

Modern Air Conditioning Practice

second edition

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Second Edition

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To Pauline and Diane

Preface

This book is a basic text for the education and training of application engineers, sales engineers, and engineering and industrial technicians. It is intended for use in organized educational programs in colleges, junior colleges, technical institutes, and area vocational-technical schools but is equally well suited to industry and military training programs or, for that matter, to individual home-study programs. It is an outgrowth of thirty years' combined experience by the authors in organizing and teaching air conditioning and refrigeration in two-year colleges—one a West Coast community junior college, the other an Eastern technical institute. In addition, both authors have been involved for many years in consulting and sales engineering in the air conditioning industry.

The text is planned for use in a two-semester basic course with three demonstrated lectures and two 3-hour laboratory periods per week, although variations of this time sequence are common. The laboratory work should consist of a series of technical investigations on equipment performance and system design, supplementing the text theory and emphasizing the use of modern methods and instrumentation.

The air conditioning industry has undergone explosive growth since the first edition of *Modern Air Conditioning Practice* was published in 1959. In that edition the industry was said to be in the *customer-acceptance* phase, with some indications that the *customer-demand* era was imminent. Since that time the industry has become one of the giants of the American economy, with hundreds of thousands of persons employed by equipment manufacturers, architects, engineers, designers, contractors, maintenance and repair shops, and appliance sales organizations. Occupations represented in the industry include the professional (mechanical) engineer and architect; the sales engineer; the application engineer; the operating engineer; the engineering technician; and a variety of craftsmen, mechanics, and repairmen. This book is intended to meet the needs, in some measure at least, of all these people in the industry.

People without a formal educational background in mechanical engineering will find that the mathematics requirements are not beyond their ability. Extensive use of graphs, charts, and tables makes for relatively easy understanding and interpretation of otherwise difficult concepts. Architects, draftsmen, salesmen, building contractors, sheet-metal contractors, refrigeration contractors, operating engineers, and service mechanics will find the book understandable and readily applicable to the design and installation problems they are concerned with daily.

Generous use is made of photographs, diagrams, and sketches to illustrate

the text. At the ends of chapters there are brief review summaries and a set of interpretive exercises followed by carefully selected problems designed to test the student's understanding and his ability to solve design and operating problems. A large number of completely solved problems are included in the text to illustrate proper methods of analysis and solution. These will be of especial value to the student who is studying air conditioning at home or on the job.

Even though the practice of air conditioning is stressed, there is solid and rigorous treatment of theory. Basic principles of physics are covered in an early chapter; the coverage of psychrometric theory related to human comfort is unusually complete, the principles of fluid flow are adequately covered, and the thermodynamics of the refrigeration cycle is thoroughly explained.

The authors express sincere appreciation to the many manufacturers of air conditioning and refrigeration equipment who responded so generously to requests for photographs and technical data. Grateful acknowledgment is also extended to the American Society of Heating, Refrigerating and Air Conditioning Engineers and to the Air Conditioning and Refrigeration Institute for the use of technical data, standards, and charts.

Technical assistance was provided by Mr. C. D. Bryson, operating engineer at Bakersfield College, California, and by Mr. W. Brasted of the State University of New York, Agricultural and Technical College at Alfred.

Finally, Eileen Harris and Susan Bach deserve our gratitude for their careful typing and preparation of the final manuscript.

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David F. Conde

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One

Introduction

Indoor climate, once adjusted to human need only by some form of heating in winter and by opening windows or using fans in summer, is now capable of being varied to meet almost any comfort or industrial demand, anywhere on earth, with precise automatic control. *Air conditioning*, common in almost every city and town in America, is now increasingly popular all over the world and is regarded as a commercial and business necessity in nearly all tropical nations. At one time, the familiar saying, "Everybody talks about the weather, but nobody does anything about it," was certainly true. Today, it is no longer true, for air conditioning engineers, contractors, manufacturers, and technicians are modifying indoor weather everywhere. Consider for a moment the consequences which would result if all air conditioning systems were to stop. Not only would temperature and humidity conditions become intolerable, but industrial production would be adversely affected, and activities involving computers, electronics, aircraft, precision manufacturing, nuclear power, optics, and synthetics—in fact most areas of modern progress—would come to a halt. Today, in business, industry, schools, hospitals, hotels, theaters, and homes, air conditioning is no longer a luxury but an essential part of modern living.

