CHAPTER 1

PRINCIPLES OF AIR CONDITIONING

LEARNING OBJECTIVES

At the end of the chapter you should be able to:

- describe what happens to Freon in an evaporator coil
- describe what happens to Freon in a condenser coil
- outline the approximate temperatures of the refrigerant in various parts of the air conditioning system
- define in one sentence each the function of the compressor, condenser, evaporator, and expansion device
- define in one sentence sensible heat
- define in one sentence latent heat
- define the latent heat of vaporization in one sentence
- describe in two sentences how air conditioners dehumidify
- describe the relative temperature of the suction and liquid lines on an operating air conditioning system
- list two types of air conditioners other than air cooled
- define what a ton of air conditioning is in BTUs per hour
- list ten factors that affect how much air conditioning is needed
- provide a range of how many square feet can be cooled by a ton of air conditioning in southern and northern climates
- explain in one sentence the implications of an undersized air conditioning system
- explain in one sentence the implications of an oversized air conditioning system

1.1 BASIC CONCEPTS

Luxury

Central air conditioning is considered a luxury rather than an essential in most parts of North America. Air conditioning systems are more common in the southern areas and are more common in humid areas than in dry areas. There are probably more air conditioners per capita in Florida than in California, for example. You probably have a good sense already as to how common central air conditioning systems are in your area.

We inspect air conditioning systems that are connected to ductwork and that deliver conditioned air to all parts of the house. The standards also ask us to inspect through-the-wall and other ductless systems.

Through-the-Wall Systems

Through-the-wall air conditioners do not have a **duct system.** These units are commonly used to heat single rooms or areas without partition walls. They may be self-contained units or may be split systems with the evaporator and fan in the wall and a remote compressor condenser coil and fan.

Split Systems

Split-system central air conditioners are the most common. They can be independent systems or incorporated with indoor furnaces and **indoor fan** coils that can be upflow, downflow, or horizontal. You may also come across single-package systems that are often on roofs, in attics, or in crawl spaces. The supply and return duct system extends outside the living space to pass the air through the air conditioning or heat pump system.

Many Limitations

As with all systems, you can't inspect everything, and with air conditioning systems, there are many limitations. For example, you shouldn't test an air conditioner when the outdoor temperature is below 65°F or has been below 65°F in the past 24 hours. If the power to the central air conditioner has been turned off, you cannot simply turn the power on and test the air conditioner, as this may damage the compressor. In many cases, you can't get a good look at the internal components of the condenser unit (removing the access panel to the condenser unit is beyond the standards), and, sometimes, you won't get a look at the evaporator coil in the ductwork inside the house.

Client Expectations

You may be tempted to think that this isn't important, since the air conditioner is a luxury item only and the house will still be habitable even if the air conditioner doesn't work. However, you should understand that the clients bought the house with central air conditioning and expect it to work. If it doesn't work and you didn't warn them of this, you should expect to receive a callback from the client.

It's worth noting that central air conditioning systems are among the most expensive mechanical components in a home and have a relatively short life expectancy.

Complicated

Air conditioning is complex. To most people, it is not obvious how on a hot summer day you can take heat out of a house and throw it outside, where it is even hotter. But that is exactly what central air conditioning does.

We'll use the split-system air-cooled central air conditioning system in this discussion since it's the most common system in homes.

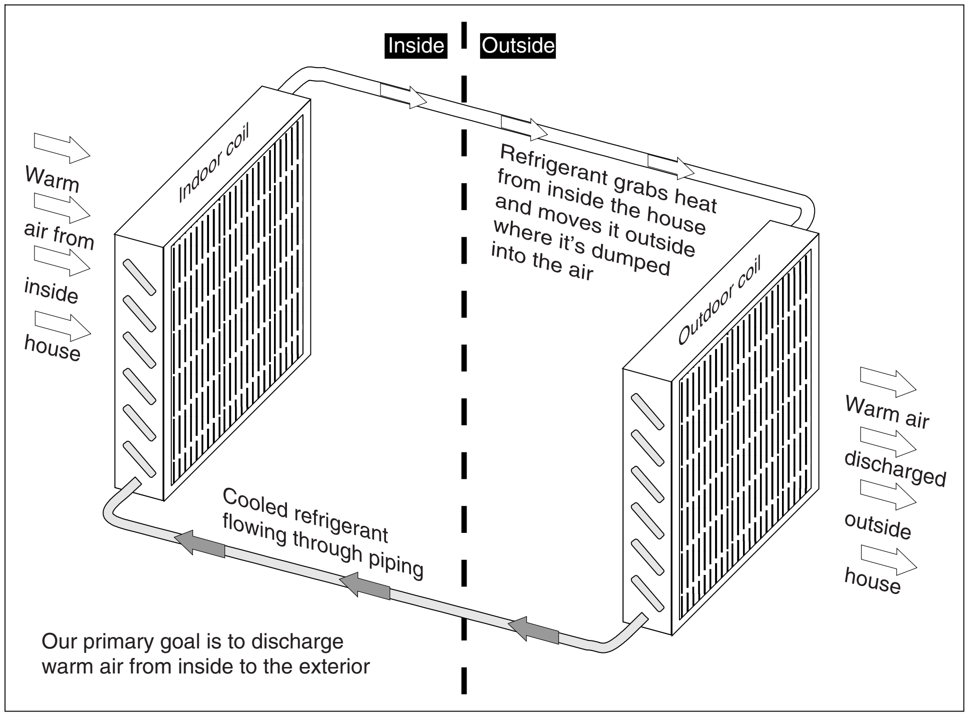
More than Cooling

Comfort involves more than cool air. Air conditioning also involves more than lowering the air temperature. It includes dehumidifying, cleaning (filtering), and circulating the air. Good air conditioning systems perform all of these functions, although most people focus on the "cool" concept. (In the broadest sense of the term, **air conditioning** also means heating, humidification, and ventilation, although we'll exclude these issues from our discussion.)

House Slowly Heats up

If the outdoor temperature is 70°F at night and all the windows in the house are open, the indoor and outdoor temperatures will both be about 70°F. As the sun comes up, the outdoor temperature may rise to 85°F or 90°F. Because of shading, thermal mass, and so on, the house will not heat up as quickly as the outdoors, but

FIGURE 1.1 Moving Heat from the Inside to the Outside



it will eventually get just as hot as it is outside. The goal is to keep it more comfortable inside the house than it is outside.

1.2 THE MECHANICS

The most common type of air conditioning that we see is technically referred to as direct expansion, mechanical, vapor-compression refrigeration system.

Like a Refrigerator

The goal with air conditioning is to capture heat in the house and throw it outside (Figure 1.1). But how can we take heat from a space that is already cooler than outdoors and dump it into the outdoor air? One of the ways we can think about it is to look at a refrigerator. If we can keep the temperature inside your refrigerator at about 40°F and it is 70°F in the kitchen, somehow we are taking heat out of that cool air and dumping it into a kitchen that is warmer. Central air conditioning and refrigerators operate on exactly the same principle. The process works something like this.

The Coils

We have two coils similar to the radiator in a car: one inside the house and one outside. We put something cold through the coil inside the house and then blow warm house air across the coil, so the coil can grab heat from the house air. This cools the house. We want to take that heat in the coil outside and dump it into the outdoor air. Let's look at how we can do this.

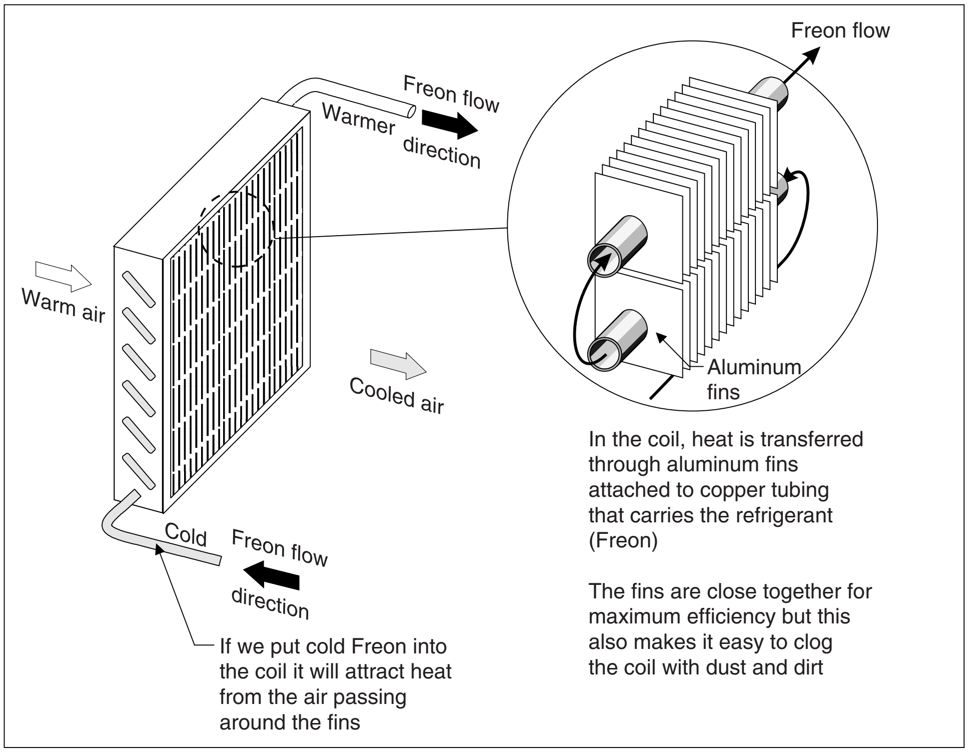
Freon

On the inside of a coil we use a substance such as Freon 12 or Freon 22 (which are brand names for a **refrigerant** that is noncorrosive, nonflammable, and nontoxic but, as we have recently discovered, not great for the ozone layer). This refrigerant is a colorless gas at atmospheric temperature and pressure. Inside the coils we manipulate the Freon to make it a liquid or a gas.

