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Phased Retrofits in Existing Homes in Florida Phase I: Shallow and Deep Retrofits

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Building America Partnership for Advanced Residential Construction

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The work presented in this report does not represent performance of any product relative to regulated minimum efficiency requirements.

The laboratory and/or field sites used for this work are not certified rating test facilities. The conditions and methods under which products were characterized for this work differ from standard rating conditions, as described.

Because the methods and conditions differ, the reported results are not comparable to rated product performance and should only be used to estimate performance under the measured conditions.

Contents

List of Figures

Unless otherwise noted, all figures were created by the Building America Partnership for Improved Residential Construction.

List of Tables

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Definitions

AC	Air Conditioning, Air Conditioner
AHU	Air Handling Unit
APS	Advanced Power Strip
CDD	Cooling Degree Day
CFL	Compact Fluorescent Lamp
CI	Confidence Interval
CMU	Concrete Masonry Unit
COVAR	Coefficient of Variation
COP	Coefficient of Performance
FPL	Florida Power & Light Company
FSEC	Florida Solar Energy Center
HDD	Heating Degree Day
HPWH	Heat Pump Water Heater
HVAC	Heating, Ventilating, and Air Conditioning
kWh	Kilowatt Hour
LED	Light-Emitting Diode
PDR	Phased Deep Retrofit
R^2	Coefficient of Determination
RH	Relative Humidity
R-Value (R-*n*)	Thermal Resistance Measure
SEER	Seasonal Energy Efficiency Ratio
SOG	Slab on Grade
TMY3	Typical Meteorological Year 3

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Executive Summary

The U.S. Department of Energy's Building America research team Building America Partnership for Improved Residential Construction is collaborating with Florida Power & Light (FPL) to conduct a phased residential energy-efficiency retrofit program. This research seeks to establish impacts on annual energy and peak energy reductions from the technologies applied at two levels of retrofit—shallow and deep—with savings levels that approach the Building America program goal of reducing whole-house energy use by 40%.

Under the Phased Deep Retrofit project, energy-efficiency retrofits were installed by local contractors and research staff in a sample of 56 existing, all-electric homes. End-use savings and economic evaluation results from the phased measure packages and single measures are summarized in this report. Project results will be of interest to utility program designers, weatherization evaluators, and the housing remodel industry.

The study homes are located in central and south Florida. They were built between 1942 and 2006 average 1,777 ft^2 of conditioned area, and have an average of 2.6 occupants. Data are collected on total house power along with detailed energy end-use data to evaluate energy reductions and the economics of each retrofit phase. Homes were audited and instrumented during the second half of 2012.

Shallow retrofits were conducted in all homes from March to June 2013. The energy reduction measures for this phase were chosen based on ease of installation and targeted lighting (compact fluorescent and light-emitting diode lamps), domestic hot water (wraps and showerheads), refrigeration (cleaning of coils), pool pumps (reduction of operating hours), and home entertainment centers (advanced power strips).

Deep retrofits were conducted on a subset of 10 Phased Deep Retrofit homes from May 2013 through March 2014. Measures associated with the deep phase of the project 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. Pool pumps were changed to variable-speed units, and ceiling insulation was augmented where deficient. Old and inefficient major appliances such as refrigerators and dishwashers were replaced with more efficient units.

Energy Savings of Shallow Retrofits

The team used several methods to examine shallow retrofit energy savings and reductions to utility-coincident peak power. Whole-house energy savings were similar between the two evaluations: 8%–10% or about 4 kWh/day. End-use savings results differed between the two methodologies. Savings from the pool pump time reduction almost disappeared in the evaluation several months later. With typical seasonal adjustments, some pump timers were likely moved back to pre-retrofit settings. Professional pushback on the timer adjustment from the pool maintenance industry was reported. Estimated savings to water heating were about 0.5 kWh/day.

The lighting retrofit consistently produced significant savings regardless of the evaluation method. End-use savings for lighting appeared to be greater in the pre- and post-retrofit October comparison than in the 30-days pre- and post-retrofit evaluation. This may have been due to greater interior illumination use during October.

The cost-effectiveness of the shallow retrofit procedure is promising. Average energy savings from the shallow retrofits was 1,310–1,530 kWh/year. The average total cost was estimated at $374, of which $253 were hard costs. Simple payback will be reached in 2 years.

The team conducted a longer-term analysis on 41 sites using monthly utility records to confirm the estimation of whole-house savings and to investigate the influence the shallow retrofits had on space conditioning. Although the shallow retrofit did not specifically address the space-condition end use, results show that cooling energy was reduced by 16% post-retrofit (1,353 kWh annual savings), which is attributed to the large reduction in released internal heat gains from the more efficient lighting. The loss in heat gains likewise influenced space-heating needs, which nearly doubled post-retrofit (629 kWh negative savings annually). In the end, the utility data analysis showed net annual savings from the shallow retrofits of 1,356 kWh (about 8.7%).

