

SMART AND COOL—THE ART OF AIR CONDITIONING

Common misconceptions can contribute to a home environment that is too cold, too hot, or too humid.

BY JOHN PROCTOR

If you're confused about how to get an air conditioning system to work well, you are not alone. Last October, builders loaded with questions showed up for a talk I gave at the Energy and Environmental Building Association (EEBA) conference. Most of the builders' questions were about their own homes—the ones they live in. Some complained that they were blasted with cold air when the air conditioning unit was on; others complained that the house was uncomfortably humid. We started talking about why oversized air conditioners cause both of these problems—and also why the situation is worse now than it was in 1995, when *Home Energy* published "Bigger Is Not Better." During that discussion last October, builders vented strong frustrations over the numerous problems they've experienced in their attempts to get their customers and their HVAC contractors to understand the advantages of properly sized air conditioners. These frustrations and questions are not at all unique to this group of builders; I get these types of questions at every presentation I give.

Homeowner Misconceptions

What follows are some of the misconceptions and questions that persist about air conditioning systems, as well as my responses to them. (For a



How much air conditioning is enough?

review of cooling terminology, see "Key Cooling Terms," p. 50.)

"My friend got a new air conditioner that was smaller than the one she had before. It runs all the time, and that's a problem." Here is a related question: Is it more economical to hop in an eight-cylinder SUV and go 1 mile, racing each block and stopping at every corner, or to hop in a six-cylinder car and drive 1 mile on the freeway from one entrance ramp the next exit? In terms of gas mileage, pollution, and economics,

the answer is clear: The single acceleration onto the freeway is much better than the stop and start of the city driving.

The situation is the same for air conditioners. Larger air conditioners start and stop all the time; they waste your precious money and contribute excessively to pollution. These problems all stem from the fact that whenever an air conditioner starts up, it is very inefficient. Once you have it running, you want it to keep running as long as you can. The air conditioner's "gas mileage" is measured in 1,000 Btu per kilowatt hour. Let's call

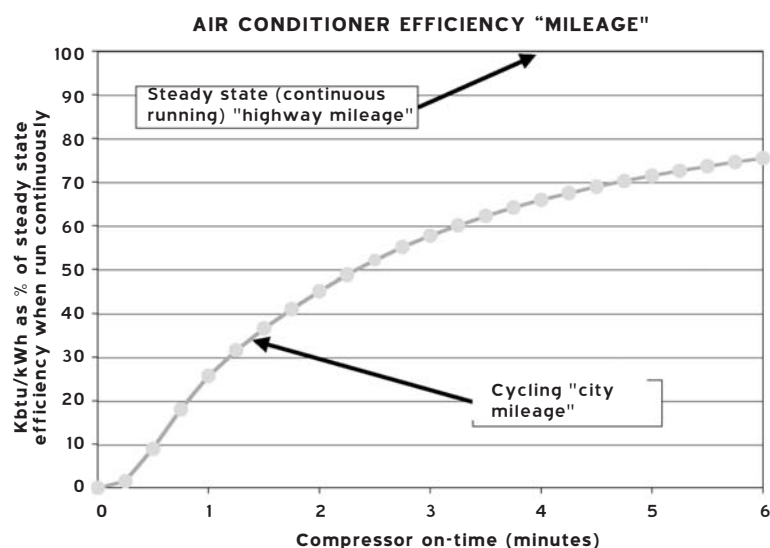


Figure 1. The efficiency "electricity mileage" (kbtu/kWh) improves when the air conditioner stays on longer. The total energy consumption drops because there are also longer pauses between cycles when the air conditioner does not run.

