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RD&D Opportunities for Large Air Conditioning and Heat Pump Systems

Final Report

Principal Investigators

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Report Prepared by

TRW
Energy Engineering Division
800 Oak Ridge Turnpike
Oak Ridge, Tennessee 37830

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Abstract

This report summarizes the marketplace factors that constrain a more rapid implementation of energy-conserving heating, ventilating, and air conditioning (HVAC) systems and system operation in commercial buildings. Recommendations for technical and nontechnical research, design, and development (RD&D) opportunities which will assist and/or motivate this implementation were developed. The focus was on large air conditioning and heat pump equipment.

Use of currently available energy-efficient equipment and systems is presently limited by the economic situation of the building owners. To date, increasing energy prices have not shown much potential for changing this situation. Although case histories of energy-efficient buildings (recent literature studies) highlight the potential of new and existing equipment and systems, the majority of systems and equipment being installed today does not measure up to that potential. The major recommendations of this study deal with developing the market for energy-efficient HVAC systems by (1) reversing existing market forces that promote energy consumption; (2) promoting technical research and educational programs covering application and operation of those systems; and (3) increasing the number of technical people competent in the area of high-efficiency system application and maintenance. Other recommendations deal with energy service, energy economics and the technical aspects of the systems, equipment, and controls.

Included in this report are discussions pertaining to system and equipment, state-of-the-art energy conservation concepts, energy use and system cost comparison, building and air conditioning equipment populations, commercial energy use patterns, the effects of nontechnical constraints, and opportunities for RD&D.

1. INTRODUCTION

1.1 Background and Purpose

This report documents an investigation of present day large heat pump and air conditioning (A/C) equipment designs and population distributions, commercial buildings population distributions, constraints on the development and use of energy efficient heating, ventilating, and air conditioning (HVAC) systems for buildings; and an evaluation of research, design, and development (RD&D) opportunities for HVAC systems in commercial buildings.

The purpose of this study was to evaluate the factors in the marketplace which constrain a more rapid implementation of energy conserving HVAC systems and system operation, with a focus on large A/C equipment. A further purpose was to recommend technical and non-technical RD&D opportunities which will assist and/or motivate this implementation. Reducing the energy used for environmental conditioning in buildings could be an important contribution to a reduction in the national energy consumption. In the commercial sector, air conditioning accounted for about two Quads (10^{15} Btu) of energy resource consumption in 1980, which is 2.5 percent of the annual consumption of energy resources in this country (Reference 1-1).

In recent years, a relatively successful heat pump development effort has occurred in government and industry. However, that effort is aimed at smaller (residential) equipment. In the commercial sector, A/C equipment and systems are more complicated. A/C equipment is but a single element in the successful design of building HVAC systems, and this equipment provides both heating and cooling energy in certain buildings. Therefore, this report presents the populations data, system descriptions, energy and system cost comparisons, and discussions of non-technical constraints for all A/C equipment which is representative of the commercial sector. An understanding of this milieu is necessary to assess the RD&D opportunities that could lead to conservation of energy.

1.2 Objectives

This investigation has been performed to provide an assessment of the energy use of A/C equipment and associated HVAC systems in the commercial

sector and the opportunities for decreasing the energy used by A/C equipment and associated HVAC systems in commercial sector buildings. The information is intended to serve as an aid in program development for DOE RD&D activities aimed at reducing commercial sector energy use.

The objectives of this study are to:

- Describe existing data bases on commercial sector buildings, A/C equipment, and energy use
- Estimate commercial building and A/C equipment populations
- Assess the effects of important non-technical factors on the development and increased use of energy conserving A/C equipment and associated HVAC systems
- Describe A/C equipment market sizes
- Perform a basic comparison of the relative energy use and installation cost of some common HVAC systems
- Synthesize an overall assessment of the interaction of the many factors affecting energy programs for reducing energy use of A/C equipment and associated HVAC systems in the commerical milieu
- Formulate recommendations for RD&D activities aimed at reducing commercial sector energy use

The final recommendations resulting from this investigation cover both technical and non-technical opportunity areas for increasing energy conservation in commercial buildings. This coverage includes the development of educational, financial, psychological, regulatory, or other mechanisms to increase the use of energy conserving equipment and systems.

1.3 Scope

This investigation concerns electric-drive, vapor compression cycle A/C equipment and HVAC distribution and control systems used for the environmental conditioning of commercial buildings. Heat pumps and compound uses of A/C equipment are of special concern because of the dual heating/cooling capability. The study was limited to larger equipment, 5 1/2 tons and larger for heat pumps and unitary equipment and 20 tons and larger for liquid chillers. These size restrictions eliminate residential-size unitary equipment and small liquid chillers, which are used mostly for process applications.

The commercial sector population of buildings used for this report includes twelve building types, which are based on the Nonresidential Buildings Energy Consumption Survey (NBECS) of the Energy Information Administration (EIA) of the Department of Energy (DOE). These types are:

- Assembly
- Automotive sales and service
- Education
- Food sales
- Health care
- Lodging
- Office
- Residential
- Retail/Services
- Warehouse and storage
- Other
- Vacant

1.4 Organization of Report

The report is organized in nine major sections. Sections 2 and 3 provide descriptions of the systems and equipment of interest and state-of-the-art energy conservation concepts for A/C systems. A discussion of the relative energy use and capital cost of various A/C systems, based on previous studies, is contained in Section 4. The important work performed for this study on commercial buildings and A/C equipment populations is documented in Section 5. Section 6 provides estimates of national energy use by A/C equipment type and building type. In this study, a major effort was aimed at non-technical constraints on the development and use of energy conserving systems and equipment. The results of that effort are reported in Section 7. Section 8 contains an overall evaluation of the factors affecting RD&D opportunities of interest for this study, and Section 9 has the results and recommendations of this study.

2. SYSTEM/EQUIPMENT DESCRIPTION

Environmental control systems can be divided into the following broad categories: cooling equipment; distribution equipment and systems; and control systems.

Cooling equipment can be subdivided into two categories: 1) air cooling equipment; and 2) water chilling equipment.

Air cooling equipment - warm air is cooled as it passes through direct expansion coils (on the finned side) and absorbs the latent heat of evaporation of the refrigerant, while the refrigerant passes through the tubes.

Water chilling equipment - water is cooled in heat exchangers (normally shell and tube). In larger capacity (>200 tons) equipment, the water passes through tubes submerged in the liquid refrigerant. The liquid refrigerant is vaporized on the tube surfaces as the heat is extracted from the warm water. This type of chiller will be referred to as a "flooded" chiller in this study. In smaller capacity (<200 tons) equipment, the water passes through the shell, and the refrigerant is vaporized in the tubes. This type of chiller will be referred to as a "direct (dry) expansion" (DX) chiller in this study.

With the exception of some direct water cooled commercial equipment, the ultimate means of transmitting cooling effect to a conditioned space is by the circulation of cooled air. Thus, direct air cooling equipment requires heat transfer across a temperature difference only once, from the air to the refrigerant. However, large energy expenditures may be incurred by air moving fans if the cooled air must be distributed long distances. With water chilling equipment, water is a "secondary refrigerant" which, in turn, must transfer heat to(from) an air distribution system. Generally, this is done in one or more air handling units dispersed throughout the building as necessary to minimize excessive air moving energy losses; water is a more energy efficient medium for long distance heat distribution. Perimeter spaces often use forced convection fan-coil units (cooling or heating) or natural convection baseboard units (heating only) along the outside wall to offset building skin losses to(from) the outside ambient. Whenever a secondary refrigerant is used, heat transfer across a second temperature difference is incurred, with an associated loss in refrigeration efficiency.

Environmental control systems perform the important function of commanding all components in the HVAC system to interact properly.

2.1 Cooling (Refrigeration)/Heat Pump Equipment

Cooling, refrigeration, and heat pump equipment of interest in this study employ the refrigeration vapor compression cycle. The heat pump is a special application of this cycle because it is reversible. The essential components of the refrigeration cycle are:

- Compressor
- Condenser
- Evaporator
- Expansion device

The refrigerant leaves the evaporator as a low pressure, low temperature, nearly saturated vapor and enters the compressor where it is compressed to a high temperature, high pressure, superheated vapor. The hot vapor enters the condenser where it is desuperheated and condensed at a constant pressure to a liquid. This liquid is expanded through the expansion device to a low pressure, low temperature, low quality vapor before entering the evaporator. The bulk temperature of the liquid refrigerant is cooled to evaporator temperature through release of the sensible cooling heat to latent heat of evaporation of a portion of the liquid (flash gas). In the evaporator, the remaining liquid is evaporated (by absorbing heat from the air being cooled) to the original saturated vapor starting point to start the cycle again. The conditioned space heat is thus absorbed by the evaporator and rejected by the condenser. The major differences in the types of refrigeration machines are: the method of compression; the refrigerants used; and the type of loads that are to be cooled. The two major equipment types are:

- Positive displacement - The increase in refrigerant pressure on the high pressure side is attained by work done on the refrigerant gas which reduces the volume of the gas in the compression chamber of the compressor. The refrigerants which are typically used for this type of machine have low specific volumes, relatively low molecular weights, and high compression ratios. Variable, as well as constant pressure loads can be handled. Commercial equipment of this type is generally limited to reciprocating or screw compressors.

- Centrifugal - The refrigerant pressure is increased by continuous exchange of angular momentum from the rotating mechanical element to a continuous refrigerant stream. The refrigerants which are typically used for this type of machine have relatively high molecular weights, high specific volumes, and low compression ratios. The loads are typically larger (higher volume of refrigerant), and these machines handle constant pressure loads.

Another subdivision of refrigeration machines is unitary equipment and applied or built-up systems. The positive displacement reciprocating compressor usually is used in unitary units which are in the smaller refrigeration capacity ranges (<100 - 200 tons), and are packaged in unitary enclosures (which include all the refrigeration components) or in the condensing unit of split systems (see Section 2.1.1). The centrifugal compressors are favored for the applied systems in the larger capacity ranges. The positive displacement screw compressor is used in both unitary and applied systems.

2.1.1 Unitary equipment

A unitary air conditioner consists of an evaporator, a compressor and condenser combination, and may include a heating function. The unitary air conditioner systems are used in various configurations ranging from one unit for each of a series of rooms to multiple room - single conditioners and single room - multiple conditioners. Unitary conditioners may be equipped with factory-built or field-fabricated air plenums, with supply air distributed in one to four directions through grilles or connected to ducts for distribution. Unitary units are available with air or water cooled condensers, with the air cooled condenser being the most favored. Normally, the ultimate heat sink for water cooled units is cooling towers. Unitary units may be supplied in roof-mounted or through the wall configurations. Some unitary units are divided into split systems where the air handling portion is separated from the compressor and condenser section. The split system will have field-fabricated refrigerant piping. The reciprocal type compressor is favored for unitary equipment because the capacity (tonnage) of these units is usually lower. Generally, these unitary units are less than 20 tons, but some units may be as large as 100 tons (multiple compressors).

2.1.2 Applied systems (chillers)

The majority of the applied systems (i.e., built-up systems) used in the United States employ a water chiller to generate cold water. A chiller is a refrigeration machine using a chiller evaporator to remove heat from the water flow and reject it to the atmosphere through the condenser circuit. Chillers can be categorized into two major classifications: 1) absorption machines; and 2) refrigerant (vapor compression) machines. Absorption machines will not be discussed in this document. Refrigerant machines can be further classified by compressor type as: reciprocating; centrifugal; and screw. These three classes are discussed in the following sections.

Compressors may be further classified by the type of driver. An open type compressor has an external driver which includes a shaft seal that separates the refrigerant cycle from the atmosphere. The hermetic compressor has the electric motor enclosed in the same housing as the compressor and operates in the refrigerant atmosphere. Also, compressors may be manufactured in semi-hermetic versions, where the cylinder heads are removable for servicing of the valves and pistons.

2.1.2.1 Reciprocating compressors.

In the positive displacement reciprocating compressor, the gaseous refrigerant pressure is increased by the coordinated action of pistons and valves. During the suction stroke of the piston, the low pressure refrigerant gas is drawn through the suction valve. Then, the piston travels to decrease the volume of the gas in the cylinder, therefore increasing the pressure. At the end of the compression stroke, the high pressure gas is exhausted through the discharge valve. These compressors can be manufactured in multiple cylinder arrangements, such as V cylinder or radial cylinder layouts. The various types of compressors may be single-acting, in which the gas is compressed in only one direction of piston travel, or double-acting, where the gas is compressed in both directions of piston movement.

Because reciprocating compressors are positive displacement machines, they can handle variable pressures better than centrifugal machines. Therefore, they are more adaptable. One disadvantage is the lack of flexibility

for capacity control. Cylinder unloading allows step changes in capacity, but the number of steps is limited by the number of cylinders. Although some would argue that, with proper application, maintenance should not be any more of a problem than with other types of compressors, reciprocating machines are generally considered to require more maintenance than centrifugal or screw machines.

2.1.2.2 Centrifugal compressors.

From a thermodynamic standpoint, the centrifugal refrigeration cycle is identical to the vapor-compression system using a positive displacement reciprocating compressor. The centrifugal compressor is a variable displacement machine consisting of one or more impellers, spinning in specially formed housings, that impart a high velocity to the refrigerant vapor and increase the kinetic energy. The energy is converted to static pressure in the expanding section of the impeller housing and develops the head pressure necessary to condense the refrigerant vapor at a given heat sink temperature.

Because of economies of scale, centrifugal compressors are used for higher capacity machines. Also, the centrifugal machine inherently handles a higher volume of refrigerant flow. Centrifugal machines can be furnished with open or hemetic drives and are available in a wide range of capacities. One advantage of the centrifugal compressor is its high rotative speed, which makes it suitable for direct connection to electric motors or steam turbines. Another advantage is the reduced number of moving parts (no piston rings or valves) to wear out, thus reducing the maintenance cost. One disadvantage is the higher performance penalty for variable pressures. Capacity control is more flexible for centrifugal compressors.

Methods of capacity control for centrifugal compressors are:

- Off-on control
- Hot gas bypass control
- Condenser water regulation
- Butterfly damper control
- Speed controls
- Variable inlet guide vanes

Off-on control - is not normally used because the continuous off-on action is prohibitive to long motor life on larger units.

Hot gas bypass control - is installed between the discharge and suction side of the compressor. When the reduced load approaches the surge envelope (at flow rates lower than the surge envelope flow rates, unstable system operation occurs with attendant violent vibrations), the bypass valve begins to open and permits high pressure vapor from the discharge side of the compressor to enter the evaporator, increasing the enthalpy of the refrigerant entering the evaporator, thus decreasing the refrigerating effect (thermal capacity). As the load is further reduced, the bypass opens wider to maintain a fixed minimum volume flow through the compressor. Bypass control is wasteful because there is no reduction of power input to the compressor as the bypass increases its function of load reduction.

Condenser water regulation - is used because a centrifugal compressor has a flat head-versus-capacity curve for a constant impeller speed. This means that a small increase in head will cause a large reduction in capacity. Reducing the amount of water flow through the condenser will increase the condenser pressure, therefore increasing the discharge head. A thermostatic control senses the chilled water temperature leaving the evaporator. A decrease in the chilled water temperature signifies a decrease in evaporator load. When the condenser water regulator senses a reduced chilled water temperature, the amount of water being delivered to the condenser is reduced and causes an increase in the condenser pressure. A disadvantage of this type of capacity control is the deposit of dissolved compounds in the condenser water on the condenser heat transfer surfaces, as the condenser water temperature rises. Another disadvantage is the increased power consumption resulting from the increase in head pressure.

Butterfly damper control - is commonly located in the suction line of the refrigeration system to lower the surge point of the compressor. A pressure drop across the butterfly damper causes the specific volume of the refrigerant gas entering the impeller to increase. This is reflected as an increase in volume flow so that the required minimum volume flow to prevent surging can be attained with refrigerant gas of less mass flow and density. Since a lower mass flow rate means less refrigerant is vaporized (in the evaporator), the system is actually operating at a lower load. The butterfly damper allows stable operation down to about 40 to 50 percent of full

load capacity. The decrease in horsepower for a butterfly damper control system follows a falling load reasonably well, but because of the resistance the damper introduces in the suction line, the power required does not fall off as fast as the capacity is reduced.

Speed control - is used to extend the stable range of the compressor to a lower load. This capacity control method is based upon reducing the impeller speed to lower the volume of refrigerant flow while operating above the surge point. Theoretically, speed control is attractive; but practically, it has limitations that make it less desirable or inadequate as the complete answer to capacity control. Generally, stepped speed control is coupled with one of the other means of capacity reduction, such as adjustable inlet guide vanes, to take full advantage of its capabilities. The advantages of infinite range speed control are partially offset by the inefficiencies of the speed reduction equipment (e.g., inverter). At the present time, infinite speed control equipment adds a considerable installed cost penalty.

Variable inlet guide vanes - work on a principle similar to butterfly damper control. The butterfly damper on the suction side of the centrifugal compressor reduces the mass flow though the impeller by introducing pressure drop. With the butterfly damper, the process is inefficient because of the turbulence created in the refrigerant flow. Inlet guide vanes, or prerotation vanes, accomplish the pressure reduction more efficiently by substantially reducing the wasteful turbulence. The inlet guide vane consists of a number of wedgeshaped, center-pivoted dampers which introduce the necessary pressure drop while imparting a spin or prerotation to the refrigerant gas in the direction of impeller rotation, thus, reducing the turbulence as the gas enters the impeller. Reduced power consumption is enhanced by the resultant velocity component in the direction of rotation which reduces the required acceleration of the gas to reach the impeller rotational velocity.

The use of variable inlet guide vanes is probably the most economical means of capacity control for centrifugal compressors when considering both first cost and operating cost. However, this is becoming a controversial subject by the manufacturers of the various types of control systems and is application dependent. Variable inlet guide vanes can move the surge point lower on the surge envelope (to a lower load) and thereby increase the stable operating range of the compressor, and they also yield a more direct

relationship between reduction in capacity and power. Capacity control can be accomplished in the 10-100 percent range.

2.1.2.3 Screw compressors.

The most common screw compressor in use in the U.S. consists of two intermeshing helical grooved rotors, with oil injection provided to limit bypass gas leakage. The male rotor is supplied with motive power while the intermeshing female rotor is driven by the male rotor. The rotors are enclosed in a stationary housing with a slide valve, for infinite capacity modulation, and discharge and entrance gas ports. The compressor functions by admitting gas into the interlobe spaces. As the rotor turns, the interlobe spaces increase in volume and admit more gas. As rotation continues, the gas in the interlobe space is carried circumferentially around the compressor housing. More rotation meshes a male lobe with the interlobe space and compresses the gas axially in the direction of the discharge port where the gas is discharged. The slide valve functions as a capacity control system by creating an opening at a variable axial location along the rotor housing. Suction gas can pass from the rotor housing to the inlet port, which minimizes thermodynamic work of the recirculation gas. Therefore, the machine has the potential for efficient part load operation. The capacity modulation slide valve is controlled by an electrically initated, hydraulic actuated control scheme. The Hall compressor, manufactured in England, consists of a helical rotor (driven) and two intermeshing free wheeling stars. This compressor uses two axial sliding valves for infinite capacity modulation.

A screw compressor has the inherent application flexibility which is common in all positive displacement machines. The machine is free of vibrations and significant noise and wear because of the pure rotary motion. The units may also be supplied in the open or hermetic drive configuration and are available in a wide range of capacities.

2.1.3 Heat pumps

A heat pump system uses refrigeration equipment to extract heat for a heat source and distribute it at a higher temperature to a conditioned space

or process load. A heat pump can also remove heat from a conditioned space and discharge it to a heat sink when cooling and dehumidification is required. Except for the reversibility function, the thermal cycle is identical to the ordinary refrigeration cycle. Changeover between the heating and cooling functions is accomplished by actuating valves in the refrigerant lines to interchange the role of the condenser and evaporator in the refrigerant cycle. The cycle reversing device is normally an electrically actuated 4-way valve or two 3-way valves.

The heat pump delivers more heat to the conditioned space than has been taken from the heat source because of the addition of the heat of compression (energy to the drive motor). The efficiency or coefficient of performance (COP - dimensionless) is defined as:

$$\text{COP} = \frac{\text{Energy out}}{\text{Energy in}} = \frac{\text{Heat discharged (condenser)}}{\text{Work input}} =$$

$$= \frac{\text{Heat absorbed (evaporator)} + \text{Work input}}{\text{Work input}}$$

When necessary in the heating mode, the condenser coil is defrosted by momentarily reversing the cycle until the ice buildup is melted. Heat pump units have additional electric resistance heaters to function as booster heaters when the heat pump is operating in more inefficient ranges, to supplement the heat source necessary for defrost, or to provide the heating function in case of malfunction.

Heat pumps are similar in appearance to normal unitary units and may be supplied in sizes up to about 100 tons.

Heat pumps may be used with the following heat source and sink combinations:

- Air-to-air
- Air-to-water
- Water-to-air
- Water-to-water

When an air-to-air heat pump is used in the heating mode, heat is extracted from the outdoor air through the outdoor coil, which functions as the evaporator, and dumped into the conditioned space through the indoor coil, which functions as the condenser. In the cooling mode, the outdoor

coil (condenser) is used to reject heat to outside air while the heat is picked up at the indoor coil (evaporator) in the conditioned air stream. Because the COP is a function of the source and sink temperature, it can vary greatly. The colder the outside air, which is the heat source in the heating mode, the lower the COP or the greater the required power input per heating unit.

Water can be used as a heat source or heat sink depending on whether the unit is in the heating or cooling mode. In the heating mode, water-to-air heat pumps have a higher, relatively constant COP, thereby, minimizing the use of the electric resistance auxillary heater. Water supplies can be taken from ground water sources or from water loops connected to other heat pump or air conditioning units. Water loops connected to air conditioning units are particularly useful in commercial buildings where, in any season, the central core often needs cooling because of the internal loading and the peripheral areas need heating. As the building load changes due to the variable solar input, this configuration is also useful for simultaneous heating/cooling in different portions of the same building. By using air as the heat source and water (to be heated) as the heat sink, an air-to-water heat pump can be modified for use as a hot water heater.

2.2 Distribution Systems

2.2.1 Single zone - central system

A single zone system is the simplest of the air distribution systems. This system schematic is shown in Figure 2-1a. A single zone system consists of a mixing, conditioning, and fan section. The conditioning section can provide cooling or heating. A single zone system may or may not have a ducted distribution system. The basic mixing and fan section designs are common to all other central systems discussed in the following descriptions and will not be mentioned further except for special considerations.

2.2.2 Multi-zone system - central system

The multi-zone system schematic is shown in Figure 2-1b. Multi-zone systems condition (heat and cool) all the air at the central system (air

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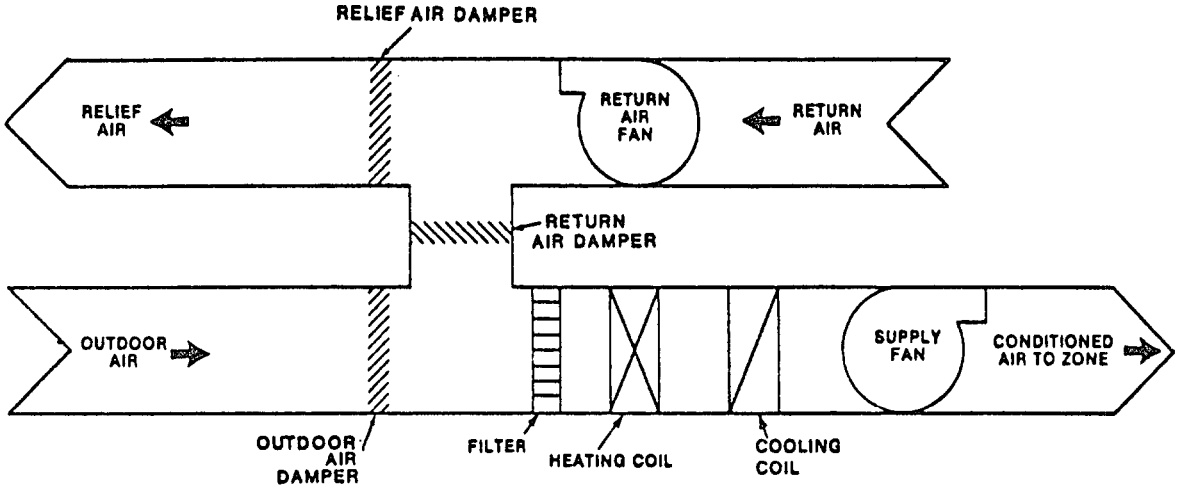

Figure 2-1a. Single Zone System

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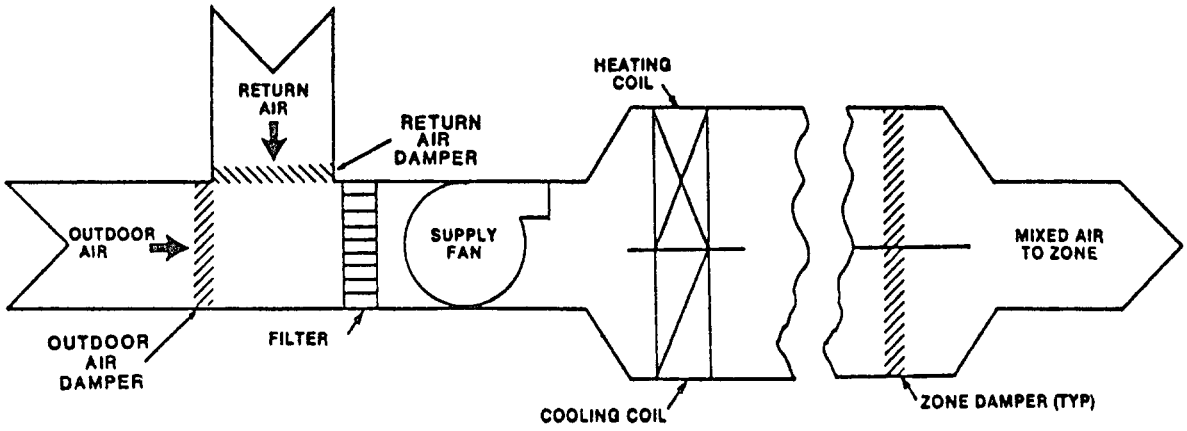

Figure 2-1b. Multizone System

handler). The heated and cooled air streams are mixed at the unit to satisfy the various zone loads. In order to control the temperature, and thus the heating (or cooling) input of each individual zone from a single source supply, hot and cold air is mixed in proportion to the demand. The extra energy used to simultaneously heat and cool air, to be mixed to satisfy zone demands, can be very appreciable.

A multi-zone system can be made more energy efficient by use of hot and cold deck temperature reset. With this change in control, the hot/cold deck temperatures are controlled by the zone with the largest demand for heating/cooling. Therefore, less mixing of hot and cold air is required and saves energy. Also, the deck temperature responds to an actual load rather than an arbitrary fixed setting based on peak conditions or schedule based on outdoor temperature.

2.2.3 Dual duct system - central system

As shown in Figure 2-1c, dual duct systems are similar to multi-zone systems. Heated and cooled air streams are mixed to satisfy zone heating or cooling loads and are equally inefficient. However, with a dual duct system, the air streams are mixed at terminal mixing boxes instead of at the central unit. As with the multi-zone system, dual duct system energy usage can be reduced by using hot/cold deck temperature reset.

2.2.4 Terminal reheat - central system

The schematic of a terminal reheat system is shown in Figure 2-1d. Usually, in a terminal reheat system, the central conditioning system supplies a fixed temperature (cold) air to the zones which can satisfy the maximum cooling load. For zone heating/cooling loads requiring less than maximum cooling, the difference, in the form of heating energy, is supplied by the terminal heating coils called reheat coils. Again, this is a dreadful waste of energy on both the heating and cooling systems. The air is overcooled and reheated only for control purposes. Occasionally, there is a humidity control requirement for reheat, but this seldom occurs.

