Bigger Is Not Better: Sizing Air Conditioners Properly

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Written by: John Proctor, Zinoviy Katsnelson, and Brad Wilson.

Article Sidebars

It is generally accepted that "the right way" to specify an air conditioning system is to calculate the loads and select a piece of equipment that will provide comfort to the customer in a wide variety of conditions. Unfortunately this is rarely practiced.

A colleague of ours (we will call him Bill) approached us at a conference seeking advice on selecting an air conditioner for his renovated home. Our recommendations included, "Be sure that the cooling load is calculated and that the air conditioner is sized to that load." When Bill attempted to follow these instructions, only one of the four contractors would submit a sizing calculation (two others just wanted to know how many square feet there were in the house).

Bill hired the contractor who did the calculation and installed a high-efficiency four-ton unit. Is this a success story? Not really. The contractor calculated a total cooling load of 37,580 BTUs per hour at 105 degrees F outside and 70 degrees F inside. While the cooling load he calculated could have been met by a three-and-a-half ton air conditioner, the contractor convinced Bill to buy a four-ton unit "because then you will always have plenty of cooling."

Bill's air conditioner short-cycles (runs for shorter periods of time than it should) even during the hottest weather and removes very little moisture from the air. What went wrong? Four things:

- The design temperature for the area is 97 degrees F. The contractor increased the outside design temperature by 8 degrees F.
- The recommended design indoor temperature is 75 degrees F. The indoor temperature was lowered by 5 degrees F. The temperature "fudges" increased the inside to outside differential by 59%.
- The contractor increased the calculated load by 20% as a safety factor.
- The equipment selected was a half-ton larger than the next highest available size to meet the load

he calculated.

A two-and-a-half ton air conditioner would have been perfect for Bill's house. Instead he paid more for an extra one-and-a-half tons of cooling. In addition to costing more to buy, Bill's air conditioner will use more energy than a properly sized system, raising his utility bills. It won't dehumidify the air as well as a smaller system would, and chances are that Bill will be less comfortable. The utility, which gave Bill a rebate for his purchase, will also lose, since the oversized unit aggravates summer peak-load requirements.

Selecting the Right Air Conditioner for the Job

Before one can design an efficient and effective air conditioning system, the load must first be calculated using established techniques. The Air Conditioning Contractors of America (ACCA) conducted an industry study of residential cooling load calculations and developed Manual J to estimate these loads (see "Calculating Loads with Manual J," p.22). Manual J was adopted by ACCA and the Air-Conditioning and Refrigeration Institute (ARI), and is the standard method of sizing loads for residences.

ACCA has also produced Manual S for selecting equipment and Manual D for duct design (revised in January 1995). Manual S provides a method to select air conditioners based on the estimated sensible and latent load calculated for the particular house in the local climate.

If mistakes are made in the load calculations or the sizing method is flawed or incorrect inputs are used, the equipment will be incorrectly sized and will not perform as it should. Field studies have shown that most equipment is substantially oversized compared to Manual J specifications. In the Model Energy Communities Project, Pacific Gas and Electric Company (PG&E) found that 53% of the air conditioners checked were a ton (12,000 Btu/h) or more oversized and a study by Pacific Northwest Laboratories found a third of the air conditioners to be a ton or more oversized.

Because of the efficiency penalty of oversized air conditioners and because oversized air conditioners contribute substantially to utility demand peaks, in 1994, PG&E commissioned a study by Proctor Engineering Group to compare common load calculations and sizing methodologies to Manual J calculated values.

What is "Proper" AC Sizing?

Since optimum efficiency is achieved at continuous running, it is important that the air conditioner be sized to achieve the longest run times possible. Manual J specifies use of the 2.5% design temperature as developed by the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE).

For instance, a 2.5% summer design temperature of 100 degrees F for Fresno, California, means that the temperature generally only exceeds 100 degrees F for 73 hours in the season (0.025 x 2,928 hours in the months of June through September). A theoretical perfectly-sized air conditioner will run continuously during those 73 hours. During the rest of the time the air conditioner will cycle and operate at less than its potential efficiency.

