92.086

Prepared by:
Proctor Engineering Group, Ltd.
San Rafael, CA 94901
(415) 451-2480

AC Sizing, Electrical Peak, and Energy Savings

White Paper

Final Report
June 2009

Primary Author
John Proctor, P.E.

Creators of CheckMe!®

EXECUTIVE SUMMARY

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 make them more efficient and reduce 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.

This paper examines existing data on whether downsizing is useful for energy savings and peak reductions.

We conclude 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 they are usually under cost effectiveness constraints. In some cases the benefits are calculated based on kWh rather than peak kW and kWh. Giving insufficient credit for reducing the cause of peak dooms the system to increasingly higher peaks.

The bottom line is: **Reducing the power draw of the air conditioners that cause electrical peak cannot be justified by energy savings. It is necessary for both the peak causal effect of air conditioners be understood and the high cost associated with that peak be fully valued.**

Table of Contents

List of Tables

List of Figures

WHAT IF AC SIZING DOESN'T MATTER?

> The paradigms on which society's perception of reality are based are highly conservative. People invest heavily in these ideas, and so are heavily resistant to changing them. They are only finally overturned by new ideas when new events occur which make the conventional wisdom appear so absurd as to be impalpable.
>
> The Affluent Society, John Kenneth Galbraith, 1969 (2nd ed)

This white paper examines conventional wisdom in the widely circulated article "Bigger is not Better" (BNB) and other documents. It addresses commonly held beliefs about the relationship between sizing and energy as well as sizing and peak electrical consumption. This paper does not address conventional wisdom concerning the relationship between dehumidification and sizing.

Energy Savings from Downsizing

> Bill's (oversized) air conditioner will use more energy than a properly sized system, raising his utility bills.
>
> BNB, *Home Energy Magazine*, John Proctor, May/June 1995

> 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.
>
> Ibid.

> Many small HVAC systems are significantly oversized, resulting in inefficient operation….
>
> "CEC Small HVAC System Design Guide", Pete Jacobs 2003

This is a widely held belief. However the direct evidence that it is true to the level normally assumed, is weak.

Some authors have reported that the energy savings from downsizing 33%[1] is between 9% (James et al. 1997) and 11% (McLain & 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).

---

[1] Eliminating a 50% oversize is reducing the size of the unit by 33%

Recent studies have shown less energy savings. A study that used monitored pre/post data from four houses where the existing air conditioners were replaced by units sized to ACCA Manual J8 (Sonne, Parker, & 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 result 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 that 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 airflow. PSC motors have the undesirable quality 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.

Three studies used an interactive model with ASHRAE Standard 152 type duct losses and intensive AC inputs based on measured in-situ data verified by the monitored data at the sites. ([EPRI] 1995, [EPRI] 1996, Proctor, Downey, and Peterson 1997) The 1995 EPRI study used monitored data from 28 new (circa 1995) air conditioning 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 EPRI study, which added 37 additional 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 (2005) sponsored an analysis of seven air conditioners in new Arizona homes (circa 1995). 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 that 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 6 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 (EPRI, Proctor, and ARTI) is that the duct systems and furnace blowers were not downsized with the air conditioners. The result is while the duct surface area and insulation remained the same, the resident time of the cooled air in the ducts was longer (lower airflow 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 the 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 AC changeout 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, CA.

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

Coefficient of Degradation

The coefficient of degradation, 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 .08 to .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.

SEER Ratings and Tonnage

> The Seasonal Energy Efficiency Rating (SEER) and Energy Efficiency Rating (EER) of air conditioners generally decrease by about 2 to 8% per ton as the cooling capacity increases.
>
> "Peak Demand and Energy Savings from Properly Sized and Matched Air Conditioners" Robert Mowris and Ean Jones 2008

The number of high SEER units listed in the ARI database drops as the tonnage increases. This may be due to the increased physical size of the high efficiency larger tonnage units making manufacture and shipping less desirable or because of lesser demand. However it should be noted that two single speed machines of equal SEER and EER are, as stated by the ratings, equal performers in test procedures.

Peak Reductions from Downsizing

> The utility, which gave Bill a rebate for his purchase, will also lose, since the oversized unit aggravates summer peak load requirements.
>
> BNB, *Home Energy Magazine*, John Proctor, May/June 1995

> The California investor-owned utility HVAC incentive programs do not currently offer incentives for downsizing air conditioners (PG&E 2006, SCE 2006, SDG&E 2006). Instead, the programs offer incentives based on dollars per unit or per ton with more money paid for larger units.
>
> "Peak Demand and Energy Savings from Properly Sized and Matched Air Conditioners" Robert Mowris and Ean Jones 2008

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 ACs within 20% of Manual J7 and 194 houses with units 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. On the local utility peak day the difference in air conditioning electric loads is shown in Figure 1.

