SUBCOURSE OD 1749

EDITION A

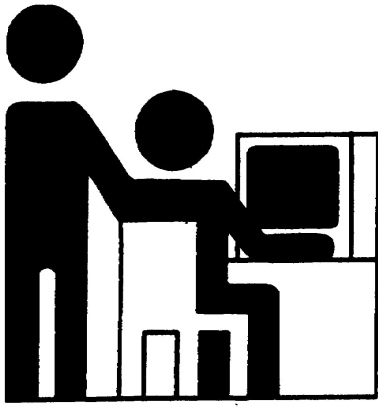
REFRIGERATION AND AIR CONDITIONING III (AIR CONDITIONING)

AIPD

READINESS/ PROFESSIONALISM THRU GROWTH

THE ARMY INSTITUTE FOR PROFESSIONAL DEVELOPMENT

ARMY CORRESPONDENCE COURSE PROGRAM



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REFRIGERATION AND AIR CONDITIONING III
(Air Conditioning)

Subcourse OD 1749
Edition A

United States Army Combined Arms Support Command
Fort Lee, VA 23801-1809

18 Credit Hours

INTRODUCTION

This subcourse is the third of four subcourses devoted to basic instruction in refrigeration and air conditioning.

This subcourse discusses airflow properties and temperature response including an explanation of air and temperature measuring devices. Instruction is also provided on the installation, operation, and maintenance of self-contained air-conditioning units. In addition, the subcourse covers the electric motor, pneumatic controls of refrigeration, the installation of ventilation systems, and the types and components of heat pumps.

There are four lessons.

1. Temperature, Airflows, and Measuring Devices.

2. Self-Contained Units and Duct Systems.

3. Controls.

4. Evaporation, Ventilation Systems, and Operation of Heat Pumps.

Unless otherwise stated, whenever the masculine gender is used, both men and women are included.

PREFACE

THIS subcourse deals with another phase of your specialty description-air conditioning. Since the principles of refrigeration and air conditioning are similar, your mastery of the subject will come easy. You will find that we discuss several components peculiar to air-conditioning systems.

To qualify you in the area of air conditioning we discuss the following systems in this subcourse:

1. Self-contained package air conditioners

2. Mechanical ventilating systems

3. Fresh sir and air duct systems

4. Control systems

5. Evaporative cooling systems

6. Heat pump systems

We're also going to refresh your knowledge of the following:

1. Components of sir

2. Temperatures, airflows, and their measuring devices

3. Design and installation factors

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ACKNOWLEDGMENT

Grateful acknowledgment is made to the American Society of Heating, Refrigeration ad Air-Conditioning Engineers; Johnson Service Company; Honeywell, Inc.; and Taylor Instrument Comp anies for permission to use illustrations and text material from their publications.

CONTENTS

Undesirable Properties of Air

HOW DOES THE atmosphere of a hospital operating room differ from the atmosphere of your work area? Well, the atmosphere of the operating room must be free of foreign matter, humidity controlled, and air-conditioned. But most work areas are not air-conditioned at all. Some may have fans to ventilate the area. Since your duties will bring you to areas in which the atmosphere is conditioned, you must know how to control the various undesirables you might find in the air.

2. The elements you will study in this chapter are foreign material, odors, and moisture.

1. Foreign Material

1. Normal air contains varying amounts of foreign materials commonly referred to as permanent atmospheric impurities. These materials can arise from such natural processes as erosion, wind, and sea water evaporation. Such contaminants will vary considerably in concentration but will range far below those caused by manmade activities.

2. Some manmade contaminants are: smoke caused by transportation and industry, chemical sanitizers, and various dusts and sprays used in agriculture.

3. **Dusts**. Dusts are solid particles projected into the air by wind, grinding, drilling, shoveling, screening, and sweeping. Generally, particles are not called dust unless they are smaller than approximately 100 microns. Dust may be of mineral type. such as rock, metal, or sand; vegetable, such as grain, flour, wood, cotton, or pollen; or animal, including wool, hair, silk, feathers, and leather.

4. **Fumes**. Fumes are solid particles commonly formed by the condensation of vapors from normally solid materials. Fumes may be formed by sublimation, distillation, galvanization, or by chemical reaction whenever such processes create airborne particles predominantly smaller than 1 micron. Fumes which are permitted to age tend to flocculate into clusters of larger size. This characteristic is often made use of when we want to remove fumes from the air.

5. **Smokes**. Smokes are extremely small solid particles produced in incomplete combustion of organic substances such as tobacco, wood, coal, oil, and other carbonaceous materials. Smoke particles vary considerably in size, the smallest being much less than 1 micron and often in the size range of .l to .3 micron.

6. **Air Filters.** Air filters are ordinarily used to remove particles such as those found in outdoor air. Filters are employed in ventilating, air-conditioning, and heating systems where the dust content seldom exceeds 4 grains per 1000 cubic feet of air. Since the purpose of a filter is to remove as much of the contamination as practical, it is obvious that the degree of cleanliness required is a major factor in determining the type of filter design to be used. The removal of these particles becomes progressively difficult as the particle size decreases. The installation of air filters will justify their cost through a reduction of equipment failure and housekeeping, and by providing dust-free air for critical manufacturing processes.

7. Air filters can generally be classified into three groups, depending upon their principle of operations: (1) viscous impingement, (2) dry, and (3) electronic.

8. *Viscous impingement type filter*. This filter consists of relatively coarse media constructed of fiber, wire screen, woven mesh, metal stampings or plates, or sometimes a combination of these. The filter may be of (1) the unit or pane) type, which is manually cleaned; (2) the disposable type, which is replaced after it has accumulated its dirt load; or (3) the automatic moving curtain type, which changes its media in the airflow when the pressure across the filter reaches a predetermined pressure.

9. The viscous impingement filter derives its name from the fact that the medium is treated with a viscous substance, frequently referred to as an oil or adhesive. In the operation of the filter, the airstream is broken down into small columns which are made to change directions, depending upon filter construction. At each change of direction, the larger dust articles continue in a straight line

because of their momentum, and when they impinge against the medium they are held by the adhesive surface. The viscous material used on this type filter requires careful selection. In general, it is considered good practice to follow the manufacturer's recommendations. However, desirable characteristics of a suitable adhesive are: (1) a low percentage volatility so as to have negligible evaporation, (2) a viscosity that varies only slightly with normal temperature change, (3) the ability to inhibit the growth of bacteria and mold spores, (4) high capillarity, or the ability to wet and retain the particles, (5) high flash and fire point, and (6) freedom from odor.

10. The arrangement of the filter medium is one of two types. The high velocity type has the filtering medium placed on edge, perpendicular to the base of the duct, so as to offer low resistance to airflow. Filters in this category carry a face velocity rating of 480 to 520 f.p.m. This filter does not have any recommended direction of airflow.

11. The progressive pack or progressive density design, in which the medium is packed more densely on the leaving air side, permits the accumulation of dirt throughout the depth of the media. Filters of this design are rated at a face velocity of 300 to 350 f.p.m.

12. Unit filters generally have metal frames which are riveted or bolted together to form a filter bank or section. The rate at which they need cleaning depends upon the type and concentration of the dirt in the air being handled. Various cleaning methods can be used, but the most widely used procedure is to wash the filter with steam or water (frequently using a detergent) and then dip or spray the filter with its recommended adhesive. Excessive adhesive should be allowed to drain off before you reinstall the filter in the air-stream.

13. Manometers or draft gauges are often used to measure the pressure drop across the filter and thereby indicate when the filter requires servicing. Unit filters are serviced when the pressure drop reaches 0.5 inches water gauge pressure. A visual inspection should be made periodically if a manometer or draft gauge is not installed in the system.

14. The disposable filter is constructed of inexpensive materials and is to be discarded after one period of use. The cell side of this design is a combination of cardboard and metal stiffeners.

15. The moving-curtain viscous filters are available in two main types. In one design the filter medium is installed on a traveling curtain which intermittently passes through an adhesive reservoir, where the medium gives up its dirt load and takes on a coating of new adhesive. The medium used in the design consists of metal panels or sections made of screen wire, stamped plates or baffles, or reinforced mesh, which is attached to a pair of chains. The chains are mounted on sprockets located in the top and bottom of the filter housing. The medium thus forms a continuous curtain which moves up one face and down the other.

16. Automatic filters of this design may often utilize a timer for periodical filter movement. The timer is so set that it allows the curtain to make one revolution every 24-48 hours.

17. The precipitated dirt must be removed from the adhesive reservoir. This is done by scraping the dirt into a tray which can be conveniently suspended from the reservoir lip. The frequency of dirt removal is variable, but in normal operation, this type of filter will require attention approximately once every 3 months. Where it is desirable to eliminate this maintenance, the adhesive may be pumped through oil clarifiers or can be allowed to circulate through large settling tanks.

18. The moving-curtain filter is also available in roll form, which is fed automatically across the filter face. The dirty medium is rewound on a spool at the bottom of the filter housing. Movement of this type filter is controlled by a pressure switch control.

19. Filters of this type are considered to be fail safe, as they have a trip switch that indicates that the filter medium is exhausted. This switch also opens the circuit to the filter drive motor.

20. At this time you must remove the old filter and spool and insert a new one. The old filter is not reusable.

21. Most automatic types of viscous filters are equipped with a fractional horsepower motor operating the drive mechanism through a gear reducer. The operating period is adjustable so that the media travel can be adjusted for changes in dust concentration. In operation the resistance of an automatic filter will remain constant as long as proper operation is obtained. A resistance of 0.4 to 0.5 inch water gauge pressure at a face velocity of 500 f.p.m. is typical of this class filter.

22. *Dry type air cleaners*. The media used in dry type air filters are usually fabriclike or blanketlike materials of varying thicknesses. Media of cellulose fiber, bonded glass, wool felt, asbestos, and other materials are used. The medium is frequently supported by a metal frame in the form of pockets or V-type pleats. In other designs the media can be constructed to be self-supporting. The pockets and pleats provide a high ratio of filter area to face area.

23. The efficiency of the dry filter is higher than that of the viscous impingement type. The wide choice of filter media makes it possible to supply a filter for any cleaning efficiency desired. The life or dust holding capacity is lower than the viscous impingement filter, because the dust tends to clog

the fine pore or openings. Dry filters have a large lint-holding capacity because of the large surface area exposed by the pleated arrangement of the media.

24. Types of media which provide extremely high cleaning efficiency consist of pleated cellulose-asbestos paper, sand beds, compressed glass fibers in the form of paper, or glass fiber blanket material. The use of these filters is limited to concentrations in the range of outdoor air and where efficiencies to 99.95 percent on submicron particles are required.

25. In some designs of dry type air filters, the filter medium is replaceable and is held in position in permanent metal cell sides. Other dry air filters are discarded after one period of use.

26. The initial resistance of a dry type filter will vary with the medium being used. A number of commercial designs have an initial resistance of 0.1 inch water gauge pressure and are replaced when a final resistance of 0.5 inch water gauge pressure is reached. The more cleaning efficiency the filter offers, the more resistance there will be to airflow. In any event, the filter should be compatible with the resistance against which the fan will be called upon to operate.

27. Automatic dry filters are similar to the roll type viscous impingement filter. These filters are not recommended for handling of atmospheric dust, but are used in such applications as textile mills, drycleaning establishments, and printing press room operation.

28. *Electronic air filters*. The two types of electronic air filters are the ionizing type collectors and charged media type collectors.

29. The ionizing type electronic air filter uses the electrostatic precipitation principle to collect particulate matter.

30. In a typical case, a potential of 12,000 volts may be used to create the ionizing zone, and some 6000 volts between the plates upon which the precipitation of dust occurs. Safety devices are used to protect personnel from shock. The door to the filter section is outfitted with a switch that will open the circuit to the filter plates.

31. The voltage necessary for operation of the equipment is obtained from high-voltage, direct-current power packs which operate from a 120-volt, 60-cycle, single-phase power supply. Power consumption is approximately 12 to 15 watts per 1000 c.f.m. plus about 40 watts required to energize the rectifier tube heaters.

32. Filters of this type have very little resistance to airflow. Therefore, care must be exercised in arranging the duct approaches on the entering and leaving sides of the filter in order to evenly distribute the air across the entire area of the filter. The efficiency of the filter is sensitive to air velocity. In most systems, resistance is deliberately added in the form of a perforated plate, prefilters, or afterfilters for the purpose of obtaining a uniform distribution of air. The resistance generally ranges from 0.15 to 0.25-inch water gauge pressure at velocities of 300 to 400 f.p.m. Screens of 16 mesh should be installed across outdoor air inlets to prevent larger foreign objects from entering the system. Special devices must be installed in front of the ionizing filter to remove excessive lint.

33. The ionizing type electronic filter is very efficient. It is available in either fixed or moving collector types. The fixed collector plates are often coated with a special oil which acts as an adhesive. Cleaning is accomplished by washing the cells in place with hot water from a hose or by means of a fixed or moving nozzle system. The bottom of the filter chamber is made watertight and is provided with a drain.

34. In one moving-plate type the grounded elements on which the dirt collects are mounted so as to form a traveling curtain. The traveling curtain intermittently passes through a reservoir containing a fireproof chemical adhesive. This unit is equipped with wipers which remove the collected dirt from the plates. The dirt then settles as a sludge in the bottom of the reservoir from which it must be removed periodically.

35. The charged media type electronic filter consists of a dielectric filtering medium, usually arranged in pleats, as in the typical dry type filter. The dielectric material may consist of glass fiber, cellulose, or other similar materials. The medium is supported on or is in contact with a gridwork consisting of alternately grounded and charged members, the latter being held at a potential of 12,000 volts d.c. so that an intense and nonuniform electrostatic field is created through the dielectric medium. Airborne particles approaching this field are polarized and drawn toward filaments or fibers of the media.

36. The precipitator of this type offers resistance to airflow. The resistance, when clean, is approximately 0.10-inch water gauge pressure at 250 f.p.m. velocities. The resistance of this type filter increases as dust accumulates on the media. Like the typical replaceable media dry filter, the charged media precipitator is serviced by replacing the medium. The dielectric properties of the media become impaired when the relative humidity exceeds 70 percent.

2. Odors

1. Odor is defined as that property of a substance which excites the sense of smell. To be odorous, a substance is usually in a gaseous or vapor state, or possesses a vapor pressure. Some odors are pleasant, others unpleasant, depending

upon their psychological and sociological association.

2. The sources of odor that cause discomfort to individuals are many. They may be introduced from the outdoor atmosphere and contain a high percentage of hydrogen sulfide, industrial effluents or smog. In enclosed areas, odors may be caused by the human body, tobacco, etc. Odors may also be caused by wet, dirty air-conditioning coils. The metals and coatings used on coils materially affect the possibility of producing objectionable odors.

3. Odor removal may be done by physical or chemical means. Ventilation with clean air, air washing or scrubbing, charcoal adsorption, and masking are physical methods; while chemical adsorption, destruction of odor sources, vapor neutralization, and catalytic combustion are chemical methods.

4. Washing and scrubbing, like filtering, are applicable to the removal of particulates and, in some cases, are means of recovery of a valuable product. Odors associated with the particulates are removed indirectly by this process. Combustion is employed to alleviate the effects of harmful exhaust gases and particulates on people, vegetation, and property.

5. Ventilation, charcoal adsorption, and masking are effective in air-conditioning for odor control. We will limit our discussion to these three.

6. **Mechanical Ventilation**. Ventilation systems supply fresh air where natural ventilation is insufficient; remove heat, vapor, or fumes from a building; and discharge these undesirables to the atmosphere. It has been found that 30 c.f.m. per person is necessary for effective ventilation in sports arenas to avoid eye Irritation, odors, and impaired visibility.

7. The actual oxygen requirement per person varies with the activity. It is normally about 0.89 cubic feet per man-hour when the activity is walking at the rate of 1 mile per hour.

8. Smoke and other solid or liquid particulates can be effectively removed by electronic precipitators or absolute liters. Odors, gases, and vapors can be removed effectively by charcoal adsorbers. Considerable fuel and power savings can result from the use of charcoal adsorbers as compared to ventilation.

9. **Charcoal Adsorption**. Charcoal adsorption is the physical condensation of a gas or vapor on the charcoal sorbent. The charcoal or carbon is especially prepared from coconut shells, peach kernels, or other materials. To increase the surface area and thereby increase the adsorption capacity, the charcoal or carbon is activated.

10. The preparation of activated charcoal is usually done in two steps: first, the carbonization of the raw material; second, the high temperature oxidizing process. The purpose of the oxidizing process is to remove from the capillaries of the raw material those substances which cannot be carbonized. This is done to create extensive surfaces on which adsorption can take place.

11. Coconut charcoal, properly prepared, is considered the standard high quality material for air or gas purification in air-conditioning systems. The quality of charcoal as an adsorber of gases is rated on the breakthrough time when subjected to the standard Accelerated Chloropicrin Test. The capacity of charcoal to adsorb gases or vapors depends primarily on the types of gases and vapors being adsorbed. Some are readily adsorbed, while others are not. Improved adsorption of various gases and vapors can be obtained by impregnation of the charcoal with certain mineral salts.

12. **Masking**. Odor masking is the process of hiding one odor by superimposing another odor to create a more overpowering sensation, preferably pleasant. The masking agent, which can be in spray cans, wick bottles, etc., does not alter the composition of the pre-existing odors. It simply covers such odors during the period of its addition to, or presence in, the air.

13. The application of a pleasant masking agent to an offensive atmosphere may result in a final combination that is still objectionable to the sense of smell. Therefore the objectionable odor concentration must not be so intense that the masking agent is itself required in objectionable quantities.

3. Air and Water Vapor

1. As we have stated previously, air is made up of various mixtures, including gases and moisture. We will discuss moisture in the air and its relation in psychrometry, and the means used to add or remove it from the air.

2. Psychrometry. Psychrometry literally means the measurement of cold. It is the name that has been given to the science that deals with air and water vapor mixtures. The amount of water vapor in the air has a great influence on equipment cooling and human comfort. Such atmospheric moisture is called humidity, and the common expression "It isn't the heat, it's the humidity" is an indication of the discomfort-producing effects of moisture laden air in hot weather.

3. The water vapor in the air is not absorbed or dissolved by the air. The mixture is a simple physical one, just as sand and water are when mixed. The temperature of the water vapor is always the same as the air.

4. When the air contains all the water it can hold, it is called saturated air. The amount of moisture present at the saturation point varies with the temperature of the air. The higher the temperature, the more moisture the air can hold.

5. **Moisture Removal**. The moisture in the air may be removed by various methods. We will discuss the mechanical and chemical methods.

6. *Dehumidifying coils*. Air can be cooled and dehumidified by passing it over the cold surfaces of cooling coils. The efficiency of this process may have to be checked if the desired values are changed or the system becomes unbalanced. In a later chapter you will become acquainted with methods of checking the efficiency of this type of system.

7. When dehumidification is accomplished with cooling coils, the coil temperature must be below the dewpoint temperature of the humid air. This low coil temperature causes the moisture in the air to condense out. The air is then reheated to lower the relative humidity. For example, an entering air condition of 100° F. dry bulb and 67 percent relative humidity could be conditioned to 70°-72° F. dry bulb and 40-50 percent relative humidity by the following procedure:

a. The air being drawn into the system is preheated if it is below 70° F.

b. The air then passes over the cooling coil. (Coil size is calculated by c.f.m., approximately 400 c.f.m. per ton of refrigeration.) The air is now cooled to approximately 33° F. and has a relative humidity of 100 percent.

c. It now passes to the reheat coil, where its temperature is increased to 65°-70° F. The relative humidity is now 20-30 percent.

d. We can now add humidity to the air if desired. Adding humidity to the air will be discussed later in this chapter.

8. *Chemical dehumidification*. Sorbents are solid or liquid materials which have the property of extracting and holding other substances (usually gases or vapors) brought in contact with them. The sorption process always generates heat, which is the major factor in dehumidification. All materials are sorbents to a greater or lesser degree. However, the term "sorbent" refers to those materials which have a large capacity for moisture as compared to their volume and weight. We will discuss the liquid absorbents and the solid adsorbent.

9. The liquid adsorbent (sulfuric acid, lithium chloride, lithium bromide, etc.) can adsorb moisture from or add moisture to the air, depending upon the vapor pressure difference between the air and the solution.

10. For dehumidification, the strong adsorbent solution is pumped from the sump of the dehumidifier to the sprayers. The sprayers distribute the solution over the contactor coils.

11. The solution, at the required temperature and concentration, comes in contact with the humid air which is flowing over the coil surface in the same direction as the liquid absorbent. Equipment is also available for counterflow operation.

12. Moisture is absorbed from the air by the solution and is maintained at a constant condition by automatic regulation of the flow of water through the cooling coils by means of a water regulating valve.

13. The heat generated in absorbing moisture from the air consists of the latent heat of condensation from the water vapor, the heat of the solution, or the heat of mixing of the water vapor and absorbent. The heat of mixing varies with the liquid absorbent used and the concentration and temperature of the absorbent. The solution is maintained at the required temperature by cooling with refrigerated or cooling tower water, or refrigerant flowing inside the tubes of the contractor coils. The quantity of coolant required is a function of the temperature of the coolant and the total heat removed from the air by the absorbent solution.

14. The dry-bulb temperature of the air leaving the liquid absorbent contactor at a constant flow rate is a function of the temperature of the liquid absorbent and the amount of contact surface between the air and the solution. In most commercial equipment the dry-bulb temperature of the air leaving the dehumidifier will be within 1° to 5° F. of the absorbent solution temperature.

15. The liquid absorbent is maintained at the proper concentration by automatically removing the water vapors condensed from the air. Approximately 10 to 20 percent of the solution supplied by the pump passes over the regenerator coil. The coil heats the solution with steam or other heating mediums. The liquid absorbents commonly used can be regenerated with 2 to 25 p.s.i.g. steam. The vapor pressure of the solution at temperatures corresponding to 2 p.s.i.g. steam is considerably higher than that of the outdoor air. The hot solution at the relatively high vapor pressure is in contact with outdoor air in the regenerator, where water is absorbed from the solution by the scavenger air. The hot moist air is discharged to the outdoors and the concentrated solution falls to the sump. The solution is then ready for another cycle.

16. The steamflow to the regenerator coil is regulated by a control responsive to the concentration of the solution circulating over the contactor coils.

17. Dehumidification by solid adsorption systems may be performed under static or dynamic operation. These desiccants can be silica gel, activated alumina, etc.

18. In the static method there is no forced circulation of air into or through the desiccant.

Instead, the air surrounding the adsorbent is initially dried. Subsequently, through convection and diffusion, water vapor (humidity) passes into the air surrounding the desiccant and then to the desiccant, where it is stored. Since considerable time is required for dehumidification, this method is used quite often in shipping and storing delicate instruments that are sensitive to moisture. Various foods, such as potato chips, also use the static method of solid adsorption dehumidification.

19. On the other hand, dynamic dehumidification is operated with forced passage of air through a desiccant bed. The only prerequisites for a dynamic dehumidifier are a desiccant bed, a fan to force the humid air through the bed, and a heater to reactivate the adsorbent.

20. As the air passes through the desiccant bed it gives up a certain amount of its moisture. The rate of moisture pickup and the humidity condition of the leaving air are functions of a great many variables. Some of these variables will be discussed later.

21. The ratio of adsorbed moisture to entering air moisture content is known as adsorption efficiency. The adsorption efficiency in dynamic uses remains constant and at a relatively high level until some point within the cycle, at which time the efficiency begins to drop. This point is known as the breakpoint, and the amount of moisture adsorbed until this point is called breakpoint capacity. It is considered ideal to have the breakpoint capacity coincide with the equilibrium capacity. In actual operation, breakpoint capacity can be a small portion of the equilibrium capacity, depending on operating conditions. High inlet temperature and humidity, small bed depths, and high airflow rates will all tend to decrease the breakpoint capacity. Regeneration of the desiccant bed should be accomplished at breakpoint capacity, but adsorption can still be carried on. The adsorption is now done at a slower rate until the desiccant is completely saturated. This saturation point is called completion.

22. To regenerate the desiccant bed, the heater is energized and the airflow through the bed is usually reversed. The temperature of the effluent air rises rapidly at first, and then virtually levels off for a period of time. This period of time represents the period during which the major portion of the heat input is being used to boil off the adsorbed water. When the latent heat (evaporization) requirements begin to diminish, the heat input goes into sensible heat gain to the passing airstream. This period, measured from the start of desorption, is called temperature rise time. Although additional regeneration can be accomplished beyond this point, it is considered uneconomical because of the slower rate of desiccant activation. Regeneration past temperature rise time, until the adsorbent is in moisture equilibrium with the airstream, is known as complete desorption or desorption to completion. The energy used in the heater per unit weight of water desorbed for any given time is called economy of desorption and is usually expressed in kilowatt hours per pound of water desorbed.

23. Some of the many variables that influence the results of a dynamic dehumidification operation are as follows:

a. Variables concerning the desiccant bed:
(1) Type of desiccant.
(2) Dry weight of desiccant.
(3) Particle size.
(4) Bulk density.
(5) Shape of bed.
(6) Area of bed normal to airflow.
(7) Depth of bed.
(8) Packing of desiccant in the bed.
(9) Pressure drop through the bed.

b. Variables concerning the air to be dried:
(1) Flow rate.
(2) Temperature.
(3) Moisture content.
(4) Pressure.
(5) Contact time between air and desiccant.

c. Variables concerning reactivation:
(1) Reactivation temperature.
(2) Rate and magnitude of heat supply.
(3) Heat storage capacity of the bed.
(4) Temperature gradient of the bed.
(5) Amount of insulation.
(6) Amount of sweep gas.

24. Solid adsorption dehumidifiers are usually of the stationary dual-bed type. One bed absorbs while the other is being reactivated. The cycle time for the dual-bed operation is normally specified by the manufacturer and is controlled by a timer. Larger units may have adjustable time cycles that can be changed for various operating conditions. Still others are operated from either manual or automatic reading of the effluent moisture content.

25. **Humidifiers**. There are many different types of humidifiers available for adding moisture to a conditioned area. The types that you will study in this section are the steam, atomizer, impact, forced evaporation, and air washer. Of these humidifiers, the steam type is the only one which puts vapor into the air. All the others consist of arrangements for exposing large surfaces of water, in the form of small droplets or wet surfaces, to the air. The water will evaporate and humidify the air.

26. Before we continue our discussion, let us review the principles of humidification. Humidity refers to the amount of moisture (water vapor) in the air Absolute humidity is the actual weight

of water vapor per unit volume of air. Do not confuse the term "absolute humidity" with specific humidity. It is a common error. Specific humidity is the actual weight of water vapor per unit *weight of dry air in the mixture*. Specific humidity is dependent upon dewpoint temperature only and is expressed in grains of moisture per pound of dry air. The continual changes in volume which takes place with changes in temperature and in water vapor content make it very difficult to base any calculations upon the volume of the mixture. Through all of these changes, the pound of dry air remains a known factor and a suitable basis for our measurements. As you work with air and water vapor mixture calculations, you will realize why this basis was chosen.

27. Relative humidity refers to the amount of moisture actually in the air as compared to saturated air. Relative humidity depends only upon the vapor pressure of the water vapor present in the air and the dry-bulb temperature. The presence of air or any other gas has nothing to do with the relative humidity of a given space.

28. Now let us get back to humidification. In order to change water to vapor we must add 1050 B.t.u.'s to each pound of water evaporated. The heat may come from the air being humidified. This procedure will cause the air to cool at the same time that its being humidified. In any humidifying process in which no external heat source is used, the wet-bulb temperature will remain constant throughout the process.

29. Let us consider a sample of air at 80° F. dry-bulb temperature, 17 percent relative humidity, which is to be humidified to 100 percent. Using a psychromatic chart, you will find that the wet-bulb temperature is 55 F. The air will become cooler until it has reached 55° F. dry-bulb temperature. At this point the air is completely saturated and the relative humidity is 100 percent. You will also notice that the dewpoint temperature has risen from 31.3° to 55° F. and that the moisture content has increased from 25.5 to 64.7 grains of vapor per pound of dry air. You have added 39.2 grains at 0.0056 pounds of vapor to the air. Let us now discuss the various types of humidifiers that use this principle. Remember, the steam humidifier is the only type that uses an external heat source.

30. *Steam humidifier*. The simplest type of steam humidifier contains a nozzle or a set of nozzles through which live steam is allowed to escape into the air. This means of humidification is seldom used because steam carries odors that are objectionable in an air-conditioning installation. It is also difficult to eliminate the hissing sound produced by the escaping steam. Another fault is that the stream humidifier often provides more heat than is desired in the conditioned area.

31. *Atomizer humidifier*. The atomizer humidifier is very effective, because water is taken from a supply tank and blown into the air in the form of a fine mist. The atomized water vapor may be sprayed into the conditioned area or into a duct leading to the area. It functions much like a can of spray deodorant or a perfume atomizer.

32. Instead of the plunger arrangement found in a perfume atomizer, compressed air passes through a narrow section of pipe at a high velocity. This movement of air causes the water to be lifted out of the tank and be blown into the room or area. The tank is usually connected to a water supply line and is kept full by a float valve.

33. This humidifier adds no heat to the conditioned area. The atomized water vapor readily evaporates by the addition of heat taken from the air within the space. The evaporation will cause the dry-bulb temperature to decrease while the relative humidity increases. The wet-bulb temperature (total heat) will remain constant.

34. While the atomizer humidifier is efficient because it uses all the water supplied to it, it is objectionable in areas where noise cannot be tolerated. The noise is caused by the high velocity air passing through the pipe. A drainpipe is not needed because the atomizer uses all its supplied water.

35. *Impact humidifier*. This type of humidifier uses an arrangement similar to an air washer. Fine jets of water are directed against a hard surface. The impact of the spray upon the surface causes the water to break up into a finer spray. The conditioned air is brought past the surface to pick up by evaporation as much of the spray as possible.

36. Eliminator plates are placed downstream from the spray to restrict large water droplets collected in the air. The water is thus prevented from entering the conditioned area and damaging the contents.

37. Twenty to fifty percent of the water supplied to an impact humidifier is actually evaporated and carried off in the conditioned air. This percentage varies because of the speed of the water leaving the jet, the entering air temperature and humidity, and the mixing of air and water vapor ahead of the eliminator plates. Greater jet velocity, higher air temperature, lower relative humidity, and better mixing of air and water will increase the percentage of evaporation.

38. *Forced-evaporation humidifier*. You know that evaporation takes place continuously from any water surface. But, do you know which factors determine the rate of evaporation? First, the rate of airflow plays an important role. If

more air is brought into contact with the water in a given length of time, more evaporation will occur. When you heat the water you are actually increasing its vapor pressure. This heating effect will allow the water to evaporate more readily.

39. Those are the two factors-airflow and heat. Now let us apply these factors to the forced-evaporation humidifier. The forced-evaporation humidifier is so named because it provides a means by which water may be evaporated into the air more than would be normal. Most of these humidifiers consist of a large shallow pan in which a steam coil is immersed. A fan blows air across the pan at a high velocity. The water level is maintained by a float valve.

40. This humidifier does not waste any water. It is simple, in that there are no moving parts. If no heat is applied to the water, the water will evaporate by the heat in the air, or adiabatically. When the Water is heated, both the wet-bulb temperature and the total heat will increase. For example, if you added 40 B.t.u.'s of heat per hour to the water, and if the air is passed over the surface of the water at the rate of 20 pounds of dry air per hour, the total heat of the air will be increased by 40/20, or 2 B.t.u.'s per pound of dry air. Thus, if the air enters the humidifier with a total heat of 250 B.t.u.'s per pound of dry air and a wet-bulb temperature of 57.8° F., it will leave with a total heat of 27.0° B.t.u.'s per pound of dry air and a wet-bulb temperature of 60.8° F.

41. *Air washer humidifier*. You have studied air washers earlier in this chapter as a method of odor removal. Now you will learn how they are used to humidify air.

42. The spray type air washer is a very effective humidifier. Two banks of sprays are directed against the airflow and one is directed with the airflow. This arrangement of spray banks is 100 percent efficient, because all the air passing through the air washer will leave saturated.

43. If fewer spray banks are used, the efficiency will decrease. A general comparison of the saturation efficiency is:

Number of banks	*Direction*	*Efficiency*
1	downstream	50-70%
1	upstream	65-75%
2	downstream	85-90%
2	opposing	90-95%
2	upstream	92-97%

44. The efficiency of a washer is usually measured by the drop in dry-bulb temperature relative to the entering wet-bulb depression. For example, if the entering air conditions are 95° F. dry-bulb and 75° F. wet-bulb temperature with a leaving air temperature of 76° F., the efficiency is 95 percent. The principal factors affecting the efficiency are air velocity, the quantity of water sprayed per unit volume of air, the length of the chamber, and the fineness of the spray.

45. Most standard rating tables are based on a velocity of 500 f.p.m. through the air washer. Velocities above 750 or below 350 f.p.m. often result in faulty elimination of the entrained moisture. The quantity of water sprayed per 1000 c.f.m. of air varies between 1.5 and 5 g.p.m. per bank. The fineness of the spray depends upon nozzle design and the water pressure supplied to the nozzle. The pressure will vary between 20-40 p.s.i.g. You will find that the air resistance of an air washer is usually 0.2 to 0.5 inches of water.

46. The material most commonly used in the construction of air washers and the other types of humidifiers is galvanized sheet steel. The maintenance that you will be required to accomplish on humidifiers consists mostly of cleaning and painting.

47. The nozzles used on impact and air washer humidifiers are designed to produce a dense spray. To do this with a reasonably low water pressure, the body of the nozzle may be designed to give the water a swirling motion as it enters the nozzle cap. The cap is cupped to give an accelerated action to the water before it emerges into a spray at the orifice. The capacities of several standard size nozzles at different pressures are:

Shank diameter	*Orifice diameter*	*Capacity of nozzle at indicated pressure (g.p.m.)*				
		10	20	25	30	40
1/4	3/32	0.33	0.47	0.52	0.57	0.66
3/8	1/8	0.59	0.83	0.93	1.02	1.18
3/8	3/16	1.27	1.79	2.01	2.20	2.54
3/8	1/4	2.01	2.84	3.18	3.48	4.02

48. Flooding nozzles are often used to provide continuous flushing of the eliminator plates. These nozzles may also be used to flush the inlet baffles when lint-ladden air is being handled. Under this condition, they operate at 3 to 10 p.s.i.g. and are spaced to handle 3 to 6 g.p.m. per foot of humidifier width.

49. Corrosion is often encountered in humidifiers. When corrosion exists you must clean the humidifier and treat the water to prevent or retard further deterioration of the equipment. Chemical treatment should be a means of maintaining a pH of 7.5 to 8.5. A corrosion inhibitor may also be used, if allowable.

50. *Humidifier operation*. A humidistat is normally used to control the operation of a humidifier. A low humidity condition is sensed by the humidistat, which in turn will start the humidifier pump, position dampers, open valves, or start fans. The maintenance, adjustment, and calibration of humidistats will be discussed later.

Review Exercises

NOTE: The following exercises are study aids. Write your answers in pencil in the space provided after each exercise. Use the blank pages to record other notes on the chapter content. Immediately check your answers with the key at the end of the text. Do not submit your answers for grading.

1. What factor determines the type of filter design you would use on a particular installation? (Sec. 1, Par. 6)

2. Which filter arrangement would you use in a duct system having a velocity of 500 f.p.m.? (Sec. 1, Par. 10)

3. The pressure drop through a duct system is 2 p.s.i.g. What has occurred? (Sec. 1, Par. 13)

4. Which type of filter requires the least amount of attention? (Sec. 1, Par. 17)

5. Which type of filter would you install in a critical area such as a missile complex? Why? (Sec. 1, Par. 19)

6. How can you increase the surface area of a dry filter? (Sec. 1, Par. 22)

7. The fan motor on an air-conditioning system overheats. The filter is clean and the fan is not malfunctioning. What has caused the motor to overheat? (Sec. 1, Par. 26)

8. How many watts will an ionizing filter consume when 3800 c.f.m. of air is being handled? (Sec. 1. Par. 31)

9. How much would it cost to operate the filter in question 8 for 1 hour at 3 cents a kilowatt? (Sec. 1, Par. 31 and Question 8)

10. The conditioned air passing through a charged media filter is not being cleaned. The dry-bulb temperature is 50° F. and the dewpoint temperature of the air is 50° F. What has caused the air to remain dirty? (Sec. 1, Par. 36)

11. A complaint is submitted to your shop about an air conditioner giving off a peculiar odor. What condition most likely caused the air to become odorous as it passed through the duct? (Sec. 2, Par. 2)

12. Air at 70' F. and 100 percent relative humidity is ____________. (Sec. 3, Par. 4)

13. How many c.f.m. can be handled effectively by a 5-ton cooling coil? (Sec. 3, Par. 7)

14. How is the quality of a liquid absorbent controlled? (Sec. 3, Par. 12)

15. The temperature of the air leaving the dehumidifier is 10° below the absorbent temperature. How can you correct this condition? (Sec. 3, Par. 14)

16. What is the adsorption efficiency of a dynamic dehumidifier when the adsorbed moisture is 20 grains and the entering air moisture content is 25 grains? (Sec. 3, Par. 21)

17. To regenerate a filter bed, 400 watts per pound of water is used. The amount of water desorbed is 3 pounds and the cost of electricity per kilowatt is 2.5¢. What is the economy of desorption and the cost of desorption? (Sec. 3, Par. 22)

18. How many B.t.u.'s are required to evaporate 9 pounds of water? (Sec. 3, Par. 28)

19. Adding moisture to the air with an atomizer humidifier will ____________ the wet-bulb temperature. (Sec. 3, Par. 28)

20. How can you control the amount of humidity added to the air with an atomizer humidifier? (Sec. 3, Par. 32)

21. What is maximum efficiency of the impact humidifier as compared to the atomizer type? (Sec. 3, Par. 37)

22. Why does the rate of airflow play an important role in evaporation? (Sec. 3, Par. 38)

23. If you added 100 B.t.u.'s of heat per hour to a forced-evaporation humidifier and air is passing through it at the rate of 20 pounds of dry air per hour, how much heat will be added to each pound of dry air? (Sec. 3, Par. 40)

24. The air leaving an air washer, used for humidification, is carrying water droplets out with it. The air velocity through the washer is 800 f.p.m. How can you correct this condition without altering the washer or changing the velocity? (Sec. 3, Par. 44)

25. The resistance of the air passing through an air washer is 2 p.s.i.g. What has caused the pressure to rise and how can it be prevented in the future? (Sec. 3, Pan. 45 and 48)

Temperatures, Airflows, and Their Measuring Devices

MOST MANUFACTURERS of automobiles in the past few years have installed warning lights to indicate heating of the engine, low amperage output, and low oil pressure. Many times you' have probably wished to know the rate the battery was charging or the temperature of the engine. The trend in some automobiles is back to the gauges which will tell the owner more precisely how his automobile is performing.

2. Lets fit this to our situation. Can you tell how hot or cold a surface is or how much air is flowing out a ceiling outlet by placing your hand on it? No, you must u some type of instrument that will indicate the true condition of the component being checked. In air-conditioning troubleshooting, you will find that the thermometer, psychrometer, and airflow measuring devices are valuable tools.

4. Temperature

1. Temperature is defined as the heat intensity or heat level of a substance. Temperature alone does not give you the amount of heat in a substance. It is an indication of the degree of warmth, or how hot the substance is.

2. The methods and scales used to measure temperatures have been arbitrarily chosen by scientists. The most common scale that you will use is the Fahrenheit scale, but we will also discuss the centigrade scale. as you may come in contact with it during an overseas tour. The Fahrenheit scale is so fixed that it divides the temperature difference from the melting temperature of ice to the boiling temperature of water into I80 equal divisions. It sets the melting point of ice at 32 divisions above the zero indication on the scale. Therefore, ice melts at 32° F., and water boils at 212° F. (32° F. + 180° F. = 212° F.) under an atmospheric pressure of 14.7 p.s.i.a.

3. The centigrade scale has coarser divisions than the Fahrenheit scale, and the melting point of ice is set at 0°. The boiling point is 100 divisions above this point, or 100° C.

4. It may be necessary to convert a Fahrenheit reading to a centigrade reading or vice versa. For this purpose, formulas have been developed. The formula to convert Fahrenheit to centigrade is:

$$C. = 5/9\ (F. -32)$$

Centigrade may be converted to Fahrenheit by using this formula:

$$F. = 9/5C. + 32$$

5. **Sensible Heat**. Sensible heat is the heat added to a substance that causes a temperature change. Likewise, heat may be removed from a substance; and if the temperature falls, the heat removed is sensible heat.

6. **Specific Heat**. The sensible heat required to cause a temperature change in substances varies with the kind and amount of the substance. This property is called the specific heat of a substance and is the amount of heat required to raise 1 pound of the substance 1° F. This value is good for computations, provided no change of state is involved. If a change of state should occur, the specific heat of the substance changes. To determine the amount of heat necessary to cause a temperature change in a substance, multiply the weight of the substance by its specific heat. Then multiply that answer by the temperature change (B.t.u. = specific heat X weight X temperature change).

7. **Latent Heat**. Latent heat is the heat that is added or taken from a substance, causing a change of state. These changes of state occur without any changes in temperature or pressure. Latent heat is commonly referred to as hidden heat. latent heat of fusion, latent heat of vaporization, and latent heat of condensation.

8. **Total Heat**. Any mixture of dry air and water vapor (atmospheric air) does contain both sensible and latent heat. The sum of these two heats is called total heat and is usually measured from 0° F.

9. Now that we've covered the various types of heat, we're ready to discuss temperature, or the intensity of heat.

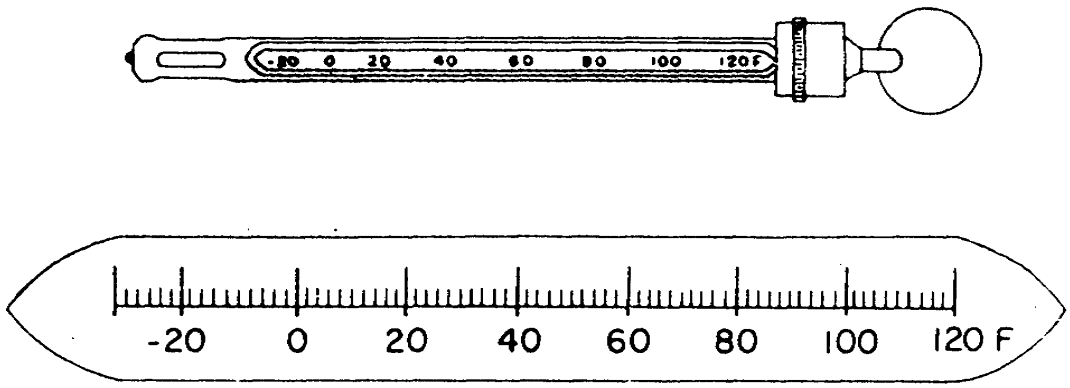


Figure 1. Thermometer.

10. **Dry-Bulb Temperature**. In air conditioning, the air temperature is listed more accurately as the dry-bulb temperature. This temperature is taken with the sensitive element of the thermometer in a' dry condition. Figure 1 shows a thermometer common to the air-conditioning trade. Unless otherwise specified, all air temperatures are dry-bulb temperatures.

11. **Wet-Bulb Temperature**. A wet-bulb thermometer is an ordinary thermometer with a cloth sleeve of wool or flannel placed around its bulb and then wet with water. The cloth sleeve should be clean and free from oil and thoroughly wet with clean, fresh water. The water in the cloth sleeve is evaporated by a current of air at high velocity. The evaporation withdraws heat from the thermometer bulb, thus lowering the temperature. This temperature is now measured in degrees Fahrenheit. The difference between the dry-bulb and wet-bulb temperatures is called the wet-bulb depression. If the air is saturated, evaporation cannot take place, and the wet-bulb temperature is the same as the dry bulb. Complete saturation, however, is not usual and a wet-bulb depression is normally to be expected.

12. The wet-bulb thermometer indicates the total heat of the air being measured. If air at several different times or different places is measured and the wet-bulb temperatures found to be the same for all. the total heat would be the same in all, though their sensible heats and respective latent heats might vary considerably. In any given samp le of air, if the wet-bulb temperature does not change, the total heat present is the same even though some of the sensible heat might be converted to latent heat or vice versa.

13. **Dewpoint Temperature**. The dewpoint depends upon the amount of water vapor in the air. If air at a certain temperature is not saturated that is, if it does not contain the full quantity of water vapor it can hold at that temperature-and the temperature of that air then falls, a point is finally reached at which the air is saturated for the new lower temperature, and condensation of the moisture then begins. This point is the dewpoint temperature of the air for the quantity of water vapor present.

14. **Relation of Dry-Bulb, Wet-Bulb, and Dewpoint Temperatures**. The definite relationships between the three temperatures should be clearly understood. These relationships are:

a. When the air contains some moisture but is not saturated, the dewpoint temperature is lower than the dry-bulb temperature and the wet-bulb temperature lies between them.

b. As the amount of moisture in the air increases, the difference between the temperatures grows less.

c. When the air is saturated, all three temperatures are the same.

5. Relative Humidity

1. The water vapor mixed with dry air in the atmosphere is known as humidity. The weight of water vapor, expressed in pounds or grains. occurring in each pound of dry air is called specific humidity. The amount of moisture that 1 cubic foot of air does hold at any given time is its absolute humidity.

2. When a gallon bucket contains 1/2 gallon of liquid, it is 50 percent full. If a cubic foot of air that could hold 4 grains of moisture holds only 2 grains, it is 50 percent full, or 1/2 saturated. The ratio of the amount of moisture which the air does contain to what it could contains is called its relative humidity. Expressed in general terms, relative humidity is defined as the actual absolute humidity divided by the absolute humidity of saturated air at the temperature being considered. The simple equation would be:

$$\%\ R.\ H. = \frac{\text{actual gains per pound X (100)}}{\text{max. grains per pound that could be held at the given temperature.}}$$

3. **Psychrometers**. Instruments for measuring wet- and dry-bulb temperatures are known as psychrometers. A sling psychrometer, shown in

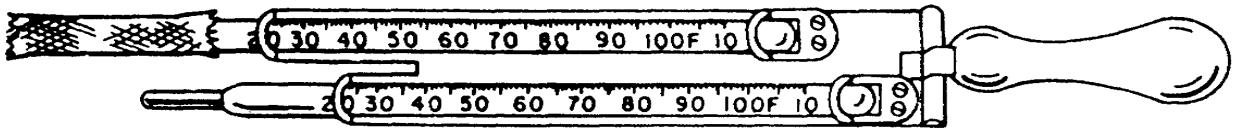


Figure 2. Sling psychrometer.

figure 2, consists of two thermometers mounted side by side on a holder with provisions so that the device can be whirled in the air. The dry-bulb thermometer is bare, and the wet-bulb is covered with a wick which should be kept wet with clean water. After whirling for a minute or two, the wet-bulb thermometer reaches its equilibrium point, and both the wet- and dry-bulb thermometers should then be quickly read. The difference between the two thermometer readings will depend on the relative humidity of the air. By a series of experiments, the effect of different relative humidities has been found through a wide range of temperatures. From these values, tables and charts have been constructed from which, when the wet-bulb and dry-bulb temperatures are known, both the relative humidity and the dewpoint temperature can be found.

4. In the aspiration psychrometer, a small fan is used to blow the air past the mounted wet- and dry-bulb thermometers to bring about the wet-bulb equilibrium.

5. There are several types of direct reading hygrometers. A hygrometer is a device that measures the relative humidity by use of a wet- and dry-bulb thermometer. In the hygrometer a pointer is actuated by some material sensitive to changes in the moisture content of the air. The pointer moves across a dial graduated in relative humidities. While these hygrometers have the advantage of reading relative humidity directly, they are not sufficiently accurate for most industrial purposes.

6. At some points in an air-conditioning system, recording psychrometers are used to provide a continuous record of both the temperature and relative humidity. Thus they eliminate the necessity for frequent sling psychrometer readings. Distilled water should be used for wetting the wet-bulb wick. If ordinary tap water is used, the dissolved solids could clog the capillaries in the cloth and the wick could become dry, resulting in an incorrect record. The air which is circulated over the bulb should be as free as possible from dust, dirt, and lint for the wick to retain its capillary action and give an accurate reading. At some locations where a low relative humidity is combined with dust-laden air and water, the wet-bulb wick may have to be changed twice daily to obtain proper accuracy. Wicks may be used over again after they are washed.

7. It is necessary to locate the sensitive wet and dry bulbs in ducts and chambers remote from the recording instrument. Remote panels are installed in ducts where natural circulation is adequate.

8. **Psychrometric Charts**. The psychrometric chart may be used in conjunction with psychrometers to determine the relative humidity of any particular space. These charts consist of straight lines and curves showing relationships between the relative humidity, dry-bulb temperature, wet-bulb temperature, dewpoint temperature, specific humidity, effective temperature, and air velocity (generally a fixed factor for each chart).

9. While relative humidity must be given consideration by all persons concerned with the conditioning of air, all major determinations for its specific control will be up to your supervisor. The amount of moisture in a space may have to be reduced, the dry-bulb temperature may have to be changed, or the source of moisture may have to be controlled. Wherever it is necessary, mechanical machinery and controls are installed to effect a continuous automatic control of this relative humidity.

10. The use of the psychrometric chart involves no more than knowing the wet-bulb thermometer reading and the dry-bulb thermometer reading. Various charts are constructed for different altitudes and situations where abnormally low surface pressures are encountered. Figure 3 illustrates the use of a psychrometric chart.

11. The procedures listed in the following paragraphs may be used to find the properties of air if two of the properties are known:

a. Dry-Bulb Temperature. The dry-bulb temperature is found by following the vertical lines down to the bottom scale of figure 3. detail A.

b. Wet-Bulb Temperature. The wet-bulb temperature is read directly at the intersection of the wet-bulb line with the 100 percent relative humidity line (saturation curve). as shown in figure 3. detail A. The scale is marked along the 100 percent line.

c. Relative Humidity. The relative humidity is read directly from the curved lines marked "relative humidity," as shown in figure 3, detail B. For points between the lines, estimate by distance.

d. Moisture Content. The moisture content or absolute humidity is read directly from the horizontal lines, as shown in figure 3, detail C. It is the weight of water vapor contained in a quantity

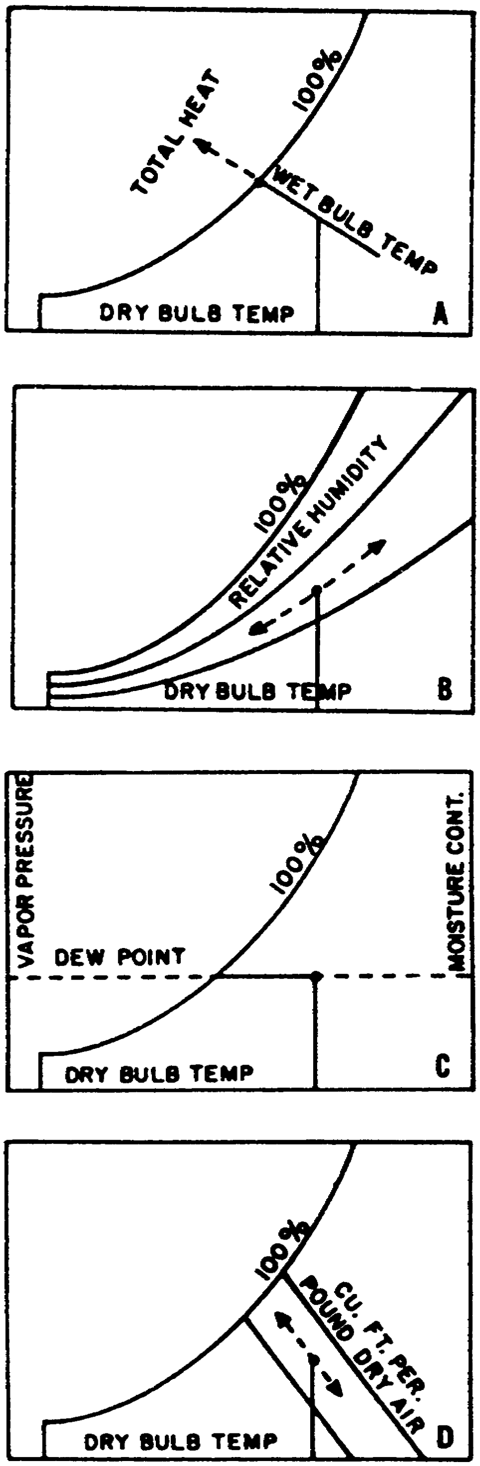


Figure 3. Segment o! psychrometric chart.

of air and water vapor mixture which will weigh 1 pound if all water vapor were extracted.

e. Dewpoint Temperature. The dewpoint temperature is read at the intersection of a horizontal line of a given moisture content with the 100 percent relative humidity line, as shown in figure 3, detail C.

f. Total Heat. The total heat is read directly by following the wet-bulb line to the scale marked "Total Heat," as shown in figure 3, detail A. Total heat refers to a quantity of air and water vapor mixture which would weigh 1 pound if all water vapor were extracted, including the heat of the water vapor.

g. Specific Volume. The specific volume is read directly from the lines marked "cubic foot per pound of dry air," as shown in figure 3, detail D. For points between the lines, estimate by distance. Specific volume is the volume occupied by a quantity of air and water vapor mixture which would weigh 1 pound if all water vapor were extracted.

h. Vapor Pressure. The vapor pressure corresponding to a given moisture content is read directly from the left-hand scale marked "pressure of water vapor," as shown in figure 3, detail C.

12. Assume that readings in an area taken with a sling psychrometer were 85° F. dry bulb and 70° F. wet bulb. Use foldout at end of this memorandum and follow along with this example. The dry-bulb temperature (85) is located at the bottom of the chart. Following the 85 line upward until it intersects the 70.5° F. wet-bulb line (slanting downward from left to right), the user marks this point. In this example, there is no wet-bulb line for 70.5° F., so it is necessary to mark the point of intersection. It will be found that under these conditions the relative humidity is 50 percent as shown by the curved line also running through this point Projecting the point horizontally to the left of the wet-bulb scale will give a dewpoint of 64.4° F. The steep diagonal line running through the point of intersection indicates that a pound of air under these condition will occupy 14 cubic feet. Projecting the point horizontally to the right shows that there are 90 grains of water per pound of dry air. The total heat, found by following the wet-bulb line upward to the left, is 34 B.t.u.'s per pound of air, which is the heat represented by the dry air plus the latent heat present at this degree of partial saturation (50 percent relative humidity). If the sensible temperature were 85° F. and the relative humidity were 70 percent the total heat would be 39.5 B.t.u.'s per pound of air.

6. Airflow

1. Most air-conditioning systems are designed to specifications, but you will find changes made and accepted that will be entered on as-built blue prints. The specific volumes of air in each individual section should be checked with the specifications or as-built drawings.

2. Air passages provide the means for air to

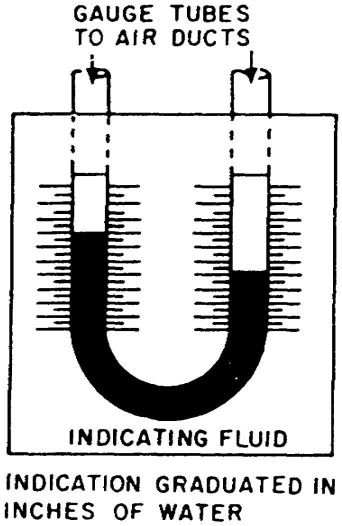


Figure 4. U-type manometer.

flow. With constantly changing requirements, a system designed for a specific need may have an entire new heat load or distribution requirement. Many of us have faced this situation, so you must understand how to make adaptations to correct the balance.

3. Air passages for air-conditioning systems in an installation contain the following: air intake, return, mixing, recirculating, exterior and exit division ducts, heating, cooling, humidification, dehumidification, air washing, filtering equipment, and inlet and discharge of the fan. The air passages from air-conditioning equipment to the spaces served are called duct systems. The distribution duct system includes the chamber, branches, risers, inlets, dampers, registers, returns, recirculating, mixing, baffling, and exit systems.

4. The factors that can affect air volume are the number of occupants, various heat transfers in building equipment. and temperature differences of interior and exterior spaces. All these factors are considered by engineers in their design of an air-conditioning system.

5. If the air weight or volume is determined and the load requirements are known, then duct and distribution systems are calculated according to velocities, pressures, and pressure drop in the duct system.

6. We will now discuss the devices used in measuring airflow and static and total pressures.

7. **Manometers**. Two types of gauges that can be used to measure air pressure are shown in figures 4 and 5.

8. The pressure required for the velocity of airflow necessary to overcome all the losses

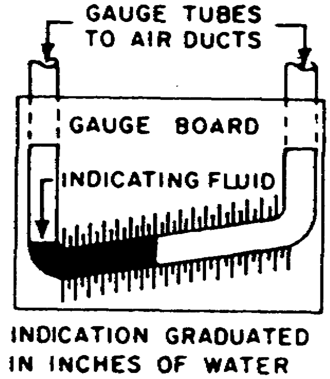


Figure 5. Slant type manometer.

throughout the duct system is called the dynamic or total pressure. The pressure required to overcome losses due to friction of duct systems is called static pressure. Figure 6 shows a slant gauge used to measure pressure differences.

9. The various pressures of air applied to an air-conditioning system are relatively small and cannot be measured in pounds for an accurate reading. Total, static, and velocity pressures for airflow in air-conditioning systems are usually measured in inches of water. The pressure of air is measured by the application of a gauge calibrated in inches of water on the scale for accurate reading, as shown in figure 4.

10. The gauge in figure 4 contains a free-flowing liquid. The connections are extended by flexible tubing to the air passages and the atmosphere. The difference in pressure of the air will cause the liquid in the tube to rise or fall, indicating the pressure on the scale in inches of water according to the connections of the gauge.

11. **Pitot Tube**. Total and static pressure for airflow through a duct system can be measured by a pitot tube. Use of a pitot tube is illustrated in figure 7. The static pressure can be found by subtracting the velocity pressure from the total pressure. The static pressure subtracted from total pressure will equal velocity pressure for air in a duct system. The total (dynamic) pressure is equal to the static and velocity pressures.

12. The use of the pitot tube for pressure indication should be done with care. The tube should be located so that an average condition of airflow

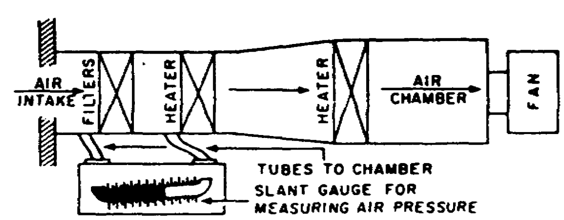


Figure 6. Measuring resistance of air filters.

will be measured in the interior of the duct. The tube should not be placed in a sharp turn in the duct, in a restricted area, in an offset, or in a section having varying airflow. Also avoid contact with material or substances that would obstruct air pressure to the pitot tube opening.

13. The pitot tube consists of two tubes, one sealed within the other. The opening of the pitot tube which faces toward the airflow measures the total pressure. The other opening of the pitot tube has airflow sweep across the opening so as to measure the static pressure. The velocity is determined by the differential reading on the gauge which is connected to the double pitot tube.

14. A certain pressure for airflow in ducts is required to cause motion and to overcome resistance and friction in the ducts.

15. Static pressure will vary according to the surface area with which the air is in contact. Some factors are: condition of air passages, construction and installation, dampers, interior design, length of duct system, leakage, eddy currents, and pulsation of airflow throughout the installation.

16. **Anemometer**. The anemometer, shown in figure 8, is used to measure air velocities at the opening of the air duct. The anemometer is moved across the entire area of the duct opening for a period of 1, 2, or 3 minutes and the average velocity in feet of air is calculated or measured.

17. The anemometer should be used with precaution and care. It requires frequent calibration or adjustment to maintain it for accurate measurement of air velocities at duct openings.

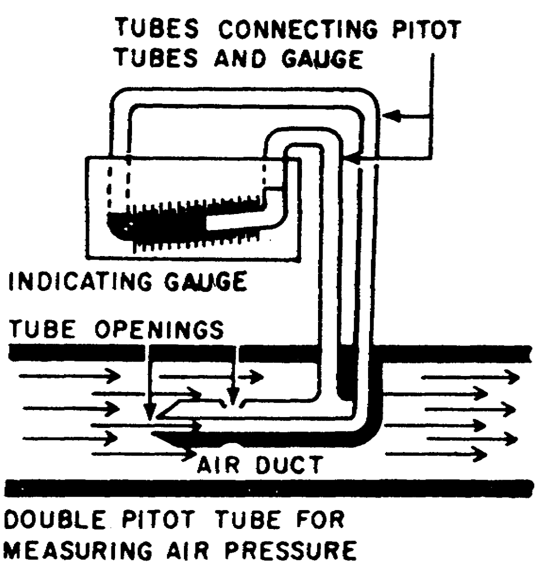


Figure 7. Measuring airflow with a pilot tube.

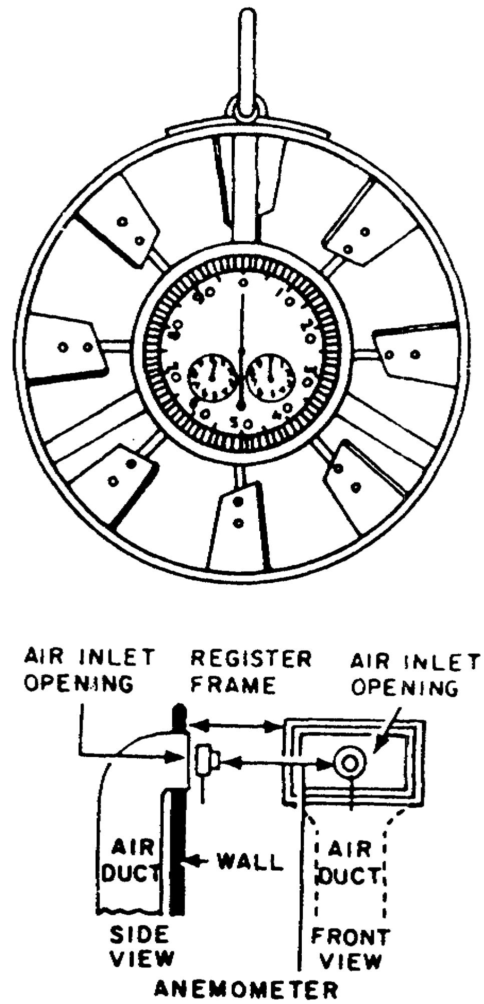


Figure 8. Use of the anemometer.

18. **Kata Thermometer**. A kata thermometer is an alcohol thermometer developed for determining very low air velocities. The bulb of the thermometer is heated in water until the alcohol rises to a reservoir above the graduated tube. The time for the liquid to cool 5° F. is observed by the use of a stopwatch, and this time is a measure of the air movement.

19. **Velometer**. The velometer is an instrument that is calibrated to read directly in feet per minute. The velocity pressure readings are converted by use of a formula without the necessity for timing. The velometer may be placed directly in the airstream or may be connected through a flexible tube to special jets which permit taking velocity readings in locations where it would be very difficult to use an anemometer or pitot tube. The velometer accuracy is within 3 percent and is much quicker to use than other instruments designed for this purpose.

Review Exercises

NOTE: The following exercises are study aids. Write your answers in pencil in the space provided after each exercise. Use the blank pages to record other notes on the chapter content. Immediately check your answers with the key at the end of the text. Do not submit your answers for grading.

1. What degree on a centigrade thermometer is equivalent to 60° on a Fahrenheit thermometer? (Sec. 4, Par. 4)

2. What degree on a Fahrenheit thermometer is equivalent to 40° on a centigrade thermometer? (Sec. 4, Par. 4)

3. How many B.t.u.'s would be required to raise the temperature of 8 pounds of cast iron 4°? (Specific heat of cast iron is 0.119)(Sec. 4, Par. 6)

4. What term is applied to the sum of sensible heat and latent heat? (Sec. 4, Par. 8)

5. If the air is dry, which thermometer will indicate the highest temperature, a dry-bulb or a wet-bulb thermometer? (Sec. 4, Pars. 10 and 11)

6. After whirling a sling psychrometer, how will the wet-bulb thermometer reading compare to the dry-bulb thermometer if the wet-bulb wick was dry while whirling? (Sec. 4, Par. 11; Sec. 5, Par. 3)

7. Will the difference in the dry-bulb thermometer reading and the wet-bulb thermometer reading become greater or less as the relative humidity decreases? (Sec. 4, Par. 11; Sec. 5, Par. 3)

8. What two factors must be known in order to determine the relative humidity? (Sec. 5, Pa. 3)

9. What type of water should be used to wet the wick of a wet-bulb thermometer? (Sec. 5, Par. 6)

10. If the total pressure of an air-conditioning system remains constant and the air ducts become partially clogged, will the static pressure increase or decrease? (Sec. 6, Pars. 8-11)

11. If the total airflow pressure is equal to 20 inches of water and the static pressure is equal to 4 inches of water, what is the velocity pressure? (Sec. 6, Par. 11)

12. Is it possible to determine static pressure with a velometer? (Sec. 6, Pars. 11 and 19)

Design and Installation Factors

COST REDUCTION has become an important part of military policy. How can you contribute to this program ? You may be called upon to install an air conditioner or to calculate the heat load of a building. In either case, your skill can determine the savings. If your unit is undersized, it will have to be supplemented with another unit. If it is oversized, the running cost will be high. You may install the correct size unit but use poor duct insulation. Once again you are defeating the purpose of cost reduction.

2. In this chapter you will study heat loads, the selection of a good location for the condensing unit, insulation, and calculating a heat load.

7. Heat Sources

1. Heat that must be removed from a building arises from various sources. Some of this heat is gained through walls, doors, partitions, windows, ceilings, and roofs, and is caused by the difference in the temperature between the conditioned and unconditioned areas. Remember, heat always travels from the warmer to the cooler mass. Engineering formulas are used to calculate heat transmission. Glass and door areas are not used in calculation of wall area but are considered in heat transmission calculations in a separate formula.

2. In calculating wall area, use the length (ft.) of exposed wall measured on the inside and the height of ceiling.

3. Consideration must be given to construction materials of the walls and ceilings. For example, brick construction has a different heat transfer characteristic than wood.

4. Special tables are used in determining heat transmission through various building materials. Listed below are some heat sources that must be considered in cooling load computations.

5. **Solar Effects**. Heat that is transmitted by radiation through glass is absorbed by inside furnishings and surfaces. When the sun's rays strike glass, the glass will absorb a small percentage of the sun's energy, but most of the energy passes through the glass and causes an increase in heat.

6. The solar heat which passes through glass is absorbed by interior furnishings, walls, and floors. This heat is quickly given up to the air. Some of the solar heat absorbed by thick walls and doors will not dissipate its heat readily, but will continue radiating heat even after the sun has set. Because of this, the heat load is more continuous.

7. The intensity of the sun radiation on walls and glass varies with the time of day, the season, and the direction the walls and windows face. All the above factors must be considered when you are computing solar heat transmission.

8. Heat delivery by sun radiation through glass may be reduced by use of awnings, Venetian blinds, or shades. Any type of shade will help reduce the load on air-conditioning equipment.

9. Special formulas and tables have been devised to determine solar heat transmission through glass and walls.

10. **Infiltration and Ventilation**. Heat and moisture are transmitted into a building by infiltration and ventilation. Air enters by leakage through window and door cracks, through doors or windows opened, and through porous walls. Special tables have been devised to determine the infiltration of air through window openings and for finding the volume of air entering from door traffic. All the above factors must be considered in cooling load computations.

11. **Occupants**. Heat load from occupants will cause an increase in sensible and latent heat. The amount of heat transmitted will vary with the degree of activity of the occupants.

12. **Equipment**. Heat load transmitted by equipment used in a building will vary with the type and operation. Electrical and mechanical equipment will have a major effect on total heat load. Tables have been developed that give values of common heat sources. All of the tables referenced in the preceding paragraphs may be found in the *American Society of Heating, Refrigerating, and Air Conditioning Engineers' Guide.*

13. Listed above are a few of the major heat transmission sources that must be considered when installing an air-conditioning unit. The total heat

load must be established before an air-conditioning unit can be installed in a building. All heat transmission sources must be used in figuring out the total heat load. When the heat load has been determined, an air-conditioning unit of correct tonnage can be installed and the proper cooling can be maintained in the building.

8. Selecting Location

1. The following are major considerations in selecting the location for air-conditioning equipment.

2. **Availability of Space**. Equipment should be located in the place most suitable for it. It may be necessary to compromise the ideal location with the actual one and to locate equipment in the space which is available.

3. **Ambient Temperatures**. Ambient temperature refers to the air temperatures surrounding the refrigeration equipment, such as the condensing unit and other parts of the system. Avoid extreme ambient temperatures, either too warm or too cold.