A properly sized air conditioner should provide maximum value to the customer as well as a reasonable profit and further customer referrals for the contractor. If an air conditioner is cycling even at four in the afternoon on the hottest days, it is a sure sign it is oversized. Incidentally, if the air conditioner is running continuously on hot days, it doesn't necessarily mean that it is the right size. It is more likely that the system is oversized and has one of three big problems: leaky ducts, improper charge, or low air flow across the coil (see "An Ounce of Prevention; Residential Cooling Repairs," Home Energy Magazine May/June U91 p. 23). or PG&E Appliance Doctor Pilot Project - Summer 1990 Activity

Oversizing: Causes and Effects

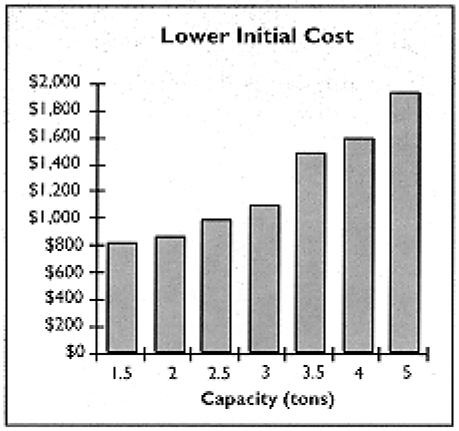

Figure 1. Initial air conditioner cost (quoted wholesale).

Customers depend on the expertise of contractors in selecting air conditioners. Yet contractors generally size air conditioners at least a half-ton larger than necessary and often oversize by a ton or more. Even the most conscientious contractor is driven to avoid call-backs (or even lawsuits). An oversized air conditioner can mask problems from duct leaks, improper flow across the coils, and improper charge.

Unfortunately, many customers think that "bigger is better," so in a competitive situation, the contractor proposing the proper size 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.

A properly sized air conditioner costs the customer less (see Figure 1). Bill's air conditioner cost him more money because it was too big. The contractor had the opportunity to discuss the value of the air conditioner based on the delivered efficiency and offer Bill equipment at a lower cost. He missed the opportunity.

Short Cycles

Air conditioners are very inefficient 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.

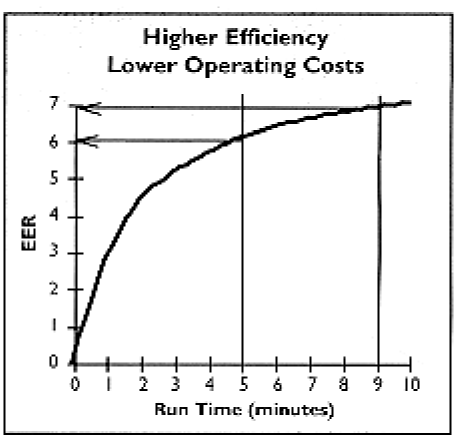

Figure 2 illustrates that if the on-time of an air conditioner is only 5 minutes the efficiency (EER) is 6.2. If a properly sized air conditioner half the size were used instead, the same amount of cooling would take place in about 9 minutes, and the efficiency would rise to 6.9. This represents a savings of 10% for the customer.

Most of the cooling season the cooling loads are well below the capacity of properly sized air conditioners, and for oversized units the short cycling is a substantial problem. Because of the short cycles, Bill's high-efficiency air conditioner is less efficient.

Moisture Buildup

The ability of the air conditioner to remove moisture (latent capacity) is lowest at the beginning of the air conditioner cycle. The moisture removed from the indoor air is dependent upon the indoor coil temperature being below the dew-point temperature of the air. The moisture then wets the indoor coil and, should the unit run long enough, will begin to flow off the coil and be removed out of the condensate drain.

For short cycles, the coil does not have time to operate at the low temperature and when the unit stops, the moisture on the coil evaporates back into the indoor air. Thus, in humid climates, a properly sized air conditioner will do a far better job of removing moisture from the air than oversized units. Bill's oversized air conditioner could not remove enough moisture from the air, so his house was cold and clammy.

