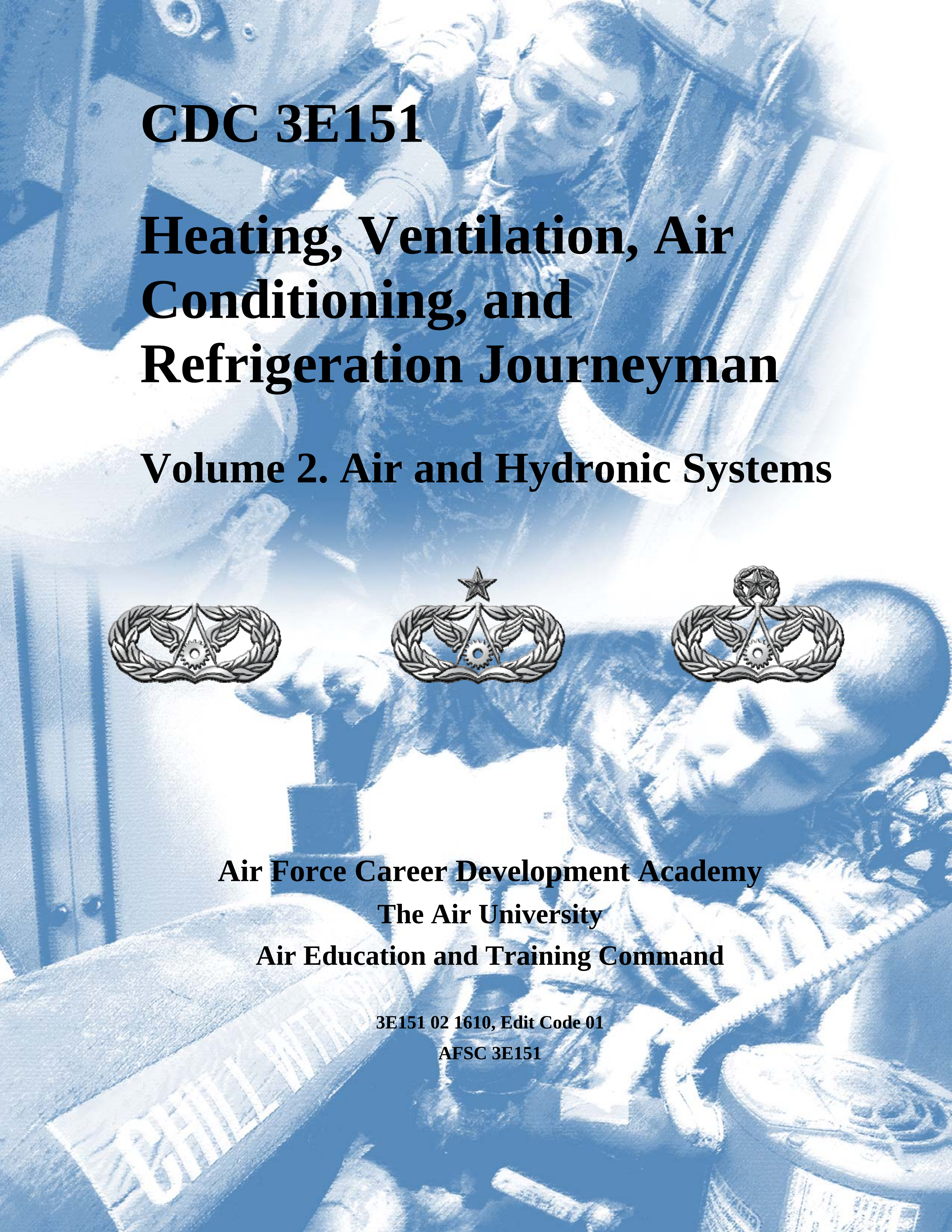

CDC 3E151

Heating, Ventilation, Air Conditioning, and Refrigeration Journeyman

Volume 2. Air and Hydronic Systems

Air Force Career Development Academy

The Air University

Air Education and Training Command

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Author: MSgt Brian Messineo
366th Technical Training Squadron
Civil Engineer Training (AETC)
366 TRS/TRR
727 Missile Road
Sheppard Air Force Base, 76311-2254
DSN: 736-2887
E-mail address: hvacr.cdc@sheppard.af.mil

Instructional Systems Specialist: Timothy Sackie

Editor: Maxine Baldwin

Air Force Career Development Academy (AFCDA)
The Air University (AETC)
Maxwell AFB, Gunter Annex, Alabama 36114-3107

Material in this volume is reviewed annually for technical accuracy, adequacy, and currency. For SKT purposes the examinee should check the *Weighted Airman Promotion System Catalog* to determine the correct references to study.

THIS SECOND VOLUME of CDC 3E151, *Heating, Ventilation, Air Conditioning, and Refrigeration (HVAC/R) Journeyman*, introduces you to air and hydronic distribution systems.

Unit 1 discusses air and hydronic distribution systems. Topics included are air distribution systems, indoor air quality, pumps and hydronic distribution systems.

Unit 2 discusses air and hydronic balancing and system drawings.

This CDC has four additional volumes. Volume 1 HVAC/R Fundamentals, Volume 3 discusses electrical concepts, Volume 4 Heating Systems and Volume 5 Cooling Systems.

This course must be completed before you can obtain a 5-skill level in the 3E1X1 career field.

A glossary is included for your use.

Code numbers on figures are for preparing agency identification only.

The use of a name of any specific manufacturer, commercial product, commodity, or service in this publication does not imply endorsement by the Air Force.

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Acknowledgement

PREPARATION of this volume was aided by Twin City Fan and Blower, who furnished technical materials for the HVAC/R system. Unit 1 of this volume uses extracts from the Twin City Fan and Blower Corporation.

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26 August 2015	Figure 1–5. Forward-curve in housing.	**1-5**	**F1-5**
26 August 2015	Figure 1–11. Centrifugal kitchen roof exhauster, upblast, direct drive.	**1-11**	**F1-11**
26 August 2015	Figure 1–13. Tube axial, belt driven.	**1-13**	**F1-13**
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NOTE:

In this volume, the subject matter is divided into self-contained units. A unit menu begins each unit, identifying the lesson headings and numbers. After reading the unit menu page and unit introduction, study the section, answer the self-test questions, and compare your answers with those given at the end of the unit. Then complete the unit review exercises.

Unit 1. HVAC/R Air and Hydronic Distribution Systems

HVAC/R DISTRIBUTION SYSTEMS can consist of both air and hydronic distribution systems. An air distribution system is basically a system that moves air and conditions a facility. These systems have numerous different components that serve various purposes. Another important factor is indoor air quality. There are many aspects of indoor air quality and each will be discussed in this unit.

Hydronic systems, hydronic simply means water, are simply water systems. They consist of piping for pumps to move hot or cold water throughout a facility. Also, they are designed with various types of components that perform different purposes. All of these items will be discussed in this unit.

1–1. Air Distribution Systems

An air distribution system is a system of components that move air into and out of the conditioned space as well as circulate air throughout the space. The air system is made of a wide array of parts and components. Main items discussed in this section will include fans and belts. Also, constant and variable air systems will be covered as well as various system components. A thorough grasp of an air distribution system is absolutely critical to your success in heating, ventilation, air conditioning and refrigeration (HVAC/R).

If you think about the title of our Air Force Specialty Code (AFSC) Heating, Ventilation, Air Conditioning and Refrigeration, you must realize that we are heating, ventilating and cooling AIR! So it is easy to understand why AIR distribution systems are so important. Let’s get started with fan and belt types used in our systems.

201. Fans and belts

As you read the next few pages, you will develop an understanding of the major fan and belt types. Each of the fans has its own distinctive characteristics and configurations that determine what kind of work the fan will do. We will also discuss the various belts used with each fan.

Fan rating and classifications

An association of fan manufacturers provides the industry with uniform standards for testing and rating fans. This association is called the Air Moving and Conditioning Association (AMCA). In conjunction with the American Society of Heating, Refrigerating, and Air-Conditioning Engineers

(ASHRAE), most fans in the industry are tested to the requirements of ASHRAE Standard 51 and AMCA Standard 210, *Laboratory Methods of Testing Fans for Aerodynamic Performance Rating.*

The important factor to recognize is that fans are tested and rated under the ideal conditions with minimal obstructions to the fan inlet or discharge. When fans are installed in HVAC unit casings and connect them to ductwork systems, there often are restrictions imposed on either the fan inlet or discharge. These restrictions affect the fan performance and this loss of capacity or increase in pressure is known as system effect. We cannot measure system effect in the field, but we can calculate it.

In a fan manufacturer's rating table, if the fan speeds and static pressures increase above certain given conditions, the "class" of the fan changes. Again, the class refers to an AMCA standard that has been developed to regulate actual structural limitations of the wheels, bearings, and housing of fans.

Fan types

In any air-handling system, a fan is the "pump" or prime mover, which creates pressure differences that cause air to flow through the system. Its application and performance are vital to the operation of the system.

Centrifugal fans

A commonly used fan for HVAC/R and industrial systems is the centrifugal fan (fig. 1–1) which has a scroll housing. Air enters a round inlet on one side or both sides and discharges 90 degrees from the intake through a rectangular opening. The acceptable revolutions per minute (rpm) range of centrifugal fans vary with the type of wheel, diameter of the wheel, and the recommended top speed.

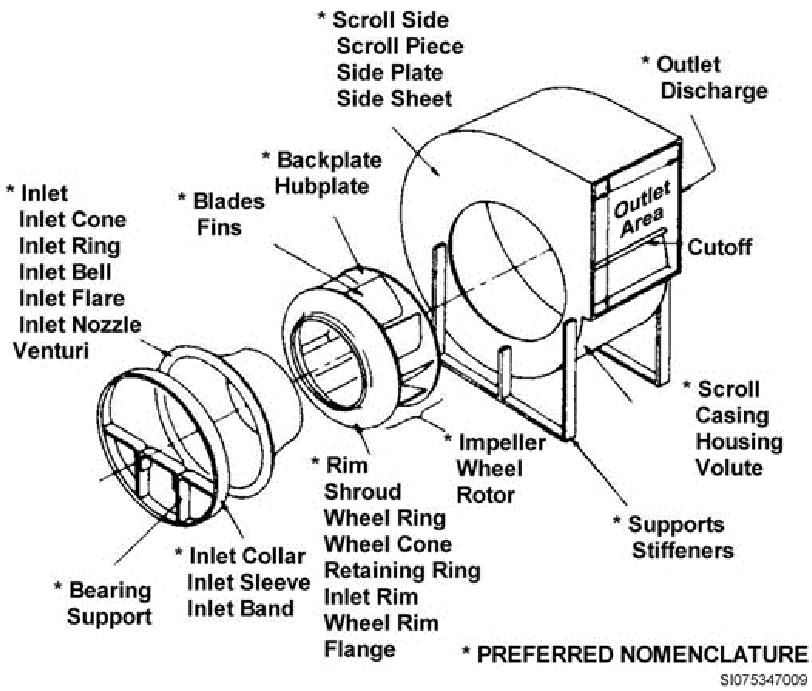


Figure 1–1. Centrifugal fan components.

You'll work with four types of centrifugal wheels:

1. Backward inclined (BI).
2. Airfoil (F).
3. Forward curve (FC).
4. Radial blade.

Backward inclined

The flat blades around a backward-inclined wheel (fig. 1–2) are inclined away from the direction of airflow. Although these wheels operate at higher efficiencies than do forward-curve wheels, they are not as quiet because they operate at higher speeds. The rpm range for backward-inclined wheels for low-pressure systems may run roughly from 400 to 1,700 rpm.

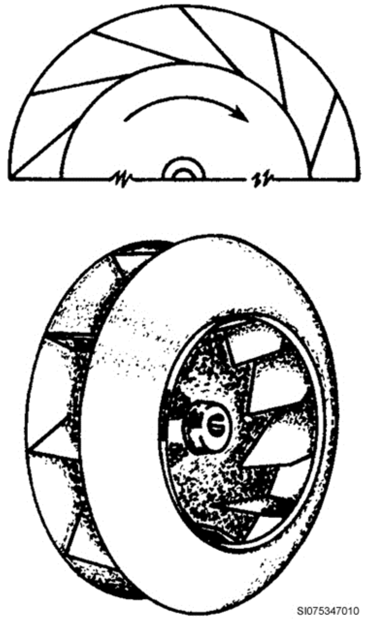


Figure 1–2. Backward-inclined centrifugal wheel.

Airfoil

Airfoil wheels (fig. 1–3) are similar to backward-inclined wheels because their blades also slope away from the direction of airflow. But their shape, instead of being flat, is similar to the wings of an airplane. Also, airfoil wheels have similar performance characteristics as backward-inclined wheels, except that they are more efficient and run at slightly higher top speeds for the same volumes of air. Hence, rpm ranges are also slightly higher. They are used more extensively for higher-volume and high-pressure systems.

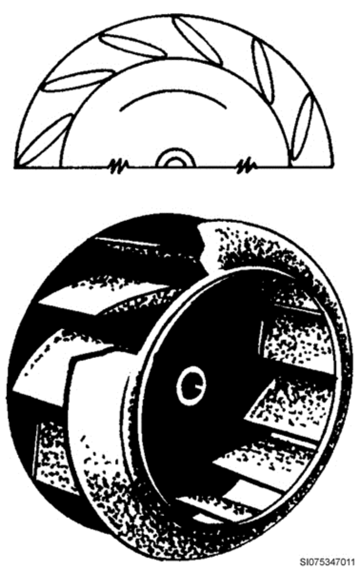


Figure 1–3. Airfoil centrifugal wheel.

Forward curve

The blades of forward-curve wheels (figs. 1–4 and 1–5) are much narrower than those in the backward-inclined or airfoil wheels, and they are curved like a crescent. The inside of the curve faces, and is slightly inclined, in the direction of airflow. The wheel speeds up the air and discharges it at a higher speed than the fan is rotating. Forward-curve wheels are the least efficient of the three wheels—backward-inclined, airfoil, and forward-curve. Forward-curve wheels move large masses of air at low rpm’s quietly and require less space.

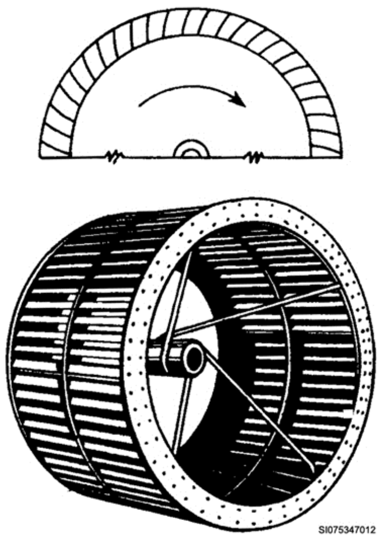


Figure 1–4. Forward-curve centrifugal wheel.

Figure 1–5. Forward-curve in housing. (Photos courtesy of Twin City Fans and Blower)

Normally, forward-curve wheels are used in residential systems, in light commercial systems, and for light-duty exhaust, where maximum air delivery and low noise levels are needed. Dormitories are another place you will see forward curved fans. They are not recommended for use where dust or fumes would adhere to blades.

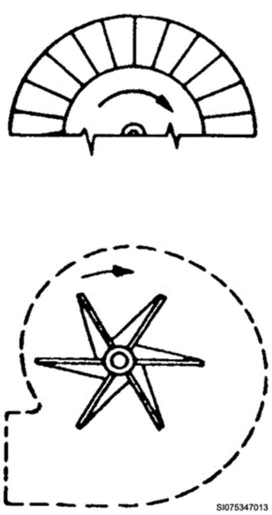


Figure 1–6. Radial-blade centrifugal wheel.

Since these fans can be found in dormitories and temporary lodging facilities the HVAC/R Shop is usually not responsible for the filter changing. The responsibility for these systems is the dorm or lodging facility managers. Unfortunately, these filters are not changed as often as they should. A clogged filter will eventually lead to dust collecting on the fan blades. Dust on the fan blades will reduce the amount of air flow which will reduce heat transfer. This will often lead to a trouble call. Also, dust on the fan blade could cause the fan to become unbalanced. This could cause the fan to wobble on the shaft and eventually ream the part of the fan that connects to the shaft. This will result in no air flow and the system will likely shut down.

Radial blade

Radial-blade wheels (fig. 1–6) have straight blades that are largely self-cleaning and which have great structural strength. This makes them suitable for industrial exhaust applications, abrasive dusts, material handling, grease, acids, and so forth. Although the radial-blade wheels can withstand high speeds and pressures, they are noisier than other types of wheels.

Widths and inlets

Centrifugal fans are constructed as either single-width, single-inlet (SWSI) or double-width, double-inlet (DWDI). The SWSI fan has one inlet opposite the drive side. The DWDI has two inlets, one on each side, and the discharge is about 75 percent wider than the SWSI.

Rotations and discharges

We always view the rotation and discharge of a centrifugal fan from the drive side (fig. 1–7). Centrifugal fans can be discharged in eight basic directions. Some of them include the discharge at the top or bottom, vertically up or down, and at a 45 degree angle upward or downward. The wheel may turn clockwise or counterclockwise.

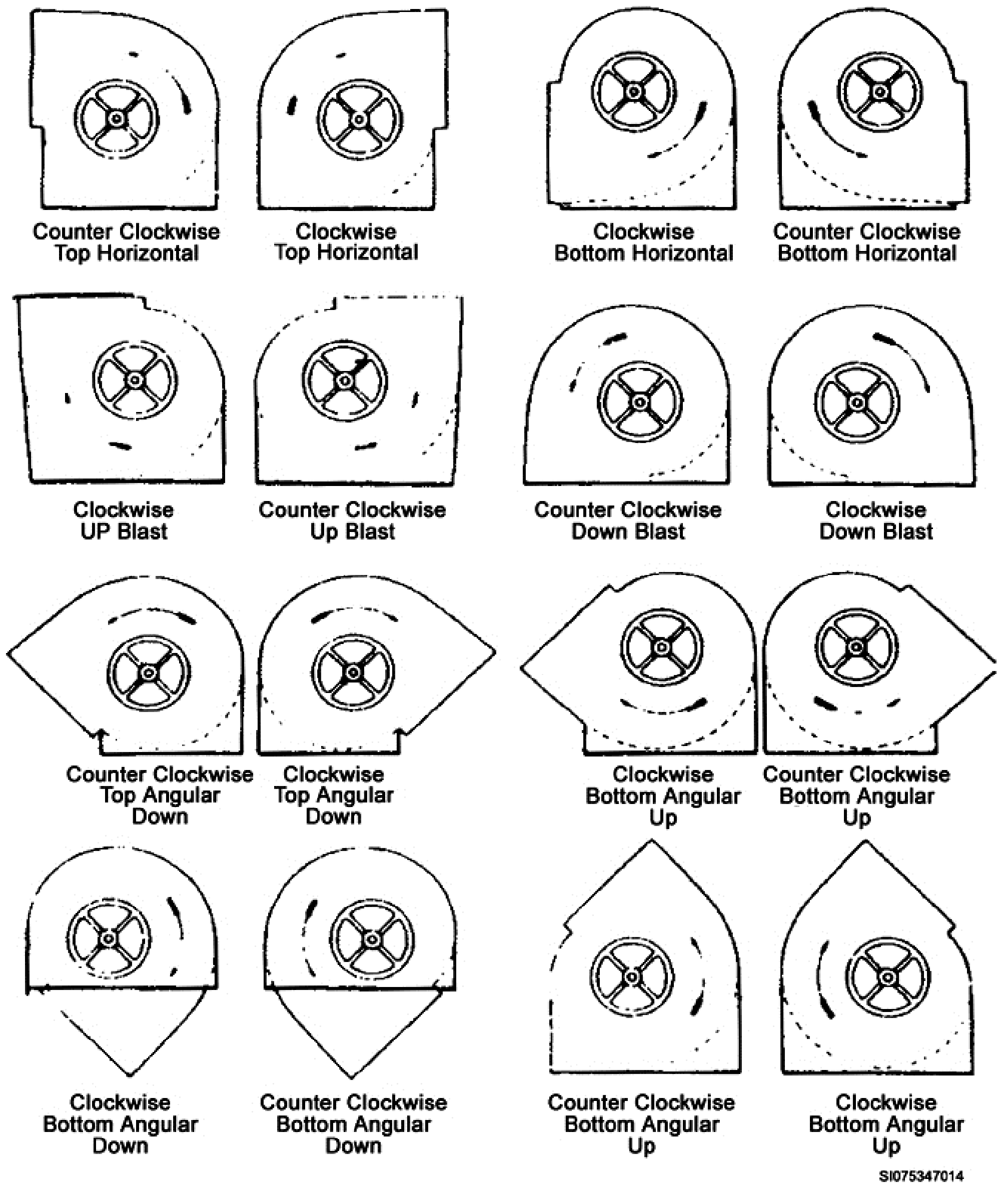


Figure 1–7. Centrifugal fan direction of rotation and discharge.

Motor and drive arrangements

There are various arrangements for motors and drives on centrifugal fans; the AMCA has assigned them number designations, as shown in figure 1–8. As you can see in the illustration, there are many ways manufacturers have selected to drive fans. Motors can be mounted inside the base and belt driven as in figure 1–8 arrangement 10 (ARR. 10 SWSI). This arrangement is generally called a *utility* or *vent set*. The most common motor and drive arrangement for an HVAC system is ARR 3 SWSI (fig. 1–8). This arrangement mounts bearings on both sides of the fan with an extended shaft for a belt-driven motor, and the motor is mounted on an integral isolation base on the floor.

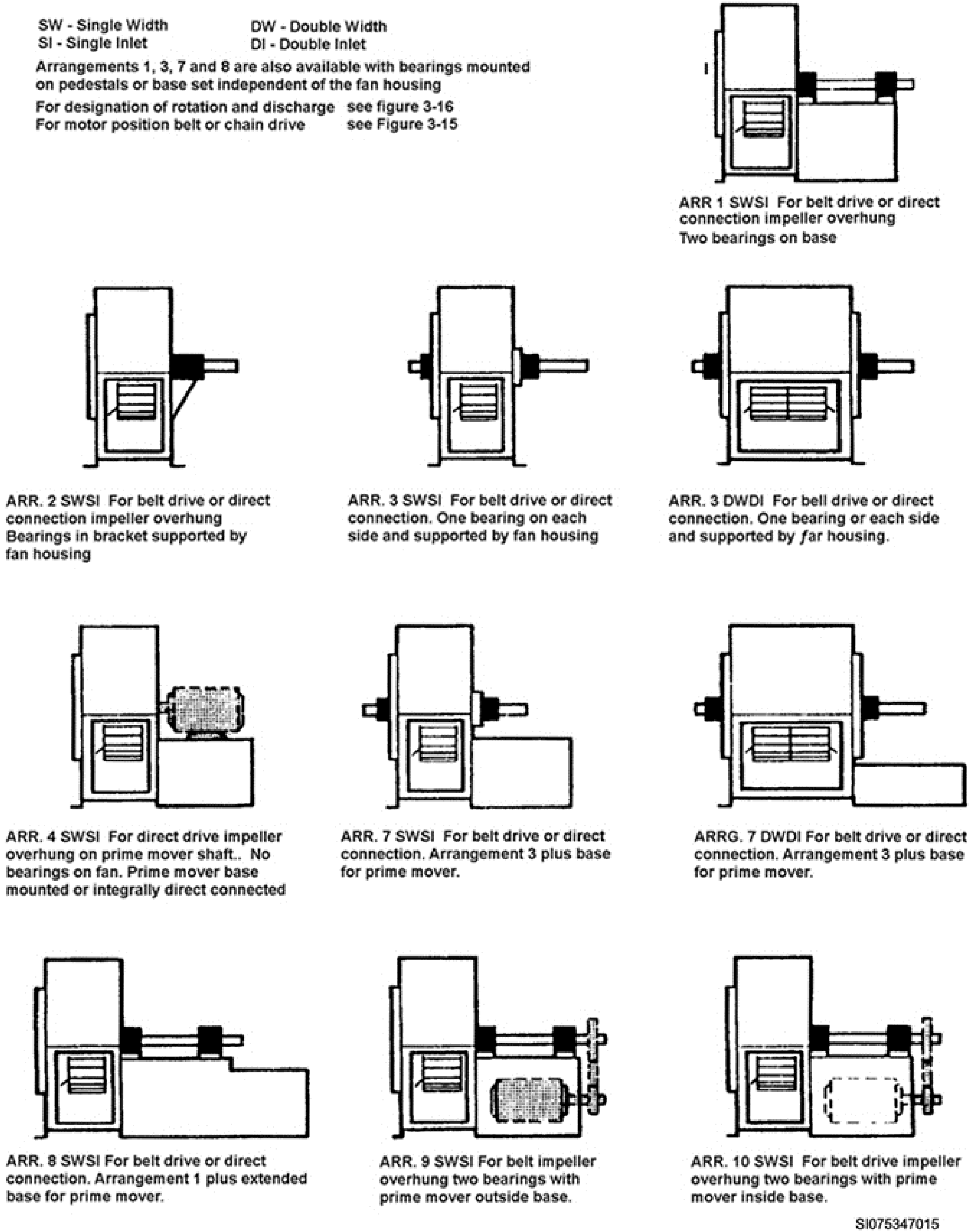


Figure 1–8. Drive arrangements for centrifugal fans.

Special-design fans

Included here are two types of special-design fans: tubular inline fan and roof exhauster.

Tubular inline

Tubular inline fans incorporate a centrifugal fan wheel in a tubular housing along with an inlet cone and vanes (fig. 1–9). The air, instead of making a 90 degree turn to discharge, as it does in a standard centrifugal fan, is straightened out with turning vanes and discharged in parallel with the intake. The performance of an inline fan is similar to a centrifugal blower.

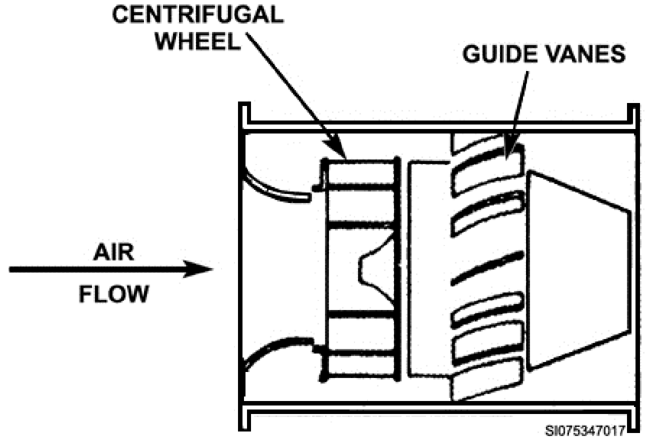


Figure 1–9. Tubular inline fan with centrifugal wheel.

Roof exhauster

A common roof exhauster is the centrifugal spun-aluminum dome type (fig. 1–10). A centrifugal fan wheel is in the lower skirt portion and a motor, either direct drive or belt drive, is located in the upper dome section. A horizontal plate divides the motor and drives from the lower wheel section and keeps the motor and drives out of the airstream. The air is drawn up through the roof opening into the inlet cone of the centrifugal wheel, makes a U-turn in the wheel, and is propelled out of the bottom periphery of the dome.

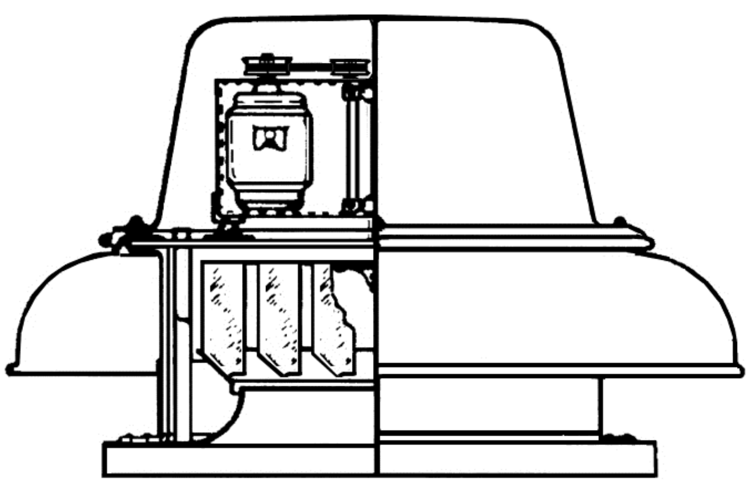


Figure 1–10. Centrifugal spun-aluminum dome roof exhauster.

Another common fan is the centrifugal kitchen roof exhauster (fig. 1–11). The air is drawn up by the fan and exhausted around the outside.

Figure 1–11. Centrifugal kitchen roof exhauster, upblast, direct drive. (Photos courtesy of Twin City Fans and Blower)

Centrifugal roof exhausters are capable of producing static pressures up to 1 inch of water pressure. They produce cubic feet per minute (cfm) that range from several hundred to 20,000. Roof exhausters can exhaust up to 100,000 cfm.

There are also dome roof exhausters with propeller fans. Roof exhausters also are constructed with flat-topped rectangular or square hoods, rather than domes. There are two types of upblast roof exhausters, as described in the following table:

Exhauster	Explanation
Dome upblast	The dome upblast exhauster is used for kitchen grease exhaust. The air is discharged upward through a ring opening on top of the dome, and the grease is dripped down and out.
Tubular upblast	The tubular upblast exhauster has a tubular housing, open on both ends, facing straight up, with a propeller fan at the bottom and butterfly dampers over the fan. It shoots the air straight up and diffuses it.

Axial fans

Axial fans move air in a flow parallel to the shaft. These fans are identified by their use rather than the shape of their blade. The three basic types of axial fans are propeller fans, tube axial fans, and vane axial fans.

Propeller

Propeller fans have a blade like an airplane propeller mounted inside a ring or plate (fig. 1–12). Table fans, which are common to home use, and ceiling fans are both varieties of propeller-type fans. Normally, such fans have a safety shroud around them. Further, propeller fans can only be used where a low volume of air movement is needed, such as for exhaust or ventilation purposes. Also, they can be direct drive or belt driven.

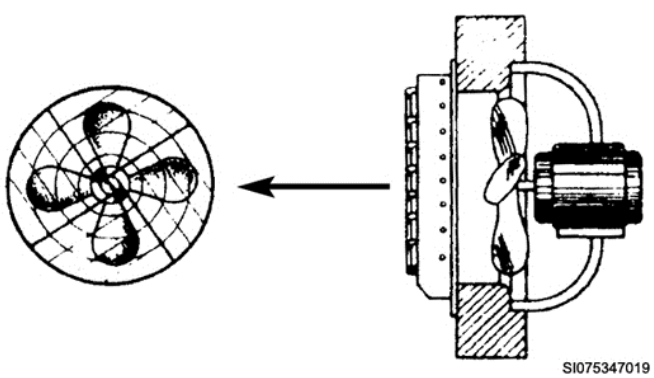


Figure 1–12 Propeller fan for condenser.

This type of fan is often used with condensers. When used with a condenser it is referred to as a condenser fan.

Tube axial

A tube axial fan is an axial fan installed inside a cylinder or tube (fig. 1–13) Such fans are built for mounting in ductwork and since the air in tube axial fans moves at a higher velocity, the increase of the spiral movement incurs greater duct pressure losses and increases the amount of noise in a duct system. Hence, these fans are normally used for industrial applications, where noise is a minor consideration and space is of no concern. They are built to be direct drive or belt driven.

Figure 1–13. Tube axial, belt driven. (Photos courtesy of Twin City Fans and Blower)

Vane axial

These fans are, in reality, nothing more than tube axial fans with vanes installed in the fan housing (fig. 1–14). The vanes are used to straighten out the spiraling motion of the air. This offers the added factors of less noise and increased efficiency. Vane axial fans can withstand pressure up to 3 inches of water (measured by a manometer). Also these fans may have adjustable airfoil blades that can increase or decrease the cubic feet per minute by changing the pitch of the blades (fig. 1–15). Vane axial fans work well in variable-air-volume (VAV) systems.

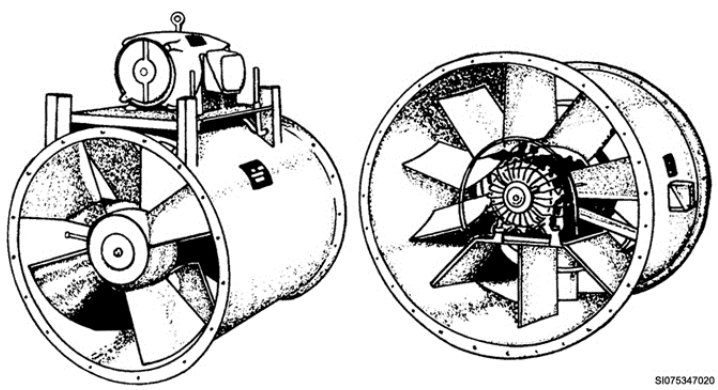


Figure 1–14. Vane axial.

Figure 1–15. Vane axial, Adjustable pitch blades. (Photos courtesy of Twin City Fans and Blower)

Fan selection software

There are numerous software programs on the market that makes selecting a fan easier. The features and capabilities that each one provides are too vast to cover in this CDC. When you are tasked with choosing a fan, research which program works best for you and gather the information to input in the software. Also, engineers in your squadron may already have a program so check with them before you purchase an application. The most important thing to know is the fan selection software that is available for you to use.

Fan drives

Fan drives are made up of a motor pulley (sheave), which is usually variable-pitch; a fan pulley (sheave), which is usually fixed; and connecting belts. The sheaves' diameters are selected to produce the needed fan rpm (figs. 1–16 and 1–17). The number of grooves is based on the amount of horsepower to be transmitted from the motor to the fan and the amount of surface contact of the belts on the sheaves. The pitch diameter of a sheave is just about equal to the outside diameter less the thickness of the V-belt. There are three different types of sheaves: fixed, variable-pitch, and automatic variable-pitch sheaves. Let's look at them now.

Figure 1–16. Drive sheave or pulley.

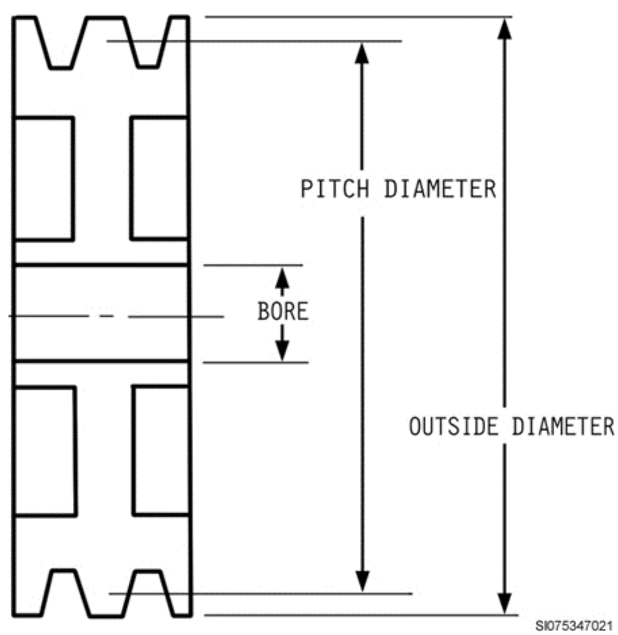


Figure 1–17. V-belt drive sheave.

Fixed sheaves

Fixed sheaves are usually cast in one piece, are nonadjustable, and have one fixed pitch diameter. They are mostly used on the fan, but they can be used on the motor, too. Fixed sheaves are either single or multiple grooved and may or may not use bushings.

Variable-pitch sheaves

Variable-pitch sheaves are also either single or multiple grooved. You can move the discs on the variable-pitch sheave (fig. 1–18) inward or outward to increase or decrease the pitch diameter. For example, a variable-pitch sheave might have a diameter range from 4 to 5 inches. Hence, with the ability to vary the motor sheave diameter 20 to 25 percent, you can vary the rpm of a fan about 12 percent if the diameter of the fan sheave is double that of the motor.

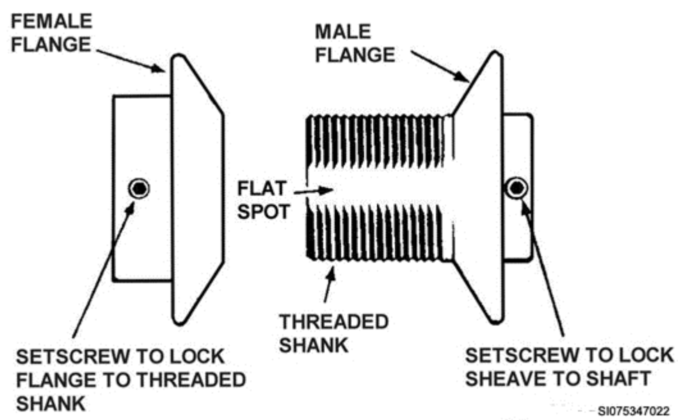


Figure 1–18. Variable-pitch sheave.

When the sheave is on the motor and you need to reduce the speed of the fan, you can widen the groove on the variable-pitch sheave. To increase the speed, the reverse takes place—tightening the groove. Be careful when you tighten the grooves, since this increases electrical current draw of the motor.

Automatic variable-pitch sheaves

A new type of sheave has been developed for VAV systems—one that increases or decreases the fan rpm 50 to 75 percent automatically in response to system load demands. The sheaves are larger and more heavily constructed, and they use a wide, rugged belt. Also, they are single grooved, and the spread on the disc is far greater than that for common variable-pitch V-belt drives.

Bushings

Sheaves may have fixed bores that allow them to only fit the exact size of the shaft. Also, they may have larger bores that accept bushings of various bore diameters. Bushings allow the sheaves to be used on different diameter shafts.

V-belts

The V-belt is one of the most popular methods of turning HVAC/R motors, fans and pulleys. The V-belt is a simple part of an air distribution system; however, this does not make the V-belt less important than any other component.

Almost all belts contain rubber, some type of fabric, and cord. The most common V-belts you will use in HVAC/R are the classic, the cogged, and the fractional horse power type of belts. A description of each belt is in the paragraphs below.

The fractional horsepower or light duty belts are annotated with a number followed by the letter “L.” Common sizes are the 3L, 4L, and 5L belts. These light duty belts will be used in residential and lighter-duty fan applications.

The classic V-belt consists of belts using the letters A through E. The total width range of these belts is ½ to 1–½ inch. Their depths vary from about ⅜ to ¾ inch. A through D are the common sizes seen in HVAC/R. These belts will more than likely be referred to simply as an "A belt" or whatever letter is on the belt being discussed, "B belt" or "C belt." The A through E belts will be used in medium horsepower applications.

The cogged or notched V-belts are annotated by a letter followed by the letter "X." For example, AX, BX, CX and DX (figure 1−19). The cog or notch on the bottom of the belt provides less slippage. This series of belts are used in medium- to high-horsepower applications. If you think about it, you want to ensure less slippage when dealing with higher horsepower applications since there will be more energy being transferred.

Figure 1–19. Cogged belt.

Many manufacturers have different part numbers for the same size V-belt. A cross reference list could help you identify what V-belt you need for the job you are on.

The rubber in the belts hardens with age and cracks, leaving only the fabric and cord to hold the belt together. You must replace belts when you find them to be defective. If more than one belt is involved, replace *all* the belts. Why is this necessary? If you replace only one of the belts, then the existing belt(s) will have a tendency to flap around. A new belt isn't stretched to the point as the old belts and the old belts will flap. Since you can't properly tighten the uneven belts it can present a difficulty in getting complete energy transfer to the sheave(s) and slippage will occur. This slippage will affect your rpm's and cfm's output of the fan.

Also check to see if the original belt actually fits the groove of the fan (or driven component) sheave. Over a period of years, a substitute belt may have been placed there and forgotten.

A properly fitting belt should be flush with, or close to, the top of the sheave. The sheave on the motor isn't always a good indication of a proper fit because of the variable-pitch-style sheave that is commonly used. More than likely, this variable-pitch sheave has been adjusted to accommodate motor amperes (amp) or cfm's versus the belt size. Remember, though, that the belt still should fit within the angled portions of the variable-pitch sheave, not the vertical portion down towards the shaft.

NOTE: If you change the belt to a new size (A to a B), remember to check the motor for correct amperes.

When requesting belts from your supplier, ensure they are in the same series, such as A, B, or C; don't mix the notched belt AX with an A or the 4L; keep them the same.

Alignment

Align new belts properly to reduce belt and bearing wear. Hence, belts must be 100 percent straight from sheave to sheave. Also, fan and motor shafts must be parallel. To align *two fixed sheaves* of equal width, use a straightedge on the sides of the sheave and a plumb bob. If the *variable-pitch sheave* on the motor is a different width than the fixed-fan sheave, align the centers of the sheaves.

There are also laser alignment tools available. There are various types but they all use lasers that line up the sheaves (pulleys). Most are quick to set up and are very accurate.

Belt alignment is absolutely critical to the operation of the system and the life of the belt. Misalignment could lead to premature belt failure, higher belt temperatures and premature wear. The consequences of misalignment will cost your shop, your base and the Air Force time and money! Do not overlook this task.

Tension

Belt tension should be reasonable. When the drive is in operation, the tight side of the belts should be straight from sheave to sheave with the slack side slightly bowed. The rule of thumb on tension for the most common situations is ½- to 1-inch deflection at the center of the span on the top or tight side of the belt, ¾ inch being the average. This generally applies for one- or two-groove sheaves, 2, 3, or 4 feet apart, center to center, and for horsepower from fractional to 10. The best practice is to consult the manufacturer. For larger-horsepower sheaves, higher rpm's, or more grooves, it is imperative to check with the manufacturer. Manufacturers set up exact tension for belts based on belt span, type, and size of belt. They determine the amount of desirable deflection at the center of the belt span and then measure the force needed at that point to produce that deflection. They then publish desirable deflections and correlated measured force in a list.

Pressures at the center of A- and B-sized belts are usually 4, 5, and 6 pounds. There is a belt tensioner available that measures the force and deflection. Some are high-tech and digital and some are simply handheld devices.

Maintenance

Fans are made to last a long time and will, depending on their use and the care they get. Fans, like other equipment that runs almost continuously and at a fairly high speed, need periodic maintenance. Since fans, motors, and belts are potential safety hazards, we need to examine this area closely.

Safety

Always use caution when you work on or near fans. When these units are operating, keep protective shields or guards in place. When you adjust or repair them, ensure the main power switch is off and locked in the OFF position. Ensure that the air pressure in the system is low before you open any access doors. If you do not do this, the door could fly open and injure someone. Always be careful when handling metal ductwork material to avoid cutting your hands on sharp edges. Make sure that the step ladders you use have nonskid bases. Always spin the fan by hand before you turn on the power. Be careful not to allow objects, such as nuts, bolts, or tools, to fall into the operating fan since one of these could become a dangerous projectile.

Inspection

Fans should be inspected periodically to make sure they are performing properly. Inspection on some fans may be hard to do as they are not placed where you can see all parts. Wear, dirt, and grime buildup can take place in hard-to-find and hard-to-reach spots. Use care to find and correct any such problems.

Impeller balance

Air that moves through the fan may leave a dirt buildup on the fan blades, shroud, and center plates. If accumulated dirt is thrown off from the blades as they spin, the resulting weight difference can cause the fan to be out of balance. If the fan loses its balance, remove it from service and give it a thorough cleaning.

If the fan is still out of balance after cleaning, balance the impeller through the use of a vibration analyzer. To balance the fan, take a vibration reading on it while it is running. Then, shut it down, place a counterbalance weight on the wheel, and bring it back to operating speed; now take a second reading. Tables and graphs in the analyzer manufacturer's manual show how to add the weights and how large they should be. Special balancing clips for this purpose are available from fan manufacturers.

In some cases, you must call in a specialist to balance the fan. For a small fan, the cost is often less to change the impeller than to have the old one balanced. If a new or balanced impeller fails to stop the vibration, then look at other fan parts that could be the source of the problem. The problem could be a bent or misaligned shaft, unstable bearing mounts, bad bearings, or a deformed fan shroud.

Lubrication

A regular lubrication program for fans depends on the location and duty of the fans. Follow the manufacturer's lubrication type and frequency instructions. Lubricate bearings at regular intervals so that you keep the bearing cavity full. Use the lubricant type recommended for the specific application by the bearing manufacturer. To keep dirt from mixing with the lubricant, wipe the grease fittings, grease cups, oil ports, and surrounding surfaces clean before you apply any lubricants. Clean the lubrication equipment before and after you use it. Keep all parts that do not need to be lubricated free from lubricants. After each operation, clean any excess lubricant from the joint.

After you lubricate the bearings, they'll run 10 to 30°F hotter than normal until the grease is purged through the seal and the bearing lubricant level is at the ½- to-¾- full mark. While the increase in temperature following lubrication is normal, any quick rise in bearing temperature or an odd noise is a sign of bearing problems. Do not over lubricate or grease bearings with a pressurized gun.

Align bearings correctly. If there is horizontal or vertical misalignment, loosen the bearing tie-down bolts and use shims to get a true parallel alignment.

If bearings are worn and need to be replaced, be sure that you do this according to the manufacturer's instructions. Different types of bearings require different installation techniques. Plain bearings, even though they are easier to install than ball- or roller-type bearings, still require precise placement of shims to make sure that the bearings are properly aligned. In many cases, we can trace bearing failure to hasty and improper installation. Therefore, to prevent future trouble, install the bearings correctly and according to the manufacturer's instructions.

202. Constant and variable air volume systems

Constant and variable air volume systems are two classifications of air distribution systems you will deal with on-the-job. Constant volume systems are older but you could still see them in many buildings at your base. The variable air volume design is newer and becoming more prevalent in the industry. Both will be covered in this section.

Constant air volume

Constant air volume systems deliver a *constant* amount of air to the conditioned space. The temperature can be varied depending on the load but the airflow stays the same. This is an all or nothing approach. Once the blower turns on it maintains its designed revolutions per minute (RPM) For example, a blower has a designed RPM of 1750. Once the blower turns on it will deliver 1750 RPM and that is it. It will not turn up to 1800 RPM or down to 1500 RPM. Therefore, we have a *constant volume* of airflow. The systems covered under constant volume are single zone, dual-duct and multizone.

Single-path, single-zone system

The simplest form of the air system is a single conditioner serving a single temperature-control zone. You can install the unit within or remote from the space it serves and can operate it with or without distributing ductwork. Ideally, this can provide a system completely responsive to the needs of the space. Well-designed systems operate efficiently and maintain close levels of temperature and humidity control. They can shut down when desired without affecting the operation of adjacent areas.

A single-zone system responds to only one set of space conditions. Its' use is limited to situations where variations occur almost uniformly throughout the zone served or where the load is stable; in multiple installations, a variety of conditions can be handled efficiently. A single-zone system would be applied to small department stores, small individual shops in a shopping center, individual classrooms of a small school, computer rooms, and so forth. We would consider a rooftop unit, for example, with a chilled-water cooling coil, serving an individual space, a single-zone system. The refrigerator system for the chilled water, however, may be remote and serve several single-zone units.

A schematic of the single-zone central unit is shown in figure 1–20. The return fan is not always necessary. You can eliminate it if air is relieved from the space with very little pressure loss through the relief system. Avoid objectionable pressurization of the conditioned space to permit entrance doors to open normally.

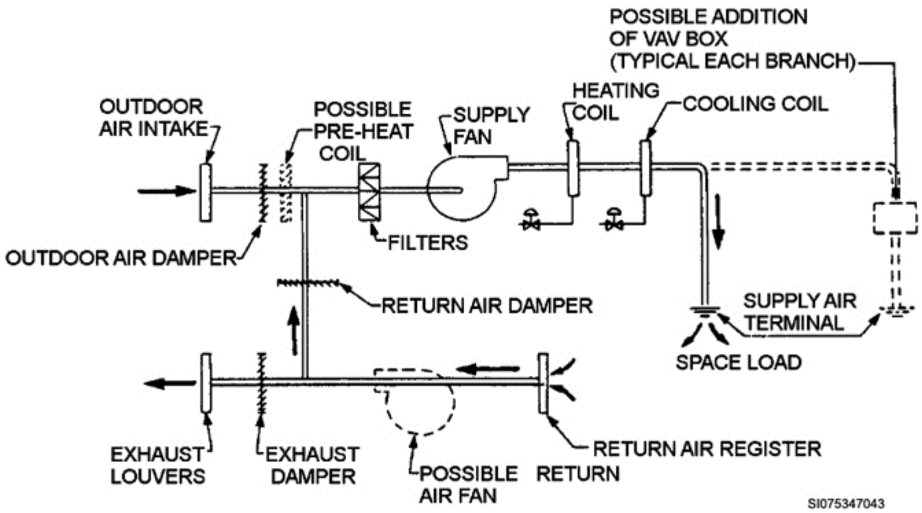


Figure 1–20. Single-duct system.

You can affect control of the single zone by varying the quantity of cooling medium, providing reheat, using face and bypass dampers, or any combination of these. Single-duct systems with reheat satisfy variations in load and/or provide summer humidity control. Single-duct systems without reheat offer cooling flexibility, but they cannot control summer humidity independent of temperature requirements.

Single-duct unit

A single-duct unit (fig. 1–21), as the name implies, has only one duct connection and is supplied with air at a temperature that will take care of the cooling load. In a very simple single-duct system, it is possible to adjust the temperature of the air to take care of the varying space load. However, in larger systems it is necessary to install a reheat coil that is regulated by a room thermostat in the box or immediately downstream from it. In this case, constant-temperature air is supplied to the box and the reheat coil (which may be hot water, steam, or electric) is operated by the room thermostat to add heat to the airstream, as required, to maintain a constant temperature within the conditioned space.

The single-duct unit usually has a manually operated damper that is adjusted when the system is initially balanced. If you look at figure 1–21, this damper is referred to as an inlet valve. It is then left in that position to maintain a constant airflow through the box. To balance a system with the manually operated damper, it is necessary to determine the airflow either by measuring the airflow at the box or, in some cases, by measuring the pressure difference across an orifice within the box. Some of the more recent single-duct units include a mechanical constant-volume regulator such as the type described for the dual-duct units. In this case, the mechanical volume regulator is preset at the factory and adjustment in the field normally is not required. Noise is also generated in these units due to pressure induction; it is necessary to have a sound baffle within the unit and also a liner to absorb the noise.

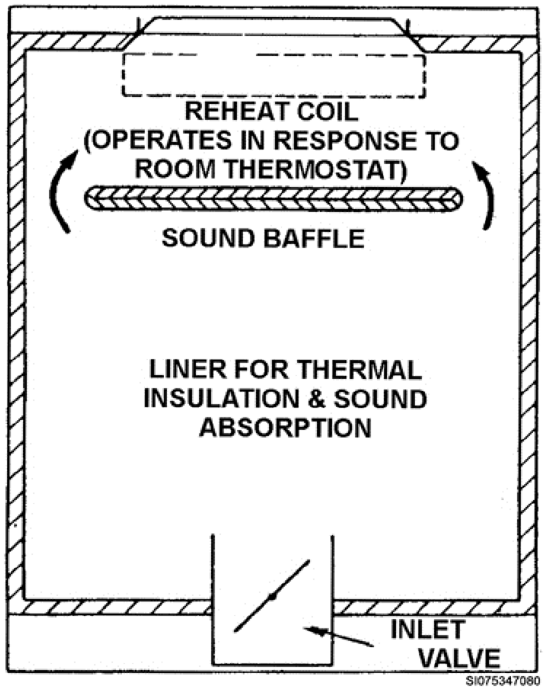


Figure 1–21. Single-duct unit.

Multiple-path systems

Multiple-path systems are those that contain the main heating and cooling coils in a parallel flow or series-parallel flow air path. These systems use either (1) separate cold- and warm-air duct distribution systems, which are blended at the terminal apparatus (dual-duct systems), or (2) a separate supply duct to each zone, with the blending of warm and cold air at the main HVAC supply-air unit.

Dual-duct

As you look at figure 1–22 this particular dual-duct system provides both the hot and cold airstreams from a central apparatus and distributes them to conditioned spaces through two parallel mains or ducts, thus providing heating and cooling at all times. In each conditioned space or zone, a mixing valve that is responsive to a room thermostat mixes the warm and cold air in proper proportions to satisfy the prevailing heat load of the space.

Let’s travel through this system starting with the supply fan near the middle of figure 1–22. The fan pushes the air to the right and the duct splits off into two, hence the name dual-duct. The path on top will pass over a heating coil. The amount of water passing through the coil depends on the position of the valve which is opening and closing based off of the thermostat, “T.” The same concept applies to the cooling coil. The air in each path will continue until it gets immediately outside of the zone where the paths will mix. Again, the room thermostat will send a signal to the motor “M” and the motor will drive the dampers open and shut.

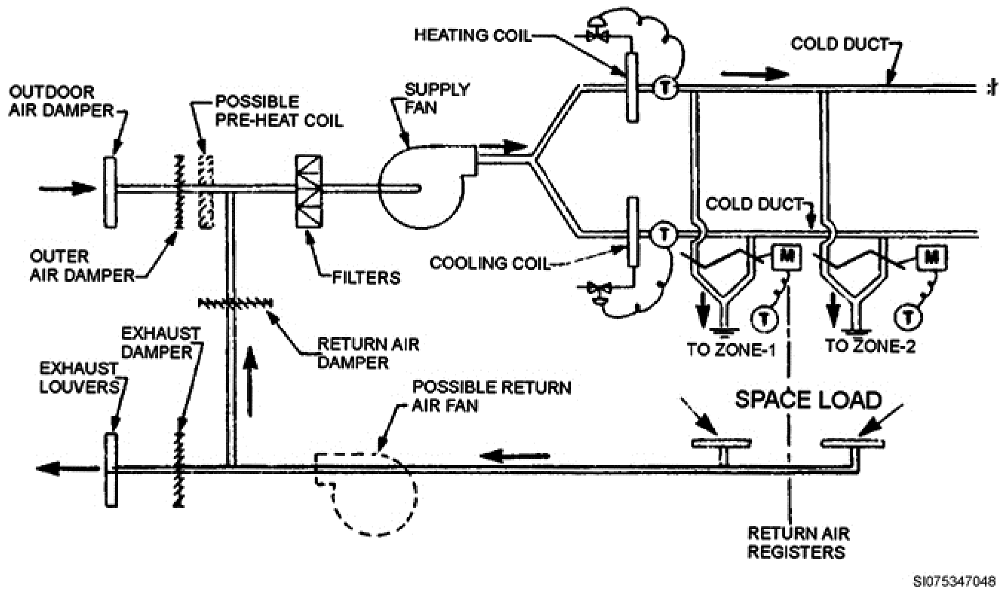


Figure 1–22. Dual-duct low-velocity system.

A typical dual-duct unit is shown in figure 1–23. The unit is supplied with both hot and cold air. The inlet valve is positioned by a motor in response to a room thermostat. This valve then supplies air at the proper temperature to satisfy the load within the space. The dual-duct unit supplies warm air for heating or cool air for cooling, or mixes the two airstreams to satisfy any condition in the space.