The 3.7 kWh/day whole-house post-retrofit savings projected by the normalized utility analysis substantiates the estimates that arose from the preliminary short-term monitored data. The savings projections are also very similar when the models are applied to Typical Meteorological Year 3 weather data that are weighted by FPL service area, which confirmed the final estimates of 8%–10%.

The FPL system peak winter hour comparison for the shallow retrofit sites showed a reduction of 0.25 kW between 7 and 8 a.m. (identified as largely the impact of the hot water tank wrap and new showerheads); however, heating demand later in the day increased after the lighting retrofit's heat gain reduction so that daily consumption increased by 8%. Unfortunately, a comparison of pre- and post-retrofit whole-house demand during the FPL system peak summer hour was not possible, because homes were not monitored before the baseline peak. However, the team was able to compare the subsample of 18 homes using the hottest day during the local peak hour in October for pre- and post-retrofit years. This comparison showed a whole-house reduction of 0.67 kW between 4 and 5 p.m. The energy use reduction for the day was 9%: energy use was 52.1 kWh pre-retrofit and 47.4 kWh post-retrofit.

Energy Savings of Deep Retrofits

For the deep retrofits, the team conducted a utility data analysis to compare 1 year pre-retrofit to 1 year post-retrofit for the 10 deep retrofit sites to evaluate energy savings. The results show that average post-retrofit annual cooling energy 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 range for individual homes was 22%–52%.

Using incremental costs and an average cost 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 a full cost of $14,323, the economics are less attractive. The simple payback for the package of measures increases to 16.9 years with a simple rate of return of 5.9%. 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 results in a 10.5-year payback.

Figure E-1 compares pre- to post-retrofit whole-house demand during the FPL system peak summer hour for the 2 consecutive years on the utility system peak days. Data showed a reduction of 1.96 kW between 4 and 5 p.m. The energy use reduction for the day was 37%: energy use was 76.2 kWh pre-retrofit and 48.3 kWh post-retrofit.

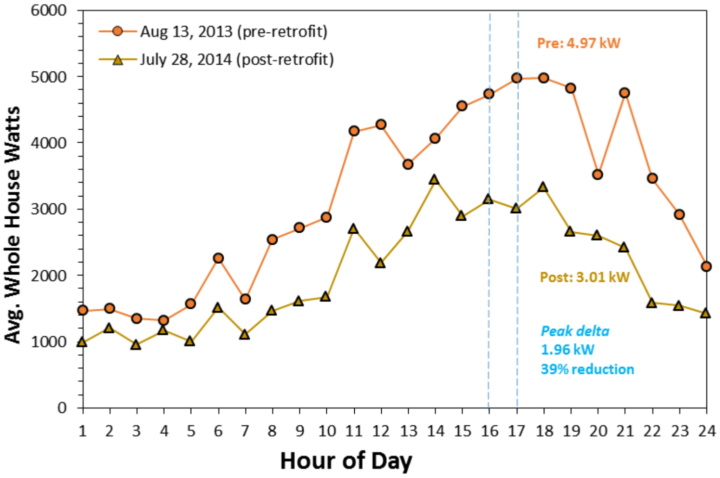

Figure E-1. Comparative analysis between pre- and post-retrofit demand for deep retrofits: FPL system peak summer day

The FPL system peak winter hour comparison revealed a post-retrofit whole-house demand reduction of 2.71 kW between 7 and 8 a.m. Daily energy use decreased by 44% post-retrofit: energy use was 67.3 kWh pre-retrofit and 37.5 kWh post-retrofit.

Estimation of Savings for Specific Measures and End Uses

The pre/post evaluation of the 10 heating, ventilating, and air-conditioning (HVAC) retrofits showed that the heat pump replacement and duct repair saved an average of 40% of pre-retrofit space-conditioning energy consumption; however, lower interior temperatures were generally chosen (by an average of ~1°F) even with the learning thermostat. Final cooling energy savings were about 15.4 kWh/day in summer or 37%. Figure E-2 graphically displays an example of 47% HVAC retrofit savings at Site 26.

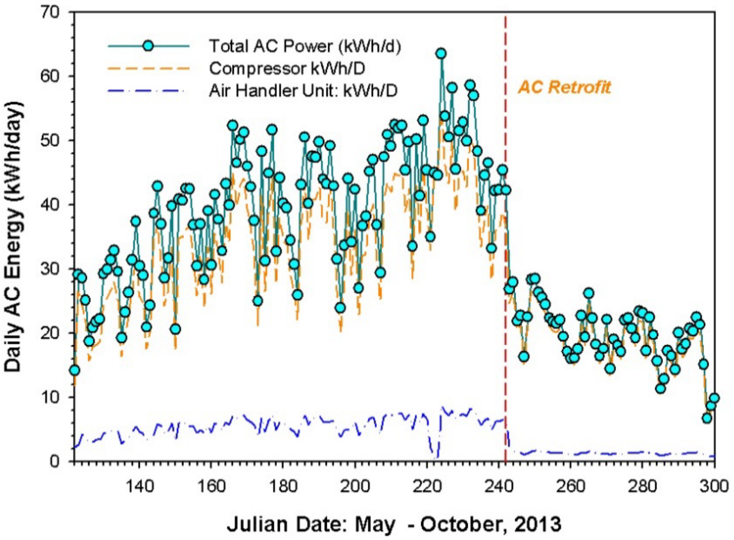

Figure E-2. Site 26 air-conditioning energy: pre- and post-retrofit, May–October 2013

Eight sites that replaced electric resistance water heaters with heat pump models exhibited large energy use reductions. Savings averaged 69% of pre-retrofit water heating energy (5.3 kWh/day).

