by John Proctor, Zinoviy Katsnelson, and Brad Wilson

SIZING AIR CONDITIONERS

WILLIAM HOPKINS

Bigger is not better, so calculate carefully and choose a unit that matches the load

A colleague of ours (we'll call him Bill) once asked our advice on choosing an air conditioner for his newly renovated home. One of our recommendations was "Be sure that the cooling load is calculated and that the air conditioner is sized for that load."

That advice proved easier to give than to follow. Only one of the four hvac contractors Bill talked to would submit a sizing calculation (two others just wanted to know the home's square footage). So Bill hired the contractor who did the calculation, and installed a high-efficiency four-ton unit. The local utility gave Bill a rebate for buying efficient equipment.

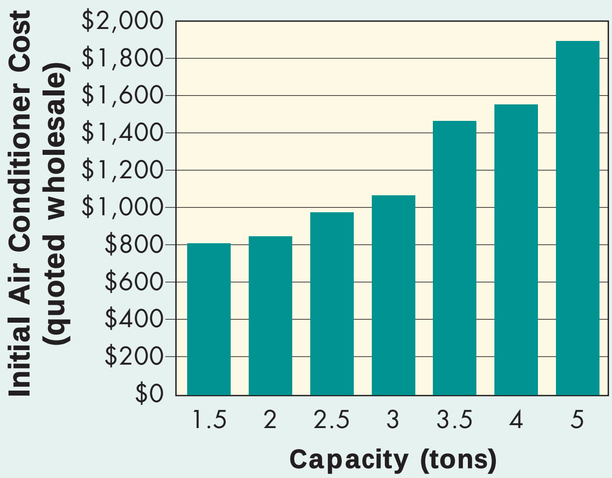
Unfortunately, this is not really a success story. Bill's new air conditioner is much too large for his house. Why did Bill get an oversized unit? Four things went wrong:

1. The design temperature for the area is 97°F. The contractor increased the outdoor design temperature by 8°F.
2. The recommended design indoor temperature is 75°F. The contractor lowered that figure by 5°F. (Added up, the temperature "fudges" increased the estimated inside-to-outside temperature difference by 59%.)
3. Next, the contractor added 20% to the calculated load as a safety factor.
4. Finally, while the cooling load he calculated was already too high and 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."

A two-and-a-half-ton air conditioner would have been perfect for Bill's house; instead, he paid extra for an additional one-and-a-half tons of cooling. Not only did it cost more to buy, Bill's air conditioner costs more to operate because it "short-cycles" — it turns on and off frequently, even during the hottest weather. And Bill's house is uncomfortable because the air conditioner removes very little moisture from the air. The utility also loses out, since the oversized unit helps to increase summer peak-load requirements.

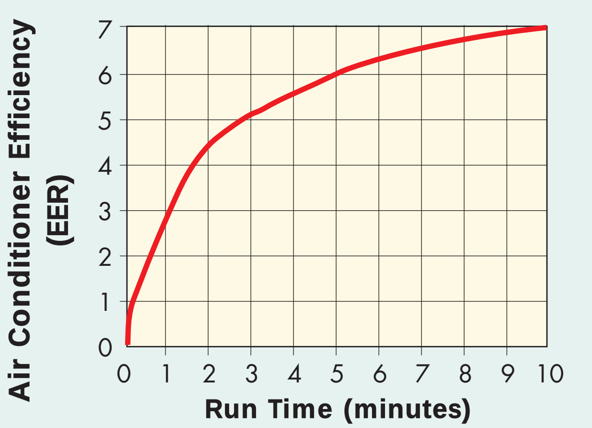
The Cost of Oversizing

A. Increased Initial Cost



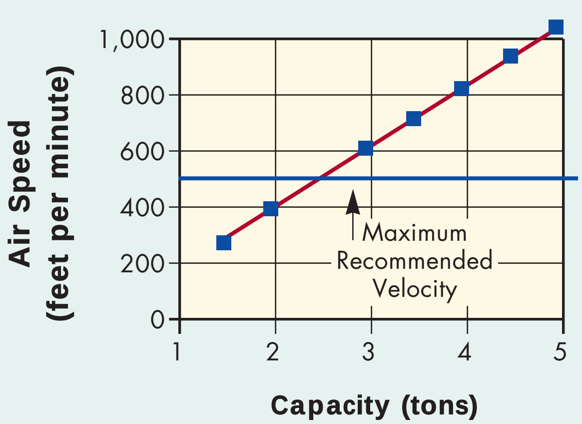
Oversized air conditioners cost customers hundreds of extra dollars up front.