1-1 *Development of the Industry*

The development of the air conditioning industry is an interesting story, illustrating well the necessity for close working relationships among scientific, engineering, production, and sales personnel. Comfort or process air conditioning had its beginnings with mechanical refrigeration in the late 1900s, but it was not until 1917, when Willis H. Carrier began a systematic study of the "conditions" of air-water-vapor mixtures, that engineering began to meet the challenge of designing suitable equipment. During the 1930s the production of air conditioners began, and by 1940 the industry was established on a firm scientific, engineering, and production basis, but with a limited market for its products.

At this point *salesmanship* entered the picture. Sales analysts refer to three different phases in the development of an industry: the *customer-resistance* phase, in which the buying public takes a dim view of the industry's product; the *customer-acceptance* phase, in which the product is accepted as generally worthwhile but each potential buyer has to be convinced of his own personal need for the product; and

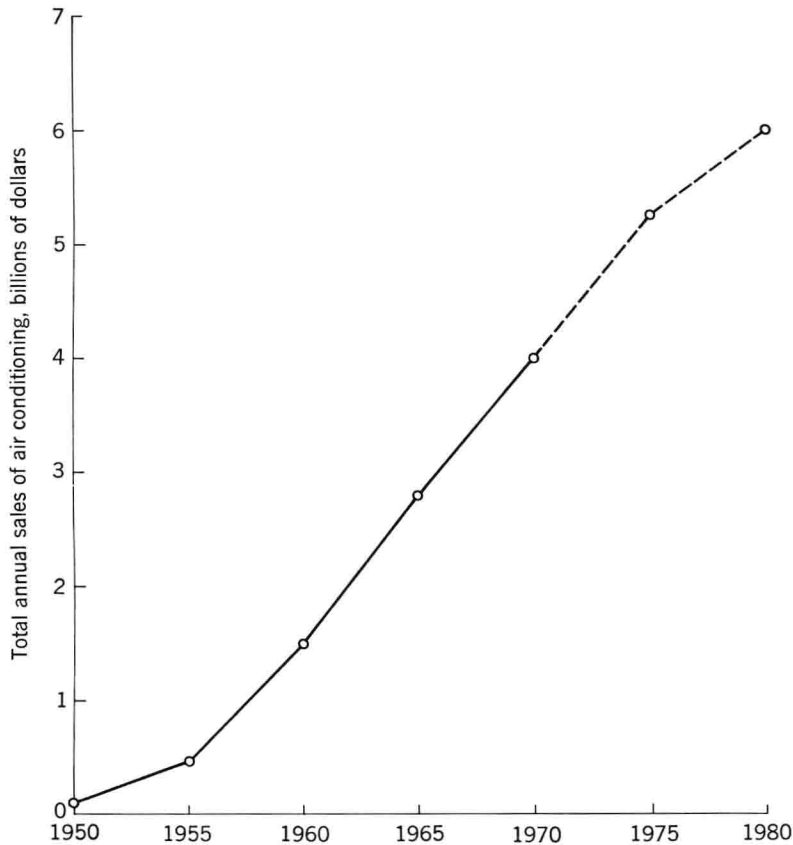


FIG. 1-1. Growth in annual sales of air conditioning equipment in the United States from 1950 to 1970 and estimated growth to 1980, in billions of dollars.

the *customer-demand* phase, in which there is a real demand for the product and the sales problem becomes merely one of selling a particular make against the competition from other manufacturers of like equipment.

The air conditioning industry entered the customer-acceptance era about 20 years ago and is now unquestionably in the customer-demand era. The homeowner has been "sold" on the benefits of air conditioning for the health and comfort of his family; businessmen

have been sold on the benefits for customer comfort and employee efficiency; and industrial production managers, on the absolute necessity for controlled temperature, humidity, and air cleanliness for precision manufacturing.

This progression of the industry from the customer-resistance stage to the customer-demand stage in a period of about 25 years has, of course, been largely due to salesmanship.