Refrigerator replacement in three homes showed average savings of 42% compared to the original refrigerator (1.3 kWh/day). Post-retrofit energy savings for the single dishwasher change-out were 32% (0.5 kWh/day), excluding hot water demand reductions. A first-of-its-kind low-energy clothes dryer produced average pre/post-retrofit savings of 22% (0.7 kWh/day) for the eight homes in which they were installed, although savings were highly variable. Savings from variable-speed pumps installed at three pool sites were very large: 80%–90% (averaging 12.6 kWh/day). However, only about half of the potential savings were achieved unless the variable-speed units were properly programmed. Table E-1 summarizes energy savings and peak hour reduction results by end use.

Conclusions

A much larger-scale deep retrofit program could be favorably designed by targeting efficiency changes at the time a homeowner replaces an aging HVAC system with an efficient one. At that point all the other improvements would be performed outright. This program model has favorable economics (payback is approximately 10 years without utility rebates) and has the advantage of engaging the homeowners at the time when large alterations are already underway. The energy savings (38%) would be highly visible to homeowners and would provide even greater reductions to the combined winter and summer coincident peak demand (see Table E-1), which would benefit the utility.

Next Steps

Future reporting will include energy use changes that result from shallow-plus and deep-plus retrofits that are underway for a number of study homes. Measures include interior-ducted heat pump water heaters, mini-split heat pumps, window retrofits, exterior insulation systems, and a much larger sample of learning thermostats.

Table E-1. Shallow and Deep Retrofit Energy Impact Results Summary

Shallow and Deep Retrofit Energy Impacts[a]	Annual Energy Savings		Summer Peak Hour Reduction[b]		Winter Peak Hour Reduction		Cost	
	kWh	%	kW	%	kW	%	Total	Incremental
Shallow Retrofits								
Space Cooling	1,353	16%	0.42	24%			$0	$0
Space Heating	(629)	–78%			(0.11)	-6%	$0	$0
Lighting and Other	664	22%	0.24	42%	(0.02)	-6%	$281	$281
Water Heating	180	11%	0.11	26%	0.36	56%	$94	$94
Pool Pump	175	14%	0.05	28%	0.00	7%	$8	$8
Whole-House	**1,356**	**9%**	**0.67**	**20%**	**0.25**	**7%**	**$374**	**$374**
Deep Retrofits (shallow and deep retrofit impacts are presented unless otherwise noted)								
Space Cooling	4,336	46%	1.92	52%			$8,016	$2,635
Space Heating	854	33%			2.26	80%		
Water Heating[c]	1,924	69%	0.26	100%	0.32	34%	$2,274	$1,478
Refrigerator (n = 3)	471	42%	0.06	48%	0.02	19%	$1,208	$0
Clothes Dryer[d]	267	22%	0.04	26%	0.08	39%	$2,620	$1,087
Dishwasher[e] (n = 1)	175	32%	(0.27)	N/A	-	N/A	$508	$0
Pool Pump[e] (n = 3)	4,599	86%	0.89	91%	(0.09)	N/A	$2,035	$1,458
Whole-House	**7,067**	**38%**	**1.96**	**39%**	**2.71**	**60%**	**$14,323**	**$7,074**

[a] Sample size varies by end use and metric. End uses cannot be summed for whole-house total. Very small sample sizes are noted as “n = *x*.”

[b] Shallow retrofit summer peak is a surrogate October date; deep retrofit summer peak is for the deep retrofit only, so results are conservative.

[c] Water heating energy savings baseline includes partial post-retrofit (shallow), so results are conservative. Water heating had no post-retrofit peak summer hour demand in the heat pump water heater segment.

[d] Cost includes the clothes washer and dryer as a set.

[e] No pre-retrofit peak winter hour demand for the dishwasher or pool pump; no post-retrofit peak winter hour demand for the dishwasher.

1 Introduction

The U.S. Department of Energy's Building America research team Partnership for Improved Residential Construction is pursuing a pilot phased energy-efficiency retrofit program in Florida by creating detailed data about the energy and economic performance of two levels of retrofit: shallow and deep. Fifty-six homes were audited and instrumented between August 2012 and March 2013.

Homeowners were recruited via a press release and ads in local newspapers. These generated an overwhelming response, presumably because participants would receive free home improvement measures. Phone screening of potential participants included ensuring that the home was all-electric, that it had no more than one heating or air-conditioning (AC) system, that occupants did not operate an energy-intensive business out of the home, and other criteria.