It is important to have an automatic airflow control device within the dual-duct unit since the pressure in the hot and cold ducts may vary over a wide range. This occurs because demand for the hot or cold air varies throughout the building. The airflow is regulated with a mechanical volume regulator.

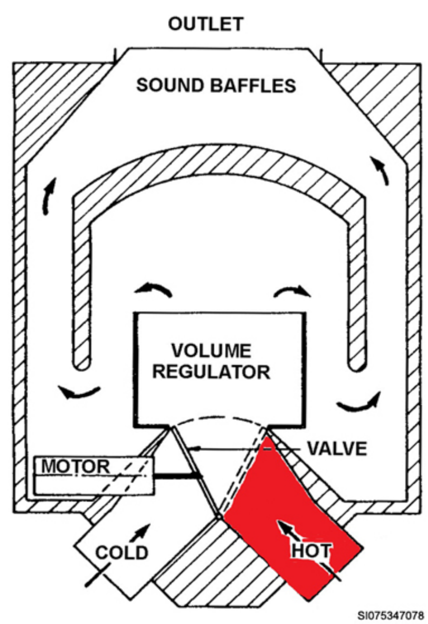


Figure 1–23. Dual-duct unit with single motor.

Mechanical volume regulators use curtains and perforated plates or damper blades, which decrease the available flow areas as the pressure at the inlet to the box increases. The inlet pressure is balanced against springs on the curtains or damper blades in such a way that the flow area varies to maintain a constant airflow rate through the box. This type of flow-regulating device depends on the energy in the flowing airstream to actuate it.

A second type of automatic flow regulation is provided by the system shown in figure 1–24. With this arrangement, two motors are positioned to maintain the space temperature by a relay. The motor connected to the hot valve responds to the room thermostat and opens or closes the hot valve to maintain proper temperature in the space. The motor on the cold valve is connected to the room thermostat but also has a relay connected to it that senses the pressure difference in the box. Therefore, the motors are positioned to maintain the space temperature, but the relay adjusts the motor on the cold valve to maintain a constant pressure difference. Both types of dual-duct units with constant-volume control are adjusted by the manufacturer and do not usually require installer adjustment.

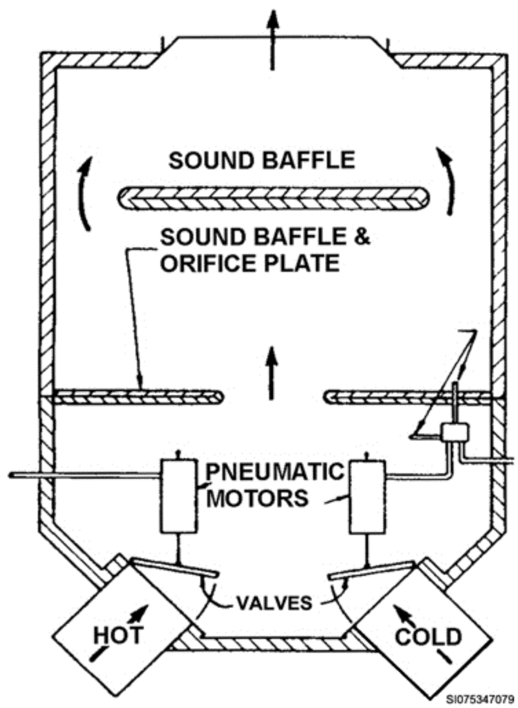


Figure 1–24. Dual-duct unit with two motors.

Sound attenuation within the terminal unit is provided by sound baffles as shown in figures 1–24 and 1–25. The sound baffles are solid metal plates installed to place a barrier in the direct line of the sound that is generated. The baffle reflects the sound back into the box where it can be absorbed by the box lining. Common materials for the box lining are glass fiber blankets. The glass fiber blanket also provides thermal insulation so that the conditioned air within the box is not heated or cooled by the air in spaces surrounding the box.

Multi-path dual-duct system (low-velocity)

We can eliminate the return-air fan on small installations if we make other relief air provisions. Return-air fans generally are required for economizer cooling cycles and in systems with substantial return-air ductwork.

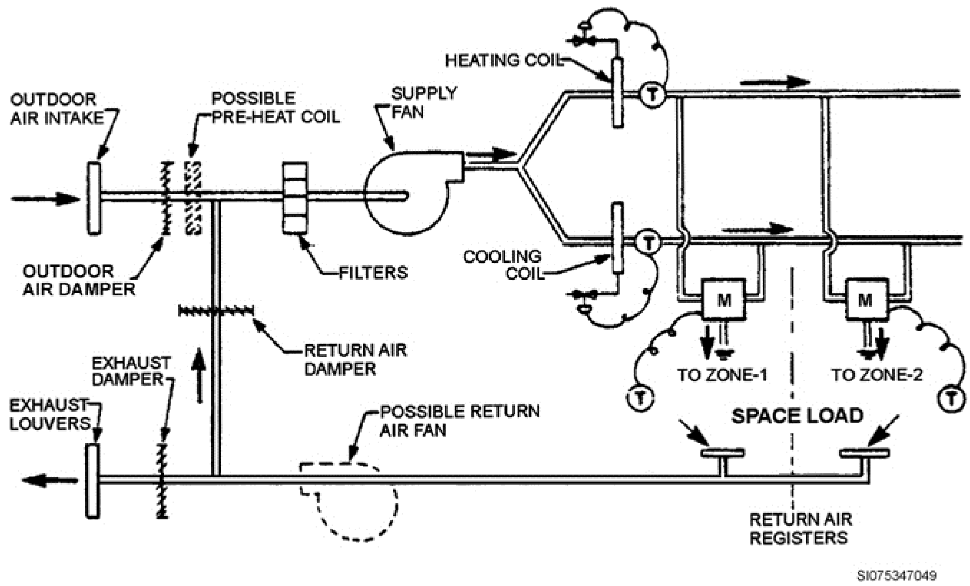


Figure 1–25. Dual-duct high-velocity system.

Multi-path dual-duct system (high-velocity)

Refer to figure 1–26. Dual-duct high-velocity systems operate in the same manner as the low-velocity systems except that the supply-air fan runs at a higher pressure and each zone requires a mixing box with sound attenuation. They are not recommended for new buildings because of their high-energy requirements. However, many of these systems exist in commercial and institutional buildings. As a large amount of energy is required to operate fans at high pressures, make a close analysis of the pressure drops within the duct system and reduce the fan pressure to the minimum pressure needed to operate the mixing boxes. Other energy-conserving modifications made to the building and its equipment often allows a major reduction in system airflow requirements.

As existing dual-duct systems need special attention, the following are some energy-saving ideas:

- Reduce the duct system pressure by replacing existing high-pressure mixing boxes with lower-pressure types.
- In conditions when there is no cooling load, install controls to close off the cold air duct, deenergize chillers and cold-water pumps, and operate the system as a single-duct system.
- Reschedule the warmer air duct temperature according to heating loads only.
- Under conditions where there are no heating loads, install controls to close off the warm-air ducts; shut off hot water, steam, or electricity to the warm duct; and operate the system with the cold duct air only. Reschedule the supply-air temperature according to cooling loads.
- Replace obsolete or defective mixing boxes to eliminate leakage of hot or cold air when the respective damper is closed.
- Provide volume control for the supply-air fan and reduce capacity, preferably by speed reduction when you can reduce both the hot-deck and cold-deck air quantities to meet peak loads. Reducing the heat loss and heat gain of the conditioned areas provides an opportunity to reduce the amount of air circulated.
- When there is more than one air-handling unit in a dual-air system, modify ductwork, if possible, so that each unit supplies a separate zone to provide an opportunity to reduce hot and cold duct temperatures according to shifting loads.
- Change dual-duct systems to variable-volume systems by adding VAV boxes and fan control when energy analysis is favorable and the payback in energy saved is sufficiently attractive.

Multi-path, multiple-zone system

Refer to figure 1–26. The multiple-zone system serves from 2 to approximately 12 zones from a single, central air-handling unit. The requirements of the different zones are met by mixing cold and warm air through zone dampers at the central HVAC unit. The zone dampers respond to zone thermostats. You can use either packaged units complete with all components or field-fabricated apparatus. Usually, we handle the return air in a conventional manner.

The multiple-zone system is similar to a dual-duct system. It can provide a smaller building with some of the advantages of a dual-duct system at lower first cost with a wide variety of packaged equipment. However, it is limited to smaller areas because of the multiple runs of single-zone ducts. Most packaged air-handling apparatus also lack the control sophistication for comfort and operating economy that can be built into dual-duct systems. In the figure, zone 1 is receiving hot air only, zone 2 is receiving cold air only, and in zone 3 the hot and cold air are being mixed.

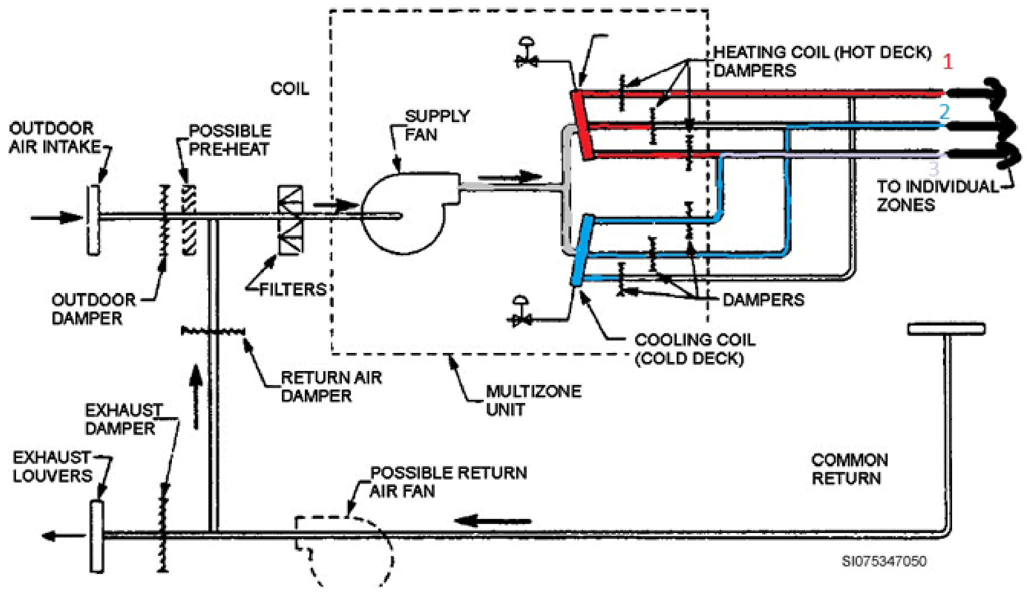


Figure 1–26. Multizone system.

A new type multiple-zone unit is now available that has individual heating and cooling coils for each zone supply duct. This new type of unit uses far less energy than units with common coils. The supply air is heated or cooled only to that degree required to meet the zone load. Where you contemplate retrofit work or when the existing multiple-zone unit is at or near the end of its useful life, consider HVAC unit replacement using a multiple-zone unit with individual zone coils.

Variable-air-volume system

Variable air volume (VAV) systems simply vary the amount of air that is put into the conditioned space. Remember the condition space is the place that the system is trying to cool. Like a dorm room, office, bay, theater, and so forth. Now let’s break down the term. The first word *variable* means “able to be changed.” The second word is very simple as it is just *air*. This is the air flowing through the ductwork to the conditioned space. The final word is *volume* which is the “amount of air.” So, VAV systems are systems that “change the amount of air that is flowing to the conditioned space.”

There are different ways to control the amount of air volume moving in the system. The first is to have the main blower change its speed. As the blower speed is reduced the air flow it provides is also reduced. As it speeds up, the air flow increases. The second way to vary the amount of air is using individual terminal units that are placed before each zone. Let’s break down each one of these concepts. It is important to know that both types of VAV systems can be used together.

VAV using variable blower speed

As dampers in the air distribution system open and close the pressure in the system changes. The blower will speed up or slow down depending on the situation. Let's use an example to help understand how this works. Dampers in the system open and close and the systems pressure changes. Sensors *sense* these changes and send a signal back to a controller. This controller *controls* a signal that is sent to the motor and the motor's speed is changed. If you think about it, it is very logical, there is a pressure change, the sensor "sees" the change, the controller decides what needs to be done and then the motor does it.

VAV's are used often in this career field. Therefore, we will look at another example. Assume the cooling demand is reduced in the building. The dampers will begin to close because less cool air is needed due to the reduced demand. Since the dampers close, the pressure in the main air system will increase. As the pressure increases, the static pressure sensor will notice and send a signal to the controller. The controller will take that signal and make a decision. That decision will be to reduce the motor speed. The controller will then slow down the motor. As the motor slows down the pressure will fall and stay within the design standards. This all happens quickly and the controller should keep the pressures within the design of the system.

You may be asking, "How does the controller slow down the motor?" The motor is usually controlled by something called a variable frequency drive. This device changes the frequency of the power being supplied to the motor and that will change the motors speed. Variable frequency drives will be covered more in depth in a different volume.

VAV boxes

Now that you understand how the blower can vary the air, we will talk about how VAV boxes vary it. Once the air leaves the blower it will eventually reach the VAV boxes. These boxes are also called terminal units. In this section, the term VAV box will be used.

There may be many zones in a building but to explain how the VAV box works we will look at only one. Look at figure 1–27 for a visual of what a VAV box looks like. The basics of the component are an air pressure sensor, a damper and the controls. See figure 1–28 for an example of a sensor and see figure 1–29 for an image of the damper from inside the box. In figure 1–28, notice the four holes where the air enters the sensor. Also, take note of the red and green striped hoses that connect to the sensor.

Figure 1–27. VAV box with reheat.

Figure 1–28. Pressure sensor.

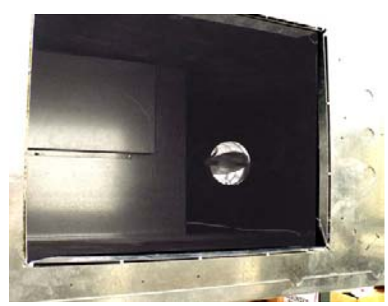


Figure 1–29. Damper from inside VAV.

Let’s say we are in cooling mode. A thermostat for the zone will send a signal to the VAV box. As the temperature rises, the thermostat will “talk” to the VAV box’s controls. The controls will take the signal and tell the damper to open. See figure 1–30 for a close up of the damper actuator and figure 1–31 for a picture of the controls. (Controls are not wired on this unit) Notice the controller and actuator on the right. This allows more cool air to enter the conditioned space. As the temperature begins to drop, the thermostat sends a signal to the boxes’ controls and the box tells the damper to begin to close. The communication between thermostat, box and damper is basically constant.

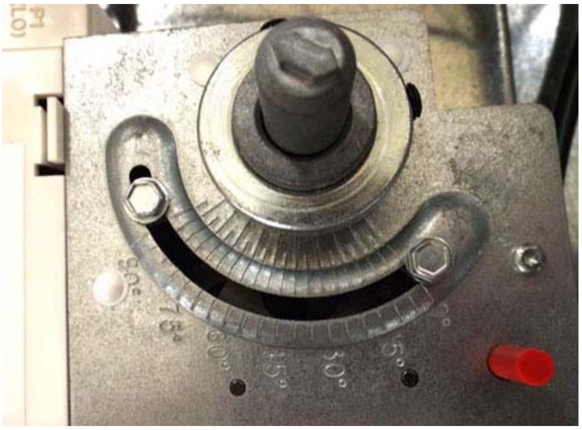


Figure 1–30. Damper actuator.

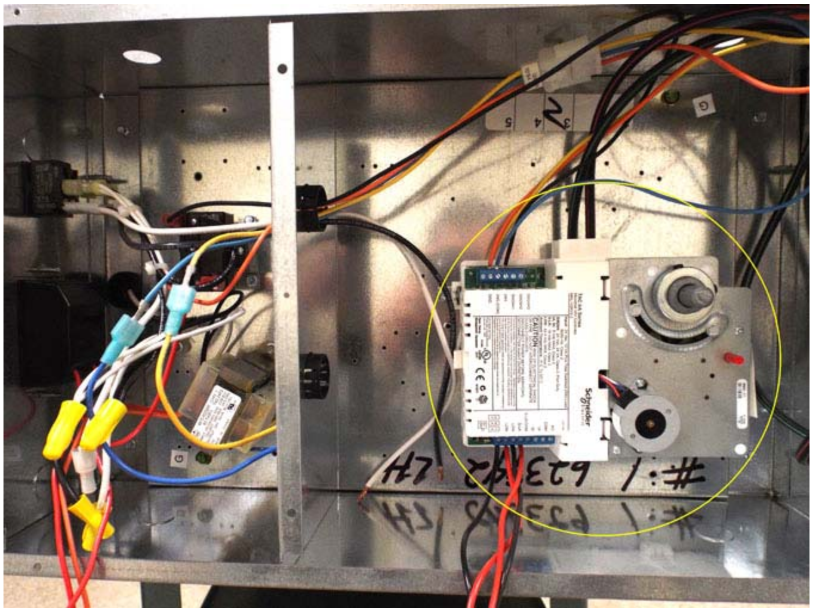


Figure 1–31. VAV control box.

Some VAV boxes have a reheat function. This type will have the same components that are listed above plus a reheat water coil or electric heat strips. Refer to figure 1–32 and 1–33 for an example reheat coil operation. Let’s start at the fan. As the air travels to the right it will pass over the cooling coil and the temperature will drop to 55 degrees. As the air takes the first “right” it travels to the reheat coil before it gets to the zone. In this instance, the valve is open and the coil has hot water traveling through it. As the cool air is passing over the hot coil and the temperature will rise. If you follow the primary air flow down to the next zone you will see there is no hot water in the coil (it’s not red). There is not hot water flowing through this coil because the thermostat in zone 2 is telling it to stay closed. So, zone 2 is getting 100% cool 55 degree air.

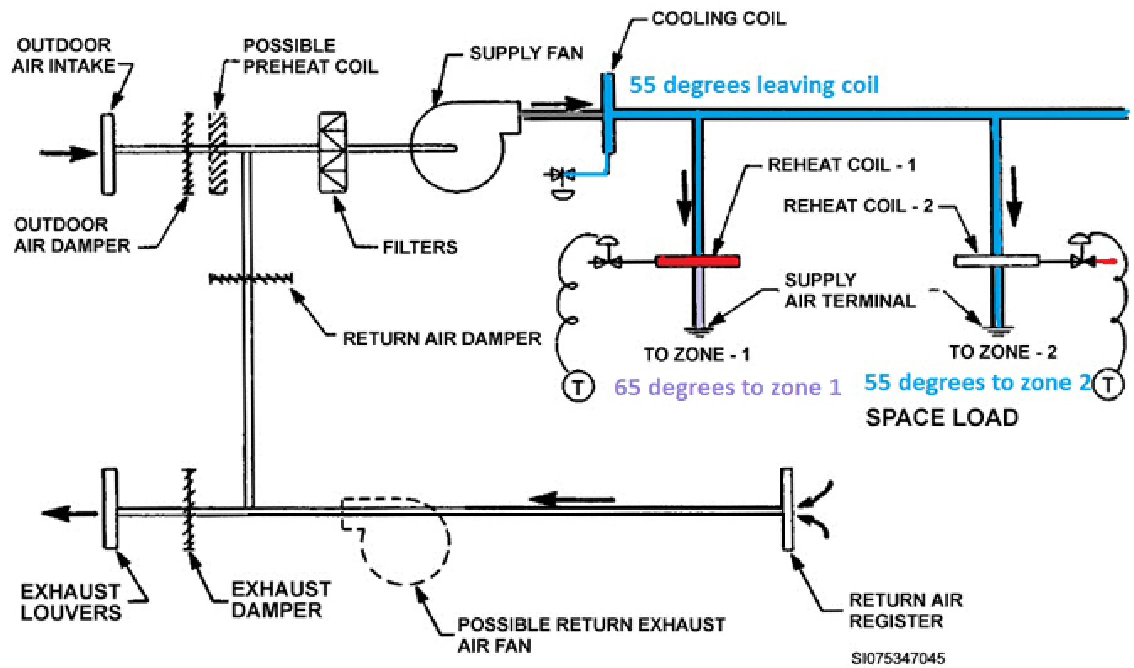


Figure 1–32. Terminal reheat system.

Figure 1–33. Terminal reheat coil.

One reason we use reheat, also known as terminal reheat systems is because they allow zone or space control for areas of unequal loading. Unequal loading means there are different loads in different areas of the building. For example, a server room with 20 servers should have a greater load than an office room with one worker. The second reason terminal reheat is used is because it provides heating or cooling of perimeter areas with different exposures. The reheat system can make up for these temperature differences.

Finally, terminal reheat is used in our VAV boxes to promote process or comfort applications where close control of space conditions is desired. Temperature and humidity need to be controlled in the conditioned space. Let's look at an example of how a reheat system can control not just temperature but humidity. The cooling coil in the air handler will dehumidify and cool when air passes over it. The humidity is brought down near its design and the temperature is brought to 55 degrees. (55 degrees is normal) What if a particular zone does not need 55 degree air? The reheat coil will allow hot water to flow through a coil and bring the air temperature back up to whatever the thermostat is calling for. Now humidity and temperature have been controlled.

The system is generally applied to hospitals, laboratories, or spaces where wide load variations are expected. Terminal units are designed to permit heating of primary air or secondary air induced from the conditioned space, located either under windows or in the duct system overhead.

In cooling, conditioned air is supplied from a central unit at a fixed cold-air temperature (commonly 55 degrees) to ensure the room with the highest load will get the cool air temperature that it needs. If one zone needs higher than 55 degree air then the conditioned space thermostat calls for heat and this will open a valve on the water or it will energize the heat strips. Now the 55 degree air is being tempered to the temperature that the zone requires.

It is possible to permit system volume variations without fan volume changes by using a simple fan bypass. It is also possible to vary zone air volume only, while keeping fan and system volume substantially constant, by dumping excess air into a return-air ceiling plenum or directly into the return-air duct system. These methods of system control do not provide the fan horsepower savings usually associated with variable-volume systems.

Pressure dependent and pressure independent

VAV systems are either pressure dependent or pressure independent. The first VAV terminal units were *pressure dependent*. They had no way for limiting the quantity of supply air. In pressure dependent systems, the volume of air supplied by the terminal unit varies depending upon the static pressure in the primary air duct. The primary-air damper in the terminal unit is controlled by a thermostat in the space. However, the airflow through the damper varies according to the static pressure in the main duct.

This design created a problem. Units that were the closest to the supply fan would receive too much primary air which could cause the condition space to become too cold. Terminal units that were farthest from the supply fan were not likely to supply enough primary air.

What was the solution? Pressure *independent* terminal units. These units have flow-sensing devices that limit the amount of flow through the VAV box. They can control the maximum and minimum cfm that can be supplied from the box and this is what makes them *independent* of the static pressure in the primary air duct. Almost all HVAC/R systems nowadays have pressure independent VAV terminals.

Induction systems

A basic schematic of an induction-type system is shown in figure 1–34. Full cooling capacity is supplied by the central equipment to the terminals. Heating the secondary or induced airstream provides the individual zone or space control. We use this type of terminal when it is desirable to introduce supply air to the space at a higher temperature or to permit higher space air movement without increasing the quantity of primary air over the amount of air required for cooling.

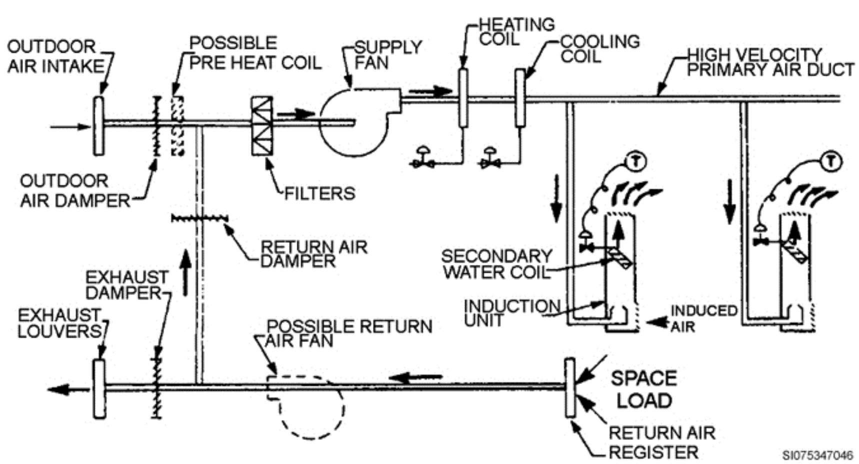


Figure 1–34. Induction system.

The primary air is discharged from nozzles arranged to induce room air into the induction unit at approximately four times the volume of the primary air. The induced air is cooled or heated by a secondary water coil. The water coil may be supplied by (1) a two-pipe system where either chilled water or heated water is available, but not simultaneously; (2) a three-pipe system where separate supplies of hot or chilled water are continuously available and, after they pass through the unit, they are mixed into a common return; or (3) a four-pipe system, where separate hot-water and chilled water systems are both simultaneously available.

Induction-type units are generally located under windows to offset winter downdrafts. Overhead installations are limited since ductwork connections carrying induced air have limited static pressure available, thereby decreasing induction air volume and unit capacity. The window installation has the advantage of providing gravity heating during off-hour operation, which permits shutdown of the primary-air system.

In the past, the primary-air supply fan operated at high pressures and required high-horsepower input. By careful analysis, design the primary-air volume and the pressure required to operate the induction terminal units to the *minimum* requirements. Existing induction unit nozzles may be worn through many years of cleaning and operation, which results in increased primary-air quantity at lower air velocities with lower induced-air volumes. Inspect induction units before you attempt any balancing work.

Single-duct induction unit

A typical single-duct induction unit is shown in figure 1–35. The induction unit is usually a single-duct unit supplied with primary air at a selected temperature. The primary air, at high pressure, is supplied to a nozzle within the unit to increase the velocity of the air behind the coil. The air discharges from the nozzle within the unit, behind a coil, and creates a low-pressure region. The low-pressure region causes air to be induced from the room; this air is pulled through a water coil mounted on the unit. The water coil, in response to a room thermostat, is supplied with heated or chilled water to maintain a mixture of primary and induced air that satisfies the load within the space and maintains a constant air temperature in the conditioned space.

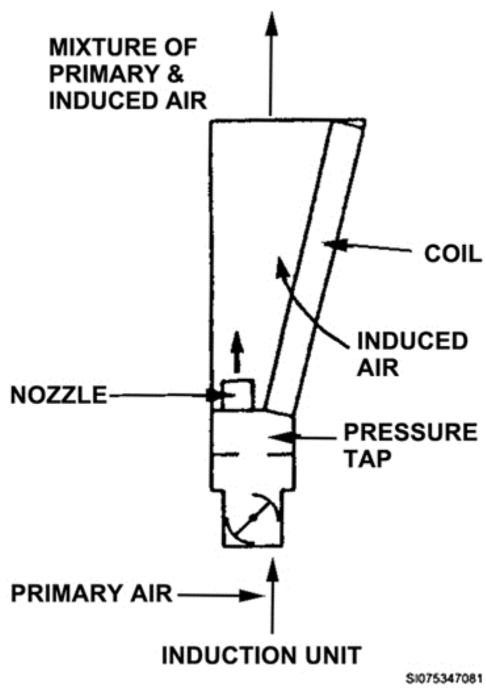


Figure 1–35. Single-duct induction unit.

A damper or pressure-reducing valve in the inlet of the unit is adjusted at the time the system is balanced to maintain the proper quantity of primary air. A pressure tap is provided on the unit so the installer can determine the quantity of primary air from a pressure measurement, which the installer then uses to refer to a calibration curve supplied by the manufacturer. This unit is also provided with a means for sound attenuation.

Dual-induction unit

Another type of induction unit, which is called the *dual-induction unit*, incorporates the features of both the dual-duct unit and the induction unit. This type of terminal unit has a dual-duct inlet valve supplied with both hot and cold air and includes a mechanical constant-volume regulator. The volume regulator is preset at the factory and no further adjustment is required for system balancing. The induction coil is included to provide additional cooling capacity. The mixture of hot and cold air is supplied to the nozzles and room air is induced through the coil. The coil is used only at times of peak load and reduces the size of the cold-air duct system required in the building. However, it is also necessary to have chilled-water piping to take care of the coils.

203. Air system components

Air system components are the components that make up the system from the previous section. You will not find every component in every air system but the devices talked about in this section are common. You must know what each component in the system is and its relationship to the rest of the components in the system. See figure 1–36 for an overview of system components.

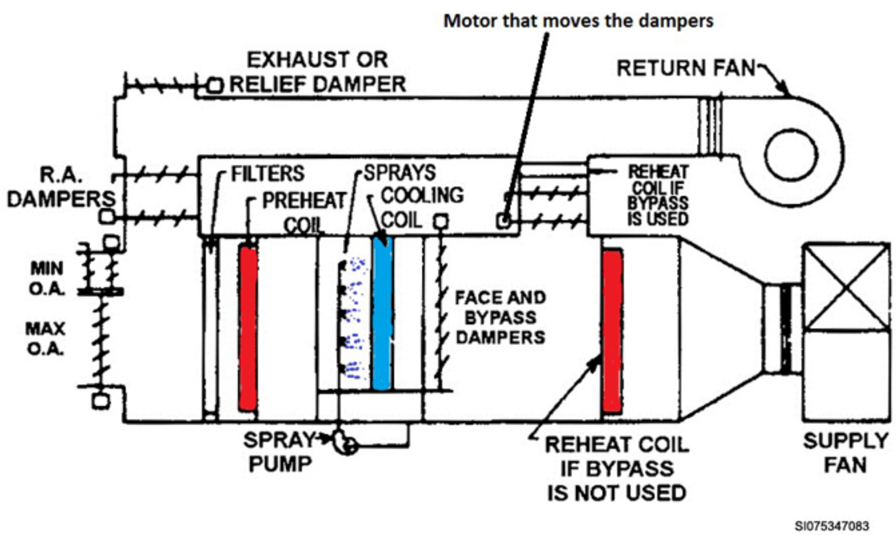


Figure 1–36. Basic central station unit components.

Outdoor-air intakes

Outside is required to be brought into the facility. These intakes allow fresh outside air into the air distribution system (fig. 1–37). Resistance varies widely depending on construction. Standard louvers, hoods, and direct openings usually are sized at 700 to 1,500 fpm through the free area of the opening. Louvers designated “storm proof” should be approximately 50 percent larger than standard louvers to minimize the resistance of the extra rain breaks in the blades. Provide flashings at the outside wall, and install weep holes or a floor drain to carry away rain or melted snow that enters the intake. In cold regions, a snow baffle may be required to direct fine snow particles to a low-velocity area below the dampers. Make sure the overall resistance of the louver, dampers, and outside-air intake duct (at maximum airflow) approximately equals the resistance of the return-air systems.

Figure 1–37. Outdoor air intake from outside of building.

Relief openings

In large buildings, construct relief openings similar to outdoor-air intakes. However, equip them with motorized or building pressure operating back-draft dampers to prevent reversal of airflow caused by high wind pressures or building stack action when the automatic dampers are open. Treat self-acting dampers to prevent rattling.

Coils

Coils will have a cooling or heating medium supplied to them such as hot water, chilled water, steam or refrigerant. When water is used in the coil, the hydronic system and the air system meet. Air passes over the coil and is conditioned depending on the temperature of the air and the coil.

Humidifiers

Humidification equipment used in central station systems usually is of the direct steam injection or heated-pan type. The steam injection type may be a steam cup mounted in the bottom of the duct, grid type, or steam-jacketed type. The latter uses a steam-jacketed manifold and condensate separator to eliminate condensate from being introduced into the airstream. The heated-pan type uses a steam or electric heating coil in the pan with a float valve to control the water level in the pan. Atomizing sprays are sometimes used but require some form of eliminator or filter to prevent carryover into the ductwork. You can use air washers for humidification or air cleaning.

Sorption dehumidification

When design criteria call for dew points near freezing, we can use sorption-type dehumidification equipment as a component part of the central equipment or as an additional component for spot dehumidification.

Bypass duct

If you do not place a heating coil in the bypass duct, use a perforated plate or manually adjustable damper to help balance apparatus resistance. For the average system, size the automatic bypass damper for 2,000 to 2,500 fpm and use in conjunction with a face damper on the coil or washer.

Heat recovery

You can place heat recovery equipment between the outdoor-air intake and the coils and, in mild climates, such equipment can replace the preheat coil. Consider air-to-air exchangers on any application where outdoor air exceeds 2,000 cfm in extreme climates. However, air-to-air heat recovery is possible only if you can locate the exhaust-air duct adjacent to the outside-air duct and if contamination of the outside air is not likely to occur. Use filters to keep equipment and coils clean.

Return-air fan

The use of a return-air fan is optional on small systems, but generally is essential for proper operation of larger systems. Its main function is to provide a positive return (and exhaust) from the conditioned area, particularly when you use mixing dampers to permit cooling with outdoor air in intermediate seasons. The return-air fan maintains a constant airflow pattern in the conditioned area, preventing pressure buildup when return air is being relieved back at the equipment. It also reduces the resistance to be overcome by the supply-air fan, thus permitting lower fan speeds and quieter operation. Locate a manual damper in the connection to the mixing plenum to assure adequate suction on the supply fan and to obtain minimum outdoor air. Consider a damper controlled by a static pressure regulator for the return-air systems to offset the stack effect in high-rise buildings.

Filters

Use manufacturers' ratings for the type of filtering medium selected. Different types vary widely in air cleaning efficiency and velocity for a given cross-sectional area. We usually select filters for ease of maintenance and to provide the highest degree of air cleanliness feasible or required by the installation. Particles in the atmosphere range in size from less than 0.01 micron to dimensions of lint, leaves, and insects. Almost all conceivable shapes and sizes are represented. This wide variety makes it impossible to design one type of cleaner that is best for all applications.

Different fields of application require different degrees of air-cleaning effectiveness. In industrial ventilation, it may only be necessary to remove the coarser dust particles from the airstream for cleanliness of the structure and protection of mechanical equipment. In other applications, we must prevent surface discoloration. Unfortunately, the smaller components of atmospheric dust are the worst offenders in smudging and discoloring building interiors. Electronic air cleaners or high-efficiency dry filters are required for small-particle removal. In clean room applications or when radioactive or other dangerous particles are present, employ extremely high efficiency mechanical filters.

The most important characteristics of aerosols affecting the performance of an air filter include particle size and shape, specific gravity, concentration, and so forth. The most important of these is particle size. You can obtain more information on the characteristics of airborne particulate matter in the ASHRAE handbooks.

Cleaning efficiency is also affected to some extent by the velocity of the airstream. The degree of air cleanliness required is a major factor that influences filter design and selection. Removal of particles becomes progressively more difficult as particle size decreases.

Types of air filters

Considerations of cost (both in initial investment and maintenance), space requirements, and airflow resistance, in addition to wide-ranging criteria as to degree of air cleanliness, have resulted in a wide variety of commercial air filters. The filters covered will be the disposable filters, washable filters, electrostatic filters, carbon filters, high efficient particulate arrestor (HEPA) filters and ultraviolet light filtration.

Disposable

These filters can be thrown away when they become dirty. This will be the most common filters you will see in HVAC/R in the Air Force.

High-loft polyester media

Spray bonded and bought in bulk, rolls, or cut pads.

Fiberglass throwaway filters

Glass fibers bonded together and coated with a dust-holding adhesive.

Pleated filters

These allow more surface area and the dirt first collects inside the "V" in the pleat. Since the dust and particles first collect here the rest of the filter is still somewhat clean and will allow airflow.

Cube filters

These filters contain 3 filter layers and have a high dust holding capacity.

Pocket filters

Vertical separators are incorporated into each pocket to effectively channel air throughout the media to prevent excessive turbulence and allow even contaminant loading throughout the life of the filter.

Figure 1–38. Washable filter.

Washable

These filters can be washed and put back into the system. Be sure to follow washing procedures prescribed by the manufacturer. Many washable filters you will see are the wire mesh type. See figure 1–38 for an example of a washable filter.

Electronic air cleaners

The electronic air cleaner filters, which are the ionizing type, are efficient, low-pressure drop devices for removing fine dust and smoke particles. Collector plates are often coated with special oil as an adhesive. Cleaning is generally done by washing the cells in place with hot water from a water hose or by means of fixed or moving nozzle systems.

Electrical forces drive most particles to the collecting surface but cannot hold them there. In fact, after a particle touches the collecting surface, the electrical force reverses and tends to pull it off; the dust is held only by intermolecular adhesion forces. It is, therefore, very important with the washed type of electronic air cleaner to be sure that either the dust is naturally adherent or the plates are always covered with adhesive.

Electronic air cleaners, however, are often used without any adhesive treatment on the plates. Under such conditions, the precipitator collects lint, dirt, and so forth, which can eventually be blown off the plates. It must, therefore, be followed downstream by a secondary filter or storage section. The accumulated dirt in the precipitator is allowed to blow off and be caught by the downstream filter. The use of an automatic replaceable-media filter for catching anything blown out of the precipitator results in an overall combination that provides a high degree of cleaning efficiency and the convenient maintenance associated with an automatic filter of this design. The carbon filter can be used as a pre-filter to the electronic air cleaner.

Carbon

This type of filter is often made from coal and coconut shells. It works very well with adsorbing solvents, organic materials and odors. The force of the air moving in the system forces these pollutants to “stick” to the activated charcoal. The pollutants liquefy and are held in place onto the filter. The odor removing capabilities of this filter make it popular in air conditioning and refrigeration systems.

High Efficient Particulate Arrestor (HEPA)

This high efficiency filter can remove up to 99.97 percent of particulates from the air. It can remove particles as small as .3 microns. Human hair is about 70 to 100 microns, so, 0.3 microns is tiny!

It is natural to think that installing a HEPA filter in place of basic filter will improve system efficiency but caution must be taken. The HEPA filter is denser than the average disposable filter. If you install a HEPA filter you may increase the resistance to air flow too much. In cooling mode this could cause a coil to freeze and in heating mode it could cause the system to overheat. In addition to causing system problems the thick filter may not even fit in the filter rack of your existing system. HEPA filters are an improvement over the electronic air cleaner. Coarse profilers placed ahead of high-efficiency dry-type filters are economically justified by the extended life they provide the main filters.

Ultraviolet

Ultraviolet light is used to kill microbes in air conditioning systems. A high efficiency filter is usually installed before the UV lights. UV lights are usually located close to the other air filter or near the evaporator. In some applications you may see UV filtration in both the supply and return runs. Ensure you never turn the light on before you install it. Also, turn the light off before performing any work on the system. Access doors should have a switch that shuts off the light when the door is opened. Finally, never look at the lamps while they are lit. It could cause damage to your eyes.

Filter loading

The rate of loading of a filter depends on the type and concentration of the dirt in the air being handled and on the operating cycle of the system. Manometers or draft gauges are often installed to measure the pressure drop across the filter bank and, thereby, indicate when the filter requires servicing. The final allowable pressure drop may vary from one installation to another, but in general, service unit filters when their operating resistance reaches 0.5 inch of water.

Maintenance

When filters in a duct system become dirty and clogged, they increase the resistance to the flow of air in the airstream and reduce the efficiency of the system. Therefore, check, clean, or change filters periodically. The frequency of cleaning and inspection depends on the type of system in which the filter is installed and the type of filter. Follow the manufacturer’s recommendations for frequency of filter changes. However, if the ventilating system is not used very much, the cleaning or renewal operation may be reduced to once during a full season. Some types of systems may need the filters to be cleaned or changed at least weekly.

To find how often filters need to be serviced, check the air pressure drop across the filter. Some systems have air-filter gauges mounted on the air-handling unit so that the air pressure drop can be read easily during daily inspection. Follow the manufacturer’s recommendation. If you cannot determine the recommended maximum resistance, use the following general rule:

> When the pressure drop across the filter is equal to or more than 25 percent of the total pressure drop across the fan, including the filter and coils, change the filter.

Dampers

The general function of dampers in an air-handling system is to control the flow of air. This may be modulating or two-position control, as required, either to control a measured variable, such as static pressure or temperature, or to initiate system operation, such as opening dampers when equipment is started.

Butterfly dampers

These dampers are used in round ducts to control airflow. They are normally opened and closed manually but some can have automatic control. These are often found in VAV boxes.

Split dampers

This type of damper is used where air splits off into two directions. As the damper moves it closes off airflow to one branch while opening airflow in another branch.

Volume dampers

A damper is a primary element in duct systems and is used for controlling airflow rates by introducing a resistance to airflow in the system. In higher-pressure systems, we refer to the damper as a “pressure reducing valve.”

Good engineering design specifies that volume control or balancing dampers be installed in each branch or zone duct. Single-leaf dampers, which are a part of a manufactured air grille, do not meet these requirements. You can use opposed-blade dampers, which are a part of manufactured air grilles, *only* when there is not enough room for regular volume dampers and when sufficient space is provided behind the grilles for proper operation of the integral dampers.

Volume dampers installed in branch ducts where the estimated static pressure is less than 0.5 inch of water gauge (in. wg) can be of a single-leaf type. Volume dampers should be installed in ductwork where the estimated system static pressure exceeds 0.5 in. wg according to top picture in figure 1–39 (A) (opposed action).

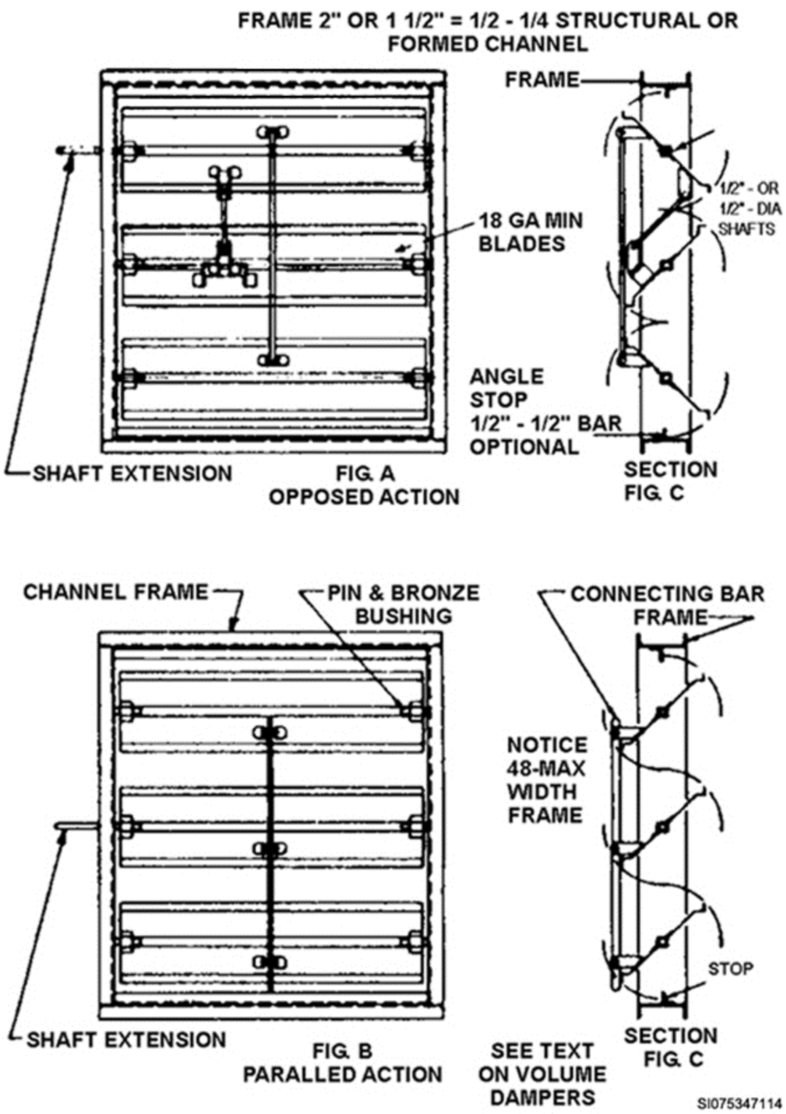


Figure 1–39. Multiblade volume dampers.

Multiblade dampers

Figure 1–39, bottom picture (paralled action) shows one of two types of multiblade dampers—the parallel-blade (shown) and opposed-blade dampers. The terms *parallel* and *opposed* refer to the movement of the adjacent blades. In the parallel-blade damper, all of the blades move in parallel. The opposed-blade damper has a linkage that causes the adjacent blades to move in opposite directions.

Partial closing of a damper increases the resistance of the duct system to airflow. The reduction in airflow with closure of the damper may or may not be proportional to the amount of adjustment of the damper. That is, closing the damper halfway does not necessarily mean that the air volume is reduced to 50 percent of that volume that flows through the damper when it is wide open.

The relation between the position of the damper and the percent of air that flows through the damper with respect to the airflow through the wide open damper we term the *flow characteristic*. Typical flow characteristic curves for the parallel-blade and opposed-blade dampers are available from the damper manufacturer. Get with your supervisor and review damper literature from the manufacturer.

The manner in which the damper reacts in the duct system is determined by how complicated the system is. If the system is very simple and the damper makes up a major part of the resistance in the system, then any movement of the damper changes the resistance of the entire system and good control of the airflow results. If the damper resistance is very small in relation to that of the entire system then it will result in poor flow characteristics.

The opposed-blade damper results in a better flow characteristic than the parallel-blade damper. The improved characteristic results from the fact that, as the opposed-blade damper is closed, it introduces more resistance to airflow for a given position than does the parallel-blade damper.

In balancing systems, remember the flow characteristics of dampers are not constant and vary from one system to another. The actual effect of closing the damper can only be determined by measurements in the particular system unless the designer has taken into account the damper flow characteristics in the system design.

It is important to understand the airflow patterns of multiblade dampers. The parallel-blade damper has a tendency to throw the air toward one side of the duct. This uneven pattern may adversely affect coil or fan performance or airflow into branch ducts if the damper is located close to any system component. Note these flow patterns when it becomes necessary to measure airflow in a duct near a damper. Where possible, make any measurements upstream rather than downstream of the damper.

Quadrants and linkages

When dampers are located within ducts and are manually controlled, they are usually secured in place with regulators or quadrants such as those shown in figure 1–40. Because regulators and quadrants vary in strength and locking ability, they should be of suitable size for the size damper with which they are used. When you set a damper, securely tighten the regulator or quadrant to ensure that the damper remains as you set it. Do not always accept the position of the regulator pointer as indicating the actual position of the damper blade. In case of any doubt, inspect the end of the damper rod at the face of the regulator. Use a hacksaw to cut a groove, which you can then use to indicate that the damper blade runs in the same direction as the cut.

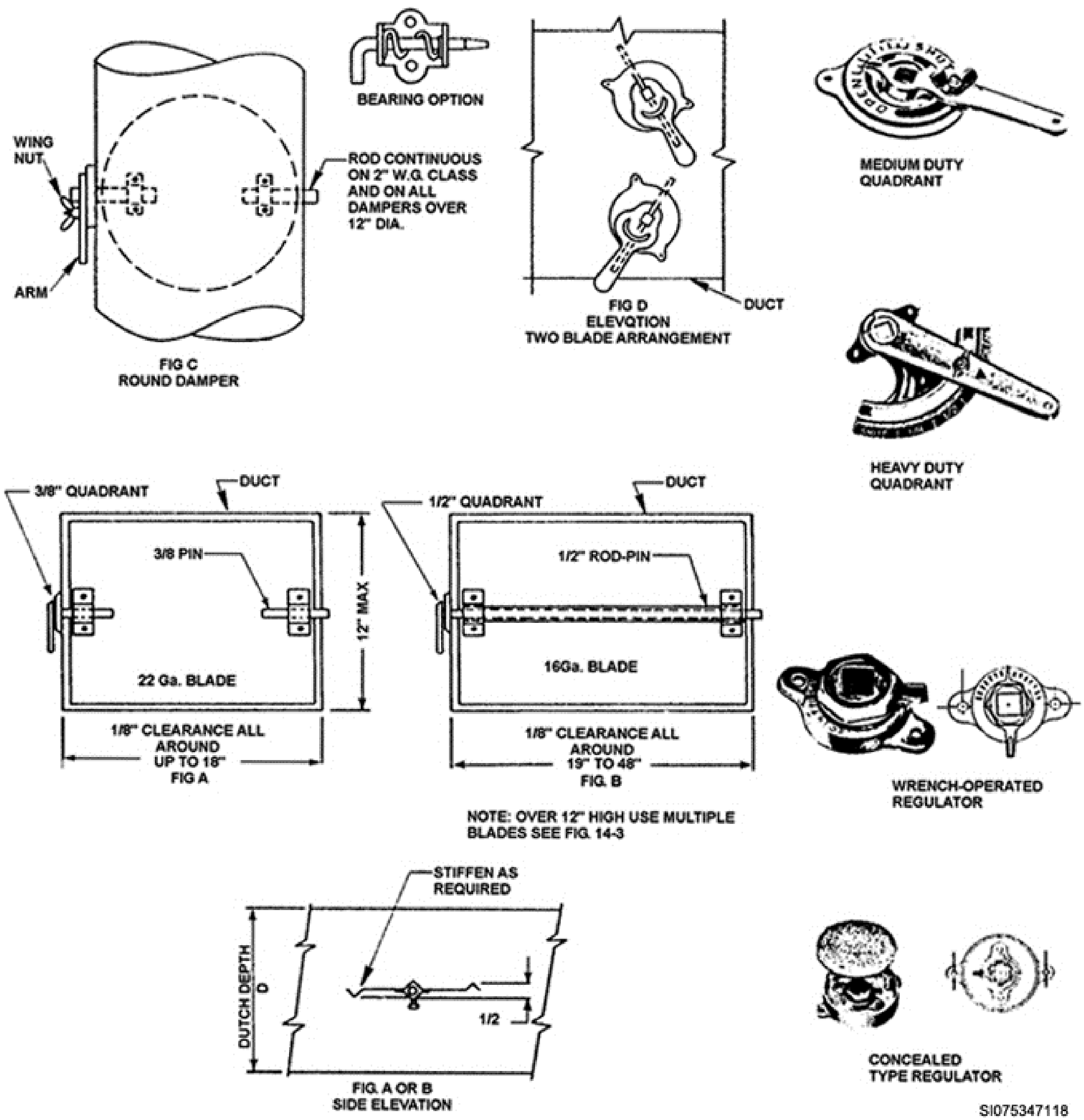


Figure 1–40. Volume dampers.

Where dampers should have tight shutoff when closed, be sure to properly adjust the linkage between blades and damper motor linkage. Cold-deck and hot-deck dampers, as used in multizone units, must close tightly, as must face and bypass dampers used in some air-handling units.

Terminal units

A terminal unit is a device or unit, often a box, located where the supply duct or duct branch terminates and the air is introduced into the space to be conditioned. There is a wide variety of terminal units. Some contain only air control dampers or valves; others may also have cooling or heating coils and other variations, such as to regulate the quantity of air or to regulate its temperature, or both.

Terminal units can be single-duct, dual-duct, or induction-type units located either in or above the conditioned space. The terminal unit has several functions. First, it must supply air at a proper temperature to take care of the load in the conditioned space. It does this in response to a room thermostat located in the space. The unit also contains some type of device to regulate the airflow to the space. This device reduces pressure in the terminal unit to a level where the air can be introduced into the space. The terminal unit must attenuate any noise generated within the unit in the reduction of the pressure. Only VAV terminal units will be covered in-depth.

Variable air volume terminal units

There are several types of VAV terminal units. The following paragraphs give a description of each type. The growing importance of VAV units cannot be stressed enough.

Fan powered VAV systems

Some VAV's you will run into will have a fan as part of the terminal unit. The two categories of fan powered VAV units are the series flow and the parallel flow. These units have fans that pull return air or air from the ceiling to mix with the supply air.

Series flow

The series flow, fan powered VAV unit will have a fan that runs continuously. The fan is *in series* with the incoming supply air. Since there is no on or off of the fan there is less sound disturbance in for the building occupants. Another reason to use the series flow is for areas that require constant air flow. Not a constant *volume* amount but constant air flow. These areas include restrooms, lobbies and hallways.

On these units, a thermostat in the zone will modulate the air damper in the unit. For example, as the load decreases the damper will close allowing less supply (also known as primary) air in the unit. The fan in the unit that runs continuously will draw in the warmer return air and mix it with the supply air to give the conditioned space its desired air temperature and volume.

Parallel flow

The fan on the parallel flow system runs intermittently. The fan is not in the supply air stream but *parallel* to it. In full-cooling mode the fan will not be on. There is enough pressure provided from the supply airstream to supply the conditioned space with the proper amount of cool air. As the load decreases, the damper begins to close. Eventually, the fan in the unit will start. As it starts it will draw in the warm air and mix it with the supply air.

Terminal reheat

As mentioned before, VAV's can have terminal reheat. A terminal reheat system uses either a hot water coil or electric heat strips to reheat the air. There is no need to try to determine which one is used more often. The infrastructure and leadership at each base factors into this decision.

Bypass type (dumping)

We can keep system volume constant with VAV room supply by continuous modulation of the excess supply into the return (bypassing the room) or by intermittent pulsation of the entire supply, alternately, between the room and the bypass. The latter employs a self-operated, fluidic controller actuated by system air pressure.

Maintenance of VAV system

When balancing a VAV system, the technician must do the following:

1. Determine whether the VAV terminal units are
   a) pressure dependent or independent;
   b) using pneumatic, electric, or system-powered controls;
   c) normally open (N.O.) or normally closed (N.C.);
   d) controlled by direct-acting or reverse-acting thermostats.
2. Inspect box for ductwork connection.
3. Lubricate and adjust dampers and linkage.

Diffusers, grilles, and registers

Some or all of these components are used in every air system. They will be covered in the air balancing lesson in the next unit.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

201. Fans and belts

1. How are fans tested by manufacturers?

2. After the fan is installed in the HVAC/R unit, where are restrictions imposed?

3. What does an AMCA class mean?

4. What is the different performance characteristic does the airfoil wheel have from the backward inclined?

5. Where are forward-curve fans not recommended for use?

6 What will a clogged filter eventually lead to?

7. Besides reduced heat transfer, what could dust on a fan blade cause?

8. Why are straight blades suitable for industrial exhaust applications, abrasive dusts, material handling, grease and acids?

