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If Bigger Is Not Better, What Is?

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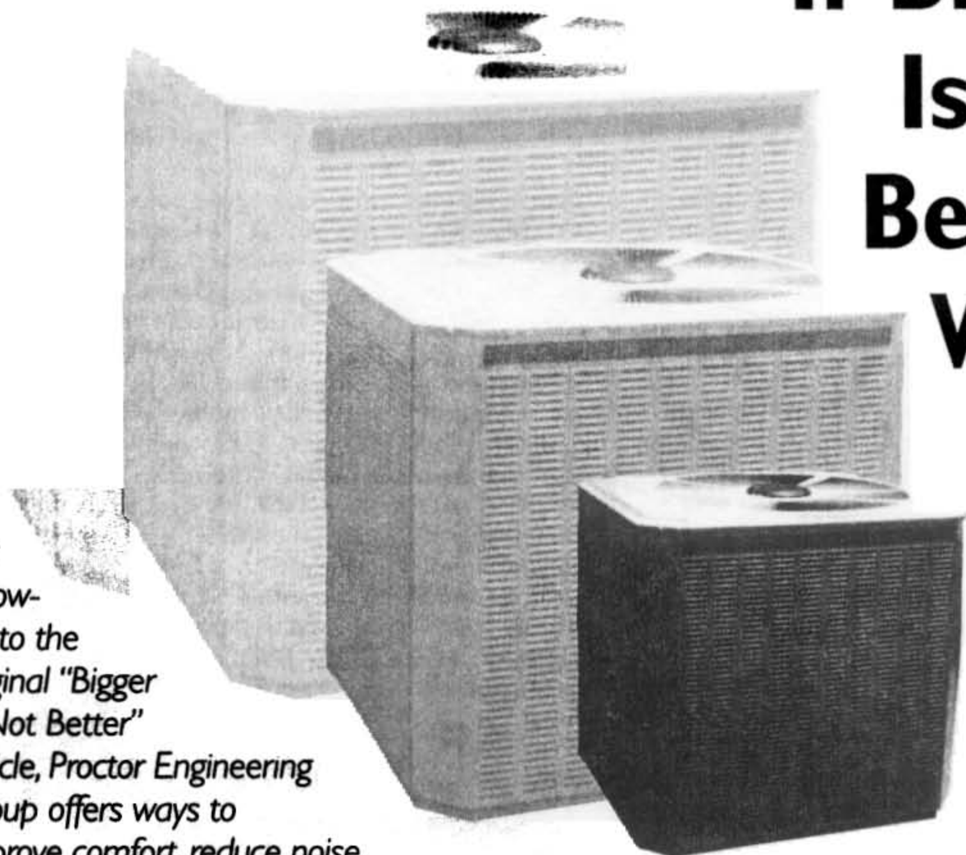
Sizing Air Conditioners:

If Bigger Is Not Better, What Is?



In this follow-up to the original "Bigger Is Not Better" article, Proctor Engineering Group offers ways to improve comfort, reduce noise, and increase efficiency when installing home air conditioners.

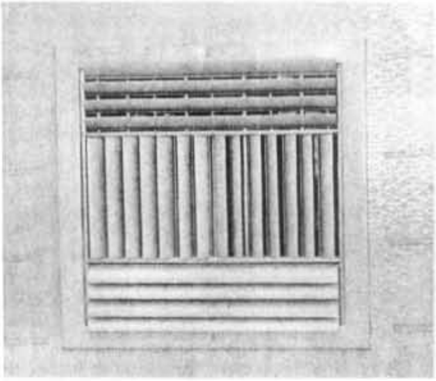
by John Proctor and Peggy Albright

Since the publication of "Bigger Is Not Better—Sizing Air Conditioners Properly" (*HE* May/June '95, p. 19), homeowners, builders, and contractors have questioned us about sizing and performance issues raised in that article. The purpose of this sequel is to answer frequently asked questions, explain the characteristics of a good air conditioning system, and describe how to get the most comfort and efficiency from a residential system.

