# The Effects of Residential Energy Efficiency on Electric Demand Response Programs

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## Abstract

*Design and efficiency of houses can affect the amount of peak load reduction available from a residential demand response program. Twenty-four houses were simulated with varying thermal integrity and air conditioner size during the summer cooling season with and without a demand response program. Improved house thermal integrity reduced the effectiveness of the demand response program in limiting peak demand. Air conditioner size had a less significant effect but still changed the demand reduction available. Both provided significant long-term reductions in demand and energy consumption. These results should be considered in the design of demand response programs, and the simulations should be expanded to include other days, locations, and home designs.*

## 1. Introduction

The effectiveness and benefits to the electric power system of residential demand response and direct load control programs to reduce peak load are well-documented. The energy efficiency of the residences involved, however, vary and often are not defined. This leaves the questions of how those efficiency characteristics influence the effectiveness of the programs, and the comfort, and therefore the response and willingness to participate, of the occupants. A related question that has received some attention is the energy conservation, in addition to peak reduction, that results from demand response or load control programs.

More efficient homes mean lower total electric energy use, which intuitively would seem to also reduce peak demand. The actual demand reduction, though, depends on the type of efficiency improvements that are made. Lower total energy use may also mean that less demand reduction is available at peak. The sensitivity of higher efficiency residences to changes in heating and cooling schedules and thermostat settings is different from lower efficiency homes, so the effects on occupant comfort may result in altered customer responses to demand response signals.

Residential energy efficiency includes a variety of features, including

- Heating efficiency (Annual Fuel Utilization Efficiency (AFUE), blower motor efficiency, Heating Seasonal Performance Factor (HSPF)) and a/c (a/c) efficiency (Seasonal Energy Efficiency Ratio (SEER), Energy Efficiency Ratio (EER), blower motor efficiency)
- Wall, ceiling, and floor insulation
- Glass coverage, orientation, and efficiency (Solar Heat Gain Coefficient (SHGC), U-factor)
- Residential size and design
- Shading and exposure to wind
- Air infiltration

The research that this paper introduces is addressing four questions:

1. How will demand response and load control programs affect the peak demand, total energy consumption, consumer comfort, and economics of residences with different energy efficiency profiles?
2. How will improved residential energy efficiency profiles affect electric system energy, system peak demand and the demand reduction available to the system from demand response and load control programs?
3. Should residential energy efficiency improvements be included in electricity markets?
4. How can demand response programs be designed to encourage energy conservation as well as peak demand reduction?

This paper addresses primarily the second question, with some discussion of the others, which will be addressed in detail in future papers. The study is performed by simulating a typical demand response program with residences of varying energy efficiency.

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Changes to system demand and energy and the availability of demand reduction through demand response are detailed for a peak summer day over a range of residential energy efficiency characteristics.

## 2. Previous work

The Federal Energy Regulatory Commission's 2009 National Assessment of Demand Response Potential [1] finds up to 100 GW, equivalent to 10%, of residential peak demand reduction potential by 2019 through demand response, including direct load control. The residential sector is found to be the largest single contributor to demand response potential, with saturation of central a/c the key factor. The study does not assume any improvements to a/c or residential efficiency over the ten-year study period. The report does, however, note efforts to integrate demand response and energy efficiency programs, and the lack of data and need for research on the effects of combined programs and of energy efficiency alone on demand response potential. The coordination of demand response and energy efficiency programs is also encouraged by the US Environmental Protection Agency's National Action Plan for Energy Efficiency [2]. Other reports and papers [3,4] have also noted a lack of available data and a research need on the effects of demand response on energy efficiency.

A 2005 review of hundreds of demand response projects in all sectors found that programs designed for peak reduction sometimes result in unintended reductions in total energy use [4]. If lighting is reduced, for example, in response to price signals, that load is not replaced by increased lighting at a later time. A/C, however, is simply moved from peak times to later, resulting in little or no net energy conservation. The conservation effect realized depends on demand response program design, and was found to range from -5% (an increase in total energy) to 20%.

Literature on the effects of residential energy efficiency on demand response participation and results is limited. One area that has been studied is the effect of a/c sizing on peak electrical loads. Proper sizing was found to have significant effects on peak loads, and thus on demand response programs [5-7]. The industry standard for a properly-sized a/c is a system that will maintain indoor air temperature of 75F for 97.5% of the hours from June through September [8-9]. Many homes actually have oversized a/c systems [5-7], which reduces system efficiency through frequent cycling. Frequent cycling also increases wear on system components, and can cause occupant comfort issues such as hot spots and high humidity.