9. When could you use the dome upblast exhauster?

10. Propeller fans can only be used where?

11. Where are fixed sheaves usually installed?

12. What does the cog on the bottom of belt do?

13. Why must you replace all of the belts when only one is bad?

14. What could happen if you misalign a belt?

15. Why must you ensure no nuts, bolts, or tools fall into the operating fan?

16. What must be done if a fan is dirty and loses it balance?

17. What happens if the fan is still out of balance after cleaning?

202. Constant and variable air volume systems

1. How many sets of space conditions does a single-zone system respond to?

2. What uses are the single-zone systems limited too?

3. What air is a dual-unit usually supplied?

4. In a multi-path, multi-zone system, what do the zone dampers respond to?

5. Describe the two ways air can be controlled in a VAV system?

6. In an air distribution system, what happens as dampers open and close?

7. If a cooling demand is reduced in a building, what will the dampers do?

203. Air system components

1. Why must "storm proof" louvers be about 50 percent larger than standard louvers?

2. On relief openings, how can you prevent back draft?

3. If you were trying to replace a reheat coil in mild weather, what piece of equipment could you use?

4. How are filters usually selected?

5. How are pollutants held in place on a carbon filter?

6. Besides the supply run, where may you see ultraviolet filtration?

7. Describe the general function of a damper in an air handling system.

8. What type of damper are often found in VAV boxes?

9. What are two reasons to use the series airflow VAV unit?

10. How does the fan run in a parallel-flow VAV unit?

1–2. Indoor Air Quality

Today, the quality of air is much more of a concern than it has been in the past. With the continuing development of new allergies and sensitivities, it is more and more important that air be fresh and free of contaminants. The concern for indoor air is obvious because that is where most people on base will be spending most of their time. On a base there are elderly people, infants, and people with medical problems. The quality of air is extremely important for these people. Also, consider air quality in places like the dining facility and in hangars.

204. Indoor air concepts

Indoor air quality is becoming a hot topic in the HVAC/R industry. Buildings are built tighter and more pollutants that are inside the condition space are staying there. In this section, air quality standards and air pollutants will be discussed. When talking about indoor air quality we must also consider the temperature, humidity and fresh air requirements.

Air quality standards

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 62 is the standard for indoor air quality. This standard sets building, design and maintenance standards for ventilation systems. ASHRAE standard 62.1 *Ventilation for Acceptable Indoor Air Quality* standard defines requirements for ventilation and air-cleaning system design, installation, commissioning, and operation and maintenance. Other standards are set by NIOSH and OSHA. Since air quality is becoming a bigger issue it is wise for you to read them so you know what the standards are. Remember the core value "Excellence in all we do." By knowing and abiding these standards you can demonstrate this core value.

Air pollutants

The effects of chemical and biological pollutants in indoor air on occupants are complex. The manifestations of these effects may range from the most obvious, such as eye irritation or odor-related nausea, to various states of disease. Some of these effects occur very soon after the beginning of the exposure, while others become apparent only after delays ranging from days for some infectious diseases to many years for substances that act as chronic poisons or carcinogens. These manifestations may be reversible and may disappear without long-range health effects when we remove the offending agent from the indoor air. Other manifestations may become irreversible health problems that need medical attention.

The chemical and biological effects are further complicated because the same pollutant may have different durations of exposure. As an example, consider a substance that causes both odor and eye irritation. The odor appears at a low concentration, while the irritation typically occurs only at a higher concentration. In addition, a prolonged exposure to the irritant tends to aggravate the eye irritation.

Below, we discuss some of the problems associated with chemical and biological indoor-air contaminants, which have become of increased concern in recent years. Sources of the harmful materials may be indoor activities and maintenance practices. Pollutants will be broken down into solids and gases.

Solid pollutants

These pollutants are particles that are suspended in the air. They consist of dust, fumes, smoke, bacteria, mold, pesticides, lead, formaldehyde, pollen and asbestos.

Dust

Dust is blow around and can settle on objects. It is very small but can cause issues such as sneezing and it carries animal or human cells. Dust mites are microscopic insects that thrive in warm and humid environments. When they die their bodies break down and mix with dust in a building. If someone is sensitive to dust it is probably because of the dust mites and their remains.

Fumes

Fumes are small particles in the air that are caused by some process, such as an industrial or chemical process.

Smoke

Smoke is caused by incomplete combustion. Particles are very small from 0.1 to 13 microns.

Bacteria

These are simple organisms that can spread diseases. Bacteria can be found anywhere but you may find it more in places in like the dining facility or in the hospital.

Mold

This is the growth of fungi on vegetable and animal matter. Moisture and high humidity are well-known as conditions that can increase mold growth. Mold can cause illnesses in humans. There are about 100,000 different types of molds and they can be found in ceilings, on drywall, under carpets and behind wallpaper.

What does mold have to do with an HVAC/R tech? HVAC/R systems are responsible for controlling moisture inside of facilities. So, if mold loves moisture, it is your job to make sure HVAC/R systems are running properly and removing moisture. This will be covered in more detail in the next section.

Pesticides

Pesticides can be used outside and inside of facilities. Pesticides protect facilities from insects and rodents.

Lead

Old lead based paint is one of the biggest sources of lead exposure in old buildings. If this paint is found, a certified contractor is required to remove it. This is not a job for the average HVAC/R technician unless special training has been acquired.

Formaldehyde

Formaldehyde is an irritant as well as an odorant. Recently, some studies have indicated that it is also a carcinogen in animals. It occurs at low concentrations outdoors. Its concentrations in indoor air are increased when some formaldehyde-based synthetic resins are used in building materials such as particleboard and insulation. Some formaldehyde is produced during incomplete combustion.

Pollen

These are small particles released by plants. Pollen gets worse during certain seasons and causes many problems for many people. Some of these problems can be hay fever and rose fever. An important number to know is the pollen count. It is the amount of pollen in a given space. Websites are available to give pollen counts for different areas in the country.

Asbestos

Inhaled airborne asbestos fibers can cause lung cancer, but only after many years of latency. Asbestos fibers, unless they are present in very high concentrations in the air, do not produce any immediately noticeable symptoms. The presence of asbestos is detectable only with specialized equipment. Asbestos and asbestos fibers have been used extensively in building materials in the past but generally are prohibited now.

At an Air Force base in 2010 there was a major asbestos issue in the HVAC/R Shop. The tiles used in the shop were held down with mastic that contained asbestos. The tiles and mastic were crumbling due to wear and tear and the asbestos became airborne. Every member of the shop had to have chest x-rays and the removal of the asbestos costs the Air Force almost $70,000. As you can see from this example, asbestos can have serious health and monetary effects.

Bio aerosols

Biological aerosols include aero-allergens and aero-pathogens. Aero-pathogens include bacteria and viruses. Aero-allergens are plant or animal materials capable of sensitizing some individuals and, thereafter, producing in them inflammatory reactions in the respiratory tract, eyes, or skin. Pollens, which produce hay fever, are rarely of indoor origin and, because of their relatively large size, are readily excluded from the indoor atmosphere by ordinary filters. Spores, which derive mainly from molds, can originate indoors or out. In addition, house dust contains many small fragments of plants, animal dander, insect parts, and fecal matter, which can produce allergic reactions.

Gas pollutants

Common gas pollutants include sulfur dioxide, carbon monoxide, carbon dioxide, nitrogen oxide, ozone, radon and organic vapors.

Sulfur based

Sulfur dioxide is an irritant with some odor and with a potential of aggravating respiratory problems. It occurs outdoors as a result of combustion of sulfur-containing fuels. It can be generated indoors if sulfur-bearing fuels are burned in unvented or poorly vented heaters.

Carbon monoxide

This pollutant is an odorless gas that combines with hemoglobin in the blood and interferes with the supply of oxygen to body tissues. Its only sensory effect is some lightheadedness and headaches, which precede more severe symptoms or death. It is produced in any process of incomplete combustion of carbon-containing materials. Typical sources are engine exhausts (which may find their way into indoor spaces), tobacco, gas stoves, and unvented or improperly functioning heating equipment.

Carbon dioxide

Carbon dioxide is a combination of carbon and oxygen that is a result of combustion and breathing. High concentrations of CO2 can indicate that other pollutants may be present.

Nitrogen Oxide

Nitrogen dioxide is principally a respiratory irritant. It can interfere with the body's defense against infections. It is a product of any high-temperature combustion. Sources in the indoor air include unvented combustion processes such as gas ranges and various types of unvented space heaters and tobacco smoking. Nitrogen oxide is a substance found in the process of making smog.

Ozone

Ozone is an odorant and irritant that can cause acute respiratory distress. Ozone is a strong chemical oxidant produced by oxidation of atmospheric oxygen to ozone under the influence of ultraviolet radiation, other ionizing radiations, or electric discharges. It is always present in outdoor air and can be generated indoors as well. Symptoms produced by too much exposure to ozone include chest pain, coughing, throat irritation and congestion. An ozone concentration of 0.1 parts per million is generally considered the maximum exposure rate for an eight-hour period. Ozone monitors measure ozone concentrations.

Radon

Radon is a radioactive gas produced by the radioactive decay of radium, a radioactive element widely distributed in the earth's crust. Radon, in turn, decays to form other radioactive elements called *radon daughters*. Breathing air containing radon daughters increases the risk of lung cancer. Radon can only be detected with a test instrument. It cannot be seen, smelled or tasted.

Radon is present in rocks and soils, groundwater, natural gas, and earth-based materials such as concrete. There are Radon Zone Maps for each state that determine radon potential and numerous other factors. Radon is believed to cause thousands of deaths each year. The Surgeon General has said that radon is the second leading cause of lung cancer in the United States.

Organic vapors

These are a major source of air pollution and consist of acetic acid, formaldehyde, ammonia, hydrogen peroxide, mercury vapor, nitrogen dioxide and ozone. These vapors can come from various household products such as paints, varnishes and cleaners.

Odors

Some animals have an incredible sense of smell that allows them to survive in the jungle or wilderness. Man also has the capability to sense very low concentrations of odors. This sensitivity varies from person to person.

When molecules of odorous substances that stimulate the olfactory nerve are sensed through the nose, the odor—good or bad—causes a reaction by the person, depending on the concentration of the odor within the ambient air. The olfactory organs are easily fatigued and soon allow the person to become insensitive to many odors, depending on the concentration; although exposure to fresh air restores the sensitivity. Sensitivity to odor intensity also can change with changes in temperature and humidity and with colds or sinus conditions.

Odors come from many sources. Outdoor air contains pollutants from auto exhausts, industrial process waste, and furnace and boiler smokestacks. There are numerous sources of odor related to the everyday activities of occupants. Odors emitted by people, food and its preparation, pets, household chemicals, and cosmetics are an integral part of indoor living. They are generally accepted as such, as long as their sensory intensity is within bounds and provided that the occupants have some means of reducing the concentration of the odors by adjusting ventilation (using exhaust fans in kitchens and bathrooms and opening doors and windows) or by turning on some odor removal device (such as a vapor filter device).

Occasionally, indoor odor sources may be in the ventilation system itself. Under certain conditions of humidity and temperature, colonies of microorganisms can develop in filters, on coiling coil surfaces, and in air ducts. Thus, especially with inadequately maintained HVAC systems, the ventilation air may contain more contaminants than does the preexisting indoor air.

Other chemicals

Chemical technology has introduced, and continues to introduce, a large and growing variety of chemicals into products that are used in building construction, furnishings, operations, and maintenance. Only a limited number of such chemicals have so far been implicated in health problems, with the present research emphasis being primarily directed toward those that may have carcinogenic or mutagenic properties.

Indoor air quality in residential and commercial systems

You will work on some buildings on base that are considered residential. There is a wide array of people that will be occupying these homes all the way from infants to elderly. It is vital for you to be able to identify indoor air quality (IAQ) problems with residential spaces. Common causes of IAQ issues involve decreased fresh air infiltration, the release of fumes, moisture infiltration, habits of the occupants and a lack of maintenance for the HVAC/R system. Refer to other texts and standards for a more comprehensive list.

Commercial buildings will often produce the same issues from many of the same sources. Something important to remember is the sensitivity of different people. The different sensitivities of people could make an IAQ problem hard to locate or there may not even be one. For example, in 2008 at an Air Force base there was an elderly person who complained of sick building syndrome (SBS). SBS is covered more in depth soon but in short it is a problem that affects 20% of a buildings population. The occupant complained of chronic sore throats, fatigue and sicknesses. A young technician who does not read their CDC’s could take these occupants complaints and spend time trying to find a problem. But a quick survey of the building’s population would quickly show this individual had health problems and no one else in the building was getting sick. Be thorough when dealing with IAQ problems and ensure all the facts are taken into account.

Residential and commercial IAQ assessments

These assessments fall in four categories:

1. Ventilation-related complaints – Symptoms caused by inadequate ventilation.
2. Source-related complaints – A source of pollution is present.
3. Chemical or biological hypersensitivity – An individual reacts to chemicals or bio aerosols that do not affect others.
4. Perceived IAQ problems – these are problems that seem like IAQ but are not. They are caused by things like stress or diseases.

Classifications of issues

There are three main issues to discuss: sick building syndrome, building related illness and multiple chemical sensitivity. Sick building syndrome or SBS is confirmed when about 20 percent or more of building occupants have symptoms of drowsiness, fatigue, respiratory problems and eye or skin irritation. The symptoms disappear when the occupants leave and the number one cause is a deficient venting system.

Building related illness or BRI, is an illness diagnosed that does not disappear when the occupants leave the building. Some examples are the flu, measles and Legionnaire's disease. In certain cases BRIs can be fatal.

Multiple chemical sensitivity is an unexplained condition that is could be the result of sensitivities to low levels of pollutants. This only happens to a very small amount of people.

Inform the customer

Pass the information you learn in this section on to the customer. They should know the importance of preventative maintenance on their systems and the effect they can have on creating pollution indoors. Other things for them to know are to use a vacuum with a HEPA filter, keep living and work spaces as clean as possible and to limit chemical use inside and around the building. It is vital to talk to the customer about these issues and build a good relationship with them. A customer that trusts you and knows you well will be more forthcoming and clear with the information they give you about their building. This is an intangible skill that can greatly increase your ability to find critical IAQ issues.

205. Air quality control

Of the methods of indoor air control, the best choice for any given space depends on specific characteristics of the space, including occupant sensitivity; building characteristics; use of the space; costs; required effectiveness; and many practical considerations of installation, operation, and maintenance. Simple solutions requiring additional ventilation air without regard to the effect on the system can be counterproductive. In this section, the following air quality control methods will be discussed: reducing or eliminating the source, air cleaning, ventilation and humidification.

Reduce or eliminate the source

The absolute most efficient way of controlling indoor air quality is to remove the source of contamination. If a source can be identified then the following three methods should not need to be adjusted. Before you get to in depth with the other methods try to identify the source first. There are numerous monitors and tools available to help you find pollutants.

Air cleaning

The air can be cleaned by filtering it or cleaning the ductwork. Ideally, 100 percent of the contaminants would be removed from every system. Unfortunately, this would be very expensive and impractical. About 90 to 95 percent filtration is the expectation for most units. If filtration is not accomplished or ductwork is old it may need to be cleaned out. Let's explore both options.

Filtration

There are numerous types of filters in the HVAC/R industry. Refer back to the previous section for a review of these filters.

Duct cleaning

Duct cleaning involves cleaning every component of the duct to include coils, condensate pans and even the fan motor and housing. Everything must be cleaned, not just the interior of the ductwork. Ducts need cleaned if there is mold growth, rats or mice, or if there are excessive amounts of dust built up inside. In the Air Force, this task has been contracted out more and more.

Ventilation

In ventilation, air that contains objectionable gaseous odors, irritants, contaminants, and toxic matter is replaced by clean outdoor air. Because using outdoor air adds substantially to the heating and cooling load, it would be desirable to reduce ventilation requirements below previously specified levels. Moreover, increasing general air pollution and proximity building have reduced the availability of outdoor air that is sufficiently clean to use for ventilation.

In planning the use of ventilation air for odor control, consider the increases in heat load and the availability of air of adequate quality. The required diluting volume of ventilation air for any given type of installation can serve as a guide to performance requirements from any selected alternative odor control method. ASHRAE Standard 62–1981, *Ventilation for Acceptable Indoor Air Quality*, defines the latest ventilation requirements.

Humidification

Humidification is more of a problem in the fall and winter when the air becomes dry. Dry air tends to dry out occupants nasal and throat passages. Also, people's skin becomes dry. Humidity is generally acceptable at about 40–60% relative humidity. Residential and commercial humidifiers can be used to keep the humidity up in a conditioned space. Different types of humidifiers will be covered in a different volume.

Odor elimination

To eliminate these odors, we must remove the source, reduce the output, or dilute the space ambient air with odor-free air from other areas or from outdoors until the concentration of the odor is undetectable. We can also remove odors chemically or physically by air washing, chemical reaction or adsorption, oxidation, vapor neutralization, and combustion.

If we use water methods to eliminate odors, we often are prohibited from dumping the water into the environment under the Environmental Protection Agency (EPA) regulations.

One form of control of unpleasant odors involves the addition of chemical vapors to the air. The ability of some chemicals to interfere with the perception of certain odors is reasonably well documented. As a rule, this effect occurs only near the threshold level of the odor perception. The preexisting odor character is modified, making it less characteristic and less attention-attracting. Sometimes the perceived overall odor intensity appears to be modestly reduced. There is no solid evidence that the odor modifiers destroy, chemically change, neutralize, or remove odorants already present in the air.

Air washing

Where odorous vapors are soluble or emulsifiable in a liquid, with or without chemical reaction, odor removal by liquid absorbents may be suitable. Absorbents can be water, modified water solutions, or oils. Odors as vapors may be removed by spray washers, packed scrubbers, and wet cooling coils, but not by the usual dry filter, unless the filter is made of special absorbent materials.

The absorbing medium becomes saturated with the contaminant. System operability may be maintained by discarding the liquid when it becomes saturated; by continuous regeneration of the liquid by heating and aeration with clean air; or by the addition of reactant or absorbent chemicals that regenerate the absorbing liquid as it accumulates odors. Disposal of the medium could be a serious problem.

Radon control

A variety of methods can be used to reduce radon in a structure. In some cases, sealing cracks in floors and walls may help to reduce radon. In other cases, simple systems using pipes and fans may be used to reduce radon. Such systems are called "sub-slab depressurization", which do not require major changes to the structure. These systems remove radon gas from below the concrete floor and the foundation before it can enter the building. Similar systems can also be installed in buildings with crawl spaces. Increased use of outside ventilation air will also reduce radon levels inside the structure, and, in many cases, may be the least expensive method and one which also solves various other IAQ problems.

Adsorption

Adsorption is the physical condensation of a gas or vapor on an activated solid substrate. These substrates are typically of high porosity. While polar absorbents, such as activated alumina and silica gel, have been used, relatively nonpolar activated charcoals or carbons are more common. These activated carbons, which are supplied by a number of manufacturers, may be made from such diverse materials as coal, coconut shells, peat, and petroleum residues, which are heated in reducing atmospheres to produce the high internal porosity. The activated material is applied to an airstream as a bed of fragments or pellets through which the air is passed. Performance can be varied according to the need by modification of the bed thickness, air velocity, total porosity, and pore-size distribution of the activated substrate. Carbons impregnated with reagent chemicals are available for specific contaminants. When the activated charcoal has adsorbed its full complement of odor, it is removed and replaced with a fresh bed of material. The used material is generally regenerated by the manufacturers for reuse.

Chemical reaction

Odors are generally subject to destruction by oxidation. While oxidizing gases, such as ozone and chlorine, can oxidize odors in water, concentrations necessary for air deodorization would be so high that they would be toxic for space occupants. It is generally agreed that the major effect ozone generates is to reduce sensitivity of the sense of smell, rather than reduce actual odor concentration.

Two types of oxidizing systems are commercially available: a washer system and a solid system. In the former, odorous air is scrubbed with aqueous solutions of potassium permanganate, chlorine, or metal ion salts. In the second system, potassium permanganate is embodied in a pelletized activated alumina substrate and applied to the airstream as a bed similar to that used for activated carbon. Carbons impregnated with reactant chemicals are available.

In the aqueous system, odors scrubbed from the air react with the oxidizing chemicals and may be converted to carbon dioxide and water or to intermediate decomposition products of generally lesser objectionability. The oxidizing chemicals are replaced periodically as they are consumed. A system is now available that regenerates the oxidizing solution electrolytically. In the solid-oxidizing systems, the activated substrate adsorbs odors and moisture from the air. The adsorbed moisture solubilizes the permanganate and activates the oxidizing system. As in the washer system, odors are converted to less objectionable species and are generally fixed in the pellets. These pellets are replaced periodically.

204. Indoor air concepts

1. If someone is sensitive to dust it is probably because of what?

2. Where may you find bacteria more than the average building?

3. What are some well-known conditions that can increase mold growth?

4. What will affect a person's sensitivity to an odor?

5. What are some causes for indoor air quality issues?

6. How can sick building syndrome be identified?

205. Air quality control

1. What is the absolute most efficient way of controlling indoor air quality?

2. When is humidification more of problem?

3. How can we eliminate odors?

4. What methods can be used to control radon?

1–3. Pumps

Centrifugal pumps are used in heating and air conditioning to produce water flow in piping. This section provides general information on centrifugal pumps and their application to heating and air-conditioning or hydronic systems. Other pumps, such as reciprocating or rotary pumps, play a minor role in the HVAC industry.

206. Pump fundamentals

Circulating pumps play an important role in the hydronic or water distribution system, but there are a few things that can affect the pump or its distribution system, such as *pressure loss* from a long stretch of pipe, numerous amount of fittings, or the different types of pressures considered as *head* on a pump. Hydronic systems are subject to the same type of pressure or friction losses as found in air distribution systems, primarily on the straight runs and in the dynamic losses of the fittings.

Hydronic pressure losses

Manufacturers normally supply pressure-loss data for equipment used in piping systems. They give pressure losses for hydronic systems in terms of *equivalent feet of pipe*, in *pounds per square inch* (psi), or in *feet of water gauge* (also *gage* [ft. wg]).

Friction losses

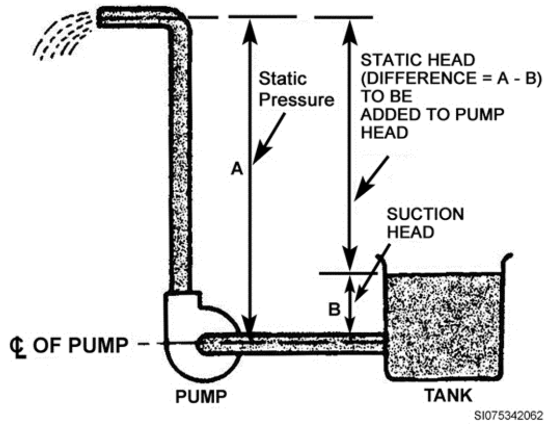
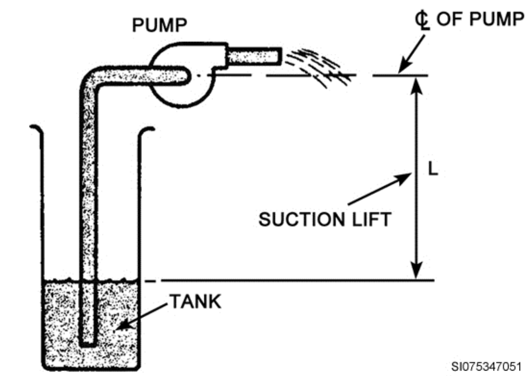
Friction loss tables for hydronic systems vary in value depending on the condition of the piping system and the type of pipe or booting used. Closed systems, where the fluid continuously recirculates, such as hot-water and chilled-water systems for HVAC work, stay relatively clean and free from deposits that could roughen the interior surfaces.

Open systems, such as domestic hot-water systems and condenser water systems with open-type cooling towers, are subject to corrosion causing higher friction in the piping, thereby having a greater pressure loss per 100 feet of pipe. Properly sized pumps used with these systems generally deliver a higher flow rate in a newly installed system. However, after a few months or years, the balancing cock at the pump, which was closed partially to reduce the flow to the design conditions, usually has to be opened.

Heads or pressures

Many different terms are associated with the head and pressures of hydronic system flow. It is good to have an understanding of these terms. You'll probably run across these terms more when you balance and troubleshoot pump, or hydronic systems, problems.

TERM	DEFINITION
Dynamic discharge head	The dynamic discharge head is calculated by using static discharge head plus friction head plus velocity head.
Dynamic suction head	The dynamic suction head is positive static suction head minus friction head minus velocity head.
Dynamic suction lift	Dynamic suction lift is the sum of suction lift and velocity heat at the pump suction when source is below pump centerline.
Friction head	Friction head is usually expressed as "the pressure in pounds per square inch" or "feet of liquid" being pumped, which represents system resistance that must be overcome.
Static head	Static head is the pressure due to the weight of the fluid above the point of measurement. In a closed system, the selection of the pump capacity is not affected by the static head, as the static head is the same on both sides of the pump. However, the pump casing must be able to handle the static head of the system.
Static suction head	Static suction head is the positive vertical height in feet from the pump centerline to the top of the level of the liquid source.
Static suction	Static suction is the distance in feet between the pump centerline and the source of liquid below the pump centerline.
Suction head	Suction head is the height of fluid above the centerline of the pump on the suction side to the level of the fluid surface, as shown in figure 1–41. The actual static-head pressure loss that is added to the piping and system pressure loss in order to size the pump is the difference between A minus B (in an open system).

TERM	DEFINITION
	 **Figure 1–41. Pump with static head and suction heads.**
Suction lift	Suction lift is the highest level of fluid in an open system that a pump must lift on the suction side of the pump from the level of the fluid surface to the pump centerline, as shown in figure 1–42. This pressure-loss value is added to any other system or pump pressure losses if additional piping or equipment is involved.  **Figure 1–42. Pump displaying suction lift.**
Total dynamic head	Total dynamic head is calculated by using dynamic discharge head (static discharge head plus friction head plus velocity head) plus dynamic suction lift, or dynamic discharge head minus dynamic suction head.
Velocity head	Velocity head is the pressure needed to accelerate the liquid being pumped. (For practical purposes, the velocity head is insignificant and is usually ignored in HVAC system calculations.)

The purpose of a pump for HVAC work is to establish fluid flow and to produce enough pressure to overcome the resistance of a system and the system components at the required design flow rate. The pump impeller produces a low to high positive pressure on the discharge side, and a lower or relatively negative pressure is developed on the suction side. Basically, the suction side of the pump pulls in and the discharge side pushes the fluid.

System elevation static/operating discharge/shutdown pressures

It is important to remember that a pump's discharge pressure is *relative* to its available suction pressure. The system elevation static pressure is of major consequence in a liquid system. During the time when the pump is running, there is a redistribution of pressure in the system because of the combination of the elevation pressures and the pressure produced by the pump. However, when the pump is shut down, the system pressure returns to the same values of elevation static established before the pump was started.

Since the operating discharge pressure produced by the pump is an increase, this value is added to the shutdown pressure in the discharge piping. Since the operating suction pressure produced by the pump is a decrease, this value is subtracted from the shutdown pressure in the suction piping. Assuming that the system piping and equipment losses were properly calculated and that the pump was properly selected to overcome those losses and to withstand the system static and dynamic pressures, it would be expected that the pump would produce the required design fluid flow. However, this may not be the case because of the pump's sensitivity to the pressure conditions at its inlet (the discharge conditions of the pump do not generally present a problem).

Suction pressure

In open systems, a pump does not "suck" water into its inlet connection; lift occurs because the pump produces a pressure at its suction that is less than atmospheric pressure; atmospheric pressure then pushes the liquid up and into the pump.

The greatest lift possible would occur if there were a perfect vacuum at the pump suction. This would be a vacuum of 29.92 inches of mercury (in. Hg), equal to 14.7 psi or 34 ft. wg. Thus, with a perfect vacuum at the pump suction, the maximum lift would be a distance of 34 feet if the liquid is water in a normal temperature range. This is only a theoretical distance for several reasons, one being that an ordinary water pump cannot produce a perfect vacuum, so the maximum lift would be less than 34 feet.

Assume that, as a practical matter, the maximum lift the pump can produce is 22 feet. However, some of this possible lift will be used up in friction loss in the suction pipe. If the friction through an intake strainer and the pipe and fittings totals 5 ft. wg, the maximum possible lift becomes a distance of 17 feet. Even after the liquid reaches the pump inlet flange, there is a further reduction of pressure between the inlet flange and the eye of the impeller. Such a reduction must exist to overcome internal losses due to friction and turbulence in the pump inlet while still providing a pressure differential between the inlet flange and impeller eye that causes flow into the impeller. Sound complicated. Let's look at this in a less technical form.

Maximum lift is decreased due to the friction of the pipe, the strainer, fittings and the inlet flange. Thus, there exists within the pump a region that has the lowest pressure in the system. The significance of this lowest pressure is that it must not be less than the vapor pressure of the liquid being pumped. If it is less, the result is a reduction in the quantity of liquid pumped and an undesirable action called *cavitation* occurs. We describe cavitation below. Let's use less technical terms again:

There is a place in the pump that has the lowest pressure in the whole system. This is important because if the pressure becomes lower than vapor pressure of the water then something called cavitation will happen. Now, let's continue with cavitation.

Cavitation

Cavitation is a basic physical principle that there exists a pressure-temperature relationship between liquids and vapors such that the boiling point of the liquid depends on the pressure to which it is subjected. Water boils at 212°F at sea level, where the pressure is 14.7 psi, but if its pressure is reduced, it boils at a lower temperature. Vapor pressure is the absolute pressure corresponding to the boiling point of the liquid at the temperature at which the liquid exists. If water is at 212°F, it boils at 14.7 psi; the vapor pressure, therefore, is 14.7 psi. Generally, available data displays vapor pressures corresponding to various temperatures of water.

For example, water at 179°F has a vapor pressure of 7.4 pounds per square inch absolute (psia). If water is being pumped that has a temperature of 179°F, the lowest pressure allowable in the system is 7.4 psia. If the pump is at sea level where atmospheric pressure is 14.7 psia, there is a difference of 14.7 – 7.4, or 7.3 psi (or $7.3 \times 2.31 = 16.9$ ft. wg) available for suction lift, suction pipe friction, and internal pump losses.

The fluid being pumped, usually water, generally contains some entrained air that was absorbed when the fluid was exposed to the atmosphere prior to being introduced into the system. This air is released because of an increase in fluid temperature, a decrease in fluid pressure, or because of the fluid vapor pressure described above. Air, which is released from the water when it is heated, must be vented from the hydronic piping (often several times at the beginning of the season). If we add fresh water to replace that amount dripped through pump packing, additional venting is required. Most of the air released in the process of heating water is removed at or near the heat exchanger or hot-water generator.

There may be a point in the fluid pumping system where air may be released from the fluid being pumped if the pressure is low enough and/or the liquid changes to a gas (or steam). Should these conditions occur the pump, which has been designed to move liquid, is generally unable to cope and the flow of liquid is either greatly reduced or stopped completely. However, at some point within the pump where the impeller produces sufficient pressure, the bubbles of gaseous liquid will liquefy and the bubbles of air are reabsorbed. This transition occurs suddenly and is accompanied by crackling or explosive noises. The phenomenon is called *cavitation* and may cause destructive pitting and wearing of the impeller and casing as well as noise and vibration. Any one or all the conditions reduce pump performance and life. The actual value in psi or ft. wg of internal pump losses depends on the pump size and design, the volume of fluid being pumped, and the vapor pressure of the fluid.

Net positive suction head

To eliminate cavitation, it is necessary to maintain a minimum suction pressure at the inlet side of the pump. In hydronic systems, the actual value in psi or ft. wg of internal pump losses depends on the pump size and design and the volume of water being pumped which is determined by the manufacturer. Manufacturers then state the pressure in numerical values of net positive suction head (NPSH). The required NPSH for a specific pump is available from the manufacturer, either in catalog data or on request. Although usually given as a single number, the value varies with flow and head. For any pump, the full range of values of each impeller size and operating speed are expressed as a curve (fig. 1–43).

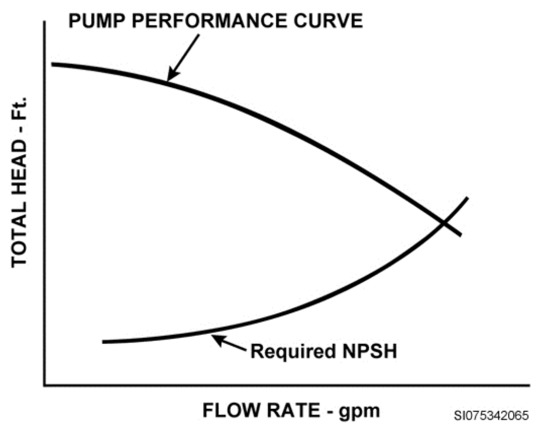


Figure 1–43. Pump curve.

Normally, we do not consider NPSH in closed systems, especially where the pump is at the bottom of a rise. Also, it is not ordinarily a factor in most open systems unless we are pumping hot fluids, when there is a considerable suction lift, or when there is considerable friction in the pump suction pipe.

Vortex

Vortex is not a pressure, but a term we use to describe whirling or spinning of the liquid in a piping system. The condition is similar to a weather cyclone or tornado and can occur anywhere in the piping system where conditions cause or allow a vortex to be produced.

On the discharge side of a pump, the worst effect of a vortex is normally noise; the configuration of the piping is usually the cause. Several elbows turning the same way may produce a vortex with a low-pressure center in the pipe. We can temporarily release noise bubbles of air in the same way as we do in pump suction with inadequate NPSH.

On the suction side of the pump, the same condition can also occur. However, the suction vortex problem is more commonly caused by placing the suction pipe termination too close to the surface of the system liquid, as might occur in a cooling tower pan. The low pressure produced at the pipe entrance produces a vortex or whirlpool similar to that produced when we remove a stopper from a sink full of water. This condition introduces air directly into the eye of the pump impeller. This impairs the efficiency of the pump and produces undesirable noise.

We can eliminate some vortex-producing conditions with proper piping. In cooling tower sumps, we often install a plate to prevent a vortex from forming.

Types

We can define centrifugal pumps (fig. 1–44) used in the heating and air-conditioning industry. Refer to the table and figure 1–44 for more information.

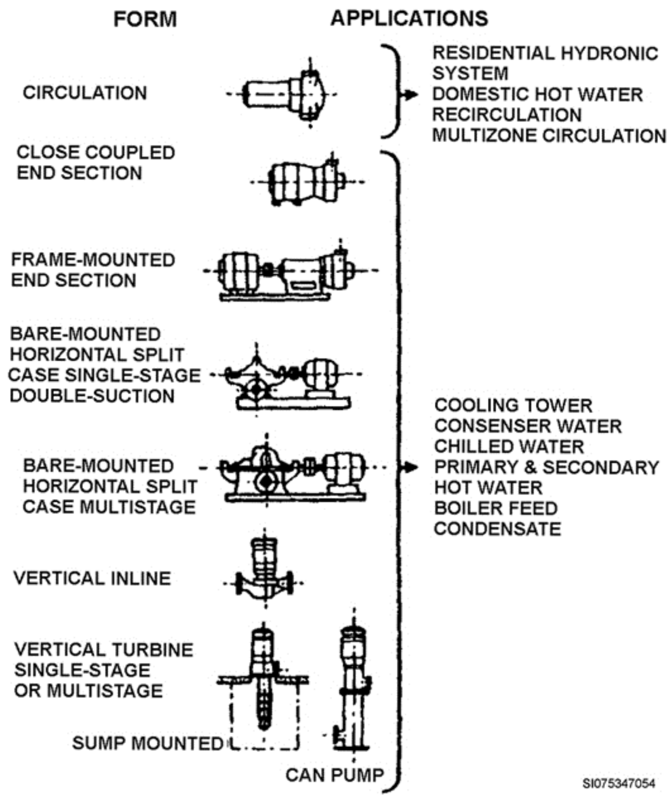


Figure 1–44. Pump mounting.

TYPES	CHARACTERISTICS
Types of impellers	Two types of pump impellers are used in these pumps—single suction and double suction. The single-suction impeller has one suction or intake, while the double-suction impeller has two suctions or intakes. Although most centrifugal pumps for heating and air conditioning are single suction, the significant example of a double-suction impeller is the single-stage, horizontal split-case pump.
Number of impellers	Pumps with multiple impellers are called *multiple-stage* pumps.
Type of casing	Like impellers, there are two basic types of casings for these pumps—*volute* and *diffuser*. The volute types include all pumps that collect water from the impeller and discharge it at a right angle to the pump shaft. Diffuser-type casings collect water from the impeller and discharge it parallel to the pump shaft. All pumps here are the volute type, except the vertical turbine pump, which is a diffuser type.

TYPES	CHARACTERISTICS
Method of connection to driver	Pumps, which are classified by the method of connection to the electric motor, can be close coupled or flexible coupled. The close-coupled pump has the impeller mounted directly on a motor shaft extension while the flexible-coupled pump has an impeller shaft supported by a frame or bracket and is connected to the electric motor through a flexible coupling.
Mounting position	Pumps are labeled by their mounting position, either horizontal or vertical. Seven significant types of pumps used in heating and air-conditioning or hydronic systems are shown in figure 1–44.Many variations of these pumps are offered by manufacturers for particular applications.

Pump construction features

Centrifugal pumps are generally offered in bronze-fitted, all-bronze, or iron-fitted construction. In bronze-fitted construction, the impeller, shaft sleeve (if used), and wear rings are bronze, and the casing is cast iron. These construction materials refer to the liquid end of the pump (those parts of the pump that contact the liquid being pumped).

The *stuffing box* (fig. 1–45, item 10) is that portion of the pump where the rotating shaft enters the pump casing. To seal undesirable leakage at this point, manufacturers use a mechanical seal or packing in the stuffing box.

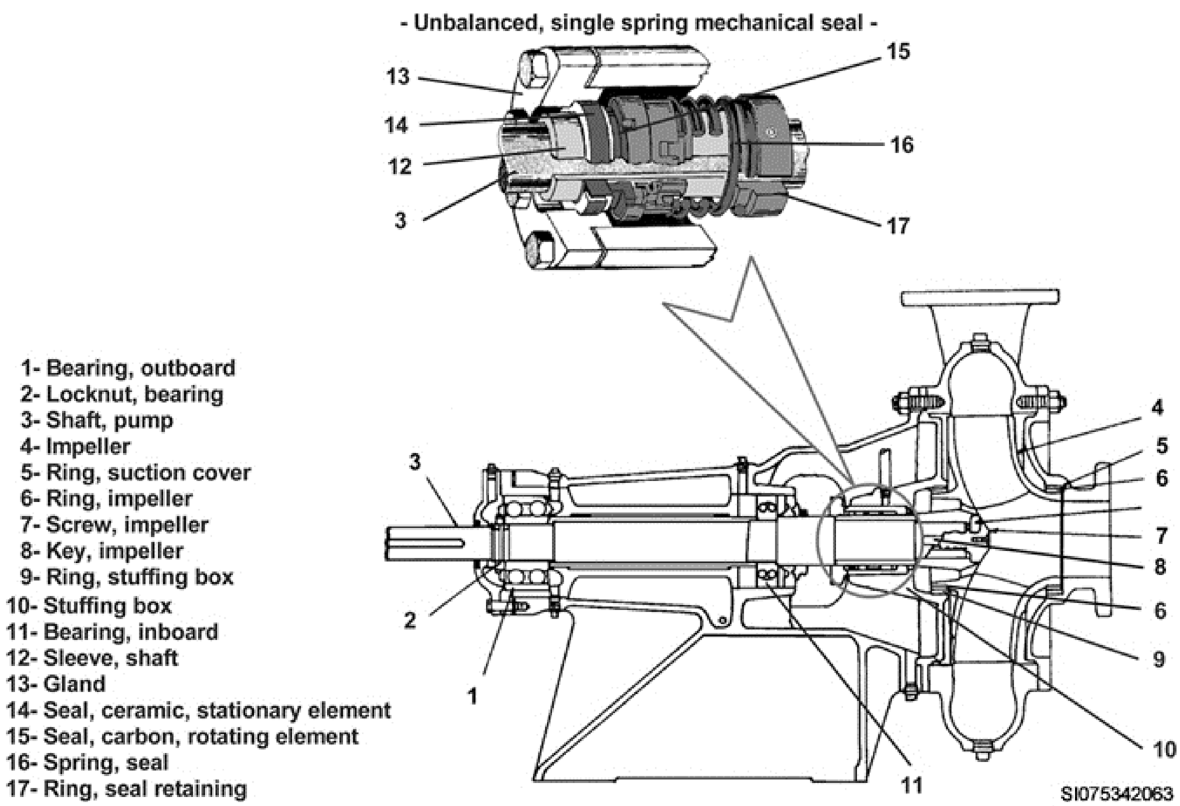


Figure 1–45. Centrifugal pump cross section.

Pumps with *packing* have been used for years if abrasive or harsh chemicals were used in the pumping loop, such as a cooling tower. Some leakage at the packing gland will be required to lubricate and cool the area between packing material and shaft. Pumps with packing are rapidly being replaced with mechanical seals since water seepage results in wasted water/money, and due to newly developed seals that can handle harsh environments.

Shaft sleeves (fig. 1–45, item 12) protect the motor or pump shaft, especially with packing.

Wearing rings are designed to prevent wear to the impeller or casing and are usually made of bronze. They are replaceable and provide a close-running clearance between the lower-pressure inlet and higher-pressure discharge region in the volute casing.

Ball bearings (fig. 1–45, items 1 and 11) are most frequently used, except in smaller pumps or "circulators," where motor and pump bearings are the sleeve type.

The *balance ring* is placed on the back side of a single-inlet, enclosed impeller to reduce the axial load. Double-inlet impellers are inherently balanced axially.

Rotation of a pump is fixed by the configuration and type of vanes and the suction and discharge connections. An arrow that indicates proper direction is often cast directly into the casing metal (fig. 1–45). In addition to proper position of the pump in the piping, rotation is also dependent on the motor or driven rotation. You must test rotation of both the motor and pump prior to operation. However, do not let pumps with mechanical seals run dry, even when you "bump" them to determine rotation.

Pumps with *mechanical seals* are used successfully in a wide variety of applications. Like pumps, many styles and types of seals are available. Unbalanced and balanced seals refer to the pressures on each side of the seal. In a balanced seal, pressures are equal on both sides of the seal. These seals which are used for higher-pressure applications, have many internal small springs controlling the pressure on the seal faces (fig. 1–46). An unbalanced seal, which has one spring controlling the pressure upon the seal faces, is most common in HVAC/R. Pressure and temperature limitations vary depending on the liquid being pumped and the style of seal. The manufacturer supplies the seal material and style after it has been informed of the type of liquid to be pumped and the temperature and pressure limitations.

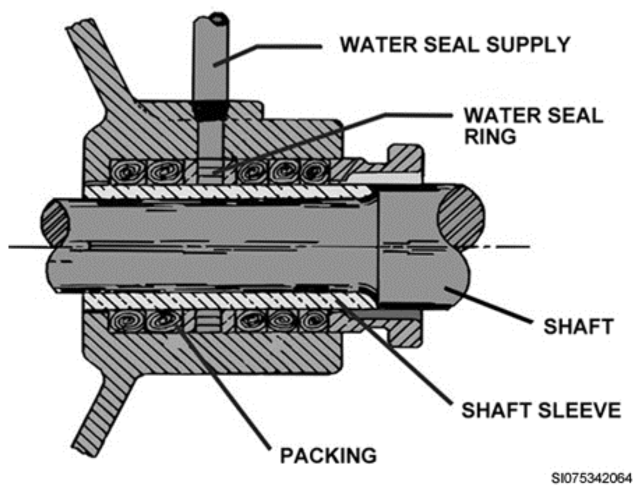


Figure 1–46. Stuffing box with packing.

Drives

A pump may be driven by any appropriate means. For the most part, HVAC/R pumps are motor driven and the shafts of the motor and pump are connected end to end by some type of coupling. Some pumps, usually those employed in pumping fuel oil, are belt driven. In this case, the belts may be used as a protective device, either slipping or breaking in the event of overload before damage to the pump can occur.

The couplings between the motor and pump shaft are made in two pieces so that technicians can disconnect the two coupling halves for removal of the pump without disturbing the motor. The coupling also serves as a means of adjustment of the pump and shaft alignment. The ideal alignment condition is that both shafts are in a straight line and concentric under all conditions of operation and shutdown. Because of temperature changes, an unequal expansion of parts causes a change of alignment during operation.

Base-mounted pumps, especially in larger sizes, require at least an alignment check in the field. This may be done in a superficial but often satisfactory way with a straightedge, since the outside perimeters of the coupling halves are machined to the same diameter and are perpendicular to each shaft. Centerlines and coupling faces must be true, as shown in figure 1–47, top view.

Operating speeds of motors usually are between 600 and 3,600 rpm, with 1,800 rpm being the most common speed. Pumps operating at higher speeds are generally less expensive; but for quieter performance, lower speeds are preferred.

Most of your older pumps were designed with a single-speed motor, but newly installed pumps and motors have been matched up to an electronic variable-frequency driver (VFD) controller. The VFD will receive an electronic input signal from your energy-monitoring control system (EMCS) or local control, to automatically maintain proper motor rpm's for the current HVAC system demands. In other words, if your HVAC system doesn't require full capacity, the VFD could run the motor at lower rpm's to save electrical energy.

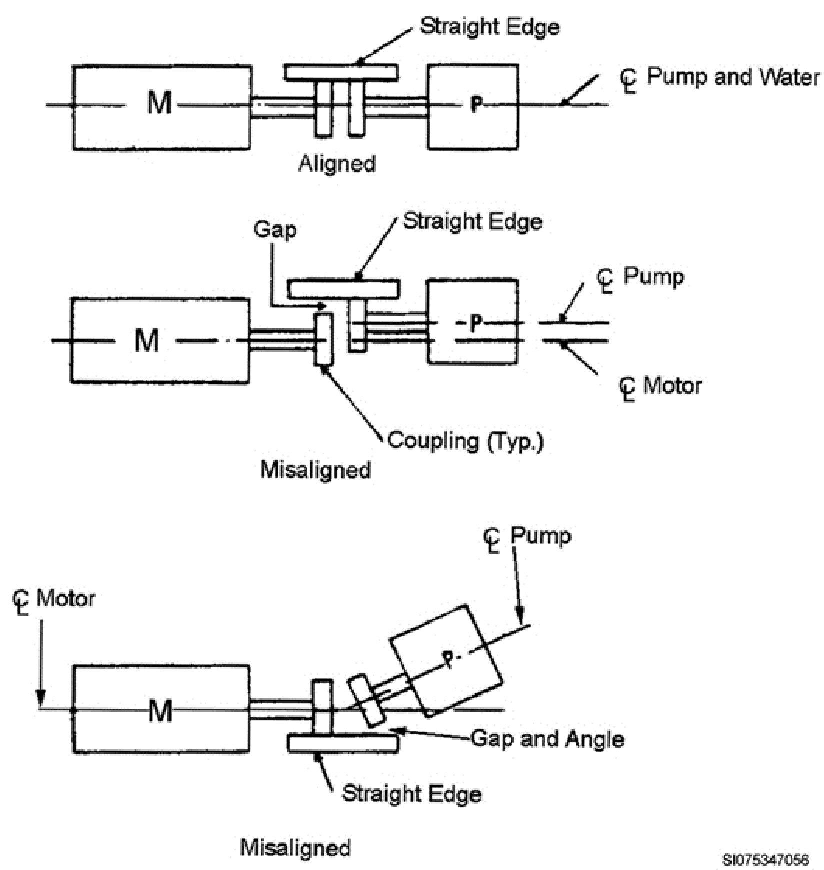


Figure 1–47. Coupling alignment with straightedge.

207. Pump maintenance

Pumps are the force that moves the water in our hydronic systems so it is crucial to keep them operating effectively. A broken pump leads to service calls and costs the Air Force time and money. A leaking pump can cost the Air Force money and it also has a cost on the environment because it is a waste of energy. Pump maintenance is not difficult but is an important task that, if ignored, could impact the mission.

Pump maintenance

Because of the wide variation in pump types, range of sizes, difference in design, and construction materials, it is quite important that you closely follow the maintenance procedures described in the manufacturer's service manuals.

Inspections

The kind and frequency of the maintenance program for pump motors varies with the size of the pump as well as the nature of the operating conditions. If the pumps are run continually, make frequent checks to note any change in pump operation. This change could be an odd noise, a large fluctuation in bearing temperatures, or leaks in a stuffing box. Visually check the pressure gauges and flowmeters, if used, to determine if they are in good condition. If recording instruments are used, make a check to see whether the pump capacity, pressure, or power consumption values call for further checks.

Lubrication

Lubricate bearings according to the type of bearing. Be sure to use the lubrication recommended by the pump manufacturer.

Stuffing boxes need considerably more maintenance than mechanical seals. Stuffing needs to be lubricated periodically and checked for fluid leaks that are more than normal. If leaks are too great, tighten the stuffing-box gland according to the manufacturer's service manual. The leakage may amount to only a few drops per minute.

Mechanical seals need little or no maintenance, but the seal can have a sudden failure that requires shutdown to change the seal. Mechanical seals made today vary in size, internal components, installation, and so forth. To ensure the seals are properly maintained, refer to the manufacturer's service manual.

Mechanical seal replacement

Mechanical seals are quickly replacing the conventional packing method used in centrifugal pumps to control leakage. This switch is due to the idea that packing methods waste resources and money, and there have been recent improvements in mechanical seals making them more flexible for all applications. Since there are so many seal types and pump configurations, we'll have to give you generic tips on how to replace the seal. The single-spring, unbalanced type will be the most common type of seal used by the HVAC/R craftsman. If you refer back to figure 1–45, you can see that, even though we are talking about one specific type of seal, there still are several different varieties to choose from.

When considering any repairs on a circulating pump, it is imperative that you find the pump manuals that explain the installation, operation, and maintenance for your specific pump when considering any repairs on a circulating pump. These manuals will give you technical data with illustrations, part descriptions, and the necessary procedures in setting up the pump. If the manuals aren't available, then consult the company that made the pump or a reputable supplier before progressing.

Seal replacement tips

In the previous paragraph, we mentioned that the single-spring, unbalanced-seal type would be the seal used in most HVAC/R applications. When observing a leaking seal, you should be looking at replacing the seal when the fluid leakage rate exceeds 5 drops per minute or when there is a need to replace the bearings. You will need to replace the seal with the exact material(s) and length that came with the pump, unless it is used for a different application than designed. There are several types of materials used for the seal faces, and they must be compatible with the type of fluid used in the system. Most HVAC/R circulating pumps in closed-loop systems require an unbalanced seal with a stationary seal face of ceramic and a rotating face of carbon. This seal is usually good for up to 250°F, with seal chamber pressures less than 200 pounds per square inch gauge (psig). If you replace the mechanical seal, then the shaft sleeve should be replaced. It doesn't always look pitted or bad, but there could be minor imperfections that could cause the seal to leak later on.

Some companies also suggest replacing the inboard and outboard bearings when replacing the seal, since these might have been the cause of initial leakage. Another thing to consider after seal replacement will be shaft alignment. Ensure the shaft is properly aligned through the pump housing past the seal chamber for proper angular and axial motion. A certain amount of motion or tolerances were designed into your particular pump that must be taken into consideration when assembling it (follow manufacturer's specifications). Also remember to properly align the pump with the motor. Lack of proper alignment with the coupling assembly could result in a bent shaft and eventually cause seal failure. An item that is sometimes overlooked and which should be inspected would be the bronze wearing ring. This ring is placed between the impeller and the volute casing. Its purpose is to provide close-running clearance between the pump's lower-pressure inlet and higher-pressure discharge region in the volute casing. This ring prevents wear to the impeller or casing, and it should be replaced if badly worn.

NOTE: Upon initial observation of a leaking circulating pump, look, listen, and feel. Look for misalignment, listen for abnormal noise, and feel for excessive vibration. These indicators will tell you what caused the problem.

Performance check

When you make *major* repairs on a pump, or if there is an indication that the system flow is not right, check the performance of the pump.

Pumps within a system react in almost the same manner as fans, and pump laws are similar to fan laws. As in fan laws, if the pump speed can be changed, the volume of liquid pumped will vary directly with the speed. The pressure or head imposed within the piping system will vary also as the square of the rpm. The power required to run the pump will vary as the cube of the rpm.

If the hydronic system was designed with a single-speed motor, we usually don't vary the speed of the pump to produce a required gallons-per-minute (gpm) delivery to the system. We normally change the impeller of the pump to one of a different diameter (within limits) or trim it to a smaller diameter. Since changing the diameter of this impeller has the same effect as changing speed, we can retest the pump laws in a different way:

1. The volume gpm varies directly with the impeller diameter.
2. The pressure or head within the system varies directly as the square of the diameter of the impeller.
3. The horsepower or power required varies directly as the cube of the diameter of the impeller.

It is more energy efficient to change the pump impeller than to throttle a pump (using a discharge valve) to change the rate of flow.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

206. Pump fundamentals

1. What effects the friction loss tables for hydronic systems?

2. What are open type systems more prone to?

3. What is the purpose of a pump for HVAC/R work?

4. Where would the greatest lift possible occur in a hydronic system?

5. How is maximum lift decreased?

6. How is the entrained air in water released?

7. What is the worst effect of a vortex on the discharge side of the pump?

8. How is suction vortex commonly caused?

9. How can some vortex-producing conditions be eliminated?

207. Pump maintenance

1. What should be done if a pump is run continuously?

2. What should be done if a stuffing box leaks too much?

3. Why are mechanical seals quickly replacing the conventional packing method?

4. What procedure is more energy efficient than throttling a pump?

1–4. Hydronic Distribution Systems

The piping and components used to circulate hot or chilled water for heating and air conditioning is called the *hydronic distribution system*. In this section, you examine the temperature classifications, types, and components of a hydronic distribution system.

A hydronic or all-water system conveys hot or chilled water to or from a conditioned space. It is also a process through which piping is connected to a boiler, water heater, or chiller with suitable terminal heat-transfer units located at the space or process. Most hydronic systems are classified as force systems in which a pump driven by an electric motor maintains the necessary flow. Water systems can be either once-through or recirculating systems.

208. Types of hydronic distribution systems

Hydronic distribution systems will be broken down two ways: classifications and designs. The importance of these system becomes clear when you consider the fact that boilers and chillers are used to help in the heating and cooling process. Boilers and chillers are equipment that heat and cool water, respectively. Once the water is conditioned it has to go somewhere. So how does the water get to where it is supposed to go? Distribution systems! The lesson will begin with the classifications.

Classifications

Hydronic systems are classified differently than pressure vessels. The American Society of Mechanical Engineers (ASME) classifies hydronic systems as “low,” “medium,” and “high” temperature,” with specific pressures relating to those temperatures. Pressure vessels are classified as either “low pressure” or “high pressure.”

Low temperature

According to the ASME boiler construction code, the maximum allowable working pressure for low-pressure heating boilers is 160 psi with a maximum temperature limitation of 250°F. The usual maximum working pressure for low-temperature-water (LTW) boiler systems is 30 psi, although boilers specifically designed, tested, and stamped for higher pressures may frequently be used with working pressures to 160 psi because of high static heads (multistory buildings).

Medium temperature

These systems operate at temperatures of 350°F or less, with pressures not exceeding 150 psi. The usual design supply temperature is approximately 250 to 325°F, with a usual pressure rating for boilers and equipment of 150 psi.

High temperature

A hot-water heating system that operates at temperatures over 350°F and pressure of about 300 psi is a high-pressure system. The maximum design supply-water temperature is 400 to 450°F, with a pressure rating for boilers and equipment of 300 psi. You must check the pressure-temperature rating of each component against the design characteristics of the particular system.