Figure 1-1 illustrates the growth in sales of air conditioning equipment for the past two decades and gives predictions to 1980. Teamwork among engineering, production, sales, and service personnel has, in a space of 20 to 25 years, brought the air conditioning industry



FIG. 1-2. Growth rate of installed value of air conditioning systems compared with growth rate of the gross national product (GNP) for the United States, 1959 to 1967. (Source of data: Heating, Piping and Air Conditioning, October 1968.)

to front-rank status and has changed the general public's concept of air conditioning as a high-priced luxury to the idea that it is a dependable, low-cost, and necessary adjunct to everyday living. Figure 1-2 shows that the rate of growth of the air conditioning industry has in recent years far exceeded that of the nation's gross national product (GNP). The future seems limited only by the ingenuity and technical skills of the industry's manpower.

New applications of air conditioning and new methods and equipment are being developed each year. The once science-fiction concept of a completely controlled environment comes nearer to reality in each decade as new engineering advances are made and as urban air-pollution problems become more serious. In the famed Houston Astrodome, the world's largest "room air conditioner" controls the environment in a space 208 ft high, extending

over 9½ acres. Six thousand six hundred tons¹ of cooling capacity, sufficient to cool all the residences in a city of about 15,000 population, provide control of temperature and humidity in this mammoth arena (Fig. 1-3).

1-2 The Physiological Basis for Air Conditioning

Seasonal extremes of heat and cold are more than most people can endure, even in the temperate zone in which the United States is located. Winter temperatures in some areas

¹ The *ton* of refrigeration capacity is defined as a heat removal rate of 12,000 Btu per hr or 200 Btu per min.



FIG. 1-3. The Houston Astrodome, nearly 10 acres of air conditioned space. Against outside summer temperatures of 100°F and high humidity, the gigantic air conditioning system installed here maintains cool, comfortable conditions for sports events. Winter air conditioning is also provided.

(Montana and the North Plains states) may run as low as fifty degrees below zero Fahrenheit. On the other hand, summer temperatures in the Central, Southern, and Southwestern states frequently exceed 105°F and in some areas rise to 120°F and more.

The temperature range within which people feel comfortable depends to a considerable degree on the clothing worn, the degree of physical activity, and the amount of moisture in the atmosphere, but for people indoors engaged in light activity the following temperature ranges generally indicate the limits of actual human comfort:

	Temperature Range, °F
Winter (normal clothing)	65-78
Summer (light clothing)	67-85

The fact that the ranges are different for summer and winter is in part due to the different clothing worn and in part due to an actual change in the body metabolism from winter to summer.

A consideration of these temperature-range-comfort figures shows that there are probably very few sections of the United States in which air conditioning of some kind (winter heating or summer cooling) is not indicated. Winter heating, of course, has been common for centuries, and human habitation of much of the United States would be impossible without it. Summer cooling, though not absolutely essential for existence, is necessary in many sections of the country for comfort and health. Nations located in tropical regions, where both temperature and humidity are high, are in even greater need of summer air conditioning. Tourism is an important industry in many of these countries, and the tonnage of installed

air conditioning will increase markedly in response to tourist demand.

Air conditioning, as the term is correctly used, implies a great deal more than mere temperature control. There are four atmospheric conditions which affect human comfort. These are:

1. *The temperature of the surrounding (ambient) air.* This is measured in degrees Fahrenheit ($^{\circ}\text{F}$).
2. *The humidity of the air.* Humidity means moisture content, and its relation to human comfort will be discussed at length in a subsequent chapter.
3. *Air purity.* People are not comfortable when breathing contaminated air even if

1-3 Classification of Air Conditioning Systems

There are several different ways of classifying air conditioning systems, and it is well to learn some of this terminology at the outset in order to follow later discussions intelligently.

1. *Classification as to major function.* Air conditioning systems are of two basic types as far as their functions are concerned.

a. *Comfort air conditioning systems.*

Their purpose is to create atmospheric conditions conducive to human health, comfort, and ef-