Bigger Still Is Not Better

Let's review why bigger is not better. Since optimum efficiency is achieved when systems run continuously, it is important that an air conditioner be sized to achieve the longest run times possible. Standard sizing calculations are based on a design temperature that is exceeded only 73 hours in a normal cooling season. An air conditioner sized to run continuously at design conditions will cost less initially and will have a lower operating cost.

Air Conditioning Contractors of America (ACCA) has published design manuals (*Manuals J, S, D,* and *T*) that produce far better results than the rough-and-tumble rules of thumb used by the vast majority of HVAC contractors. A contractor will achieve (and the customer will enjoy) a much higher-quality job if these manuals are followed



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Equipment sizing is not the only key to comfort—small details in register placement and design can have a great impact on air flow and overall comfort. For example, the louvers of this air-conditioning register are designed to spread air in four directions.

in the design and installation of central air conditioning systems. A recent investigation of new houses has shown that an air conditioner delivering a capacity equal to *Manual J* would be adequate even during extraordinarily hot summers (see "How Big Is Big Enough?").

The main problems typically found in the field are improperly sized air conditioners, improperly designed duct systems, poor grille selection, and poor installation of all three components. These problems are most easily avoided in new construction, but retrofit contractors can and should follow the recommendations in this article whenever feasible.

The Disadvantages of Oversizing

In recent years Proctor Engineering Group has investigated air conditioner comfort, efficiency, and economy in a range of locations. One interview, with a homeowner in Palm Springs, California, brought out several issues that we have found repeatedly. This house was a moderate sized older home with beautiful overhangs shading the east and west windows. I was invited to sit at the kitchen table to talk with the owner, a man in his early 60s. He complained that his cooling bills were high and he was never comfortable during the cooling season (which extends over most of the year in Palm Springs).

As we talked the air conditioner came on and a strong stream of cold air moved by my shoulder. The owner went over to the supply register and closed the damper. He came back to the table explaining that with the register open he was blasted with cold air that made him uncomfortable. The noise coming from the closed register made it hard to have a conversation at the table. He stated that the system was always noisy. When I suggested that we move to another room for our conversation, he said, "That wouldn't make any difference, there are only hot places and cold places; no place is right in this house. We are looking for a new house."

The situation we found in this house exists, in various degrees, in millions of homes across the United States. The heating and cooling distribution system was not matched to the cooling loads of the individual rooms or to the needs of the occupants. On top of that, the air conditioner was not matched to the distribution system. Discomfort and expense are the inevitable results.

Bigger Is Not Better—Comfort Is Better

In 1923, in an effort to pinpoint the indoor environment conditions that make people comfortable, F.C. Houghten and C.P. Yaglou conducted studies to determine how people feel under varying temperature and humidity conditions. The result of this research was the identification of a "comfort zone" based on temperature and humidity. The modern version of this comfort zone is shown in Table 1. Tolerance to heat is

Table 1. Summer Comfort Zone.

Relative Humidity	Maximum Comfortable Temperature	Minimum Comfortable Temperature
60%	78.5°F	72.5°F
50%	79°F	73°F
40%	79.5°F	73.5°F
30%	80°F	74°F

affected by the amount of humidity in the air—at higher temperatures, the humidity level must be held lower to ensure comfort.

The comfort zone was found to be acceptable to 90% of test subjects drawn from a range of age groups and genders, with work and life-styles involving varying levels of activity and clothing. An air conditioning system that establishes and maintains indoor conditions within this zone will provide thermal comfort. It will produce a neutral sensation—occupants will feel neither too hot nor too cold.

An air conditioner can easily bring the temperature inside a house into the comfort range. In fact, bigger air conditioners virtually ensure that the temperature at the thermostat can be as cold as we set it. Unfortunately, cold alone is not comfortable. In fact, it is distinctly uncomfortable. To maintain a general level of comfort, the moisture level must also be controlled. This is best achieved by smaller, not larger, air conditioners.

