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# Phased Deep Retrofit Project: Real-Time Measurement of Energy End-uses and Retrofit Opportunities

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## Disclaimer

# Phased Deep Retrofit Project: Real-Time Measurement of Energy End-uses and Retrofit Opportunities

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## ABSTRACT

This paper describes how utilities can "make reductions real" through real-time measurement of energy end-uses and corresponding retrofit opportunities. A field evaluation of the methodology was conducted from 2012 to 2016 with Florida Power and Light (FPL), an investor owned utility. A collaborative program between the U.S. Department of Energy (DOE) Building America and FPL led to an ambitious residential energy-efficiency retrofit study aimed to represent FPL's customer base. Fifty-six existing, all electric, occupied Florida homes were instrumented to collect one-minute data on most all energy end-uses in advance of energy-efficiency retrofits. Baseline measurements enabled the development of end-use profiles for the utility's service territory. The sample then served as a testbed to evaluate and quantify energy and peak demand reductions from a variety of packaged retrofits ("shallow" and "deep") and individual emerging technologies. Many of the measures produced impressive energy-use savings for homeowners and reduced demand during utility-coincident peak summer and winter hours. This paper presents details on the recruitment, monitoring equipment, statistical evaluation, and the innovative data platform used to collect and manage millions of data points. Using lessons learned from the Florida study, a similar project is in the planning stages for California. In addition to efficiency retrofits, the California study aims to evaluate advanced meter infrastructure (AMI) data disaggregation schemes, solar electric output by tilt, orientation and location, influence of electric vehicle charging, and distributed electrical storage.

### Introduction

The University of Central Florida's Florida Solar Energy Center, with funding from the US Department of Energy's Building America program, collaborated with Florida Power & Light (FPL) to conduct a pilot phased residential energy-efficiency retrofit program. The partnership was formed given complementary interests of the partners: Building America has a goal of large, whole house energy use reduction for existing homes, and seeks solutions to technical and market adoption barriers. FPL, in addition to updating information on the magnitude of various energy end-uses across their service territory, was interested in evaluating individual component technologies and retrofit packages that might help meet future energy use and peak reduction goals.

For the Phased Deep Retrofit project (PDR), a total of 56 all electric homes were recruited, with two years of pre-enrollment monthly utility data obtained for each research site. The homes were spread across the utility partner's territory in east Central Florida, southeast Florida, and southwest Florida. The study sites were audited with a detailed protocol, including blower door and duct leakage testing. They were then instrumented to capture energy consumption on up to 18 end-uses. Detailed, monitored end-use data were collected pre- and post-retrofit, along with monthly utility billing data. Increasingly for utility program evaluations, algorithm-based AMI disaggregation methods are used for formalized measurement and verification purposes. While rigorous and widely accepted, such methods have their drawbacks including the need for very large sample sizes for statistical significance, and large end-use estimation errors. For instance, in a 645-home study, Cetin, Siemann, and Sloop (2016) found prediction of disaggregated HVAC loads erred by almost 18%. In contrast, direct detailed measurement of energy end-uses provides for much greater accuracy and therefore smaller sample sizes can be used with greater confidence. Moreover, direct measurement allows for potential improvement to AMI disaggregation estimation schemes by providing true power for refined estimation algorithms.

## Sample Recruitment, Characteristics, and Representativeness

The 56 all-electric, single-family homes, located in Central and South Florida, comprised an opportunity sample. The study originally recruited 60 sites, but four homes were lost through attrition. FPL assisted with recruitment via press releases, and participants were largely self-selected within program limits. This media outreach generated an overwhelming response as participants were eager to receive free home improvement measures. Sample selection avoided the newest homes and targeted moderately-sized dwellings to make results more appropriate to retrofit programs aiming to reach older, less efficient houses. Living area ranged from 1,000 to 2,650 $ft^2$; vintage ranged from 1942 to 2006; ceiling insulation R-value averaged 22 $hr/ft^2$-$^oF$/Btu; and airtightness averaged 8.5 air changes per hour at 50 Pa. As representative for Florida, a typical study home had single-glazed windows, slab-on-grade foundation, masonry walls, asphalt shingle roof, electric resistance water heating and a 10-year plus central air conditioning system. One third of the homes had pools. PDR project intent:

- Be statistically meaningful, representing all-electric homes geographically in Florida
- Include only homes that were to be occupied year-round (not seasonal)
- Be typical of existing single-family housing with construction from 2006 or earlier
- Include a representative saturation (33%) of swimming pools.

With these selection guidelines, it was hoped that the measured electricity use would be typical of all electric non-seasonal, single-family homes in the FPL service territory.

## Measurement and Equipment

Detailed audit data were obtained from all homes: house size and geometry, insulation levels, materials, finishes, and equipment. Each home received and envelope airtightness test conducted with a blower door and a duct leakage test using duct blaster equipment. Photographs were also taken of the home exteriors, appliances, equipment, thermostats, and associated labels. Showerhead flow rates were measured using a flow-catch apparatus showing a range of audited flows of 0.9 – 4.4 gpm.