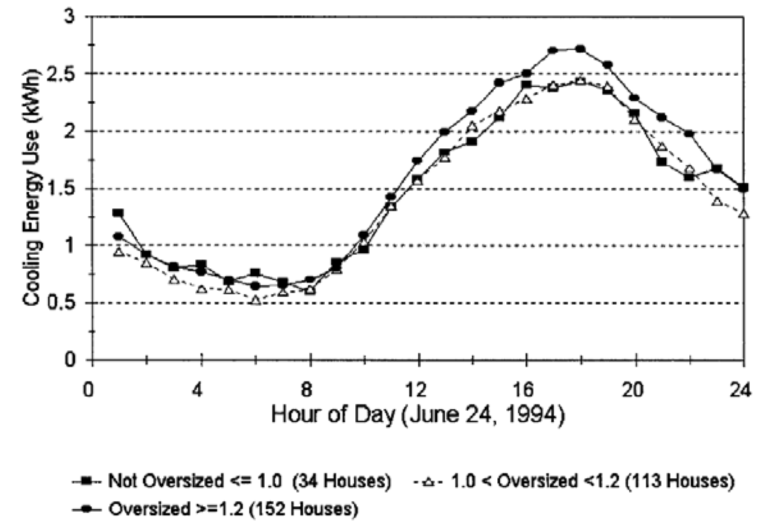


Figure 1. Florida Residential Peak Electrical Load

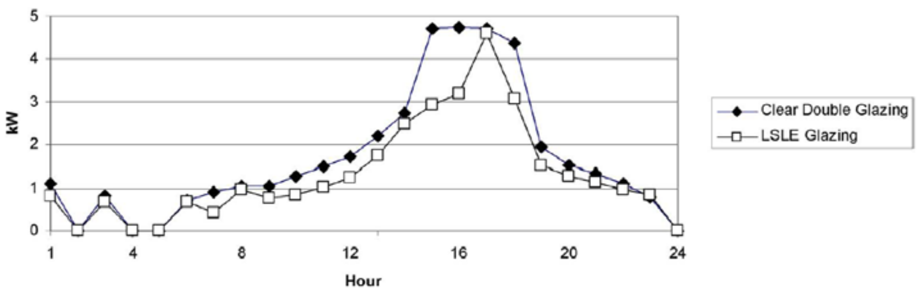
The ARTI (2005) study of new Arizona homes (circa 1995) predicted the average peak reductions shown in Table 1.

Table 1. Predicted Peak Reductions from Downsizing (ARTI 2005)

Sizing Reduction (% of original size)	13%	23%	31%	37%
Diversified Peak Reduction	8%	10%	12%	14%

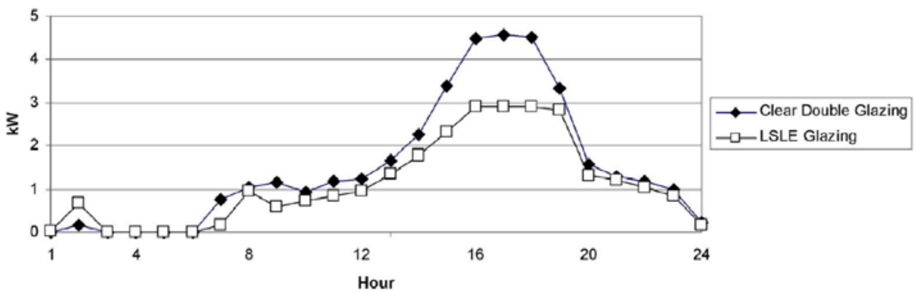
The ARTI study noted that the diversified peak reductions come from reducing the capacity of air conditioners running continuously at peak and this is practical on a lesser number of air conditioners for each increasing downsize category, since comfort issues will override.

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. Figures 2 and 3 show the reduced peak in the downsized house between the two years (2000 – Low Solar Heat Gain Low E Glazing with 3.5 ton AC and furnace air handler, 2001 – Low Solar Heat Gain Low E Glazing with 2.5 ton AC and furnace air handler).



Peak day cooling electricity consumption after glass change, September 19, 2000.

Figure 2 – Low Solar Low E vs. Clear Double Glazing 3.5 ton ACs



Peak day cooling electricity consumption after downsizing in the LSLE house, August 16, 2001.

Figure 3 – Low Solar Low E Glazing 2.5 Ton vs. Clear Double Glazing 3.5 ton

Diversified Peak Reduction is not the Same as Reduced Connected Load

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.

REFERENCES AND BIBLIOGRAPHY

[ARI. 1984]. ARI Standard 210/240-84, Unitary Air-Conditioning and Air-source Heat Pump Equipment. Air-Conditioning and Refrigeration Institute. Arlington, VA.