Freon Goes in Circles

The Freon runs in a loop, passing through the indoor coil, through a copper pipe to the outdoors, through the outdoor coil, and back inside through another pipe to the indoor coil (Figure 1.2).

FIGURE 1.2 Heat Transfer at the Inside Coil



Cool Freon Liquid into Evaporator

Let's follow the Freon from the point that it comes into the evaporator (indoor) coil. As it enters the coil, it is a cold liquid, perhaps 20° to 40°F. The cold liquid in the coil feels the warm house air on the other side of the coil. If the house air is about 75°F and the Freon is at 30°F, heat is going to move through the coil (which is just a heat exchanger) and warm the liquid. As it warms up, the liquid boils off into a gas.

Freon Sucks Heat from House

As the Freon inside the coil changes from a liquid to a gas, it sucks heat out of the house air. Logically enough, this is called the **evaporator coil** (Figure 1.3) because the Freon inside is evaporating from a liquid to a gas.

50°F Gas Leaves Evaporator

The Freon leaves the evaporator coil as a gas that is warmer than the liquid coming in but still cooler than the air around it. The temperature of the gas might be 50°F.

Gas Goes Outside

Now we want to dump the heat from the Freon gas outdoors (Figure 1.4). We have a problem. If you take 50°F Freon and pass it through an outdoor coil where the air temperature is 85°F or 90°F, we are just going to heat up that Freon gas and actually collect more heat. That won't work! What we want to do is get rid of the heat.

Compress the Gas to Heat It up

The solution involves a **compressor** (Figure 1.5), which we can think of as a pump. This compressor squeezes the gas, which heats it up. There is a gas law that says that if you increase the pressure on a gas, you also increase its temperature. This is great! We take a gas at 50°F, squeeze it really hard to build up pressure and raise the temperature. The low-pressure gas at 50°F that entered the compressor leaves the compressor at a much higher pressure and temperature.

Hot Gas to Condenser Coil

If the temperature coming out is 170°F (to 230°F), we can pass this hot gas through the outdoor coil and blow some outdoor air across it. The Freon is now able to dump its heat into the 85°F or 90°F outdoor air. So, the heat we removed from the house can be thrown away outdoors! Before you go any further, make sure you understand the mechanics so far.

FIGURE 1.3 Evaporator Coil—Collecting Hot Air Inside the House

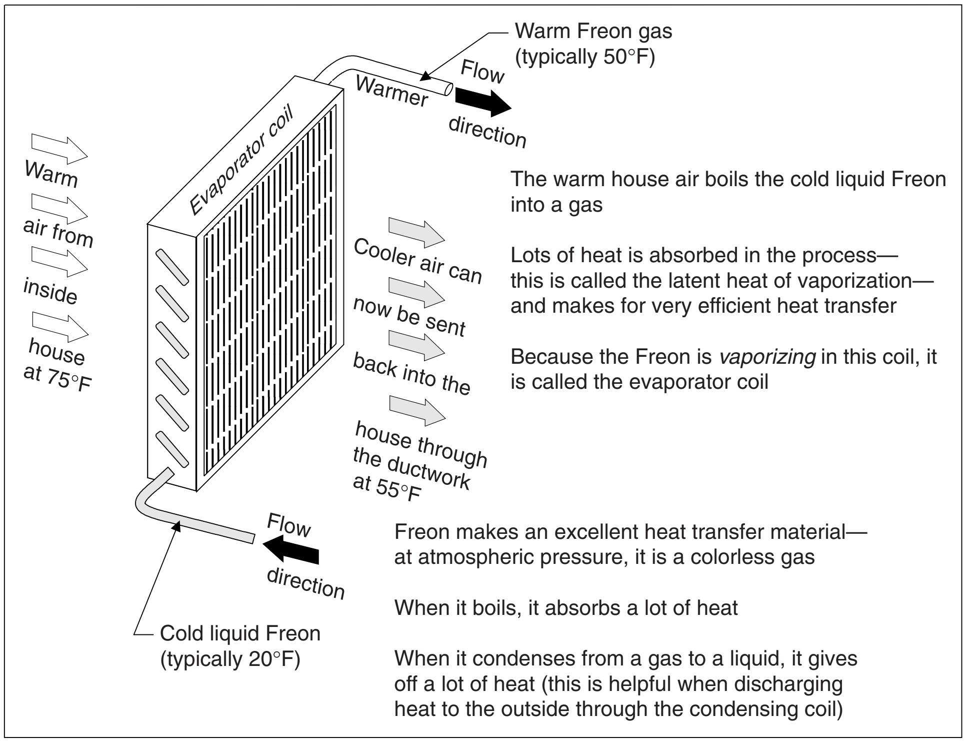
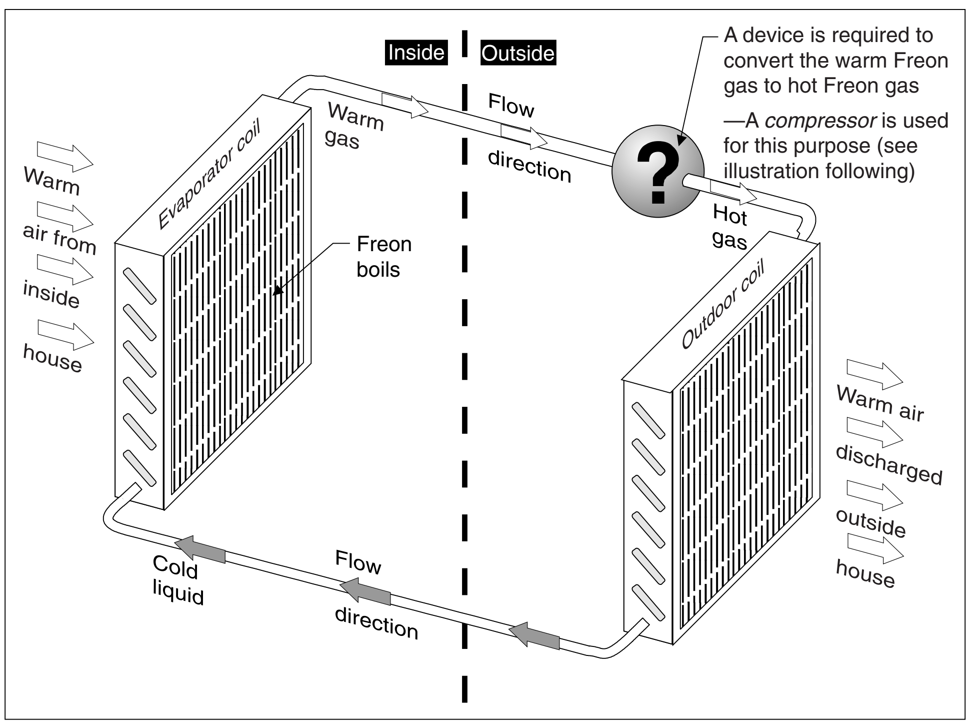


FIGURE 1.4 The Freon Gas Goes Outside



Gas Cools and Condenses

As the hot, high-pressure gas moves through the outdoor coil and gives off its heat, it cools to the point where it condenses back to a liquid. Logically enough, the outdoor coil is called the **condenser coil** (Figure 1.6) because the Freon inside condenses from a gas to a liquid.

FIGURE 1.5 Compressors—Heating up Freon Gas

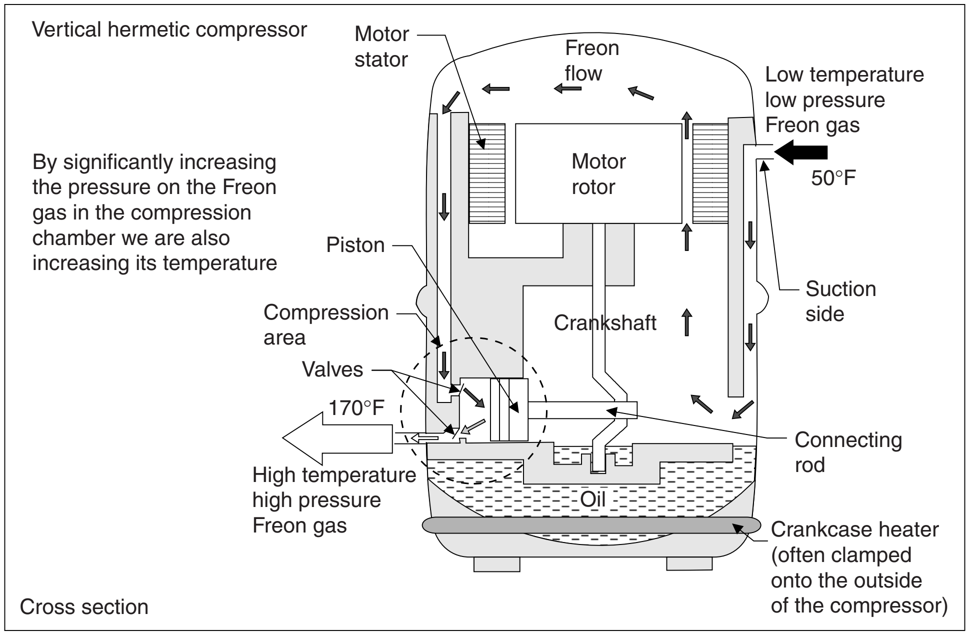
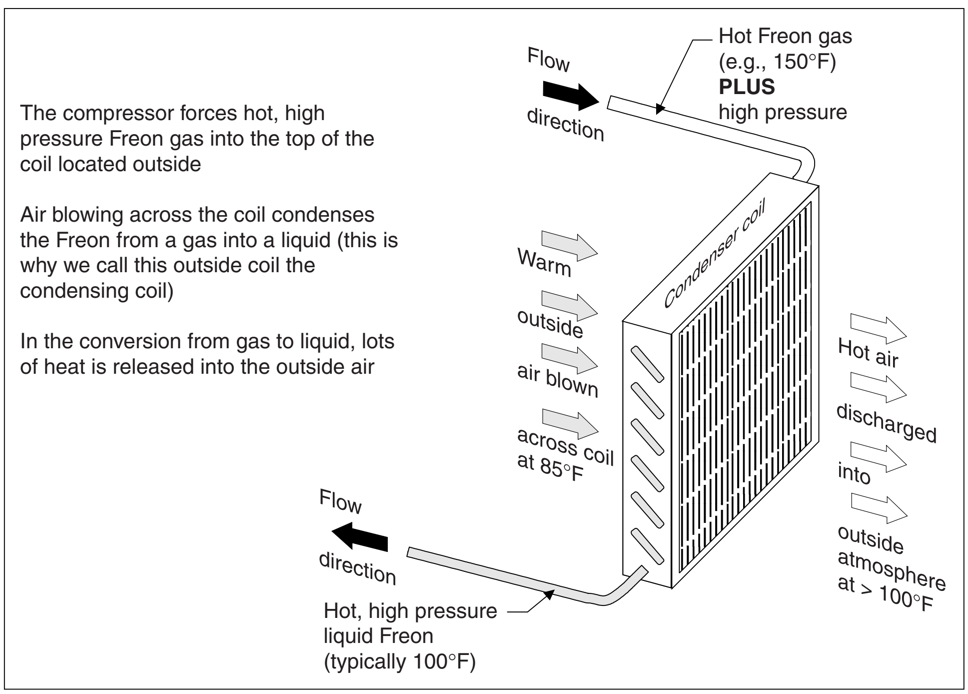