A terminal reheat system can be improved by using a zone optimizing load analyzer. With this type of control, the cooling requirement of each

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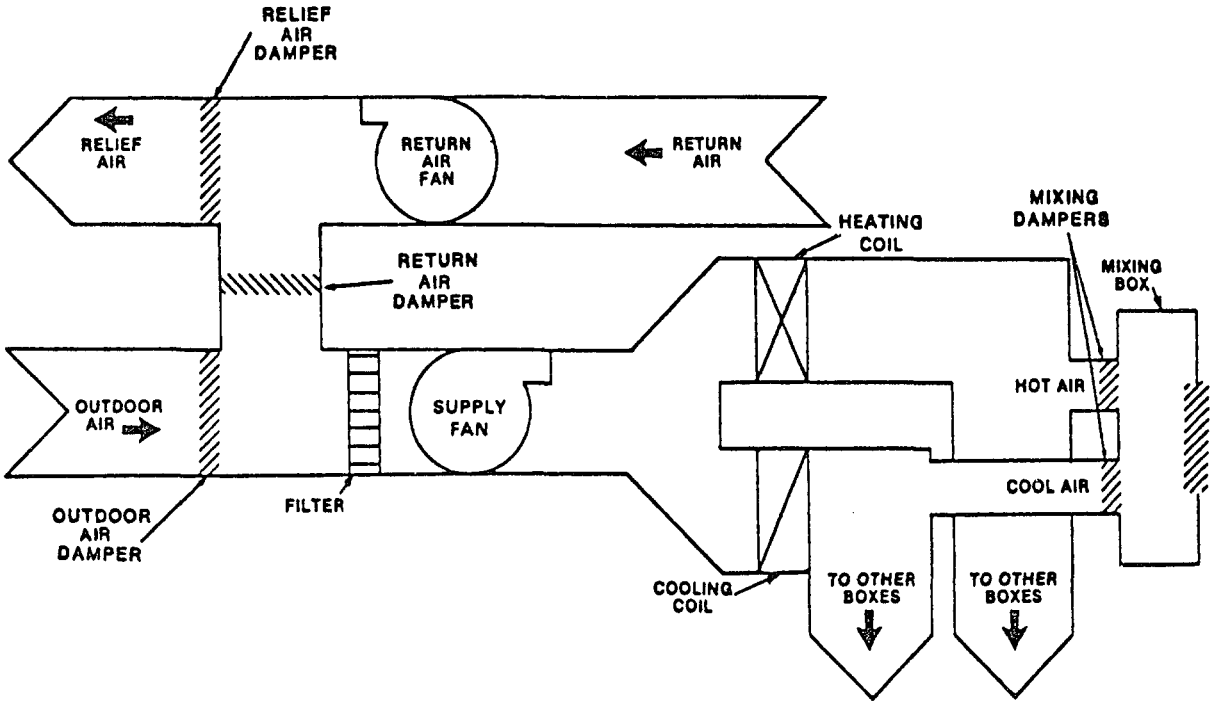

Figure 2-1c. Dual Duct System

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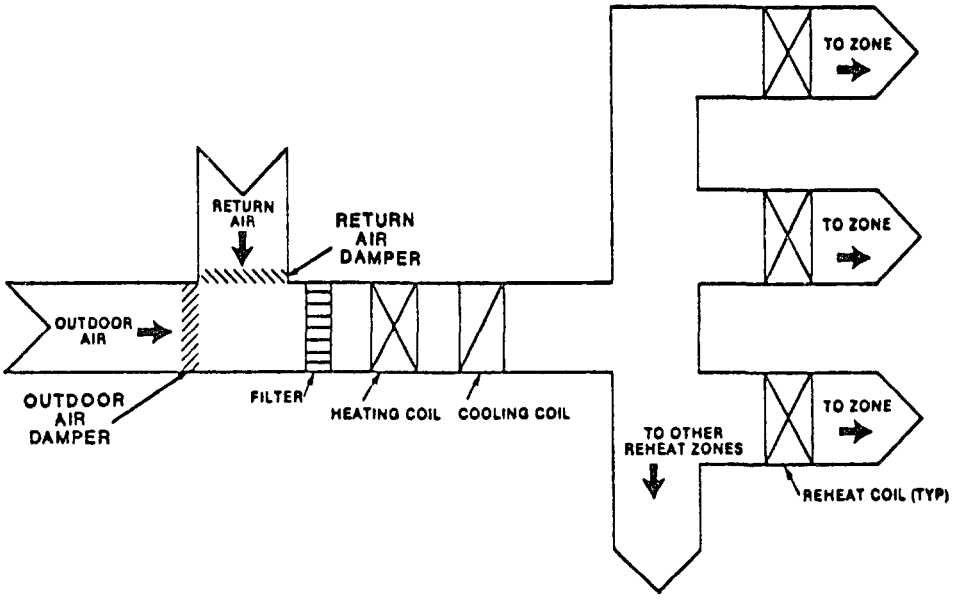

Figure 2-1d. Terminal Reheat System

zone is monitored, and the (cold) supply air temperature is adjusted to minimize the amount of reheating required.

2.2.5 Variable air volume (VAV) systems - central system

In a VAV system (Figure 2-1e) the amount of fixed temperature air supplied by the central conditioning section is varied at each of the zones to satisfy zone load requirements. The volume of air delivered to each zone is determined by terminal flow control units. The overall system static pressure is maintained by adjusting the total air flow of the system to the level needed for the terminal flow control units to function properly. System flow can be adjusted by:

- Fan inlet vane dampers (Figure 2-1e)
- Variable fan speed (Figure 2-1e)
- Fan inlet or outlet (throttling) dampers (Figure 2-1f)
- Bypass loop (located at the fan section) (Figure 2-1g)

Typically, the bypass loop method is used for smaller systems where other methods of flow control might be too expensive. In some systems, terminal reheat coils are added (Figure 2-1h) when the terminal flow control units have a minimum flow setting and only cold air is supplied by the central conditioning section.

Presently, the VAV application is considered the most energy efficient distribution system for multiple zone applications. Due to the recent economic and code pressures for reduction in energy use, a rapid increase in usage of this application is occurring.

2.2.6 Fan coil units, unit ventilators - distributed system

Schematics of fan coil units and unit ventilators are shown in Figures 2-1i and 2-1j. Both units consist of a cabinet with a heating and/or cooling coil, fan and filter. The units can be either floor or ceiling mounted and used with a two-, three-, or four-pipe water distribution system. The fan coil units use 100 percent return air, while unit ventilators use return and outside air.

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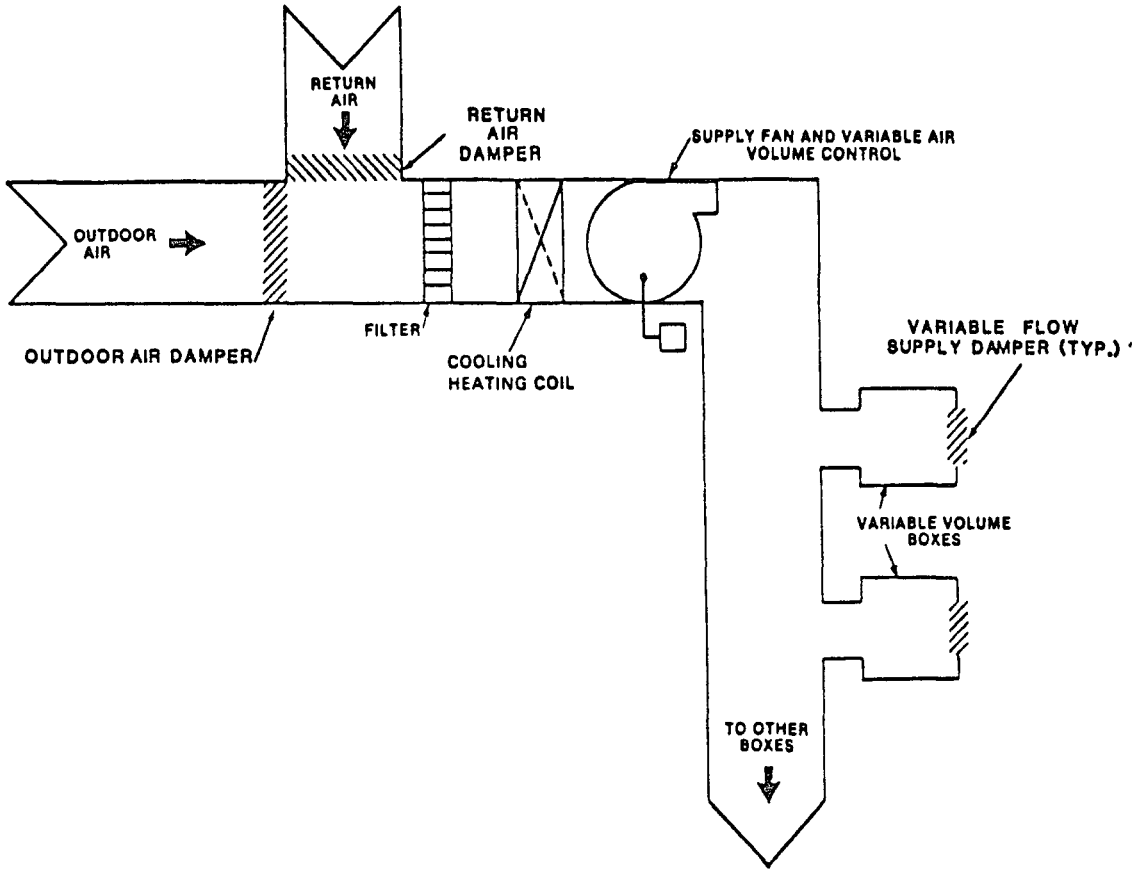

Figure 2-1e. Variable Air Volume System

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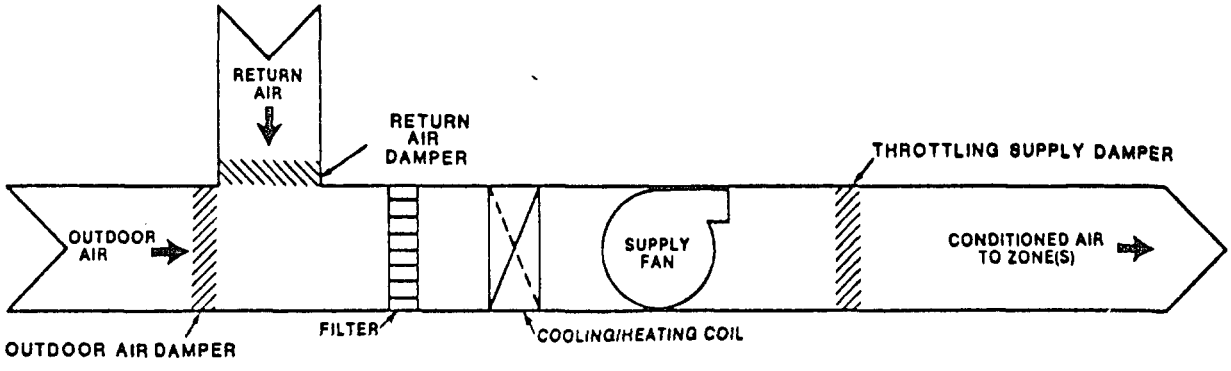

Figure 2-1f. Throttling Variable Air Volume System

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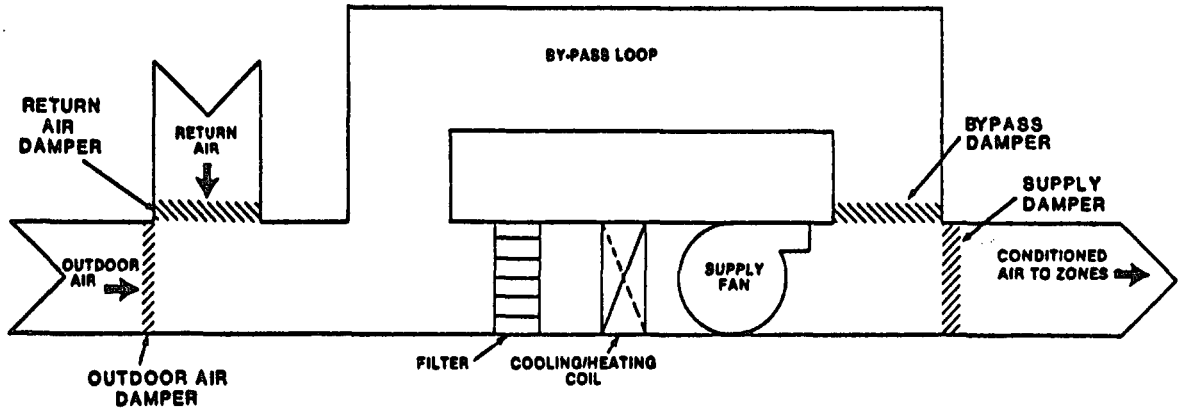

Figure 2-1g. Bypass Variable Air Volume System

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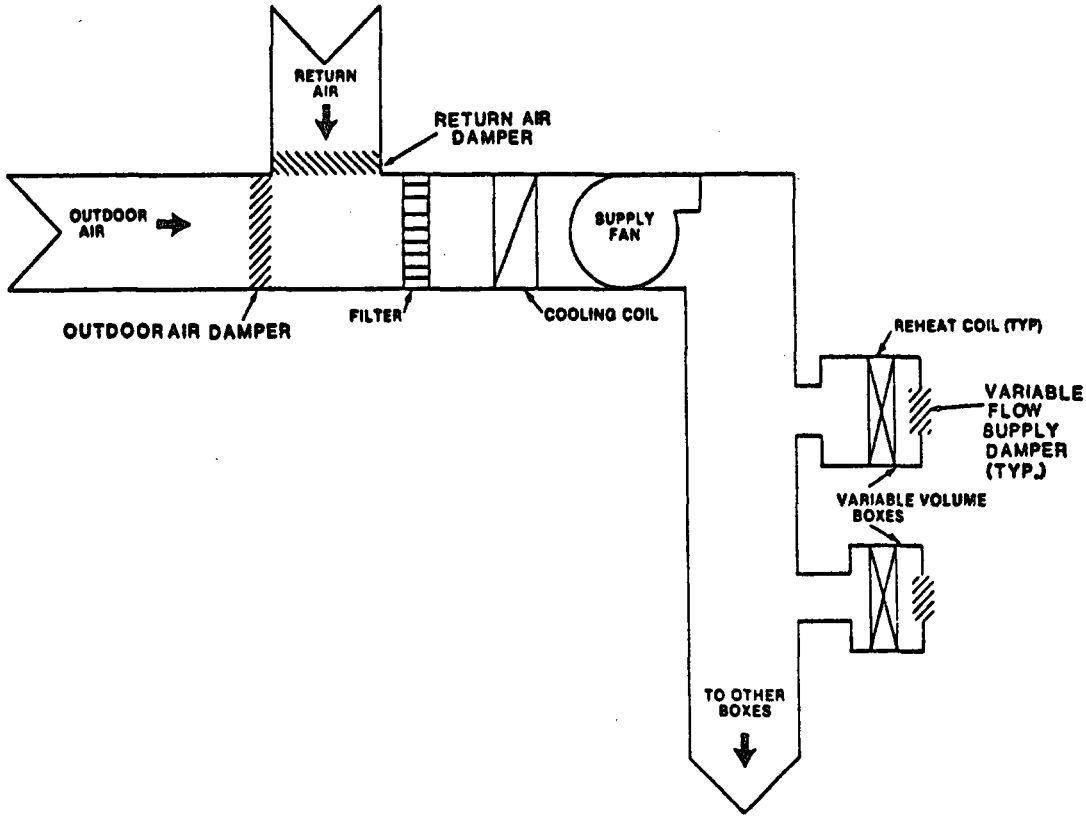

Figure 2-1h. Variable Air Volume System with Terminal Reheat

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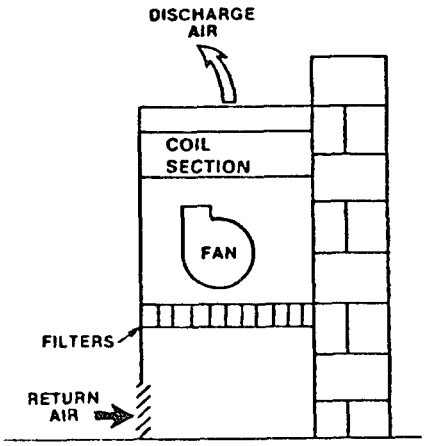

Figure 2-1i. Fan Coil Units

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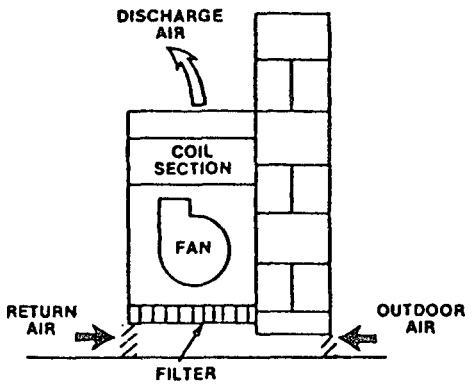

Figure 2-1j. Unit Ventilators

The characteristics of two-, three-, and four-pipe heating systems are:

- A two-pipe system can not provide cooling and heating capabilities simultaneously
- A three-pipe system can supply either cooling or heating to any zone, but the return flows from all zones are mixed
- A four-pipe system can supply either cooling or heating to any zone, and the return systems are independent of one another

2.2.7 Induction air

The induction air unit is designed for use in multi-room buildings such as office buildings, hospitals, hotels, and apartments. The unit is particulary useful for buildings that require cooling in one room and heating in another. Some of the features of induction units are:

- Smaller Space Requirements - The use of water to provide the room cooling requirements reduces the air quantity distributed to each space when compared to the air quantity distributed in all-air systems
- Individual Room Control - Zoning problems are eliminated since each room is a zone
- Elimination of Winter Downdraft - The unit is installed in under-the-window configurations, which eliminates downdrafts
- Minimum Service - Individual fans are not located in the rooms
- Quiet Operation - Fans are located in remote areas

- Central Dehumidification - All dehumidification is performed at the primary coil in the central apparatus area

The system functions by mixing outside air (makeup air) with the mainstream return air, filtering the air stream, then conditioning the air for distribution throughout the building complex by the high pressure primary fan and ductwork to the individual induction units. The induction unit is supplied with the high pressure primary air stream which is discharged through nozzles in the unit to induce room air flow across the coil.

2.2.8 Humidification/dehumidification

An important aspect of air conditioning systems is the control of moisture. Moisture can be removed during dehumidification of the air stream, or moisture can be added to dry air flows in the process of humidification. Normally, dehumidication for comfort cooling is maintained satisfactorily during the air cooling process; that is, the dew point of the cooled air is sufficiently low to maintain a relatively satsifactory humidity in the conditioned spaces.

Usually, dehumidification is achieved by using the refrigeration method because air washers are not normally used. Air washers have the advantage of controlling odors because an odor is usually caused by vapors of some type mixing in the air. Many of the vapors will dissolve in the water sprays as the air is passed through the washer.

Various processes for dehumidification are used, including: cooling the air below the dew point with refrigeration apparatus; air washing with cold water to condense the water vapor in the air stream; and chemical dessicants for chemically absorbing the moisture. The refrigeration process condenses the moisture on the cold coil surface and collects it in drip pans for disposal. Both methods are energy-intensive because mechanical refrigeration is used to generate either the cold metallic surface for the coil or to cool the water below the dew point of the air to be dehumidified before introduction into the air washer. The chemical dehumidification process also requires an energy input as the chemicals are dried or rejuvenated by heating them to drive out the trapped moisture.

Humidification can be achieved through water sprays (air washing) and steam sprays. During the water spray method, water with a temperature

higher than the intended air dew point temperature is sprayed into the air flow through spray headers to increase the moisture content of the air. Steam humidification is achieved by spraying steam into the air stream to add to the moisture content. Other direct contact water/air mixing processes with heat addition can also provide humidification.

2.3 HVAC Control Systems

The design and operation of the HVAC control system plays a major role in the success of achieving an energy efficient system. Even when properly sized to meet the design conditions, the equipment will operate at part-load a large percentage of the time. Under these part-load conditions, the control system is most important for adequate performance of the HVAC equipment.

Control systems are designed to function in one of two major modes: 1) open loop control which anticipates the effect of external disturbances on the system before the corrective action is taken; or 2) closed loop feedback systems where the controller measures the actual changes in the controlled variable and actuates the controlled device to bring about a counter change in the controlled variable. The corrective action is a continuous process until the variable is at the desired value. The closed loop system is a considerable improvement over the open loop control scheme, and is used in the design and construction of environmental systems.

Control systems may be further categorized by the type of desired control action. The desired control actions are:

- Two-position action
- Timed two-position action
- Floating action
- Proportional action
- Proportional plus automatic reset action

Two-position action - the controller can only control to a maximum or minimum state, or can be either on or off.

Timed two-position action - a variation of the two-position control action, often used to vary the percentage of on-time as a function of the system load.

Floating action - similar to two-position control action in which the controller can perform only two operations, moving the controlled device, usually at a constant rate, toward either its open or closed position. Usually, there is a neutral zone between the two positions which allows the controlled device to stop at any position whenever the controlled variable is within the differential of the controller.

Proportional action - used to respond to slight changes in the controlled variable where the controlled device is positioned proportionally.

Proportional plus automatic reset action - combines floating action with proportional action to achieve both the stability of proportional control, with a relatively wide throttling range, and the invariable control point of floating control. The system functions the same as the proportional action, with the automatic reset serving to shift the control point back to the set point whenever any offset occurs.

Another categorization of control systems is localized versus central control. Central systems have the advantages of: reduced operating cost due to manpower savings; reduced energy consumption; ease of identification of early symptoms of pending equipment failure, allowing corrective action to be undertaken before expensive equipment damage occurs; and the integration of other features essential to building management such as fire protection, detection and security functions. These systems allow review of instantaneous data on conditions within the building to help building personnel make the necessary decisions on the equipment. In an emergency, the systems also aid in implementing life safety decisions based upon an accurate assessment of the building conditions.

The specification of control equipment should be consistent with the accuracy of control required. It is neither good practice nor economical to select equipment capable of producing more precise control than the application requires. Also, it is not desirable to complicate the system to obtain special sequences or cycles of operation if they do not aid either control requirements of energy efficiency.

Control systems are implemented pneumatically, electronically, or electrically, and by hybrid pneumatic/electric combinations.

Pneumatic control systems use compressed air to supply energy for the operation of valves, motors, relays, and other pneumatic control equipment.

Elements typically making up pneumatic control systems are:

- A source of clean, dry, oil-free air to provide the operating energy
- Air lines, usually plastic or copper tubing, from the air supply to the system devices
- Sensing devices to detect and measure a change in the controlled variable
- Regulating devices, "controllers", such as thermostats, humidistats, pressure regulators, transducers, relays and switches
- Controlled devices such as valve or damper motors

Pneumatic control systems operate on a varying air pressure of 3 to 15 psig. Air is taken from the supply main at a constant pressure and delivered to the controller which varies the air pressure in proportion to the sensed variable. The final control element assumes a position proportional to the pressure supplied by the controller. The major advantages of pneumatic systems are the ability to obtain sufficient, actuating force on the controlled devices to perform the actuating job and the ability to accurately control to close tolerances.

The disadvantages of pneumatic systems include susceptibility of the air lines to fouling by dirt, leaks, and condensed oil clogging the minute parts in the controlling devices. The compressed air must be continuously maintained in a clean, dry state.

Electric control systems operate on a 4-20 milliamp (mA) signal generated by the controller in proportion to the sensed variable. Electric control proportional action is more difficult to achieve than in pneumatic systems, and it is harder for the electric actuators to generate sufficient force to operate the controlled device. In some quarters, electric control systems are considered more reliable than pneumatic because of the lack of leaks and fouling by dirt or oil contamination. Others feel that pneumatic control is more reliable, if properly maintained.

Pneumatic control systems are usually preferred in larger installations, while electric systems are often used in smaller installations.

Varying performance requirements are usually imposed upon the specifications for the control system. The more important performance parameters are:

- Set Point - the desired control system operating point
- Control Point - the specific value to which the control system is actually controlling to
- Hunting - an undesirable condition where the control system seeks the desired set point, but goes into a periodic oscillation as the system attempts to tune itself to the desired set point, usually attributed to the presence of non-linearities in the system
- Proportional Band - the range in which the controlled variable changes to move the controlled device from one extreme to another
- Response Time - the time it takes the control system to correct disturbances such as a rapid change in the cooling load
- Offset - a steady-state effect - the lower the offset the better the accuracy of control
- Throttling Range - the total amount of change in the controlled variable required for the controller to move the controlled device from one extreme to the other
- System Stability - goes hand in hand with Hunting. A stable system will not undergo periodic oscillations

A control system consists of a sensor, a controller and a controlled device. Sensors are designed to measure many parameters. The sensors of interest to HVAC control schemes are:

- Temperature (dry bulb)
- Wet bulb or dew point temperature or relative humidity
- Pressure
- Flow

Controllers compare the value of the set point to the control point, and when a difference occurs, generates a signal to the controlled device for corrective action. The controlled device reacts to the control signal and varies the controlled parameter. Some examples of controlled devices are: motorized (electric) valves; pneumatic diaphrams and cylinders; and variable speed load modulation devices.

Control systems need a variety of support or auxillary type devices. Pneumatic systems require air compressors, air dryers, oil filters, pressure regulators, storage vessels, etc. Electrical control systems require power supplies, electrical filters, emergency power back-up equipment, etc. These support devices complicate the ease of installation, reliability, and operating procedures.

Typical examples of the commonly used HVAC control systems are:

- Steam Flow Control - used in controlling the amount of steam admitted into steam-to-water heat exchanges and steam flow into large air heating coils

- Air Distribution Control - used to control the volume and heat content of the air streams used in variable air volume distribution systems, mixed air control, face and by-pass damper control, and multi-zone systems

- Water Flow Control - used in modulating the flow rate of chilled or hot water to water-to-air coils, heat exchangers, unit heaters, chillers, etc.

Recognition of energy conservation, as a primary design parameter, requires the minimal use of heating or cooling energy in any given installation. The HVAC control system plays a vital role in accomplishing this requirement.

3. STATE-OF-THE-ART ENERGY CONSERVATION CONCEPTS

Notable progress has been made in the last decade in improving the efficiency of air conditioning systems and equipment. Some manufacturers have been offering more energy efficient machinery for years at a premium first cost; however, low cost energy has minimized the available market and severely limited production and R&D investment. Recent increasing energy costs and new building energy codes have reduced the risk of investment in efficiency. The result has been a moderate resurgence in efficient equipment design led by the few who paved the way prior to the "energy crisis". The same stimulus is causing other manufacturers to offer newly designed, more efficient lines of equipment. Also, high energy costs are causing HVAC system designers to modify the traditional system design to save considerable amounts of energy.

3.1 Cooling/Heat Pump Equipment

In the last few years, advances in more efficient cooling and heat pump equipment have been achieved by almost every manufacturer. The majority of manufacturer research and development efforts are aimed at energy conservation. One notable equipment improvement which may impact all equipment is the use of higher efficiency electric motors. These motors have definite applications in pumps, fans, chillers, etc. The following sections will discuss many of these efforts and advances.

3.1.1 Unitary

Manufacturers are producing new types of unitary equipment. Versions are being offered which incorporate variable speed or flow controls along with sophisticated analog computer circuitry to read sensor signals. These signals vary hot/cold deck temperatures, readjust motor speeds, and position hot/cold deck dampers. The computer control will select the best method for satsifying zone demands to minimize the aggregate energy expenditure of the unit. Two-speed compressors and motors are offered as a compromise to infinite speed control for improvement in part load efficiency. Because of the relatively limited performance and load range improvements achieved for

the smaller, single-phase machinery, the partial load performance of the two-speed motor/compressor combination for that equipment has been questioned by some.

Unitary units are offered in a modular concept which contains the main air handler and evaporator supplying multiple, zone sensor controlled, terminal air blender units. The evaporator is supplied from water-cooled or air-cooled condensing units either as part of the air handler package (self-contained) or remotely connected by extended refrigerant lines. If a water cooled condensing unit is utilized, the only central (common) part of the system would be the condenser water loop. This water loop can be piped for use with cooling towers or used with heat pump equipment for heat reclamation.

The air blender unit operation is similar to a conventional variable air volume unit. These units have the capability of utilizing an economizer cycle for free cooling by use of outdoor air or for reclaiming heat energy from the building lighting or other internal loads. These units are equipped for variable speed control on the blowers and multi-unit, two-speed compressors in the compressor/condenser package. Modular construction allows individual units to service individual building occupant space, thus allowing customization of the operation sequence to conserve energy in partial occupancy situations. The modular concept makes it easier to manage load shedding and demand limiting while maintaining optimum comfort conditions on a spot or limited basis. Floors with a critical need, such as computer rooms or operating suites, can operate properly while other areas can limit the operation with an attendant reduction in energy consumption. Special applications, such as computer rooms, can also be equipped with specifically designed, more efficient equipment.

3.1.2 Applied systems (chillers)

Applied or built-up systems are also experiencing energy conserving improvements. Areas discussed in the following sections are:

- Open versus hermetic compressors
- Load modulation
- Thermal energy storage

- Maintenance
- Evaporative coolers
- Double bundle and free cooling chillers

3.1.2.1 Open versus hermetic compressors.

In the engineering and marketing community, there is considerable debate over the use of hermetic versus open drive compressors. Hermetic units have gained popularity over open drive units in the past. Hermetic compressors are the most favored because of cost and lack of complicated shaft seals. An important disadvantage of hermetic compressors is the contamination of the refrigerant circuit upon failure of the electric motor (burn out).

Open drive units have the advantage of a versatile selection of drivers. Steam turbines or various types of electric motors may be employed presenting additional system applications such as cogeneration. For the same motor efficiency, an equivalent open drive compressor is more energy-efficient than a hermetic compressor. However, if the open drive machine is placed in a room which requires air conditioning or requires exhaust air which displaces air in a cooled space, there may be a system efficiency penalty because the motor waste heat must be rejected through the refrigeration circuit via the air handlers and chilled water loops to the chiller condenser and the ultimate heat sink. The reciprocating open compressor has the added feature that, as the speed is decreased, it becomes more efficient and reliable. For hermetic centrifugal units, the efficiency penalty resulting from cooling the motor with suction gas is overcome in some systems by cooling the motor with high pressure liquid, which is flashed to high pressure gas. Using this approach, motor heat is rejected through the condenser, and the efficiency penalty is negligible.

3.1.2.2 Load modulation.

For centrifugal units, as discussed in Section 2.1.2.2, inlet guide vanes are an efficient method of chiller capacity modulation. Presently, one manufacturer is offering equipment which will control the speed of the compressor, by use of an inverter, and simultaneously control the operation

of the inlet guide vanes. At this time, due to economies of scale and market size, the inverter unit is used only on centrifugal units.

The inverter controls both frequency and voltage by changing the incoming alternating current (AC) to direct current (DC) and then synthesizing the DC into the desired AC frequency and voltage. The inverter allows for variable speed control when applied to standard AC motors. The capacity control system monitors the chiller's control system to detect minute changes in the chiller load. In order to respond to fluctuations in the cooling load, the capacity control system directs the necessary control inputs to the inverter circuit so that it may modulate the frequency and voltage supplied to the chiller motor. At the same time, the capacity control system gives information to the inlet guide vane control circuits to properly set the guide vanes to the optimum position required for the compressor to efficiently operate at its new speed.