An oversized a/c, which is manifested in a larger-than-optimal compressor and motor, will have a higher peak demand than a properly sized unit. Its total run time will be lower, however, than a properly sized unit. Reduced efficiency caused by cycling of oversized units results in higher total energy consumption. Diversity across all the a/c on a feeder will reduce feeder peaks, but the reduced efficiency of oversized units may still cause a higher peak than that seen with properly-sized units. In the 2.5% of summer hours that exceed the properly-sized units' abilities to maintain indoor temperature at 75F, these units will run constantly. Oversized units may still cycle, but will result in better occupant comfort, increased energy consumption, and higher peak loads that the optimally-sized units [5].

ASHRAE standard 55-2010 [10] defines acceptable indoor temperatures for buildings. The actual acceptable indoor temperature depends on a number of factors, including occupant clothing and activity level, air movement, outdoor temperature, and humidity. The absolute acceptable range is thus very wide, 19-28C (67-83F), and requires the use of graphic or computer analysis to determine actual acceptable values.

Temperature variations within the allowable range over a given time period, however, are more definitely defined in the standard. The allowable cyclic variation in temperature within a period of 15 minutes or less is 1.1C (2.0F). Non-cyclic changes over periods longer than 15 minutes are referred to as drifts (passively controlled changes) or ramps (actively controlled changes). These allowable changes are shown in Table I [10].

**Table I. ASHRAE Standard 55-2010 limits on temperature drifts and ramps [10]**

| Time period, h | 0.25 | 0.5 | 1.0 | 2.0 | 4.0 |
|---|---|---|---|---|---|
| Maximum Operative Temperature Change Allowed, °C (°F) | 1.1 (2.0) | 1.7 (3.0) | 2.2 (4.0) | 2.8 (5.0) | 3.3 (6.0) |

Indoor temperature was monitored in 100 residential buildings that were among 3,200 participants in a Southern California Edison direct-load control program [11]. Participants' a/c units were cycled off during electric system peaks for periods of 5, 10, and 20 minutes. Residents in the 100 monitored buildings were surveyed regarding their comfort and response during the cycling events.

The results showed a few homes with air temperature changes of greater than 2F for outdoor temperatures exceeding 80F when compressors were cycled off for 20 minutes. When surveyed, 4 of 16 respondents said they noticed their a/c being cycled, but only one reported any discomfort as a result, and that was mild.

There were no data reported on the length of time required or energy used to reduce the indoor temperature when compressors were cycled back on. These are functions of compressor size and building thermal efficiency, which were not considered in the study, although they could also affect occupant comfort, response to, and ultimately the effectiveness of demand response and load control programs.

Improved building thermal efficiency (higher insulation levels, more efficient glass, reduced infiltration, etc.) should be expected to reduce the variations in temperature as compressors are cycled off. Properly-sized compressors will take longer to reduce temperatures to previous levels. Both may affect the actual capacity reductions available through demand response and load control programs.

Statistical analyses of critical-peak pricing programs [12, 13] have shown that high-use single family homes respond with significantly higher peak reductions (0.15 kWh/h, 7.8% [12]) than low-use single family homes (0.03 kWh/h, 3.2% [12]). This would seem to imply that as a home becomes more efficient, there will be less peak reduction available, although many other variables are involved as well. Overall energy use is decreased, however, so perhaps less peak reduction is needed as buildings become more efficient.

## 3. Gridlab-D and the Residential Model

The residential module [14] of Gridlab-D [15] software is used in this research. Gridlab-D is agent-based open source electric distribution simulation software that couples traditional distribution power flow models with advanced load, automation, and market models. The residential module models the energy use within a single-family home of:

- Water heater
- Lights
- Dishwasher
- Range
- Microwave oven
- Refrigerator
- Plug loads
- Heating and cooling

A number of parameters describing each type of load allows significant flexibility in modeling the types of devices installed and the use of those by the occupants.

Heat gains and losses for each home are modeled as:

- Conduction through exterior walls, roof and fenestration
- Air infiltration
- Solar radiation
- Internal gains from lighting, occupants, applicances, and other end-use devices.

The structure and loads are modeled as dc circuit components using the equivalent thermal parameter (ETP) approach, which is common for building thermal modeling. It allows, with reasonable computing requirements, the simulation of large numbers of buildings along with power flow modeling of the associated distribution system. The main limitation of ETP is that it only accounts for sensible heating and cooling loads, i.e., those loads that result in a temperature change. Most heating loads are sensible, but dehumidification during cooling is a latent load that is not modeled by ETP. Humidity can be a significant factor in occupant comfort. More sophisticated dedicated building simulations [16] also model moisture, as well as $CO_2$ and contaminants. These more accurate models have not been integrated with power flow models, and doing so would result in much higher computing requirements.