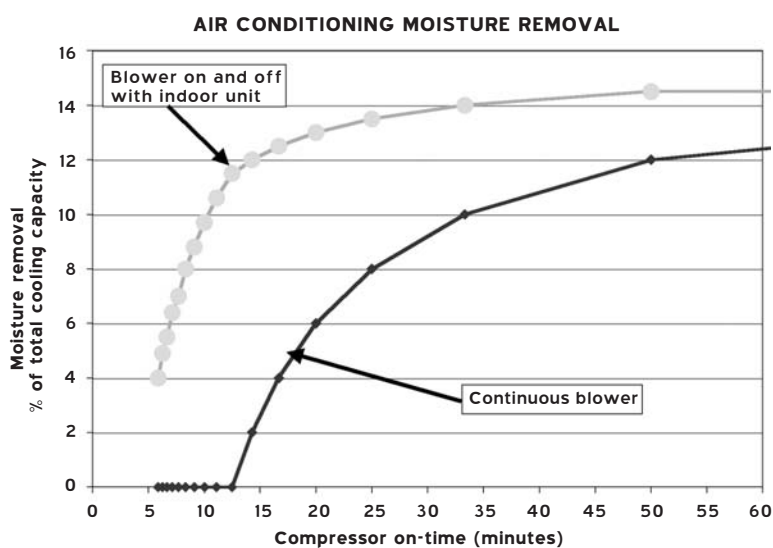


Figure 2. An air conditioner connected so that the blower turns on and off with the compressor provides the most moisture removal. In addition, that moisture removal improves dramatically when the compressor runs longer. Continuous blower operation, on the other hand, reduces moisture removal to zero, unless the compressor runs for more than 13 minutes.

that figure electricity mileage. The electricity mileage of the air conditioner gets better the longer it runs (see Figure 1). The simple fact is that larger air conditioners run very short cycles, with worse electricity mileage, than smaller units.

"A bigger air conditioner will make me more comfortable." Unfortunately, the intuitive way to achieve comfort—put in a bigger air conditioner—is incorrect. Instead, comfort comes from an air condition-

ing system that keeps the inside humidity low, distributes the cooling to all rooms of the house based on what each room needs, is quiet, and does not produce blasts of cold air.

Homeowners from West Texas to the California coast live in a dry climate. They generally only have to worry about how much the air conditioner lowers the temperature measured by the thermostat (the dry bulb temperature). The ability of an air conditioner to lower dry bulb temperature is known as sensible capacity.

Homeowners in the rest of the United States, and in particular western microclimates, have to worry about the amount of moisture the outside air brings into the home. When it is hot and humid outside, the air entering the building is cooled, but unless moisture is removed from the incoming air, the indoor relative humidity rises, often making a home feel damp and uncomfortable.

A standard thermostat does not measure the amount of moisture in the home. So setting the thermostat lower does not ensure comfort. What we need in the hot-humid climates is to remove moisture.

Can an air conditioner do that? Yes and no. Air conditioners almost always remove some moisture from the air, and that moisture stays on the inside coil. (The ability of an air conditioner to remove moisture is known as latent capacity.) But in order to remove a significant amount of moisture, the air conditioner must run long enough for the condensed water to run off the coil and down the condensate drain. For a coil that is starting dry, this can be as long as 10 to 20 minutes. A short run time—which is what larger air conditioners generally provide—fails to remove sufficient moisture in a wet climate. An air conditioner connected so that the blower turns on and off with the compressor provides the most moisture removal. In addition, moisture removal improves dramatically when the compressor runs longer (see Figure 2). Smaller air conditioners will run longer and do a better

job of removing moisture than larger units. The effect of running the blower all the time (an increasing practice) is dramatic as well—in a very different way. Under continuous blower operation, moisture removal is zero until the compressor is running over 13 minutes every time it comes on. Most compressor runs are less than 10 minutes.

“Are you saying that running the blower continuously is a bad idea?” You bet! First of all, running the blower continuously will cost you big time. In Wisconsin, for example, running a standard blower year-round will cost you an additional 3,560 kWh (\$365 at 10¢/kWh) just to pay for running the blower. On top of that, running the blower all the time increases duct system losses. The outside air leakage into the house increases by a factor of four in many houses when the blower is on. This brings hot moist air into your home in the summer, and cold air into your home in the winter.

“A bigger air conditioner doesn’t cost that much more.” If your contractor is offering to upsize your air conditioner for very little more, he or she is cutting corners that will cost you comfort and money. A larger air conditioner requires a larger furnace (air handler) and larger ductwork. Without proper ducts and a proper furnace, the air conditioner will be noisy and inefficient.