All homes received simple pass-through retrofit measures conducted by research staff. The shallow retrofits were applicable to all homes and provided critical data to the design of deep retrofits that make a major impact on whole-house energy use, peak demand, and greenhouse gas emissions. Contractors of the various trades involved conducted deep retrofits on a subset of ten of the shallow-retrofitted homes.

The project is being pursued as a collaborative energy research/utility partnership effort with Florida Power & Light (FPL) to audit and retrofit a large number of occupied homes using a phased approach (pass-through audit/simple measures followed by or coupled with deep retrofits) that would result in significant energy savings. The study identifies measured energy savings and peak demand reductions of the retrofit levels and technologies. Findings potentially provide robust guidelines that field auditors could apply by spending limited time in a home and recommending cost-effective options. This pilot effort could be used to refine a potentially larger statewide or even national program with climate-specific applications.

1.1 Background

Residential retrofit programs can be effective, but contemporary larger-scale data are limited. An early large-scale evaluation and audit program in the 1980s achieved significant energy savings in the Hood River Conservation Project. There, Oregon homes received comprehensive retrofits of 15 improvements with a verified 12% savings and a 91% participation rate among several utilities' territories (Hirst and Trumble 1989). Even though dated, that project might serve as a template for a national effort.

Furthermore, during the 1990s in Florida, the Florida Solar Energy Center (FSEC) demonstrated a 14% energy reduction in ten retrofitted Habitat for Humanity homes (Parker, Sherwin, and Floyd 1998). By incorporating research findings and using improved equipment, FSEC also conducted deep retrofit projects in which it has profoundly reduced homes' energy use by applying audits, new technologies, and monitoring. For instance, in one project in an occupied home, FSEC demonstrated a reduction in measured energy use of 45% (Parker et al. 1997). Another occupied home has been progressively retrofitted in recent years to obtain zero net energy (Parker and Sherwin 2012). However, no project has attempted such improvements in a larger sample of homes.

1.2 Technical Approach

Before the project began, the team used Building Energy Optimization software to analyze the potential savings of the shallow retrofit. In consultation with FPL, FSEC recruited 56 all-electric homes from within its service territory. The team created a prototype building with characteristics similar to the average for the aggregate Phased Deep Retrofit (PDR) sample. Indicated end-use and total electricity consumption was compared to the unaltered PDR sample with good correspondence (approximately 15,000 kWh/year before intervention). FSEC simulated a total lighting change-out, a slightly better insulated hot water tank, and reduced pool pump hours (divided by 3 to accommodate for pool saturation in the sample). Indicated electricity savings were approximately 9%–10%, which was close to the measured savings.

Each home was audited, instrumented, and characterized in detail. After the homes were monitored for several months, installed shallow retrofit measures were deployed in each home and generally included:

- Hot water tank and pipe insulation wrap
- Change-out of all eligible light fixtures to compact fluorescent lamp (CFL) or light-emitting diode (LED) equivalents
- Cleaning of refrigerator coils
- Replacement of eligible, homeowner-selected showerheads with low-flow showerheads
- Reduction of pool pump hours
- Advanced power strips (APSs) for home offices, gaming consoles, and entertainment centers.

Deep retrofits were then conducted on ten of the 56 homes to evaluate possible savings from much more aggressive reduction efforts. These deep retrofits were designed based on a computerized analysis from audit and pre-retrofit monitoring data to increase their effectiveness. The savings of the deep retrofits were not estimated in aggregate, because this was done individually in an attempt to settle on the measures. These deep retrofits consisted of installing ceiling insulation; heating, ventilating, and air-conditioning (HVAC) equipment; appliances; and learning thermostats. Measures were identified as most productive by reducing data collected in the first phase along with generic results of energy simulations and optimizations. Each of the ten deep retrofit homes received a new, very high-efficiency heat pump space-conditioning system that was installed at the homeowner’s expense as a buy-in to the program. The installed measures largely include, but are not limited to, the following:

- High-efficiency heat pump for space conditioning
- Duct system testing and sealing and bedroom pressure mapping and pressure relief
- Learning thermostat
- Heat pump water heater (HPWH)
- Upgrading to R-38 ceiling insulation

- ENERGY STAR® refrigerator
- ENERGY STAR clothes washer
- Low-energy clothes dryer
- ENERGY STAR dishwasher
- Variable-speed pool pump.

2 Monitoring Data

2.1 Description of All Sites

The 56 all-electric field test homes are located in central and southern Florida. Originally the sample was to be weighted equally between central and southern Florida. However, difficulty with recruitment made it necessary to locate most of the residential sites in central Florida to meet the project schedule. Table 1 shows selected fundamental characteristics of the homes, including their locations, years built, occupancy, conditioned floor areas, and whether the homes have pools.