4. Excessively warm locations result in high heat leakage and service loads. High ambient temperature can give high condensing pressures with consequent loss of capacity. An ambient temperature of 10° F. above normal may increase the heat load and decrease equipment capacity to the extent where the operating time increases 25 percent above normal.

5. Consideration must be also be given to low temperature to which the equipment may be exposed. Do not install water-cooled equipment in locations colder than 40° F. to avoid frozen water-lines in condensers.

6. **Ventilation**. Proper ventilation is very important for carrying heat away from the condensing equipment. It is most important to air-cooled equipment which uses air to carry heat away from the condenser. It is also important to water-cooled equipment, even though water removes heat from the condenser. The heat from the compressor and motor must be carried away by the surrounding air, and this cannot be accomplished without adequate ventilation. Keep all ventilation facilities such as doors and windows free of barriers and other obstacles so that the air can be properly circulated.

7. **Radiant Heat**. Part of the heat given off by a hot object such as a hot stove, boiler, furnace, or even a hot brick is radiant heat. Avoid installing refrigeration equipment near such objects. It is not Sways possible, but the extra load of radiant heat should be avoided whenever possible.

8. **Electric Supply**. Be sure that the proper power is furnished before selecting a location. Check the electric supply to be sure there is correct voltage, frequency (cycles per second), phase, and capacity of the wiring. If the equipment has a motor requiring 220-volt, 60-cycle, 3-phase alternating current, it will not run on 110-volt, 60-cycle, single-phase alternating current. Consult a qualified electrician on suitability of electric supply for motors installed on equipment. Motors should never be connected to a source of electric current until you are sure that available current is the same as that specified on the nameplate.

9. **Water Supply**. Before selecting a location for water-cooled refrigeration equipment, check the water supply for available capacity and maximum temperature. The capacity of a water-cooled condensing unit depends upon whether or not it is supplied with enough cool condensing water. Rated capacities of condensing units are usually based on 75° F. condensing water being available. Higher temperature water requires more water supplied. If enough water is not available, the capacity of the condensing unit may be reduced 5 percent for each 5° F. higher than the correct temperature of condensing water.

10. **Drain**. Check location of suitable drain and its capacity before installing equipment. Drain lines are connected to sewers through an open sight connection. If possible, trap and vent the sewer branch to guard against entry of sewer gas into the rooms.

11. **Accessibility**. When selecting the location of equipment, consideration must be given to its accessibility for cleaning and servicing. It is not always possible to find all the room you actually need. Whenever possible, leave enough room for a workman to get at all sides of the unit, and enough room to permit removal or replacement of any major assemblies, such as motor, compressor, and condenser.

12. Accessibility to those parts of equipment subject to preventive maintenance and inspections, or requiring readjustment, repair, or replacement must be given special preference. See that oil wells of motors, belts, air-cooled condensers, service valves, and especially suction service valves on compressor, gauge, and gauge ports, controls, and nameplate data are readily accessible.

9. Insulation

1. Insulation represents the composite covering which consists of the insulating material, lagging, and fastening. The insulating material offers resistance to the flow of heat; the lagging, usually of painted canvas, is the protective and confining covering placed over the insulating materials; the fastening attaches the insulating material to the piping and to the lagging.

2. **Insulation Temperatures**. Insulation covers a wide range of temperatures, from the extremely low temperatures of the refrigerating plants to the very high temperatures of boilers. No one material could possibly be used to meet all the conditions with the same efficiency. Cork, rock wool, or hair felt is used for low temperatures. Such basic minerals as asbestos, carbonate of magnesia, diatomaceous earth, aluminum foil, argillaceous (clay-like) limestone, mica, fibrous glass, and diatomaceous silica are employed for high temperatures. Because of its high degree of refractoriness, diatomaceous silica forms the base of practically every high temperature insulating material.

3. **Insulating Material Requirements**. The following quality requirements for the various insulating materials are taken into consideration in the standardization of these materials:

a. Ability to withstand highest or lowest temperature to which it may be subjected without its insulating value being impaired.

b. Sufficient structural strength to withstand handling during its application, and mechanical shocks and vibrations during service without disintegration, settling, or deformation.

c. Stability in chemical and insulation characteristics.

d. Ease of application and repair.

e. No hazard in case of fire.

f. Low heat capacity, when used for boiler wall insulation, so that starting-up time may be minimized.

4. **Insulating Materials**. Listed below are a few of the more popular insulations that you may encounter in air-conditioning work.

5. *Cork*: Cork in block sections or compressed board form, coated with a special retardant cover, is used (where authorized) for temperatures below 50° F. It use is generally limited to refrigeration spaces where it will not be a serious fire hazard. Molded cork pipe covering, treated with a fire-retardant compound, is used on refrigerant piping.

6. *Mineral or rock wool*. Mineral or rock wool is a fiber made by sending a blast of steam through molten slag or rock. The rock fibers are usually from dolomite rock, composed of calcium and magnesium oxides and silicates. The fibers are brittle, of low tensile strength, light in weight, and resistant to moisture. The fibers are used in wire-reinforced pads for insulating large areas.

7. *Hair felt*. Hair felt, 1 inch or more in thickness, may be used in any service where the temperatures do not rise above 119° F. When combined with heavy asphalt-impregnated paper, this material is used on cold-water lines where the temperature range is from 50° to 90° F. When suitably waterproofed, it may be used for refrigerator piping.

8. *Asbestos*. Molded sheets, pads, blankets, or tapes of long asbestos fibers are suitable for insulating temperatures up to 850° F. This insulation material is cheaper and lighter than the diatomaceous earth type and is durable and rugged. The pads or blankets are used for insulating flanges or valves which must be taken down fairly often, as well as for turbine casings. The pads are molded to fit any shape, and the outer surface is fitted with metal hooks to facilitate their installation and removal. The blankets are generally made 1 inch thick, 40 inches wide, and fitted with hooks. The tapes are used for covering ½a-inch and smaller piping with curves and bends. They can be used for temperatures up to 750° F.; they tend to reduce fire hazards, but they have poor insulating quality.

9. *Magnesia and asbestos*. The magnesia and asbestos mixture, of which about 85 percent is magnesia, is the most common material used for hot piping. It is obtained commercially in pulverized form, in sheets, in shaped blocks, and in cylindrical sections for standard pipe sizes. Its principal features are low heat conductivity, ease of application, light weight, low cost, and chemical inactivity. The chief disadvantage is the limited temperature range, as the mixture calcines and decomposes at about 500° F.

10. *Diatomaceous earth*. The diatomaceous earth (sand formed from skeletons of certain microscopic plants) materials are combinations of the earth and magnesium or calcium carbonates, bonded together with small amounts of asbestos fibers. These materials are heavier, more expensive, and less insulating than others, but their high heat resistance allows their use for temperatures up to 1500° F. When practical, pipe coverings are made up with this material as an inner layer and with an outer layer of the magnesia-asbestos material. This lightens the overall weight.

11. *Aluminum foil*. Aluminum foil is the most effective insulating material for high temperatures. The foils are produced commercially from pure aluminum and are supplied in long, thin sheets, some 12 inches to 16 inches in width. The covering is light, particularly for large piping for which it is best suited. There is very little uncleanliness connected with the installing or removing of aluminum foil; it is easy and economical to manufacture and, because of its light weight and low inertia, it stands up well under vibration or shock.

12. There is more than one method of applying aluminum foil. The following is the most common of these methods. One or more layers of foil are wrapped about the material to be insulated, leaving a 3/8-inch airspace between each layer, and with a sheet metal cover to protect the foil. The airspace between the layers of foil is kept by

first hand-crinkling the foil so that its surface becomes uneven. This type of insulation serves to reduce to a minimum any convection current present in the air pockets.

13. The chief objections to the use of aluminum foil for insulation are the weight of the sheet metal cover necessary to cover the assembly and the high skill necessary for its application or repair.

14. *Fibrous glass slabs*. Fibrous glass slabs are used widely for insulating living quarters. The glass fibers in the pressed slabs are 4 inches or more in length and 0.0005 to 0.0008 inch in thickness. The slabs have a low moisture-absorbing quality and offer no attraction to insects, vermin, fungus growth, or fire. The slabs are first cut to shape, then secured in place by mechanical fasteners (as quilting pins), and finally covered with glass cloth facing and stripping tape (held in place by fire-resistant adhesive cement).

15. *The insulating cements*. Insulating cements are composed of many varied materials. These materials differ among themselves as to heat conductivity, weight, and physical characteristics. Typical of these variations are the asbestos cements, diatomaceous cements, and mineral and slag wool cement. These cements are less efficient than other high-temperature insulating materials. They are valuable for patchwork emergency repairs and for covering small irregular surfaces (valves, flanges, joints, etc.). The cements are also used for a surface finish over block or sheet forms of insulation, to seal joints between the blocks, and to provide a smooth finish over which asbestos or glass cloth lagging may be applied.

16. **Insulation Application**. In applying insulating material, care should be taken that air does not circulate through the insulation, that moisture is kept from reaching the insulation, and that the insulation will not move or slip.

17. All sections or segments of the pipe coverings should be tightly butted at joints and secured with wire loops, metal banks, or lacing. Block insulation should be secured with 1/8-inch steel wire and galvanized mesh wire or expanded metal lattice. Insulating cement is used to fill all crevices, to smooth all surfaces, and to coat wire netting before final lagging is applied.

18. Moistureproofing is important for insulation over heated surfaces. Even though the temperature of the insulation dries off moisture, the heat loss is increased due to the evaporation. Moisture also impairs many insulating materials. This moistureproofing is also very important for low temperatures. At very low temperatures, the insulation should be air-sealed. Moisture drawn into low-temperature insulation condenses and freezes, thus lessening the efficiency and eventually causing disintegration.

19. The same insulating material employed on the piping may be used on pipe fittings, flanges, and valves. These components require additional consideration during installation.

20. When a permanent type of insulation is applied to a piping 4 inches and larger in size, a block insulation 1 inch thinner than that on the adjacent piping may be used for the bodies of flanged fittings and valves, for the entire surface of a threaded fitting, for the entire surface up to the bonnet of screwed valves, and for the flanges. The total thickness of insulation on the valve or fitting is made equal to that on the adjacent piping by applying insulating cement. The pipe insulation should be stopped short of the flanges and leveled off to enable the flange bolts to be removed. On piping under 4 inches in size, the insulation of the fittings may consist entirely of insulating cement, the same thickness as that of the adjacent piping.

21. When a removable type of insulation is applied, the flanges should be insulated with asbestos felt pads, sectional pipe insulation of the same thickness as that on adjacent piping, or block insulation 1/2 inch thinner than that on the adjacent piping and covered with 1/2 inch of insulating cement.

22. **Installation Precautions**. The following general precautions should be observed with regard to the application and maintenance of insulation:

a. Fill and seal all air pockets and cracks. Failure to do this will cause large losses by conduction and convection currents.

b. Seal the ends of the insulation and taper off to a smooth, airtight joint. Sheet metal lagging should be used at joint ends and at other points where insulation is liable to damage. Flanges and joints should be cuffed with 6-inch lagging.

c. Cotton duck covering, fitted over insulation, should be smooth and well sewn (not less than three stitches per inch). It should be covered with two coats of lead and oil paint. Too much paint will cause the cotton duck to crack and split.

d. Keep moisture out of all insulation work. Moisture is an enemy of heat insulation as much as it is of electrical insulation. Any dampness increases the conductivity of all heat-insulating materials.

e. Insulate all hangers and other supports at their point of contact with the pipe or other units they are supporting. Failure to insulate these supports will cause a considerable quantity of heat to be lost by conduction through the support.

f. Sheet metal covering should be kept bright and not painted unless the protecting surface has been damaged or worn off. The radiation from bright-bodied and light-colored objects is considerably less than from rough and dark-colored objects.

g. Once installed, heat insulation requires careful inspection, upkeep, and repair. Any lagging and insulation that is removed to make repairs should be replaced just as carefully as when originally installed. Old magnesia blocks and sections broken in removal can be mixed with water and reused in the plastic form. Save all old magnesia for this use.

h. Insulate all flanges with removable forms. The forms can be made up as pads of insulating material wired or bound in place, and the flange can be covered with sheet metal casings which are in halves and easily removable.

10. Making Survey for Air-Conditioning Installation

1. We will now-relate the facts we have discussed to a specific air-conditioning installation. This installation is at Denver, Colorado. You may be called upon to determine the size of a unit needed at your installation. The primary difference between this example and your base would be the mean wet- and dry-bulb temperatures.

2. **Cooling Load Requirement.** In this chapter we have discussed heat sources in an area that is to be conditioned. These heat sources are as follows:

a. Solar heat load on walls, roofs, and glass.

b. Human heat load.

c. Infiltration and ventilation.

d. Machinery,

3. Upon adding the values of the heat sources listed, you would have a load that is called total internal cooling load.

4. Special consideration must be given to location of a room or building when cooling load calculations are being made. The interior load may change from one portion of the buildings to another. Varied heat loads from equipment, solar radiation, and occupants will alter the calculations. When calculating heat load, always consider the peak load that could be reached in the building.

5. With a building that may have a changeable heat load. an experienced air-conditioning man cannot state definitely the time of day that the building cooling load would be at a maximum. Therefore, it is necessary to calculate cooling load for this establishment at several different periods during the day. These times should be chosen when the values of the various heat sources are at their maximum.

6. **Calculation of Cooling Load**. Problems in calculating cooling load can be done with mathematical exactness or by rough approximate estimates. The method that is used to calculate a cooling load depends upon the purpose for which the results will be used. Rough estimates are very inaccurate, and your plant may not meet cooling load requirements.

7. The mathematical exactness method is quite complicated and requires very accurate information regarding construction materials. It may require the drilling of holes through walls, roof, and floors to determine construction materials. Some principles used in determining the size of refrigeration plant required for a typical installation are mentioned below.

8. **Rate of Heat Flow Through Walls**. The rate at which heat is transmitted through walls, floors, and roofs is dependent on the following factors:

a. Unit heat transfer coefficient (U-factor). The U-factor depends on wall material and thickness.

b. Area of the heat-transmitting surface.

a. The temperature difference between the sides of the wall.

9. The heat transfer coefficient is the combined rate of transmission of any substance expressed in B.t.u. per hour per square foot of area per degree Fahrenheit mean temperature difference. It combines the amount of heat transmitted by radiation, conduction, and convection into a single quantity referred to as the U-factor.

10. The basic heat transfer formula is expressed as $Q = UA\ (T_1 - T_0)$. This formula is used in most calculations.

Q = solar radiation in B.t.u. per hour.

U = coefficient of heat transfer in B.t.u. per square foot taken fromtables.

A = area of transmitting surface in square feet.

T_1 = inside building temperature.

T_0 = outside building temperature.

11. Another formula that is used in calculations for radiation through glass is expressed as Qg = Ag Ig Fg

Ag = area of glass in square feet.

Ig = coefficient of heat transfer for glass taken from table.

Fg = glass radiation factor.

The following is a list of heat loads:

a. Load from solar radiation.

b. Sky radiation.

c. Outdoor-indoor temperature differential for glass areas, exterior walls, partitions, ceilings, and floors.

d. Load due to ventilation.

e. Load due to heat sources within the conditioned spaces such as occupants, lights, fans, power, and other heat-generating equipment

12. This data is available in ASHRAE Guides and manufacturers' manuals.

13. Specifications of Building To Be Air Conditioned.

Location:	Denver, Colo. Southern exposure.
South wail:	Front 20 ft. inside, 12 ft. high; plate glass 10 ft. x 6 ft. high; door 3 ft. x 7 ft. (glass).
North wall:	20 ft. inside, 12 ft. high; plate glass, 2 windows 5 ft. x 3 ft. high; wooden door 3 ft. x 7 ft.
East wall:	20 ft. inside, 12 ft. high; plate glass, 2 windows 5 ft. x 3 ft. high.
West wall:	20 ft. inside, 12 ft. high; plate glass. 2 windows 5 ft. x 3 ft. high.
Floor:	Wooden lath and covered with 1/4-inch linoleum laid on wooden floor.
Ceiling:	4-inch wooden rafters, metal lath plaster below with 1-inch wooden roof deck, covered with roofing paper.
Occupancy:	5 employees (manual labor).
Equipment:	Electric lights 2000 watts, two 1/2-hp. motors, stove burner heating water, coffee urn (12 inch).

Outside design condition: Denver, Colo., 95° F. dry bulb and 78° F. wet bulb.
Inside design condition selected as 81° F. dry bulb and 68° F. wet bulb.
All walls are constructed of 12-inch brick plastered inside.
Heat gain calculation at peak load approximately 1:00 p.m.

South wall 20 ft. X 12 ft. = 240 sq. ft. gross.
Area glass l0 ft. X 6 ft. = 60 sq. ft.
Area door 3 ft. X 7 ft. = 21 sq. ft.
Transmission coefficient for glass 1.13.
Transmission coefficient for brick .34.
Heat transmission through wall = 757 B.t.u./hr.
Heat transmission through glass = 1280 B.t.u./hr.
Heat transmission by solar radiation = 3300 B.t.u./hr.
South wall heat gained = 5337 B.t.u./hr.
North wall 20 ft. X 12 ft. = 240 sq. ft. gross.
Area glass 5 ft. X 3 ft. (2) 30 sq. ft.
Area door 3 ft. X 7 ft. = 21 sq. ft.
Heat transmission through wall = 900 B.t.u./hr.
Heat transmission through glass = 475 B.t.u./hr.
Heat transmission through door = 332 B.t.u./hr.
North wall heat gained = 1707 B.t.u./hr.
Fast wall 20 ft. X 12 ft. = 240 sq. ft. gross.
Area glass 5 ft. X 3 ft. (2) 30 sq. ft.
Heat transmission through wall = 1000 B.t.u./hr.
Heat transmission through glass = 475 B.t.u./hr.
Fast wall heat gained = 1475 B.t.u./hr.
West wall 20 ft. X 12 ft. = 240 sq. ft. gross.
Area glass 5 ft. X 3 ft. (2) 30 sq. ft.
Heat transmission through wall = 1000 B.t.u./hr.
Heat transmission through glass = 475 B.t.u./hr.
West wall heat gained = 1475 B.t.u./hr.
Floor 20 ft. x 20 ft. = 400 sq. ft.
Transmission coefficient is .24.
Heat transmission through floor = 1344 B.t.u./hr.
Ceiling and roof 20 ft. x 20 ft = 400 sq. ft.
Transmission coefficient is .32
Heat transmission through roof = 1790 B.t.u./hr.
Solar radiation through roof = 3460 B.t.u./hr.
Total heat gain through roof = 5250 B.t.u./hr.
Total heat gain through walls and roof is equal to 5337 +F 1707 + 1475 4- 1475 + 1344 + 5250 = 16,588 B.t.u./hr.
Heat gain from occupants.
Sensible heat loss = 200 B.t.u./hr.
Latent heat loss = 460 B.t.u./hr.
Total heat gain sensible (5 men) = 1000 B.t.u./hr.
Total heat gain latent (5 men) = 2300 B.t.u./hr.
Total heat gain from equipment.
Heat gained from coffee urn.
Latent heat = 1200 B.t.u./hr.
Sensible heat = 1200 B.t.u./hr.
Electric motor = 640 B.t.u./hr. (sensible)
Electric light = 7816 B.t.u./hr. (sensible)
Stove burner = 3150 B.t.u./hr. (sensible)
= 3850 B.t.u./hr. (latent)
Total sensible heat gain from equipment = 18.566 B.t.u./hr.
Total latent heat gain from equipment = 5.050 B.t.u./hr.
Approximate total cooling load in B.t.u./hr.

	Sensible	Latent
1. Through walls and solar radiation	16.588	
2. Human load	1.000	2,300
3. Equipment	18,566	5.050
	36,154	7,350

14. An additional factor of 10 percent is often added as a safety factor to the sensible load to take care of additional energy that may be added to the internal system. Therefore, total cooling load requirements become:

Sensible load = 36.154 X 1.10 = 39,769 B.t.u./hr.
Latent load = 7,350 B.t.u./hr.
Total cooling load = 47.119 B.t.u./hr.

Refrigeration $= \frac{47,119}{12,000} = 3.9$ tons of refrigeration equivalent to cooling load. This calculation is approximate because there are other factors that must be considered in cooling load calculations. Ventilation, infiltration, and duct losses are part of your cooling load requirements and will change in value with each installation.

15. Cooling load formulas and tables can be found in *American Society of Heating, Refrigerating and Air-Conditioning Engineers' Guide, Fundamentals and Equipment, 1963.*

Review Exercise

NOTE: The following exercises are study aids. Write your answers in pencil in the space provided after each exercise. Use the blank pages to record other notes on the chapter content. Immediately check your answers with the key at the end of the text. Do not submit your answers for grading.

1. Calculate the following wall areas. The outer dimensions are 10' x 14' and the walls are 8" thick. (Sec. 7, Par. 2)

2. A complaint is received from one of the base housing units. The user tells you that the air conditioner will not cool down the house sufficiently.. After questioning her, you find that she has all the drapes on the windows open and also that she didn't start the unit until noon. What directions should you give the user? (Sec. 7, Pars. 5-8)

3. Which type of heat load will affect humidity the most? (Sec. 7, Par. 11)

4. The normal ambient temperature for a condensing unit was 80° F. when it was installed. Additional units have been installed in the area and the ambient temperature is now 105°. This increase in temperature is affecting the operating time of the units. How could you correct this situation? (Sec. 8, Pars. 4 and 6)

5. How much efficiency would a condenser lose if the water supplied to it was 85° F. instead of 75° F.? (Sec. 8, Par. 9)

6. Which type of insulation should you use on a 40° F. cold storage room? (Sec. 9, Par. 5)

7. The strainer on a low-pressure steam coil installation must be removed periodically for cleaning. How would you insulate the strainer? (Sec. 9, Par. 8)

8. A new barracks is being built and you are called upon to insulate it. What type of insulation would you use and why would you select that particular type? (Sec. 9, Par. 14)

9. The temperature of the hot water at the heating coil is 130° F. The design coil temperature is 180° F. and the supply temperature from the boiler is 185° F. Why is the temperature dropping from 185° to 130° F.? (Sec. 9, Par. 18)

10. You are insulating a 2-inch pipe with 3/4-inch insulation. How much insulation and what type of insulation should you put on a globe valve? (Sec. 9, Par. 20)

11. Find the solar radiation through a brick wall 20' x 40' which has a 30° F. temperature differential. (Sec. 10, Pars. 10 and 13)

12. Find the heat gain of a brick wall 10' x 12' which has two 2' x 4' glass windows. The outside temperature is 94° F. and the inside design temperature is 72° F. (Sec. 10, Par. 13)

13. Which type of heat load will give off the most latent heat gain? (Sec. 10, Par. 13)

14. Find the total cooling load when the sensible load is 42,156 B.t.u.'s and the latent heat load is 8,750 B.t.u.'s. (Sec. 10, Par. 14)

15. What size unit would you install if the sensible load is 57,150 B.t.u.'s and the latent load is 9,170 B.t.u.'s? (Sec. 10, Par. 14)

Self-Contained Package Air-Conditioning Units

MOST SERVICEMEN call these air conditioners window- and floor-mounted units. You will find that they are identified in this manner throughout the chapter. The self-contained units differ from the remote units discussed in another volume (Equipment Cooling) of this course in that one housing contains all the components.

2. These units are usually found in offices or in a portion of a building that is separate. One example is a panel room in a heat and power building. It would be impractical to air-condition the entire building because of the heat load from the diesel engines, furnaces, refrigeration equipment, etc. The panel room houses gauges, recorders, and various instruments that the duty engineer observes to oversee plant operation.

3. You will study the window- and floor-mounted units. Included under these topics are installation, operation, maintenance, and various components peculiar to these systems.

11. Window-Mounted Units

1. The window-mounted air conditioner is a factory-made incased assembly, designed as a unit for mounting in a window or through a wall. It is designed fir free delivery of conditioned air to an enclosed space without ducts.

2. This air conditioner has a prime source of refrigeration and dehumidification, and a means of circulating and cleaning the air. It may also include means for ventilating and heating. The basic function is to provide comfort by filtering, cooling, dehumidifying, and circulating the room air; and to provide ventilation by introducing filtered outdoor air into the room or exhausting room air to the outside. If heating is provided, steam coils, hot water coils, or electric resistance heaters may he used, or the conditioner may be designed as a heat pump unit. We will discuss the heat pump later in this volume.

3. **Sizes and Classifications**. The cooling capacities of window-mounted air conditioners range approximately from 4000 to 36,000 B.t.u./hr. or 1/3 to 3 tons. Remember, whenever you want to convert B.t.u.'s to tons, 12,000 B.t.u.'s equals 1 ton. The sizes had commonly been designated in terms of horsepower, but this proved to be inaccurate because various refrigerants differ in cooling efficiency. Capacities (sizes) are now measured in B.t.u./hr.

4. Most of these air conditioners are designed as household appliances and are equipped with line cords that may be plugged into a standard I15-230 plug receptacle with a ground. Conditioners requiring 115 volts are usually limited to a current load of 12 amperes, which is the maximum allowable load of a single -outlet 15-ampere circuit. This is in compliance with the National Electric Code (N.E.C.). 1959. A very popular I 115-volt model is one which is rated at 7.5 amperes. This rating allows the unit to he plugged into any standard 115-volt 15-ampere circuit. large units, generally over 10.000 B.t.u./hr. are designed as 230-volt units, which can be plugged into a 230-volt circuit within the limitations set forth by the National Electric Code.

5. There are also units which are designed for ;application to the particular power supplies you may encounter in countries outside the United States. Remember, always read the nameplate before plugging in a unit.

6. Many mounting designs are available for particular applications of window-mounted air conditioners. A few of the various mountings are:

a. Inside flush mounting. The interior face of the conditioner is approximately flush with the inside edge of the window sill.

b. Balance mounting. The unit is installed approximately half inside, and ha1f outside the window.

c. Outside flush mounting. The outer face of the unit is flush or slightly beyond the outside wall.

d. All-in-mounting. The unit is completely inside the room so that tie window can be closed.

e. Upper sash mounting. The unit is mounted in the top of the window.

f. Built-in mounts. The mounts are used for installing units in the walls of hotels, motels, residences, etc.

7. There are many special mounts that can be used. We will not discuss each one. A special mounting may be used for casement windows, swinging windows, and office windows with swinging units, to permit window washing. Special mounts are also used for transom windows over doorways.

8. **Installation and Operation**. Installation procedures vary because units can be mounted in several ways. It is important to consider the most suitable mounting for the installation, the user's desires, and existing building codes.

9. *Electrical system*. We've already discussed the electric power source needed for a 115- or 230-volt unit, but we didn't cover proper grounding of the unit. All window type air conditioners, regardless of voltage or amperage rating, must be grounded. Most units are equipped with grounding type male plugs. These plugs are used with a grounded (three-prong) 115-volt receptacle.

10. The National Electric Code states that non-current-carrying metal parts which are liable to become energized shall be grounded under one or more of the following conditions:

a. Where permanently connected to metal-clad wiring.

b. When in a wet location and not isolated.

c. When within reach of a person standing on the ground outside the building.

d. When in a hazardous location.

e. When in electrical contact with metal or metal lathe.

f. Where the voltage is more than 150 volts to ground.

11. Can you think of any installation that wouldn't require grounding? It's very doubtful that you can, so remember, whenever you install a unit, make sure it's grounded.

12. Can you plug the unit into any receptacle? Yes, if the total load of the air-conditioning equipment does not exceed 80 percent of the current rating of the branch circuit, provided the voltage rating is satisfied. If the branch circuit also feeds lighting units or other appliances, the total load of the air conditioner shall not exceed 50 percent of the current rating of the circuit.

13. If a question about the power source or grounding arises, contact an electrician. He is a specialist in electricity, as you are in refrigeration. The manufacturer includes instruction sheets with his unit. You will find these helpful in mounting and installing the unit.

14. Through-the-wall units with steam or hot wire coils must be wired in or connected with armored cable or conduit. The electrician should complete this task. When the cooling unit can be removed without disturbing the heating system, it is customary to provide enough wire to facilitate installation and servicing without disconnecting the entire air conditioner.

15. The electrical system of an air conditioner consists of an appliance cord, plug, thermostat, fan motor(s), starting relay, starting capacitor, running capacitor, compressor motor, overload protector, and switches that control the flow of current to the various electrical portions of the system. Now we will discuss each electrical component.

16. The appliance cord and plug are manufactured as one unit. The cord is usually a three-wire cord with two current-carrying conductors and a ground wire. The conductor should be the correct size to carry the current that is necessary to operate the unit. The round third terminal of the service plug (1 15-volt) is the grounding terminal and should never be removed.

17. The control switch (es) mounted on the control panel of the unit directs electric current to various portions of the system to satisfy the desires of the user. All functions of the switch (es) are clearly marked.

18. The thermostat automatically controls the operation of the compressor motor, fan motor, and accessories to provide the comfort conditions required by the user. This control is accomplished by a feeler bulb located in the return airstream. The ambient temperature of the feeler bulb causes a bellows in the thermostat to expand or contract. This in turn causes the thermostat switch to open or close electrical contacts to the compressor and fan motors. Some thermostats have positions which afford the user constant operation.

19. The fan motor(s) and fans provide the forced air through the evaporator and condenser coils. The fan motor always operates when the compressor is running.

20. The starting relay, used frequently on 115-volt units, may be of the voltage operated type with normally closed contacts. The relay magnetic coil is wired in parallel with the starting winding of the compressor motor. Voltage developed by motor operation at 80 to 90 percent of full speed is impressed on the relay coil, which opens its contacts. With the relay contacts closed, the starting and running capacitors are wired in parallel with each other and in series with the compressor motor starting winding. When the relay contacts open, the starting capacitor is disconnected, but the running capacitor remains in series with the starting winding.

21. The starting capacitor stores electricity and provides power for extra compressor motor starting torque at the starting instant. This capacitor remains in the circuit for only a brief

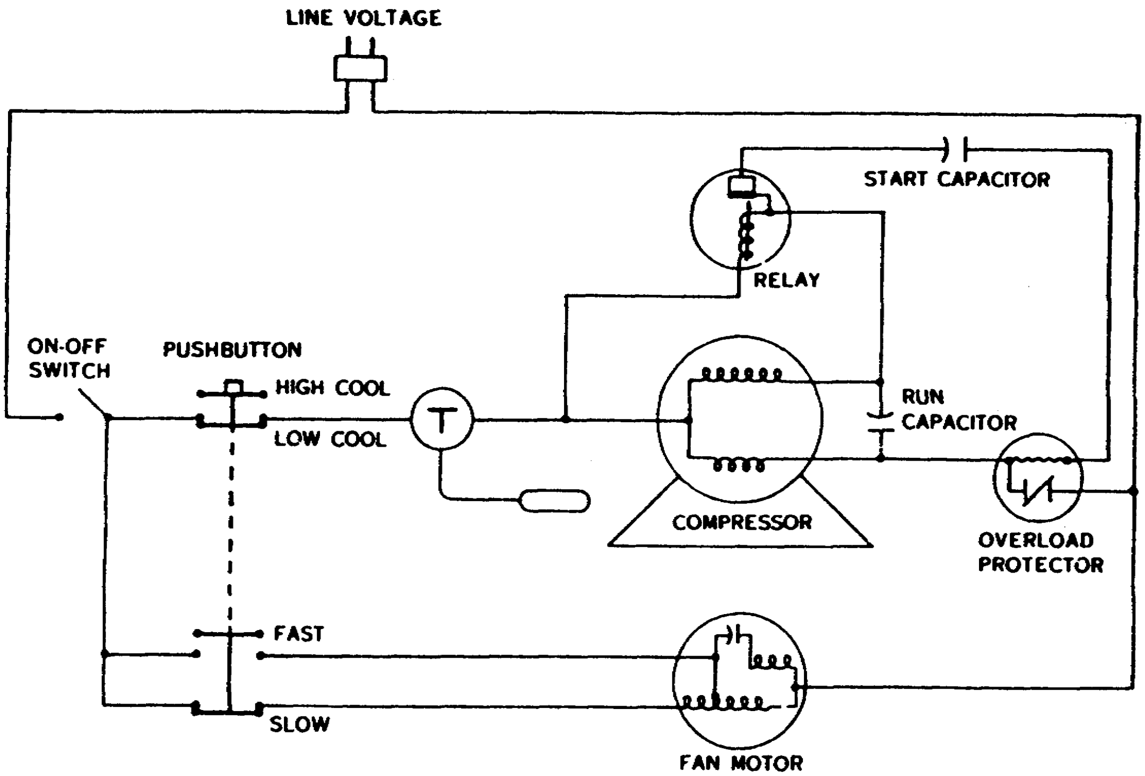


Figure 9. Room air-conditioner wiring diagram.

interval at startup. If the starting relay fails to quickly take the starting capacitor out of the circuit, it is possible that the starting capacitor will fail.

22. The running capacitor, which can be a heavy-duty, oil-filled capacitor, is used in the circuit to reduce the current requirements of the compressor motor power factor.

23. The compressor motor may he of various types. Two common types arc the capacitor start-capacitor run and the permanent-split capacitor motor. The permanent-split capacitor motor doesn't use a starting relay.

24. The motor overload protector is used on all compressor motor:; to protect them against excessive current draw and abnormal heat. The overload protector is usually mounted either under the terminal block cover or on top of the compressor against the shell. The overload protector consists of a bimetal strip with contacts and, in some cases, a heater clement. Excessive current draw will cause the heater element or the bimetal strip itself to heat up, thereby causing the contacts to open. Excessive compressor shell temperature can also cause the bimetal strip to open the contacts.

25. When the bimetal contacts open, they remain open until the temperature of the heater and/or compressor shall have cooled enough to cause a reset action. When making replacements, never use an unknown type of overload protector. Replace the overload protector with a like unit, as shown in an illustrated parts breakdown for that specific air conditioner. Be certain, also, that the overload protector has good metal-to-metal contact with the compressor shell to protect the compressor motor.

26. The operation of the electrical system for all window-mounted air conditioners are similar. We will use an air conditioner with a two-speed fan motor as an illustration. Figure 9 shows the wiring diagram for this air conditioner. With the pushbutton switch in the cooling position, current is applied to the fan motor Remember, the fan motor always operates when the compressor motor is running. Current also passes the thermostat. If the thermostat is calling for cooling, the compressor motor is energized. The compressor starts to rotate, helped by the starting capacitor. The start capacitor is in the circuit when the compressor motor starts, because the starting relay contacts on the voltage type relay are always closed when the relay coil is not energized. When the compressor reaches 80 to 90 percent of full speed, the voltage developed in the start winding is impressed upon the relay coil. The voltage developed at this speed is enough to pull the relay contacts open and take the starting capacitor out

of the circuit. The compressor continues to run on the run winding and the running capacitor. Now we'll turn our thoughts to the refrigeration cycle.

27. *Refrigeration cycle*. The refrigeration cycle of an air conditioner consists of a compressor motor, condenser coil, evaporator coil, capillary tube, strainer assembly, and its interconnecting tubing.

28. The fan motor(s) circulates air to remove the heat picked up by the refrigerant system. The condenser fan brings in outside air and forces it through the condenser coil, where it picks up heat and carries it to the outside air. The evaporator blower wheel recirculates room air, passing it through the cold evaporator, where moisture in the air condenses and its heat is absorbed by the refrigerant in the cooling system. The refrigerant system is hermetically sealed.

29. The compressor pumps the low-pressure gas from the interior of the compressor shell into the discharge line. The high-pressure gas, with its heat concentrated by compression, is forced into the condenser. The high-pressure gas is raised in temperature, at the compressor, above the outside air temperature which is being used to cool the condenser. The hot gas gives up its heat as it passes through the condenser coils. The hot refrigerant gas gives up enough heat to condense to a liquid. High-pressure liquid refrigerant leaves the condenser. It now passes through a strainer assembly. The strainer is an enlarged tube with a very fine mesh screen to remove any foreign particles. The high-pressure liquid now enters the capillary tube. The capillary tube acts as a restrictor (metering device) and separates the high side of the system from the low side.

30. The high-pressure liquid refrigerant is reduced in pressure by the restrictive action of the capillary tube. The liquid enters the evaporator low-pressure area, which was created by the suction stroke of the compressor. The liquid refrigerant exposed to this reduced pressure begins to boil and absorb more heat from the recirculated warm air. The boiling action of the liquid refrigerant progresses throughout the evaporator tubes, picking up heat as it travels. This low-pressure liquid now changes to low-pressure gas which is drawn out of the evaporator and back to the compressor, where the cycle is repeated.

31. *Airflow system*. The airflow system consists of a fan motor(s), evaporator blower wheel, condenser fan(s), and their housings. Two-speed or variable-speed fans and controls may be used. Many air conditioners have two separate airflow systems. These systems are the room air cooling, ventilating circuit and the condensing or outside air circuit. They are separated by a bulkhead and gasket

32. To maintain peak performance, it is important that the filter, evaporator coils, and condenser coils be kept clean. Any restriction of airflow to these components will result in reduced unit capacity.

33. The evaporator blower wheel draws the room air through the louvered grille of the cabinet, through the filter, then through the evaporator coils. It is then discharged back into the room.

34. The condenser fan draws its air from the outside. It then passes this air over the compressor and electrical controls and out the condenser, where it carries off heat collected from the room air and the various components of the air conditioners. The condenser fan is often equipped with a slinger ring that removes condensate water collected from the evaporator. This is done by slinging the condensate on the condenser where it evaporates.

35. Air seals are provided around the outer edge of the evaporator housing and in the front grille to restrict airflow to its proper path. Now that we've discussed the various systems, we can relate the troubleshooting techniques you might use on them.

36. Trouble Diagnosis and Testing Procedures. There are various pieces of test equipment you could use to diagnose trouble. These are the ohmmeter, volt-wattmeter, load checker, test starting set, and psychrometer.

37. *Electrical system*. If you find the air conditioner inoperative with the service cord plugged into a power supply, check the electrical outlet with a test lamp or voltmeter. If power is not available, you must check the possible faults which we will discuss in the next paragraphs.

38. First, examine the fuse box for blown fuses (circuit breaker for tripped breakers) and be certain fuses are of the time-delay type and of the correct size as indicated on the front of the air conditioner. If no power is available at the line side of the fuse box, tell the user and advise the electric shop.

39. To determine if the power supply is adequate, check the voltage at the power source with a voltmeter. The voltage must be within ±10 percent of the voltage required with the air conditioner on maximum cooling. A load checker may be used to simulate the wattage that the air conditioner will draw.

40. If the correct voltage is available at the receptacle, examine the service plug to be sure it is making good contact with the receptacle. Remove the service plug from the receptacle and check the service cord with an ohmmeter. Full continuity should exist the length of the service cord. You must check all the connections within the air conditioner to insure that they are securely fastened and making good contact.

41. Another possible fault could be grounding. The third wire of the service cord (green) is grounded to the chassis and will eliminate the

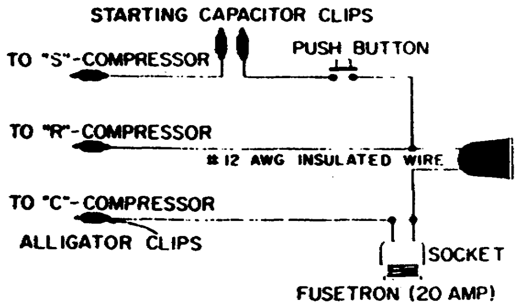


Figure 10. Test starting set.

shock hazard. Internal grounds will cause fuses to blow or, if of a minor extent, cause excessive power consumption and breakdown of components. Grounded current-carrying paths in the electrical system should not be allowed to exist.

42. Grounds nay he eliminated by testing each wire or component with an ohmmeter. With the ohmmeter on a high scale, test between the wire and any bright metal of the chassis, such as the copper tubing. No continuity should exist between the wire or electrical components and the chassis. Continuity should exist between the round prong of the service plug and the chassis. This is the grounding line.

43. To check the starting relay, disconnect the service cord from tie power source and expose the relay. With the ohmmeter, test the relay switch contacts for continuity. If there is no continuity, replace the relay. Another malfunction that may exist within the relay is a grounded relay coil. If an ohmmeter check indicates no continuity across the coil, the relay must he replaced.

44. The starting and running capacitors may be checked with an ohmmeter. The capacitors must be removed from the circuit and fully discharged before making a test. You can discharge the capacitors by shorting the capacitor leads. The first indication you should observe with the ohmmeter is a short circuit (needle will swing toward 0) and then the reading should slowly change to indicate a resistance reading of approximately 100,000 ohms.

45. To test the compressor motor, you must first disconnect the service plug from the power source. Now attach the test starting set, shown in figure 10, to the compressor motor. You may use the starting capacitor on the air conditioner if you've already tested it and found it not malfunctioning. The test set plug should be connected to the same or equivalent power supply used for the air conditioner. Push down the push button switch, then release it. The compressor motor should start. If it didn't start or if it blew fuses repeatedly, replace the compressor. If the compressor starts, the trouble is in one or more of the other electrical components.

46. One of the components that may be faulty is the overload protector. The contacts in the overload protector are normally closed. An ohmmeter check between any two of the terminals should indicate continuity. If no continuity exists, the overload protector must be replaced. If the overload protector opens repeatedly and the voltage, wattage, and temperature of the compressor are normal, substitute a known good protector. If the opening continues, the trouble lies elsewhere.

47. Another component that may be malfunctioning is the thermostat. The thermostat test is very easily made. Set the thermostat to its coldest position and test for continuity between the two terminals. If there is no continuity, the thermostat must be replaced. Make sure that the thermostat feeler bulb is above 70° F. To make it that warm, hold the bulb in your hand.

48. We have discussed the troubleshooting techniques that you may use on the electrical system of an air conditioner. Remember that all conditioners are not alike. Therefore you should always refer to the manufacturer's manual and wiring diagrams.

49. *Refrigeration system.* In the event a user complains of insufficient cooling or no cooling, there are some logical checks you should make before troubleshooting the refrigeration system. One would be the electrical system and the other the airflow. We've already discussed the electrical system, so we'll discuss what to check in the airflow.

50. Check the airflow system for cleanliness of the filter, evaporator coils, and condenser coils. If these are clean, check the fan speed. The fan speed may be checked with a portable tachometer. These malfunctions are the primary causes of low or no cooling. If no electrical or airflow fault is found, you must then troubleshoot the refrigeration system.

51. The correct refrigerant charge will be indicated by normal amperage draw. The amperage may be found on the data plate. Low amperage draw is an indication of low refrigerant charge, while a high draw may be an overcharge or dirty condenser.

52. Another test you may accomplish to check refrigerant charge is the "frost back test." With the unit running, block the evaporator air inlet with a piece of cardboard. After a period of time, the suction line should frost back to the compressor. A partial frost back indicates a low refrigerant charge. If the suction line does frost back to

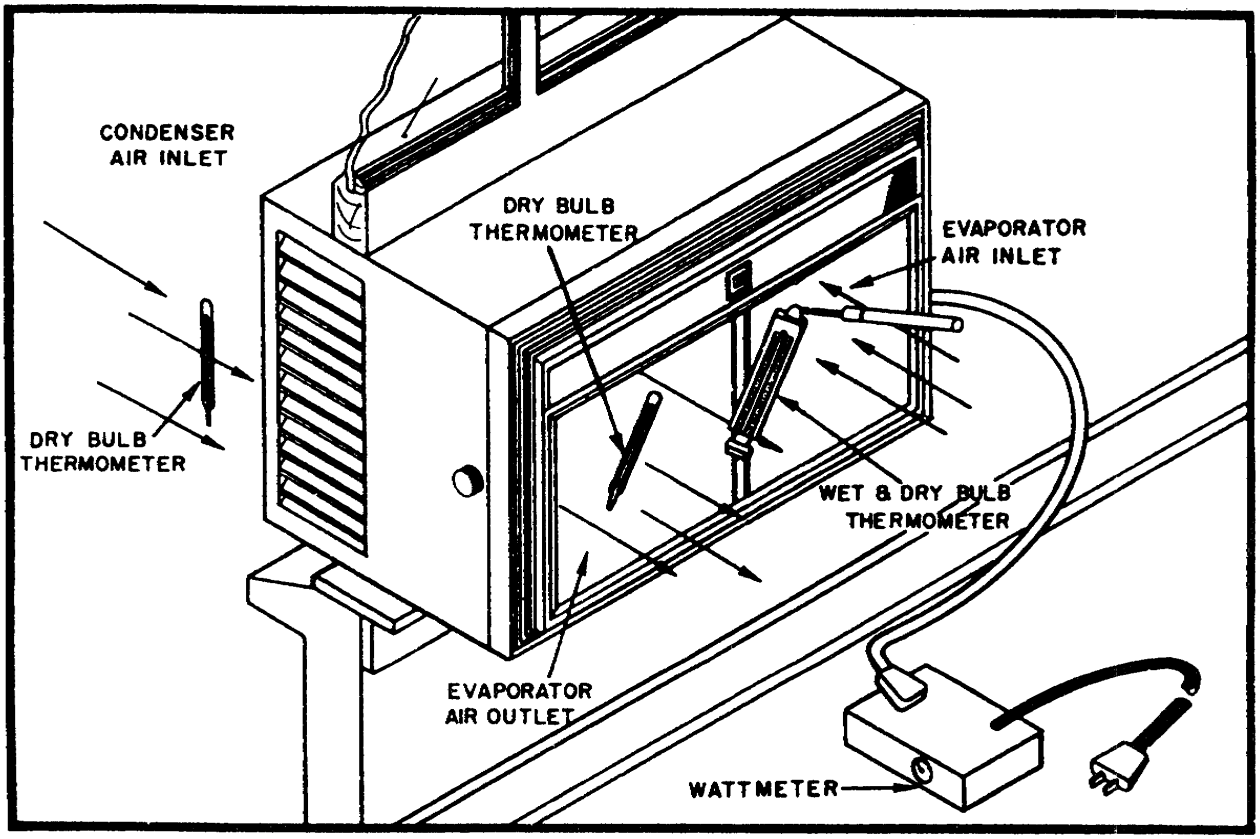


Figure 11. Thermometer placement for performance tests.

the compressor, the air conditioner should be given a performance test to determine that it is operating to its fullest efficiency.

53. Two dry-bulb thermometers, one psychrometer, and a wattmeter are needed for this test. Before you make the test, allow the unit to operate at full capacity for one-half hour. Be sure that the damper doors in the unit and any doors or openings to the room are closed so that no outside air is allowed to enter the room and no cooled air is allowed to leave the room.

54. Next, you must position the louvers on the front of the air conditioner so that the conditioned air flows upward. Now you place the various instruments that you will use to obtain values for comparison with performance data and tables in their pertinent places. One of the dry-bulb thermometers is suspended in the condenser inlet airstream. You must be careful not to allow it to make contact with any metal parts and must keep it out of the direct rays of the sun. The remaining dry-bulb thermometer is supported in the approximate center of the evaporator air outlet stream. The psychrometer is placed in the center of the evaporator inlet airstream. Be certain that you wet the wet-bulb wick. The wattmeter is connected in series with the power supply to the air conditioner. Figure 11 shows the various locations of these instruments during the performance test of a window air conditioner. Read the temperatures and wattage draw when the lowest wet-bulb temperature is obtained. All readings should be taken as nearly simultaneously as possible.

55. At this point you need a helper stationed outside to read the inlet condensing air temperature. These readings are now compared to the performance table values. Each manufacturer has these tables available for each model he produces. You cannot perform the test accurately without them. These tables contain information such as condenser inlet air temperature, evaporator inlet air temperature (wet bulb), evaporator inlet-outlet air temperature differential, total wattage, low side pressure, and high side pressure.

56. Let's assume the following readings were taken from an Anthony make air conditioner, model 21-9588-06. This is a 1-H.P. 115-volt unit. Figure 12 is the performance table for this air conditioner. The condenser air inlet temperature is 95° F. and the evaporator air inlet temperature is 67° F. You must now refer to figure 12. Under column A we find the 95° F. condenser air inlet temperature, and in column B we find the 67° F. evaporator air inlet temperature. When we follow to the right from the 67° F. reading, we find the following values:

Evaporator Inlet-Outlet Air Temperature Differential 17°-24° F.

AIR-CONDITIONER
MODEL NUMBER 21-9588-06

A	B	C	D	E	F
Condenser Air Inlet Temperature (Dry Bulb) °F.	Evaporator Air Inlet Temperature (Wet Bulb) °F.	Evaporator Inlet-Outlet Air Temperature Differential (Dry Bulb) °F.	Watts Total To Unit	Low Side Pressure	High Side Pressure
	79	8-14	1250-1450	77-81	300-320
	75	11-18	1275-1460	75-79	300-320
95	71	15-21	1290-1460	73-77	310-330
	67	17-24	1290-1470	71-75	300-330
	63	19-25	1290-1480	70-74	300-330

Figure 12. Performance chart.

Watts Total to Unit 1290-1470 Watts.
Low Side Pressure 71-75 p.s.i.g.
High Side Pressure 300-330 p.s.i.g.

57. From these performance values, we find that the normal air temperature drop across the evaporator is 17°-24° F. If the temperature drop exceeded 24° F., you could Suspect a dirty filter, incorrect fan speed, or a restriction in the evaporator airflow. A temperature less than the minimum (17° F.) could indicate low line voltage, air leakage from normal paths, or a dirty condenser

58. Well, let's say that we've found the air conditioner operating at its fullest capacity and the user still complains of insufficient cooling. One possible remedy would be to replace the unit with a unit of larger capacity or install an additional unit.

59. If you have determined, by use of the performance test, that the air conditioner is not operating at its fullest capacity, you must troubleshoot the unit. The last possible fault you should troubleshoot is a low refrigerant charge. If leak testing is necessary, you could use the following test procedures.

a. Expose the unit and the refrigeration component.

b. Examine all components and tubing for breaks, cracks, and traces of oil. (Since a small amount of oil travels through the system with the refrigerant, a trace of oil would be a good indication of a leak.)

c. With a halide leak detector, probe every joint for a leak source.

60. A soap-water solution may also be used for finding leaks. Finding a leak is one of three conditions that may make entry into the sealed unit necessary. The other conditions are restrictions and compressor and/or compressor motor failure.

61. **Service Procedures**. The service literature published by the manufacturer contains replacement diagrams for each model he produces. The knowledge you will gain from a close examination of these diagrams will help make the replacement of any part of an air conditioner readily possible. A step-by-step procedure is usually given on more difficult part removal items. This procedure is usually brief and keyed to a picture by numbers. To replace parts that you've removed, reverse the sequence you used to remove them.

62. *Filters*. Dirty filters, along with low voltage, are the major causes of poor performance of an air conditioner. You should familiarize the user with the location of the filter and with the fact that it should be inspected frequently for cleaning or replacement. Aluminum mesh type filters may be cleaned as often as necessary without damage. The filter should be cleaned with hot soapy water, then flushed thoroughly. After the filter is dry, it should be recoated with a domestic mineral oil or commercial type metal filter coating. You should explain to the user that the entire surface of both faces of the filter requires recoating. This procedure increases the dirt enhancing quality of the filter.

63. *Condenser and evaporator.* The coils of the condenser and evaporator should be cleaned periodically. You may accomplish this task with a soft brush or a vacuum cleaner.

64. *Condensate disposal system.* In order to reduce the humidity in the conditioned area, an appreciable amount of air-conditioner capacity is required. This is referred to as latent load,

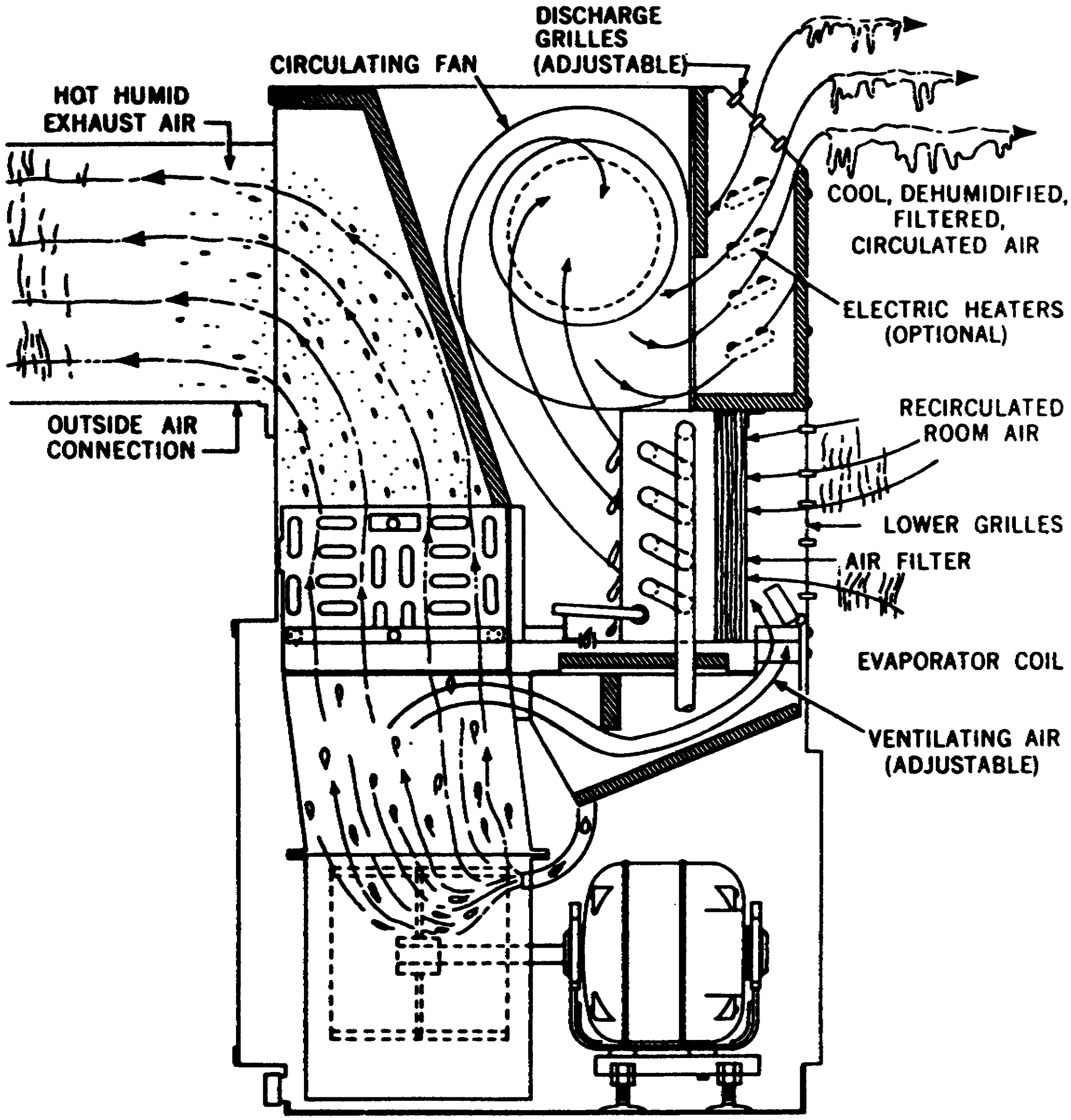


Figure 13. Sectional view of an air-cooled floor-mounted air conditioner.

while the actual reduction of air temperature is called the sensible load.

65. As the room air passes through the evaporator coils, the moisture in the air condenses. This condensate then drains back to the condenser housing sump, where it is drained or picked up by the slinger ring of the condenser fan. The slinger ring blows the water into the hot surfaces of the condenser coil. This moisture helps to cool the condenser coil as it is vaporized and blown into the outside air. It is important to keep the condensate drain clear to allow free drainage of this water. Proper slope of the air conditioner to the rear provides for this drainage.

12. Floor-Mounted Units

1. The floor-mounted or console air conditioner may have either water-cooed or air-cooled condensing units. The air-cooled model is gaining in popularity due to water restrictions. Figure 13 shows an air-cooled console unit. Note how the condensate from the evaporator coil is entrained in the condenser air. We also find that two separate fans and motors are used to move the air, while the window-mounted air conditioner normally uses one Fresh air or ventilating air is bypassed from the condenser air just as it leaves the condenser fan.

2. This air conditioner is applied to either resi-

dential or commercial use. The latter is used for comfort cooling and control of temperature and humidity for manufacturing purposes. In residences it is used for comfort only.

3. We won't discuss each component of the various systems which make up the air-conditioner, as they are directly related to components that we've already discussed. Instead, we will discuss each system briefly with more thought concentrated on components peculiar to this unit.

4. **Refrigeration System**. The refrigeration system consists of a compressor, cooling coil, condenser, expansion device, and the necessary interconnecting tubing. The components peculiar to this system are the different types of condensers, expansion devices, and compressor capacity controls.

5. *Condensers*. We will discuss the various types of condensers that you may find on this air conditioner and how they are cleaned. The most common is the air-cooled condenser. The air-cooled condenser consists of coils over which air is blown. Refrigerant cooling is obtained by adequate condenser surface and maximum sir circulation over the outside coil and fin surface.

6. Ordinary brushes and mild soap cleaning solutions will remove the usual dirt and dust deposited on air-cooled condensers. However, in some applications, the materials that may be deposited on the condenser cannot be removed by these means. If this situation arises, you can make a good cleaning agent by mixing 1/2 pound of trisodium phosphate with 1 gallon of water. After you use an acid or alkaline solution, you should rinse or flush the condenser with large quantities of clear water.

7. Another problem that you may have to cope with is carbon deposits. There is more danger to restricted airflow in using a solution which would loosen, or partially loosen, the carbon deposit than there would be in using a solution which would not remove all of it. The loosened particles could plug the condenser. The most satisfactory method of cleaning the inner portion of the condenser is to use superheated steam. You will find that this method will do a thorough job of removing all the loosened material from the inside of the condenser, and will prevent formation of any oxide or other material on the coils and fins. One precaution you should apply when using superheated steam is to be sure that the temperature of the steam is not above the melting point of any of the materials from which the condenser is constructed.

8. One water-cooled condenser (shell-and-tube) consists of a gas type sealed shell containing a copper coil or tubes. The hot refrigerant gas is admitted into the condenser shell and flows down over the condenser tubes in which cooling water is circulated. The gas condenses on the surface of the tubes and runs to the bottom of the condenser shell. These condensers are used frequently where the cooling load is heavy and the ambient temperature may rise over 90° F.

9. The tubes in a shell-and-tube condenser have a tendency to become coated, and sometimes even filled, with deposits (magnesium, calcium, etc.) from the water that passes through them. The safest method that you may employ for cleaning a water tube is soft metal brushes. You should start with a small diameter brush and increase the diameter of the brushes until one that is just the diameter of the inside of the tube is used. Do not attempt to apply force to the brush rod with a hammer. A large piece of scale or deposit could cause the rod to deflect and rupture the tubing wall opposite the deposit. Most tubes are not galvanized or coated with a surface-protecting material, so you should oil each tube after it has been cleaned. This may be done by drawing an oil-soaked cloth through the tube. The film of oil will prevent oxidation and will be washed off in a short time after water has run through the tube.

10. Another water-cooled condenser is the double-pipe condenser. This type of water-cooled condenser has become very popular because of its performance and its convenience of manufacture. The double-pipe condenser consists of one pipe inside a large pipe. The ends of the larger pipe are sealed against the inside pipe so that liquids or gases may be directed through its entire length.

11. The water usually passes through the inner pipe, and the refrigerant through the outer. The counterflow principle is usually employed so that the lowest temperature water comes in contact with the lowest temperature refrigerant This type of operation could lower the leaving refrigerant temperature to the same temperature of the incoming. water. However, a 10° differential is considered satisfactory.

12. Liquid cleaning with solutions of strong caustic soda or mild muriatic acid is practically the only cleaning method you can use on this type of water-cooled condenser. You should test the strength of the solution before you use it, as it may weaken the tube. The manufacturer usually recommends the strength of solution you should use on his condenser and how to test it. When you mix the solution, always add the acid to the water and wear the appropriate safety equipment.

13. On large equipment, double-pipe condensers are made of iron pipe. These are so constructed that the return ells can be removed. This exposes the inner tube so that it may be cleaned with a brush, as were the tubes in the shell-and-tube condenser.

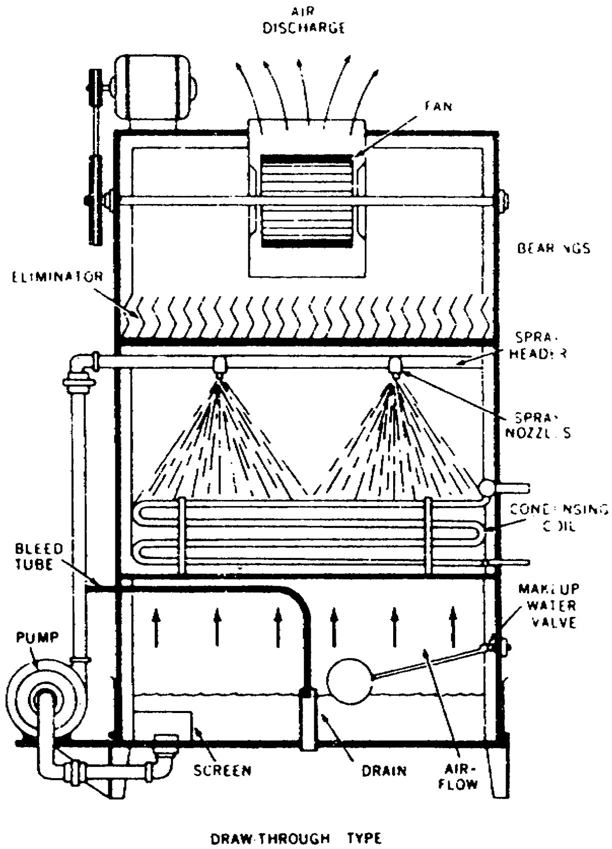


Figure 14. Evaporative condenser.

14. The repair of water-cooled condensers is usually performed by the manufacturer, unless it is otherwise specified in the manufacturer's service publication. In this case a detailed breakdown and procedure are given.

15. The evaporative condenser, shown in figure 14, consists of a fan and motor, eliminators, condensing coil, waterpump, spray headers and nozzles, a water sump, and a makeup water valve.

16. The operation of the evaporative condenser is similar to that of the cooling tower except that condensing coils are installed in the airflow. The two types of evaporative condensers are the draw-through and the blow-through. We will limit our discussion to the draw-through type, as it is the most popular of the two.

17. First, we'll discuss the operation of the evaporative condenser. In the draw-through type, we find that the air enters at the sump plenum, then flows up through the condenser coils, spray nozzles, eliminators, and out to the atmosphere. The entering air causes the water on the condensing cods to evaporate. The evaporation process removes heat from the refrigerant within the coils, causing the high-pressure gas to condense. The moisture-laden air then passes on to the eliminator plates, which are closely spaced surfaces that provide abrupt changes in airflow direction. The moisture particles are deposited on these surfaces and drained back to the sump. Effective elimination of moisture from the leaving air is essential to prevent projection of mist which can deposit moisture on surrounding surfaces. The carryover of water particles will also tend to form scale on the fan blades, thereby causing operational difficulties.

18. Scale is formed by low soluble salts. Polyphosphate chemicals may be added to the water, thereby enabling the water to become supersaturated without precipitation of scale-forming solids. Let's look at figure 14 again. We haven't mentioned the bleed tube which allows some of the pump discharge water to -drain off. What does that have to do with the formation of scale? Before we answer that question, let's state a few facts.

a. The water contains suspended solids (salts, iron, etc.).

b. The cycles of concentration increase each time the water circulates through the system (evaporization of water).

c. The dissolved solids are less soluble because of changes in the water temperature (water heated by condenser coils).

19. With these facts in mind, we find that bleeding off some of the recirculated water and replenishing it with makeup water will decrease the amount of solids suspended in the cooling water. Remember, the cycle of concentration is the ratio of bleedoff water hardness to makeup water hardness. The bleedoff water rate is directly proportional to the amount of water being evaporated. Continuous bleedoff, with rates based on condenser evaporation rate and makeup water hardness, decreases the precipitation of scale on the condenser coil. Scale on the condenser coil surface decreases the heat transmission through the surface and may reduce airflow.

20. Normally the next component in the refrigeration system is the receiver. Since you are already familiar with the receiver, we will bypass our discussion of it and proceed to the expansion device.

21. *Expansion device*. The most common expansion device used on this air conditioner is the thermostatic expansion valve with an external equalizer and distributor. The external equalizer is used to compensate for the pressure drop across the evaporator. A valve with an internal equalizer would cause the evaporator to starve because the pressure sensed under the valve diaphragm would be the inlet evaporator pressure. Let's set up an example to clarify our discussion.

22. Figure 15 shows a thermostatic expansion valve (for refrigerant -12) with an internal

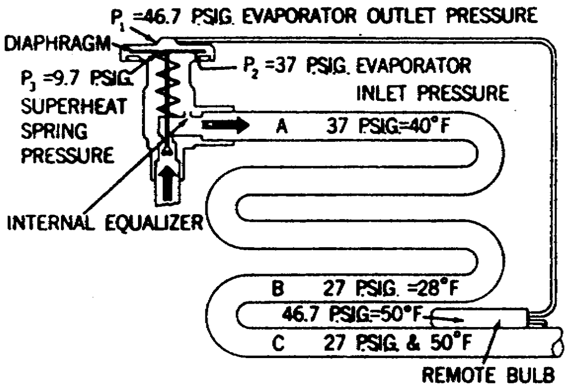


Figure 15. Thermostatic expansion valve with an internal equalizer.

equalizer. We are going to give the evaporator a 10-p.s.i.g. pressure drop across it. We find that the pressure acting on the lower side of the diaphragm is 37 p.s.i.g., which is causing the valve to close. With the valve superheat spring set at a compression equivalent to 10° F. superheat or a pressure of 9.7 p.s.i.g., the required pressure above the diaphragm to equalize the forces is 46.7 p.s.i.g. (37 + 9.7). Using your temperature-pressure chart, you will find that this pressure corresponds to a saturation temperature of 50° F. Therefore, the refrigerant temperature at point C must be 50° F. if the valve is to be in equilibrium. Since the pressure at this point is only 27 p.s.i.g. and the corresponding saturation temperature is 28° F., a superheat of 22° F. (50 - 28) is required to open the valve. This increase in superheat makes it necessary to use more of the evaporator surface to produce this higher superheated refrigerant gas. Therefore the amount of evaporator surface available for absorption of latent heat of vaporization of the refrigerant is reduced. The evaporator would be starved before the required superheat is reached. This starving effect increases as the load increases.

23. To compensate for an excessive pressure drop through an evaporator, you should install a valve of the external equalizer type, with the equalizer line connected into the evaporator (at a point beyond the greatest pressure drop) or into the suction line (on the compressor side of the remote bulb installation). The most common installation is in the suction line. When this valve is used, the true evaporator outlet pressure is exerted under the diaphragm. The operating pressures on the valve diaphragm are now free from any effect of the pressure drop, and the valve will respond to the superheat of the refrigerant gas leaving the evaporator.

24. The same pressure drop still exists through the evaporator; however, the pressure under the diaphragm is now the same as the pressure at point C, or 27 p.s.i.g. The required pressure above the diaphragm for equilibrium is 27 + 9.7, or 36.7 p.s.i.g. This pressure corresponds to a saturation temperature of 40° F., and the superheat required is now 40 - 28, or 12° F. The use of an external equalizer has reduced the superheat from 22° F. to 12° F. Thus the capacity of a system will be increased.

25. The expansion device shown in figure 16 is the thermostatic expansion valve and pressure drop distributor. This arrangement is used on the multicircuit evaporator to assure that an equal mixture of gas and liquid refrigerant reaches each evaporator circuit An external equalizer is used to compensate for the pressure drop caused by the distributor. An internally equalized valve would limit the action of the valve and cause the evaporator to starve.

26. The maintenance and servicing of this valve is similar to that of the common thermostatic expansion valve.

27. Our next discussion will cover the various capacity controls that may be used on the system. These are the hydraulic cylinder unloader and the compressor bypass valve.

28. *Capacity controls*. The hydraulic cylinder unloader is used to improve compressor capacity control during light load conditions. The unloader accomplishes this by holding open the suction valve on some cylinders and allowing the piston to draw gas on the downstroke, but on the upstroke it returns the gas to the suction line without compressing it.

29. On single-step unloader systems, one-half of the cylinders are unloaded, while on multistep unloaders the cylinders are unloaded in increments. These increments depend on the number of cylinder in the compressor. Figure 17 and 18 illustrate a typical unloader mechanism, loaded and unloaded. The bottom portion of each figure shows the capacity control actuator.