Within the residential module is the house class, which specifically models a single-family home. The default house is a single-story structure with 2,500 $ft^2$ of floor area. All parameters for the default house and HVAC system are outlined in [17]. For this research the default house with three different levels of thermal integrity, shown in Table II, was simulated in Wichita, Kansas, US. Typical Meteorological Year data (TMY2) [18] was used.

**Table II. House Thermal Integrity**

| | Little (old home, insulated) | Normal (old home, upgraded) | Good (very well insulated) |
|---|---|---|---|
| R-value, walls (°F-$ft^2$-hr/Btu) | 19 | 30 | 30 |
| R-value, ceilings | 11 | 11 | 19 |
| R-value, floors | 4 | 19 | 22 |
| R-value, doors | 3 | 3 | 5 |
| R-value, windows | 1.2 | 1.7 | 2.1 |
| Air exchanges per hour | 1.5 | 1.0 | 0.5 |

For each thermal integrity level, the a/c was sized [8-9] to maintain the indoor air temperature at 75° F (74$\pm$1° F to allow for the 2° F thermostat deadband) during 97.5% of the hours in the June through

September cooling season. Oversized units for each level were also simulated. The six cases simulated are shown in Table III.

The hottest day of the TMY2 year data for Wichita is July 15, with a maximum outdoor temperature of 105 °F. The plot of indoor and outdoor temperatures on July 15 for a house with good thermal integrity and a properly-sized a/c are shown in Fig. 1. The relatively large time steps in the outdoor temperature are a result of the TMY2 hourly data. A/C thermostat cycling can be seen on the indoor temperature plot. The a/c was unable to maintain indoor air temperature below 75 °F between 2 pm and 6 pm, with a maximum indoor temperature of 79.1°F at 4 pm.

**Table III. Simulated houses**

| Case | Thermal Integrity | A/C size (Btu/hr) |
|---|---|---|
| 1 | Little | 87,900 (oversized) |
| 2 | Little | 56,800 (proper) |
| 3 | Normal | 56,800 (oversized) |
| 4 | Normal | 36,350 (proper) |
| 5 | Good | 36,350 (oversized) |
| 6 | Good | 28,550 (proper) |

## 4. Demand Response Program

A simple load control program, one of the protocols used in [11], which has the best documentation for occupant comfort, is used in this study. In the load control program simulated, each residential a/c on the system is cycled off for one 20-minute period during the system peak period of 2-4 pm. When multiple houses are simulated, the initiations of the 20-minute shutoffs are spread evenly throughout the 2 hour peak period. The use of this simple program also allows better isolation of the effects of efficiency without the added complications of consumer response.

The July 15 temperatures for the house with good thermal integrity and a properly-sized a/c, which is cycled off for 20 minutes starting at 3 pm, are shown in Fig. 2. The 20-minute shutoff can be seen as a sharper rise in indoor temperature. The resulting effects on occupant comfort are shown in Table IV. The amount of time the indoor temperature was outside the $74 \pm 1^{o}$ F a/c design bandwidth during the June-September cooling season increased with demand response cycling. The amount of time on July 15 that the indoor temperature was above $75^{o}$ F, and the maximum indoor temperature that day, also increased with a/c cycling. Oversized a/c was better able to maintain indoor temperatures below $75^{o}$F. Improved thermal integrity tended to improve occupant comfort, both with and without cycling. More details of this work, including results for other cycling periods and days of the year, will be presented in another paper.

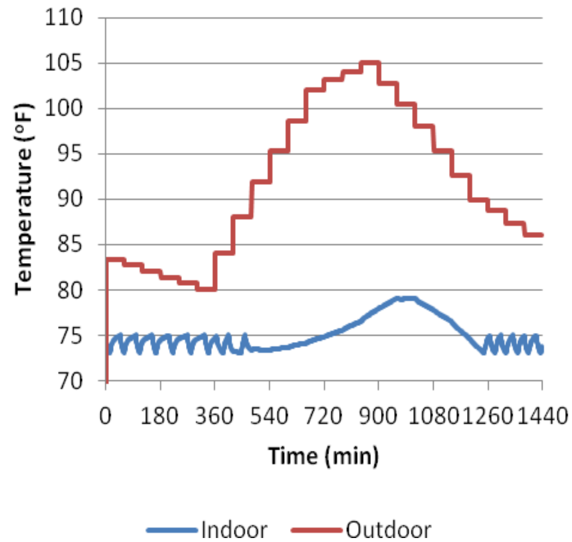


**Fig. 1. Indoor and outdoor temperatures on July 15, default house, 28,550 Btu/hr a/c unit.**

A distribution feeder with 24 houses was modeled to determine the effects of thermal integrity and a/c sizing on the effectiveness of the demand response program that cycles the a/c of each of the 24 houses off for 20 minutes during the two-hour 2-4 pm peak period. Every 5 minutes one home's a/c shutoff cycle begins, so the cycles are evenly distributed throughout the 2-hour period. The Table III houses were used in varying combinations.