Table 1. Selected Site Characteristics of PDR Sample

Site	Town	Year Built	Occupants	Conditioned Floor Area (ft^2)	Pool? (1 = Y, 0 = N)
1	Merritt Island	1961	4	2,459	0
3	Merritt Island	1993	1	1,856	1
4	Melbourne	1971	2	1,166	0
5	Rockledge	2006	2	2,328	0
6	Palm Bay	1981	2	1,542	0
7	Merritt Island	1989	2	2,650	1
8	Grant-Valkaria	1997	4	2,134	0
9	Melbourne	1984	2	1,013	0
10	West Melbourne	2003	2	1,627	0
11	Cocoa Beach	1958	3	1,672	0
12	Port Orange	1984	3	1,594	1
13	Merritt Island	1963	2	1,052	1
14	Melbourne	1942	2	2,016	0
15	Melbourne Beach	1975	2	1,359	1
16	Indialantic	1982	3	2,231	1
17	Indialantic	1964	2	1,456	1
18	Cocoa	1995	2	1,802	1
19	Melbourne	1988	3	2,554	0
21	Cocoa Beach	1981	2	2,096	1
22	Cocoa Beach	1955	2	1,743	0
23	Palm Bay	1980	3	1,946	0
24	Cocoa	1986	3	1,978	0
25	Melbourne	2000	2	1,940	1
26	Palm Bay	1999	5	1,502	0
27	Palm Bay	1995	2	2,050	0
28	Merritt Island	1966	2	2,622	1
29	Cocoa	1985	2	1,215	0
30	Merritt Island	1976	3	1,819	0
31	Cocoa	1989	2	1,474	0
33	Hollywood	1969	3	1,752	0
34	Pembroke Pines	1978	2	1,910	0
35	Plantation	1993	2	1,637	0

Site	Town	Year Built	Occupants	Conditioned Floor Area (ft^2)	Pool? (1 = Y, 0 = N)
37	Cocoa	1993	6	1,654	1
38	Palm Bay	2006	3	1,665	0
39	Palm Bay	1981	4	1,559	0
40	Titusville	1993	3	1,983	0
41	Bonita Springs	1998	2	2,471	1
42	Naples	2001	3	1,666	0
43	Fort Myers	2000	2	1,383	0
44	Naples	1998	2	1,808	1
45	Davie	1987	2	1,500	1
46	Naples	1989	2	2,172	1
47	Fort Myers	1990	4	1,088	0
48	Naples	1973	4	1,436	0
49	Fort Myers	1979	2	1,701	0
50	Melbourne	1958	4	2,168	1
51	Cocoa	1994	2	2,233	0
52	Cocoa	2000	2	1,540	0
53	Melbourne	1980	1	1,677	0
54	Palm Bay	1999	2	1,390	0
55	Melbourne	1976	4	1,980	1
56	Merritt Island	1963	3	1,000	0
57	Melbourne	1993	1	1,406	0
58	Rockledge	1979	2	2,020	0
59	Melbourne Beach	1985	2	2,300	1
60	Palm Bay	1987	3	1,520	0
Averages		**1984**	**2.6**	**1,777**	**34%**

Among the 56 sites with varied construction characteristics, the average vintage is 1984, ranging from 1942 to 2006. Condition floor area averages 1,777 ft^2 and ranges from 1,000 to 2,650 ft^2. The average occupancy is 2.6 persons, varying from 1 to 6. This compares very well with statewide census averages. No homes built more recently than 2006 or larger than 3,000 ft^2 were accepted for the study to make results more appropriate to retrofit programs that target older and less-efficient homes. Nineteen sites (34%) had pools and associated pool pumping. Swimming pool pumps are a known major energy end use.

2.2 Description of Deep Sites

Table 2 summarizes the ten deep retrofitted sites and provides locations, years of construction, occupancy, conditioned floor areas, and whether the homes have pools.

Table 2. Selected Site Characteristics of PDR Deep Retrofit Homes

Site	Town	Zip	Year Built	Adults	Children	Pool? (1 = Y, 0 = N)	Conditioned Floor Area (ft^2)
7	Merritt Island	32952	1989	2	0	1	2,650
8	Grant-Valkaria	32949	1997	2	2	0	2,134
10	West Melbourne	32904	2003	2	0	0	1,627
19	Melbourne	32940	1988	3	0	0	2,554
26	Palm Bay	32907	1999	2	3	0	1,502
30	Merritt Island	32952	1976	2	1	0	1,819
37	Cocoa	32927	1993	4	2	1	1,654
39	Palm Bay	32907	1981	4	0	0	1,559
40	Titusville	32780	1993	3	0	0	1,983
51	Cocoa	32926	1994	2	0	0	2,233
Averages			**1991**	**2.6**	**0.8**	**20%**	**1,972**

The deep retrofit for each home included installation of a high-efficiency air-source heat pump HVAC with a seasonal energy efficiency ratio (SEER) value ranging from 16 to 18 and a heating seasonal performance factor ranging from 9 to 9.5. Other site-specific deep retrofit measures were chosen based on audit data, customized simulations, and end-use load profiles to optimize the energy savings potential in all homes. General house construction descriptions and the time span of the deep retrofit measure installations follow. A detailed summary of the deep retrofit homes' pre- and post-retrofit characteristics is provided in Appendix A.