Chilled water

A chilled-water cooling system operates with design supply-water temperature of 40 to 55°F and at pressure less than 125 psi. You can use antifreeze or brine solutions for systems (usually process applications) that require temperatures below 40°F. Well-water systems may use supply temperatures of 60°F or higher.

Dual temperature

A combination hot-water heating and chilled-water cooling system that circulates hot and/or chilled water to provide heating or cooling using common piping and terminal heat transfer apparatus is a dual-temperature system. These systems are operated within the pressure and temperature limits of LTW systems, with usual winter design water temperatures in a 100 to 150°F range and summer supply-water temperatures from 40 to 55°F.

The most economical hydronic distribution system layout is one where the portion of the system with the largest flow-rate requirements has mains that are run by the shortest route to the terminal equipment. Branch, or secondary, circuits are then connected to these mains.

Hydronic distribution supply and return mains are most frequently located above hallway ceilings; above hung ceilings; in wall hung along a perimeter wall; and in pipe trenches, crawl spaces, or basements. System piping need not be run at a definite level or pitch, but may change up or down as required by architectural or structural needs. We divide water system piping into two arbitrary classifications, as identified in the following table:

WATER SYSTEM PIPING	
Classification	**Consisting of**
Pipe circuits suitable for complete small systems or for terminal or branch circuits on large systems.	Series loop. One-pipe. Two-pipe reverse-return. Two-pipe direct-return.
Main distribution piping used to convey water to and from the terminal units or circuits in a large system.	Two-pipe direct-return. Two-pipe reverse-return. Three-pipe. Four-pipe.

Series loop

A series loop is a continuous run of pipe or tube from the boiler or chiller supply connection back to the boiler or chiller return connection. Terminal units are a part of the loop. Figure 1–48 shows a system of two series loops on a supply and return main (split series loop). We can use one or many series loops in a complete system. Loops may connect to mains, or all loops may run directly to and from the boilers or chillers.

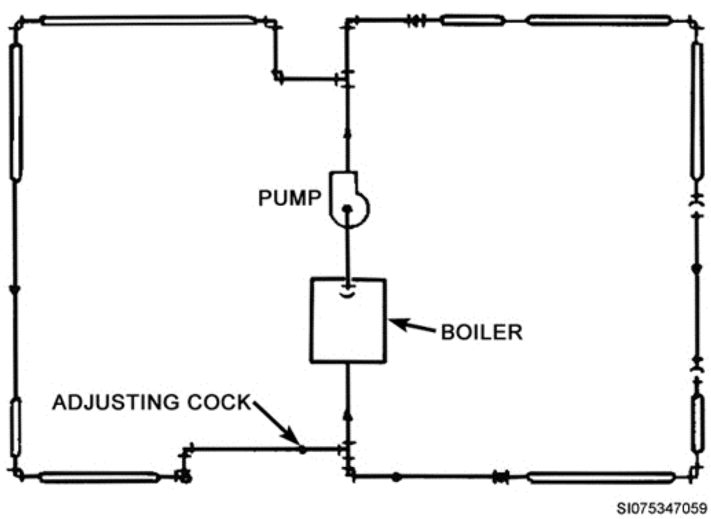


Figure 1–48. A series-loop system.

In the heating mode, the water temperature drops progressively as each room terminal unit transfers heat to the air, the amount of drop depending on the unit output and the water flow rate.

You must know the true system operating water temperature and flow rate to calculate the average water temperature (AWT) for each unit in the loop. If all terminal units are in series on one loop in one zone of interconnecting air space, you can consider the entire set of units one terminal device; you can then size all units at the AWT of the loop. One floor of a small dwelling with open interior doorways is such an interconnecting space. If individual units on a loop are in separate enclosed spaces, you must size each unit using the actual AWT for that unit.

A decrease in loop water flow rate increases the temperature drop in each unit and in the entire loop. The average water temperature shifts downward progressively from the first to the last unit in series. Unit output gradually lowers from first to last on the loop. Consequently, comfort cannot be maintained in separate spaces heated with a single series loop if water flow rate is varied. Control of output from individual terminal units on a series loop is impractical except by control of heated airflow. You can use manual dampers on natural convection units and automatic fan or face-and-bypass damper control on forced-air units.

One pipe

One pipe circuits (fig. 1–49) use a single loop as a supply and return main for each terminal unit; a supply and return tee are installed on the same main. One of the tees is a special diverting tee, which creates a pressure drop in the main flow to divert a portion of the main flow to the unit. For instance, the first terminal unit (return) diverting tee is usually sufficient for upfeed (units above main) systems. Two special fittings (supply and return tees) usually are required for downfeed units to overcome thermal head. Because diverter tees are proprietary, consult the manufacturer's literature for flow rates and pressure-drop data.

Unlike series-loop systems, one-pipe circuits allow manual or automatic control of flow to individual connected heating units. On-off rather than flow modulation control is preferred. The length of the piping loop and the load imposed on a one-pipe circuit are usually small because of its limitations.

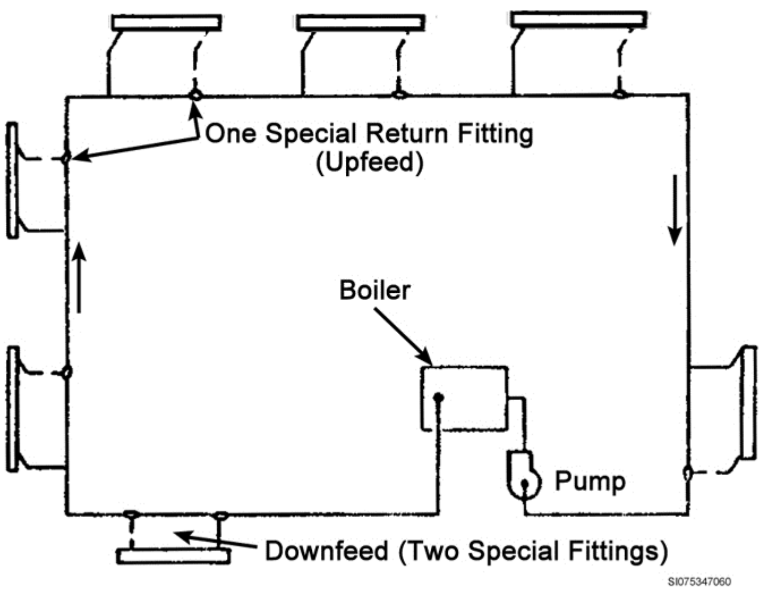


Figure 1–49. A one-pipe system.

Two pipe

Two-pipe circuits have one pipe carry water to the terminal unit and separate pipe carry water back to the boiler or chiller. There are two types of two pipes systems: direct return and reverse return.

Direct return

The direct-return returns the water about the same way it was supplied to the terminal unit (fig. 1–50). Return water from each unit takes the shortest path back to the boiler or chiller. The direct-return system is popular because less return main piping is required. Piping to and from each terminal unit will be different. The closest terminal unit will have the shortest piping arrangement and the furthest arrangement will have most piping. This creates different pressure drops throughout the unit. Because there are different pressure drops throughout the unit the water will flow at different rates. Since there are different flow rates the system will need to be balanced more carefully.

Operating (pumping) costs are likely to be higher with a direct-return system because of the added balancing fittings pressure drops at the same flow rates.

Reverse return

The reverse return, as shown in figure 1–51 return main flow is in the same direction as supply flow. The terminal unit that is closest to the boiler or chiller will have the shortest supply length but will have the longest return length. It is the *reverse* of the direct return system. After the last unit is fed, the return main returns all water to the boiler. However, circuit balancing valves are usually required on units or subcircuits. Since water flow distance from and to the boiler is virtually the same through any unit on a reverse-return system, balancing valves require very little adjusting.

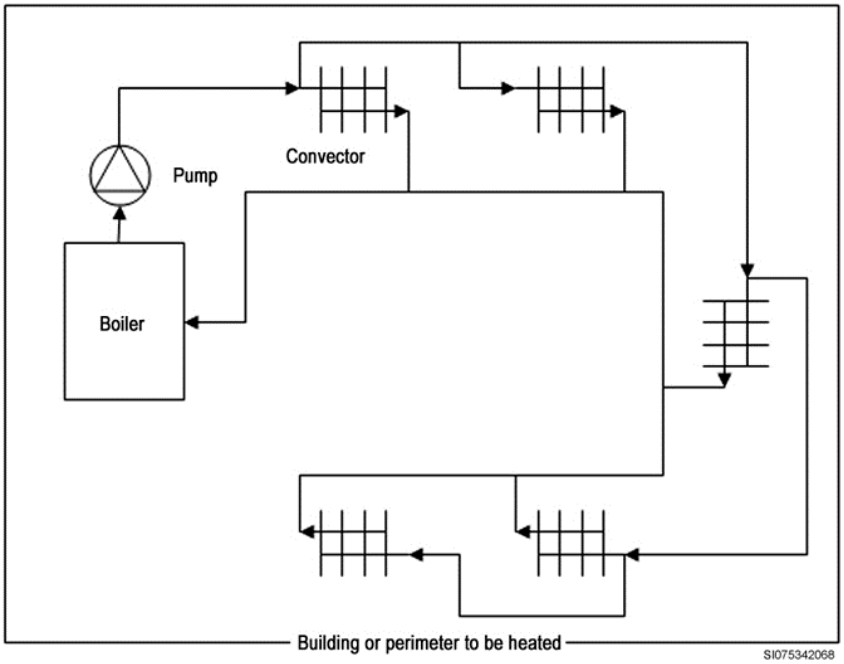


Figure 1–50. Direct-return two-pipe system.

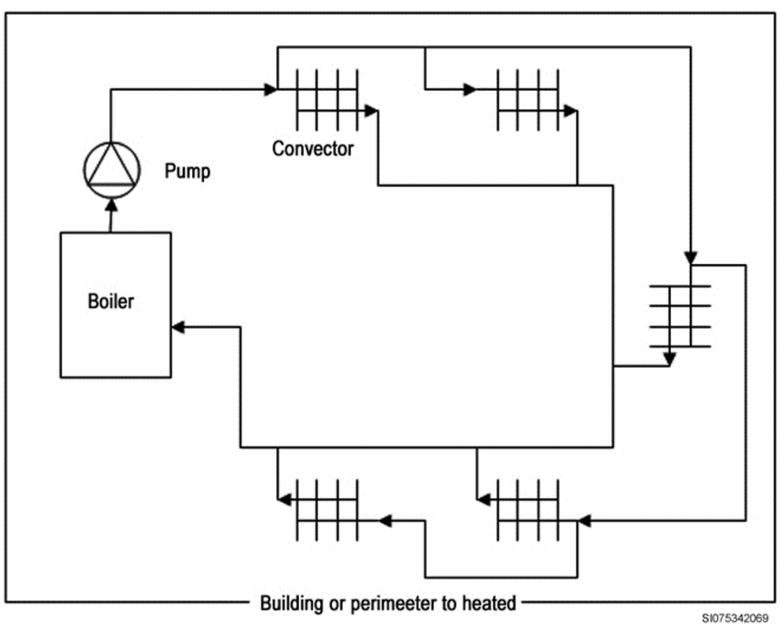


Figure 1–51. Reverse-return two-pipe system.

Combination piping

The basic piping arrangements that have been mentioned so far exist only to describe function. One type can grade into another. A piping system in a large building can contain up to all four types and, thus, cannot be described as a particular type. Figure 1–52 shows a primary circuit and two secondary pumping circuits. As pipe lengths and number of units vary, and as circuit types are combined, basic names for piping circuits become meaningless.

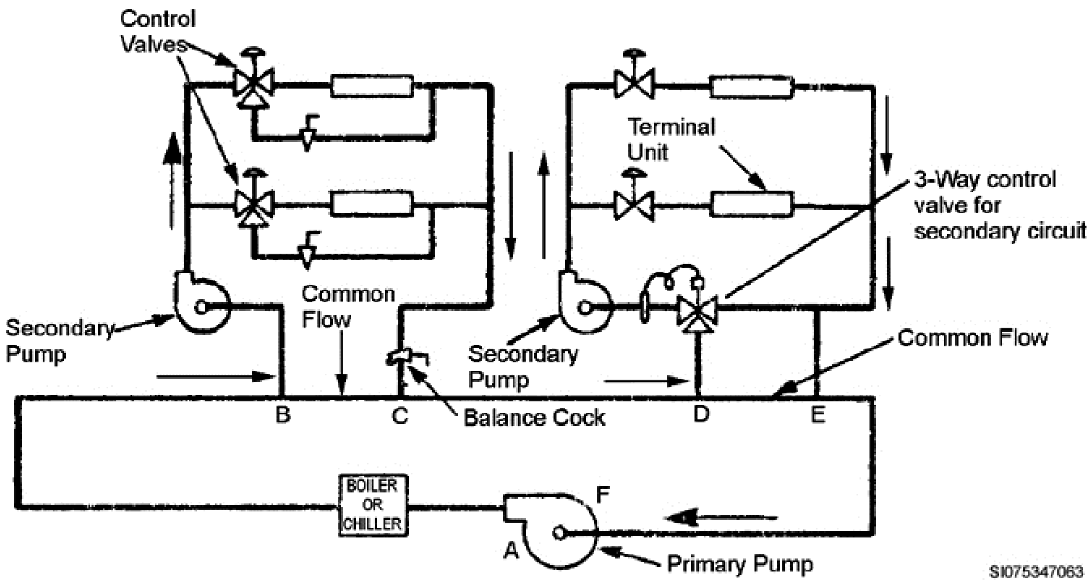


Figure 1–52. Example of primary and secondary pumping.

Three pipe

The three-pipe system normally used with induction systems satisfies variations in load by providing independent sources of heating and cooling to the room unit in the form of constant temperature primary or secondary chilled and hot water.

When used with an induction unit, the three-pipe system contains a single secondary water coil. A three-way valve at the inlet of the coil admits the water from either the hot-water or cold-water supply as required. The usual room control for three-pipe systems is a special three-way modulating valve, which modulates either the hot or the cold water in sequence, but does not mix the streams.

During periods such as spring and all, if both hot and cold secondary water is available, we can operate any unit within a wide capacity range from maximum cooling to maximum heating within the limits set by the temperature of the secondary chilled or hot water. We can operate any unit in the system through its full range of capacity without regard to the operation of any other unit in the system, recognizing the operating cost and energy penalty that results from simultaneous heating and cooling loads. We select all units on the basis of their peak capacity requirements.

The return-mix three-pipe room unit is provided with a single coil that receives either hot or cold water. A modulating three-way valve at the inlet to the unit admits either hot water or cold water to the secondary coil (fig. 1–53). The three-way valves are a special design in which the hot port gradually moves from open to fully closed and the cold port gradually moves from fully closed to open. The valves are constructed so that at midrange there is an interval in which both ports are completely closed. Room control action is the same during all seasons. Three pipe systems are not widely used anymore.

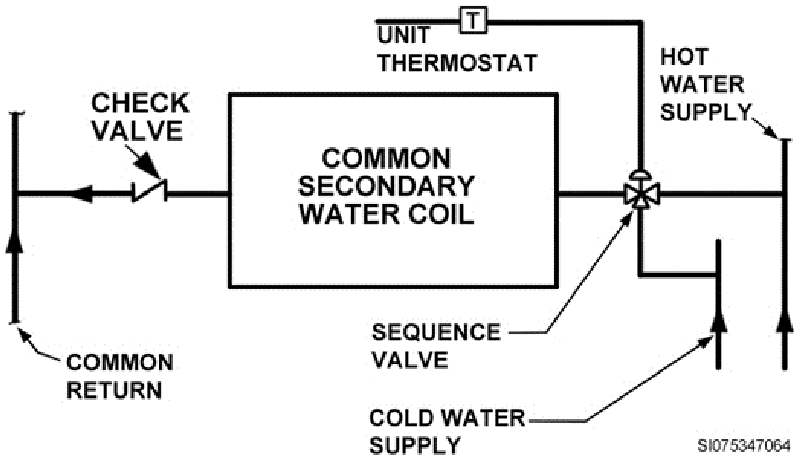


Figure 1–53. Return-mix system room unit control.

Four pipe

Four-pipe systems for induction, fan-coil, or radiant-panel systems derive their name from the four pipes to each terminal unit. These four pipes consist of a cold-water supply, a cold-water return, a warm-water supply, and a warm-water return. The four-pipe system satisfies variations in cooling and heating to the units using primary air, secondary chilled water, and secondary hot water.

The terminal unit is provided with two independent water coils, one served by hot water; the other by cold water. During peak cooling and heating, the four-pipe system performs in a manner similar to the two-pipe system, with essentially the same operating characteristics. During the period between seasons, we can operate any unit at any capacity level from maximum cooling to maximum heating with high energy consumption if both cold water and warm water are being circulated. We can operate any unit at or between these extremes without regard to the operation of any other unit (fig. 1–54).

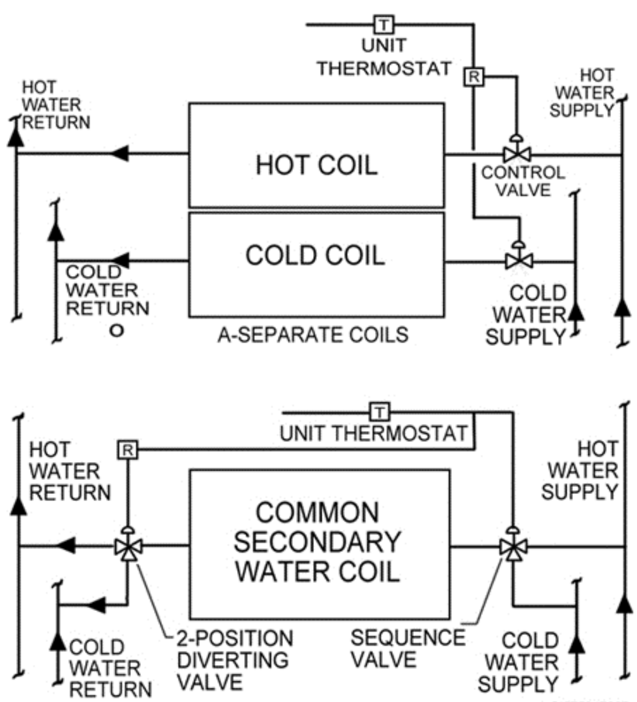


Figure 1–54. Four-pipe system room unit control.

Figure 1–54 also shows another unit and control configuration that is sometimes used. A single secondary water coil is provided at the unit, and three-way valves located at the inlet and leaving side of the coil admit the water from either the hot-water or cold-water supply.

Nowadays, it is rare in the Air Force to see a chiller and boiler running during the same season. The cost of doing this is too high. The Air Force has an obligation to spend tax payer's money wisely and not waste it. We also have an obligation to the environment and running both systems at the same time is a waste of energy.

209. Hydronic system components

Let's take a look at the components that make up the hydronic system. Hydronic devices use water to produce varying amounts of heating and cooling. Components such as boilers, chillers, pipes, terminal units, valves and coils will be covered in this section. Let's start our discussion by looking at boilers and chillers.

Boilers and chillers

Boilers and chillers are the systems that heat and cool the water, respectively. These systems will be covered later in the CDC's.

Piping

Piping is all of the copper or black iron that it takes to take the heated/cooled water from the boiler/chiller to the conditioned space. Also,

Terminal units

Terminal units fall under the same concept as they did with air systems.

Radiators and convectors

Cast-iron radiation and cabinet convectors are widely used in LTW systems. Ceiling-hung radiators are frequently used where floor space may not be available for other units. You must consider pressure limitations for cast-iron radiation. Convectors are used extensively in areas where high output is needed, where space is limited, and where linear heat distribution (such as finned-tube radiation) is not desired. Typical areas heated include corridors, entries, restrooms, storage areas, workrooms, and kitchens.

Radiators

We apply the term *radiator* to heat-distributing units composed of cast-iron hollow sections joined by nipples. Three types of radiators are now manufactured: column, small-tube, and wall. In the past, a large-tube radiator was manufactured, but it has been replaced by the small-tube (with a spacing of 1¾ inches per section), which occupies less space and can be recessed. Radiators are heated by conduction through contact with steam or hot water. They then transfer the heat to rooms or areas by radiation and convection. Usually, units that have large, exposed heating surfaces emit more radiation heat than those with concealed surfaces. The total amount of heat transferred from the radiator to the surrounding area depends on the heating surface area, average surface temperature of the unit, nature and finish of the surface, unit configuration, ambient room temperature, and location of the unit.

Place radiators where the heat loss is greatest (e.g., beneath the windows of a room). If you place a radiator along an inside wall, cold infiltrated air (which is heavier than warm air) will cross the room near the floor and chill the occupants. If you locate the radiator properly, the infiltrating air will be warmed by the radiator, rise, cross the ceiling, and go down the opposite wall before it comes in contact with the room occupants.

Radiators are rated in terms of square feet of equivalent direct radiation (EDR). Standard conditions for hot-water heating systems assume a radiator is located in still air at 70°F and is supplied with water at 180°F. The temperature of the water flowing through the radiator drops 20°F to give an average radiator water temperature of 170°F and a heat emission of 150 British thermal units (Btu) an hour per square foot of EDR. When the standard conditions vary, an installer must correct the heat emission per square foot of EDR accordingly. Use figure 1–55 to estimate radiator heat emission at different average water and room-air temperatures.

AVE. RADIATOR WATER TEMP. (°F)	EMISSION PER SQUARE FOOT OF EQUIVALENT DIRECT RADIATION (BTU/HR) ROOM AIR TEMPERATURE (°F)		
	65	70	75
170	160	150	140
175	170	160	150
180	180	170	160
190	200	190	180
200	220	210	200
210	240	230	220
215	250	240	230
230	280	270	260
250	330	315	310
270	375	360	350

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Figure 1–55. Radiator heater emissions.

The square feet of EDR depend on radiator capacity and configuration. (See the manufacturer's catalog.) The following example shows how to use figure 2–1 to estimate heat output:

> A radiator with 376 square feet of EDR, located in a room at 75°F, is supplied with water at 220°F. The temperature drop through the radiator is 20°F, the water outlet temperature is 200°F, and the average water temperature is 210°F.

Determine the total heat output of the radiator by multiplying the heat emission per square foot of EDR by the total square feet of EDR. On figure 1–55, you see that for an average water temperature of 210°F, the heat emission per square foot of EDR in a room at 75°F is 220. Therefore,

$$220 \times 376 = 82{,}720 \text{ Btu/hr, the radiator heat output.}$$

Convectors

A convector is a heat-distributing unit that operates by the convection principle. Air enters the enclosure through an opening below the heating element and is discharged at another opening above the heating element. Since the convection principle is used, no mechanical device is required to recirculate the room air through the unit. Cold air enters the convector below the heating element, is heated by contact, and is convected upward through the outlet opening of the enclosure.

The types and design of enclosures vary with requirements. Outlet air openings are usually grilled; inlet openings can be either open or grilled. Convectors may be free-standing, recessed, or wall-hung (fig. 1–56).

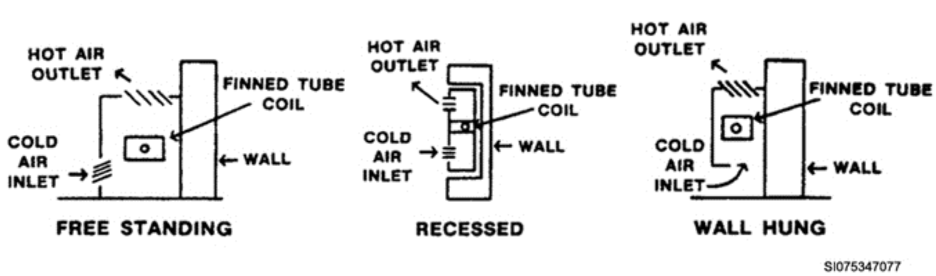

Figure 1–56. Types of convectors.

Convectors, like radiators, are rated in terms of square feet of EDR. Water ratings are normally given in Btu/hr at specified average water temperatures and temperature drops. To determine the amount of EDR, consult the manufacturer's catalog for this information, which varies with convector size and design. To determine convector heat output, multiply the square feet of EDR by the heat emission per square foot of EDR for existing water and entering-air temperatures.

Baseboard and finned-tube radiation

Baseboard and finned-tube radiation permits the blanketing of exposed surfaces for maximum comfort. Baseboard and finned-tube elements are generally rated at various average water temperatures and at one or more water velocities. Velocity corrections may be applied. Many designers feel that these units are, thus, limited to systems designed to a 20°F temperature drop. However, careful selection can result in successful application with temperature drops much higher than 20°F.

Operation

Baseboard radiation consists of long and low heating units, generally installed along the bottom of outside walls. These units resemble and replace conventional baseboards. They operate by the convection principle, although in most cases a substantial portion of their total heat output is transferred by direct radiation to cooler surfaces.

Baseboard units are suitable for use with hot-water heating systems. Below are the main advantages:

1. Ease of installation along cold walls and under areas where the rate of heat loss is greatest.
2. Heat distribution near the floor that gives a more uniform temperature from floor to ceiling.
3. Practically no interference with furniture.
4. Ease of concealment.
5. Convenience of installation (to prevent cold floors) in houses without basements.
6. Perimeter heating.
7. Even wall-to-wall temperatures.

Types of baseboard units

Baseboard units may be of three basic types: radiant, radiant-convector, and finned-tube.

Radiant

Radiant-type units are usually constructed of hollow cast-iron or steel sections. When no space is available for floor or wall mountings, the units are suspended from ceilings. However, suspended units transfer less heat by convection than do floor or wall units.

Radiant-convector

Radiant-convector units have enclosures with air inlets at the bottom and air outlets at the top. In some designs, the openings have grills or dampers to regulate the airflow. The heating elements consist of hollow cast-iron or steel sections. A large percentage of the total heat output of these units is transmitted by convection due to the design of the air inlets and outlets. These units are used for installations with high heat loss or scarce wall space.

Finned-tube

The heating elements of finned-tube baseboard units consist of tubes on which lightweight fins are mechanically bonded or embedded to increase the heating surface. The tubes may be ferrous or nonferrous (usually steel or copper) with fins of steel or aluminum. The units come in standard lengths for ease of installation. The heating elements are concealed by enclosures of several designs. The total heat output per linear foot varies by a considerable percentage according to the different designs, sizes, and materials used. In general, baseboard installations are designed for minimum output per linear foot, which compensates for the total heat losses. Units are usually installed along as much of the exposed wall as possible. When it is desirable, you can use dummy sections without heating elements to provide continuity in the installation and to simulate a conventional baseboard.

Unit ventilators

Unit ventilators, originally developed for specific application in school classrooms, are being used today in a much wider range of applications. The parts of a unit ventilator consist of a forced convection heating or cooling unit with dampers. The dampers permit introduction of controlled amounts of outdoor air to provide a complete cycle of heating, ventilating, ventilation cooling, or mechanical cooling. Condensation may be a problem during summer operation unless chilled-water flow is stopped when fans are not operating. Condensate drains are necessary. Comparatively low supply temperature and rise may be required.

Fan coil and induction

Fan-coil units are generally used, with or without outdoor air, in chilled-water/hot-water systems. The same coil is often used for both heating and cooling. Individual control is usually achieved by the use of valves or by using intermittent or multispeed fan operation. Hot-water ratings are usually based on flow rates or temperature drops at various entering water and air temperatures. Temperature drops of 40 to 60°F are frequently used. Induction units are similar to fan-coil units except that air circulation is provided by a central air system, which handles part of the load, instead of by a blower in each cabinet.

Unit heaters

Unit heaters are available in several types: horizontal propeller fan, down blow, and cabinet. They are used where high output in a small space is required and where no cooling is to be added. Cabinet units are frequently applied in corridors and at entrances to blanket doors that are frequently opened. Normally, unit heaters do not provide ventilation air.

Panel heating

With panel heating, large zones of interior room surfaces are heated to relatively low temperatures—80 to 125°F. Heat is transferred by radiation and convection from the panels to the air and surrounding surfaces. Primarily, the percentage of radiation and convection heat output will vary with location of the heated panels. More than 90 percent of the total heat output from ceiling panels is transferred by radiation; the rest by convection. The radiation heat output is less from wall panels and even less from floor panels because the ambient air, warmed by conduction through the heated surfaces (wall or floor), sets up convection currents. This effect is relatively unimportant in ceiling panels because, normally, a thin blanket of heated air lies against the ceiling and most of the heating below is by radiation.

Heat emission from heating panels is usually expressed in Btu’s per square foot of surface per hour. Emissions vary according to panel surface temperature, ambient-air temperature, and average surface temperature of unheated surfaces. The greater the temperature difference between panel surface and ambient air and between panel surface and unheated surfaces, the greater is the heat release from the panel.

Hot water panel heating systems

We divide the types of panel heaters used in hot-water heating systems into three groups: ceiling panel, wall panel, and floor panel.

Ceiling panel

For hot-water heating systems, piping or tubing is embedded in ceilings. In concrete-slab ceilings, the piping or tubing is embedded in the lower part of the slab, close to its lower surface. In other installations, pipe or tubing is embedded in a metal lath and plaster ceiling. The lath is in contact with the piping; the plaster is applied to the lath.

Wall panel

Designs similar to those described for ceiling panels are sometimes used for wall panels.

Floor panel

For hot-water systems, the piping is completely embedded in the floors and does not rest on an interface. Reinforcing steel rods, pieces of pipe or stone concrete mounts are generally used to support and position the piping. Do not use absorbent or organic material, such as wood, for this purpose. The Air Force uses panel heating most frequently to heat hangars and to melt snow. To melt snow, a mixture of antifreeze and hot water at relatively low temperature is circulated through sinuous or grid coils embedded in concrete slabs or blacktop.

Maintenance

Maintenance requirements vary with the different types of equipment, as shown in the table below:

Type of Equipment	Maintenance Requirements
Fan coils/unit heaters	• Brush and vacuum coil, fan, and housing as required. • Lubricate fan motor bearings per manufacturer's recommendations. • Check belts and sheaves. Replace as required. • Check and clean strainers. • Check steam traps and hand valves. • Inspect electrical connections, contactors, relays, and operating safety controls. • Check unit operation and adjust as required.
Induction units	• Visually inspect coil. Clean as required. • Check and clean drains and drain pans. • Clean discharge grille. • Check and clean strainers. • Check steam traps and hand valves.
Radiation	• Visually inspect fins/cast iron. Clean as required. • Check and clean strainers. • Check steam traps and hand valves.
Unit ventilator	• Brush and vacuum grilles, coils, fan, and unit interior. • Lubricate fan and motor bearings per manufacturer's recommendations. • Check belts and sheaves. Replace and adjust as required. • Check and clean drains and drain pan. • Check and clean strainers. • Check steam traps and hand valves. • Inspect filters. • Check unit operating conditions. • Lubricate and adjust dampers and linkage. • Clean and paint exterior surfaces as required.

Valves

There are many different types of valves available. One-way, two-position, proportional, and three-way are but a few. Just as there are many different types, there are many ways to control these valves. Let's look at a brief explanation of these valves.

One-way

A one-way valve is a valve that allows flow in one direction only. This type of valve prevents back flow. We may, to some extent, compare it to a diode in electronics.

Two-position

A two-position valve is one that has only an open and a closed position. Either the valve allows water to pass through an opening (port) or it stops it.

Proportional

A proportional valve has an infinite number of positions along its stroke, varying from closed to open, in which it can stop to allow a certain percentage of flow through the valve. This type of valve is sometimes called a *control* or *throttling* valve. It determines the amount of heating or cooling a particular space receives.

Three-way

Three-way valves are so named because of the three ports on the body. There are three types of three-way valves—mixing, diverting, and sequencing.

The mixing valve has two inputs marked “A” and “B” and one output, “AB.” Two seats, an upper and lower, are needed to have shutoff on either input. One characteristic of this valve is that it has a constant flow. An application for a mixing valve is shown in figure 1–57. Here the mixing valve, which is on the return side, controls flow through the coil or bypasses the coil.

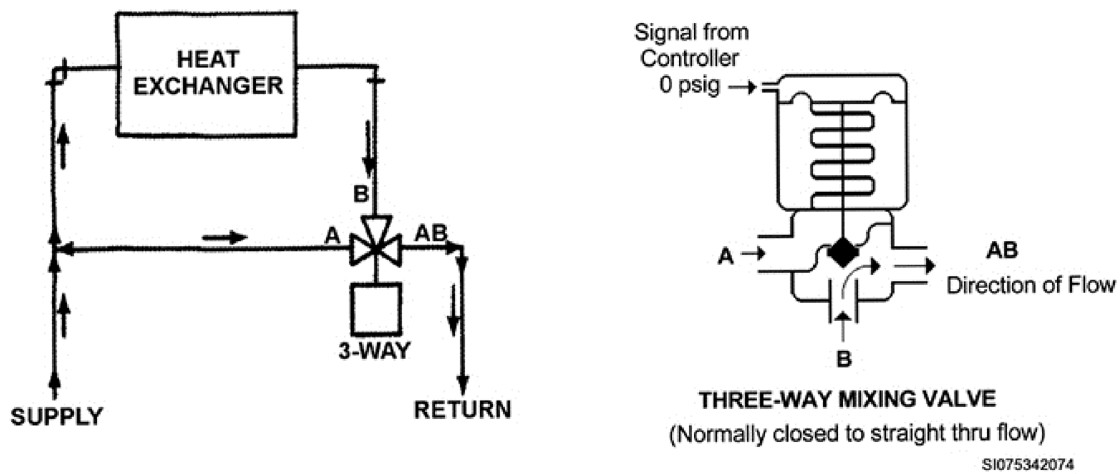

Figure 1–57. Three-way mixing valve on bypass application.

The diverting valve has one input and two outputs. Most diverting valves are labeled “B” for inlet and “A” and “AB” for outlets. The plug on this valve is a stainless-steel cylinder with vertical holes through it. These holes allow flow from B to A. There are two seats, upper and lower, for shutoff on either output.

Figure 1–58 shows a diverting valve application. The valve on the supply side diverts the flow through the coil or bypasses the coil. The mixing valve is used more often, where possible, due to the greater cost of a diverting valve.

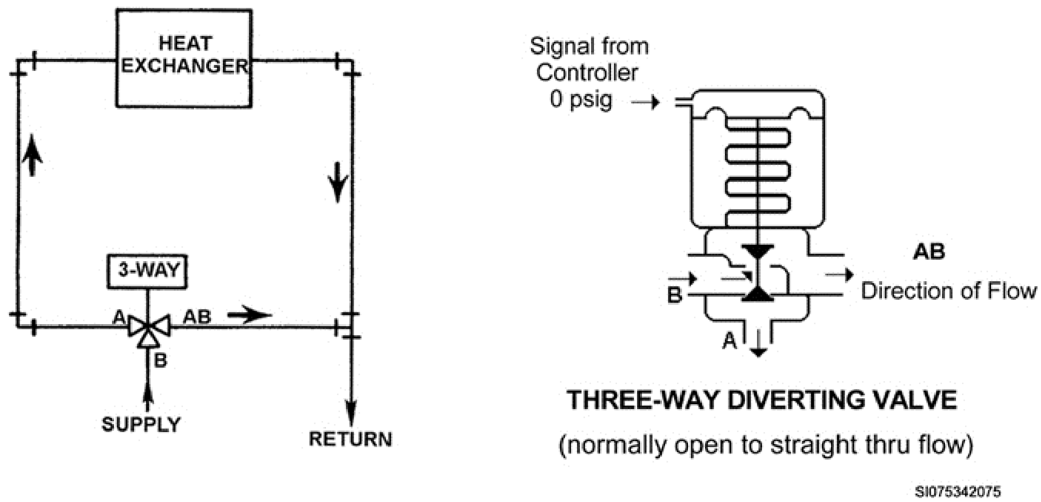

Figure 1–58. Three-way diverting valve on bypass application.

The sequencing valve also has two inputs and one output like a mixing valve, but no mixing occurs in this valve. It can be described as a two-position valve. In actual operation, there are three positions:

1. Flow from A to AB.
2. Flow from B to AB.
3. A dead band between them where no flow occurs.

Figure 1–59 shows an application of the sequencing three-way valve. Notice the physical connection resembles a two-position valve.

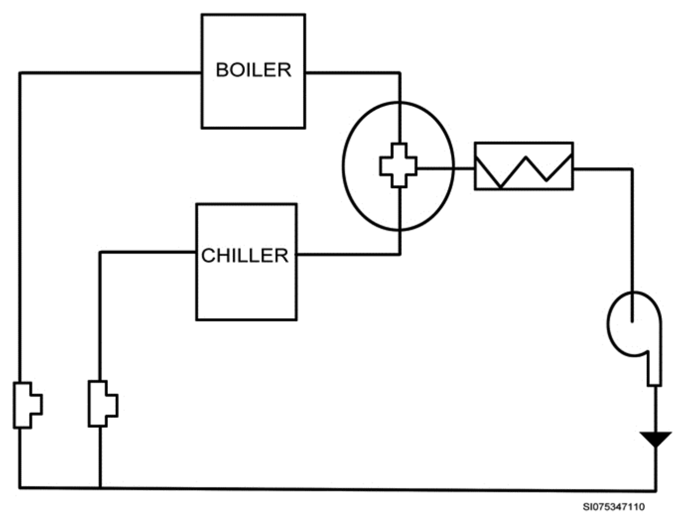

Figure 1–59. Three-way sequencing valve application.

Balancing valves

In our hydronic systems there are often more than one terminal unit that needs water supplied to it. Each terminal unit is designed to receive a certain amount of water. Balancing valves are valves that can be adjusted to allow a specified amount of water to each terminal unit. Balancing hydronic systems will be discussed more in depth in the next unit.

Flow control

This type of valve will ensure water flows in the direction that it is supposed to. Some have a bypass valve that can be used in an emergency to allow gravity circulation.

Pressure reducing

Water that comes from the city is usually much higher than the water in our HVAC/R systems. The pressure reducing valve or PRV is installed in the make-up water line to reduce city pressure to safe limits for our systems. The PRV is sometimes called a feed valve.

Mixing valves

This valve has two inlets and one outlet. It takes hot water from one inlet and cooler water from the other and mixes them. Hence the name mixing valve. The valve will receive an input of a water temperature and then determines an output temperature. The valve adjusts internally and mixes the water to create the desired water temperature. This adjustment happens automatically.

Air control and venting

If air and other gases are not eliminated from the hydronic piping flow circuit, they may cause “air binding” in the terminal heat transfer elements. This binding causes noise and/or reduction in flow in the piping circuit. Vent high points in piping systems and terminal units with manual or automatic air vents. As automatic air vents can malfunction, provide valves at each vent to permit service without draining the system. Pipe the discharge of each vent to a point where you can drain water to prevent damage to the surroundings. If the system uses a standard compression or expansion tank, you can remove free air contained in the circulating water from the piping circuit and trapped in the expansion tank by air separation devices. If the system uses a diaphragm-type tank, vent all air from the system.

Water coils

The performance of water coils depends on the elimination of air from the water circuit and proper distribution of water. Unless it is vented, air may accumulate in the coil tube circuits and cause a reduction in thermal performance and possible noise or vibration in the piping system. Air vent connections are usually provided on the coil water heaters. Depending on performance requirements, the water velocity inside tubes usually ranges from approximately 1 to 8 fps and the design water-pressure drop across coils varies from about 5 to 50 feet head of water.

Chilled-water coils

Manufacturers’ ratings are listed for 300 to 800 fpm face velocity. Carryover is possible from wet coils at 800 fpm. Coils are manufactured with various water circuits to obtain 1 to 8 fps water velocity and with various fin spacing, face areas, length, number of rows of tubes, and direction of airflow. This permits a wide selection of coils to meet almost any structural condition and air-conditioning performance requirement.

Hot-water coils

Comfort heating systems employing hot water usually require not more than one or two rows of tubes in the direction of airflow in order to produce the desired heating capacity. To produce the most efficient capacity without excessive water-pressure drop through the coil, various circuit arrangements are used.

A single-tube serpentine circuit arrangement can be used on small-size booster heaters that require small water quantities up to a maximum of approximately 4 or 5 gpm. With this arrangement, a single tube handles the entire water quantity, provided the tube is circuited in such a manner that it makes a number of passes across the airstream. When hot-water coils are used with entering-air temperatures below freezing, give consideration to piping the coil for parallel flow rather than counterflow. This provides the highest water temperature on the air side. Coils piped for counterflow have the water entering the coil in the tube row on the leaving-air side of the coil. Coils piped for parallel flow have the water entering the tube row on the entering-air side of the coil.

Coil rating

Steam and hot-water coils are usually rated within the limits shown in the following table, but these limits can be exceeded for special applications:

Steam and Hot-Water Coils	Limits
Air face velocity	Between 200 and 1,500 fpm, based on air at standard density of 0.075 lb./cu ft.
Entering-air temperature	20 to 100°F for steam coils; 0 to 100°F for hot-water coils.
Steam pressures	From 2 to 250 psi at the coil steam supply connection (pressure drop through the steam control valve must be considered).
Hot-water temperatures	Between 120 and 250°F.
Water velocities	From 0.5 to 8 fps.

Coil heat transfer

In HVAC systems, it is practical to consider that in a heating coil or heat exchange device, the heat rejected by one fluid is equal to the heat absorbed by the other fluid and that the amount lost to the surroundings is negligible. Using the specific heat of water calculation (C_p = 1.0 Btu/1 lb. °F), we can obtain the amount of heat transferred per hour by using the following equation:

$$Q = 500 \times \text{gpm} \times \Delta T$$

Where:

Q = heat flow (Btu/hr)

gpm = gallons per minute

ΔT = temperature difference (°F)

Example:

Find the heat flow when a heating coil with a water flow of 140 gpm has a 20°F ΔT.

$$Q = 500 \times 140 \times 20$$
$$Q = 1{,}400{,}000 \text{ Btu/hr}$$

Water heat exchangers

Water heat exchangers are designed for pumped flow of boiler water through their shells. Baffles mounted on the tube bundle direct the water flow across the tubes through the length of the heat exchanger. The hot-water supply enters at the bottom of the shell and leaves at the top opening, which permits any entrained air to follow the water flow.

Depending on its elevation above the boiler, convection flow may exist when the circulating pump is not running. In many cases a flow control valve is installed to prevent gravity circulation when the pump is not energized.

The medium being heated passes through the tubes as directed by the exchanger construction. In most instances, the tube bundle consists of U-bend–type construction and makes it possible to have two, four, or six pass flows through the heat exchanger by providing the proper partitions in the head.

For the two pass flows, water enters the bottom head opening, passes through the bottom section of the tube bundle first, and then passes through the top half, leaving by way of the top opening. Notice that although the hottest water also enters the shell due to the action of the baffles, it is controlling the coldest water in the shell of the exchanger. This maintains the largest temperature differential between the medium in the tubes and the medium in the shell at all times.

For the four-pass operation, the head openings are side by side in the top half of the head with a vertical partition separating them. The water makes two passes through each half of the tube bundle for a total of four passes. Additional head partitions are used to provide a total of six passes of water.

Drains and shutoffs

Equip all low points with drains. Make provisions for separate shutoff and drain valves for individual equipment so you do not have to drain the entire system for service or repair.

Balance fittings

Install balance fittings or valves as needed to permit balancing of individual terminals and major piping subcircuits.

Pitch

You can run hydronic piping level, providing you maintain flow velocities in excess of 1½ feet per second (fps). Otherwise, pitch the piping up in the direction of flow to a high point containing an air vent or a run out up to a room terminal unit.

Strainers

Use strainers where necessary to protect equipment in the system. Analyze strainers placed in the pump suction carefully and size them large enough to avoid cavitation. Large separating chambers are available that serve as main air venting points as well as a dirt strainer ahead of pumps. Automatic control valves or spray nozzles operating with small clearances or openings require protection from pipe scale, gravel, welding slag, and so forth, which may readily pass through the pump and its protective separator. Individual fine mesh strainers often are required ahead of each control valve. Condenser water systems without water-regulating valves do not necessarily require a strainer. If the system uses a cooling tower, strainers provided in the tower basin or at the pump are usually adequate.

Thermometers

Install thermometers or thermometer wells to assist the HVAC/R mechanic in troubleshooting. Use permanent thermometers with correct scale range and separable sockets at all points where temperature readings are regularly needed. Install thermometer wells where readings are needed only during start-up and balancing.

Flexible connectors

Flexible connectors are recommended at pumps and machinery to reduce pipe vibration. Vibration can be transmitted through the water across a flexible connection and can reduce the effectiveness of the connector. Flexible connectors can also help prevent damage caused by misalignment of equipment piping.

Gauge connectors

Install gauge cocks at points where pressure readings are required. Note that gauges permanently installed in the system deteriorate due to vibration and pulsation. Usually, they cannot be counted on to be reliable when you need them.

Pump location

Pump location varies with the size and type of system. Sometimes pumps are in the supply main from the boiler and/or chiller, while other times it has the pump in the return piping. Also, you may see that the system has three pumps: two pumps acting as secondary pumps on the boiler/chiller supply lines and a primary pump on the return line. HVAC/R system engineers often design a hydronic system that they are familiar with, but the size of the system and the types of circuits are big factors on how it is designed.

Maintenance

Maintenance of coils, regardless of the type, is essential if acceptable design heat transfer is to be maintained. The type of coil is not as important as the principle behind maintaining a clean coil. It is always advisable to check with the manufacturer's instructions or the local policies regarding the cleaning and/or maintenance of coils.

Cleaning

When they are in constant use, most finned coils gather dirt and coatings that cut down on their heat transfer. It is clear that the coils must be cleaned if the system is to work as it was designed to do. Use the following steps as a guide to cleaning coils; modify the steps as the need of any one coil requires.

1. Take out the access panels for the coil. If they are placed in a duct section, remove the access panels on each side of the coil.
2. Isolate the ducts in and out of the coil by taping plastic over the open ends so that no dirt from the coil gets in the ducts.
3. Remove as much loose dirt and lint as possible with a vacuum cleaner.
4. Use a commercial coil cleaning fluid to clean the coil. There are several solvents on the market. Check to ensure the one you use is approved by the coil manufacturer. Spray the solvent on the coil in full compliance with the instructions.
5. Wash the coil with a spray of water after the cleaning agent has been on the coil the recommended length of time. Do not use too high a pressure for it can bend the fins. Do not place the stream at an angle to the fins since this might also bend them. Flush the coils by directing the stream straight through as the air would flow.
6. Use a wire brush to clean the drip pan and any panels that show rust. Take care not to damage the coil fins while using the brush.
7. Flush the drip pan and drain line until they are clean. If there is a trap, be sure that it is clean and water drains freely.
8. Measure the number of fins per inch and get a fine comb with its number of teeth equal to the number of fins to use in straightening any fins that are bent.
9. If the coil is not as clean as it should be, examine it and go through the cleaning procedure again.
10. Paint the drip pan and any panels that need painting with a good moisture-proof paint.

Tube fouling

Fouling or scaling on the inside of the tubes is caused by a buildup of various solids that deposit on the surfaces. Fouling cuts down the heat transfer and water flow, both of which have the effect of reducing the system's capacity. Tube fouling generally results from corrosion. Rust or sludge deposits usually build up on the inner tube surfaces. You can remove them with a good brushing. However, coils that are built to be cleaned by mechanical means are rare. In some cases, fouling is severe enough to require chemical cleaning. The time required to clean up the system depends on the extent of contamination; however, in most cases, 24 hours is adequate. Any closed system sufficiently fouled to require chemical cleaning is the victim of severe and abnormal corrosion; have it checked by the base corrosion engineer before you return it to service. After cleaning, drain and thoroughly flush the system.

Winterizing

If a water coil is used just in the summer season, it may need to be winterized, depending on the winter inlet temperatures. If freezing temperatures are possible, the coil must be protected either by draining and drying or by antifreeze. In both cases, close the main inlet and outlet valves. The ways in which the coil can be drained may vary depending on the coil manufacturer's design, but usually you can open the vent and drain connections to let the coil drain. In some cases, you must use air to force the water from the coil.

The purpose of the heat exchanger is to cause an exchange of heat between the medium in the tubes and the medium in the shell. Most commonly, heat exchangers are used to heat water from steam. There are, however, applications where high-temperature water is used to heat lower-temperature water. Likewise, in cooling applications, low-temperature chilled water at 40°F is used to chill other water at 50°F; refrigerants are used to chill water, also. In general, the medium being heated or cooled circulates through the tubes, while the medium doing the heating or cooling is in the shell.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

208. Types of hydronic distribution systems

1. What can you use with process applications below 40 degrees?

2. What is the most economical hydronic distribution system layout?

3. What do you need to calculate the average water temperature?

4. On a direct return system, the closet terminal unit will have the shortest piping and the furthest arrangement will have the most piping, what does this create?

5. How much adjustment is needed on a reverse return system?

6. What position are the ports of a three way valve if the valve is at midrange?

209. Hydronic system components

1. What does the total amount of heat transferred from a radiator to the surrounding area depend on?

2. What mechanical device is used with convectors?

3. Where is the pressure reducing valve installed?

4. What does the performance of water coils depend on?

5. Why are flexible connectors recommended at pumps?

6. During preventative maintenance of drip pans and panels, what may you need to do?

7. What does fouling on the inside of tubes cause?

Answers to Self-Test Questions

201

1. Under ideal conditions with minimal obstructions to the fan inlet or discharge.
2. The fan inlet or outlet.
3. That there is a standard developed to regulate actual structural limitations of the wheels, bearings, and housing of fans.
4. Airfoil wheel are more efficient and run at slightly higher top speeds for the same volumes of air.
5. Where dust or fumes would adhere to blades.
6. Dust collecting on fan blades.
7. The fan to become unbalanced.
8. They have straight blades that are largely self-cleaning.
9. When dealing with kitchen grease.
10. A low volume of air movement is needed.
11. On the fan.
12. Provides less slippage.
13. The existing belt(s) will have a tendency to flap around if you don't.
14. Could lead to premature belt failure, higher belt temperatures and premature wear.
15. They could become a dangerous projectile.
16. Remove it from service and give it a thorough cleaning.
17. Balance the impeller through the use of a vibration analyzer.

202

1. One.
2. Situations where variations occur almost uniformly throughout the zone served or where the load is stable.
3. Only if 100 percent outdoor air is used for cooling purposes.
4. Hot and cold air.
5. Zone thermostats.
6. The first is to have the main blower change its speed. As the blower speed is reduced the air flow it provides is also reduced. As it speeds up, the air flow increases. The second way to vary the amount of air is using individual terminal units that are placed before each zone.
7. The system pressure changes.
8. Begin to close.

203

1. To minimize the resistance of the extra rain breaks in the blades.
2. Equip them with backdraft dampers.

3. Heat recovery equipment.
4. For ease of maintenance and to provide the highest degree of air cleanliness feasible or required by the installation.
5. The pollutants liquefy and are held in place.
6. In the return run.
7. To control the flow of air.
8. Butterfly dampers.
9. Since there is no on or off of the fan there is less sound disturbance in for the building occupants. Another reason to use the series flow is for areas that require constant air flow.
10. Intermittently.

204

1. Dust mites and their remains that are in the dust.
2. Dining facility or hospital.
3. Moisture and high humidity.
4. Temperature and humidity.
5. Decreased fresh air infiltration, the release of fumes, moisture infiltration, habits of the occupants and a lack of maintenance for the HVAC/R system.
6. SBS is confirmed when about 20 percent or more of building occupants have symptoms of drowsiness, fatigue, respiratory problems and eye or skin irritation.

205

1. To remove the source of contamination.
2. In the fall and the winter.
3. Remove the source, reduce the output, or dilute the space ambient air with odor-free air from other areas or from outdoors until the concentration of the odor is undetectable. We can also remove odors chemically or physically by air washing, chemical reaction or adsorption, oxidation, vapor neutralization, and combustion
4. Sealing cracks in floors and walls may help to reduce radon. In other cases, simple systems using pipes and fans may be used to reduce radon.

206

1. Vary in value depending on the condition of the piping system and the type of pipe or booting used.
2. To corrosion causing higher friction in the piping, thereby having a greater pressure loss per 100 feet of pipe.
3. To establish fluid flow and to produce enough pressure to overcome the resistance of a system and the system components at the required design flow rate.
4. If there were a perfect vacuum at the pump suction.
5. Decreased due to the friction of the pipe, the strainer, fittings and the inlet flange.
6. This air is released because of an increase in fluid temperature, a decrease in fluid pressure, or because of the fluid vapor pressure described above.
7. Noise.
8. By placing the suction pipe termination too close to the surface of the system liquid.
9. With proper piping.

207

1. Make frequent checks to note any change in pump operation.
2. Tighten the stuffing-box gland.
3. The idea that packing methods waste resources and money, and there have been recent improvements in mechanical seals making them more flexible for all applications.
4. Changing the pump.

208

1. Antifreeze or brine solutions.
2. One where the portion of the system with the largest flow-rate requirements has mains that are run by the shortest route to the terminal equipment.
3. The true system operating water temperature and flow rate.
4. Different pressure drops throughout the unit.
5. Very little.
6. Closed.

209

1. The heating surface area, average surface temperature of the unit, nature and finish of the surface, unit configuration, ambient room temperature, and location of the unit.
2. Since the convection principle is used, no mechanical device is required to recirculate the room air through the unit.
3. Installed in the make-up water line to reduce city pressure to safe limits for our systems.
4. Elimination of air from the water circuit and proper distribution of water.
5. To reduce pipe vibration.
6. Paint the drip pan and any panels that need painting with a good moisture-proof paint.
7. Fouling cuts down the heat transfer and water flow, both of which have the effect of reducing the system’s capacity.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

1. (201) What affect will dust on fan blades have on heat transfer?
   a. It will reduce heat transfer.
   b. It will increase heat transfer.
   c. It will maintain heat transfer.
   d. It will add heat to due latent heat in the dust.

2. (201) Where do you view the rotation and discharge of a centrifugal fan?
   a. Looking from above.
   b. From behind the fan.
   c. On the pull side.
   d. On the drive side.

3. (201) Why are vanes used in the vane axial fan?
   a. To decrease total duct pressure.
   b. To increase total duct pressure.
   c. To cause turbulence of the straight moving air.
   d. To straighten out the spiraling motion of the air.

4. (201) What will allow a sheave to be used on different diameter shafts?
   a. Shafts.
   b. Bearings.
   c. Bushings.
   d. Shaft thinner.

5. (201) Where will the classic V-belts (A through E) be used?
   a. Medium horsepower applications.
   b. Low horsepower applications.
   c. High horsepower applications.
   d. The highest of all horsepower applications.

6. (201) If you have four belts and one is bad, how many should you replace?
   a. 1.
   b. 2.
   c. 3.
   d. 4.

7. (202) In a single-duct unit, why is the manual damper left in its initial position?
   a. To provide a constant pressure decrease.
   b. To provide a constant pressure increase.
   c. To maintain a constant airflow through the box.
   d. To vary the amount of airflow that is allowed through the box.

