SIZING Air Conditioners

It is "common knowledge" that downsizing air conditioners makes them more efficient and reduces peak load. But does it?

BY JOHN PROCTOR, P.E.

Air conditioning is the cause of electric utility peak. Reducing that peak is a high priority for society, since producing and distributing peak electricity is the least effective use of limited resources.

It is "common knowledge" that downsizing air conditioners makes them more efficient and reduces peak. If that common knowledge is true, and if the improvements are sufficiently large, then it appears obvious that downsizing should be investigated for every new air conditioner installed (see "Bigger Is Not Better: Sizing Air Conditioners Properly," *HE* May/June '95, p. 19). But common knowledge doesn't always stand up to testing over time.

Questioning Assumptions

For energy efficiency:

- What is worse, an oversize house or an oversized air conditioner?
- What is worse, the unrepresentative SEER test or an oversized air conditioner?
- What is worse, a restrictive duct system or an oversized air conditioner?
- What is worse, an under-insulated ceiling or an oversized air conditioner?

The answer in every case, heretical though it may seem, is that the oversized air conditioner is the smaller problem. In fact, it may be no problem at all. Traditionally, oversized air conditioners are considered responsible for significant excessive energy consumption. Changes in the design of air conditioners, along with new research, call the traditional beliefs into question.

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Energy Savings from Downsizing

Some authors have reported that the energy savings from downsizing 33% (eliminating a 50% oversize is reducing the size of the unit by 33%) is between 9% (James et al., 1997) and 11% (McLain and Goldenberg, 1984). The James study was based on a multivariate regression analysis of 15-minute submetered data from 308 homes built between 1990 and 1993. The McLain paper is based on a simulation model. A study with more-robust modeling predicted an 8% savings from a 33% downsizing (Henderson, 1992).

Recent studies have shown less energy savings. One study used monitored pre/post data from four houses where the existing air conditioners were replaced by units sized to ACCA *Manual J8* (Sonne, Parker, and Shirey, 2006). The average reduction in size was 31%. The rated efficiencies of the units were similar (the average new unit rated slightly higher than the old unit). The results of this test were mixed:

House L had the unit downsized by 28%. This house had an energy savings estimated between 8% and 13%. The change in rated SEER at this house implied a 3% savings from the change in rating. The resultant additional 7.5% savings could be attributed to the downsizing. The James regression (James et al., 1997) would imply a savings of about 7.7%. This is good agreement with the James regression.

House M had the unit downsized by 34%. This house had an energy consumption increase estimated between 8% and 18%. This is substantially greater than implied by the change in SEER, which translates to an increase of 2%. The James regression would imply an energy savings of 9%.

House J had the unit downsized by 30% with no change in rated SEER. This house had an energy consumption increase between 0% and 16%. The James regression would imply an energy savings of 8%.

House N had the unit downsized 32%. The change-out at this house occurred late in the season, so the data are slim. A comparison using the limited data indicates that the energy consumption was higher with the smaller post change-out unit.

There are components of this test that may mitigate the results. The largest is that the existing duct system and air handlers remained in place. This means that the duct systems were relatively oversized for the new smaller units, and the permanent split capacitor (PSC) motors were also oversized for the needed air flow. PSC motors have the undesirable attribute of drawing almost full power even when they are on their lowest speed tap. Oversized duct systems in the attic with the smaller units' longer run times result in more duct conduction losses in the attic.

Traditionally, oversized air conditioners are considered responsible for significant excessive energy consumption. Changes in the design of air conditioners, along with new research, call the traditional beliefs into question.

Three studies used an interactive model with ASHRAE Standard 152-type duct losses and intensive A/C inputs based on measured in situ data verified by the monitored data at the sites (Blasnik et al.,1995; Blasnik et al.,1996; Proctor et al., 1997). The 1995 study used monitored data from 28 new (circa 1995) A/C systems in Las Vegas. That study showed potential energy savings of 2% to 4% from 23% downsizing (from average 1.49 x *Manual J7* to 1.15 x *Manual J7*). The model was further upgraded with additional in situ data for the 1996 study, which added 37 new Las Vegas systems to the monitoring. The 1996 study showed a reduced 1% savings from the same downsizing. The 1997 study addressed new homes in the Northeast. A stratified random sample of 51 homes yielded a 1% to 2% savings estimate for downsizing.

ARTI sponsored an analysis of seven air conditioners in new Arizona homes circa 1995. (Proctor and Pira, 2005). These units were intensively monitored cycle by cycle. The monitoring equipment recorded instantaneous sensible capacity at the end of the cycle and the cycle average sensible capacity for each cycle. Each datum (instantaneous and average) comes from the same unit, with identical condenser and evaporator air entering conditions. Analysis of these field data showed that the standard model for cycling behavior of air conditioners was a rather poor fit for five of the seven units. In addition, the field-monitored units showed an average cycle sensible capacity of 94.3% of steady-state capacity at six minutes, compared to laboratory tests that show an average sensible capacity of less than 80% for that length cycle. It was hypothesized that the additional early capacity was due to evaporation of water from the coil early in the cycle. When the standard model was tuned to the field data, the energy savings were estimated to be 4.6% for a sizing reduction of 31%.