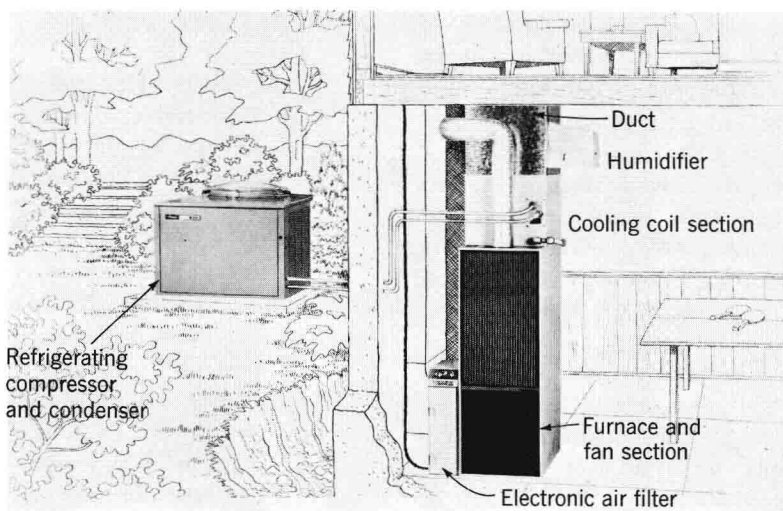


FIG. 1-4. Phantom drawing of a year-round air conditioning system for a small residence. The refrigerating equipment is outdoors (left) to minimize noise in the house. The cooling coil, humidifier, and electronic air filter are attached to the gas-fired furnace in the basement. A duct system carries conditioned air to the rooms of the house. (Airtemp Div., Chrysler Corp.)

it is within acceptable temperature and humidity ranges.

4. *Air movement.* Even if temperature, humidity, and air purity are satisfactory, a certain amount of air motion seems to be necessary for human comfort.

True air conditioning implies that all four of these atmospheric conditions for human comfort are being met.

iciency. Air conditioning systems in homes, offices, stores, restaurants, theaters, hospitals, schools, and churches are of this type (Fig. 1-4).

b. *Industrial air conditioning systems.*

The purpose of these systems is to

control atmospheric conditions primarily for the proper conduct of research and manufacturing operations. Manufacturing tolerances in the electronics, space, and computer industries and in all high-speed automated manufacturing are such as to require absolute control of temperature, moisture, and air purity. Air conditioning systems in paper mills, textile mills, candy factories, and printing or photo processing plants are also essential for these industries. Some of these industrial systems incidentally serve human comfort, but some do not.

It should be noted here that the major emphasis in this book will be on comfort air conditioning. The many and varied problems related to industrial air conditioning are beyond the scope of an elementary text.

2. *Classification as to season of the year.*

a. *Winter air conditioning systems.*

These systems, when properly designed and installed, maintain indoor atmospheric conditions for winter comfort, namely, temperature, humidity, air purity, and air movement. The major problems of winter air conditioning are to heat the air and bring the moisture content (humidity) up to an acceptable level. Winter heating is accomplished by distributing heated air to spaces by ductwork (Fig. 1-4) or by distributing heat in the space by fin-tube radiation (Fig. 1-5) or by convectors or fan-coils. Heat is supplied by furnaces or boilers fired with gas, oil, or coal; or by electrical resistance heaters. Humidification of the air in the heated



FIG. 1-5. Perimeter heat distribution by baseboard radiators. The decorative metal covers enclose hot-water (or steam) pipes to which copper or aluminum fins have been added to obtain an extended surface for maximum radiation and heat transfer to room air. (Nesbitt Div., ITT Corp.)

space is often necessary to attain a comfortable condition. Humidifiers may be of the simple pan type or spray type or the more complex rotary type. *Electric heating* by resistance elements, infrared radiant heat, or with heat pumps is finding increasing application in residential, commercial, and industrial fields.

b. *Summer air conditioning systems.*

These systems control all the four atmospheric conditions for summer comfort. The major problems are to cool the air and to remove excess moisture from it. Cooling is ordinarily accomplished by mechanical refrigeration. Removal of the moisture (dehumidification) is accomplished as condensation of water vapor in the air occurs on cold coil surfaces.

c. *Year-round air conditioning systems.*

These systems are composed of heating and cooling equipment with automatic controls and associated components to produce the four atmospheric conditions for human

comfort at all times of the year. The design and application of this type of system will receive considerable emphasis in this book.

3. *Classification as to equipment arrangement.*

a. *Central-station systems.* This type of system is one in which the various apparatus components are selected by the design engineer, purchased from the manufacturer, and erected on the job, usually in a central equipment room or mechanical room. The entire process of conditioning the air is done in the *central station* or mechanical room, and the conditioned air is delivered to the various rooms of the building through sheet-metal ducts. Some large-capacity systems are of this type, but these systems are not well adapted to hotel and office-building installations where individual room control is essential. In recent years this type of system is declining in favor, being largely replaced by the *combination system* (see below).

b. *Unitary systems.* The last five years have seen, and most future predictions point to, a continually increasing use of unitary systems. These systems make use of air conditioners which are completely factory assembled or *packaged*. Single air conditioners may serve an entire building through suitable duct systems, or multiple units may be used to serve various areas. Many of the current unitary or packaged units are designed to be located outside the conditioned space such as on the rooftop (see Fig. 1-6) or on the ground in order to minimize lost floor space.

c. *Combination systems.* This type of system combines the features of central-station and unitary systems.