Figs. 3 and 4 show typical load profiles for the 24 homes with and without a/c cycling. The noisy shape of the load curves shows the limited diversity obtained from only 24 houses. Peak demand reduction is seen in Fig. 4 during the demand response event from 2-4 pm. The peak demand during the event for this case is 126 kW without cycling and 111 kW with, a 12% reduction.

In order to represent a program with a larger number of participants and thus more diversity, the energy reduction during the 2-hour demand response event can be used. This results in the integral of demand during the period, effectively smoothing the load curves. The energy reduction during the event for this case is 29 kWh, which converts to a demand reduction of 14.5 kW, or still 12%. For this case, the energy and demand reduction are the same, but for other cases, they do not, so the energy reduction, representing a significantly larger sample size, will be used in demand reduction calculations.

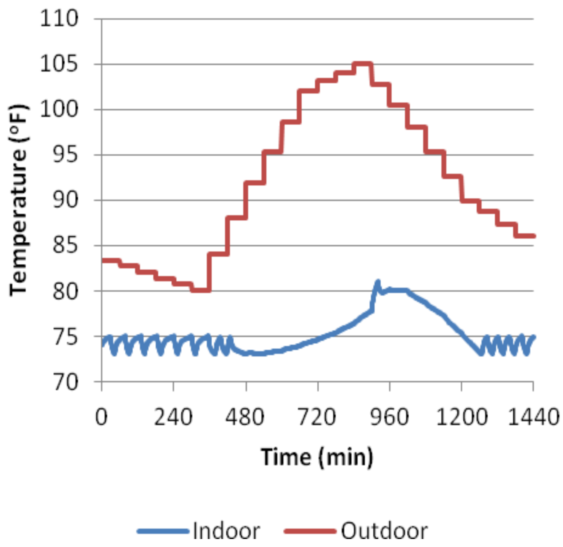


**Fig. 2. Indoor and outdoor temperatures on July 15 with 20 minute a/c cycling**

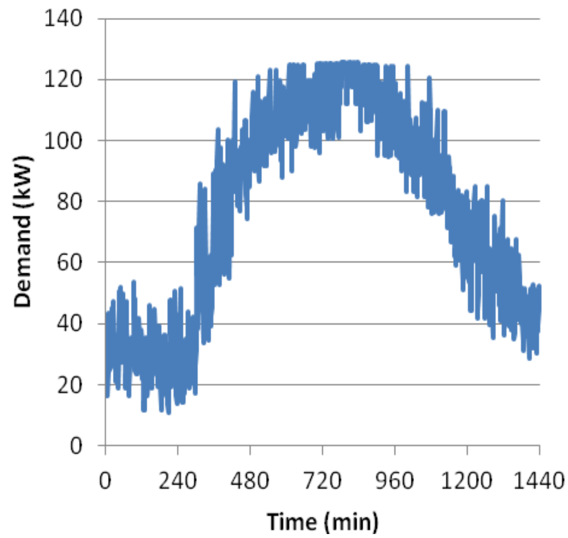


**Fig. 3. Feeder load profile without cycling (mix of a/c sizes and thermal integrity values)**

**Table IV. Effects of a/c cycling on occupant comfort.**

| Case | Length of a/c shutoff (min) | Time outside $74 \pm 1\,^{\circ}$F bandwidth (% of summer season) | Time above $75^{\circ}$F (min), July 15 | Maximum indoor temperature, July 15 |
|---|---|---|---|---|
| 1 | none | 0 | 0 | 75.0 |
| | 20 | 1.0% | 28 | 80.5 |
| 2 | none | 2.5% | 414 | 80.8 |
| | 20 | 4.1% | 427 | 85.6 |
| 3 | none | 0% | 0 | 75.0 |
| | 20 | 0.9% | 21 | 78.5 |
| 4 | none | 2.5% | 390 | 80.0 |
| | 20 | 4.2% | 413 | 82.7 |
| 5 | none | 0.0% | 0 | 75.0 |
| | 20 | 0.9% | 55 | 77.8 |
| 6 | none | 2.5% | 348 | 79.1 |
| | 20 | 4.2% | 361 | 81.0 |