B. Increased Operating Cost



Oversized units cost more to operate: A system that runs for only five minutes at a time on the hottest days of the year is 10% less efficient than one that cycles on for nine minutes. On days when the cooling load is lighter, the energy penalty is even higher.

C. Increased Noise



Higher-capacity air conditioners create a higher air speed at return grilles, reducing filter effectiveness and creating excessive noise.

Most Contractors Oversize

Bill's story is a common one. Contractors generally size air conditioners at least a half-ton larger than necessary and often oversize by a ton or more. (A "ton" of cooling is equivalent to 12,000 Btu per hour — the amount of heat it takes to melt a ton of ice in an hour.)

It is no surprise that air conditioners are oversized. Even the most conscientious contractor wants to avoid callbacks (or even lawsuits). An oversized air conditioner can mask problems from duct leaks, improper flow across the coils, and improper charge (too much or too little coolant).

In addition, contractors are hesitant to adopt an unfamiliar method of sizing when the methods they have developed over the years have served them well. However, the advantages of a correctly sized air conditioner are so great that these barriers need to be overcome. Customers pay a price for oversized air conditioners (see chart A at left), and in many climates, lose comfort as well.

Oversizing Penalties

Unfortunately, many customers think that "bigger is better," so in a competitive situation, the contractor proposing the properly sized unit may lose the bid. Why is bigger not better? There are three main penalties for oversizing air conditioners: short cycling, moisture buildup, and noisy operation.

Short cycles. Air conditioners are very inefficient when they first start operation, and the efficiency of the typical air conditioner increases the longer it runs. So it is far better for an air conditioner to run for longer cycles than for shorter ones.

For example, if the on-time of an air conditioner is only 5 minutes, the efficiency (EER) is 6.2 (see chart B at left). With a properly sized air conditioner (about half the size), 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 electric ratepayer. For most of the cooling season, the cooling loads are well below the capacity even of properly sized air conditioners. Oversized units never work at full capacity, even on the hottest days, and the short cycling is a substantial problem.

Moisture buildup. The ability of the air conditioner to remove moisture (its "latent capacity") is lowest at the beginning of the cycle. To remove moisture from indoor air, the coil must be colder than the dew-point temperature of the air. The moisture then wets the coil and, if the unit runs long enough, will begin to flow off the coil and drain out of the condensate drain. But 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. So in humid climates, an oversized air conditioner does a poor job of removing moisture from the air.

Noisy operation. The speed of the air blowing through the supply registers and the speed of the air being drawn into the return grille affect an air conditioner's performance. If the air speed is too high, it will be noisy and uncomfortable, and the return grille filter's effectiveness will be reduced (see chart C at left).

The speed through the grilles depends on the size of the air conditioner (a larger unit has more airflow 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.

Alternatives to Manual J

While Manual J is simplified, it is still not simple. Because of the many values and tables, it is easy to make mistakes when using it. To reduce the chance of error, it is wise to use either a set of tables specific to the contractor's service area or a computer program.

Often, however, the result of using an alternative method is an oversized cooling system, as in the case of our colleague, Bill. Because oversized air conditioners are less efficient and increase utility demand peaks, Pacific Gas and Electric Company (PG&E) retained our firm, Proctor Engineering Group, to evaluate load calculation and sizing methods commonly used by contractors and to approve any methods that compared favorably with Manual J calculations.

To qualify for PG&E's air conditioner rebates in 1994, contractors had to submit their load calculation methods along with the actual calculations for each job. The submitted calculations were all over the place (in one extreme case, the calculated load was three times the Manual J value).

Altogether, we approved half of the submitted methods, either as-is or with modifications, for use in PG&E's service territory. Approved methods yield building loads within 20% of Manual J, and include eleven worksheets, two calculator methods, and seven computer programs. Of the approved computer methods, *RHVAC* from Elite Software (P.O. Box 1194, Bryan, TX 77806; 800/648-9523) was the most user-friendly. *Right-J* from Wrightsoft Corp. (394 Lowell St., Suite 12, Lexington, MA 02173; 800/225-8697) faithfully followed Manual J.

Check for error. With the amount of data required to do an accurate load calculation, the possibility of errors is increased. Many computerized methods of load calculation don't have checking procedures to catch operator errors. For example, some computer programs allow input window areas to exceed wall areas. To guard against such mistakes, we recommend that contractors check all numbers for consistency. For example, in typical construction, total area of exterior walls facing north or east is usually equal to the total area of the opposite south or west walls; ceiling area per story is usually equal to the building footprint area; window area is usually from 10% to 25% of the floor area; and total wall area is always bigger than the window area.