Furthermore, it is more difficult to install the larger ductwork to get proper flow to every room. The larger furnace has a larger blower motor that uses more energy. There is significant increase in blower energy consumption when a 4-ton air handler is used instead of a 3-ton air handler in otherwise identical homes (see Figure 3).

“Any new air conditioner is as good as any other.” Most residential air conditioners consist of an outdoor unit and an indoor unit. The outdoor unit consists of the compressor, the condenser coil, and the outside fan. The indoor unit consists of an inside coil on a

furnace (air handler). These components are shipped from the factory, and final assembly takes place at your home. The outdoor unit is joined to the inside coil by a set of copper lines that carry the refrigerant to and from the inside coil. Builders or homeowners who look only to the lowest bid are pretty much guaranteed to get what we call a business as usual installation. These installations are fast and cheap, but they result in a number of problems. Those problems include

- too much or too little refrigerant;
- low air flow through the inside coil;



Proper installation takes time and competent technicians.

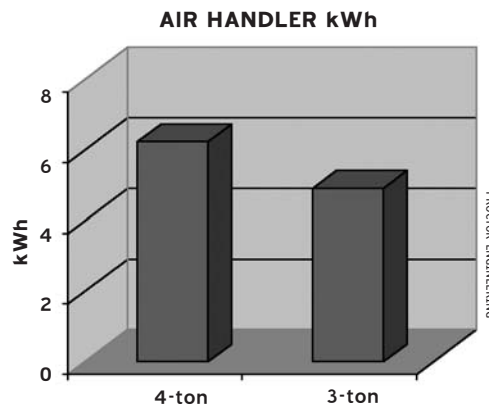


Figure 3. In a side-by-side test of identical homes, the 3-ton air conditioner ran 30% more than the 4-ton unit. The 3-ton air handler still used 27% less energy.

- ducts that leak over 20% of the air they carry;
- low-quality brazed joints that leak refrigerant;
- refrigerant contaminated with air, moisture, oxidation, and particles; and
- callbacks, warranty costs, and frustrated customers.

It is worth paying extra to have a duct system that is tested and shown to have less than 10% leakage (a new duct system should be built and tested to leak less than 6%). It’s also worthwhile to have the installation commissioned and verified. These two steps alone will produce an average energy savings of 24%–35%, depending on the local climate and on air conditioner usage.

“If I’m not comfortable, it’s the HVAC contractor’s fault.” A contractor’s ability to make a homeowner comfortable is severely limited by the performance of the house and by the willingness of the builder or homeowner to pay for a high-quality installation.

In some ways, buildings have gotten much better over the last 15 years. Insulation is more common, low solar heat