FIGURE 1.6 Condenser Coil—Exhausting Hot Air to the Outside

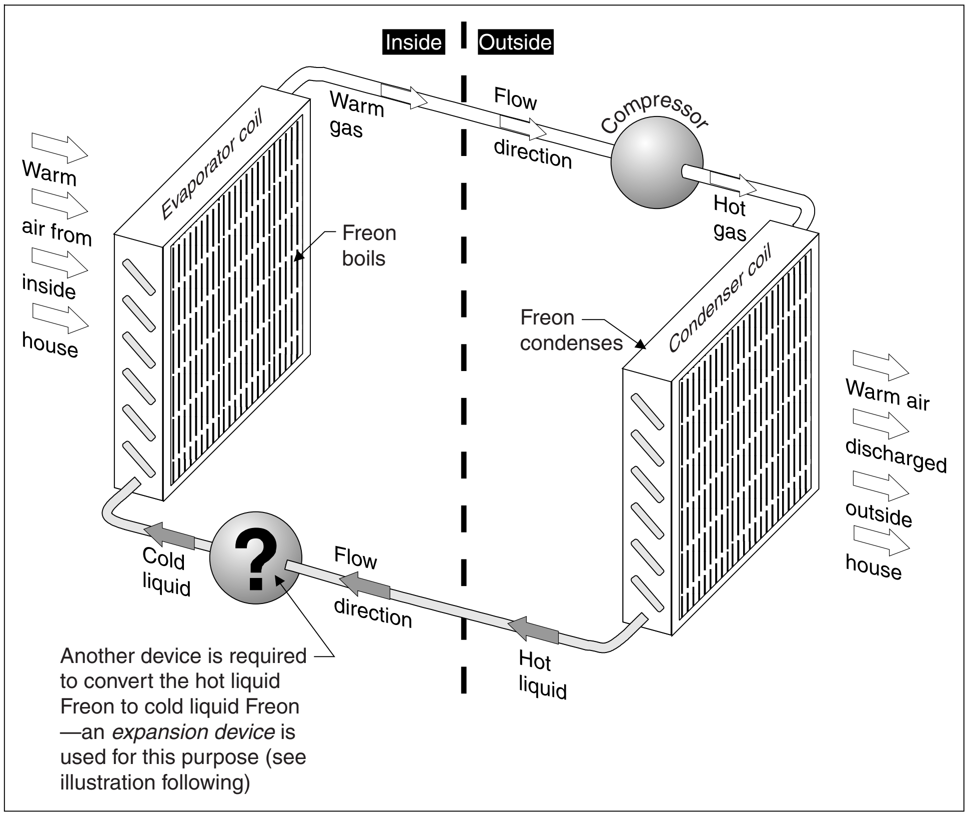


Incidentally, an air conditioner is working properly if the air coming off the **outdoor fan** is even hotter than the outdoor air. That is because we are passing the 85°F or 90°F air across a coil where the Freon gas inside is at 170°F.

Getting Ready to Boil the Freon Again

After the Freon goes through the condenser coil, we end up with a high-pressure liquid that is still relatively warm. It might be between 95°F and 110°F, for example. The compressor is pushing this hot, high-pressure liquid through a pipe back into the house (Figure 1.7).

FIGURE 1.7 Hot Liquid Back to House



Hot Liquid Back to House

This liquid is too warm to pick up heat from the house. At 95°F to 110°F, this is not going to allow us to steal any more heat from the house. Now we have another problem.

Lower the Pressure to Cool the Liquid

However, we can use another little trick to cool off that liquid. If we pass it through a restriction (a capillary tube or thermostatic expansion valve, for example),we can allow only a little bit of the high-pressure liquid to move through the pipe at a time (Figure 1.8). This means that on the discharge of the bottleneck, the liquid will be at a much lower pressure.

Cool Liquid to Evaporate

As we lower the pressure, we also the lower the temperature. The liquid that came into the bottleneck at 95°F to 110°F comes out colder (20° to 40°F) and may already be starting to boil! Now we are ready to go through the evaporator coil again, collecting heat from the 75°F house air and boiling the Freon off to a gas.

1.2.1 Review

Indoors

To recap, we can think about a cold, low-pressure liquid entering an evaporator coil. The warm house air gets blown across the cool coil by the furnace fan. The house air gives up its heat to the cold liquid, boiling the liquid off into a relatively cool gas. The cooled air that passed over the coil is distributed through the house.

Outdoors

The cool gas in the pipe moves outside and is squeezed by the compressor into a high-temperature, high-pressure gas. This hot gas passes through the condenser coil. Blowing outside air across the condenser cools the hot gas inside, releasing heat to the outdoor air that has been stolen from the house. As the gas is cooled, it condenses back to a liquid.

FIGURE 1.8 Expansion Devices—Cooling Hot Liquid Freon

The capillary tube is a bottleneck designed to restrict the flow of liquid Freon

At the discharge point of the bottleneck, the Freon is at a much lower pressure

When the pressure is reduced the temperature also goes down

The Freon coming out of the tube may be about 20°F and is ready to go into the evaporator coil to collect more heat

The expansion device is typically just upstream of the evaporator coil

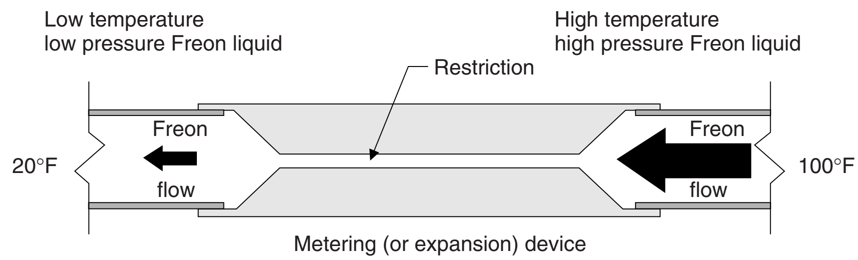
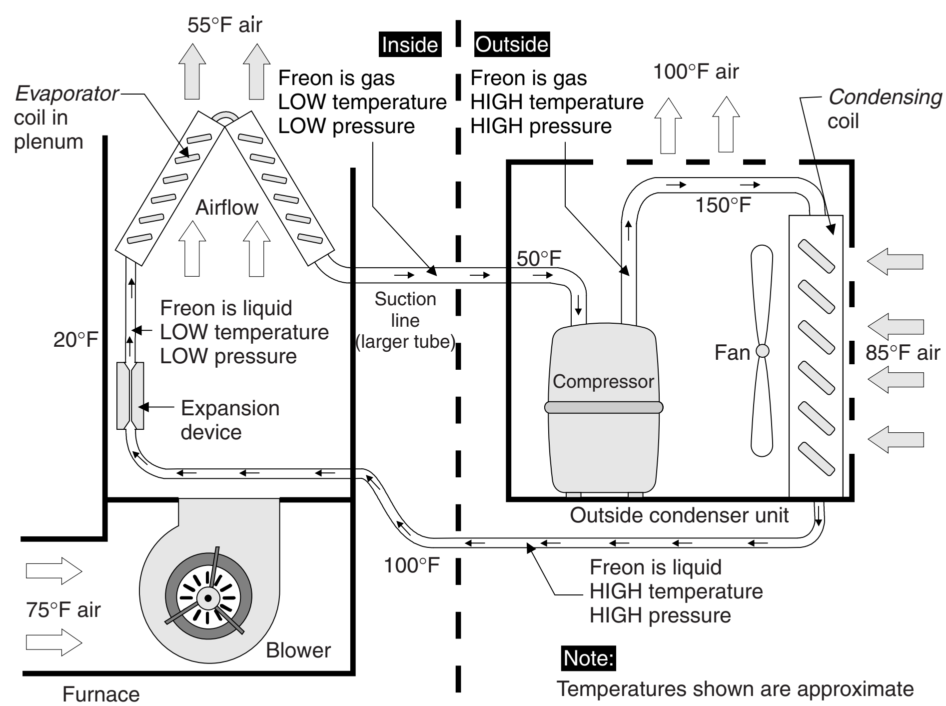


FIGURE 1.9 Air Conditioning—Schematic of System



Indoors Again

This hot liquid gets pushed back into the house. Just before it goes into the evaporator coil, it goes through the bottleneck (capillary tube or expansion valve), which lowers the pressure and temperature dramatically. Again, we have the cold liquid entering the evaporator coil, starting the process over. Figure 1.9 summarize the entire process.