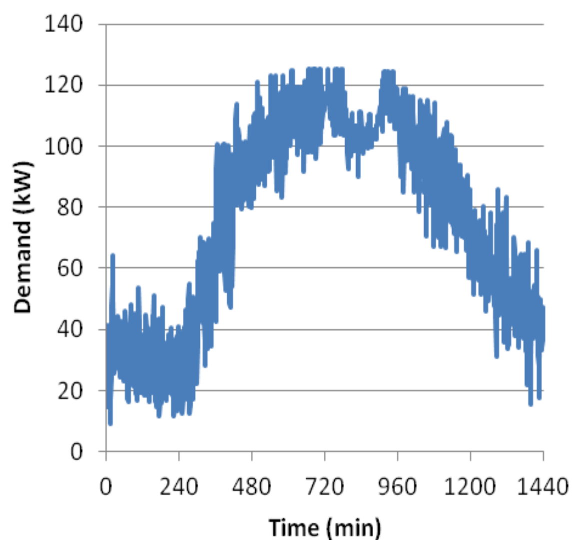


**Fig. 4. Feeder load profile with 20-minute cycling (mix of a/c sizes and thermal integrity values)**

## 5. Effects of Thermal Integrity on Demand Response Peak Load Reduction

To study the effects of thermal integrity on demand response results, three combinations, each with 24 homes are used:

- All homes with oversized a/c
- A mix of oversized and properly sized a/c
- All homes with properly sized a/c

In each case, three combinations of thermal integrity were modeled:

- 1/3 little, 1/3 normal, 1/3 good
- 2/3 normal, 1/3 good
- All good

The results are in Table V. The effect on demand reduction obtained from 20-minute a/c cycling is presented, as is the demand reduction obtained from overall reduced consumption due to improved thermal integrity. The columns in this table are:

- Case:
  A: Mix of houses with little, normal, and good thermal integrity
  B: Mix of houses with normal (2/3) and good (1/3) thermal integrity
  C: Houses with all good thermal integrity
- Demand Reduction from DR (kW): The different in peak demand with and without cycling; this is the result of the demand response (DR) program.
- Demand Reduction from DR (%): Demand Reduction from DR (kW) divided by the peak (without cycling) demand (kW). Again, this is the result of the demand response (DR) program.
- Demand Reduction from Efficiency: The difference in peak demand, without cycling, between the two improved thermal integrity and the lowest thermal integrity cases. This is the result of improved thermal integrity.

Fig. 5 show the total demand reduction obtained from cycling for the three house combinations. As home thermal integrity improves, the reduction in demand available from cycling is reduced. This is because the time that a/c runs in the improved homes is reduced, reducing energy use and the demand diversified across all homes included in the demand response program.

This reduction in demand that results from improved thermal integrity (with or without cycling) is shown in Fig. 6. Regardless of a/c size, improved thermal integrity provides significant demand reductions due to reduced energy use.

Because improved thermal integrity reduces diversified peak demand, the relative reduction available from cycling as thermal integrity improves is different from the absolute reduction available. Fig. 7 shows, though, that the relative demand reduction obtained, regardless of a/c size, still decreases with improved thermal integrity.

The details of reduced energy consumption resulting from both demand response and improved thermal integrity are shown in Table VI. This table again shows the significant reduction in energy consumption that results from improved efficiency. The values are comparable to those shown in Fig. 6 for demand reduction. This particular demand response program, however, 20-minute a/c cycling during system peaks, did not result in any significant energy conservation.

**Table V. Effects of thermal integrity on demand reduction**

| Case | Cycle (min) | Demand Reduction from DR (kW) | Demand Reduction from DR (%) | Demand Reduction from Efficiency (%) |
|---|---|---|---|---|
| All oversized a/c | | | | |
| A | 0 | | | |
| A | 20 | 15 | 11% | |
| B | 0 | | | 16% |
| B | 20 | 10 | 9% | |
| C | 0 | | | 28% |
| C | 20 | 7 | 8% | |
| All proper a/c size | | | | |
| A | 0 | | | |
| A | 20 | 14 | 14% | |
| B | 0 | | | 16% |
| B | 20 | 12 | 13% | |
| C | 0 | | | 26% |
| C | 20 | 10 | 13% | |
| Mixed a/c sizing; half proper, half oversized | | | | |
| A | 0 | | | |
| A | 20 | 15 | 12% | |
| B | 0 | | | 11% |
| B | 20 | 10 | 10% | |
| C | 0 | | | 22% |
| C | 20 | 8 | 9% | |