Side benefits to this type of chiller capacity control are: 1) prolonging the life of the motor due to the ability of the inverter circuit to soft start the motor; 2) reducing wear on the rotating components by minimizing the compressor speed to adequately match the cooling load; and 3) quieter operation due to the reduction in speed.

For reciprocating units above twenty tons, the major method of load modulation, because it is inexpensive and effective, is the use of cylinder unloading for step changes in capacity. The use of multiple reciprocating compressors allows system capacity to be controlled by switching units on and off. Also, some two speed units are available.

3.1.2.3 Thermal energy storage.

Thermal energy storage (TES) has important applications with respect to utility load leveling and consumers' cost. From the utilities' viewpoint, energy storage could alleviate peak demand on the power system, which obviates the need (and cost) of additional power generation and distribution equipment. The utilities could generate most of the electric power by constantly using large, baseloaded nuclear and fossil units. These units operate at a higher efficiency and consume the least expensive fuels. This type of operation would save the utility the additional expense of buying very costly electricity from neighboring utilities, or from using oil-fired

gas turbine peaking units during peak demands. Often, older and smaller, less efficient fossil-fired units are placed in standby service and also used as peaking units.

Consumers will also benefit from energy storage. They will be able to recharge their storage medium when off-peak rates are in effect (during the evening hours) and extract energy from the storage device, for heating or cooling, during peak rate periods in the daytime.

TES abilities allow the building energy system operator to run chillers during the nighttime hours. The advantages of nighttime operation are: 1) possible lower electrical rates; and 2) operation of the chiller at lower condenser temperatures, due to the lower nighttime ambient air temperatures, which improves the efficiency of the chiller.

Presently, the various methods of energy storage being researched are: rock storage beds; water storage devices; and phase change materials. Materials that may be used in the rock storage method are steel, ceramic brick, and various ores. When air is to be the energy exchange medium, rock storage is favored. Water storage methods offer ease of construction and distribution. Phase change materials occupy the least volume of these methods but have the drawback of being corrosive and harder to handle (with the exception of ice). Phase change materials are often packaged in plastic containers to prevent corrosion.

As a form of phase change energy storage, ice has the ability to store the same amount of energy as the water storage methods in approximately one-tenth of the volume. This compactness makes it cheaper than water storage. Ice storage systems function by using the latent energy in water when it is changed to ice. Ice is manufactured at night (off-peak) and melted during the day to provide the cooling required in the conditioned space. Presently, positive displacement compressors are used to obtain the low refrigerant temperatures needed to form the ice. Heat rejected from the ice making machine condensers is a source of energy which can be used to produce hot water, therefore serving a dual purpose.

3.1.2.4 Chiller modifications and alternate arrangements.

Chillers can be modified for special applications. Two of the most noted modifications are double bundle and free cooling.

Double bundle. The chiller is modified by hydraulically separating the tube side of the condenser into two sections. One section is used with a cooling tower or other heat sink such as normally would be employed. The other set of tubes is used to capture the energy which is usually rejected through the heat sink and put it to work in a useful purpose, such as producing hot water or heating perimeter areas. This "free" heating is at the expense of a somewhat reduced cooling system efficiency due to the higher condensing temperatures generally required. However, the overall heating/cooling system efficiency can be significantly improved. The main limitation in the use of the double bundle chiller with centrifugal compressors is that a higher speed or a higher-lift impeller is necessary to produce the high condenser temperature. For reciprocating units, no modifications are required.

Free cooling. Free cooling is another modification which adapts the normal chiller to function as a simple heat exchanger, when the condenser coolant is available at a temperature lower than the chilled water supply temperature. Free cooling can obtain up to 45 percent of the chiller capacity without compressor operation. Installation of free cooling capacity is not a major overhaul of the chiller. It requires the installation of a refrigerant vapor line between the evaporator and the condenser, a liquid refrigerant return line between the condenser sump and the evaporator, and addition of two valves with associated control equipment.

Upon changeover to free cooling, the shutoff valve in the refrigerant gas line is opened and a lockout circuit prevents compressor energization. Liquid refrigerant drains by gravity from the condenser to the evaporator, flooding the tube bundle. Since the refrigerant temperature and pressure will be higher in the evaporator than the condenser, due to the water temperature difference, the refrigerant gas boiled off in the evaporator will flow to the condenser. The gas condenses and flows back to the evaporator. The natural circulation cycle is sustained as long as the necessary temperature differential exists between the evaporator and condenser. The difference in temperature between the evaporator and condenser determines the rate of refrigerant flow and thus the free cooling capacity.

Another method of free cooling being used is the cooling tower and heat exchanger method. Whenever the cooling tower water temperature is below the desired chilled water temperature, the heat exchanger system allows the

operator to bypass the chiller and connect the cooling tower directly to the heat exchanger to cool the chilled water circuit. When the water temperature is high, most cooling towers can operate successfully in cold weather. At low leaving temperatures of 45°F to 50°F, operation during subfreezing weather is more difficult and necessitates winterization of the cooling tower to prevent reduced heat capacity and damage.

Alternate arrangements of the chiller may be utilized. Cascade systems encompass a variety of possible arrangements, each with its own advantages and disadvantages. One possible arrangement of cascade chillers is for the condenser of the low stage to be used as the heat source of the higher stage. Thus, the condenser water of the high stage can be used for heating water or for space heating. The low stage is sized and operated for cooling loads only. Heat absorbed by the low stage machine can be rejected by the high stage machine to heating coils or for process use. When higher temperature heat is not required, the low stage condenser rejects heat directly to the cooling tower and the high stage unit is secured.

3.1.2.5 Evaporative cooling.

One concept that has not received much attention is the use of evaporative cooling (both indirect and direct). Although this method of cooling is most effective in arid regions, one manufacturer has demonstrated reasonable paybacks using evaporative cooling in Chicago. Evaporative cooling may not seem feasible in the eastern part of the U.S., but a significant number of hours exist during a typical cooling season in the eastern U.S. when evaporative cooling would lower cooling equipment loads. High coefficients of performance (COP's) of 10 or more are possible for certain periods of the year.

Water availability and quality are developing as long term problems for evaporative cooling systems and all water-cooled systems. Since water provides a lower condensing temperature than air, energy use is affected. The weather during the summer of 1980 caused a focus on water availability and quality. Availability continues to be a problem in the western U.S. and is becoming a problem in parts of the eastern U.S. The quality of water has become a problem for water-cooled equipment in certain coastal areas due to the influx of brackish water as fresh water is depleted. Water problems may

become as difficult as energy problems by the turn of the century and have the potential to affect energy use.

3.1.3 Heat pumps

Although heat pumps have been studied and used for a number of years, they are just now making an impact upon the energy market and showing up in applications in increasing numbers. Most units are in the lower tonnage range (< 5 tons) and are normally used in residential or small commercial applications.

Recently, two significant design modifications have been employed in the heat pump cycle: 1) improved refrigerants; and 2) extended ranges of efficient operation.

A recently introduced refrigerant (Reference 3-1) was developed to achieve energy savings through a reduced need for auxillary electric heat on cold days when the air temperature drops below 30°F. The refrigerant is a mixture of two well known refrigerants which makes use of the optimum properties of both. However, this application is still in the conceptual RD&D stage. The other development, extended range heat pumps, will perform efficiently over a larger range of air temperatures (down to 35°F) and also minimize the use of electric resistance auxillary heat.

Newer heat source/sinks are being pursued. Water heat sources for heat pumps are being implemented. A relatively new concept used is the ground water heat source. In this application, heat is taken from ground water, at temperatures (approximately 50-60°F) in a more efficient range for heat pump operation. Fire sprinkler systems in newer building designs are used to circulate waste heat from the center core of a building, through heat pumps to the perimeter. Earth is another potential source of heat which has a steady-state temperature in a range more favorable for optimum use of the heat pump. The heat pump can also be used as a water heater with the surrounding air as the heat source. Another potential use is the temperature amplifier. Although temperature amplifiers are limited in their applications, they may be used in commercial buildings to collect otherwise wasted heat, such as from computer rooms or laundry facilities.

3.2 HVAC Distribution Systems

Along with new developments in equipment, advances are being made in energy efficient system designs. One of the most prominent examples of increased system efficiency is the variable air volume system design (previously discussed in Section 2.2.5) which offers upwards of 60 percent fan energy savings. It is estimated that HVAC system fan motors consume approximately 1.0 Quad/year of resource energy in the United States, in addition to the 2.0 Quads for cooling energy (see Table 6-5). Other improvements in systems include: more efficient air foil shapes for fan blades, which have potential savings of 30-40 percent over forward curved fan blades; variable inlet guide vanes on fans; improved duct construction methods to minimize duct leakage and reduce pressure drop; improved controls; and variable speed motors (see Section 3.1.2.2). Insulated return air ducts, instead of above ceiling return air plenums located underneath the roof or uninsulated return ducts, also offer energy saving potential.

3.3 Controls

Numerous controls and control schemes exist to improve the overall efficiency of commercial HVAC systems. Some of these schemes include basic practices used in residential applications, such as thermostat set back/setup and increasing the heating to cooling thermostat deadband. Usually, other schemes are associated exclusively with commercial applications. These include:

- Scheduling and duty cycling
- Reduced air circulation
- Outdoor air reduction
- Low leakage dampers
- Hot/cold deck temperature reset
- Zone optimizing analyzers
- Economizer cycles, cold air temperature reset, and enthalpy control

- Conversion of constant volume systems to variable air volume
- Automated energy management systems

3.3.1 Scheduling/duty cycling

Automatic scheduling of HVAC equipment can save energy by not operating equipment unnecessarily. Four areas where scheduling can prove beneficial are:

1) Fan and pump energy
2) Cooling energy for outdoor air
3) Heating energy for outdoor air
4) Lower/higher unoccupied period space temperatures during the heating/cooling season

Energy savings are obtained by scheduling equipment to turn on and off to conform to the hours the building is occupied. Additional savings are obtainable by varying equipment starting time, based on outdoor air temperature, to minimize warm-up or cool-down after an unoccupied period.

Duty cycling conserves energy by shutting down the HVAC system for a portion of its normal operational period. Any HVAC system can be considered for duty cycling. However, systems where ventilation is critical should not be considered.

3.3.2 Reduced air circulation

Reducing the total amount of circulated air is one of the most effective means of conserving energy. The fan or "pumping" power can be a very significant percentage of total heating/cooling costs. Theoretically, the reduction in energy consumption by a fan decreases as the third power of the decrease in circulated air. Thus, a 10 percent reduction in circulated air could save $[1-(1-0.10)^3] = 27$ percent of the fan energy consumption. In practice, this calculation is usually a good estimate of the savings.

Many buildings have more air circulated than is necessary. Reducing circulated air is often easily done, with no discomfort or inconvenience to people in the conditioned space. The cost of changing or adjusting sheaves on the fan and motor to reduce the amount of circulated air is minimal relative to the savings in energy cost.

To determine the optimum amount of recirculated air, an analysis should also include the penalty, if any, for the extra mechanical refrigeration (compressor power) required due to the subsequent reduction in suction pressure. Also, the attendant loss in refrigeration capacity should be considered in parallel with the reduction in cooling supplied to the space from the reduced air flow.

3.3.3 Outdoor air reductions and low leakage dampers

Reducing the amount of outdoor air for ventilation can reduce the cooling or heating load on HVAC equipment. Three ways to reduce the outdoor air are:

1) Reduce fixed exhaust requirements

2) Shut off the outdoor air damper during unoccupied periods

3) Reduce the minimum outdoor air required for ventilation during occupied periods

The minimum outdoor air reduction can be accomplished for any system that provides outdoor air to a building by adjusting the damper linkage or positioning switch.

The installation of low leakage dampers prevents unwanted outdoor air from entering a building when outdoor dampers are closed. The leakage of unwanted outdoor air into the system creates an unnecessary load on the equipment. Low leakage dampers restrict leakage to 1 percent, while standard dampers can allow from 5 percent to 30 percent leakage.

3.3.4 Hot/cold deck temperature reset

Hot/cold deck temperature reset is also described in Sections 2.2.2 and 2.2.3. These controls compare zone loads and adjust the hot/cold deck temperatures to match the load for the zone(s) with the largest heating/cooling load by means of a load optimizer control.

One problem with this type of control is that each zone thermostat is capable of controlling deck temperature. Misadjustment of thermostats and highly variable loads, such as conference rooms, may cause extreme deck temperatures. One solution is to use locking themostat covers and eliminate the highly variable load zones' input to the load optimizer.

3.3.5 Zone optimizing analyzers

As mentioned in Section 2.2.4, Terminal Reheat Systems can be improved by using zone optimizing load analyzers. These analyzers measure the demand of each zone, and set the cold supply air temperature to minimize the amount of reheat and cooling required. The same problems mentioned in "Hot/Cold Deck Temperature Reset" apply to this type of control.

3.3.6 Economizers, cold air temperature reset, and enthalpy control

The term "economizer" can mean many different things for HVAC controls. Originally, an economizer meant HVAC central system controls that introduced outdoor air to offset as much mechanical refrigeration as possible, when the outdoor temperature was in the right range to provide cooling. While this system was intended to save energy, the opposite was often the case. Most cooling controls at that time simply maintained a constant cold air temperature (typically 55°F) to satisfy the maximum cooling load. Whenever a zone called for less than maximum cooling, or called for heating, the difference was made up by heating energy. When cooling was supplied by some type of mechanical refrigeration system, the constant 55°F air would only be supplied during the cooling season when the refrigeration system was running. When the economizer was introduced to reduce the mechanical refrigeration required for cooling the air to 55°F, the HVAC system could and did maintain the constant 55°F air all during the heating season by the introduction of cold outdoor air. Some system designers overcame this pitfall by providing for summer/winter changeover. The problems associated with this type of manual changeover caused many designers to choose an "automatic" system with the constant 55°F cold air temperature.

Adding cold air temperature reset can significantly reduce the energy costs for the economizer system when compared to the economizer system alone or an HVAC system without cold air reset. With this modification, the cold air temperature is reset to provide only the cooling required for the zone with the highest cooling load. This adjustment of cold air temperature saves the cooling and heating energy.

Part of the control scheme required for an economizer is the high limit control. This control tells the system when the outdoor air is too warm to

provide cooling. This control requirement can be accomplished by sensing outdoor air dry bulb temperature and selecting a cut-off temperature for returning to minimum outdoor air. A more sophisticated approach is the use of enthalpy controls, where the enthalpy of the outdoor air is measured. Enthalpy controls prevent the use of slightly cooler (62-70°F) air when the humidity is high, and the enthalpy of the outdoor air is higher than the enthalpy of the return air. In this case, more cooling energy would be required to cool the outdoor air. When the outdoor air is not too humid (at 62-70°F), and the outdoor enthalpy is lower than the return air enthalpy, less mechanical cooling is required to cool the outdoor air.

One anomaly occurs with enthalpy control. Hot, dry outdoor air (78-83°F) may have a lower enthalpy than return air which has picked up moisture from people, plants, or HVAC system humidifiers. In this case, outdoor dry bulb temperature sensing may have to override the enthalpy control, since hot, dry air requires more mechanical cooling than the return air and may require more humidification if the HVAC system has a humidifier.

3.3.7 Variable air volume (VAV) retrofits

Conversion of constant volume air distribution systems to variable air volume (VAV) can save energy. In a constant volume reheat system, converting to a VAV system will eliminate reheat in most interior zones and reduce it in exterior zones. In a dual duct system, converting to a single duct VAV system eliminates the wasteful mixing of the heated and cooled air streams. Retrofitting an existing system usually involves removing any old, constant volume regulators and adding a VAV sensor/controller to control existing fans or dampers. Sometimes, other controls must be added to prevent central fans from producing excessive negative static pressures in the building.

3.3.8 Automated energy management system

An Automated Energy Managment System (AEMS) has the potential to save 10 to 20 percent or more of the energy consumption in a typical commercial building. Additional consumer and utility cost savings and utility energy

savings can be achieved by the demand limiting function of the AEMS. Commerical electric bills are composed of two charges, energy and demand. The energy charge is based upon actual consumption while the demand charge is based upon the peak electrical energy used during the billing period. AEMS can control the demand charge by selectively switching or cycling selected electrical loads to limit the peak demand. Energy demand can be conserved with the AEMS by performing various optimizations on the environmental control equipment such as: chilled water temperature reset; chiller sequencing and optimal operation; variable load modulation in chillers, fans, and pumps; precise enthalpy switchover; hot/cold deck temperature reset; and a host of other functions. By continuously and automatically monitoring all HVAC system parameters, the AEMS aids in optimizing all equipment usage and system coordination, thus saving energy cost.

AEM allows full facilities management because an operator can monitor the complete building complex from one central console. Also, building systems such as life safety and security can be incorporated in the AEMS. Manpower and maintenance expense are minimized because of the central console. An AEMS aids the building operator in developing a strategy for increased building efficiency by providing hard copy output of the present and previous building information. Trend spotting for the maintenance aspect is used to identify equipment malfunction and inefficient operation as the problems develop. The systems are computerized, using the latest in microprocessor technologies, and are coupled with a human engineered color console to provide efficient information transfer and control. Distributed systems are being developed which allow microprocessors to be used in individual equipment control, such as variable air volume distribution boxes, and then linked through multiplexers to the central computers, for higher level control decisions and operator intervention.

3.3.9 Chiller supply water temperature reset

By changing the required chilled water temperature as a function of chiller load, considerable energy may be saved. This saving is typically a 1-1.5 percent increase in efficiency for each degree in chilled water supply temperature increase. (Changes in condenser water temperature (decrease) can also achieve similar savings. Temperature reset is usually limited by surge restrictions.)

The chiller supply temperature is usually designed for full load conditions. Most of the time the full design load condition does not exist. During the part load conditions, the chilled water supply temperature can be increased to increase the efficiency of the unit. The maximum call for cooling capacity can be obtained by comparing the signals being fed to the cooling coil valves. The coil calling for the greatest amount of cooling can be selected and this cooling requirement used to determine the necessary chilled water temperature. Any time a cooling coil is not using full chilled water flow, it implies that supply water of that low temperature is not required. The chilled water supply temperature controller should then be reset to some higher value. If no cooling coil calls for full chilled water flow at this new temperature setting, the controller is again reset to a higher temperature. The chilled water temperature should not be readjusted downward until one of the cooling coils cannot produce sufficient cooling to satisfy its load requirements. This condition can be sensed by observing any cooling coil valve which is receiving a control signal beyond what should be required for full chilled water flow to the coil. At this time, the chilled water controller should gradually be reset to a lower temperature until all cooling coil valves are positioned within their control ranges.

3.4 Maintenance

Energy intensive environmental control equipment must be maintained at peak condition to reduce energy consumption. Portions of this equipment which must be adequately maintained are: controls; condensers; cooling towers; filters; duct systems; and water treatment.

The controls must be adequately maintained because they have a vital impact on the operation of the equipment and system. Calibration must be accurately checked periodically and pneumatic control systems instrument air supplies must be moisture and oil free to prevent clogging of the minute orifices.

With time, condensers experience fouling of heat transfer tube surfaces. For flooded chillers, water chiller operators can maintain peak performance conditions by installing condenser tube-cleaning equipment. The tube-cleaners keep the fouling factor of the condenser tubes at low values

by removing deposits on the tube's interior surfaces. Tube-cleaning systems operate "on-load" to prevent taking the chiller off-line for maintenance. Several concepts are used, such as: 1) brush systems, which function by pushing stiff bristle brushes through the tubes with the condenser water flows; and 2) pushing oversize sponge rubber balls through the tubes. In the brush scheme, the flow is momentarily reversed with 4-way reversing valves to force the brushes back to the original starting position. The brushes are stopped at the end of the tube to await reversal of flow for repetition of the process. The ball system catches the balls in traps downstream of the condenser and returns them to the upstream portion of the condenser to start the cycle again. In addition to energy savings, tube-cleaners decrease the amount of chemicals needed for water treatment and reduce the maintenance and downtime expense of the chillers. For dry expansion chillers, the brush cleaning method would not apply, but keeping heat transfer surfaces clean is still important.

Cooling towers must be inspected for broken or unbalanced fan blades, clogged or disrepaired baffles and algae growth on the important portions, thus preserving maximum heat transfer.

Filters have to be inspected and replaced to prevent a clogged or partially clogged filter from increasing the static pressure on the fans which increases the fan's power requirements.

Water treatment is important to prevent deposit buildup due to biofouling agents and mineral deposits. These deposits degrade the performance of heat transfer surfaces and increase pumping horsepower requirements in piping systems.

Duct systems must be maintained properly to prevent leaks. Duct system leakage contributes to inefficient operation by losing the air which has already had the fan energy expended on it. Estimates of duct leakage on a typical system are 10 to 15 percent.

4. ENERGY USE AND SYSTEM COST COMPARISON

The effects of system type and control on energy consumption and system cost for a specific building type and size in Kansas City are shown in Figure 4-1 and Table 4-1. The building is a 40,500 square foot office building. The energy consumption was calculated by using the NASA Energy-Cost Analysis Program (NECAP) (Reference 4-1). These results are shown numerically for the three base systems and with the economizers and deck temperature reset controls (controls changes) in Table 4-1 (see Sections 3.3.4 and 3.3.6 for the controls discussion). The percentage reductions in energy use are calculated by using the unmodified dual duct system as the reference (base) system. The effects of control changes on energy used for each individual system are shown in Table 4-1. Since the individual values are percentages, the values in the "total" column are not equal to the sum of the percentages. Also shown are the relative performances of individual systems compared to the dual duct base system with and without the controls changes.

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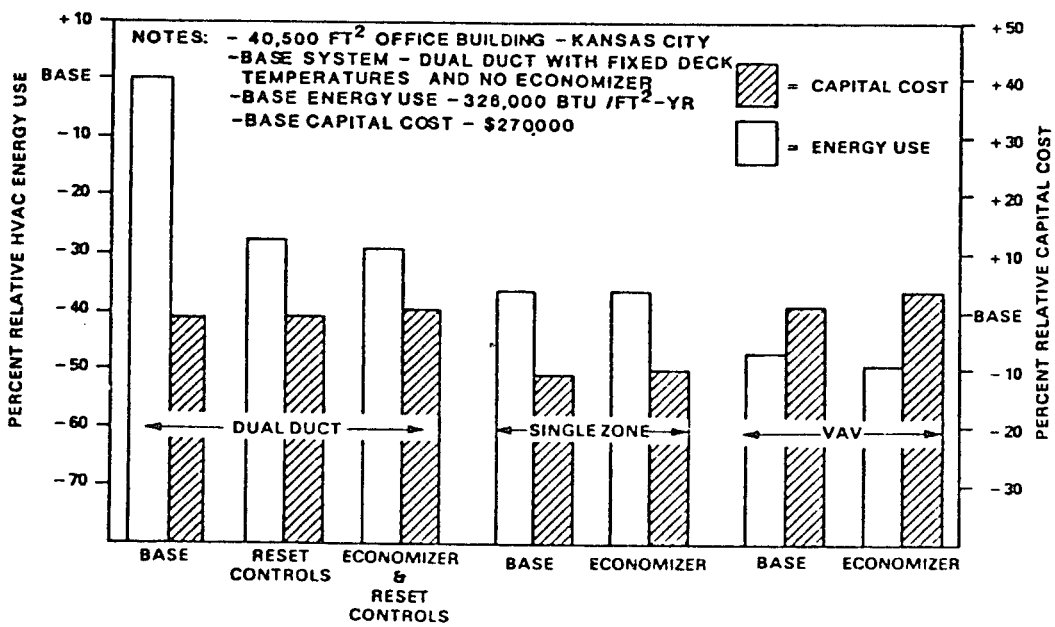

Figure 4-1. Percent Relative Cost and Energy Use of Dual Duct, Single Zone, and VAV Systems

Table 4-1. Effects of System Type and Controls on Energy Use for a 40,500 ft^2 Office Building in Kansas City

SYSTEM	HEATING		COOLING		FAN		TOTAL	
	INDIVIDUAL SYSTEM	DUAL DUCT BASE	INDIVIDUAL SYSTEM	DUAL DUCT BASE	INDIVIDUAL SYSTEM	DUAL DUCT BASE	INDIVIDUAL SYSTEM	DUAL DUCT BASE
Dual Duct	Base		Base		Base		Base	
Deck Reset Controls	21		42		0			
Economizer & Deck Reset Controls	21		45		0		24	
VAV	Base	51	Base	31	Base	60	Base	47
Economizer	0	51	17	42	0	60	4	49
Single Zone	Base	37	Base	43	Base	0	Base	36
Economizer	0	37	1	44	0	0	1	36

NOTES: DUAL DUCT BASE SYSTEM – FIXED DECK TEMPERATURES AND NO ECONOMIZER

In Table 4-1, under the column heading "Individual System", each system is treated as a base system. The effects of the controls changes are shown relative to each individual system base. Under the column heading "Dual Duct Base", the performance of each individual system base and of each controls change is shown relative to the dual duct reference base.

For this discussion, economizer means a fresh air, return air, exhaust air damper system with controls that modulate the dampers to introduce outdoor air for cooling, as demanded by zone thermostats. No outside air is introduced above the reasonable switchover temperature, which is 70-72°F for Kansas City, for typical room thermostat setpoints and return air temperatures.

For this particular building, building occupancy, and location, a small amount of additional capital results in a 50 percent reduction in energy use for the VAV system relative to the dual duct reference base system. However, by adding deck reset controls to the dual duct system, half of the savings shown for the VAV system can be achieved. As used in this example of a smaller building, adding deck reset controls is not difficult. When a large number of zones are present, this controls change becomes more difficult (see Section 3.3.4). Readers are cautioned to remember the complexity of HVAC system/building/climate interactions. Some important variables are local energy costs and availability, building size, type and occupancy, HVAC system type and control strategy, and climatic and microclimatic variables such as temperature, humidity, solar flux, wind, shading, and wind effects.

TRW believes the results shown are useful in discussing general relationships and trends for the energy use and installation costs of HVAC systems, but each building tends to have a "personality" of its own. Due to the tremendous variety of building and system designs, it should not be assumed that the comparisons shown here can be extended easily to individual buildings.

The effects of geographic location and system controls for a small, multi-zone system are shown in Table 4-2. The data are for a 4,000 square foot U.S. Army office/training facility (Reference 4-2). In all locations shown, the use of an economizer with a multi-zone system acutally increases the total energy use of the system. This is caused by the nature of economizer control, which is to minimize cooling. However, in all cases shown, the heating energy is substantially increased. Also, location must be taken into consideration when deciding on HVAC systems and controls, as shown in Table 4-2.

Table 4-2. Effects of Location and Controls on Energy Use for a a Multi-Zone HVAC System for a 4,000 ft^2 U.S. Army Office/Training Facility

ALL CASES ARE FOR A MULTIZONE SYSTEM	CHARLESTON				FT. WORTH				BISMARK				PHOENIX			
	GC	CEU	FEU	TEU	GC	CEU	FEU	TEU	GC	CEU	FEU	TEU	GC	CEU	FEU	TEU
Base Dual-Point Thermostats and No Economy Cycle	–	–	–	–	–	–	–	Base	–	–	–	–	–	–	–	–
Dual-Point Thermostats and Temperature Economy Cycle	-26	27	0	-8	-22	32	0	-4	-8	66	0	-3	-29	24	0	-5
Dual-Point Thermostats and Enthalpy-Temperature Economy Cycle	-24	28	0	-6	-21	32	0	-3	-8	66	0	-3	-28	25	0	-5
Dual-Point Thermostats Enthalpy-Temperature Economy Cycle, and Deck Reset Controls	44	45	0	41	–	–	–	–	14	69	0	17	–	–	–	–
Dual-Point Thermostats Enthalpy-Temperature Economy Cycle, Deck Reset Controls, and No Minimum Ventilation Requirements	86	52	-46	65	–	–	–	–	67	70	-44	63	–	–	–	–

GC – Gas Consumption
CEU – Cooling Energy Use
FEU – Fan Energy Use
TEU – Total Energy Use

NOTE: A NEGATIVE VALUE MEANS ENERGY USE INCREASED

5. BUILDING AND A/C EQUIPMENT POPULATIONS

As part of the effort to identify RD&D needs for A/C equipment and systems, existing information was reviewed and analyzed from major studies on commercial buildings and A/C equipment populations. The results of the review and analysis are presented in this section.

5.1 Commercial Buildings Populations

In the recent past, major efforts aimed at establishing commercial buildings populations have been undertaken by the Federal Government. The agencies and sources include:

- Bureau of the Census of the Department of Commerce, nonresidential construction statistics
- Oak Ridge National Laboratory (ORNL), Commercial Energy Use Model for the Department of Energy (DOE)
- Brookhaven National Laboratory (BNL), using data from the Office of Industrial Economics (OIE) of the Treasury Department (Honeywell report)
- DOE Energy Information Administration (EIA), Nonresidential Building Energy Consumption Survey (NBECS)

5.1.1 Background

In late 1979, the Energy Information Administration (EIA) of the Department of Energy conducted the "Nonresidential Building Energy Consumption Survey" (NBECS) (Ref. 5-1). The "Building Characteristics" report of the survey shows the total number of commercial buildings by type and provides a breakdown of commercial buildings by type of A/C equipment. A breakdown by building size category (class) is provided for nonresidential buildings. The "Fuel Characteristics ..." report of the survey reported estimates of total square footage for each building size category.

The EIA defines a nonresidential building as a "roofed or walled structure that is used for some purpose other than just a residence" (with a few exceptions). The scope of this definition is quite broad and includes some buildings that are primarily residential, as well as commercial and industrial buildings. The term residential (for nonresidential buildings)

applies to structures where the primary activity in the building is that of a residence for one or more households, but some kind of commercial activity occurs in the residential building.

Almost 4 million buildings were classified as commercial and the remaining 243,000 as industrial. Preliminary estimates of the total floor area of the nonresidential buildings were reported as 54,581 million square feet. See Section 1.2 for a breakdown of building types.