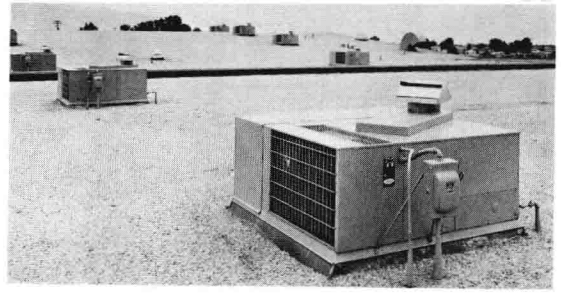


FIG. 1-6. Rooftop unitized air conditioners for year-round service. Multiple units provide all the capacity required and also give zone control. (Day and Night Manufacturing Co.)

The heating and refrigeration equipment is in a central mechanical room (Fig. 1-7). Heat energy is supplied in pipes to the several unit air conditioners in the form of steam or hot water. Chilled water from the central refrigerating equipment is also piped to the air conditioners. An air conditioning unit may be installed in and serve a single room, or it may have its own equipment room and serve an entire *zone*. Heating and cooling units composed of fans, coils, filters, dampers, and controls and known as fan-coil air handlers (Fig. 1-8) may be used to provide year-round air conditioning in rooms or zones, and fin-tube radiation and convectors may supply additional heating. The performance of the air conditioning unit is governed by a thermostat in each room it serves.

1-4 Air Conditioning System Components

In subsequent chapters detailed descriptions of the various equipments required to do the

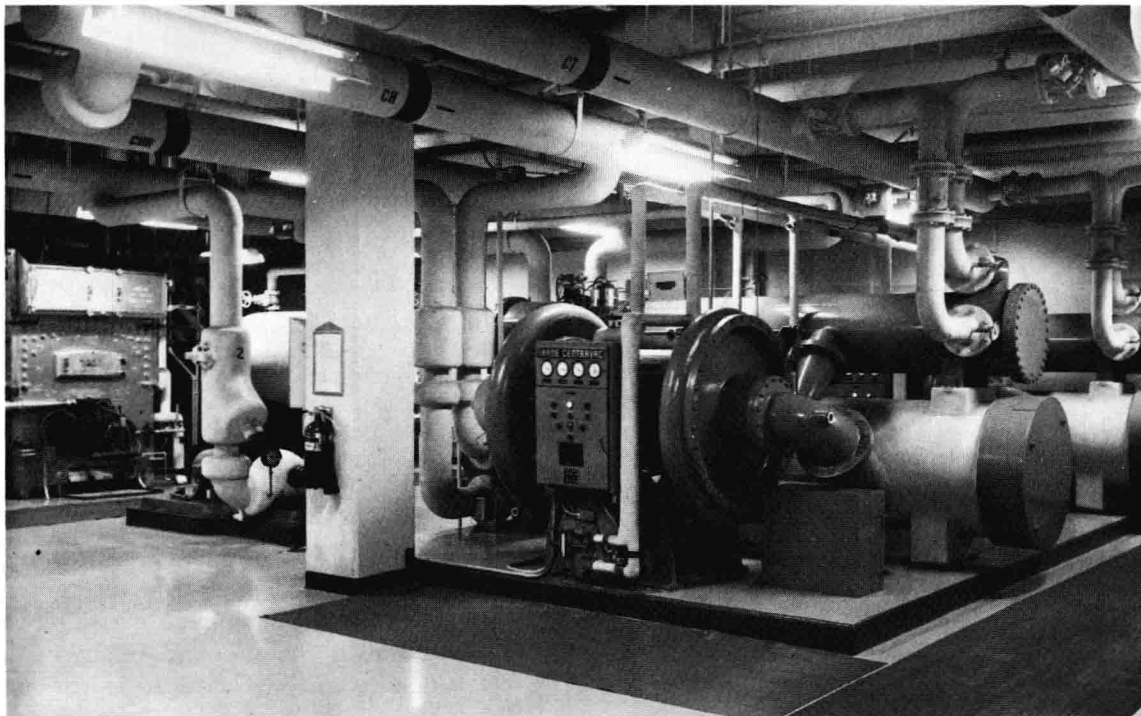


FIG. 1-7. Mechanical room of a combination air conditioning system. The heating boilers are at the left and the refrigerating equipment at the right. Hot water and chilled water are pumped to unit air conditioners in or near the spaces to be cooled. (The Trane Co.)