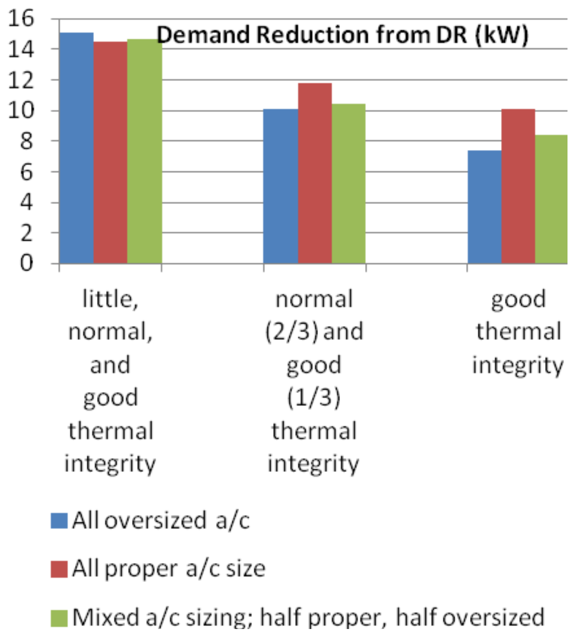


**Fig. 5. Absolute demand reduction from 20-minute a/c cycling**

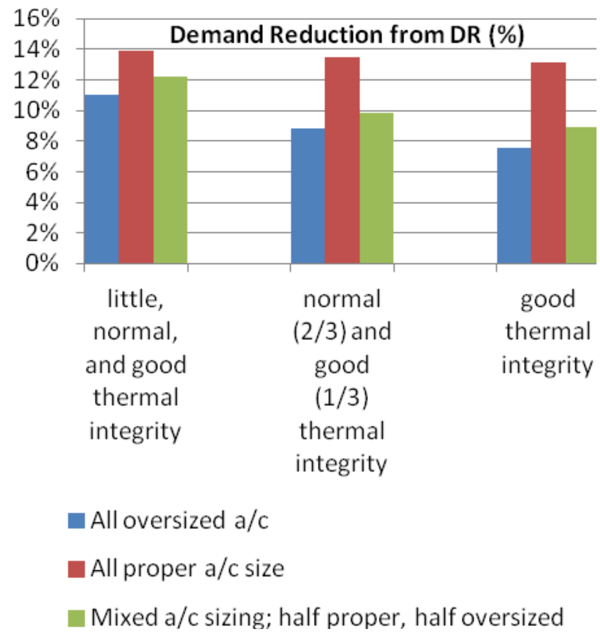


**Fig. 7. Relative demand reduction obtained from 20-minute a/c cycling.**

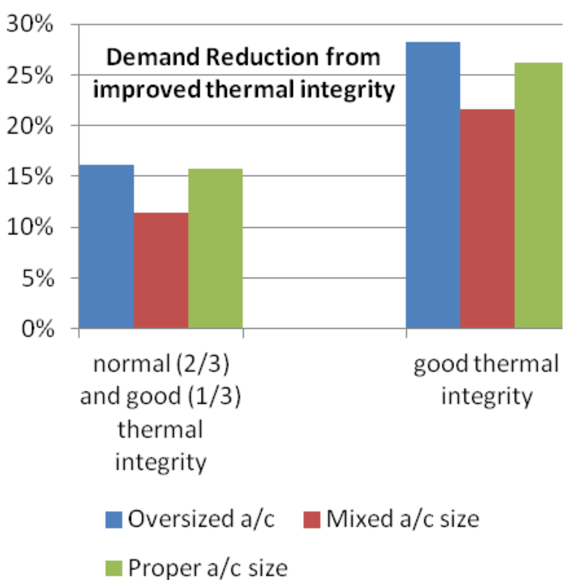


**Fig. 6. Reduction in peak demand due to improved thermal integrity, without cycling.**

**Table VI. Effects of thermal integrity on energy consumption**

| Case | Cycle (min) | Energy Conservation (%) from DR | Energy Conservation (%) from Efficiency |
|---|---|---|---|
| All oversized a/c | | | |
| A | 0 | | |
| A | 20 | 1% | |
| B | 0 | | 16% |
| B | 20 | 0% | |
| C | 0 | | 28% |
| C | 20 | 0% | |
| All proper a/c size | | | |
| A | 0 | | |
| A | 20 | 1% | |
| B | 0 | | 15% |
| B | 20 | 1% | |
| C | 0 | | 25% |
| C | 20 | 1% | |
| Mixed a/c sizing; half proper, half oversized | | | |
| A | 0 | | |
| A | 20 | 1% | |
| B | 0 | | 15% |
| B | 20 | 1% | |
| C | 0 | | 26% |
| C | 20 | 0% | |

## 6. Effects of A/C Unit Size on Demand Response Peak Load Reduction

The same data used in the previous discussion of thermal integrity are now presented in an order that allows the effects of a/c size on demand response effectiveness to be observed. For each thermal integrity case, homes are now grouped by a/c size:

- All oversized
- Half properly sized, half oversized
- All properly sized.