Sponge Analogy

You can think of air conditioning as a sponge. The sponge contains heat from the house. We squeeze (compress) it to get rid of the water (heat) outside then let it expand (**expansion device**) as it comes inside so we can soak up more water (heat).

1.2.2 Comfort—What Causes It?

Sensible Heat

We should define a couple of terms here. **Sensible heat** is the heat a thermostat senses. When the temperature goes up, there has been an increase in the sensible heat.

Latent Heat

Latent heat is hidden. It involves adding or removing heat without changing the temperature. How does this happen? When we change a liquid to a gas (boiling or evaporation), we have to add heat, but we don't need to change the temperature. Boiling 212°F water produces 212°F steam. Similarly, we can remove heat by condensing gases to liquids, without lowering the temperature. Air contains latent heat in the water vapor that is in the air. Removing the vapor removes heat but doesn't lower the temperature.

Dry Air Feels Cooler

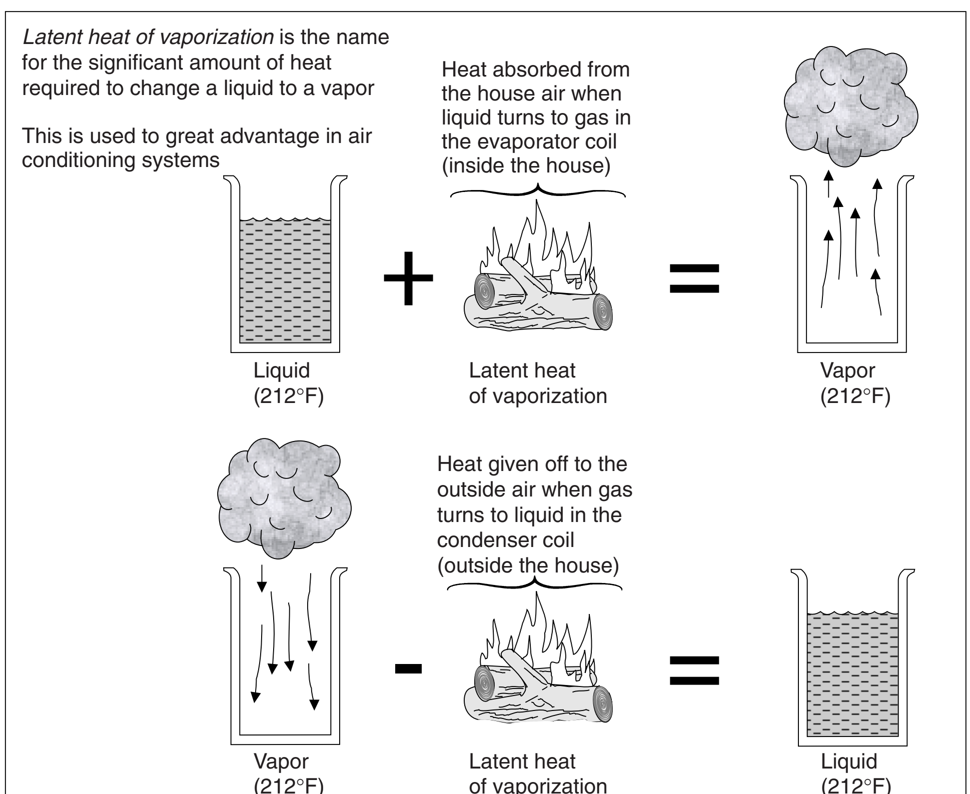
Let's think about comfort. It is easy to understand that people are more comfortable at 70°F than 100°F. But there is more to it. Most people have experienced how much more uncomfortable it is on a hot, humid day than on a hot, dry day. It helps to understand why that is.

Evaporative Cooling

The human body cools itself by sweating. When moisture evaporates off the surface of the skin, there is a great deal of cooling that takes place. Dogs accomplish much the same thing by panting.

There is something called the **latent heat of vaporization** (Figure 1.10). The key is that it takes lots of energy to convert liquid to a gas.

FIGURE 1.10 Latent Heat of Vaporization



Latent Heat of Vaporization

Here is an example of the latent heat of vaporization. One British Thermal Unit (BTU) is defined as the amount of heat required to raise 1 pound of water 1°F. To heat 1 pound of water from 32°F to 212°F, you have to add 180 BTU to it (212°F – 32°F = 180°F). To turn that 1 pound of 212°F water into steam (which is also 212°F), you have to add another 970 BTU to it! It takes five times as much energy (heat) to boil water than it takes to warm it up from 32° to 212°F. Notice that the steam is the same temperature as the water despite the addition of all that heat!

When a liquid changes to a gas, a tremendous amount of energy is absorbed. That's why having sweat evaporate off our skin is so helpful in keeping us cool.

Low Humidity Lets Skin Moisture Evaporate

People are comfortable when the humidity is lower because it is easier for the moisture on their skin to evaporate. The process of evaporation removes heat. It easy to understand how fans help keep people comfortable. As water is also evaporates off the skin, the air immediately adjacent to the skin becomes saturated and cannot hold any more moisture. The faster that air moves across your skin, the more quickly the saturated air is carried away and replaced by dry air, which allows more evaporation.

Lower Humidity More Comfortable in Summer

So if we want to keep people comfortable inside their houses, we need to cool the air and lower the humidity. If we can keep the house about 15°F to 20°F cooler than it is outside, that is usually adequate. In the winter, we set our thermostats around 70°F. In the summer, 75°F is usually just fine. If the outdoor temperature reaches 100°F, we cannot expect an air conditioning system to keep the house at 75°F. But if it is that hot outside, even 80°F with low humidity will feel relatively comfortable inside the house.

The latent heat of vaporization is also useful in the Freon lines. We can collect heat when boiling Freon and release heat when condensing it. It helps make air conditioners efficient.

1.2.3 Dehumidifying

Air Conditioners Dehumidify

We have explained how the house temperature can be dropped in an air conditioner but have not addressed the humidity. Part of the function of central air conditioning is to dehumidify the house air. Let's look at humidity reduction. When you pour lemonade into a glass on a hot summer day, the outside of the glass may sweat. That's because you are cooling the air around the glass down to a point where it cannot hold all of the moisture that's in it as vapor, and the humidity falls out as condensation.

Sweat Collects on Evaporator Coil

The evaporator coil works the same way. If you think of the evaporator coil as a cold glass of lemonade, it is easy to imagine how the outside of that coil will sweat as the warm, moist air from the house passes over it. The liquid in the coil is very cold. As the air outside the coil gives off heat, it also loses its ability to hold moisture. Condensation forms on the outside of the evaporator coil. The air gives up its moisture as it passes over the coil. As we discussed, the drier air helps people feel cooler by allowing sweat to evaporate from their skin.

Condensate Is Collected

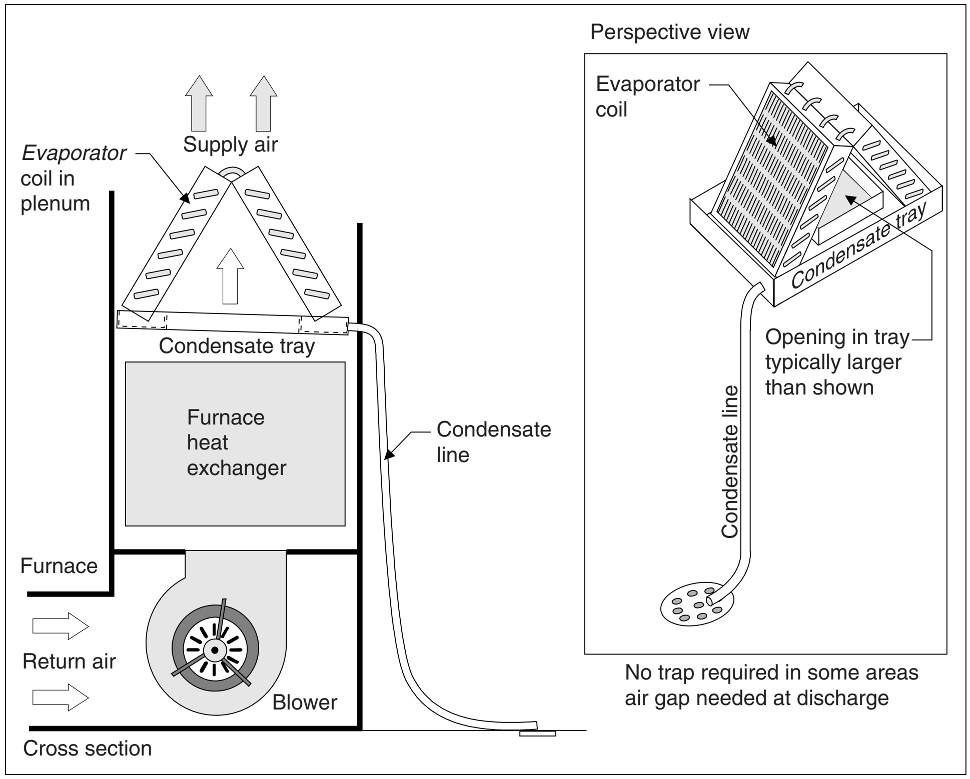
The moisture that forms on the coil is collected in a pan below the coil. The water is drained from the pan through a condensate tube to a floor drain or sink, to the outside or some other acceptable discharge point (Figure 1.11).

1.2.4 System Components

Fans and Coils

When an air conditioning system is running, fans are blowing air across the evaporator and condenser coils. Inside the house, we use the furnace fan, if there is one.

FIGURE 1.11 Discharging Condensate



If there is no forced-air heating, we put in a separate fan to move air across the coil and through the ducts. Outdoors we put a fan in the cabinet with the condenser and compressor.

The evaporator coil and condenser coil in an air conditioner are heat exchangers, although they are not usually referred to as such. Their function is to transfer heat from the house air into the refrigerant inside and to move heat from the refrigerant into the outdoor air.