House power and the various end-uses were monitored by a 24-channel data logger (Powerhouse Dynamics SiteSage) using 20- and 50-amp current transducers. While most end-uses were directly measured at the circuit, “lighting and other” were obtained by subtracting all the end-uses from the measured house total power. These data loggers have a stated accuracy of ±1% between 10% and 130% of their rated output. A portable power logger (WattsUp?) was used to obtain energy use data on some remote end-uses that were not on isolated circuit breakers, i.e. washing machines, the main home entertainment center, game systems, and home office and computer workstations. The WattsUp? is accurate to 1.5% of stated full load. Portable loggers (Point Six and Onset HOBO) were used to take temperature and humidity data. These have a stated accuracy of ±0.95°F for temperature and ±3.5% RH for relative humidities up to 85%. Data are retrieved daily over the Internet via broadband connection on a 1-hour time step. For greater resolution, 1-minute data are retrievable for all end-uses. Ambient temperature and relative humidity (RH) data were obtained from nearby National Weather Service stations, typically less than 20 miles away from the study site with a stated accuracy of ±1°F.

Periodically, Florida utilities are required to perform a home energy survey (HES) of the housing characteristics in their service territory for submission to the Public Service Commission. The 2010 survey provides a convenient method to compare the characteristics of the homes in the PDR opportunity sample to the larger statistically drawn survey evaluated by FPL (FPL 2010). A comparison of the HES Public Service Commission's survey and PDR data revealed that the samples are quite comparable relative to both electricity use and demographics (Sutherland et al. 2016). Indeed, the average total measured annual electricity use in the sample and in the FPL survey were within 5% of each other (16,963 vs. 17,843 kWh).

## Data Management Platform Pre-Retrofit Data

A dedicated website ([www.infomonitors.com/pdr/](www.infomonitors.com/pdr/)) was developed to host the large quantity of monitored energy data from the project. Hourly data are available for each site and for each energy end-use. The platform provides detailed and summary data in table or graphical form, with flexibility in chosen dates and sites for evaluation. While the website has unrestricted access, to minimize influence on behavior, study participants were not made aware of its existence nor their unique identification number until the end of the study. Figure 1 depicts an end-use bar for each site for the first full year of monitoring (2013). The different colors in each bar represent the amount of energy used by varying end-uses and demonstrates that each home has a unique energy use profile. Space cooling (bright blue) is the dominant end-use (as expected in a hot-humid climate), however cooling is not the highest use for each site. Other typical large end-uses are lighting and other plug loads (orange) and pool pump (light green). The interior temperature (orange dots) and relative humidity (teal dots) are indicated at the top of the figure.

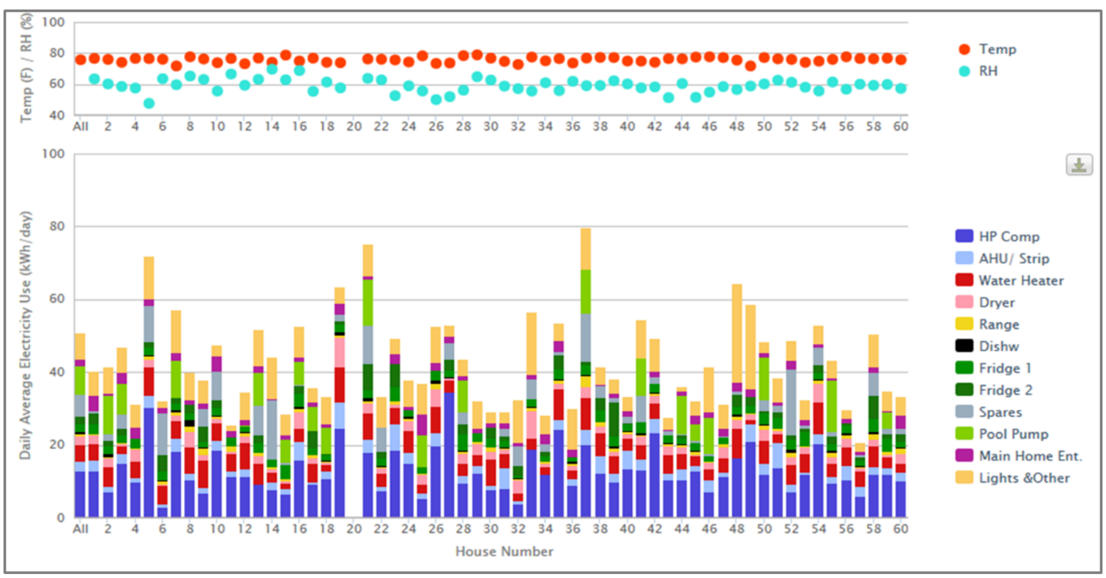


Figure 1. PDR home end-use during 2013, by site.

Figure 2 represents these same data in aggregate. And while space cooling (bright blue) makes up 37% of the whole house daily consumption for the sample average, it is notable that there are many other end-uses that represent large contributions to aggregate use. These large end-uses include water heating (11%, bright red), lighting (8%, orange), fans and plug loads (8%, dark red), pool pumps (7% with its contribution diminished over the full sample, light blue), and refrigeration (7%, dark and light green).