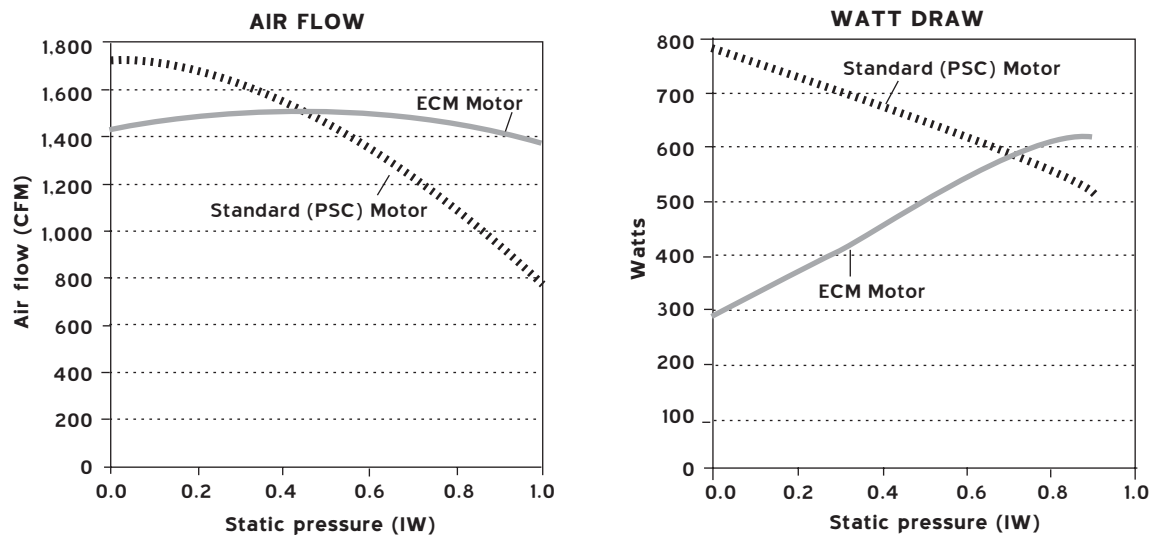


Figure 4. The air flow and watt draw of a standard permanent split capacitor (PSC) motor as well as of an electrically commutated motor (ECM) in the same furnace with the same blower are shown here. The flow and watt draw drops when a PSC motor encounters increased flow resistance. An ECM system works to maintain a constant air flow and the watt draw rises with increased flow resistance. (Figure courtesy of Bruce Wilcox, LBNL, and PG&E Laboratory).

gain roofs are available, and newer, high-efficiency glass can block much of the heat gain during the summer. In many homes, 50% or more of the heat gain at the hottest part of the day comes through the windows. When low solar heat gain windows are used, the air conditioner can often be downsized by as much as 1 ton.

None of these improvements has reduced the amount of moisture generated in the home or the amount of moisture entering the home with outside air. As the heat gain through walls, roofs, and windows is reduced, moisture removal becomes a larger and larger part of the cooling load. Simply put, if you live in a leaky house, most thermal improvements will make your house more susceptible to moisture problems. Therefore reducing house air leakage is a very high priority in moist climates.

“My contractor can tell what size air conditioner I need just by calculating the floor area.” If you let the contractor use this method, he will probably oversize your air conditioner by a ton or more. In order to use the floor area method, contractors have to deal with all the differences between homes

by always installing large air conditioners. This means that your new air conditioner will do a poor job of removing moisture, will have low air flow across the inside coil, will be noisy, will cost you more to purchase, and will increase your utility bill for 15 to 20 years.

Contractor Misconceptions

It’s not just the homeowners who are confused. Here is the contractors’ side of the equation.

“Customers will not pay for quality; they want the biggest air conditioner for the least money.” There will always be customers—and builders, too—who just want the lowest price. However, there is a growing recognition that smaller air conditioners do a better job of dehumidification, and that better installations save energy and money. Installation specifications are being enforced in some states and are under consideration by EPA for Energy Star products.

One of the biggest hurdles you will face is finding a way to convince the customer that you are doing a better job than your competitors. Some of the

most exciting results we have seen involve contractors who take pride in doing a better job and are comfortable with ethical third-party verification to their customers. These contractors refuse to sell business as usual jobs. They are paid for their higher value, have high customer satisfaction, and experience very few callbacks and warranty calls.

“If I use ACCA Manual J, I have to use higher outdoor temperatures than they specify and lower indoor temperatures than they specify. And I have to add a fudge factor at the end just to make sure there is enough cooling.” This is a very common misunderstanding among contractors. To figure out whether *Manual J* produces load estimates that are too small, we monitored homes in three states. We found that, on average, the actual sensible load was two-thirds of what *Manual J* estimated. This means that *Manual J* actually overestimates a home’s air conditioning needs. Simply put, if the contractor uses *Manual J* without any fudge factors and selects an air conditioner to just meet the sensible and moisture removal loads, the air conditioner will be properly sized. In addi-

KEY COOLING TERMS

Sensible cooling load. The heat gain of the home due to conduction, solar radiation, infiltration of outside air, appliances, people, and pets. Burning a light bulb, for example, adds only sensible load to the house. This sensible load raises the dry bulb temperature.

Dry bulb temperature. The temperature measured by a standard thermometer.