30. To understand the complete operational cycle, you should think of the unloader mechanism

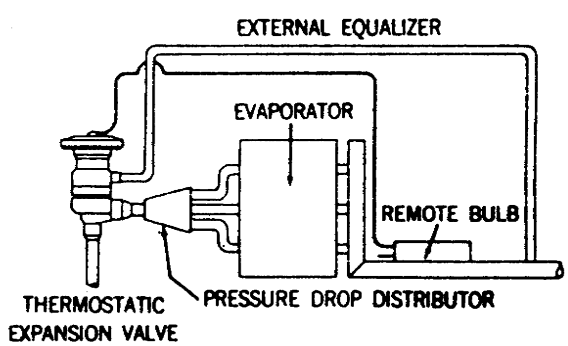


Figure 16. Single outlet expansion valve with a pressure drop distributor.

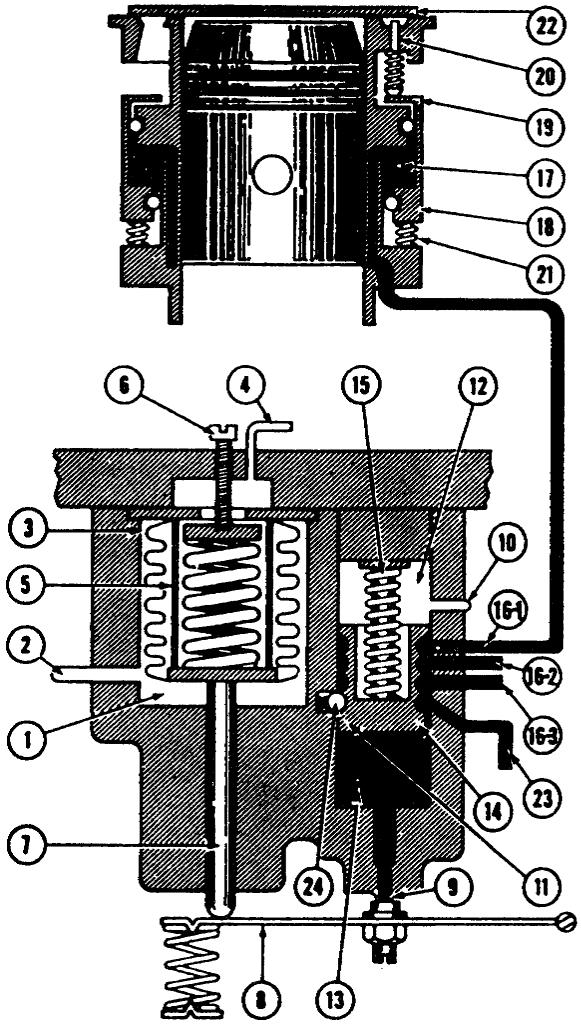


Figure 17. Hydraulic cylinder unloader (loaded).

as two distinct components, the capacity control actuator and the cylinder unloader mechanism.

31. The capacity control actuator reacts to variations in refrigeration load requirements and transmits them to the cylinder unloader mechanisms which load or unload the cylinders. To perform this dual function, the capacity control actuator consists of a pressure-sensing device, which is sensitive to variation in suction pressure; and a valving mechanism, which regulates the oil pressure to the various cylinder unloader mechanisms.

32. The pressure-sensing devices (fig. 17) consist of a chamber (1) connected to the suction line (2) and a bellows (3), which is vented to atmosphere (4). The function of the pressure-sensing device is to maintain, as nearly as possible, a predetermined suction pressure. This pressure is the maximum pressure required to satisfy the refrigeration system. The specific set point is maintained by a balance of forces. Suction pressure is balanced against a combination of atmospheric pressure and force from a spring (5). The amount of spring tension is adjustable by a set screw (6). When the system requires less than full-refrigeration load, the suction pressure will fall below the predetermined point, causing an unbalance within the device, and the unloading cycle will commence. The drop in suction pressure permits the bellows (3) to expand, forcing the plunger (7) against the lever (8), and moving it downward. The downward movement of this lever opens the regulated orifice (9). The opening and closing of this orifice controls the action of the valving mechanism.

33. The function of the valving mechanism is to supply each of the cylinder unloaders with oil under pump pressure when full compressor capacity is required and to relieve this pressure when the cylinders are to operate unloaded. This valving mechanism consists of a hydraulic cylinder, containing an annularly grooved, floating piston

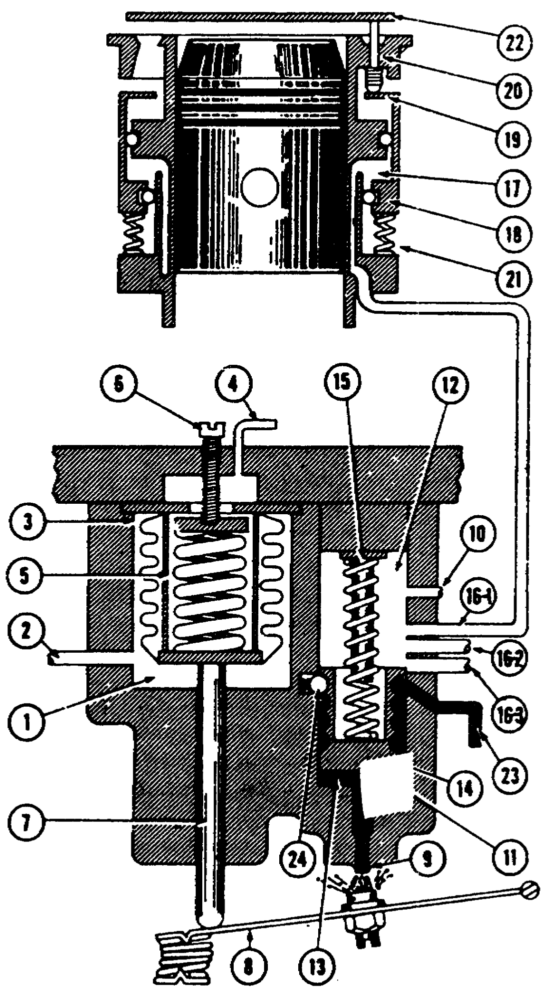


Figure 18. Hydraulic cylinder unloader (unloaded).

(11). The annular grooves are constantly fed with oil through a line (23).

34. Above the piston is a chamber (12) vented to the crankcase through an orifice (10). Below the piston is another chamber (13) connected to the annular grooves in the piston by an orifice (14). It is also connected to crankcase pressure through a regulated orifice (9). Located within the hydraulic cylinder is a spring (15), which tends to move the floating piston toward the lower chamber.

35. Under full capacity operation, as shown in figure 17, the regulated orifice (9) is shut off and the oil pressure in the lower chamber (13) increases because oil under pump pressure is being supplied through orifice (23). This pressure overcomes the force of the spring (15) and the floating piston (11), which rises in the cylinder. As it rises, the annular grooves in the floating piston coincide in sequence with lines 16-1, 16-2, and 16-3 to the cylinder unloaders, providing them with full oil pressure and permitting them to operate at full capacity. To make figures 17 and 18 as simple as possible, only line 16-1 is connected to a cylinder unloader mechanism. Lines 16-2 and 16-3 are, in reality, connected to identical mechanisms; and while this discussion is concerned with only one unloader mechanism, we could extend it to cover them all.

36. When full compressor capacity is not required, the regulated orifice (9) is opened through the movement of the lever (8); oil bleeds through it, and pressure within the lower chamber approaches crankcase pressure, as shown in figure 18. Under these circumstances, the force of the spring (15) overcomes the pressure in the lower chamber, and the floating piston (11) is moved downward so that lines 16-1, 16-2, and 16-3 become connected in sequence to crankcase pressure through the orifice (10). The spring-loaded ball (24) permits the piston to move only in distinct increments, one groove at a time.

37. In this manner the valving mechanism supplies or withdraws from each cylinder unloader the oil pressure that operates the unloader mechanism.

38. When oil from the forced feed lubricating system flows through line 16-1 from the valving mechanism to the cylinder unloader, it enters the annular chamber (17). The inner wall or unloader cylinder is firmly anchored to the cylinder liner; the unloader piston (18), however, is free to move. The up and down movement of this unloader piston raises and lowers the takeup ring (19), which, in turn, raises and lowers the suction valve lift pins (20).

39. Under full capacity operation (fig. 17), oil flows into the annular chamber (17) under pressure sufficient to contract the unloader piston springs (21). When oil pressure forces the springs to contract, the unloader piston (18) moves down, and takeup ring (19) and the suction valve lift pins (20) move with it. This permits the suction valve (22) to function normally and the cylinder operates at full capacity. When the compressor is to operate at less than full capacity (fig. 18), crankcase pressure flows through the orifice (10), which allows the pressure in the annular chamber (17) to dissipate; the cylinder unloader springs (21) expand, lifting the unloader piston (18). This raises the takeup ring (19) and the valve lift pins (20), and holds the suction valve (22) open so that the controlled cylinder is operating in an unloaded condition.

40. You will find that the compressor unloader is sensitive to variations in suction pressure. It may be desirable to unload the compressor in response to variations in air temperatures. This can be accomplished also through the use of pneumatic or electric controls. By introducing controlled air pressure from a pneumatic thermostat to the inside of bellows (3), in place of normal atmospheric pressure, the suction pressure at which unloading begins can be varied, thus making compressor operation responsive to variations in air temperature as sensed by the pneumatic thermostat. When electric control of unloading is desired, the screw (6) is replaced by a mechanical device. It resets the suction pressure which causes unloading to begin. This device is driven by an electric motor that is positioned by an electric thermostat.

41. The hydraulic cylinder unloader may be adjusted to maintain a balance between the load and compressor capacity. This adjustment is usually made after an installation. We will discuss this adjustment, but you should follow the manufacturers recommendations while performing this task on your specific piece of equipment. Before you adjust the capacity control, you must load the system either naturally or artificially until design suction pressure is reached with the adjusting screw (6) turned all the way out. Now, slowly open the suction shutoff valve until the suction pressure is 2 p.s.i.g. below the design pressure.

42. The next step is to turn the adjusting screw clockwise until the first cylinder unloads. Just before it unloads, the control oil pressure will drop to approximately 26 p.s.i.g. below oil pump pressure. The control oil pressure is present in line 16-1. When the cylinder unloads, there will be a distinct change in the sound of the compressor and in the amperage being drawn. The remaining cylinder are automatically unloaded as suction pressure drops.

43. Maintenance of the cylinder unloader can be found in the manufacturer's publications. We

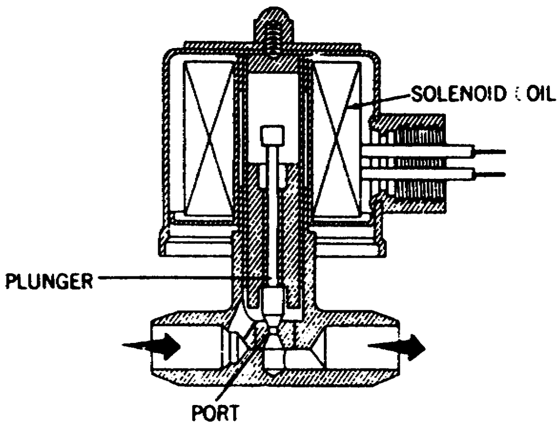


Figure 19. Direct-acting solenoid valve.

will not discuss it as it may not be applicable to your equipment and would only tend to confuse you.

44. The next capacity control device you will encounter is the compressor bypass valve. A special solenoid hot gas valve, installed in a bypass line around one or more cylinders, will provide compressor capacity control. The valve may be operated either by a thermostat or a switch. A check valve is required in the discharge line beyond the bypass line to prevent a reverse flow of discharge gas from other cylinders.

45. There are two types of solenoid valves you may find on this installation: the direct-acting, shown in figure 19, and the pilot-operated, illustrated in figure 20. In the direct-acting type, the pull of the solenoid coil opens the valve port directly by lifting the pin out of the valve seat. Since this valve depends solely on the power of the solenoid coil for operation, its port size for a given pressure differential is limited by the solenoid coil size.

46. Therefore large solenoid valves are usually of the pilot-operated design. In this type the solenoid plunger does not open the main port directly, but merely opens the pilot port (A). Pressure trapped on top of the piston (B) is released through the pilot port, thus creating a pressure unbalance across the piston (B). The pressure underneath is now greater than that above and the piston moves upward. This opens the main port (C). To close port C, the coil is deenergized, causing the plunger to drop and close the pilot port (A). Now the pressures above and below piston (B) equalize. The piston (B) will now close the main port (C). The pressure difference across the valve, acting upon the area of the valve seat, holds the piston in a tightly closed position.

47. You may have to select a solenoid valve while performing your routine duty. You'll find that there are many applications for this device. When you select a valve, you should know the fluid to be controlled, cap city (in tons of refrigeration), maximum operating pressure differential, maximum working pressure, and electrical characteristics. The capacities of solenoid valves are given in tons of refrigeration at standard conditions for the various refrigerants, with a pressure drop across the valve of 2 or 4 p.s.i.g. for liquids and 1 p.s.i.g. for gas. Most manufacturers publish tables extending these capacities for higher pressure drops.

48. You'll find that all solenoid valves are rated in terms of the maximum operating pressure differential (m.o.p.d.) against which the valve will open. Let's use an example here to clarify our discussion. With the valve closed and an upstream pressure of 150 p.s.i.g. against a downstream pressure of 50 p.s.i.g., the pressure differential across the valve would be 150 - 50, of 100 p.s.i.g. The m.o.p.d. of this valve must be equal to, or in excess of, the valve (100 p.s.i.g.).

49. Now that you've selected the valve, the next step is to install it. Remember, most solenoid valves are designed to operate in a vertical position and, therefore, must be installed in a horizontal line. Special valves are available to be installed in any position. When installing the valve, be sure the arrow on the valve body points in the direction of refrigerant flow. The final step in the installation of the valve is the electrical wiring. You must be sure that the voltage, type of current, and frequency marked on the valve nameplate are compatible with the system voltage, current, and frequency.

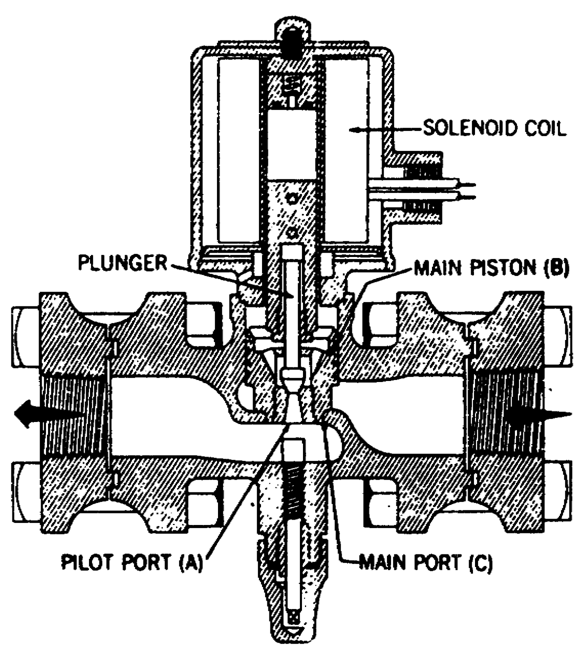


Figure 20. Large pilot-operated solenoid valve.

50. Should the valve fail to function after installation, the following are some of the probable causes of failure and suggestions for correcting them:

a. Solenoid valve fails to open.

(1) System operating pressure too high. The m.o.p.d. rating of the valve may be lower than the actual differential. A valve with a higher m.o.p.d. must be used.

(2) Valve body or internal parts are warped. These faults are caused by excessive wrench torque or high brazing temperatures.. You must replace the damaged part or the entire valve as required.

(3) Dirt or sludge causing valve to stick. You must dismantle the valve and completely clean the interior and component parts. Use an approved cleaning agent.

(4) Low voltage. Check the power supply with a voltmeter. The applied voltage must be at least 85.percent of the rated voltage given on the nameplate. For example, a 115-volt solenoid requires at least 97.75 or 98 volts. If the voltage Is lower than 98 volts, the cause of the voltage drop must be determined and corrected. Common causes of voltage drops are undersized supply lines, other loads connected in series with the coil, loose or faulty connections, and faulty control switches or devices.

(5) Coil burnout. Excessive voltage is the primary cause of coil burnout. Coils should not be subjected to voltages higher than 10 percent above the rated nameplate voltage-126.5 volts for a 115-volt rated coil. High ambient temperatures can also cause coil burnouts. Use a special high-temperature coil if your evaluation established overheating as the fault.

b. Solenoid valve fails to close.

(1) Valve body or internal parts are warped. Cause and correction same as (2) under subparagraph , Solenoid valve fails to open.

(2) Dirt or sludge causing valve to stick. Cause and correction same as (3) under subparagraph a.

(3) Electrical circuit closed. Troubleshoot electric circuit and repair or replace the faulty component (switch, relay, thermostat, etc.).

(4) Congealed oil causing valve to stick. Refrigerant oil should be of the proper type for temperature range of the system. Corrections is the same as (3) under subparagraph .

51. These service hints are general in nature and can be applied to most solenoid valves. If problems arise beyond this scope, you should consult the manufacturer's service manual.

52. There are many other components that we might discuss but they are peculiar to one manufacturer only.

53. We will now enter into discussion of the air-handling system. The components that will be discussed are fans, motors, and drives.

54. Air-Handling System. The air-handling system on the floor-mounted air conditioner in similar to that on the window-mounted type except that the components are larger.

55. Fans. The two types of fans common to this air conditioner are the propeller and centrifugal fans. The propeller fan consists of a propeller, or disk wheel, within a mounting ring or plate; the centrifugal fan consists of a fan rotor, or wheel, within a scroll type of housing.

56. In some air-conditioning systems, it is desirable to vary the volume of air handled by the fan. This may be done by a number of methods. Where the change is made infrequently, the pulley, or sheave, on the drive mo or or fan may be changed to vary the speed of the fan and alter the air volume. Dampers may be placed in the duct system to vary the volume. Variable-speed pulleys or transmissions, such as fan belt change boxes, or electric or hydraulic couplings, may be used to vary the fan speed. Fan volume can also be varied with the use of variable-speed motors and variable-inlet vanes.

57. From the standpoint of power consumption, the reduction of fan speed is most efficient when a direct mechanical method is employed. Inlet vanes save some power, while dampers save the least

58. When considering first, or initial cost, you'll find that damper are usually the lowest. Air supply demands and noise will dictate which type of control to install

59. Fan selection as to size and type depends on capacity, static pressure or system resistance, air density, type of application, arrangement of system, prevailing sound level, nature of load, and type of motive power available. To help you make your choice, a fan manufacturer will furnish you information on different sized fans working against different static pressures. Some of the important information is as follows: (1) volume of air (c.f.m.), (2) outlet velocity, (3) r.p.m., (4) brake horsepower, (5) tip or peripheral speed, and (6) static pressure. The most efficient operating point is usually shown by either boldface or italicized figures in the capacity tables.

60. Many fan applications and the corresponding types of fans commonly used are listed in the following paragraphs.

61. Unitary systems are equipped with centrifugal or propeller fans,, the later usually being limited to the relatively small suspended type (window-mounted) where no duct work is involved. Fans for units having considerable internal, or possible external resistance, a mostly of the forward-curved blade, or so-called mixed-flow centrifugal type. The latter is really a centrif-

ugal type with axial inlets, having a pressure curve resembling a backward-curved-blade centrifugal fan. Both types have the high capacities requisite for a compact unit.

62. Cooling tower fans are usually of the propeller type, but axial types are used for packed towers, and occasionally a centrifugal fan is used on the forced-draft tower.

63. Circulating fans are invariably of propeller, or disk type, and are made in a vast variety of blade shapes and arrangements. They are designed for a pleasing appearance as well as for efficiency.

64. We will discuss the maintenance of fans in Chapter 5. Now let's move on to the motors used on the floor-mounted unit.

65. *Motors*. Room air conditioner use motors ranging from 1/6 horsepower to 6 horsepower. Motors in most cases are controlled directly by the system controls, such as thermostats, timers, pressure switches, or other automatic devices. The most common voltage application is 115 or 230 volts.

66. The necessity for low current draw on a 115-volt circuit also makes it necessary to use permanent-split-capacitor motors for the fans on room air conditioners. Shaded pole motors are used when current draw isn't a problem.

67. The hermetic compressor design makes it impossible and unnecessary to service compressor motors. Fan motors are accessible and you should service them as recommended by the manufacturer's instructions.

68. Permanent-split-capacitor motors do not require a starting switch, but the capacitor-start induction-run and the capacitor-start capacitor-run motors use a starting switch.

69. Motor protection is similar to that described in the previous section. Most compressor motors and air-moving motors are equipped with thermal protectors. These may be hermetically sealed for installation within the compressor shell or open for mounting on the outside compressor shell. Hermetically sealed protectors provide better protection where conditions such as loss of charge, obstructed suction line, or low ambient temperatures on stalled rotors can be troublesome.

70. When applying an electric motor, the following characteristic are important:

a. Mechanical arrangement including the position of motor and shaft.

b. Speed range.

c. Horsepower.

d. Torque.

e. Inertia.

f. Frequency of operation.

71. The torque required to operate the driven machine (compressor) at every moment between initial startup and eventual shutdown is an important factor in determining the type of motor to be used.

72. The torque available at standstill, the starting torque, is usually welt above the torque at rated full load. The starting torque may be less than I00 percent, or as high as 300 percent of full load torque.

73. The starting current is usually 400 to 600 percent of the current at full load.

74. Full-load speed also depends upon the design of the motor. For induction motors, a speed of 1725 r.p.m. is typical for 4-pole motors, and a speed of 3450 r.p.m. for 2-pole motors (60-cycle). Full-load torque is the torque developed to produce the rated horsepower at the rated speed. Motors have a maximum or breakdown torque which cannot be exceeded without causing an abrupt change in speed. The relation between breakdown torque and full-load torque varies with motor design.

75. The required horsepower also determines the motor rating. The horsepower delivered by a motor is a product of its torque and speed. Since a given motor will deliver increasing horsepower up to a maximum torque, a basis for horsepower rating is needed. The National Electrical Manufacturers Association bases horsepower rating upon breakdown torque limits. Full-load rating of general purpose open type motors is related to the winding temperature rise, with a temperature rise limit of 40° C. by thermometer and of 50° C. by resistance for Class A insulation. Higher temperature rises may be allowed for enclosed and special-purpose motors.

76. The service factor of a general purpose motor is defined as "a multiplier which, applied to the normal horsepower rating, indicates a permissible loading which may be carried under the conditions specified for the service factor." Motors, other than general purpose motors, have a service factor of 1.0.

77. In this chapter the last subject we shall discuss is that of drives.

78. *Drives*. The fans and compressor motors are usually direct drive. Fans over 30 inches in diameter are belt driven to reduce the speed below that of the driving motor and to meet the sound level requirements. Housed fans in the smaller sizes (up to l0 inches) are either direct driven or belt driven, in accordance with sound level and other application requirements. Larger-size housed fans are exclusively belt driven.

79. Adjustable pitch pulleys are usually provided to permit you to balance air delivery against system resistance.

Review Exercises

NOTE: The following exercises are study aids. Write your answer in pencil in the space provided after each exercise. Use the blank pages to record other notes on the chapter content. Immediately check your answers with the key at the end of the text. Do not submit your answers for grading.

1. Before you plug in an air-conditioning unit you should read the _____________. (Sec. 11, Par. 5)

2. When proceeding to plug in an 155-volt air-conditioning unit you find that the receptacle is for a two-prong plug and the A/C unit hat a three-prong plug. You cut off the round prong and make your connection. What condition exists with the round prong removed? (Sec. 11, Pars. 9, 10, and 16)

3. Is it permissible to connect a 9.5-ampere rated air conditioner to a 15-ampere circuit if other equipment connected to the same circuit uses 4 amperes? (Sec. 11, Par. 12)

4. You receive a work order to replace an air-conditioner compressor motor that has burned out due to an overload. What other unit should you replace? (Sec. 11, Pars. 24 and 25)

5. As the room air passes through the its heat is absorbed by the refrigerant. (Sec. 11, Par. 28)

6. At what component of the air-conditioning unit is the temperature of the refrigerant gas raised above the outside air temperature? (Sec. 11, Par. 29)

7. What three components of an air-conditioning unit will collect dir and thus restrict airflow through the unit? (Sec. 11, Par. 32)

8. Before you check a capacitor with an ohmmeter you should __________________ the capacitor. (Sec. 11, Par. 44)

9. During the process of troubleshooting an inoperative. compressor motor, you check the overload protector with an ohmmeter. What is the condition of the protector if. the meter indicates zero? (Sec. 11, Par. 46)

10. Does a low- or high-wattage draw indicate a low refrigerant charge? (Sec. II, Par. 51)

11. What are the two major causes of poor performance of an air-conditioner? (Sec. 11, Par. 62)

12. What precaution should be observed when cleaning an air-conditioner condenser with superheated steam? (Sec. 12, Par. 7)

13. When mixing a liquid acid cleaning solution should you add the water to the acid or the acid to the water? (Sec. 12, Par. 12)

14. What will .result if the water bleed tube of the evaporative condenser should become clogged? (Sec. 12, Pars. 18 and 19)

An air-conditioning compressor was written up because it would not unload during light load conditions. What could prevent the compressor from unloading? (Sec. 12, Pars. 31-39)

What part of the capacity control actuator regulates the oil pressure to the compressor cylinder unloader mechanisms? (Sec. 12, Par. 31)

What pressure in the cylinder unloader mechanism will hold the compressor suction valves open? (Sec. 12, Par. 39)

18. Should the air-conditioning compressor be loaded or unloaded when adjusting the cylinder unloader system? (Sec. 12, Par. 41)

19. When you are preparing to install a solenoid valve, what two things on the valve should you check? (Sec. 12, Par. 49)

20. You have been assigned the task of replacing a solenoid valve that has a burned out coil. What should you check for before installing the new valve? (Sec. 12, Par. 50)

21. What are the two methods of varying the volume of air handled by an air-conditioning system? (Sec. 12, Par. 56)

Fresh Air and Air Duct System

YOU HAVE probably heard this statement many times: "This room is smoky." As an air-conditioning mechanic you should be particularly interested. Why is the room smoky? Why can't the air-conditioning system handle the smoke? What can you do to correct this situation?

2. These questions and many others you may come upon will be answered in this chapter. Such subjects as dampers, fans, coils, and air duct systems are discussed. You will also learn how to determine duct sizes and how to balance a system.

13. Dampers

1. Dampers of the following types are usually installed in an air-conditioning system:

a. Bypass damper (A of figure 21).
b. Mixing damper (B of figure 21).
c. Air intake damper (C of figure 21).
d. Volume damper, as shown in figure 22.
e. Recirculating damper (D of figure 21).

2. Bypass dampers control and regulate the airflow from return ducts and the intake openings. The air is diverted in specific directions to avoid airflow through a certain duct area. Mixing dampers are usually installed at duct and intake openings to provide a mixture of air from the exterior and interior spaces to the air-conditioning equipment. Mixing dampers control and regulate the airflow from room areas and the fresh air intake. The purpose of a mixing damper is to mix these volumes of air in the proper proportion. The volume damper is installed in the interior of the duct, as shown in figure 22. It provides a division for air volume to the openings by changing the area of the passageway. The volume damper is generally constructed of one blade and is fastened to the side of the duct with indicating sections on the exterior side of the duct surface for adjustments.

3. Intake dampers are installed at the opening connections to the air-conditioned equipment. These dampers usually control and regulate the airflow from the duct system connecting the spaces served to the equipment. The recirculation damper and exhaust damper are usually connected to a common motor by linkage. The linkage is arranged so that when one damper is open, the other damper is closed. Usually they can be at any position, from fully open to fully closed.

4. Dampers are installed in numerous ways to regulate and control air movement. They may have either one or several blades and may have automatic or manual controls.

5. **Operation and Controls**. All dampen operate either manually or through the use of automatic controls. Automatically controlled dampers are generally used in large air-conditioning systems and are operated by a motor. The motor operates pneumatically or electrically, and moves the dampers to various positions. The size, material, methods of operation, leverage, location, and signs of the motor vary with the manufacturer's specifications and installation requirements. Motor control and operation was covered in the preceding chapter.

6. Manual damper control is done through the use of rope or cable extensions. They are generally used as exit or intake dampers located in remote locations or inaccessible places in the system.

7. **Maintenance**. A few defects that might occur in the operation of a damper or louver follow:

a. Bent shafts.
b. Binding of blades or operating mechanism.
c. Bent rods or levers.
d. Air leakage.

The most common defect that causes erratic damper operation is binding blades.

8. Wherever possible, you must inspect damper operation; and if any of the above defects are found, immediate action must be taken to repair the unit.

9. Most large dampers are built as a single unit and constricted with a frame to fit the duct and chamber opening. If the unit needs to be replaced, the complete damper unit can be taken out and a new damper installed. Whenever the services of a sheet metal worker are needed, the civil engineering section should be notified according to local procedures.

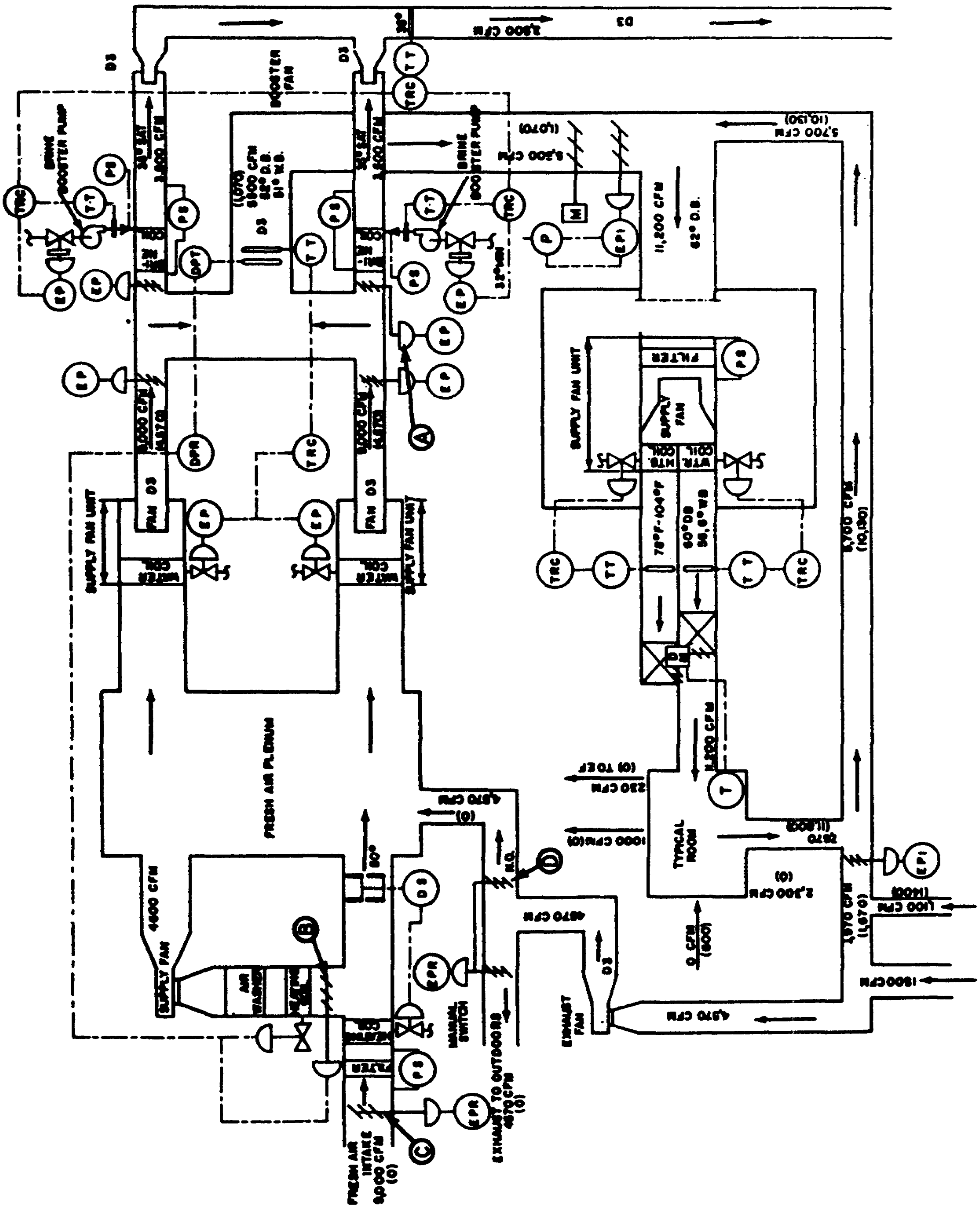


Figure 21. Typical air-conditioning system.

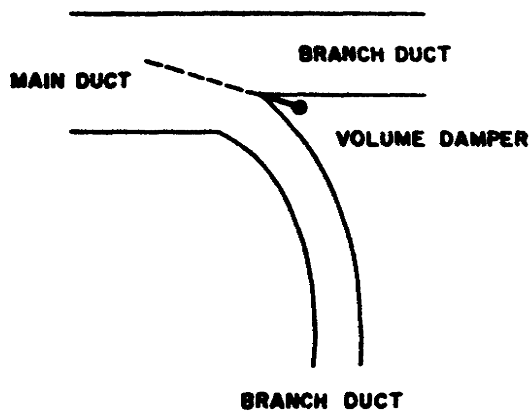


Figure 22. Volume damper.

10. You should refer to construction drawings and specifications for location of dampers and installation details.

14. Fans

1. Fans are used for circulation of air in duct systems and are usually of one of the following types:

a. Multiblade fans with blades curved backwards.

b. Multiblade fans with blades curved forward.

c. Multiblade fans with blades curved backward at the tip and forward at the heel.

d. Multiblade fans with radial blades.

e. Propeller or disk type.

2. The forward blade fan is a commonly used fan. It operates at a relatively low tip speed for a given pressure. It is compact in size and quiet in operation. The motor used with this type of fan should have a greater capacity than is actually needed by the fan. Forward blade fans do not operate well in parallel. The backward blade fan requires higher speeds for equivalent efficiency.

3. The propeller, or disk type fans are seldom used in duct systems. They develop relatively low pressures. The propeller fan is used for moving large quantities of air against low pressure with free exhaust.

4. The following information is required in selecting a fan for a given installation:

a. The number of c.f.m. of air to be moved.

b. The static pressure required to move air through the system.

c. The motive power available.

d. The operation of fans in parallel or singularly

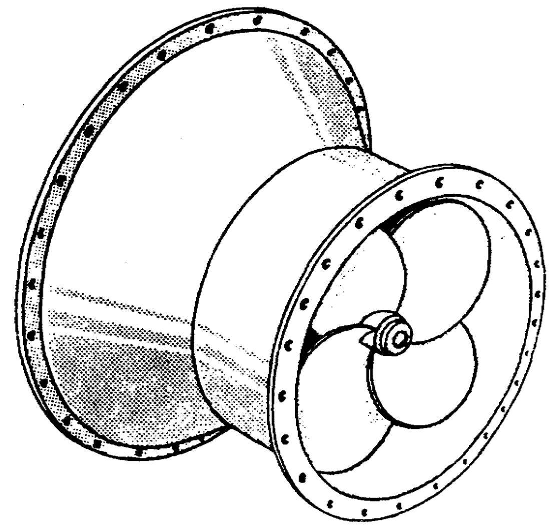
e. The degree of noise permissible.

f. The nature of the load.

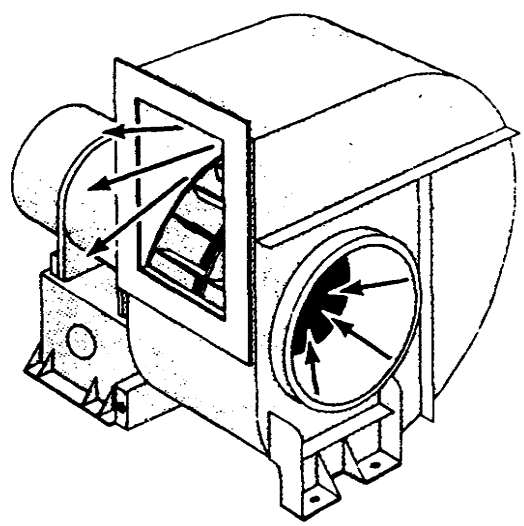
5. Knowing the above information, you can refer to the manufacturer's manuals to determine the specifications of each size fan.

6. Figure 23 illustrates two different type fans that may be used in an air-conditioning system.

7. **Supply and Booster Fans**. Depending on their use in a duct system, a fan may be referred to as a supply fan or a booster fan. If a fan is furnishing or supplying a large volume of air, it is often referred to as a supply fan, its name being derived from the fact that it supplies the air. A booster fan is used in distributing air to a certain portion of the duct system. This fan helps in



A. TUBEAXIAL



B. CENTRIFUGAL

Figure 23. Types of fans.

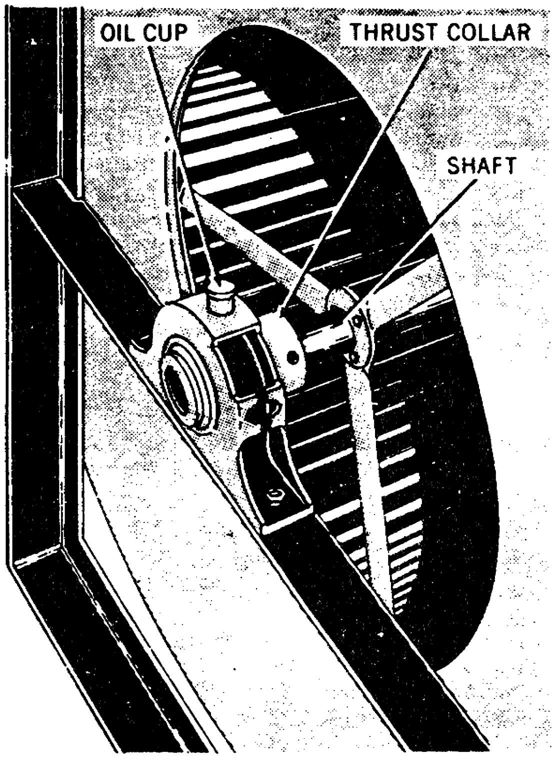


Figure 24. Blower bearing.

moving a specific amount of air to a portion of the building.

8. **Maintenance**. Once a year you should completely disassemble and inspect fans for defects. Bearings on fan shaft or motor are cleaned, checked for wear, and replaced if necessary. Ball bearings are repacked with grease and sleeve bearings are lubricated with oil or grease as prescribed by the manufacturer. When handling fan wheels, you must be careful not to bend them. This will cause them to wobble. Rusted surfaces should be cleaned and painted to reduce corrosion.

9. The blower wheel is inspected for proper alignment and freedom of rotation. Bent vanes must be repaired. Axial clearance is checked to insure that the wheel is not binding on the scroll. The adjustment is made by relocating the position of the shaft thrust collar, as shown in figure 24. Total axial movement of the shaft after final adjustment should be approximately 1/32 inch. The thrust collar is locked in place with a thrust collar set screw; worn thrust washers must be replaced. Periodic soakings of the washer in oil prolongs its life. The blower shaft sleeve bearings are normally lubricated with oil, while the ball bearings are packed with grease. Grease cups are generally refilled once a year, but should be inspected frequently for lubricant. During periodic inspections, you may find the blower surfaces rusted. You must clean it and apply a coat of rust-resistive paint.

10. Fan noise may be caused by improper fan selection. The tip speed required for a certain capacity and pressure varies with the type of blade. You must remember that a fan has a rated capacity and if it operates beyond this, it will become noisy. Other factors that could cause noisy operation are loose or worn belts; improper construction of ducts and airways; and loose fan mountings.

15. Evaporator or Chilled Liquid Coil

1. Chilled water coils are designed to conform to all the specifications and to handle the necessary chilled water that may be required by changing load conditions in a building. The fin metal is generally made of copper or aluminum, as these metals readily conduct heat. Fin type construction gives more surface area. The plate-fin coil used for the refrigerant circulating system and the chilled water circulating system are similar, differing only in minor construction aspects; one system is filled with refrigerant and the other with chilled water.

2. **Operation and Controls**. The duct type, plate-fin cooling coil is supplied with a coolant control assembly, which is fitted with a drip pan and drain. The related duct thermostat bulb is fitted within the air inlet duct. The coil tubing passes through plates or fins of thin metal stacked six to the inch, the entire length of the coils. The airflow through the coil is parallel to the fins which may be curved slightly to create a turbulent flow of the air. Thus, all the air is caused to come in contact with the cooling surfaces. The coils are preferably installed on the intake side of the recirculating fan in the system so that the coil inlet face is always open and free for cleaning. Slight deviations in air quantity from the cooling ducts will materially alter the performance of the system. The designated air quantities should be limited to plus or minus 5 percent so that the proper operating speed for the circulating fan in the air ducts is maintained.

3. **Maintenance**. In most installations, cooling units are provided with filters in front of the coils to prevent the coil from becoming coated with foreign materials. These filters must be inspected and cleaned at frequent intervals. Where filters are not provided, a linty, matlike accumulation will form at the intake side of coils. Too much of this accumulation would result in a marked decrease of airflow over the coils. A film of dust, organic material, and grease will also form on the entire cooling surface, reducing the rate of heat transfer and creating a source of objectionable

odors. Therefore, the coils should be inspected frequently and cleaned as often as necessary.

4. **Cleaning**. In cleaning coils, a regular check-off list is generally followed for the entire air duct system. First, you must stop the fans, then open the coil access plates. After this is done, brush the intake side of the coil to loosen the lint and dirt. If this material is caked on the fins, use the special combs with teeth spaced to fit between the fins. Wire brushes may be used if care is taken to avoid damage to the fins.

5. **Leaks**. Coils that develop leaks must be repaired immediately. Repairing a leak can develop into a major job. It may require the coil to be drained so that proper maintenance can be performed. Manufacturer' maintenance manuals generally give coil structural material and recommended procedures for repairing coils.

6. **Replacement**. Every air-conditioning Installation has its own peculiarities as to design and installation; therefore it is impossible to give specific procedures on coil replacement information relative to your particular installation can probably be located in the constructed prints and manufacturers specifications and handbooks.

16. Brine and Heating Coils

1. Brine coils are used in air-conditioning systems that require low temperatures for dehumidification purposes. The brine (usually ethylene glycol) flowing through coils is designed to withstand low temperatures. Location of the brine coils for your installation can be found in construction drawings.

2. **Operation and Controls**. Brine coils operate on the same basic principle as the chilled water coils except for minor engineering differences. Refer to construction drawings and manufacturer's manuals and handbooks for detailed information concerning operation and controls.

3. **Maintenance**. Maintenance for the brine coil is accomplished in the same manner as maintenance on chilled water coils, as explained previously. One maintenance precaution that must be taken in repair or replacement of the brine coil is the preservation of the brine.

4. **Heat Coils**. Heating coils are used to heat the air pressure through coils for humidification purposes. These coils are supplied with hot water or steam. Hot water coils should not be operated with final air temperature below 50° F. Construction characteristic and location of the heating coils can be found in installation drawings, manufacturer's manuals, and handbooks.

5. The operation, control, and maintenance of heating coils are very similar in principle to that of the chilled water coils explained previously. Many heating coils are controlled by an automatic temperature control; this control throttles the steam or water to the coils to help protect against subfreezing air coming into direct contact with the hot coil. This can become very dangerous and would result in damage to the equipment. A bypass damper control is used on hot water coils under the above circumstances, which allows the maximum amount of water to flow into the coil.

6. Heating coils are constructed to withstand high pressures and may or may not be of the self-draining type, therefore provisions are made for draining in case of repair or replacement.

17. Air Duct Systems

1. The duct system is used to distribute conditioned air from one location to another. This system may cost 25 percent of the initial investment. The resistance of a duct system is a substantial portion of the static pressure against which the fan operates-an important item in annual power cost. For this reason, in larger installations economies can be realized by designing the ducts to balance first cost against operating cost rather than by using the rule-of-thumb methods sometimes permissible on smaller installations.

2. **Pressure Losses**. Along an ideal frictionless duct system, total pressure-the sum of static and velocity pressures-remains constant in an actual system, losses occur due to two effects: friction losses and dynamic losses. Friction losses are primarily from surface friction, while dynamic losses result from sudden changes in velocity or direction, or from other eddy sources. Most of the pressure drop in a straight duct is caused by surface friction. You will find that various equations are used to calculate losses. These formulas are slanted toward design engineering. You will not be required to study them.

3. **Duct Sizing**. Ducts are sometimes sized by selecting a velocity at the fan discharge and by making arbitrary reductions in velocity down the run, usually at each branch or takeoff.

4. This method, called the velocity reduction method, has simplicity to recommend it, but it takes no account of the relative pressure losses in various branches. It use is acceptable only for estimating simple layouts. The method is not recommended for actual design.

5. The following table presents maximum design velocities considered good practice for conventional systems in various applications. Quality and size of installation, power costs, space limitations, and noise are the factors which should be considered in the selection of the proper velocity.

RECOMMENDED MAXIMUM DUCT VELOCITIES, IN F.P.M.

APPLICATION	*SUPPLY DUCT*		
	Trunk and Large Rises	*Small Rises and Branches*	*Return Mains*
Residences	800	600	600
Apartments and hotel bedrooms	1,500	1,100	1,000
Theaters	1,600	1,200	1,200
Private offices-deluxe		1,100	800
Private offices-average		1,300	1,000
General offices	2,200	1,400	1,200
Restaurants	1,800	1,400	1,200
Shops-small		1,500	1,200
Department stores-lower floors	2.100	1,600	1,200
Department stores-upper floors	1,800	1,400	1,200

6. **High-Velocity and High-Pressure Air Distribution**. In recent years there has been a trend toward higher duct velocities to reduce duct size at the expense of increased friction. Any system with velocities greater than 2,000 f.p.m. is usually considered to be a high-velocity system. Because of the higher average static pressure (5 to 10 in. w.g. at the fan), these systems are frequently called high-pressure systems.

7. In these systems, relatively high duct pressures are necessary to obtain stable control of variable volume outlets, or to obtain the required velocity for high induction terminal units. Increased stability is inherent in outlets with high design pressure drops (1/2 in w.g. or greater), since a given change in duct static pressure, due to throttling of a portion of the outlets, has a decreasing effect on the airflow through the remaining outlets as the design pressure drop increases. For example, a duct static pressure increase of 0.20 in. w.g. will increase the airflow through an outlet designed for a 0.20-in. drop by 41 percent, but by only 10 percent through one designed for a 1.0-in. drop.

8. When high outlet discharge velocities are used, high-temperature differentials between room and supply air may be employed, since induction within the room will afford adequate mixing of the supply stream before it enters the occupied zone. For example, a 30° F. difference may be used instead of the 20° F. differential common to conventional systems, with a one-third reduction in the supply-air volume. Some systems employ high velocity in the main ducts, with sound-attenuation boxes where the velocity is reduced.

9. The space saved as a result of using high velocities should be balanced against increased first and operating costs. It is necessary to use fans of heavier construction for the higher static pressures. Great care is needed in the construction of duct work to prevent leakage, and it is common practice to seal all joint and seams with sealing compound, tape, or by welding or soldering. Round duct is preferred to rectangular because of its greater rigidity, which allows the use of lighter gauges and avoids the need for reinforcing members. Spiral conduit, made from 2 1/2- to 6-in. zinc-coated steel or aluminum strip spirally wound with a double-locked seam, is light, tight, and strong. Particular care should be given to the selection of fittings to avoid excessive pressure drops and noise generation. Avoid using 90° fittings, or fittings that are sleeved into the inside diameter of the main duct. The problem of maintaining satisfactory sound levels is magnified, and outlets with a low level of noise generation and a high degree of sound attenuation are required. The higher sound level of a high-pressure fan ordinarily requires the use of a sound absorber immediately downstream. Lined duct may be used where space permits; otherwise a baffle, cell, or plenum type absorber is required. Special attention should be given to the design of fan isolation and the use of flexible connections.

10. It is good practice to examine the critical (maximum pressure drop) run of conduit after preliminary sizing is completed and to reduce velocity at selected points if a significant reduction in fan horsepower can be effected. Sometimes the use of more costly special fittings of low dynamic loss can be justified for such runs. Conversely, where excess static pressure is to be dissipated in shorter runs, it may be desirable to size certain portion for higher velocities.

11. **Duct Materials**. The composition of ordinary galvanized-steel sheets includes approximately 0.10 percent carbon, 0.40 percent manganese, and minute quantities of phosphorus, sulphur, and silicon, with a heavy zinc coating. Of somewhat superior resistance to atmospheric corrosion (where high moisture conditions are encountered) is galvanized copper-bearing steel with a copper content of about 0.20 to 0.30 percent. Aluminum duct should be fabricated from 2S or 3S 1/2 or 3/4 hard stock; 3S is preferred for larger ducts.

12. Exhaust ducts for chemical laboratories and other applications involving corrosive fumes use copper, stainless steel, monel metal, lead-coated, or lead itself when necessary. Intake and exhaust hoods are frequently made of copper although this refinement is necessary when galvanized-steel construction is accessible for inspection and painting. Materials other than metal may be used in ducts for reasons of appearance or cost.

13. *Board material*. Such materials are cut to desired size and fastened by various means, with corner trim or edges and band trim along the seams. Most materials in use include in-

sulation value as a property. Besides filling the requirements for any ducts, the material should be fireproof, verminproof, moldproof, free from odor, and not subject to deterioration from water or vapor penetration.

14. *Prefabricated materials*. These ducts and fittings are available in standard even-inch dimensions in the smaller sizes and are designed primarily for the residential and small commercial market. They must meet standards similar to those specified for the board materials.

15. **Sheet-Metal Standards.** Ducts and sheet-metal connections may be fabricated according to several methods of construction. It is not too important which method we use, but the construction must meet the following standards:

a. Materials of suitable quality for the purpose.

b. Proper gauge for strength.

c. Cross breaking and reinforcement, where needed, for rigidity and freedom from mechanical noise induced by vibration.

d. Tightness of seams and corners to minimize leakage.

e. Freedom from sharp internal edges to avoid noise regeneration.

f. Conformance with design standards to permit desired airflow.

16. To insure desired airflow without excessive frictional and dynamic losses design standards are essential to govern the fabrication of shapes, fittings, vanes, and connections to equipment. Nearly all of these standards are based on two fundamentals of airflow:

a. Air flowing from the chamber or conveyor of smaller section area into one of larger area tends to continue in a straight line. Air will not diverge, unless changed by vanes, at an included angle greater than about 20°.

b. Air flowing from a chamber or conveyor of larger section area into one of smaller area tends to converge uniformly and follows the laws of entrance to orifices in fluid flow.

17. **Duct Heat Gains and Losses**. Whenever the air inside the duct is at a temperature different from the ambient temperature, heat will be transmitted outwardly or inwardly. The gain or loss, if of appreciable magnitude, may be important because:

a. Transmission to or from a space not being treated, but through which the duct passes, is a total loss of heating or cooling effect.

b. Transmission to or from the same space being conditioned may put too large a part of the heating or cooling effect where it is not wanted. The correction in the first case is either insulation (or dead air space) or a greater investment in heating or cooling capacity, or both. The correction in the second case is a redistribution of the air to the various supply grilles to compensate for the cooling or heating effect of the duct surface.

18. **Heat Insulation**. Insulation is employed for two reasons: (a) to reduce loss of heating or cooling effect or (b) to prevent sweating of the duct. Determination of the first effect is computed by use of the following equations:

$$Q = UA\ (t_1 - t_0.)$$

where Q = heat loss (B.t.u./hr)

U = B.t.u./(hr)(sq ft.)(°F. diff.) average values

values

A = duct surface (sq. ft.)

t_1 = air temperature inside duct (°F.)

t_0 = air temperature outside duct (°F.)

19. The economic value of insulation depends upon the total annual cost of the heating or cooling effect saved. A precise answer can be obtained only by a study of the particular application.

20. Sweating occurs when the temperature of the duct surface is below the dewpoint of the air touching it. For bare-sheet-metal duct:

$$f_0\ (t_0 - t_3) = U\ (t_0 - t_1)$$

$$t_3 = t_0 - \frac{U\ (t_0 - t_1)}{1.6}$$

where t_3 = duct surface temperature (°F.)

U = overall transmission coefficient

f_0 = surface conductance of outside duct surface

21. **Air Leakage and Duct Maintenance**. Air leakage varies over wide limits, depending on air pressure, type of construction, and workmanship, principally the last. Actual tests on typical supply systems have shown leakages from 5 to 30 percent. Corner holes normally account for only a small portion.

22. The largest source is at transverse seams located against the wall or ceiling in such manner that tight joints are almost impossible. Allowance should be made for leakage, depending on job conditions. For supply systems with static pressure in excess of 1 inch w.g., calking, felting, or soldering is recommended.

23. Ventilating and air-conditioning ducts normally require little maintenance. When they are dry the deterioration by corrosion is usually negligible. Periodic cleaning is important because even with comparatively efficient air-cleaning devices, dirt accumulates over a period of time. A shift in dampers will frequently blow a cloud of dirt into the room. More important is the real fire hazard of such an accumulation, which has been recognized by the Fire Underwriters. Ducts should be provided with access doors to allow for cleaning.

24. **System Balancing**. With the fan in operation, adjust the damper op the air-intake trunk until the velometer shows an air intake equal to

one-half the dwelling's cubic volume per hour. After you have done this, you must lock the damper in place.

25. A formula for calculating air quantities required for sensible cooling load is:

$$\text{Quantity of air (c. f. m.)} = \frac{\text{sensible heat load (B.t.u./hr.)}}{1.08 \times \text{temperature change}}$$

26. Temperature change is the difference (°F.) between the room temperature and the temperature of the entering air. Another rule of thumb that you may use to estimate the quantity of cooling air required is to figure on eight air changes per hour in the area to be conditioned.

$$\text{Quantity of air (c.f.m.)} = \frac{8 \times \text{room volume (cu. ft.)}}{60 \text{ min. /hr.}}$$

27. You should not use this rule if the risers are smaller than standard (3 1/4" x 14") or if the branch ducts are less than the equivalent of an 8-inch round duct. Another exception is when unusually large amounts of glass or exposed wall are present.

28. At all T-type duct transitions, check the first grille downstream from each branch with all of the grille frets or louvers in straight-flow position. Adjust the branch dampers until the velometer registers equal velocity through the grilles on both trunks. After you have equalized the velocities, you must lock the dampers in position. Continue this procedure along the duct system to any addition T-type transitions until all the T-type transition dampers are adjusted.

29. If splitter dampers are installed, follow the same procedure until approximately the same air velocity over the entire duct and grille system has been reached.

30. *Proper quantity of return air*. After you know the total quantity of air required for cooling the conditioned area, you must adjust the air-conditioner blower drive for delivery of the design airflow. Check the delivery as close to the fan outlet as possible. The air velocity times the total outlet area will determine the total air volume being circulated. For example:

80 f.p.m. X 8 sq. ft. = 640 c.f.m. being circulated

31. Once the airflow is adjusted to the desired cubic feet of air per minute, you will have to tighten the nuts on the fan sheave for permanent adjustment of airflow. At this time you should check the current the blower motor is drawing to b certain that it is capable of driving the fan without overloading and burning out.

32. You must be sure that the return-air grille is large enough to handle all the air supplied to the space. Any lack of return air can seriously affect system operation.

33. *Balancing air discharge grilles*. High-side-wall, double-deflection supply-air grilles predominantly used in average sized systems will be discussed first. You must use the design data to find the amount of air required for each room or area. The grilles are usually dampered. Equalize and properly deflect the air delivery to the various areas by adjusting the louvers or grille frets.

34. Starting with the grilles closest to the blower, adjust the front horizontal grille frets so that you achieve the proper blow and drop. Blow and drop will be discussed later in this volume. A lighted match, warm thermometer, or rubbing alcohol on the exposed surface of your arm will help you to determine just how accurately the desired vertical flow of air is being achieved. Constant association with airflow will enable you to tell just what the air deflection is doing by the sensation of the airflow over your body. By adjusting the rear frets of the grille, the horizontal width of the air pattern is established. The ultimate goal is to achieve an even air pattern about 5 ½ to 6 feet above the floor level over the greatest amount of room area while attaining as close as possible the cubic feet of air required for the particular room. Then continue to the next closest grille to the supply blower, and so on to the last grille. It is possible that proper airflow from distant grilles cannot be attained. It is then necessary to return to the grilles closest to the blower outlet and partially close some of their rear frets, thereby forcing more air to the distant parts of the system. Continue the adjustment of rear grille frets in the same sequence until there is ample air supply to all rooms. 35. In checking the air volume from the grille, play the recording air-measuring instrument over several locations on the grilles and average the readings for final tabulation of total airflow. In setting the supply-air delivery patterns, refrain from projecting supply air directly toward a return grille.

36. The ceiling diffuser must be adjusted to pattern the airflow over most of the ceiling area. The diffuser usually has adjustable rings, dampers, or diffusing grids which will do the same thing as a high-side-wall grille when it is adjusted for patterning air delivery to the conditioned area.

37. The flush-floor diffuser with bars or frets is adjusted to pattern air sweep in an arc toward the ceiling. This will blanket the conditioned area just as high-side-wall grille does.

38. The baseboard type of diffuser has a balancing damper for controlling airflow. This diffuser does a good job, even though it has a minimum of adjustments that you can use for balancing.

39. The low-side-wall diffuser has grids, vanes, or frets for producing air patterns. It can produce an excellent cooling or heating condition when the

air is deflected properly. You will encounter few problems with high-side-wall or ceiling diffusers. Care should be taken with the other types of diffusers, especially in relation to obstruction which interfere with the required air pattern. Such devices must be balanced differently for summer and winter conditions.

Review Exercises

NOTE: The following exercises are study aids. Write your answer in pencil in the space provided after each exercise. Use the blank pages to record other notes on the chapter content. Immediately check your answers with the key at the end of the test. Do not submit your answers for grading.

1. What type of dampers regulate airflow from return ducts? (Sec. 13, Par. 2)

2. The damper in a duct is operating erratically. What is the most probable cause? (Sec. 13, Par. 7)

3. Which type of fan is most commonly used in a duct system? (Sec. 14, Par. 2)

4. What type of fan would you install in an area where large amounts of air are to be exhausted? (Sec. 14, Par. 3)

5. How is the axial clearance adjusted on a blower wheel? (Sec. 14, Par. 9)

6. Why are the fins a cooling coil made of aluminum-or copper? (Sec. 15, Par. 1)

7. How many fins would a 2-foot coil contain? (Sec. 15, Par. 2)

8. How would you straighten the fins on a coil? (Sec. 15, Par. 4)

9. Why is a brine solution used as a coolant in an air-conditioning system? (Sec. 16, Par. 1)

10. Which type of pressure loss is caused by an elbow in the duct? (Sec. 17, Par. 2)

11. Why isn't the velocity reduction method used for sizing duct for complex systems? (Sec. 17, Par. 4)

12. A system with a velocity rating of 2400 f.p.m. is considered a _______________ system. (Sec. 17, Par. 6)

13. How are duct joints sealed? (Sec. 17, Par. 9)

14. What type of material would you construct a duct with if corrosive fumes are to be handled? (Sec; 17, Par. 12)

15. What occurs when air flows from a small chamber to a large area? (Sec. 17, Par. 16)

16. What is the loss of cooling effect of a 12-square foot duct with a temperature differential of 10° and a U-factor of 1.14? (Sec. 17, Par. 18)

17. Where does most duct air leakage occur? (Sec. 17, Par. 22)

18. How much air is required when the sensible heat load is 49,000 B.t.u./hr. and a temperature change is 15°? (Sec. 17, Par. 25)

19. How can you determine the vertical flow of air from a grille? (Sec. 17, Pa. 34)

20. The horizontal airflow pattern is controlled by the _______________ _______________ of the grille. (Sec. 17, Par. 34)

21. Which type of diffuser is the hardest to use for balancing? (Sec. 17, Par. 38)

Controls

YOUR BRAIN is a control system. It controls your movements and it responds to various situations. Have you ever touched something hot? You really let go of it fast, didn't you? The control system of an air conditioner acts like a brain. It senses a change and responds with a corrective action.

Three types of control systems will be discussed. These are motor, electric, and pneumatic controls. Responsive devices sensitive to temperature, pressure, and humidity will also be studied.

18. Responsive Devices

1. Most automatic controls function because they are responsive to changes in temperature, pressure, and humidity. We will discuss the various responsive devices that you will encounter in your control system.

2. **Temperature-Responsive Devices**. Many of the automatic control units such as the thermostat, fan switch, etc., must be responsive to temperature changes. The temperature change actually makes and breaks electrical contact within each unit.

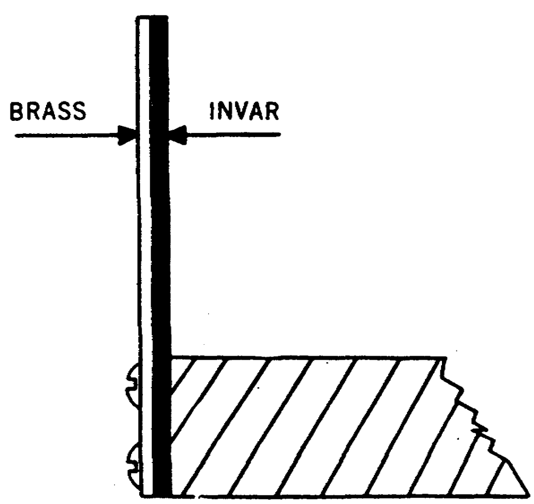


Figure 25. Bimetal strip.

This action is an indicating signal transmitted to the primary control for specific action such as starting or stopping the operation of a piece of refrigeration equipment.

3. *Bimetal strip*. To accomplish the above specific action, the automatic control unit may be equipped with a bimetallic strip. This strip is made by welding together two pieces of dissimilar metals such as brass and "Invar," as illustrated in figure 25. At a certain predetermined temperature, this strip does not deflect or bend. However, when the strip is heated, it will tend to bend in the direction of the metal which has the least amount of expansion, as shown in figure 26.

4. By welding two electrical connections and contacts to the arrangement shown in figure 27, an electrical switch is constructed. This switch can be used to control an electrical circuit responding to temperature changes.

5. The bimetal strip is the basic principle of operation of many of the temperature responsive automatic units. However, some units may be operated by a bimetallic strip in the form of a

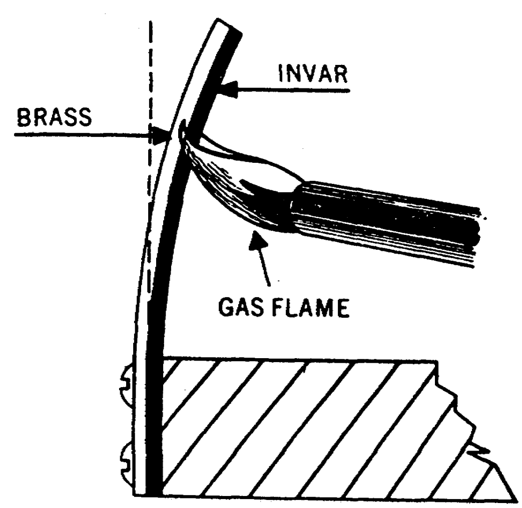


Figure 26. Bimetal strip being heated.

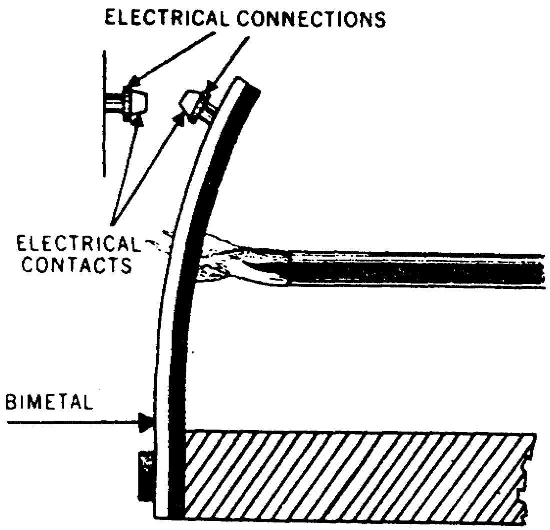


Figure 27. A bimetallic switch.

spiral, a U-shape, a Q-shape, or even a helix, as shown in the illustrations in figure 28.

6. *Vapor-tension device*. Another very common type of temperature-responsive device is one in which the effects of the temperature changes are transmitted into motion by a highly volatile liquid. The most commonly used vapor-tension device of this type is a simple compressed bellows, shown in figure 29. It is made of brass and partially filled with alcohol, ether, or some other highly volatile liquid not corrosive to brass. When the temperature around the bellows increases, the heat gasifies the liquid, causing the bellows to extend and close a set of electrical contacts, as shown in figure 30. When the bellows cool, they contract and open the electrical contacts. This vapor-tension principle also is used to operate some of the automatic control units.

7. *Remote-bulb device*. Not all the liquid-filled devices are limited to just a simple bellows as described above. There are remote-bulb type devices that not only have bellows but also have a capillary tube and a liquid or gas-filled bulb, as shown in figure 31. When the liquid or gas in the bulb is heated, part of the liquid gasifies or the gas expands and forces its way through the capillary tube into the bellows. The increase of pressure inside the bellows causes the bellows to extend and close a set of electrical contacts. When the bulb cools, the gas liquefies, causing a decrease of pressure in the bellows. This causes the bellows to contract and open the set of electrical contacts.

8. **Pressure-Responsive Devices**. Pressure-responsive devices are incorporated in refrigeration and air-conditioning systems to operate and regulate valves, controllers, operators, etc.

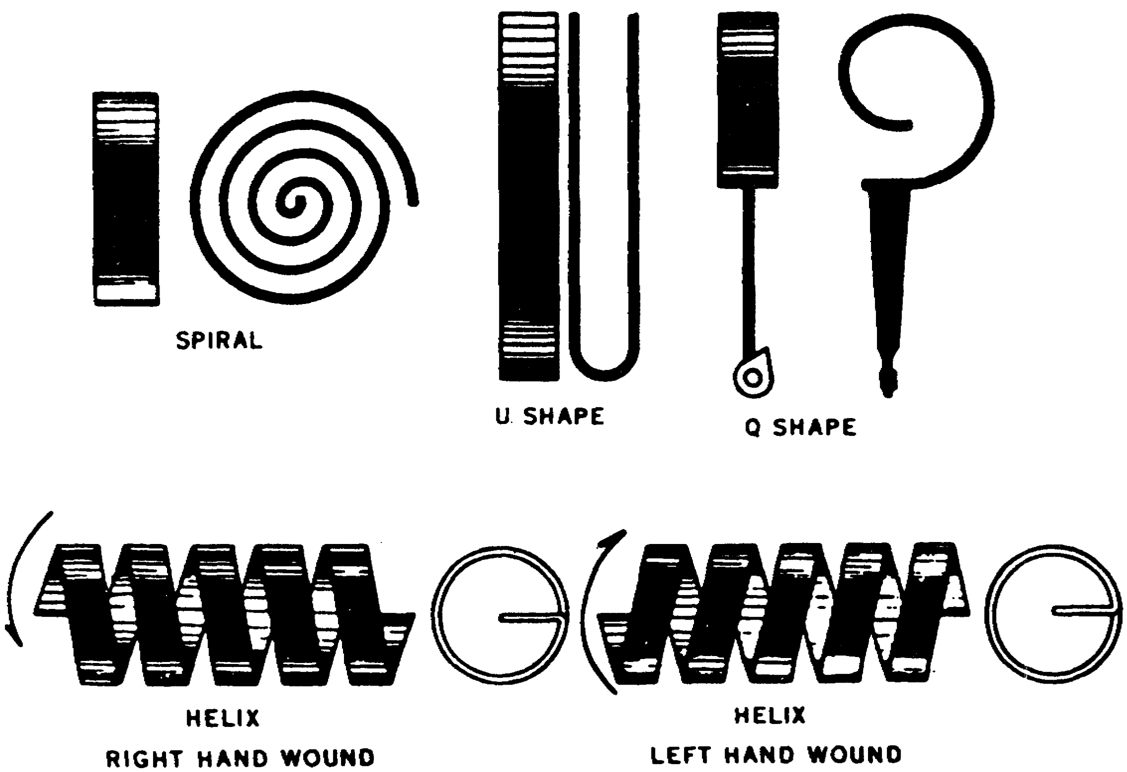


Figure 28. Various shapes of bimetal strips.

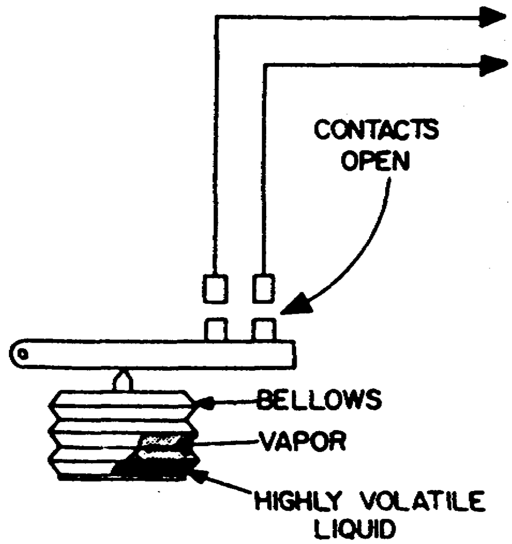


Figure 29. Bellows contracted when cooled.