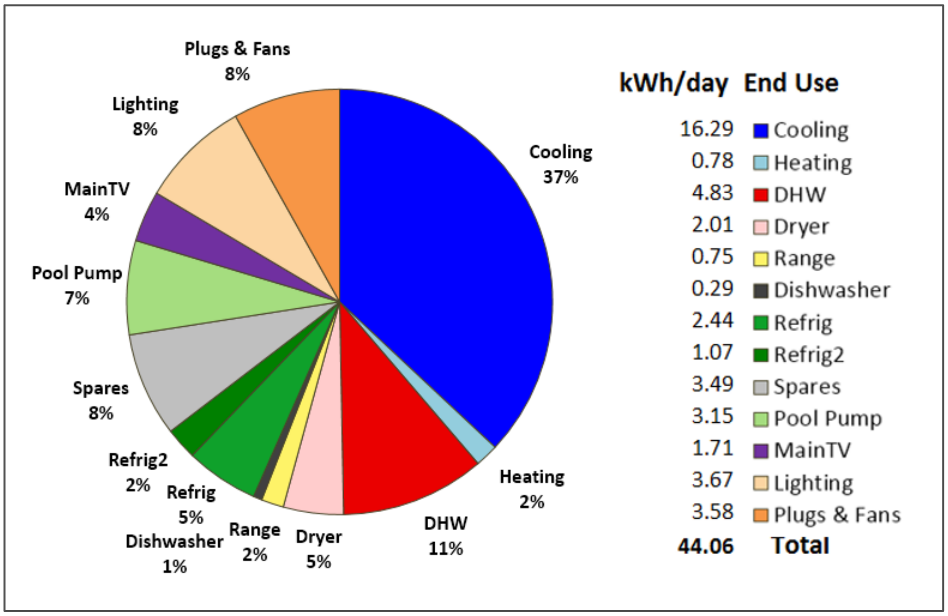


Figure 2. PDR home end-use during 2013, in aggregate. Average total whole house energy use = 44.1 kWh/day; 16,080 kWh/year.

Finally, by averaging the energy use for all homes by hour of day, we can see the makeup of the daily demand profile as shown in Figure 3. Beyond space cooling, lighting and other (orange) and water heating (red) are significant contributors to peak load.

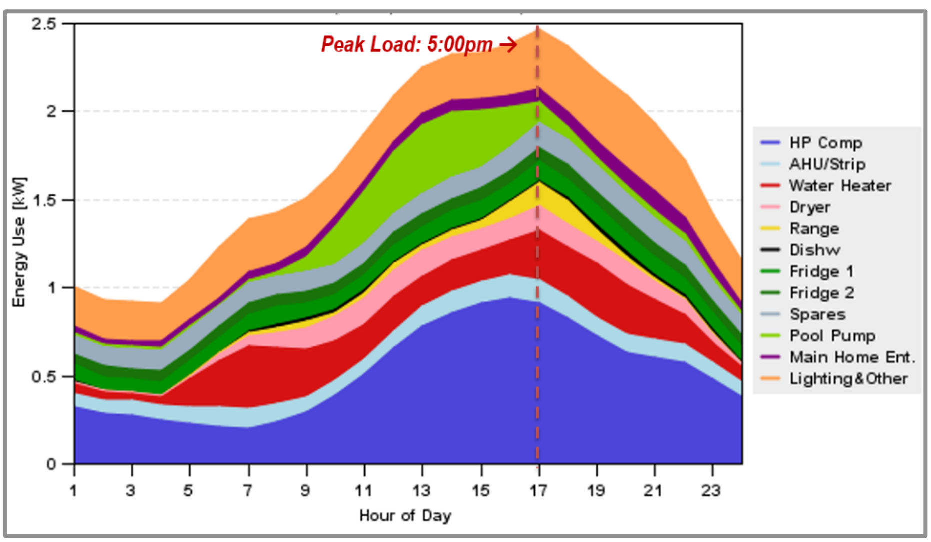


Figure 3. Daily demand profile by end-use for the PDR homes during 2013.

The plots in Figure 4 below provide examples of how the data can highlight time-related tendencies for an individual end-use – water heating energy in this case. The platform also allows for end-use examination of individual sites, groups of specific sites (e.g. all the deep retrofit homes), or the entire PDR sample. In the graphic presentation, the average water heating energy use for all PDR sites plotted hourly, daily, and by time of day.