Latent cooling load. The net amount of moisture added to the inside air by plants, people, cooking, infiltration of outside air, and any other moisture source. The amount of moisture in the air can be calculated from a combination of dry bulb and wet bulb temperature measurements.

Wet bulb temperature. When a wet cotton wick is placed over a standard thermometer and air is blown across the surface, the water evaporates and cools the thermometer below the dry bulb temperature. This cooler temperature is called the wet bulb temperature, and depends on how much moisture there is in the air.

Design conditions. Cooling loads vary with inside and outside conditions. A set of conditions specific to the local climate is necessary to calculate the expected cooling load for a home. Inside conditions of 75°F and 50% relative humidity are usually recommended. Outside conditions are selected for the 2.5% design point.

2.5% design. The outside summer temperatures and coincident air moisture content that will be exceeded for only 2.5% of the hours from June to September. In other words, 2.5% design conditions are outdoor temperatures that are historically exceeded in 73 of the 2,928 hours in these summer months.

Capacity. The capacity of an air conditioner is measured by the amount of cooling it can do when it runs

continuously. The total capacity is the sum of the latent capacity (ability to remove moisture from the air) and sensible capacity (ability to reduce the dry bulb temperature). Each of these capacities is rated in Btu per hour (Btu/h). The capacity depends on the outside and inside conditions. As it gets hotter outside (or cooler inside), the capacity drops. The capacity at a standard set of conditions is often referred to as "tons of cooling."

Tons of cooling. Air conditioner capacity is rated at 95°F outside with



SEER. The seasonal energy efficiency ratio is a standard method of rating air conditioners based on three tests. All three tests are run at 80°F inside and 82°F outside. The first test is run with humid indoor conditions, the second with dry indoor conditions, and the third with dry conditions cycling the air conditioner on for six minutes and off for 24 minutes. The published SEER may not represent the actual seasonal energy efficiency of an air conditioner in your climate.

Manual J. A widely accepted method of calculating the sensible and latent cooling (and heating) loads under design conditions.

Manual S. The ACCA method of selecting air conditioning equipment to meet the design loads. It ensures that both the sensible capacity and the latent capacity of the selected equipment will be adequate to meet the cooling load.

Manual D. The ACCA method for designing duct systems. Contractors often find it a laborious process and most duct systems are just installed—not designed. The amount of time necessary to

design a duct system is certainly warranted in tract construction, where the design is used repeatedly, and for custom homes, where the total cost of the home warrants a proper design. In short, designing a duct system is essential for proper equipment performance and customer comfort.

External static pressure. The pressure drop external to the furnace (air handler). The external static pressure includes the pressure drop across the A/C coil, any humidifier, any high-efficiency air filter, and the duct system. Most furnaces are certified at 0.5 inches of water column (WC) external static pressure. However, average systems operate at 0.75–1 inch WC.

an inside temperature of 80°F and 50% relative humidity. Each ton of air conditioning is nominally 12,000 Btu/h (this comes from the fact that it takes 12,000 Btu/h to melt a ton of ice over a 24-hour period). While an air conditioner may be called a 3-ton unit, it may not produce 36,000 Btu/h. There is a wide variety of actual capacities that are called 3 tons.

EER. The energy efficiency ratio is the efficiency of the air conditioner. It is capacity (in Btu/h) divided by the electrical input (in watts). EER changes with the inside and outside conditions, falling as the temperature difference between inside and outside increases. EER should not be confused with SEER.

tion, it will provide good comfort even when the weather is scorching hot.

“Customers want air conditioners that are oversized.” Customers depend on the expertise of contractors in selecting an air conditioner. Yet contractors generally size air conditioners at least 1/2 ton larger than necessary and often oversize them by 1 ton or more. Even the most conscientious contractor is driven to avoid callbacks (or even lawsuits). If the air conditioning system isn't working properly (duct leaks, improper flow across the coils, improper charge), an oversized air conditioner can mask the problem. Unfortunately, many customers think that bigger is better, so in a competitive situation, the contractor who proposes a properly sized unit may lose the bid. Contractors are hesitant to adopt an unfamiliar method of sizing when the methods they have developed over the years have served them well—“I've done it this way for 30 years and I've never had a complaint.” It is no surprise, then, that air conditioners are oversized. However, the advantages of a properly sized air conditioner are so large that these barriers need to be overcome. Customers pay a price for oversized air conditioners and, in many climates, lose comfort as well.