Refrigerant

The refrigerant is the vehicle that collects heat from the house, moves it outside, and releases it into the outdoor air.

Compressor and Expansion Device

The compressor in the condenser cabinet is squeezing a cool, low-pressure gas into a hot, high-pressure gas. The expansion device (capillary tube or thermostatic expansion valve) near the evaporator coil is converting a hot, high-pressure liquid to a cool, low-pressure liquid.

1.2.5 The Freon Lines

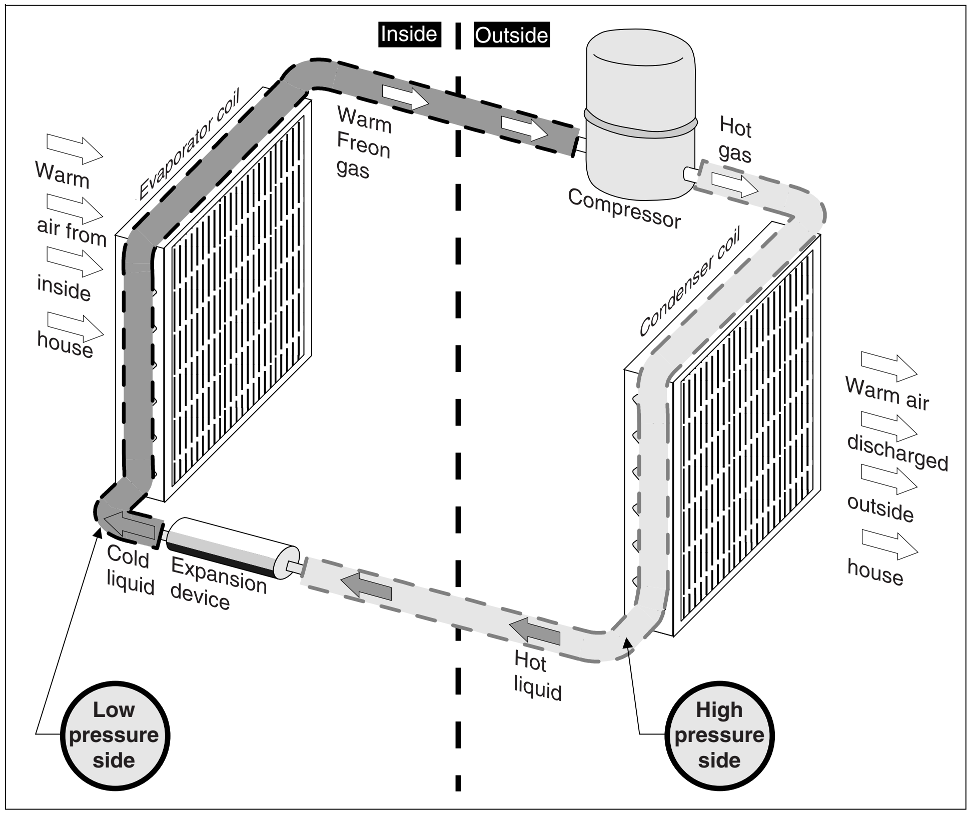
High-Pressure and Low-Pressure Sides

Some people talk about the high-pressure and low-pressure sides of an air conditioning system (Figure 1.12). The high-pressure side is from the discharge side of the compressor, through the condenser coil, through the liquid line, and up to the expansion device. The low-pressure side is from the expansion device, through the evaporator coil, and out through the **suction line** to the inlet side of the compressor.

Suction Line Insulated

The larger copper tube (suction line) that carries the cool low-pressure gas from the evaporator coil out to the compressor is insulated. This is because we do not want to dump more heat into the gas as we move outside. Remember, we are trying to dump heat from inside the house to the outdoors, not collect outdoor heat.

FIGURE 1.12 High-Pressure and Low-Pressure Sides



Gas Line Should Be Cool

The other reason to insulate the suction line is to prevent sweating on the pipe. This gas is cool relative to the house air and the outside air. If uninsulated, it would have condensation all over it.

When you are inspecting and operating air conditioners, you should check to see that the large suction line is cool to the touch any place where there is no insulation. If there is condensation on the small uninsulated sections of the pipe, that is fine. You do not want to see frost; that indicates a problem.

Liquid Line Should Be Warm

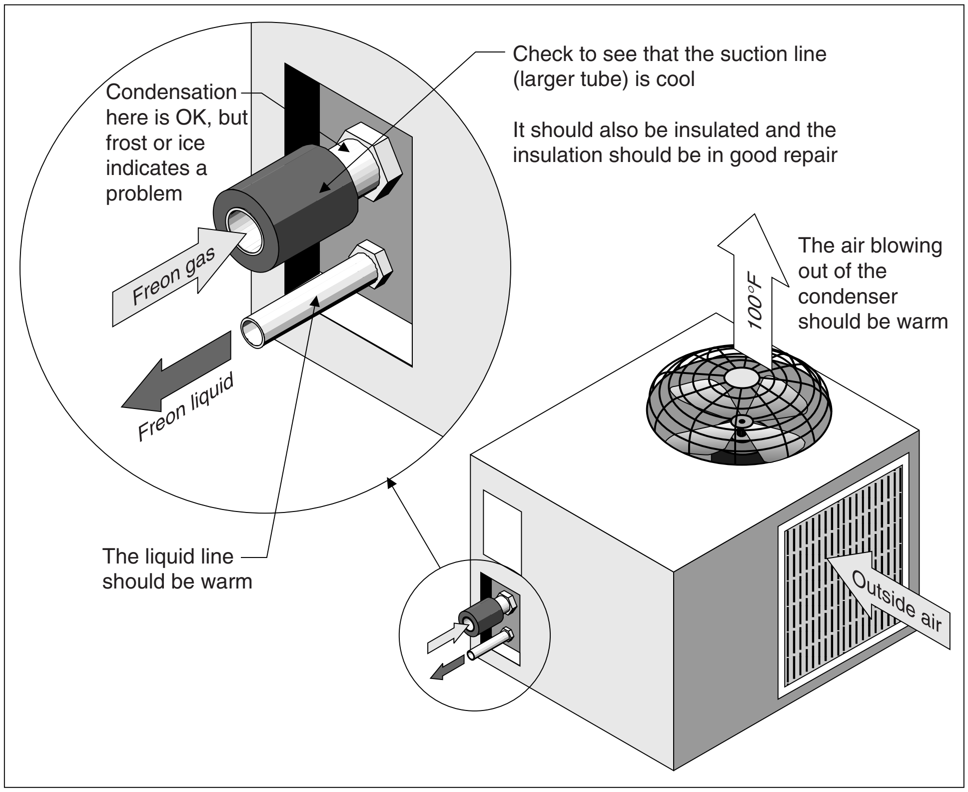
The uninsulated copper line coming from the condenser coil back into the house contains a warm liquid. The **liquid line** is smaller than the suction line that carries a gas. This is logical because gas takes up more space than liquid. Because this smaller line carries a warm liquid, when the air conditioner has been running for 15 minutes or so, this line should feel warm to the touch.

1.2.6 Is it Working Properly?

When an air conditioner is running properly at steady state, the house air temperature drops by 15°F to 20°F (some say 14°F to 22°F) as it moves across the evaporator coil. For example, 75°F house air would come out of the evaporator coil at 55°F to 60°F.

One can also make sure that the air coming off the **condenser fan** outside is warmer than the outside air. You can sense this with your hand (Figure 1.13).

FIGURE 1.13 Inspecting the Condenser Unit



1.2.7 Seasonal Energy-Efficiency Ratio

The SEER is simply a ratio of how many BTUs per hour you're getting out of the system relative to the watts of electrical energy consumed to run the unit.

$$\text{SEER} = \frac{\text{Total Cooling Output over Season}}{\text{Total Electrical Input over Season}}$$

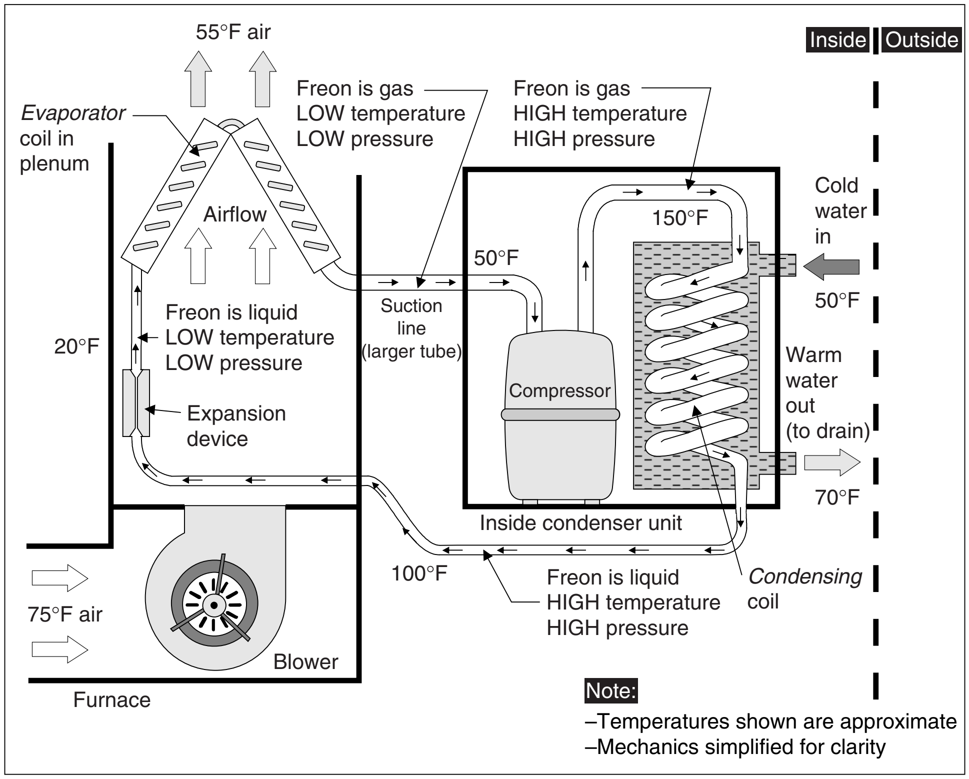
SEER ratings of 6 are typical for old air conditioners. New air conditioners are typically around 10, and high-efficiency air conditioners are typically about 14. While some clients may ask, most inspectors do not report on efficiencies, and the standards don't require it.