9. *Bellows*. One type of pressure-responsive device uses the action of a bellows in a similar way to the remote-bulb device mentioned previously. In this case the bellows extends and contracts in response to the changes in pressure. The action caused by the movement of the bellows opens and closes a set of electrical contacts.

10. *Bourdon tube*. Another pressure-responsive device used in a pressure gauge is illustrated in figure 32. In this unit the pressure acts inside a hollow, flattened, bent tube called a Bourdon spring tube. The pressure inside the tube tends to straighten it, moving the mechanism which turns the pointer. The pressure gauge measures pressures in pounds per square inch.

11. **Humidity Responsive Devices**. Humidity-responsive devices e regularly used to cause the opening or closing of solenoid or motorized valves which, in turn, control the flow of water or steam to the humidifying equipment.

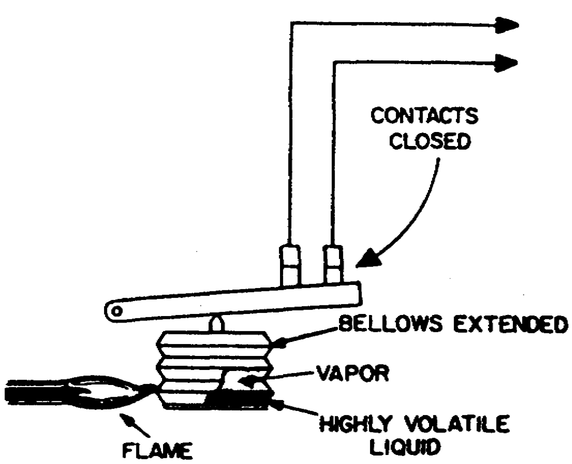


Figure 30. Bellows extended when heated.

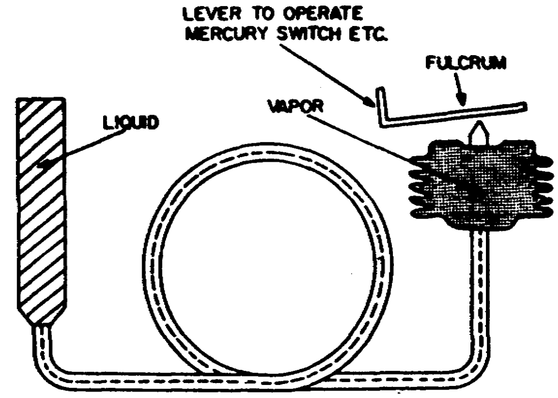


Figure 31. Remote bulb device.

12. Humidity-responsive devices are designed with sensing elements which am very sensitive to humidity changes. Usually these sensing devices activate the action of a switch. A typical humidity-responsive device is shown in figure 33. The sensing element in this device is a number of human hairs which lengthen when the humidity is high and shorten when the humidity is low. The lengthening and shortening action of the hairs moves the lever, which. in turn opens and closes the contact points to a humidifying unit.

19. Motor Controls

1. A motor control is similar to a switch installed in a motor circuit that opens and closes the power lead to the motor. The major difference is that the motor control acts automatically in response to temperature or pressure changes.

2. **Function of Motor Controls**. The function of any motor control is to maintain a relatively constant temperature within the refrigerated space.

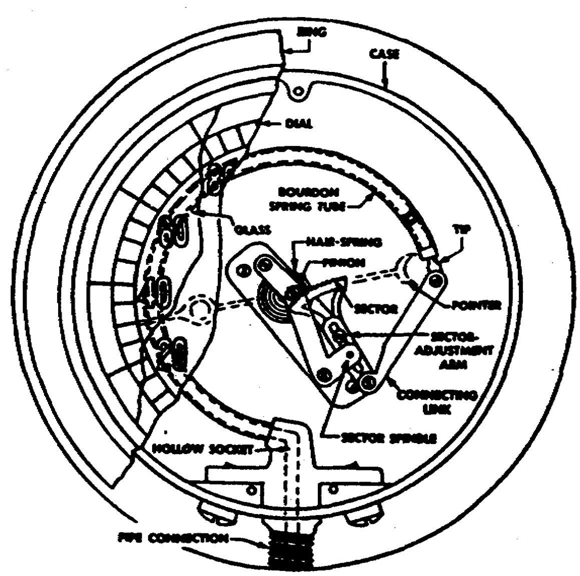


Figure 32. A pressure gauge showing the Bourdon tube.

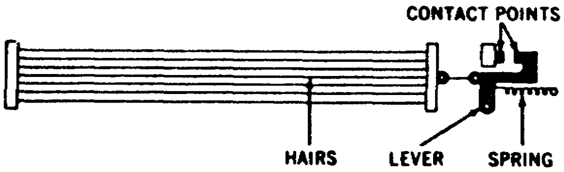


Figure 33. A humidity responsive device.

This may be done by starting the unit when the temperature rises and stopping it when the temperature reaches its set point (control is satisfied). The temperature is constantly rising and failing between predetermined set points (cut-in and cut-out).

3. **Low-Pressure Motor Control**. We can control the temperature of a refrigerated space through low side pressure. If we control low side pressure, we ultimately control the temperature of the refrigerant in the evaporator. A pressure-temperature relationship chart is needed for the following example. Our system contains R-12, and the desired space temperature is 40° F. Now, using the chart, we find that we must control the low side pressure at 37 p.s.i.g. Therefore, we have controlled temperature by pressure.

4. A bellows, diaphragm, or Bourdon tube is used to motivate the points in the low pressure control (LPC).

5. The differential, cut-out minus cut-in, is set by regulating the amount of force exerted upon the bar by the adjusting spring. There are many variations in the characteristics of individual types of motor controls. Each control has an adjustment of one kind or another. This allows the control a wide range of applications.

6. One of the more useful tools in control adjustment is the pressure control setting chart. The settings for most applications can be found by referring to this chart.

7. If the particular application desired is not found on this chart, the next approach to use is the pressure-temperature relationship chart.

8. Assume that the desired cut-in pressure is 25 p.s.i.g. and that the cut-out pressure is 10 p.s.i.g. The differential would be 15 p.s.i.g. Since most controls have only two setting. to make, cut-in and differential, we find that knowing the cut-out pressure is an important factor.

9. The two scales (one for cut-in and the other for differential) are located on the front of the control. The adjusting screws are located on top of the control. The adjusting screws are turned until the pointers indicate the pressures desired. Make sure that you read the scales very carefully. The unit should be allowed to cycle once. The cycling ON should take pace when the low side pressure is 25 p.s.i.g., and the OFF cycle should occur when the pressure drops to 10 p.s.i.g. These pressures may be observed on a gauge installed in the suction line.

10. **Thermostatic Motor Control**. The thermostatic motor control (TMC) operates on temperature rather than on pressure. These motor controls can be used on most types of refrigeration and air-conditioning units. They must be used on all units that utilize high or low side floats and capillary tube refrigerant control devices.

11. *Principles of operation*. The operating principle of the thermostatic motor control is based on a physics law which states that matter will expand when heated and contract when cooled. The power element uses this law in its function.

12. The element is a sealed container filled with a liquid, gas, or combination of the two. Any change in temperature surrounding the element will cause a pressure change within the element. The power element consists of three parts-a feeler bulb, capillary tube, and bellows. Any leak in the power element will render it useless.

13. The feeler bulb of the power element is located in suck a position as to be sensitive to any change in the temperature of the controlled space. For domestic units this location is right on the evaporator so as to control the evaporator temperature. It might also be fastened inside the refrigerated space.

14. Any rise in temperature will heat the bulb, causing the charge to expand. This expansion will be transmitted through the capillary tube to the bellows, causing the bellows to expand. Attached to the bellows and inserted into the housing to rest against one end of the lever system is a short push rod. The pressure of the power element will expand the bellows, pushing the rod against the lever. This lever will cause other levers to move, and the net result will be a set of electrical contact points closing. Closing of the points will cause the motor to start, and the unit will be in operation.

15. As the temperature at the feeler bulb drops, so will the temperature of the bulb. This causes a drop in power element pressure and will reduce the "push" on the lever system. Part of the lever system consists of a spring which counteracts the power element pressure. As the element pressure drops, the spring will pull the points apart and stop the unit.

16. When you turn the adjusting knob clockwise, the spring will become compressed, causing the cut-in temperature to rise. Compressing the spring puts more pressure in opposition to the power element and demands that the element heat up even more to overcome this increased pressure, closing the points. The converse (turning the knob counterclockwise) will decrease spring tension and lower the cut-in point

17. The TMC has a second spring that works in conjunction with the power element instead of

against it. This spring is used to set the "cut-out" temperature (on some controls) or the differential (on other type controls).

18. *Location of feeler bulb*. Normally, the feeler bulb will be tightly clamped to the evaporator. The TMC will operate on the evaporator temperature. The bulb can be located elsewhere if the situation demands it; some bulbs will be located in the cold box rather than on the evaporator. In this case the TMC will operate on the cold box temperature. On ice-making machines the feeler bulb should be located in the ice bin. In this application the TMC will shut the unit off when the ice level reaches the feeler bulb and cools it. When the ice level falls below the bulb, the bulb will warm up and turn the unit on. If the refrigerated space has forced air circulation, the TMC bulb should be mounted in the return airstream.

19. *Replacement*. The control mechanism is so delicately built that it is impractical to repair in the field. If operation is erratic because of power element failure, mechanical (lever) action failure, or contact point failure, you should replace the entire switch.

20. *Checking thermostatic motor controls*. Thermostatic motor controls are very delicate instruments. However, if they are not misused, they will give years of trouble free service. Thermostatic motor controls are subject to several troubles, each of which usually requires replacement of the complete control. Some of the more common troubles are treated in the following paragraphs.

a. Loss of Charge. Occasionally the power element will lose part or all of its charge. This charge is very small and any loss at all will cause the unit to fail. A kinked or clogged capillary tube will give the same indication as a loss of charge. Usually a power element failure requires replacement of the complete control. However, it is possible to get replacement power elements for some controls, although care must be taken to insure that you have the correct replacement item.

b. Burned Contacts. Even though there is snap action when the points open and close, they will burn. In such cases the points will either stick closed or become pitted and never close. In some cases the point can be filed and the control will operate satisfactorily for a period of time. Filing the points should be considered a temporary repair and the control should be replaced as soon as possible.

c. Wear. The parts of a TMC are light and do not move very far, but they do move many, many times each day. One should not become too concerned about wear unless the unit has been in use a long time. However, the TMC will wear out; when it does, remove and replace it.

d. Electrical. Low and high voltages, high current flow, frayed insulation, bad electrical contacts, and various other electrical malfunctions will cause the TMC to fail. Electrical troubles can often be determined and repaired without having to replace the control.

20. Electric Controls

1. There are many devices that may be used in single- or three-phase circuits. We will cover each of these devices and how they operate.

2. **Switches**. The two types of switches used in electric controls are the snap action and mercury. These switches help. to reduce the problem of arcing when a circuit is open or closed.

3. **Relays**. There are many types of relays used in electrical application. The type that we are interested in is the control relay. These are relays that open or close an electric circuit of higher voltage by the use of lower voltage. These relays might be defined as an electrically operated switch. The main use of this relay is to remotely control an electrical device such as a fan motor or pump.

4. **Control Transformers**. A control transformer steps voltage down to operate different kinds of electrical controls. Line voltage applies to wiring or devices using 110 or 220 volts. In control terminology, low-voltage control takes in all controls and controlled devices that use 25 volts or less.

5. **Magnetic Starter**. Three-phase motors must have at least two of the leads open to stop their operation. The device that opens these wires (circuit) is a line starter or magnetic starter. A magnetic starter is nothing more than a larger control relay which electrically operates two or more switch contacts.

6. **Trouble Analysis**. Before you can effectively troubleshoot a control circuit or system, you should know the circuit and how it operates. You can study the circuit in a wiring diagram of that particular circuit. Studying the diagram will give you a knowledge of the circuit as it should normally operate. If the system does not function properly, the circuit is defective and an analysis of the trouble and its location must be made.

7. *Types of trouble*. In practically all defective circuits, one .of the following types of trouble will exist:

a. Open-A circuit that has a break in any part of the circuit between the load and source.

b. Short-A circuit in which a conductor comes in contact with a point or object that it is not supposed to touch.

(1) Direct short-A circuit in which one of the hot conductors comes in contact with a neutral conductor. This type of short circuit will "blow" a fuse or trip a breaker because there isn't any resistance in the circuit.

(2) Cross short-A circuit in which two of the hot conductors make contact. This short will cause an electrical feedback even though one of the conductors is open.

c. Low power-This trouble causes units to operate improperly. Two effects are sluggish motors and dim lights. Low voltage may be caused by loose, dirty, or corroded connections as well as a low power source.

8. *Location of trouble*. As soon as you have studied the wiring diagram, the next step is to check out the circuits with the appropriate test equipment.

9. Opens may be checked with a voltmeter or by a continuity Lest. The continuity of a circuit may be checked by a continuity meter or light, an ohmmeter, or a bell. The power must be off when making continuity tests. An ohmmeter will indicate infinity across an open circuit, while the light or bell would not function.

10. A short can be located with an ohmmeter or by a continuity test. When checking a circuit with an ohmmeter, a zero-resistance reading indicates a short, and an infinity reading indicates an open. Remember, when using an ohmmeter to test a circuit, the circuit power source must be off.

11. **Major Advantages of Electrical Controls**. Electrical energy is commonly used to transmit the change in space condition sensed by the controller to other components of the system. This signal from the controller will translate into work at the final control element. For this purpose, electricity has the following major advantages:

a. Electric controls are available wherever there is a source of power.

b. Electric wiring is usually easy to install.

c. Electric power readily amplifies the relatively feeble impulse received from the sensing element.

d. The impulse received from the sensing element can be applied directly to produce one or several combinations or sequences in electrical output. This allows one actuator to perform several desired functions.

e. It readily permits remote control. The controller can be a considerable distance from the controlled space or element.

12. **Modes of Electric Controls**. All control systems do not use the same types of action to accomplish their purposes. The method by which a control system acts is called the control mode. We will discuss the two-position, proportional position, and floating controls.

13. *Two-position control*. In two-position controls the final control element occupies one of two possible positions (open or closed). The following is a list of systems that can use two-position control operation.

a. Domestic heating systems. (You may be called upon to calibrate and troubleshoot controls used on heating systems.)

b. Electric motors on unit heaters and refrigeration machines.

c. Water sprays for humidification.

d. Electric strip heaters.

14. There are two values of the controlled variable which determine the position of the final control element. Between these values there is a zone in which the controller cannot initiate an action of the final control element. This zone is called the differential gap. As the controlled variable reaches the higher of the two values, the final control element assumes one of its two positions, which corresponds to the demands of the controller, and remains there until the controlled variable drops back to the lower value. The final control element then travels to the other position as rapidly as possible and remains there until the controlled variable again reaches the upper limit.

15. There are two varieties of two-position control which have been developed. The first, and oldest, may be called simple two-position control. This has been more or less standard in the past and, as its name implies, it is fairly elementary. The second, which may be called timed two-position control, is a later development which is rapidly replacing simple two-position control.

16. In simple two-position control, the controller and the final control element interact in the manner previously described without modification from any source, either mechanical or thermal. The result is cyclical operation of the equipment under control. The controlled variable fluctuates back and forth between two values determined by the magnitude of the differential and the lag in the system. Since the action of the controller is such that it cannot change the position of the final control element until the controlled variable reaches one or the other of the two limits of the differential, these limits become the minimum possible swing of the controlled variable.

17. In simple two-position control, the controller never catches up with the controlled condition. Thus it corrects a condition that has already passed, rather than one which is taking place or is about to take place. Consequently, simple two-position control is applicable only to systems in which total system lag (including not only transfer lags but also measuring and final control

element lags) is small. For this reason, simple two-position control rarely finds application in comfort heating control, but lends itself to the control of certain industrial processes and auxiliary processes in air conditioning.

18. There is no single control point in simple two-position control. Rather, the controlled variable cycles back and forth between two extremes. It is convenient to think of the control point as being midway between the two extremes and offset as being a sustained deviation of this control point. Thus, offset is a shifting of the whole curve either up or down, and the mean value is either raised or lowered so that it no longer corresponds to a point midway between the upper and lower limits of the controller differential.

19. Offset (on a temperature control system, for example) is caused by the fact that the average value of the controlled variable must be lower under heavy load conditions and higher under fight load conditions in order that heat can be supplied at the lower or higher rate needed. At peak load the burner must remain on 100 percent of the time. Therefore the controlled variable cannot rise to the upper limit of the thermostat differential; otherwise the burner would be shut off. Likewise, under minimum load the controlled variable cannot fall to the lower limit of the differential or the burner would be turned on.

20. Since the amount of offset is limited in this way by the differential, it is usually a serious problem in simple two-position control unless it happens that a wide differential must be used.

21. The ideal method of heating any space is to replace lost heat in exactly the amount needed. With two-position control, this is obviously impossible since the burner is either "full-ON" and the heat delivered at any specific instant is either too much or too little. However, a close approximation of the ideal method .of heat delivery can be had by using timed two-position control. In this method of control, heat is delivered in measured quantities on a "percentage ON-time basis" so that fluctuations of the control point are, for all practical purposes, eliminated.

22. For example, suppose we have a domestic heating system with a two-position control which is required to make up a heat loss of 20,000 B.t.u. in 1 hour at a certain load. The total capacity of the burner is 40,000 B.t.u. per hour. This means that the burner will have to operate 30 minutes out of the hour, whether it is on for 30 minutes and off for 30 minutes, on for two 15-minute periods and off for two 15-minute periods, on for six 5-minute periods and off for six 5-minute periods, or any other combination in the same ratio.

23. In many cases the longer cycles would be unsatisfactory because the variations in temperature would be too great. Dividing the heat into the correctly sized packages, so to speak, and delivering them at the right time gives a closer approximation of the desired result.

24. In timed two-position control, the basic interaction between the controller and the final control element is the same as for simple two-position control. However, the controller responds to gradual changes in the average value of the controlled variable rather than cyclical fluctuations. The gradual changes modify the timing action to meet the changes in load.

25. Timing action may be provided mechanically, for example, by a cam mechanism. The chief disadvantage of this method is that only the relative duration of the ON and OFF periods may be varied with changes in load. The frequency remains fixed.

26. Thermal timing devices are more convenient and flexible. Placing side-by-side a heating element and a temperature-sensitive element controlling the power supply to the heating element creates a thermal timer. As long as the ambient temperature is within certain limits, the thermal timer will cool on its ON point, energize the heater, heat to its OFF point and deenergize the heater, again cool to its ON point, and repeat the cycle. As the ambient temperatures decline, the time required for the timer to heat to the OFF point increases, and the cooling time decreases. Thus the timer automatically changes the ratio of ON to OFF time. Moreover, the nonlinear shape of the heating and cooling curves may be utilized to vary the total cycle time also, and therefore the frequency of the cycles.

27. In the latest models of domestic heating thermostats, this principle is utilized by taking full advantage of the effect produced by the artificial heater long included as standard in similar thermostats. The ON and OFF points of the thermostat are fixed by adjustment of the setting dial, and a small offset in room temperature is allowed to measure changes in heating load so as to vary the timing pattern of the thermostat.

28. In the two-position "weatherstat system," the weatherstat, located outdoors, operates in essentially the same way by turning its own heat supply (and simultaneously that of the building or zone) on and off so as to maintain its own temperature within its differential. Here the ambient temperature variation which causes variation in the timing pattern is the full range of "effective" outdoor temperature (including the effects of sun and wind), which constitutes the heating load.

29. In electronic systems the ambient temperature at the timer or cycle is, in effect, held constant by means of an ambient temperature compensator, and the ON and OFF points are reset by remote temperature elements such as a room

thermostat, an outdoor compensator, or any other temperature controller suitable for this purpose either alone or in combination. Raising the operating range of the cycle is equivalent to reduction of the ambient temperature, and thus increases the percentage of ON time.

30. In whatever form the principle is applied, timed two-position control offers a great advantage over simple two-position control in that it greatly reduces the swings in the controlled variable resulting from a large total lag. Since the controller need not wait until it can detect cyclic changes in the controlled variable and then signal for corrective action, control system lags have no significant effect, and the lags in the heat source and distribution system serve only to smooth out the "humps" and "valleys" in heat delivery so as to approximate closely the results of a continuous-delivery system with proportional position control.

31. In timed two-position control, the addition of heat to the thermostat bimetal is a factor in offset.

32. In analyzing the cycle of a thermostat used in this type of control, you can see that the control point must vary if the bimetal is to heat and cool at different rates necessary to time the cycle for the various load conditions. As the outside air temperature decreases, the heat loss from the space increases, and the ON cycle of the burner must lengthen in order to replace heat lost at an increased rate. This means that the heating rate of the thermostat bimetal must be slower so that the burner will remain on longer. It also means that the cooling rate of the bimetal during the OFF part of the cycle must be faster so that the burner will come on sooner. Both of these demand that the difference between the bimetal temperature and the air temperature become greater. This difference is secured by a sustained deviation of the room temperature, which is called offset.

33. Quantitatively, in timed two-position control, offset is equal to the total added heat minus the manual differential of the thermostat. Total heat is equal to the difference between the maximum temperature of the bimetal and the temperature of the air surrounding it. Manual differential is the differential for which the thermostat is set.

34. Both offset and temperature swing can be reduced to negligible quantities by using a relatively narrow manual differential (such as 1 ½° or 2°) and a small amount of artificial heat applied directly to the sensing element.

35. *Proportional control.* If proportional control the final control element moves to a position proportional to the deviation of the value of the controlled variable from the set point. There is one and only one position of the final control element for each value of the controlled variable within the proportional band of the controller. Thus, the position of the final control element is a continuous linear function of the value of the controlled variable.

36. Because there is but one position of the final control element for each value of the controlled variable, a sustained deviation is necessary to place the final control element in any position other than the middle of its range (assuming the set point to be in the middle of the proportional band). Offset therefore becomes a major problem in proportional position control.

37. As an example, suppose we have proportional control of a hot water coil used in heating a room. Under ideal load conditions, the thermostat is in the middle of its proportional band, the coil valve is half open, and there is no offset. Now suppose that the outside temperature drops, increasing the load on the heating coil. At once, more heat is required in steady supply to replace the heat which is being lost from the room at a greater rate. To deliver the required heat, the coil valve must open further and remain in that position as long as the increased load exits. To do this, the temperature must deviate from the set point and sustain that deviation because the position of the final control element is proportional to the amount of deviation.

38. As the load condition increases from the ideal, offset increases toward colder; and as the load condition decreases from the ideal, offset increases toward warmer.

39. *Floating control*. Floating control is a mode of control in which the final control element moves at a predetermined rate in a corrective direction until the controller is satisfied or until a movement in the other direction is desired. The direction of movement corresponds to the direction of deviation of the controlled variable. Floating control is further divided into several subclasses, two of which are of interest to us:

a. Proportional-speed floating control in which the final control element is moved at a rate proportional to the deviation of the controlled variable.

b. Single-speed floating control in which the final control element is moved at one speed throughout its entire range.

40. Either is adaptable to systems having a fast reaction rate, a slight transfer lag, and a slow load change. In general, proportional-speed control can be used in systems having somewhat faster load changes than those operating successfully with single-speed floating control.

41. **Series 20 Control**. The series 20 control circuit acts to make and break an electrical circuit which results in two-position response. This con-

trol is designed for low voltage, two-position control of:

a. Motorized valves.

b. Motorized dampers.

c. Relays.

42. Series 20 control circuits are not "fail safe" and should not be used where continued operation of the controlled equipment would be hazardous if the power failed. Series 20 motors (and equipment under their control) remain in whatever position they happen to occupy at power failure.

43. A series 20 control circuit consists of one holding and two starting circuits. The motor rotates in one direction only, making a half turn each time one of the starting circuits and the holding circuit are completed. The holding circuit is made-at the beginning and broken at the end of each half turn by a cam and switch arrangement on the moor.

44. Figure 34 illustrates a complete series 20 control loop. The equipment includes a thermostat, an actuator, a valve, and a control transformer.

45. Let's assume that the temperature in the water tower drops to the set point on the thermostat. The bellows will contract, causing the R and B leads to contact. The starting circuit is now established. The motor is energized and starts to rotate clockwise. As the motor and cam rotate, the right blade of the maintaining switch makes contact with S-2, and the holding circuit is established. The holding circuit is independent of the starting circuit. Once it is completed, it furnishes current to the motor, regardless of the thermostat action.

46. When the motor shaft has rotated 180°, the cam opens contact S-1. All circuits are incomplete, the motor stops, and the steam valve is now completely open and will remain open until the red and white leads make contact in the thermostat.

47. You can see that this is going to cause a rise in temperature of the water. The rise in temperature will become sufficient to move the thermostat blade to contact the W lead. Now the starting circuit is reestablished. The motor is energized and begins to rotate once again in the clockwise position. As the motor and cam rotate, the left blade of the maintaining switch makes contact with S-l, and the holding circuit is established. Once again, the motor will rotate a 180° before the cam breaks the holding circuit.

48. The steam valve is closed and will remain there until the thermostat calls for it to open. The control of the valve in this manner will produce the two-position response which was pointed out before

49. **Series 40 Control**. The series 40 control circuit acts to make and break an electrical circuit which results in two-position response. This circuit is a line voltage control circuit which is switched directly by the single-pole, single-throw switching action of a series 40 controller. Series 40 is a two-position control and requires two wires. It can be used to control fans, lights, electric motors, and other standard line voltage equipment, as well as a series 40 controlled device and line voltage. The series 40 control circuit depends on the equipment under control as to whether it is "fail safe" or not.

50. In operation the equipment under control is energized when the controller switch is closed and deenergized when it is open. Normally the series 40 controller makes and breaks the load directly, as shown in figure 35. It is possible for loads to exceed the controller rating. In this situation a simple control relay is used between the controller and the load circuit.

51. Figure 35 shows a complete series 40 control loop. It includes a series 40 thermostat series 40 controlled device, and line voltage. The thermostat is sensing the temperature of the water. A drop in temperature below the set point causes the mercury bulb to rotate, allowing the mercury to close the circuit to the solenoid valve. The solenoid opens the valve and allows the steam to enter and heat the water. This cycle continues as the temperature changes, and you can see that this is ON and OFF control or two-position.

52. **Series 60 Control**. The series 60 control circuits make and break electrical circuits which results in two kinds of response. Series 60 controls can be used as two-position and floating response.

53. The series 60 two-position control circuit is similar to the series 20 except that series 60 is a line voltage circuit. It can be used for industrial application, using line voltage equipment and installations where single-pole, double-throw control of line voltage is required. It is not a "fail safe" control circuit and should not be used where it would be hazardous.

54. The series 60 floating control produces another response that is different from two-position. Series 60 floating control is commonly applied to motorized valves on tank level control systems, motorized dampers for static pressure regulation, and specialized pressure and temperature control systems.

55. The series 60 floating control circuit uses either low voltage or line voltage, depending on the equipment selected. The basic pattern of the floating control circuit is like that of the two-position circuit except that the motor is reversible and limit switches are substituted for maintaining switches.

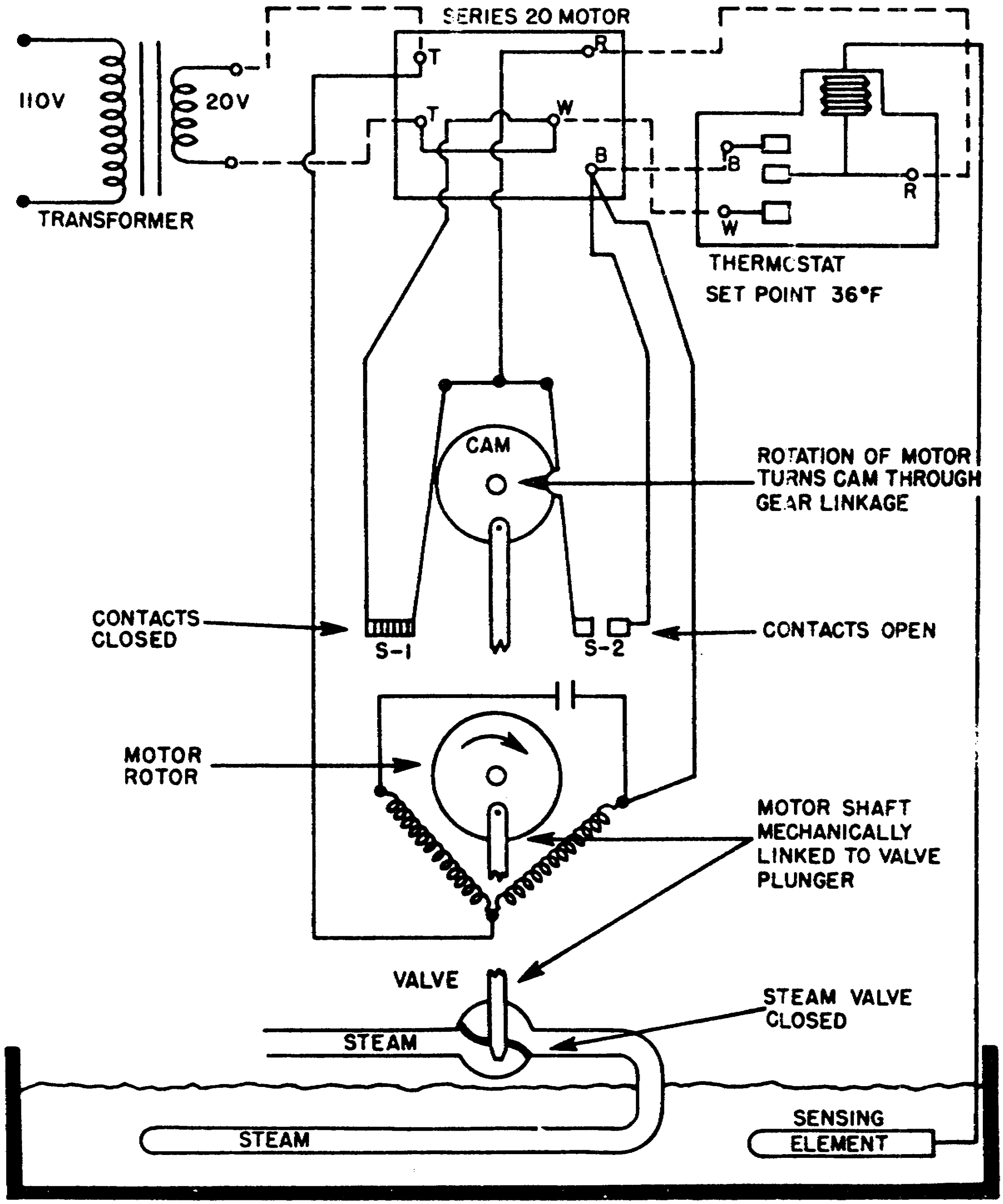


Figure 34. Series 20 control loop.

56. In floating control there is no fixed number of positions for the final control element. The valve or damper can assume any position between its two extremes as long as the controlled variable remains within the values corresponding to the neutral zone of the controller. Furthermore, when the controlled variable is outside the neutral one of the controller, the final control element travels toward the corrective position until the value of the controlled variable is brought back into the neutral zone of the controller or until the final control element reaches its extreme position.

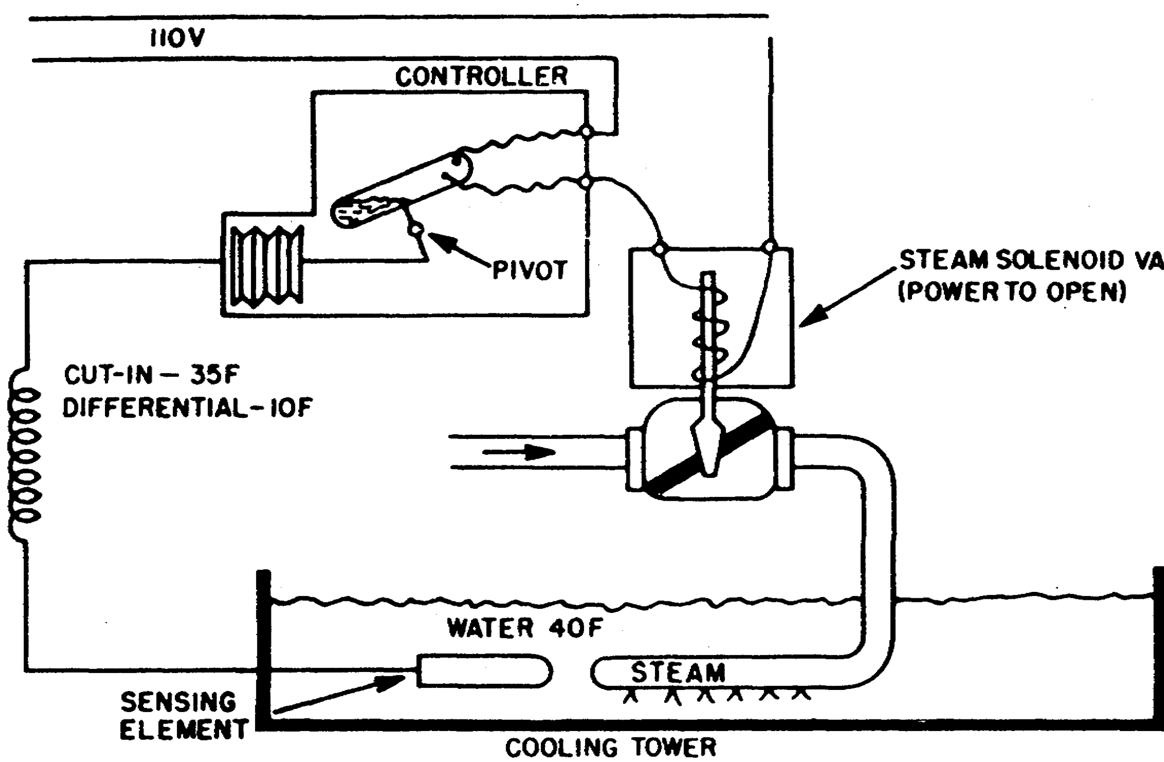


Figure 35. Series 40 control loop.

57. Figure 36 shows a series 60 two-position and floating control circuit. You can see that the two are different in the voltage operation as well as in the response.

58. Because of the close similarity of the series 20 and series 60 circuits, we will not discuss its operation to a great extent. The main difference is that the 60 operates on line voltage, whereas 20 uses low voltage.

59. Figure 36, B, illustrates a complete series 60 floating control circuit. The equipment includes a temperature floating controller and a floating control motor.

60. Referring to figure 36,B, when the temperature drops, the controller blade completes a circuit from contacts R to B. This causes the motor to energize by line voltage. The capacitor in the circuit causes the motor to turn clockwise, which will establish a corrective action of the final control element.

61. The motor moves at a single speed toward opening the valve. It will stop if sufficient heat is added to raise the temperature on the thermostat to open R and B. If not, it runs until the limit breaks and stops the motor.

62. On a rise in temperature, the thermostat closes R to W. This allows line voltage to go into the motor through W and once again energizes the motor. The capacitor in the circuit now causes the motor to rotate in the counterclockwise direction. The motor rotates, closing the valve, until the temperature is corrected or until the limit of its travel is reached by limit switch S2. The motor would remain here until heat causes a rise in temperature sufficient to cause the thermostat to float the blade back to the neutral position if the desired temperature is satisfied.

63. **Series 90 Control**. The series 90 control circuit acts to balance a bridge which results in modulating or proportional control response.

64. The series 90 control circuit is a low-voltage bridge circuit which operates to position the controlled device (usually a damper or motorized valve) at any point between full-open and full-closed. It can be used to operate motorized valves, motorized dampers, and sequence-switching mechanisms.

65. Figure 37 shows a typical application of a series 90 control circuit. The temperature of the equipment cooling space is being controlled by governing the amount of air that moves across the direct expansion (DX) coil. The thermostat modulates to control the modulating motor. The motor, in turn, proportionally controls the face and bypass dampers to control temperature.

66. Figure 38 shows how a balancing relay is made. The balancing relay is applied to the series 90 control circuit. The amount of current passing through coils 1 and 2 governs the position

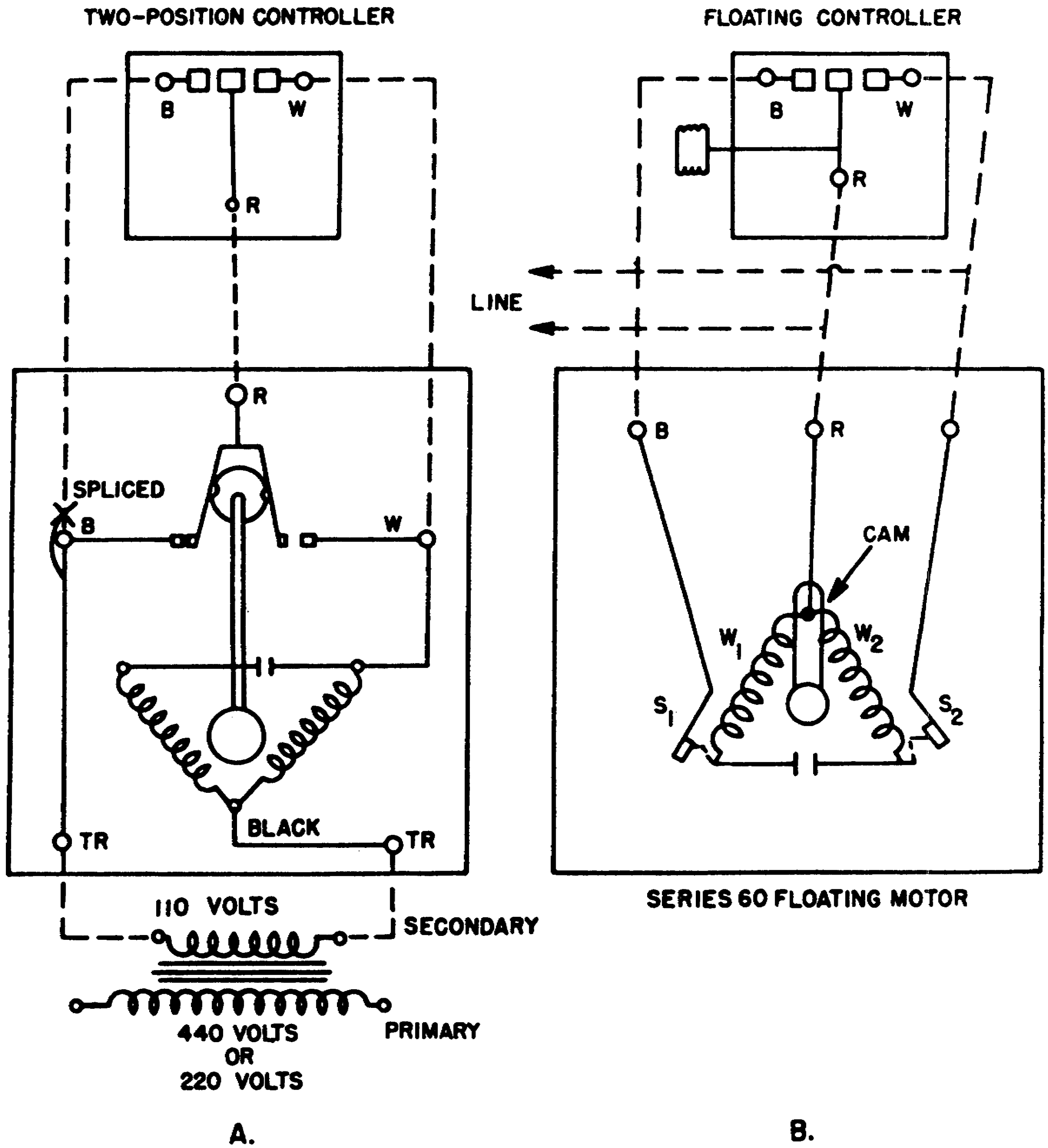


Figure 36. Series 60 control loop.

of the contact blade in respect to the two contacts of the motor.

67. When equal amount of current flow through both coils of the balancing relay, the contact blade Is in the center of the space between the two motor contacts, and the 24 volts cannot be applied to the motor. You see that there is current flow in each coil even though the motor isn't running.

68. In figure 38, if coil C_1 receives more current flow, and thus becomes stronger, the contact blade moves to the left and completes the circuit between motor winding W_1 and the transformer. Current also passes through the capacitor and W_2. The motor will rotate in the clockwise direction. When coil C_2 receives more current flow, the contact blade will move to the right and a circuit is made once again to the motor. The capacitor is now in series with winding W_1. You know that this causes the motor to rotate in the opposite direction now.

69. Figure 39 illustrates a bridge circuit which

is used in the series 90 control circuit. It consists of two potentiometers and the coils of the balancing relay. One potentiometer is located in the motor, and its wiper is moved by the rotation of the motor. The other potentiometer is in the controller, and its wiper is moved by the thermal system.

70. The thermostat is satisfied and the bridge is balanced. Power (24 volts) is applied to the bridge by the transformer. There is a path for current flow; in fact there are two paths for current flow. The left circuit has a total of 135 ohms resistance plus coil C_1. The right circuit has a total of 135 ohms resistance plus coil C_2. The amount of current flow is equal in both circuits. This is called a balanced bridge.

71. Figure 40 illustrates a complete series 90 control circuit. It consists of a modulating controller, modulating motor, and control transformer.

72. Referring to figure 40, you see by the dotted wipers that the temperature has increased. The wiper in the controller potentiometer is now at a new position on the resistance. The left circuit now has 97 ½-ohms resistance plus coil C_1. The right circuit now has 162 ½-ohms resistance plus coil C_2. Current will flow in the left and right circuit, as indicated by the arrows. According to Ohm's law (E = IR), 25 amps will flow through the left circuit and .15 amps will flow through the right circuit. As a result of the unbalance of the bridge, coil C_1 has a stronger magnetic field and coil C_2 has a weaker magnetic field.

73. Power is now applied to the motor windings, and the motor begins to rotate. The motor runs clockwise. As it turns clockwise, it moves the wiper on the motor potentiometer to the right, as shown. Now the circuits on the left and right are once again balanced in resistance. The balancing relay is balanced, and power is broken to the motor. The chilled water valve was opened during the change of the motor. The

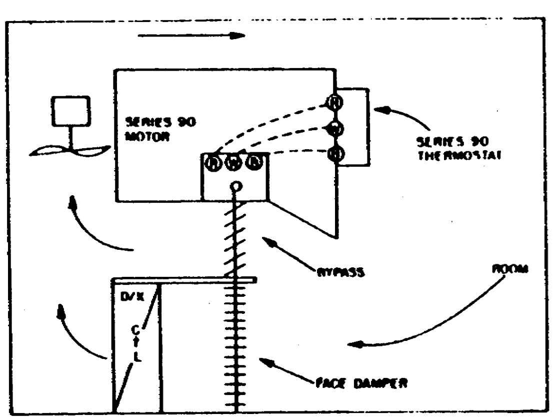


Figure 37. Series 90 application.

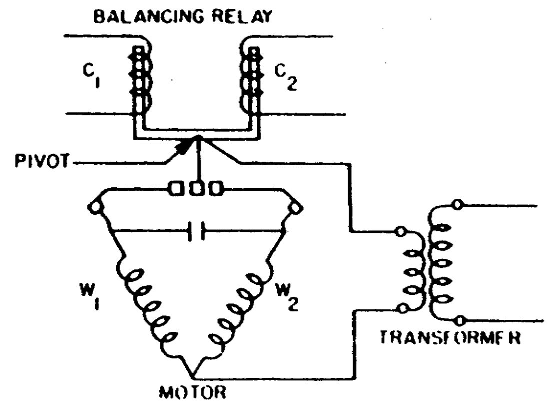


Figure 38. Series 90 balancing relay.

temperature rise indicates that more cooling is needed. The series 90 control circuit will continually reposition the valve to correspond to the changes in temperature.

74. Modulating control is a much better mode of control that two-position. As you have seen, any change with modulating control immediately causes a proportional change of the final control element. But we must remember that if we want to have more accurate control, it costs more.

75. **Electrical Actuator Adjustment**. We have discussed the electric controls that may be used to control temperature, pressure, flow, humidity, and any other variable. Those controls must be installed, adjusted, and calibrated properly before they are able to control those variables.

76. One of the important items that has to operate properly is the final control element, such as the damper, louver, valve, or any device that might be used to control the control agent.

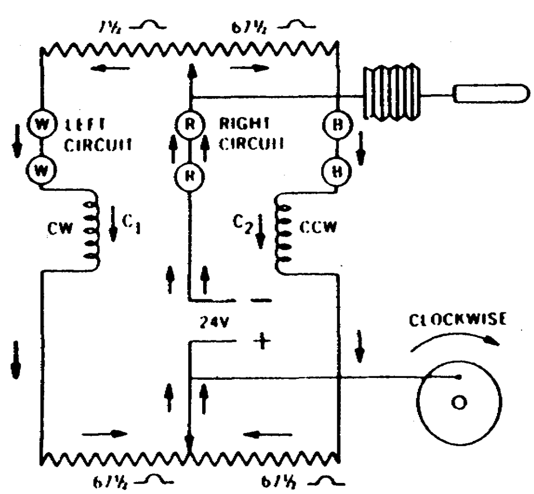


Figure 39. Current flow at one instant in a balanced bridge circuit.

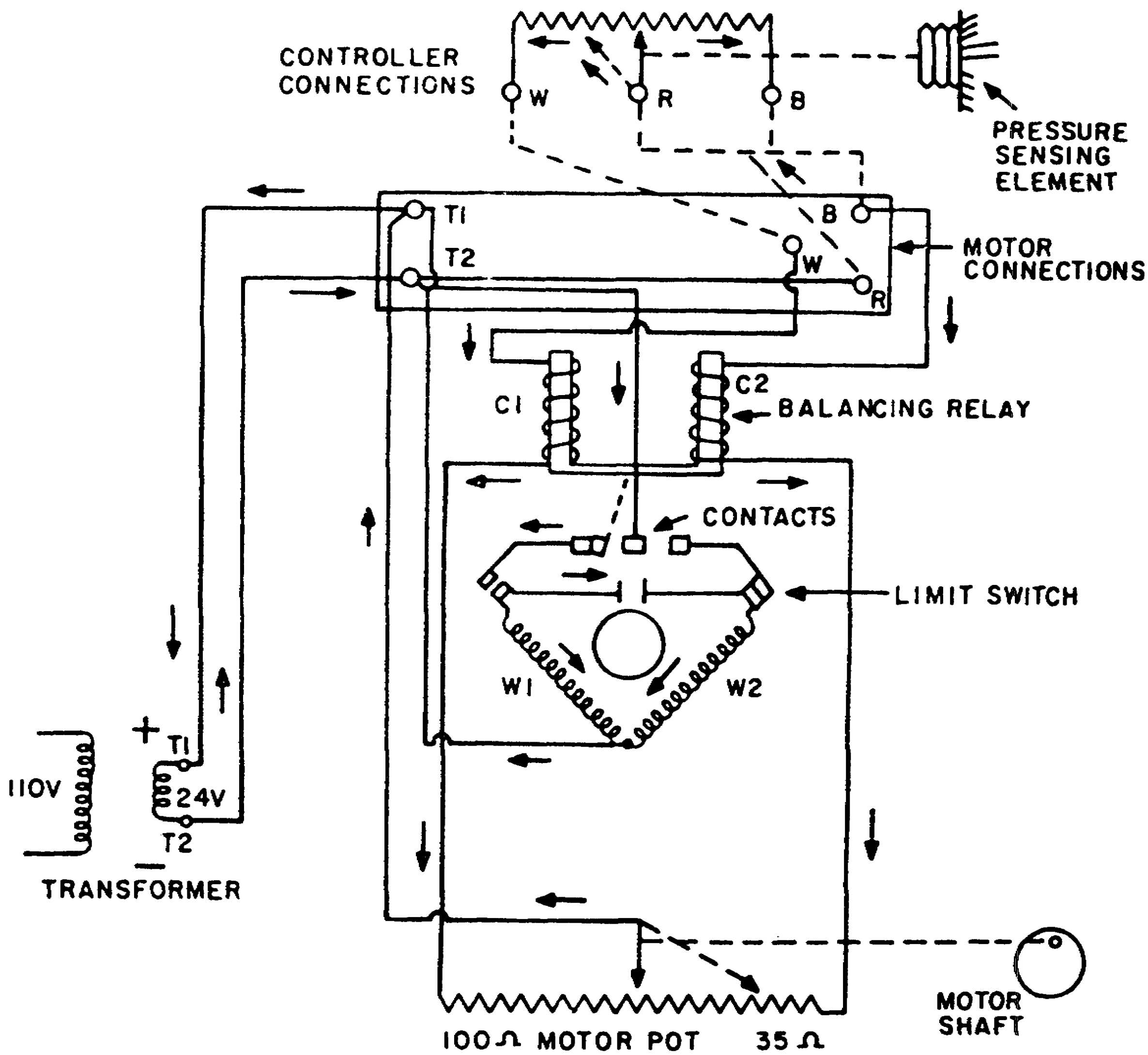


Figure 40. Complete series 90 control circuit.

77. For example, if temperature is being controlled, the control loop may be properly operating to maintain the temperature. But let us look at the control loop from the standpoint that the actuator isn't in adjustment with the chilled water valve. Now, the control loop cannot possibly maintain the temperature. Why can't the control loop be able to control the temperature? Well, look at figure 41 and we will see why.

78. Figure 41 illustrates a control loop in which the actuator is out of adjustment with the final control element. The temperature in the duct is below the set point. The controller sensed this and controlled the actuator (modulating motor) in a manner to compensate for the lower temperature.

79. The controller signaled the actuator to close the valve so that the temperature could increase. The actuator moved to this position, stopping at the extent of its travel. The linkage between the actuator and the valve causes the valve to remain open, so chilled water continues to flow through the coil.

80. With the actuator out of adjustment, the control system will not function properly. So we see why it cannot control. Therefore the actuator must be adjusted to the device it operates.

81. **Electrical Control Applications**. Electrical controls can be applied any time that a measured variable is to be maintained. As you have seen in the previous discussions, the controller senses the measured variable, and the final control element regulates the control agent to maintain the measured variable at a set point.

82. *Maintaining temperature in a space with series 90 control*. In figure 42, a system controlling temperature is illustrated. You can see that

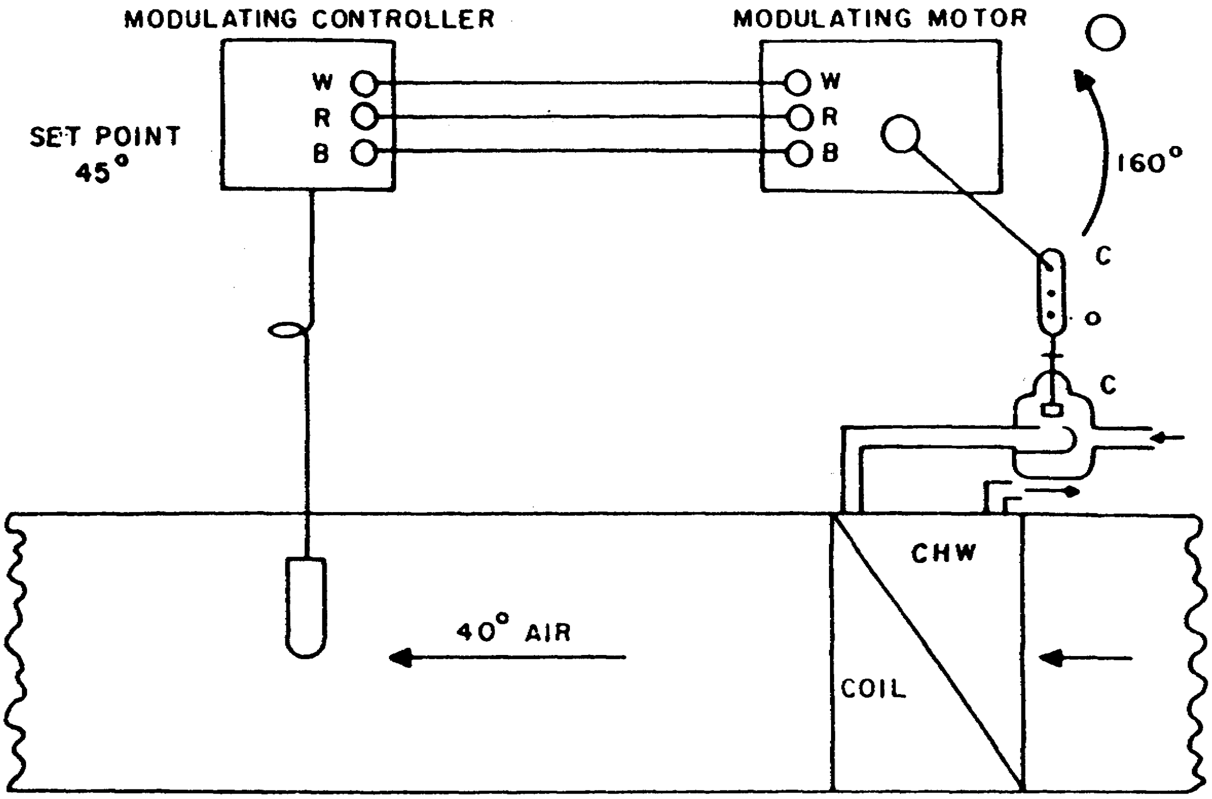


Figure 41. Actuator out of adjustment.

a series 90 modulating control circuit is being used to maintain the temperature.

83. The thermostat, T-l, is set to maintain a desired temperature of 72° F. If, for instance, the temperature sensed by the bulb is 72° F., the controller operates the motor to position the face and bypass dampers at a halfway position. This would mean that the bridge circuit of the series 90 control is balanced because the temperature is at set point.

84. When the temperature drops below set point (72° F.), the bridge circuit is unbalanced and the motor will run clockwise to close the face dampers and open the bypass dampers. This allows more air to pass through the bypass dampers. The result is less cooling because less air is cooling in contact with the coil. The series 90 motor runs until the bridge is once again balanced. The motor will hold the dampers in this position until the thermostat senses a temperature change which will once again unbalance the bridge.

85. When the temperature increases above set point, the bridge becomes unbalanced in the opposite direction. The controller now causes the motor to rotate in the counterclockwise direction. The motor now opens the face dampers and closes the bypass dampers. Now more cooling is produced because of the greater amount of air coming in contact with the cooling coil. The motor will run (opening the face dampers) until the bridge is once again balanced.

86. Operating in this manner, the temperature is controlled by this modulating control system.

87. *Maintaining relative humidity with series 90 control*. If we are to maintain humidity, it first has to be measured by a controller. The humidity controllers usually employ hair, leather, wood, or some moisture-sensitive element to sense humidity and to convert it into movement. This movement, in turn, operates the controller.

88. Looking at figure 43, you will see a modulating control system maintaining humidity. The humidity controlled senses the percent of humidity as the air moves through the duct. This control circuit operates in the same manner as the previous system which was maintaining temperature. The main difference between the two systems is the sensing device which operates the wiper in the controller.

89. As the humidity increases above set point (50 percent) the hair expands in length. This allows the spring tension to move the wiper arm on the potentiometer. The bridge is then unbalanced and the series 90 motor is started rotating counterclockwise. The motorized valve is modulated toward close due to the increased humidity. The motor will continue to run (closing the valve)

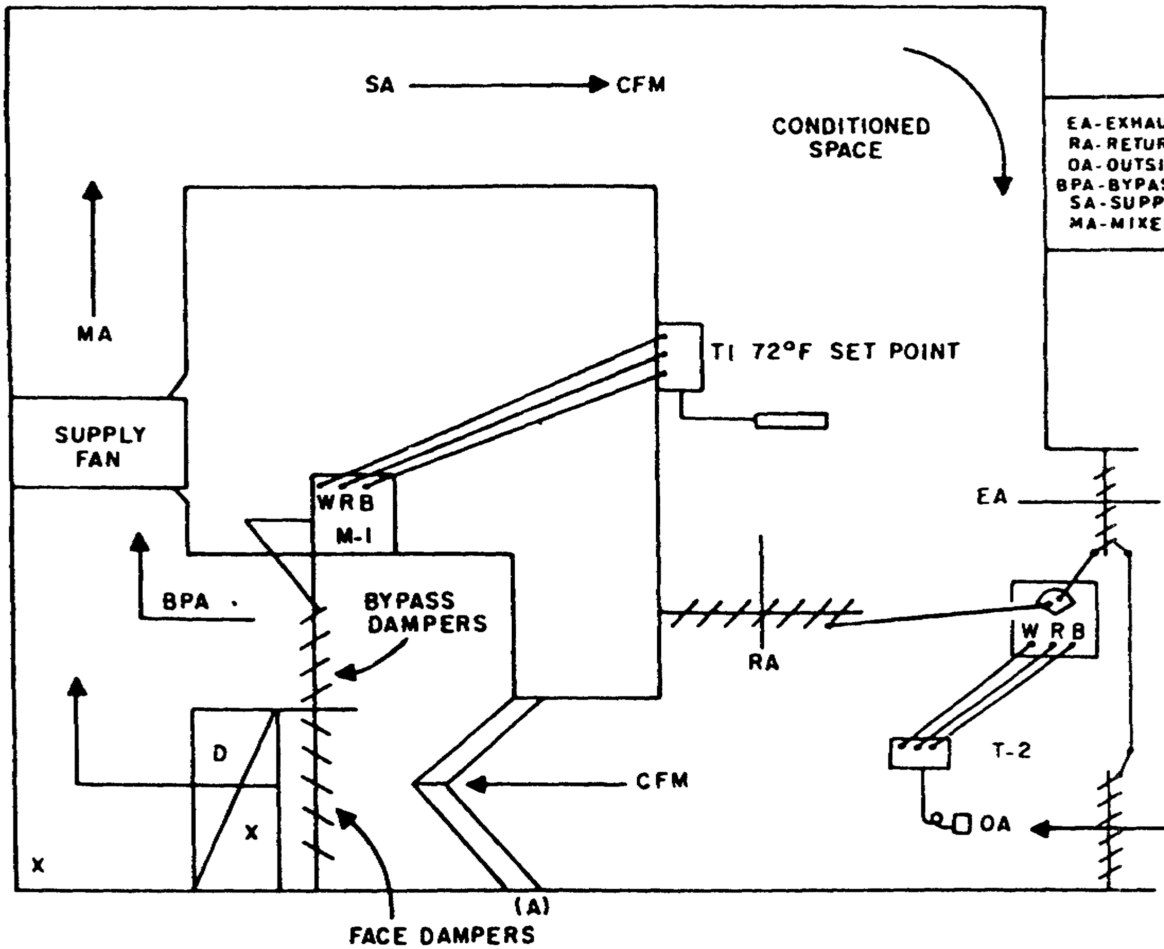


Figure 42. Maintaining temperature with a series 90 control.

until the potentiometer in the motor balances the potentiometer in the humidity controller.

90. The opposite action occurs when the humidity drops below set point. The bridge is unbalanced in the left circuit now. The motor rotates clockwise and modulates the motorized valve toward open. The motor will run (opening the valve) until the bridge is balanced. The system will remain here until the humidity changes.

91. *Maintaining temperature and relative humidity with high limit control*. A control system which maintains temperature and humidity at a high limit is illustrated in figure 44. The system is composed of several units that we have discussed before, but in this case they are used in conjunction with each other. The devices are a series 90 motor, thermostat, and humidistat.

92. The control circuit of the temperature control system with high limit humidity is diagramed in figure 45. As you can see, the series 90 thermostat has two potentiometers. The wipers of these pots are moved by the temperature sensed by the bulb ("pots" is short for potentiometers).

93. The front pot forms a bridge circuit with the series 90 motor that operates the face and bypass dampers. The only thing abnormal in this part of the temperature circuit is the pot of the humidistat being in the blue wire of the right circuit

94. The rear pot forms a bridge circuit with the series 90 motor which operates the reheat valve. The rear pot is somewhat out of line with the front pot. A factory calibration, the "dead" spot is about 7/64 inch. You can see in figure 45 that the wiper in the rear pot cannot start to operate the reheat valve at the instant the front pot wiper reaches B. The temperature must drop farther for the rear wiper to reach W, where it will begin to unbalance the bridge circuit.

95. If you will refer to figures 44 and 45, we will discuss the operation of the control system and its circuit as it functions to maintain the temperature and relative humidity at a high limit. The set point is 72° F., which the control system strives to maintain. We have seen that the face and bypass dampers will be at midposition when the temperature is at set 'point. It will modulate the face and bypass dampers to control the temperature. The system operates in this manner until the humidity reaches the high limit.

96. Let us go through the operation when the humidity increases above the high limit. This

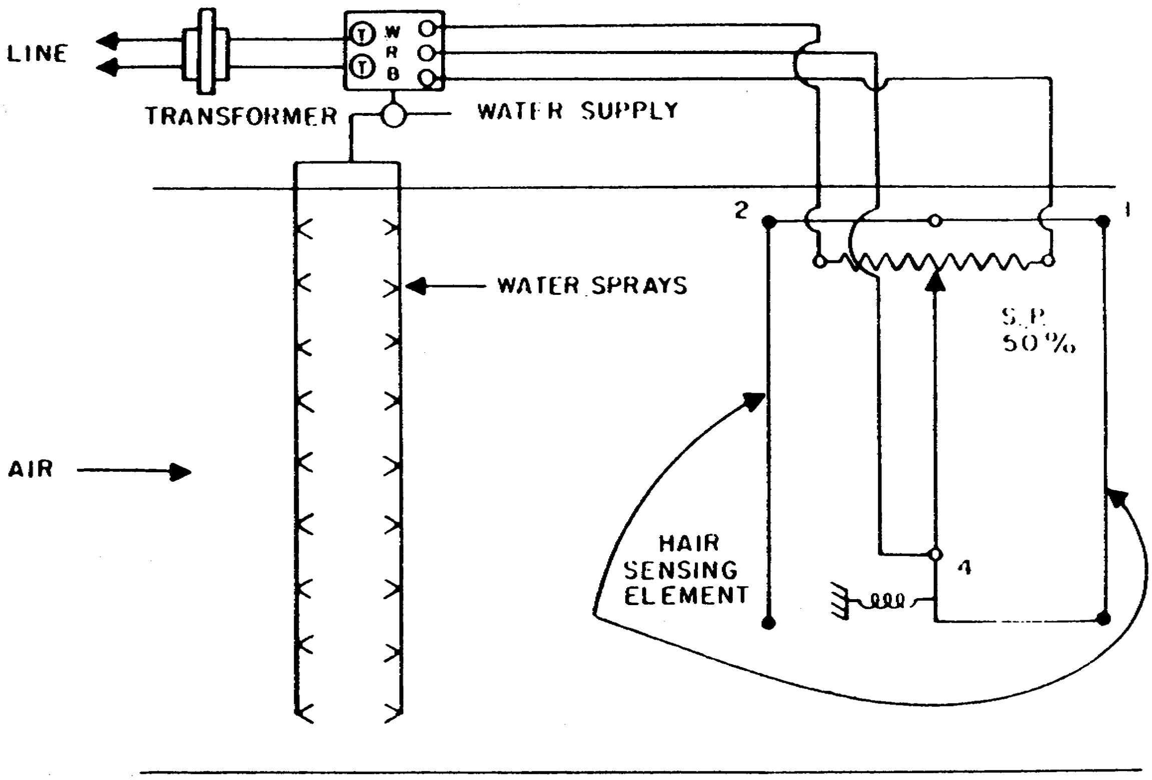


Figure 43. Maintaining relative humidity with a series 90 control.

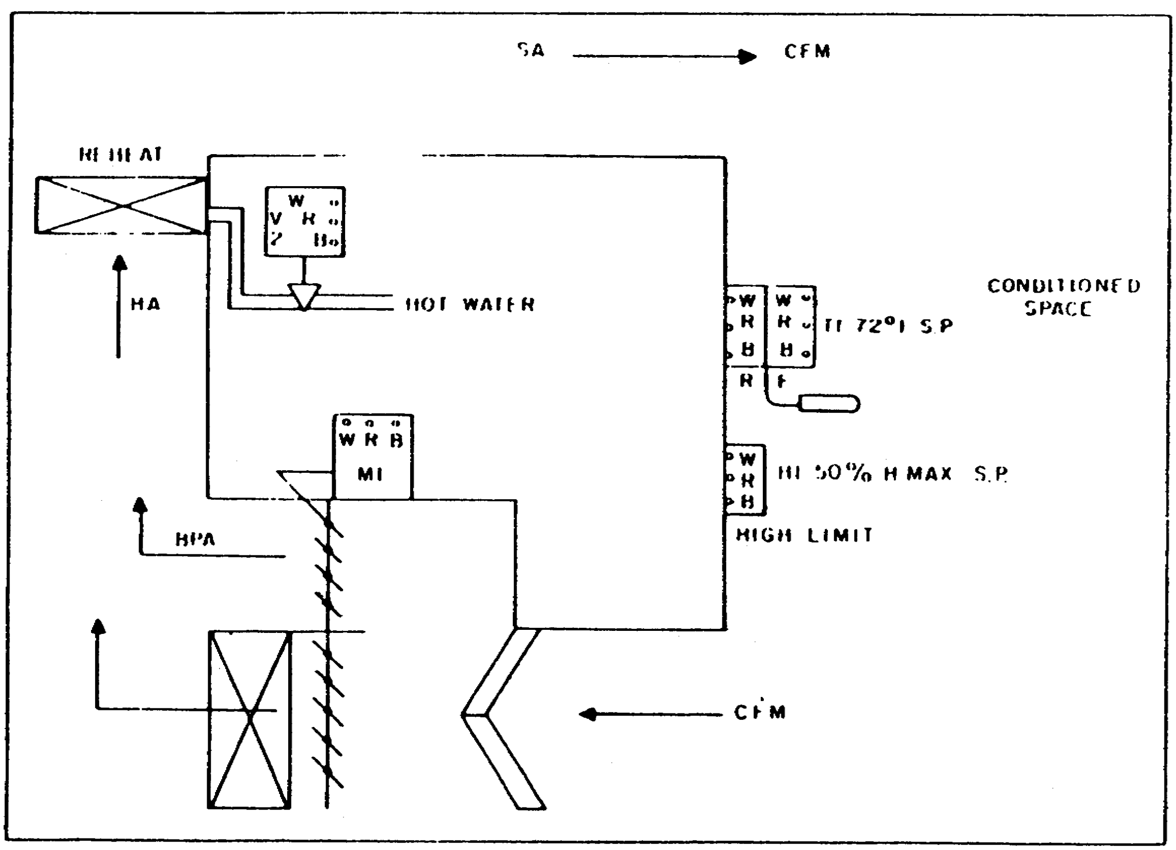


Figure 44. Maintaining temperature and humidity with a high limit humidity control.