“The new air conditioners with two-speed compressors, variable-speed blowers, and ECM motors will eliminate humidity and air flow problems. On top of that, they use less power and the customer can use a constant fan.” Multispeed units step down to a lower capacity so that they run longer. This helps with moisture removal. The variable-speed blowers can also be controlled to lower air flow when the humidity is high—a feature that helps to remove moisture. However, there are real limits on what these machines can do. Even under the most favorable moisture removal conditions,

if the indoor humidity is to be held at 50%, the latent load cannot exceed 25% of the total cooling load. When these electrically commutated motors (ECM) are faced with restrictive ducts, filters, and other paraphernalia, they are controlled to spin faster and work harder in an attempt to maintain the air flow. To do this, they increase their power draw. When the work gets too hard—above 0.8 inches of water column (IWC)—they give up and may burn out. The watt draw of a standard permanent split capacitor (PSC) motor doesn't change much in relation to changing air flow, while the watt draw of the ECM increases sharply as it



This technician is taking the final readings for a third-party verification of a high-quality installation.

attempts to maintain air flow (see Figure 4, p. 49).

It is important to realize that the efficiency gains of two-speed machines occur primarily on low speed. When the temperature is very hot, two-speed machines may not be better (and may sometimes be worse) than single-speed 13-SEER or higher machines. This occurs when the two-speed machines run on their less efficient high speed (see Figure 5). It is imperative that a two-speed air conditioner runs on its low speed almost all of the time. Duct losses and poor installation can cause these units to run on high speed more

than they should, robbing customers of the high efficiency they paid for.

Ways Contractors Can Control Moisture

The primary actions to control moisture in homes in moist or wet climates are as follows:

- Reduce air leakage into the house through the building shell.
- Provide controlled and adequate ventilation through mechanical means.
- Eliminate duct leaks to and from outside. Duct leaks cause moist air to be drawn in from outside.

- Reduce internal moisture sources as much as possible. Use vent fans in areas where moisture is generated, such as bathrooms and kitchens.

- Reduce heat gains to the return ducts by placing them within the building envelope or (if you have to put them in the attic) by reducing their surface area and insulating them well.

- Use the smallest air conditioner that will meet *Manual J* estimated loads.

- Reduce the cooling blower speed to 300–350 CFM per ton.

The secondary actions to control moisture in homes in moist or wet climates are:

- Precondition (dehumidify) the ventilation air by using an energy recovery ventilator or a dehumidifier on the incoming air.

- Add a dehumidifier.

Recommendations for Customers

There are many contractors who would like to do the job right. “I love to do houses but only if we can do them properly. I try to work inexpensively, but not cheaply.” (One contractor's response in a Florida Solar Energy Center survey).

If you are purchasing air conditioning equipment, here is what you should do:

- Give the contractor the Recommendations for Contractors listed below and insist that the contractor follow those recommendations.
- If the contractor wants to size by floor area, find another contractor.
- Insist on a copy of the calculations (or computer inputs and outputs)—even if you don't understand them.
- Be willing to pay for the time the contractor must spend to do the job right. Don't take the lowest bid.

Recommendations for Contractors

To offer your customers the most energy-efficient and problem-free air conditioner, observe the following:

Sizing

- Calculate the sensible and latent loads for each installation using ACCA *Manual J* or equivalent.
- Use design outdoor conditions and daily temperature range exactly for your exact location per *Manual J* or *ASHRAE Handbook of Fundamentals*. If this isn't possible, use the data for the closest location with a similar climate.
- Use standard 75°F design indoor temperature.
- Pay great attention to window type, material, and interior shading. An error in this area can throw off the window heat gain estimate by as much as 100%.
- Always account for the effect of the overhang shading. This is one of the most efficient load reduction measures.
- Calculate infiltration rate depending on the airtightness of the building, based on blower door measurements. While you are at it, measure the duct leakage and fix it when the air conditioner is installed.
- Calculate the latent load based on the number of people in the building and the outdoor air humidity ratio. Do not use a "typical" multiplier (neither

1.3 nor any other) to calculate the total load from the sensible load.