1.2.8 Summary

To summarize the process one more time, we take a cold, low-pressure liquid and pass it across the evaporator coil inside the house. The 75°F house air blows across it and comes off the coil at 55°F or 60°F. The cold liquid Freon that went into the evaporator coil comes out as a low-pressure gas.

This cool, low-pressure gas is taken outside and compressed into a hot, high-pressure gas. This hot gas is passed through the condenser coil, where 85°F to 90°F (for example) outdoor air is blown across it. The hot gas gives off some of its heat to the outdoor air. This causes the hot gas to condense back to a warm liquid. The outdoor air may enter the coil at 85°F and leave at 100°F (a 15°F to 20°F temperature rise is typical.) The warm liquid is carried back into the house, where it passes

FIGURE 1.14 Water-Cooled Air Conditioning—Schematic of System



through the expansion device (bottleneck). This drops its temperature and pressure so that it can enter the evaporator coil as a cold liquid, ready to get boiled off.

One Little Twist

Water-Cooled Systems

Some people are not happy keeping things simple. They decided if we could dump heat into the outside air, we could also dump it into water. So they built air conditioners that dump heat into the domestic water in the house. Since this water is usually about 50°F, we can dump a lot of house heat into it.

Water Passes over Condenser

The evaporator coil sits in the house air system just like we have been talking about and works the same way as before. And we still use a condenser coil. There is Freon inside the coil (as usual), but on the outside is water (Figure 1.14). The water flows through the condenser coil without the need for a fan. The water is pushed by city water pressure (or pump pressure on a private water supply).

Condenser and Compressor Are Indoors

The condenser coil does not have to go outside any more. We can put it close to the evaporator coil. That means the compressor can be indoors too. On the downside, the water that passes through the air conditioning system cannot be used for drinking or washing. It is no longer considered potable.

Waste Water

Some maintain that these air conditioning systems are wasteful, since the outgoing water is usually dumped down a drain. Some systems can use the air conditioning discharge water to water the lawn or fill a swimming pool, but even then, some municipalities have banned these systems because of their high water consumption.

Rivers, Lakes, Wells, and Ground

There are other places to dump the heat, including lakes, rivers, ponds, wells, and the ground. Systems have been developed to use these. All of these systems operate on the same principle we have discussed. Many use an intermediate liquid (brine, antifreeze, etc) to carry heat from the condenser to the water or ground. These systems typically use pumps to move the intermediate liquid.

Other Twists

Gas Chillers

Gas chillers work differently than conventional residential air conditioners and have become so rare that they do not warrant discussion here.

Evaporative Coolers

We'll briefly discuss evaporative coolers, an entirely different air conditioning system used in very dry climates.

Whole-House Fans

We'll also touch on whole-house fans, which aren't really air conditioners at all but do help to cool houses.

Heat Pumps

Heat pumps will be discussed in Chapters 9 and 10. We strongly encourage you to finish the air conditioning discussion before starting the heat pump chapters.

1.3 DUCTLESS AIR CONDITIONING

Alternative to Central Systems

Air conditioning is expensive to add to homes that do not have ducts. Ductless air conditioning is becoming a popular option because it is not disruptive to install and can provide several cooling zones. Ductless systems are available as air- or water-cooled units.

Scope of Inspection

We inspect permanently installed systems with or without ducts. We don't inspect window air conditioners or other systems that can be removed without tools and that plug into 120-volt convenience receptacles.

Split Systems

There are two common types of ductless systems: split systems and single component systems. Split systems have a condenser cabinet with a compressor, condenser coil, and fan on the ground or on the roof, the same as any central split system. The evaporator coil and house air fan are inside the home, in the area to be cooled. There is a **condensate collection** and discharge system for the interior component. There are two refrigerant lines, often in a conduit, joining the outdoor condenser unit to the evaporator inside the home.

Compact

Split systems, also called mini-splits, are easy to install and only require a 3-inch-diameter hole through the house wall. The indoor components can be wall or ceiling mounted and don't take up much space. Some are sold with remote controls so they can be mounted out of the way, high on walls or on ceilings.

Quiet

These have the advantage of a remote compressor (the noisiest part of an air conditioner), so the home is quieter. Some interior fans are multi-speed to minimize noise. There are also quieter condenser fans in some systems that operate at very low rpm (less than 900 rpm).

Multi-Zone Systems

Split systems can be multi-zone, with one condenser unit serving up to four evaporators in four different parts of the home.

Large Capacity

Split systems are available with cooling capacities up to 60,000 BTU/hr (5 tons).

Heat Pumps Too

Heat pumps are also available as ductless systems. Some have built-in supplementary electric heating.

Single-Component Systems

Single-component systems are also called through-wall or package systems. These are self-contained systems with the condenser, compressor, and evaporator all in the same cabinet, installed in the wall of the room or area to be cooled. These units are common in motels and apartments. These single-component systems are noisier than split systems because the compressor is in the wall. Some include electric elements for supplementary heating. Single-component systems may be wired directly into the panel or may plug into a 240-volt receptacle.

Inspection Issues

The inspection procedures for ductless systems are similar to central systems. There is no distribution system to worry about, and there is often much less you can see, especially on single-component systems. There is typically a filter access panel, but that is about all that is accessible. On ceiling and high wall-mounted units, the standards suggest you don't have to open these panels since they are not within normal reach. Dirty air filters are a common problem with ductless systems, especially when the system is out of reach of the average person.

Airflow Issues

Ductless air conditioners can blow air up to 40 feet in an open area, but since there is no distribution system, even cooling or heating in multiple rooms from a single system is unlikely. In small rooms, air can bounce off walls or furnishings and create short cycling and comfort problems. These systems are often located near the top of the stairwell in a two-story home in an effort to cool as much of the home as possible.

Condensate Damage

Condensate discharge systems are often on the building exterior, below the wall-mounted evaporator. Discoloration or damage to the wall is a possibility if the condensate is allowed to run down the wall surface.

1.4 AIR CONDITIONING CAPACITY

Most home inspectors give their clients some indication as to whether the air conditioning system is sized properly even though it's not required by the standards. Let's look at the cooling capacity.

A Ton of Ice

The cooling capacity of air conditioners is usually measured in tons. One ton equals 12,000 BTU (British Thermal Units) per hour (Figure 1.15). The term **one ton** comes from the amount of heat required to melt a block of ice that weighs one ton.

Factors Affecting Cooling Load

The amount of cooling required depends on a large number of factors. These include the outdoor temperature; the outdoor humidity; the level of insulation in the house; the amount of air leakage in the house; the amount of southern-, eastern-, and western-facing glass in the house; whether this glass is single, double, or triple glazed; whether the glass is a low emissivity glass; and whether window treatments (curtains or blinds) are kept closed or open. Other factors include the amount of shading

FIGURE 1.15 One Ton of Cooling

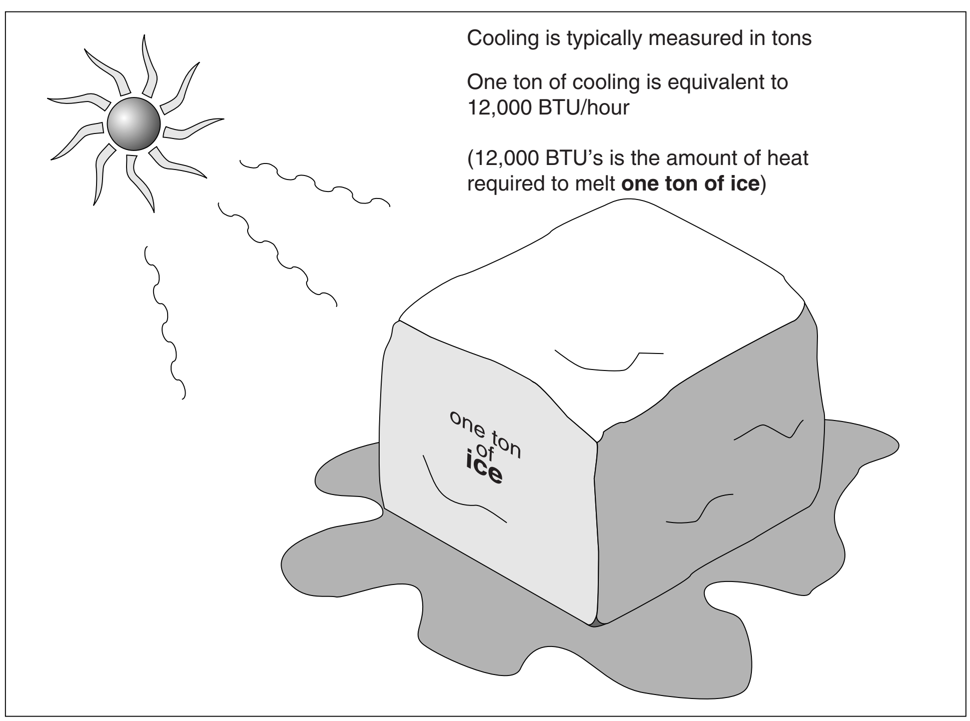
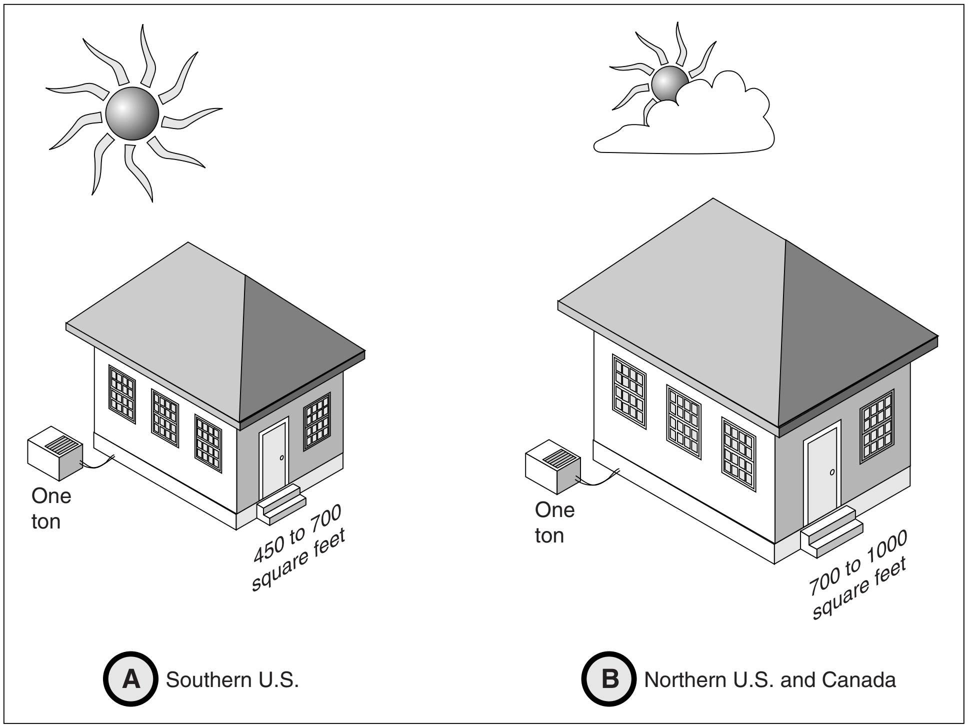