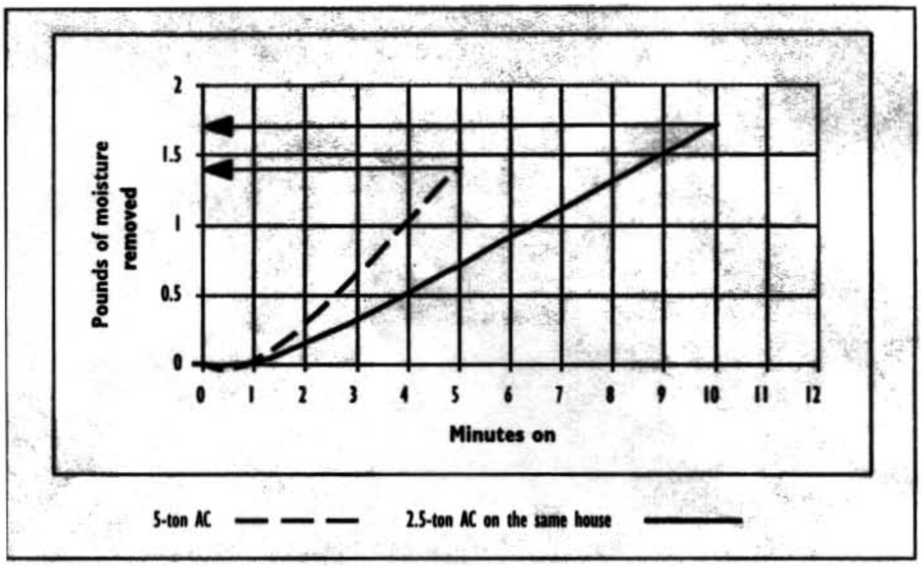


Figure 1. Smaller air conditioners remove more moisture from a house. In this example, a 5-ton unit running for five minutes removes 1.4 pounds of water. A 2.5-ton air conditioner in the same house, running for ten minutes, removes 1.7 pounds of moisture—an increase in moisture removal of 21%.

Recommendations

- Wherever possible, reduce the cooling load of the house. Overhangs above east and west windows are particularly effective in reducing cooling load.
- Perform *Manual J* for all installations, and select equipment using *Manual S.*
- Ensure that the system installed never exceeds the capacity of the equipment suggested by *Manual S.*
- Size duct systems based on *Manual D.* If in doubt, size upward.
- Determine the grille location and characteristics using *Manual T.*
- Confirm proper evacuation of the line set and indoor coil with a micron gauge.
- Confirm proper charge using the manufacturer's suggested method.
- Confirm proper air flow by test. The flow can be determined from the coil pressure drop when pressure/flow data are available from the coil manufacturer. Or it can be determined with a duct test rig or flow hood.
- Increase the duct insulation to at least R-8 (especially on long runs in the attic).
- Confirm that the duct leakage is less than 3% of coil air flow for a new system and less than 6% of coil air flow for an existing system.

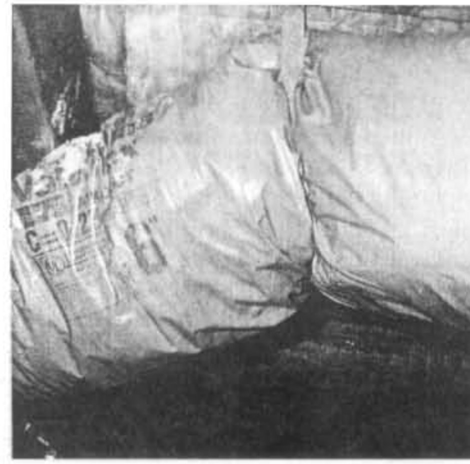
proper implementation of ACCA procedures. These problems can be further reduced by ensuring that the assumptions built into the manuals are not violated. For example, it is assumed that there is no duct leakage in the system. Any longtime reader of *Home Energy* will immediately note that this assumption is violated in nearly all homes (including new ones). Proper installation of the duct system and leakage testing are essential to obtain comfort.

Another assumption is that the conduction losses are the same percentage of the delivered cooling regardless of the length of the duct run. This would be an insignificant assumption in a heavily insulated system (R-4 is not heavily insulated). Long duct runs through the attic lose over 15% of their cooling capacity before the conditioned air reaches its destination. Long duct runs need additional insulation to deliver the proper amount of cooling to the distant rooms.