A major proprietary source of data has been the F. W. Dodge Division of McGraw-Hill Information Systems. The ORNL "Commercial Energy Use: A Disaggregation by Fuel, Building Type, and End Use" (Reference 5-2), and "Buildings Energy Use Book" (Reference 5-3) both rely on Dodge floor space data.

In 1978, ORNL (Reference 5-2), as part of the development of the "Commercial Energy Use Model," estimated the energy-using commercial building stock in terms of floor space for ten commercial subsectors. These subsectors were:

- Retail/Wholesale (stores and mercantile buildings)
- Office (offices and bank buildings)
- Automotive (commercial garages and service stations)
- Warehouse
- Education (public and private elementary, secondary, higher education and related buildings)
- Health (public, private, and all other health treatment and related buildings)
- Public (Federal, State, and local administration, penal and correctional, post office, and police and fire buildings)
- Religious (house of worship, residences, and religious training buildings)
- Hotel/Motel
- Miscellaneous (passenger terminals, freight terminal buildings, hangers and other miscellaneous nonresidential and nonindustrial buildings)

The major comparison of this section will be between the ORNL and NBECS estimates of commercial floor space and number of commercial buildings. Other sources of data will be ancillary.

5.1.2 Comparisons of building population estimates

Each study of building populations used a different methodology for classifying buildings. The Honeywell report (Reference 5-4), which uses the OIE and other data, has 22 types of buildings. The ORNL commercial model has 10 types, and the EIA uses 13 types of nonresidential buildings. This diversity between studies prevents a direct comparison of building types, so only aggregate information can be compared meaningfully. Energy consumption in the commercial sector varies sharply from building type to building type depending upon such things as specific usage, hours of operation and occupation density, in addition to environmental considerations such as ambient temperature, relative humidity, wind speed and direction, and solar radiation.

Figure 5-1 is a matrix comparing the ORNL Commercial Energy Use Model and the DOE/EIA NBECS building types for commercial buildings. The crossover of building types is indicated, depending upon the predominant building activity. For example, the ORNL "religious" corresponds to the EIA types of "assembly and residential," while the EIA "assembly" includes some of the ORNL "religious," "miscellaneous," and "retail/wholesale." In addition, the EIA lists "vacant" buildings, which the ORNL model does not account for separately.

5.1.2.1 NBECS nonresidential buildings data.

In addition to providing breakdowns by building type, NBECS divides buildings into seven area class subdivisions (buildings grouped by total square footage categories). These divisions are shown in Table 5-1. The NBECS data for the number of buildings and estimated square footage are shown in Table 5-2.

5.1.2.2 ORNL commercial buildings data.

The ORNL Commercial Energy Use Model uses a method of additions for determining the existing commercial floor space. The floor space is added annually for each building type in the commercial building sector covering the period from 1924 to 1977, and corrections are made for removals. The base stock for 1924 had to be determined to allow estimates to be made.

		NBECS CLASSIFICATION											
	TYPE NUMBER	1	2	3	4	5	6	7	8	9	10	11	12
TYPE NUMBER	ORNL CLASSIFICATION	Assembly	Auto Sales&Service	Education	Food Sales	Health Care	Lodging	Office	Residential	Retail/Services	Warehouse&Storage	Other	Vacant
1	Retail/Wholesale	●			●					●			No Corresponding Types
2	Office							●					
3	Automotive		●									●	
4	Warehouse										●		
5	Education			●									
6	Health Care					●	●						
7	Public Administration							●		●		●	
8	Religious	●							●				
9	Hotel/Motel						●						
10	Miscellaneous	●		●							●	●	

Figure 5-1. Comparison of ORNL and NBECS Commercial Buildings Classifications

Table 5-1. Description of NBECS Area Class Limits for Nonresidential Buildings

NBECS AREA CLASS	FLOOR AREA LIMITS OF BUILDINGS (FT^2)
1	1,000 or less
2	1,001 to 5,000
3	5,001 to 10,000
4	10,001 to 25,000
5	25,001 to 50,000
6	50,001 to 100,000
7	Over 100,000

Table 5-2. Total Square Footage of NBECS Nonresidential Buildings by Area Class (1980)

AREA CLASS	NUMBER OF BUILDINGS ($x\ 10^3$)	PERCENT OF TOTAL BUILDINGS	ESTIMATED TOTAL FT^2 ($x10^6$)	PERCENT OF TOTAL FT^2	CALCULATED AVERAGE SIZE (FT^2)
1,000 or less	677	16	377	1	557
1,001 to 5,000	1,729	41	4,675	9	2,704
5,001 to 10,000	801	19	5,755	11	7,184
10,001 to 25,000	596	14	9,249	17	15,518
25,001 to 50,000	237	6	8,164	15	34,447
50,001 to 100,000	121	3	8,231	15	68,025
100,000 or greater	77	2	18,130	33	235,455
Totals	4,238	100	54,581	100	12,879

The U.S. Department of Commerce, Bureau of the Census, publishes monthly data on the total nonresidential construction activity. The total annual additions (ft^2) for the years 1960 to 1976 are plotted in Figure 5-2 together with the ORNL data. This comparison of the industry shows consistency in terms of the annual high and low points. The Census data is higher in all years given, which may be due to the inclusion of all nonresidential buildings in the Census data. This difference ranges from a high of 17 percent in 1973 to a low of 13 percent in 1976. Quantitative comparisons of the total building stock cannot be made because there is no data available on floor space removals at any period of time.

Estimates of the number of commercial buildings, the total area, and the average area per building for 1980 were developed by DOE in Reference 5-5, using data from the ORNL model. These estimates are presented in Table 5-3.

5.1.2.3 Commercial buildings data based on NBECS.

The NBECS data presented in Table 5-2 have been extrapolated for this study to provide estimates of commercial floor space by building type. Using the average size for each area class and the number of buildings in each area class for each building type, the average area for each of the

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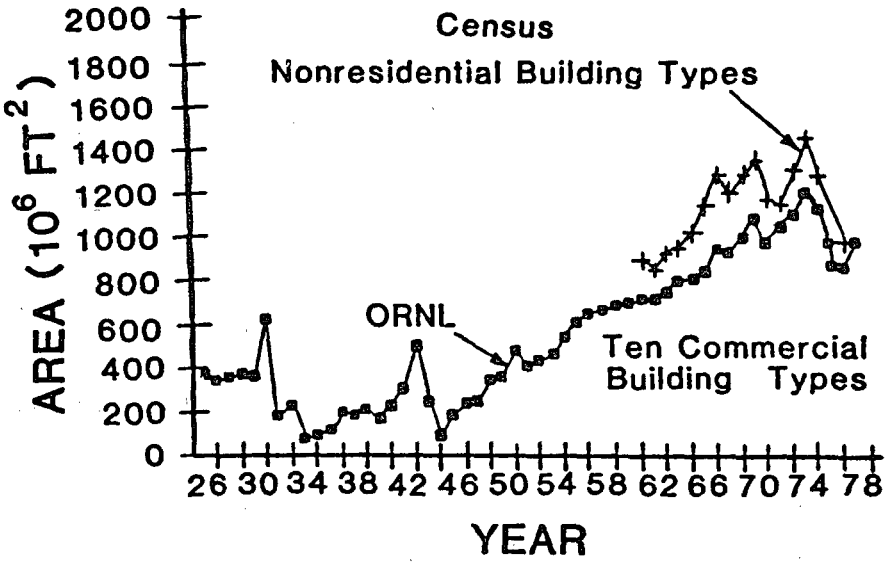

Figure 5-2. Bureau of the Census and ORNL Floor Space Additions

Table 5-3. Estimates of the Number, Square Footage, and Mean Area by Building Type Using the ORNL Commercial Energy Use Model Data (1980)

ORNL BUILDING TYPE	1980 SQUARE FOOTAGE (10^6 FT^2)	1980 BUILDINGS (THOUSANDS)	MEAN SQUARE FOOTAGE
Retail/Wholesale	5,946	367	16,196
Office	5,361	309	17,362
Automotive	691	63	10,907
Warehouse	2,806	138	20,361
Education	7,240	159	45,426
Hospital	2,293	69	33,284
Public	1,262	93	13,594
Religious	1,561	201	7,767
Hotel/Motel	1,788	44	40,565
Miscellaneous	3,963	353	11,215
Total	32,911	1,796	18,325 (Avg.)

commercial buildings types was calculated. The averages were used to estimate total square footage for each building type. These estimates of total floor space for the 12 NBECS building types, along with the number of buildings and the averages developed, are shown in Table 5-4. The data on the number of commercial buildings from the NBECS report, given by type and area class, are shown in Table 5-5.

Table 5-4. Estimates of the Number, Square Footage, and Mean Area by Building Type Using the NBECS Data (1980)

NBECS BUILDING TYPE	1980 SQUARE FOOTAGE (10^6 FT^2)	1980 BUILDINGS (THOUSANDS)	MEAN SQUARE FOOTAGE
Assembly	5,189	448	11,582
Auto Sales/Service	2,050	401	5,112
Educational	6,414	161	39,838
Food Sales	1,986	366	5,426
Health Care	1,472	44	32,771
Lodging	1,918	101	18,803
Office	7,513	600	12,522
Residential	3,069	347	8,844
Retail/Service	7,070	714	9,902
Warehouse/Storage	6,534	430	15,195
Other	3,180	237	13,474
Vacant	1,462	146	10,083
Totals	47,849	3,995	11,887 (Avg.)

NOTE: Data May Not Sum Due To Rounding

Table 5-5. NBECS Commercial Building Types by Area Class - Number of Buildings (Thousands) and Percent of Row Totals (1980)

NBECS BUILDING TYPE	TOTAL	NBECS AREA CLASS						
		1,000 or less	1,001 to 5,000	5,001 to 10,000	10,001 to 25,000	25,001 to 50,000	50,001 to 100,000	Over 100,000
		1	2	3	4	5	6	7
Assembly	448 (100)	44 (10)	156 (35)	131 (29)	79 (18)	25 (6)	8 (2)	5 (1)
Auto Sales & Service	401 (100)	92 (23)	197 (49)	78 (19)	28 (7)	5 (1)	1 (--)	1 (--)
Education	161 (100)	10 (6)	33 (21)	21 (13)	31 (19)	30 (19)	24 (15)	13 (8)
Food Sales	366 (100)	70 (19)	207 (57)	51 (14)	31 (8)	5 (1)	2 (--)	1 (--)
Health Care	44 (100)	4 (9)	15 (35)	9 (20)	6 (14)	2 (4)	4 (8)	4 (9)
Lodging	101 (100)	10 (10)	33 (33)	22 (22)	16 (16)	13 (13)	4 (4)	3 (3)
Office	600 (100)	89 (15)	259 (43)	115 (19)	86 (14)	27 (4)	13 (2)	12 (2)
Residential	347 (100)	41 (12)	177 (51)	45 (13)	64 (19)	11 (3)	6 (2)	2 (1)
Retail/Services	714 (100)	123 (17)	292 (41)	152 (21)	95 (13)	31 (4)	14 (2)	7 (1)
Warehouse & Storage	430 (100)	79 (18)	169 (39)	59 (14)	64 (15)	33 (8)	17 (4)	10 (2)
Other	237 (100)	58 (24)	76 (32)	38 (16)	39 (16)	16 (7)	5 (2)	5 (2)
Vacant	146 (100)	37 (26)	59 (40)	24 (16)	12 (8)	9 (6)	2 (2)	2 (1)
Totals	3,995(100)	655 (16)	1,672 (42)	745 (19)	551 (14)	207 (5)	101 (3)	65 (2)

NOTE: Data May Not Sum Due To Rounding

5.1.2.4 Results of the comparison.

The ORNL "Commercial Energy Use Model" helped to fill a large information gap concerning the commercial building sector in 1978. This model was based on the best available data, which was very meager. Because of this lack of data, the Office of the Consumption Data System (CDS) within EIA embarked on NBECS. In the preface to their documents, CDS explains that this is the first time that anyone "has developed a method of collecting data on a statistical sample of nonresidential buildings across the country."

Comparison of Tables 5-3 and 5-4 shows that the ORNL data may underestimate the number of commercial buildings by a factor approaching two. Different definitions of buildings can be responsible for some difference, but not on the scale indicated. The mean square footage of an "average" commercial building is 1.5 times higher using the ORNL data, which indicates that a significantly larger number of smaller buildings are present in the NBECS sample. Since the NBECS data represent the first chance to make estimates of energy based on a real national sample, they will be used in this report for projections and calculations.

5.1.3 Commercial buildings populations data base

The information in Table 5-5 is taken directly from NBECS, and the data in Table 5-4 was extrapolated from the NBECS data as described in Section 5.1.2.3. Further breakdowns, which comprise the buildings population data base for this report, are presented in Tables 5-6, 5-7, and 5-8. These breakdowns are based on the averages shown in Table 5-5 and those presented in Table 5-2. Figure 5-3 shows a breakdown of the number of buildings and area data from Table 5-2 for each area class. The majority of the buildings (42%) are in the range of 1,001 to 5,000 square feet, while the largest percentage of the square footage (34%) is in the class of over 100,000 square feet.

Table 5-7 presents a breakdown of the number of commercial buildings by Census region and building type (from NBECS directly). Table 5-8 shows the estimated total floor area for all commercial buildings with a breakdown by Census region and building type.

Table 5-6. NBECS Commercial Building Types by Area Class - Estimated Square Footage (10^6 ft^2 - 1980)

NBECS BUILDING TYPE	TOTAL	NBECS AREA CLASS						
		1,000 OR LESS	1,001 TO 5,000	5,001 TO 10,000	10,001 TO 25,000	25,001 TO 50,000	50,001 TO 100,000	OVER 100,000
		1	2	3	4	5	6	7
Assembly	5,189	25	422	94	1,226	861	544	1,162
Auto Sales & Service	2,050	51	532	560	435	172	68	232
Education	6,414	6	89	151	481	1,033	1,633	3,021
Food Sales	1,986	39	560	366	481	172	136	232
Health Care	1,472	2	41	65	93	69	272	930
Lodging	1,918	6	89	158	248	448	272	697
Office	7,513	49	700	826	1,335	930	884	2,789
Residential	3,069	22	479	323	993	379	408	465
Retail/Services	7,070	69	789	1,091	1,474	1,068	952	1,627
Warehouse & Storage	6,534	44	457	423	993	1,137	1,156	2,324
Other	3,180	32	205	273	605	551	340	1,162
Vacant	1,462	21	159	172	186	310	136	465
Totals	47,849	366	4,522	5,349	8,550	7,130	6,802	15,106

Note: Data May Not Sum Due To Rounding

Table 5-7. NBECS Commercial Building Types by Census Region - Number of Buildings (Thousands) and Percent of Column Totals (1980)

NBECS BUILDING TYPE	TOTAL	NORTH EAST	NORTH CENTRAL	SOUTH	WEST
Assembly	448 (11)	57 (8)	146 (12)	199 (13)	46 (8)
Auto Sales & Service	401 (10)	77 (11)	145 (12)	122 (8)	57 (10)
Education	161 (4)	23 (3)	35 (3)	75 (5)	28 (5)
Food Sales	366 (9)	56 (8)	118 (9)	139 (9)	53 (9)
Health Care	44 (1)	7 (1)	18 (1)	15 (1)	5 (1)
Lodging	101 (3)	13 (2)	12 (1)	54 (4)	23 (4)
Office	600 (15)	104 (15)	192 (15)	199 (13)	105 (18)
Residential	347 (9)	131 (19)	109 (9)	78 (5)	29 (5)
Retail/Services	714 (18)	114 (16)	227 (18)	277 (19)	96 (17)
Warehouse & Storage	430 (11)	59 (8)	137 (11)	157 (11)	77 (13)
Other	237 (6)	34 (5)	68 (5)	94 (6)	40 (7)
Vacant	146 (4)	23 (3)	39 (3)	70 (5)	13 (2)
Totals	3,995 (100)	699 (100)	1,246 (100)	1,480 (100)	571 (100)

Note: Data May Not Sum Due To Rounding

Table 5-8. NBECS Commercial Building Types by Census Region - Estimated Square Footage (10^6 ft^2 - 1980)

NBECS BUILDING TYPE	TOTAL	NBECS AREA CLASS			
		NORTH EAST	NORTH CENTRAL	SOUTH	WEST
Assembly	5,189	660	1,691	2,305	533
Auto Sales & Service	2,050	393	741	624	291
Education	6,414	916	1,394	2,988	1,115
Food Sales	1,986	304	640	754	288
Health Care	1,472	229	589	491	164
Lodging	1,918	245	226	1,015	432
Office	7,513	1,302	2,404	2,491	1,315
Residential	3,069	1,159	964	690	256
Retail/Services	7,070	1,129	2,248	2,743	951
Warehouse & Storage	6,534	897	2,082	2,386	1,170
Other	3,180	458	916	1,267	458
Vacant	1,462	232	393	706	131
Total	47,849	7,924	14,288	18,460	7,104

Note: Data May Not Sum Due To Rounding

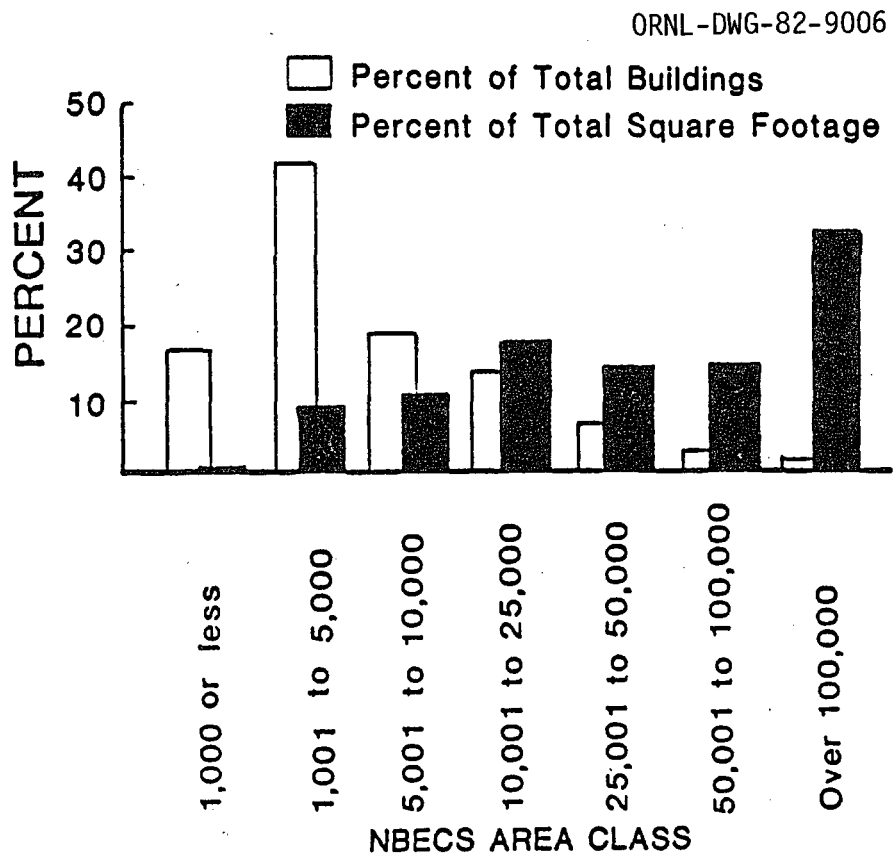

Figure 5-3. Number of Buildings and Square Footage Totals for the Seven NBECS Area Classes of Nonresidential Buildings (1980)

"Office" buildings and "Retail/Services" buildings account for 30 percent of all commercial footage. The distribution of square footage by Census region is: 17 percent North East; 32 percent North Central; 33 percent in the South; and 17 percent in the West.

5.1.4 Estimates of future U.S. building growth

A comparison of the ORNL Commercial total floor space by building type for the years 1970, 1975, and 1980 is given in Table 5-9. The total stock increased at a rate of 3 percent per year for the periods of 1970 to 1975, 1975 to 1980, and 1970 to 1980.

Table 5-9. Comparisons of ORNL Commercial Floor Space for 1970, 1975, and 1980 (10^6 ft^2)

ORNL BUILDING TYPE	1970	1975	1980
Retail /Wholesale	4,084	5,241	5,946
Office	3,452	4,180	5,361
Automotive	531	618	691
Warehouse	1,784	2,291	2,806
Education	5,985	6,564	7,240
Health	1,705	2,010	2,293
Public	1,002	1,168	1,262
Religious	1,324	1,405	1,561
Hotel/Motel	1,369	1,448	1,788
Miscellaneous	3,000	3,383	3,963
Total	24,236	28,308	32,911

By the year 2000, commercial floor space is forecasted to increase 64 percent, totaling over 50 billion square feet according to ORNL predictions (Reference 5-6). Using the NBECS data, this same percentage increase would predict over 75 billion square feet. Between 1980 and the year 2000, an annual growth in new building stock of approximately 3.4 percent per year was predicted, while the decay rate should average 1.5 percent per year. Therefore, in the year 2000, 54 percent of the building stock is estimated to have been constructed after 1981.

5.1.5 Limitations of available data

The total commercial floor space area predicted by the ORNL additions method with extrapolations from 1977 to 1980 was 32.9 billion square feet. This contrasts with the estimates based on the NBECS data of over 47 billion square feet in 1980 for this report. Floor space totals for the ORNL model were estimated using a three step process of: estimating the stock prior to 1926; summing additions to the stock from various sources; and subtracting floor space removals from the stock.

The ORNL floor space estimates of the stock prior to 1924 were determined by several methods, depending on the building type (see Reference 5-2). The floor space additions for subsequent years were taken from several sources, and the accuracy of that information is difficult to evaluate. A heavy reliance appears to be placed on the F. W. Dodge data. For a discussion of the problems encountered in projecting the commercial building stock using this approach, the reader should consult Reference 5-2.

The EIA-NBECS data is based upon a sample number of buildings (from the 48 contiguous states), and therefore, the results are subject to sources of sampling error, non-sampling error, and bias. The standard error (for sampling) for the national total of 4,238,000 nonresidential buildings is $\pm$ 398,000, and for the 3,995,000 commercial buildings, the standard error is $\pm$ 384,000. For the breakdowns, the relative error increases since the samples are smaller.

The data base for this study relied on the EIA-NBECS survey to arrive at the estimates of floor space. Only the total square footage of the nonresidential buildings was estimated by EIA for each of the seven area classes (not by building type). A direct comparison to commercial buildings can be made only by the assumption that the area of industrial buildings can be subtracted from the total of all nonresidential buildings because of equal distribution.

The assumptions made for certain projections in this report increase the potential error of those parts of the buildings population data base, and the extrapolations made should be recognized as such. However, this information has been determined to be the best available at this time for this study.

5.2 A/C Equipment Populations and Market Patterns

In contrast to the work aimed at establishing commercial buildings populations, very little has been done to determine A/C equipment populations in commercial buildings nationwide. Only two sources of this information could be located: NBECS and a study by Thermo-Electron Corporation (TECO) (Reference 5-7).

The information on the A/C equipment market is available from several sources and is commonly found. The Air-Conditioning and Refrigeration Institute (ARI) and the Current Industrial Reports series of the Bureau of the Census are the sources most commonly used and the sources for the data on market patterns in this report.

5.2.1 Background

The TECO report, released in December 1978, was intended to establish a comprehensive data base of energy using appliances used by commercial buildings, along with an estimate of present and future energy consumption. For A/C equipment, the populations of electric-drive equipment which are estimated for 1975 are:

- Year round A/C unit (4.5 - 53 tons)
- Condenser only A/C (4.5 - 53 tons)
- Horizontal A/C unit (4.5 - 53 tons)
- Heat pumps (package and split - 4.5 - 21 tons)
- Centrifugal chillers (75 - 1000 tons)
- Reciprocating chillers (6.5 - 125 tons)

These populations were estimated for all commercial buildings which have a classification in the Standard Industrial Classification (SIC) Manual of the Office of Management and Budget under divisions F through K and parts of E (communications and utilities). This population of commercial buildings should cover better than 90 percent of the commercial floor space accounted for by the ORNL model. However, the total primary energy use of the TECO inventory of electric-drive A/C equipment is more than a factor of two below the energy use estimated for A/C equipment in the commercial sector by the ORNL model for 1975 (Reference 5-2).

The NBECS data provided a breakdown of A/C equipment into the categories of:

- Window units
- Package units
- Central system
- Combination/other
- No air conditioning

The data are presented as the number of buildings with such an air-conditioning system by building type, and again as the number of buildings with such a system by area class (1-7) and by year constructed. Examination of the NBECS data shows that a determination of which buildings use window or some other type of air conditioning unit and which have no air conditioning at all is more important and fundamental at this time than determining the actual breakdown of central systems.

A/C equipment shipments are listed each year for a large number of categories by ARI and the Bureau of the Census. A history of these shipments can be used to establish market patterns for the commercial building sector. Although these shipments go to commercial and industrial buildings, an examination of Tables 5-2 and 5-4 show that commercial buildings account for 88 percent of the floor area of nonresidential buildings. Examination of the NBECS data shows that about one-third of industrial and one-third of commercial buildings are not air-conditioned. These factors indicate that these shipments data are representative of the commercial buildings sector. The ARI data covering heat pumps do not include units which are exported. Data covering all other equipment were corrected to account for exports.

5.2.2 The TECO A/C populations estimates

The TECO study contains estimates of the 1975 populations of appliances in the commercial sector for appliance types ranging from boilers to light bulbs (lamps) to coffee makers. The items of interest for this study are in the air conditioning category. The data from Table 5.2 of that study are presented below in Table 5-10. Resource energy consumption was calculated in that study by assuming a conversion efficiency of 0.294 from fuel to end use.

Also in Table 5-10, the calculated total capacity (tonnage) for each equipment type and revised values of coverage size, total capacity, and resource energy consumption are shown. The last three columns were generated for this report because the average size reported for some equipment types was less than the lower limit given in the size range column (see Table 5-10).

Table 5-10. Commercial Sector Electric Drive Large A/C Appliance Inventory and Energy Use from the TECO Study (1975)

APPLIANCE TYPE	SIZE RANGE (TONS)	TECO AVERAGE SIZE (TONS)	INVENTORY (THOUSANDS)	CALCULATED CAPACITY (10^6 TONS)	RESOURCE ENERGY CONSUMPTION (10^{12} BTU/YEAR)	REVISED AVERAGE SIZE (TONS)	REVISED CAPACITY (10^6 TONS)	REVISED RESOURCE ENERGY CONSUMPTION (10^{12} BTU/YEAR)
HEAT PUMP (SINGLE & SPLIT)	4.5-21	3.3	128	0.4	16	10	1.3	40
YEAR ROUND A/C	4.5-53	5.0	656	3.3	130	10	6.6	170
CONDENSER (SPLIT SYSTEM)	4.5-53	4.2	1,752	7.4	293	10	17.5	430
HORIZONTAL A/C	4.5-53	5.0	879	4.4	174	10	8.8	230
RECIPROCATING CHILLER*	6.5-125	20	67.4	1.3	54	37	2.5	60
CENTRIFUGAL CHILLER*	75-1,000	333	37.5	12.5	116	400	13.3	220
TOTALS			3,520	29.3	783	—	50.0	1,150

* INCLUDES SCREW COMPRESSOR UNITS

The calculated total A/C equipment capacity is 29.3 x 10^6 tons and the annual resource energy consumption is 780 x 10^{12} Btu/year, using the TECO average sizes. However, some of the averages are obviously wrong, and these averages do not compare with the averages determined for this study for shipments from 1970-1979 (see Section 5.2.4). The revised averages yield a total A/C capacity of about 50 x 10^6 tons in 1975, and the revised resource energy consumption is 1,150 x 10^{12} Btu per year. In contrast, the estimate of total A/C capacity reported for this study for 1980 is 95 x 10^6 tons (see Section 5.2.3), and the estimated resource energy consumption of A/C equipment in commercial buildings reported by ORNL (Reference 5-2) for 1975 was 1,830 x 10^{12} Btu/year.

An examination of the NBECS data indicates that a 20 percent increase in A/C equipment capacity (tonnage) would be reasonable from 1975 to 1980. Also, the types of A/C systems included in the TECO study should account for 60-70 percent of the total capacity estimated from the NBECS data. Applying these two factors to the total capacity estimated for this report (from the NBECS data) results in a total 1975 capacity of 45-55 x 10^6 tons. The revised TECO estimate of about 50 x 10^6 tons is in agreement. Applying the 60-70 percent factor to the ORNL estimate of total A/C energy use in 1975 yields 1,100-1,300 x 10^{12} Btu/year. Again, the revised estimate of resource energy consumption of 1,150 x 10^{12} Btu/year using the TECO A/C equipment populations is in agreement.

The TECO estimates of A/C equipment populations appear to represent a reasonable, detailed breakdown of specific types of A/C equipment in commercial buildings as of 1975. The categories used appear to exclude unitary air conditioners in the "other than horizontal" category - a category which is 20-30 percent as large as the "horizontal" A/C category. However, this apparent exclusion does not detract from the value of this data.

5.2.3 1980 A/C populations estimates using the NBECS data

In this section, estimates of United States A/C equipment populations are obtained from the EIA NBECS data. These estimates include absorption A/C equipment, but for comparison purposes the information is still valuable. The data on A/C equipment is given in terms of total tonnage and total number of commercial buildings with such equipment. The total tonnage estimates are arrived at by developing estimtates of the total floor area with cooling for each NBECS commercial building type. Additional estimates of the typical number of square feet per ton are made for each building type to arrive at the final estimates of total installed A/C equipment capacity. The floor area estimates are based on the NBECS data, and the key assumption is that of equal distribution of A/C equipment types within each building size class and building type. This assumption allows the use of average building sizes for each size class and building type.