FIGURE 1.16 How Much Area Can One Ton Cool?



from trees, roof overhang, awnings, or buildings and how much heat is generated in the house by the people and equipment inside.

Guidelines

Despite all these variables, most people like to have guidelines. Home inspectors are no exception. In the southern United States, 450 to 700 square feet of floor area per ton of cooling is considered appropriate (Figure 1.16). In the more moderate climates, such as the northern United States and southern Canada, 700 to 1,000 square feet per ton may be adequate. Speak to air conditioning contractors and other inspectors in your area to find the appropriate range for your area. (Note: These guidelines assume 8-foot ceilings.)

Duct Capacity Problems

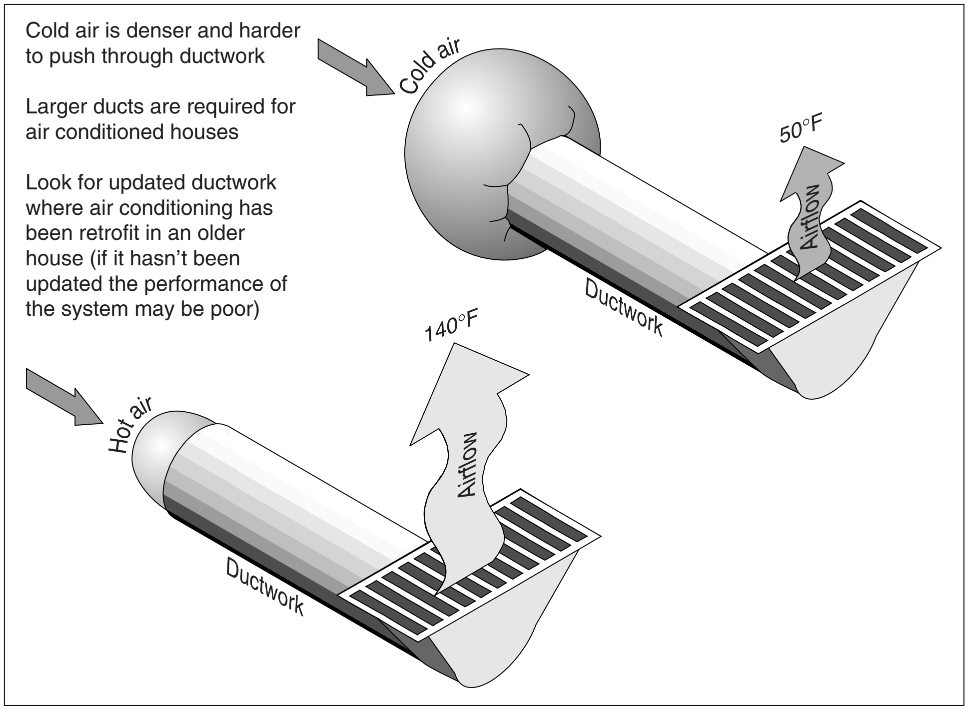
The capacity of the equipment is only one part of the equation. Many air conditioners that underperform are a result of a duct system incapable of circulating the conditioned air adequately through the system. This is particularly true where air conditioning has been added to a house with ducts that were designed for a heating system only.

Moving Heavy Air with More Obstructions

Adding central air conditioning to an existing furnace system may lead to inadequate air distribution for several reasons. First, the evaporator coil presents an additional obstruction to airflow and reduces the rate of air movement through the system. Second, during the cooling season, we are trying to move air that is at 55°F rather than air that is at 140°F (which is what we see in the heating season). The cooler air is more dense (heavier) and more difficult to move through the ducts (Figure 1.17). We also have to move more air since the difference in temperature between the conditioned air and the room air (about 15°F to 20°F) is less than with a conventional oil or gas furnace (60°F to 70°F), for example.

A larger fan is only helpful up to a point. We don't want to increase the air speed beyond 500 feet per minute (about 5 miles per hour) or we'll get excessive noise and uncomfortable drafts in the home.

FIGURE 1.17 Larger Ducts Are Required for Air Conditioning



Air conditioning systems typically move 400 to 450 cubic feet of air per minute per ton through a system. Heating systems only need to move about half this much.

What Constitutes Good Performance

Most air conditioning systems are designed with a slightly different goal than heating systems. During the heating season, our goal is typically to keep the house at roughly 70°F regardless of how cold it is outside. During the cooling season, while it may be ideal to drop the temperature to 75°F, remember that the air conditioning system is also dehumidifying the air. As long as a 15°F differential between the outdoor temperature and indoor temperature is achieved, the house will feel relatively comfortable if the air has been dehumidified properly. When it's 100°F outside, an indoor temperature of 80°F to 85°F may be acceptable. Clients should understand that this temperature differential indicates good performance.

Uneven Cooling

One of the common complaints with air conditioning is that different levels of the house are cooled with different effectiveness. For example, it may be 75°F on the main floor, but 85°F on the second floor. This is usually a function of the distribution system rather than the capacity of the unit.

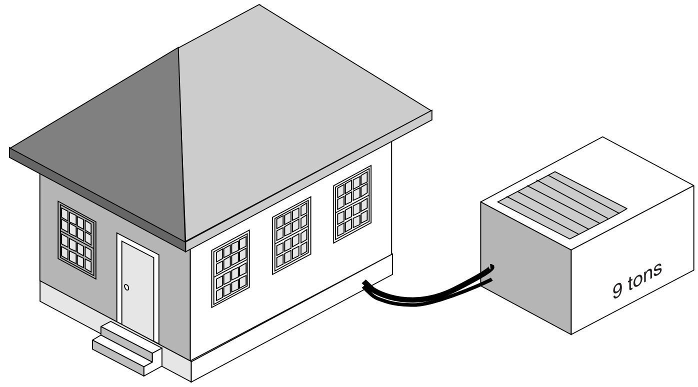
Better to Undersize than Oversize

Many air conditioning manufacturers and installers recommend slightly undersizing an air conditioning system rather than oversizing (Figure 1.18). The reason for this is two-fold. First, air conditioners that are slightly undersized tend to have longer running periods. This means fewer stops and starts, and potentially a longer compressor life.

House Is Cold and Damp

Second, and perhaps more importantly, the risk in oversizing a unit is an uncomfortable climate. Oversized air conditioners come on for short periods of time and drop the air temperature quickly. Because of their large capacity, they satisfy the thermostat before the system has a chance to do much **dehumidification.** This can lead to a cold, clammy environment inside the house.

FIGURE 1.18 Bigger Is not Better



An air conditioner that is **too large** will:

Cycle on and off more frequently—potentially causing premature compressor failure

Cool the house too quickly—(satisfying the thermostat and shutting down) before the house can be sufficiently dehumidified

1.5 CONDITIONS

These are the common capacity issues:

1. Undersized
2. Oversized

1.5.1 Undersized

CAUSES

Undersized air conditioners may result from poor installation practices that do not include a heat gain calculation or do not adequately recognize the characteristics of the home. Undersized units may also be a result of house changes or additions. For example, the addition of skylights or the removal of mature trees can increase the heat gain dramatically.

IMPLICATIONS

During moderate weather, the air conditioner may function adequately, but during hot weather, the air conditioner may not be able to achieve a 15°F to 20°F temperature differential between indoors and outdoors.

STRATEGY

The first step is to determine the size of the air conditioning system. This can often be done by reading the model number on the data plate (Figure 1.19). This is typically located on the outdoor (condenser) unit. The size may be recorded in thousands of BTUS per hour or in number of tons.