Noisy Operation

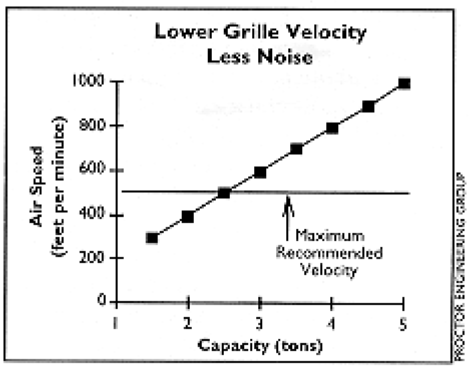

Figure 3. Air speed for a standard 2 ft x 2 ft return grille

The speed of the air blowing through the supply registers and the air being drawn into the return grille affects an air conditioner's performance. If the air speed is too high, it will be noisy and uncomfortable, and the return grille filter effectiveness will be reduced. The speed through the grilles depends on the size of the air conditioner (a larger unit has more air flow and higher air speed) and the area of the grille (a smaller grille causes higher air speed).

With a properly sized air conditioner, it is easier to have sufficient supply and return grille area to keep the air speed low and the noise at a minimum. Common complaints about oversized air conditioners are that they blast frigid air and that they are noisy. A properly sized air conditioner, with proper ductwork and grilles, will provide longer cycles, more consistent temperatures, and better mixing of the house air. ACCA Manual D specifies a maximum return grille velocity of less than 500 ft per minute and a maximum supply outlet of less than 700 ft per minute.

Figure 3 shows that for a standard 2' x 2' return grille, the 500 ft per minute requirement is exceeded with all units over 2 and one-half tons, with the resulting increase in noise.

Sizing Up the Sizing Calculations

To qualify for PG&E's air conditioner rebates in 1994, contractors were required to submit their load calculation methods, and they had to submit the actual calculations for each job. We compared over 40 different load calculation methods submitted by manufacturers, distributors, and contractors to Manual J. Manual J was used as a baseline because it is the most widely accepted load calculation methodology and is generally recognized as providing a safe estimate of cooling load. (Some experts believe Manual J consistently overestimates the load by about 20%, as a built-in "safety" factor.)

In the second part of the study, Proctor Engineering Group compared four different equipment selection methods to determine how close the selected equipment capacity came to the calculated load. The capacity of an air conditioner is dependent not only on the outdoor conditions, but also on the actual indoor conditions (temperature and humidity). Proctor Engineering Group developed a procedure for estimating the expected indoor humidity at design conditions. By knowing both indoor and outdoor conditions, the capacity of the selected air conditioner was determined. For both parts of the study, loads were calculated for buildings of different age and construction in two different climate zones.