- Site 7 is a 2,650-ft^2, two-story home built in 1989 with two occupants. Construction is slab-on-grade (SOG) with a combination of a concrete masonry unit (CMU) walls (first floor) and frame walls (second floor). Retrofit measures, detailed in Appendix A, began Sept. 24, 2013 with the HVAC system installation and concluded November 9, 2013 with the ceiling insulation upgrade.
- Site 8 is a 2,134-ft^2, single-story home built in 1997 with four occupants. Construction is SOG with frame walls. Retrofit measures began Aug. 23, 2013 with the HVAC system installation and concluded Oct. 25, 2013 with appliance installations.
- Site 10 is a 1,627-ft^2, single-story home built in 2003 with two occupants. Construction is SOG with CMU walls. Retrofit measures began May 31, 2013 with the HVAC system installation and concluded Dec. 6, 2013 with the ceiling insulation upgrade.
- Site 19 is a 2,554-ft^2, single-story home built in 1988 with three occupants. Construction is SOG with CMU walls. Retrofit measures began Aug. 26, 2013 with the HVAC system installation and concluded Nov. 18, 2013 with appliance installations.
- Site 26 is a 1,502-ft^2, single-story home built in 1999 with five occupants. Construction is SOG with CMU walls. Retrofit measures began Aug. 30, 2013 with the HVAC system installation and concluded Nov. 11, 2013 with the insulation upgrade.

- Site 30 is a 1,819-ft^2, single-story home built in 1976 with three occupants. Construction is SOG with CMU walls. Retrofit measures began Sept. 9, 2013 with the HPWH installation and concluded Nov. 11, 2013 with the insulation upgrade.
- Site 37 is a 1,654-ft^2, single-story home built in 1993 with six occupants. Construction is SOG with frame walls. Retrofit measures began Aug. 29, 2013 with the HVAC system installation and concluded Feb. 24, 2014 with the insulation upgrade.
- Site 39 is a 1,559-ft^2, single-story home built in 1981 with four occupants. Installed retrofit measures began Sept. 3, 2013 with the installation of the HVAC system and concluded Oct. 25, 2013 with the appliance installations.
- Site 40 is a 1,983-ft^2, single-story home built in 1993 with three occupants. Construction is SOG with frame walls. Retrofit measures began Sept. 13, 2013 with the HVAC system installation and concluded Nov. 22, 2013 with the ceiling insulation upgrade.
- Site 51 is a 2,233-ft^2, two-story home built in 1994 with two occupants. Construction includes a crawlspace and frame walls. Retrofit measures began Aug. 27, 2013 with the HVAC system installation and concluded Mar. 26, 2014 with the ceiling insulation upgrade.

2.3 Audit and Instrumentation Installation

Installations and audits began in August 2012. Table 3 shows the months the sites were audited and instrumented.

Table 3. Sites Installed by Month in 2012

Month	Total Cumulative Installations
August 2012	10
September 2012	26
October 2012	32
November 2012	44
December 2012	57
January 2013	59
March 2013	60

Because the program availability was not widely advertised either by FSEC or FPL, how well such a program would be received in a much wider program context cannot be determined. However, a main reason for the strong response in central Florida came from a press release that was printed in *Florida Today* along with a follow-up story by a columnist. Figure 1 shows the geographic distribution of study sites in Florida.

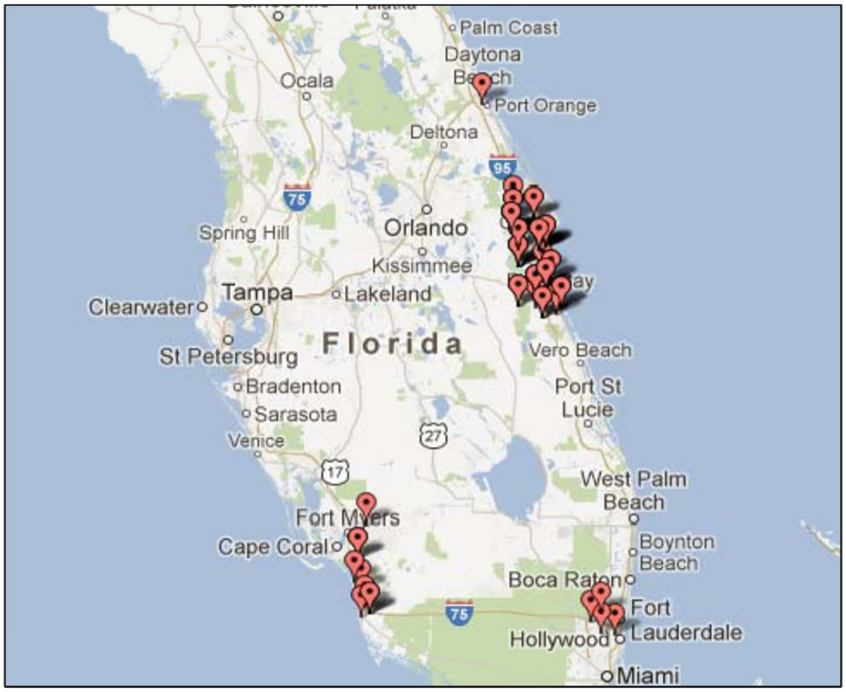

Figure 1. Geographic distribution of the PDR sites in Florida

2.4 Measurements and Equipment

Detailed audit data were obtained from all homes and include house size and geometry, insulation levels, materials, finishes, and equipment. Blower door and duct leakage tests were completed on each home. Detailed photographs were also taken of the home exteriors, appliances and equipment, and thermostats. Showerhead flow rates were measured during the shallow retrofits.