8. (202) Which design(s) do multiple-path systems use?
   a. Multiple cooling duct boxes or a separate supply duct to each zone.
   b. Single-blended variable boxes for variable flow.
   c. Separate cold- and outside-air duct distribution systems or single-blended variable boxes.
   d. Separate cold- and warm-air duct distribution systems or separate supply duct to each zone.

9. (202) Why are multi-path, multi-zone systems limited to smaller areas?
   a. Because of the dual-duct design.
   b. Because the fans on these systems are weaker.
   c. Because of the multiple runs of single-zone ducts.
   d. Sheet metal does not come in any larger sizes for these systems.

10. (202) If a cooling demand is reduced in a building, what will the supply dampers do?
    a. Begin to close.
    b. Begin to open.
    c. Open 100 percent.
    d. Shut immediately.

11. (202) What is one reason for the use of terminal reheat?
    a. To only control the temperature.
    b. Terminal reheat is used in every HVAC/R system.
    c. Make up for steady temperatures around the perimeter of a building.
    d. Allow zone or space control for areas of unequal loading.

12. (202) What makes an independent variable air volume (VAV) system truly independent?
    a. They can control the maximum and minimum cfm that can be supplied from the box.
    b. It is controlled by the main duct static pressure sensor.
    c. They rely on the static pressure in the primary air duct.
    d. It has no physical connections to the primary air duct.

13. (203) How do you prevent carryover into the ductwork while using atomizing sprays?
    a. Using an adsorbent.
    b. Using velocity pressure.
    c. Using static pressure.
    d. Using an eliminator or filter.

14. (203) When is the use of a return air system generally essential?
    a. On smaller systems.
    b. On larger systems.
    c. On medium systems.
    d. On every HVAC/R system.

15. (203) What is the result of a dirty or clogged filter?
    a. Resistance to flow and reduced efficiency.
    b. Increased airflow and reduced efficiency.
    c. Decreased airflow and increased efficiency.
    d. Increased heat transfer.

16. (203) What causes the adjacent blades on an opposed-blade damper to move in opposite directions?
    a. A linkage.
    b. Load wiring.
    c. A volume damper.
    d. The parallel design.

17. (204) What does carbon monoxide combine with to interfere with the oxygen supply?
    a. Tobacco smoke.
    b. Other air pollutants.
    c. Hemoglobin.
    d. White blood cells.

18. (204) What will affect a person's sensitivity to an odor?
    a. Time of the year.
    b. White blood cells.
    c. Temperature and humidity.
    d. Time of the day or time of year.

19. (204) What can make locating an indoor air quality issue difficult?
    a. Static pressure.
    b. High velocity pressure.
    c. The different sensitivities of people.
    d. An overwhelming amount of trouble calls.

20. (205) How can air be cleaned?
    a. By cleaning the condensate drain of debris.
    b. By filtering the air and cleaning the ductwork.
    c. By reducing static pressure to cause particles to fall out of air.
    d. By increasing the velocity pressure to eliminate particles.

21. (205) What should be considered while planning the ventilation for odor control?
    a. The number of occupants in the facility.
    b. Decreases in heat load and the availability of air of inadequate quality.
    c. Decreases in heat load and the availability of air of adequate quality.
    d. Increases in heat load and the availability of air of adequate quality.

22. (206) When would the greatest pump lift possible occur?
    a. With the biggest pump possible.
    b. When there is the minimum water flow possible.
    c. If there were a perfect vacuum at the pump suction.
    d. If there perfect pump discharge conditions.

23. (206) What may cavitation cause?
    a. Pitting and extremely high discharge pressures.
    b. Pitting and wearing of the impeller.
    c. Pitting and wearing of seals.
    d. Pitting and vortex.

24. (207) What should be done if a stuffing box leaks too much?
    a. Lubricate the bearings.
    b. Seal the packing with grease.
    c. Tighten the stuffing-box gland.
    d. Tighten the mechanical seal.

25. (207) A leaking seal is replaced when the fluid leakage rate exceeds
    a. 1 drop per minute.
    b. 3 drops per minute.
    c. 5 drops per minute.
    d. 7 drops per minute.

26. (207) What should you check when you are making major repairs on a pump?
    a. Static head.
    b. Suction lift.
    c. Total static head.
    d. The performance of the pump.

27. (208) In a series loop system, how does unit output change from the first to last unit?
    a. It stays uniform throughout.
    b. It gradually lowers.
    c. It quickly lowers.
    d. It gradually increases.

28. (208) What is required for one-pipe down feed units to overcome thermal head?
    a. Two special fittings.
    b. Three special fittings.
    c. Two check valves.
    d. Three check valves.

29. (208) Why does a direct return system need to be more carefully balanced?
    a. Because the check valves cause uneven flow.
    b. Because all the units have the same flow rate.
    c. Because of the special tees installed.
    d. Because there are different flow rates.

30. (209) Where should radiators be located?
    a. Where heat loss is the greatest.
    b. Where heat loss is the least.
    c. Where there is no heat loss.
    d. Where there is the greatest heat gain.

31. (209) What does the square feet of equivalent direct radiation depend on?
    a. The piping to the radiator.
    b. The supply piping to the radiator.
    c. Radiator capacity and configuration.
    d. Radiator location and configuration.

32. (209) What effects are caused by air binding in a piping circuit?
    a. Noise and reduction in flow.
    b. Increased heat transfer.
    c. Increased system efficiency.
    d. Air kept where it needs to be.

33. (209) What flow arrangement should be used when hot water coils are used with freezing temperatures?
    a. Four pipe versus three pipe system.
    b. Three pipe versus four pipe system.
    c. Parallel-flow rather than counter-flow.
    d. Counter-flow rather than parallel-flow.

34. (209) What should all low points be equipped with in a hydronic system?
    a. Pump discharges.
    b. Take offs.
    c. Intakes.
    d. Drains.

Please read the unit menu for unit 2 and continue ➔

Student Notes

Unit 2. Air and Hydronic Balancing

SYSTEM OPTIMIZATION means the act of making a system as perfect, effective, or functional as possible. Any air-conditioning system must be balanced if it is to operate with optimum efficiency and satisfaction. Balancing is the regulating of the correct flow of air and water throughout the system. We cover procedures for balancing air and water distribution systems in this unit.

2–1. Air Balancing

Air distribution systems are designed to condition the air within the system and then to distribute this treated air to the proper place, in the proper amounts, and with the least possible annoyance to people. The old techniques of simply turning on the fan and listening to it running, feeling the air coming from outlets with your hand, blowing cigarette smoke at it, or letting a tissue flutter in the breeze are about as technically accurate as is tuning the motor of a car by only listening to it. Air balancing is needed to ensure that the right quantities of air are being delivered to individual outlets to satisfy space loads as per design. It is also necessary to ensure that the fan is pumping out the correct total quantity of air.

Before you begin balancing a system, there are mental procedures, safety precautions, and equipment and system checks to consider. You should know about flow and pressure basics, fans, drives, air diffusing equipment, pumps, and so forth. After you review and think about these items, you and a technician are ready to proceed with the system balancing procedures. To familiarize you with the needed information, let's begin with flow and pressure basics.

210. Basic ductwork designs

Our purpose is to deliver the correct quantity of air to the conditioned space as it needs it. This will ensure the comfort of the occupants and that any mission critical equipment is maintained at its design temperatures. The air delivered to the conditioned space is called the supply air or primary air. The supply air is brought to the terminal units, registers, grilles or diffusers via the supply duct system.

Before the types of duct configurations are discussed it is important to know more about the supply duct system. One of the most important aspects of duct design is ensuring the ductwork is sized properly. Ductwork can either be properly sized, oversized or undersized.

If the ductwork is oversized then it will present some critical issues. The initial issue is that oversized ductwork is more expensive to install. If the designer of the building did some math wrong and selected ductwork that is too large, then it will cost the Air Force more money than necessary to install it. The oversized ductwork will now cause the air to move slower than needed. Components such as diffusers and grilles are designed to have the air moving at a certain speed for it to function properly. Below is a math example to enhance your understanding:

$$\text{Air Volume (cfm)} = \text{Air velocity (ft/min)} \times \text{Cross sectional area } (\text{ft}^2)$$

Not a math wizard? Don't worry, let's break down each component. First, air volume. Air volume is the amount of air moving through our system. It is commonly measured in cubic feet per minute or cfm for short. The second component, air velocity, is how fast the air is moving. As you can see, it is measured in feet per minute. Finally, we have the cross sectional area of the ductwork. This relates to the size of the ductwork. So there are three factors here: volume, velocity and cross sectional area. Let's talk about how changing the cross sectional area affects the air velocity. Remember air velocity must be accurate at our diffusers and grilles. For the sake of easy math, use a cfm of 100 and a cross sectional area of .5 ft^2. Now look at the equation below:

$$100 \text{ cfm} = \text{Air velocity (ft/min)} \text{ X } .5 \text{ ft}^2 \text{ (divide the } .5\text{ft}^2 \text{ on both sides)}$$

$$\text{Air velocity (ft/min)} = 100 \text{ cfm}/.5\text{ft}^2$$

$$\text{Air velocity} = 200 \text{ ft/min}$$

So with a cfm of 100 and cross sectional area of .5ft^2 there is an air velocity of 200 ft/min. Assume the diffuser you are dealing with is designed to receive 200 ft/min. Everything is okay!

Now, we will come full circle. Assume the engineer messed up on his/her math. He/she wants the cross sectional area to be .75ft^2. Now do the math:

$$100 \text{ cfm} = \text{Air velocity} \times .75 \text{ ft}^2$$

$$\text{Air velocity} = 100 \text{ cfm}/.75 \text{ ft}^2$$

$$\text{Air velocity} = 133.33 \text{ ft/min}$$

As you can see, the oversized duct has reduced the air velocity by 66.67 ft/min! This is not good. Since the air velocity is to low at the diffuser, the air will not come out with the required force. It should be easier to see the relationship between oversized ductwork and air velocity. Oversized ductwork slows the speed of the air.

In addition to oversizing a duct system during the design phase, a duct can be undersized. An undersized duct will also alter the air velocity. Revisit the math problem from before. Instead of oversizing, the engineer made a mistake and called for an undersized duct. He/she wants a duct with a cross sectional area of .25 ft^2. One more time, look at the math:

$$100 \text{ CFM} = \text{Air velocity} \times .25 \text{ ft}^2$$

$$\text{Air velocity} = 100 \text{ cfm}/.25 \text{ ft}^2$$

$$\text{Air velocity} = 400 \text{ ft/min}$$

This is way too much air. Now, you may think the more the better but this is not the case. Consider the occupants of the building. Now that there is too much air velocity the noise levels have gone up. The increase in noise levels is aggravating to the building occupants, so, they call in a service call and you have to go out and troubleshoot.

Besides the increased noise level, too much air velocity alters the air patterns. Again, air outlets are designed for a certain velocity, if it doesn't get that velocity then they will not function properly.

Nearly every air distribution system is different and would be impossible to cover in this text. Therefore we will focus on the relationship of the facts about these systems and will not try to cover every system you may see. This approach will not overwhelm you and allows you to gain the knowledge and confidence needed to work on these systems.

Ductwork must also be designed to deliver different amounts of air to different rooms in a facility. Now we can get into the ductwork designs to see how the air is supplied to these different rooms. There are numerous designs of ductwork that will accomplish this important task. There are four types of supply ductwork that are important and they are listed below:

1. Plenum system.
2. Extended plenum system.
3. Reducing plenum system.
4. Perimeter loop system.

Plenum system

This type of system is sometimes referred to as a radial design because the ductwork will "radiate" from the plenum. This design is easy to install and does not cost very much. Since it is easy to install, a worker with little experience could set it up. These systems often have a single return system. The fact there is only a single return contributes to the cheaper installation cost.

Extended plenum system

The name of this system tells you what it is. This system *extends* the plenum. The reason for extending the plenum is for use in longer structures. After the plenum has been extended there are branch duct that *branch off* from plenum. The reason duct branches off is to supply air to the terminal units or supply outlets. The branch ductwork can be round, square or rectangular. A disadvantage to this system is that the air velocity decreases the further away the air gets from the blower. The reason this happens is because as the air leaves the blower some of the air is being put into different conditioned spaces. As this air is put into the spaces the volume of air goes down. As the volume of air goes down, so does the velocity. By the time the air gets to the end of the plenum there is less air velocity than there was originally.

Reducing plenum system

How can the extended plenum air velocity problem be solved? The answer is by reducing the plenum size as the air gets further from the blower. The reducing plenum system uses this concept. This system is in essence an extended plenum system. The difference is the plenum reduces in size as it gets further away from the blower. The reason the plenum reduces in size is to maintain air velocity.

Perimeter loop system

This duct system is installed in a concrete floor. It runs around the perimeter of a structure. The ductwork is placed around the perimeter because this is where the greatest heat loss occurs. You could see these systems in colder climates.

There are many concepts that fall into this category. Each concept will be broken down individually. After each concept is covered, they will be put together to show how they are combined to create a whole air distribution system.

211. Flow and pressure characteristics of HVAC/R systems

To balance and troubleshoot systems well, it is important that you know the basic operations and characteristics of airflow and pressure, the meaning of specific important terms, and a few simple formulas. Next, you must know the properties of air and how it behaves under different conditions.

Also, the nature of air pressure and pressure drops in ducts, plenums, and components must become second nature to you.

Description of air

Air is invisible, tasteless, and odorless. To recognize air, use its identifying factors: pressure, temperature, weight, and heat energy; the space it occupies; and the speed of its movement. Also, as you already know, air is a gas made up of oxygen, hydrogen, nitrogen, and a few other elements. In HVAC/R work, we consider and treat air as an individual gas and not as a compound. Further, air has patterns that you must visualize for proper system balancing.

The *molecules* in air move in all directions at the same time. Also, they are always in constant motion, except at absolute zero (–460°F), where they are totally at rest. There is no heat or energy at this point.

Behavior of air

Air is highly elastic and easily compressed. It compresses in an HVAC/R system from its own momentum and weight. For example, when air hits the back of a 90° elbow, it crushes together. Air changes its shape easily—moving about in any way it can, taking the course of least resistance, oozing this way or that, moving about in rippled waves or layers and billows. To get a better idea of this, swing your open hand through the air in front of you. As the palm of your hand pushes against the air, the air compresses at once in front of your hand and swerves around the sides. This creates a vacuum and turbulence behind your hand and causes ripples and waves outward in all directions.

When air is *heated,* its molecules move faster. Further, as air in an open system is heated, it expands. For example, if you increase the temperature of the air in an open system 60°F through a heating coil, its volume increases about 10 percent. Also, keep in mind that warmer air rises; as air in a closed system is heated, its pressure increases. For example, when you heat a pressure cooker on a stove, the pressure doubles or triples.

Naturally, then, as air is *cooled,* its molecules slow down. As air in an open system is cooled, it contracts. For example, if you decrease the temperature of the air in an open system 20°F through a cooling coil, its volume decreases about 4 percent. Also, keep in mind that cooler air falls. As air in a closed system is cooled, the pressure goes down.

Note, too, that air expands and fills *whatever space* there is to occupy. Imagine for a moment that all of the air is sucked out of the room you are sitting in and that the room is made a vacuum. Then, let's say that you take a small rubber syringe full of air and squirt it into the room. It expands, fills the entire room, and is at a very low pressure.

Then, as the air is *compressed,* the temperature and pressure rise. For example, if you compressed 1 cubic foot of air at 70°F, 14.7 psi into ½ cubic foot, the temperature would rise to 250°F, and the pressure would rise to 40 psia. Then, if you expanded the volume of air 100 percent, the temperature would drop to 50°F, and the pressure would go to about 6 psia.

Standard air

Standard air is defined as "air at 70°F and 50 percent relative humidity at 14.7 psi atmospheric pressure." Under these conditions, air has a density of 0.075 lb/cu ft and contains $^{1}/_{1,000}$ pound per pound of moisture or 55 grains per pound of dry air. Also, it contains heat energy of 16.8 Btu/lb of dry air or 34.0 Btu/lb of saturated air. Further, at 1 pound of dry air, it occupies 13.5 cu ft.

Airflow formula

The formula for calculating the volume of airflow through a duct is:

$$\text{cfm} = A \times V$$

Where:

cfm = cubic feet per minute

A = area of the duct in feet per minute
V = velocity in feet per minute

For example, if you are working with a 24-by–12-inch duct that has a cross-sectional area of 2 feet, and the velocity of the air is 1,000 fpm, you would get

$$\text{cfm} = 2\ \text{ft}^2 \times 1{,}000\ \text{fpm}$$
$$\text{cfm} = 2{,}000$$

If vanes, bars, or other things obstruct the area of airflow, you must subtract the area of obstruction from the total area; hence, if vanes obstruct 0.5 square foot of area in the 24-by–12-inch duct, you get

$$\text{cfm} = (2\ \text{ft}^2 - 0.5\ \text{ft}^2) \times 1{,}000\ \text{fpm}$$
$$\text{cfm} = 1.5\ \text{ft}^2 \times 1{,}000\ \text{fpm}$$
$$\text{cfm} = 1{,}500$$

Air pressure

What is air pressure? Pressure is a force over a certain area, such as pounds per square foot (psf) or pounds per square inch (psi). If you put a 144-pound weight on top of a 1-square-foot area, the pressure would be 144 psf or 1 psi, since there are 144 square inches in 1 square foot (fig. 2–1).

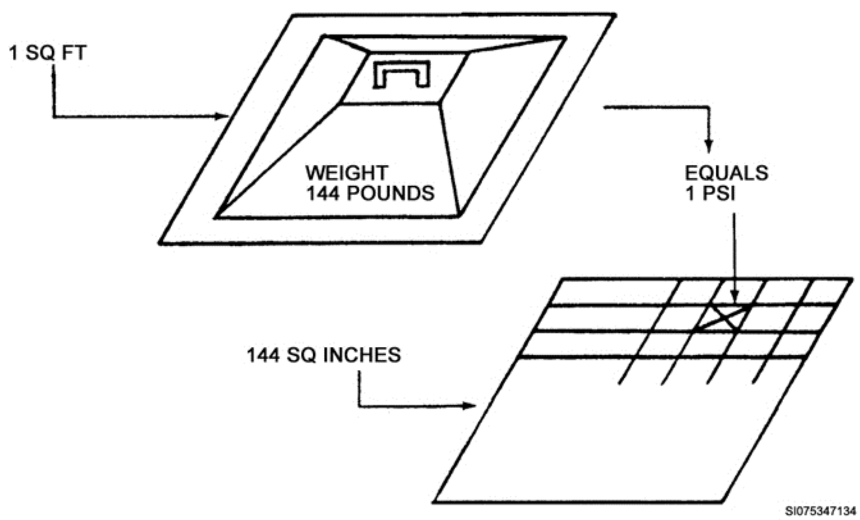

Figure 2–1. Pressure measurement

We measure pressure in air balancing by the number of inches the pressure can lift a column of water in a tube. If the pressure in the duct were 2 inches, that amount of force can push up or lift the water 2 inches in a vertical column.

One inch of water column (wc) pressure is a very small amount of force. You can see this and other pressure relationships from the following:

1 ft WC = 0.432 psi
27.7 in. WC = 1 psi
407 in. WC = 14.7 psi

Gauge pressure

Gauge pressure is the amount of pressure under or over the surrounding atmospheric pressure. As you use a U-tube manometer to measure pressure, the atmospheric pressure on the right side opposes the pressure being measured on the left side. The atmospheric pressure on the right side is automatically subtracted. Only the difference is shown on the manometer, which is the gauge pressure. For example, if the pressure in the duct were 408 in. wc and the U-tube read 1 in. WC, the atmospheric pressure of 407 (14.7 psi) in. wc is counteracting or being subtracted from the pressure in the duct being measured (fig. 2–2).

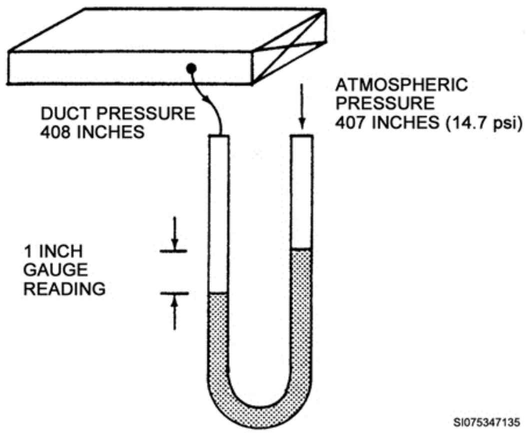

Figure 2–2. U-tube manometer reading.

Absolute pressure is atmospheric pressure plus the gauge pressure. It is the full pressure in the duct without the atmospheric pressure being subtracted from it. The absolute pressure in our example is 407 + 1 = 408 in. WC (fig. 2–2).

Total pressure

At any point, total pressure in a duct is equal to the sum of the velocity and static pressure. The formula reads:

Total pressure (TP) = velocity pressure (VP) + static pressure (SP)

or

$$TP = VP + SP$$

Conversely,

$$VP = TP - SP$$

$$SP = TP - VP$$

Velocity pressure

Velocity pressure is the force in the direction of airflow created by the movement of the air due to its weight and inertia.

The formula for converting velocity pressure (VP) to feet per minute (fpm) is:

$$\text{fpm} = 4{,}005 \times \sqrt{VP}$$

For example, you have just taken a ballpark velocity pressure reading from a duct. The pressure is 0.05 in. wc:

$$\text{fpm} = 4{,}005 \times \sqrt{.05}$$

$$\text{fpm} = 4{,}005 \times 0.223$$

$$\text{fpm} = 893$$

Static pressure

Static pressure is a measure of resistance to the movement of air being forced through a system—resistance caused by ductwork, outlets, equipment components, and so forth. Static pressure imparts a force in all directions. It is a nonmoving potential force that exists at every point and is independent of the air velocity force.

If static pressure is positive, as in a discharge (supply) duct, it exerts an outward or bursting pressure against the walls of the duct (fig. 2–3).

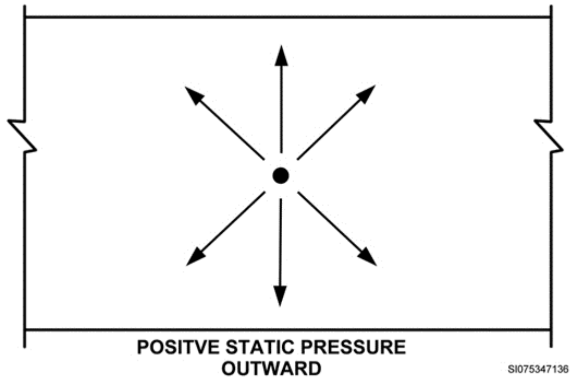

Figure 2–3. Positive static pressure outward.

If static pressure is negative, as in a suction (return) duct on the intake side of the fan, it exerts an inward or suction force on the walls of the duct (fig. 2–4). Excessive negative static pressure can cause a duct to collapse inward.

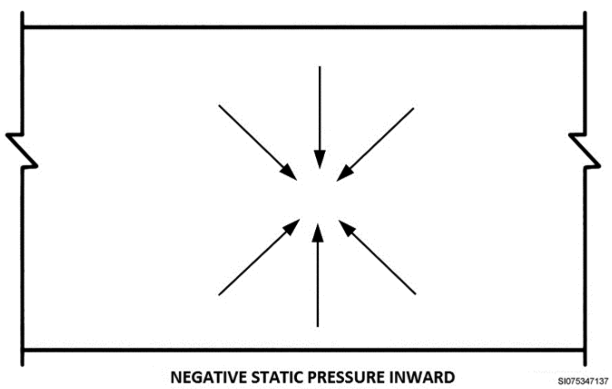

Figure 2–4. Negative static pressure inward.

A difference in static pressure between two points in a system causes airflow, but if there is no difference, no airflow occurs.

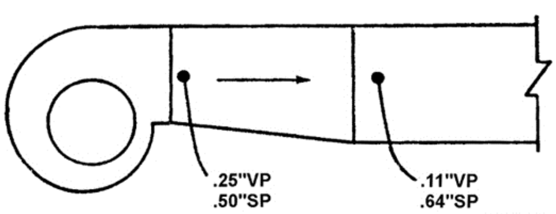

Figure 2–5. Velocity and static pressure conversion.

Velocity and static pressure conversion

As the velocity of air is decreased in a duct without changing the volume of air, the reduced amount of velocity pressure is converted into static pressure. Then, as the velocity pressure is increased, the same conversion occurs, but now static pressure is converted into velocity pressure. The total pressure in each case remains about the same if the conversion losses are small. In the last part of this example, notice how the static pressure was *converted* into velocity pressure and no pressure was really lost.

A velocity-pressure-to-static-pressure conversion generally occurs in the transition duct at the discharge of a fan. Figure 2–5 shows the velocity pressure at 0.25 inch and the static pressure at 0.5 inch right at the fan discharge. After the expanding transition increases the area of the duct and slows down the air velocity, the velocity pressure is reduced 0.14 inch from .25 inch down to 0.11 inch.

This pressure loss is regained in the static pressure that rises from 0.5 inch to 0.64 inch. If you must reduce the size of a duct in a system because of space problems, the opposite occurs, and the additional velocity pressure energy needed for the increased velocity is drawn from the reduced static pressure energy needed.

Fan pressure

The pressure at the discharge of the fan is no more or no less than the amount of force needed to push the specific amount of air coming out of the fan against the resistance of the discharge duct system. What does that mean? All it means is that the fan makes just enough force to move the air through every component on the discharge side. Remember the components from the last unit?

Intake pressure applies also to the suction side of the fan. The intake pressure is the force needed to draw the total volume of air through all of the intake components (fig. 2–6, number 1). Thus, it overcomes the sum total of the resistance. The gauge pressure drops from its maximum at the discharge (fig. 2–6, number 2) or intake of a fan to zero at the ends of the duct runs (fig. 2–6, number 3).

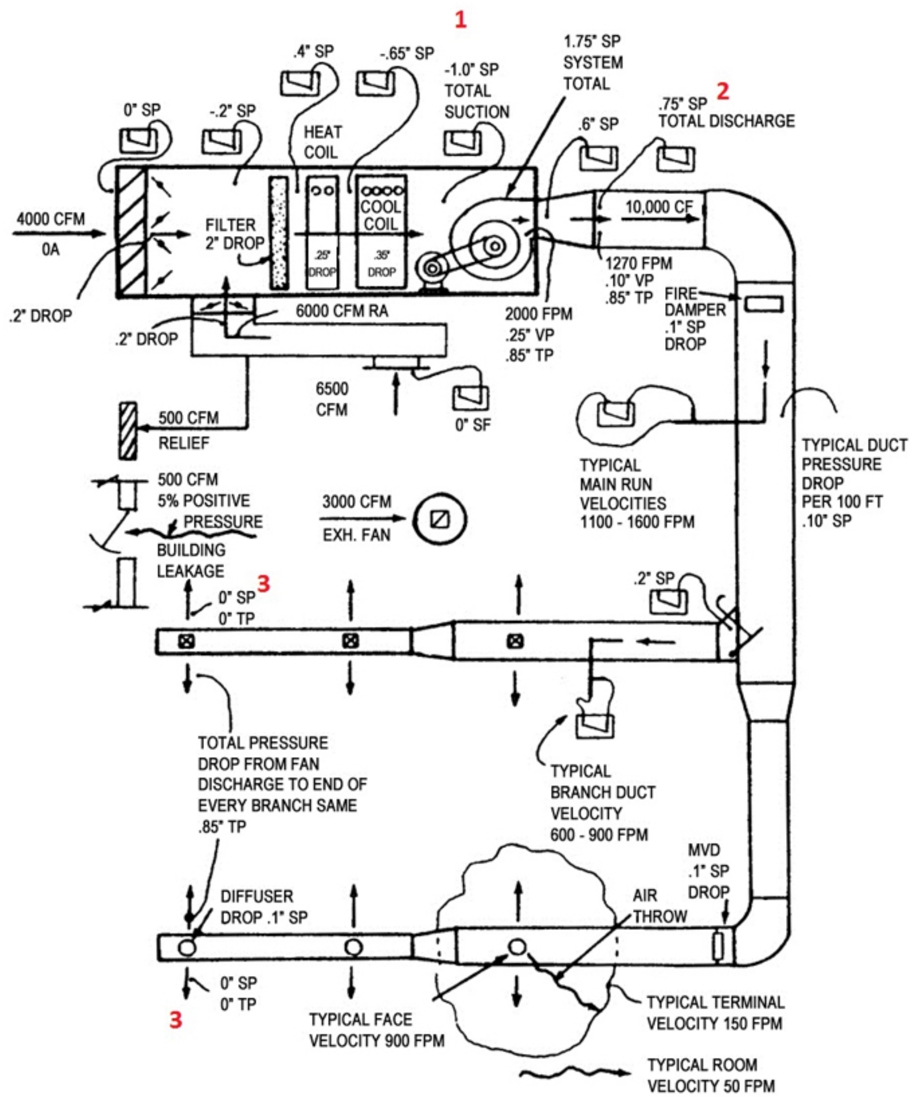

Figure 2–6. The air cycle.

212. Fan system measurement

One of the important steps in balancing an air distribution system is knowing how to measure fan pressures and how to or how much to change a fan's rpm's or cfm's. Reading the following paragraphs on fan definitions, fan laws, and fan system curves will lay the groundwork for you to understand how and why fan distribution systems behave the way they do.

Fan definitions

The *fan volume* or *airflow* (cfm) produced by a fan will not change with changes in air density, but the static pressure developed by a fan will vary in direct proportion to the changes in air density.

Fan total pressure (TP) is the difference between the total pressure at the fan outlet and the total pressure at the fan inlet.

$$\text{Fan TP} = \text{TP (outlet)} - \text{TP (inlet)}$$

The fan total pressure is the measure of the total mechanical energy added to the air or gas by the fan. This is measured as shown in figure 2–7. In this figure total pressure readings are being taken from the return and supply sides of the fan. The right hand side of the U-tube manometer is pushing down and lifting up the left hand side. This is because the pressure in the discharge (supply) is greater than the suction (return).

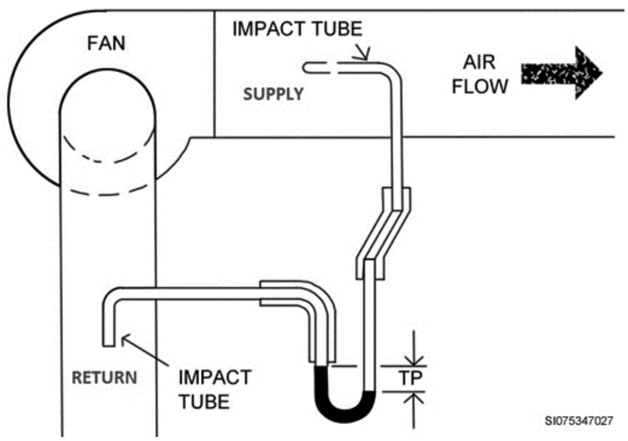

Figure 2–7. Fan total pressure.

Fan static pressure (SP), which relates to the system pressure, is often confusing. Fan static pressure (fig. 2–8) is the fan total pressure less the fan velocity pressure. It can be calculated by subtracting the total pressure at the fan inlet from the static pressure at the fan outlet:

$$\text{Fan SP} = \text{SP (outlet)} - \text{TP (inlet)}$$

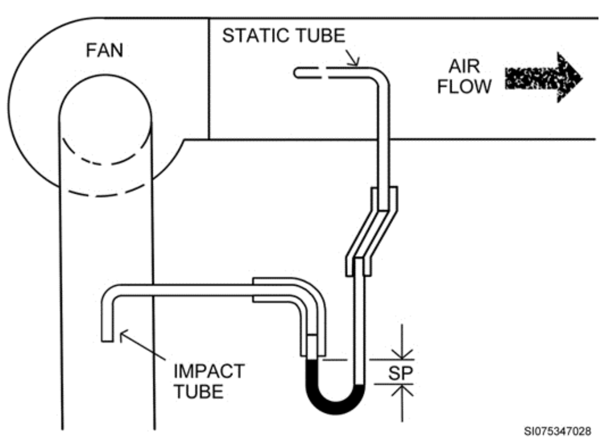

Figure 2–8. Fan static pressure.

In figure 2-8, the tube in the discharge is a *static* tube and is measuring the discharge (or outlet) static pressure. This is a positive static pressure since it is on the discharge and is greater than the total pressure on the suction. Look at the manometer, the static discharge is pushing down on the column of liquid because it is the greater pressure. At the fan return-air connection, you measure total pressure at the fan inlet and not the static pressure.

Fan velocity pressure (VP) is the pressure corresponding to the fan outlet velocity (fig. 2–9). It is the energy per unit volume of the airflow. In this figure, notice a pitot tube is used to take the measurement. Also, notice that only one tube is placed inside the ductwork. Finally, take note that the tube is placed facing the opposite of the airflow and it is on the discharge side of the fan. The pitot tube will give you the difference between the total and static discharge pressure which is the fan velocity pressure.

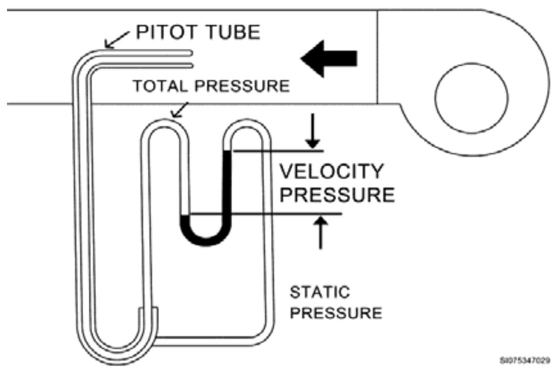

Figure 2–9. Fan outlet velocity.

Fan outlet velocity is the theoretical velocity of the air as it leaves the fan outlet and is calculated by dividing the air volume in cfm by the fan outlet area in square feet. However, all fans have a nonuniform outlet velocity; that is, velocity varies over the cross section of the fan outlet. The fan outlet velocity, as calculated above, is only a theoretical value that could occur at a point removed from the fan. Therefore, take all pressure measurements for velocity (velocity pressure), total pressure, and static pressure downstream from the fan discharge in a straight duct section where the flow is more uniform.

Actually, almost all of the fan discharge airflow occurs at the side of the outlet farthest from the fan shaft. Velocity readings taken at the side nearest the shaft may actually indicate airflow from the discharge duct back into the fan.

Brake horsepower (bhp) is the actual horsepower required to drive the fan. It is greater than a theoretical “air horsepower” because it includes loss due to turbulence and other inefficiencies in the fan, plus bearing losses. Brake horsepower is an important value because it is the power that a fan motor must furnish.

Tip speed is also called *peripheral velocity*. Tip speed equals the circumference of the fan wheel times the rpm of the fan and is expressed in feet per minute (fig. 2–10).

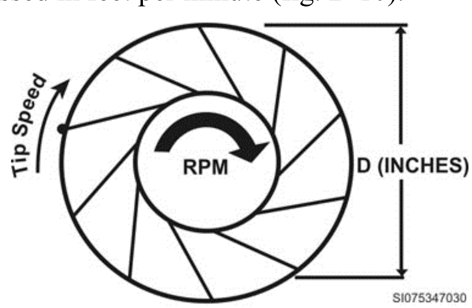

Figure 2–10. Tip speed.

Fan fundamentals

We can use fan curves or tables published by the fan manufacturer to determine the output of a fan under certain conditions. The following fan law equations allow the calculation of the necessary changes to be made to a system or a system component. The abbreviations used in the equations are explained in the following table:

Abbreviation	Meaning
cfm	airflow
rpm	fan revolutions per minute
SP	static pressure
bhp	brake horsepower

Fan laws

Some of the equations you need to determine system changes are simple math equations with fan terms applied. Before you begin with the fan equations, take a look at the following basic math equations without the fan terms applied.

In the following fraction, we know that

$$\frac{100}{25} = 4$$

The following math expression is the same as saying

$$25\overline{)100}^{\,4}$$

Taking this a step further, you can now see that

$$\frac{100}{25} = \frac{4}{1}$$

If we plug the fan terms into these math expressions or formulas, you can find information about changes that need to be made to a fan system.

The change you wish to make to a fan system determines which equation to use. A common thread between all of the equations is that you must have some information about the system before you can begin to use the equations. For instance, using the same expression, or equation, as above, you can find the new fan speed (in rpm's) when you know three of the four values for the equation.

The first equation we cover is the new fan speed equation. Use this equation when you must change the fan speed. You can change the fan speed by varying the pulley pitch or changing one or both pulleys in the fan system.

We can write the new fan speed equation as follows:

$$\frac{\text{rpm2}}{\text{rpm1}} = \frac{\text{cfm2}}{\text{cfm1}}$$

If you plug in some numbers, you'll have

$$\frac{\text{rpm2}}{1} = \frac{100}{25}$$

To explain this situation in fan terms, let's say that we have a current fan cfm value of 25 cfm and it is operating at 1 rpm. The new desired cfm is 100. You need to know how many rpm's to increase the fan and if the fan motor will support those rpm's (brake horsepower is covered later in this lesson).

As we stated earlier, you must have three of the four values to find the fourth. In this example, the answer for rpm2 is 4. All you had to do to this equation was plug in the fan terms.

$$\frac{4}{1} = \frac{100}{25}$$

Now, take a look at some different numbers, but the same basic equation. Using the following values, you can determine the new rpm2 value. A fan is operating at 13,930 cfm (cfm1) and 636 rpm (rpm1). You are to change the airflow to 15,500 cfm (cfm2). Now that you have three of the values for the equation, it is possible to determine what the new rpm or rpm2 will be. This is the same basic equation; however, mathematically, it is written a bit differently. There is more than one way to solve this particular equation.

$$\text{rpm2} = \text{rpm1} \times \frac{\text{cfm2}}{\text{cfm1}}$$

or, using the values above,

$$\text{rpm2} = 636 \times \frac{15{,}500}{13{,}930}$$

Breaking the equation down even further, you can see that 15,500 ÷ 13,930 = 1.113.

To finish this equation, take the quotient, 1.113, and multiply it by the current fan rpm, or 636. The product of this equation gives you the new rpm fan speed of 708 rpm. An alternative to doing the equation this way is to multiply 636 by 15,500 and get a product of 9,858,00. Now, take this product and divide it by 13,930. The result is 708 (rounded up).

The formula for finding the new fan speed is

$$\frac{\text{cfm2}}{\text{cfm1}} = \frac{\text{rpm2}}{\text{rpm1}}$$

The formula for determining the new static pressure in inches looks like this:

$$\text{in. w.c} \frac{\text{SP2}}{\text{SP1}} = \left(\frac{\text{rpm2}}{\text{rpm1}}\right)^2$$

The equation for finding the new brake horsepower is

$$\frac{\text{bhp2}}{\text{bhp1}} = \left(\frac{\text{rpm2}}{\text{rpm1}}\right)^3$$

When you attempt to increase the airflow in a system without making other changes, the brake horsepower (and the energy consumption) increases dramatically.

The total system pressure that a system fan must handle is the sum of the friction losses of each straight duct section, the dynamic losses of each duct fitting or obstruction, and the pressure loss of each duct component such as coils, filters, dampers, and so forth, in the connected supply and return systems, which have the highest pressure losses.

In a given duct system with a known airflow rate and when all automatic dampers are stable, you can measure a specific total pressure.

System resistance curve

System resistance is the sum total of all pressure losses through filters, coils, dampers, and ductwork. The system resistance curve (fig. 2–11) is a plot of the pressure required to move air through the system. For fixed systems—that is, with no changes in damper settings, and so forth—the system resistance curve for any system is represented by a single curve. For example, consider a system handling 1,000 cfm with a total resistance of 1.0 in. wc static pressure. If the cfm is increased, the static pressure resistance increases.

System effect factor

The system effect factor is a calculated pressure loss factor that recognizes the effect of fan inlet restrictions, fan outlet restrictions, or other conditions that can influence the performance of a fan installed in a system. Think about this: If you add a restriction such as a filter to an air system, won't it effect how well the fan will function? Of course it will! In short, this is the *effect* the *system* has on fan performance.

System operating point

The operating point (fig. 2–11) at which the fan and system will perform is determined by the intersection of the system resistance curve and fan performance curve. Every fan operates only along its performance curve for a given speed (rpm). If the designated system resistance is not the same as the resistance in the installed system, the operating point will change and the static pressure and volume delivered will not be as calculated.

In figure 2–12, the actual system has more pressure drop than predicted in the design. Thus, airflow volume (cfm) is reduced and static pressure is increased. The shape of the horsepower curve typically would result in a reduction in bhp. Typically, the rpm would then be increased and more bhp would be needed to achieve the desired cfm. In many cases, when there is a difference between actual and calculated fan output, the difference is due to a change in system resistance rather than to any shortcomings of the fan or motor. Frequently, the mistake is made of taking pressure readings across the fan and concluding that if the fan is at or above design requirements, the system airflow is also at or above design requirements.

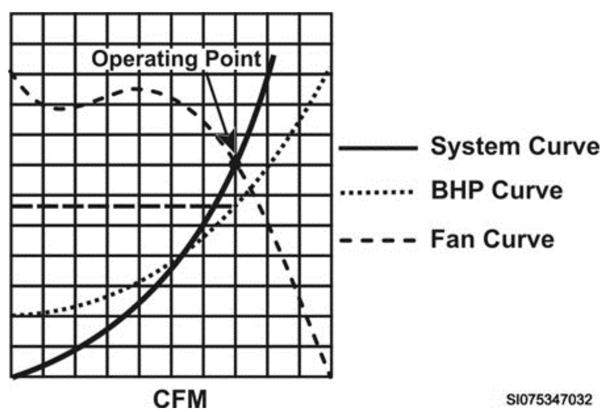

Figure 2–11. Operating point.

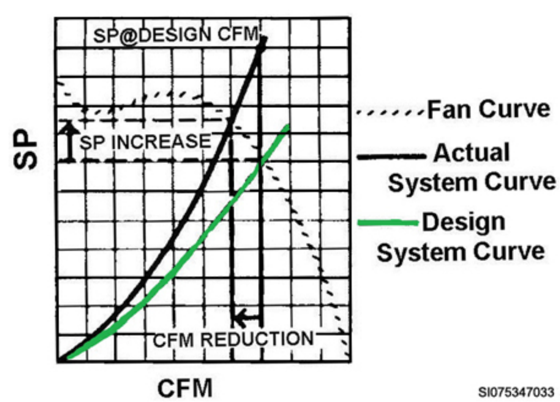

Figure 2–12. Variations from design-air shortage.

Fan law relationships

The fan law equations shown below apply a change only in fan rpm (with the system remaining unchanged), and are graphically shown in figure 2–13. Let us break down this graph. First, as stated the system does not change therefore the system curve on the graph did not change. The rpm changed though. The bottom curve gives you rpm1 and its corresponding static pressure and cubic feet per minute. The rpm then moves to rpm2. Notice how the static pressure and cubic feet per minute both went up. You may be thinking, “So what?” Well, this shows us that by changing the rpm of a fan we increase the cubic feet of air that is moved per minute which results in a rise in static pressure! This shows you that you cannot just go around tinkering with a fan’s rpm!

$$SP_2 = SP_1 \times \left(\frac{rpm_2}{rpm_1} \right)^2$$

$$rpm_2 = rpm_1 \times \frac{cfm_2}{cfm_1}$$

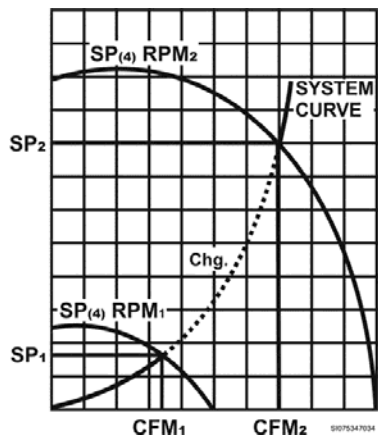

Figure 2–13. Fan law rpm changes.

Air density changes

The fan volume or airflow measured in cfm will not change with changes in air density. A fan is a constant-volume machine and will produce the same airflow no matter what the air density may be (fig. 2–14). This figure shows you static pressure (SP) on the left and cubic feet per minute (cfm) on the bottom. The upward sloping line closet to the bottom represents the original air density. A rise in density is demonstrated by the next upward sloping curve. Notice the vertical line rising up from “cfm.” This vertical line represents NO change in air volume. This graph has shown us how density does not effect air volume because a fan is a *constant-volume machine.*

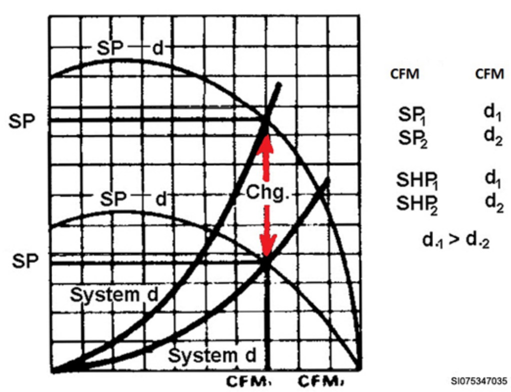

Figure 2–14. Effect of density change (constant volume).

The static pressure developed by a fan varies in direct proportion to the changes in air density. In other words, the heavier the air, the more pressure produced. If static pressure is held constant, airflow and fan speed vary inversely as the square root of the air density (fig. 2–15).

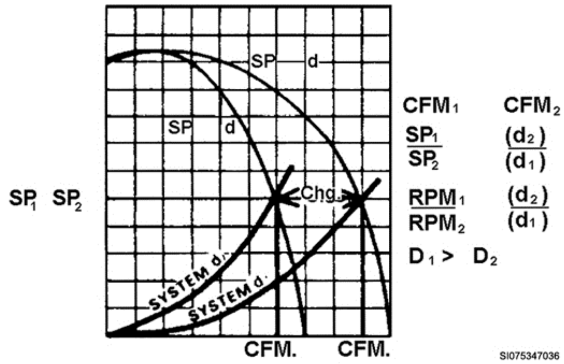

Figure 2–15. Density change (constant static pressure).

Fan/system curves

For a fixed fan and duct system, an increase or decrease in the system airflow volume rate increases or decreases the system resistance.

If the airflow rate is increased to 120 percent of design volume, the system resistance increases to 144 percent of the design. A further increase in volume results in a corresponding increase in system pressure. A decrease in airflow to 50 percent of design volume would result in a decrease to 25 percent of the design resistance. Notice that these percentages do not correspond to a 1-to–1 ratio. The designers of these systems can furnish you with a duct system curve chart that shows the proportional rate of change in resistance as volume in the duct system changes. These charts may be of possible value in troubleshooting and balancing a system. It may be necessary to contact the system manufacturer(s) and the design engineer(s) for assistance.

If the system characteristic curve, composed of the resistance to flow of the system and the appropriate system effect factors, has been accurately determined, then the fan selected develops the necessary pressure to meet the system requirements at the designated airflow rate. If the system resistance has been accurately determined and the fan properly selected, their performance curves will meet the design airflow (cfm) conditions.

The airflow rate through the system in a given installation may be varied by changes in the system resistance from fan inlet vane dampers, resetting balancing dampers, and the operation of mixing boxes, terminal units, and so forth. As an example, the airflow rate may be varied from 100 percent of the design airflow volume to approximately 80 percent by increasing the system resistance. Similarly, the flow rate can be increased to approximately 120 percent of the designed volume by decreasing the system resistance.

Effect of changes in fan speed

As stated earlier, increases or decreases in fan speed alter the airflow rate through a system. Figure 2–16 shows the increase in cfm when the speed of a fan is increased 10 percent to point 2. The 10 percent increase in cfm, however, extracts a severe horsepower penalty. According to the fan laws, the brake horsepower increases 33 percent. Only 10 percent more air is needed, but the selected motor horsepower is not capable of a 33 percent increase in load and the fan is moved into another pressure classification. The increased power requirements are the result of the increased work done. The greater volume of air moved by the fan against the resulting higher system resistance to the airflow is a measure of the increased work done. In the same system, the brake horsepower increases as the third power of the speed ratio and the fan efficiency remains the same at all points on the same system curve.

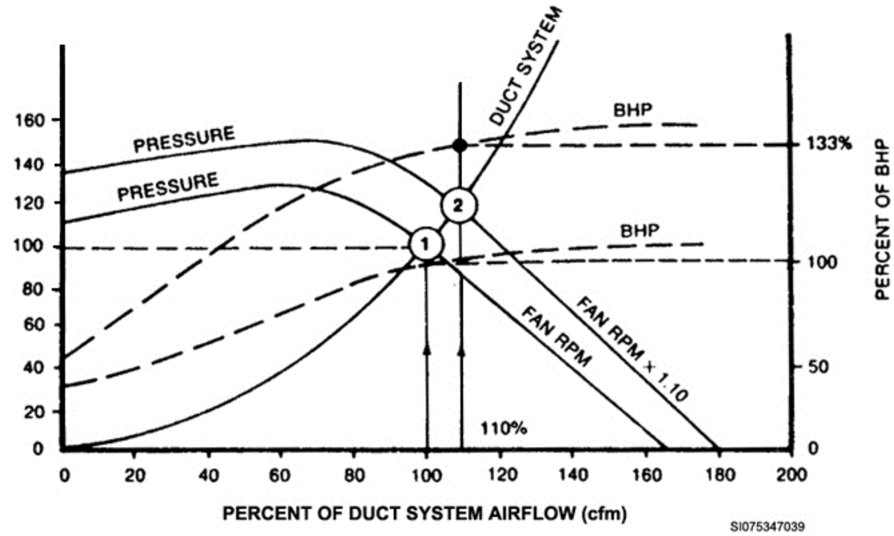

Figure 2–16. Effect of 10 percent increase in fan speed.

Effect of density on system resistance

The resistance of a duct system is dependent on the density of the gas flowing through the system. Standard air density of 0.075 lb/cu ft is used for rating fans in the industry. Figure 2–17 shows the effect on the fan performance of a density different from this standard air value.

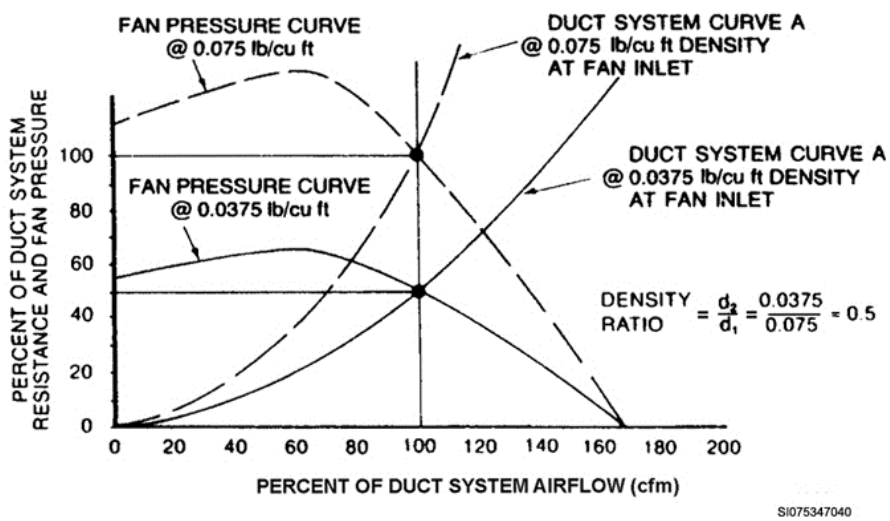

Figure 2–17. Density effect.

The fan pressure at the fan inlet varies directly as the ratio of the actual air or gas density to standard air density. This density ratio must always be considered when selecting fans from manufacturers' catalogs or curves for other than standard air conditions. However, when system pressure losses have not been accurately estimated, or when undesirable fan inlet and discharge conditions exist, designed airflow performance may not be attained.

Effects of errors in estimating system resistance

You may encounter situations where an actual duct system has more resistance to flow than was expected. The fan is operating as tested. This condition is generally the result of an inaccurate estimate of system resistance to flow. All losses must be considered when calculating system pressure losses or the final system will be more restrictive than designed and actual flow rate will be deficient For example, if you forget to take into account two coils in the air system then you have underestimated the system pressure.

If the actual system pressure loss is greater than design, an increase in fan speed may be necessary to achieve the design volume rate. Before attempting to increase the speed of any fan, check with the fan manufacturer to determine if the speed can be safely increased, and also determine the expected increase in horsepower. The connected motor may not carry the increased fan brake horsepower.

"Safety factor" cautions

System designers sometimes add "safety factors" to their estimate of the system resistance to compensate for unknown field conditions. These safety factors may compensate for resistance losses that were overlooked, and the actual system will deliver the design airflow. Occasionally, however, the estimated system resistance, including the safety factors, is in excess of the actual installed system conditions. Since the fan has been selected for design conditions, it delivers more air because the actual system resistance at the design airflow rate is less than expected. This result may not necessarily be an advantage because the fan usually operates at a less efficient point on the performance curve and may require more horsepower than at the design airflow. Under these conditions, it may be necessary to reduce the fan speed; or system volume dampers can be adjusted to increase the actual system resistance to the original design system resistance (not always the most energy efficient way to solve the problem).

213. Air volume measurement

The ability to use testing and balancing instruments is the single most important area in balancing. Testing and balancing revolves around the correct selection and use of instruments. It revolves around work and calculations based on instrument readings.

It is imperative that a technician be aware of all instruments available for balancing, have an in-depth knowledge about them, be able to select the proper ones for each particular application, and be skilled in the appropriate application and use of them. The facts about these instruments were discussed in the last volume. This section will talk about their use. The three categories of instruments we examine in this lesson are as follows:

1. Rpm reading instruments.
2. Pressure reading instruments.
3. Air-velocity reading instruments.

Rpm reading instruments

In testing and balancing, we use rpm instruments to measure the rpm's of fans, pumps, and motors to determine if they are running at the right speed. Every fan has a recommended maximum operating speed that must not be exceeded.

The most common types of rpm instruments (tachometers) used in air balancing are listed below. We will explain the first three types.

- Direct-contact, manually timed revolution counters.
- Direct-contact, automatically timed chronometric tachometers.
- Photo tachometers.
- Direct-contact, instantaneous-reading, spring-dial tachometers similar to automobile speedometers.
- Stroboscopic (electronic) counters.

Direct-contact, manually timed revolution counters

Direct-contact, manually timed revolution counters are small and inexpensive rpm reading instruments. Easily carried in your pocket, they are available at any time. The recommended maximum speed is 1,000 rpm for constant service; however, for intermittent service, as in balancing, 2,500 rpm is acceptable.

You must take timed readings with a watch that has a second hand or with a stopwatch. Apply the rubber tip of the revolution counter to the end of the rotating shaft. When you push the plunger in, a clutch engages a mechanical counter. The counter can turn in either direction—clockwise or counterclockwise.

Direct-contact, automatically timed chronometric tachometer

Probably the most practical and accurate of the direct-contact-type tachometers is the automatically timed chronometric counter. It incorporates a combination revolution counter and precision stopwatch in one unit. It is self-timing and self-zeroing. Simply press and release the operating button. The counter zeros itself, counts for 6 seconds, automatically stops, computes, and locks in the rpm for a 1-minute period.