The four A/C equipment categories used for NBECS are listed in Section 5.2.1. For NBECS, the EIA estimated that window units were used in 814,000

commercial buildings (20%), package units in 746,000 buildings (19%), central systems in 709,000 buildings (18%), and 278,000 (7%) had an air conditioning system classified as "other" or a combination of either window, package, or central system. The remaining 1,449,000 buildings (34%) were reported to have no air conditioning equipment.

A breakdown of the number of nonresidential buildings by area class and A/C equipment type is presented in Table 5-11. This breakdown is taken directly from the NBECS documents. A breakdown of the number of commercial buildings, also directly from NBECS, by commercial building type and A/C equipment type is presented in Table 5-12. This information was used to develop Tables 5-13 and 5-14. Using a process similar to that for the square footage estimates for commercial buildings, the total floor area for each A/C equipment type by building area class was estimated. These estimates are shown in Table 5-13. Using the average building size for each area class and the number of commercial buildings in each category, the data in Table 5-14 were generated.

To obtain estimates of total A/C capacity for each commercial building type, estimates of the number of square feet per ton were developed and applied to the total area cooled for each commercial building type. The tonnage estimates are shown in Table 5-15 and Figure 5-4. See Figure 5-1 for a list of the NBECS commercial building type numbers.

5.2.4 A/C equipment market patterns

Commercial A/C equipment activity historically follows the patterns of the construction industry, which is the driving factor for the market. The 1973 shipments of electric-drive A/C equipment were 632 thousand units - the peak for the decade (1970-79). A sharp decline occurred in 1975, and shipments have been sluggish since then, with 1980 shipments falling off from the previous year (largely due to the decrease in the unitary sector).

The unitary equipment sector (other than heat pumps) consists of four basic categories. Air conditioners are classified as horizontal units, other than horizontal, year round, and remote condenser (split system). Heat pumps are divided into single package and split systems.

The built-up equipment sector reported here includes reciprocating and centrifugal chillers. Depending on size, screw compressor chillers are reported under one of the two chiller categories shown in this report.

Table 5-11. NBECS Nonresidential Building Area Class by A/C Equipment Type - Number of Buildings (Thousands - 1980)

NBECS AREA CLASS (FT^2)	A/C EQUIPMENT TYPE					
	WINDOW UNITS	PACKAGE UNITS	CENTRAL SYSTEM	COMBINATION/ OTHER	NO COOLING	TOTAL
1,000 OR LESS	192	52	65	16	352	677
1,001 - 5,000	359	291	302	93	685	1,729
5,001-10,000	130	182	152	65	271	801
10,001-25,000	108	165	130	61	133	596
25,001-50,000	41	65	44	30	56	237
50,001-100,000	19	28	32	20	22	121
100,000 Or Greater	8	17	24	18	10	78
TOTALS	856	800	749	302	1,530	4,238

Notes: Data May Not Sum Due To Rounding
Includes Data For 243,000 Industrial Buildings

Table 5-12. NBECS Commercial Building Types by A/C Equipment Type - Number of Buildings (Thousands - 1980)

NBECS BUILDING TYPE	TOTAL	WINDOW UNITS	PACKAGE UNITS	CENTRAL SYSTEM	COMBINATION/ OTHER	NO COOLING
Assembly	448	47	85	95	46	175
Auto Sales & Service	401	70	25	28	16	262
Education	161	37	28	31	13	52
Food Sales	366	95	106	77	25	64
Health Care	44	9	7	15	7	5
Lodging	101	30	10	16	10	35
Office	600	108	188	186	61	59
Residential	347	137	33	36	22	118
Retail/Services	714	169	163	130	35	216
Warehouse & Storage	430	47	40	54	17	272
Other	237	54	50	23	20	90
Vacant	146	10	12	18	6	100
Totals	3,995	814	746	709	278	1,449

Notes: Data May Not Sum Due To Rounding

Table 5-13. NBECS Nonresidential Buildings Area Class by A/C Equipment Type - Estimated Square Footage (10^6 ft^2 - 1980)

NBECS AREA CLASS	A/C EQUIPMENT TYPE					TOTALS
	WINDOW UNITS	PACKAGE UNITS	CENTRAL SYSTEM	COMBINATION/ OTHER	NO COOLING	
1,000 Or Less	107	29	36	9	196	377
1,001-5,000	971	787	817	251	1,852	4,675
5,001 -10,000	934	1,307	1,092	467	1,947	5,755
10,001-25,000	1,676	2,560	2,017	947	2,064	9,249
25,001-50,000	1,412	2,239	1,516	1,033	1,929	8,164
50,001-100,000	1,292	1,905	2,177	1,360	1,497	8,231
100,000 Or Greater	1,859	3,951	5,578	4,184	2,324	18,130
Totals	8,251	12,778	13,233	8,251	11,809	54,581

Notes: Data May Not Sum Due To Rounding

INCLUDES DATA FOR 243,000 INDUSTRIAL BUILDINGS

Table 5-14. NBECS Commercial Building Type by A/C Equipment Type - Estimated Square Footage (10^6 ft^2 - 1980)

NBECS BUILDING TYPE	COOLING TOTALS	WINDOW UNITS	PACKAGE UNITS	CENTRAL SYSTEM	COMBINATION/ OTHER	NO COOLING
Assembly	3,160	544	984	1,100	533	2,027
Auto Sales & Service	711	358	128	143	82	1,339
Education	4,303	1,461	1,105	1,224	513	2,111
Food Sales	1,638	513	573	416	136	347
Health Care	1,278	303	235	505	235	194
Lodging	1,240	564	188	301	188	677
Office	6,777	1,348	2,346	2,321	762	739
Residential	2,025	1,217	293	319	196	1,044
Retail/Services	4,928	1,675	1,616	1,289	347	2,139
Warehouse & Storage	2,398	714	608	820	258	4,133
Other	1,980	728	674	310	269	1,200
Vacant	464	101	121	181	60	999
Totals	30,902	9,526	8,871	8,929	3,579	16,949

Notes: Data May Not Sum Due To Rounding

Table 5-15. Estimated Total Installed A/C Capacity by NBECS Commercial Building Type (1980)

NBECS BUILDING TYPE	ESTIMATED FT^2/TON	TONS / 1000 FT^2	COOLED AREA (10^6 FT^2)	ESTIMATED A/C CAPACITY (10^6 TONS)	PERCENT OF A/C CAPACITY
Assembly	330	3.03	3,160	9.57	10
Auto Sales & Service	600	1.66	711	1.18	1
Education	260	3.84	4,303	16.52	17
Food Sales	315	3.17	1,638	5.20	5
Health Care	260	3.85	1,278	4.91	5
Lodging	300	3.33	1,240	4.13	4
Office	320	3.12	6,777	21.14	22
Residential	600	1.66	2,025	3.36	4
Retail /Services	325	3.08	4,928	15.18	16
Warehouse & Storage	350	2.86	2,398	6.86	7
Other	320	3.12	1,980	6.18	6
Vacant	350	2.86	464	1.33	1
Total	320 (Avg.)	3.09 (Avg.)	30,902	95.6	100

Note: Data May Not Sum Due To Rounding.

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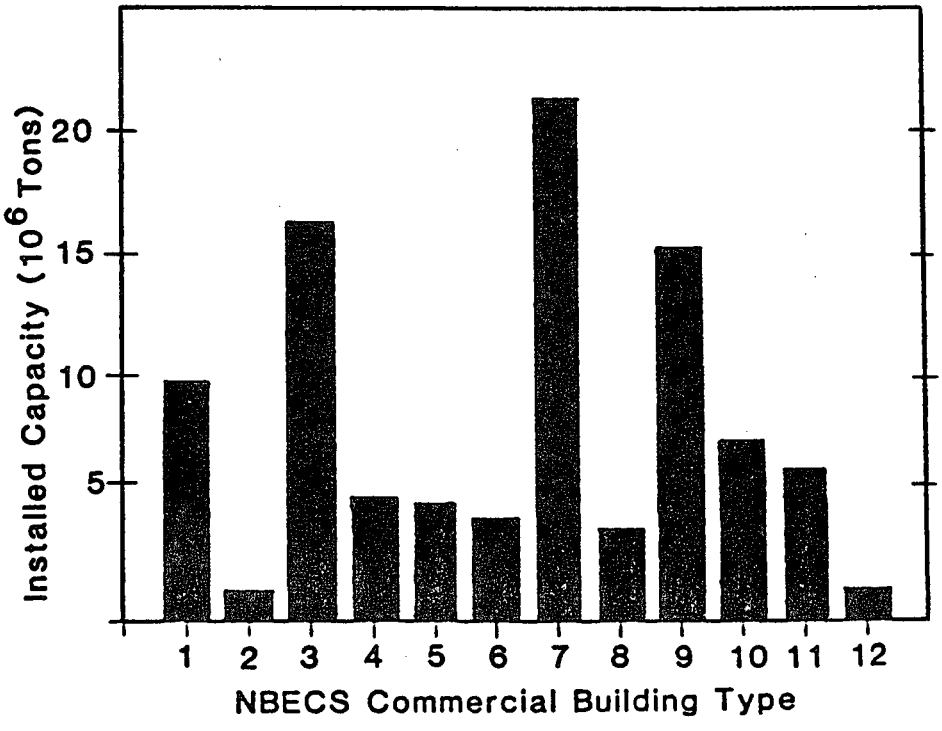

Figure 5-4. Total Installed A/C Capacity by Commercial Building Type (10^6 Tons - 1980)

The A/C equipment shipments in these two categories - unitary and built-up - are shown in Table 5-16 and Figure 5-5 for the period 1970-1980. These shipments include those destined for industrial sites, but the pattern should be representative of the commercial sector also. The total tonnages of these shipments are shown in Table 5-17 and Figure 5-6. All shipments have been corrected for exports.

For this study, particular emphasis was placed on large A/C systems. Figures 5-5 and 5-6 show the dominance of unitary equipment in number and tonnage. However, when shipments of equipment in the larger sizes described in the Introduction to this report are examined, the picture changes. As Figures 5-7 and 5-8 show, for the sizes of A/C equipment selected, unitary equipment still dominates in number of units (91 percent) shipped, but chiller tonnage (56 percent) exceeds unitary (43 percent). An examination of the TECO populations of A/C equipment (Section 5.2.2, Table 5-10) shows that unitary A/C equipment represents about 70 percent of the total A/C capacity (tonnage) in commercial buildings. The inclusion of shipments to all nonresidential buildings in the market patterns data should cause a shift toward water chiller equipment. Readers should keep this in mind. However, chillers shipped to industrial sites often have building space conditioning as a large percentage of their total load (energy use).

The estimates of unitary equipment shipments and tonnage were obtained from a market report by W. E. Hill and Company (Reference 5-8), with extrapolations for 1977-1980 based on ARI data reported in the 1981 Statistical Panorama (Reference 5-9) and Bureau of the Census data (Reference 5-10). Built-up equipment shipments were taken from Statistical Panorama, and tonnage estimates were based on Bureau of the Census data.

The average size of all commercial unitary shipments is 5-1/2 to 6 tons. The average size of commercial unitary shipments in the 5-1/2 to 100 ton range is 11 tons. These averages indicate the preponderance of unitary tonnage in the smaller sizes. The average size of all reciprocating chillers shipped is 37 tons, while the average size of reciprocating chillers shipped in the 20 tons and up category is 57 tons. The average size of centrifugal chillers shipped, hermetic and open, is 400-450 tons. If A/C equipment size is restricted to 20 tons or greater, the total unitary capacity (tonnage) becomes a small portion of the total.

Table 5-16. Annual U.S. Commercial Shipments of A/C Equipment 1970-1980 (Number of Units)

YEAR	UNITARY	BUILT-UP	TOTAL
1970	400,000	12,400	412,000
1971	425,000	12,000	437,000
1972	566,000	11,300	577,000
1973	620,000	12,400	632,000
1974	500,000	13,300	513,000
1975	367,000	11,100	378,000
1976	459,000	9,400	468,000
1977	465,000	10,300	475,000
1978	430,000	9,800	440,000
1979	522,000	9,800	532,000
1980	446,000	12,100	458,000

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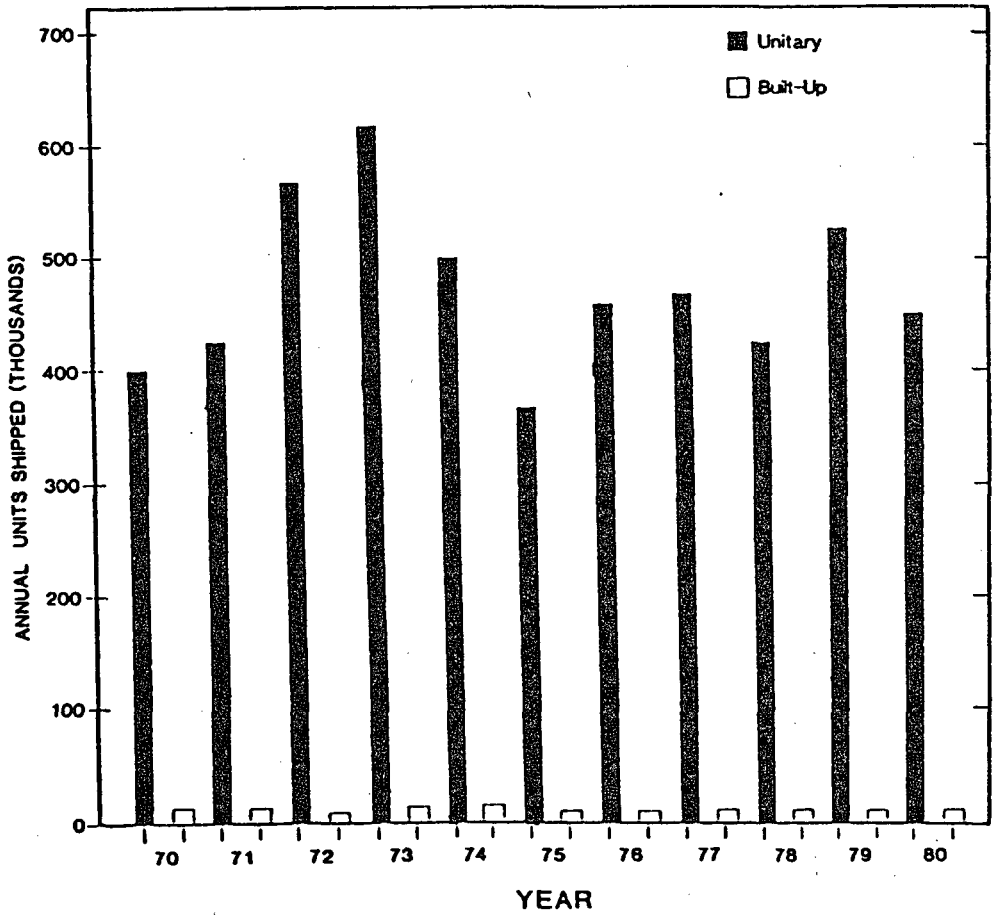

Figure 5-5. Annual U.S. Commercial Shipments of A/C Equipment for 1970-1980 (Thousands of Units)

Table 5-17. Annual U.S. Commercial Shipments of A/C Equipment for 1970-1980 (Thousands of Tons)

YEAR	UNITARY	BUILT-UP	TOTAL
1970	2,300	1,700	4,000
1971	2,500	1,700	4,200
1972	3,100	1,300	4,400
1973	3,500	1,700	5,200
1974	3,100	1,900	5,000
1975	2,200	1,900	4,100
1976	2,700	1,400	4,100
1977	2,700	1,300	4,000
1978	2,600	1,400	4,000
1979	3,000	1,400	4,400
1980	2,600	1,900	4,500

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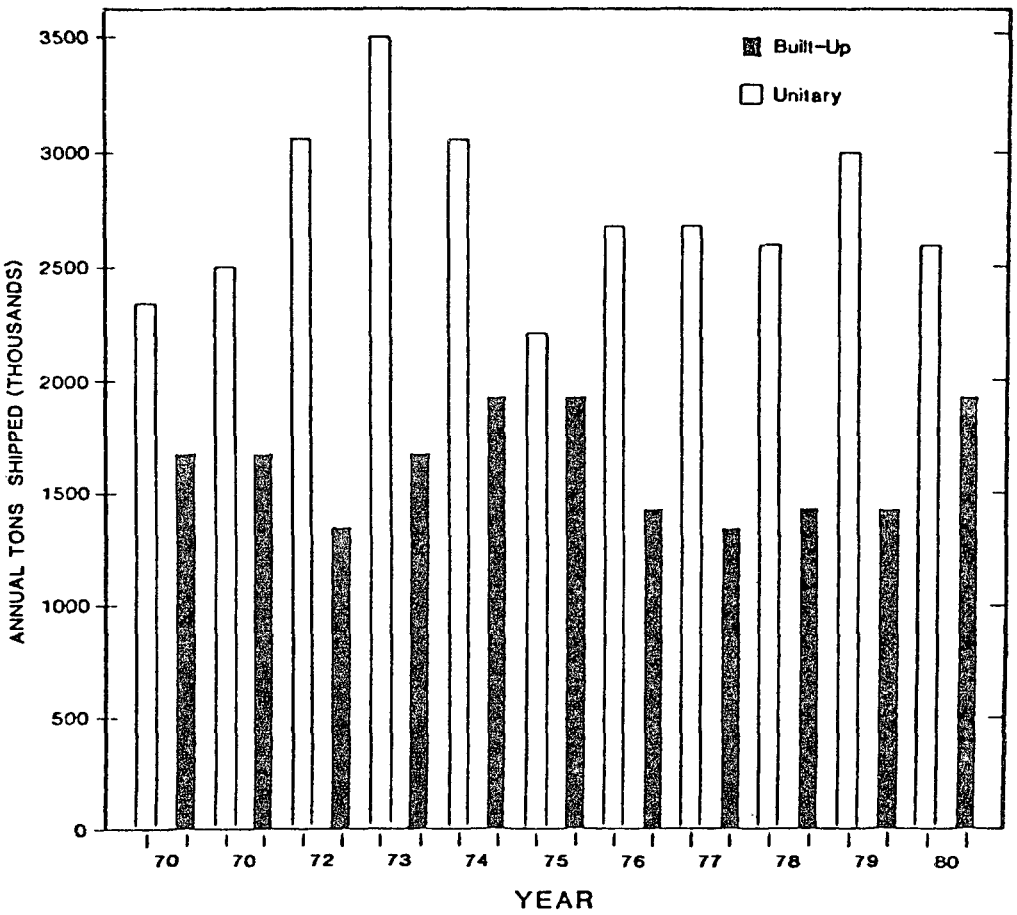

Figure 5-6. Annual U.S. Commercial Shipments of A/C Equipment for 1970-1980 (Thousands of Tons)

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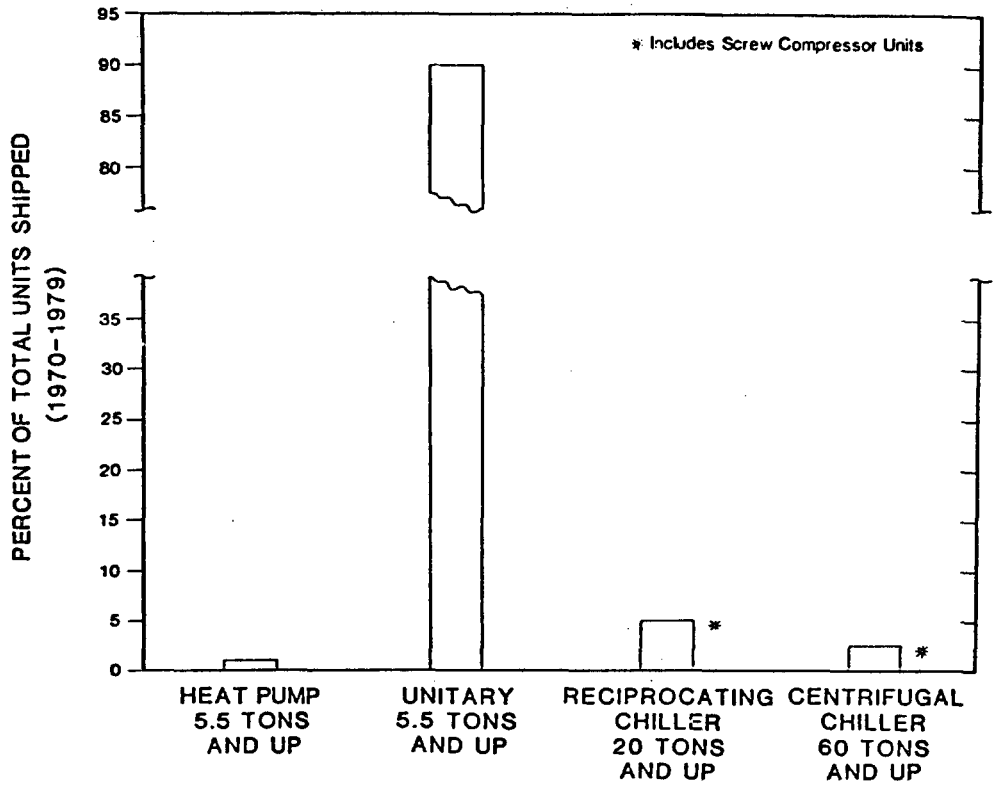

Figure 5-7. Market Size of Total Units Shipped by A/C Equipment Type for Larger Sizes (1970-1979)

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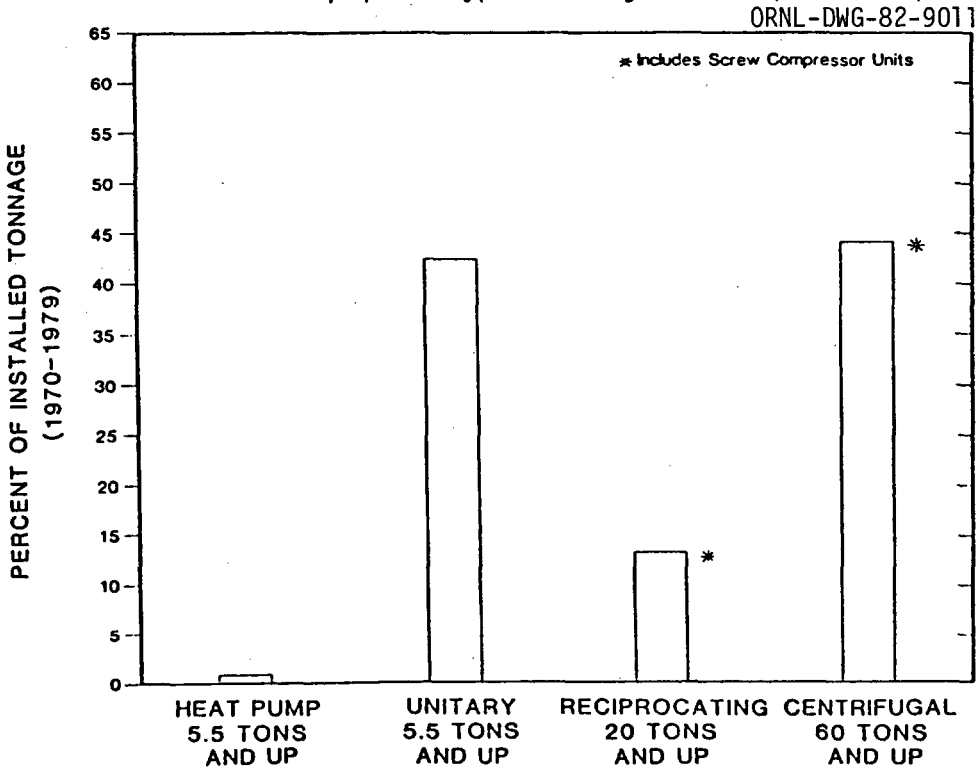

Figure 5-8. Market Size of Total Tonnage Shipped by A/C Equipment Type for Larger Sizes (1970-1979)

5.2.4.1 Heat pumps.

Small (less than 15 tons) unitary heat pumps represented 20 percent of the entire unitary market (number of units shipped) in 1979. In 1976, shipments increased 100 percent over the previous year due to escalation of energy prices, primarily in the residential sector. The commercial sector has followed traditional construction industry patterns. The breakdown by residential and commercial markets is shown in Figure 5-9. These data are from ARI for small heat pumps only (see discussion below), and packaged terminal air conditioners in a heat pump configuration, water source heat pumps, and room unit heat pumps are not included. Exports have been excluded.

Commercial (non-residential) sector shipments of unitary heat pumps are shown in Figure 5-10 for the period 1960-1980. The breakdown of split systems and single package units is also shown. As this figure indicates, split systems were taking a larger percentage of the market as the entire heat pump market grew in the years 1971 to 1978. In 1980, the entire (unitary and heat pump) market declined, and this trend toward split systems was reversed. In 1980, of the 423,000 small, air/air unitary heat pumps produced, 8400 were in the 5 1/2 to 15 ton range. Of the remaining 415,000 units (which were less than 5 1/2 tons), 63,000 were units for the commercial (nonresidential) sector.

Only a small portion of the heat pump market is in the 5 1/2 to 15 ton range (2 percent in 1980). The percentage of shipments in the 15-100 ton range is even smaller - typically 0.5 percent or less. In the 15-20 ton range, more split systems are typically shipped. In the 20-100 ton range, more package units are typically shipped. The number of units shipped in these size ranges is so small that meaningful trends cannot be stated.

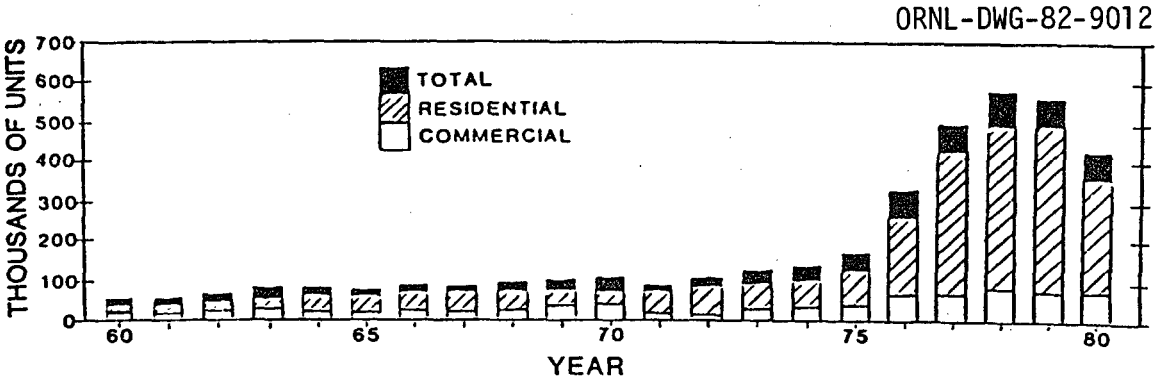

Figure 5-9. Annual U.S. Shipments of Unitary Air/Air Heat Pumps - Residential and Commercial for 1960-1980 (Thousands of Units Less Than 15 Tons in Size)

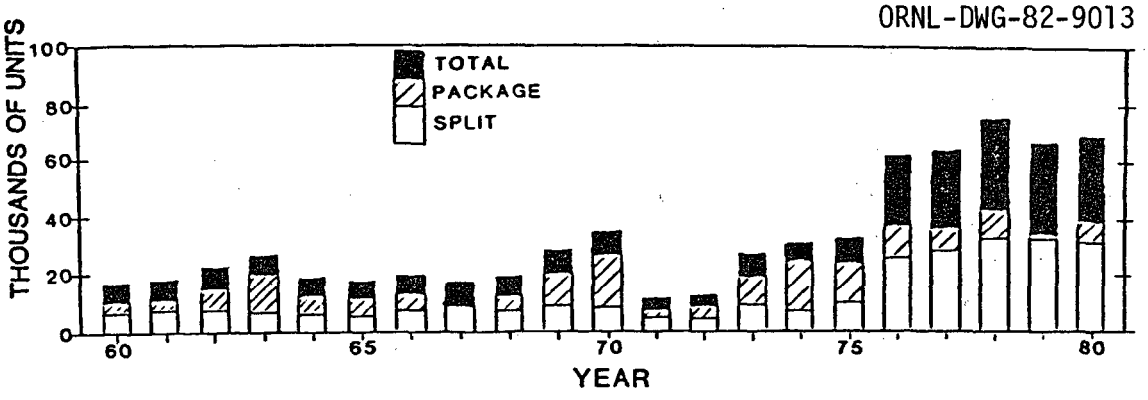

Figure 5-10. Annual U.S. Commercial Shipments of Air/Air Heat Pumps for 1960-1980 (Thousands of Units Less Than 15 Tons in Size)

6. ESTIMATES OF U.S. A/C EQUIPMENT ENERGY USE

Several studies have been undertaken to estimate energy consumption of commercial buildings in the United States in recent years. This section deals with the estimates of consumption from the ORNL Commercial Energy Use Model, which estimates the national total and breaks it down into end uses by fuel type and commercial building type. The commercial buildings and A/C equipment populations established in Section 5 and the Energy Use Indices (EUI's) developed by ORNL are used to establish a data base of A/C equipment energy consumption in commercial buildings.

6.1 United States Energy Use

In 1977, the total national energy consumption was about 76 Quads (10^{15} Btu). Consumption increased to about 79 Quads in 1979 and decreased in 1980 to 76 Quads - a decrease of about 3.5 percent over the previous year. The breakdown by end use sector in 1980 is shown in Table 6-1. Figure 6-1 shows the commercial buildings energy use fraction for 1980. Energy use data were taken from Reference 6-1.