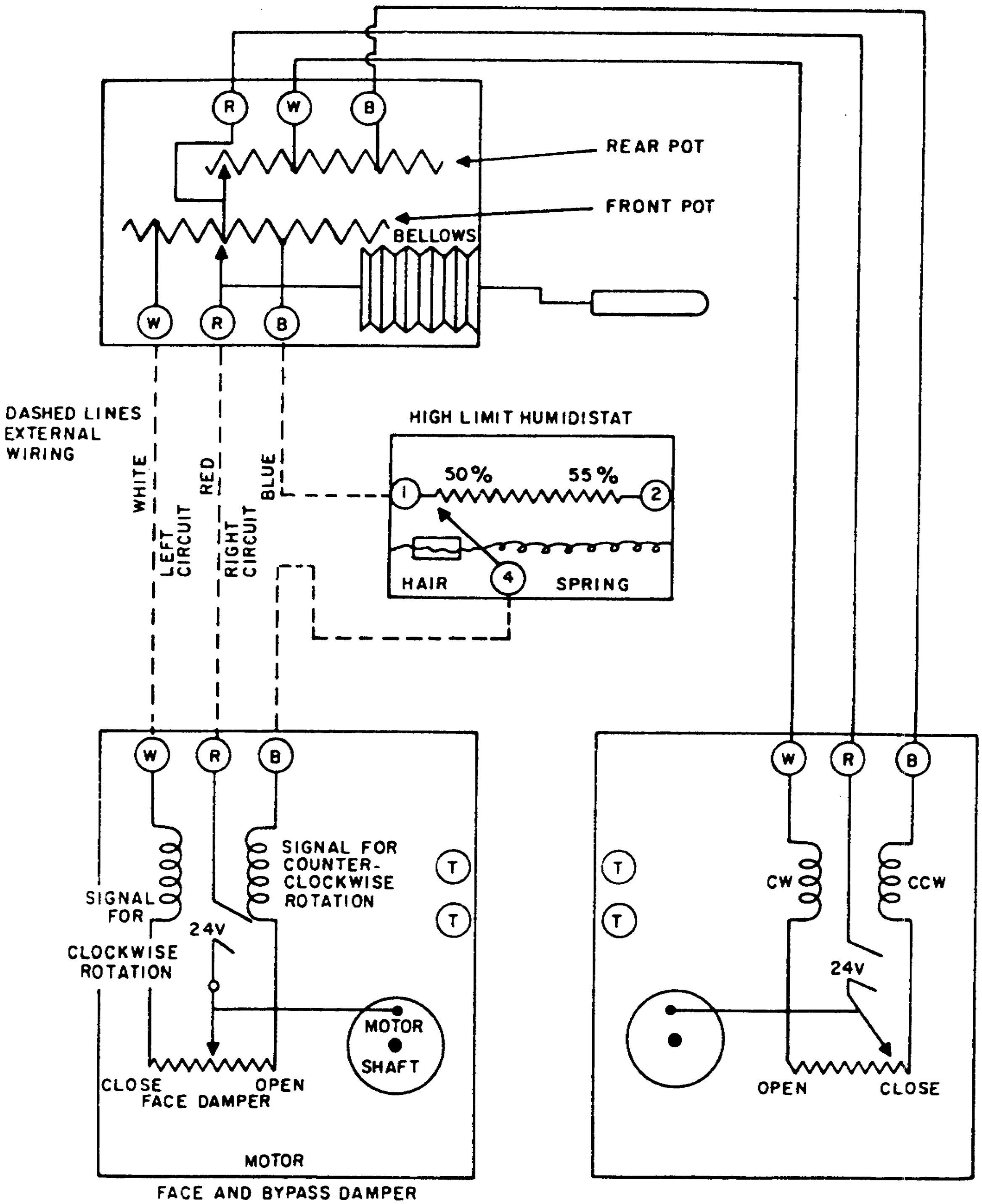


Figure 45. Temperature and high limit humidity control circuit.

causes more resistance to be placed in the right circuit. The motor runs clockwise, opens the face dampers, and closes the bypass dampers. Of course, this allows more of the air to come in contact with the coil. As a result, a greater amount of moisture is removed from the c.f.m. moved through the duct. In other words, the high limit humidistat overrode the thermostat and caused the face damper to open more than the thermostat wanted it to open. Naturally, if the face damper is open more than the thermostat is calling for it to open, the room temperature will drop below the desired value.

97. The rear pot of the thermostat now comes into action. The drop in temperature causes the rear wiper to begin unbalancing the bridge circuit

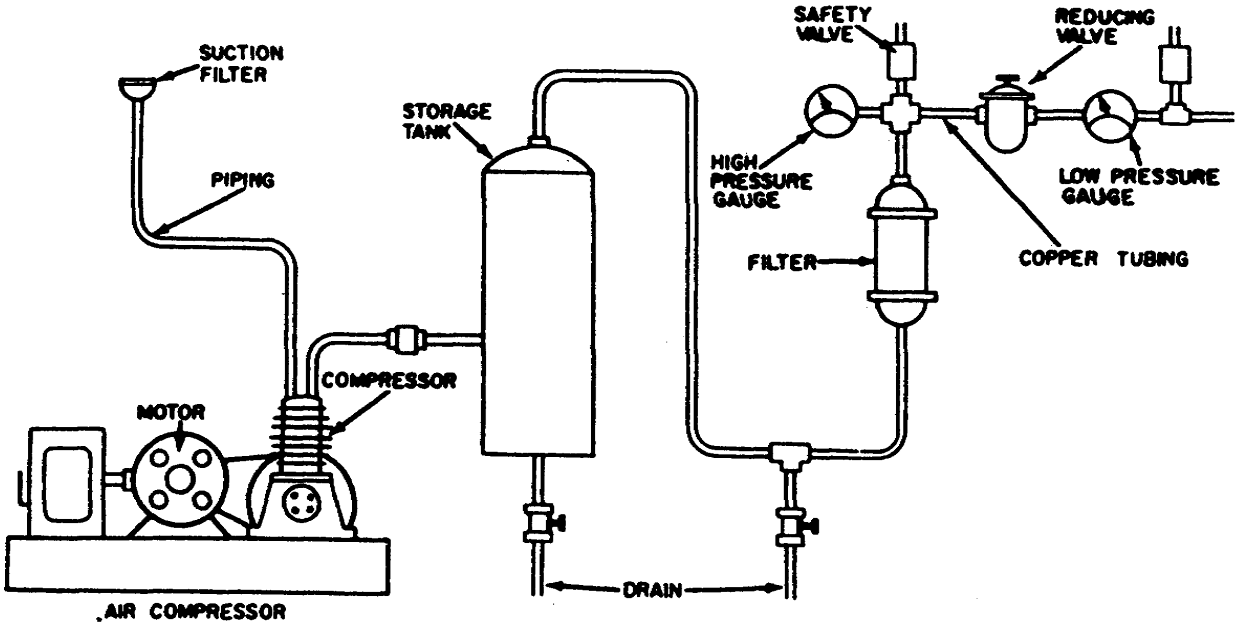


Figure 46. Air compressor station.

of the reheat valve. The reheat valve brings the temperature back up to the desired amount by adding heat through the steam coil. When the sensible heat is added, it also lowers the relative humidity. The temperature and humidity both have now been satisfied for the desired conditions. This system continually strives to maintain temperature and a maximum humidity within the limits of the controllers.

21. Air Supply

1. Almost all large air-conditioning systems require a supply of compressed air. It is used to operate valves, controllers, transmitters, thermostats, humidistats, receivers, etc. Such air can be furnished to an installation by two possible sources:

a. Compressed air may be available in the building by a remote compressor system.

b. Compressed air may be furnished by a compressor station installed within the building. Figure 46 illustrates a simple, typical air-supply system. It consists of a compressor, storage tank, filter, pressure gauges, safety valve, pressure reducing valve, etc.

2. **A Compressor Components**. Compressors are made in a number of different sizes and designs. They are driven by electric motors or gasoline engines. Some are the single-stage type, while others are of the multistage type. The multistage compressor is designed to develop higher pressures than the single-stage unit. Compressors are cooled either by air or by a liquid coolant. Compressor units are mounted in a variety of ways: stationary, on skids, and with single or several wheels which have rubber tires or steel rims.

3. Most of the air compressors installed in large buildings are anchored tightly to the floor and are driven by an electric motor. The compressor is connected to the motor by a belt-drive arrangement. Belt-driven compressors usually have more than one belt. If one belt needs changing, they all must be replaced. New belts should be adjusted to specifications and then checked regularly because they sometimes stretch. The air compressor is very similar in construction to the refrigeration compressor. Care and maintenance procedures are the same.

4. *Air cleaners and filters*. The air in an air compressor must be clean to protect the air compressor and other controls and equipment operated by the air pressure. A defective air cleaner will not filter the air. The minute particles in dirty air are apt to restrict the flow of air, reducing the efficiency of the compressor and operating air controls. Air cleaners may be constructed of screen mesh or may be a filter disc type. No matter what type cleaner is used, it must be serviced periodically. Operating conditions will determine the service requirements. Regardless of how frequently a cleaner is serviced, you must never use a volatile cleaner such as gasoline or diesel fuel for cleaning purposes. A nonvolatile cleaner is required because, as the air is compressed, it generates heat and the combination of compressed air and fuel plus generated heat leads to explosions. The higher the compressor pressures are, the higher the temperature and the greater the emphasis which must be placed on safety precautions. A bomb explodes because the internal pressures

are greater than the housing can stand. Therefore, several safety devices are built into the air compressor systems.

5. For efficiency and safety, air enters the filter and passes on to the low-pressure cylinder. As air leaves the low-pressure cylinder, it is cooled in the intercooler before being compressed in the high-pressure side. The air must be cooled again in some manner because heated air doesn't have the body that cold air has under pressure.

6. To clean a dry pad filter, shake out the dirt from the element and blow air through the filter in a reverse direction. Then clean the filter with a nonflammable cleaning fluid.

7. *Controls*. Safety controls are required for a compressed air unit. Pressure regulators, relief valves, safety valves, pressure switches, etc., are some of the devices for control of compressed air and compressor operation.

8. Relief valves' are installed in the receiver and intercooler to relieve excessive pressures. Relief valves and safety pop valves are usually set at the factory and the setting should not be changed, although some units may be disassembled for inspection. Some installations require special valves in addition to the standard relief valves. If a valve is disassembled for service, all parts should be thoroughly checked. Proper operation of safety valves is very important, as the name implies. Excessive internal pressures can cause the air compressor unit to explode, so be sure that only recommended procedures and parts are employed when servicing a valve. Cleaning is also important so that this valve will not stick open, thus causing the second-stage pressure to drop to zero.

9. *Intercooler*. In the compressor the air is compressed and then sent into an intercooler, where it is cooled. The intercooler consists of a tank with coils through which air or water is passed to cool the compressed air. Under normal operating conditions the air can be kept at a reasonable temperature by use of aftercoolers. The aftercooler is generally located between the air compressor and storage tank. Its function is to cool the air to a desirable temperature and to condense moisture out of the air.

10. *Air tank*. The air tank is a storage facility for the compressed air. This tank is a sealed unit and will require minor maintenance. All piping connections must be fit tight, and valves adjusted according to specifications. The air tank is generally located in a cool place for efficient unit operation.

11. *Chemical drier*. A means of removing moisture from the air is the use of a chemical drier for absorbing moisture. After the chemical in the drier has become saturated with moisture, it must be reactivated by heat or be replaced. The drier in the air compressor system is in many ways similar in construction to the type of dehydrator used in a refrigeration system. The dehumidifying cartridge containing the chemical is generally placed in the pressure line. One type of chemical that has been successfully used is calcium chloride. Refer to the manufacturer's manual for recommended procedures for cartridge reactivation or replacement.

12. *Motor*. The motor size will vary with the compressor size. Refer to the motor nameplate data for specification. Maintenance such as cleaning and lubrication should be done periodically.

13. *Traps and drains*. Traps and drains are used to remove moisture that may have accumulated in the system. The size of the air control system will determine the number of traps and drains that are used. These components must be cleaned periodically to remove any moisture that may have collected in the system. Refer to control air system diagram for actual location of these components. Generally, a trap or separator is located near the aftercooler

14. *Gauge*. Gauge locations will vary with each control air system. Most gauge locations are visible to the operator so that he can make an accurate reading on the air pressure. The air pressure must remain constant for accurate control operation; therefore a close inspection must be maintained on gauge readings. If there is a variation in air pressure, the cause must be found immediately and corrected.

15. **Maintenance**. Before starting the compressor, make sure the crankcase is filled to the proper level with a recommended grade compressor oil. The crankcase is filled to the line on the oil indicator or oil level elbow located near the bottom of the compressor base. All compressor parts are oiled from this base reservoir. A close check must be periodically maintained on the oil level for proper lubrication.

16. If the compressor is new, it should be drained and refilled every 2 weeks of constant operation. When the compressor is "broken in," drain and refill after every 2 or 3 months of daily operation or the equivalent.

17. The unit must be kept clean, since dirt is responsible for most compressor troubles. The air filters should be checked periodically and cleaned weekly with a nonexplosive solvent or by blowing air through the filter media. Make sure dry filters are free of all moisture. The screen type filter should be dipped in oil for better filtering action.

18. Special care must be given to make sure that all components are free of moisture. The air storage tank must be drained of moisture at least once a week and, if necessary, more often. Chem-

ical driers are used for extracting moisture from the air in excessively humid areas.

19. The belts should be tight enough to prevent slippage, but not so tight as to cause excessive strain on the motor shaft or bearings. V-belts require more slack than fiat belts.

20. Exhaust and intake valves may become dirty after a period of operation. This can result in valve leakage and cutting down on efficient compressor operation. Periodically, valves should be removed, inspected, and thoroughly cleaned. If they continue to leak after cleaning, they should be replaced. An indication of valve leakage is any dark spots on the valve seat or polished surface. Pop-off safety valves should be blown off every 6 months to insure against sticking. Reducing valves should be checked periodically to insure that they maintain the correct system pressure at all times.

21. **Troubleshooting**. If there is a pressure loss in the receiver, it can be caused by insufficient power unit operation, slipping drive belt, leaky pipe joints, obstructed air intake filter, obstructed or burned valves, or worn rings. Knocks usually result from insufficient or improper lubrication, too thin a cylinder head gasket, worn bearings, loose flywheel, or foreign materials on the top of the piston. If the compressor begins to knock, it should be shut down immediately and the trouble reported so that the necessary repairs or adjustments can be made.

22. Pneumatic Control System

1. The pneumatic control system, illustrated in figure 47, consists of five major parts. They are:

a. Source of air supply.

b. Lines leading from the source of supply to the controllers (thermostats, humidistats, etc.). These lines are referred to as supply pressure lines.

c. The controllers, thermostats, humidistats, recorders, etc.

d. The lines leading from controllers to the controlled devices such as valves, dampers, etc. These lines are referred to as control pressure lines.

e. The controlled devices (dampers. valves, etc.).

2. **Lines**. In order for the controller or any pneumatic control device to operate successfully, the devices must be connected to a regulated air supply. This air must be clean and dry and supplied at a pressure from 15 to 20 p.s.i.g. The installation must be planned to prevent water, oil, or dirt being carried through the piping into the control or instruments.

3. All tubing, pipes, and fittings must be clean inside and free of burrs. Shellac or a recommended joint compound may be applied sparingly

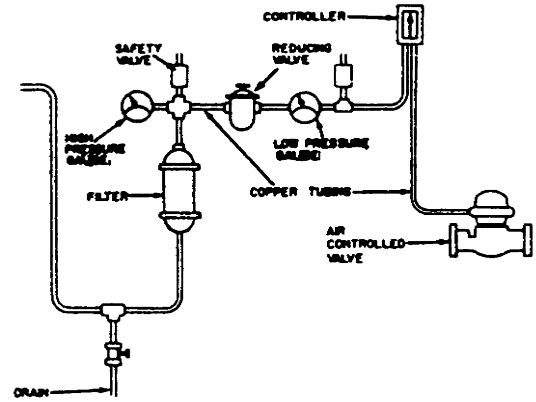


Figure 47. -Typical air supply system.

to the male threads. All joints should be checked under pressure with a soap and water solution.

4. In reference to figure 48, the supply header furnishes air to a series of instruments in a building area. Note that the supply header is pitched 1/4 inch to 1 foot to help in the drainage of entrained oil or moisture. Sumps and drains are located in the low points of the system and should be blown off daily. The sump can be constructed of pipe of sufficient volume to hold all the collected water until it is blown out. Clean brass or iron pipe and fittings ½2 inch or larger should be used for the header.

5. The tubing that supplies air to the instruments should be taken fi6m the top of the header. This is an added precaution against letting the moisture enter the instruments and other controlling devices. The connections can be made at the side of the header when necessary, but never at the bottom.

6. The air connections at the instruments are 1/4-inch National Pipe Thread (N.P.T.), 3/8-inch copper tubing (not less than .300 inch inside diameter (I.D.), or 1/4-inch iron pipe standard (I.P.S.). Brass pipe is used for the air supply piping. Where corrosive conditions require it, 1/4-inch I.P.S. clean, new, black iron pipe can be used. Copper tubing is most practical and can be kept free from leaks. The output piping to control valves should be ¾3/-inch copper tubing with few exceptions.

7. The air filter and supply pressure regulator, shown in figure 48, are installed in the supply piping immediately before the instrument. These components must be firmly supported to prevent the sagging of tubing. Arrows on these devices indicate how they must be connected in the system. Shutoff valves are installed in the system to enable the repairman to remove devices without shutting off the whole air-supply system.

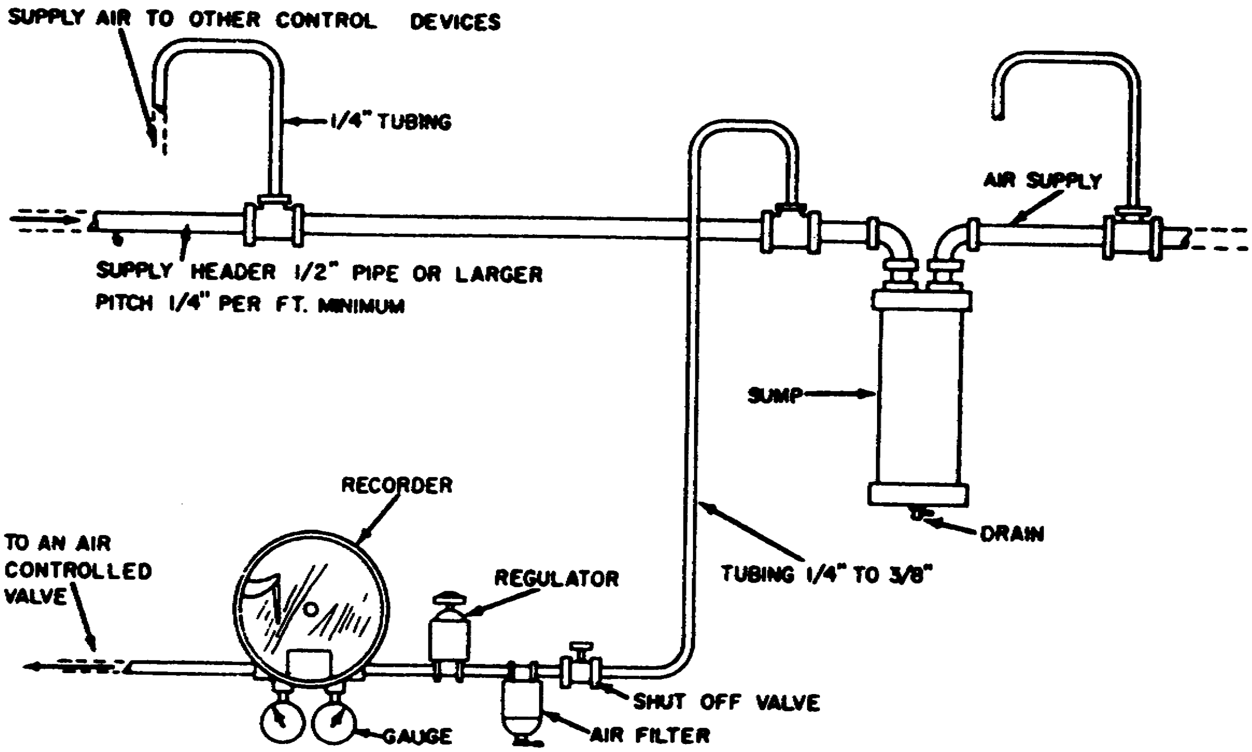


Figure 48. Air distribution piping.

8. The air filter catches any moisture, dirt, oil, and other foreign materials that may pass through the system piping. Most filters have a rated capacity as to the amount of moisture they can hold; therefore, they must be checked and drained periodically. Normally, this operation should be done daily, but under severe conditions of heavy moistened air it must be done more frequently. Close attention must be given to this detail for efficient and successful instrument and control operation.

9. The filter may be serviced by removing the bottom cover and removing the filtering element. The filter may be cleaned with an approved cleaning solvent or compressed air. Whenever the filter element looks too dirty, it should be replaced with a new element.

10. Pneumatic piping for instrumentation in large installations becomes complicated. Many instruments are located at designated positions in the duct system and must have compressed air piped to them; therefore it is advisable to refer to the installation schematic drawings when determining the exact location of piping and associated controls.

11. **Reducing Valve Station**. The supply pressure for most single temperature controllers runs approximately 15 p.s.i. Figure 49 illustrates an air filter and a reducing station for a single pressure system. Where two or more controllers or temperature thermostats are required, a dual-pressure system is used. The supply pressure for a dual installation is approximately 15 to 20 p.s.i. Figure 50 shows a reducing valve station for a dual pressure system and illustrates a valve and switch for selecting either of the two pressures.

12. In most installations the air piping for the control system is concealed internally into the building structure. Generally, very little servicing is required unless there is some possible damage due to building alterations. Piping in the fan and equipment rooms is often exposed. In most instances the exposed lines are run along out-of-the-way places with properly designed supports and hangers. Extra precautions must be taken so that the lines do not become damaged.

13. **Instruments and Controls**. Automatic controls are designed to do a specific job in an air-conditioning system. The controls may open

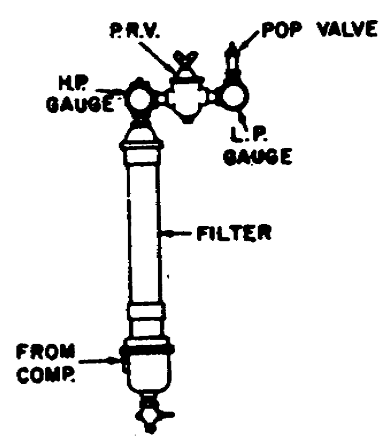


Figure 49. Single-pressure system.

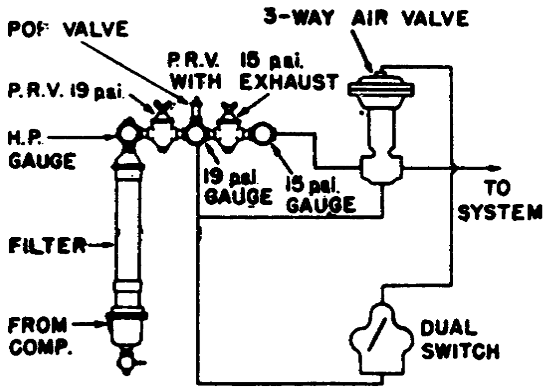


Figure 50. Dual-pressure system.

or close valves and dampers, and operate other equipment automatically whenever the need arises. Years of research have gone into the design of these controls; and if they are properly installed and maintained, they will function efficiently. The type and number of electric and pneumatic controls used will vary with the size of air-conditioning installation and with equipment usage in the building.

14. In equipment cooling, many different types of instruments and controls are needed to control the conditioned air at a required temperature and humidity. All instruments, whether they are recording, indicating, or control type, must operate and record accurately. You learned earlier in this chapter that special care h given to the compressed air supplied to the controls. It must be a clean, dry air and supplied at approximately 20 p.s.i.g. This air pressure initiates control operation.

15. *Location*. The location of controls and instruments will vary with each air-conditioning installation. Generally, a control is mounted near the device it operates. For example, a damper motor is usually located near the damper it operates. To find the exact location of controls, refer to your installation air-conditioning drawings.

16. All controls and instruments must be installed in a clean, dry location. They must be mounted securely to prevent sagging or vibration and must be accessible for cleaning, adjusting, and repair.

17. *Terminology*. Before you can understand the operating principles of controls, you must know the terms that are applied to instrumentation. The following is a list of some of the most common terms and their meanings:

a. Direct-acting controller is a control that is adjusted to give an increasing air output pressure with an increase in the variable, whether it is temperature, pressure, flow, vacuum, or liquid level.

b. Reverse-acting controller is a control that is adjusted to give a decreasing air output pressure with an increase in the variable, whether it is temperature, pressure, flow, vacuum, or liquid level.

c. Direct-acting diaphragm valve is a valve that closes when the air pressure is applied to its diaphragm motor. It may be referred to as an air-to-close valve.

d. Reverse-acting diaphragm valve is a valve which opens when the air is applied to its diaphragm motor. It may be referred to as an air-to-open valve.

e. Set point is the value of the controlled variable that is asked of the controller by setting the indicator to that value.

f. Control point is the *actual* temperature, pressure, flow, vacuum or liquid level at any given instant regardless of what the set point may be.

g. Proportional control is the type of control action where the control signal varies in proportion to changes in the controlled variable, and may be any value from minimum to maximum.

h. Sensitivity of a controller is the ratio of output pressure change to the movement of the pen or indicating pointer.

i. High sensitivity results in a large output pressure change for a given pen or pointer movement.

j. Low sensitivity gives a small output pressure change for a given pen or pointer movement.

k. Throttling range is used to designate the sensitivity of a controller and is expressed as the movement of the pen or pointer in percent of chart, or scale, width necessary to cause a full opening or closing of the control valve.

l. Automatic reset response is only used when automatic reset is adopted to the controller. It is an additional output pressure change resulting from a control point change and provides at a rate dependent upon the proportional response. It acts in the same direction as the proportional response and continues until the set point and control point are together.

m. Reset action is the control action in which the corrections are made in proportion to the time a condition has been off and the amount of deviation.

n. Controlling medium is the liquid, vapor, or gas, the flow of which through the diaphragm valve is varied in accordance with the demands of the process.

o. Processed or controlled medium is the liquid, vapor, gas, or solid which is to be maintained at a constant value by varying the flow of the controlled medium.

p. Load change is any factor which requires a change in the flow of the controlling medium in order to maintain the control point of the process.

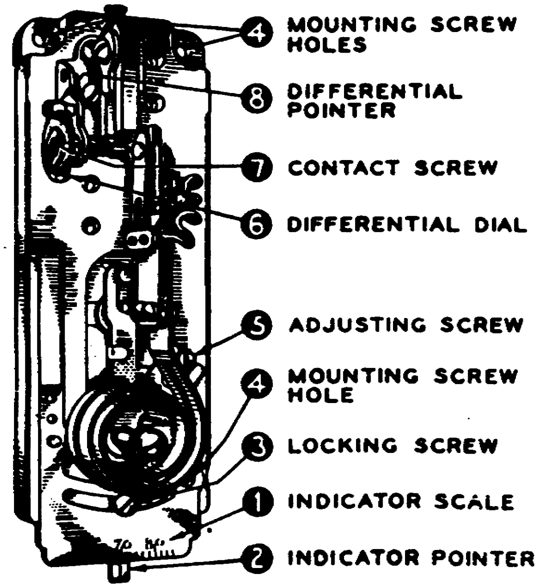


Figure 51. Spiral bimetallic thermostat.

These factors may include a change in the temperature, pressure, rate of flow, or composition of either the controlling or the controlled medium.

q. Hunting is the changing or variation of the controlled variable about the control point, generally caused by excessive diaphragm valve movement.

r. Wandering is an irregular shift of the controlled variable about the control point resulting from frequent load changes.

18. **Thermostat**. The thermostat is a nerve center of heating and cooling control centers and operates either pneumatically or electrically. The thermostat is a sensitive unit that responds to changes in room temperature and indicates where more or less heat is required. It transmits its indicating signal to the primary control for action. On an electric thermostat this is done by the making and breaking of electrical contact within the thermostat itself; within the pneumatic thermostat a pressure relay regulates the air to the controlled unit.

19. Thermostats usually differ in construction according to the type of primary control with which they are used. Probably the most common type of thermostat is the spiral bimetallic type shown in figure 51.

20. Figure 51 illustrates a remote bulb type thermostat. This type of thermostat is used in installations where severe vibration may exist at the point of measurement, or where it is desirable to have an instrument at a central location. The capillary tube shown in figure 52 is usually a liquid-filled element. It is sensitive to temperature changes and will control temperature accordingly.

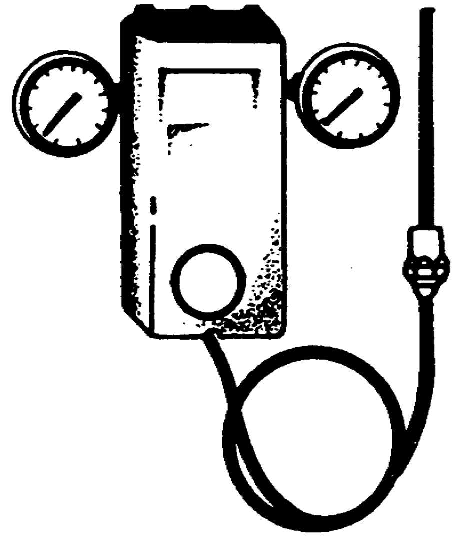


Figure 52. Remote bulb thermostat.

21. Another type of thermostat frequently used is a bellows type shown in figure 53.

22. *Location*. The location for a thermostat should be representative of that part of the building where a required temperature is to be maintained. It should be installed where it will be exposed to free circulation of air, free from drafts, and away from the direct rays of the sun or any type of radiant heat.

23. *Maintenance*. The internal mechanism of a thermostat should be cleaned of dust and dirt. The contacts should be cleaned by drawing a piece of hard-finish paper (such as a common post card with a hard smooth finish) between the contacts. Never use emery cloth or other abrasives to clean the contacts. For recommended procedures or part replacement. refer to the manufacturer's maintenance manual.

24. **Humidistat**. Figures 54 and 55 illustrate

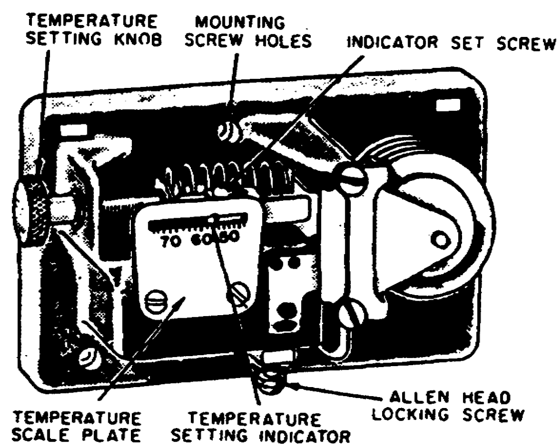


Figure 53. Bellows type thermostat.

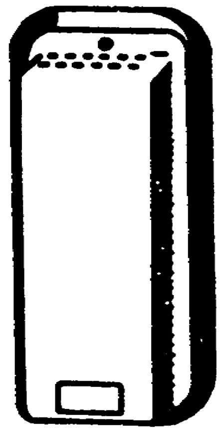


Figure 54. Room humidistat.

room and insertion type humidistats. The humidistat is designed for the accurate control of the addition to or removal of moisture from air in a system or space. Room humidistats are available with various elements consisting of wood, hair, or animal membrane with adjustable sensitivity. Insertion humidistats are designed for accurate control of the relative amounts of moisture in heating, ventilating, and air-conditioning ducts.

25. *Operation*. Under normal operating conditions, the humidistat will control the humidity within 1 percent relative humidity. Most humidity controls operate electrically to regulate dampers, valves, or other regulating devices. For example, when a humidifying device having a spray nozzle is used, a solenoid valve is ordinarily inserted ahead of the nozzle. A humidistat in the conditioned space energizes the solenoid when the relative humidity drops below the humidistat setting. As soon as the humidity in the conditioned space is brought up to that required to satisfy the humidistat, the circuit is opened and the solenoid shuts off automatically.

26. *Maintenance*. The humidistat is a very delicate instrument and must be handled with

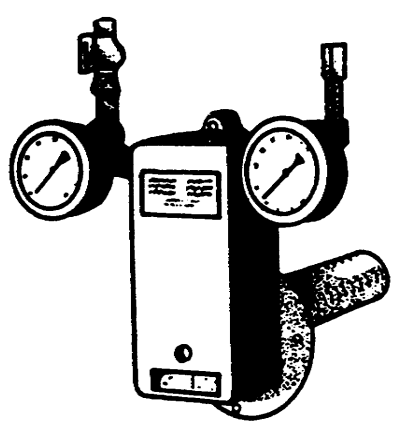


Figure 55. Insertion type humidistat.

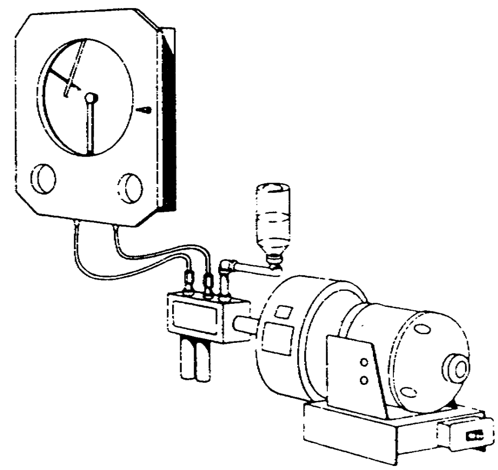


Figure 56. Hygrometer with motor-driven fan.

care. The instrument must be encased at all times and kept free of dust and other foreign materials. It must be mounted securely and located where there is a good circulation of air through its mechanism. All adjustments must be made with special precautions since they are very sensitive devices. Refer to the manufacturer's manuals for recommended maintenance and adjustment procedures.

27. **Hygrometers**. The hygrometer is a device used to measure, record, and control humidity. There are many types and designs of these instruments made by various manufacturers, but their principles of operation are similar.

28. The hygrometer gives instantaneous readings of a measured area and will regulate valves or other controls to maintain a necessary humidity.

29. There are two types of hygrometer instruments. They are referred to as recording and recording-controlling types.

30. Figure 56 shows a recording-controlling type hygrometer. This instrument is installed in the area in which the humidity is to be measured. When the instrument is installed within an area, the air to be measured is circulated through the wet- and dry-bulb housing by a suction fan, as shown in figure 56. The fan draws the air through the bulb housing by use of an intake and exhaust port, usually located in back of the panel housing, creating conditions similar to those which psychrometric tables are obtained. In applications where bulbs of hygrometers must be located inside an apparatus, room, or duct, and where a continuous source of water supply is not available, a water feed instrument, as illustrated in figure 57, is used. The water supplied to the instrument must be cleaned and constant.

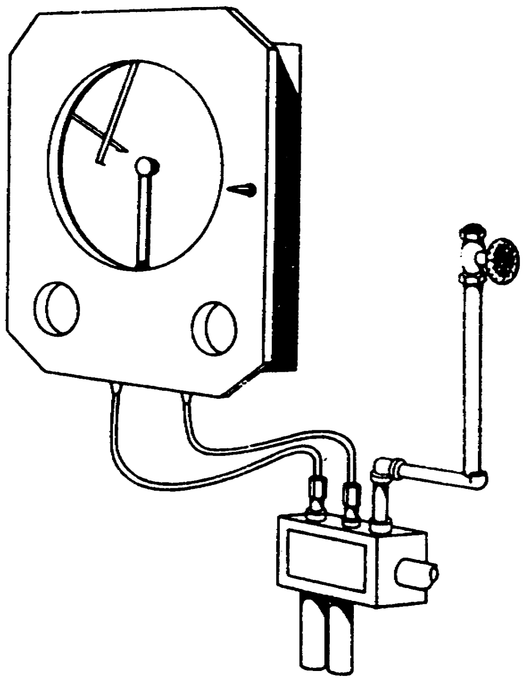


Figure 57. Water feed hygrometer.

31. *Operation*. The operating principles of a hygrometer are similar to the operating principles of a sling psychrometer, while on a hygrometer these temperatures are transmitted through a Bourdon tube to an instrument mechanism which records the temperature and humidity. Refer to the manufacturer's manual for specific hygrometer instrument action.

32. *Maintenance*. The instrument mechanism is similar in construction to the type used in transmitters and recorders, a explained later in this chapter; therefore its components can be maintained in the same manner. The major difference in hygrometer construction is the addition of water to the wick. The water and wick must be kept clean r accurate instrument operation. Periodic cleaning of the wick is required. Refer to manufacturer's maintenance manuals for specific instructions for maintenance and adjustment procedures.

33. **Controlled Operator**. Controlled operators require position changing according to variations of a controlled medium. For example, damper operators position dampers in many ways to regulate airflow, some of which are illustrated in figure 58. Blades may be used in parallel or opposed operation, depending on their use in duct system.

34. *Damper operators*. The damper operator is generally of the piston type, a shown in figure 59. The piston is attached to an operating stem

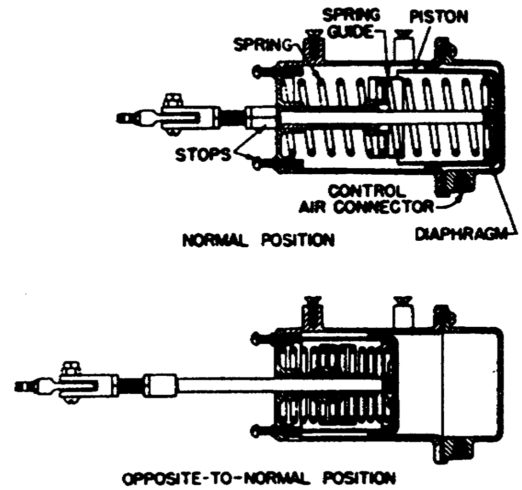


Figure 58. Damper control air movement.

and, as air is applied to the diaphragm, the piston is forced to move outward, causing the stem to move in the same direction. This forces a tension on the spring. The air that is fed from the controller to the damper operator usually ranges from 0 to 15 p.s.i., different spring ranges are available for different applications. Generally, 5-to 10 p.s.i. spring range is the most commonly used spring design tension; and with such a spring tension, the operator is in normal position when the control pressure is 5 p.s.i., a illustrated in figure 59. It is in its opposite-to-normal position when the control pressure is above or below 5 p.s.i. under normal load conditions. At

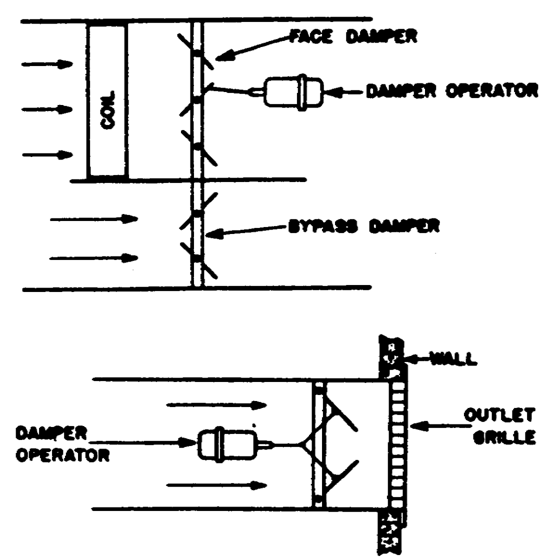


Figure 59. Piston damper operation.

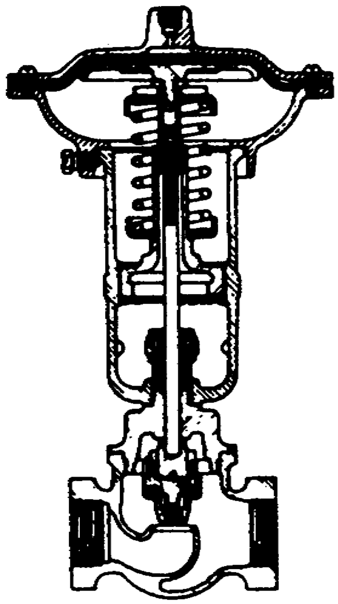


Figure 60. Diaphragm valve.

5 p.s.i., the operator assumes a midposition which is proportional to the air pressure.

35. Operators are generally mounted on the damper frame wherever possible and are connected directly to a damper louver. They can be mounted externally on the duct and operate through a crank arm on a shaft extension to the damper louver.

36. *Pneumatic valves*. Pneumatic valves consist of a diaphragm or bellows and a spring. Figure 60 illustrates a typical diaphragm valve. Its operation is very similar to that of the damper operator. The valve spring acts to either open or close the valve in accordance with the applied air pressure. The bellows type valve is generally used on convector, unit ventilators, and radiators where space is more restricted. Diaphragm valves are generally used on larger cooling and heating coil installation. There are many types and designs

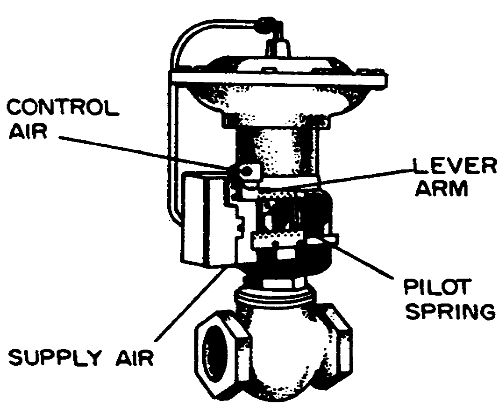


Figure 61. Valve with positioner.

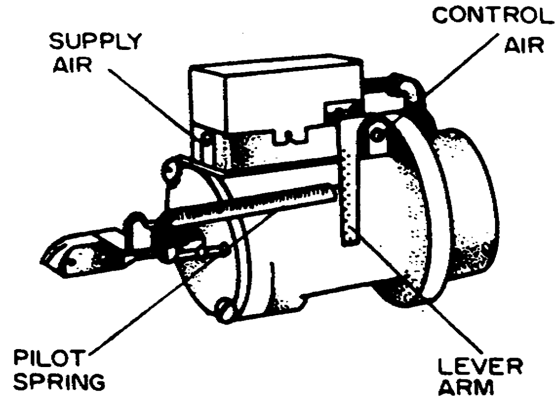


Figure 62. Damper operator with positioner.

of valves to meet various requirements. Each type will have its own specific performance rating.

37. *Positioner for operators*. Figures 61 and 62 illustrate how a positioner can be applied to a valve or damper operator. The positioner provides a means of getting greater accuracy in positioning an operator and also increases the repositioning power.

38. In reference to figures 61 and 62, note that the positioner has a supply-air connection. Internally it has supply and exhaust valves like a pneumatic relay. The valves are operated jointly by the pressure from the controller and by the spring attached to the operator stem. A small change in control pressure can produce a large change in pressure on the operator until the stem moves sufficiently to cause the spring to stop the operation.

39. When positioners are used, the spring determines the operating range of the valve or damper operator. The range can be adjusted over a wide limit.

40. *Maintenance of controlled operators*. One of the most important things to remember when inspecting a damper operator is to make sure the stems or levers are clean. They must be lubricated as required. Keeping the unit clean is very important. If the diaphragm needs replacing, the following procedure is recommended:

a. Remove the cylinder head and throw away old diaphragm.

b. Place new diaphragm in its proper position.

c. Roll back flange and insert the piston in the diaphragm.

d. Place the assembly on the upper end of the cylinder with the loop of the diaphragm between the piston and the cylinder wall. Make sure that the diaphragm does not wrinkle.

e. Put the cylinder in place with the air connection in the desired position and tighten the screws uniformly.

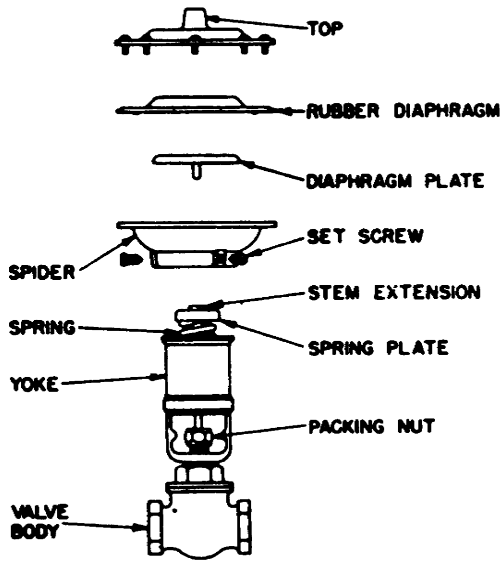


Figure 63. Exploded view of diaphragm valve.

41. The damper must be checked periodically for rust and corrosion. If corrosion deposits are found, they should be removed immediately with a steel brush, and the surface should be repainted. All pivots, linkage, and levers should be cleaned to remove dirt and other foreign matter is that they may operate freely.

42. The following components of a valve should be checked periodically and replaced if found unserviceable:

a. Leaky or worn diaphragm.
b. Leaky packing nut.
c. Worn or pitted valve or valve seats and disks.
d. Weak or broken spring.
e. Corroded or dirty valve stem.

43. Figure 63 shows the exploded view of a diaphragm valve. Note the positions of each component in this valve. Care must be taken when replacing the rubber diaphragm. A kinked diaphragm will cause erratic operation.

44. **Controllers**. Controllers are used to regulate valve, dampers, and other devices by me of pressure or temperature. Because there are so many different designs of controllers, it is impossible to cover each controller difference in this memorandum. To understand the specific operation, maintenance, and calibration of any instrument or control, always refer to the manufacturer's manual in this section a general discussion will be given on controller operation, maintenance, and calibration. Figure 64 illustrates a typical controller. This type of controller records graphically the variations in temperature or pressure of a measured process.

45. *Operation*. Figure 64 illustrates a typical controller installation. The purpose of the controller in this system is to control the temperature of a process by operating a direct-acting diaphragm valve on a steam supply line. To understand its operation, let us assume that the temperature of the process is below that for which the controller is set. Because the temperature is low, the air regulating mechanism in the controller allows the valve to remain open, ,allowing more steam to flow into the process. As the temperature increases toward the control point setting, the bulb measures this increase. As soon as the control point is reached, the Bourdon tube uncoils. This action forces a change in the internal pressure regulating mechanism in the controller and forces air pressure down on the regulation valve, forcing it to close.

46. *Maintenance*. The chart on the controller must be replaced periodically. The chart on most controllers can be removed easily by disengaging the pen from the chart and removing the chart from the hub. Place a fresh chart on the clock hub and rotate it until the correct time line is opposite the reference arc, which is usually indi-

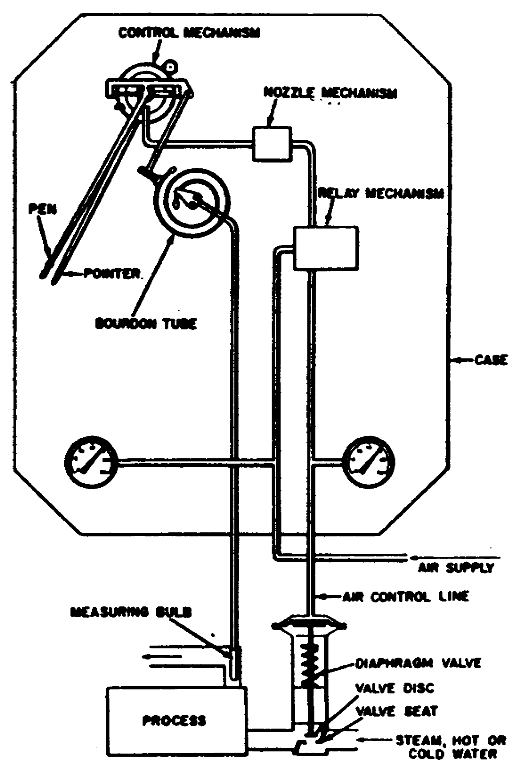


Figure 64. A typical controller installation.

cated on the control face. The clock face generally has small pins or clamps mounted in it, the purpose of which is to hold the paper and serve as a means of driving the chart.

47. You should fill the pen with manufacturer's recommended grade and type of ink. General instructions as to how to fill the pen are supplied with the ink. Occasionally it is necessary to wash the pens with water or alcohol.

48. If the pen fails to touch the chart paper because of insufficient tension on the pen arm, bend the pen arm slightly toward the chart so that the pen touches the chart lightly. If the pen fails to follow the time line, adjust the chart so that a time line corresponds to the reference arc. Bend the pen so that it rests on the time line matching the reference arc.

49. The following precautions should be followed to improve controller efficiency and operation:

a. Do not allow water or steam to come into direct contact with the instrument. If it is necessary to wash out pipes, tanks, or other apparatus with steam or hot water, remove instrument bulb first.

b. Do not subject the pressure element of instrument to a higher pressure than maximum range of the chart unless the instrument is designed to take care of it.

c. Do not allow the controller door to remain open longer than is necessary.

d. Blow out the compressor receivers periodically to remove moisture and other foreign material.

e. Blow out moisture traps at regular intervals.

50. *Calibration*. The procedures you will study here are considered as basic control calibration for most types of controls-pneumatic, electric, and electronic. The control manufacturer furnishes pamphlets with his control to guide you in servicing and calibrating a specific control. The basic procedures are:

a. Set the controller set point to the sensed variable-temperature, pressure, humidity, etc.

b. Adjust the controller to the midrange of the controlled device.

c. Set the dial to the desired value.

51. **Transmitters**. The transmission system consists of a transmitter and a receiver. The transmitter and receiver with their connecting tubes and accessories form a system that measures the magnitude (temperature or pressure) of a process change and indicates this value at the receiver.

52. The transmitter or receiver may be either an indicating or recording type instrument. These instruments can be used as temperature or pressure transmitters, depending on the type of variable that needs to be measured.

53. *Temperature transmitter*. In using the temperature transmitter, the bulb of the tube system is placed in the apparatus to be measured at the point where the temperature is to be controlled and where the circulation is a maximum. It should not be too close to a radiating coil or an open steam inlet.

54. If the bulb is to be placed into a separable bulb, well, or stem, these units should be fitted into the apparatus first. Then insert the bulb and tighten the coupling nut.

55. Installations where a well is-furnished with a thermospeed sleeve must be given special consideration. To install a bulb with thermospeed sleeve, first separate the bulb from the well. Then screw the well tightly into the apparatus. Start the bulb into the well carefully to avoid any damaging. Force the bulb as far as it will go into the well, then tighten sufficiently to hold the bulb in place.

56. If the tube system is of a vapor pressure type, make certain the elevation of the bulb with respect to the instrument case is the same as that for which the controller is designed. Should the elevation be slightly different, it will be necessary to reset the pen to agree with the reading of an accurate test thermometer. Bulb elevation data will be given on the data plate of the instrument or in the manufacturer's maintenance manuals.

57. *Pressure transmitter*. Where pressure transmitters are used to measure the pressure of hot, moist atmosphere, a condensate loop should be installed beneath the instrument. The added pipe length protects the instrument from the effect of high temperature, and the loop retains condensate when the apparatus is shut down.

58. If the medium being measured is corrosive, the pressure element should be protected by use of a purge system or suitable sealing liquid.

59. *Operation*. Figure 65 illustrates schematically a transmission system which measures the temperature of a process.

60. The transmitter shown in figure 65 is actuated by a Bourdon tube. With an increase in process temperature, the Bourdon tube tends to uncoil and actuates components in a pressure mechanism. The mechanism, in turn, establishes an equilibrium at a new output air pressure, proportional to the pointer movement. The output line from the transmitter is connected to a bellows of a receiver, as shown in figure 65. The air pressure within the bellows actuates the pen of the instrument. The receiver pen then records values which are identical to those indicated to the transmitter pointer.

61. The dotted portion of figure 65 illustrates the receiver controller. This part of the instrument

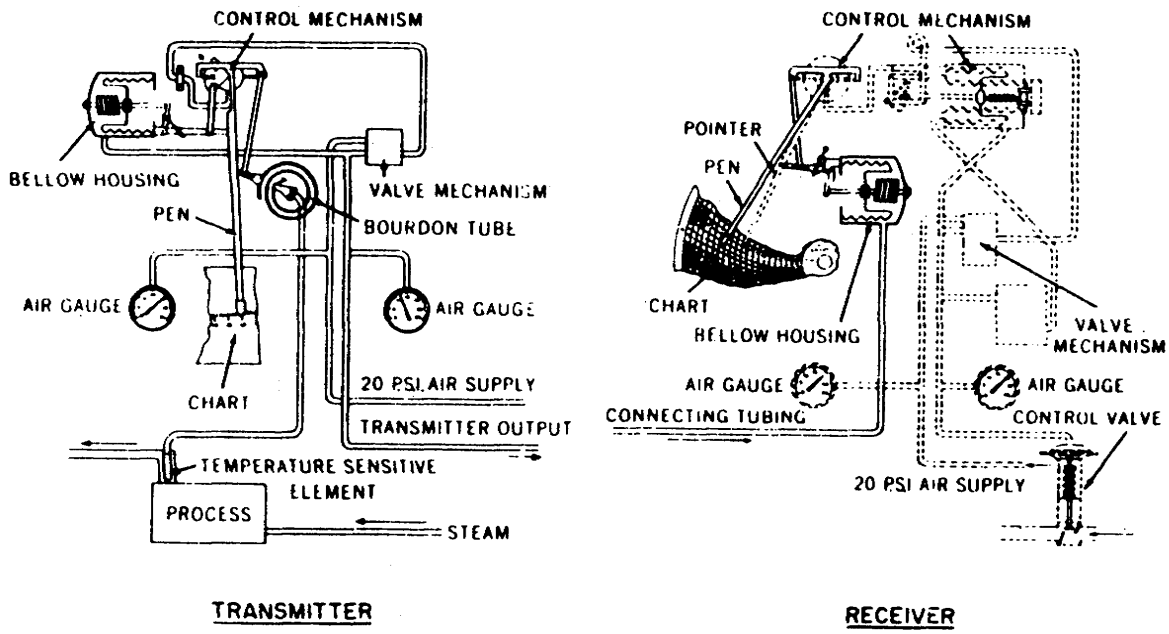


Figure 65. A typical transmission system.

regulates a valve which controls a fluid or gas entering a process.

62. *Maintenance*. The transmitter or receiver must be mounted on a wall or panel where it will be free from vibration. It should not be installed where extreme temperatures may damage the delicate components.

63. The chart must be replaced at designated periods. Replacement procedures will vary with instrument design. Some transmitters are designed to use a type of disc chart similar to the one shown in figure 65, while others use a chart in the form of a roll. When a chart is replaced, care should be exercised to set it at the reference point so that the chart will record accurately for the particular time.

64. The pen must be filled with a recommended instrument ink. If the ink does not flow, start it flowing by touching the pen with the filler. Dried ink may be removed by washing the pen with warm water. If the pen fails to touch the chart, bend the pen arm inward so that it will hear lightly on the chart. If the pen does not follow the reference arc, adjust the length of the pen arm by bending the pen point to a length indicated by the time reference arc on the chart plate.

65. **Temperature and Pressure Recorders**. The temperature or pressure recorders operate on the same general principles as other type controls. The Bourdon tube principle is adapted to the recorder operation. The temperature or pressure recorder is used to record graphically the temperature or pressure of a process or apparatus operation. The thermal bulb attached to the recorder is placed in the process that is to be measured. Any change in the process temperature is transmitted through the Bourdon tube to the recorder mechanism and is shown graphically on the recorder chart. Figure 66 shows a typical type temperature or pressure recorder.

66. Figure 67 illustrates a typical temperature recorder installation. The connecting tubing from the recorder is placed in such a position that it will not receive additional heat from heat surfaces such as boilers radiators, pipes, etc. The bulb of the instrument is placed at the point where circulation is best. This is necessary for an accurate measurement and recording.

67. Figure 68 illustrates a typical pressure recorder installation. On liquid line installations excessive pulsations may occur; in such a condition, a needle valve, as shown in figure 68, is installed in the line. The oil seals are installed in the line to prevent excessive pressures and corrosive liquids from damaging the instrument.

68. The components of a temperature or pressure recorder are similar to other types of controllers and transmitters; therefore maintenance procedures are similar.

69. Chan replacement is done periodically. When replacing a chart, make sure the chart is inserted properly into the pins or clamps mounted on the clock hub. Rotate the chart until the correct time line is opposite the reference arc inscribed on the control face. Special guides attached to the recorder door generally hold the chart flat against the plate.

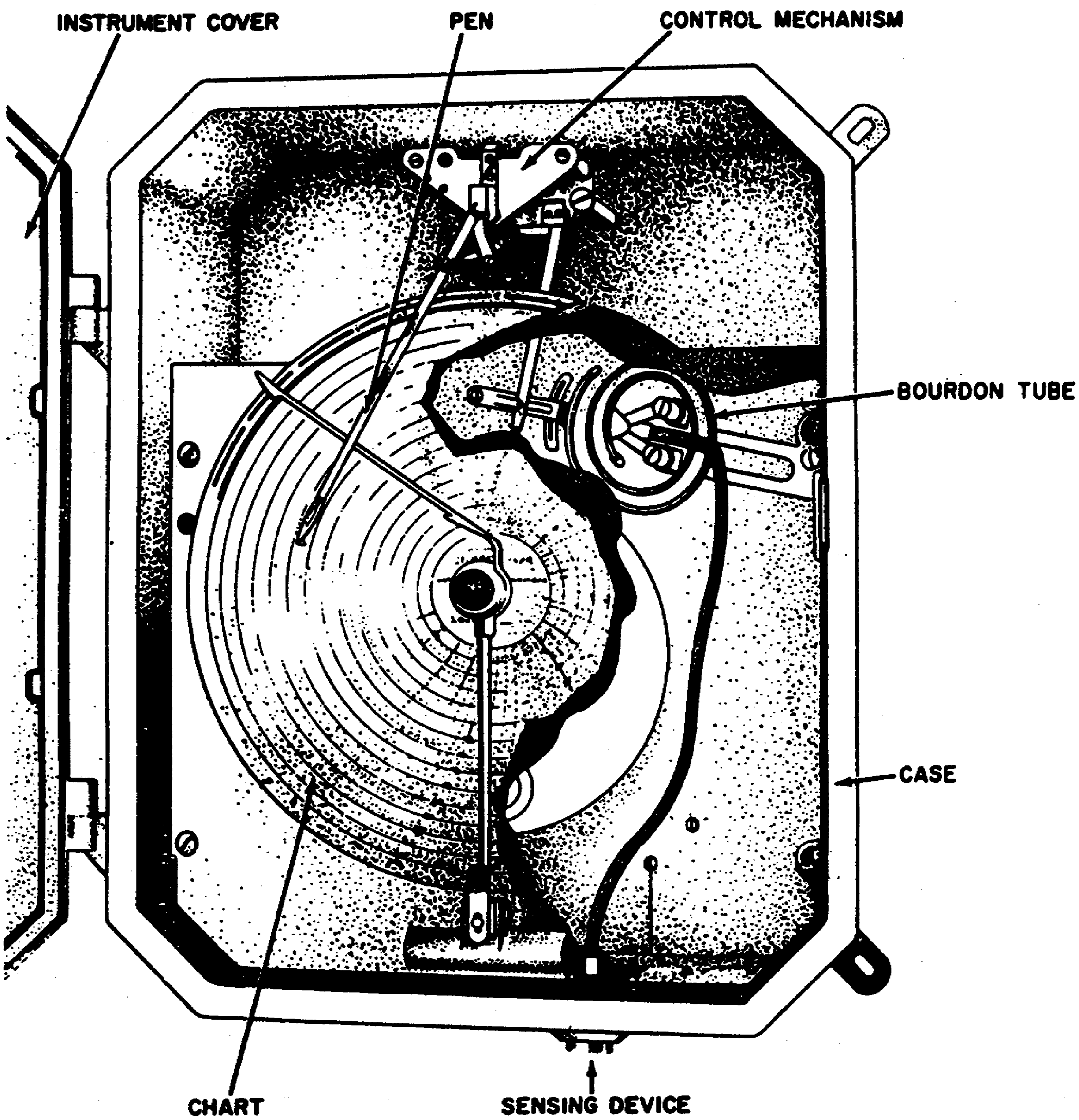


Figure 66. A typical recorder.

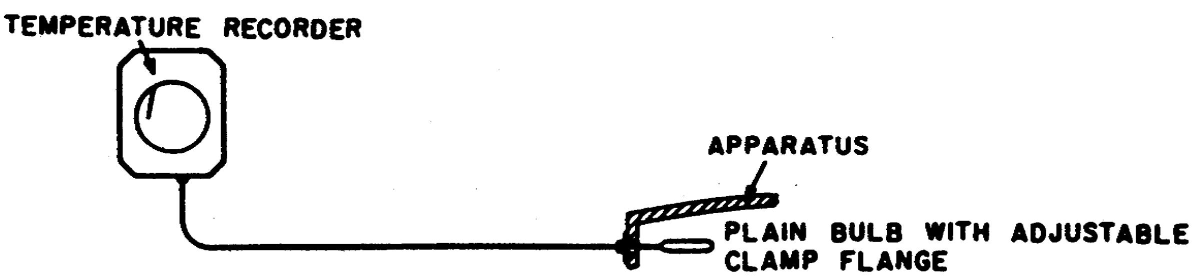


Figure 67. Temperature recorder installation.

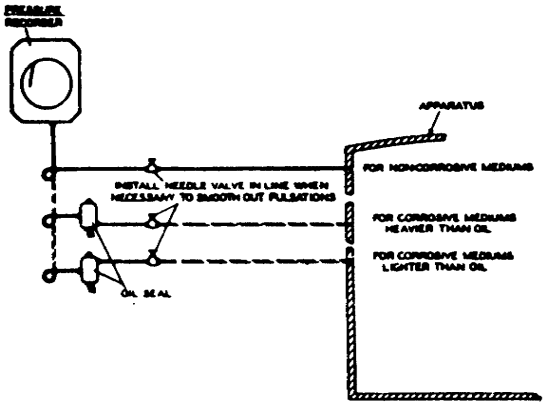


Figure 68. Pressure recorder installation.

70. Adjusting and cleaning of the pen is done as discussed previously in this chapter.

71. Recorders are calibrated and adjusted to testing conditions at the factory. Do not make any adjustments unless it is certain that the instrument is out of adjustment. Refer to the manufacturer's maintenance manuals on procedures for calibration of their instrument.

72. The following precautions must be observed when using a temperature or pressure recorder:

a. Never allow a stream of water or jet of steam to come into direct contact with the instrument mechanism

b. Never wash or flush out pipes, tanks, or apparatus with steam or hot water, as it might allow the bulb of the instrument to reach a higher temperature than maximum range on the chart unless the instrument is designed to take care of these high temperatures. It is recommended that the bulb be removed when cleaning the apparatus.

c. Never subject the Bourdon spring of a pressure recorder to a higher pressure than the maximum range of the chart unless the instrument is designed for higher pressures.

d. Never allow the door of the instrument to remain open any longer than necessary. Keep the instrument clean and free of dust and other foreign materials.

73. **Electric Fire Protection Control**. The purpose of the fire protection control is to protect the installation against the spread of fire by automatically switching off air-conditioning fans and closing dampen. If a fire starts, fans become quite a hazard by increasing the intensity of the fire and helping it circulate through fire walls and from room to room. Most air-conditioning systems that use fan installations use some type of fire protection device in connection with these fans.

74. *Operation and construction*. The back plate and helix tube of a fire protection control is made of steel to form a strong incasement. The sensitive bimetal helix reacts instantly to a temperature change, the rotation of the helix being transmitted by a cam or roller follower to a switch. The electrical contacts are enclosed in a dustproof case, and the contacts are opened by the cam or roller follower in the event the air temperature around the helix exceeds the cutout setting.

75. The cutout point is adjustable, approximately from 75° F. to 160° F. It is provided with a dial stop to prevent the adjustment from exceeding a maximum of 125° F.

76. The cam has both a high and low limit stop and will not rotate forward to the ON position even if the fire comes in contact with the bimetal helix. If the temperature becomes high enough to reach the cutout setting, the control may lock out and will require manual reset before the unit may be placed back into operation. The manual reset lever is exposed for easy setting ;and is located on the control housing. Removal of the cover exposes the instrument terminals and wiring.

77. *Maintenance*. Field repairs are not recommended by the manufacturer. If the control is not functioning properly, it is recommended that the unit be replaced.

78. **Airflow Detector and Control**. The air-flow detector type instrument is used to control and detect airflow movements.

79. *Operation*. The airflow instrument contains a heat source within its flow-sensing leg and operates on the principle of heat transfer. The electrical mechanism in the ambient compensating leg is actuated whenever there is a change in rate of flow beyond the set point of the unit. If there is a greater transfer of heat away from the flow-sensing leg containing the heat source than that for which the unit is set, the contacts in the electrical mechanism remain closed. If the heat transfer is less than the set value, the contacts of the electrical mechanism will open.

80. Since this device actually controls an electrical circuit by a switch action, it can be used to, control fans, alarm systems, air circulators, and other air-conditioning and dust collecting systems.

81. *Maintenance*. The airflow measuring instrument should be placed in a duct area with the two legs side by side in the airflow stream. The electrical connector should face either downstream or upstream. It can be placed in other directions, but this results in some calibration changes. The set point is generally set by changes in turbulence, but the instrument may be located in a turbulent region if it is calibrated in position. Airflow measuring devices require very little maintenance since they are hermetically sealed. It is recommended that the instrument be replaced if you find that it is not functioning properly.

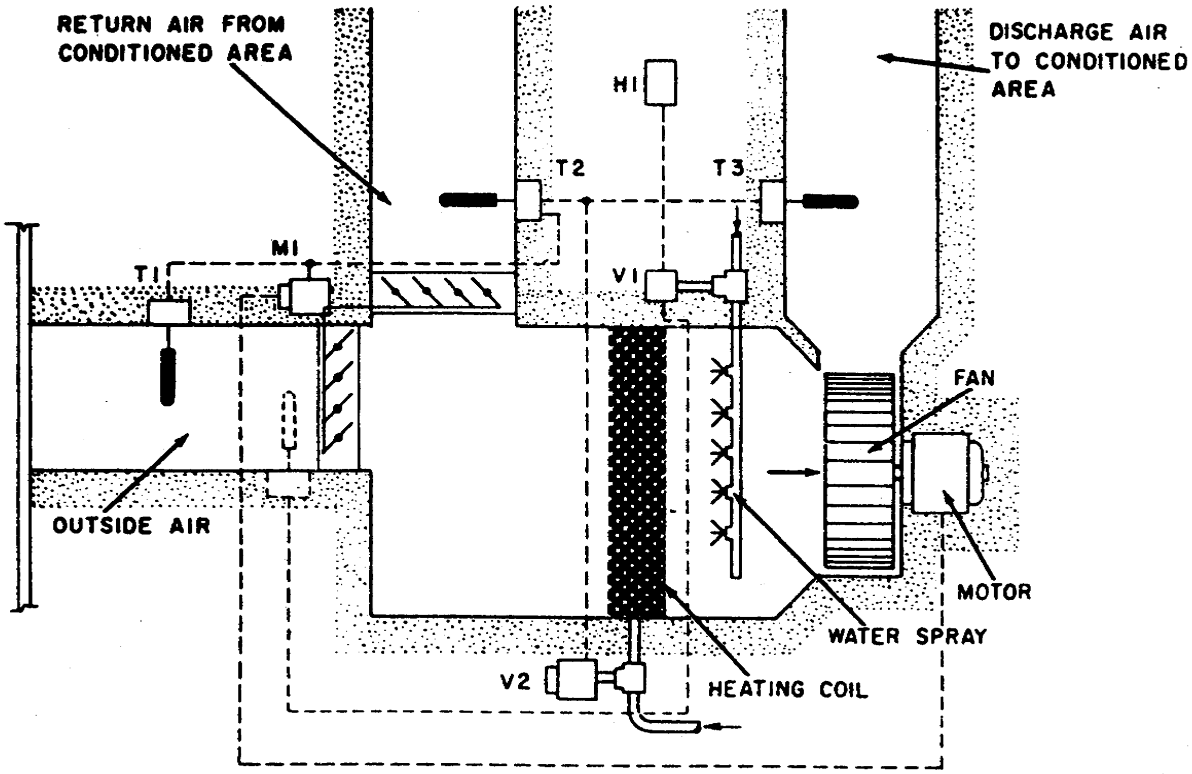


Figure 69. Schematic of an air-conditioner system.

82. *Calibration*. With the instrument installed, energize the heater for approximately 5 minutes to obtain an equilibrium. The airflow through the instrument should be maintained at the desired point for approximately 1 minute. Proceed to adjust the instrument to the point where electrical contacts just operate. Simulating decreased air-flow conditions or dirty filters may be accomplished by blocking off a section of the clean filter media. It is recommended that you refer to the manufacturers' maintenance manuals for specific instructions on calibration for their instrument.

83. **Control System Operation**. So far in this chapter you have not been shown how control instruments are used in a control system. Figure 69 is a simple sketch of a control system and illustrates operation of a heating and ventilating fan air-conditioning system.

84. In reference to figure 69, insertion thermostat T2 measures the temperature of return air and regulates modulating motor valve V2 in accordance with the heat measured in the conditioned area. The insertion thermostat T3 measures the temperature of the discharge air into the conditioned area and adjusts V2 to keep the air from entering the conditioned area at too hot or too cool a temperature. As the return air rises in temperature, T2 will close valve V2; and if the air continues to rise in temperature, T2 will shift the control of damper motor M1 to insertion thermostat T1 to take in a volume of outdoor air for cooling. This quantity of air will vary with the outdoor air temperature to keep the air that is entering the coil at-the setting of T3. Humidity controller HI operates a solenoid valve V1 to add moisture to the air when required. A control panel is used to monitor all operations and control the positioning of the dampers and the closing of the dampers when the fan stops.

85. Special procedures must be followed when replacing an instrument or control that is not operating properly. Since every air-conditioning control system has its design differences, it is impossible to give specific information or replacement procedures. It is recommended that you refer to your installation SOP, and ask your supervisor for information regarding instrument or control replacement procedures.

CAUTION: Check all system components for proper operation before adjusting, repairing, or replacing a control. Many times, controls are functioning properly but the equipment they control needs servicing.