Photo tachometer

This type tachometer reads rpm's directly and instantly. No contact with the shaft or pulley is required, as with mechanical-contact tachometers. Where space conditions are such that you cannot reach the end of the shaft, you can direct the light beam of the photo tachometer toward the shaft or pulley from any available vantage point. No connections or wires are needed, as the photo tachometer has a self-contained power source of throwaway batteries. Reflective tape or paint needs to be placed on the shaft. The photo tachometer will *see* the tape or paint and count the revolutions.

Pressure reading instruments

You use the pressure reading instruments for reading air velocities in ducts; pressure drops across components; fan inlet and discharge pressures; pressures in ducts, plenums, spaces, outside; draft in flue or chimney. These readings you take with the following instruments:

- Inclined liquid manometer.
- Vertical liquid manometer.
- Pitot tube.
- Magnehelic pressure gauges.
- Digital and U-tube manometers.

Use the manometers and gauges with the pitot tubes, straight metal tubes, and various static pressure sensors. See figure 2–18 for examples of how to connect various instruments.

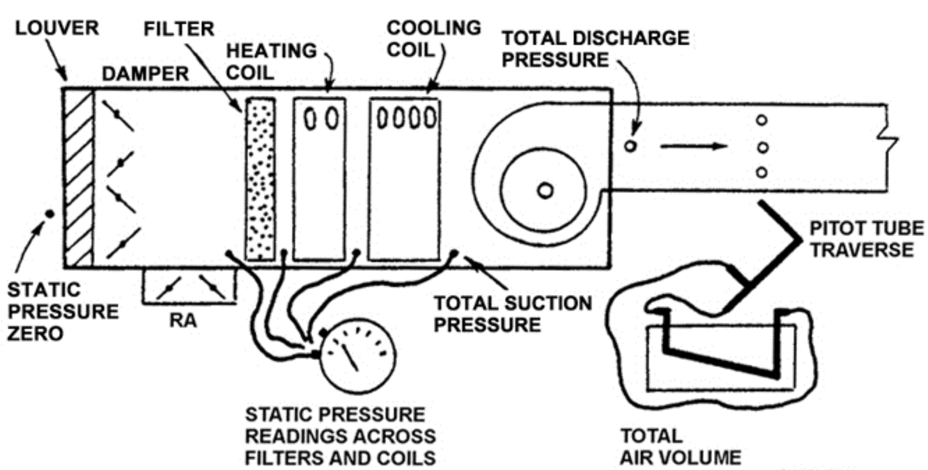

Figure 2–18. Reading total volume of air, fan pressure, and pressure drops.

Inclined liquid manometer

Use the quarter-inch inclined gauge (fig. 2–19) for taking accurate air velocity traverse with the pitot tube in low-pressure ducts in a range between 400 and 2,000 fpm. Then, multiply the air velocity times the duct cross-sectional area to determine the air volume.

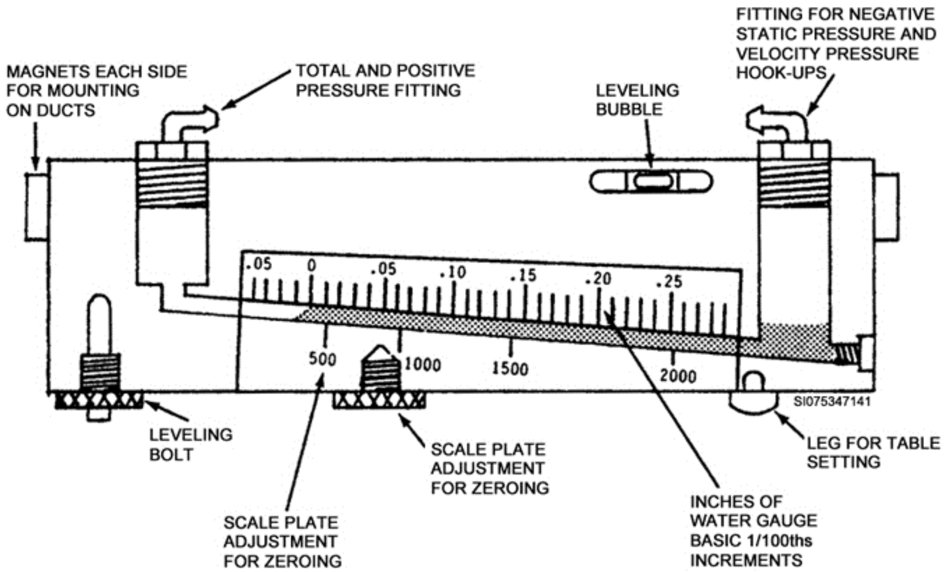

Figure 2–19. Inclined manometer.

How to use

To use the inclined manometer, follow these steps:

1. Open fittings on each side 1½ turns to vent. If there are air bubbles in the fluid, tilt the fluid into the right reservoir to remove.
2. Loosen the scale plate adjustment for zeroing later.
3. Attach tubes to each side of the gauge.
4. Turn gauge stand, which is on left side, perpendicular to instrument for table settings. Level, using leveling screw on left side and bubble on top.
5. For mounting on ductwork vertically, use the two magnets on the side. Place them against the duct and level the gauge.
6. Zero by moving the scale plate so that the zero scale line and the top edge of the meniscus align. Tighten the scale knob on bottom after zeroing.
7. When the gauge is level and zeroed, attach the hoses to the pitot tube. Attach the left side to positive, right side to negative.

Vertical inclined manometers

A popular and extensively used air-reading manometer used by balancers is the dual-purpose, combined inclined and vertical manometer (fig. 2–20).

You use it for high-pressure systems as well as to read air velocities from 400 fpm to 10,000 fpm and pressures from 0 to 10 in. wc. You also use it with a pitot tube for airflow readings in ducts and fan inlets and to read discharge static pressures and pressure drops across system components.

Scales

The upper part of the 400–10 is an air-inclined gauge with a black scale over the fluid that reads from 0 to 1 inch and a red scale underneath that reads from 500 to 4,000 fpm.

The vertical scale reads from 1 to 10 inches in black to the right. The scale underneath reads from 5,000 to 12,000 fpm.

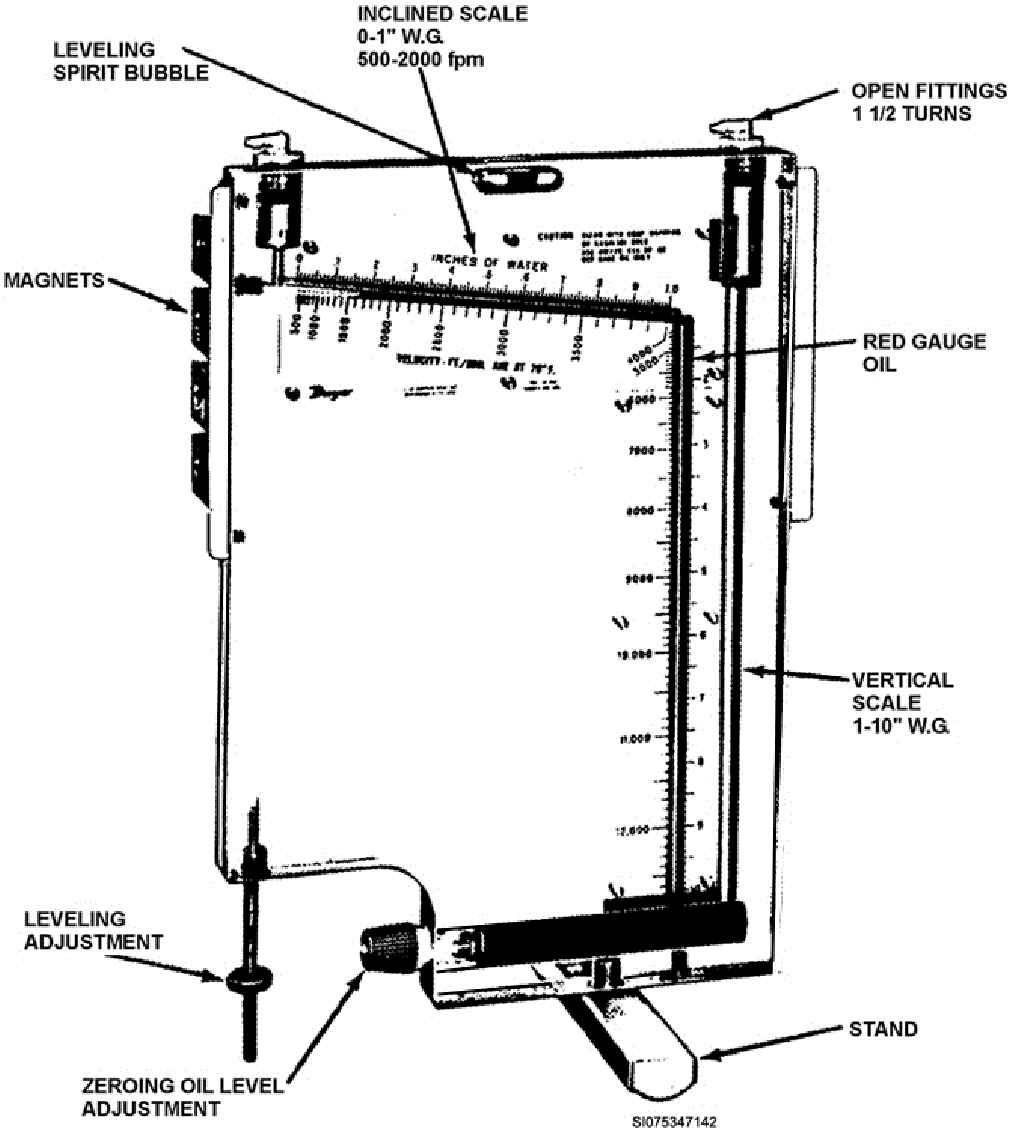

Figure 2–20. Vertical manometer.

Accuracy

You can read the 400–10 accurately to about 0.01 inch on the upper inclined scale and to about 0.03 inch on the vertical scale. Velocities between 500 and 2,000 fpm are difficult to read with an accuracy of better than ±25 fpm. For accurate low-pressure system velocity readings, the quarter-inch manometer is better.

Tubing

The rubber tubing provided with the instrument can be a problem. It has a tendency to get brittle and crack with age. This results in leakage and consequent erroneous readings. The tubing can easily be kinked during a reading. Fluid from the manometer that accidentally enters the rubber tubing also causes incorrect readings.

In place of the rubber tubing, we recommend that you use 10- to 20-foot lengths of clear or urethane tubing; strap them together except at the ends.

How to use

To use the vertical manometer, follow these steps:

1. Open fittings on each side 1½ turns to vent. If there are air bubbles in the fluid, tilt fluid into right reservoir to remove.
2. Attach tubes to each side of the gauge.
3. Turn gauge stand, which is on the bottom left side, perpendicular to instrument for table settings. Level, using leveling screw on left side and bubble on top.
4. For mounting on ductwork vertically, use the magnets on each side. Place them against the duct and level the gauge.
5. Zero by adjusting the oil-level knob on bottom left side so that the zero scale line and top edge of meniscus are aligned. If there is too little or too much fluid, add or remove a necessary amount.
6. When the gauge is leveled and zeroed, attach hoses to the pitot tube. Attach the hose from the left side of the manometer to the total pressure leg of the pitot tube and the hose from the right side to the static pressure leg for velocity pressure readings. Connect to the left-hand side of the gauge for positive above-atmospheric pressure readings or connect to the right side for negative under-atmospheric pressures. Connect to both sides for simultaneous differential pressure readings.

Pitot tubes

Use the pitot tube (fig. 2–21) with manometers to sense both total and static pressure in ducts and plenums. Insert it into the airstream parallel to and facing the airflow.

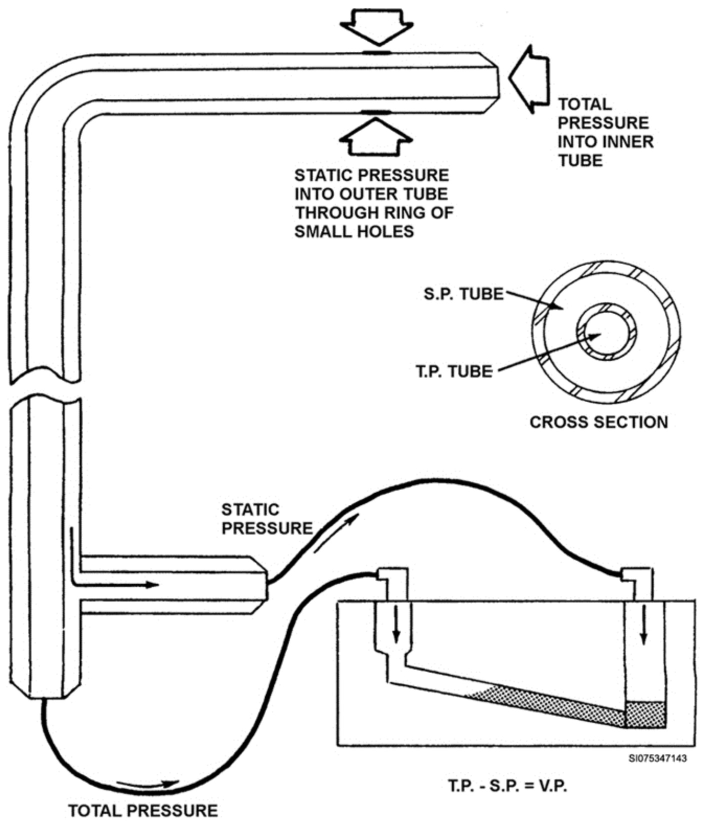

Figure 2–21. Pitot tube.

To read the total air volume being delivered by the fan, you make a pitot-tube traverse in the discharge duct with a manometer and pitot tube.

Pitot tubes are double-wall tubes that are constructed of stainless steel. The inner tube senses total pressure and the outer tube senses the static pressure.

The total pressure enters the center of the tip of the leg facing the airstream and comes out of the center of the bottom. When you insert the pitot tube into the airstream, static pressure enters through a ring of small holes around the main leg, travels through the outer tube, and leaves the short leg near the bottom. The reason the pitot tube reads static pressure on the outer tube is because the static pressure is pushing outwards or pulling inwards depending on if the fan pressure is positive or negative.

You can read static and total pressures separately with a single hookup to either the static or the total pressure legs. Look at figure 2–22, number 1, you can see an example of a single hookup if you look at the "TOTAL INTAKE STATIC PRESSURE" connection.

Read velocity pressure readings with the pitot tube by hooking up to both sides of the manometer at the same time. Hook up the static pressure leg and the total pressure tubes to the designated spot on the manometer. The two forces act against each other in the manometer and results in a velocity pressure reading. One example of this is in figure 2–22, number 2 "SUPPLY VELOCITY PRESSURE." You can see both sides of the manometer are connected.

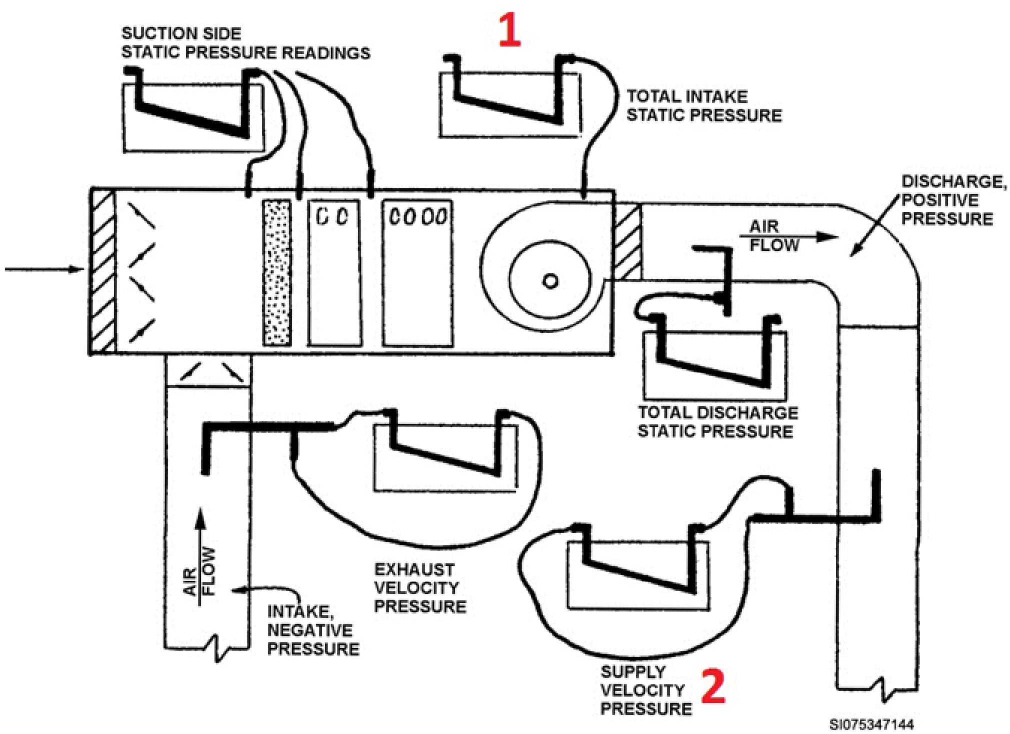

Figure 2–22. Velocity pressure hookups.

Hookups between pitot tubes and manometers for static and velocity pressure readings at the fan, in ducts, and at other system components are shown in figures 2–22 and 2–23. In figure 2–23 the fan static is measured directly at the fan intake and discharge. The external static pressure of a factory-assembled HVAC unit is measured at the intake and discharge outside the entire unit. Notice on the pitot tubes in figure 2–23 that only the static connection is hooked up while measuring the external static pressure of the unit.

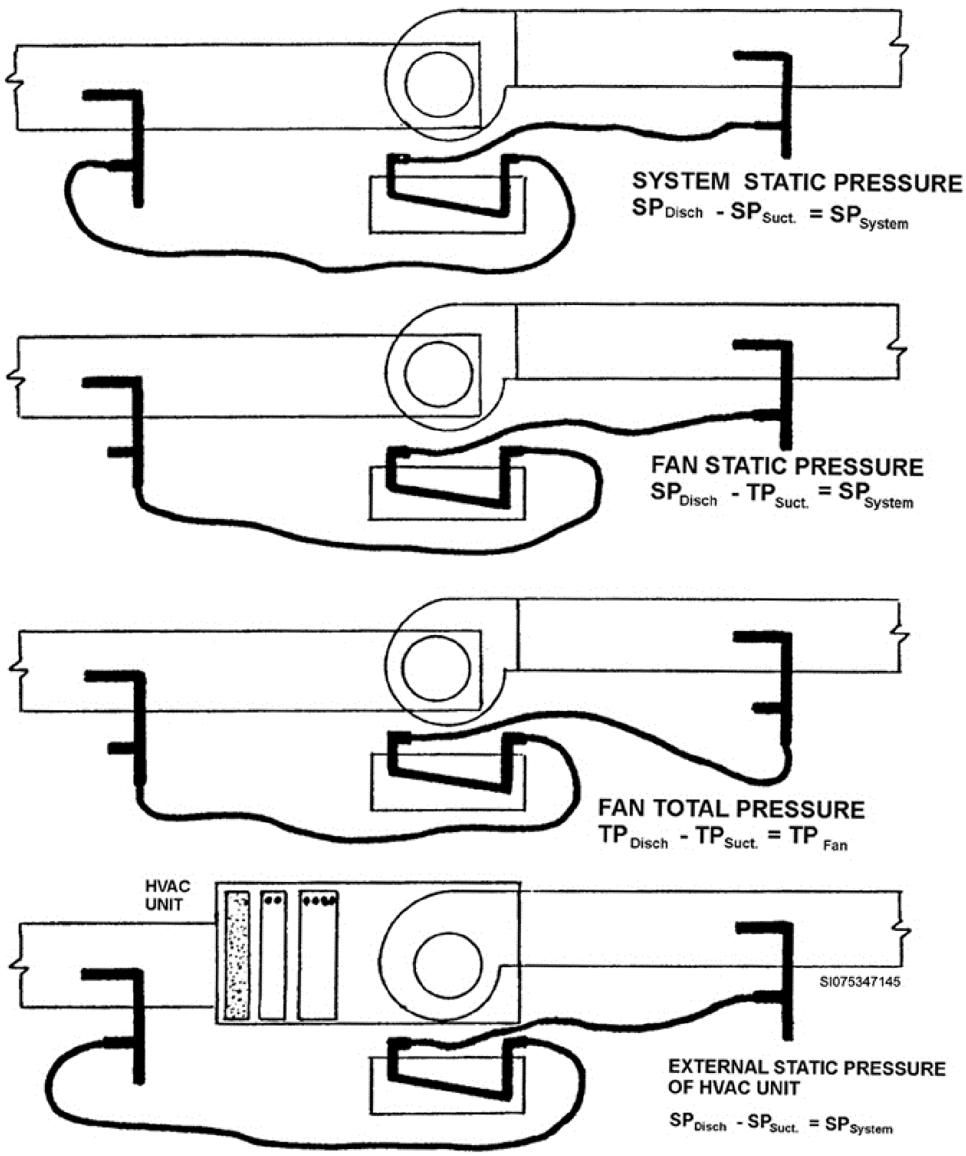

Figure 2–23. Static pressure hookups.

You must know what you are checking before you place the pitot tube in the ductwork. If you don't know why you are placing the tubes in certain places then you are absolutely wasting your time.

Magnehelic gauges

The inclined and vertical draft gauges are excellent and highly accurate instruments for velocity pressure readings. However, they take a relatively long time to set up, they have to be releveled each time they are moved, and they can be knocked over accidentally. Consequently, they are not very practical for the many static pressure readings that you must make in balancing.

To overcome these problems, a series of direct-reading air pressure gauges were developed. Called *magnehelic gauges*, they are extremely portable, quick to set up, and far handier than the liquid gauges. Like the liquid gauges, we use them with pitot tubes, straight tubes, static sensors, rubber tubes, and so forth.

The magnehelic is a dry-type manometer that uses an internal bellow, which is connected to the scale needle for sensing pressure.

Uses

The magnehelic gauge (fig. 2–24) has many uses in the balancing, servicing, and maintenance of air distribution systems. You can use it for reading

1. pressure drops across filters, coils, and dampers, duct runs in balancing, and troubleshooting;
2. fan inlet and discharge pressures;
3. pressures at the inlet of constant-volume and VAV terminal boxes;
4. orifice valves in induction units; and
5. pressure differential or velocity at flow or pressure measuring stations.

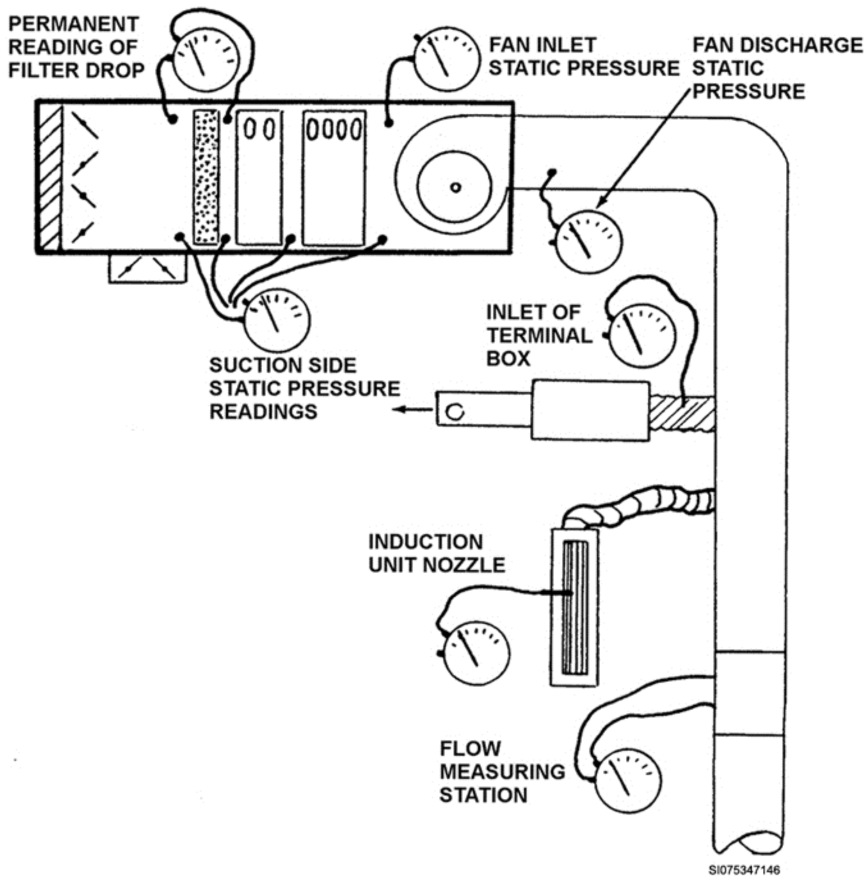

Figure 2–24. Pressure readings with magnehelics.

Zeroing

Magnehelic gauges 1 inch through 10 inches read accurately in either the vertical or the horizontal position, but they have to be zeroed for the position in which they are applied. Adjust the zeroing screw at the bottom of the face with a screwdriver to zero the gauge.

Ranges

Magnehelics come in a variety of ranges of inches of water column, such as 0 to 0.25 inch, 0 to 0.5 inch, 0 to 1 inch, 0 to 2 inches, 0 to 3 inches, 0 to 5 inches, and 0 to 10 inches.

There are also combination pressure and air-velocity reading models available where the pressure scale is on the top and the fpm scale is directly below. However, as we mentioned, when we use them with a pitot tube, they are not accurate enough for low-velocity systems.

Calibration

The magnehelic gauge needs more frequent calibration because it is a mechanical instrument and is sensitive to physical abuse, dirt, dust, corrosive gases, and fluids. You can compare the magnehelic gauge against a micromanometer, hook gauge, or inclined gauge of known accuracy. You can recalibrate it yourself by removing the window and scale plate and adjusting the range spring clamp.

How to use

Follow these steps when you use a magnehelic gauge:

1. Select the appropriate scale for reading. Use the smallest scale gauge possible for maximum accuracy.
2. Zero for a vertical or horizontal position reading.
3. Connect hoses to either one or both ports on the upper left side and then to the straight metal tube, pitot tube, or static probe. For a single positive static reading, connect to the upper high-pressure port; for a negative reading, connect to the lower pressure port.

If you are reading the pressure difference across a component with one reading rather than two, connect hoses to both ports and to the pressure sensors on the upstream and downstream side of the component.

Digital and U tube manometers

Manometers (fig. 2–25) are instruments for measuring positive, negative, or differential pressures with laboratory precision. There are digital and liquid manometers. You may see more digital manometers make their way into Air Force HVAC/R shops. The water manometer is still used though. Since the water version uses water instead of oil of a different density, the U-tube gives you the full scale measurement of inches of water column.

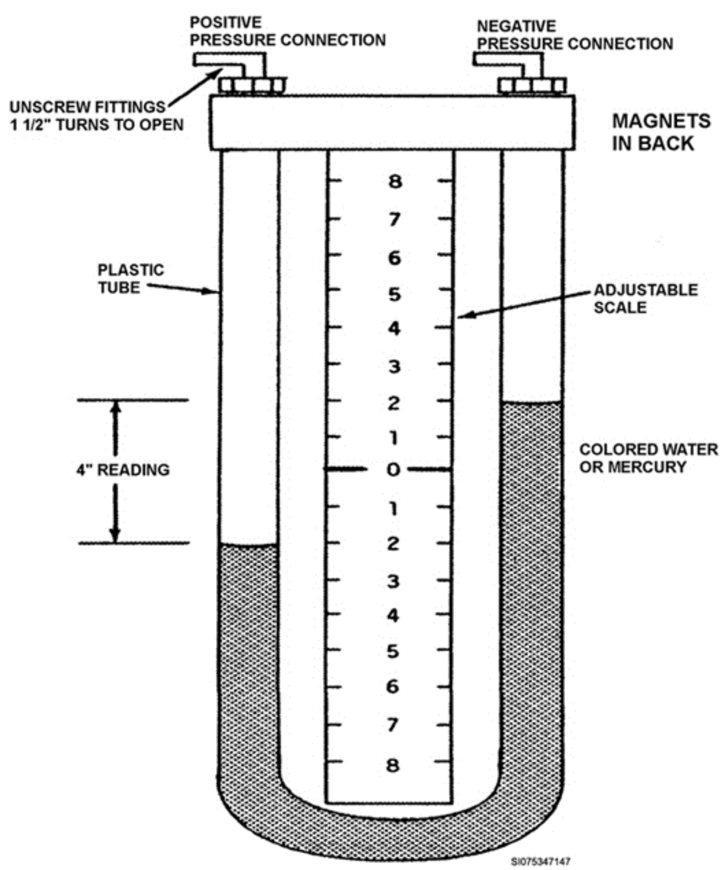

Figure 2–25. Digital and U-tube manometer.

The digital manometer will be discussed more than the U-tube because it is the newer technology. Most digital manometers are simple to use. Since the functions of manometers vary by company only the general procedures for using one will be covered.

Start by turning the device on with the ON/OFF switch. Next, zero the device by having both ports vented to the atmosphere and press the *zero* button for as long as the manufacturer specifies. Select the *units* you want displayed. You can connect hoses that stand alone or you can connect hoses that connect to a Pitot tube. The hoses or Pitot tube are placed in the airstream and a reading is displayed on a screen for the technician. It truly is that simple.

Use U-tube and digital manometer gauges for reading:

1. Air pressure drops across system components.
2. Natural gas pressures in gas piping for heating equipment.
3. Pressure drops across hydronic system components.

Air-velocity reading instruments

Another set of instruments are used to measure outlet air velocity. You use these instruments for reading:

1. Grilles and registers.
2. Ceiling diffusers.
3. Exhaust hoods.
4. Duct openings.
5. Airflow through filters, coils, and louvers.

The velocity reading instruments involved are the anemometer, velometer, and flow hood.

Anemometers

As an air balancer, you use anemometers to read air velocities in feet per minute at grilles, louvers, exhaust hood openings, duct openings, filters, and coils.

The operation is simple. The tool consists of a fan wheel that is placed in an airstream. As the air pushes against the fan wheel a number is displayed on a screen. There are many units of measure velocity could be given but the number an HVAC/R technician should be most concerned with is feet per minute. In addition to measuring air velocity some anemometers can measure temperature, relative humidity, dew point and cubic feet per minute.

The degree of accuracy in an anemometer also varies with the speed of the air flowing through it. Manufacturers provide correction factor charts for adding or subtracting fpm from the actual reading.

On a practical basis, correction factors are not needed for the normal HVAC temperatures in the 0 to 140°F range, and for altitudes other than between sea level and 1,000 feet above sea level. Again, read and learn the manufacturer's manuals on how to use the anemometer in your shop. Take special note of its temperature and airflow limitations.

If you use the anemometer regularly, check its calibration accuracy about once a year. Check it against another calibrated anemometer or a pitot traverse.

Velometers

The velometer is an instantaneous, direct-reading, air-balancing instrument that reads air velocities in feet per minute and pressures in inches of water column. The velometer excels in reading supply-air velocities at ceiling diffusers. Its versatility also includes reading exhaust velocities at grilles, hoods, and duct openings; air currents in open spaces; velocities at filters, coils, and louvers; pitot-tube traverses; and static pressure.

The internal sensor is made so that the instrument can be held in either a horizontal or a vertical position. The instrument doesn't require correction factors for different density air. It operates on the pitot-tube principle where pressure is applied on a vane that travels in a circular tunnel. Two hoses are used with the newer models.

The velometer excels in reading supply-air velocities at ceiling diffusers. This is its most popular use for balancers, even though it can also do many other things. Its versatility also includes reading exhaust velocities at grilles, hoods, and duct openings; air currents in open spaces; velocities at filters, coils, and louvers; pitot-tube traverses; and static pressure.

The actual velocities of lighter, lower-density air, such as in higher altitudes or at lower temperatures, are greater than shown on the meter. The opposite is true for heavier-density air, such as for colder air or air at below sea level, where the actual velocities of the air are less than those shown on the meter.

Flow hoods

A flow hood completely surrounds and covers a diffuser or grille, forces all the air to flow through the diffuser or grille, and measures airflow directly in cfm with one reading in a few seconds.

They avoid the potentially erroneous readings of diffusers due to jet velocities and misdirected airflow from dampers behind grilles. Flow hoods are especially practical in existing buildings where the manufacturers or Ak (area factors) of the outlets are not known, in wide open areas, and where there are a multitude of ceiling diffusers and grilles. They handle air-light troffers and linear and perforated diffusers well. Do *not* use them where the ductwork and outlets are exposed or where there are no ceilings or walls.

The designer of a flow hood must take the back pressure on the diffuser that is created by the flow hood into consideration and compensate for it in the design of a proper flow hood. The flow hood consists of a nylon cloth top, an aluminum bottom housing with an averaging manifold to sense the total and static pressure at 16 traverse points, a specially adapted velometer, and a range selector that allows direct cfm readings on three velometer scales ranging from 50 to 2,000 cfm.

The three cfm scales (50–500, 400–1,000, and 800–2,000) are represented in black. The maximum recommended exhaust usage is 1,300 cfm. The accuracy of the flow hood is ±3 percent of scale or better. Five standard top sizes are assembled from interchangeable frame members:

1. 24 by 24 inches.
2. 25 by 47 inches.
3. 13 by 47 inches.
4. 13 by 60 inches.
5. 36 by 36 inches.

214. General procedures for air balancing

What is balancing? It is simply "moving air around"! To achieve effective balancing you must understand how air moves and what effect resistance has on its movement in the system. Unfortunately, there is no one complete specific balancing procedure that applies to all systems. There are some general things that you must do and a few general procedures that apply to each system, such as preparing reports, checking out equipment, and then balancing outlets and ducts. Beyond these, each system has variations in the balancing procedure that require that each be handled independently.

The testing and balancing procedures common to all systems are as follows:

1. Prepare test reports.
2. Check that the building and systems are complete and functional.
3. Check out equipment.

4. Balance outlets and duct runs.
5. Recheck equipment readings.
6. Finalize test reports.

Step 1, Prepare test reports

Test reports are an absolute necessity in balancing. They prevent chaos, errors, and generally a big mess of indecipherable and incomplete paperwork. Test reports enable you to keep things organized, clear, and neat. They show the procedure and guide the sequence of work. They act as a constant reminder of what information is needed. They are excellent records to which you can refer later. You can return to the reports to see how the systems were, how they should be, and what is actually different. Use reports as the basis of redesign and/or problem analysis.

Organized reports done on forms are easy to read, not only for you but also for others, such as the designers or building engineers. Most of all, forms ensure better, faster, and more efficient balancing and fewer callbacks. Currently try to complete your reports using a laptop and keep them saved digitally. This cuts down on paper usage which helps the environment.

Pay attention! Talking about reports is a boring subject to read about. This is understood. The real problem occurs if you lose focus. These reports may sound boring and time consuming but you can be assured that if you don't take the time to prepare reports you will spend much more time later on trying to figure out what you are doing!

Types

There are a number of different types of test reports used in air balancing. The most widely used and critical are the *fan test report* and the *outlet air-balance report.* They provide the basis of essential data on the fan and the balance condition of the outlets.

The *pitot-tube traverse sheets* are more of a worksheet than a report you distribute or keep for record purposes. Larger, more complicated projects require *general information sheets* and *system recaps* to tie everything together and to keep track of the balancing progress. *Schematics* of the systems, which number the outlets and clearly show the routing, and so forth, are frequently needed for larger systems, systems that are spread out, systems with messy blueprints, and systems where no blueprints are available.

Preparation procedure

The first stage in the testing and balancing procedure is the preparation of test reports. This involves studying the plans, specifications, and equipment drawings to become familiar with the systems. Decide on the best method to balance the systems. Select and check out appropriate instruments.

Complete equipment test report sheets for each system. List outlets on air-balance sheets in the sequence of balancing together with their types, sizes, Ak factors, required air quantities, and velocities. Depending on the size and complexity of the project and systems, general information sheets, system recaps, and schematic drawings may be required. The procedures involved are discussed in the following 10 separate side headings.

Obtaining system reference material

Gather the following reference information:

1. Blueprints.
2. Specifications.
3. Fan submittal drawings.
4. Air-handling-unit drawings.
5. Grille performance data and airflow factors.
6. K-factor data.

Your supervisor will show you where to find all of the information above.

Studying plans and specifications

Read the equipment schedules on the blueprints. See what types of systems and equipment there are, how the ductwork is routed, and where dampers are located; and determine the size and capacity of outlets. Then, read what the specification requirements are on balancing. Ask and answer the following questions while you are reading the requirements from the manufacturer:

- What degree of accuracy is called for—±5 percent, ±10 percent, or something else?
- Do you have to balance in summer or winter? Should heating and cooling be on or off?
- Should the outside-air damper be open or closed?
- What instruments and procedures are required? Is certified balancing required?
- Can the contractor balance, or must the balancing be done by an independent balancing company? Can your shop balance the system?
- Should the building be occupied or empty?
- Are new filters required?
- Are temperature readings required?

Planning the best system balance and determining instruments to use

Plan how you can best balance the system. Then determine what test equipment to use.

Filling out a general information sheet

Completion of a general information sheet involves using the following steps:

1. Describe the types of systems with key descriptive terms, such as low-pressure, high-pressure, variable-air-volume, single-zone, rooftop, split-system, return-plenum ceilings, etc. Since we are discussing the most common type, your sheet would read "low-pressure, constant-volume, single-zone."
2. Indicate the manufacturer of the grille, diffusers, and terminal boxes.
3. Describe the types required and furnished.
4. Check off the test equipment to be used and indicate the models and last calibration dates.
5. Check off the status of completion of the building and systems.

Filling out an air system recap sheet

Complete this sheet on all but the smallest of projects. This means that if there are several supply, return, and exhaust systems, it is best to work with a recap sheet. The recap gives an instantaneous overview of the whole project, helps to keep track of the progress on the project, and provides the key data on the systems.

You need to list systems in groups, supplies, returns, and exhausts, along with their location, design cfm, rpm, ampere (amp), and static pressure. Keep track of your progress by checking the status boxes listed below on the following page of the recap sheet:

1. System ready for balancing.
2. Equipment checked out.
3. Systems balanced.

Then, fill in key fan performance data, cfm, percent design, rpm, amps, static pressure, and any problems as you proceed through system by system. After all the information is compiled and you are familiar with the project and the balancing requirements, you can begin the actual filling out of system reports.

Filling out the fan test report

To complete the fan test report, follow the steps listed in the following table:

Step	Box	Instructions
1		Work system by system.
2		Refer to both the manufacturer's equipment submittals and the equipment schedules on the blueprints.
3		Write in the fan test report headings.
4	Fan Data	Write in the manufacturer, model, size, type fan, wheel type, wheel condition, drive information, bearing condition, and cutoff plate checkoff.
5	Fan Performance	Write in the design cfm of the fan, the design total of outlet cfm (because it might be different from the fan due to error or changes), design rpm, and static pressure. These design figures are filled in initially, and the actual final figures are filled in upon completion of the balancing.
6	Conditions	Indicate the conditions at the time of balancing of the control dampers, vortex damper, filters, coils, and various air temperatures, if required.
7	Motor	This box calls for motor data. Write in the manufacturer's mounting frame number, the design of the internal frame (T or U), and service factor. This box then provides spaces for you to write in the rated and actual horsepower, brake horsepower, amps, voltage, rpm, and phase.
8	Starter	Write in the manufacturer, model, size, class of the starter, and required and actual protective overload sizes.
9	Static Pressure Drops	This is the last box. It covers actual static pressure drops across the filter and coils and the fan inlet and discharge static pressures that you read and fill out in the field.

Drawing a schematic of the system

A schematic drawing gives you a clear-cut, easy-to-read picture of the duct routing, outlet and damper locations and data, central equipment, and so forth, without clutter, unneeded information, or other distractions. Schematics allow you to plan the sequence of balancing more easily and help you determine where to take pitot traverses. They are also smaller, more compact, easier to carry around, and easier to open and close than larger blueprints that usually are in bulky rolls and have many unneeded drawings sandwiched in between. Schematics focus only on your work and not that of the plumbers, pipe fitters, and electricians. They do away with all notes and lines that are there only for construction purposes and not for balancing.

The situations where schematic drawings provide a great service are (1) when there are no blueprints available; (2) when blueprints are smeared and hard to read; (3) when there are long, spread-out, winding duct runs; and (4) when the system spans several Floors. Schematics are not always needed. If a system is small and clear drawings are available, schematics are not needed. Simply-laid-out medium and large systems that cover one area with uncluttered drawings do not require a schematic; neither do systems with relatively straight duct runs and few outlets. You must look at every job and system independently to determine whether the blueprints work as they are or whether a separate schematic drawing is required.

You can prepare schematics (fig. 2–26) by tracing from the original blueprints—a very fast and effective method—or by freehand-drawing and shrinking your product to an 8½-by–11 or 17-by–11-inch drawing. Show main equipment: louvers, automatic dampers, filters, coils, fan inlets, discharge dampers, and total cfm. Draw outlines of central equipment components; then identify and connect them with an airflow line. Draw single-line ductwork routing with trunk and main branch sizes. Show the cfm's and sizes of main duct and major branches for possible pitot-tube traverses.

Show all outlets by using circles or boxes identified with cfm's and sizes. Number all outlets in sequence of balancing. Show dampers: splitter, volume, fire, and extractors (use a line with a hook on the end).

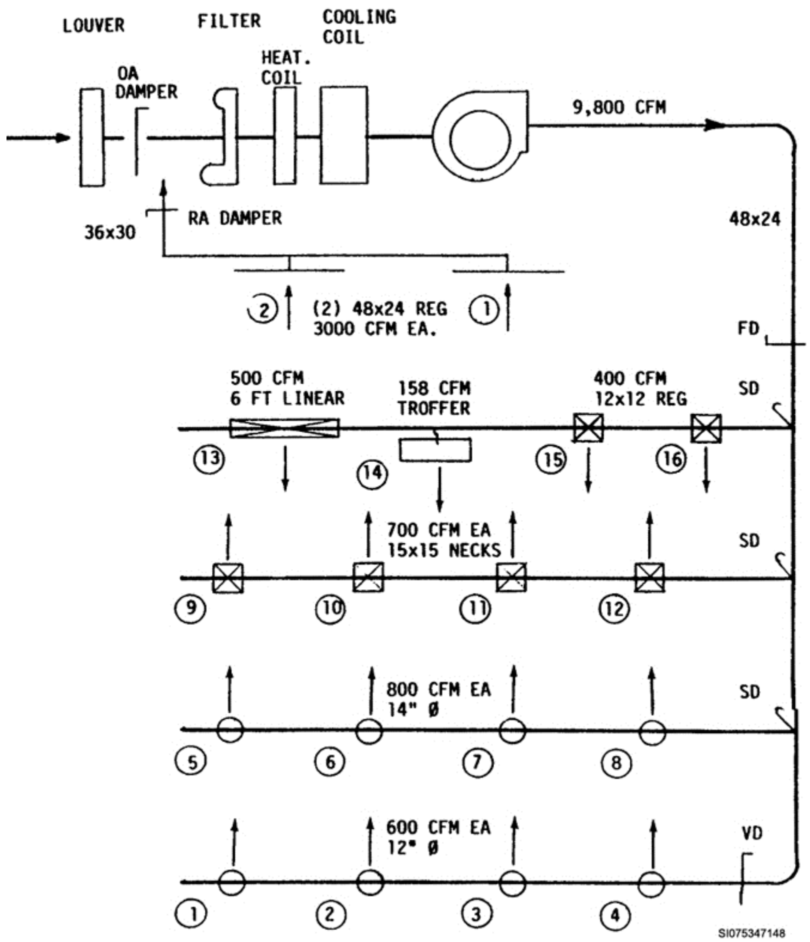

Figure 2–26. Example of a system drawing.

Preparing an outlet air-balance report

As you prepare this report, you must take these actions:

1. Work with blueprints, shop drawings, schematics, and the grille schedule from the manufacturer.
2. Number the outlets on the blueprints, if they are suitable for use, or on the schematic diagram in the sequence that they are to be balanced—usually from the end of the run toward the fan.
3. Fill in the heading on the report.
4. List the outlets in the sequence of the balance: 1, 2, 3, and so forth.
5. Fill in the location, sequence number, size, model number, and required cfm of each outlet.
6. Recheck drawings for all outlets to ensure that you pick up all of them.
7. Add up the outlet cfm's, and compare them with the fan cfm.
8. Look up the Ak factors for each outlet. Base this on the type of outlet, size, and instrument used.
9. Finally, the technician you are working with calculates the required velocities for each outlet and writes them in. This completes all of the work that can be done in the office on the outlet report. During balancing, write the percents of design in the preliminary columns. Calculate final velocities and cfm's from them and enter them in the final column.

Filling out the headings on rectangular pitot-tube traverse sheets

Fill out these sheets for main ducts, major branches, and so forth. Indicate the location of the duct, area serviced, duct size, and required cfm and rpm. Then, at the job site, confirm that the duct is easy to get to, there is sufficient straight duct to take a valid pitot shot at the selected point, and the duct actually installed is the size shown on the drawing.If all check out, determine spacing, number of points, and their locations on the pitot sheet. Take the readings and write in either the velocity pressure (if the manometer you are using does not read directly in fpm) or the actual fpm (if it does). Next, you convert Vps to fpm with the chart in the bottom corner, add fpm vertically and then horizontally for the total, and divides by the number of points read for average fpm. Then, the technician calculates the actual cfm and percent of design.

Filling out the headings on round pitot-tube traverse sheets

Round pitot-tube traverses are roughly the same as rectangular ones, except for the number of points to be read and the fact that their locations are already listed in a chart. Heading, calculations, and so forth are the same as those for rectangular pitot traverses.

Step 2, Check that the building and systems are complete and functional

We are now at step 2. Does this seem like a lot of information? Well, it is. We are not talking about what a hammer does or how to change a filter. This section is covering how to balance an entire air distribution system. No one said it was going to be quick. Stay focused! You got this.

Now, after the reports are prepared, inspect the job site to see that the building and systems are architecturally, mechanically, and electrically ready to be balanced. Invariably, new as well as old buildings may only be half-ready when balancing starts. In fact, it is often your quality control check that will uncover a multitude of missing or incorrect items. As you inspect each system, report the inadequacies, see that action is taken, and move on to the systems that are ready for balancing.

To check a building and its systems are ready for balancing, you must follow these procedures. Use figure 2–27, an example of a drawing, as practice to correlate the steps and the difference aspects of the drawing):

1. Check to see if the areas are enclosed with partitions and walls.
2. Check to see if ceilings are installed, windows are glazed, and doors are installed. If spaces are not architecturally sealed, abnormal positive or negative pressures may throw the balance way off. Next, are the HVAC systems complete?
3. Check to see that the fans, motors, drives, filters, chillers, boilers, coils, valves, grilles, diffusers, dampers, and so forth, are all installed. Outlet and equipment readings are invalid if some grilles, dampers, filters, or coils are missing. A final duct connection to a fan, hood, or diffuser prevents balancing completely. (Realize how long this step could take. It is asking to check an entire buildings worth of components. Depending on the building it could take a long time.)
4. Check to see that the control dampers are installed and—if the system is to be run on an automatic mode—ensure that they are hooked up to motors.
5. Ensure that the entire control system is installed and in proper operation if automatic mode is required.
6. If the system must be in a heating or cooling mode during balancing, ensure that control valves, sensors, and so forth, are installed, hooked up, and in operation. (Again, a potentially time consuming check.)
7. Check to see if motors are wired, starters are installed, and transformers are installed and checked out.
8. Ensure that fuses and thermal overloads are installed for balancing.

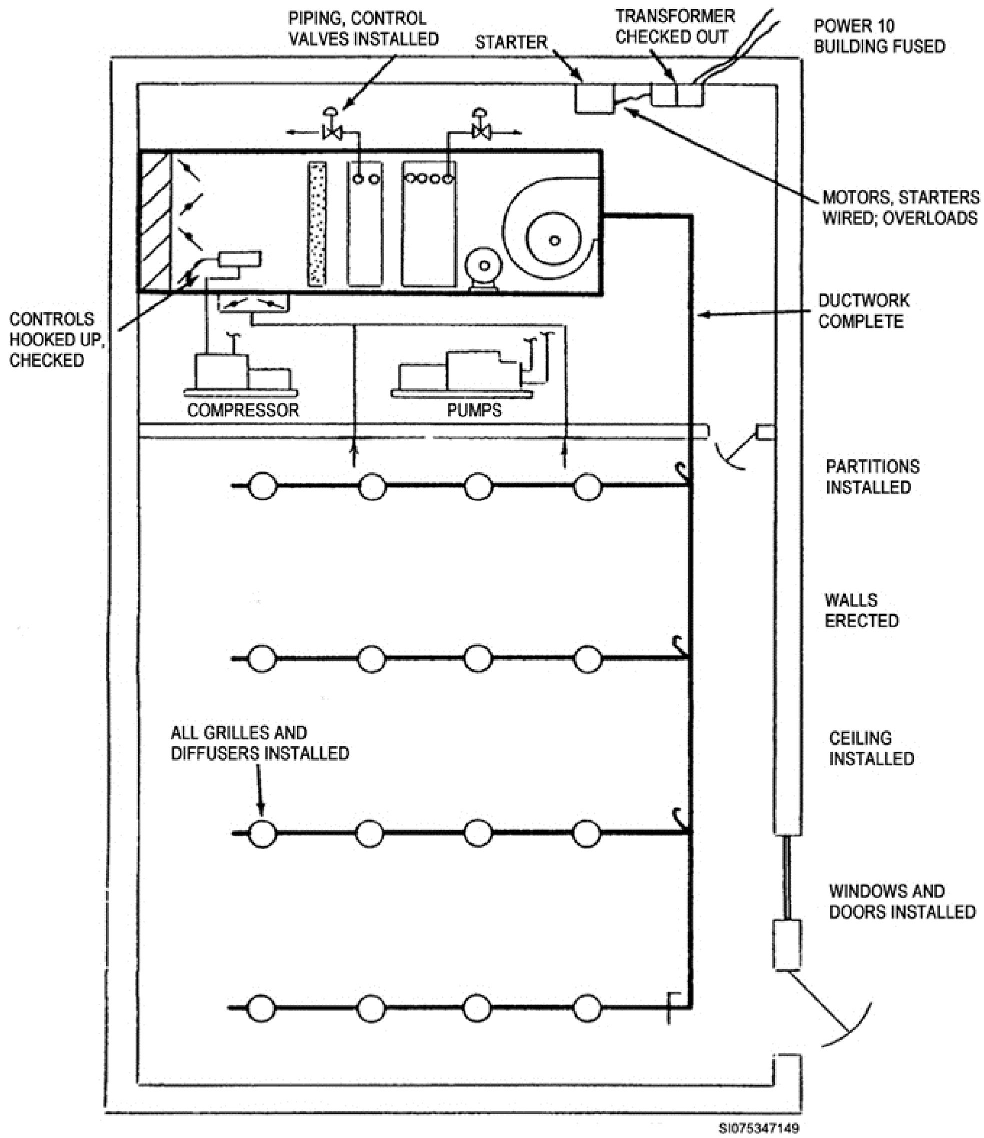

Figure 2–27. Checking that a building and system are complete.

After you determine which systems are truly complete, choose the first one to balance and proceed with an in-depth equipment checkout.

Step 3, Check out equipment

The first part of actual field testing and balancing consists of checking out and setting up equipment (fig. 2–28). You must do this very critical part of the procedure before the actual outlet balancing. The purpose of the equipment checkout is to ensure that the equipment operates and performs properly, for protection of the equipment and safety of personnel, and to set it up for testing conditions. It is also vital that the correct total amount of air and pressure be at the fan before balancing proceeds. We cover the basic procedures for checking out equipment, each separately, in sequence in the following discussion.

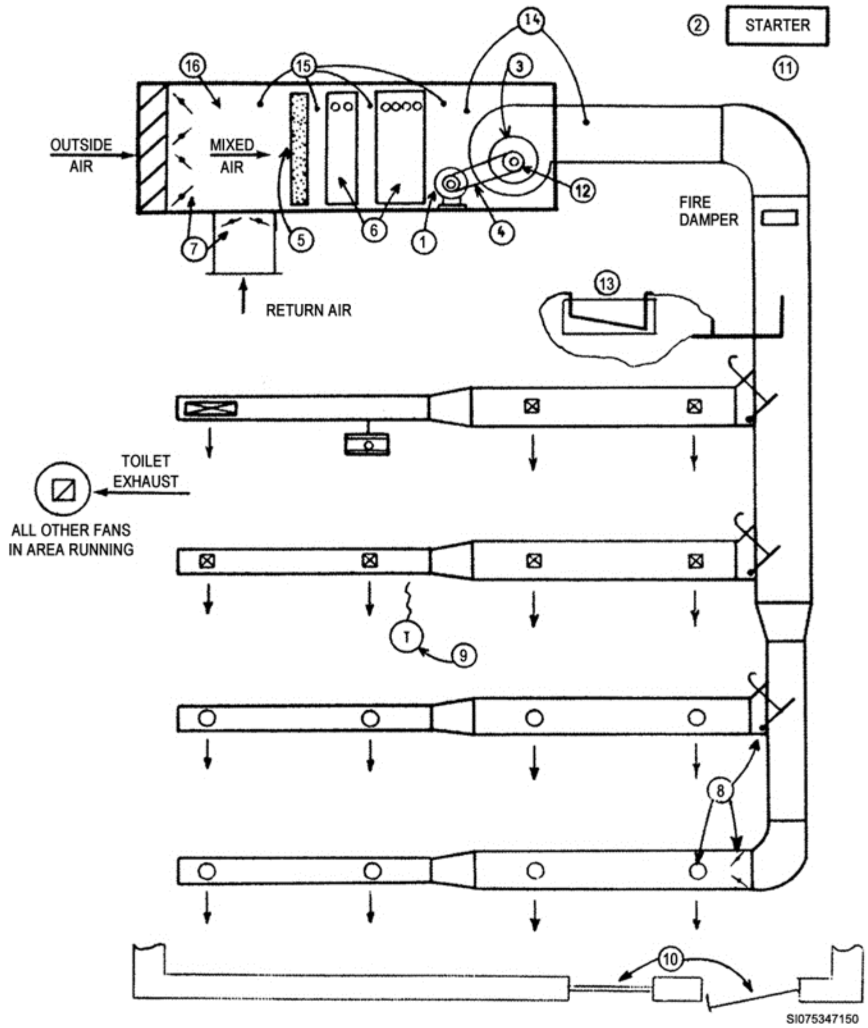

Figure 2–28. Equipment checkout.