Drafts Destroy Comfort

A draft exists when unwanted air movement causes cooling on one part of a person's body. The colder the air and the faster it is blowing, the more offensive drafts are. Air conditioning drafts are characterized by cold, high-velocity air striking the body. Studies show that these drafts are even more offensive if they are intermittent.

An oversized air conditioner is a major contributor to drafts, because it is almost always married to a duct system that is too small. The ducts are unable to deliver the amount of air necessary for proper air conditioner performance (more on this later). The result is a poor compromise—air flow that is too low for the air conditioner and too high for the duct system. The "low" air flow across the oversized coil produces colder delivery temperatures, and the "high" air flow through the ducts and grilles produce high pressures, noise, and high velocities at the grilles. The grilles themselves are often too small and without proper throw or spread (particularly the cheapest ones). When low delivery temperatures are coupled with high-velocity discharge through inappropriate and poorly placed grilles, occupants experience drafts.



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The constriction of this duct has the unfortunate result of reducing the air flow across the cooling coil.

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Water and air are being evacuated from the lines and indoor coils of this air conditioner. This process, which is often overlooked or avoided by installers, can assure that units are properly charged, and also provides an opportunity to check for leaks.

Bigger Is Not Better—Quiet Is Better

We all know how noisy forced-air cooling systems can be. The noises can come from the grilles, the ducts, and the air handler fan. Our perception of noise is affected by both the frequency and the level of the sound. Higher-frequency sounds (such as those generated by high discharge velocities at grilles) are more offensive than low-frequency sounds (such as those generated by the fan). For grilles there is a Noise Criteria (NC) rating that mimics the human perception of sound. The NC for a particular grille increases as more air is forced through it.

When an air conditioner and duct system are properly sized to meet the cooling load, they can easily distribute the cool air without being noisy. To design a quiet system, keep every supply grille below NC-25 with a face velocity below 700 feet per minute.

Grilles with dampers are invariably noisier than equivalent grilles without dampers. When the dampers are partially closed, the pressures and leaks in the ducts increase and the air flow across the coil is reduced. Occupants generally close dampers to redirect air to another room that needs more delivery. If the system is

How Big Is Big Enough?

An air conditioner sized to ACCA *Manuals J* and *S* is big enough. Industry specialists who design and sell air conditioners have long used *Manual J* as a standard method for determining the amount of cooling needed to deliver thermal comfort to single-family residences. The procedure is used to calculate room-by-room loads for duct design purposes and whole-house loads for equipment selection. It was jointly developed by ACCA and the Air-Conditioning and Refrigeration Institute (ARI), and is based on a number of sources, including the *ASHRAE Handbook of Fundamentals*.

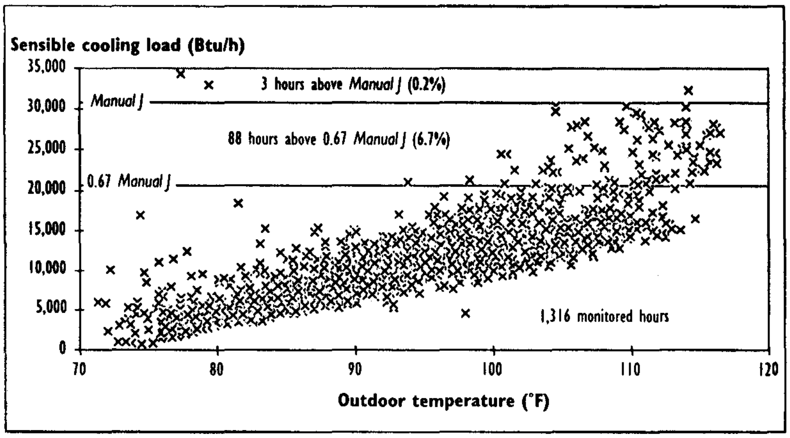


Figure 2. Hourly sensible cooling load versus outdoor temperature monitored for a house in Phoenix, Arizona during an extraordinarily hot summer. *Manual J* overestimated the sensible cooling load for this house by at least 50%. Even during this hot summer, an air conditioner sized to two-thirds of *Manual J* would have been more appropriate.