23. Graphic Panel

1. The graphic panel, as the name implies, is a graphic illustration showing flow diagrams, recording and indicating devices, switches, and controlled equipment used in a building. The graphic panel in an air-conditioning installation shows

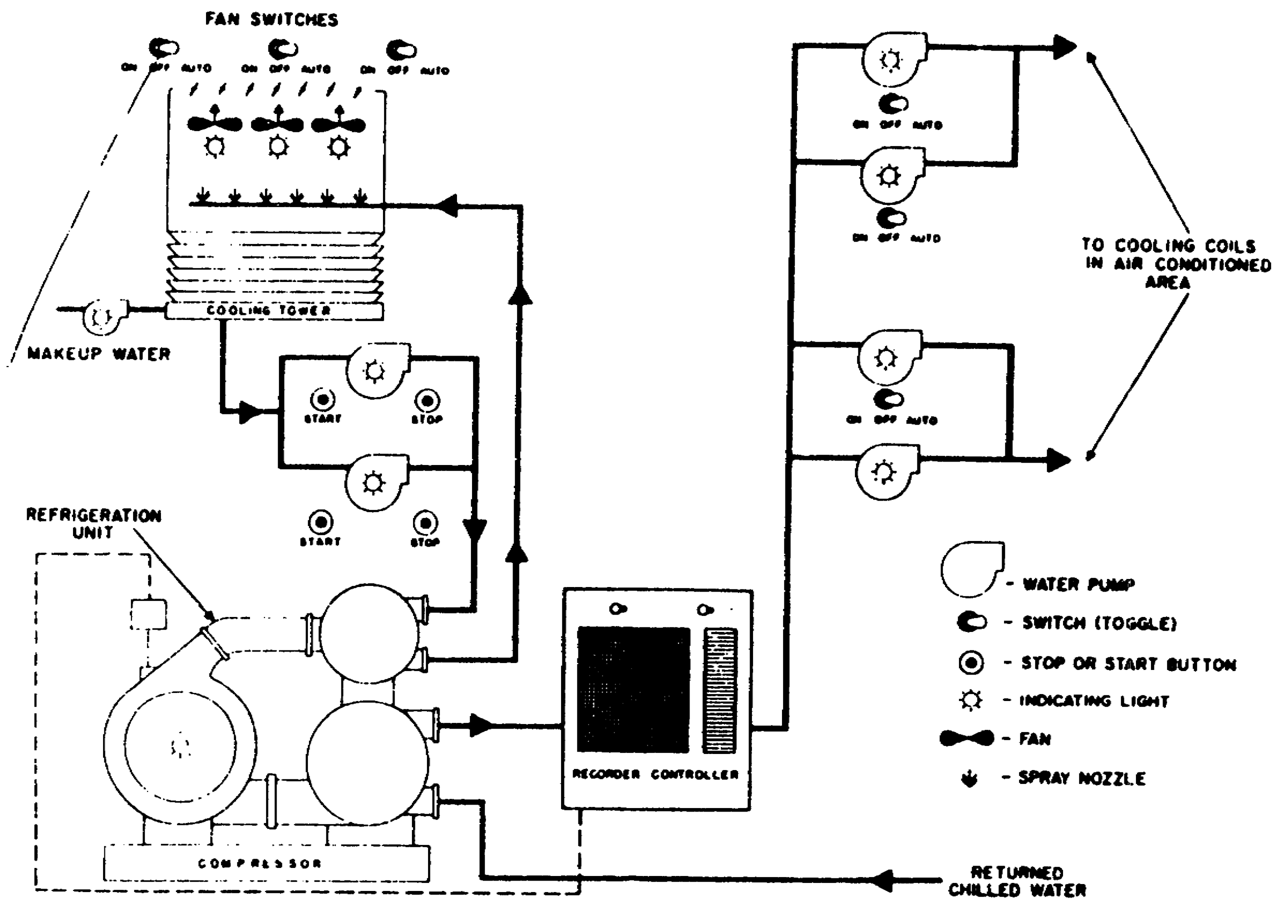


Figure 70. Sectional view of a graphic panel.

graphically the complete installation with indicating, recording, and control instruments. These instruments arc mounted in such a position, with appropriate symbols and flow lines that they represent schematically the systems they monitor and control. The graphic illustration will vary with the size and necessary instrumentation required in the building air-conditioning system. The panel is assembled from one or more sections and is so arranged that the operator monitoring the controls can easily see the lights, controls, and instruments mounted on the graphic panel. Some of the control instruments on the panel that can be used are: fan and pump control switches; damper controls; pressure, temperature, and humidity indicator and recorders; and associated controllers with manual, automatic, and cascade controls. Pilot lights on the panel give a continuous information concerning the operation of fans, pumps, and other equipment.

2. The graphic panel illustrated in figure 70 provides a graphic representation of refrigeration equipment, pumps, fans, and flow lines. The pilot lights indicate the operation of the cooling tower fans, chilled water pumps, and condenser water. The chilled water temperature is always indicated and recorded. Complete monitoring of the controls is done by. means of selector switches, pushbutton switches, and recording controllers to provide remote control of equipment as represented on the panel.

3. The graphic panel shown in figure 70 is only a sectional view of an air-conditioning system; if the other sections were shown, the complete air-conditioning system would be graphically illustrated.

4. Most graphic illustrated panels use colors to identify components and flow lines. The following colors can identify most components, but this color code system may not be standard on all graphic panels.

Steam flow lines and heating coil ....Red
Cooling water now lines and cooling coil .... Blue
Condenser water line..Green
Duck work...Black
Control wiring and piping ....Yellow
Background ....Tan, gray, blue, or green

5. The sections of the panel generally illustrate the following systems and controls:

(1) The refrigeration system.
(2) Water circulating systems.
(3) Air systems.
(4) Room induction system and exhaust fans.
(5) Interior zones.

(6) Temperature and flow recorders and indicators

(7) Building air-conditioning system.

6. The graphic panel can be installed in any available space a building. It is generally installed inside a room, away from the operating refrigeration equipment. The advantages of having the panel installed in a separate room are cleanliness, less noise, and better lighting facilities. In some installations the panel is mounted in the same room as the operating equipment.. This arrangement allows the monitoring operator to be in direct contact with the refrigeration equipment operator in case trouble develops in the air-conditioning system. In either case, the monitoring operator must be in contact with tie equipment operator at all times by voice or through an annunciator system. Close cooperation between all operating personnel is very important for efficient and effective equipment operation. In some installations, more than one graphic panel is installed in the building for a more complete monitoring system.

Review Exercises

NOTE: The following exercises are study aids. Write your answers in pencil in the space provided after each exercise. Use the blank pages to record other notes on the chapter content. Immediately check your answers with the key at the end of the test. Do not submit your answers for grading.

1. What principle of operation does a thermostatic expansion valve use? (Sec. 18, Par. 6)

2. The control response a motor control uses is _____________. (Sec. 19, Par. 2)

3. How would you set a LPC for a wider differential? (Sec. 19, Par. 5)

4. At what pressure will the compressor cutoff if the LPC settings are 40 p.s.i. and 15 p.s.i.? (Sec. 19, Par. 9)

5. You have received a complaint from the messhall. The newly installed walk-in, used for fresh vegetables, is too cold. The system uses an automatic expansion valve and a low-pressure motor control. How would you correct the below-design temperature in the walk-in? (Sec. 19, Par. 10)

6. An ice cube maker is out of order. You find the storage bin is nearly empty. After troubleshooting the system you locate the trouble in the bin thermostat. What malfunction most probably caused the thermostat to become inoperative? (Sec. 19, Par. 12-15)

7. You find the air conditioner is not operating and that someone has inked the feeler bulb of the TMC. What has caused the air conditioner to become inoperative, and how would you correct the malfunction? (Sec. 19, Par. 20)

8. Why are snap action and mercury switches used in electric controls? (Sec. 20, Par. 2)

9. What type of short exists when the ohmmeter connected to a terminal of the TMC and the TMC case indicates zero ohms? (Sec. 20, Par. 7)

10. Which mode of electric control would you use to operate a refrigeration unit? Why? (Sec. 20, Par. 13)

11. A simple two-position control is used to open a set of louvers when the temperature is 80° F. and to close them when it is 70° F. What is the control point temperature? (Sec. 20, Par. 18)

12. How does the timed two-position control differ in response from the simple two-position control? (Sec. 20, Par. 24)

13. How is the heating rate of a bimetal element in a thermostat dampened? (Sec. 20, Pars. 31 and 32)

14. You are installing a cooling coil that is used to cool an area within close tolerances. What type of control would you install? Why? (Sec. 20, Pars. 35-37)

15. The controls for a system used for heating and cooling must be replaced. The new control system must operate gas valves for heating and relays for cooling. Lag time is not a problem. What type of control would you install? (Sec. 20, Par. 41)

16. How is the rotation of a series 20 motor controlled? (Sec. 20, Pars. 43-46)

17. Which type of electric controls acts similar to a single-pole, single-throw switch? (Sec. 20, Par. 49)

18. The series 60 motor used on a motorized valve to maintain a liquid level in a tank is burned out. Can you substitute it with any series 60 motor? Why? (Sec. 20, Par. 55)

19. Can you substitute a series 60 two-position motor for a series 20 motor? Why? (Sec. 20, Par. 58)

20. How does the amount of current flowing through a series 90 balancing relay affect the operation of a series 90 control? (Sec. 20, Pars. 66-68)

21. When will the series 90 motor stop running? (Sec. 20, Par. 73)

22. The damper in a duct system is dosed, but the control is calling for e airflow. What has most probably malfunctioned? (Sec. 20, Pars. 79 and 80)

23. What is the main difference between a series 90 humidity control system and a series 90 temperature control system? (Sec. 20, Par. 88)

24. Which side of the bridge would be the proper place to connect a humidistat for high limit control in a temperature control circuit? (Sec. 20, Par. 93)

25. One belt of a three-belt set driving an sir compressor is broken. How many belts would you install? Why? (Sec. 21, Par. 3)

26. What would you suspect if the air compressor begins to lose efficiency? (Sec. 21, Par. 4)

27. The first stage of a two-stage compressor is operating normally but the output of the second stage s zero. The compressor has an intercooler between stages. What has caused the second-stage pressure to drop to zero? (Sec. 21, Par. 8)

28. You have just finished installing an air compressor. What should you check before you start the compressor? (Sec. 21, Par. 15)

29. What will probably occur if you replace a standard air compressor head gasket with a thin head gasket? (Sec. 21, Par. 21)

30. What are supply-air lines? Control air lines? (Sec. 22, Par. 1)

31. How much pitch must you allow for a supply air header 12-feet long? (Sec. 22, Par. 4)

32. What factor determines the frequency of draining moisture from the compressor air filter? (Sec. 22, Par. 8)

33. What type of controller would you install if you wanted a steam valve to open on a decrease in temperature? (Sec. 22, Par. 17)

34. How do you clean the contact points on a thermostat? (Sec. 22, Par. 23)

35. Under normal conditions, how dose to the set point will a humidistat control the humidity of the conditioned air? (Sec. 22, Par. 25)

36. Which type of controller is used to measure, record, and control humidity? (Sec. 22, Par. 27)

37. The piston type damper operator is at its normal position. The control line pressure is 3 p.s.i.g. Why hasn't the operator begun to open the damper? (Sec. 22, Par. 34)

38. What determines the operating range of a positioner used for damper operation? (Sec. 22, Par. 39)

39. After overhauling a damper operator, you notice that it is operating erratically. What has caused this erratic operation? (Sec. 22, Par. 43)

40. The pen on a recorder chart is skipping on the chart. What should you do to correct this fault? (Sec. 22, Par. 48)

41. When is it necessary to install a condensate loop on a pressure transmitter? (Sec. 22, Par. 57)

42. The recorder you are going to install has been removed from a cannibalized building. The pen is full of dried ink. How should you clean the pen? (Sec. 22, Par. 64)

43. The system fan is off and the dampers are dosed. The fan switch is in the ON position. What caused the system to shut down and how would you restart it? (Sec. 22, Pars. 73, 75, and 76)

44. How can you check the operation of an air-flow detector? (Sec. 22, Par. 82)

45. Why is a graphic panel an asset in an air-conditioning system? (Sec. 23, Par. 1)

46. On graphic panels, temperature is always indicated and recorded. (Sec. 23, Par. 2)

47. A malfunction is shown on a graphic panel. The component indicated on the panel is color coded green. What system is malfunctioning? (Sec. 23, Par. 4)

Evaporative Cooling

CAN YOU RECALL your days at the local swimming pool or perhaps at the beach? If a slight wind was blowing, you will remember that you were more comfortable in the water than out of it. When you climbed out of the pool, the water in your wet bathing suit evaporated rapidly to leave your skin chilled from the loss of heat. Though you didn't give it much thought at the time, you were really experiencing evaporative cooling.

2. Applying the same principle, our older surgeons used an ether spray to freeze those portions of the skin in which incisions were to be made. Rapid evaporation of the ether reduced the temperature of the skin and underlying flesh to the freezing point. You can demonstrate this principle for yourself by wetting your hand with alcohol or water and holding it in the airstream from a fan.

24. Principle and Application of Evaporative Cooling

1. In an evaporative cooler the air is drawn through a finely divided water spray or a wet pad so that a portion of the water is being continually evaporated. The latent heat of evaporation, which must be passed on to the water to evaporate it, is supplied from the heat of the incoming air, thus reducing the dry-bulb temperature, an increase in the relative humidity and dewpoint temperature, and an unchanged wet-bulb temperature.

2. The water which is recirculated continually through an evaporative cooler assumes the wet-bulb temperature of the entering air after a short period of operation. The recirculated water will remain at the air wet-bulb temperature with no external heating or cooling. Makeup water is added to replace the evaporated water.

3. The temperature reduction, which can be made in the air passed through an evaporative cooler, depends entirely on the wet-bulb temperature of the air which is to be cooled. The wet-bulb temperature of the air entering the evaporative cooler is at the lowest temperature to which the circulating air may be cooled.

4. Evaporative cooling should not be used to cool air for spaces requiring constant temperature and humidity control, such as hospital operating rooms and certain types of highly technical electronic equipment. Evaporative cooling is best suited and chiefly used for cooling the space for the comfort of personnel.

5. **Application**. As we have shown, evaporative cooling depends on the evaporation of water; thus, it can be successful only under atmospheric conditions of a low relative humidity. It can be used only where the difference between the outdoor we-bulb and dry-bulb temperature is relatively high. In the arid regions of the southwestern United States, where there is low relative humidity, properly installed and operated evaporative cooling units cool comfortably. This type of system brings in 100 percent outside air. It may be equipped with a humidistat so that when the inside humidity is high and the cooler cannot function properly as an evaporative cooler, the water is cut off and the unit can operate as a straight mechanical ventilating unit. Whenever the outdoor wt-bulb temperature is 73° F. or lower, effective cooling and indoor comfort can be maintained by evaporative cooling.

6. The leaving air temperature of an evaporative cooler usually is just short of saturation; that is, the dry-bulb temperature of the air leaving a cooler does not quite reach the wet-bulb temperature of the air entering the cooler. An evaporative cooler operating at 90 percent efficiency will cool the air a number of degrees equal to 90 percent of its original wet-bulb depression. The measurement of the approach to the entering wet-bulb temperature is the saturation efficiency of the cooler. Air entering at 95° dry-bulb and 75° wet-bulb will be cooled to 77° if the cooler is operating at90 percent efficiency. Computation: The depression amounts to 950 (dry-bulb temperature) minus 75° (wet-bulb temperature), or 20°. Ninety percent of 20 is 18. Subtract 18 from 95° (the dry-bulb temperature) and you have 77?, which is the temperature to which the air is cooled.

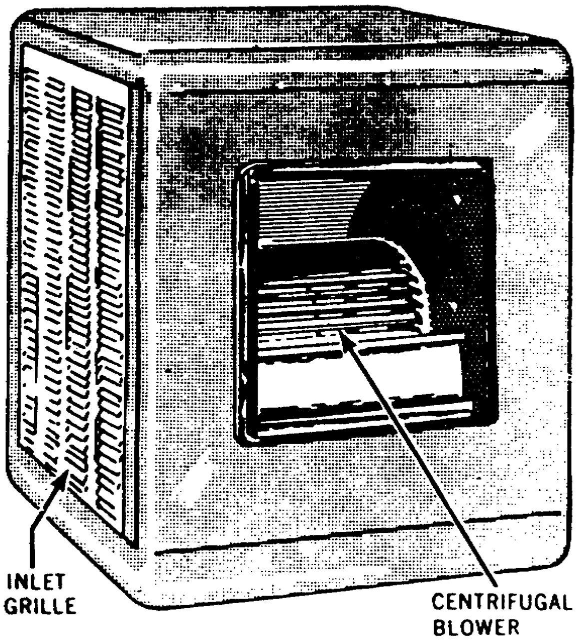


Figure 71. Evaporator cooler.

7. **Components of Evaporative Cooling Units**. Components of evaporative cooling units are very much the same in each type except that some have a different method of supplying the water to the evaporating pads.

8. *Drip units*. Typical drip type evaporative cooler components consist of the following: a motor-driven fan, or blower; a circulating water pump, piping, and water distributors; a water collecting pan with water makeup float valve and drain; and water evaporating surfaces. All these components are assembled in a weatherproof cabinet, the complete assembly being known as a self-contained unit. It will range in size from the small, one-room cooler with a capacity of about 700 cubic feet per minute (c.f.m.) to the large industrial coolers with capacities up to about 30,000 c.f.m.

9. The small, one-room cooler normally uses a propeller fan; the larger coolers use a squirrel-cage or centrifugal blower. The propeller fan cooler discharges the cooled air directly into the conditioned space from the vaned air-discharge outlet of the unit. Duct work for air distribution is never attached to this type of unit.

10. Coolers of 2000-c.f.m. capacity and above use the squirrel-cage blowers which are driven by a motor with a V-pulley and a V-belt. Figure 71 illustrates this type. Electric motors vary in size according to the size of the fan blade or blower:

11. The recirculating water pump is a vertical-shaft, directly connected unit of light construction. The pump impeller is suspended in the pump housing from a ball-bearing motor shaft, which eliminates pump bearings and packing. The pump housing has a wire-mesh screen through which the water passes as it is drawn in by the pump impeller and forced through the discharge tube to the distributor. Pumps sit in the water of the collecting pan or are sometimes mounted on a special frame. In either case, they must be insulated to prevent vibration and transmission of noise. Figure 72 illustrates this type of water pump and its breakdown.

12. A water distributor is a trough which receives the water from the recirculating water pump through the distributor head and distributes it evenly over the top of the evaporating surface pads. One distributor is provided for each pad in the cooler. The water flows through weirs (triangular openings) of the trough onto the pads which are on the air inlet sides of the cooler. (See fig. 73.)

13. The piping system consists of a T-fitting or a water distributor head with one inlet and three outlets which are connected by pipe or tubing to the water distributors. The inlet connection from the pump is usually a rubber hose. In figure 74 you can see that the quantity of water which flows to the branch piping system is regulated by an adjustable hose clamp which throttles the flow of water in the hose connecting the water pump to the water branch tubes. The quantity of water which flows through the branch tubes to the troughs is equalized by rubber or metal metering rings placed in each branch tube.

14. The water collecting pan forms the bottom of the cooler and contains the water, the water float makeup valve, and water drain standpipe, as shown in figure 75. The makeup valve controls the level of the water in the collecting pan and automatically admits water to replace any that is lost through evaporation and bleedoff.

15. Water in the collecting pan should be kept at a depth sufficient to keep the recirculating pump primed. The overflow pipe consists of a removable length of pipe, the top of which is slightly below the top edge of the collecting pan. When the water level in the collecting pan rises to the top of the overflow pipe, the excess water flows into the pipe and is carried away to a drain.

16. Some drip type evaporative coolers (the older models and the small, one-room type) are not equipped with a recirculating water pump or troughs. In these coolers the water is supplied directly to the distributors. In this case the distributors are usually copper tubes with small holes drilled about I inch apart in order to give an even distribution of water over the top edge of the evaporating pads. The flow of water is controlled by a water valve mounted on the inside of the front panel. Other models, in order to control

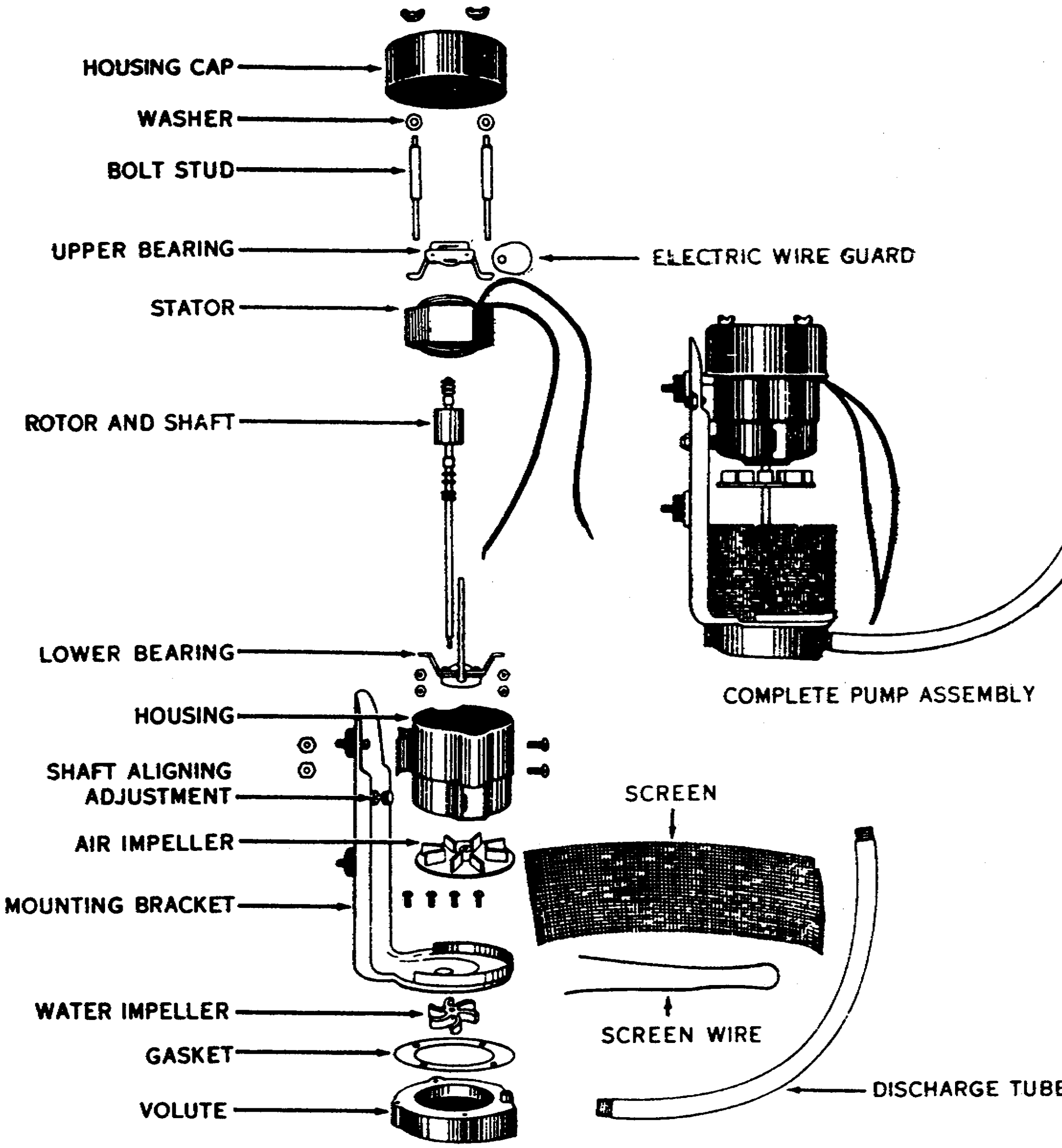


Figure 72. Breakdown of water pump.

the flow of water, use an electric solenoid water valve which opens and closes when the cooler is turned on and off. In this case the quantity of water also is regulated by an adjustable hose clamp on the hose feeding water to the distributor header and by metering rings in the branch pipes or tubes. Many coolers of this type have been installed in the past on military bases; however, present military design criteria do not permit installation of a drip type cooler that does not have a recirculating water pump.

17. The water evaporative surface of drip type evaporative coolers consists of one or more pads of aspen wood excelsior, redwood excelsior, a mixture of redwood and aspen wood excelsior, glass wool, or a fiber made of other materials. The bulb excelsior is inserted in either cheesecloth, hardware cloth, or a metal frame to bind and hold the material together in pads. The pads are held in place by a barbed rack or other suitable means. Each pad is placed in a louvered frame, as you can see in figure 76. The louvered frames are fitted into openings on two sides and on the back of the cooler through which the air is drawn by the fan. The louvers serve a double purpose: they help to distribute the air uniformly over the entire area of the water evaporating pads, and they prevent water from wetting the area surrounding the cooler.

18. Spray units. Spray units (sometimes called

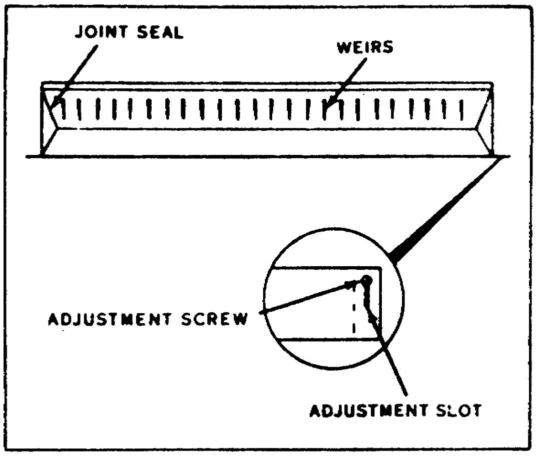


Figure 73. Weirs.

air washer units) are made in sizes ranging from 3500 c.f.m. through 12,000 c.f.m. They are larger in dimension and weigh considerably more than the drip type unit. They are designed to keep the pads free of excess dust and water solids for a longer period of operating time than are the drip type units. They use sprays to wet and contin-

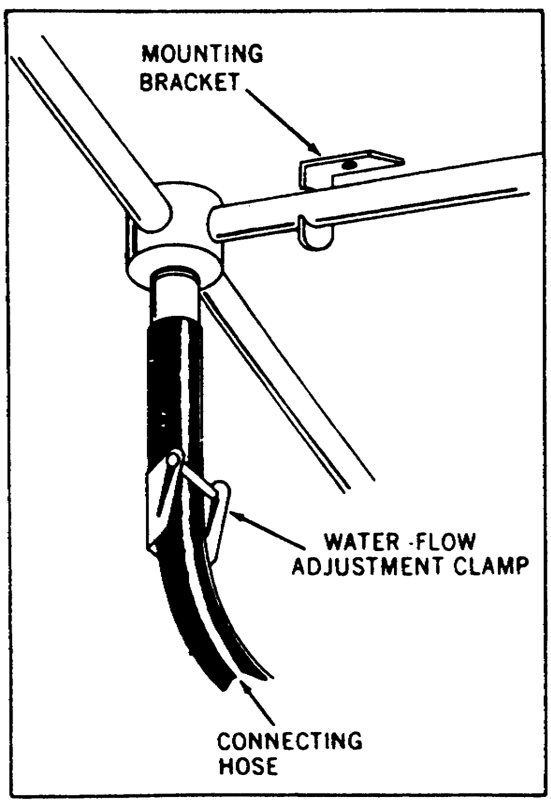


Figure 74. Waterflow adjustment.

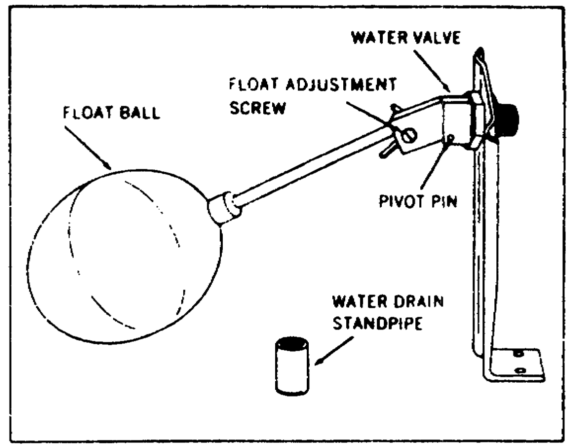


Figure 75. Water makeup valve and standpipe.

uously wash down the inlet side of the filter pads and partially saturate the incoming air by direct contact as the air passes through the s prays.

19. There are two main types of spray designs used by manufacturers, with essentially the same results. These are the "spray nozzle" and the "rotating disk" (sometimes called slinger), shown in figures 77 and 78. Both spray type units consist of the following principal components: piping; water collecting pan with makeup float valve and drain; recirculating water pump; evaporative filter and eliminator pads; sprays, either nozzle or spray disk; and a motor-driven blower-all assembled in a self-contained weatherproof cabinet.

20. The piping system consists of the supply line and piping to the spray nozzle. The collecting pan forms a part of the bottom of the evaporative cooler cabinet, which contains the float-actuated water makeup valve and drain. Since the float controls the water valve, it also controls the level of the water in the collecting pan. The spray disk, or wheel, assembly of the evaporative cooler supplies a continuous sheet of atomized water over the air inlet face of the evaporative filter pad. The spray disk collecting pan is located below and in front of the center of the filter pad. The water in the collecting pan is supplied to the disk, or wheel, by a water pump similar to those used on drip type units. The centrifugal action of the rotating disk distributes the water evenly in all directions in a vertical plane so that the resulting curtain of spray water falling over the entire inlet face of the evaporative filter pads washes down the air inlet side of the pads continuously.

21. The automatic flush valve consists of an electrically operated solenoid valve and an electric timer combined in one unit. This valve flushes the water from the water collecting pan regularly and automatically. This action helps to keep the

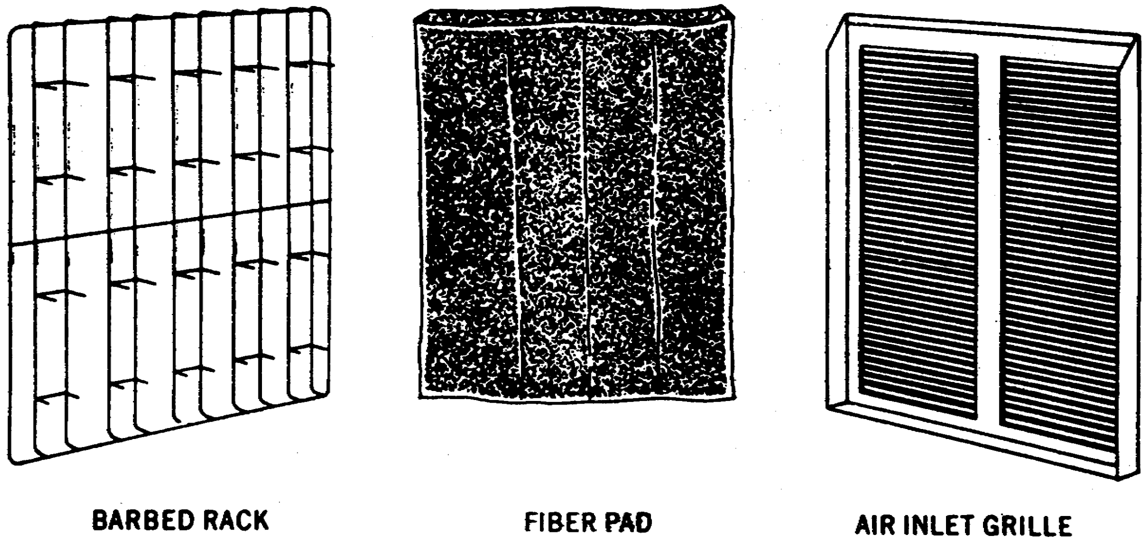


Figure 76. Breakdown of side panel.

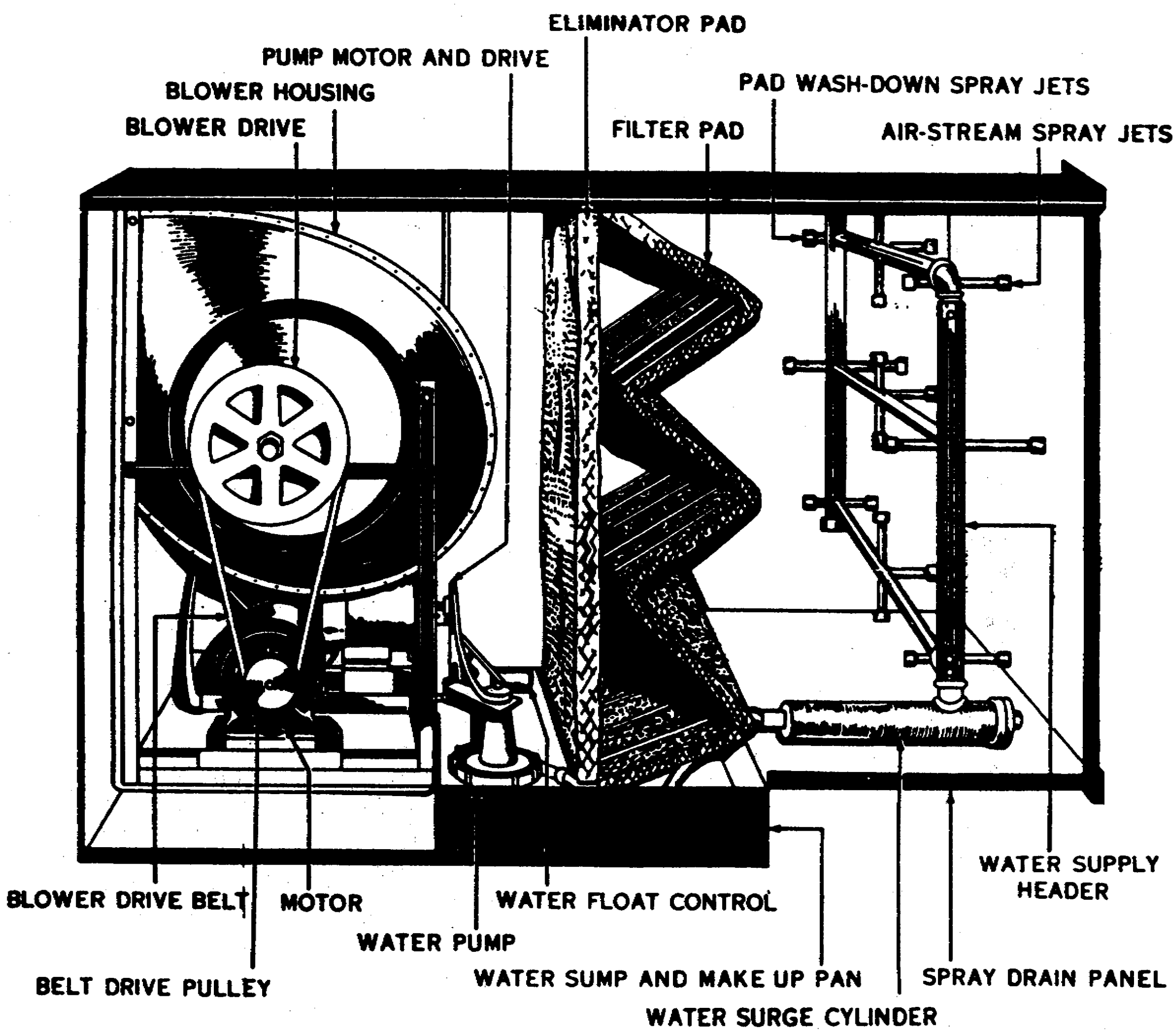


Figure 77. Spray nozzle evaporative cooler.

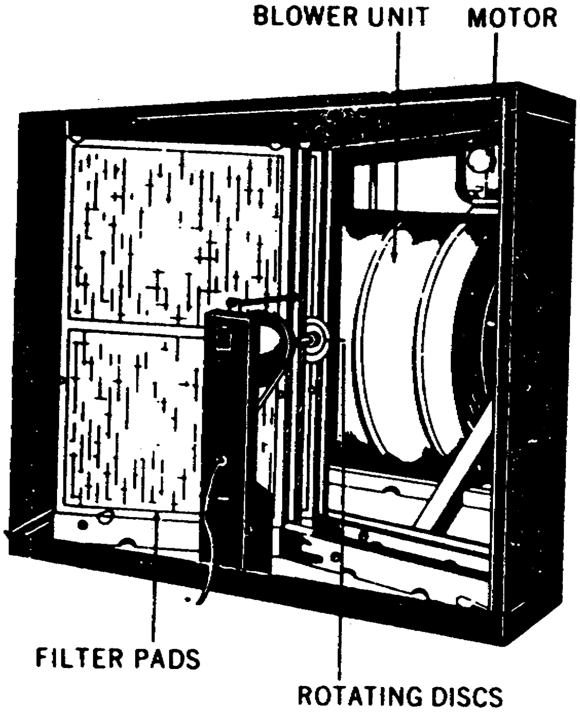


Figure 78. Rotating disc evaporative cooler.

collecting pan clean. The solenoid valve is operated by means of a coil of wire wound on a soft iron spool which forms an electric magnet. When the current flows through the coil, the valve stem is lifted to open the valve. When current is cut off, the valve is closed either by gravity or by a spring. The operating solenoid part of the valve is completely enclosed. The water drain is controlled by a plunger, and a diaphragm isolates the working mechanism of the valve from the water. The valve assembly is also provided with an overflow connection and a manual operating lever to completely drain the water collecting pan.

22. The electric timer regulates the flushing action of the solenoid valve. It consists of a 1-hour electric timeclock which is adjustable from 0 to 2 1/2 minutes drain time. The settling of the drain time will depend on the dirt content of the air entering the cooler, the salt content of the water, and the resistance in the waste plumbing.

23. The spray nozzle does the same things as a spray disk. Nozzles are usually mounted in both a vertical and a horizontal position: the vertical nozzles are used for washing (down the evaporative filter pads, and the horizontal nozzles for forming a curtain of spray water over the entire air inlet area. Water is supplied to the nozzles through the piping system by a centrifugal pump of large capacity and heavy-duty construction, mounted in the water collecting pan. Figure 79 illustrates this type of water pump which is completely sealed. All recirculating water pumps have a screen of sonic type to prevent particles of dirt and foreign matter from getting into the water piping system.

24. Evaporative filter pads and eliminator pads are usually made of fibers of various materials and are supported by angle frames and heavy wire mesh. Normally, spray type evaporative coolers use a specially treated hygroscopic spun glass for filter pads. This material assists in holding the fibers in place and helps the water adhere to the surface. The evaporative filter pads form the water evaporating surface. The eliminator pads remove the moisture from the cooler air after it leaves the evaporative filter pads and prevent waterdrops from being carried over into the fan and motor of the cooler unit.

25. Blower fans, known also as centrifugal fans, are used on spray type units. The fan and the motor which drives it are both equipped with grooved type pulleys and are connected with V-belts. The fan has a self-aligning, self-oiling bearing on each side of the impeller wheel. Blower fans are designed and rated for air delivery against 1/4 -inch water gauge static pressure resistance at the discharge outlet of the unit. If the static pressure is greater than 1/4 inch, water gauge efficiency will be lost. Blower fans, depending on size, are normally used to supply air through a duct system.

26. **Rotary-Drum Evaporative Units**. As the name implies, the rotary-drum evaporative cooling unit uses a rotating drum, powered by a reduction gear and motor. Figure 80 illustrates a partly dissembled rotary-drum unit. Other principal components are the exterior air-filter unit, the rotor housing, the water tank and the float-actuated water makeup valve, an automatic flush valve, and a motor-driven fan or blower. All of these components are mounted in a metal weatherproof cabinet. The rotary-drum type evaporative coolers are usually made in sizes ranging from 2500

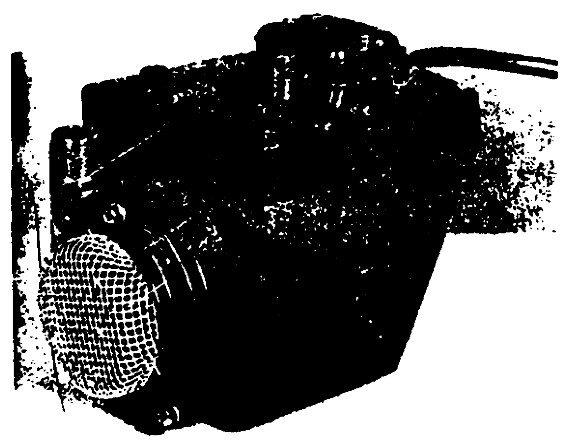


Figure 70. Sealed water pump.

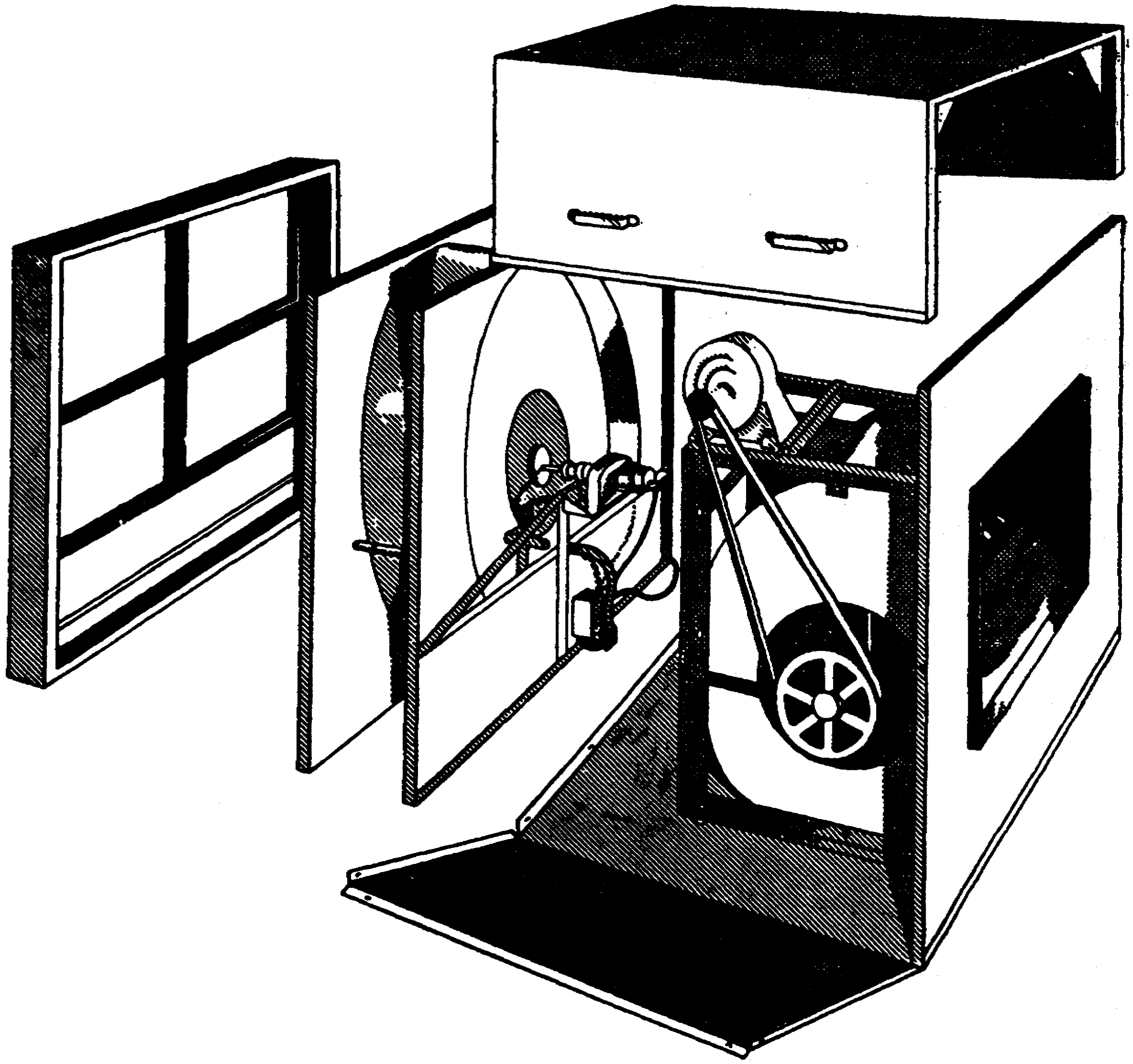


Figure 80. Breakdown of rotary-drum evaporative cooler.

through 6000 c.f.m. Blowers and motors are designed the same as for the drip type evaporative cooler units.

27. The rotor, which is driven by an electric motor at an approximate speed of 1 1/2 r.p.m., is cylindrical and consists of alternate layers of corrugated and flat screen wound on a drum. It revolves in the rotor housing, the lower portion being constantly wet by its immersion in the water tank of the housing. When in operation, the rotor continuously exposes an evenly wetted surface to the incoming air. The rotor housing contains the revolving rotor and supports the rotor bearings and the electric gear motor. The lower portion of the rotor housing forms the water tank. The float-actuated water makeup valve controls the water level in the tank.

28. The automatic flush valve empties the water from the tank automatically. This action, which helps to keep the rotor and water tank clean, is repeated regularly by an electrically operated solenoid valve. The operating solenoid of the valve is completely enclosed. The water drain is controlled by a plunger, and a diaphragm isolates the working mechanism of the valve from the water. The valve assembly is provided with an overflow connection. A manually operated valve is also provided to completely drain the water tank.

29. The action of the solenoid valve is regulated by an electric timer, a 1-hour electric timeclock with contacts that open and close according to the time limit for which the timer is designed. The setting of the drain time, usually adjustable

from 0 to 2 1/2 minutes, is dependent on the amount of dirt in the air that enters the cooler, the salt content of the water, and the resistance in the waste or drain plumbing.

30. The filters of the rotary-drum type evaporative cooler, called air filters, are usually of the impregnated, washable, metal type. The filter unit is located on the air intake side, where the air can be cleaned as it enters the cooler.

31. **Slinger Type Evaporative Units**. The slinger type unit may be constructed as a double unit. The metal weatherproof cabinet may contain two sets of the principal components, such as two sets of spray wheel assemblies. The blower, or fan, of the slinger type evaporative cooler is the same as on the rotary-drum unit-a motor-driven centrifugal blower. It is driven by a V-belt connecting the blower and motor by means of grooved pulleys. The blower which is used to supply air through the duct system is designed and rated for air delivery against V4 -inch water gauge static pressure resistance at the discharge outlet. It has two self-aligning, self-oiling bearings, one on each side of the blower wheel. The electric motor operating the blower is mounted high in the metal cabinet to protect it from too much moisture.

32. The electric motor operating the spray wheel is scaled in a waterproof assembly with water-seal packing around the shaft to the spray wheel. The spray wheel picks up water from the collecting pan and distributes it in all directions in a vertical plane by the centrifugal action of the rotating spray wheel. This action supplies a continuous sheet of atomized water which is sprayed over the air inlet side of the evaporative filter pad. As the air passes through the water, dust and dirt are removed and the air is partially cooled. This continuous sheet of atomized water also continually washes the dirt from the pad. The water collecting pan, which is located below and in front of the evaporative filter pad, forms a part of the bottom of the evaporative cooler cabinet. A float-actuated water makeup valve, which controls the level of water, is contained in the collecting pan.

33. The automatic flush valve assembly consists of the flush valve, which flushes the water from the water collecting pan regularly and automatically; solenoid valve; and timer. The timer is electric and has an adjustable drain-time setting which regulates the flow of current to the solenoid valve. The solenoid valve operates the drain valve. This assembly is very similar to the flush valve assembly used with the rotary-drum type evaporative cooler.

34. The evaporative and eliminator pads are usually made of various washable materials supported by angle frames and heavy wire mesh. The fibers are impregnated with a hygroscopic material which not only helps to hold the fibers in place but also treats the fibers so that water will adhere to their surface. The evaporative filter pads form the water filter and evaporating surface, and the eliminator pads remove moisture from the cooled air. The eliminator pads also prevent small drops of water trapped in the air from being carried over into the fan and motor of the blower compartment.

35. The cabinets for slinger type evaporative coolers are usually constructed the same as those for other large type evaporative coolers. Heavy-gauge galvanized steel is used to enclose the entire unit. The sides are removable to provide access to the interior.

25. Installation Procedures

1. The size and style of the unit determine the location and the type of structure required to support it.

2. **Locations**. Units mounted in building windows are of the small, propeller fan and blower types. These are light in weight and will not do damage to the building structure.

3. The large, heavy, blower type units must be mounted on self-supporting platforms adjacent to, but independent of, the building. In some cases--the air washer type unit, for instance--it may be more economical to mount the unit on a concrete platform.

4. The dimensions and operating weight of the cooler should be determined before starting construction of the supporting structure or mounting platform. A walkway with guard rails round the cooler will give you a safe working area. Each platform should also have a ladder, built as part of the structure.

5. Never mount cooler units on the building roof. Each unit must be mounted on the platform so that it is rigid and level. In some cases this may require shims and the bolting down of the unit. Every cooler manufacturer furnishes mounting and installation instructions with each type of unit. You should understand these instructions before installing the cooler.

6. **Connections**. The various connections required for evaporative coolers must be installed as specified for each cooler. Check the instructions and see that the proper size pipe, valves, switches, wire, and fuse boxes are installed. Only in this way can you be sure that the equipment will give the expected service.

7. *Water supply and drain*. The small, window type evaporative cooler normally uses 1/4-inch copper tubing to carry the water supply. A 1/4-inch fitting is located on the side of the sillcock valve which is installed on any ordinary 1/4-inch outside water valve (garden hose).

8. Large units must have a water supply line of at least 3/4-inch pipe or tubing. A globe shutoff valve is installed in the supply line on the inlet side to the unit. Coolers using a water solenoid valve instead of a recirculating pump should have a water strainer installed on the inlet side of the solenoid valve. A water faucet with a hose bibb should be installed in the supply line near each cooler. This is to be used in washing down the interior of evaporative coolers immediately after heavy duststorms or when maintenance service is being done.

9. The water drain or was system for evaporative coolers should be at least 1 1/4 inches in diameter to reduce drain stoppage. The drain system should be connected to the sewer or to a street drainage system. In freezing areas the water supply system should be insulated against freezing, or the unit may be installed to permit the complete draining of the system.

10. *Electric connection*. Small propeller units (window type) are usually connected by inserting the electric cord plug into a convenient outlet. Thus they can be placed in or out of operation by a toggle switch on the front of the unit.

11. The larger units should be equipped with their own fuses. Sometimes this may require a separate main switch and fuse box, depending on the power requirements of the unit. Pushbutton stations or toggle switches are used to start and stop equipment operation. Other units may require two separate switches, one for the water recirculating pump motor and one for the blower motor, hooked in series with one of the motor leads. This allows the unit to be used for ventilation. The larger units usually require magnetic starters and sometimes have pilot lights or other devices to indicate when and what part of the cooling unit is in operation. All switches, controls, pilot lights, and Indicators should be mounted on a control panel located in a convenient place. Each large evaporative cooler should have a disconnect switch mounted inside the unit to permit maintenance personnel to control the unit operation while performing maintenance service.

12. **Air Distribution and Supply Ducts**. Duct work for evaporative cooling systems is designed and installed in the same manner as that refrigerative air-conditioning systems. There must be a properly sized supply duct and adequate exhaust outlets.

13. *Supply ducts*. The supply duct enters the building below the roof bearing plate direct from a unit which is mounted on a structure platform. The duct must be installed without cutting any structural members of the building. A slide damper of air stop should be provided for winter closure of the duct system.

14. When practical, corridor space should be used as a plenum for air distribution ducts. The plenum must be airtight except for supply outlet grilles. Air supply branch ducts to rooms or spaces a located to provide an even distribution of air. Branch ducts and multiple air outlets from the main duct usually have dampers or splitters to balance the flow of air. When the system is checked and adjustments are made, the dampers or splitter should be locked in place so that unauthorized persons cannot readjust them. Directional flow vanes are usually installed on the supply outlet so that air may be directed where required. Do not use wire mesh screens on supply outlets; they provide no means of directing the flow of air.

15. *Exhaust outlets*. To have proper cool air circulation throughout the various spaces and rooms of a building, each room must have a proper size exhaust outlet leading to the outside of the building. Exhaust outlets should have louvers or adjustable vents for regulating the circulation of air. Exhaust fans may be installed to insure positive air circulation through spaces with high temperatures, such as messhalls and areas around ranges.

16. If windows are used as exhaust outlets, they should be raised to a fixed position. Window stops should be installed to prevent personnel from raising windows in excess of 4 inches. Not less than 2 square feet of louvered exhaust openings should be provided for each 1000 cubic feet of air delivered to a room or space when such exhaust openings are used in lieu of raised windows. All doors should be kept dosed to maintain a balance of the airflow throughout the conditioned space.

17. **Automatic Controls**. Automatic controls are not essential but are convenient. When automatic thermostat and humidity controls are used, they should be checked for proper operation and also should be adjusted, set, and locked in position to prevent readjustment by the using organization.

18. A thermostat is used to prevent the temperature from going below a predetermined value. The thermostat controls the operation of the blower and water pump by starting and stopping them when the temperature in the cooled area is above or below the predetermined thermostat setting (usually 80° F.).

19. In some areas the evaporative cooler will have a humidistat to control the humidity of the space being cooled. The humidistat when used, controls the starting and stopping of the water pump whenever the relative humidity in the space being cooled is below or above the predetermined humidistat setting (usually 55 percent). Usually these controls are not used together. In case they

are, the thermostat is usually connected to operate the blower and the humidistat to control the water pump. In any case, they are connected to permit a constant supply of air by continuous operation of the blower, thus turning the unit into a straight mechanical ventilation system when atmospheric conditions prevent the unit from functioning as an evaporative cooler.

20. **Startup Checks and Adjustments**. The successful functioning of evaporative air coolers depends directly upon the manner in which they are operated. Normally, the using organization is responsible only for starting and stopping evaporative air cooling units and systems. The personnel of the using organization must be instructed thoroughly in the operation of electrical switches, water valves, and other controls. They are cautioned not to start the blowers prior to starting the water pumps after long shutdown periods.

21. **Startup Procedures**. When a new or inactive evaporative air cooling unit is to be placed in service, you should perform the startup services to prepare the equipment for operation. Before starting the equipment, you must inspect all parts, accessories, and units to see that they are secure and correctly adjusted. Seasonal startup is scheduled well ahead of the time the equipment is to be used. This allows ample time for inspection and startup services. During initial startup procedures, all supply outlets, vanes, dampers, and splitters should be opened for normal airflow. Moist rags should be placed over the supply air outlets into each space being air-conditioned to catch the dust and construction dirt before it is discharged into the space where occupants are on duty.

22. The ratings of motor overload protection devices should be checked against the motor nameplate ampere ratings. If the devices are oversize or undersize, thermal elements of the proper size should be installed.

23. An ammeter should be connected to the blower motor circuit prior to starting the motor. Starting and running currents should be recorded when the blower is first operated, with all pads and filters dry and in place. If the running current is equal to or less than the overload rating of the motor, then the motor will not be overloaded under final load conditions.

24. Testing the unit with clean, dry pads assures you that the unit can be operated subsequently without water for ventilating purposes, since pads are always in place when the unit is operating. If the running current is in excess of the motor overload rating, you must determine the cause. In many cases, overload is due to excessive fan speed. Correct this before continuing the operation of the motor. The fan speed should be reduced by adjusting the variable-pitch motor pulley or by reducing the size of the motor pulley. Where this is impractical, the blower pulley size should be increased. You should use pulleys of the correct size rather than attempt to cut down the original ones. An ammeter should be used to check the starting and running currents of the pump motor after the water collecting tank has been filled and the pump first operated. If the running current is in excess of the motor overload rating, determine the cause and correct it before continuing the operation of the pump.

25. During the initial operation of the unit with water on the pads or sprays, air delivery in the supply ducts should be determined by a velometer or other velocity-indicating instrument. Take readings at a sufficient number of cross-sectional spots in the same section of the supply duct so that you can arrive at an average velocity reading. Multiply the average velocity by the square-foot, cross-sectional area of the duct. This computation will give the quantity of airflow in cubic feet per minute. If the rate of air delivery approximates the designed capacity of the system, the unit should be continued in operation. If the rate of air delivery is considerably in excess of design capacity, reduce the fan speed. In such a case, the fan motor is usually overloaded and the velocity of the air through the water evaporating pads is excessive. If this is the case, drops of water may be carried over into the fan compartment and cause shorting of electrical circuits, motor "burnouts," rapid deterioration of belts, and excessive rust and corrosion. After balancing air distribution to all spaces by the use of velocity indicating instruments, lock all dampers, splitters, and directional flow vanes in their final position in such a manner that tampering or readjustment is impossible except by the maintenance personnel. Units which operate at efficiencies below 80 percent require adjustment to improve their performance.

26. **Shutdown Services.** When evaporative air cooling equipment is to remain idle for long periods of time, you must perform the preventive maintenance shutdown services. This service protects the equipment, conserves critical materials, and prepares the equipment for minimum startup service. All parts, accessories, and equipment are inspected to insure proper servicing for seasonal shutdown or standby condition.

27. The shutdown service for evaporative air cooling equipment depends upon its condition and the method of storage. Usually the coolers are drained and washed out with water under pressure. If they are to remain attached to the building, they should be protected from the weather by some type of cover. Normally these coolers should be removed from the building, stored in a dry place, and overhauled during the winter season. This procedure puts the coolers in good

condition for the next season's run. Having been overhauled, they should give very little trouble during the cooling season.

26. Preventive Maintenance and Inspections

1. Definite procedures for the preventive maintenance of refrigerating and air-conditioning equipment are necessary for efficient operation. The objectives of preventive maintenance are as follows: to prevent breakdown, to insure proper maintenance, to provide immediate and adequate minor repairs and avoid major repairs, to control maintenance costs, to establish specific personnel assignments, and to develop minimum but adequate maintenance records and data.

2. Well-planned inspections and up-to-date and correct records are required for a successful preventive maintenance program. Inspection is a key phase of preventive maintenance. It is a simple fact that when minor deficiencies are overlooked, they can cause major breakdowns in the future. This eventually defeats any preventive maintenance program. The responsibility of detection is the duty of all personnel assigned to preventive maintenance.

3. **Servicing Components**. Table 1 contains instructions which will serve as guide procedures for inspecting and servicing the components of evaporative air cooling equipment. It may be necessary to supplement these instructions and procedures with the manufacturer's instructions where the equipment is not standardized in design.

TABLE 1

INSPECTING AND SERVICING PROCEDURE

Item	*Inspected For*	*Service to be Accomplished.*
Filter.	Algae, water solids, pollens, etc.	Wash with garden hose.
	Pad construction (layers evenly distributed).	Fluff the fibers or replace the filter.
	Sagging pads.	Replace filter.
Pad frame and retaining screens.	Dirt and scale.	Clean and paint or replace.
Troughs and weirs.	Dirt and scale.	Clean and paint or replace.
	Plugged slots.	Clean with a thin blade made to fit the slot.
Piping system.	Leaks.	Repair or replace as required.
Piping system.	Internal scale formation.	Disassemble and clean with a wire brush.
Spray nozzle.	Dirt and scale.	Clean nozzle or file with a strand of wire.
Rotary disk water distributor.	Freedom of shaft rotation.	Clean with solvent or fine emery paper and lubricate.
	Scale on disk surface.	Clean with wire brush.
Water distribution system (piping, spray nozzle, trough, etc.).	Dirt and scale.	Clean with a 10-percent solution of muriatic acid. After this is done, paint components as necessary to retard corrosion.
Water float valve.	Freedom of lever movement.	Straighten lever, clean, or replace.
	Positive water level.	Adjust the floatball position with respect to the lever pivot (level should be set to permit a constant overflow *into the overflow* standpipe).
	Floatball corrosion.	Remove and replace with nonferrous metal or plastic ball.
Water circulating pump.	Lubrication.	Lubricate with SAE 20 oil.
	Dirty bearing.	Clean and lubricate.
	Binding shaft and impeller.	*Disassemble and* adjust (shim impeller).
	Rusted surfaces.	Clean and paint or replace.
	Alignment of belt drive.	*Realign with* straightedge or dial indicator.
	Belt wear.	Replace with like item.
Cabinet and water makeup tank.	*Rust and scale.*	*Clean and paint* with asphalt base paint.
	Bent or distorted vanes.	Straighten and repair.
Motor.	*Dirt or rust on* exterior surface.	*Clean and paint.*
	Internal moisture.	Shield or relocate motor.
	Bearings for wear.	Replace.
	Lubrication of bearing.	Relubricate.
	Brushes for cleanliness.	Clean with solvent or fine sandpaper.
	Brushes for wear.	Replace.
	Brush holder for roughness.	Sand surfaces smooth before re-

TABLE 1 Cont'd

Item	*Inspected For*	*Service to be Accomplished.*	*Item*	*Inspected For*	*Service to be Accomplished.*
		placing brush.	Blower wheel.	Freedom of rotation.	Adjust axial clearance ($\frac{1}{32}$ inch).
Propeller fan.	Bent blades.	Replace (balanced at factory).		Worn thrust washers.	Replace.
	Cleanliness of fan blade.	Clean and polish.		Blower shaft bearing lubrication.	Oil sleeve bearings and grease pack ball bearings.
	Fan shaft bearing lubrication.	Lubricate only when needed.			
	Fan drive for tension.	Adjust belt so that the deflection halfway between the pulleys is approximately 1 inch.	Platform and structure.	Rot.	Repair or replace as necessary.
				Condition of paint.	Brush surface, then repaint.

4. **Major Repairs**. Major repairs and renovation of evaporative air cooling units should be done during the winter every year. At post where there are a great many units to maintain, the shop space should be sufficient to permit proper repair of the units. Smaller units can be removed from their platforms and taken into the shop as self-contained units. Since large units are not readily movable, their component parts should be removed to the shop. All units should be dismantled every year, thoroughly overhauled, cleaned, and painted to prevent rust. It is best that fans be dismantled and wheels and scrolls cleaned and painted. Both inside and outside casings, pad frames, eliminators, water makeup pans, and metal structural parts should be cleaned and painted. Pads should be replaced as required. The best practice is to see that the water distributing system and the spray pump are dismantled and inspected for cleanliness or excessive impeller wear. Badly worn impellers should be replaced. All bearings on the fans, pumps, and motors must be cleaned, checked for wear, and replaced when necessary. All the ball bearings should be repacked with grease and the sleeve bearings lubricated with oil or grease as necessary. It is approved practice that units, when repaired, be replaced on their stands and their air intake louvers suitably covered to prevent the pads and the equipment from becoming dust laden.

Review Exercises

NOTE: The following exercise are study aids. Write your answers in pencil in the space provided after each exercise. Use the blank pages to record other note on the chapter content. Immediately check your answers with the key at the end of the text. Do not submit your answers for grading.

1. Agree. Disagree. Evaporative cooling removes heat from the air to evaporate the water. (Sec. 24, Par. 1)

2. With an evaporative cooler, the air can be cooled to its ____________________ temperature. (Sec. 24, Par. 3)

3. List the following cities in order of the best environment for evaporative cooling:
   New York, New York.
   New Orleans, Louisiana.
   Dallas, Texas.
   Phoenix, Arizona.
   (Sec. 24, Par. 5)

4. What would be the most probable cause of low water supply to the distributor in an evaporative cooler? (Sec. 24, Par. 11)

5. Which type of evaporative cooler would you install in a dusty area? (Sec. 24, Par. 18)

6. On spray type evaporative coolers that utilize a flush valve, what controls the frequency of operation? (Sec. 24, Par. 22)

7. What maintenance Is required when water droplets are being blown into the room from a spray type evaporative cooler? (Sec. 24, Par. 24)

8. A small evaporative cooler is connected to a building using duct work. The duct work contains four elbows and a diffuser. What may happen to the evaporative cooler? (Sec. 24, Par. 25)

9. Which evaporative cooler would require a heavy structure to support it, the 3000 c.f.m. drip type or 3000 c.f.m. rotary-drum type? (Sec. 25, Par. 1)

10. The drain on an evaporative cooler is plugging up regularly. How can you correct this condition? (Sec. 25, Par. 9)

11. A new evaporative cooler, drip type, is installed in the messhall. Two switches are included with the unit. What function could these two switches serve and how are they connected? (Sec. 25, Par. 11)

12. You have just installed an evaporative cooler in a room. What size exhaust opening should be provided to allow proper cool air circulation? (Sec. 25, Par. 15)

13. A complaint is submitted to the refrigeration shop about excessive noise from the evaporative cooler. You find that the window opposite the cooler is open 2" and the cooler is rated at 4500 c.f.m. The window measures 2 1/2' x 5'. How can you correct the complaint? (Sec. 25, Par. 16)

14. What precaution should you give to the user after you have checked the cooler for season operation? (Sec. 25, Par. 20)

15. The blower motor on an evaporative cooler has burned out. How could this have been prevented? (Sec. 25, Par. 22)

16. How can you reduce the speed of the blower in an evaporative cooler? (Sec. 25, Par. 24)

17. How many c.f.m. is being delivered from a 12" x 24" duct when the average velometer reading is 50 f.p.m.? (Sec. 25, Par. 25)

18. What service must you perform on the troughs and weirs of a drip type evaporative cooler? (Sec. 26, Par. 3)

19. How is the water distribution system cleaned? (Sec. 26, Par. 3)

20. What size feeler gauge is used to adjust the axial clearance of the blower wheel? (Sec. 26, Par. 3)

Mechanical Ventilation

HAVE YOU EVER waved a paper in front of your face on a warm day? This is one form of ventilation system. The air moving across your face helped the moisture (sweat) evaporate. This evaporation process removed heat from your body so that you felt a cooling sensation.

2. You will study various ventilation systems and their application. There are many factors which must be considered when you install a ventilation system. These factors are discussed in this chapter.

27. Ventilation and Distribution

1. When ventilating a room or building, the factors to consider are the tightness of construction, the number of occupants, and the kind of work being done. Whenever human beings work in close quarters, the gaseous products from respiration, the odors from perspiration, and the heat radiated from the body should be removed. All of these byproducts of human activity tend to reduce human efficiency.

2. Proper air distribution is essential in a ventilating system. The system not only should deliver a definite amount of air to a room but also should distribute it evenly. If this is not done, the occupants will be uncomfortable from drafts, stuffiness, and temperature differences between the floor and ceiling.

3. For instance, in comfort ventilation, a corner or spot near a window will be noticeably hotter or cooler than the rest of the room. Since individual comfort is, in this case, the main purpose of ventilation, you are really interested only in distributing the air over the floor area of a room to a height of about 7 feet. Complete air distribution is more important when removing fumes and vapors from a building or room. Poor air distribution causes gas fumes and vapors to remain in various areas of the building and creates an explosion hazard. In all cases where air is exhausted from a space, replacement air must be supplied.

4. **Air Distribution Standards**. Air from fans and duets is delivered to a room through grilles. The purpose of a grille is to distribute the air evenly and silently, without creating drafts.

5. So that the people will not have a feeling of stuffiness, there should be a slight movement of air at all times. An air movement of 25 to 35 feet per minute (f.p.m.) is most satisfactory, but air motions of 20 to 50 f.p.m. will usually prove acceptable.

6. Grille manufacturers normally rate their grilles as follows:

a. Quantity of air in cubic feet per minute (c.f.m.).

b. Outlet velocity in f.p.m.

c. Nominal grille size.

d. Blow of air in feet. (By "blow" we mean the horizontal and vertical distance a stream of air travels from the grille until it slows to a maximum velocity of 50 f.p.m.; see fig. 81.)

e. Drop of air in feet. (By "drop" we mean the vertical distance the lower edge of a horizontal projected airstream drops between the grille and the end of the blow.)

7. **Air Distribution Limiting Factors**. A few of the air distribution limiting factors are discussed in the following paragraphs.

8. *Blow*. The blow at a grille must be sufficient to produce satisfactory conditions throughout the conditioned area. Overblowing results in drafts and underblowing may cause improper air mixing. If cooling air is being supplied, the cool air may drop too fast to permit proper mixing with the warmer room air. Experience has shown that the blow should be about three-fourths of the distance toward an outside wall or window. This distance should be modified if the room height or height of a beam is such that the drop will cause a draft over the people inside.

9. *Drop*. Place the grilles so that the airstream at the end of the blow is not less than 6 feet above the floor level. However, the airstream should not touch the ceiling as this may cause a dirt streak on the ceiling.

10. *Air motion*. To achieve desirable air motion in a building or a room without exceeding velocity limits is one of the more critical air

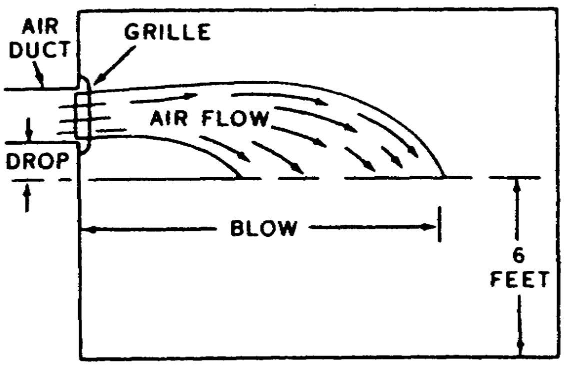


Figure 81. Blow and drop.

distribution problems. Some of the factors which are apt to cause the motion of the air to exceed desirable limits are: (1) excessive air discharge velocities, (2) high number of air changes per hour, (3) premature drop of cold air into the conditioned space, and (4) overblowing of the air.