Step 1, Check the motor data plate

Since the weakest link in the system is the motor, it is imperative that it be protected. Check the motor data plate (fig. 2–28, item 1) first for maximum amp load, voltage, phase, rpm, service factor, and other data. In order to take these measurements you will need a clamp-on ammeter and multimeter if you the ammeter doesn't have leads. Also you need an rpm measurement device. Record and compare with the design requirements written on the equipment sheets. If there are discrepancies in the voltage, phase, or rpm, reconcile them.

Step 2, Check thermal overloads

Next, go to the starter and check that there are thermal overloads (fig. 2–28, item 2) installed. Sometimes, the electrician has forgotten or hasn't gotten to them yet, or they are lying in the bottom of the box. In a three-phase system, there must be three overloads, one for each line. If the thermal overloads are not installed, do *not* test the system until they are installed. This means, you need to check with the electricians and check your shop stock. If you can't find any on base, then you need to order the overloads.

Not only must the thermal overloads be installed, but they must be of the correct size and not exceed the motor data-plate amps. For example, if the maximum data-plate amps are 12.0, the thermal overload must be rated for a maximum of 12 amps, plus or minus a few tenths. The correct size overload is normally on a chart on the inside of the starter cover. Locate the maximum amps in the column and read the required heater size next to it. Usually the heater number is stamped on the face of the heater itself and is visible when it is installed.

To change an overload, follow these steps:

1. Turn the power off at the starter and safety switch.
2. Unscrew the overload.
3. Pull it out. Usually there are two screws holding the overload in place—one on the top and one on the bottom of it.
4. Check that the starter is of the correct voltage, phase, and size.

Step 3, Check the fan wheel

Inspect the fan wheel (fig. 2–28, item 3) next. Is it the correct type and size? On centrifugals it could be one of four basic types—backward inclined, airfoil, forward curve, or paddle wheel. Is it installed to rotate in the right direction? Sometimes the factory installs a fan wheel backwards in a fan, or if the fan is knocked down and assembled on the job site, workers frequently install it backwards.

Why do you think the fan being installed the proper way is important? Take for instance in 2008 a worker in a deployed location installed a fan wheel backwards. There was a trouble call for no A/C. Another technician went to the job site and realized there was very low, if any, airflow. Upon further investigation, he realized the fan wheel was installed backwards. He installed it properly and the system worked fine. This allowed the Wing Commander to complete his required duties. Now, you should definitely understand the importance of checking the fan wheel for air balancing.

Is the gap and centerline alignment between the wheel and the inlet cone on centrifugal fans correct? Incorrect alignment can cause internal fan cycling and major havoc on the fan performance and reduce airflow 30, 40, or 50 percent. Check to see that the wheel is securely fastened to the shaft. Check also that the bearings are greased properly if they are not of the permanently lubricated type.

Last, bump the fan to check the rotation of the wheel. Bumping the fan simply means to turn the fan on and off again quickly. Frequently, motors are wired in reverse. To reverse the direction of a three-phase motor, switch two leads at the motor or starter. For single-phase starters, check the motor wiring diagram.

Step 4, Check drives

Inspect the drives (fig. 2–28, item 4). Is the belt tension correct? On multibelted drives, is the tension the same on each belt? Unequal tension could indicate that the belts are of different lengths and are not a matched set. Is the alignment correct? Cockeyed belts wear out very quickly and do not efficiently transmit horsepower. Catastrophes have occurred when new or remodeled systems were first turned on. Ducts have burst apart or collapsed faster than you could whip your hand back to the starter.

The technician you are working with makes a rough mental calculation of the pulley diameter ratio and compares it with the motor fan rpm ratio. This rough mental check involves dividing the fan pulley (sheave) diameter by the motor pulley (sheave) diameter and comparing that ratio to the motor rpm divided by the fan rpm.

For example, if the fan sheave is 10 inches in diameter and the motor sheave is 5 inches in diameter, divide 10 by 5, and the ratio is 2. Now compare the motor rpm of 1,800 divided by a design fan rpm of 900. The answer turns out to also be a ratio of 2, so all is well. If the ratios do not match within 5 or 10 percent, reconcile the discrepancy before you turn on the fan.

Record pulley (sheave) diameters, belt sizes, the true center distance from the motor shaft to the fan shaft, and available motor movement back and forth for tension adjustment in case you or a colleague must change the drives.

Step 5, Check filters

Inspect the filters (fig. 2–28, item 5) to see that they are installed and clean. On new jobs, if the installed filters are a temporary construction set, replace them with the permanent set. If they are a permanent set, make sure that they are not excessively dirty or clogged. This could involve buying multiple filters just so you can balance the system.

Step 6, Check cooling and heating coils

Inspect the cooling and heating coils (fig. 2–28, item 6). In built-up housings, are they properly blanked off all around the tops, bottoms, and sides so that air does not bypass the coil? Are there large gaps where the piping connections protrude through the side of the housing? If so, seal these properly.

Check to see if the coils are clean. If you must balance the system with the heating or cooling on, are the coils and control valves in proper operation? If you must do the balancing in a cooling mode and the cooling system is not operable, for whatever reason, you can block off portions of the coil face areas with cardboard or polyethylene.

Step 7, Check and setting automatic dampers

The next step in the equipment checkout is to check and set the automatic dampers (fig. 2–28, item 7) in their balancing positions. There are two approaches to setting outside-air, return-air, and exhaust control dampers.

The first approach is to use a separate return-air fan to set the outside air to 100 percent open, the return air to 100 percent closed, and the exhaust dampers to 100 percent. This approach is based on assuring that the supply fan can handle the full volume of air without the help of the return-air fan in this extreme condition. After balancing on 100 percent, swing the outside-air damper to its minimum position and spot-check the outlets.

The second approach is just the reverse. Set the outside air at its minimum position and the return air at its maximum; then, after balancing this way, spot-check the system in the 100 percent outside-air mode.

If there is no separate return-air fan and the supply fan is handling both the supply and return, the maximum load on the fan is when the minimum outside air and maximum return air are being drawn, which is the appropriate mode in which to balance. You must do spot checking in the maximum outside-air and minimum return-air positions.

If face and bypass dampers are automatically controlled by a heating coil, ensure the face damper is 100 percent open and the bypass 100 percent closed.

Step 8, Check outlet and ductwork dampers

After the central equipment is set up, go through the spaces served by the system and shine a flashlight through all outlets (fig. 2–28, item 8) to make sure that all of the dampers are 100 percent open before you turn on the system. Also, check that splitter dampers are positioned at roughly a 30 to 45° angle and that other manual volume dampers are 100 percent open.

Step 9, Check thermostat settings

Check the thermostat settings (fig. 2–28, item 9) in low-pressure, constant-volume, single-zone systems. In the winter, leave the thermostat on its normal setting for winter and summer conditions. In the summer, if the cooling is in operation, set the thermostat to maximum cooling, usually 55°F, so that the coil is wetted and the system is balanced under its maximum load.

Step 10, Check windows and doors

Ensure that all windows and doors (fig. 2–28, item 10) are closed in their normal position before you turn on the equipment. Do this to prevent possible abnormal positive or negative pressures that may throw the balance seriously off.

After you complete the inspection and setup of the equipment and ductwork, turn on the equipment to be balanced, plus all other systems that serve the same area, and take startup readings. Upon startup, listen for bursting or collapsing ducts, a rubbing fan wheel, motor or bearing noises, or a rumbling or clanging of any type. Observe the operation of the automatic dampers. If you see or hear something erratic, turn the fan off immediately. Check out and rectify the problem before proceeding.

The six basic actions involved in startup readings in turn and in sequence are covered in the following discussion. Since this is part of step 3, check out equipment, we will continue our numbering with number 11.

Step 11, Take amp and volt readings

Since the motor can be burned up so quickly, the first thing to do after you start the equipment is to check the amp (current) draw to make sure that it is not exceeding maximum motor amps and the voltage to confirm that it is in the correct range (fig. 2–28, item 11). Normally this is done with a clamp-on meter at the starter. Clamp the jaws around each wire, *one at a time*, and read the amps. Then, use the probes to read voltages across the terminals.

If there is a big difference between the current on the legs, or if the voltage deviates greatly from design or fluctuates, there must be electrical system problems that have to be resolved before you can proceed with any further testing of the system.

Step 12, Take fan rpm readings

Immediately after the amp-volt reading, check the fan rpm reading (fig. 2–28, item 12) to see that it is approximately as per the design. Use your tachometer as described in the manufacturer’s literature. If the rpm of the fan is grossly higher or lower than design, do the following:

1. Check the motor rpm to see if the wrong-speed motor was installed.
2. Check the pulley (sheave) diameters to see if you have the correct diameter ratio.
3. Check to see if the blueprints, fan drawings, or test report sheets are in error, or if there was a change in them or from them.

The drive belts may simply be riding too high or low in the variable-pitch motor sheave. If the current draw permits it, change the variable-pitch sheave to get the fan at the correct rpm.

Step 13, Check total airflow

Now that you already know two characteristics of the fan performance—amp (current) draw and rpm—check a third critical aspect on low-pressure systems at this point. Check the total airflow (fig. 2–28, item 13) at the fan to see if you have about the correct amount of air before you balance the outlets. It is generally best to always do this on larger systems with many outlets.

The main exception to this procedure is small systems with few outlets, where it is easier and faster to read all of the outlets and to total them up than to take a total airflow reading at the fan. Pitot shots also depend on ease of access of main ducts, complications of routing, and number of floors or different spaces the system serves.

The most accurate method of taking a total airflow reading is with a pitot-tube traverse in a straight run of ductwork—the longer, the better. Do *not* take such readings in or near fittings or right after dampers, coils, and so forth, because the readings are not reliable at these places. Read enough points for a valid velocity average.

To determine an accurate average air velocity in a duct, take a number of readings over the cross-sectional area of airflow and average them out. The basic approach for you to determine the number of pitot-tube traverse points to read is to divide the cross-sectional area of the duct into *equal* size spaces and take readings in the center of each. This may result in anywhere from 3 to 12 points being read horizontally across the duct and anywhere from 2 to 12 rows vertically, depending on the size of the duct.

Also, your *equal spacing between points of reading* may be between 4 and 12 inches; this again is relative to the duct size as per the chart on your pitot-tube traverse worksheet, as shown below:

Recommended Equal Spacing Between Points of Reading	
Width Range of Duct in Inches	***Spacing in Inches***
8–12	5
15–24	6
25–36	7
37–48	8
49–60	9
61–72	10
73–84	11
85–96	12

Generally, your first and last points in a row are anywhere from 1 to 6 inches inward from each side of the duct. Your procedure for determining the number of points in a horizontal row or vertical column is to divide the width or depth of the duct by the recommended equal spacing between points of reading and to split the remainder at the sides of the ducts.

For example, say that you must do a pitot traverse of a 40-by–18-inch rectangular duct (fig. 2–29). Divide the recommended 8-inch spacing from into the 40-inch width and write in the equal spacings on the pitot traverse worksheet. This gives four equal 8-inch spaces, with 8 inches remaining.

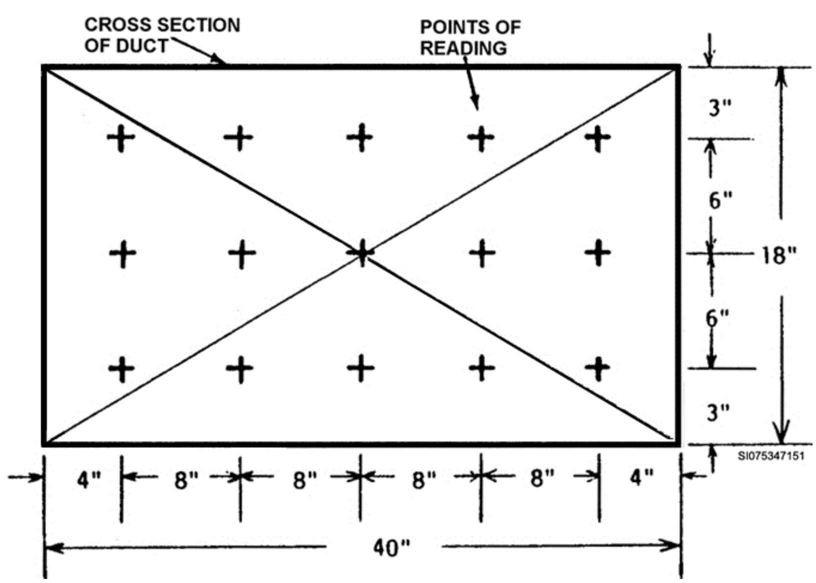

Figure 2–29. Example layout of points of reading for pitot traverse.

Now, divide the remaining 8 inches in half for the spaces on the sides and write these on the worksheet. This makes the spaces on the sides 4 inches each (fig. 2–29).

Treat the depth of your duct in a like manner. Divide the recommended 6-inch spacing from the chart into the 18-inch depth and write in the equal spacings on the worksheet. This gives two equal 6-inch spaces, with 6 inches remaining. Now, divide the remaining 6 inches in half for the spaces top and bottom and write these on the worksheet. This makes the spaces on the top and bottom 3 inches each (fig. 2–29).

Now, you can mark off and determine the number of points for the pitot traverse on the worksheet. This gives five points for each horizontal row and three points for each vertical column (fig. 2–29). There are five points across the width and three points across the depth, or a total of 5 × 3 = 15 points you have marked on the worksheet.

After you lay out the traverse on the worksheet, determine whether to take the readings through the bottom or side of the duct. Mark your points as shown in figure 2–29 and drill ⅜-inch-diameter holes at these points. Now, with tape or a marking pen, mark the depth of insertion for each point to be read on the Pitot tube. On newer pitot tubes there may be numbers on the tube so you will not have to measure and mark your points.

Set up your manometer, connect the hoses, insert the tube in each hole, and read each point. If your gauge has fpm on the scale, read it directly and record the fpm. If your gauge only has velocity pressure in inches of water gauge on the scale, read and record the readings on your worksheet. You must record *every* point in the traverse, even if the velocity is zero! Also, close the holes you drilled with a suitable plastic or metal hole plug. Do not use duct tape to seal your holes.

If you cannot take a pitot-tube traverse in the main discharge duct due to fittings, equipment, lack of straight duct, inaccessibility, and so forth, you can take traverse readings with an anemometer on the discharge side of a filter or coil. Usually these readings are not very accurate, but they provide a rough idea of the total cfm's to determine if the fan is running all right and if balancing the outlets is feasible.

Step 14, Read fan intake and discharge static pressure

If there are no problems thus far with the amp draw, fan rpm, or total airflow, you do not need to take fan static pressure readings on low-pressure systems. If there are problems with amp draw, fan rpm, or total airflow, the fourth characteristic of performance, fan static pressure, becomes a gap in the puzzle that you must fill. The technician with whom you are working should check the four readings against a fan chart to analyze the problem and confirm the readings. Since the fan charts are in brake horsepower instead of amps, the technician must convert the amp reading to brake horsepower.

If you are taking a pitot-tube traverse of the fan discharge duct, you can also take a discharge static pressure reading (fig. 2–28, item 14) at the same time. Also, with the manometer still set up for the discharge reading, you can stretch the tubing and pitot tube over to take an intake reading of the fan without making another setup. If you are not taking a pitot-tube traverse, use a magnehelic gauge to read the intake and discharge pressures.

Step 15, Read static pressure drops across filters and coils

The pressure drops across the filters and coils are not absolutely necessary if there are no problems with the amps, cfm, or fan statics or if the specifications don't require it. As a reference for balancing problems at the outlets or for future problems, they become valuable. They also serve as a good check against the design engineer's calculations and equipment manufacturer's catalog ratings.

Take the pressure drops across the filters and coils along with the fan static pressure and pitot-tube traverse. A magnehelic gauge with a 0-to–1-inch or 0-to–3-inch scale is simple, versatile, and quick. Just drill holes at the intake of the filter between the filter and first coil, between the coils, and at the fan intake. Take individual static pressure readings at each point and subtract upstream from downstream readings to arrive at the drops.

Step 16, Check stratification

Air in an occupied space must be kept moving to prevent stagnation or stratification. Warm air tends to rise; cold air tends to settle. In a room where the air is not deliberately moved, the air assumes levels by temperature. Air stratification through coils, filters, louvers, dampers, and so forth, can cause coil freeze-up, underheating or overheating or cooling, and great energy inefficiency.

If the arrangement of the outside airflow and return airflow into the mixing plenum gives any indication that there might be poor mixing of the air, such as temperature or velocity stratification, check for stratification.

A typical temperature stratification problem occurs when the outside air and return air flow into the mixing chamber in parallel (that is, on the top or bottom or along the sides of each other) and don't mix. Hot air flows through the top of the coil, and cold outside air flows through the bottom. In many cases, this results in coil freeze-ups.

Step 4, Balance outlets and branch ducts (proportionate balancing)

After you find the equipment to be correct and the total cfm in the right range, you can balance the outlets and branch ducts. First, walk through the various areas served by the system to see if there are any problems with temperatures, drafts, air noises, and so forth. Also, spot-check some end, middle, and starting outlets to determine roughly the extent of imbalance. Then, proceed with the balancing.

Some of the basic concepts of balancing outlets and branch ducts are as follows:

1. Use branch duct dampers for balancing wherever possible. Use outlet dampers behind diffusers and grilles only for *minor* balancing or trim adjustments.
2. Changing airflow at any outlet or branch duct always affects airflow at some other outlet or branch. Generally, this change is in greater proportions downstream than upstream. For example, when you cut down 100 cfm at an outlet, 80 cfm might go downstream and the remaining balance might go upstream.
3. Air always takes the course of least resistance. For example, when air has a choice of direction at a duct junction, more air flows down the branch of lesser resistance until the total pressure drops or the two equalize.
4. Air quantities change with resistance. Increases or decreases of resistance in a system change the cfm per the square root of the ratio of old to new resistance. Roughly, cfm decreases one unit of percent for every three or four units of static pressure increase. That means, if the static pressure is increased 100 percent in a system due to dampering, the cfm decreases 25 percent or 33 percent.
5. Damper throttling reduces fan airflow. This means that every time you close an outlet or duct damper, you increase the resistance of the system and decrease the total cfm from the fan. Remember this for later on.
6. Pressure drops in air systems are parallel in nature in exactly the same way as voltage drops are in a parallel electrical circuit (fig. 2–30). Just as the voltage drop is the same across each leg of the parallel electrical circuit, so is the total pressure drop the same from the discharge of the fan to the end of each branch in the air distribution system.

One of the most effective methods of balancing known today is the *proportionate* method. This method results in the least amount of energy usage by the fan or pump. In proportionate balancing, all outlets and branch ducts in the system, starting with those farthest from the fan, are brought to about the same percent of design the goal is ±5 percent.

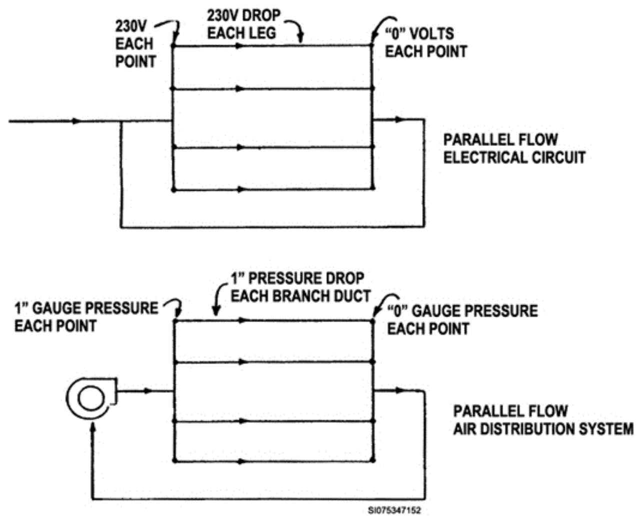

Figure 2–30. Parallel pressure drops.

The advantages of the proportionate method of balancing HVAC systems are as follows:

1. It is the most effective method known today for balancing HVAC systems.
2. It requires the least amount of damper throttle down and the least input of resistance to achieve the balance, all of which results in minimum energy consumption for system operation.
3. It is a systematic approach that ensures a consistently good balance, unlike the hit-and-miss or multiple-pass methods.
4. It allows you to change the cfm at the fan without having to rebalance the outlets. The air at the outlets automatically changes proportionately up or down and maintains the balance.
5. The overall cfm loss due to throttling dampers is minimum.
6. Low-pressure, constant-volume, single-zone systems can be proportionately balanced.

Before we get to the proportionate balancing procedures ensure the air handler or furnace is operating at 110 percent of CFM. Also, ensure the duct leakage is less than 10 percent.

There are eight basics steps for performing proportionate balancing:

1. Spot-check the end outlets and outlets closest to the fan to get an idea of how disproportionate the balance is. Read the last two outlets on the longest duct run and set them at the same percent.
2. Go to the third-to-last outlet, determine its percent of design, and adjust it to within 5 percent of the previous outlet.
3. Go to the fourth-to-last outlet and adjust it to within 5 percent of the previous outlet. Split the difference four ways this time and distribute.
4. Go to the second-to-last branch and proportionately balance it in exactly the same manner as the first branch.
5. Balance the last two branches against each other so that they are the same percent of design, just as the end two outlets were in each branch.
6. Go to the third-to-last branch and proportionately balance its outlets again in the same way.
7. Go on to branches 4, 5, and so on, toward the fan, proportioning the outlets on the branches and each entire branch to the previous one.
8. Go back to the fan and reread the total cfm, amps, and static pressure. Compare the fan cfm with the outlet cfm and adjust the fan up or down, if needed, according to the general procedure.

Spot-check the end outlets and outlets closest to the fan

The first step in proportionate balancing is to spot-check the end outlets and outlets closest to the fan (starting with the last two outlets on the longest run) to get an idea of how disproportionate the balance is. If the end outlets are very low and the outlets nearest the fan very high, adjust main and branch duct dampers to bring them within a more reasonable range. Start the actual proportionate balancing with the longest duct run with the most resistance.

Read the last two outlets and set them at the same percent of design. Read the last outlet on the longest duct run (branch—B1, B2, B3, or B4, etc.) and determine its percent of design. The “percent of design” is the actual reading divided by the required. For example, if you read 800 fpm and the required is 1,000 fpm, you have 80 percent of design. If the last outlet is under 60 percent of design, adjust the branch duct damper to bring it up to 70 or 80 percent of design. Do not touch the outlet damper at this time. Leave it 100 percent open.

Now, read the *second-to-last* outlet. If it is a higher percent of design than the last outlet, throttle it down half the percentage difference.

For example (fig. 2–31, point A), if the last outlet is 70 percent of design and the second-to-last is 90 percent, cut the second-to-last down to 80 percent and see if the last outlet is brought up to 80 percent. If the second-to-last outlet happens to be a lower percent of design than the last outlet, cut the last outlet down instead to get both outlets the same percent of design.

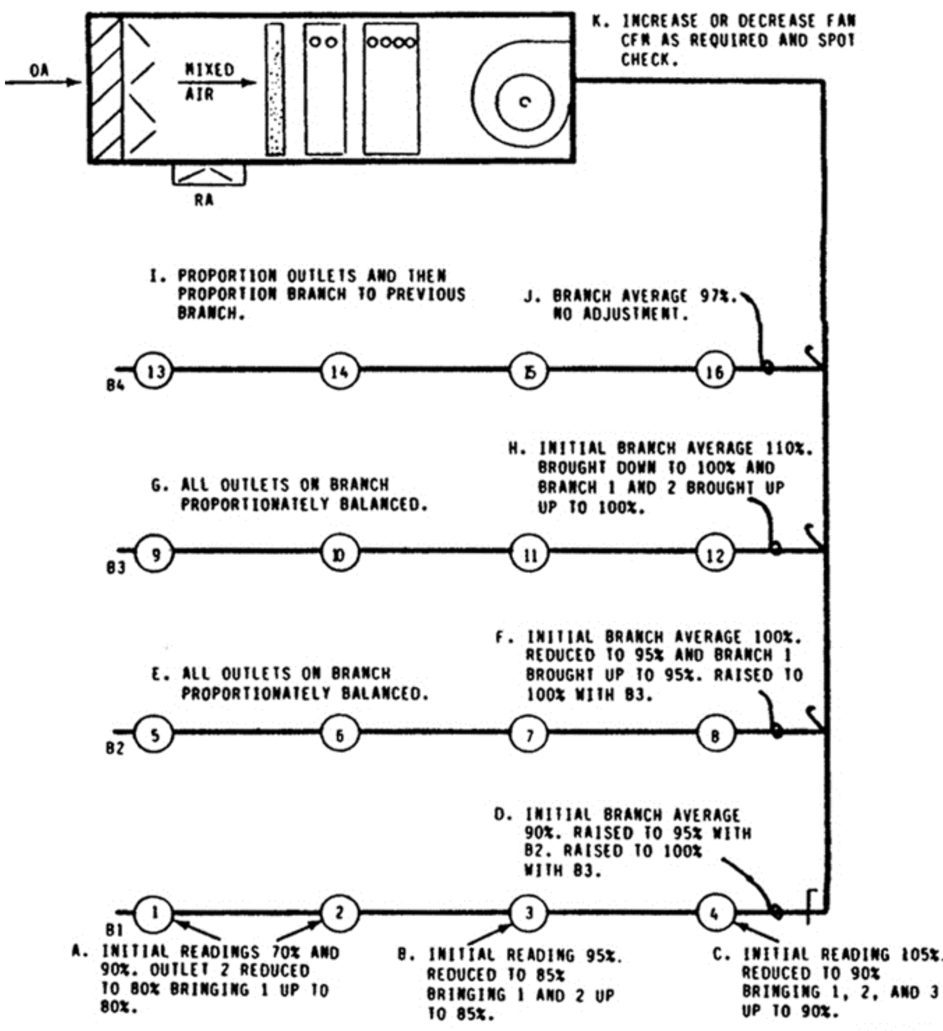

Figure 2–31. Proportionate balancing (low-pressure, single-zone system).

Go to the third-to-last outlet

After the last two outlets are the same percent of design as the second step, go to the third-to-last outlet, determine its percent of design, and adjust it to within 5 percent of the previous outlet. Split the difference in percentage between the three outlets three ways and reduce the third-to-last outlet two-thirds of the difference. The intent here is to leave one-third at the outlet and push two-thirds down to the last two outlets.

For example (fig. 2–31, point B), if the third outlet is 95 percent of design, the difference between it and the last two outlets—both at 80 percent—is 15 percent. Reducing the third outlet two-thirds of the difference (2/3 X 15=10), or 10 percent, changes it from 95 to 85 percent. The 10 percent cut down splits itself between the last two outlets, thereby raising each of them from 80 to 85 percent.

Check to see if the second-to-last outlet actually raised about 5 percent. If not, adjust the third outlet accordingly. You need not check the last outlet because it changes proportionately. In practice, usually most of the air moves downstream, but a small part also moves upstream, *so the changes in percentages may not be perfect and more adjustments may be needed.*

Go to the fourth-to-last outlet and subsequent outlets

Now, as the third step, go to the fourth-to-last outlet and adjust it to within 5 percent of the previous outlet. Split the difference four ways this time and distribute—one part remains; three parts to be sent downstream.

Proceed on to subsequent outlets, setting them to within 5 percent of the previous ones by distributing the percentage difference equally among the outlet itself and the outlets downstream. You need check only the previous outlet each time and not the others downstream, except for an occasional spot check if you are in doubt. As we stated earlier, they come up proportionately.

Go to the second-to-last branch

Now, let's assume that you have brought up all the outlets on the farthest branch to 90 percent of design (fig. 2–31, point C). As the fourth step, go to the second-to-last branch and proportionately balance it in exactly the same manner as the first branch; balance the two end outlets at the same percents of design and balance subsequent ones to within 5 percent of the previous outlets (fig. 2–31, point E).

Balance the last two branches

Now, let's say that the second-to-last branch ends up with an average of 100 percent of design (fig. 2–31, point F). As your fifth step, balance the two branches against each other so they are the same percent of design, just as the end two outlets were in each branch. Split the percent difference and reduce the second-to-last branch from 100 to 95 percent (fig. 2–31, point F). Check a typical outlet on the last branch to see if it is brought up to 95 percent (fig. 2–31, points D and F). If it is brought up, you need check no other outlets as we assume they changed equally in terms of percent of design.

Go to the third-to-last branch

Having gotten the last two branches the same percent of design, for your sixth step, go to the third-to-last branch and proportionately balance its outlets again in the same way (fig. 2–31, point G). Then, bring the entire branch to within 5 percent of the second-to-last branch and check it out again by spot-checking the outlets (fig. 2–31, points H, F, and D).

Go to subsequent branches

Now, the seventh step is to go on to branches 4, 5, and so on, toward the fan. Proportion the outlets on the branches and each entire branch to the previous one (fig. 2–31, point I).

After all the outlets and branches in the system are proportionately balanced, you'll find that they are, as an average, lower, at, or higher than design. It could be 120, 110, 100, 90, or 80 percent or anything in between or even beyond (fig. 2–31, points J, H, F, and D). Whatever the average turns out to be doesn't matter. The point is that all the outlets and branches are proportioned. If you need to increase or decrease the cfm at the fan, you can do such adjustments without losing the balance. Outlets and branches rise or fall roughly the same percent as the fan. You need make only spot checks to verify that the balance is not lost.

Go back to the fan

The eighth and last step in balancing a low-pressure, single-zone system is to go back to the fan and reread the total cfm, amps, and static pressure. Compare the fan cfm with the outlet cfm and adjust the fan up or down, if needed, according to the general procedure (fig. 2–31, point K).

Step 5, Recheck equipment readings

After the outlets and branch ducts are in proportionate balance (e.g., they are all approximately at the same percent of design), whatever it may be (85, 95, 100, or 115 percent), return to the fan and recheck the total cfm, amps, and discharge static pressure.

Outlet cfm low or high

If the total outlet cfm is 10 percent or more under or over the design cfm, increase or decrease the fan rpm by bringing the outlet cfm up as close as possible to 100 percent of design. Remember, if the outlets are proportionately balanced, they all increase or decrease in roughly the same percentage as the fan cfm. If you increase the fan 12 percent, the outlets each do likewise. If you decrease the fan 15 percent, the outlets do likewise.

If you must increase the cfm, proceed as follows:

1. Check the actual amps against the motor-rated amps to see if there are any left to work with.
2. Check to see if there is any room on the variable-pitch drive on the motor to alter the rpm.
3. Using fan law number 1, calculate the new rpm needed to achieve the new cfm.
4. Calculate what the new static pressure and brake horsepower are.
5. Compare the brake horsepower with the actual horsepower of the motor.
6. Determine if you need new belts or sheaves.
7. Check the motor movement forward and backward in regard to whether you can reuse the belts or not.
8. If a new motor is indicated, consider if you can live with less cfm to retain the existing motor. After changing the cfm at the fan, spot-check outlets to verify they have increased or decreased proportionately.

Low-pressure ductwork that happens not to be sealed in any way might leak anywhere from 5 to 15 percent; the average is about 8 percent. Under these conditions of leakage, the fan cfm generally runs about 8 percent more than the total of the outlets. This, of course, varies with many factors already listed.

Fan and outlet cfm discrepancies

If there is a large discrepancy between the fan and outlet cfm (15 or 20 percent or more), check the following:

1. Ductwork leakage.
2. Accuracy of pitot-tube traverse or other method of reading total cfm.
3. Instrument calibration, zeroing, method of reading is correct.
4. Incorrect Ak factors.
5. Open ducts, missing end caps, large gaps at connections.
6. Arithmetic cfm extensions and totals in error.
7. Design errors or changes.

Step 6, Finalize the test reports

In the final phase of testing and balancing, (1) calculate the final cfm of each outlet from the percents of design; then (2) total the outlet cfm's, determine the percent of design of this total, recheck figures, note and explain problems, and generally complete reports for record purposes and submittal to the engineer if required. After completing and recording the readings for each pitot-tube traverse point, add up the fpm's and divide by the number of points for the average velocity. If velocity pressures are to be recorded in inches of water, you must convert them to fpm, first, before you add them together. Otherwise, the average fpm you determine is erroneous. Do not add the inch readings together, only the fpm. Also, note that in proportionate balancing, you enter only the percents of design on the outlet air-balance sheets during balancing. Convert the percents into cfm after balancing is completed.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

210. Basic ductwork designs

1. What is the initial issue with oversized ductwork?

2. With regards to airflow speed, how are diffusers and grilles designed?

3. Using the equation, Air Volume (cfm) = Air velocity (ft/min) x Cross sectional area (ft^2), find the air velocity with cfm of 150 and a cross sectional area of .5ft^2.

4. Using the equation, Air Volume (cfm) = Air velocity (ft/min) x Cross sectional area (ft^2), find the air velocity with cfm of 250 and a cross sectional area of .6ft^2.

5. Using the equation, Air Volume (cfm) = Air velocity (ft/min) x Cross sectional area (ft^2), find the air velocity with cfm of 250 and a cross sectional area of .5ft^2.

6. Without using math, which measurements will product the higher air velocity: 250 cfm and cross section area of .5ft^2 OR 250 cfm with a cross section area of .6ft^2.

7. If air velocity is too low at the diffuser, how will airflow be affected?

8. Besides noise, what affect will too much air velocity have?

9. If you are a worker with very little experience, which ductwork would be easy to install?

10. How can the extended air velocity problem be solved?

211. Flow and pressure characteristics of HVAC/R systems

1. At what point is there no heat or energy?

2. What does air compress from in an HVAC/R system?

3. How are the molecules in air affected as they are heated?

4. How much pressure would lift 2 inches in a vertical column?

5. How much force (not quantity) is one inch of water column?

6. How would you obtain velocity pressure if you had total and static pressure?

7. Where will you likely find a positive static pressure?

8. Where will you likely find a negative static pressure?

9. What causes airflow in a system?

10. Where will a velocity pressure to static pressure conversion generally occur?

11. How much force does a fan make?

212. Fan system measurement

1. How would you acquire the fan total pressure?

2. If you wanted to find the total mechanical energy added to the air by a fan, what measurement would you use?

3. How do you obtain fan static pressure?

4. When would the fan speed equation be used?

5. If you have a system with 200 cfm's and operates at 10 rpm's but you now need 100 cfm's, what will the new rpm be? (Use $\frac{\text{rpm2}}{\text{rpm1}} = \frac{\text{cfm2}}{\text{cfm1}}$)

6. What would you use if you wanted to plot the pressure required to move air through a system?

7. System resistance will increase.

8. What is the relationship between fan pressure at the fan inlet and air density?

213. Air volume measurement

1. Where should you place the rubber tip of the timed revolution counter?

2. How do level the quarter-inch inclined gauge?

3. Why is static pressure pulled into the outer portion of the pitot tube?

4. What must you ensure you know before you place the tubes into the system?

5. What could affect the degree of accuracy of an anemometer?

6. What type of measurement does the velometer excel at?

214. General procedures for air balancing

1. What is the second step in filling out a general information sheet?

2. When could the air system recap sheet be bypassed?

3. What is the final step in filling out the fan test report?

4. When filling out an outlet air balance report, what step comes after you fill in the heading report?

5. When filling out a pitot tube traverse sheet, what is accomplished after the location of the duct, duct size and required cfm and rpm are obtained?

6. During step 2, what is the job site inspected for?

7. What is effected if spaces are not architecturally sealed?

8. Which connection(s) could prevent balancing completely?

9. What is the first thing checked in step 3?

10. After the motor date plate is checked, where should you check the thermal overloads?

11. In what positions should windows and doors be before you turn on the equipment?

12. What should be done immediately after taking amp and volt readings?

13. If there is a large discrepancy between the fan and outlet cfm, what should be checked?

2–2. Hydronic Balancing

You perform water balancing separately from air balancing. We balance water-flow systems by direct flow measurements when possible rather than by pressure drop or temperature readings that might compound errors for various reasons. Circumstances may not always allow complete flow measurement throughout the system. A combination of flow, pressure, and temperature balance might be required. Even though flow measurement is the most accurate method, it is not always economical or necessary to install flow measuring stations at every terminal.

In general, we attain the balance of a water-flow system by flow and pressure readings and confirm it by total heat transfer and by using air and water temperature readings.

215. Hydronic volume measurement

Hydronic flow measurement is an important skill to learn. It is not a task that you will perform everyday but when the time comes for you to use it, you need to be able to perform.

Reading the actual flow is the most accurate and positive technique. The instruments covered in this unit deal with flow measurement. Pressure drop and temperature readings are less reliable and are subject to other variables.

There are a number of different types of flowmeters available that are manufactured specifically for flow measurement and they include the orifice-plate flowmeter, venturi flowmeter, circuit testers, pitot-tube flowmeter. The section will begin with the orifice-plate flowmeter.

Orifice-plate flowmeters

Sharp-edge orifice plates have a high degree of accuracy and are relatively low cost. The temporary pressure drop across the orifice-plate opening, in inches of water, is correlated against the flow in gallons per minute (GPM) by the manufacturer in the laboratory (fig. 2–32).

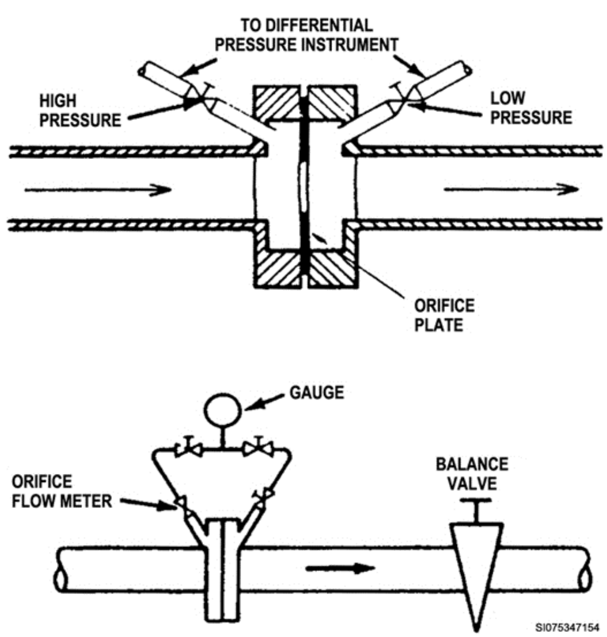

Figure 2–32. Orifice-plate flowmeter.

The manufacturer prepares calibration curves for the equipment and furnishes them with the orifice plate. Normally, you can measure the orifice at maximum flow with a 100-inch differential pressure gauge.

Install the orifice plate a straight length of pipe upstream and downstream of the plate. Determine the length of the pipe by the size of the orifice, according to the manufacturer's instructions.

The orifice plate is used with a differential pressure gauge or digital manometer. The balancer hooks up the gauge to the orifice plate, notes the pressure drop, and reads the gpm off the calibration curve based on the pressure drop.

If balance valves are used with orifice plates, install the valve a sufficient distance upstream or downstream from the orifice plate to avoid flow turbulence at the plate.

Venturi flowmeters

The venturi flowmeter (fig. 2–33) measures flow in much the same way as the orifice plate. The narrow neck of the venturi causes a pressure drop, and like the orifice plate, the manufacturer develops a calibration curve of pressure drop in inches of water versus gpm flow and provides it along with the meter.

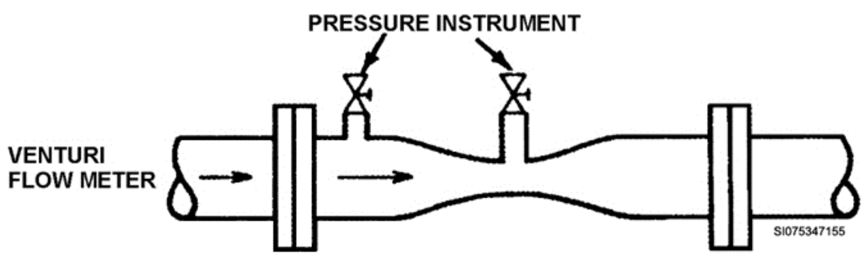

Figure 2–33. Venturi flowmeter.

You must install appropriate lengths of straight pipe on either side of the meter also. The balancer reads the pressure drop with a differential pressure gauge or digital manometer that is hooked up to the venture meter. The balancer reads off the gpm from the calibration curve according to the pressure drop.

Circuit testers

A circuit tester (fig. 2–34) is a variable-orifice flowmeter that combines a flowmeter and a balance valve into one unit. In addition to its functioning as a balancing flowmeter, it also serves as a shutoff valve.

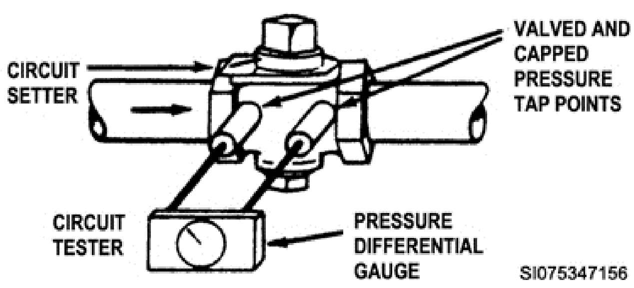

Figure 2–34. Circuit tester.

Readings are in feet of water rather than inches; consequently, a foot-reading differential is required. The procedure, again, is the same as with the orifice plate and venturi: read the pressure drop and determine gpm from the curve.

To measure the pressure attached one end of two tubes to the circuit tester and attach the other end to a digital manometer. The manonmeter will display the flow rate.

Pitot-tube flowmeters

The pitot-tube flowmeter measures pressures in much the same way as a pitot tube does in air balancing. One tube, with several openings, faces the airstream and measures the total pressure. The other tube, with a single opening, faces downstream and measures the static pressure. The instrument automatically subtracts the static pressure from the total pressure, leaving the velocity pressure, which is correlated to gpm flow on a chart according to the size meter used and the diameter pipe.

There are two newer balancing tools available for balancing: digital manometers and ultrasonic flow meters. Digital manometers can be used with the previous devices to give pressure readings. The ultrasonic flowmeter does not have to be connected into the system and can take the reading from outside the pipe.

Finding the differential pressure on the annubar chart

To find the differential pressure on the annubar chart (fig. 2–35), follow this procedure:

1. Enter the chart with the flow rate: “US Gallons/minute (GPM).”
2. Go vertically down the chart to the normal pipe size.
3. Read the differential pressure on the scale on the right.
4. If needed, find the approximate velocity (ft/sec) of the water on the scale on the left.

Example:

Assume water is flowing at 300 GPM in a 5-inch pipeline. What is the differential pressure? Follow the dotted lines on the chart to find a differential pressure of 8.4 inches of water (fig. 2–35).

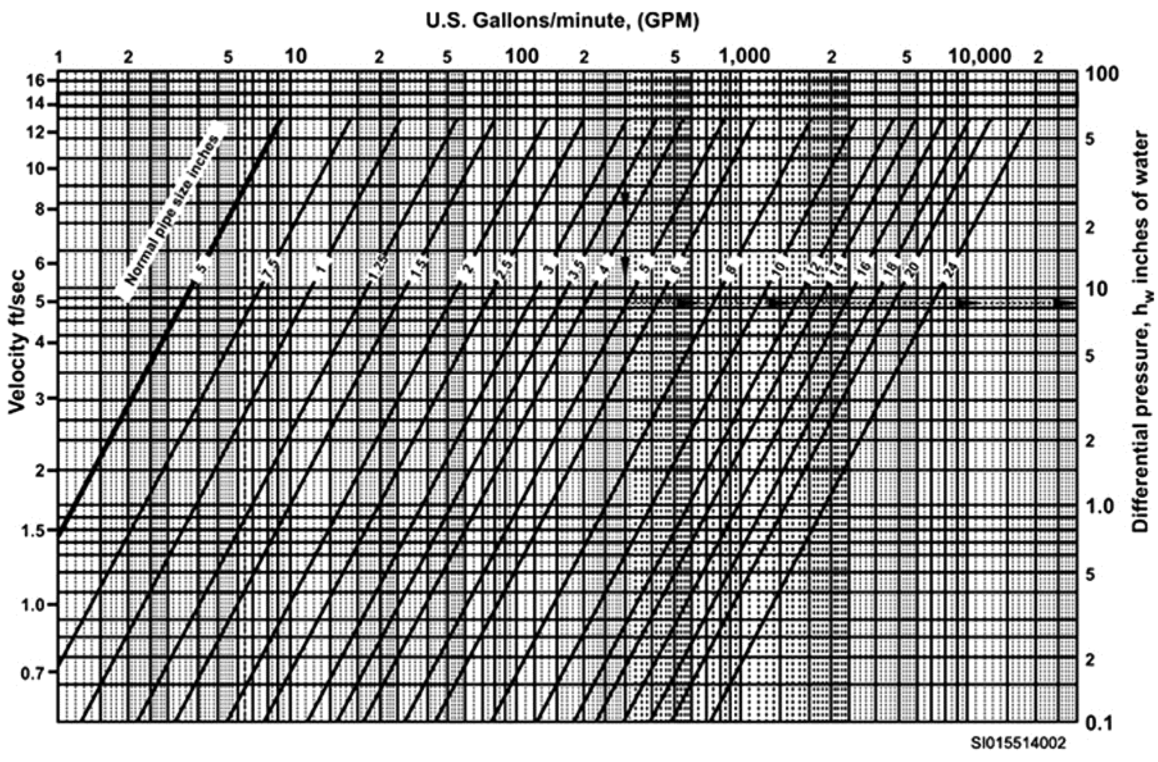

Figure 2–35. Annubar differential pressure chart.

Ultrasonic flow measurement

Sensors in this flow meter send and receive signal across the cross sectional of the pipe. The signals will have different transit times. The amount of time it takes one signal to reach the other side of the pipe determines the flow rate. The more flow, the more time between signals being received. Sensors can be inside or outside of the pipe.

216. General procedures for hydronic balancing

Generally, we attain a good balance in a water-flow system by starting the balance at branch circuit terminals, then going through the main circuits, then to the equipment room, and finally to the main system pump. The right spot to start can vary at times, depending on the conditions of the system. There are circumstances when it is more efficient or simpler to start at the pump. Sometimes it is best to start on a primary circuit rather than a secondary one.

The most important consideration is adequate flow rates at the terminal units with correct heat transfers. Whether the pump meets the design flow rate is not the prime goal. The sum of the terminals and the overall system dictates the true system curve and the resultant pump flow.

Water-balance test reports preparation

The necessity of working with test report forms in water balancing is just as important as it is in air balancing. Good organization, an outline of the information needed, a guide to the sequence of work, readability, and good records are all required equally. Also, flow diagrams are generally required because of the frequent difficulty of following piping systems on blueprints when you are balancing (fig. 2–36).

Piping systems are closed as opposed to air systems that are open. Water is a noncompressible fluid, while air is a compressible one. The behavior of pressure is different in a closed system than it is in an open one. In an open system, the gauge pressure at an air outlet is always zero; whereas the gauge pressure at the water-leaving side of water terminals is never zero.

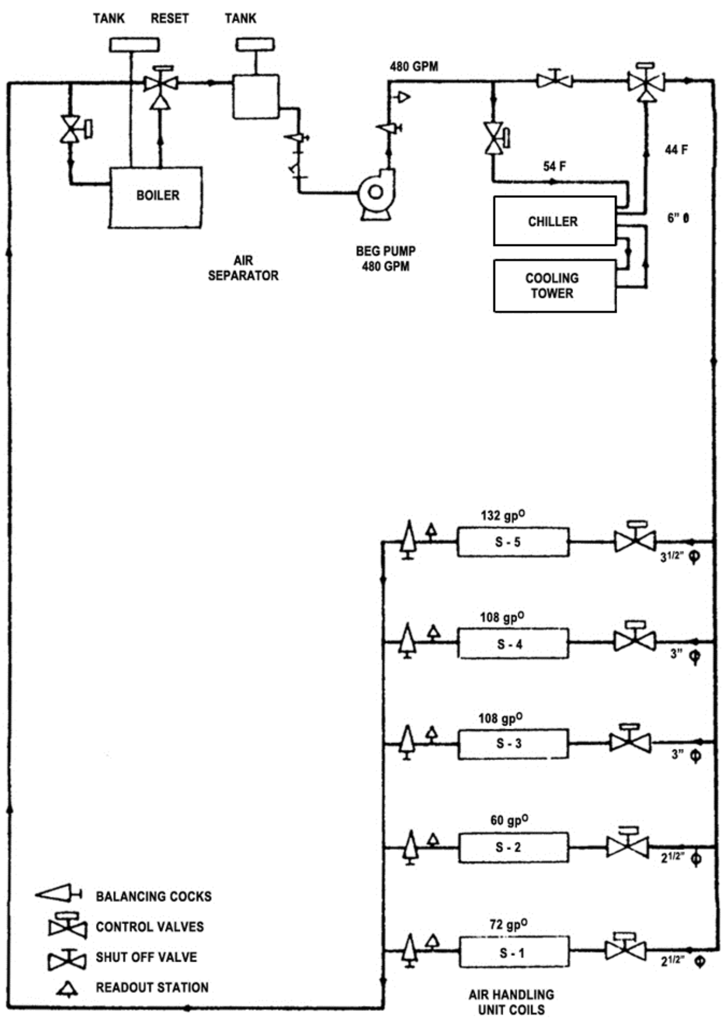

Figure 2–36. Two-pipe heating and cooling piping system.

With these things in mind, you are now ready to go through the steps of preparing water-balance test reports. There are nine steps, which we cover in sequence in the following table:

Step	Instructions
1. Obtaining system reference material	Gather this required information: blueprints, HVAC unit, shop drawings, coil, specifications, valve, pump submittals, cooling tower, chiller.
2. Studying plans and specifications	Read the blueprints and shop drawings to become familiar with the types of systems and equipment. Study the routing of the piping and note valve and coil locations. Determine what specifications call for in the way of balancing.
3. Planning the balancing method and selecting instruments	Plan the best way to balance the system. Then determine what test equipment you are to use.
4. Preparing the flow diagram	Draw a flow diagram, if there is none available. Note the central equipment, terminals, piping, diameters, valves, etc.
5. Filling out the pump test report	Follow these steps in order: 1. Fill in the standard information in the heading. 2. Enter pump data: manufacturer, model, size, type, and impeller size. 3. Enter design performance figures: gpm, rpm, and full-flow and no-flow heads. Fill in the suction and discharge pressure readings at full flow and no flow at the job site. 4. Fill in the motor data: manufacturer, serial number, mounting frame number, type of internal winding frame, service factor, rated hp, bhp, voltage, rpm, and phase. Obtain the rated amp from the data plate at the job site as well as the actual readings. 5. Enter the starter data: manufacturer, model, size, and class. Obtain the required overload size from the inside of the cover on the starter and the actual overload installed by inspection.
6. Filling out the flow or pressure-drop water-balance report	Follow these steps: 1. List the primary and secondary circuits in groups and in sequence. 2. List the valves and terminals in the sequence they occur. Start at the pump. Include their identification and location, if needed. 3. Indicate the size. 4. Enter the required cfm and the differential pressure reading required for the particular flow measuring device being used or from the manufacturer's published pressure drop across the item at design flow. 5. List the bypasses. 6. When proportionate-balancing terminals, list the percents of design in preliminary readings and gpm only for the final.
7. Filling out the temperature water-balance report	Fill out this report for systems without flow measuring stations at terminals that are generally reheat coils, induction units, and baseboard radiation units. List the coil identification and room number in sequence, from the pump out. List primary circuits and secondary circuits as separate groups. Indicate sizes, design entering- and leaving-water temperatures, and entering- and leaving-air temperatures.

Step	Instructions
8. Filling out the chiller test report	If there are chillers, fill out a chiller test report. Start with the standard heading, then the basic compressor data: manufacturer, model, size, type, capacity, refrigerant, pounds, and serial number. The manufacturer normally checks out the refrigerant pressures and temperatures on the compressor, evaporator, and condenser in the startup; these are generally part of the water balance. Fill in design water pressures, temperatures, and flows on the evaporator and condenser. Fill in design electrical data: hp, kW, voltage, phase, etc., on the compressor and starter. Fill in the conditions at test time at the job site: refrigerant and oil levels, water control settings, temperature and pressure cutouts, and purge operation.
9. Filling out the air-cooled condenser and compressor reports	If there are air-cooled condensers and compressors, fill out the appropriate report. Fill in head data, compressor data, manufacturer, model, size, type, capacity, refrigerant, pounds, and serial number. Fill in design pressures and temperatures on the suction and discharge side of the compressor. Enter compressor motor and starter electrical data. Fill in condenser design temperatures and pressures for liquid line and air. Indicate condenser fan hp, amps, and volts.

Chilled and hot-water balance procedures

A considerable difference exists between air-balance and water-balance requirements. Air balance requires a remarkably precise flow definition because the air is the prime heating or cooling load medium. A reduction in airflow to less than the design requirement sets up a linear, or directly related, reduction in load ability for given inlet and outlet air conditions across a terminal heat transfer unit. Since the water flow rate differs, in that it is not linearly related to terminal unit heat transfer capability, the flow rates need not be as precisely defined for the same degree of balance as for air. The problem of defining adequate flow rate is related to the relationship between heat transfer and water flow for water-to-air terminal units.

It is not possible to list all variations of procedure to cover balancing of water systems. Aim the generalized procedure at providing system balance together with minimal operating cost. Eliminate excess pump head (excess operating power) by trimming the pump impeller, rather than allowing the excess head to be absorbed by throttle valves.

You can achieve the desired object—balance with lowest cost operation—either by preset, using calibrated balance valves followed by final adjustment and impeller trim, or by setting of system balance valves while, at the same time, maintaining close watch and control of pumped flow by use of the pump throttle valve. When you achieve final balance valve setting, eliminate excess pump head (pump throttle valve head loss) by trimming the pump impeller.

Now, we cover a general basic procedure based on job setting of the system balance valves. There are 15 basic steps in this procedure. We examine each briefly in the following table:

Step	Instructions
1. Studying the drawings	Note the type systems, equipment, and their capacities. Note the location of control valves, balancing cocks, flow measuring stations, thermometers, and pressure measuring stations.
2. Planning the balancing method and selecting instruments	Plan the best way you can balance the system. Then determine what test equipment you are to use.
3. Preparing a flow diagram	Develop a flow diagram with piping, valves, measuring stations, flows, equipment ratings, and sizes. Note *diversity* between pump and total terminal flows due to three-way bypass valves, etc.