The results are shown in Table VII. The cases in Table VII are:

D: All oversized a/c

E: Mixed a/c sizing; half proper, half oversized

F: All proper a/c size

The effects of a/c size on absolute demand reduction obtained from 20-minute cycling are shown in Fig. 8. Changing a/c size does not have a significant effect on the absolute demand reduction available through the demand response program. For the normal/good thermal integrity case, for example, peak reduction increased from 10 kW to 12 kW as a/c went from oversized to properly sized. For the little/normal/good thermal integrity case, the demand reduction available actually decreased with properly sized a/c.

Improved a/c size significantly reduces motor size and thus peak demand, as is shown in Fig. 9, so a significantly higher demand reduction might also be expected during demand response events. But because this is the hottest day of the year, the properly sized units will all be running almost constantly, while some of the oversized units will be off because they have reduced the indoor temperature below 73$^{o}$ F. The demand response program simulated in this work signals each a/c to turn off on a set schedule whether it is actually operating at that time or not. Because some of the oversized units are already off, the result is that the demand response program will on the average turn off more smaller units that larger on the hottest day. The result is that the change in demand during the event is about the same for the three cases. This is probably very sensitive to a/c size, thermal integrity, weather, and other variables, and warrants further study.

Relative demand reduction from cycling, shown in Fig. 10, is more significantly affected by a/c size. For all thermal integrities, improved a/c size results in a higher percentage of demand reduction available. This is because the actual demand reduction (Fig. 8) stays fairly constant, while the peak demand (Fig. 9) is significantly reduced, so the constant reduction is a higher percentage of the reduced demand.

Table VIII shows the energy conservation obtained from properly-sized a/c. A/C size without cycling provides some improvement in energy efficiency for the reasons discussed previously. And as also previously stated, this demand response program provides no significant energy conservation.

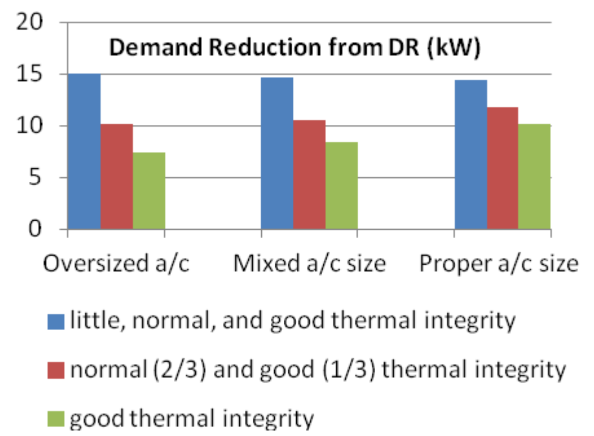


**Fig. 8. Absolute demand reduction from 20-minute a/c cycling**

**Table VII. Effects of a/c size on demand reduction**

| Case | Cycle (min) | Demand Reduction from DR (kW) | Demand Reduction from DR (%) | Demand Reduction from a/c sizing |
|---|---|---|---|---|
| little, normal, and good thermal integrity | | | | |
| D | 0 | | | |
| D | 20 | 15 | 11% | |
| E | 0 | | | 12% |
| E | 20 | 15 | 12% | |
| F | 0 | | | 24% |
| F | 20 | 14 | 14% | |
| normal (2/3) and good (1/3) thermal integrity | | | | |
| D | 0 | | | |
| D | 20 | 10 | 9% | |
| E | 0 | | | 7% |
| E | 20 | 10 | 10% | |
| F | 0 | | | 23% |
| F | 20 | 12 | 13% | |
| good thermal integrity | | | | |
| D | 0 | | | |
| D | 20 | 7 | 8% | |
| E | 0 | | | 4% |
| E | 20 | 8 | 9% | |
| F | 0 | | | 22% |
| F | 20 | 10 | 13% | |

