 quads of cooling energy are Centrifugal Chillers (14%), Reciprocating Chillers (12%), Rotary Screw Chillers (3%), Heat Pumps (7%) and Room AC (5%). The most important types of heating equipment and their portion of the 1.7 quads of heating energy are Packaged Units (25%), Boilers (21%), Furnaces (20%), and Unit Heaters (18%).

The building type with the highest HVAC energy use is the office category. Next in importance are the Mercantile & Service and Public Building categories. All three of these building types have a medium amount of energy usage intensity (85 to 115 kBtu/sqft/year for total HVAC primary energy intensity), but represent a large amount of floorspace (roughly 10 billion sqft each for Office and Mercantile & Service, and roughly 7.5 billion sqft for Public Buildings). The building types with the highest energy use intensity are Food Service, Food Sales, and Health Care, with primary energy use intensities including all HVAC energy of 280, 190, and 180 kBtu/sqft/year respectively. These building types represent a moderate amount of floorspace, and for this reason are not the most important to overall energy use. Building types such as Education, Warehouse/Storage, and Lodging have relatively low HVAC energy use intensity.

Dependence of HVAC energy use on region is a strong function of climate, with higher cooling energy use in warmer regions and higher heating energy use in cooler regions. The South has the highest overall energy use intensity, including all HVAC equipment. The Pacific region is unique in that it has relatively low heating and cooling energy use.

The energy use estimates of this study, while based on rigorously-developed building load data, HVAC system operational models, and commercial floorspace segmentation, are a first step in enhancing an understanding of the potential for reducing energy use of this equipment. 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 (i.e. SEER) 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.

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## APPENDIX 1: BUILDING SEGMENTATION

The building stock segmentation developed in this study is represented by the building/system distribution and the regional distribution presented in the following tables.

**Table A1-1: Floorspace Segmentation - Building Type and System Type (million sqft)**

| | Education | Food Sales | Food Service | Health Care | Lodging | Mercantile and Service | Office | Public Buildings | Warehouse/ Storage | Totals |
|---|---|---|---|---|---|---|---|---|---|---|
| Individual AC | 805 | 0 | 83 | 134 | 1,669 | 333 | 1,257 | 371 | 119 | 4,771 |
| Packaged | 2,204 | 534 | 1,100 | 557 | 283 | 5,820 | 4,450 | 3,337 | 1,482 | 19,767 |
| Central VAV | 551 | 0 | 0 | 401 | 85 | 1,081 | 2,322 | 847 | 0 | 5,287 |
| Central FCU | 466 | 0 | 0 | 334 | 707 | 831 | 484 | 0 | 0 | 2,822 |
| Central CAV | 212 | 0 | 0 | 802 | 85 | 249 | 1,161 | 741 | 102 | 3,352 |
| Not Cooled | 3,522 | 20 | 64 | 159 | 779 | 2,507 | 561 | 2,168 | 2,285 | 12,065 |
| Totals | 7,760 | 554 | 1,247 | 2,387 | 3,608 | 10,821 | 10,231 | 7,464 | 3,988 | 48,064 |

**Table A1-2: Floorspace Segmentation: Geographic Region (million sqft)**

| Northeast | Midwest | South | Mountain | Pacific | Total |
|---|---|---|---|---|---|
| 9,919 | 12,382 | 16,667 | 3,272 | 5,824 | 48,064 |

Sources: CBECS 95 (Reference 3); References 4, 5, 6; ADL estimates

Note: Percentages represent portion of cooled floorspace rather than portion of conditioned (heated and/or cooled) floorspace.

**Table A1-3: Cooling Equipment Segmentation By Building Type (million sqft)**

| Building Type | Education | Food Sales | Food Service | Health Care | Lodging | Mercantile & Service | Office | Public Buildings | Warehouse/ Storage | Totals |
|---|---|---|---|---|---|---|---|---|---|---|
| Rotary Screw Chiller | | | | | | | | | | |
| Air Cooled | 254 | 0 | 0 | 223 | 57 | 166 | 387 | 741 | 9 | 1837 |
| Water Cooled | 49 | 0 | 0 | 67 | 57 | 166 | 193 | 265 | 0 | 797 |
| Reciprocating Chiller | | | | | | | | | | |
| Air Cooled | 509 | – | – | 624 | 198 | 499 | 1,548 | – | 34 | 3,411 |
| Water Cooled | 85 | – | – | 89 | 85 | 249 | 290 | 106 | 7 | 912 |
| Absorption Chiller | 31 | – | – | 45 | 57 | 83 | 97 | 106 | 1 | 419 |
| Centrifugal Chiller | 297 | – | – | 490 | 424 | 998 | 1,451 | 271 | 60 | 4,091 |
| Heat Pump | 352 | – | – | 81 | 42 | 729 | 667 | 489 | 188 | 2,549 |
| Packaged AC | 1,851 | 534 | 1,200 | 476 | 240 | 5,091 | 3,782 | 2,949 | 1,295 | 17,217 |
| PTAC, WLHP | – | – | – | – | 1,252 | – | 629 | – | – | 1,881 |
| Room AC | 805 | – | 83 | 134 | 417 | 333 | 629 | 371 | 119 | 2,890 |
| Totals | 4,233 | 534 | 1,182 | 2,229 | 2,829 | 8,314 | 9,673 | 5,296 | 1,712 | 36,003 |