House power and the various end uses are monitored by a 24-channel data logger (eMonitor), which is supplemented by portable loggers (LaCrosse and HOBO) to take temperature and humidity data and a portable power logger (Watts up?) to obtain energy use data about the main home entertainment center, game systems, and home office and computer workstations. Data are retrieved daily over the Internet via broadband connection on a 1-hour time step. Ambient temperature and relative humidity (RH) data are obtained from nearby weather stations. Table 4 summarizes the measurements and equipment that are used to conduct field testing and data acquisition for the project.

Table 4. Equipment Used for Field Testing

Measurement	Equipment Used
House Envelope Airtightness	Blower door and manometer
Duct Leakage	Duct blaster
Temperature and RH	HOBO temperature and RH logger LaCrosse temperature and humidity logger
Entertainment Centers, Game Systems, Home Office/Computer Workstations	WattsUp.com
Detailed House Power (Total, HVAC, Water Heating, Cooking, Clothes Drying, Refrigeration, Pool Pump)	eMonitor by Powerhouse Dynamics

3 Pre-Retrofit Data

A dedicated website ([www.infomonitors.com/pdr/)](www.infomonitors.com/pdr/) has been set up to host the monitored energy data from the project.

Data are available for each site and for each energy end use. Samples of energy end-use data from the site database for a single site are illustrated in Figure 2 through Figure 6, both as time series over the entire period and as daily end-use load profiles averaged over the 24-hour cycle.

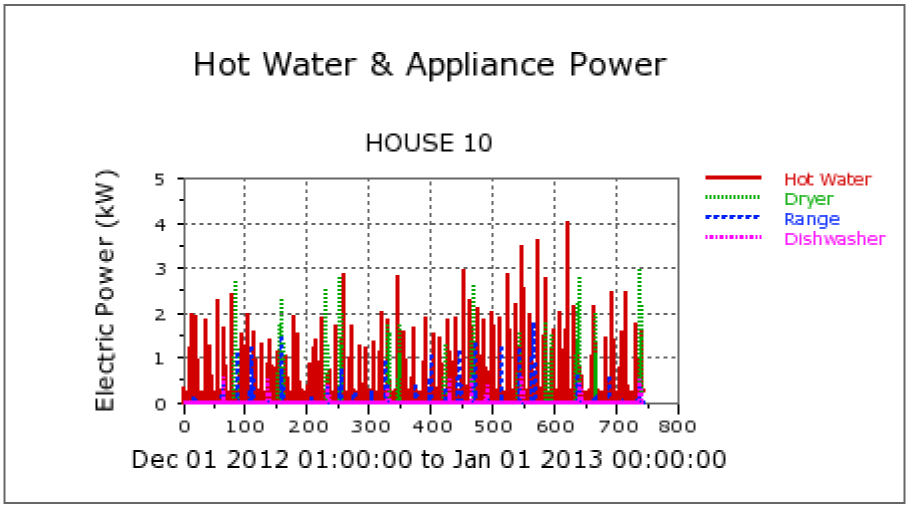

Figure 2. Site 10: Appliance electricity use for December 2012 (time series)

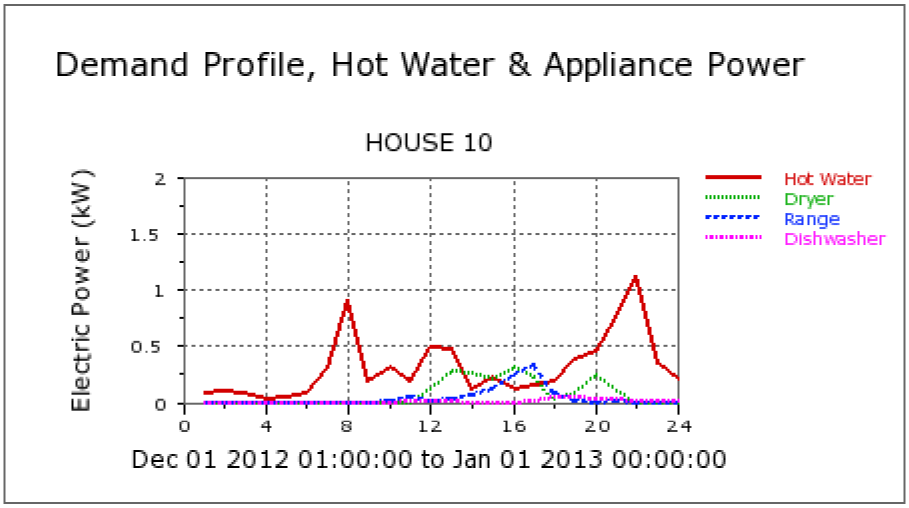

Figure 3. Site 10: Average appliance electricity demand for December 2012 (profiles)