Table 6-1. 1980 U.S. Energy Use by End Use Sector (Quads)

END USE SECTOR	QUADS (10^{15} BTU)	% OF TOTAL
Residential & Commercial	27.27	36
Industrial	30.29	40
Transportation	18.63	24
Total	76.20	100

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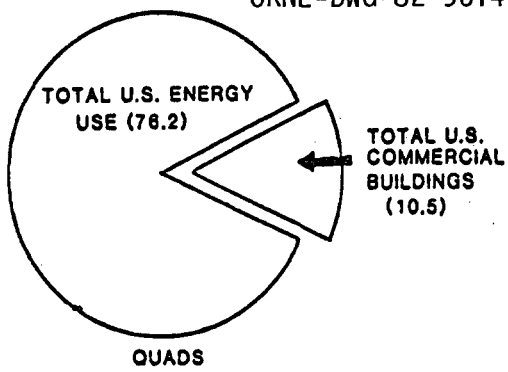

Figure 6-1. Estimated 1980 Total U.S. Energy Use (Quads)

Estimates of energy consumption of buildings in the commercial sector, based on the ORNL Commercial Energy Use Model, were 10.36 Quads in 1977 with projections of it increasing to 13.3 Quads by the year 2000. Table 6-2 shows the consumption in the residential and commercial sector by fuel type in 1977 (Reference 5-3). Estimates of the end use of energy by fuel in the commercial building sector in 1977 is shown in Table 6-3 (Reference 5-3). Figure 6-2 shows the air conditioning portion of commercial sector energy use for 1980.

6.2 Breakdown of Building Sector A/C Equipment Energy Use

The most widely accepted source of commercial energy consumption data is the ORNL Commercial Energy Use Model. This model is based upon data available from the Edison Electric Institute (EEI), the American Gas Association (AGA), and the Bureau of Mines (BOM). The commercial model subdivides end use into five categories, fuel type into four categories, and building type into the ten categories discussed in Section 5. Energy Use Indices (EUI's) (Btu/ft^2 of floor space/year) have been developed and are used in the ORNL Commercial Model for each building type, fuel type, and end use. For this study, the EUI's used in the ORNL model have been modified for the 12 EIA commercial building types.

Table 6-2. 1977 Residential and Commercial Energy Consumption (Quads)

FUEL	SPACE HEAT	AIR COND	WATER HEATING	LIGHTS	OTHER	TOTAL
Electricity	0.37	2.03	0.04	2.23	0.85	5.62
Gas	1.94	0.16	0.09	---	0.20	2.39
Oil	1.90	---	0.10	---	---	2.00
Other	0.35	---	---	---	---	0.35
Total	4.56	2.19	0.23	2.23	1.05	10.36

Table 6-3. 1977 Commercial Buildings Energy Use by Fuel and End Use

FUEL	RESIDENTIAL QUADS (10^{15} BTU)	COMMERCIAL QUADS (10^{15} BTU)
Electricity	7.81	5.62
Gas	5.30	2.39
Oil	2.40	2.00
Other	0.62	0.35
Total	16.12	10.36

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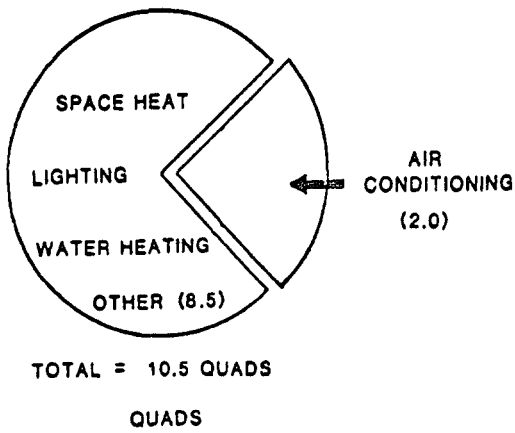

Figure 6-2. Estimated 1980 U.S. Commercial Buildings Energy Use by End Use (Quads)

Table 6-4 presents the results of the ORNL "Commercial Model" in terms of cooling floor space, EUI and fuel type for the years 1970, 1975, and 1977. Figure 6-3 presents the 1977 EUI's for cooling for the ten commercial building types used by ORNL, and Figure 6-4 presents revised EUI's for the 12 NBECS building types for 1980. See Figure 5-1 for a list of the commercial building types (and type numbers) used for ORNL and NBECS.

Table 6-4. Commercial Floor Space, Cooling EUI Estimates, and Cooling Energy Use by Fuel Type from the ORNL Commercial Energy Use Model

YEAR	1970	1975	1977
Cooled Floor Space (10^6 Ft^2)	13,100	17,400	19,600
Total Floor Space (10^6 Ft^2)	24,100	28,300	30,100
EUI (10^3 BTU/Ft^2-Yr)	122	113	112
Energy Use (10^{12} BTU/YR)			
- Electricity (Primary)	1,470	1,820	2,030
- Gas	130	140	160
Total	1,600	1,960	2,190

A comparison of Figures 6-3 and 6-4 shows quite a difference in uniformity. The arrangement of building types is arbitrary, and in both cases, the types are presented in the same order presented in the reference documents. The revised EUI's presented in Figure 6-4 are the result of careful comparison of the total floor area cooled and precent of total floor area that is cooled floor area for corresponding building types from the ORNL model and NBECS. The ORNL model is very useful for predicting the total energy consumption by building type for different end uses. However, as shown in Section 5.1, the total commercial floor area (the resulting total cooled floor area also) used in the ORNL model appears to be low. This factor affects the values of the EUI's used. One further limitation when using the EUI's from the ORNL model is that the percentage of floor area cooled is assumed to be a constant (average) for all building types. Therefore, a building type which has a higher percentage of total floor area cooled than the "average" would have an EUI that is overestimated to account for the lower estimate of cooled floor area that the "average" indicates.

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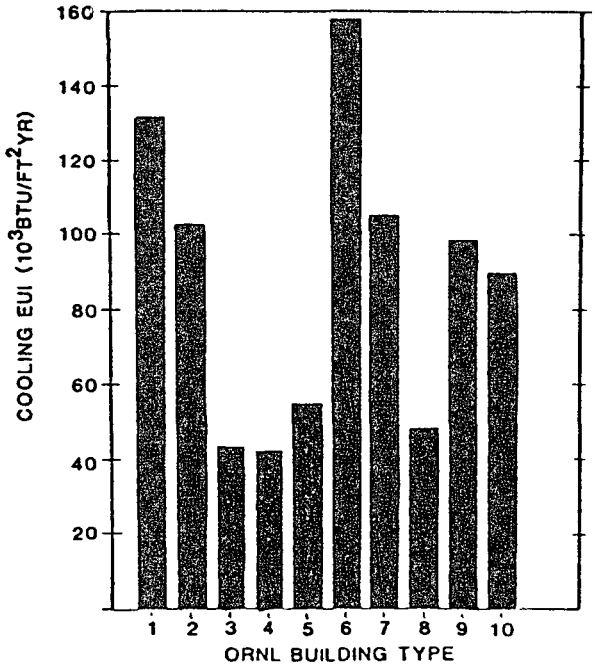

Figure 6-3. ORNL Cooling Energy Use Indices (EUI's) by ORNL Commercial Building Type (1977)

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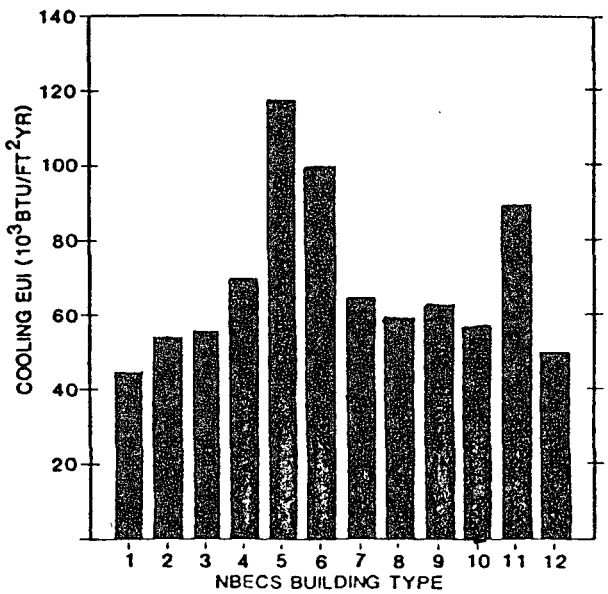

Figure 6-4. Revised Cooling EUI's Using the NBECS Commercial Building Types (1980)

As the present study shows, the recent appearance of the NBECS reports offers significant opportunities for refining and upgrading present knowledge of the characteristics of commercial sector energy use.

The EUI's in Figure 6-4 are not completely objective. For certain building types, the ORNL estimates of floor area very nearly matched the estimates in this report - when descriptions of buildings within certain building types are examined. As a result, certain EUI's were adjusted differently than others. Furthermore, for the NBECS type "Food Sales," the EUI was assumed to be a small percentage higher than the new "Retail/Services" EUI, which resulted from the ORNL "Retail/Wholesale" EUI being modified to account for total floor space and percent of total floor space cooled. Also, a further small change was made in the new "Retail/Services" EUI to account for this increase in the "Food Sales" EUI. The new "Assembly" EUI was not considered to be affected significantly by the "Food Sales" adjustment. For the new "Vacant" building type, the EUI is only an educated guess. The new "Residential" EUI was considered to be 90 percent of the new "Office" EUI.

Estimates of A/C equipment energy use using the new floor area and EUI data are presented in Table 6-5 and Figure 6-5. Estimates of energy use by A/C equipment type are shown in Table 6-6 and Figure 6-6.

Two important items that emerge from these estimates are:

1) In comparison with the expected average EUI from the ORNL Commercial Energy Use Model of 105,000-110,000 Btu/ft^2-yr, the average EUI is 64,000 Btu/ft^2-yr.

2) Central systems, package equipment systems, and window units each account for about 30 percent of cooling energy consumption in commercial buildings.

While a certain amount of work could still be expended refining the EUI and energy consumption data in this report, the essential information and acceptable estimates are shown here. Future work could include comparisons with other data sources to refine the estimates of energy use. The data in this section are considered to be the best available at this time.

Table 6-5. Estimated Energy Use Indices (EUI's) and Energy Use for the NBECS Commercial Building Types (1980)

NBECS TYPE NUMBER	NBECS BUILDING TYPE DESCRIPTION	COOLING AREA (10^6 Ft^2)	EUI (BTU/Ft^2-Yr)	COOLING ENERGY CONSUMPTION (QUADS)
1	Assembly	3,160	44,000	0.14
2	Auto Sales & Service	711	53,000	0.04
3	Education	4,303	55,000	0.24
4	Food Sales	1,638	70,000	0.11
5	Health Care	1,278	117,000	0.15
6	Lodging	1,240	97,000	0.12
7	Office	6,777	64,000	0.43
8	Residential	2,025	58,000	0.12
9	Retail/Services	4,928	62,000	0.31
10	Warehouse & Storage	2,398	56,000	0.13
11	Other	1,980	90,000	0.18
12	Vacant	464	50,000	0.02
	Totals	30,902	64,000 (Avg.)	1.99

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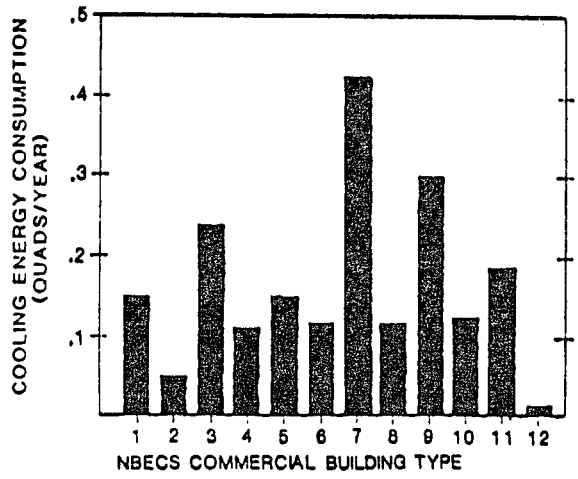

Figure 6-5. Estimated Cooling Energy Consumption for the NBECS Commercial Building Types (1980)

Table 6-6. NBECS Commercial Building Types by A/C Equipment Type - Estimated Annaul Cooling Energy Consumption (10^{12} Btu/year - 1980)

NBECS BUILDING TYPE	A/C EQUIPMENT TYPE				
	WINDOW UNITS	PACKAGE UNITS	CENTRAL SYSTEM	COMBINATION/ OTHER	TOTAL
Assembly	24	43	48	23	139
Auto Sales	19	7	8	4	38
Education	81	61	68	28	237
Food	36	40	29	10	115
Health	35	27	59	27	150
Lodging	55	18	29	18	120
Office	87	151	149	49	434
Resident	70	17	18	11	117
Retail	104	100	80	22	306
Warehouse	40	34	46	14	134
Other	66	61	28	24	178
Vacant	5	6	9	3	23
Totals	622	565	571	233	1,991
Percentage	31	28	29	12	100

Note: Data May Not Sum Due To Rounding.

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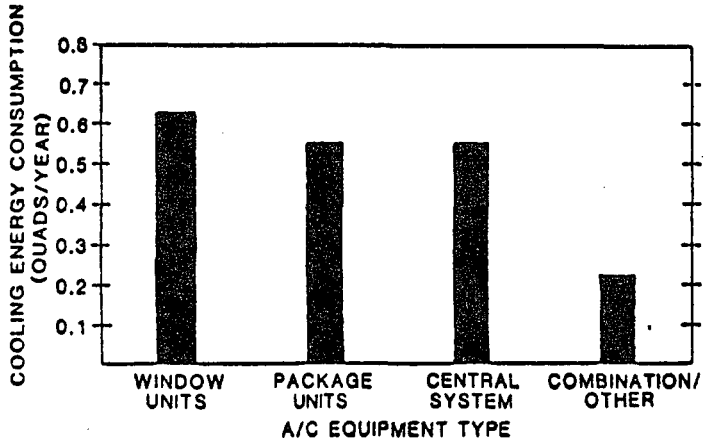

Figure 6-6. Estimated Cooling Energy Consumption in the Commercial Sector by A/C Equipment Type (1980)

7. NON-TECHNICAL CONSTRAINTS ON THE DEVELOPMENT AND USE OF ENERGY CONSERVING SYSTEMS

Through the study of References 7-1 and 7-2 and contacts with many individuals across the country, an encompassing view was developed of the non-technical problems that are impeding the use of energy efficient HVAC systems. The primary impediment to the technical development of energy conserving systems is the poor market for energy efficient HVAC systems caused by non-technical constraints. Despite this impediment, energy efficient HVAC systems have been and still are being developed by manufacturers, usually when the costs for energy efficient equipment can be justified in the present market. The identity of individuals who supplied information which aided in the development of this view of non-technical constraints is being kept confidential in order to minimize the reluctance of participants to divulge complete and accurate information.

For this report, non-technical constraints are divided into the following groups:

- Institutional constraints
- Economic constraints
- Educational/informational/psychological constraints

Institutional constraints include regulations and codes that affect purchase decisions (e.g., tax laws and ventilation regulations), the difficulty of architectural/engineering (A&E) firms having to perform adequately within allotted budgets, the inability to allocate funds for conservation because of other priorities, and other similar considerations.

Economic constraints include the availability of capital and the lower relative cost of energy compared to captial costs.

Educational/informational/psychological constraints include the lack of desire of some building owners to learn about energy saving programs, negative reactions to such programs ("energy conservation means discomfort"), the lack of knowledge or indifference of building maintenance personnel, a mistrust of claims made for energy savings, and inertia to change.

One important consideration concerning the energy management market is the variety of customers. Energy management refers to the management of energy use which can lead to reductions in use and cost through analysis and

monitoring. This report specifically addresses A/C equipment and systems that use A/C equipment. The intent of the report is to help develop methods of reducing energy use in A/C systems. The intent is not to save cooling energy at the expense of other energy uses in buildings. Therefore, energy management must be considered. For this report, four categories of potential energy management projects are important. These categories result from the inherent differences between new and retrofit construction and profit and non-profit entities. The four categories are:

- Taxable new construction
- Non-taxable new construction
- Taxable retrofit construction
- Non-taxable retrofit construction

These four categories will be addressed in Section 7.2.

7.1 Institutional Constraints

Institutions are established practices, relationships, or organizations in a society. In this section, the institutions to be considered are the established practices and relationships present regarding the development and use of energy conserving HVAC systems for:

- HVAC Equipment Manufacturers
- HVAC System Designers
- HVAC System Installers
- HVAC System Owners
- Regulatory and Standards Writing Bodies

7.1.1 HVAC equipment manufacturers

For the most part, HVAC equipment manufacturers (including HVAC controls manufacturers) need no convincing that energy conserving equipment and systems should be developed, and they are developing such equipment and systems.

A lead time is required, but the effort is being made now. For development of technology radically different from today's, or where a market may be uncertain, the government should and often does provide funds to promote development. At this time, high efficiency cooling equipment and energy conserving HVAC systems can be provided to those commercial sector customers who desire such equipment.

7.1.2 HVAC system designers (architectural and engineering firms)

As mentioned previously, A/C equipment is only a small part in the successful design of HVAC systems in commercial buildings. The complexity of these systems requires more effort in design and installation. The usual designers of larger HVAC systems are mechanical engineering firms or architectural and engineering (A&E) firms. However, many HVAC systems are designed by mechanical contractors; but these systems tend to be simpler, and the contractor is performing an engineering function in those cases. All of these firms will be referred to as A&E firms in this report to simplify the discussion. However, the only common attribute is the function of designing HVAC systems.

In some instances, it may be advantageous to use independent architects and engineers instead of HVAC contractors for design because:

- They interface with installers and owners
- A common design is used for securing bids from contractors for installation (most important)
- They are specialists in design (important for more complicated systems)
- Many can arrange for a larger staff (for larger projects)

Some design firms specialize in the design and construction of particular facilities, and these firms are usually much larger than typical architectural and engineering firms.

The primary function of A&E firms is to satisfy their customers with a safe, professional job, while producing a profit. During the design stage, a design must be produced which:

- Satisfies the customer's requirements for thermal comfort

- Offers dependable, safe performance (which keeps the customer happy, causes less trouble for the designer, and enhances the designer's reputation)
- Will not cost too much to operate
- Does not exceed the budget

After the design of a new or remodeled facility is complete and construction is ready to begin, the owner commits to borrow the capital, and the rules of the game change somewhat. Two primary considerations affect all decisions after the project is financed:

1) Complete the project in time - every day means extra interest charges with no income

2) Do not exceed the budget

For new construction projects, reducing energy consumption through redesign, or any other modifications, usually cannot be considered once the capital is borrowed. The situation may be different for projects financed by issue of tax-free, long-term bonds or internal investment (equity) capital, but the majority of buildings are financed by taxable entities with borrowed money (debt capital). The primary sources of this captial are insurance companies.

For retrofit projects, the duration of the project usually is not as critical, since income is not reduced much, if at all. Therefore, staying within the budget is more important.

Historically, the HVAC system design of a new facility has been one of the first items subjected to cuts by a prospective owner (or architect) when a lower construction cost is desired. Although the increasing cost of energy has reduced this trend, the recent high interest rates (1980-1981) have increased the importance of reducing first cost. Overall cost reduction decisions are normally made by the architect, who usually has the responsibility for controlling costs. Thus, mechanical (HVAC) design engineers will often lose their "case" unless they are sufficiently convincing and influential to get a favorable decision from the building owner; assuming the owner is aware of the implications of life cycle costing and concerned about profits several years hence.

The linearity of the typical HVAC design process can be seen in the typical HVAC product selection process shown in Figure 7-1. The process

typically moves from customer to architect to engineer to contractor. If a building construction schedule will be limited by long equipment lead times, some purchases of HVAC equipment are handled by engineers acting on behalf of the customer. Several possible paths of HVAC equipment procurement are shown in Figure 7-2. The number of steps in product selection and possible procurement paths show that many interactions can occur and many individuals are involved who could have an impact on the A/C equipment used in buildings.

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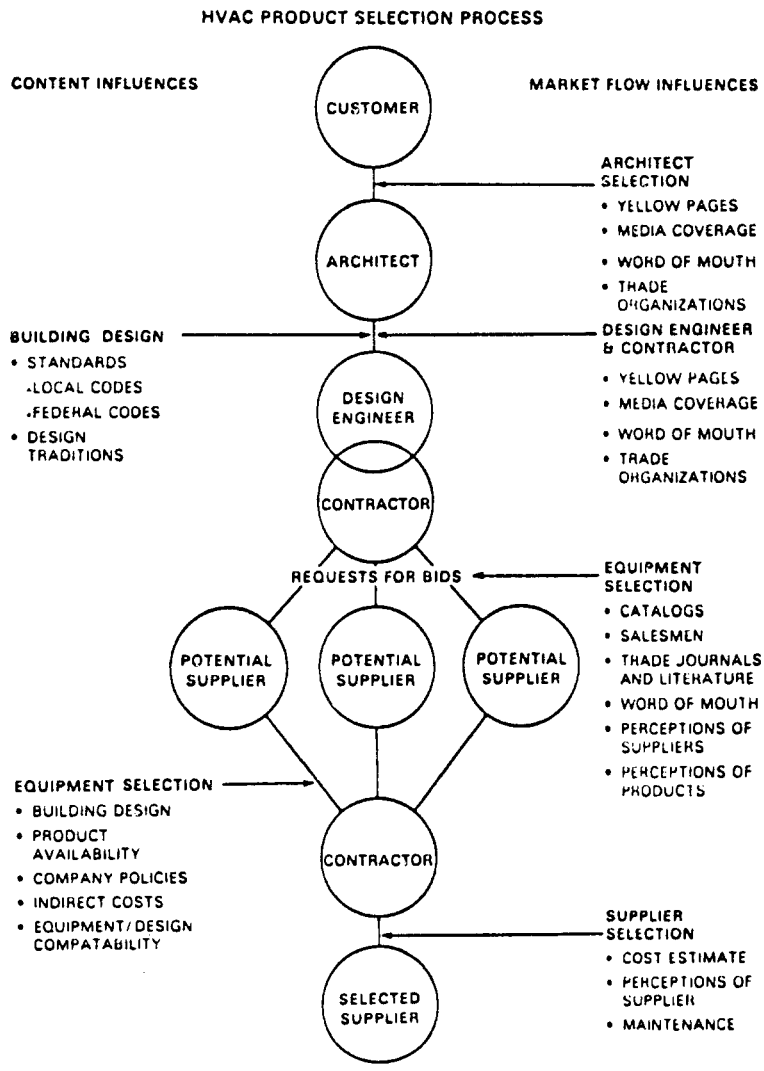

Figure 7-1. Typical Flow Pattern for the Selection of HVAC Equipment for Commercial Buildings

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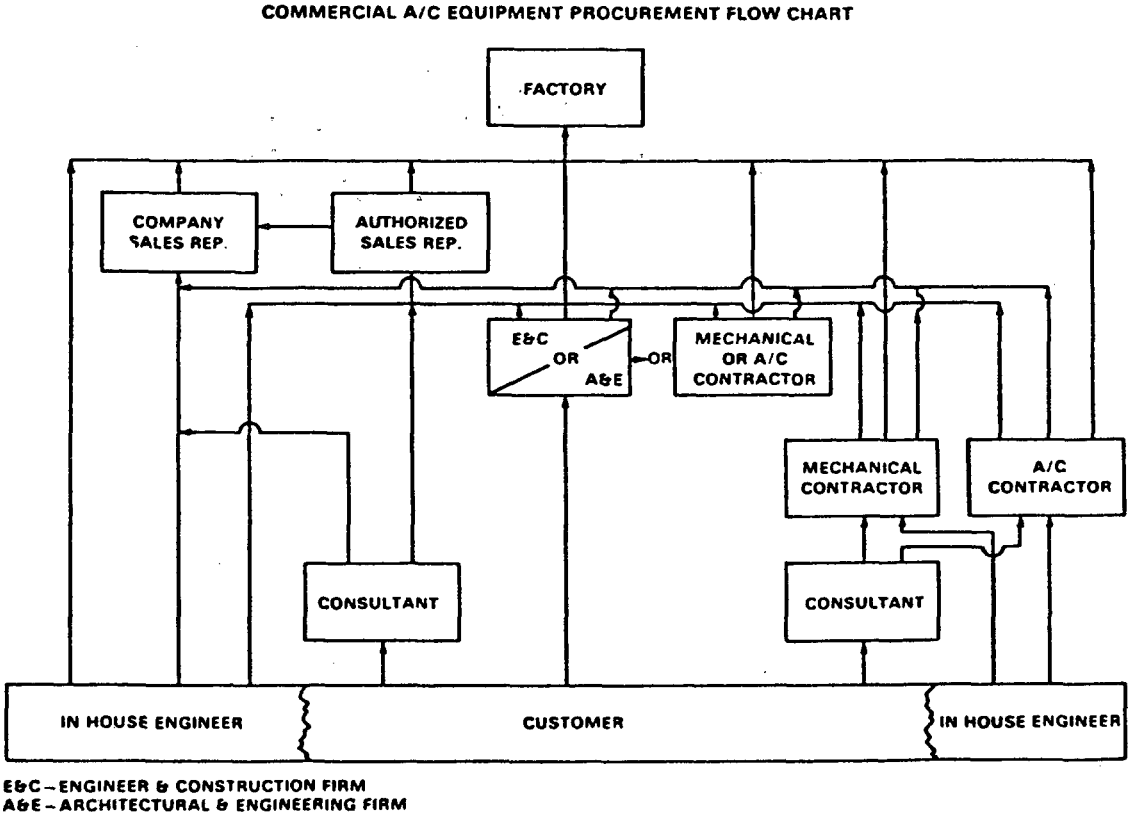

Figure 7-2. Procurement Paths for Commercial A/C Equipment

When the design process is too linear, the HVAC equipment and the building will be considered as two entirely separate items when, in reality, they should be considered as one system. This method of design can lead to the selection of a less than optimal HVAC system. The HVAC designer is often forced to make the HVAC system fit the building, when changes in building design could greatly reduce energy consumption. Thus, architects and engineers must design together to reduce energy use. Some firms have established energy coordinators to facilitate this interaction.

Finally, A&E firms must maintain competitive pricing for their work. This requirement can cause problems, especially when an A&E firm is unable to keep up with the state-of-the-art in HVAC system design techniques (see

Section 7.1.3). Due to the highly competitive nature of their business, many A&E firms are unable to pay the salaries or offer the benefits demanded by the desirable young graduates of engineering schools. Also, new graduates usually are not given challenging work or put in a career development program, and both of these practices tend to limit the stimulation and development of new and innovative ideas. In the reverse case, those making the final decision (managers who are usually older employees) may reject a new design due to the manager's lack of understanding of the newer methods and/or equipment associated with new (risky) ideas. (For a further discussion on pricing, see Section 7.2.2.)

7.1.3 HVAC system installers

The energy use of HVAC systems can be extremely affected by the quality of the installation. Also, proper installation is an important factor in determining equipment life. Potential problems range from improperly charged cooling (refrigeration) equipment to leaky air ducts to fouled (and unfunctioning) control elements. Installation problems can be caused by: a lack of qualified installation personnel; a lack of project inspection by the designers; inadequate installation procedures from the manufacturer; or some combination thereof. The interaction of several parties involved in the installation of HVAC equipment can cause more mistakes to occur. Frequently, installers must "field design" portions of HVAC systems such as the air distribution or refrigerant piping system. The level of "field design" required of the installer depends on the level of detail in the design drawings and specifications.

A lack of qualified installation personnel can lead to poorly operating or inefficient installations. Generally, efficiency is associated with variable control of fluid flows, temperature adjustments, varying capacity, etc., and the control sub-system which controls all these factors is becoming a sophisticated "brain" not well understood by the average installer. Poor installation results range from the simple mislocation of a thermostat (e.g., near an outlet grill) to a misapplied software program of a computer controlled system.

Some of these problems could be solved by post-installation inspection and testing. The HVAC designer also has a role to play as an installer, by

performing some of the inspection and testing. However, the fee negotiated for design often is not sufficient to allow significant inspection. Proper installation of systems is the responsibility of the installer. However, if the installer is following an engineer's design, the engineer becomes involved and shares the responsibility. One further complication is that the nature and solution of installation problems uncovered by an inspection are not always relayed to the installing personnel in a manner which allows them to learn from their mistakes. Corrections to the installation, if any, may be made without explaining the reasons for the corrections. This procedure does not improve the situation for the next system the installer works on.

7.1.4 HVAC system owners

One important problem concerning owners is that they are not energy experts and probably do not have the time or inclination to develop such talents. A problem of trust arises when owners must depend on external people or organizations to provide them with estimates of dollar savings from energy system retrofits. (See Section 7.2.3, "Taxable Retrofit Construction," for further discussion.)

Some obstacles to the design and implementation of efficient HVAC systems are created by the owners and/or users of the HVAC system. According to industry contacts, these obstacles are often caused by corporate inertia and lack of awareness or understanding of HVAC systems and operating costs.

One hindrance to efficient design and operation of HVAC systems is "corporate inertia", which refers to the resistance to change of a corporation or organization. Corporate inertia, which usually has a magnitude proportional to the size of the organization, has three main causes:

1) Lack of contact between upper management and informed staff

2) The corporate reward structure

3) Resistance to change

Upper management, which makes the final decision on capital allocation. normally does not get involved with detailed technical matters such as the advantages of efficient HVAC design; they see only the cumulative results or

"bottom line" operation of the entire facility. At this level, the important decisions involve dollars and cents, and energy costs are sometimes dwarfed by other operating expenses.

Each of the parties in a corporate hierarchy has specific responsibilities. The need for communication, along with a well informed upper management staff, is of utmost importance to understand the impact of the details that went into formulation of the "bottom line" recommendations. For example, a compromise might be reached to achieve a reasonably, if not most, efficient HVAC system if procedures, funding, and scheduling are provided for reiterative evaluations of the HVAC design.