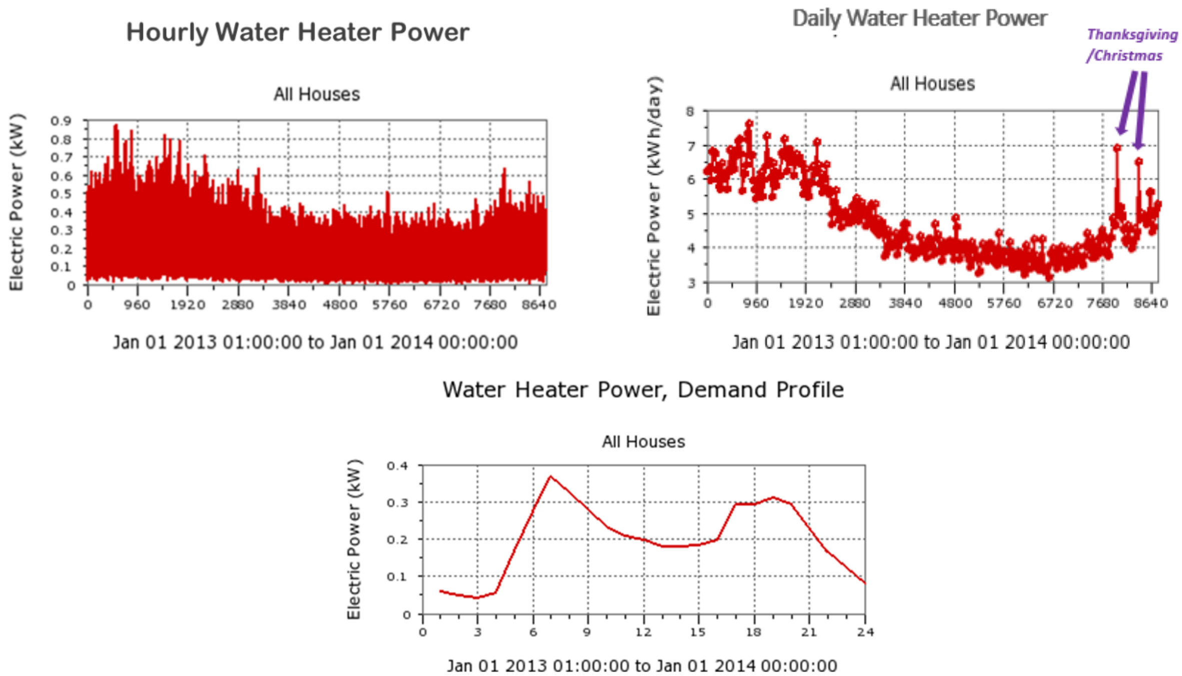


Figure 4. PDR sample water heating energy plotted hourly average (upper left), daily average (upper right), and average daily load shape (lower).

The hourly average data plot (upper left) illustrates that water heating energy use is about double in winter than in summer; the daily average plot (upper right) shows water heating energy use spikes dramatically during the Thanksgiving and Christmas holidays; the daily average load shape (lower) displays the bi-modal distribution of water heating energy thought the day, with the first and highest peak demand at 7:00 am and then a second, smaller, but broader peak from about 5:00 to 8:00 pm.

## Retrofit Scope

The shallow retrofits were installed on the whole 56-home sample by project staff. Shallow measures included the installation of compact fluorescent and LED lamps to reduce lighting energy use. To reduce domestic hot water energy, water heater tank wraps were applied and low-flow showerheads were installed if the flow of the existing head exceeded 2.2 gallons per minute. Refrigerator coils were cleaned if dirty. Also, pool pump timers were reset to reduce of operating hours when they exceeded 5 hours per day. “Smart plugs” were provided for home entertainment centers when measured standby power loads exceeded 10 watts continuous demand. The installations were installed at the homeowners’ discretion (for instance smart plugs were often not installed even where applicable, due to homeowner pushback). Audits conducted at the time of the shallow retrofits provided more detailed input data to the tailored design of each deep retrofit.

The deep retrofits, installed by local contractors, were applied to a sub-sample of 10 homes. Deep retrofit efficiency measures included replacement of air-source heat pumps, duct repair, and substitution of conventional thermostats with learning thermostats. Heat pump water heaters were installed to reduce water heating energy use. Pool pumps were changed to variable-speed units, and ceiling insulation was augmented where deficient. Old and inefficient refrigerators and dishwashers were replaced with more efficient units when indicated.

Phase II of the PDR project included evaluation of single-measure advanced technologies applied to homes that could be studied in isolation and used to refine a retrofit package and identify technologies less well-proven. Phase II involved the installation of eight energy-efficiency retrofit measures: Supplemental mini-split heat pump (MSHP), complete central system replacement with a mini-split or multi-split heat pump, ducted and space-coupled heat pump water heater (HPWH), exterior insulation finish system (EIFS) for walls, high-efficiency window retrofit, learning thermostat, heat pump clothes dryer, and variable-speed pool pump.

## Methodology

Several evaluation methods were used to assess the energy impacts of interventions described. Evaluations included measured impacts on whole house energy savings as well as individual end-uses. Most often, a weather-normalized, space-conditioning disaggregated utility data analysis compared 1 year pre-retrofit to 1 year post-retrofit for both the shallow and deep retrofit packages to evaluate whole-house and space conditioning savings. Energy demand impacts were assessed on the FPL system peak winter and summer hours for all measures.