Blasnik, M., J.P. Proctor, T.D. Downey, J. Sundal, and G. Peterson. 1995a. Assessment of HVAC installations in new homes in Nevada Power Company's service territory. Research Project 3841-03, Final Report. Palo Alto: Electric Power Research Institute, Inc. TR-105309 and TR-15310.

Blasnik, M., Downey, T., Proctor, J. and Peterson, G. 1996, "Assessment of HVAC Installations in New Homes in APS Service Territory" Final Report Proctor Engineering Group, San Rafael, California.

Galbraith, J. 1969, *The Affluent Society* (2nd ed)

Henderson, H. 1992. "Dehumidification at Part Load." In *ASHRAE Transactions* Vol.98, Part 1, 370-380, 3579. Atlanta, GA. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Henderson, H. and Rengarajian, J. 1996. "A Model to Predict the Latent Capacity of Air Conditioners and Heat Pumps at Part-Load Conditions with Constant Fan Operation" In *ASHRAE Transactions* Vol.98, Part 2, 266-274, 3958. Atlanta, GA. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Jacobs, P. 2003. "CEC Small HVAC System Design Guide", California Energy Commission, Sacramento CA.

James, P., Cummings, JE., Sonne, J., Vieira, R. and Klongerbo, J. 1997, "The Effect of Residential Equipment Capacity on Energy Use, Demand and Run-Time", *ASHRAE Transactions* V. 103, Pt. 2., BN-97-2-4 (4082). American Society of Heating Refrigeration and Air-Conditioning Engineers. Atlanta, Georgia.

McLain, H. and Goldenberg, D. 1984. "Benefits of Replacing Residential Central Air Conditioning Systems" in *Proceedings of 1984 ACEEE Summer Study on Energy Efficiency in Buildings.* pp. E226-237. American Council for and Energy Efficient Economy. Washington, D. C.

92.086

Mowris, R. and Jones, E. 2008. “Peak Demand and Energy Savings from Properly Sized and Matched Air Conditioners” in *Proceedings of 2008 ACEEE Summer Study on Energy Efficiency in Buildings.* American Council for and Energy Efficient Economy. Washington, D. C.

Neal, L. and D. O’Neal 1994. “The Impact of Residential Air Conditioner Charging and Sizing on Peak Demand.” in *Proceedings from ACEEE 1994 Summer Study on Energy Efficiency in Buildings*, Vol. 2, pp. 189-200.

Neme, C., J. Proctor, and S. Nadel. 1999. Energy Savings Potential from Addressing Residential Air Conditioning and Heat Pump Installation Problems. American Council for an Energy Efficient Economy Report #A992, February.

Peterson, G. and J. Proctor. 1998. “Effects of Occupant Control, System Parameters, and Program Measures on Residential Air Conditioner Peak Loads.” In Proceedings from the ACEEE 1998 Summer Study on Energy Efficiency in Buildings, 1:253-264. Washington, D.C.: American Council for and Energy-Efficient Economy.

Proctor, J. 1995. “Bigger is not Better” *Home Energy Magazine*, May/June

Proctor, J. 1997. “Field Measurements of New Residential Air Conditioners in Phoenix, Arizona.” In ASHRAE Transactions, 1997, V. 103, Pt. 2. Atlanta, Georgia: American Society of Heating Refrigeration and Air-Conditioning Engineers

Proctor. J., T. Downey, M. Blasnik, and G. Peterson 1997. Residential new Construction Pilot in Nevada Power Company Service Territory. Electric Power Research Institute TR-108445. Final Report July 1997. Palo Alto, CA.

Proctor, J. and Pira, J. 2005 System Optimization of Residential Ventilation, Space Conditioning, and Thermal Distribution” Final Report. Prepared for the Air-Conditioning and Refrigeration Technology Institute. ARTI-21CR/611-30060-01. Arlington, VA.

Proctor, J. and Cohn, G. 2006 “Two-Stage High Efficiency Air Conditioners: Laboratory Ratings vs. Residential Installation Performance” in *Proceedings of ACEEE 2006 Summer Study on Energy Efficiency in Buildings*. Washington, DC. American Council for an Energy Efficient Economy

Sonne, J., Parker, D. and Shirey, D. 2006. Measured Impacts of Proper Air Conditioner Sizing in Four Florida Case Study Homes. FSEC-CR-1641-06. Cocoa Beach, Florida: Florida Solar Energy Center.

Wilcox, B. and Larsen, J. 2004, “Measured Cooling Load, Energy, and Peak Demand Savings from High-Performance Glass in a California Production House” In *Proceedings of ASHRAE Performance of Exterior Envelope of Whole Buildings IX International Conference*. Atlanta, GA. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