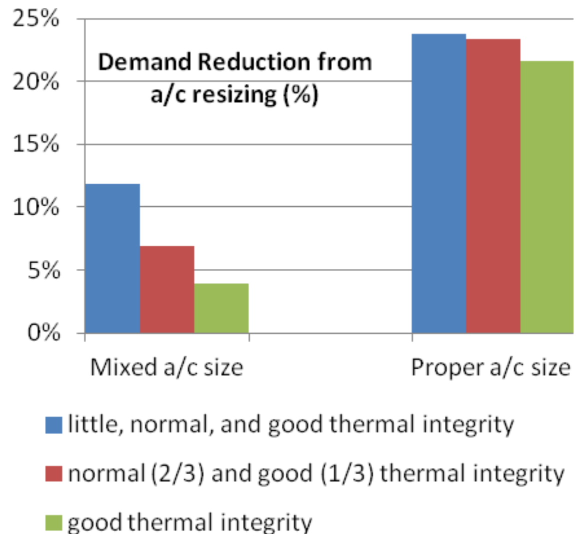


**Fig. 9. Reduction in peak demand due to improved a/c sizing, without cycling.**

**Table VIII. Effects of a/c size on energy consumption**

| Case | Cycle (min) | Energy Conservation (%) from DR | Energy Conservation (%) from a/c sizing |
|---|---|---|---|
| little, normal, and good thermal integrity | | | |
| D | 0 | | |
| D | 20 | 1% | |
| E | 0 | | 2% |
| E | 20 | 1% | |
| F | 0 | | 4% |
| F | 20 | 1% | |
| normal (2/3) and good (1/3) thermal integrity | | | |
| D | 0 | | |
| D | 20 | 0% | |
| E | 0 | | 1% |
| E | 20 | 1% | |
| F | 0 | | 3% |
| F | 20 | 1% | |
| good thermal integrity | | | |
| D | 0 | | |
| D | 20 | 0% | |
| E | 0 | | 0% |
| E | 20 | 0% | |
| F | 0 | | 1% |
| F | 20 | 1% | |

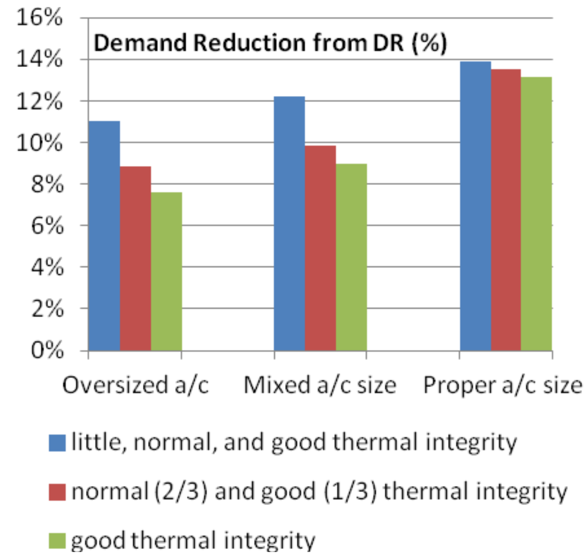


**Fig. 10. Relative demand reduction from 20-minute a/c cycling**

## 7. Conclusions

This study simulates 24 typical houses on a distribution feeder on the hottest day of the year in Wichita, Kansas. A demand response program that cycles a/c off for 20 minutes during the system peak is modeled. The reduction in peak demand, both absolute (kW) and relative (%), available from demand response is reduced by improved thermal integrity of the houses. These reductions could reduce the effectiveness of demand response programs and should be considered as programs are designed.

Replacing oversized a/c with properly-sized units had only a slight effect on the absolute peak demand reduction available from the demand response program, sometimes increasing and sometimes decreasing the reduction. This is because the demand response program on the average turns off more properly-sized units, which run continuously on the hottest day, than oversized units, which still cycle off when they reach 73$^{o}$ F. This will be studied more, however, and may be different for other house designs, thermostat settings, or demand response programs. Relative demand reduction available from demand response increases as a/c is reduced to its proper size.

While the peak demand reduction obtained from demand response was decreased by improved thermal integrity, significant reductions in demand (with or without the demand response event) are provided by both improved thermal integrity and improved (reduced) a/c size. Improved thermal integrity reduces overall energy consumption for cooling, and thus also reduces the demand diversified over a large number of homes. Improved a/c size results in smaller compressor motors and thus lower demand from individual homes and for the whole system.

Improved thermal integrity also provides significant energy reductions. Reduced a/c size provides more limited, but still significant, reductions in energy. The cycling program itself resulted in no significant energy conservation. Demand response programs for conservation will require different designs than those for peak demand reduction. Previous research has indicated, though, that combined programs are possible.

The demand reductions obtained by improved insulation, some reduced air infiltration measures, and improved a/c size (assuming the correctly sized unit is not replaced by a larger one later) are permanent and require no further action by anyone. The reductions obtained by other air infiltration measures such as window caulking and weather seals require maintenance and periodic replacement. Improved thermal integrity and a/c sizing, however, even though they result in significant reductions in demand and energy, are not now included in electricity markets. Demand response programs, however, are becoming more commonly included as resources in electricity markets. It would be an interesting study to see how capacity and energy payments for the long term load reductions provided by efficiency programs would affect the economics and financing of those programs.

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