One factor of importance with respect to the Sonne (direct change-out) study described above and the combination monitoring/modeling studies (Blasnik, Proctor, and ARTI) is that the duct systems and furnace blowers were not downsized with the air conditioners. The result is that while the duct surface area and insulation remained the same, the resident time of the cooled air in the ducts was longer due to lower air flow and longer run times. This effect substantially increases the conduction losses from the duct system. This effect for an attic system is about 6% at 95ºF ambient and about 10% at 115ºF. This effect appears sufficient to overwhelm any potential savings from increasing the run time of the air conditioner.

In an experimental study of two proven identical and unoccupied homes (Wilcox and Larsen, 2004), two successive changes were made. First the windows were changed in one home, resulting in a 29% reduction in air conditioner energy use. Subsequently the air conditioner, furnace, and indoor coil were downsized in the high-performance glass home from the original 3.5 tons to 2.5 tons, a reduction of 28%. In the summer after the A/C change-out, the relationship between the energy use (kWh) of the two air conditioners remained essentially the same. Over the season there was a 2% relative energy use increase with the downsized unit. As with the Sonne study, the duct system was not changed in the house with the downsized unit. The identical house experiment was conducted in Roseville, California.

All of the above studies concentrated on single-speed machines. A study of dual-speed air conditioners (Proctor and Cohn, 2006) concluded that "the two dual-stage units with fan-off at or near compressor off show little or no cycling degradation. The lack of degradation can be interpreted to indicate that there is little if any savings available for downsizing these dual-stage units. This is consistent with the long cycle times that minimize the startup

Table 1. Predicted Peak Reductions from Downsizing

	HOME 1	HOME 2	HOME 3	HOME 4
Sizing reduction (% of original size)	13%	23%	31%	37%
Diversified peak reduction	8%	10%	12%	14%

Source: Proctor and Pira (2005).

losses and minimize the effect of the fan only 'tail', which can provide a positive efficiency boost in dry climates. *Downsizing the dual-stage machines would cause them to run more in the lower efficiency high-speed mode.*" (emphasis added).

Coefficient of Degradation, SEER Ratings, and Tonnage

The coefficient of degradation (Cd), which is used in the DOE test procedure to estimate the effects of cycling, has been improving (smaller is better) since it was first produced as part of SEER. Looking at the change in Cd from the CEC 2002 database to the 2009 database, the median Cd has dropped from 0.08 to 0.07. Practitioners who use Cd estimate that the maximum savings available from downsizing is half of Cd. That translates to 3.5% for today's air conditioners.

Peak Reductions from Downsizing

The evidence supporting the hypothesis that downsizing is beneficial in reducing peak kW is more convincing than the evidence that downsizing saves kWh over a cooling season.

The James et al. (1997) study of 174 houses with A/C within 20% of *Manual J7* and 194 houses with A/C greater than 120% of *Manual J7* provides sufficient information to infer an average sizing increase for the 120%+ units of 22% to 28% compared to the <120% units. These homes (120%+) averaged about 13% (0.3 kW) greater electrical load for peak cooling between 4 and 5 pm.

As noted in the James study, the peak residential cooling load occurs when absent residents return home around 6 pm.

The ARTI (2005) study of new Arizona homes (circa 1995) predicted the average peak reductions shown in Table 1. The ARTI study noted that the diversified peak reductions come from reducing the capacity of air conditioners running continuously at peak, and this is practical on a lesser number of air conditioners for each increasing downsize category, since comfort issues will override other considerations.

The Roseville Experiment (Wilcox and Larsen, 2004) clipped the peak electric kW by 39% from a downsizing of 29% with no apparent change in comfort conditions for a house with a constant thermostat setting.

While it is often assumed that the peak reduction achieved by downsizing is proportional to the percentage reduction in tonnage, it is not. The assumption is correct only for homes where the oversized units are running continuously on peak. In actuality, most homes have units cycling on peak (Peterson and Proctor, 1998). As a result, the diversified peak reductions are substantially less than that predicted by the change in tonnage.

A New Conventional Wisdom?

Based on the facts, it seems that there are only very small energy savings available from downsizing air conditioners, but downsizing can produce sizable peak reductions.

When utilities have to select the programs for their energy efficiency portfolios, they have to take into account all the direction they have been given by the regulatory bodies. In many cases, California included, they have been given goals to reduce peak loads and save energy. At the same time, they are usually under cost-effectiveness constraints. In some cases the benefits are calculated based on kWh rather than on peak kW and kWh. Giving insufficient credit for reducing the cause of peak dooms the system to increasingly higher peaks.

The bottom line is: We cannot justify reducing the size of air conditioners by energy savings alone. We need to understand that air conditioners create costly peak power, and we can reduce peak by reducing the size of air conditioners.

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>> For more information:

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