In Air Conditioning, If Bigger Is Not Better, What Is?

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Since the publication of **Bigger is Not Better - Sizing Air Conditioners Properly** in the May/June 1995 issue of Home Energy, homeowners, builders, and contractors have corresponded with the magazine and with Proctor Engineering Group discussing sizing and performance issues raised in that article. Many readers have asked "What if" questions pertaining to their own air conditioning systems.

A number of quality contractors have used reprints of the article to explain to their customers the advantages of a properly designed system. Yet over sizing is a way of life in the marketplace. The purpose of this sequel is to answer frequently asked questions, to explain the characteristics of a good air conditioning system, and to describe how you can get the most comfort and efficiency from your residential system.

Bigger is Not Better Summary

Since optimum efficiency is achieved at continuous running, it is important that the 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 due to its longer run times.

Primary Recommendations:

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

The primary problems in the field include 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 situations will also benefit from following the recommendations in this article whenever they can be applied.

The Disadvantages of Improperly Sized Equipment

In recent years Proctor Engineering Group has investigated air conditioner comfort, efficiency, and economy in a wide range of locations. One interview with a home owner in Palm Springs, California summarizes a number of 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 got up, 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. I asked him about that problem and he responded 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 nor 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 of these mismatches.

Bigger is not Better, Comfort is Better

In 1923, in 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. As you know, your tolerance to heat is 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 that are 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 insure that the temperature at the thermostat can be as cold as you 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 and moisture control is best achieved by smaller, not larger, air conditioners.

Smaller Units Remove More Moisture

An air conditioners ability to remove moisture increases when the equipment runs for longer periods of time. At the beginning of every cycle in hot moist climates, the air conditioner puts moisture into the house as water is evaporated off the inside coil. Since a smaller air conditioner runs longer to keep the house at the temperature set point, it removes more moisture than a larger unit would be able to achieve.

A 5-ton unit X, running for five minutes would remove 1.4 pounds of water. A 2.5-ton air conditioner, in the same house, running for ten minutes would remove 1.7 pounds of moisture. This is an increase in moisture removal of 21%.

The amount of moisture removed is not only a function of how long the air conditioner runs, but also its Sensible Heat Ratio (SHR - the percentage of the total capacity delivered as lower house temperature).

A low Sensible Heat Ratio will result in more moisture removal. For hot wet climates where moisture removal is important, air flow across the coil should be reduced slightly to increase the SHR and the air conditioner condensing unit and indoor coil combination should be chosen to have a low SHR. Please note, if you don't use the outdoor unit manufacturer's indoor coil, you cannot use their published SHR.

Typical matched units from major manufacturers have Sensible Heat Ratios in the 68% to 80% range when it is 95¡F outside and 75¡F with 50% relative humidity inside. Even Temperatures are Necessary for Comfort Our homeowner in Palm Springs didn't have a problem with moisture, but he did have a problem with uneven temperatures. When the air conditioner was on, portions of his home and even different parts of individual rooms were at significantly different temperatures. Stagnation of air in one part of a room (one corner, at head level, etc.) makes people uncomfortable. Proper mixing of the air and proper distribution to individual rooms avoids this problem.

The following describes two methods designers can use when attempting to get proper distribution and mixing of the air.

An old method is to use a large air handler fan to circulate air all or most of the time. This is sometimes effective in mixing the air but at a high price. There is an old rule of thumb that between four and six house volumes of air must pass through the air handler in an hour. At six air changes this means a 1400 sf. home would have to have a continuously running fan that delivers 1120 CFM (equivalent to almost 3 tons) regardless of the cooling load of the house. The common practice is to install an air conditioner (inside and outside unit) with the capacity to meet those flow requirements.

- There are many disadvantages to this scenario:
- the need for a larger and more expensive duct system to handle the increased flow
- increased duct conduction due to constant circulation and the larger surface area of duct system
- reduced latent capacity due to constant circulation and short compressor cycles (caused by the oversized outdoor unit)
- increased cooling load due to duct leakage effects and fan energy delivered as heat

A better solution is, to design and install a delivery system that properly distributes the cooling to each room, then to select and place supply grilles that promote mixing by "throwing" the delivered air into the right places in the room. Air Conditioning Contractors of America has produced manuals to guide contractors in this process (Manual D-Duct Design and Manual T-Terminal Design).These Manuals lead the installing contractor through the process of selecting the proper size duct and type of register based on the location of the register, size of the room, restriction the duct run, and the dimensions and heat gain of the room. Unfortunately, only the best contractors and builders ever pay attention to these critical details.

The problems of stagnation and overheating can be reduced by proper implementation of ACCA procedures. These problems can be further reduced by ensuring that the assumptions built into these manuals are not violated. For example, it is assumed that there is no duct leakage in the system. Any long time 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 (and R-4 is not heavily insulated). Long duct runs through the attic loose 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.

Uneven temperatures have become more common due to the "modern" practice of severely reducing overhangs above the windows. Without overhangs, rooms with west facing windows will overheat in the afternoon since their need for cooling can easily double Drafts Destroy Comfort

A draft exists when unwanted air movement causes cooling on one part of your 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 your body. Studies show that these drafts are even more offensive if they are intermittent.