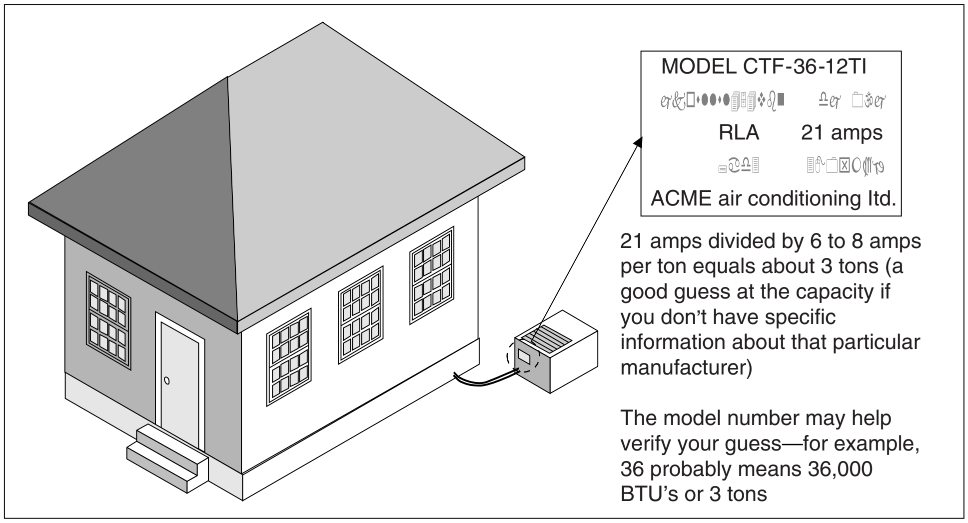
Carrier's Blue Book

Sometimes it is difficult to translate a model number into a system capacity. The Carrier Blue Book available through ASHI® or Carrier Corporation in Indianapolis is an excellent reference guide, with the model, serial numbers, and SEER (Seasonal Energy-Efficiency Ratings) of many residential air conditioning systems used in the United States.

Guessing the Size

If the size cannot be determined from the model number on the data plate, the size can be approximated from the Rated Load Amperage (RLA) on the data plate. A typical reciprocating compressor will be rated at 6 to 8 amps per ton of cooling.

FIGURE 1.19 Guessing the Size



The newer high-efficiency units and scroll compressors will draw less current, more like 5 amps per ton. Be sure to make it clear that this is an approximation only.

Use House Square Footage

The next step is to roughly calculate the above-grade square footage of the home. Divide the square footage into the number of tons and determine the number of square feet per ton.

If the number of square feet per ton exceeds the ranges we discussed, it is probably best to describe this as marginal or suspect capacity and to recommend further investigation. There may be a number of factors in the home that cause the guidelines not to apply.

Guidelines

It's also possible to find a system that seems to be just fine with respect to capacity using your guideline and yet it isn't really big enough. When considering the square footage of the house, the basement is not usually considered. However, if the basement has a walk-out with a large glass surface facing south, east, or west, the air conditioning load may be far greater than contemplated.

Measure Temperature Drop across Indoor Coil

If the system is adequately sized and is working properly, the air temperature entering the evaporator coil will be whatever the room temperature is. Let's say it's 75°F. The air coming off the coil should be 14°F to 22°F cooler (some say 15°F to 20°F). If the inlet temperature is 75°F, the air coming off should be 55°F to 60°F. This can be measured with a thermometer with a sharp probe that is pushed into a joint or hole in the supply plenum immediately downstream of (or after) the evaporator coil (Figure 1.20).

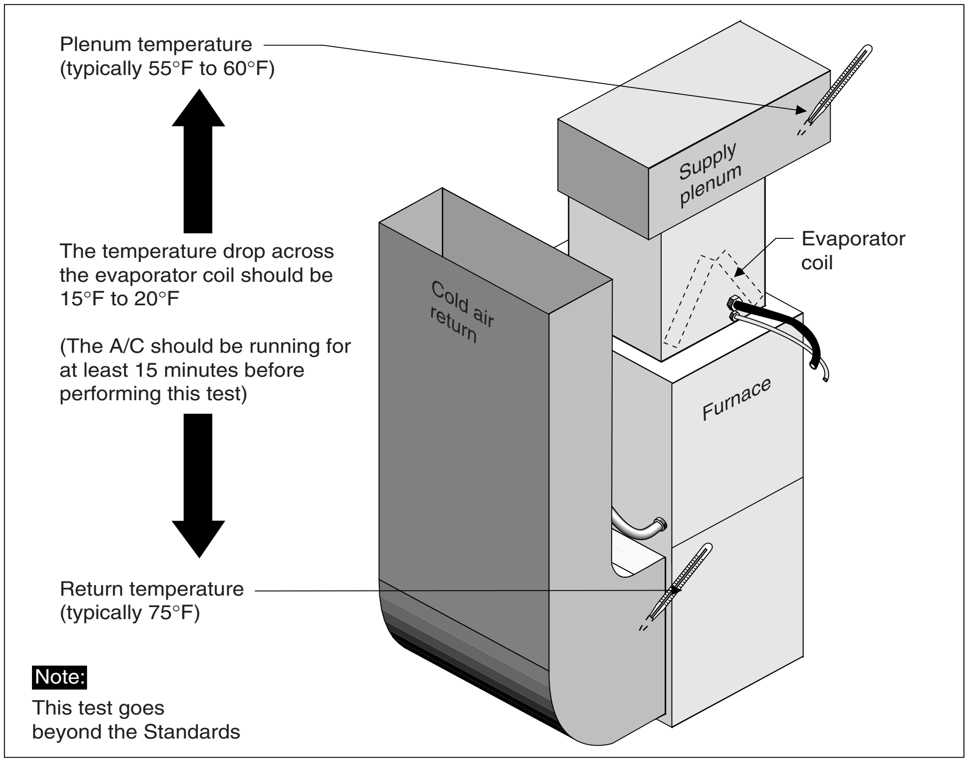
If the temperature drop is different, the problem may be size related or may indicate a need for servicing. This test should be compared with your approximation of the size of the air conditioner, based on the number of square feet per ton. Make sure the temperature drop is measured after the system has established equilibrium. The unit should run for at least 15 minutes before checking the temperature split.

Note: Measuring this temperature split is beyond the standards but is mentioned because many inspectors do it.

1.5.2 Oversized

An **oversized** air conditioner is susceptible to short cycling, inadequate dehumidification, and large temperature variations in the house.

FIGURE 1.20 Measure Temperature Drop across Inside Coil



CAUSES

Oversized air conditioners are usually the result of a design or installation problem.

IMPLICATIONS

Oversized units will have a shortened life expectancy and will provide a less comfortable environment. The largest comfort issue is the lack of dehumidification. Because the temperature drops rapidly with an oversized unit, there is not an adequate volume of air movement across the coil to extract the water from the house air. This results in a house that is cold, but with a humid, swamp-like environment. Since compressors experience most damage on startup, short cycles also mean more startups and a shorter life.

STRATEGY

Other than the rough guideline test, it is difficult to know whether and how much the unit is oversized. Some public utilities indicate that a unit may be as much as 25 percent oversized without adverse effect. The temptation to oversize may become apparent when we talk about heat pumps. Since heat pumps have to deal with a much larger temperature differential from outside to inside, the tendency is to make the heat pump large enough to meet the heating demand. This makes it too large for the cooling load. There are some strategies to address this problem, but within this context, we are watching for oversized cooling units.

One way inspectors identify an oversized air conditioner is by sensing the cold damp environment when walking into a house. Also, an air conditioner that short cycles (turns on and off every 5 minutes) is a suggestion that the unit may be oversized.

Two surveys have shown that one third to one half of all residential air conditioning systems are oversized.

While the standards don't require it, most inspectors will red-flag systems that seem too big or too small. They will usually phrase it as a question rather than as a conclusion.

CHAPTER REVIEW QUESTIONS

Instructions: Answer the following questions on a separate sheet of paper, then check your results against the answers provided in Appendix E. If you have trouble with a question, refer back to the chapter to review the relevant material.

1. Central air conditioners are most like which household appliance?
   - **a.** A stove
   - **b.** A refrigerator
   - **c.** A microwave
   - **d.** A trash compactor
   - **e.** A garbage disposal
2. In what state is Freon when it is in the suction line?
3. What is the temperature of Freon when it leaves the evaporator coil?
4. What is the temperature of Freon as it enters the evaporator coil?
5. What is the temperature of Freon as it enters the compressor?
6. What is the temperature of Freon when it leaves the compressor?
7. What is the temperature of Freon when it enters the condenser coil?
8. What is the temperature of Freon when it leaves the condenser coil?
9. What is the temperature of Freon when it enters the expansion device?
10. What is the temperature of Freon when it leaves the expansion device?
11. In what state is Freon in the compressor?
12. In what state is Freon in the expansion device?
13. When you compress gas, you cool it.
    True False
14. The evaporator coil is outdoors in a split system.
    True False
15. Which of the Freon lines is insulated?
16. Define, in one sentence, sensible heat.
17. Define, in one sentence, latent heat.
18. How many BTUs are required to convert 1 pound of water at 212°F to steam at 212°F?
19. Explain in two or three sentences how people's bodies are cooled by evaporative cooling.
20. Explain in two sentences how air conditioners dehumidify houses.
21. Where is condensate collected in an air conditioning system?
22. Which side of the air conditioning loop is the high-pressure side?
23. Which side of the air conditioning loop is the low-pressure side?
24. When the system is operating, which of the refrigerant lines will feel warm?
25. When the system is operating, which of the refrigerant lines will feel cool?
26. One ton of air conditioning is equivalent to how many BTUs per hour?
27. List ten items that affect the amount of air conditioning needed in a home.
28. How many square feet can one ton of air conditioning cool in Florida?
29. How many square feet can one ton of air conditioning cool in Michigan?
30. Oversized distribution ductwork is a common problem with central air conditioning.
    True False

31. An undersized air conditioner is better than an oversized one.

True False

32. The typical temperature drop from outdoors to indoors with a properly operating air conditioning system would be about 15°F.

True False

33. What kind of temperature drop would you expect to find in the house air as it passes over the evaporator coil?

KEY TERMS

air conditioning	latent heat	suction line
refrigerant	latent heat of vaporization	liquid line
compressor	dehumidification	duct system
evaporator coil	condensate collection	oversized
expansion device	condenser fan	undersized
condenser coil	outdoor fan	one ton
sensible heat	indoor fan	