Most Contractors Oversize

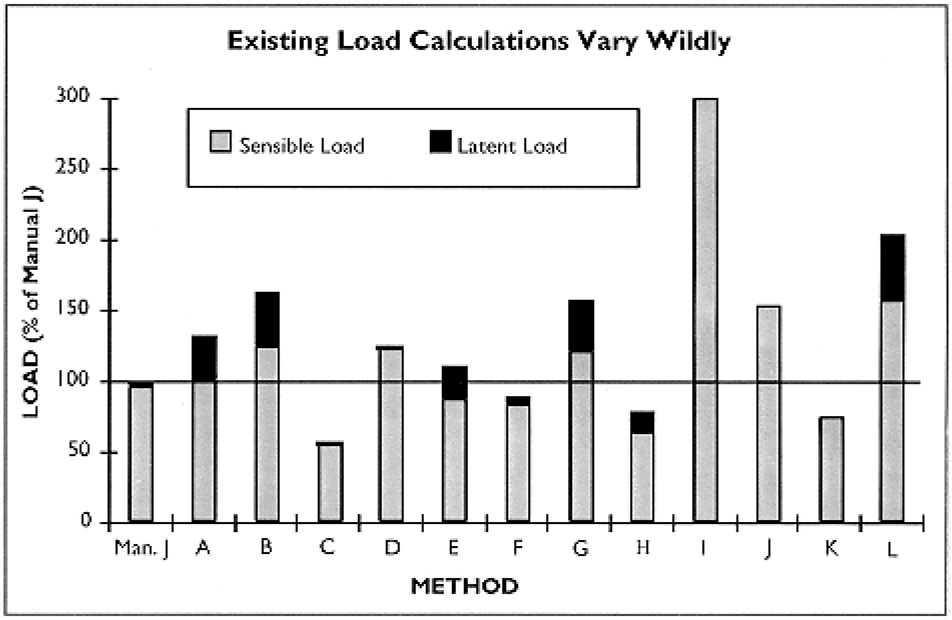

Figure 4. Examples of submitted load calculation results

The submitted calculations were all over the place (see Figure 4). In the extreme, the calculated load was three times the Manual J calculated load.

Of the 40 load calculations that were submitted, we approved those that yielded building loads within 20% of Manual J as received. This group included four worksheets, one calculator method, and five computer programs. The approval process was interactive and led to many stimulating conversations. David, a contractor for over 20 years, shared some of the "seat of the pants" methods he had observed through the years.

One method was to "buy the distributor's overstock," another was to "install the rejected unit from a previous job," and still another was to "install the unit sitting in the truck or at the shop." David referred to these methods as "sizing by cost."

Contractors submitted methods that they sincerely believed would properly size air conditioners. Some of the methods, however, were based on information from as long ago as 40 years. These methods did not take into account the latest efficiency developments in building insulation, windows, and air tightness.

The methods were often handed down from the person who taught them the business. "I learned this from my father and it has always worked." Since the contractors had received few or no complaints of inadequate cooling, they considered their methods sufficient. Unfortunately, they were significantly oversizing units; particularly on newer more energy-efficient homes. In an effort to properly determine cooling load, some contractors had spent good money on computer programs, had developed their own methods from books in the library, or borrowed from other contractors in the area. Proctor Engineering and PG&E worked with these contractors to find ways to bring their methods within 20% of Manual J. With changes, an additional ten methods were approved. This second group included seven worksheets, one calculator method, and two computer programs.

Altogether, 50% of the submitted methods were approved for use in PG&E's service territory. Methods that will calculate loads within 20% of Manual J will vary with the climate because of the way latent loads are treated. Of the approved computer methods, RHVAC from Elite Software was the most user friendly. Right-J from Wright Associates faithfully followed ACCA Manual J. A number of the methods did not calculate the latent load of the home.

Many assumed that the latent load was 30% of the sensible load. The actual latent load is highly dependent on the air tightness of the home, the local climate, and the interior moisture sources (such as people). For hot, dry climates, the latent load will be far less than 30%, particularly if the house has a large amount of air leakage from the attic. For humid climates, the latent load can be higher than 30% of the sensible load if the house has a significant amount of air leakage. In all cases, infiltration loads (air leakage) were not specifically addressed or were calculated by an oversimplified procedure. Contractors often assumed that infiltration rates were the same in all buildings or only depended on floor area. With the widespread use of blower door testing, we now know that homes vary significantly in their leakage rate.

With the amount of data required to do an accurate load calculation, the possibility of errors is increased. Even the computerized methods of load calculation were seriously lacking in error checking procedures that could catch operator errors. For example, window areas can exceed wall areas, or wall areas facing north can be one square foot with a south wall of 300 square feet and east and west walls of 200 square feet. Many of the methods also oversimplified the process and gave insufficient options for climate, building assemblies (windows, doors, walls, etc.), and shading.

Don't Duck the Duct Factor

The effect of duct leakage has only recently been investigated to any significant extent. As a result, cooling loads due to duct leakage are not included in any of the methods. Duct leakage has three effects on design cooling load. First, a supply leak is a direct loss in capacity. Second, a return leak will often bring in superheated attic air. Third, the difference between supply leakage and return leakage will cause increased infiltration. While it is tempting to treat duct leakage as additional infiltration, the effect is actually more complex.