Despite the widespread use of this procedure, many contractors have been reluctant to believe that *Manual J* can deliver adequate cooling under design conditions. One reason for this reluctance has been the lack of information about how actual cooling loads compare to *Manual J* estimates. Many who have used *Manual J* extensively have long suspected that it has an oversizing margin. Until recently, however, no field studies had been performed to verify this anecdotal evidence.

New data show that *Manual J* indeed overestimates the sensible cooling load in hot, dry climates. It is likely that the same holds true in hot, moist climates. Proctor Engineering Group, the Electric Power Research Institute, Nevada Power, and Arizona Public Service monitored air conditioning systems installed in new homes in Phoenix, Arizona, and Las Vegas, Nevada. By testing the actual cooling capacity required to maintain comfort under severe conditions, these tests have yielded the first measurements that confirm and quantify the overestimation by *Manual J*.

The studies showed that even during an extraordinarily hot summer, when almost 200 hours exceeded design conditions (design conditions are exceeded only 73 hours in a typical summer), the actual sensible cooling loads of the houses were less than *Manual J* estimates.

At the most intensively monitored sites in the studies, we recorded air flow, temperature drop, and moisture removed from the conditioned air. The research team calculated the actual capacity delivered by the air conditioner for every air conditioner cycle.

The systems were monitored from July 30 through September 25, 1995. Occupants were free to adjust their thermostat settings to any value, but most kept a constant thermostat setting. Most of the systems monitored were typical installations (including leaky ducts, which increased the cooling load that the equipment needed to deliver).

Figure 2 shows the hourly sensible cooling load and the outdoor temperature in one typical house. The duct system had a 12% return leak and a 6% supply leak. Outdoor temperatures at this house ranged as high as 116°F (according to ASHRAE *Fundamentals*, the mean extreme temperature for Phoenix is 112.8°F). Even though this time period was extraordinarily hot, the sensible load requirements for all but 3 (0.2%) of the 1,316 monitored hours were less than the *Manual J* estimated cooling load. *Manual J* overpredicted the design load for this house by almost 50%.

There was no need to oversize the air conditioner beyond the *Manual J* cooling load because *Manual J* already overestimated that load. The air conditioner installed in this house had a design sensible capacity 24% larger than *Manual J*—excess capacity that was not useful. The homeowners paid approximately $330 in additional first costs, and they will pay unnecessary additional operating costs every summer month for the life of the system.

designed correctly, neither register dampers nor inline balancing dampers should be needed.

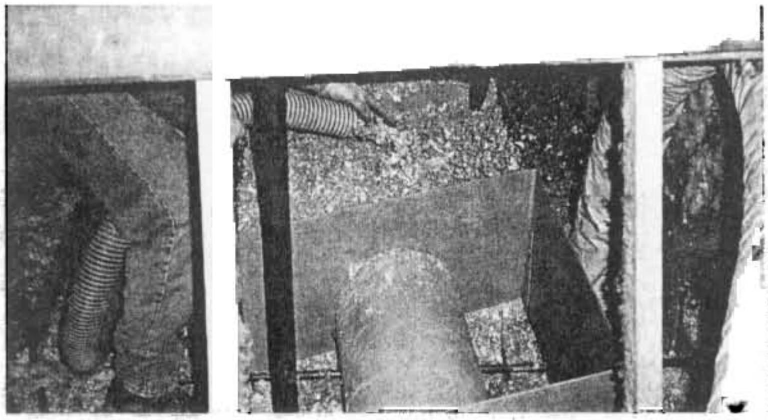
Bigger Is Not Better—Efficient Is Better

There is a lot of emphasis on the rated efficiency of air conditioners. Unfortunately, this necessary attention to equipment design has overshadowed efforts to improve the selection and installation of the entire air conditioning system. Builders, contractors, and the buying public all incorrectly assume that if they spend the money on a high-efficiency air conditioner, they have gotten all the efficiency they can. But common problems such as oversizing, improper installation, low air flow, and leaky duct systems mean that customers don't get the efficiency they paid a premium for.