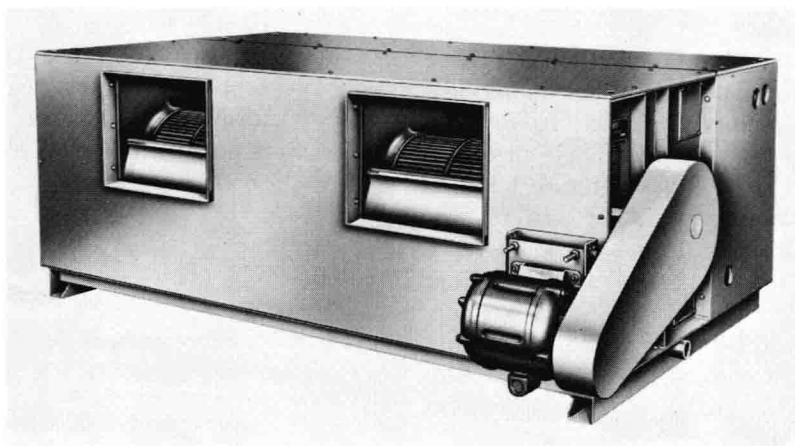


FIG. 1-8. An air conditioning unit (fan-coil air-handling unit) to be installed as a component of a combination system. These units are factory-assembled; they house the heating and cooling coils, blowers, filters, humidifier, and all necessary controls for automatic operation. (The Trane Co.)

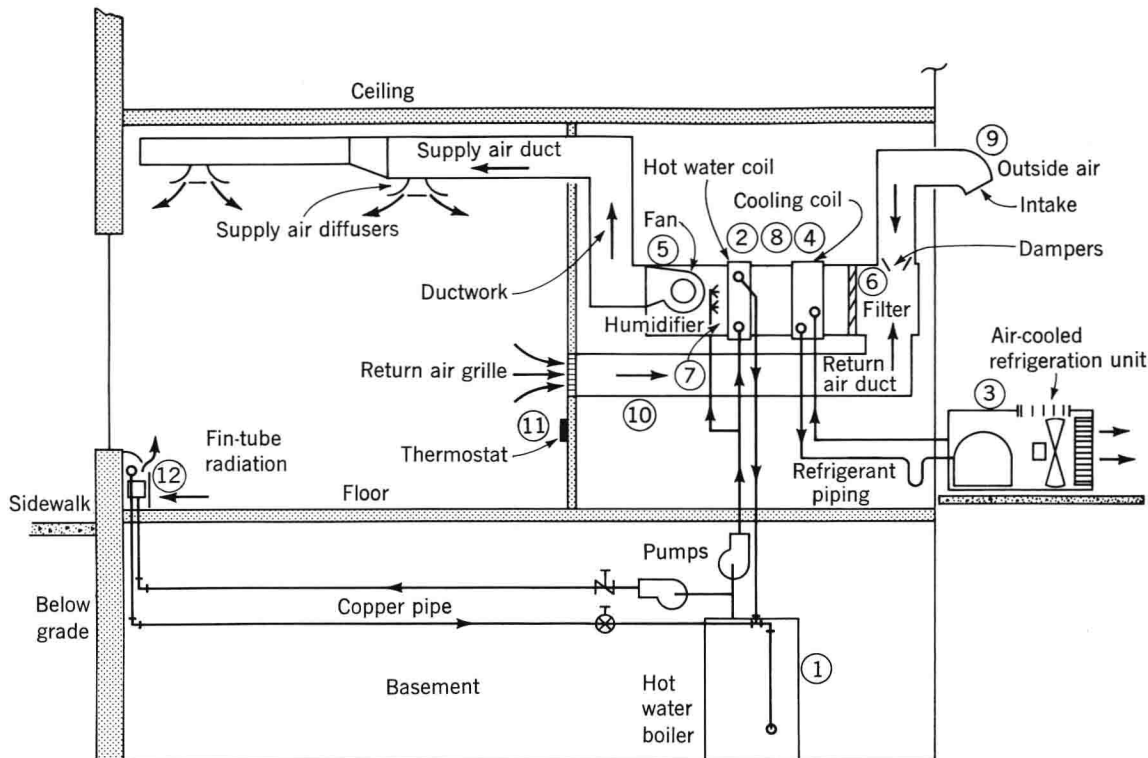


FIG. 1-9. Schematic diagram of a year-round air conditioning system for a small commercial establishment such as a retail store.