11. *Temperature differential*. Temperature differential is an important factor affecting grille performance. An air differential of 5° requires little concern, but a differential of 50° requires considerable care in the proper location and selection of grilles.

12. *Dirt*. Although the supply air may have been carefully filtered, it still contains small dust particles which will settle on ceilings and walls. A good rule is to locate the grille at least two widths below the ceiling and make sure that the air does not shoot up. and hit the ceiling during the blow.

13. *Noise*. Grille noise is usually caused by the air discharge velocity and the grille size. To insure quiet operation, make sure that the manufacturer's recommendations are not exceeded and that air distribution over the grille is fairly even.

14. The next subject we will discuss is ventilating fans. We will learn how to select a specific fan for a particular application.

28. Ventilation Fans

1. The devices used to produce airflow are referred to as fans, blowers, exhausters, and propellers.

2. **Types of Fans**. The fans used with ventilating systems are divided into two groups, radial-flow and axial-flow.

3. *Radial-flow fans*. Radial-flow fans-more popularly called centrifugal, blower, or squirrel-cage-are used when a considerable amount of duct work is involved. The principal feature which distinguishes one type of centrifugal fan from another is the curvature of the blades. The main types are the forward curved blade, the radial blade, and the backward curved blade. The tip of the forward curved blade inclines in the direction of rotation, while the radial blade is straight, and the tip of the backward curved blade inclines in a direction opposite to the rotation. The performance characteristics of each fan depends, of course, on its type. For a given output, the forward curved blade is used for relatively low speed operation. The radial blade is used for average speed operation, while the backward curved blade is used for relatively, high speed operation.

4. *Axial-flow fans*. The axial-flow fan is one in which the air flows in line with the impeller axis, within a cylinder or ring. These fans are divided into various types. Among the more popular types are: the propeller, tube-axial, and vane-axial.

5. The old design of propeller fan, which consists of a propeller wheel within a mounted ring or plate, will not handle air against high resistance. It is not suited for a system with ducts, grilles, filters, etc. However, the propeller fan can be used to remove air from areas to the outside atmosphere without a duct.

6. Recently, fan manufacturers have developed a special type of propeller fan which can move large volumes of air against considerable frictional resistance. This fan has a large hub and short adjustable blades. It is highly efficient, but operates at high speeds. This high speed operation causes noise. therefore it should be used only in applications 'where noise presents no problem.

7. The tube-axial fan consists of an axial-flow wheel within a cylinder. It is normally used against appreciable frictional resistance.

8. The vane-axial fan is similar to the tube axial type. It consists of an axial-flow fan within a cylinder, with guide vanes before or after the fan. The purpose of the guide vanes is to increase its efficiency. A fan of this type is more often used against moderate frictional resistance.

9. **Fan Capacity**. The most important factor to consider when selecting a fan for a specific job is the proper capacity. Too often the fan is selected on the basis of diameter only. However, to determine the fan capacity you must calculate the c.f.m. and the static pressure. After you calculate the c.f.m. and static pressure, select the fan on the basis of efficiency, noise, cost, and physical size. You can estimate fan efficiency by dividing the power output by the power input. Total efficiencies range from 50 to 65 percent in small propeller fans to nearly 80 percent in centrifugal fans. Fan manufacturers publish data which will aid you in selecting the correct fan size. The noise level of the fan is an important factor which must be considered before selection. Office

buildings require quieter operating fans than do industrial shops.

10. Computing fan capacity is quite simple. You must know what size fan will make a given number of air changes in a room in an hour. Once you know the c.f.m. of air needed, you can select the fan capable of delivering that amount. Multiplying the dimensions (length X width X height) of a room by the air changes required per hour will give you the total quantity of air to be moved per hour. Stating this as an equation, we can say:

$$Q = \frac{CV}{60}$$

where Q = quantity of air per minute (c.f.m.)
C = air changes per hour
V = volume of room in cubic feet
60 = minutes/hour

11. Now suppose you want to find the fan capacity for a room requiring 12 air changes per hour. Suppose the room is 100 feet by 25 feet by 14 feet. Substituting in the formula,

$$Q = \frac{12 \times 100 \times 25 \times 14}{60} = \frac{420{,}000}{60} = 7{,}000 \text{ c.f.m.}$$

Therefore the fan capacity must be 7,000 c.f.m.

12. **Fan Motors**. Ventilating fans are usually driven by electric motors. Small fans, especially those which are operated at high speeds, are normally connected directly to the motor shaft. Large fans and those which operate at lower speeds are connected to motors through pulleys.

13. When you select a fan motor, it should be one size larger than is required for normal load conditions. This is necessary because larger volumes of air may be required.

14. Some type of thermal switch should be provided in the air inlet duct to break the circuit to the motor in the event of a fire. Thermal switches of this type are usually set to open the motor circuit whenever the inlet air exceeds 135° F. Electric fan motors should also have manual electric switches so that you can control the operation of the motors when servicing them.

29. Air Ducts

1. Air ducts are pipes used to carry and distribute fresh air or exhaust air from a building or room. Ducts are usually constructed of galvanized sheet steel. Two types of ducts are round and rectangular. Round ducts require less metal to carry the same amount of air, but rectangular ducts are used in most installations because of space considerations.

2. The correct size of ducts to be installed may be determined by using various charts and formulas procured from manufacturers of air-conditioning equipment. However, for all practical purposes, it should be the same size as the outlet opening of the fan assembly.

3. **Friction Losses in Ducts**. When air flows through a duct, it loses some of its pressure because of friction. The greater the amount of air flowing through a duct of a given size, the greater is the friction loss. Furthermore, the power needed to deliver a certain amount of air increases rapidly as the size of the duct decreases. For this reason, ducts should be of sufficient size to keep friction losses to a minimum. Friction losses are usually computed by the use of formulas; however, charts procured from manufacturers may be used.

4. To measure the air velocity through a duct or grille, the ventilating system must be in operation. Several different instruments may be used to measure this velocity. These include the "Alnor" velometer and the anemometer. The "Alnor" velometer is the one most commonly used. It is a convenient instrument for spot readings and is adaptable to many uses. For example, it measures velocities within an enclosure or duct, and at grilles. It is sufficiently accurate for all practical purposes. The anemometer is a propeller or revolving vane instrument which' is connected through a gear train to a set of recording dials. The dials indicate the linear feet of air passing the instrument in a unit length of time (feet per minute).

5. **Duct Fire Dampers**. Fire dampen are used as safety devices to shut off the airflow in supply and exhaust ducts in case of fire. To automatically shut off the air, ducts may be equipped with dampers and fuse links. These should be provided when recommended by the National Board of Fire Underwriters.

6. Now that we have the air flowing through the duct, we must furnish some sort of outlet for it. This will be the subject for our next discussion.

30. Air Outlets

1. Air supply outlets are either of the wall or ceiling types. A number of different kinds of each have been developed. The type and kind required will depend upon the air distribution system you are using and the physical layout of the room or building.

2. **Wall Outlets**. Wall outlets are classified according to the type of openings. They are as follows: (1) perforated grilles, (2) vaned grilles, (3) registers, (4) slotted outlets, (5) ejector nozzles, and (6) wall diffusers.

3. *Perforated grilles*. Perforated grilles have a small vane ratio and are not adjustable. They are generally used where .the direction of the airflow is not controlled. Perforated grilles may also be used as return grilles.

4. *Vaned grilles*. Vaned grilles are either of the fixed or adjustable types. They may be used for wall, floor, and baseboard applications. The fixed type is used where the direction of the airflow

is not controlled, while the adjustable type is used where the proper control of the air is essential. Vaned grilles are widely used, since they may be installed either vertically or horizontally. This permits a wide selection of grilles to meet particular requirements.

5. *Registers*. Perforated grilles designed with dampers or an arrangement of adjustable louvers are called registers. These units have a poor air outlet distribution and, for this reason, have only a limited use.

6. *Slotted outlets*. These outlets may be procured in a number of different designs, perforated, slotted, or a combination of both. They are used frequently in a long narrow room with a low ceiling. However, the air quantity and distribution must be carefully planned; changes after installation are difficult. The blow for these outlets is less than for other types, therefore they can be used where obstructions might prevent proper distribution by other grilles.

7. *Ejector nozzles*. Ejector nozzles consist of a pressure reduction box, sound reduction box, and diffuser. Ejector nozzles give a long blow. They are used in places where cooking, drying, freezing, etc., are in process. Because of noise limitations, they are not used where comfort is the primary objective.

8. *Wall diffusers*. The design of wall diffusers is similar to ceiling outlet diffusers, which we will discuss next.

9. **Ceiling Outlets**. Ceiling outlets most commonly used are of three types. These are as follows: (1) plaques, (2) ceiling diffusers, and (3) perforated ceilings and panels.

10. *Plaques*. Plaque outlets are of simple design. The plaque is a flat surface, such as a thin piece of board or metal, constructed an inch or two below the opening. The air hits the board or plate and flows through the opening between the plate and the ceiling and outward into the room. The plaque outlet is not widely used because the flow of air is difficult to control.

11. *Ceiling diffusers*. Ceiling diffusers are either round or rectangular shaped and are installed flush with the ceiling, or parallel and below the ceiling. Performance of the different types varies according to the principle used. Some have no internal induction, but hasten external induction by supplying air in multiple layers. Others have internal induction and distribute air over an entire half sphere.

12. *Perforated ceiling and panels*. In these types of outlets, the air is diffused through perforations. These panels are neat in appearance and maintain a low rate of air movement.

13. We'll discuss the location of these outlets and grilles in the next section.

31. Location of Supply and Return Grilles

1. A room having air supply grilles without return grilles must have some type of opening into a corridor or adjoining room. This opening is required so that air can leave the conditioned room. If 3000 c.f.m. of air is continually supplied to a room, 3000 c.f.m. must somehow leave the room. Some of the air passes out through cracks or around the windows or doors if the room has no return air register. This leakage, however, is normally not sufficient; and a relief opening is needed to insure that the air has a free exit path. The relief opening acts in much the same way as any opening in a recirculation air duct, except that no fan is moving the air through it.

2. The term "envelope" is defined as the outer boundary of an airstream. The envelope of a supply grille is a sharp beam similar to a beam from a searchlight. Some air from the stream discharged by the grille leaves the envelope and mixes with the adjacent room air, causing eddy currents and air motion in the air next to the envelope. The location of the return outlets may affect the pattern of the supply-air envelope in the plan and elevation pattern.

3. Supply-air envelopes, as they appear in a plan view, are determined by the type of grille selected. Different manufacturers offer grilles having different plan view standard envelope patterns. The plan view envelope is ordinarily called the deflection of the grille. Standard deflections are available from manufacturers. Grilles are also available with vertical vanes or bars adjustable either individually or in groups of five or six vanes. With such grilles, adjustments may be made in the field after installation to obtain any deflection desired. Fixed deflection grilles cannot be tampered with and consequently lack the flexibility of the adjustable type. Figure 82 illustrates an elevation (side view) of a room having a high air-supply outlet and a low return opening. This arrangement insures that the conditioned air will be blown across the room above the breathing level, will drop to the floor at the opposite wall, and will be slowly drawn across the room at the breathing level to the return register. Figure 83 illustrates an incorrect location for a return outlet. It shows that the air in half the room would have little motion. If occupants were near the return grille, they would be covered with a blanket of cold air. The cold air would not have an opportunity to mix with the warm room air.

4. Sometimes fresh air must be supplied from outlets located in the ceiling. Figure 84 illustrates an arrangement where the air supply grille is located in the middle of the ceiling with a low return opening located in the wall. This layout is satisfactory because the air will he blown

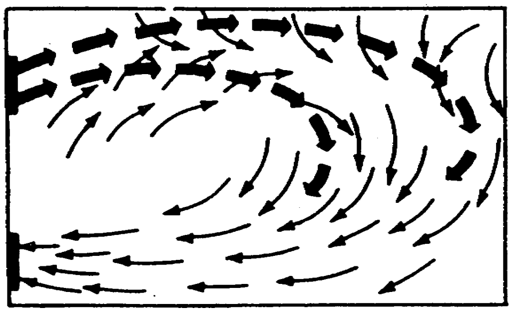


Figure 82. High supply outlet and low return.

across the room above the breathing level of the occupant.

5. Figure 85 shows a common method of supplying and returning air from one grille. This arrangement with the air supply grille and return opening built into' the same supply duct is unusual and not often used. It is interesting, however, to note the airflow pattern. The apparent "dead spot" near the floor is of little importance.

32. Ventilating Equipment Components and Installation

1. When installing a ventilating system, you must consider several factors. First of all, for comfort, a certain number of air changes an hour are needed. This number varies according to the temperature and humidity of the region as well as the purpose for which the building or room is intended. For instance, in setting up a ventilating system for a large messhall, you must remember that the ventilating problems for the kitchen will differ from those for the main dining room, even though the two are part of the same building. Because of the purpose of the room, removing heat, moisture, and odors are your main concern in the kitchen, while in the dining room your biggest item is supplying the proper amount of air for the number of occupants. Moreover, in planning you must consider the temperature extremes

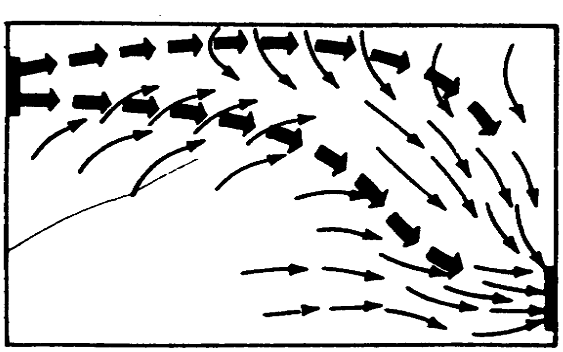


Figure 83. Incorrect installation of high supply outlet and low return.

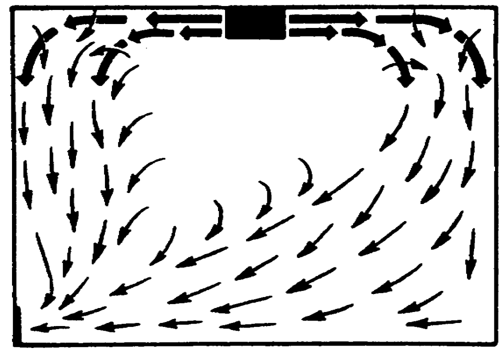


Figure 84. Ceiling supply outlet and return at floor level.

and the humidity of the region. For example, generally speaking you can set up fairly comfortable surroundings by supplying an air change of 8 to 10 times an hour. However, during hot weather, 20 to 30 complete air changes are desirable in northern climates; and as many as 60 may be needed in southern regions.

2. Obviously you cannot rigidly follow a set pattern, since each installation will carry its own particular problems. However, each manufacturer has certain specifications for the installation of his particular ventilating equipment. These specifications may vary from those of other manufacturers. Also, the installation of identical equipment may vary due to location, source of power, local installation procedures, codes, regulations, etc.

3. When installing a ventilating system, you should consult text books, ventilation guides and manuals, and manufacturer's data and catalogs. These will be especially helpful when you are determining the quantity of air that must be removed to carry away gases, fumes, dirt, heat, vapors, and other undesirable foreign matter. Re-

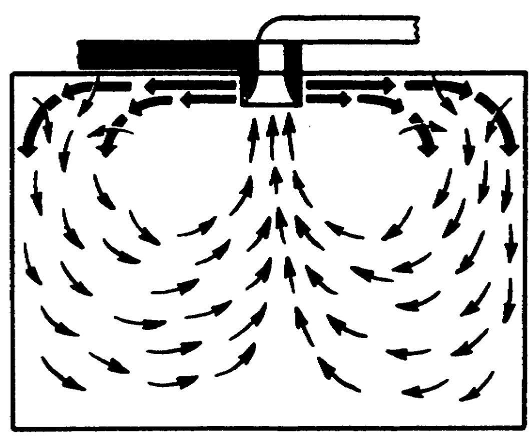


Figure 85. Supplying and returning air with one fixture.

member, also, that you must comply with the safety practices of the National Safety Council and the Fire Underwriter's Board.

4. **Removal of Heat, Odors, and Gases**. The most common method used to remove heat, odors, and gases is by operation of propeller fans. The installation of fans in the attic will draw outside air into the building through the windows, doors, and other openings and discharge the contaminated air through the attic to the atmosphere. Satisfactory ventilating effects are usually obtained by providing approximately 60 air changes per hour. The accepted procedure is to install one or two large capacity fans instead of many small ones. Where a single fan is used, it should be installed as near to the center of the room as possible. In cases where many fans are used, the total volume of air to be moved should be divided among the fans in relation to their capacity. For instance, if four exhaust fans are required to ventilate a rectangular building, they should be installed in a manner to permit each fan to ventilate one-fourth of the building.

5. The following paragraphs discuss various standards used for different applications.

6. *Attics*. Vertical and horizontal fans are frequently used to ventilate attics. These units draw outside air into the building through windows, doors, and other openings and discharge it through the attic to the outside.

7. *Dishwashing spaces*. Dishwashing spaces, when constructed as a separate room, should be provided with an exhaust ventilation capable of producing 90 air changes per hour. The capacity of the fan should be based on the floor space measured to the bottom of the hood. If the dishwashing machine without a hood is installed in a separate room, not less than 60 air changes per hour should be provided for the entire room.

8. *Kitchens*. The ventilating equipment installed in large kitchens should be capable of supplying 20 air changes per hour. Horizontal exhaust fans are generally used in kitchens and are normally placed at ceiling level. Exhaust openings at the outside of the wall should be provided with louvers to keep out the weather. A bird screen (an ordinary window screen) should be placed between the fan and louvers to keep out birds and insects.

9. Kitchen ranges or deep fryers should be equipped with ventilating hoods. The effectiveness of these hoods depends upon exhausting large quantities of air in order to remove the vapors. These hoods should extend approximately 1 foot beyond the outside edges of the equipment they serve. The bottom tip of the hood is usually 6h feet to 7 feet above the floor. Hoods and exhaust ducts are usually constructed of galvanized sheet or cement asbestos board. A double canopy hood is constructed with an inner shell which forms an air passage between the shell and the hood. The air inlet extends completely around the perimeter of the hood and has a 2- to 3-inch space between the bottom tip of the hood and the inner shell. Inner shells have openings at the top for exhaust air from the center of the hood area. The fan selected for a single canopy hood should have a capacity of 200 c.f.m. per linear foot of hood perimeter, while the fan for a double canopy hood should have a capacity of 150 c.f.m. per linear foot.

10. Round ducts are normally used with hoods. They extend from the hood, through the ceiling and roof, and terminate with a weatherproof cap. The vertical propeller fan is normally used in this application.

11. Fan guards must be installed on all fans to protect personnel from accidental contact. Kitchen exhaust hoods and ducts should be installed at least 18 inches away from the stove. Most kitchen range hoods have grease filters. These filters should be cleaned weekly to reduce fire hazard. Fans and duct work should have a sufficient number of access doors to permit easy cleaning.

12. *Dining area*. The ventilating equipment installed in messhalls should be capable of 10 air changes per hour. The fans generally used are of the propeller type. They are installed in the wall at ceiling level. The exhaust openings should be equipped with bird screens. Either wood or metal louvers should be installed over the openings to keep out the weather. Automatic louvers are preferable.

13. *Laundries*. The ventilating equipment installed in laundries should be capable of 30 air changes per hour.

14. *Barracks*. The ventilating equipment installed in barracks should be capable of supplying fresh air at a rate of 15 c.f.m. for each occupant.

15. *Offices*. The ventilating equipment installed in offices and other similar spaces should be. capable of delivering 10 c.f.m. per person.

16. *Theaters and chapels*. In windowless or crowded enclosures (theaters and chapels) 10 c.f.m. per occupant is required. Another method of calculating this requirement is to provide 2 c.f.m. for each square foot of floor area.

17. **Removal of Hazardous Fumes and Vapors**. The removal of hazardous fumes and vapors from buildings or spaces is accomplished by the use of special explosion proof or spark proof ventilating fans and motors. Fans and motors of this type are entirely enclosed so that any electrical sparks from either unit cannot cause an explosion. The maximum conveying velocities for hazardous fumes and vapors are approximately 2000 f.p.m.

18. When installing a system for removing hazardous fumes and gases you must take care to locate the exhaust fans so that the fumes and vapors are positively removed and do not create a dangerous situation by remaining in the building. Some hazardous fumes and vapors are lighter than air, while others are heavier. Consequently, the specific gravity of each hazardous gas determines the location of the fan. Following are a number of gases and their specific gravity:

Type Gas	*Formula*	*Specific Gravity*
Acetylene	C_2H_2	0.90
Ammonia	NH_3	0.59
Butane	C_4H_{10}	2.01
Carbon dioxide	CO_2	1.527
Carbon monoxide	CO	0.967
Chlorine	$C1_2$	2.49
Hydrochloric acid	HC1	1.26
Nitric oxide	NO	0939
Sulphur dioxide	SO_2	2.263

19. If the specific gravity of the gas is less than one, the gas is lighter than air and will rise to the ceiling. If the specific gravity is more than one, the gas is heavier than air and sinks to the floor. The exhaust fan should always be placed so that it removes the air as fast as the vapor is released. Some of the buildings and rooms in which hazardous fumes and vapors are generated are garages, paint shops, refrigeration shops, battery shops, etc.

20. *Garages*. In garages where toxic and explosive gases cannot be ventilated by gravity, forced ventilation must be used. The system should be capable of supplying or exhausting a minimum of 1 c.f.m./square feet of floor space. Carbon monoxide produced from the incomplete burning of gasoline is lighter than air. For this reason, the exhaust fans used to remove this gas must be installed at least 7 feet above the floor. Gasoline vapors must also be removed. Since these vapors are heavier than air, they must be exhausted at floor level.

21. *Paint shops*. Paint shops should be provided with both supply and exhaust ventilation that are capable of producing 20 air changes per hour. Horizontal propeller fans are generally used and installed in the wall at a height of approximately 7 feet.

22. In paint shops and paint spray booths the electrical circuits which operate the exhaust fan and the air compressor should be interconnected so that the compressor can run only when the exhaust fan is operating. Such a safety measure lessens the probability of personnel being overcome by paint fumes. It is also desirable for the ventilating system to operate for a short time after painting operations have ceased.

23. When installing an exhaust system for a paint shop or paint booth, some means must be provided to filter the particles of paint out of the air as it is forced through the exhaust grille and out of the building.

24. To filter out paint particles from the exhaust air, various types of filters and louvers may be installed at the grille. If the paint shop is located in an isolated area, less rigid precautions need be taken.

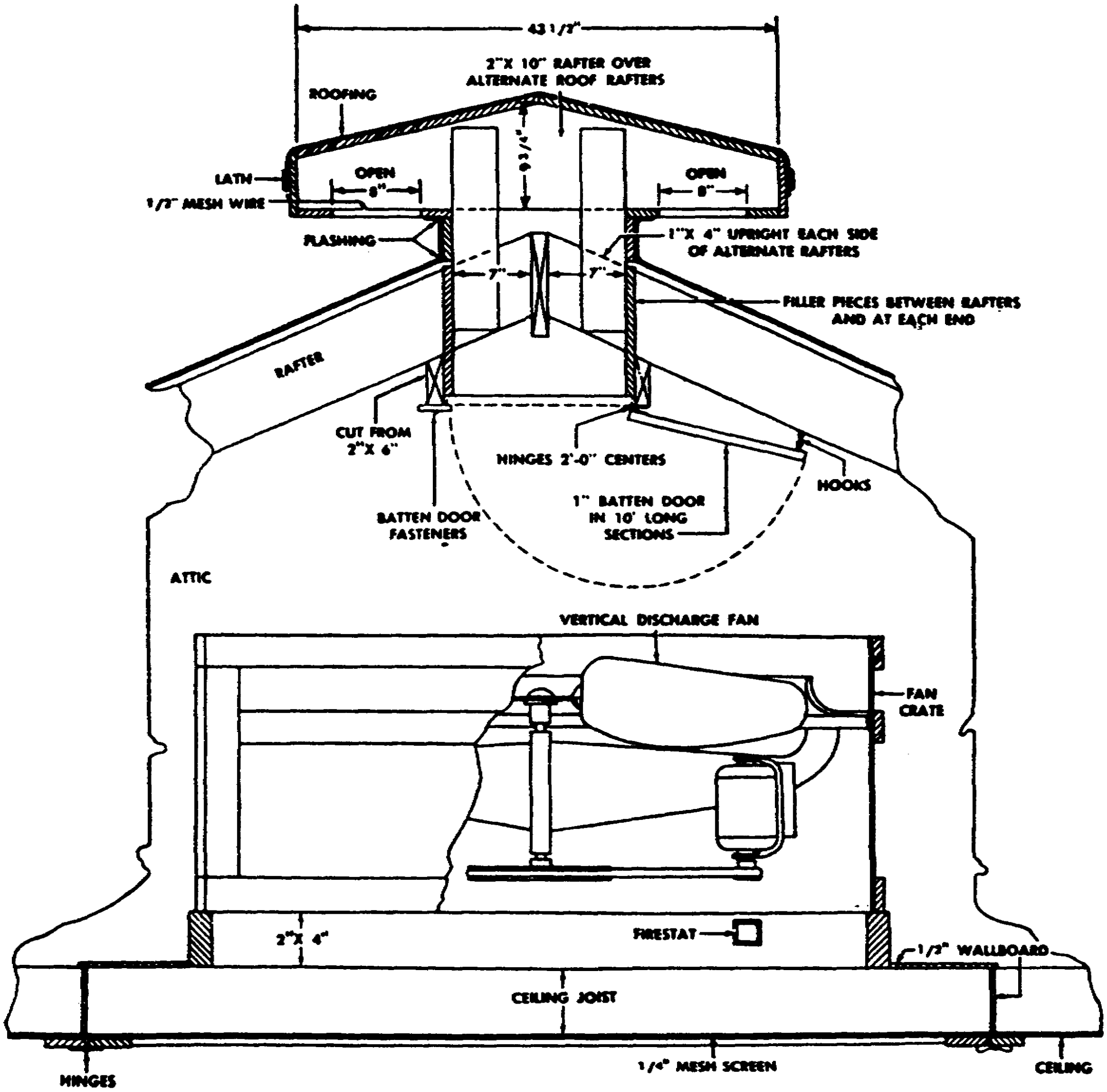
25. **Removal of Foreign Particles**. Many shops need an exhaust system with & collector to gather up and hold material that might clutter up the area. With this system, the airflow must be sufficient to catch the dust, chips, metal filings, etc., as they are produced. Air ducts or exhaust pipes carry these materials through the exhauster to the collector. If the collector is not used, the system must be designed so that the exhaust will not contaminate the fresh air which is reentering the building.

26. A local exhaust system consists essentially of four parts: (1) hoods or partial enclosures, (2) air ducts, (3) a collector, and (4) an exhauster. Data pertaining to the quantity of air that must be removed in order to control hazards or nuisances is available, as well as information on the necessary entrance velocities to hoods having different sizes and shapes.

27. The size of air ducts depends on the amount of air to be moved and on minimum and maximum air velocities. The minimum velocity must be strong enough to keep particles from settling in the ducts, while the maximum velocity is limited by noise. If quiet operation is necessary, the velocity should not exceed 1200 f.p.m. In carpentry or machine shops the system must pull air over the article being worked on and must carry off the dust or chips. The air velocity for this application depends on the weight and size of the dust particles or chips. Fine, dry dust requires a velocity of approximately 3000 f.p.m., while larger particles, heavy loads, and moist materials require air velocities up to 6000 f.p.m.

28. Fans are the most common type of exhauster. Propeller type fans prove satisfactory in low velocity systems; but the centrifugal type fan is necessary for a high resistance, high velocity system.

29. **Vertical Discharge Ventilating System**. A vertical discharge ventilating system, shown in figure 86, is designed with a vertical discharge propeller fan. The complete system is mounted on the ceiling joists in the attic of the building to be ventilated. With this arrangement, air is drawn into the building through the doors, windows, and other openings, then circulated through the building and finally exhausted through the fan into the attic. From the attic the air is forced out into the atmosphere through a ridge ventilator. Instead of ridge ventilators, gables, roof monitors, cupolas, and other similar openings may be used.



VERTICAL DISCHARGE FAN AT CEILING LEVEL USING RIDGE VENTILATOR

NOTE: LENGTH OF VENTILATOR REQUIRED-1 FOOT PER 1200 CFM CAPACITY OF FAN INSTALLED

Figure 86. Vertical discharge ventilating tan.

Doors between the rooms on this system must remain open or be louvered so that the air can circulate throughout the building. By looking at figure 86, you will notice that a bird screen is installed at the, exhaust opening of the ridge ventilator and another screen is installed over the air intake opening in the ceiling.

30. This ventilating system is also equipped with a batten door which, when closed, stops airflow through the attic. The construction of the fan crate is also shown in this installation. It is designed with a fan shroud, which makes the operation of the fan more efficient.

31. Sleeve bearing fans and motors without thrust bearings should not be used in conjunction with vertic2a discharge ventilating systems. Fans and motors used in vertical discharge systems must be equipped with thrust type ball bearings.

32. **Vertical Discharge Ventilating Supply System**. Buildings or rooms with high internal heat loads, such as auditoriums, classrooms, and laundries, frequently use a vertical discharge ventilating supply system. In this system, large propeller type supply fans mounted from the ceiling blow the air down over the occupants. Air should be drawn in from the outside through louvered

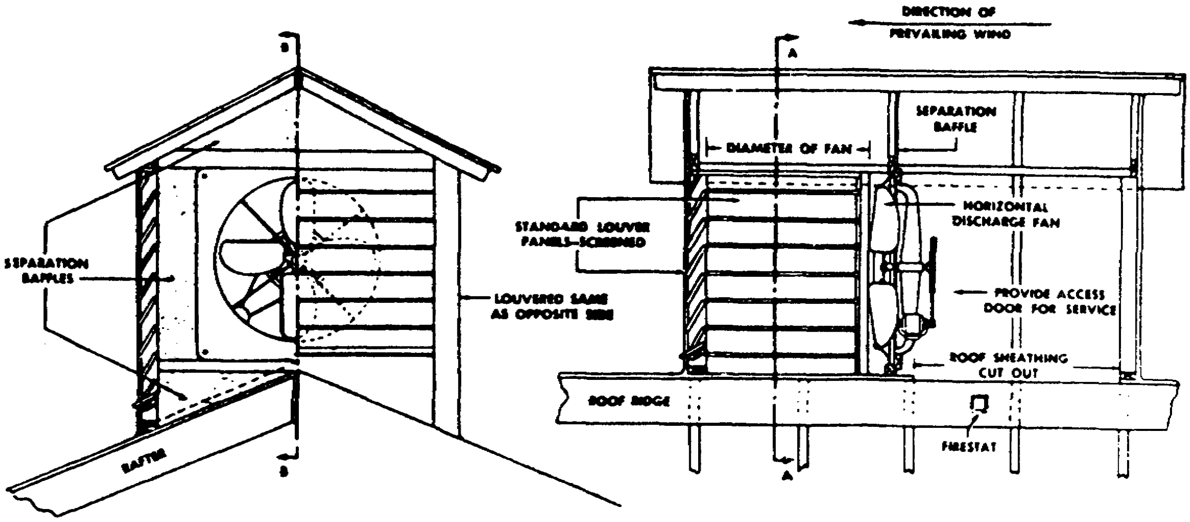


Figure 87. Horizontal discharge fan.

monitors to the fan. Then, after passing over the occupants, the air can be vented to the outside through windows and doors.

33. **Horizontal Discharge Ventilating System**. Horizontal discharge ventilating systems are usually installed in the outside wall of a building or in a roof monitor, as shown in figure 87. Louvers which open and close automatically are generally installed in the outside wall. In a ventilating system of this type the air is drawn through the building in the same manner as with vertical discharge fans previously discussed. However, the air is not pushed through the attic openings as in the case of vertical discharge fans. Instead, it is pulled through by suction and then forced through the opening into the atmosphere.

34. **Louvers**. Louvers are generally used when installing horizontal discharge exhaust fans in roof monitors or roof gables. They can also be used to weatherproof horizontal exhaust openings. Fixed wooden louvers, unless properly made, may restrict air movement or give insufficient protection against bad weather. Wood louvers set in the frame at a 60° angle and spaced so that 2 inches of the opening is left between the crosspieces will keep out the rain. Figure 88 shows the major dimensions and capacities of louver panels constructed from l-inch wood stock.

35. For structural reasons, do not construct louver lengths to exceed 5 feet. If the capacity requires greater length, use multiple sections.

36. Automatic louvers for use with horizontal discharge ventilating systems can be procured from fan manufacturers. Various methods are used to open and close them. They may be actuated by an electric solenoid or a motor. When the fan is installed next to the louver panel, the louvers are actuated by air pressure. Air pressure produced by the fan forces the louvers open, which are hinged at the top of the louver frame. When the fan stops, the force of gravity closes them. The installation of metal louvers is simple. They are attached to the exhaust opening by wood or sheet metal screws.

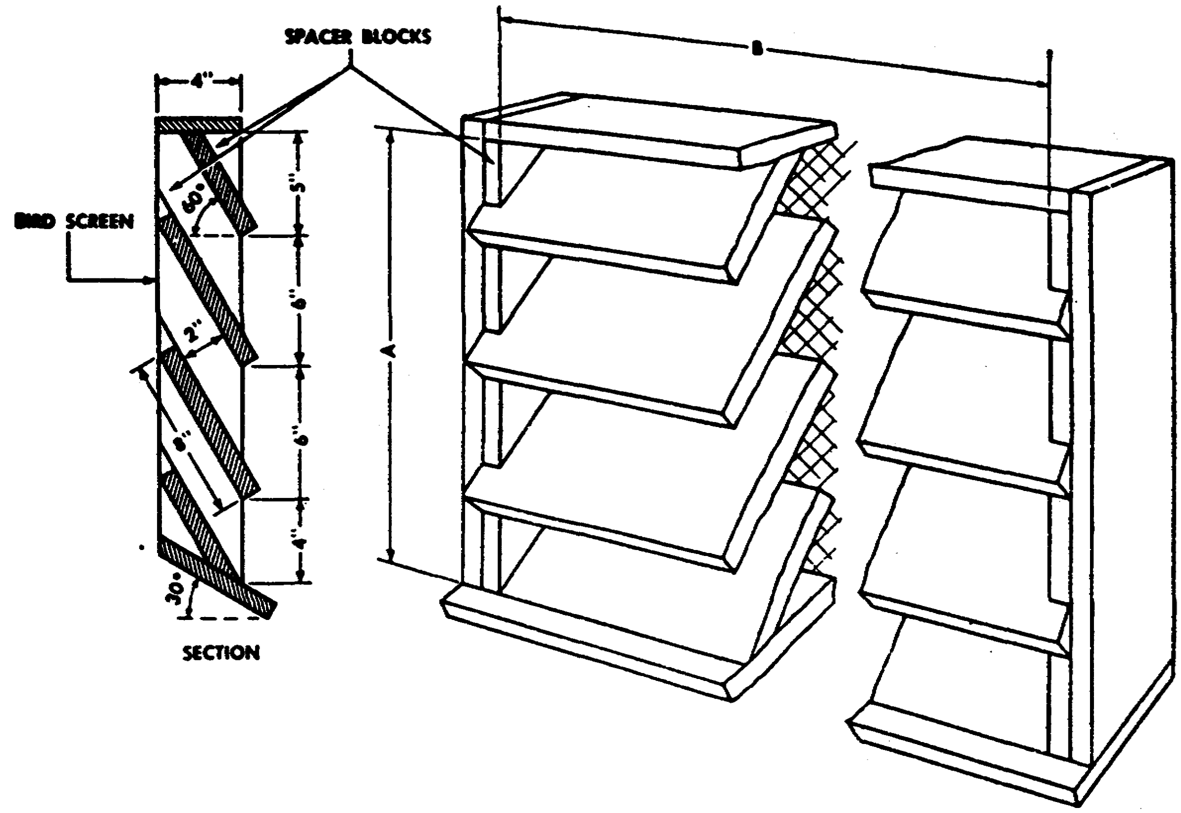
37. **Fans**. Fans installed in ceilings or roof must be installed without cutting any structural members of the building. Ceiling and roof construction must be strengthened to support the additional weight. Access doors to attics or fan enclosures must be provided -for inspection and maintenance purposes. You must use unpainted canvas or other flexible material to connect ducts to fan outlets or inlets.

38. Fan drive motors should be protected by either built-in or external thermal overload devices. A thermal switch may be installed in the inlet airstream of a fan for the purpose of stopping the fan in case of fire. These switches are usually set to open the circuit to the fan drive motor when the inlet air exceeds 135° F.

39. **Filters**. Air filters should be installed in all supply ventilating systems where dust or other foreign matter may be harmful to the activities conducted in the ventilated space. Special conditions may require the use of absorbents or electrical precipitators. Filters or dust collectors may be required on exhaust systems in special uses where the fan discharge would create an objectionable condition in the immediate vicinity or area.

40. **Ducts**. Dusts used for ventilation are usually constructed of galvanized sheet steel. Their construction should be as smooth as possible where the air passes over the inner surfaces. Ducts should be airtight and rigidly attached to reduce vibration.

41. When installing ducts for ventilating purposes, follow these suggested rules:



NO OF LOUVERS	NO OF OPENINGS HIGH	DIMENSION A IN INCHES	SQ FT OF FREE AREA PER FOOT	CAPACITY OF INCREMENTS OF 1 FT FOR DIMENSION B				
				1 FT	2 FT	3 FT	4 FT	5 FT
2	1	9	.1667	200	400	600	800	1000
3	2	15	.333	400	800	1200	1600	2000
4	3	21	.500	600	1200	1800	2400	3000
5	4	27	.667	800	1600	2400	3200	4000
6	5	33	.833	1000	2000	3000	4000	5000
7	6	39	1.000	1200	2400	3600	4800	6000
8	7	45	1.167	1400	2800	4200	5600	7000
9	8	51	1.333	1600	3200	4800	6400	8000
10	9	57	1.500	1800	3600	5400	7200	9000
11	10	63	1.667	2000	4000	6000	8000	10000

CAPACITY OF LOUVER FRAME PANEL PER LINEAR FT BASED ON MAXIMUM 1200 FPM VELOCITY THROUGH FREE AREA.

NOTE: DO NOT EXCEED ABOVE CAPACITIES OR 1200 FPM VELOCITY. LOWER VELOCITIES ARE RECOMMENDED WHEN SPACE IS AVAILABLE.

Figure 88. Wood louver details.

a. Use smooth duct materials to decrease air friction.

b. Avoid sharp turns.

c. Pipe the air as directly as possible to the required location.

d. When a duct must be altered to go through an opening or between structural members of a building, make the change as slight as possible.

33. Inspection and Maintenance of Mechanical Ventilating Equipment

1. The primary reason for inspections and maintenance is to let us determine the operating

condition of an item of equipment and :to correct any discrepancy which may be found. -These services should be performed on equipment at periodic intervals according to an inspection and maintenance schedule. You must maintain inspection and maintenance records for all of the ventilating equipment. Inspections and maintenance services should be scheduled to permit only a minimumof interference with the using organization.

2. Major repairs of ventilating equipment should be done during the winter season or when the equipment is not in use. Regular inspections show us when certain items of equipment are in need of major repairs.

3. **Inspections and Maintenance Services**. Definite procedures for inspection and maintenance services of ventilating systems are necessary if we are to have efficient and safe operation. The following paragraphs discuss these services in general. The instructions given here should serve as a guide for inspecting and maintaining all mechanical ventilating equipment. It may be necessary to supplement these procedures with the manufacturer's instructions, since the equipment is not standardized in design and may require slightly different maintenance. Whenever warranted, tile frequencies of inspections and maintenance services should be adjusted to meet local operating conditions.

4. **Fan Assembly**. Fans should be inspected periodically for proper operation, lubrication, and cleanliness. Fan blades must be properly aligned and free to rotate within their housings. The pulleys on the fan shaft and the motor shaft can be checked for alignment by using a straightedge. Loose pulleys must be tightened.

5. You must replace all defective fan blades. Dirty fan blades will cause vibration; therefore they must be cleaned. Fan blades may be cleaned by using a suitable cleaning solvent or detergent and clean rags. After you do the cleaning, you must tighten all bolts, nuts, and screws on the fan assembly.

6. The axial clearance of each centrifugal fan must be checked to insure that the fan wheel is not binding in the scroll. The axial clearance may be adjusted by relocating the position of the shaft thrust collar. After final adjustment, the total axial motion should be approximately 1/32 of an inch. Also after final adjustment, lock the thrust collar in place with the thrust collar setscrew. Worn thrust washers must be replaced.

7. Inspect and lubricate fan drives in accordance with manufacturer's instructions. If the drive unit for the fan has a direct flexible connection, inspect the couplings periodically for wear and alignment.

8. The inspection and lubrication of fan bearings, especially of continuously operated fans, should be performed at regular intervals. The shaft sleeve bearings of fans are lubricated with oil, while ball bearings are packed with grease. The fan grease cups require filling once each year. Over lubrication will cause oil to drip from the bearing, which will result in unsightly collections of oil and dirt.

9. Each fan should be disassembled and inspected for defects yearly. Clean the fan shaft bearings and check each bearing for wear. Replace any bearings which are unserviceable. Clean and paint the interior and exterior of the fan housing, the fan wheel, and similar items with rust resistive paint. Care should be taken when working on fan wheels, as they are statically and dynamically balanced.

10. *Lubrication of motor sleeve bearings*. Lubricate motor sleeve type bearings to the proper level, preferably when the motors are at a stand-still rather than when they are running. This procedure will prevent any false oil level indication. The oil level should be observed for a few seconds to determine that it is at the proper level. Use a good grade of oil to lubricate sleeve type bearings.

11. *Cleaning ball bearings*. Motors equipped with ball bearings and which operate at 1800 revolutions per minute and lower should be cleaned and lubricated yearly. Motors operating above 1800 r.p.m. should be disassembled every 6 months. The bearings should be cleaned with approved solvent and repacked with new grease. You must be sure that no dirt and grit enter the bearing chambers. If the motor is provided with self-sealed prelubricated ball bearings, the manufacturer's recommendations should be followed for cleaning and relubricating procedures.

12. *Cleaning sleeve type bearings*. Before cleaning the bearings, you must drain the oil from the bearing chambers. Then flush the bearing chamber with an approved solvent, allow sufficient time for the bearing to dry, and refill the chamber with clean oil.

13. **Duct Maintenance**. Inspect duct periodically for air leaks, cleanliness, and structural condition. Repair or replace the defective ducts or duct connections. Remove all accumulations of foreign matter on the interior of the ducts. If applicable, inspect sound absorbing and insulating material on the interior of the ducts to determine that the materials are insulated securely and adequately. Inspect the duct hangers and supports and repair or replace as necessary.

14. All ducts should be cleaned annually. Protective paints should be applied to the air ducts to protect them from corrosion. One of the more effective protective coatings is red lead paint. Apply three coats of paint. The first coat should be a rust resistive type such as red lead paint;

the second coat should also be a rust resistive paint but tinted to the desired color. Finally a chlorinated rubber-base paint is used for the finish coat, particularly where the presence of highly corrosive gases would injure standard paints.

15. **Hood Maintenance**. Inspect all the hoods for the following conditions: broken or cracked surfaces, poor connections to exhaust ducts, and accumulations of material such as dust, dirt, or grease. Repair or replace any defective hoods. Remove all accumulations of foreign matter by washing the hoods with hot water, steam, or an approved solvent You must include some measurement of relative airflow through the hoods. Static pressure or hood suction measurements will prove useful during this check if data is available on air volumes and pressures at the time the exhaust system was installed. A marked reduction in air suction can be traced to one or more of the following conditions: (1) reduced performance of the exhaust fan due to belt slippage or an accumulation of material on the fan wheel or in the fan housing, (2) incorrect direction of rotation of the exhaust fan, (3) reduced airflow caused by defective exhaust piping, and (4) losses in suction due to additional exhaust points being added to the system. Clean and/or paint hoods as necessary.

16. **Filter Maintenance**. When filters become dirty and clogged, they increase the resistance to the passage of the airstream and thus reduce the efficiency of the system. Therefore, filters should be inspected and cleaned or replaced periodically. The frequency of inspection and cleaning will depend on the- type of system in which the filter is installed and on the type of filter. Usually, filters should be cleaned or renewed at least every 2 or 3 months. However, if the ventilating system is used moderately, the cleaning or renewal operation may be reduced to once during a full season. Under dusty conditions the filters may require cleaning or renewal weekly.

17. *Viscous impingement filters*. Viscous impingement filters, throw-away type, should be discarded when they become dirty. However, certain types of viscous impingement filters are designed to be cleaned and reused. Cleaning may be accomplished by using hot water, steam, or a cleaning solution that will remove the adhesive coating. After the filters are washed, they should be dried. To recoat the filters, dip them in an adhesive bath long enough to coat all of the surfaces. Then remove the filters and allow them to drain for approximately 10 to 12 hours. You should use the adhesive coating recommended by the manufacturer.

18. Special filter cleaning equipment, such as washers and oilers, may be used to recondition these filters. Dirty filter are placed into a three-stage washing machine. The first operation removes loose dust and dirt by ordinary washing. Next, the filters are washed by a hot alkaline solution under pressure. After the filters are washed in the alkaline solution they are rinsed with clear water. The filters are now drained, dried, and immersed in a high-temperature filter adhesive bath. After the filters are removed from the adhesive bath, they are placed in a centrifuge where excessive adhesive liquids are removed. The reconditioned filters are then installed in a ventilating system or stored in special storage racks.

19. *Grease filters*. Grease filters are cleaned in hot soapy water, or by spraying them with hot water. Use a pressure of approximately 20 pounds per square inch and direct the spray at the outlet side of the filter. After the filter is washed, place it in a vertical position and allow it to drain.

20. *Electrical precipitators*. Electrical precipitators may be cleaned in place manually with a brush or automatically by washing the plates with hot water sprayed from fixed or moving nozzles. Precipitators which may be washed in place are provided with drains to carry away the waste water. Before any cleaning operation is performed, you must turn off the electricity. It is best to follow the manufacturer's instructions to determine the exact method of cleaning and the frequency of cleaning electrical precipitators.

21. **V-Belts**. Inspect V-belts for breaks, evidence of wear, and proper tension. A belt is tensioned properly, if it has a deflection of 1/2 inch midway between the pulleys. If a belt is too loose it will slip; while an excessively tight belt will cause increased loads and premature bearing wear. Multiple V-belts must have the same tension; otherwise the tighter belt will carry most of the load and wear out sooner.

22. The recommended procedure for V-belt replacement is (1) loosen the motor at its base and shift it closer to the fan, (2) place the belt on the motor pulley, (3) slip it over the fan pulley, (4) align the pulleys and belt, (5) adjust the belt tension, and (6) tighten the motor mounting bolts in the V-groove of pulleys. V-belts must fit; otherwise rapid wear, noise, and slipping will result.

23. Multiple V-belts are furnished in matched sets by manufacturers to insure uniformity of length and tension. If a V-belt in a multiple V-belt set needs to be replaced, be sure to replace the entire set, even when some of the old belts seem to be in good condition.

24. **Louver Maintenance**. Inspect louver assemblies periodically to determine that they are intact and that they control the airflow properly. Replace or repair any loose or defective louvers. Wooden louver assemblies should be painted ap-

proximately once each year. Check the freedom of movement of automatic louvers and correct any deficiencies. Place winter enclosures in position at the beginning of the winter season and remove them at the beginning of the summer season.

Review Exercises

NOTE: The following exercises are study aids. Write your answers in pencil in the space provided after each exercise. Use the blank pages to record other notes on the chapter content. Immediately check your answers with the key at the end of the test. Do not submit your answers for grading.

1. When is it important that complete air distribution be accomplished? (Sec. 27, Par. 3)

2. What are two ways you could reduce excessive grille noise? (Sec. 27, Par. 13)

3. Which type of fan is normally used in a ventilating system with considerable duct work? (Sec. 28, Par. 3)

4. You are to select a fan for a room requiring 30 air changes per hour. The size of the room is 14 feet by 60 feet by 60 feet. What must the fan capacity be? (Sec. 28, Pars. 10 and 11)

5. If you needed to reduce the friction loss of an air duct, would you increase or decrease the size of the duct? (Sec. 29, Par. 3)

6. Why are duct fire dampers used in mechanical ventilation systems? (Sec. 28, Par. 5)

7. What type of grille should you select for an air outlet located in the floor and the airflow must be controlled ? (Sec. 30, Pars. 2-7)

8. Which wall outlet is used for long narrow rooms? (Sec. 30, Par. 6)

9. What determines the pattern of the supply air envelopes? (Sec. 31, Par. 3)

10. List several factors that must be considered when preparing to install a ventilating system. (Sec. 32, Pars. 1-3)

11. Where should you install a fan in a room that contains carbon dioxide? (Sec. 32, Pars. 18 and 19)

12. What safety measure could you add when installing an exhaust fan in a paint spray booth? (Sec. 32, Par. 22)

13. What factors determine the desired air velocity in a ventilating exhaust system? (Sec. 32, Pars. 26-28)

14. What would result from poorly constructed fixed wooden louvers? (Sec. 32, Pars. 34)

15. When is it necessary to install filters in the exhaust system? (Sec. 32, Par. 39)

16. Dirt on the fan blades will have what effect on the fan operation ? (Sec. 33, Par. 5)

17. What will result from the overlubrication of fan motors and other ventilating equipment? (Sec. 33, Par. 8)

18. What determines the frequency of cleaning an air filter? (Sec. 33, Par. 16)

19. What will excessively tight fan belts cause? (Sec. 33, Par. 21)

Heat Pumps

AT THE conclusion of this chapter you will know what heat pumps are and will understand their operating principles. We will also discuss the different types of heat pumps, their sources and sinks, heat storage, and pump components.

34. Performance

1. The operating principle of the heat pump is that of the heat-power thermodynamic cycle governing the conversion of mechanical energy to heat. It is derived from the Second Law of Thermodynamics (Carnot's Principle). The law states that the efficiency of a thermodynamic engine is proportional to the amount of heat transferred from the source of heat to the condenser; and that heat passes only from a warmer to a colder body. However, Carnot's formula for figuring the coefficient of performance (COP) cannot be applied to an actual system. It is used only on an ideal compressor, with an ideal refrigerant.

2. "Coefficient of performance (COP) " is a term used to express the ratio of output to input. We use the term "coefficient" because in a refrigeration system the performance will be greater than 100 percent. A simple formula to express this is:

$$\text{COP} = \frac{\text{output}}{\text{input}}$$

The *actual* coefficient of performance is the ratio of refrigeration effect to the actual work input. The work input is figured in brake horsepower of the compressor.

$$\text{Actual COP} = \frac{\text{refrigeration effect}}{\text{b.hp. X 2545}}$$

Using this formula on a refrigeration system, we must know the rated capacity of the compressor in B.t.u.'s (refrigeration effect) and the brake horsepower. The 2545 is a constant used to convert b.hp. into B.t.u.'s. For example, you have a compressor rated at 500,000 B.t.u.'s/hr. It is using R-12 in a 46° F. evaporator that has a 12° F. superheat. The compressor's discharge pressure corresponds to 110° F. Under these conditions the brake horsepower is 42. You would figure the actual COP as follows:

$$\text{Actual COP} = \frac{500{,}000}{42 \text{ X } 2545} = \frac{500{,}000}{106{,}890} = 4.67 \text{ to } 1$$

In this actual situation we have put in 106,890 B.t.u.'s and received 500,000 B.t.u.'s of refrigeration effect, a ratio of more than 4 1/2 to 1.

3. In figuring the coefficient of performance of a heat pump, we must include the heat equivalent of the compressor. Thus we use the following formula:

$$\text{Heat pump COP} = \frac{\text{refrigeration effect + work input}}{\text{work input}}$$
$$= \frac{\text{refrigeration effect + b.hp. X 2545}}{\text{b.hp. x 2545}}$$

We shall use the same rating of 500,000 B.t.u.'s/hr. If all the other conditions are the same as in the previous problem, the b.hp. will be 42. We can find the ratio by the following method:

$$\text{Heat pump COP} = \frac{500{,}000 + 42 \text{ X } 2545}{42 \text{ X } 2545}$$
$$= \frac{500{,}000 + 106{,}890}{106{,}890}$$
$$= \frac{606{,}890}{106{,}890}$$
$$= 5.67 \text{ to } 1$$

The input of 1 B.t.u. has given us a higher output on the heat pump cycle.

4. The heating coefficient of performance (COP) of an installed heat pump is the ratio of useful heating effect to the heat equivalent of the total energy required to operate the system. If total energy input of all auxiliaries such as fans and pumps is not included, it should be so stated.

5. Now we'll compare the economy of a heat pump to an electrical resistance heater. We will use a 50,000-B.u/hr. electrical resistance heater in our example.

3410 B.t.u./hr. = 1kw.-hr. (Kw.-hr. = kilowatt-hour)

$$\frac{\text{50,00 B.t.u./hr.}}{\text{3410 B.t.u./hr.}} = \text{14.6 kw.-hr.}$$

6. At 3 cents per kw.-hr., the heat load would cost 14.6 X .03 = $.438/hr. = $.438 X 24 or

$10.50/day. The monthly electric bill would be $315.00.

7. Actually, the cost is much less than this, as the heat load of a house averages much less than 50,000 B.t.u./hr. At this point we will introduce a new term--'"degree day." Degree day is a unit based upon temperature difference and time. It is used in estimating fuel consumption and in specifying the nominal heating load of a building during winter months. For any 1 day, when the mean temperature is less than 65° F., there exists as many degree days as there are Fahrenheit degrees difference in temperature between the mean temperature for the day and 65° F. The average or mean temperature in our example is 35° F. over a 9-month period. We will assume that we have 10,000 degree days. The heat load for 50,000 B.t.u./hr./70° F. temperature difference house would be: $\frac{50,000}{70}$ or 714 B.t.u./degree F./hr. The heat load for 24 hours would be: 714 X 24 = 17.136 B.t.u./degree day; $\frac{17,136}{3410}$ = 5.02 kw.-hr./degree day. 5.02 X .03 X 10,000 = $1506/seasonal cost for heating by electrical resistance.

8. The heat pump reduces this cost considerably because it uses electricity only to drive the compressor. The refrigeration cycle permits the condenser to release three or four times as much heat as it takes in electrical energy to drive the compressor. This coefficient of performance means that 1 kw.-hr. of electrical energy driving the compressor can release not 3410 B.t.u./hr., but 3410 X 3 or 10,230 B.t.u./hr.

9. You can increase the efficiency further by using a warmer heat source than the outside air. Some heat sources you might use are well water, lake water, or earth. If you could find a well furnishing 60° F. water, the coefficient of performance would be 4 or 5 and this factor would bring the cost of operation close to that of the oil or gas heating system.

10. The term "performance factor" is similar to coefficient of performance but is used when referring to values based on an extended period of performance. The period of time covered would be given when using this term. If supplemental heat is involved, its effect should also be specified.

35. Types of Heat Pumps

1. Heat pumps a classified according to the type of heat source and sink, heating and cooling distribution fluids, thermodynamic cycle, building structure, and size and configuration. We will discuss the more common types (shown in fig. 89) in the following paragraphs.

2. **Air-to-Air (Refrigerant Changeover).** This is the more common type heat pump system.

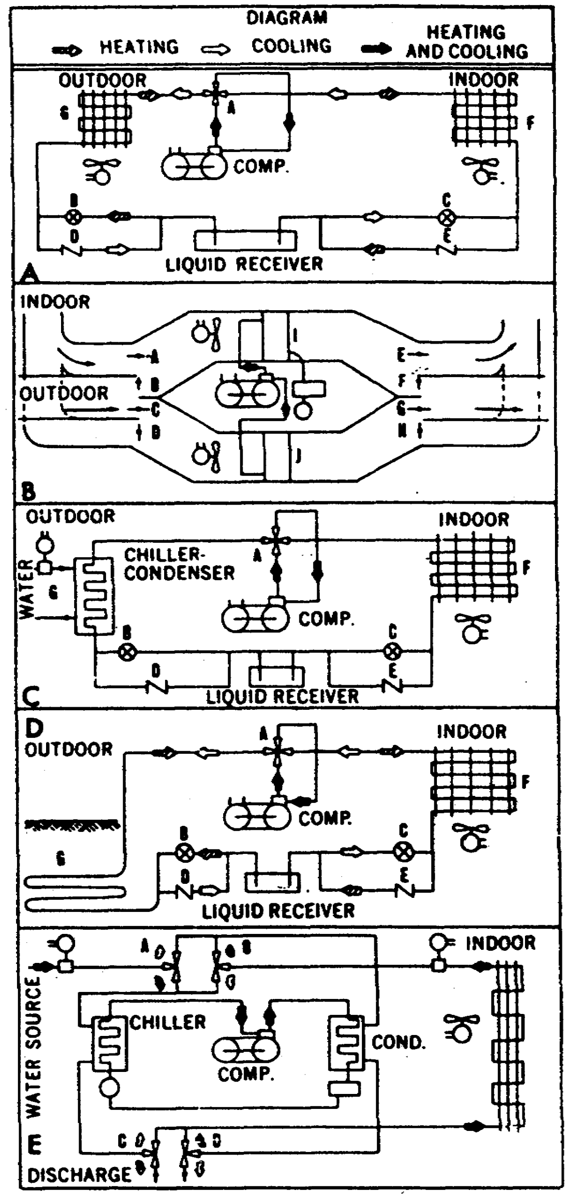


Figure 89. Types of heat pumps.

Figure 89,A, shows the refrigerant flow. You will notice that two expansion valves, two check valves, and a changeover valve are used to control the direction of refrigerant flow. The changeover valve (A), which receives a signal from a room thermostat, controls the function of the two heat exchanger coils.' The flow, when cooling is desired, is indicated with the plain arrow. Expansion valve C will act as the metering device for coil F and check valve D will allow the hot liquid refrigerant to pass into the receiver. When heating is desired (determined by the thermostat), the indoor coil F must take on the function of a condenser and the outdoor coil G, the evaporator. Expansion valve B will act as the metering device and check valve E will allow flow to the receiver.

3. In small units, the expansion and check valves may be replaced with a capillary tube. A few installations have been made in which the forced convection indoor coil has been replaced by a radiant panel.

4. **Air-to-Air (Air Changeover).** The heat pump circuit shown in figure 89,B, is the air-to-air (air changeover) type. Changeover is accomplished with dampers which control the flow of air across the two heat exchanger coils. Figure 89,B, shows the system when heating is desired. The indoor air is passing through damper A, over coil I, and out damper E, while the outdoor air is passing through damper C, over coil J, and out damper G. During the cooling cycle, dampers A, C, E, and G are closed and dampers B, D, F, and H are open? This arrangement permits outdoor air to pass through damper B, over coil I, and out damper F. The indoor air will now pass through damper D, over coil J, and out damper H.

5. The dampers may be electrically or pneumatically operated.

6. **Water-to-Air (Refrigerant Changeover).** This heat pump is illustrated in figure 89,C. The water-to-air heat pump uses water as a heat source and sink, and uses air to transmit heat to or from the conditioned space. The operation is similar to the air-to-air type (refrigerant changeover).

7. During the cooling cycle, the refrigerant passes through the changeover valve A to heat exchanger G. Check valve D will permit flow to the receiver, and expansion valve C will meter the flow to the coil F. When heating is desired, the changeover valve A will divert the refrigerant flow to coil F. Check valve E will allow refrigerant to pass to the receiver, and expansion valve B will meter the flow of refrigerant to heat exchanger G.

8. The coefficient of performance for this type heat pump is higher than the air-to-air types.

9. **Earth-to-Air (Refrigerant Changeover).** Earth-to-air heat pumps employ direct expansion of the refrigerant in an embedded coil, as illustrated in figure 89,D. They may also be of the indirect type which we've discussed under the water-to-air type.

10. The operation of this system is identical to the air-to-air (refrigerant changeover) type except that the outdoor coil is embedded in the ground.

11. **Water-to-Water (Water Changeover).** This type heat pump uses water for the heat source and sink for both heating and cooling operation. Changeover may be accomplished in the refrigerant circuit, but in many installations it is more convenient to perform the changeover with valves, as illustrated in figure 89,E.

12. Valves A, B, C, and D are controlled by a room or space thermostat. When the thermostat senses that cooling is needed, valve (A) will allow the water to pass through the condenser and discharge it out valve D. The return water will flow through valve (B) to the chiller and back to the supply through valve (D).

13. During the heat cycle, the valves will be positioned to permit water to pass through valve A to the chiller and then discharge through valve C. The return water will flow through valve B to the condenser. From the condenser it will flow through valve D to the supply inlet of the coil.

14. An earth-to-air heat pump (not shown in fig. 89) may be like the earth-to-air type shown, except for the substitution of a refrigerant-water heat exchanger for the finned coil shown on the indoor side. It may also take a form similar to the water-to-water system when a secondary-fluid ground coil is used.

15. Some heat pumps which use earth as the heat source and sink are essentially of the water-to-air type. An antifreeze solution is pumped through a loop comprised of a pipe coil embedded in the earth and the chiller-condenser.

16. Other types of heat pumps, other than those listed, are possible. An example is one which uses solar energy as a source of heat. Its refrigerant circuit may resemble the water-to-air, air-to-air, or other types, depending on the form of solar collector and the means of heating and cooling distribution which is employed.

17. Another variation is the use of more than one heat source. Some heat pumps have utilized air as the primary heat source, but are changed over to extract heat from another source (water earth, etc.) during peak load periods. When solar energy is used, another source must be used during periods of insufficient solar radiation.

36. Heat Sources and Sinks

1. The more practical choice of heat source and sink for a particular application will be influenced primarily by geographic location, climatic conditions, initial cost, availability, and type of structure. A more detailed discussion of design and selection factors for each heat source and sink follows.

2. **Air**. Outdoor air offers a universal heat source and heat sink medium for the heat pump. Extended-surface forced convection heat exchanger coils are employed to transfer the heat between the refrigerant and air. These surfaces are as much as twice the size of the indoor coil surface. The volume of outdoor air handled is also greater in about the same proportion. The temperature dif-

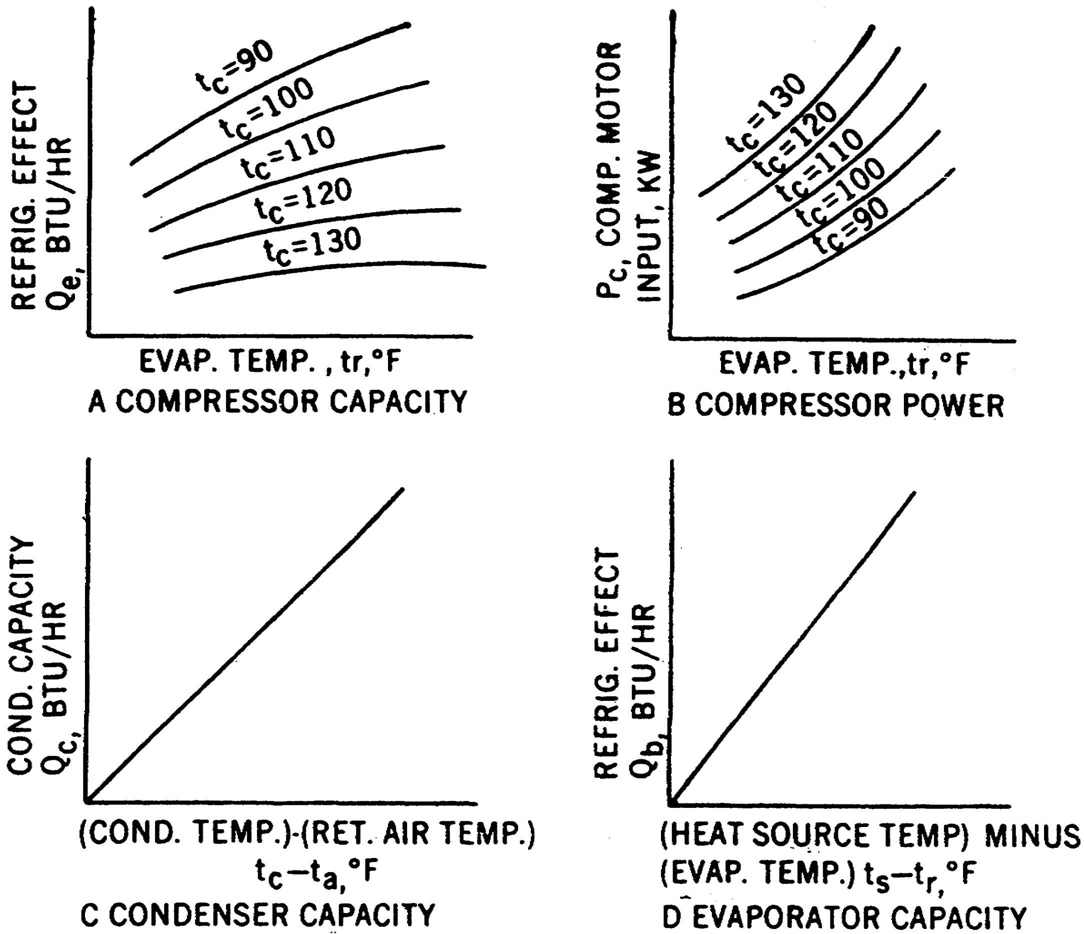


Figure 90. Heat Pump component performance characteristics.

ference, during heating, between the outdoor air and the refrigerant is approximately 10°-25° F.

3. **Selection**. The two factors that you must consider when selecting a heat pump are the variation in outdoor air temperature and the formation of frost. As the outdoor temperature decreases, the capacity of the heat pump (during heating operation). also decreases. Selecting a heat pump for a specific air temperature is more critical than for a fuel-fired system. Care must be exercised to size the equipment for as low a balance point as is practically possible for heating without having excessive and unnecessary cooling capacity during the summer periods.

4. The procedure for finding this balance point (outdoor temperature at which the capacity matches the heating requirements) will be discussed in the following paragraphs.

5. The performance characteristics of a heat pump system can be estimated by evaluating and individual components. Figure 90 illustrates the data that manufacturers make available with their heat pump.

6. The conditions of system balance can be established by the following procedure:

a. Choose a combination of evaporator refrigerant temperature Tr and condensing temperature Tc.

b. Determine the compressor refrigerating effect from performance curves similar to those shown in figure 90,A.

c. Determine the compressor power input (Pc) in kilowatts, as illustrated in figure 90,B.

d. Determine the condenser capacity from

Qe = Qe + 3413 Pc - Qce

where

Qc = condenser capacity (B.t.u./hr.)

Qc = compressor refrigeration effect (evaporator capacity)(B.t.u./hr.)

Qce = heat loss from compressor to surrounding air (B.t.u./hr.)

Pc = power input (kw)

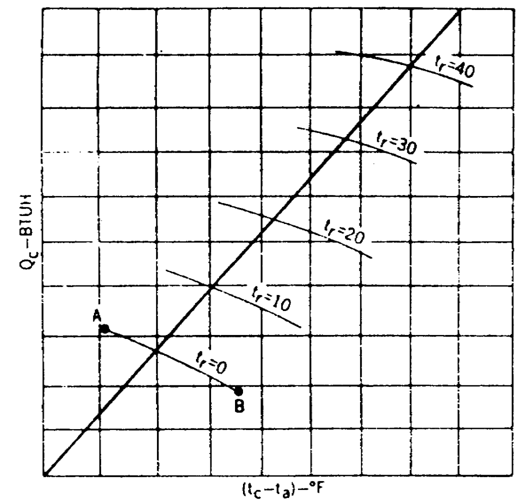


Figure 91. Heat pump system balance.

e. Plot Qc obtained from step *d* on a chart similar to 90,C.

f. Select other condensing temperatures in combination with the original evaporator temperature from step a and repeat steps *b-e* as necessary to determine the condenser capacity at which the system balances. Points A and B on figure 91 represent the results of these calculations. Two points will normally be sufficient to determine the balancing condenser capacity.

g. Select other evaporator temperatures and repeat steps *a-f.*

h. For each evaporator find the corresponding heat source temperature (Ta) from a chart similar to 90,D.

7. Once the conditions of system balance are known, it is relatively easy to establish the heating performance characteristics. The net heating effect may consist of condenser heat, or depending upon the system design, may also include heat losses from the compressor, motor, and refrigerant subcooler coil (if used).

8. For a heat pump which employs a constant temperature heat source, a few computations will generally establish the balancing conditions for Tr and Tc. A heat pump which uses a variable heat source such as air requires a wide range of Tr to establish balancing conditions.