How should the loss due to duct leakage be taken into consideration when an air conditioner is sized? The answer of course is simple. Don't take duct leakage into account - fix the leaksdegrees

Sizing by the Square Foot

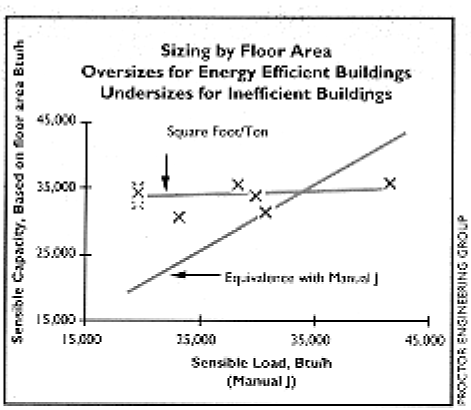

Figure 5. Sizing by house floor area.

The "square-foot-per-ton" sizing method avoids calculating the cooling load of the building and proceeds directly from the square footage of the building to the size of the air conditioner. No contractor submitted such a method for approval but a number of contractors reported that they often used this method, or knew others who did. In a study by the Florida Solar Energy Center, 25% of the contractors reported that they size by floor area (see "How They Size Air Conditioning Systems in Florida," above).

While this approach is rapid and simple, it does not account for orientation of the walls and windows, the difference in surface area between a one-story and a two-story home of the same floor area, the differences in insulation and air leakage between different buildings, the number of occupants, and many other factors. In some cases contractors attempt to cover these variables by categorizing the home as low (a new home in a moderate climate), average, or high (an old home in a hot climate) but this method also falls short of properly sizing air conditioners.

Figure 5 was produced with those types of categorizations.

Selecting Equipment with Manual S

Manual J (or other methods) gives a contractor both the sensible and latent design loads for the house. A common, but wrong, practice is to divide the total cooling load by 12,000 Btu/h per ton and choose an air conditioner with that nominal tonnage. Nominal tonnage does not indicate capacity under differing design conditions.

Manual S provides a process for selecting equipment that will meet the sensible and latent loads at Manual J design conditions. Its primary strength is that it guides the user to select an air conditioner that has a sensible capacity between 100% and 115% of the calculated sensible load. This is a major improvement over a number of other methods. The two main weaknesses of Manual S are that it dictates using 50% (or 55%) indoor relative humidity and it sets no upper limit for latent capacity. In dry climates the infiltrating air carries less moisture into the house, the indoor relative humidity is lower, and the latent load is lower. With less moisture in the house air, the air conditioner runs at a higher sensible capacity.

Table 1: Manual S Oversizes in Hot, Dry Climates

	Wet (Florida)	Dry (Nebraska)	Very Dry (California)
Sensible load at design	22,220 Btu/h	22,220 Btu/h	22,220 Btu/h
Sensible capacity of selected air conditioner at design	24,002 Btu/h	24,002 Btu/h	24,002 Btu/h
Design oversize	8%	8%	8%
Actual indoor relative humidity in a design day (75°F inside)	50%	35%	31%
Actual sensible capacity of selected air conditioner in a design day	24,002 Btu/h	27,916 Btu/h	28,874 Btu/h
Actual sensible oversize (latent capacity meets latent load in all cases)	8%	26%	30%

As shown in Table 1, Manual S could result in the selection of the same equipment in both humid and dry localities, with very different results. Both Manual J and Manual S are methods that "safely" oversize air conditioners. In dry climates, Manual S will oversize even more. If these two methods are applied there is absolutely no reason to build in additional safety factors when selecting air conditioning equipment.

Problems with Manufacturer's Data

Air conditioners selected based on standard indoor conditions of 80 degrees F with 50% relative humidity (which is the standard ARI capacity rating condition) will be incorrectly sized for 75 degrees F. Unfortunately, many of the major manufacturers provide information only at 80degreesF. It would be a great improvement if the manufacturers provided tables that presented the sensible and latent capacities at 75 degrees F for a variety of indoor humidities.

John Proctor is president and Zinoviy Katsnelson is a senior research engineer with Proctor Engineering Group. Brad Wilson is a senior program development manager at Pacific Gas and Electric Company in San Francisco, California.

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See The Sidebars to this Article

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