Energy impact evaluations for retrofit measures not targeting space conditioning were performed by comparing pre- and post- monitoring results. These included lighting, water heating, and appliance energy use reductions. In the case of lighting which was not an isolated measurement, the category of 'lighting and other plug loads' is the difference between whole house energy use and all the remaining measured circuits combined. Using data on installed lighting wattage collected during the shallow retrofits, we determined that the pre-retrofit lighting consumption was roughly 51% of the "plug loads and other" end-use. Measured energy use for the shallow retrofits were evaluated in two ways. The first method was 30-day pre- versus 30-days post-retrofit, which occurred between spring and summer 2013. Because weather influences many end-use loads, savings were normalized for weather differences. This was necessary to avoid underestimating savings for measures in which energy use naturally increases with higher seasonal temperatures (e.g., refrigerators) or overestimating savings from others that naturally drop (water heating). The second energy use evaluation method compared the month of October (a moderate weather month) before and after the retrofit. In using the same calendar month for each period, this investigation essentially excluded space-conditioning changes. There are benefits of one evaluation over the other; the short-lived nature of the first evaluation (30-day pre/post) minimizes influences outside of the intervention, such as behavioral changes, while the second evaluation (Octobers) considers savings persistence that the first evaluation method may miss.

### Statistical Evaluation of Space Cooling and Heating Measures

Measures impacting space conditioning required more sophisticated treatment. Linear regression analysis against outdoor temperature was used to project savings for the deep and advanced technology measures that influence space-cooling and space-heating energy use. This included the installation of space conditioning equipment and air sealing, space-coupled heat pump water heater, wall exterior insulation finish system (EIFS), advanced window replacement, and the learning thermostat. The same general model – using measured cooling and heating electrical power and then modeling against outdoor weather conditions – was successfully applied for each of these evaluations.

From an evaluation standpoint, we found that weather had the strongest statistical power to account for differences in average daily space heating and cooling energy use. Daily averages were much superior to hourly data since many building elements such as slab, concrete walls and high-density furnishings respond slowly to the daily temperature and solar irradiance harmonics that are naturally associated with the daily cycle. Time lapsed temperatures for regressions were also found to be inferior to the use of a simple daily average as prescribed in the ASHRAE "toolkit" guide to estimating residential energy savings (Haberl, Culp, and Claridge, 2005). Averaging the hourly temperatures into daily averages was a better statistical predictor of space-conditioning energy than estimating heating degree days and cooling degree days at a 65°F base for the same periods as anticipated by the ASHRAE "toolkit." The coefficients of determination tended to be much superior, mainly because heating degree days and cooling degree day periods with zero or negative numbers that were truncated by the degree-day procedure influence daily space-conditioning needs. For example, predawn periods with temperatures below 65°F reduce the required cooling, whereas the degree day calculations assume that these hours have a cooling degree day value of zero; as a result, daily average temperatures were used for the analysis. Space-conditioning energy was then plotted against average outdoor temperature, and the daily average balance temperature for heating and cooling was determined. In some homes with very tight temperature control, these were often the same. The typical daily balance point was approximately 65°F, although this varied from one site to the next.

To estimate pre- and post-retrofit annual space conditioning energy use, regressions were used to normalize daily average temperatures against monitored daily HVAC energy use; then we assumed the same outside temperatures were applied to the resulting site-specific, pre- and post-retrofit regression results. The period after the measure installation was then compared to the pre-installation period. This allowed for an evaluation of how energy use changed after the retrofit.

Next, the pre- and post-retrofit regression results from the weather-normalization evaluation described above were applied to regional TMY3 weather data. This allows the savings estimates to be extended to the various climate zones (Miami, West Palm Beach, Fort Myers, and Daytona) that FPL typically uses for forecasting purposes. For more details on the evaluation methodology including parameters, results and statistical inference, see Parker et al. 2016 and Sutherland et al. 2016.

## Shallow Retrofit Results Summary

Predicted whole-house savings for the shallow retrofit package were similar regardless of analysis method**.** Adjusting for weather-related changes over the 30 days before and after the shallow retrofits, overall savings in homes averaged 4.2 kWh/day or 10.3% of pre-retrofit monthly consumption. Comparing pre-retrofit October to post-retrofit October for a subset of the data set, savings averaged 3.6 kWh/day or 7.9% of pre-retrofit monthly consumption. The utility bill data analysis indicated the more severe post-retrofit weather eroded 25% of the actual whole-house energy savings.

Average annual post-retrofit energy bill reduction was 1,030 kWh (2.8 kWh/day; 7%); the weather-normalized post-retrofit energy savings was 1,356 kWh (3.7 kWh/day; 9%). The normalized savings were found highly significant at a 95% confidence interval. Whole-house energy demand during the FPL system peak hour was reduced 0.67 kW in summer at 5 PM and 0.25 kW in winter at 7 AM, as shown in Table 1. The average cost including labor for the retrofits was $374 per site.

Although space conditioning energy use reduction was not specifically targeted by any of the shallow retrofit measures, significant interactions between the shallow measures and space heating and cooling were observed. In particular, annual cooling energy appeared to be strongly affected, likely from reduced internal gains from the lighting retrofit, but also systematic changes to thermostat preference.

From a participant perspective, the cost-effectiveness of the shallow retrofit outcome looks very promising for broad application. With an estimated annual savings of 1,310–1,530 kWh/year at a per-site average cost of $374, a simple payback is reached in about 2 years, all measures included. The corresponding rate of return on investment for participants is exceedingly positive (higher than 42%). One possible programmatic issue with the shallow retrofit, confirmed by the utility bill data analysis, is that its modest savings levels may be hidden from consumers by both seasonal weather changes as well as weather variations between pre and post intervention years.