Step	Instructions
4. Preparing test reports	Fill out equipment data sheets for pumps, chillers, etc., and balancing sheets for coils, control valves, heat exchangers, etc., listing them along with catalog flow ratings, pressure drops, temperature drops or rises, and whatever is required. List flow and pressure measuring stations.
5. Checking that systems are functional and complete	Ensure that systems are hydronically and electrically functional and that controls and air distribution are complete. Sometimes you must balance the air distribution system first.
6. Checking motor data plate and overloads	Check pump motor data plate. Compare the rated amps with the starter thermal overloads.
7. Checking pump characteristics	Check pump size, rotation, alignment, couplings, and lubrication.
8. Inspecting the system	Confirm that piping has been pressure tested. Ensure that the system has been filled, flushed out, and refilled, and that it is clean. Make sure that the strainers are clean. Make sure that water level in the expansion tank is at the proper level.
9. Venting the air	If air and other gases are not removed from piping systems, they can air-bind terminal components, cause the flow to stop, and possibly cause air noises in the piping. Air in piping and components is displaced to high points and compressed when systems are filled with water. Normally, piping systems are provided with air vents for purging the entrapped air. After the venting of the system, the boiler airtrol fitting removes air entrained in the recirculating water.
10. Checking the control valves	Check that control valves are operative and set for design flow. If three-way automatic valves are used, set all bypass-line balancing cocks to restrict water to 90 percent of design through the terminals.
11. Checking balancing cocks	Open balancing cocks 100 percent of preset.
12. Taking pump startup readings	This procedure requires you to act as follows: Read pump static pressure first with the pump off. Start the pump, vent the air, and allow the flow to stabilize. Take initial amp and volt readings. Slowly close the balancing cock in the pump discharge line. Now, read the shutoff discharge and suction pressures and total head. Slowly open the discharge balancing cock and read the discharge and suction pressures at the same time with a differential gauge (fig. 2–37). Consider the pressure at the pump not as a positive indicator of the pump flow, but more as a reflection of the system resistance. If there is a total-flow measuring station in the discharge line, read the flow and compare it with pressure measurements and curves.
13. Balancing water terminals	In balancing water terminals, proceed as indicated here. If flow or pressure reading stations exist by the central equipment (such as by chillers, boilers, etc.) or in the circuits by terminals, read the initial flows or pressures and record without making any adjustments. Compare the central equipment readings with design and catalog data and note flows that are high or low. Determine the percentage of design at the terminals by dividing actual flow or pressure reading by the design flow or pressure. If any of the terminals that are low are not fully open, open them 100 percent. Throttle down the design terminal valves one by one, starting with the highest one and working toward the lowest until all are proportionately balanced. Three readings may be needed.
14. Rechecking equipment readings	After you attain proper flow in each terminal, verify the performance of the terminals by reading water or air temperatures in and out and the air volumes. Now calculate the total heat transfer by the air or water volume and temperature change.
15. Completing the test reports	After you complete the balancing, take final amps, pump differential pressure, and strainer drop readings. Recheck figures, note and explain problems, and generally complete reports for record purposes and submittal to the engineer, if required.

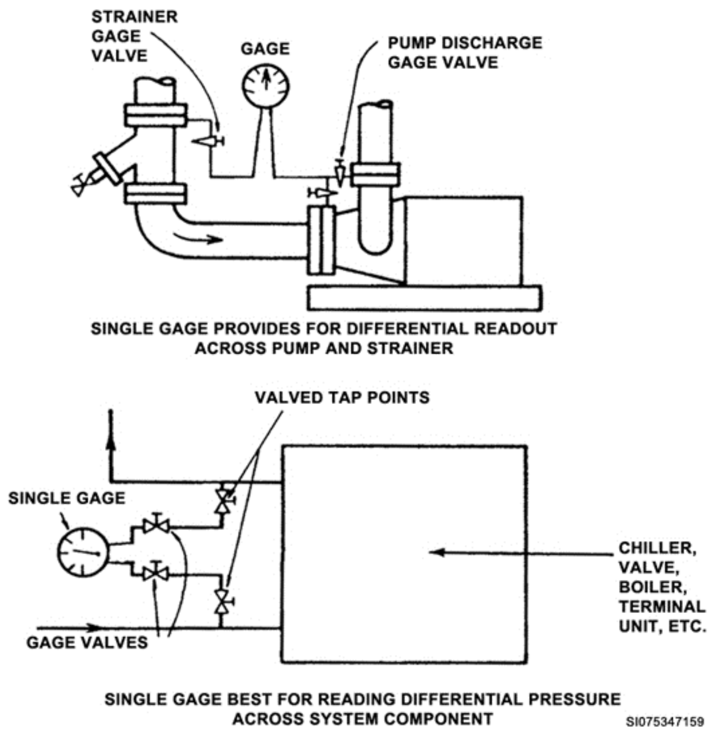

Figure 2–37. Differential pressure reading.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

215. Hydronic volume measurement

1. Explain the operation of the orifice-plate flowmeter.

2. Where should the orifice-plate flowmeter be installed?

3. How do you take a reading with the orifice plate and dial-type pressure gauge?

4. Using the annubar chart in figure 2–35, find the gpm in a 5-inch line with a differential pressure of 8.4 inches of water.

216. General procedures for hydronic balancing

1. List the nine procedures for preparing water-balance test reports.

2. What are the five steps for filling out a pump test report?

3. What are the six steps for filling out a flow or pressure-drop water-balance report?

4. What are the 15 basic steps for balancing chilled and hot-water systems?

5. How do you take pump startup readings?

6. How do you balance water terminals?

2–3. System Drawings

When you perform your duties, you encounter numerous references to plans, drawings, prints, and blueprints. Learning to read and interpret drawings is one of the requirements of Civil Engineering personnel. Blueprint reading is a task in which there is no substitute for experience. Learning to use prints involves knowing the purpose of prints; knowing the types of prints; knowing how to handle prints; and understanding the alphabet of lines, line explanations, projected views, and symbols and their uses. In addition to prints, control systems have displays that must learn to be read.

When you travel on unfamiliar roads, you probably use a road map to guide you. If you don’t, you’ll probably spend some time getting lost. When you’re laying out or doing a piping repair job on an HVAC/R system, you’ll also need something to guide you. Otherwise you’ll probably lose your way. Blueprints or drawings are usually available for all HVAC/R systems. These are designed to give a pictorial view of the systems; however, to understand these blueprints and drawings, you need to know the different symbols used to represent pipes, fittings, and valves.

217. Basics of system drawings

A symbol is a pictorial representation of something. When we discuss HVAC/R piping symbols we’re referring to pictures that represent pipe, fittings, valves, major components, and accessories installed in HVAC/R systems. Typical symbols are used so frequently that all who use the drawings must understand their meaning. Sometimes the draftsman who prepares the drawings includes a key or a legend to explain what each symbol means. When there’s a legend, always consult it for the print, drawing, or schematic with which you’re working. Some symbols have a universal meaning, while others don’t. In this lesson, we’ll discuss the symbols used in a legend and two types of blueprints.

Legend

When blueprints are drawn a legend is normally created. This legend is used to explain what the symbols used on the blueprint mean. Unfortunately there’s a lack of complete standardization of the symbols used to depict valves, fittings, and pipe used for piping systems. The reason we call your attention to the lack of a complete set of standards is to inform you that there’s room for error and to caution you not to make assumptions when you’re looking at blueprints. The safest thing you can do when you’re attempting to read blueprints is to look for the legend. If there’s no legend, study the print carefully and if possible get help from the personnel who developed the blueprint.

To teach what each symbol represents would be pointless. There is no reason to teach symbols in this CDC. The amount of symbols is too vast to expect anyone to memorize. The key to reading prints is knowing how to use them and experience.

Earlier we said that blueprints can be closely related to a road map. Just as a road map provides information about what roads to take to get from one area to another, blueprints tell you how to get from one place in a system to another. The blueprints used for installation of HVAC/R systems are normally provided by the engineering flight or the contractor that installs the equipment.

As you learned in the apprentice course, there are many types of blueprints. For our discussion, we'll look at two basis types:

1. Double line.
2. Single line.

Basic interpretation

When reading a blueprint, first identify whether the print is a double line drawing or a single line drawing. A double line drawing is a clearer representation of how a system will actually look, but it takes up more space. Double line drawings are actually scaled down versions of what the piping system will look like when it's finished.

The other type—single line—makes use of symbols to represent the valves, fittings, pipes, and accessories. The single line takes up less space, and a thorough understanding of what each symbol represents is necessary to understand the drawing. In fact, you must be thoroughly familiar with the symbols that represent the valves, fittings, pipes, and accessories. With this knowledge, you can begin to understand system drawings.

Remember that a working drawing will include all piping, fittings, and dimensions of the job. Once you've located the locations of the pipes and fittings, determine the sizes as indicated on the drawing. Make sure you recheck each part of the system for completeness and any possible error.

Unless you're assigned to the vertical section of civil engineering, you probably won't use blueprints for installation of HVAC/R equipment on a regular basis. However this doesn't mean you don't need to know how to read blueprints. You'll find there will be times when you need to read a blueprint in order to troubleshoot an HVAC/R system.

Below are four steps you'll find helpful when you're using a blueprint for troubleshooting.

1. Use the print to gain a firm understanding of the system and *what's supposed* to be happening.
2. Use the print and all other information to determine *what's actually* happening.
3. Use the blueprint to develop a list of *possible causes* for what's happening.
4. Investigate the possible causes to determine the *actual cause* of the problem.

Earlier we talked about using road maps to find our way. Some road maps show a lot of detail while others don't. Blueprints are a lot like this. In fact, the blueprints you use to install an HVAC/R system will show numerous things. Some of them are as follows:

1. Type of pipe to use.
2. Length of pipe sections.
3. Diameter of pipe to use.
4. Valve type(s).
5. Location of any valve(s).
6. Method of connecting pipes and valves.

One very important fact to remember about blueprints is you must have the correct blueprint when you install piping systems.

218. Understanding system drawings

Now that you have the concepts down you need to understand the system drawings. Time and experience are priceless when it comes to learning HVAC/R system drawings. This section will cover blueprints, scaling, and as built drawings. We will begin with blueprints.

Blueprints

The simplest and most often used copying process for making prints that you use is blueprints. Blueprints are made by placing a sheet of special translucent tracing paper over the drawing and in close surface contact with it. You then expose the two sheets to a strong light in a printing frame or machine made for this purpose. This process produces a print with a blue background and white lines.

Handling of prints

Prints can be much more useful if the user properly cares for them. Avoid smudging, tearing, spilling coffee, and so forth. Your careless handling of project drawings may cause costly errors.

Sometimes, each shop has drawings of existing facilities with additional equipment or new construction features designated for the purpose of maintaining system changes. These drawings are usually kept in racks or tubes for easy access. If drawings become damaged or unreadable, you can obtain copies from the Engineering Section.

The on-the-job handling of prints is very important since smudging and tearing usually occur there. The “thumbing space” left on the outer edge of the print is designed to prevent this. Never use greasy, dirty fingers or instruments to trace lines. If you have trouble following lines on the drawing with your eye, use a clean, nonmarking, dull instrument. Avoid screwdrivers and other sharp tools. Never depend on readings from a print when that reading has been obscured by a smudge or tear.

Identifying lines

The most basic symbol and the one requiring the greatest understanding is the “line.” You must understand the thickness of the line and the configuration used to use a blueprint or drawing properly. On drawings, heavier lines are used for the border, medium lines are used for the object, and finer lines are used for centerlines and dimension lines. The following explanations aid in identifying lines used on drawings.

Borderline

The heavy line around the outer edge of the print is the borderline. It informs the reader that the intended illustration is complete within these borders. Exactly what the illustration is supposed to be is noted on the legend in the lower right corner, along with other necessary reference information.

Object line (visible line)

The object or visible line outlines the specific item illustrated by the draftsman. It is a medium-weight line that shows the shape of the object to the reader. It is used to outline buildings, partitions within the structure, piping, conduit, and so forth. It is the most important line on the print because it forms the object in question.

Centerline

The centerline is used when it is necessary for the reader to use the center of an object as reference. When it is used, the centerline usually adds great significance to the drawing.

Extension and dimension lines

Extension lines are used to bring meaning to dimension lines. The centerlines and extension lines serve as stops for dimension lines. The extension lines do not touch the object, but start about $^{1}/_{16}$ inch from the object line and extend about ⅛ inch beyond the dimension arrow. In instances where the dimension must be located inside the object, the object lines serve as stops.

Section lining (shading)

Used on detail drawings to indicate material to be used, section lines also may be used to show a cutaway of an object.

Break lines

Drawing a detail of piping, shafting, and so forth, is usually done with break lines. Uses of conventional break lines are illustrated in figure 2–38.

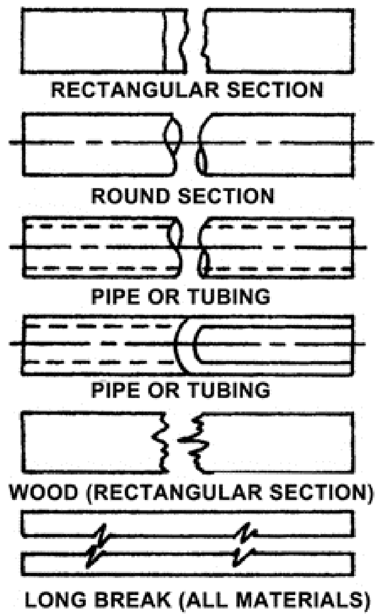

Figure 2–38. Break lines.

Hidden lines

Hidden lines are medium lines consisting of short, evenly spaced dashes that show hidden features of the object.

Views and details of prints

The shape of a structure is shown on drawings by certain views. The size of the structure is usually shown by figured dimensions, which are indicated by dimension lines, arrowheads, and extension lines. Overall relationships are shown in general drawings. The specific and general notes provide additional information about the size and kind of material. For you to have a clear understanding of the size, shape, kind of material required, and method of assembly, you must be provided with different views. The draftsman gives you these views in general and detailed drawings. General drawings consist of elevations and plans; detailed drawings consist of sectional and detailed views.

Elevation

Elevations are external views of a structure and show the front, the rear, and the side views. Figure 2–39 shows an elevation plan of the four sides of a cottage. An elevation is a picturelike view of a building that shows the exterior materials of the foundation, walls, and roof. It also shows the location of windows and doors. An elevation may also show the ground level that surrounds the building. Usually, specific notes that identify the building materials are given on the drawings. When more than one elevation view is shown, each view is identified by a title, such as “north elevation” or “south elevation.”

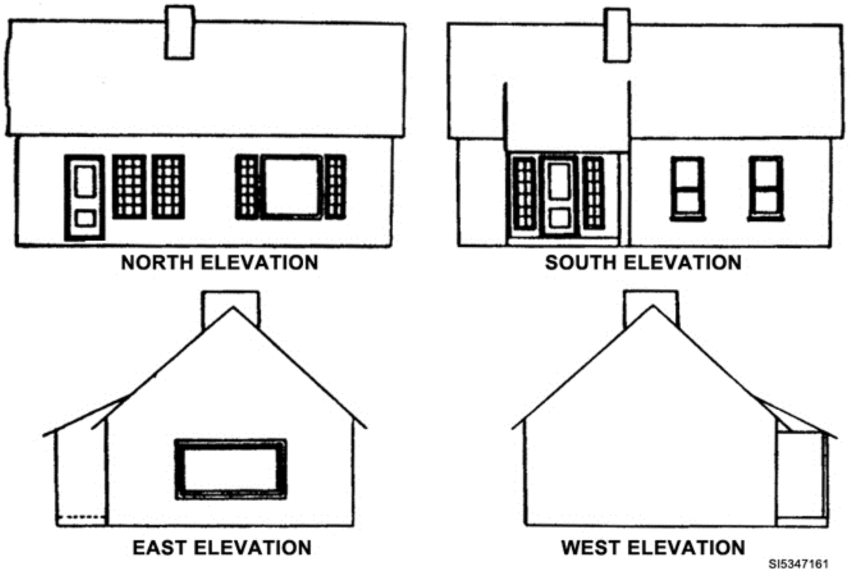

Figure 2–39. Elevations.

Plan

A plan shows a top view. There are several types of plan views used for specific purposes, such as site plan, foundation plan, and floor plan. In your work, you use floor plans more than the other types. Floor plans are horizontal cross-sectional views of a building. They show you the view of a building as if you were looking down from a point directly above the building. Horizontal surfaces, such as floors, appear without distortion. All vertical surfaces, such as walls, appear as lines. A floor plan shows you the shape of the building, the arrangement, the size, and location of doors and windows. Floor plans may also show the general location of heating, plumbing, and electrical systems and equipment.

Sectional

A sectional view is one in which a part of the building or structure is cut away to show the concealed features. This view shows how a structure looks when it is cut vertically by a plane and provides important information on dimensions, size and type of material, and structural arrangement. Like elevations, sectional views are vertical projections. Because the view must show certain details, sectional views are drawn to a large scale. This makes them easy to read and provides information that cannot be shown on elevation and plan views. Sectional views are commonly called *cross sections* because they show an object as if it were cut in half or across the object. Sectional views allow you to look inside an object.

Detail

Detail views are large-scale drawings that show how the parts of a building or structure are placed and connected. They are closely related to sectional views. In fact, sections are often used as parts of detail drawings.

Print or isometric

A print is a copy of a drawing that includes dimensions of the structure or equipment. A print or isometric view is usually made up of three views: the top view, the front view, and the side or end views. These views are composed of lines and symbols that are visible when the structure is viewed from these particular positions, as shown in figure 2–40. For example, in figure 2–40 the front (F) detail (A) illustrates how an object would appear to an observer who views it from the front. The side (S) detail (B) shows how the object appears when viewed from the side; the top (T) detail (C) shows how it would look from the top.

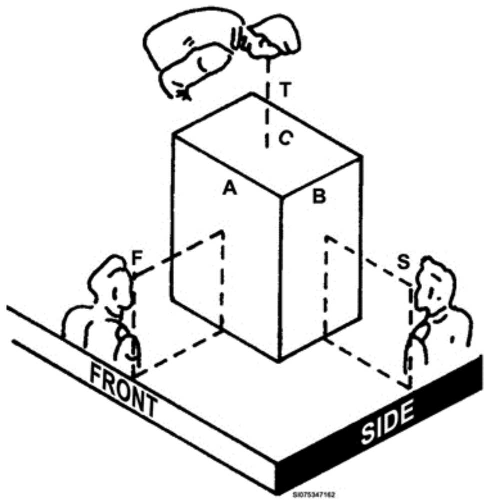

Figure 2–40. View of a subject.

Orthographic

When all of these views (front, top, and side) are placed on a single sheet, they are laid out as shown in figure 2–41. The front and side views are elevations, and the top view is the plan view, or architectural drawing.

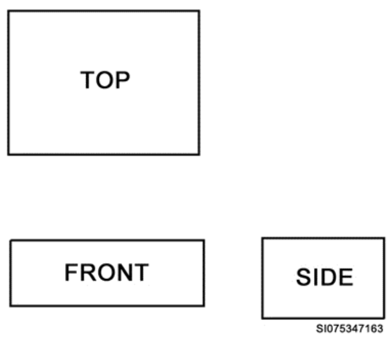

Figure 2–41. Single-sheet object view.

Symbols

A symbol is a graphic representation of an object. Because of the small scale used in drawings, draftsmen must use symbols to include all the factors needed to represent complete information about the construction materials.

Typical symbols are used so frequently that all who use the drawings must understand their meaning. Sometimes the draftsman who prepares the drawings includes a key or legend to explain what each symbol means. However, in most cases, there is no legend.

Scaling

Drafting people draw objects full size when the details of the object are clearly shown and the size of the paper conveniently permits such a scale. They prepare enlarged views of sections when the actual size of the object is so small that full-sized representations would not clearly present the features of the object. They make reduced-scale prints of large objects that can be shown clearly in a smaller scale. The prime reason for reducing the scale of drawings is so they can be placed on smaller sheets without crowding the views. The scale of prints is generally noted in the title block as “full size,” “enlarged view,” or at a reduced scale, such as 1″ = 10′, ¼″ = 1′, and other similar notations.

The process of measuring dimensions on a print is called *scaling*. Important dimensions are normally shown on the print and should not be scaled because of the possible distortion of the print on cloth or paper.

Methods of scaling

When you are using the architect's or engineer's scale, the method of scaling is that of determining the scale of the print from the notations given, such as 1″ = 10′, 1″ = 20′, and the like. Then, you select the corresponding scale on the architect's or engineer's scale. While using the proper scale, measure the desired dimensions on the print. For example, if the scale of the print is 1″ = 100′, then a dimension that measures 20 divisions on the engineer's scale (10 divisions per inch) represents a distance of 200 feet.

When you are working with graphic scales, the method you usually use is to mark off the length of the dimension desired onto a slip of paper, place the slip of paper on the graphic scale, and read the distance of the dimension that you marked.

Identifying components

Interpreting drawings is as easy as following a road map. Of course, just like anything new, interpreting drawings takes time to learn. The hardest part is learning the symbols. The symbols used in drawings are really illustrations of words or groups of words.

Can you imagine a drawing without the use of symbols? Every item in construction would have to be written on the drawings by the draftsman. One can easily see why symbols are necessary to the draftsman and also why an efficient blueprint reader must know how to interpret them.

Figure 2–42 shows the symbols for some common building materials. Notice that they are different from each other and that they frequently resemble the material that they symbolize. Figures 2–43 through 2–47 show some common symbols used on blueprints. You see most of these symbols as you review blueprints on the job. The only intent of this section is to show you the how different symbols can be. Don't try to memorize all of these symbols. You will learn them with time and experience.

Whenever you devise a symbol that is not used in standard practice, place that symbol in a legend. Polyvinyl chloride (PVC) and soil pipe are examples of devised symbols indicated on blueprints. Figure 2–47 shows some abbreviations used on blueprints.

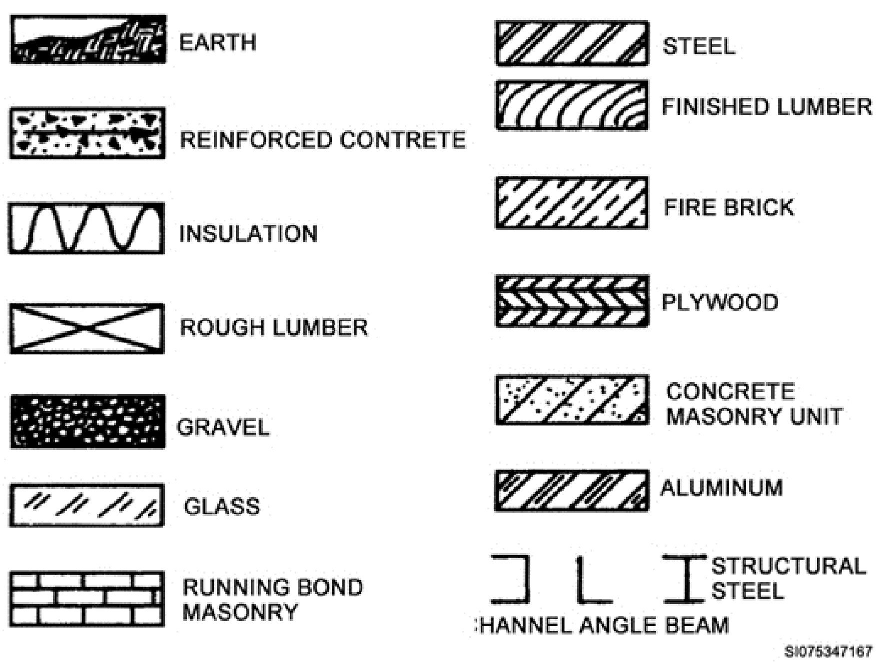

Figure 2–42. Materials symbols.

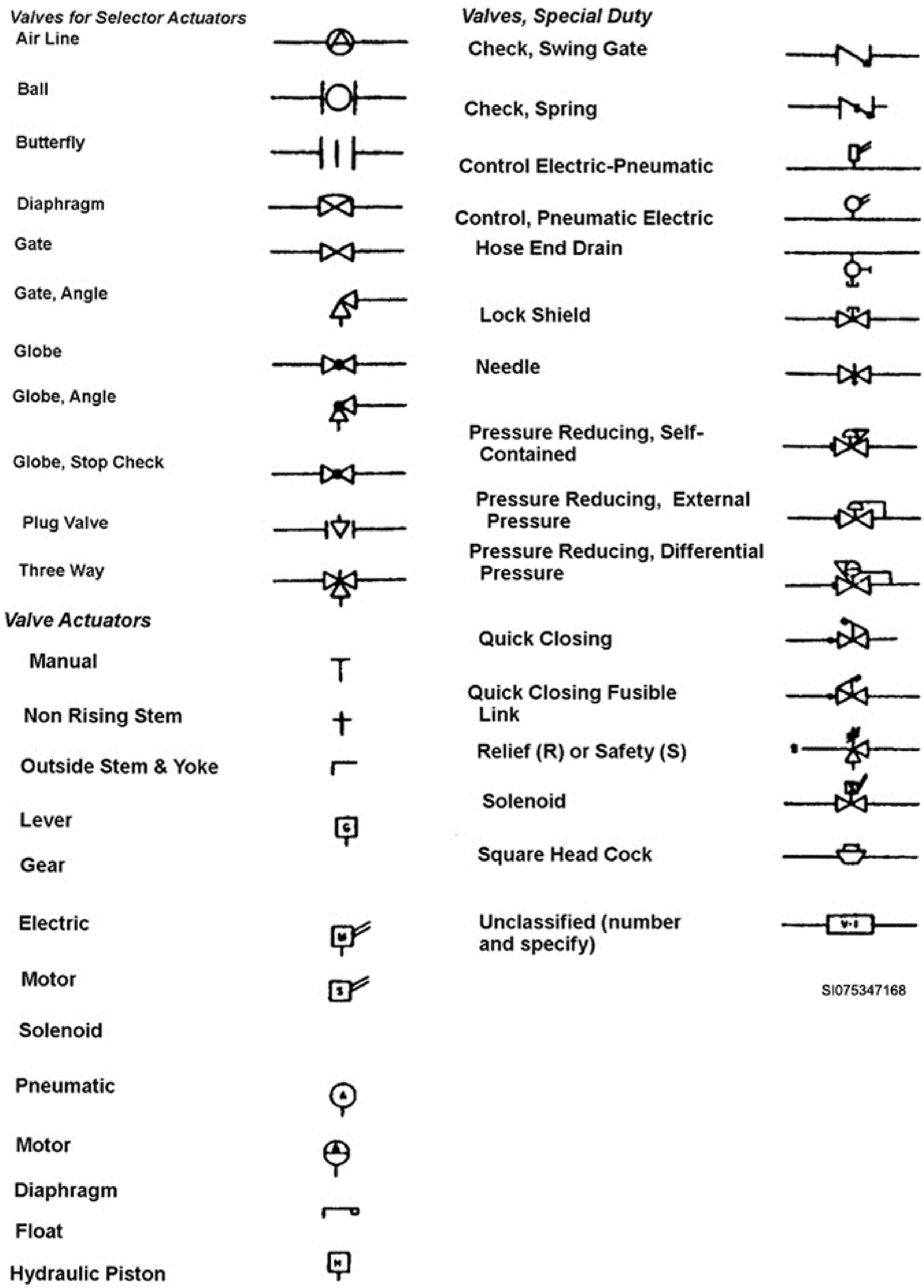

Figure 2–43. Valves and valve actuator symbols.

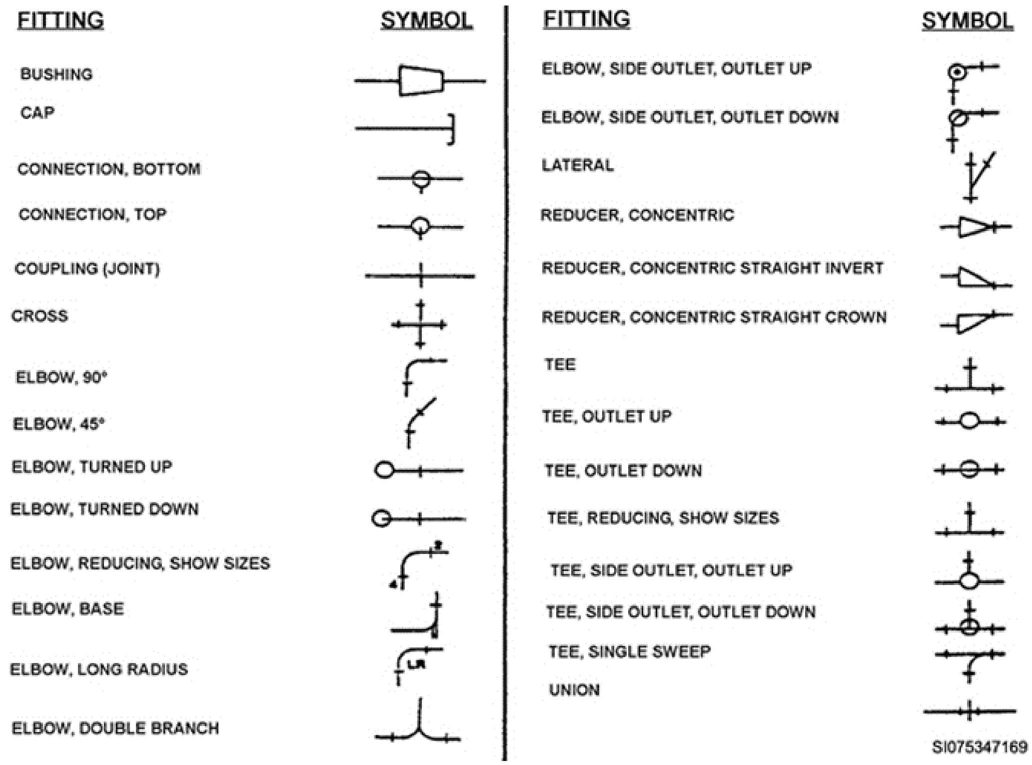

Figure 2–44. Fittings.

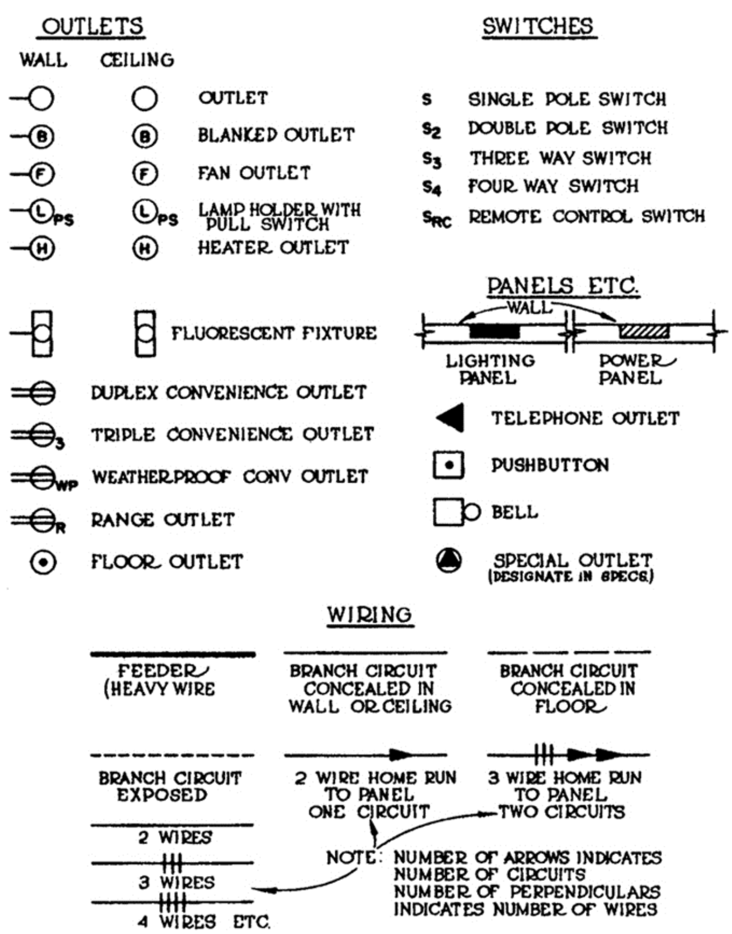

Figure 2–45. Electrical symbols.

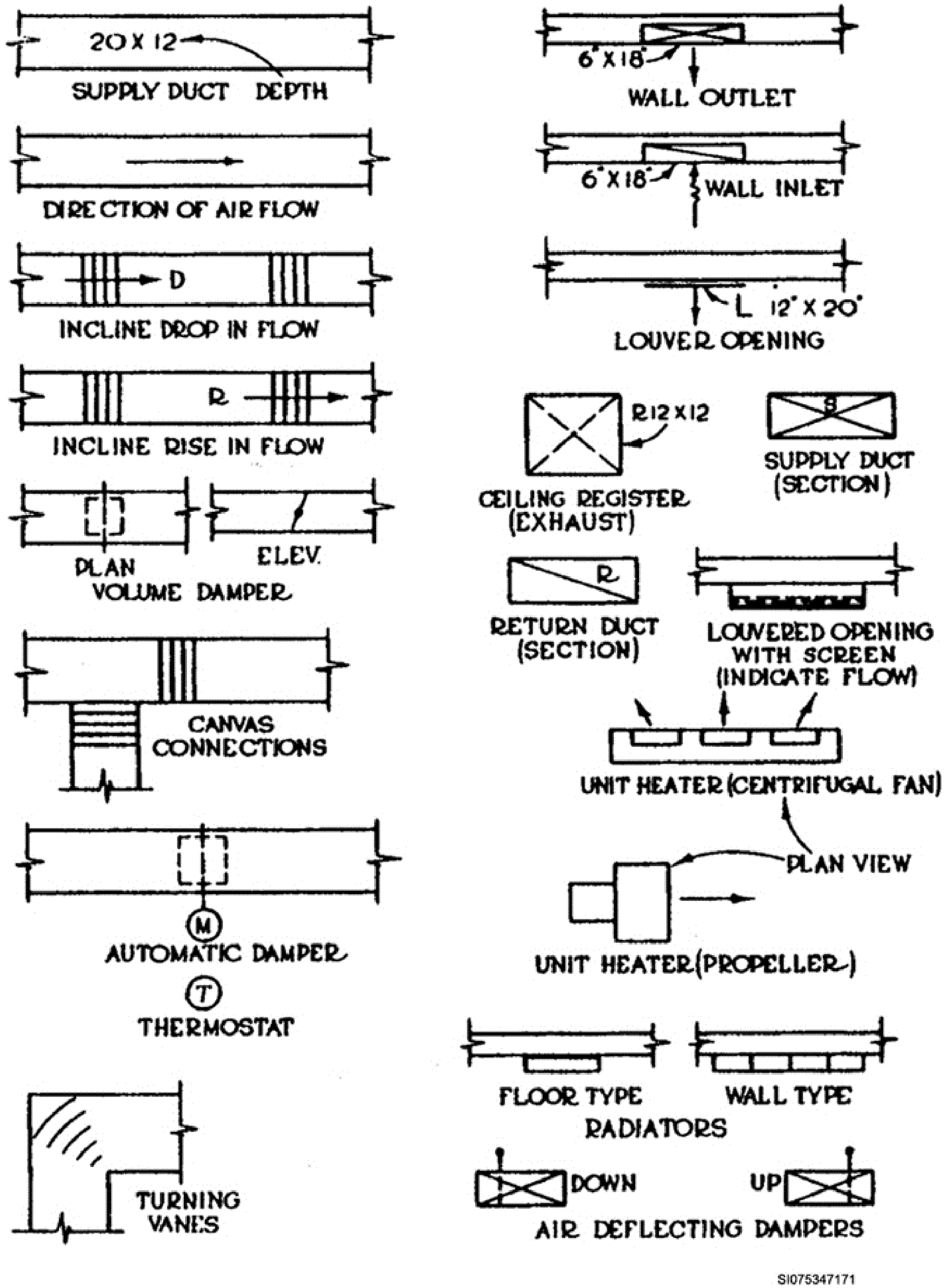

Figure 2–46. HVAC symbols.

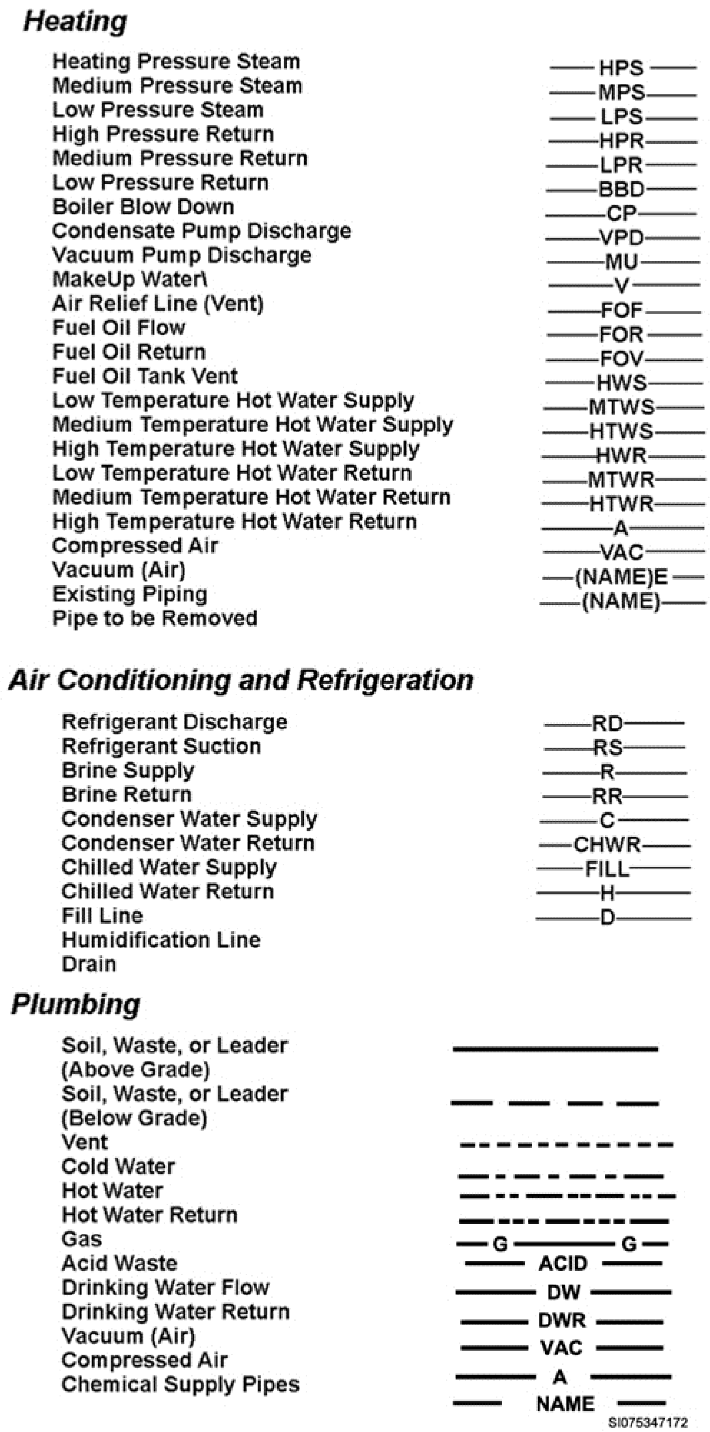

Figure 2–47. Abbreviations.

As-built drawings

As-built drawings are the final working drawings that are used as contract documents. These drawings have been revised and corrected to show all changes that might have been made during construction. They include the final layout of the various mechanical and electrical services, utility services, communication ducts, and sewers beyond the 5-foot line around the building. Usually, changes to these drawing are made by the contractor or by in-house construction management personnel. Do not confuse these drawings with the *design drawings.*

Correcting the final working drawings to reflect conditions facilitates maintenance, fire protection, and other future modifications. Update record drawings that are maintained by Base Civil Engineering (BCE) to reflect as-built conditions of completed facilities. Out-of-date record drawings can result in incorrect designs for future projects and costly, unnecessary change orders. In short, show any changes made from the original drawing on the as-built drawing.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

217. Basics of system drawings

1. What is the legend used for on system drawings?

2. What is the key to reading blueprints?

3. What should you do first when reading a blueprint?

4. What are double line drawings the scaled down version of?

218. Understanding system drawings

1. Why are important shop drawings kept in racks or tubes?

2. If drawings become damage where can you obtain copies?

3. When would object lines be used in a drawing?

4. What does a detailed drawing consist of?

5. Why would a draftsman reduce the scale of a drawing?

Answers to Self-Test Questions

210

1. It is more expensive to install.
2. They are designed to have the air moving at certain speed.
3. 300 feet per minute.
4. 416.67 feet per minute.
5. 500 feet per minute.
6. 250 cfm and cross section area of .5ft².
7. Air will not come out with the required force.
8. It will alter air patterns.
9. Plenum system.
10. By reducing the plenum size as the air gets further from the blower.

211

1. At absolute zero (–460°F).
2. It compresses in an HVAC/R system from its own momentum and weight.
3. Its molecules move faster.
4. It will lift the water 2 inches in a vertical column.
5. One inch of water column (wc) pressure is a very small amount of force.
6. VP = TP – SP.
7. In a discharge duct.
8. In a suction duct.
9. A difference in gauge static pressure between two points in a system.
10. In the transition duct at the discharge of a fan.
11. No more or no less than the amount of force needed to push the specific amount of air coming out of the fan against the resistance of the discharge duct system.

212

1. Take the difference between total pressure at the fan outlet and total pressure at the fan inlet.
2. Fan total pressure.
3. Take the difference of the static pressure readings at the fan outlet and total pressure readings from the fan inlet.
4. When you must change the fan speed.
5. 5 rpms.
6. System resistance curve.
7. What effect does increasing airflow in a system have on system resistance?
8. Fan pressure at the fan inlet varies directly with the air density.

213

1. On the end of the rotating shaft.
2. Use the leveling screw on the left and the bubble on top.
3. Because that is where the static pressure is pushing out or pulling inwards.
4. You must know what you are checking.
5. The speed of the air flowing through it.
6. Supply air velocities at ceiling diffusers.

214

1. Indicate the manufacturer of the grille, diffusers, and terminal boxes.
2. The smallest of projects.
3. Static pressure drops.
4. List the outlets in the sequence of the balance: 1, 2, 3, and so forth.
5. At the job site, confirm that the duct is easy to get to, there is sufficient straight duct to take a valid pitot shot at the selected point, and the duct actually installed is the size shown on the drawing.
6. To see that the building and systems are architecturally, mechanically, and electrically ready to be balanced.
7. Abnormal positive or negative pressures may throw the balance way off.
8. A final duct connection to a fan, hood or diffuser.
9. Check the motor data plate.
10. At the starter.
11. Normal positions.
12. Check the fan rpm reading.
13. Ductwork leakage; accuracy of pitot-tube traverse or other method of reading total cfm instrument calibration, zeroing, method of reading is correct; incorrect Ak factors; open ducts, missing end caps, large gaps at connections; arithmetic cfm extensions and totals in error; and design errors or changes.

215

1. The temporary pressure drop across the orifice plate opening, in inches of water, is correlated against the flow in gpm by the manufacturers in their laboratory.
2. Install the orifice plate a straight length of pipe upstream and downstream of the plate.
3. The balancer hooks up the gauge to the orifice plate, notes the pressure drop, and reads the gpm off the calibration curve based on the pressure drop.
4. 300 gpm.

216

1. (1) Obtaining system reference material.
   (2) Studying plans and specifications.
   (3) Planning the balancing method and selecting instruments.
   (4) Preparing the flow diagram.
   (5) Filling out the pump test report.
   (6) Filling out the flow or pressure-drop water-balance report.
   (7) Filling out the temperature water-balance report.
   (8) Filling out the chiller test report.
   (9) Filling out the air-cooled condenser and compressor reports.
2. (1) Fill in standard information in the heading.
   (2) Enter the pump data: manufacturer, model, size, type, and impeller size.
   (3) Enter the design performance figures: gpm, rpm, and full-flow and no-flow heads.
   (4) Fill in the motor data: manufacturer, serial number, mounting frame number, type of internal winding frame, service factor, rated hp, bhp, voltage, rpm, and phase.
   (5) Fill in the starter data: manufacturer, model, size, and class.
3. (1) List the primary and secondary circuits in groups and in sequence.
   (2) List the valves and terminals in sequence along with their identification and location, if needed.
   (3) Indicate the size.

(4) Enter the required cfm and the differential pressure reading required for the particular flow measuring device being used or from the manufacturer's published pressure drop across the item at design flow.

(5) List the bypasses.

(6) When proportionate-balancing terminals, list the percents of design in preliminary readings and gpm only for the final.

4. (1) Studying the drawings.
   (2) Planning the balancing method and selecting instruments.
   (3) Preparing a flow diagram.
   (4) Preparing test reports.
   (5) Checking that systems are functional and complete.
   (6) Checking the motor data plate and overloads.
   (7) Checking pump characteristics.
   (8) Inspecting the system.
   (9) Venting the air.
   (10) Checking the control valves.
   (11) Checking the balancing cocks.
   (12) Taking pump startup readings.
   (13) Balancing water terminals.
   (14) Rechecking equipment readings.
   (15) Completing the test reports.
5. Read pump static pressure first with the pump off. Start the pump, vent the air, and allow the flow to stabilize. Take initial amp and volt readings. Slowly close the balancing cock in the pump discharging line. Now read the shutoff discharge and suction pressures and total head. Slowly open the discharge balancing cock and read the discharge and suction pressures at the same time with a differential gauge. If there is a total-flow measuring station in the discharge line, read the flow and compare it with pressure measurements and curves.
6. If flow or pressure reading stations exist by the central equipment, such as by chillers, boilers, etc., or in the circuits by terminals, read the initial flow or pressures and record without making any adjustments. Compare the central equipment readings with design and catalog data, and note flows that are high or low. Determine the percentage of design at the terminals by dividing actual flow or pressure reading by the design flow or pressure. If any of the terminals that are low are not fully open, open them 100 percent. Throttle down the design terminal valves, one by one, starting with the highest one and working toward the lowest until all are proportionately balanced. Three readings may be needed.

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1. To explain what the symbols used on the blueprint mean.
2. Knowing how to use them and experience.
3. Identify whether the print is a double line drawing or a single line drawing.
4. What the piping system will look like when it's finished.

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1. For ease of access.
2. Engineering Section.
3. To outline buildings, partitions within the structure, piping, conduit and so forth.
4. Sectional and detailed views.
5. So they can be placed on smaller sheets without crowding the views.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

35. (210) How does an oversized duct affect airflow?
    a. Ductwork will not affect airflow.
    b. It increase the feet per minute.
    c. It slows the air down.
    d. It speeds the air up.

36. (210) What effect will too much airflow have on noise?
    a. The levels will be eliminated.
    b. The levels will decrease.
    c. The levels will increase.
    d. It will sound softer.

37. (210) What effect will a single-return on a plenum system have on installation cost?
    a. A single return will be the same cost as any other system.
    b. It will make the installation cost more expensive.
    c. It will increase the installation cost by 65 percent.
    d. It will make the installation cost cheaper.

38. (210) Why does the plenum reduce in size?
    a. To maintain static pressure.
    b. To maintain air velocity.
    c. To increase air velocity.
    d. To decrease static pressure.

39. (210) Why are perimeter loop systems placed around the perimeter of a building?
    a. To prevent stratification.
    b. To prevent static pressure loss.
    c. Because that is where the greatest heat loss occurs.
    d. Because that is where the least amount of heat loss occurs.

40. (211) What do we treat air as in HVAC/R?
    a. As five molecules.
    b. As a compound.
    c. As an individual gas.
    d. As a single molecule.

41. (211) Besides its molecules increasing speed, what else happens when air is heated?
    a. It contracts and increases volume.
    b. It expands and decreases volume.
    c. It expands.
    d. It contracts.

42. (211) You are going to calculate airflow volume, which formula would you use?
    a. cfm = A x 2V.
    b. V = A x cfm.
    c. cfm = A/V.
    d. cfm = A × V.

43. (211) What is relationship between air velocity and static pressure?
    a. If static pressure drops, air velocity rises.
    b. If static pressure rises, air velocity drops.
    c. Static pressure is dependent of air velocity.
    d. Static pressure is independent of air velocity.

44. (211) Where will you likely find a negative static pressure?
    a. At the diffusers.
    b. In the suction ductwork.
    c. In the discharge ductwork.
    d. While using a flowhood on a diffuser.

45. (211) Where is gauge pressure at its *maximum* in an air system?
    a. Before the fan intake.
    b. At outside air intake.
    c. At suction.
    d. At discharge.

46. (211) Where is gauge pressure normally at zero in an air system?
    a. At the ends of duct runs.
    b. At the fan intake.
    c. At the fan discharge.
    d. Zero pressure will never be achieved.

47. (212) What is relationship between static pressure and density?
    a. They both rely on air velocity.
    b. They are directly proportional.
    c. They are indirectly proportional.
    d. There is no relationship.

48. (212) To acquire the fan's total pressure, you take the difference between
    a. the static pressure at the fan outlet and total pressure at the fan inlet.
    b. the total pressure at the fan inlet and static pressure at the fan inlet.
    c. the total pressure at the fan outlet and total pressure at the fan inlet.
    d. the total pressure at the fan outlet and static pressure at the fan inlet.

49. (212) How would you obtain fan velocity pressure?
    a. Take reading from discharge duct.
    b. Take reading from intake duct.
    c. Take the difference between the total fan outlet and fan inlet pressures.
    d. Take the difference between the total and static discharge pressures.

50. (212) Why must all pressure measurements be taken downstream of the fan discharge?
    a. Static pressure is the strongest downstream.
    b. Because the flow is more uniform downstream.
    c. Because the flow is less uniform downstream.
    d. The fan discharge is most uniform at discharge.

51. (212) How will brake horsepower be affected if revolutions per minute are increased and no other changes made?
    a. It will decrease as energy consumption increases.
    b. It will increase as energy consumption decreases.
    c. It will decrease along with energy consumption.
    d. It will increase along with energy consumption.

52. (212) What effect does cubic feet per minute (cfm) have on static pressure?
    a. They have no relationship unless density is factored.
    b. As cfm increases, static pressure decreases.
    c. As cfm increases, static pressure increases.
    d. As cfm decreases, static pressure increases.

53. (212) What effect does air density have on fan airflow?
    a. Air density helps maintain constant airflow.
    b. Air density increases airflow.
    c. Air density reduces airflow.
    d. No effect.

54. (213) When using a quarter-inch inclined gauge, where are the hose(s) attached on the gauge?
    a. Connect the left side to negative.
    b. Connect the right side to positive.
    c. Right side to positive and left side to negative.
    d. Left side to positive and right side to negative.

55. (213) How is the pitot tube placed in the airstream?
    a. Parallel and facing the airflow.
    b. Parallel and facing away from airflow.
    c. Perpendicular to the airflow.
    d. Perpendicular and facing away.

56. (214) In air balancing, what do schematics allow the technician to plan?
    a. Plan the sequence of balancing and determine where to take pitot traverses.
    b. Plan the sequence of electrical components.
    c. Focus on plumbing.
    d. Focus on electricians.

57. (214) In air balancing, where do schematics provide the best service?
    a. When blueprints are available.
    b. When blueprints are easy to read.
    c. When the system spans several floors.
    d. When ductwork is very short and close.

58. (214) What is the *third* step in air balancing?
    a. Check the equipment.
    b. Finalize the reports.
    c. Prepare the reports.
    d. Check out the building reports.

59. (214) Which step in air balancing is “balance outlets and branch ducts”?
    a. 1.
    b. 2.
    c. 3.
    d. 4.

60. (214) When are diffusers and grilles used in air balancing?
    a. They are the only choice to balance a system.
    b. For minor balancing or trim adjustments.
    c. For major balancing adjustments.
    d. Never.

61. (214) What is the first step in *proportionate* balancing?
    a. Spot-check end outlets and outlets closest to fan.
    b. Balance the last two branches.
    c. Go to the fourth-to-last outlet.
    d. Go to the third-to-last outlet.

62. (214) What is the next step after a system has been proportionately balanced?
    a. Recheck equipment readings.
    b. Fill in the worksheets.
    c. Prepare the reports.
    d. Finalize reports.

63. (214) What is the final general air balancing step?
    a. Prepare fan report.
    b. Prepare the final outlet.
    c. Finalize the test reports.
    d. Fill in general information worksheet.

64. (215) If balancing valves are used with orifice plates, why is the valve installed with sufficient distance up or down stream?
    a. To avoid flow turbulence of the plate.
    b. To utilize the turbulence of the plate.
    c. Because lower pressures are required for proper readings.
    d. Because higher pressures are required for proper readings.

65. (216) "List the valves and terminals in the order they occur" falls under which step of preparing water-balance test reports?
    a. Fill out the chiller test report.
    b. Fill out the temperature water-balance report.
    c. Fill out the flow or pressure-drop water-balance report.
    d. Fill out the air-cooled condenser and compressor reports.

66. (216) "List the coil identification and room number in sequence" falls under which step of preparing water-balance test reports?
    a. Fill out the chiller test report.
    b. Fill out the temperature water-balance report.
    c. Fill out the air-cooled condenser and compressor reports.
    d. Fill out the flow or pressure-drop water-balance report.

67. (216) What is one step in balancing water terminals?
    a. Read discharge line flow and compare with pressure measurements and curves.
    b. Read and record initial flows without making adjustments.
    c. Compare actual total head with pump catalog curve.
    d. Read shutoff discharge and suction pressures.

68. (217) Why is it important for you to know there is not a complete set of standards for symbols?
    a. To discourage you from using the legend.
    b. So you can try to memorize every symbol.
    c. To create a sense of urgency when reading prints.
    d. There's room for error and to caution you not to make assumptions with blueprints.

69. (217) Which agency can a HVAC/R technician acquire blueprints?
    a. Engineering flight or the contractor.
    b. The blueprint and printing shop.
    c. Plumbing shop.
    d. Public health.

70. (217) Once all pipes, fittings and sizes are determined, what should you recheck?
    a. The pipes.
    b. Only the fans.
    c. The electricians to determine power.
    d. Each part of the system for completeness.

71. (218) If a draftsman is creating detailed drawings, what type of views should be used?
    a. Geographical location.
    b. Year the device was made.
    c. Sectional and detailed views.
    d. The manufacturer.

72. (218) How should elevation views be shown when more than one view is used?
    a. By a title.
    b. Diffuser adjuster.
    c. Diffuser modifications.
    d. A flow hood will be combined with other tools to capture all of the air.

Glossary of Abbreviations and Acronyms

A	airfoil
AFSC	Air Force Specialty code
Ak	area factors
AMCA	Air Moving and Conditioning Association
amp	ampere
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASME	American Society of Mechanical Engineers
AWT	average water temperature
BCE	Base Civil Engineering
bhp	brake horsepower
BI	backward inclined
Btu	British thermal units
cfm	cubic feet per minute
cu ft	cubic feet
DWDI	double-width, double-inlet
EDR	equivalent direct radiation
EMCS	energy-monitoring control system
EPA	Environmental Protection Agency
FC	forward curve
fpm	feet per minute
fps	feet per second
ft wg	feet of water gauge
GPM	gallons-per-minute
HEPA	high efficient particulate arrestor
HVAC/R	heating, ventilation, air conditioning and refrigeration
IAQ	indoor air quality
in. Hg	inches of mercury
in. wg	inch of water gauge
lb	pounds
LTW	low-temperature-water
NPSH	net positive suction head
PRV	pressure reducing value
psf	pounds per square foot
psi	pounds per square inch
psia	pounds per square inch absolute
psig	pounds per square inch gauge
PVC	polyvinyl chloride
RPM	revolutions per minute
SBS	sick building syndrome
SP	static pressure
SWSI	single-width, single-inlet
TP	total pressure

VAV	variable-air-volume
VFD	variable-frequency driver
VP	velocity pressure
wc	water column

Student Notes

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