A majority of contacts stated that a breakdown in the transfer of information often exists in corporations. This breakdown is caused by a combination of upper management not wanting to be bothered with details and middle management being reluctant to provide needed information. The reluctance on the part of lower and middle management to inform upper management of technical matters is caused by fears in taking a risk and by the corporate reward structure. Before making a suggestion to upper management, middle management must be assured that the change is technically sound, that upper management will be receptive, and possibly, that some personal benefit will result (salary increase, promotion, etc.). Waiting for this assurance can cause extended delays in information transfer; delays which are not available in most tight scheduling situations.

7.1.5 HVAC system operators

HVAC systems operation often suffers from a lack of proper system maintenance. Poor or improper maintenance can be caused by the lack of properly trained maintenance personnel or the lack of interest or incentive for maintenance personnel to perform beyond a certain level. These personnel, or HVAC system operators, have the responsibility to keep HVAC systems running in the most efficient manner, and to keep building occupants comfortable. Often, these two duties cause conflicting action, especially when the operator is unsure of the system or unable to make alterations to meet changing needs. Talented, qualified operators are few and far between, but they usually can lower energy costs while keeping building occupants comfortable.

7.1.6 Regulatory and standards writing bodies

Energy codes are a recent occurrence in the area of building and HVAC system design. Building and life safety codes have been present for many years, and they serve to promote the public good. Since codes tend to be inflexible, occasions arise when certain building or life safety codes do not properly address an application. In these cases, code officials are usually petitioned for a variance. Since changes in codes tend to occur very slowly, response capability to quick changing needs or discoveries regarding their application is limited. When conservation of energy was perceived to be for the public good, codes were enacted to enforce energy conservation in new building designs. The American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Standard 90 and the proposed Building Energy Performance Standards (BEPS) are examples of energy codes. ASHRAE Standard 90 was used to develop model energy codes for adoption by states as part of their building code requirements, while BEPS is Federal in scope. Presently, final regulations on BEPS do not appear to be forthcoming. The inherent inflexibility of codes, the difficulty of obtaining variances, and other considerations have caused a negative reaction to energy codes. Ironically, these regulations and standards were originally intended to insure energy conservation as a common good. The negative reactions caused by these regulations and standards resulted either from feelings of powerlessness, of limited flexibilty, or that a practical and effective approach was not taken. A common reaction to regulations is not "How can I comply?", but "How can I get around them?"

ASHRAE Standard 90, dealing with insulation, HVAC systems, and other energy systems, has been attacked by some building owners as being "too strict" and causing "excessive expenditures". Whether or not the standard is "too strict", the result has been a lowering of opinion by certain building owners, A&E firms, and others with respect to energy conservation.

The Federal Building Energy Performance Standards (BEPS) have experienced a very poor reception among building owners and A&E firms. According to those affected, BEPS are "too strict and too complex" to be practical and economical. The negative feelings regarding BEPS are detrimental to energy conservation, and many individuals and groups continue to attack them vigorously. The strictness is open to question. The complexity is truly a problem, especially regarding implementation.

In addition to the Federal regulations, some states have enacted their own regulations. According to some A&E firms, some states continue to require more ventilation air than is deemed necessary, which requires more energy to heat or cool. Also, some states have regulations requiring double-walled heat exchangers for potable water. Double-wall heat exchangers are more costly, larger, and less efficient than a single-wall unit. Of course, all this is for the common good, but value judgements make the common good different from state to state. In many cases, manufacturers feel that single-wall heat exchangers will not pose a health hazard (e.g., when the "other" fluid is not toxic or where the pressure differential causes mass movement away from the potable fluid).

7.2 Economic Constraints

Economic constraints on the use of energy efficient HVAC systems are the most limiting. Economic constraints involve: manufacturers of HVAC equipment; the designers of HVAC systems (A&E firms); and the owners and/or users of the HVAC systems. Economic constraints are most detrimental to energy conservation in general.

7.2.1 HVAC equipment manufacturers

The economic problems associated with the manufacture of HVAC equipment are tied to the cost of capital and the expected rate of return on investment. Specifically, problems are caused by the risks associated with the development of new models and inventory costs.

Risks are involved with the prediction of future market trends and the development of product lines to meet anticipated demand. However, as stated in Section 7.1.1, available research budgets are directed toward the development of energy conserving systems.

7.2.2 HVAC system designers (A&E firms)

Because of the pressures from clients to hold down initial costs, a sophisticated energy use and economic analysis (life-cycle cost comparison) usually is not performed. A&E firms do not push for such analyses because

their clients assume the A&E firms are giving them the best system possible, but they are really getting the best system possible with certain design tools. Initial cost is often the only criterion used. Refer to Sections 7.1.2 and 7.2.3 for other information.

7.2.3 HVAC system owners

The four categories of energy management projects listed at the beginning of Section 7 define the types of building owner and building project discussed in this section.

Taxable New Construction. An owner who pays taxes can deduct energy costs as operating expenses from gross income when calculating tax payments. Any savings in operating expenses increases revenue, which is taxable. No tax credits are presently available for energy saving investments with new construction. This lack of incentives may have occurred partially because BEPS were to guarantee that new buildings would be energy efficient. A large portion of new retail/services and office buildings, which represent approximately 40 percent of all present air-conditioning capacity of commercial buildings in this country (see Table 5-15), are built speculatively. Such an owner has little concern for energy consumption, except to be sure that energy use is not excessive. The speculative owner is more concerned with first cost than other owners are. The reasons for this will be discussed later in this section. A discussion of capital availability is given below.

Non-Taxable New Construction. Generally, building owners who do not pay taxes are more concerned about energy costs, since operating expenses do not enter the tax picture, and the buildings usually are used or occupied completely by the owner. For this type of owner, minimizing energy consumption in new construction is given more careful consideration, weighing the cost of energy and the cost of achieving low energy consumption. First costs are still critical, as will be discussed below. The present lack of low-cost capital is a problem for state and local governments. The Federal government, which is also in this category, is a major competitor for capital.

Taxable Retrofit Construction. Retrofit construction can include simple adjustments of HVAC controls or complicated installation of heat

recovery equipment. Most owners are interested in those items which will save energy without costing much money. When a sizeable investment is required, two big hurdles must be overcome:

1) Capital availability

2) Credibility of the savings

Capital availability is an important part of the first cost problem for all four of the cases discussed here, and the discussion of this problem is given below. Credibility of the savings is crucial in deciding to proceed with a retrofit. This problem exsits for new construction also, but definition of energy consumption has not even occurred for most new construction, which can make discussion of savings moot. Also, a lack of definition makes discussion of savings more nebulous to the owner. For retrofit, a building owner must rely on a person proposing changes for reducing energy costs. If the savings do not materialize, who is liable? Most building owners do not have the time or inclination to become knowledgeable in this area, so the credibility issue is born. Again, savings in operating expenses become revenue and are taxable.

One special problem occurs with property management companies which act as agents for building owners. Many of these companies have fee structures based on a percentage of gross revenues which pass through the building. Therefore, a reduction in energy costs reduces gross revenues through the building and correspondingly reduces the management company's fee. This is a truly negative incentive to save energy.

Non-Taxable Retrofit Construction. Non-taxable retrofit construction is similar to non-taxable new construction. As with taxable retrofit, the difference lies in the known energy consumption and cost for existing facilities. The issue of credibility of savings is an important one for this category also.

7.2.3.1 Availability of capital.

The economy of the United States has a finite ability to generate capital. Extra dollars may be printed at times, but the capital base (in constant dollars) is not necessarily increased. As capital becomes scarce, an increase in the cost of capital can restrict the number of borrowers who

can afford the cost, which limits the activities of the borrowers. In the case of HVAC systems, an increase in the cost of capital raises the incremental costs for energy efficient systems (when they are more costly than less efficient systems). In early 1981, with the relatively high cost of capital, these incremental HVAC costs nad become prohibitive.

The limited abiltity of the United States' economy to generate capital affects businesses, in that all businesses compete for this capital. The Federal government also competes, and the inclusion of the Federal government in this competition limits the capital available for businesses. These factors mean that each business must make decisions about the allocation of available capital. Therefore, the benefits of using funds for the incremental costs of (more efficient) HVAC systems must be evaluated with benefits from using these funds for other opportunities.

Capital can be restricted in two ways: 1) the high cost of borrowing money (interest); and 2) decisions on the allocation of scarce capital resources (opportunities). A doubling of the interest rate causes an approximate doubling of monthly finance charges. This restriction is easy for most people to understand.

The opportunity restriction is less clear. One of the main objectives of businesses is to generate more profits. Therefore, the first priority placed on the allocation of capital is for activities which maximize profits. The financial return for an energy efficient HVAC system, for either new construction or retrofit, must be attractive when compared to the expected financial return if the same capital was allocated for competing activities (opportunity cost).

One consideration of the effects of interest rates will be discussed here. Figure 7-3 shows a comparison of the prime interest rate charged by banks and the percentages of sales dollar value for applied (built-up) and unitary systems. For the period 1970-1979, the sales of unitary systems have tracked the prime interest rate with a time lag of about two to three years. Since three years is the expected delay from financing to complete construction of larger buildings, which tend to have applied systems, the hypothesis that new construction shifts from applied systems to unitary systems when interest rates increase is worth consideration. In general, applied systems cost more to install than unitary systems. However, these trends are only shown to indicate that the hypothesized relationship between

interest rates and the types of HVAC systems that are installed should be investigated.

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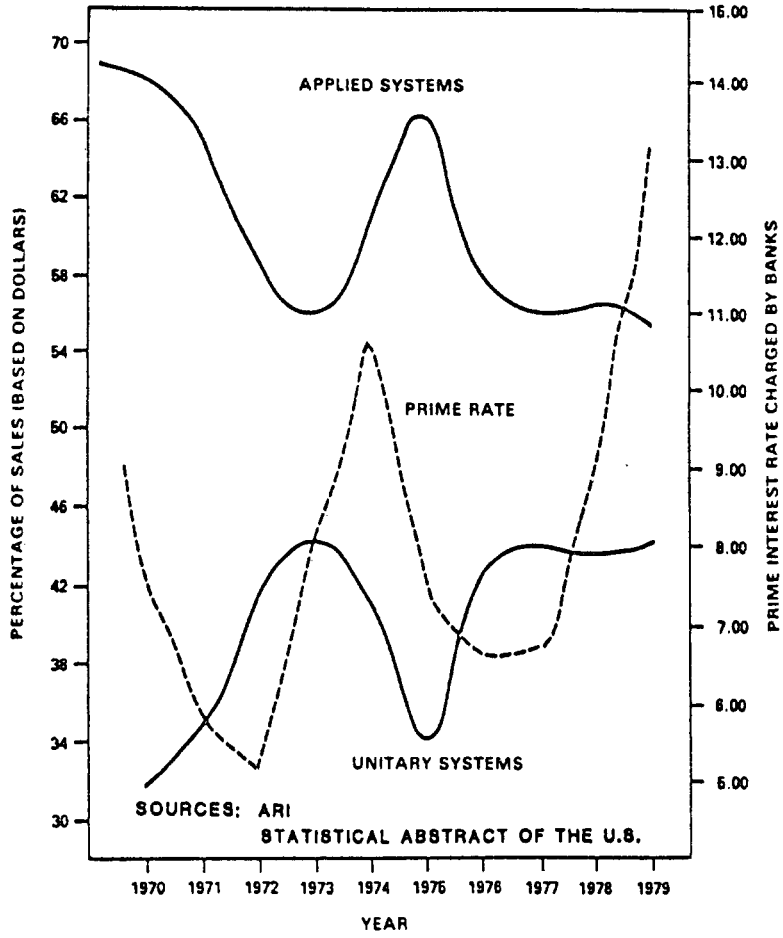

Figure 7-3. Yearly Percentage of Applied and Unitary HVAC System Installations with Superimposed Commercial Bank Prime Interest Rate

7.2.3.2 Real energy costs for businesses.

This section will cover the case of taxable retrofit construction described previously. To gain a better perspective of what energy costs

really mean to a business, the following examples are presented, based on work presented in Reference 7-3. The reader should keep in mind that the examples are meant to be extreme. The first example concerns a business which:

1) **has a 50 percent tax rate**

2) **has a ratio of energy costs to after tax profit of 20 percent**

These values are representative of a typical large business. If this business reduces energy use by 30 percent in one year (assuming all forms of energy used cost an equal amount per Btu), and other factors remain constant, their after tax profit will increase 3 percent. On the other hand, if this business does not reduce energy use, and energy costs increase by 40 percent in one year, their after tax profit will decrease 4 percent. The company that reduced energy use by 30 percent would see a 0.2 percent increase in after tax profit if their price of energy increased 40 percent. Percentagewise, that is not much incentive. The dollar values of savings might be large, but at upper management levels, decisions must be made on a relative basis. Also, the capital used to reduce energy consumption could have a large dollar value.

All these cases assumed that income remained constant. If income is increasing with respect to energy costs, the effects of energy costs and possible savings have a less noticeable effect for each case. A second example concerns those conditions more typical of a smaller business which:

1) **has a 30 percent tax rate**

2) **has a ratio of energy costs to after tax profit of 30 percent**

If this business reduces energy use by 30 percent in one year, with other factors constant, their after tax profit increases 6.4 percent. An increased energy cost of 40 percent in one year, with no reduction in use, will decrease after tax profit by 8.3 percent. A decrease in energy use of 30 percent, coupled with an increase in energy prices of 40 percent, will increase after tax profit 0.5 percent. This company has somewhat more incentive to conserve, but it is also likely to have less access to capital. See Table 7-1 for a comparison of all these cases.

Table 7-1. Change in After Tax Profit Resulting from Drastic Changes in Energy Cost and Energy Use (Percent)

PERCENTAGE CHANGE IN AFTER TAX PROFIT

ASSUMPTIONS: 1) All Other Factors Remain Constant.
2) The Cost Per BTU Of All Fuels Used Is The Same.

BUSINESS A: 50% Tax Rate
20% Ratio Of Energy Costs To After Tax Profit

BUSINESS B: 30% Tax Rate
30% Ratio Of Energy Costs To After Tax Profit

CASE	BUSINESS A	BUSINESS B
1) Reduce Annual Energy Use By 30%	3.0%	6.4%
2) Annual Energy Costs Increase By 40%	-4.0%	-8.3%
3) (1) & (2) Occur Simultaneously	0.2%	0.5%

One constraint that has been cited as affecting energy conservation in buildings is the lease structure that allows energy cost increases to be passed through to tenants. The examples discussed in this section are meant to stress a critical point. Generally, building owners are not put in an uncompetitive position by not conserving energy. The constraint is not pass-through clauses in leases; it is the minimal impact that energy costs tend to have on a business' competitive position. After tax profit does not change considerably, and if most other businesses are not conserving, their cost of business remains on a par. Costs can be passed through to tenants or other customers. The economic motivation for energy conservation in the commercial sector is less than might be expected, even with rising energy costs.

7.2.3.3 Government regulations.

The Metropolitan Medical Center (MMC) in Minneapolis, Minnesota provides a good example of economic constraints on energy conservation caused by government regulations (Reference 7-4). Medicaid and Medicare are set up to reimburse hospitals for expenses - which include energy costs - but not

for capital items. Therefore, hospitals are reimbursed for consuming energy. MMC's director of plant operations has had an active program of facilities modifications and operations reviews to save energy, and the savings for this program amount to about 8 percent of the annual energy costs. However, certain projects have questionable futures because of the reimbursement practices of Federal health care programs. One project involved converting the HVAC systems from constant volume to VAV systems.

The Medicare/Medicaid penalties occur because the installation of energy saving systems reduces operating expenses for the hospital. According to the director of plant operators at MMC, one-half of the expected first year's annual saving must be refunded to the government, and the operating budget used to figure government payments to MMC is reduced by the expected first year savings from the second year on. The net effect is to change a three year payback on capital improvement programs to about six years. The Federal programs may appear to be saving taxpayer's money, but the real effect is to foster inefficiency of energy use and cause more dollars to be spent. If MMC were allowed to keep all the savings from a capital improvement project for the expected payback period, the government would spend no more money during the payback period than if MMC had done nothing. After that time, the government could reduce the operating budget used to calculate payments and receive the benefits from lower operating expenses of the facility.

Another example of government regulations restricting energy conservation is the implementation of the Energy Tax Act of 1978. The intent of this act was to provide investment credits to commercial sector businesses for energy saving capital improvements. Because the wording of the law used the phrase "commercial process", the Internal Revenue Service (IRS) ruled that only firms employing a commercial process of some kind could qualify. Practically <u>all</u> commercial businesses, except laundries and restaurants, were excluded. One contact informed TRW that DOE had hired a research firm, Andrulis Research, to estimate the total value of investments that had been foregone because of this ruling. Also, this contact mentioned that personnel at DOE were very upset with the IRS ruling and that new legislation to change the phrase to "commercial activities" has been planned. The entire commercial sector was essentially passed over by this ruling.

Having all branches of government work together is a difficult task, but the problem of certain rulings and regulations inhibiting energy conservation exists. The effects of this problem must be considered for energy conservation programs or plans.

7.3 Educational, Informational, and Psychological Constraints

Incentives to increase the use of energy conserving equipment and systems should be coupled with a program to insure that specifiers, purchasers, and users are able to make decisions based on up-to-date, factual information. The design of systems and purchase of equipment are affected by the educational/informational levels of the individuals making decisions regarding those systems and equipment. Also, the effectiveness of incentives depends on these levels of education and information. Another influence is the attitudes of individuals towards systems, equipment, and energy saving concepts. This section discusses the constraints on the use of energy conserving systems and equipment affected by these levels and attitudes.

7.3.1 Up-to-date information

The information explosion in technical areas has made "keeping up" with developments difficult for the technical person. For persons outside a particular field, staying abreast of developments in that field becomes time consuming and difficult. However, building owners often make no decisions regarding energy equipment and systems in their buildings because they are not informed about the best alternatives available to them for reducing energy use. Also, an owner must have faith in the "calculated" energy savings for a particular system. A building owner will often employ a facilities engineer to oversee day-to-day operations of building systems and equipment. Often, this engineer does not have a degree. In addition to staying up-to-date on maintenance and inspection procedures and equipment, this engineer often must act as an energy advisor to the building owner. Keeping A/C equipment and HVAC systems properly maintained is also a primary task of this engineer. Staying up-to-date in all these areas requires that certain trade-offs be made regarding the relative importance of and time

spent on each. One of the difficult choices building owners will face regarding energy conserving systems, equipment, and ideas is hiring an A&E firm (consulting engineering firm). Such a project can be expensive, and the amount of dollar savings for a particular project cannot be verified until after the money is spent. The building owner must also rely on the engineers to assure that no significant changes in comfort level will occur if system changes are made. In a study of automated energy management systems for small buildings (Reference 5-4), which were defined as buildings under 75,000 square feet, the "highly accurate sources of information" in this energy conservation field were identified as:

- Trade Journals - apartment buildings and schools
- Manufacturers - office buildings
- Colleagues - apartment and office buildings

Other sources that were mentioned more than once included the Department of Energy, trade associations and co-workers. No engineers of any kind were mentioned. In the same study, the "most influential sources of information" in this energy conservation field were:

- Manufacturers - apartment and office buildings
- Co-workers - apartment and office buildings and schools
- Bankers and Investors - apartment buildings

Other sources that were mentioned more than once included the Department of Energy, colleagues, trade journals and associations, and HVAC contractors. HVAC engineers were mentioned only once, as were tax consultants. The fact that building owners do not rely on HVAC engineers for information or advice on automated energy management systems for small buildings may be partially due to the lack of contact between small building owners and engineers. For these systems, however, A&E firms are not as well informed as they should be. Also, small building owners often lack the funds to hire A&E firms to study their energy systems and use. Automated energy management systems require very specialized information; this topic is indicative of how difficult maintaining up-to-date capability in the buildings energy conservation field can be. In the future, a working knowledge of micro- and minicomputers will be required of A&E firms as these devices assume more and

more control of the energy systems in commercial buildings. Keeping informed is an educational/informational problem for building owners, maintenance staff, HVAC contractors, and HVAC engineers.

To avoid energy waste, the maintenance staff must also keep informed of maintenance and inspection procedures to keep equipment operating properly.

In addition to the information explosion problem affecting up-to-date information in the field of energy conservation, the problem of design inertia also affects the timeliness of design information used by HVAC engineers. The saying, "because we've always done it that way," tells the whole story. Change requires effort, causes stress, and implies personal growth. Learning to design HVAC systems in new ways, using new equipment and new system/equipment combinations involves changes. People resist change because change requires effort; the status quo is more comfortable. Thus, concept inertia is a psychological problem related to change that can affect building owners, maintenance staff, and HVAC contractors and engineers regarding building and energy system design and use.

7.3.2 HVAC engineer training

One consulting firm vice-president who was interviewed by TRW in the course of this investigation stated that the education of engineers was the most serious problem confronting his firm - both for energy conservation work and regular HVAC project engineering. He stated that an architect comes out of school prepared to design buildings. However, because of the broad nature of engineering education, five years of work experience may be required before an engineer would be a qualified project engineer for building HVAC and energy systems.

Engineering schools do not train individuals to become building energy systems engineers, so beginning engineers must rely on experienced engineers for their training. Thus, training is limited by the background and knowledge of the experienced engineers who are willing to take time for the new engineer's training. Also, the vice-president had worked with an engineering school to develop a curriculum for such an engineering course of study, but instructors were not available to teach the type of courses required. Academic traditions would probably preclude the use of less-than-doctorate level instructors. However, qualified people with this expertise often have

only a master's level of education - sometimes only a bachelor's level. The present lower salary level of university instructors is also a difficult problem affecting engineering education. An informant with a work history in the fields of education and engineering stated that the problem of industry needs and the engineering curriculum has been addressed many times before. The usual conclusion is that the existing curriculum must cover the basics and should not be changed. The only solution appears to be a five-year program or the establishment of special Masters level programs.

As a result of the less specialized training of the engineer and of the linear flow in the building design process, architects generally dominate the design of a building. An architect trains for this specific job and is exposed to many facets of building design and the structure and form of buildings. On the other hand, the engineer usually has little background in buildings technology to begin with and is not as capable of providing input to affect the building design. However, the "total design" of buildings, where the interaction of the building skin and structure and all the energy using systems of that building are accounted for, is a required step for maximizing energy conservation. This concept changes the linearity of the design process to a more parallel process. The overall energy efficiency of buildings cannot be maximized without the input of all the design disciplines concerning the performance of the building and energy systems, including building and systems interaction.

7.4 Solutions to Non-Technical Constraints

Two observations appear important when the non-technical constraints on the development and use of energy conserving HVAC systems in buildings are put in perspective. They are:

1) Market constraints (non-technical) affecting the use of energy conserving HVAC systems completely overshadow constraints involving technical development

2) Building owners and their economic situations are the key to increased use of energy conserving HVAC systems and energy conservation in general

With these two observations established, approaches to overcome certain non-techncial constraints will be described.

7.4.1 Present day approaches

Some approaches presently used or attempted to stimulate energy conservation, including the use of energy efficient HVAC systems, are:

- National Seminars sponsored by DOE
- Manufacturer-sponsored training sessions for interested engineers and operators
- Educational (technical) literature from manufacturers and trade organizations (e.g., ASHRAE)
- Investment tax credits
- Development of computer simulation programs to estimate energy use
- Manufacturers contacting A&E firms during the design stages of a building
- Adoption of State energy codes
- Federal energy codes (BEPS)

The majority of these programs affect the manner in which the engineer (A&E) operates, and thus, direct the building owner's decisions. However, today some programs are focused on the building owners, in an attempt to affect the economic factors surrounding an energy conservation investment. Manufacturers of control systems for commercial buildings are offering creative financing for energy conservation (energy management) investments. These financing arrangements may include lower interest rates and choice of installment purchase or operating lease. The choice of owning or retaining an operating lease depends on the building owner's financial situation. One company offering this service had half the installations leased and half purchased.

A further attempt to improve the building owner's position is made by the use of a limited warranty on energy savings, which are offered in some cases. This offer addresses the problems of "credibility of the savings" (see Sect. 7.2.3). Along with capital availability, dealing with this problem is important when attempting to influence building owners' decisions regarding energy saving investments. Further discussion of these problems and descriptions of important considerations affecting energy conservation are given in the following section.

7.4.2 Approaches for the future

Businesses often arrange for accountants to keep their financial records. Building owners have janitorial firms clean their buildings. Many people and organizations retain lawyers to handle legal matters. All these arrangements occur because a need is served. Having knowledgeable people provide certain services relieves a person of the responsibility of acquiring adequate knowledge to personally perform the task. Arranging for people willing and able to provide certain services which a person does not have time, or perhaps inclination, to perform can be beneficial for all concerned.

What happens with building energy systems, including HVAC systems? Usually, building owners or property management firms hire a maintenance staff. However, the efficient operation of HVAC and other energy systems is not in the best interest (financial) of some property management firms, due to fee structures (see Sect. 7.2.3), and in some cases causes conflicts for the maintenance staff (see Sect. 7.1.5). Is there a place for energy system specialists to arrange with building owners to handle the operation, maintenance, capital improvements, and billing associated with building energy systems?...to reduce the energy use and costs of building energy systems?...to assume responsibility for energy cost reductions?

Today, over 140 companies are selling space heating and hot water in France. These companies are referred to as "chauffage" or "comfort" companies, and they control roughly 70 percent of the heating market for commercial buildings in France. The oldest companies are 11 years old.

Energy Services. In Reference 7-1, the idea behind chauffage companies is extended to a concept called "energy services". Energy services represent a new business opportunity in the United States. The objective of energy services is to operate energy systems, at specific output levels, for customers at the lowest cost. The potential investment for commerical buildings estimated in Reference 7-1, based on building structure improvements, cogeneration in buildings, and new HVAC equipment, is $40 billion (1978 dollars). Automated energy management systems may offer additional potential. Energy services represent a marketing approach to energy using

systems and energy systems operation. A company offering energy services in the HVAC field could agree to:

- Operate the HVAC systems in a building
- Maintain specific temperature (and humidity) comfort levels
- Bill tenants for their use of HVAC energy
- Maintain the HVAC equipment and systems in proper working order
- LOWER THE OWNER'S HVAC OPERATING COSTS

The energy services concept need not be circumscribed by limiting application areas for individual companies. A logical extension of HVAC energy services is building energy services. The interaction of building energy systems and the common billing of fuels (electric, gas, oil, etc.) almost require that all energy systems in a building be covered. The building energy services company's objective would be to sufficiently lower the energy system operating costs of a building, while maintaining acceptable levels of comfort, lighting, etc. for each tenant, to generate acceptable profits from billing the tenants or owner for energy and provide them with lower energy bills than they had previously.

Implications of the building energy services company are:

1) The owner is relieved of the responsibility of maintaining the energy systems in the building

2) The energy services company must be free to invest in and make necessary modifications to reduce energy costs

3) Tenants would pay for energy based on use instead of area occupied

4) The comfort, lighting, and other energy system levels must be specified prior to the service arrangement

5) Energy uses would be metered better

6) An acceptable method of accounting for the variable effects of weather on energy costs must be developed and accepted

7) Based on varying occupancy requirements, an acceptable method of charging tenants or the owner must be developed and accepted

8) Acceptable contractural obligations would have to be researched and defined

9) The owner must arrange for special services involving the building energy systems, which relieve him of the task of dealing with energy management and complicated energy systems

10) THE OWNER COMMITS NO CAPITAL AND EXPECTS TO REDUCE ENERGY COSTS

The energy services concept appears very promising for the future. The companies offering these services would have to be technically competent and economically viable. The types, size, and occupancy would determine how the concept is approached for different buildings. The energy services companies would become retailers of energy, with traditional suppliers becoming wholesalers of energy. The companies that could offer the best service and owner incentives would have tremendous growth opportunities. Saving 10 percent of the energy bills for the 2.0 Quads of energy used in the commercial sector for electric air conditioning in this country represents an annual dollar value of roughly $700 million. This amount does not consider heating, fan, lighting, or other energy used in buildings. (See Section 9 for further discussion.) The promise of energy services lies in the potential profits for effective offerors.

Energy economics. The energy services concept does not solve all the problems previously discussed. The competitive position of most businesses is not determined by whether energy is conserved, and many business decision makers find the dollar values of energy savings from energy conserving systems small in relation to the investment. One contact told TRW that his perception was, "People will spend money to make money, but they won't spend money to save money." Savings do not show up as increased sales, and facilities investment may be more critical.

Unless the economic situation of building owners is affected, changes in speculative, new building/HVAC design and retrofitting of existing buildings and HVAC systems are unlikely. TRW has tried to demonstrate, in Sect. 7.2.3.2, that increasing energy costs by deregulation or other means does not sufficiently affect the competitive positions of businesses to cause serious changes in energy attitudes - justifiably so from an economic standpoint.

Energy services companies would concentrate their efforts on large buildings with high energy bills where the potential for profit is greater. Also, unless the energy services concept can be extended to cover new construction, new buildings would continue to be built with unnecessarily high energy consumptions. Affecting business attitudes toward energy is necessary to cause a fundamental change in thinking. Energy codes often cause

negative reactions regarding compliance, expecially when saving energy is viewed as not in the best interest (financial) of those affected. Energy is a commodity that is measured and sold according to the amount used, and economic influence can be exerted based on actual measurements of energy used. Saving energy can be accomplished by affecting the economic situation of businesses (including building owners) enough to attract the decision makers' attention and convince them that saving energy is financially beneficial. Comptrollers and accountants could become overnight experts on energy.