**Shallow Retrofit: Evaluation of Individual Measures**

Evaluation of the individual measures indicated the lighting retrofit measure as most effective. The initial analysis presented an average daily savings of 1.2 kWh/day; the 2012 versus 2013 October analysis reported even greater savings, 2.4 kWh/day (453 and 874 kWh/year, respectively). Simple payback for the lighting retrofit averaged 4.9 and 2.7 years, depending on evaluation method. Tank insulation wraps/ showerhead change-outs cut average water heating energy by 0.4 kWh/day or 7%. Refrigerator coil cleaning was not statistically effective and uptake on smart power strips was poor.

We discovered the shallow retrofit caused significant indirect changes to space-heating and space-cooling energy use. Strong evidence indicated that the lighting retrofit's reduction in heat gains was responsible. An end-use disaggregation, completed in concert with the shallow retrofits in 41 homes, showed annual space cooling decreased by 1,353 kWh (16%) coincident with the lighting retrofit when normalized to pre-retrofit weather. Meanwhile, the evaluation predicted that post-retrofit annual space heating would nearly double, with an increase of 629 kWh. The predicted annual baseload savings of 632 kWh is about half the space-cooling energy savings. Detailed space-heating and space-cooling evaluation of hourly monitored thermostat setting data on nine study homes confirmed the above interaction of the lighting retrofit on space-conditioning energy use.

Potential savings from reducing pool pumping hours appeared significant, but in practice was difficult to achieve. In the 19 project homes with pools, nine were already operating less than 5 hours/day and were not altered. Each of the 10 homes for which hours were reduced saved an average of 4.6 kWh/day. However, the reduction in energy use was short-lived. The savings observed during the immediate post-retrofit analysis was markedly diminished in the evaluation looking several months after the intervention. Many pump timers were likely moved back to pre-retrofit settings given pool maintenance pushback on hours of operation. Subsequent research showed that variable-speed pool pumps offer a better option to reduce pool pump energy use with very good customer acceptance.

Given the interest in household standby loads (clocks, GFIs, computers and fans), we also evaluated minute data to examine the lowest electricity demand for the residual loads over the entire year of 2013. In 53 homes with suitable data, we found that the average minimum residual demand- not including the measured end-uses- was 86 Watts (range 25 - 203 Watts). The time of the minimum demand typically came during early morning hours in February or March - a period of little space conditioning in Florida. Results for shallow retrofit measures are discussed in detail in Parker et al. 2016.

## Deep Retrofit Results Summary

For the deep retrofits, an analysis compared one year pre-retrofit to one year post-retrofit for the 10 deep intervention sites to evaluate energy savings. The results show that, accounting for weather, average post-retrofit annual cooling energy use was reduced by 46% (4,336 kWh savings), space heating by 33% (854 kWh), and base-load by 17% (1,878 kWh). Whole-house savings were 38% (7,067 kWh). The savings range for individual homes was 22%–52%. The average overall utility bill savings were slightly lower. Utility coincident peak demand reduction averaged 39% for peak summer hour (excluding the shallow retrofit demand reduction), and 60% for peak winter hour. Peak summer demand reduction on utility reported peak days for the deep sites is displayed in Figure 5 and in Table 1.

Using the incremental package costs at an average of $7,074, simple payback for the improvements was 8.3 years for a 12% simple after-tax rate of return. If the retrofits were completed outright as in this study and with an average full cost of $14,323, the economics are less attractive. However, a useful model for a utility "deep retrofit program" would target homeowners who need to replace their air conditioning and heating systems—at which point all the other improvements would be performed outright. This scenario achieves a 10.5-year payback.