air conditioning job will be given. These discussions would not be meaningful here at the outset because of a lack of scientific and technological background on the part of the beginning student. However, as an aid in relating the basic science and technology of the next several chapters to the actual job of air conditioning, there will be described here briefly in words and with diagrams and photographs the essential components of a typical year-round air conditioning system. To simplify the discussion an example of a medium-sized installation for a small clothing store will be used. Figure 1-9 shows a vertical cross-sectional sketch of the store, with a central duct dropped slightly below the ceiling, with air registers evenly spaced to deliver conditioned air to the sales floor. The supply duct would be boxed in (or "furred") as a part of the decorative ceiling

treatment. Note also the return-air grille and duct. Also shown is a diagrammatic sketch of the mechanical spaces enlarged so that all the essential components can be located. Brief mention of each apparatus component and of its function follows. The code numbers on the diagram can be used to identify the equipment.

1. A hot-water boiler furnishes hot water under pressure and at a temperature of about 220°F to the
2. Hot-water coil in the air conditioning unit. This coil is made up of many turns of copper tubing, with multiple copper fins, to transfer the heat to the air as it is blown over the coil. Hot

- water may also be pumped to fin-tube radiation (12) for extra heat near an outside wall or display window.
3. The *refrigerating machinery* comprises a multicylinder reciprocating-type compressor, driven by an electric motor, and an air-cooled condenser. The compressor uses a refrigerant known as Freon-22 and supplies this refrigerant as a liquid to the
 4. *Cooling coil*, where the liquid boils off, or evaporates, at a temperature of about 40°F. When the system is on the cooling cycle, with the proper amount of air blowing over the cooling coil, the temperature of the air coming off the coil can be controlled to suit the outside-air condition and the condition desired in the space being cooled. The cooling coil serves as the dehumidifier for the summer cycle. As warm, humid air hits the cold surface of the coil, moisture condenses out of the air and drips off the coil to a drain below. Air leaving the cooling coil thus contains less moisture than air entering the coil.
 5. The *blower*, or fan, is designed to pull the proper amount of air across the coils and force it out through the supply duct to the several registers.
 6. The *filter section* filters both recirculated air and fresh outside air, removing dirt, pollen, and other foreign matter.
 7. The *humidifier* is a spray type and puts additional moisture (if needed) in the supply air stream during the winter heating cycle. Its operation is controlled by a device called a *humidistat* in the conditioned space or in the supply air duct.
 8. The *air conditioning plenum* is a large sheet-metal housing, insulated on all surfaces, which contains the heating and cooling coils, the blower, and the filters. The outside-air duct and the return-air duct feed into a mixing chamber behind the blower and filter.
 9. The *outside-air intake* brings in fresh outside air to meet local code requirements, usually 15 cu ft per min per person (average occupancy) in the conditioned space.
 10. The *return-air duct* brings air from the conditioned space back to the air conditioner for mixing with outside air and reconditioning.
 11. The *thermostat* in the conditioned space acts as a master controller for numerous other controls (to be described in later chapters) which keep the entire system in automatic operation.
 12. Fin-tube radiation near floor.

1-5 Occupational Opportunities in the Industry

As a student beginning the study of air conditioning, you are probably thinking seriously of a career in the industry.

The opportunities for technically minded people are many and varied and will increase greatly as the industry continues to grow. It is estimated that nearly 25,000 additional persons will be needed each year to fill the demands for trained personnel during the next decade. Most manpower authorities are agreed that the greatest need will be for technicians, mechanics, and sales engineers with a rapidly increasing number of employers and employment opportunities from which to choose.

Air Conditioning Engineering

The professional air conditioning engineer is (usually) a graduate mechanical engineer. He may work on the design and development of