- Calculate ventilation load (latent and sensible) when mechanical ventilation is used.
- Select equipment based on the manufacturer's detailed performance data. Do not rely on the nominal tonnage at 95°F outside.

Coil Matching

Correctly match the indoor evaporator coil to the outdoor coil for the system, according to the manufacturer's specifications or Air Conditioning and Refrigeration Institute (ARI) standards.

Brazing, Leak Testing, and Evacuation

- Purge refrigerant lines and indoor coil with inert gas during brazing, to prevent oxidation.
- Prior to start-up, evacuate systems to 500 microns or less.
- Isolate the system from the vacuum pump and let sit for at least five minutes. The micron gauge should not raise more than 300 microns above the initial vacuum level.

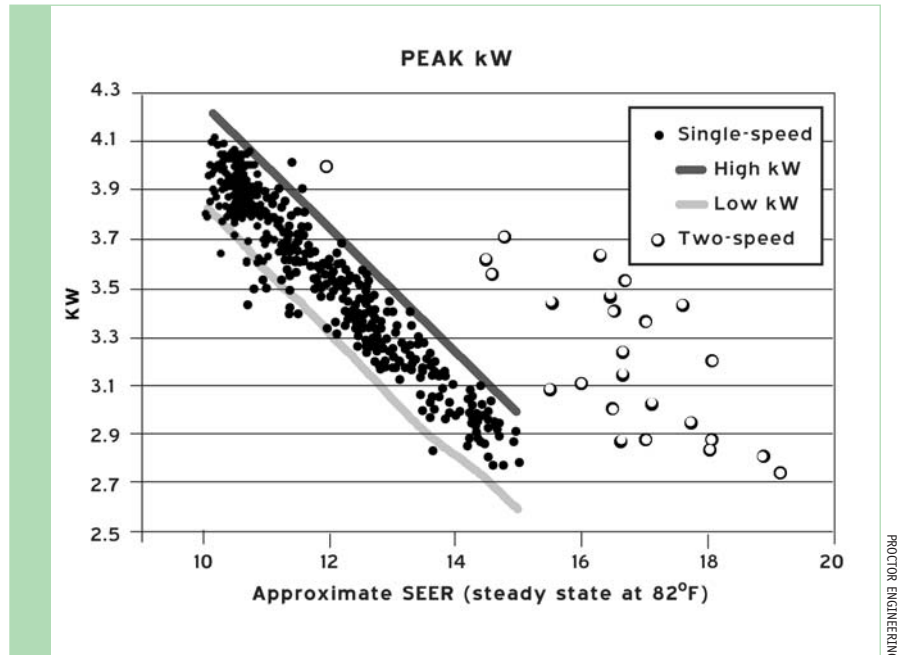


Figure 5. At peak conditions (in this case a load of 26,000 Btu/hr at 82°F outside temperature), two-speed machines may not be better (and are sometimes worse) than single-speed SEER 13+ machines. At high temperatures, two-speed machines run on their less efficient high speed.

Air Flow

- Measure air flow using the pressure-matching method, the flow grid method, or a method with equivalent accuracy.
- Verify that air flow is at least 350 CFM per ton in dry climates and at least 300 CFM per ton in moist or wet climates, when measured through a wet coil (unless the manufacturer specifies a lower air flow for the local design conditions). Air flow must meet these criteria before refrigerant charge tests.

Refrigerant Charge

Verify refrigerant charge using the superheat method or subcooling method. When weather conditions make this impossible, the charge may be weighed in. The charge adjustment must be calculated based on the differences between the standard coil and the installed coil, and between the standard lineset and the installed lineset.

John Proctor, P.E. is president of Proctor Engineering Group, Ltd., in San Rafael, California. He is a frequent contributor to Home Energy magazine.