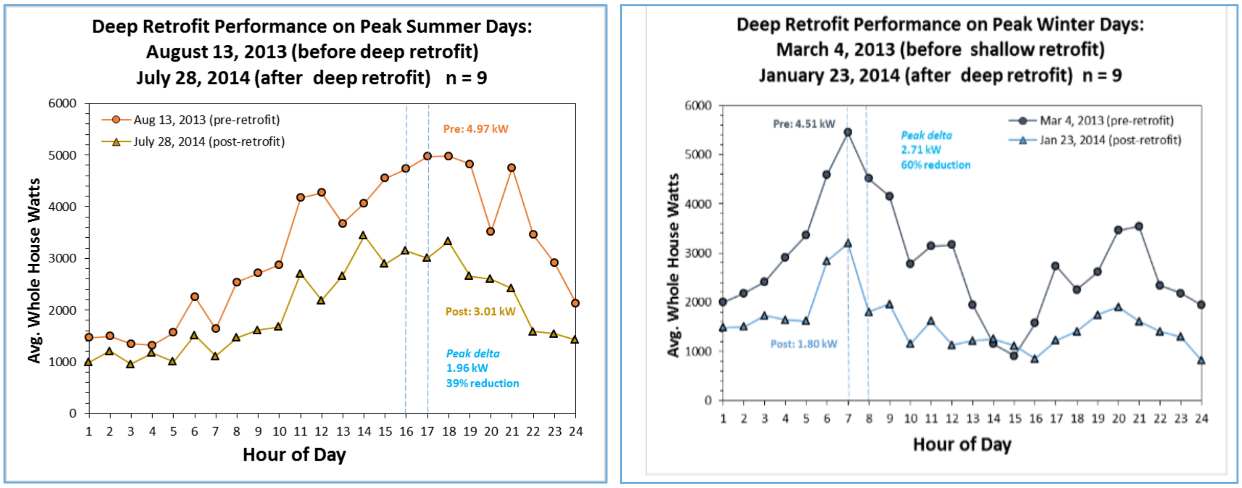


**Figure 5.** Deep retrofit peak summer hour demand reduction was 1.96 kW, 39% over pre-retrofit (left). Winter reduction was 2.71 kW, 60% over pre-retrofit (right).

### Deep Retrofit: Evaluation of Individual Measures

The individual deep retrofit components were also evaluated separately (Parker et al. 2016). The pre- to post-retrofit evaluation of the 10 HVAC retrofits showed that the heat pump replacement and duct repair saved an average of 40% of pre-retrofit HVAC consumption, but that lower interior temperatures were generally chosen (by an average of ~1°F), even with the learning thermostat. Despite this "takeback," cooling savings were about 15.4 kWh/day (37%). Another noteworthy finding: the eight heat pump water heaters replacing electric resistance units showed consistently large energy use reductions with savings of 69% (5.3 kWh/day).

## Shallow Plus: Evaluating Specific Advanced Technologies

The "shallow plus" evaluation segment of the project examined individual promising technologies that were evaluated singly so impacts could be isolated. Results of all "shallow plus" measures analyzed in this phase of the project can be found in Sutherland et al. 2016. Highlights:

### Mini-split Heat Pumps

Very substantial savings were found from application of ductless mini-split heat pumps (MSHP). These systems have no duct system and often have high energy efficiency levels. One-ton high-efficiency 25.5 seasonal energy efficiency ratio (SEER), 12 heating seasonal performance factor ductless MSHPs were installed in the main living area of 10 Central Florida homes. These supplemental units were installed with the goal of reducing space-heating and space-cooling energy by minimizing the run time of the less-efficient existing central system. Results suggest cooling energy use savings of 33% (2,007 kWh/year or 7.0 kWh/day) and heating energy use savings of 59% (390 kWh/year or 6.8 kWh/day), for a total annual savings of 34%. The average percent heating energy reductions were considerably greater than cooling for the six homes with electric resistance central heating. While the cost-benefit analysis suggests a payback of 14 years and an annual rate of return of 7%, improved economics are expected as the MSHP market continues to mature with lower costs. A large added non-energy benefit to the consumer is a redundant heating and cooling system—highly desirable given the failure rate of central systems, which tend to be replaced every 12 years and serviced even more often. Electrical demand reductions during peak system hours were very good: 0.50 kW (16%) for summer and 2.06 kW (56%) for winter, as shown in Table 1. Further research on the supplemental MSHP in a cooling-dominated climate is warranted. In addition to achieving large energy savings, the supplemental MSHP showed a potential to improve interior temperature and relative humidity conditions. Full change-outs from central systems to multi-split systems in larger samples are desirable. A thorough description of the project's mini-split heat pump evaluation is given in Sutherland, Parker, and Martin (2016).

**Learning Thermostats**

"Learning" or connected thermostats regulate the home temperature by self-programming depending on heuristic evaluation of user control habits as well as sensed homeowner occupancy. Evaluations of 22 Nest thermostats showed an average space cooling energy savings of 9.6% (498 kWh/year or 2.1 kWh/day)—but with a very high degree of variation. The median savings were 6.3% (219 kWh/year or 1.0 kWh/day). Six of the 22 sites experienced negative savings, which was largely an artifact of pre-retrofit thermostat habits. Average heating season savings were 9.5% (39 kWh/year or 1.1 kWh/day), although the median was higher at 18.5% (35 kWh/year or 1.9 kWh/day). Simple payback based on median savings for the Nest is estimated to be approximately 4 years with an annual rate of return of 24%. Electrical demand reductions during peak system hours were 0.18 kW (7%) for summer and 0.25 kW (14%) for winter. On a site-by-site basis, we found that pre-installation thermostat behavior and consumers' willingness to use available Nest features made an appreciable difference in realized savings. In particular, defeating the occupancy-sensing "away" function appeared to adversely affect savings. With its low cost and quick payback, the learning thermostat is a good addition to the shallow retrofit package. Evaluation of this measure - described by Parker, Sutherland, and Chasar (2016) - found that learning thermostats resulted in increases to time-weighted interior temperatures for cooling and decreases for heating. These changes were associated with observed HVAC energy use reductions.