**Table A1-4: Heating Equipment Segmentation by Building Type (million sqft)**

| Building Type | Education | Food Sales | Food Service | Health Care | Lodging | Mercantile & Service | Office | Public Buildings | Warehouse/ Storage | Totals |
|---|---|---|---|---|---|---|---|---|---|---|
| Packaged Unit | | | | | | | | | | |
| Gas | 1,252 | 361 | 744 | 322 | 173 | 3,445 | 2,559 | 1,927 | 876 | 11,649 |
| Electric | 136 | 39 | 81 | 35 | 18 | 374 | 278 | 209 | 95 | 1,263 |
| Furnace | | | | | | | | | | |
| Gas | 450 | 66 | 288 | 71 | 251 | 1,890 | 817 | 1,107 | 811 | 5,751 |
| Oil | 120 | 18 | 77 | 19 | 67 | 505 | 218 | 296 | 217 | 1,536 |
| Electric | 90 | 13 | 58 | 14 | 50 | 378 | 163 | 221 | 162 | 1,150 |
| Unit Heater | | | | | | | | | | |
| Gas | 470 | 33 | – | 148 | 407 | 1,174 | 745 | 457 | 640 | 4,074 |
| Electric | 254 | 18 | – | 80 | 220 | 634 | 403 | 247 | 346 | 2,202 |
| PTHP, WLHP | – | – | – | – | 835 | – | 419 | – | – | 1,254 |
| Individual Space Heater | | | | | | | | | | |
| Radiant | 40 | 3 | – | 13 | 35 | 100 | 64 | 39 | 55 | 349 |
| Baseboard | 40 | 3 | – | 13 | 35 | 100 | 64 | 39 | 55 | 349 |
| Boiler | | | | | | | | | | |
| Gas | 2,329 | – | – | 649 | 632 | 940 | 1,658 | 1,096 | 243 | 7,548 |
| Oil | 1,367 | – | – | 381 | 371 | 552 | 973 | 643 | 143 | 4,430 |
| Heat Pump | 352 | – | – | 81 | 42 | 729 | 667 | 489 | 188 | 2,549 |
| District Heating | 858 | – | – | 560 | 481 | 0 | 1,204 | 695 | 158 | 3,957 |
| Totals | 7,760 | 554 | 1,247 | 2,387 | 3,608 | 10,821 | 10,231 | 7,464 | 3,988 | 48,060 |

## APPENDIX 2: BACKGROUND DATA

The data in this appendix were used as input for the study's segmentation calculations.

**Table A2-1: Heated/Cooled and Total Floorspace**

| | Heated Floorspace (million square feet) | Cooled Floorspace (million square feet) | Total Floorspace (million square feet) |
|---|---|---|---|
| **Northeast** | 9,919 | 5,936 | 11,883 |
| *New England* | *2,697* | *1,432* | *3,140* |
| *Middle Atlantic* | *7,222* | *4,504* | *8,743* |
| **Midwest** | 12,382 | 7,997 | 14,323 |
| *East North Central* | *8,219* | *5,032* | *9,655* |
| *West North Central* | *4,163* | *2,965* | *4,668* |
| **South** | 16,667 | 14,716 | 20,830 |
| *South Atlantic* | *7,621* | *6,776* | *9,475* |
| *East South Central* | *3,953* | *3,292* | *4,917* |
| *West South Central* | *5,093* | *4,648* | *6,438* |
| **West** | 9,096 | 7,352 | 11,736 |
| *Mountain* | *3,272* | *2,574* | *3,855* |
| *Pacific* | *5,824* | *4,778* | *7,881* |
| **Totals** | **48,064** | **36,001** | **58,772** |

Source: Allan Swenson Fax 10/8/97 (Reference 4)