— J.P.

How to Size Right

Oversized air conditioners commonly draw the complaints that they are noisy and blast frigid air. A properly sized air conditioner, with proper ductwork and grilles, will provide longer cycles, more consistent temperatures, and better mixing of the house air.

The most important factor in sizing an air conditioner is the load calculation. The standard method for calculating residential cooling loads is Manual J. It was jointly developed (along with Manual D for designing ductwork, and manual S for choosing equipment), by the ACCA and the Air-Conditioning and Refrigeration Institute (ARI).

Manual J procedures are based on a number of sources, including an industry study of residential load calculations and the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) *Handbook of Fundamentals*.

Because it is the result of a process that involved a large part of the hvac industry, Manual J is widely accepted. In fact, it is the basis for many of the other commonly used methods, including many of the computer programs.

To calculate cooling loads, Manual J evaluates heat gain using wall and roof square footage, and a Heat Transfer Multiplier (HTM). The HTM takes into account construction, R-values, orientation, shading, solar gain, thermal storage, temperature difference, daily temperature swing, and roof color.

Manual J is a simplified adaptation of more complex modeling. Its assumptions are realistic but conservative — the hvac contractors who participated in writing the manual made sure to build in a safety margin that prevents systems from being undersized. In addition, Manual S, the guide to selecting equipment, makes assumptions about dehumidification needs that exaggerate the load in dry parts of the country (see table).

Adding any further fudge factors, or using more simplified rules of thumb, would turn these built-in safety margins into an excessive and costly oversizing. So to make the best use of Manual J, stick to its methods strictly, particularly in two main areas: design temperature and latent load.

Design Temperature

Since an air conditioner reaches peak efficiency when running continuously, it is important to size units to achieve the longest run times possible.

Manual J specifies use of the 2.5% design temperature as developed by ASHRAE. For instance, a 2.5% summer design temperature of 100°F for Fresno, Calif., means that the temperature generally only exceeds 100°F for 73 hours in the season (0.025 x 2,928 hours in the months of June through September). A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Air leakage and heat loss from ducts add to the load on an air conditioner. Sealing and insulating the ducts allows you to select a smaller unit.

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. If an air conditioner is cycling at four o'clock in the afternoon on the hottest days, it is a sure sign it is oversized.

Cooling and Dehumidification

Air conditioners both cool and dehumidify the air. Both processes consume energy, so both have to be considered when sizing a system: The equipment must have the capacity to handle both the *sensible* and *latent* loads.

The *sensible load* is the heat gain of the home due to conduction, solar radiation, infiltration, appliances, people, and pets. Burning a light bulb, for example, adds only sensible load to the house.

The *latent cooling load* is the load created by moisture in the air, whether that moisture is brought in by humid outdoor air infiltrating the home, or added by an indoor moisture source such as people, plants, cooking, and so on.

A number of the sizing methods submitted by contractors in our study did not calculate the latent load of the home at all. Many assumed that the latent load was 30% of the sensible load, but the actual latent load depends on the airtightness of the home, the local climate, and the interior moisture sources.

Our recommendation is to use Manual J to calculate both the sensible load and the latent load, with the latter based on the number of people and the outdoor air humidity ratio. 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.

Manual S Oversizes in Hot, Dry Climates

Manual S assumes a 50% relative humidity when allowing for latent loads (dehumidification needs). In dry climates, where less capacity is needed to remove moisture, more energy will be available for sensible cooling, so equipment chosen using Manual S will be oversized without additional "fudge factors."

	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	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	8%	26%	30%

Duct Leakage

Manual J does not account for the common problem of leaky ductwork, which can cause even an oversized air conditioner to run continuously on hot days, wasting electricity.

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.

For sizing purposes, it is tempting to treat duct leakage as additional infiltration. But because the complex effect of duct leakage has only recently been investigated to any significant extent, Manual J does not include duct leakage in the cooling load calculation, and neither should you. Instead, prevent the leaks (or fix them in existing systems).

The existing duct leakage in homes consumes some (but usually not all) of the safety margin built into Manual J. If duct leakage were brought under control, units could be sized smaller than Manual J recommends.

Infiltration. One shortcoming of Manual J is that it estimates a building's infiltration rate based on floor area and three levels of construction tightness: Best, Average, or Poor. Whenever possible, however, we recommend calculating the infiltration rate based on blower-door measurements. This is far more accurate. ■

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