An effective way for the government to change the energy use of this country would be to establish a free market for energy, so that energy decisions are not influenced by taxes or incentives. However, given the all pervasive nature of taxes and their influence on energy supplies (conservation increases available supplies), an effective way for the government to change the energy use of this country is to change the tax structures so that saving energy is profitable, and energy use, beyond certain levels, becomes economically difficult. Gradually implementing such a program is desirable. Some ideas that could be considered are:

- Introducing energy taxes based on energy use which would be comparable to income taxes (income tax credits could be given, but using more energy should decrease after tax profit considerably)

- Introducing income tax credits based on low levels of or reductions in measured energy use

- Continuing to consider income tax credits for capital investment in energy saving projects

- Eliminating deductions of energy costs as operating expenses - perhaps only for energy use above certain levels

Some important considerations to remember are:

- This study concerns the commerical sector, and implementing tax structure changes for the industrial sector would take longer and be more complicated

- Businesses which use energy to produce a service ("commerical processes"), such as laundries and restaurants, will probably require special treatment

- Extensive installation of energy metering equipment would result

- Phased tax adjustments will allow capital markets, building/HVAC system designers, and manufacturers time to adjust, while gradually showing business decision makers what to expect

- Special consideration would have to be given to businesses which are already using less energy

- Standards for new construction, such as BEPS, would not require mandatory compliance. Those buildings which use no more than the required amount of energy the first year (based on actual utility or supplier billing or other data) would have no tax penalty. Using less than the required amount would lead to a tax credit, and using more would lead to a tax penalty. Businesses could choose their course of action.

- Legal considerations, such as requiring energy taxes to be paid regardless of profit and loss figures (eliminating the use of "dummy" businesses as "energy tax shelters"), would have to be researched carefully

Consideration must also be given to non-profit organizations, because taxes will not affect them. The existing schools, hospitals, and government buildings grants program, Title III of the National Energy Conservation and Policy Act (NECPA) of 1978, is an example of what can be done for this sector. One alternative would be to offer grants to energy services companies to operate the energy systems in these buildings at specified energy consumption levels. Consideration would have to be given to existing energy system operating personnel (especially additional training).

Since energy is an economic commodity, the economic approach to achieving energy conservation is the most logical one to take. Economics determine the success or failure of a business and form the primary standard by which all commercial activities are measured. When the government is convinced that conserving energy is not only beneficial to our national well-being, but can be very good business while reducing energy costs to the consumer, some creative legislation will emerge which makes energy conserving buildings and energy systems financially imperative.

8. EVALUATION OF FACTORS AFFECTING RD&D OPPORTUNITIES IN THE COMMERCIAL SECTOR FOR HVAC SYSTEMS AND EQUIPMENT

An understanding of some important characteristics of the commercial HVAC milieu is necessary for evaluating RD&D opportunities for HVAC systems and equipment. These characteristics can be used to evaluate distributions, concentrations, and bottlenecks. The areas of the commercial HVAC milieu which will be discussed in this section are:

- Building and equipment populations
- Market patterns and leverage
- Potential energy conserving system concepts
- Non-technical constraints
- Major bottlenecks
- Savings potentials
- Opportunity areas for RD&D

8.1 Building and Equipment Populations

Two characteristics that help to put the commercial building population data in perspective are:

1) Only slightly more than one-half of the total existing floor space is in buildings less than 50,000 ft^2 in size

2) Buildings greater than 50,000 ft^2 account for only five percent of the total number of buildings

However, one contact reported a drastic trend toward smaller buildings in the past two years - only four buildings greater than 20 stories were reported to be built in 1980. One builder strategy behind this trend is the construction of two or more buildings on one site. The second building can be built while the first is producing income.

No information is available which cross-indexes the actual energy use of buildings by size, but economies of scale usually allow more impressive investments in energy conserving equipment with greater resultant energy savings in larger buildings.

8.2 Market Patterns and Leverage

The data on larger A/C equipment for the period 1970-1980 (see Figures 5-4 and 5-5) show that:

1) Chillers accounted for about 60 percent of the total cooling capacity (tonnage)

2) Unitary equipment accounted for about 90 percent of the total number of units shipped

When discussing market sizes, confusion of these two characteristics causes misunderstanding. From the capacity point of view, work on chiller-based systems and unitary-based systems appears equally important. Regarding systems, ARI data (see Figure 7-3) show that applied (built-up) systems accounted for 55-65 percent of total sales dollars during the period 1971-1979. For heat pumps, work on equipment above 15 tons is not important relative to existing capacity. Future capacity for sizes above 15 tons also appears to be limited.

One industry contact informed TRW that the east and west coasts have definite equipment patterns influenced by the strength of particular trades and climatic variables. The east coast has "wet" systems, which means that chilled water systems predominate because designers and installers prefer to pump liquids and water is plentiful. The west coast has "dry" systems which means that direct (dry) expansion refrigeration systems for cooling predominate because designers and installers prefer to pump air and water is scarce in many areas.

8.3 Energy Conserving System Concepts and Opportunities

The first part of an energy conserving system, efficient equipment, is available. However, since manufacturers test their own equipment, little backup data is available on equipment performance. Despite the lack of backup data, equipment is not a major limiting factor for energy conserving systems in 1981.

The system concepts covering equipment application, configuration and control which lead to reduced energy consumption have progressed to the point where knowledge of which "standard" HVAC systems are efficient is

widespread among designers. However, knowledge of system dynamics (including the building) and human comfort in a dynamic environment are not well known. Also, knowledge of new system concepts, which include designing the building and HVAC system as part of an overall "system", optimization of the "system" based on controls capabilities and configurations, and increasing the adaptability of the "system" to its environment (allowing continual instead of annual optimization) is still in the formative stage. The area of system concepts development presents extensive RD&D opportunities.

One concept that has not received much attention is the use of evaporative cooling (both indirect and direct). One manufacturer has demonstrated reasonable paybacks using evaporative cooling in Chicago. Evaporative cooling may not seem feasible in the eastern part of the U.S., but a significant number of hours exists during a typical cooling season in the eastern U.S. when evaporative cooling would lower cooling equipment loads. High coefficients of performance (COP's) of 10 or more are possible for certain periods for the year.

8.4 Non-Technical Constraints - Major Bottlenecks

At this time, non-technical constraints form a greater barrier to use of energy conserving equipment than any technical constraints. A representation of group hierarchy involved in the use of HVAC systems in the commercial sector is shown in Figure 8-1. The user group is the bottleneck affecting the use of energy conserving HVAC systems. The applications of energy conserving systems and equipment is far below the capability of existing technology.

When viewed in the context of the building owner's situation, energy conservation is acceptable as long as the cost is not high and time is available to consider it. Designers must do the best job possible with the negotiated fee, and installers must complete the job on time. First cost is important because, in cognizable recent history, the cost of money has always been higher than the cost of energy. Also, the cost of energy often does not have enough impact to affect the competitive position of businesses. Understanding and dealing with the building owner's situation is crucial to reducing the energy consumption of buildings. Increased knowledge on the part of designers and installers and increased efficiency of HVAC

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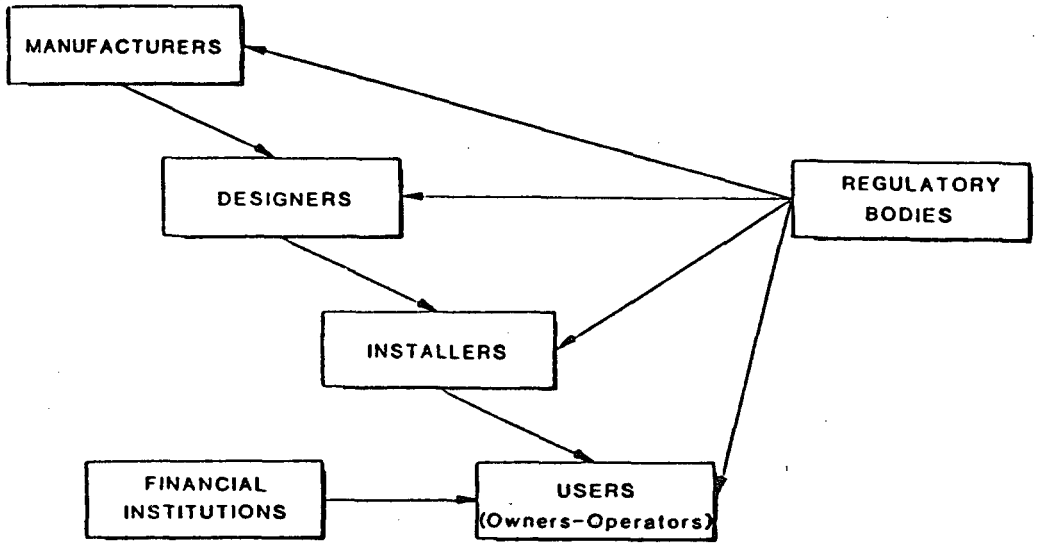

Figure 8-1. Hierarchy of Major Groups in the Commercial HVAC Milieu

equipment and systems will more readily result from a demand by the customer. According to sources interviewed by TRW, the existing customer demand is low. Increasing the user demand for energy conserving systems, including HVAC systems, is the most effective way to improve and develop energy conserving HVAC equipment and systems.

The energy services concept described in Section 7.4.2 has the potential to increase this user demand enough to incite a major improvement in energy systems operation and retrofit installation. Offering capital improvements for energy systems (without using the building owner's capital), generating profits from the savings in energy bills, and offering part of the savings to the building owner and/or tenants are the attractive features of the energy services concept. This concept has not been fully developed and offers potential for innovative energy businesses. Research into and publicity for this concept should receive the highest priorities.

A very effective means of increasing user demand for energy conserving systems can be developed by legislating changes in the tax structure. These changes should include both punitive and beneficial measures to affect the

largest number of users. An extensive research program prior to the proclamation of such a tax initiative is necessary (see Section 7.4.2). Phased implementation would allow adjustment time for all affected users and the economy.

Increasing the user demand for energy conserving systems can lead to other bottlenecks affecting the use and development of such systems. However, this approach is necessary to stimulate change, and the successive impediments will not be approached aggressively and conscientiously without prior economic stimulation. After the tax structure changes occur, the primary slowdowns will result from a lack of:

- Knowledge concerning complex building/HVAC system behavior and how to reduce energy costs
- Technical people to effect the system changes required
- Capital
- Manufacturing capacity to meet a large short-term demand
- Confidence in technical companies to perform such changes if too many companies jump in over their head and system failures result

Subsequent to an initiative for tax structure changes, research into these expected slowdowns should be part of the research performed for the tax initiative.

8.5 Savings Potentials

Commercial sector energy use increased from 9.9 percent of the total national energy consumption in 1950 to 13.3 percent in 1975 (Reference 5-2). The total national energy consumption was 76 Quads in 1980 (Reference 5-3), of which about 2 Quads was for commercial sector A/C equipment (based on this study). In 1980, the total commercial sector energy consumption was about 10.5 Quads. Thus, A/C equipment accounted for about 19 percent of commercial sector consumption.

An estimate of the total potential savings from improved efficiency of equipment and systems for the entire buildings sector was 35 percent of all energy used, calculated against a 1973 base (Reference 7-1). The actual improvement from 1973 to 1978 was estimated at 2 percent of all energy used (Reference 7-1), which shows that significant improvements can still be

made. An estimate of the total potential savings for commercial buildings in 1980 was 24 percent (Reference 7-2). Application of the 24 percent figure to the 10.5 Quads yields 2.5 Quads of potential savings for commercial buildings. Assuming that the 24 percent figure can be applied proportionately to A/C system energy, a potential yield of 0.5 Quads in energy savings from improved efficiency of A/C systems is possible. Thus, a crude estimate of the potential savings estimates are:

- All commercial energy systems - 2.5 Quads/year
- Commercial A/C systems - 0.5 Quads/year

Based on data in Reference 5-2, TRW estimated the average dollar value of commercial energy per million Btu's in 1980 to be $4.80. Using the savings estimates above, potential annual energy dollar savings can be calculated as:

- All commercial energy systems - $12 billion/year
- Commercial A/C systems - $2.4 billion/year

Using 1978 dollars, an estimate of the total investment, covering all commercial energy systems, that could be made to achieve these savings was approximately $40 billion (Reference 7-1). An average simple payback of about 3.5 years can be calculated from this number. Inclusion of automated energy management systems should decrease the payback period.

These estimates are not presented because of their inherent accuracy. The purpose is to show that potentially large energy and dollar savings do exist, and economic incentives are required to stimulate energy savings investments. A large market should be available for the energy services concept with expected simple paybacks of two years or less. The thrust of this market will probably be toward large buildings with high energy bills.

9. RESULTS AND RECOMMENDATIONS

9.1 HVAC System Energy Use and Installation Cost Comparison

A comparison of HVAC systems energy use and installation costs shows the benefits of variable air volume (VAV) and even single zone systems over dual duct systems. Generally, multi-zone systems operate on a par with dual duct systems. Hot and cold deck reset controls improve the performance of dual duct or multi-zone systems. In the building examined for this report, a slight increase in capital cost for the VAV system resulted in a 45 percent decrease in total HVAC energy use, compared to a dual duct system without deck reset controls.

A regional comparison of the energy use of different control schemes for a multi-zone system is also discussed. The effects of climate cannot be ignored, and the type of control system used is affected by climate. Multi-zone (and dual duct) systems have a major disadvantage due to the mixed air stream being directed over both heating and cooling coils. Because of this, economizer control is not usually beneficial, and in many cases, will increase the heating energy used. This increase in heating energy results from improving the performance of the cooling coil, by using outside air, without consideration for increasing the load on the heating coil.

Overgeneralization or extrapolation of the relative costs and performance shown in this report can lead to serious errors. Building size, shape, type of occupancy, and geographic location will affect the performance of HVAC systems, which alters the choices for the best energy performer for each building. The results of this report on energy and installation costs are generally indicative of the energy use of HVAC systems. The observation that buildings and energy systems are almost as varied as human personalities implies that a separate and distinct analysis is required for every building to select an optimum HVAC system.

9.2 Commercial A/C Market

In late 1979, there were approximately 4 million buildings in this country being used for some type of commercial activity. In comparison, there were approximately 240,000 industrial buildings. The total floor area

was approximately 50 billion square feet, with 30 billion square feet that are cooled (air conditioned). The aggregate energy use index (EUI) for cooling is 64,000 Btu/ft^2-year, based on 2 Quads/year of resource energy used for cooling commercial buildings. This EUI is roughly 60 percent of the aggregate EUI used for the ORNL "Commercial Energy Use Model."

Four percent of commercial buildings account for about half (46 percent) of total commercial floor area (buildings which are larger than 50,000 ft^2). Retail/services and office buildings account for 30 percent of the total floor area and almost 40 percent of the total cooled floor area.

The commercial A/C equipment market has been characterized by equipment type and sizes. Window units were shown to account for a very large portion of total capacity. Excluding window units, the commercial A/C market is dominated by shipments and tonnage of unitary equipment. In the larger size equipment ranges described in the Introduction, chiller tonnage is equally as important as unitary tonnage. For equipment sizes of 20 tons and up, unitary capacity becomes a small portion of the total.

9.3 Sources of Data

An extensive survey of reports and data sources covering A/C equipment and buildings population distributions was conducted. Important sources of information were:

- Bureau of the Census data on nonresidential construction activity
- Buildings data base at ORNL
- "Commercial Energy Use Model" of ORNL
- "NBECS" survey by EIA
- Office of Industrial Economics, Treasury Department, data on taxable commerical entities
- "Air Conditioning and Refrigeration Equipment" annual report of the Bureau of the Census
- Air-Conditioning and Refrigeration Institute data
- TECO study

Extensive classifications of buildings by type, floor area, and energy use were performed using these sources. Also, estimates of installed A/C capacity were developed from these sources.

9.4 Overall Assessment of RD&D Opportunities

The dominant factors (whether technical or non-technical) affecting the use and development of energy conserving equipment and systems in 1981 are the high cost of (debt) capital relative to energy and existing tax structures, both of which reduce the impact of energy costs on the competitive position of businesses. The high cost of money affects the amount that a builder/developer can set aside for engineering design, efficient energy systems, and project inspection. Extra funds are required, but seldom provided for energy use and life cycle cost analyses. Paying for more energy is still less expensive than paying for more (debt) capital to reduce energy use. Many buildings are built speculatively with a lesser concern for energy use, and obtaining tenants or owners for these buildings is not difficult. Usually, energy costs do not impact building rental or leasing costs enough to make buildings with greater than desirable energy consumption uncompetitive. This situation exists because the cost of capital is high relative to the cost of energy and energy costs are deducted from gross income when computing taxes.

The highest priority for RD&D work should be placed on developing the market for state-of-the-art energy conserving equipment and HVAC systems. Today, the state-of-the-art systems concepts and equipment are not being applied in the majority of buildings, and extensive development of the next generation of concepts and equipment is premature. Developing the market for existing technology is the most logical way to promote the use of energy conserving systems and foster:

- Development of new and innovative systems concepts
- Conscientious, dedicated application of and request for energy conserving systems
- Assiduous operation and maintenance of HVAC systems and monitoring of energy use
- Development of professional energy services companies

Second level priority RD&D work should involve development of:

- Building/HVAC system/human comfort dynamics information

- Education programs for designers, operators, and owners covering building energy system design, equipment, and system concepts
- Advanced building/energy system concepts

This work could proceed in parallel with or precede the high priority work, since it would be adding to the knowledge of people concerning certain important topics. However, TRW does not view the second priority work as independently capable of achieving a more rapid implementation of energy conserving HVAC systems design and operation.

9.5 RD&D Recommendations

The RD&D recommendations of this report are divided into two categories: 1) high priority; and 2) second priority. The high priority recommendations deal with development of the market for energy efficient HVAC systems, which is a reversal of present approaches that mandate the performance of buildings based on predicted energy consumption performance or prescribed specifications. The factors constraining the existing market are non-technical in nature and cannot be solved by straightforward, technical approaches. TRW is recommending the development of a marketing approach to energy supply through conservation. This approach allows building owners to make choices about energy conservation based primarily on economics, which they understand. The second priority recommendations deal with technical research and education programs. The technical research work involves system design concepts and the dynamic interaction of people, buildings, and systems. The technical education programs are aimed at increasing the number of technical people capable of providing competent energy system efficiency improvement services to building owners, when owners begin to demand these services in response to market pressures derived from the high priority programs.

The distribution of window units, package units, and central systems in commercial buildings determined for this report suggests that development of high efficiency window units would have as large an impact (or larger) on energy use in the commercial sector as improvements in either central systems or package equipment. Since this report deals with large A/C equipment and systems, window units will not be discussed further in this section.

The application of heat pumps, which is of special interest for this report, can benefit equally with other A/C equipment from the high priority recommendations in this report. A/C equipment which is specifically called "heat pump" has the largest effect on energy use in equipment sizes below 15 tons, and therefore, equipment and system improvement efforts should be aimed at this size range. For equipment above the 15-20 ton size, commercial sector tonnage (capacity) is dominated by central chiller systems. Chillers can already act as reverse cycle heat pumps with external modifications of the water piping or use of a double bundle condenser. Since the proportions of building load for heating and cooling are important for overall performance, and high COP equipment is already available, system factors are usually more important than equipment factors alone. This report covers electric drive A/C equipment, and waste heat or heat engine based heat pump applications should appear in the near future (1985-1990). The high priority recommendations of this report are also considered to be important for these applications.

9.5.1 High priority recommendations

The decisions made in the HVAC market today will affect our country for 20 years or more. Estimates of the total dollars spent on energy in this country show buildings (residential, commercial, and industrial) accounting for 40 percent of the expenditures (Reference 7-1). Two methods of developing the market for energy efficient HVAC (and other) systems are covered in these recommendations. The first method involves assisting and publicizing the development of "energy services" companies. The second method involves changing the economic situation of building owners so that energy efficiency will become a market choice. Special considerations for non-taxable entities will be described.

The energy services concept has good potential for existing large buildings (buildings with high energy bills). However, smaller buildings and new construction will not benefit. Despite the "lip service" paid to energy conservation for a number of years, energy efficient systems are not widespread. Building construction and retrofit considerations are dominated by first cost because capital is more expensive than energy. Also, many buildings are built speculatively, with less consideration given to energy.

These observations were developed and reinforced by contacts that TRW made around the U.S., and the situation is not expected to change. Increasing energy prices were viewed by many contacts as the only force for change. The position taken for this report is that increasing energy prices will not be as effective as expected. Therefore, further changes in building owners' economic situations (e.g., a change in tax structure) is required. Such changes will require that programs dealing with non-taxable entities be developed.

The energy services concept is already present in this country. Certain manufacturers and A&E firms (consultants, including special energy consultants) began offering "share the savings" plans in the middle of 1980, where capital and installation are provided for energy efficiency improvement capital items by the manufacturer or consultant. The savings from the installation of the capital items are then shared by the installer and building owner. This savings provides the return on investment for the installer and incentive for the building owner. These plans have been criticized (Ref. 10-1) as: 1) not providing as much savings to the owner as when the capital items were purchased outright; and 2) being based on questionable depreciation techniques for the third-party businesses which are providing the capital. The first criticism ignores the fundamental problem of "credibility of the savings," where building owners, who are not energy experts, need assurance that the savings will materialize. The second criticism involves a decision for the Internal Revenue Service (IRS) or the Tax Court.

While "share the savings" plans are an example of energy services, much more can be done. The concept of providing professional services for building energy systems can include complete responsibility for energy operations in buildings. The recommended potential RD&D work, in order of priority, for the "energy services" concept includes:

1) Researching and publicizing the energy services concept and the role of energy services companies as professional energy systems operators

2) Developing acceptable methods (guidelines or models) for estimating the savings resulting from the operation of buildings by energy services companies (which will be used to determine fees)

3) Developing criteria for energy services contracts

4) Educating building owners about the recommended criteria for energy services contracts

5) Developing an energy services grants program for non-taxable entities (schools, hospitals and public buildings)

6) Examining utility regulations which might hamper the energy services concept

This marketing approach to increasing the use of energy conserving systems requires business people, lawyers, and engineers to help in the development of programs. While engineering input may not be as pronounced as in energy programs of the past, more work for engineers will potentially result, and building owners retain freedom of choice.

Energy economics. Changing the economics of energy use, based on metered energy use, is critical to affecting the energy use decisions of today, which will affect the economic and energy condition of this country for many years. This report has described why increasing energy prices are not as effective as they might seem. The most effective way to increase available energy supplies through use of energy conserving systems is to change existing tax structures. To argue that tax structure changes (tax incentives) are an artificial contrivance in a free market is one-sided. Existing tax structures for commercial building owners are often a disincentive for reducing energy use. In addition, the necessary tax advantages aimed at increasing energy production indirectly subsidize consumption. The use of energy efficient systems represents an increase in available energy and long-term capital resources, and the use of tax incentives for such purposes is prudent from both a resource and economic standpoint. While increased energy resources from exploration and drilling may be forthcoming, many years may elapse between discovery and reasonable production. The time lag for energy conserving HVAC systems is usually less than one year between the beginning of facilities modification and the start of energy savings. Several factors limit how much available energy supplies can be increased through use of energy conserving systems in buildings, but the major limit today is the economic situation of building owners.

The recommended potential RD&D work, in order of priority, for "energy economics" includes:

1) Developing a phased-in energy tax plan for commercial buildings' energy use. Commercial process energy use could be exempted if

the owner installed separate metering. At master-metered sites, where offices or other commercial buildings predominate, the site owner would be responsible for collecting and paying the taxes, as a pass-through item, based on the whole site. Again, exemptions could be obtained for process use if separate metering was installed. Income tax credits are a positive approach which should be used, but using more premium energy per square foot than a prescribed standard should affect after tax profit considerably, in relation to the deviation from the standard. Energy tax deductions should probably not be allowed.

2) Developing phased-in tax credits, in parallel with energy taxes, for using less premium energy per square foot than a prescribed standard, in relation to the reduction below the standard. After tax profit should benefit from good performance. For both items one and two, extensive business and legal research is required.

3) Developing the standard language and procedures by which Congress would prescribe in pertinent energy legislation that DOE determine the energy-related criteria to be used by the IRS when setting up tax regulations for the subject legislation.

4) Investigating the removal of energy costs as a deductible operating expense.

This study indicated that mandatory compliance with energy efficiency regulations is counterproductive. However, affecting the bottom line of business balance sheets is speaking the language of business. Methods of achieving energy conservation and the level of energy consumption are not prescribed, but forcefully encouraged. This method is the best way to foster conscientious energy use and improved efficiency.

Priorities. The energy services work and the energy economics work are equally urgent. Items with equal numbers for both programs share equivalent priority. Both programs can proceed in parallel.

9.5.2 Second priority recommendations

The second priority recommendations are of two types: those contingent on the high priority programs; and those of an independent, technical nature. The recommendations related to the high priority programs involve educational programs and research into potential bottlenecks for the high priority programs. The independent, technical work involves research into HVAC systems, buildings, human factors, and the HVAC/building design process.

9.5.2.1 Contingent recommendations.

While the RD&D work described in this section is not viewed as independently capable of causing significant increases in the use of energy efficient HVAC systems, some benefits can be expected from more informed designer and user groups. As an example, informing these groups about the benefits of heat pumps can, and perhaps already has, led to a significant increase in use. However, overall use of heat pumps still suffers from market economic conditions.

The high priority program that these recommendations are contingent on will be enclosed in parentheses after each. The recommended potential RD&D work, in order of priority, includes:

1) Developing seminars and educational programs for A&E firms (consultants) which offer instruction or sharing of knowledge concerning energy efficient building/energy-system design (energy services and energy economics)

2) Developing seminars and educational programs for building owners concerning the potential energy savings and technical services they should expect and concerning energy efficient building/energy system design (energy services and energy economics)

3) Developing and publicizing potential methods of offering energy services for buildings and marketing approaches for those methods (energy services)

4) Developing seminars and educational programs for A&E firms (consultants) which offer instruction or sharing of knowledge concerning methods of offering energy services for buildings and successful marketing approaches for those methods (energy services)

Some of this work may be accomplished within a reasonable time by the private sector with no assistance from DOE, but a lack of qualified technical people could be a serious bottleneck for the high priority programs. This work could also proceed independently, but research of all the potential energy services for buildings would be necessary as a minimum.

9.5.2.2 Technical recommendations.

While the RD&D work recommended in this section is not viewed as independently capable of causing significant increases in the use of energy efficient HVAC systems, the work is intrinsically valuable for the long-term

benefits resulting from the knowledge gained concerning HVAC systems, buildings, and the design process.

A/C equipment. The A/C market for the commercial sector is dominated by unitary equipment which has an average size of five to six tons. RD&D work in this area should follow existing programs for the residential and commercial sectors. For larger A/C equipment (20 tons and up), which was of special interest for this study, unitary capacity in the commercial sector is inconsequential. Therefore, the remainder of this section will deal with liquid chiller systems.

The merits of large screw and centrifugal liquid chillers for energy conserving HVAC systems appear to depend on application. Also, some controversy exists concerning actual part load efficienices for all large chillers. The screw machine appears well suited for ice generation as a thermal energy storage medium and for producing chilled (42°F) and hot (120-130°F) water simultaneously (heat pump application). Heat pumps in cascade with chillers serving the building core may offer the most opportunity for heat pump and chiller uses in an energy conserving system. Further study of the best applications for screw and centrifugal liquid chillers is needed.

In addition to cooling produced from the vapor compression refrigeration cycle, a significant assist is available from evaporative cooling equipment in climates which are not too humid. One manufacturer is claiming Energy Efficiency Ratios (EER's) of 60-120 Btu/Watt-hour (COP of 17-35). A more complete study of the benefits of the cooling assistance of evaporative cooling equipment by climate and problems with water quality and supply is suggested.

HVAC systems. The overall HVAC system is crucial in any consideration of reducing energy consumption. A preferred system for heating and cooling large buildings is one which uses chiller heat reclaim. Condenser heat is recovered in larger buildings to heat perimeter areas of the building while the rest of the building is cooled (during the heating season). The use of either a double-bundle heat exchanger or a heat pump cascaded with the building core cooling equipment offers simultaneous heating and cooling. A study of building size, configuration, and type of occupancy, together with climatic effects to determine the parameters and possible change points affecting the most energy efficient and cost effective designs is needed to establish benchmarks for all designers to examine.

The ASHRAE Task Group on Dynamic Response has developed a research program aimed at defining recommended and/or standard operating procedures for buildings and associated energy systems which will maintain comfort while allowing better management of energy. The program will examine:

- Human comfort and health
- HVAC system controls
- Building and system characteristics
- Testing and building/system classification

This program could represent a major improvement in knowledge concerning the dynamic behavior of buildings, and pursuit of this work is recommended for the long-term benefits in improved buildings operation and reduced energy consumption.

An important consideration which follows from the ASHRAE work is combining the design of the HVAC system and building into a total system. This combination implies that the HVAC system and building are designed together ("total design") to take advantage of load profiles and the environment as much as possible. A further extension of this concept involves continual optimization of building performance to maximize the possible energy savings. A continual monitoring system would be necessary. The monitoring system would check building temperatures and loads every hour or minute of the day and adjust the HVAC system or building components to meet the various building loads and respond to the environment hour by hour. By means of certain specialized building components, the building would become part of the HVAC system. Further study of building/energy system integration would be worthwhile.

The HVAC systems design process. The HVAC system design process should be examined by technical and behavioral investigators to determine the effects of existing, common design process flows on present HVAC system design and on the "total design" concept.

One possible aid that could improve the design process is the development of energy consumption analysis computer programs which could be used on small office computer systems. The computer program would allow energy systems to be tested and optimized by many more firms than presently have access to such methods.

Priorities. The order of priority for these recommendations, highest to lowest, is:

1) ASHRAE dynamic response program

2) HVAC system benchmark equipment configurations

3) Further implications of HVAC systems "total design" beyond the ASHRAE work and continual optimization systems design

4) Technical and behavioral study of the HVAC systems design process

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