9. Figure 92 shows the performance characteristics of a typical heat pump determined either from actual system tests or from an analytical procedure such as we've discussed. Heating and cooling loads for typical residence are also shown in figure 92. If the balance point is above the heating design temperature (Td), then supplemental heat will be required, as. shown by the shaded area in figure 92.

10. We've just. discussed one of the factors that you must consider when selecting a heat pump; now we'll discuss the other-frost formation.

11. When the surface temperature of an outdoor air coil is 32° F. or lower, frost will form. The accumulation of frost will tend to reduce heat transfer, which reduces the capacity of the system. Research has shown that with a nominal amount of frost deposit, the heat transfer capacity of the coil is not substantially affected. The nominal amount is 2.5 pounds/square feet of coil face surface. The number of defrosting operations required will be influenced by the (1) climate, (2) air-coil design, and (3) hours of operation.

12. Experience has shown that little or no defrosting is required with temperatures below 20° F. and below 60 percent relative humidity. However, under very humid conditions; when small suspended water droplets may be present in the air, the rate of defrost may be three times as great as you would predict, using psychrometric theory.

13. *Coil construction*. The air-source heat pump uses the extended or fin type coil. The external surface of the tube is known as the primary, and the fin surface is called the secondary. The primary surface consists of tubes which may be staggered, or placed in line with respect to the heat flow. The staggered arrangement is preferred because it obtains a higher heat transfer value.

14. A more important factor in the performance of extended surface coil is the bond between the tube and fin A firm contact between the tube

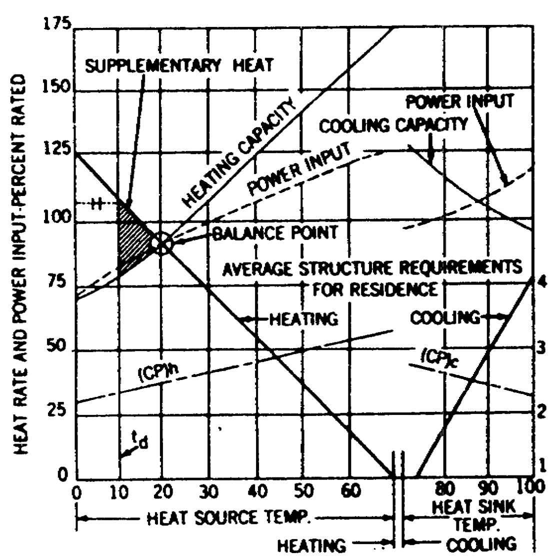


Figure 92. Heat pump operating characteristics.

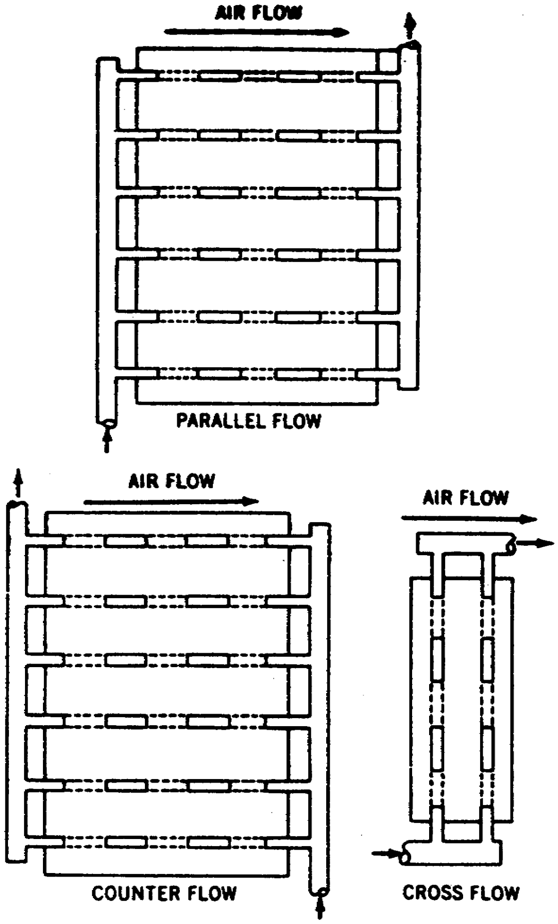


Figure 93. Condensing media flow.

and fin will insure free heat transfer from the fin to the tube.

15. Most coils are constructed of aluminum fins and copper tubes, but copper fins on copper tubes are also used. Fin spacing varies from 8 to 14 per inch. The fin spacing will be determined by the (1) duty to be performed, (2) possibility of lint accumulation, and (3) consideration of frost accumulation.

16. *Coil flow arrangements*. In air-cooling coils the air usually flows at right angles to the tubes. In a one-row coil the direction of airflow would be at right angles to the tube, but in multiple-row coils the airflow may be circuited, as shown in figure 93. Most dry expansion coils use the counterflow circuit to secure the advantage of the highest possible mean temperature difference. Crossflow is also used, but is difficult to control because of the problem of equal parallel circuit loading.

17. *Coil selection*. The various factors you must consider when selection a coil are:

a. The duty requPb4 and de capacity needed to maintain balance with other system components.

b. Temperature of entering air (D.B. and W.B.).

c. Available cooling media and operating temperatures.

d. Space and size limitations.

e. C.f.m. limitations.

f. Allowable frictional resistances in air circuit and cooling media piping system.

g. Characteristics of individual coil designs.

h. Installation requirements.-type of automatic control etc.

i. Coil air face velocity.

18. Coil ratings are based on a uniform face velocity. Airflow interference, caused by air entrance at odd angles or by blocking a portion of the coil face, will affect performance. To maintain the rated performance of the coil, it is necessary that the air quantity (c.f.m.) be adjusted while the system is operated and kept at this value.

19. You'll find that the more common causes of airflow reduction are (1) dirty filters, (2) dirty coils, and (3) frost accumulation on the coil. You will avoid these difficulties if you implement a good preventive maintenance program.

20. In the selection of coils, sufficient surface area must be installed to transfer the total heat load from the air to the cooling media-refrigerant. This transfer must occur under the required temperature conditions and maximum flow rates of both air and refrigerant. The coil total heat capacity must be in balance with the capacity of related equipment, such as the compressor. Therefore, in making coil selections you will have to consult manufacturer's rating tables or the manufacturer's local representative.

21. *Heat transfer and airflow resistance*. The rate of heat transfer from the air to the refrigerant is affected by three resistances. These three resistances are:

(1) From the air to the surface of the tube - usually external surface or air-film resistance.

(2) The resistance to the conduction of heat through the fin and tube metal.

(3) The resistance to the flow of heat between the internal surface of the metal and the fluid in the tube.

22. The metal to heat conduction and the internal tube surface resistances are comparably low. The resistance that you would be more interested in is the external surface or air-film resistance. You may overcome this resistance by extending the coil surface by means of fins.

23. The transfer of sensible heat between the cooling medium and the airstream is influenced by

(1) The temperature difference.

(2) The design and surface arrangement of the coil.

(3) The velocity and character of the airstream.

(4) The velocity and character of the medium in the tubes.

24. **Water**. Water is considered to be an ideal heat source subject to the considerations listed below:

(1) City water--availability, high operating expense, scale formation on coils, and low temperature during the winter season.

(2) Well water-availability, original cost of drilling the well, composition of water (calcium, magnesium), and the life of the well (dry up).

(3) Surface water-availability, and it may contain chlorides and micro-organisms (algae).

(4) Waste water-availability temperature, and it is very difficult to mass produce this type heat pump.

25. City water is not a good heat source because of its nonavailability and its high operating cost. Well water is particularly attractive from the standpoint of its relatively high and nearly constant temperature (50° F. in northern areas and 60° F. or higher in the south). You can obtain information on well water availability, temperature, and chemical and physical analysis from local U.S. Geological Survey offices. These offices are located in most major cities.

26. Utilization of water during cooling operation follows the conventional practice with water-cooled condensers. Water-refrigerant heat exchangers generally take the form of either shell-and-coil or shell-and-tube type direct-expansion water coolers. These heat exchangers are circuited to permit usage of the shell-and-coil or shell-and-tube as a refrigerant condenser during the heating cycle and as a refrigerant evaporator during the cooling cycle.

27. **Earth**. Heat transfer through buried coils has not been used extensively because of high installation cost, ground area requirements, and the uncertainty of predicting performance.

28. Compositions of soil vary quite widely (wet clay to sand) and affect the thermal properties and overall performance.

29. Earth coils, usually arranged horizontally, are submerged 3 to 6 feet below the surface. A lower depth may be preferred but excavation cost requires a compromise. The mean ground temperature for a specific area generally follows the mean annual climatic temperature.

37. Heat Storage

1. The use of heat storage can improve the performance of a heat pump. Installations of heat pumps with heat storage have been made in large buildings.

2. We'll all have to agree that all materials possess the property of heat storage. The structural materials of a building are always in the process either of absorbing heat from or delivering heat to the interior space. This effect is more pronounced in cooling operation where greater air temperature variation is tolerated. Heat storage tends to reduce the rate of temperature change and helps in some measure to reduce the peak load requirements.

3. A heat pump, with heat storage capabilities, can serve not only to reduce the size of a heat pump necessary for a given load but also to provide a more desirable electric load. This may be done by shifting part of the load to the time of day when the cost of power is least. Power is the cheapest during off-peak time. The electric hot water heater is a common example of such a heat storage application.

4. There are two types of heat storage systems that have been employed: (1) sensible heat storage systems, and (2) latent heat storage systems. The latter is actually a combination of the two. Heat storage, in the heat pump system, may be utilized on the high side when heat is available at a temperature suitable for direct heating. It is used on the low side as an intermittent heat source at temperatures lower than the heated space.

38. Heat Pump Components

1. The components used in heat pumps and the practices followed bear a direct relationship to the air conditioner discussed earlier in this volume. In this section we will discuss the component peculiar to this system-the reversing or change-over valve. Our discussion will cover the operation and application of the valve.

2. **Operation**. The 4-way reversing valve is operated by a solenoid pilot 3-way valve which actuates the piston-operated main valve (reversing valve). The pilot valve may be a separate component or an internal part of the main valve. The pilot valve directs the actuating pressures-compressor discharge and suction-to the top of the main valve piston. Figures 94,A, and 94,B, illustrates a heat pump system, during both heating (B) and cooling (A) cycles, using a typical 4-way reversing valve. You can see that the main valve is externally operated by a solenoid pilot 3-way valve: There are also two thermostatic expansion valves and two check valves used in the system.

3. Now we'll cover the cooling cycle (fig. 94,A). The pilot valve is energized, thus allowing compressor suction pressure to the top of the main valve piston. This causes the main piston

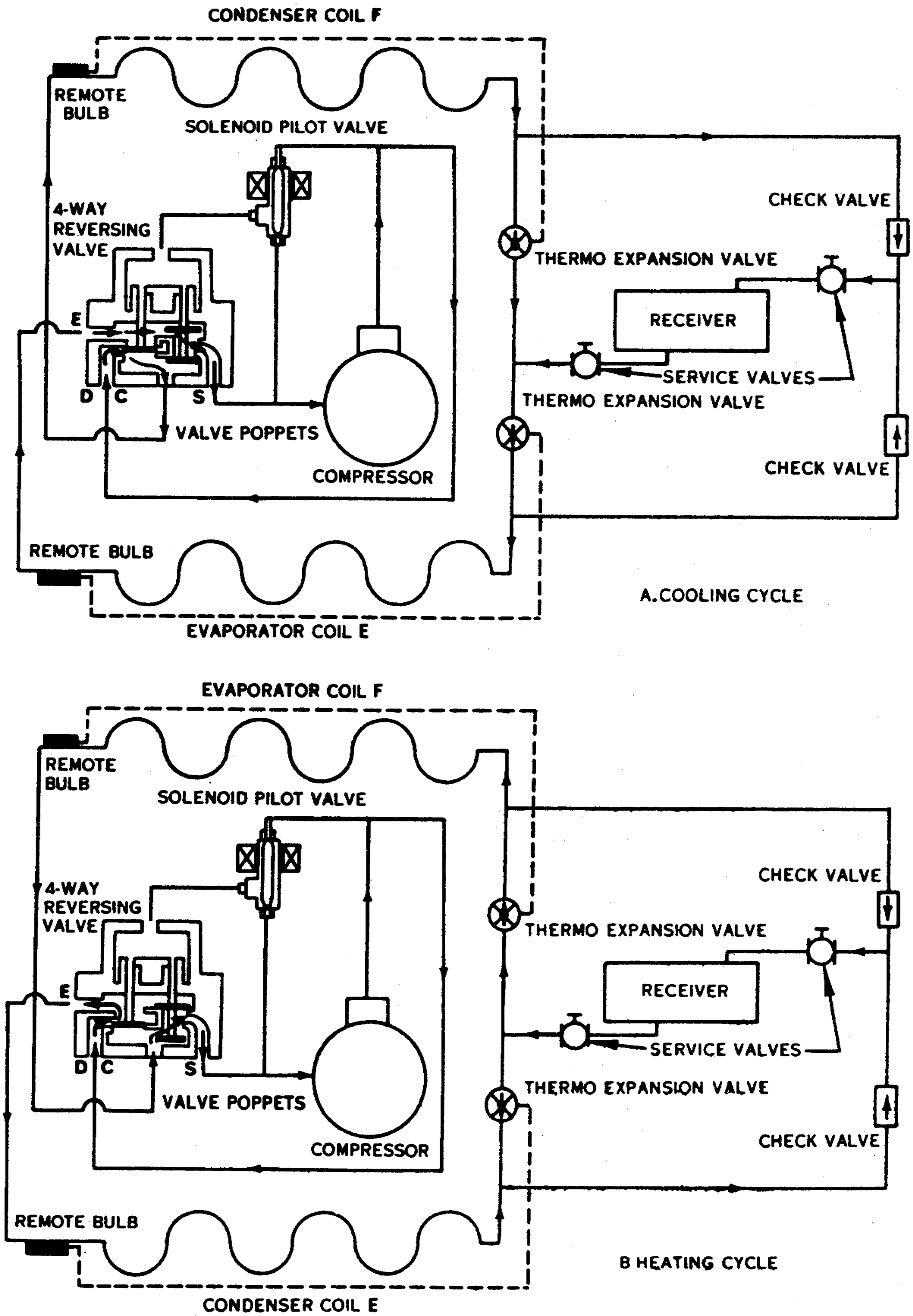


Figure 94. Heat pump system with 4-way reversing valve, solenoid pilot 3-way valve, two thermostatic expansion valves, and two check valves.

to rise. With the main valve piston in this position, the compressor discharge follows path D to C, while the suction gas (from the evaporator to the compressor) follows path E to S.

4. During the heating cycle, shown in figure 94,B, the pilot valve is deenergized. This allows the compressor discharge pressure to be admitted to the top of the main valve piston and to move the piston down. In this position the compressor discharge gas follows path D to E, and the evaporator return pressure from C to S.

5. We can summarize our discussion of the two cycles by stating that by energizing and deenergizing the pilot valve, the direction of refrigerant flow is reversed. We can also conclude that the main valve piston is held in position by the pressure drop across the closed valve poppets.

6. **Application**. We've already covered one application of the reversing valve; now we'll discuss two more. They are shown in figures 95 and 96. Figure 95 shows a system with one 4-way reversing valve, one solenoid pilot 3-way valve, one thermostatic expansion valve, and four check valves. The system shown in figure 96 uses a 3-way reversing valve, a 4-way reversing valve, a solenoid pilot 3-way valve, and two thermostatic expansion valves. This system allows refrigerant to flow in one direction in the heat exchanger coils, while the other systems allow flow in either direction.

7. It is imperative in the system shown in figure 96 to provide positive free draining of the liquid refrigerant into the top of the receiver from the bottom of the coil when the coil is used as a condenser. In addition, it may be necessary to allow for drainage of liquid refrigerant from the condenser before reversing the 4-way valve. If caution is not taken, the liquid refrigerant can enter the compressor and cause serious damage.

8. When a water cooled condenser is used in the system, it is necessary to add additional control devices to protect it against freezeup. Freezeup may occur during the heating cycle because the condenser is used as a heat source (evaporator). Two methods of protection are shown in figures 97 and 98.

9. Figure 97 shows a system using an *evaporator pressure regulator* (EPR), connected to the condenser. The EPR is used to prevent freezeup of the water flowing through the condenser during the heat cycle. When the system is returned to the cooling cycle, the EPR valve must be bypassed by a check valve which will allow the hot gas to flow to the condenser. A solenoid water valve must be used to bypass the condenser water regulating valve during the heat cycle. This will permit a full flow of water through the condenser.

10. A constant pressure liquid expansion valve is used in the system shown in figure 98. It feeds liquid refrigerant to the condenser when it is used as an evaporator during the heat cycle. The valve must be adjusted to prevent the suction pressure from falling below the pressure corresponding to the refrigerant saturation temperature 33° F. during the heat cycle. This valve must be bypassed with a check valve which will permit the condensed liquid refrigerant to flow to the receiver during the cooling cycle. In addition, the connection to the receiver, to which the valve is connected, must have a dip tube (quill) to insure an adequate supply of liquid refrigerant to the valve. A solenoid water valve must be- used to bypass the condenser water regulating valve when the condenser serves as an evaporator. This is done to insure complete evaporation of all of the refrigerant being fed by the constant pressure liquid expansion valve. Liquid refrigerant must never be allowed to return to the compressor.

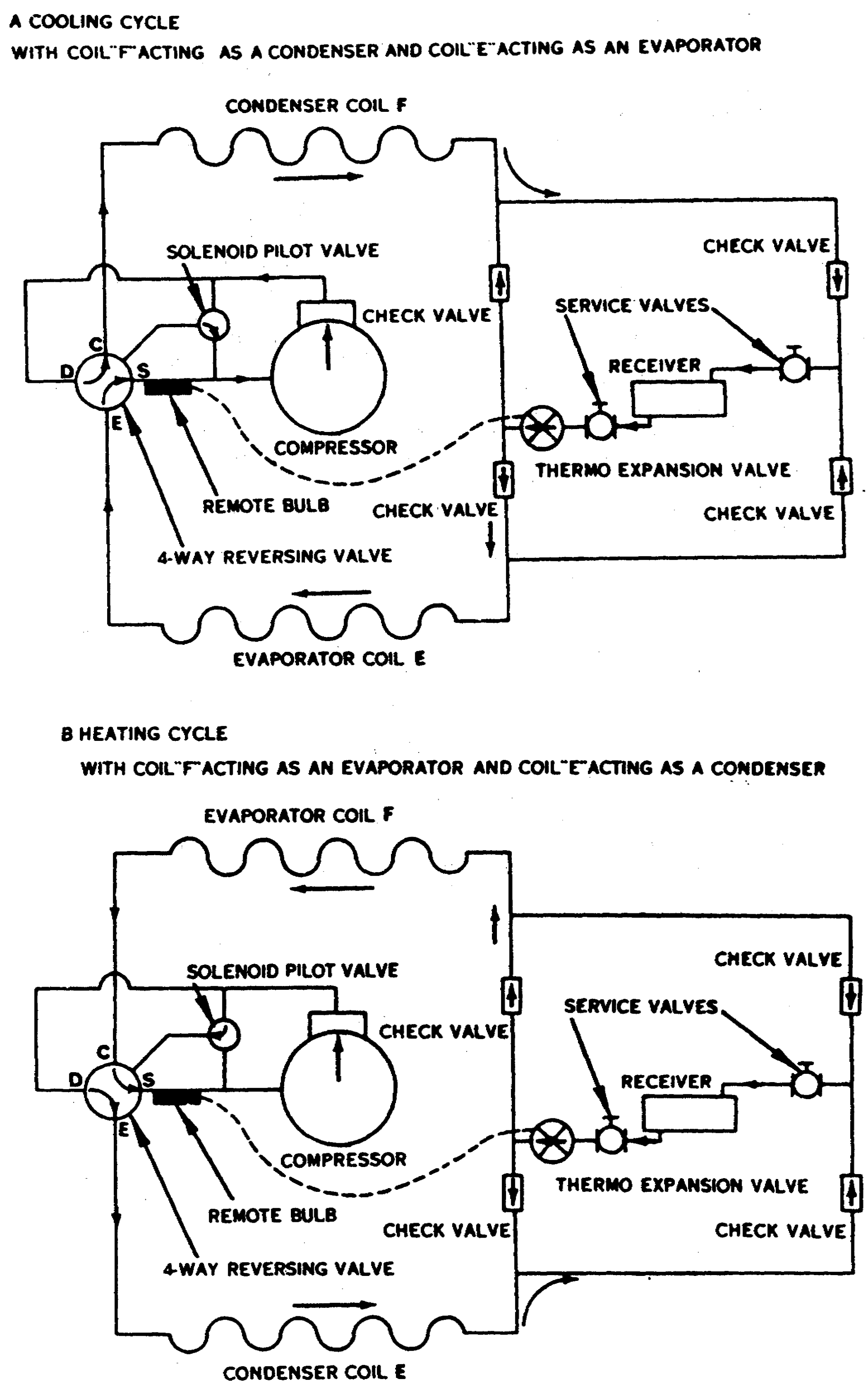


Figure 93. Heat pump system with 4-way reversing valve, solenoid pilot 3-way valve, thermostatic expansion valve, and four check valves.

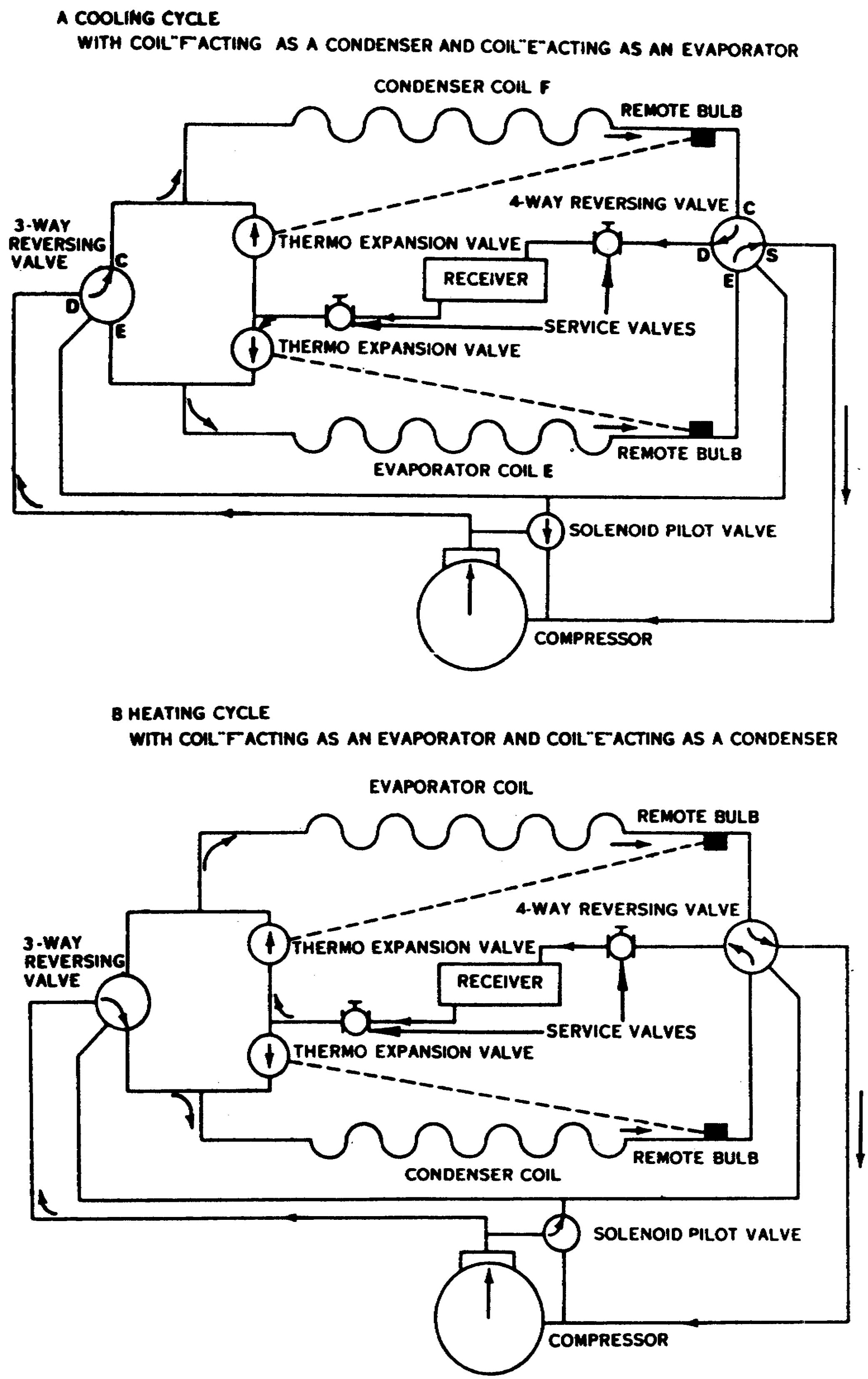
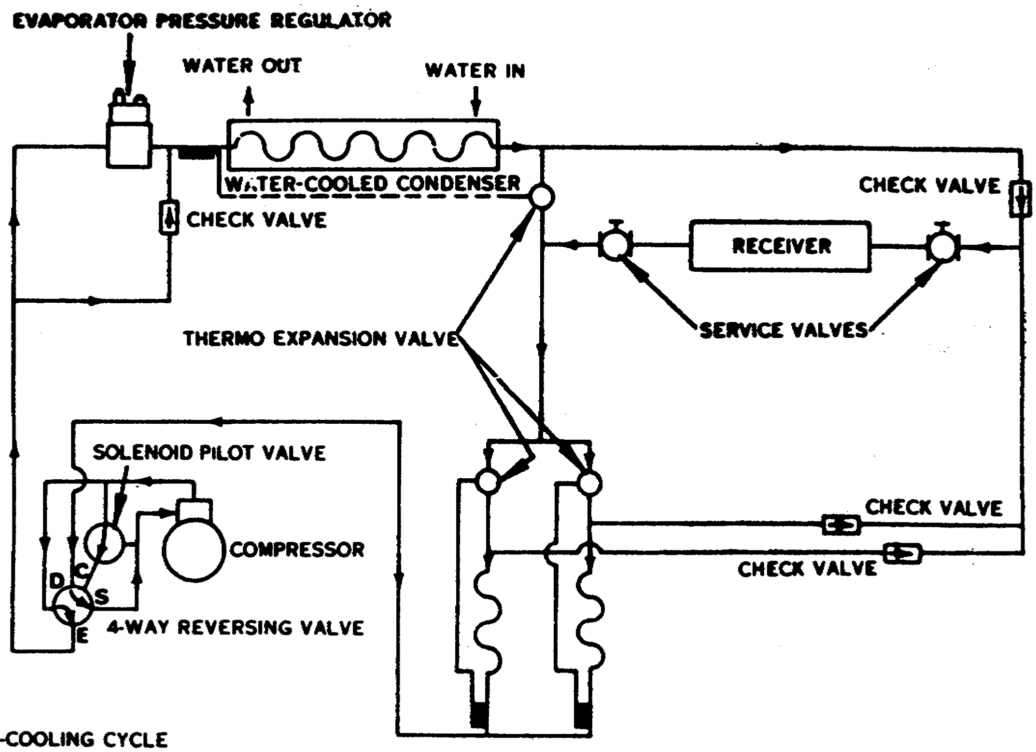
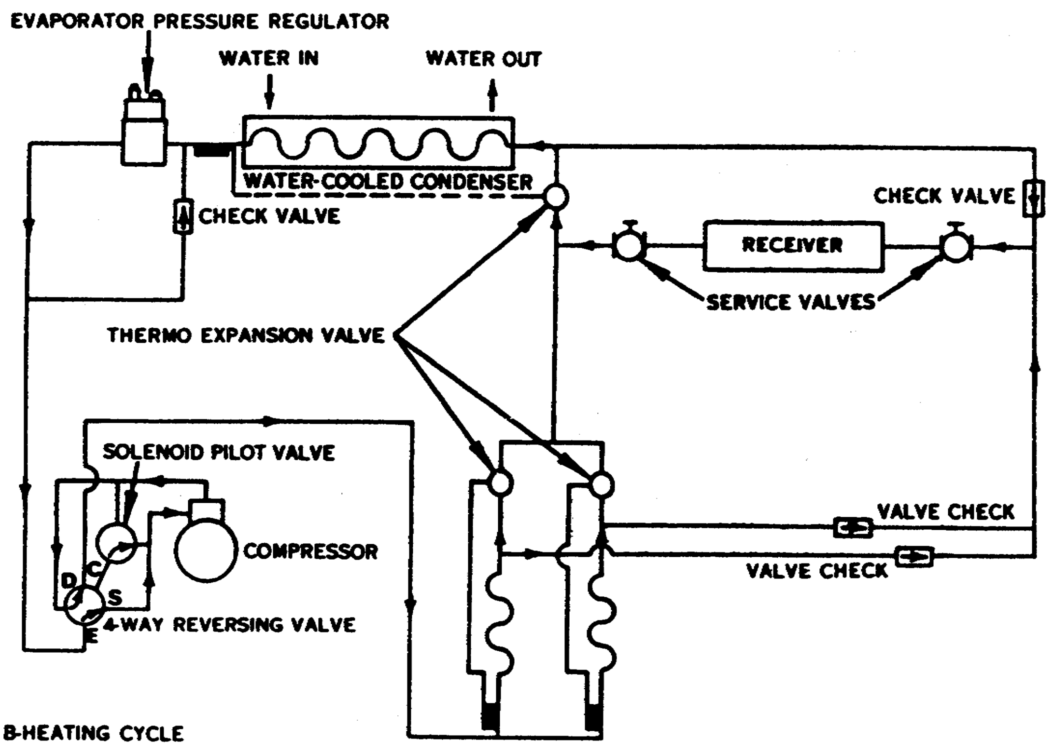


Figure 96. Heat pump system with 3-way reversing valve, 4-way reversing valve, solenoid pilot 3-way valve, and two thermostatic expansion valves.

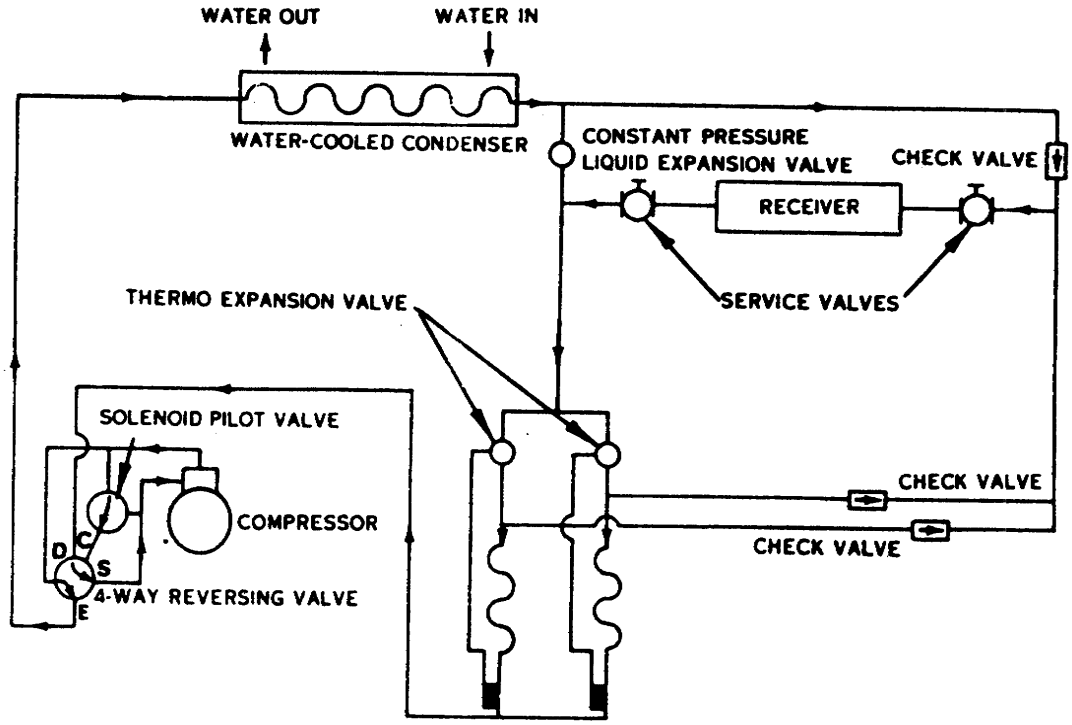


A-COOLING CYCLE
WITH MULTIPLE COILS ACTING AS EVAPORATORS AND WATER-COOLED CONDENSER AS A CONDENSER

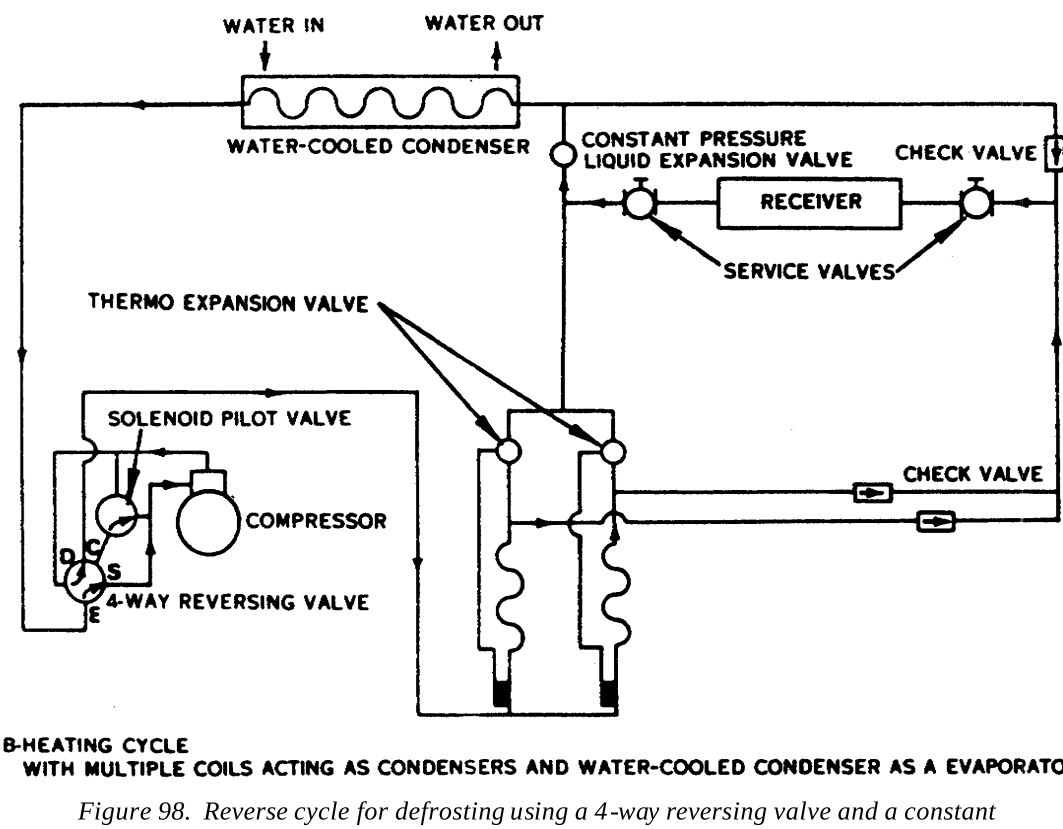


B-HEATING CYCLE
WITH MULTIPLE COILS ACTING AS CONDENSERS AND WATER-COOLED CONDENSER AS A EVAPORATOR

Figure 97. Reverse cycle for defrosting using a 4-way reversing valve and an evaporator pressure regulating valve.



A-COOLING CYCLE
WITH MULTIPLE COILS ACTING AS EVAPORATORS AND WATER-COOLED CONDENSER AS A CONDENSER



B-HEATING CYCLE
WITH MULTIPLE COILS ACTING AS CONDENSERS AND WATER-COOLED CONDENSER AS A EVAPORATOR

Figure 98. Reverse cycle for defrosting using a 4-way reversing valve and a constant pressure liquid expansion valve.

Review Exercises

NOTE: The following exercises are study aids. Write your answers in pencil in the space provided after each exercise. Use the blank pages to record other notes on the chapter content. Immediately check your answers with the key at the end of the test. Do not submit your answers for grading.

1. What is the COP of a refrigeration cycle when the refrigeration effect is 300,000 B.t.u.'s and the brake horsepower is 40? (Sec. 34, Par. 2)

2. How much would it cost to operate a 100,000 B.t.u./hr. electrical resistance hear for 1 day? The cost of electricity is 2 a kilowatt-hour. (Sec. 34, Pars. 5 and 6)

3. How many degree days would you have if the average temperature for a 90-day period is 5° F.? (Sec. 34, Par. 7)

4. Why is a hat pump less expensive to operate than an electric resistance heater? (Sec. 34, Par. 8)

5. Which type of heating system is the cheapest to operate, the air-to-air heat pump or an oil fired heating system? (Sec. 34, Par. 9)

6. How many expansion devices does an air-to-air (refrigerant changeover) heat pump have? (Sec. 35, Par. 2)

7. What is the maximum temperature of the refrigerant during the heating cycle when the outside temperature is 50 F.? (Sec. 36, Par. 2)

8. Why is outdoor temperature an important factor in selecting a heat pump? (Sec. 36, Pars. 3-9)

9. Will 40 pounds of frost substantially affect a 5' x 4' coil? (Sec. 36, Par. 11)

10. How many fins does a 4-foot coil contain? (Sec. 36, Par. 15)

11. What are the most common causes of airflow reduction? (Sec. 36, Par. 19)

12. Why isn't city water considered a good heat source? (Sec. 36, Par. 24)

13. Which water source is considered the best heat source? Why? (Sec. 36, Par. 25)

14. Why is heat storage beneficial to a heat pump? (Sec. 37, Par. 2)

15. The heat pump is operating as an air conditioner. The room temperature falls below the thermostat setting, but the unit will not reverse its cycle. Which component has most likely malfunctioned? (Sec. 38, Par. 2)

16. What occurs when the pilot valve is energized? (Sec. 38, Par. 3)

17. An open in the pilot valve solenoid will cause the heat pump to operate on the cycle. (Sec. 38, Par. 4)

18. How can you prevent freezeup of a water-cooled condenser during the heat cycle? (Sec. 38, Pars. 9 and 10)

Answers to Review Exercises

CHAPTER 1

1. The factor that determines the type of filter design you would use is the degree of cleanliness required for the conditioned area. (Sec. 1, Par. 6)
2. The filter arrangement used in a duct system having a velocity of 500 f.p.m. is with the filtering medium placed on edge. (Sec. 1, Par. 10)
3. When the pressure drop through a duct system is 2 p.s.i.g. the filters are dirty. (Sec. 1, Par. 13)
4. The traveling media filter requires the least amount of attention because the media roll usually lasts 3 months. (Sec. 1, Par. 17)
5. The type of filter you should install is a moving curtain filter because it is considered to be fail safe. When the media runs out, an indication it given and the circuit to the filter motor opens. (Sec. 1, Par. 19)
6. The surface area of a dry filter may be increased by pleating the filtering medium. (Sec. 1, Par. 22)
7. The initial resistance of the filter is higher than the resistance at which the fan will operate. This condition will cause the motor to overheat. (Sec. 1, Par. 26)
8. An ionizing filter handling 3800 c.f.m. of air will consume 97 watts. (Sec. 1, Par. 31)
9. The cost of filter operation for 1 hour is $.17

   97 X 60 = 5820 watts
   5820 watts = 5.82 kilowatts
   5.82 X $ .03 = $.175

   (Sec. 1, Par. 31 and Question 8)
10. A dry-bulb temperature of 50° F. and a dewpoint temperature of 50° F. is 100 percent relative humidity. This high humidity will impair the dielectric properties of the filter. (Sec. 1, Par. 36)
11. The most probable cause of an odor in an air-conditioning system is a wet, dirty cooling coil. (Sec. 2, Par. 2)
12. Air at 70° F. and 100 percent humidity is saturated. (Sec. 3, Par. 4)
13. 2000 c.f.m. can be handled effectively by a 5-ton cooling coil. (Sec. 3, Par. 7)
14. The quality of a liquid absorbent is controlled by the automatic regulation of cooling waterflow through a cooling coil in the absorbent sump. (Sec. 3, Par. 12)
15. The air temperature should be within 1° to 5° of the absorbent temperature. To lower the temperature differential, more contact surface should be added or the absorbent temperature should be lowered. (Sec. 3, Par. 14)
16. The adsorption efficiency of a dynamic dehumidifier with an entering moisture content of 25 grains and an adsorbed moisture content of 20 grains is 80 percent, or $\frac{20}{25} = \frac{4}{5} = .8 = 80$ percent. (Sec. 3, Par. 21)
17. The economy of desorption is 1200 watts and the cost it $ .30.

   400 X 3 = 1200 watts
   1200 watts = 12 kilowatts
   12 X .025 = .30

   (Sec. 3, Par. 22)
18. To evaporate 9 pounds of water, 9450 B.t.u.'s must be added to the water. 1050 X 9 = 9450 B.t.u.'s. (Sec. 3, Par. 28)
19. Adding moisture to the air with an atomizer humidifier will *not affect* the wet-bulb temperature. (Sec. 3, Par. 28)
20. A humidistat can be used to control a valve in the compressed air line. As more air is allowed to pass through the line, more moisture will escape into the air. (Sec. 3, Par. 32).
21. The maximum efficiency of the impact humidifier as compared to the atomizer type is 50 percent. The atomizer uses 100 percent of the water supplied to it, while the impact uses 20 to 50 percent. (Sec. 3, Par. 37)
22. The rate of airflow is important because more evaporation will occur in a given period of time with an increase in c.f.m. (Sec. 3, Par. 38)
23. 100 B.t.u.'s added to a forced-evaporation humidifier per hour with an airflow rate of 20 pounds of dry air per hour will add 5 B.t.u.'s to each pound of dry air. (Sec. 3, Par. 40)
24. To correct this condition-water droplets leaving the washer-you could install a bypass duct and allow a velocity of 500 f.p.m. to pass through the washer. (Sec. 3, Par. 44)
25. The pressure has increased because the eliminator plates have become plugged. This condition can be prevented by installing flooding nozzles in the air washer. (Sec. 3, Par. 44)

CHAPTER 2

1. On a centigrade the thermometer 15.5° is equivalent to 60° on a Fahrenheit thermometer:

   $C = \frac{5}{9}(60 - 32); C = \frac{5}{9} \times \frac{28}{1}; C = \frac{140}{9}$;

   C = 15.55°

   (Sec. 4, Par. 4)
2. On a Fahrenheit thermometer 104° is equivalent to 40° on a centigrade thermometer.

   $F = \frac{9 \times 40}{5} + 32; F = \frac{360}{5} + 32; F = 72 + 32; F = 104°.$

   (Sec. 4, Par. 4)
3. It would require 3.8 B.t.u.'s to raise the temperature of 8 pounds of cast iron 4°. (B.t.u. = 0.119 X 8 X 4. B.t.u. = 0.119 X 32, B.t.u. = 3.8) (Sec. 4, Par. 6)
4. The term applied to the sum of sensible heat and latent heat is "total heat" (Sec. 4 Par. 8)

5. The dry-bulb thermometer will always indicate a higher temperature than the wet-bulb thermometer except when the air is saturated; then they will both indicate the same. (Sec. 4, Pars. 10 and 11)
6. After whirling a sling psychrometer with the wet-bulb thermometer wick dry, the psychrometer thermometers would read the same. (Sec. 4, Par. 11; Sec. 5, Par. 3)
7. The difference in the dry-bulb thermometer reading and wet-bulb thermometer reading will become greater as the relative humidity decreased. (Sec. 4, Par. 11; and Sec. 5, Par. 3)
8. In order to determine the relative humidity, the dry-bulb and wet-bulb temperatures must be known. (Sec. 5, Par. 3)
9. Distilled water should be used to set the wick of a wet-bulb thermometer to help prevent the clogging of the wick. (Sec. 5, Par. 6)
10. If the total pressure of an air-conditioning system remains constant and the air ducts become partially clogged, the static pressure will increase to over-come the added resistance and the velocity pressure will decrease. (Sec. 6, Pars. 8-11)
11. If the total airflow pressure is equal to 20 inches of water and the static pressure is equal to 4 inches of water, the velocity pressure is equal to the total pressure minus the static pressure or 16 inches of water. (Sec. 6, Par. 11)
12. Yes, it is possible to determine static pressure with a velometer. The velometer indicates the velocity pressure which you would subtract from the total pressure to get the static pressure. (Sec. 6, Pars. 11 and 19)

CHAPTER 3

1. In calculating the wall area you must subtract 16” from the length to find the inside wall area. The ceiling sits on top of the wall so that the height measurement is not affected. The wall area is 126.67 square feet.
   10' = 120" height
   14'= 168" length
   168"- 16"= 152"
   120" X 152" = 18240 square inches
   18240 ÷ 144 = 126.67 square feet
   (Sec. 7, Par. 2)
2. You should tell the user to draw the drapes to help eliminate solar heat gain and to start the unit earlier so that it wouldn't work against a peak load condition. (Sec. 7, Pars. 5-8)
3. The heat load from occupants will affect humidity the most. (Sec. 7, Par. 11)
4. To remove the heat which is causing abnormal unit operation, you should ventilate the area. (Sec. 8, Pars. 4 and 6)
5. The efficiency that would be lost is 85 - 75 or 10 percent. (Sec. 8. Par. 9)
6. Cork should be used to insulate a 40° F. storage room, because this particular application is not considered a fire hazard area. (Sec. 9, Par. 5)
7. You should insulate the strainer with an asbestos pad or blanket to facilitate the cleaning of the strainer. (Sec. 9, Par. 8)
8. You should use fibrous glass dabs, because they have a low moisture-absorbing quality and offer no attraction to insects, vermin, fungus growth, or fire. (Sec. 9, Par. 14)
9. The most probable cause of a 55° F. temperature reduction is moisture in the insulation around the pipe. The evaporation of the moisture will cause a heat loss. (Sec. 9, Par. 18)
10. When you insulate a valve in a 2-inch pipeline the insulation should be the same thickness as the pipe. The insulation usually consists entirely of insulating cement. (Sec. 9, Par. 20)
11. The solar radiation through a 20' x 40' brick Wall with a 30° F. differential is
    $Q = UA (t_1 - T_0)$
    Q = .34 x 800 (30)
    Q = 272 x 30
    Q = 8160 B.t.u./hr.
    (Sec. 10, Pars. 10 and 13)
12. The gross area of the wall is 120 square feet. The window area is 16 square feet.
    Glass = 1.13 X 16 X 22 = 397.76 B.t.u./hr.
    Brick = 120 - 16 = 104 sq. ft.
    104 X .34 X 22 = 777.48 B.t.u./hr.
    Total heat gain = 397.76 + 777.48 = 1175.24 B.t.u./hr.
    (Sec. 10, Par. 13)
13. Human load will give off the most latent heat gain. (Sec. 10, Par. 13)
14. To find the total cooling load, you must add 10 percent to the sensible load.
    Total load = 42,156 + 4,215.6 + 8,750 = 55,121.6 B.t.u.
    (Sec. 10, Par. 14)
15. 57,150 B.t.u. (sensible)
    5,715 B.t.u. (safety factor)
    9,170 B.t.u. (latent)
    72,035
    72,035 total heat load.
    12,000 B.t.u. per ton of refrigeration.
    72,035
    12,000 = approximately 6 tons.
    (Sec. 10, Par. 14)

CHAPTER 4

1. Before you plug in an air-conditioning unit you should read the *nameplate* to check the power requirements of the air conditioner. (Sec. 11 , Par. 5)
2. When the round third prong is removed from an air-conditioning unit plug an ungrounded condition will exist. When the air-conditioning unit is not grounded, a possible electrical shock hazard also exists. (Sec. 11, Pars. 9, 10, and 16)
3. It is not permissible to connect a 9.5-ampere rated air-conditioner to a 15-ampere circuit when other equipment are using the same circuit. The total load of the air conditioner shall not exceed 50 percent of the current rating of the circuit if the circuit feeds other equipment. (Sec. II, Par. 12)
4. If you are to replace an air-conditioner compressor motor that has burned out due to excessive overload, you should also replace the motor overload protector. If the overload protector was operating correctly, the motor would not have burned out from an overload. (Sec. 11, Pars. 24 and 25)

5. As the room air passes through the evaporator its heat is absorbed by the refrigerant. (Sec. 11, Par. 28)
6. The refrigerant gas temperature is raised at the compressor above the outside air temperature. (Sec. 11, Par. 29)
7. The air filter, evaporator coils, and condenser coils will collect dirt and thus restrict airflow which will result in reduced air-conditioning unit output. (Sec. 11 Par. 32)
8. Before you check a capacitor with an ohmmeter you should discharge the capacitor. (Sec. 11, Par. 44)
9. If the ohmmeter indicates zero (no continuity) when you check an overload protector. the protector is defective and should be replaced. (Sec. 11, Par. 46)
10. A low wattage draw is an indication of a low refrigerant charge. (Sec. 11, Par. 51)
11. The two major causes of poor performance of an air conditioner are dirty filters and low voltage. (Sec. 11, Par. 62)
12. When using superheated steam to clean a condenser, be sure that the temperature of the seam is not above the melting point of any of the materials from which the condenser is constructed. (Sec. 12, Par. 7)
13. When mixing water and acid, always add the acid to the water. If water is added to the acid, rapid heating will occur which will cause the acid to spew from the container. (Sec. 12, Par. 12)
14. If the water bleed tube of the evaporative condenser should become clogged, the formation of scale will increase. The bleeding off of some of the recirculated water and replenishing it with makeup water will decrease the amount of solids suspended in the cooling water. (Sec. 12, Pars. 18 and 19)
15. Two of the conditions that would prevent the compressor from unloading are; a broken spring in the hydraulic cylinder which moves the floating piston when the oil pressure is relieved or the oil pressure is not released from the valving mechanism hydraulic cylinder. There are several causes that would prevent the release of the oil pressure. Some of these causes are: defective pressure-sensing device, broken mechanism that opens the bleed orifice (item 9 in fig. 18), and a clogged bleed orifice (items 9 and 10 in fig. 18). (Sec. 12, Pars. 31-39)
16. The pan of the capacity control actuator that regulates the oil pressure to the compressor cylinder unloader mechanisms is the valving mechanism. (Sec. 12, Par. 31)
17. Spring pressure in the cylinder unloader mechanism will hold the compressor suction valves open. (Sec. 12, Par. 39)
18. The compressor must be loaded before adjusting the unloader system. (Sec. 12, Par. 41)
19. Before you install a solenoid valve, check the valve data plate for the power requirements and the arrow on the valve body for direction of liquid flow thru the valve. (Sec. 12, Par. 49)
20. Before you install a new solenoid valve in place of a burned out one, you should find the cause for the burned out coil. You should check the voltage of the power source and the power requirements of the valve. Another possible cause could be high ambient temperatures. Sec. 12. Par. 50
21. The two methods of varying the volume of the air handled by an air conditioning system are by the use of dampen or by varying the speed of the fans. (Sec. 12, Par. 56)

CHAPTER 5

1. Bypass dampeners are used to regulate airflow from return ducts. (Sec. 13, Par. 2)
2. One probable cause of erratic damper operation is binding blades. (Sec. 13, Par. 7)
3. The forward blade fan is most commonly used in a duct system. (Sec. 14, Par. 2)
4. The propeller, or disc, type fan should be installed in an area requiring large amounts of exhaust air. (Sec. 14, Par. 3)
5. The axial adjustment of the blower wheel is accomplished by relocating the shaft thrust collar. (Sec. 14, Par. 9)
6. Cooling coils are made of copper or aluminum because these metals readily conduct heat. (Sec. 15, Par. 1)
7. A 2-foot coil would contain 144 fins-24 X 6 = 144. (Sec. 15, Par. 2)
8. You would straighten the fins with a special fin comb. (Sec. 15, Par. 4)
9. Brine solution is used in a system that requires a low temperature for dehumidification purposes. (Sec. 16, Par. 1)
10. The type of pressure loss caused by an elbow in the duct is dynamic loss. (Sec. 17, Par. 2)
11. The velocity reduction method of duct sizing is not used because it does not take any account of the relative pressure losses in various branches. (Sec. 17, Par. 4)
12. A system with a velocity rating of 2400 f.p.m. is considered a high-velocity system. (Sec. 17, Par. 6)
13. Duct joints are sealed with compound, tape, or by welding or soldering. (Sec. 17, Par. 9)
14. The type of duct materials you would use when corrosive fumes are to be handled are copper, stain less steel, monel lead-coated or lead. (Sec. 17, Par. 12)
15. When air flows from a small chamber toward a large area, the air tends to flow in a straight line. (Sec. 17, Par. 16)
16. The loss of cooling effect of a 12-sq. ft. duct having a differential of 10° and a U-factor of 1.14 is 136.8 B.t.u/hr.
    $Q = UA\,(t_1 - t_0)$
    $Q = 1.14 \times 12 \times 10.$
    Q = 136 B.t.u./hr.
    (Sec. 17, Par. 18)
17. Most duct air leakage occurs at transverse seams located against a wall or ceiling. (Sec. 17, Par. 22)
18. The amount of air required when the sensible hit load is 49000 B.t.u./hr. and the temperature change is 15° F. is 3025 c. f. m.
    $$\text{c.f.m.} = \frac{49000}{1.08 \times 15}$$
    $$\text{c.f.m.} = \frac{49000}{16.2}$$
    c.f.m. = 3025
    (Sec. 17, Par. 25)

19. You can check the vertical flow from a grille by using a lighted match, a warm thermometer, or alcohol on your arm. (Sec. 17, Par. 34)
20. The horizontal airflow pattern is controlled by the *rear frets* of the grille. (Sec. 17. Par. 34)
21. The baseboard type of diffuser is the hardest to use for balancing because it has few adjustments. (Sec. 17, Par. 38)

CHAPTER 6

1. The thermostatic expansion valve uses the vapor-tension principle in its operation. (Sec. 18, Par. 6)
2. The control response a motor control uses is *two-position*. (Sec. 19, Par. 2)
3. To set a LPC for a wider differential you would turn the adjusting screw so that more force is exerted upon the bar. (Sec. 19, Par. 5)
4. The compressor will cut off at 25 p.s.i.
4 0 p.s.i. - 15 p.s.i. = 25 p.s.i.
(Sec. 19, Par. 9)
5. Since the system uses an automatic expansion valve, a low-pressure motor control cannot be used to control compressor cycling. You must install a thermostatic motor control and adjust it to the desired cutout and cut-in temperatures. (Sec. 19, Par. 10)
6. A broken feeler bulb on a thermostat will give the sale indication as a filed ice bin. (Sec. 19, Pars. 12-15)
7. The air conditioner is not running because the kinked feeler bulb acts as if a loss .of power element charge and will not close the contacts in the TMC. To correct this condition, you must replace the power element or the entire TMC. (Sec. 19. Par. 20)
8. Snap action and mercury switches are used to prevent control failure due to arcing when the circuit is open or closed. (Sec. 20, Par. 2)
9. A direct short is indicated when the ohmmeter reads zero ohms resistance. (Sec. 20, Par. 7)
10. The mode of electric control you would use to operate a refrigeration unit is two-position because the unit requires on-off operation. (Sec. 20, Par. 13)
11. The control point would be at any point between the two extremes because the control cycles the louvers between the extremes and is never satisfied. (Sec. 20, Par. 18)
12. The timed two-position control responds to gradual changes in the controlled variable, while the simple two-position control responds to one of two extremes. (Sec. 20, Par. 24)
13. A heater is used to slow down the action of the bimetal element. (Sec. 20, Pars. 31 and 32)
14. You should install a proportional response control because system offset is minimized. (Sec. 20, Pars. 35-37)
15. Since lag time is not a problem, a simple two-position control, series 20, can be used. It is cheaper, easier to maintain and calibrate, and safer because it operates at low voltages. (Sec. 20, Par. 41)
16. The change in variable causes a bellows to expand and make a circuit to the starting winding of the motor. The motor is energized and begins to rotate clockwise. After it has rotated 180°, a cam operated switch will break the circuit and stop the motor (Sec. 20, Pars. 43-46)
17. The series 40 control action is similar to a single-pole single-throw switch. (Sec. 20, Par. 49)
18. No, you can't substitute it with anything but a series 60 floating motor because it is revertible and the two position is not. (Sec. 20, Par. 55)
19. You cannot substitute a series 20 motor with a series 60 because the 20 operates on low voltage, while the 60 uses line voltage. (Sec. 20, Par. 58)
20. The amount of current flowing through the relay will affect the position of the contact blade between the two motor contacts which, in turn, controls the position of the controlled device. (Sec. 20, Pars. 66-68)
21. The series 90 motor will stop running when the balancing relay is balanced. (Sec. 20, Par. 73)
22. The most probable cause of a damper remaining closed when the control calls for it to be open is loose locknut on the linkage to the damper shaft (Sec. 20, Pars. 79 and 80)
23. The main difference between a series 90 humidity control system and a series 90 temperature control system is the sensing device which operates the controller wiper. (Sec. 20, Par. 18)
24. The humidistat is wired into the blue wire of the right circuit. (Sec. 20, Par. 93)
25. When one belt in a set breaks. you must replace the complete set because the remainder of the belts are stretched and the new belt will not have the proper tension. (Sec. 21, Par. 3)
26. A compressor losing efficiency is usually caused by defective air cleaner. (Sec. 21, Par. 4)
27. When the first stage is operating at normal and the second-stage pressure is zero, the pressure relief valve is stuck open. (Sec. 21, Par. 8)
28. Before you start a newly installed compressor, you must check the oil level in the compressor crankcase (Sec. 21, Par, 15)
29. If you replace the standard head gasket with a thin head gasket, the compressor will probably knock (Sec. 21, Par. 21)
30. Supply-air lines are lines connecting the controllers to the air source, and the control air lines connect the controllers to the controlled device. (Sec. 22, Par. 1)
31. You must allow a 1 1/2-inch pitch for a 12-foot supply-air header, 1/8 inch per foot of header.
3 inches. 1/4 inch per foot. (Sec. 22, Par. 4)
32. The amount of moisture present in the air determine the frequency of draining the filters. (Sec. 22, Par. 8)
33. You would install a reverse acting controller so that a decrease in temperature will cause an increase in air pressure to the valve. (Sec. 22. Par. 17)
34. You clean the contact points on a thermostat by drawing a piece of hard-finish paper between then (Sec. 22, Par. 23)
35. Under normal conditions, a humidistat will control the humidity within 1 percent R.H. of the set point (Sec. 22, Pat. 25)
36. Hygrometers are the controllers used to measure, record, and control humidity. (Sec. 22, Par. 27)

37. The spring in the piston type damper operator usually functions between 5 and 10 p.s.i.g. At 3 p.s.i.g. the damper should be at its normal position. (Sec. 22, Par. 34)
38. The spring attached to the operator stem determines the operating range of the positioner. (Sec. 22, Par. 39)
39. When you overhauled the operator you probably kinked the diaphragm, which would cause erratic operation of the damper operator (Sec. 22, Par. 43)
40. To correct a skipping pen, you must bend the pen arm slightly toward the chart. The pen should rest on the chart lightly. (Sec. 22, Par. 48)
41. A condensate loop should be installed on a pressure transmitter when it is used to measure the pressure of a hot, moist atmosphere. (Sec. 22, Par. 57)
42. The dried ink may be cleaned from the pen by washing it in warm water. (Sec. 22. Par. 64)
43. The fire protection control has malfunctioned or was activated and shut the system down. You should check the fire protection control, then reset it. (Sec. 22, Pars. 73, 75, and 76)
44. You can check the operation of an airflow detector by blocking off a section of the filters or by closing a damper before the air reaches the instrument. (Sec. 22, Par. 82)
45. A graphic panel is an asset because you can monitor and control the entire system from one central location. (Sec. 23, Par. 1)
46. On graphic panels, *chill water* temperature is always indicated and recorded. (Sec. 23, Par. 2)
47. When a green coded component on the graphic panel is malfunctioning you are having trouble with the condensing water system. (Sec. 23, Par. 4)

CHAPTER 7

1. Disagree. Evaporative cooling changes sensible heat to latent heat but doesn't affect the wet-bulb temperature (total heat). (Sec. 24, Par. 1)
2. With an evaporative cooler, the air can be cooled to its *wet-bulb* temperature. (Sec. 24, Par. 3)
3. Phoenix, Arizona, is first because it has a high average dry-bulb temperature and low wet-bulb temperature. Dallas, Texas follows second and New York is third. New Orleans is fourth because its average dry-bulb temperature is in the middle 90's and the wet-bulb temperature in the mid 80,s. (Sec. 24, Par. 5)
4. The most probable cause of low water supply to the distributor in an evaporative cooler is a plugged pump intake screen. (Sec. 24, Par. 11)
5. The spray type evaporative cooler should be-installed in a dusty area because it keeps the pads free of dust for a longer period of time. (Sec. 24, Par. 18)
6. An electric timer controls the frequency of operation of the flush valve on spray type evaporative coolers. (Sec. 24, Par. 22)
7. The eliminator pads must be placed when water droplets are carried in the air to the conditioned area. (Sec. 24, Par. 24)
8. Since centrifugal fans are rated for a delivery against 1/4-inch water gauge static pressure, nothing would happen unless the pressure exceeded ¼ inch. If it exceeded 1/4 inch the cooler would lose efficiency. (Sec. 24, Par. 25)
9. The 3,000 c.f.m. rotary drum would require a heavy structure because of its sis and weight. (Sec. 25, Par. 1)
10. The drain should be 1 1/4 inch in diameter to reduce stoppage. If stoppage occurs with a larger drain you must flush, the cooler sump more often. (Sec. 25, Par. 9)
11. The function of the two switches is to cont the operation of the recirculating pump motor and the blower or fan motor. They are connected in series with one of the motor leads. This procedure allows the cooler to be used as a ventilation system. (Sec. 25, Par. 11)
12. You must provide an opening large enough to exhaust all the air brought into the area by the evaporative cooler. The size of the opening is obtained from the cooler manufacturer or data books. (Sec. 25, Par. 15)
13. The exhaust opening is not sufficient (less than 1 square foot) and is causing noise. You must allow 9 sq. ft. of louvered exhaust for a 4500 c.f.m. evaporative cooler. (Sec. 25, Par. 16)
14. You should caution the user not to start the blower before the water pump. (Sec. 25, Par. 20)
15. The burned-out motor could have been prevented by installing a motor overload protective device in series with the motor lead. (Sec. 25, Par. 22)
16. You can reduce the spied by adjusting the motor pulley or by reducing the size of the motor pulley? (Sec. 25, Par. 24)
17. 100 c.f.m. is delivered from a 12” X 24” duct with a velocity reading of 50 f.p.m.
    12” X 24” = 288 sq. in.
    288 sq. in. = 2 sq. ft.
    50 X 2 = 100 c.f.m.
    (Sec. 25, Par. 25)
18. The service that you must accomplish on troughs and weirs of a drip type evaporative cooler is cleaning, painting, or replacement. (Sec. 26, Par. 3)
19. The water distribution system is cleaned by flushing it with a 10 percent solution of muriatic acid. (Sec. 26, Par. 3) 20. The axial clearance of the blower wheel is 1/32” To adjust the clearance you would use a .030 feeter gauge because 1/32” = .0313. (Sec. 26, Par. 3)

CHAPTER 8

1. Complete air distribution is important when hazardous vapors and fumes may exist in an area such as a battery shop. (Sec. 27, Par. 3)
2. The two ways you could reduce grille noise are: change the size of the grille or reduce the air discharge velocity. (Sec. 27, Par. 13)
3. The radial-flow fan is normally used in a ventilating system which has considerable duct work. (Sec. 28, Par. 3)
4. The fan capacity must be at least 1,260 c.f.m. for a room 14 feet by 60 feet requiring 30

air changes per hour. To find what capacity fan is needed use the formula

$Q = \frac{CV}{60}$; $Q = \frac{30 \times 60 \times 60 \times 14}{60}$; $Q = \frac{75600}{60}$

Q= 1,260 c.f.m.

(Sec. 28, Pars. 10 and 11)

5. To reduce air duct friction loss you would increase the duct size. (Sec. 29, Par. 3)
6. Duct fire dampers are used to automatically shut off fans and ducts in event of a fire. (Sec. 29, Par. 5)
7. The type of grille that should be used in a flood air outlet which requires controlled airflow is a vaned grille. (Sec. 30, Pars. 2-7)
8. Slotted outlets are used for long narrow rooms. (Sec. 30, Par. 6)
9. The pattern of the supply air envelope is determined by the air outlet grille. (Sec. 31, Par. 3)
10. Several of the factors that must be considered when preparing to install a ventilating system are: the purpose of the building or room to be ventilated, the temperature and humidity of the region; the size of the building or room, the number of occupants, and local and national codes and regulations. (Sec. 32, Pars. 1-3)
11. In a room that contains carbon dioxide the fan should be located close to the floor. The specific gravity of carbon dioxide is 1.527 which is heavier than air; so it will settle to the floor. (Sec. 32, Pars. 18 and 19)
12. When installing an exhaust fan in a paint shop or paint spray booth, the electrical circuit for the fan and air compressor should be interconnected. This will insure that the fan is operating when spray painting is being done. (Sec. 32, Par. 22)
13. The factors that determine the desired exhaust air velocity are: what is to be exhausted, amount to be exhausted, and the desired noise level. (Sec. 32, Pars. 26-28)
14. Poorly constructed fixed wooden louvers would result in restriction of airflow and insufficient protection against bad weather. (Sec. 32, Par. 34)
15. Filters should be installed in the exhaust system when the discharge would create an objectionable condition in the immediate area. (Sec. 32, Par. 39)
16. Dirt on the fan blades will unbalance the fan and cause fan vibration during operation. (Sec. 33, Par. 5)
17. Overlubrication of fan motors and other ventilating equipment will result in collections of oil and dirt which could restrict airflow, cause motors to overheat, and present a fire hazard. (Sec. 33, Par. 8)
18. The frequency of cleaning an air filter depends on the following: type of system in which the filter is installed, how much the system is used, and weather conditions. (See. 33, Par. 16)
19. Excessively tight fan belts will cause an increase in the fan motor load and premature bearing wear. (Sec. 33, Par. 21)

CHAPTER 9

1. $COP = \frac{300,000}{40 \times 2545}$

   $= \frac{300,000}{101,800}$

   = 2.94 to 1

   (Sec. 34, Par. 2)
2. 100,000 B.t.u./hr. = 29.2 kw.-hr

   29.2 X .02 = $.584 per hour

   .584 X 24= $14.02 per day.

   (Sec. 34, Pars. 5 and 6)
3. You would have 5400 degree days.

   65 - 5 = 60 degree days per day.

   60 X 90 = 5400 degree days.

   (Sec. 34, Par. 7)
4. The heat pump is cheaper to operate because it uses electricity only to drive the compressor. The refrigeration releases more heat per watt consumed. (Sec. 34, Par. 8)
5. The oil-fired heating system is cheaper than the air-to-air heat pump. (Sec. 34, Par. 9)
6. The air-to-air (refrigerant changeover) heat pump has two expansion devices. (Sec. 35, Par. 2)
7. The maximum temperature of the refrigerant when the outside temperature is 50° F. is 75° F. (Sec. 36, Par. 2)
8. Outdoor temperature is an important factor because a balance point above the design temperature would require supplemental heating which is not economical. (Sec. 36, Pars. 3-9)
9. 40 pounds of frost on a 5-feet x 4-feet coil will not substantially affect the coil because the nominal amount it could hold is 50 pounds. (Sec. 36, Par. 11)
10. A 4-foot coil can contain 384 to 672 fins. (Sec. 36, Par. 15)
11. The most common causes of airflow reduction are dirty filter, dirty coils, and frost accumulation on the coil. (Sec. 36, Par. 19)
12. City water is not considered a good heat source because of its poor availability and high operating cost. (Sec. 36, Par. 24)
13. Well water is considered the best heat source because of its relatively constant temperature. (Sec. 36, Par. 25)
14. Heat storage is beneficial to a heat pump because it tends to reduce the rate of temperature change and helps to reduce peak load requirements. (Sec. 37, Par. 2)
15. The solenoid pilot 3-way valve has probably malfunctioned when the unit will not reverse its cycle. (Sec. 38, Par. 2)
16. When the pilot valve is energized, suction pressure is allowed to pass to the top of the main valve piston. This will cause the piston to rise, allowing the compressor discharge to pas to the condenser. (Sec. 38, Par. 3)
17. An open in the pilot valve solenoid will cause the heat pump to operate on the heat cycle. (Sec. 38, Par. 4)
18. To prevent freeze-up of a water-cooled condenser during the heat cycle, you should install an evaporator pressure regulator or a constant pressure liquid expansion valve on the condenser. (Sec. 38, Pars. 9 and 10)