Correct Air Flow Helps Make an Efficient System

Most air conditioners are designed to have 400 CFM per ton of air flow across the inside coil. When the air conditioner is coupled with a duct system that meets *Manual D* criteria, the proper flow is achieved. However, since air conditioners are commonly oversized for the heat gain of the home and the duct systems are not designed to *Manual D*, even new systems are usually deficient in air flow. This situation only gets worse as the inside coil picks up dirt.

In a recent laboratory test of a high-efficiency air conditioner, Proctor Engineering Group found a 7% drop in efficiency when the air flow was reduced by 30%. In order to ensure that the design air flow is being achieved, the installing contractor must measure and correct the air flow across the inside coil.



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These cardboard frames are specifically designed for insulating over ducts. The walls of the boxes allow weatherizers to build up a deeper layer of insulation around long duct runs.

Proper Charge Helps Make an Efficient System

A new split system air conditioner comes from the factory with the proper amount of factory-installed charge for a standard length of refrigerant lines. When the unit is installed, the contractor needs to evacuate the lines and indoor coil and weigh in any additional charge needed if the installed lines are longer. Evacuation also allows the installer to check for leaks. Most of the time, evacuation is not done. As a result, air and moisture are captured in the line set and coil, the unit ends up undercharged, and leaks are not detected. In many cases the amount of undercharge is severe.

In the summer of 1995, Proctor Engineering Group and Arizona Public Service Company monitored a group of 22 newly constructed homes. Nearly all of those homes had undercharged air conditioners. One of the worst units had 62% of the correct charge (and 79% of proper flow). The homeowner complained to the builder that the air conditioner was not working right. She was told that the wrong amount of insulation had been installed in her attic, and an insulation contractor was called in to apply additional insulation. Shortly thereafter, the true problem showed itself when the air conditioner compressor failed.

Eliminating Duct Leaks Helps Make an Efficient System

The evidence against leaky and underinsulated ducts continues to mount. Leaky ducts are a large contributor to system inefficiency that gets worse when it's hotter outside. The Arizona Public Service Company test found that sealing a 13% supply leak saved 22% of the cooling energy consumption when outdoor temperatures were between 100°F and 105°F.

To ensure a tight duct system, the installing contractor must test duct integrity using specialized tools (see *HE* Sept/Oct '93 for more information on duct testing).

A Smaller Air Conditioner Helps Make an Efficient System

Air conditioners are very inefficient when they first start operation. It is far better for the air conditioner to run long cycles than short ones, because efficiency increases the longer it runs. For example, increasing the run time from five minutes to nine minutes resulted in an energy savings of 10% for the unit described in "Bigger Is Not Better" (*HE* May/June '95).

Because of the inefficiencies associated with the start-up of the air conditioner, a smaller unit will produce the same amount of cooling with lower energy consumption, under most conditions.

It is not uncommon for poor cooling performance to be attributed to insufficient equipment size, when in fact there is more than enough cooling capacity. We know designers who determine the system air flow based on floor area (this oversizes the air conditioner in energy-efficient homes), and then try to squeeze down the size of the duct system so that it can be installed in the house. They explain that they can't use a higher insulation level on the ducts because there is no room, and, when faced with poor performance, increase the size of the air conditioner.

Most household air conditioning problems will be eliminated when the capacity of the air conditioner is reduced to ACCA *Manual J* and *Manual S* standards; an appropriately designed, insulated, and leakproof distribution system is used; and the system is installed to meet the manufacturer's standards.

Resources

F.C. Houghten and C.P. Yaglou: ASHVE Research Report No. 673, "Determination of the Comfort Zone," ASHVE *Transactions*, Vol. 29, 1923, p. 361.

Manual J, D, S, and *T.* Available from Air Conditioning Contractors of America, 1712 New Hampshire Ave., NW, Washington, DC 20009. Tel: (202)483-9370.

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