**Table A2-2: Cooled Floor Area (raw data)**

| | Building/System Breakdown | | | Disaggregation for Central (Source 1) | | |
|---|---|---|---|---|---|---|
| **Building Type** | **System Type** | **Cooled Floorspace (million sqft)** | **Source** | **FCU (million sqft)** | **VAV (million sqft)** | **Ducted (million sqft)** |
| **Education** | Residential Type | 542 | 2 | | | |
| | Heat Pump | 481 | 2 | | | |
| | Individual AC | 1090 | 1 | | | |
| | Central | 1304 | 2 | 427 | 506 | 1112 |
| | Packaged | 1984 | 2 | | | |
| **Food Sales** | Residential Type | 149 | 2 | | | |
| | Heat Pump | | 2 | | | |
| | Individual AC | | 1 | | | |
| | Central | | 2 | | | |
| | Packaged | 312 | 2 | | | |
| **Food Service** | Residential Type | 299 | 2 | | | |
| | Heat Pump | | 2 | | | |
| | Individual AC | 181 | 1 | | | |
| | Central | | 2 | | | |
| | Packaged | 724 | 2 | | | |
| **Health Care** | Residential Type | 547 | 2 | | | |
| | Heat Pump | 300 | 2 | | | |
| | Individual AC | 627 | 1 | | | |
| | Central | 1288 | 2 | 569 | 906 | 1236 |
| | Packaged | 1221 | 2 | | | |
| **Lodging** | Residential Type | 397 | 2 | | | |
| | Heat Pump | 721 | 2 | | | |
| | Individual AC | 1389 | 1 | | | |
| | Central | 781 | 2 | 411 | 316 | 626 |
| | Packaged | 1101 | 2 | | | |
| **Mercantile and Service** | Residential Type | 1206 | 2 | | | |
| | Heat Pump | 936 | 2 | | | |
| | Individual AC | 856 | 1 | | | |
| | Central | 1190 | 2 | | 558 | 1120 |
| | Packaged | 5330 | 2 | | | |
| **Office** | Residential Type | 1478 | 2 | | | |
| | Heat Pump | 2034 | 2 | | | |
| | Individual AC | 924 | 1 | | | |
| | Central | 3382 | 2 | 489 | 2177 | 3191 |
| | Packaged | 5178 | 2 | | | |
| **Public Assembly, Public Order and Safety Religious Worship** | Residential Type | 1267 | 2 | | | |
| | Heat Pump | 634 | 2 | | | |
| | Individual AC | 1105 | 1 | | | |
| | Central | 1141 | 2 | | 575 | 1068 |
| | Packaged | 2428 | 2 | | | |
| **Warehouse/Storage** | Residential Type | 417 | 2 | | | |
| | Heat Pump | 216 | 2 | | | |
| | Individual AC | 324 | 1 | | | |
| | Central | 90 | 2 | | | 89 |
| | Packaged | 1071 | 2 | | | |

**Sources: 1. Alan Swenson Fax, 10/14/97, Table 4 (Reference 5)**
**2. Alan Swenson Fax, 10/16/97, Table 11 (Reference 6)**

**Table A2-3: CBECS95 Cooling Equipment Data**

| Cooling Equipment (more than one may apply) | Total Floorspace of All Buildings | Total Floorspace of all Cooled Buildings | Residential-Type Central Air Conditioners | Heat Pumps | Individual Air Conditioners | District Chilled Water | Central Chillers | Packaged Air Conditioning Units | Swamp Coolers | Other |
|---|---|---|---|---|---|---|---|---|---|---|
| Residential-Type Central Air Conditioners | 9,238 | 9,238 | 9,238 | 917 | 2,424 | 169 | 1,432 | 2,885 | 356 | Q |
| Heat Pumps | 6,931 | 6,931 | 917 | 6,931 | 1,519 | 175 | 1,179 | 2,857 | 508 | Q |
| Individual Air Conditioners | 12,494 | 12,494 | 2,424 | 1,519 | 12,494 | 298 | 2,398 | 4,976 | 417 | 188 |
| District Chilled Water | 2,521 | 2,521 | 169 | 175 | 298 | 2,521 | Q | 649 | Q | Q |
| Central Chillers | 11,065 | 11,065 | 1,432 | 1,179 | 2,398 | Q | 11,065 | 4,796 | 530 | 291 |
| Packaged Air Conditioning Units | 26,628 | 26,628 | 2,885 | 2,857 | 4,976 | 649 | 4,796 | 26,628 | 1,303 | 316 |
| Swamp Coolers | 2,451 | 2,451 | 356 | 508 | 417 | Q | 530 | 1,303 | 2.451 | Q |
| Other | 949 | 949 | Q | Q | 188 | Q | 291 | 316 | Q | 949 |

**Source: CBECS95 Table BC-36**
**Q: data not reported because it is based on too few survey responses**

Table A2-4 below shows shipment data for unitary AC equipment reported in Current Industrial Reports: Refrigeration, Air-Conditioning, and Warm Air Heating Equipment, Annual 1994, U.S. Department of Commerce, August 1995 (Reference 13).

**Table A2-4: Unitary AC Shipment Data (1994)**

| | <65,000 Btu/hr | >65,000 Btu/hr | Total |
|---|---|---|---|
| Single Package AC | | | |
| Horizontal | 165,296 | 47,389 | 212,685 |
| Other | 4,855 | 2,391 | 29,667 |
| Year-Round AC, Single-Package and Split (No Heat Pumps) | 373,641 | 119,714 | 493,405 |
| Air Source Heat Pumps (no Room AC) | | | |
| Single-Package | 139,986 | 8,560 | 148,546 |
| Split | 835,782 | 11,857 | 847,639 |
| Split System AC Coils | | | |
| With Blower | | | 1,164,039 |
| Without Blower | | | 1,564,582 |
| PTAC | | | 100,595 |
| PTHP | | | 75,552 |
| Water-Source Heat Pump | | | 99,321 |
| Room Air-Conditioner | | | 3,265,427 |