Oversized air conditioners are a major contributor to drafts. An oversized air conditioner is almost always married to a duct system that is 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 oversize 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. When low delivery temperatures are coupled with high velocity discharge through inappropriately selected (small and without proper throw or spread - often the cheapest) and poorly placed grilles, occupants experience drafts.

Bigger is not Better, Quiet is Better

We all know how noisy forced air cooling systems can be. These noises can come from the grilles, the ducts, and from the fan. Our perception of noise is affected by both the frequency and the level of the sound. Higher frequency sounds (the sounds generated by high discharge velocities at grilles) are more offensive than lower frequency sounds (the sounds 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 is sized to meet the cooling load it is easier distribute the cool air without being noisy. When a duct system is being designed, the NC level and face velocity of every supply grille should be considered and held below NC-25 and 700 fpm for a quiet system.

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 they believe needs more delivery. If the system is designed correctly dampers, either at the register or in line balancing dampers should not 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 emphasis on equipment design has overshadowed efforts to improve the selection and installation of the entire air conditioning system. It is incorrectly assumed by builders, contractors, and the buying public that if you spend the money on a high efficiency air conditioner you have gotten all the efficiency you can. But common problems such as over sizing, improper installation, low air flow, and leaky duct systems mean that customers don't get the efficiency they paid a premium for.

A System with 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 the air flow across the inside coil.

An Air Conditioner with 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 set 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 for the line set length increase over the standard length. Most of the time this is not done. This results in, leaks not being detected, air and moisture being captured in the line set and coil, and the unit ends up undercharged. 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 twenty two newly constructed homes.

Nearly all of those homes had undercharged air conditioners. One of the worst units had 62% of 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 under insulated ducts continues to mount. Leaky ducts are a large contributor to system inefficiency and the negative effect increases with outdoor temperature. The Arizona Public Service Company test found that sealing a 13% supply leak saved 22% of the cooling energy consumption in the 100¡F to 105¡F temperature range.

To ensure a tight duct system the installing contractor will have to do a test of duct integrity using specialized tools. (See the Sept/Oct Î93 issue of Home Energy for more information on duct testing.)

A Smaller Air Conditioner helps make an inefficient system efficient when they first start operation. It is far better for the air conditioner to run longer cycles than shorter ones. The efficiency of the typical air conditioner increases the longer it runs. For example, increasing the run time from 5 minutes to 9 minutes resulted in a savings of 10% for the unit described in "Bigger is not Better" HE May/June 1995.

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

Bigger is not Better, But 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 the Air Conditioning Contractors of America (ACCA) and the Air-Conditioning and Refrigeration Institute (ARI) and it is based on a number of sources including the ASHRAE Handbook of Fundamentals.

Despite the widespread use of this procedure, many contractors have been reluctant to accept the ability of Manual J to 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. While many who have used Manual J extensively have long suspected it has an over sizing margin, field studies had not been performed to verify this anecdotal evidence.

New data show that Manual J overestimates the sensible cooling load in hot dry climates. It is likely that the same is true of the sensible load in hot moist climates. Proctor Engineering Group, 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 present in Manual J.

The studies showed that even when faced with 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, the data acquisition equipment 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 that increase the cooling load that the equipment needed to deliver). One typical house illustrates the overestimation contained in Manual J. System 26 had an 11.6% return leak and a 6% supply leak Figure 2 displays the hourly sensible cooling load against the outdoor temperature.

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 extra ordinarily hot, the sensible load requirements for all but 3 hours (0.2%) of the 1316 monitored hours the load was less than Manual J estimated cooling load. Manual J over predicted the design load for this house by almost 50%.

These data illustrate that there was no need to oversize the air conditioner beyond the Manual J cooling load because Manual J already overestimates that load.

In fact the air conditioner installed in this house had a design sensible capacity 24% larger than Manual J and that excess capacity was not useful. Because of the over sizing however, the homeowners paid approximately $330 in additional first costs and they will pay additional unnecessary operating costs every summer month for the life of the system.

Using Your Foot for Target Practice

We know designers who determine the system air flow based on floor area (this oversize's the air conditioner in energy efficient homes), 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. If the goal is comfort or efficiency, they are shooting themselves in the foot.

Summary

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. Usually, in a residential system, this situation is caused by poor design and installation that: reduce the capacity of the system by incorrect charge, low air flow, and duct leakage, cause noise, drafts, and uneven cooling by using an oversized air conditioner relative to the cooling load and undersized ducts relative to the oversized unit. 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 leak-proof distribution system is used, and the system is installed to meet the manufacturers standards These systems will have higher efficiencies because they will run longer cycles and will circulate air as needed a larger percentage of time. Properly designed and installed air conditioners are reliable and will deliver comfort to each room of the house for less cost.

Recommendations Summary List

- Where ever 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.
- Insure 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 upwards.

- 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 manufacturers suggested method.
- Confirm proper airflow by test. The flow can be determined from the coil pressure drop when pressure/flow data is available from the coil manufacturer or can be determined with a duct test rig or flow hood.
- Increase the duct insulation above R-4 (at least 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.

The report discussed in this article is available from Proctor Engineering Group, 818 Fifth Ave., Suite 208, San Rafael, CA 94901.

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