**Heat Pump Clothes Dryers**

Electric clothes dryers represent 5% (790 kWh) of annual energy use in Florida homes—the second largest appliance energy consumption, behind refrigeration. In eight project test sites, electric resistance clothes dryers were replaced with a new fully-condensing unvented Whirlpool Heat Pump Clothes Dryer (HPCD). The estimated median energy savings were 34% (264 kWh/year or 0.72 kWh/day), and average annual savings are 36% (308 kWh/year or 0.85 kWh/day). Estimated electrical demand reductions during utility coincident peak summer system hour were 0.09 kW (or 48% of dryer contributed peak demand) as shown in Table 1. Although unvented HPCDs use less electricity than standard resistance dryers, they release a significant amount of heat during operation. The interior-located unvented units led to very high utility room temperatures and increases in space-cooling energy that likely compromise identified savings. Given the heat issue, these unvented appliances are appropriate in a cooling-dominated climate only if installed outside the conditioned space. We anticipate another technology marketed by LG—vented HPCD—may be the most appropriate system type for Florida. Further research is warranted (see Martin, Sutherland, and Parker 2016).

**Variable Speed Pool Pumps**

A third of Florida homes have pool pumps, which often use more than 3,500 kWh/year. Replacing standard pool pumps in five Central and South Florida homes with variable-speed pumps resulted in large energy and demand savings. Pre/post energy savings averaged 68% (7.3 kWh/day) and ranged from 49%–80% (4.9–10.3 kWh/day). Mean annual energy cost savings amounted to $320 (2,665 kWh/year) with an exceedingly rapid simple payback of 2.7 years. Electrical demand reductions during peak summer system hour were very large: 1.08 kW (86%) as shown in Table 1.

Table 1. Summary of Peak System Hour Demand Impacts

| Retrofit Package or Measure | Peak Summer Demand Pre (kW) | Peak Summer Demand Post (kW) | Peak Summer Demand Delta (kW/%) | Peak Winter Demand Pre (kW) | Peak Winter Demand Post (kW) | Peak Winter Demand Delta (kW/%) |
|---|---|---|---|---|---|---|
| **Shallow Retrofit** | **3.41** | **2.74** | **0.67/20%** | **3.72** | **3.47** | **0.25/7%** |
| **Deep Retrofit** | **4.97** | **3.01** | **1.96/39%** | **4.51** | **1.80** | **2.71/60%** |
| **Min-Split Heat Pump** | **3.12** | **2.61** | **0.50/16%** | **3.71** | **1.65** | **2.06/56%** |
| **Learning Thermostat** | **2.40** | **2.23** | **0.18/7%** | **1.78** | **1.54** | **0.25/14%** |
| **Heat Pump Clothes Dryer** | **0.18** | **0.09** | **0.09/48%** | **n/a** | **n/a** | **n/a** |
| **Variable Speed Pool Pump** | **1.26** | **0.18** | **1.08/86%** | **n/a** | **n/a** | **n/a** |

## Conclusions

Fifty-six all electric Florida homes were recruited, audited, and instrumented to capture energy consumption on up to 18 end-uses. Detailed, monitored end-use data were collected pre- and post-retrofit. The resolution of end-use data enabled the identification of phenomena and unexpected behavior that would have gone unnoticed using algorithm-based disaggregation methods or other methods often used for formalized measurement and verification purposes.

Baseline measurements from the project allowed development of seasonal end-use load profiles for the utility service territory. The sample then served as a testbed to evaluate energy and peak demand reductions from a variety of packaged retrofits (shallow and deep) and individual emerging technologies. Shallow retrofit energy savings of 8-10% were demonstrated as well as annual energy reductions averaging 38% for deeper retrofits. Individual technology evaluations showed large potential for mini-split heat pumps with 34% HVAC energy use reduction, and learning thermostats with 10% HVAC reduction. Variable-speed pool pumps demonstrated 68% energy use reductions while heat pump clothes dryers showed 34% lower dryer energy use versus conventional resistance models. Potential improvements to both the shallow and deep retrofit segments were identified. Refrigerator coil cleaning can be dropped and smart power strips could be optional for the shallow retrofit segment, while routinely installed learning thermostats could significantly bolster performance.

As shown, utilities could potentially offer programs to capture the described project savings. Scaled-up programs, marketed and incentivized, could help utilities meet their energy use and peak reduction goals. Barriers to large-scale implementation include Florida's reliance on Rate Impact Measure (RIM) evaluations that focus on revenue losses as well as homeowner aversion to larger capital investments. These might be addressed through rebates and efficient program design.

## Future Effort

Using the lessons learned from this study, a similar project is being planned for California. In addition to efficiency retrofits in its varied climates, the California study has goals of creating a legacy sample for baseline end-use load profiles and how they naturally change over time. It would also be possible to closely evaluate impacts from roof-based photovoltaic (PV) panels by orientation, tilt and location as well as how shading from PV arrays influence cooling loads. The project plan also includes an evaluation of how on-site battery storage and electric vehicle charging can influence the load shapes.

Detailed end-use monitoring allows evaluation of end-use disaggregation schemes using Advanced Meters Infrastructure (AMI) data. Utility time series data could be run through existing disaggregation schemes to compare estimates to actually measured energy-end-uses. Moreover, the accuracy of the disaggregation procedures converting AMI data into end-uses could likely be improved by evaluation of how to reduce errors in estimation (Mayhorn et al. 2015).

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