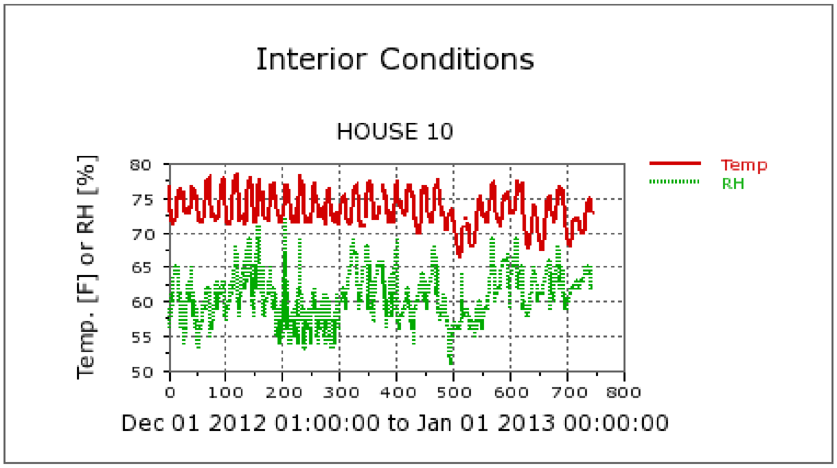

Figure 4. Site 10: Hourly interior temperatures and humidities during December 2012

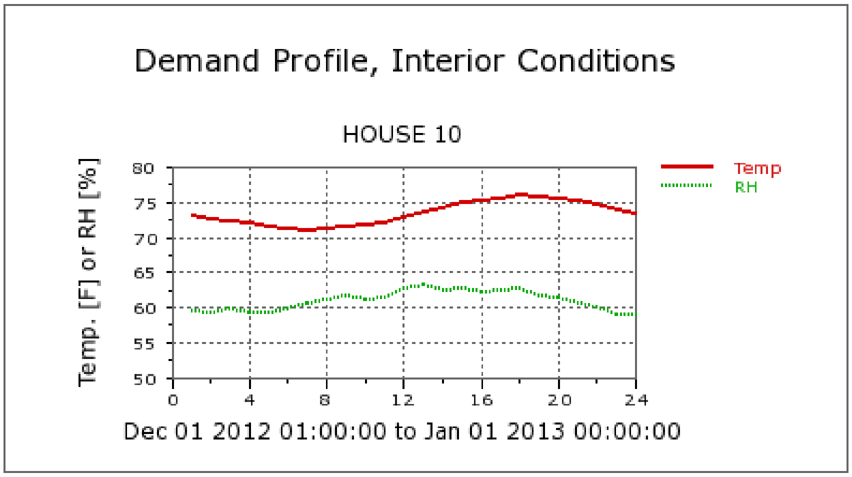

Figure 5. Site 10: Average interior temperatures and humidities during December 2012

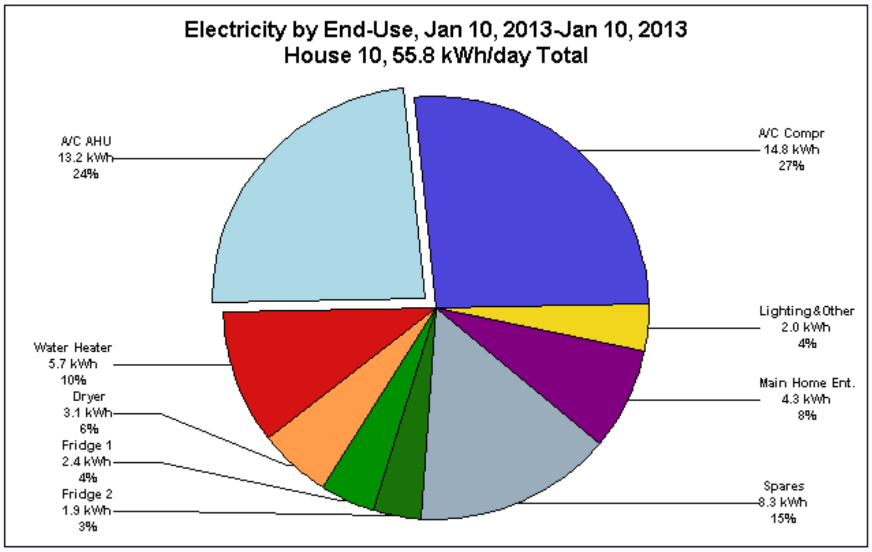

Figure 6. Components of energy end-use loads for January 10, 2013 at Site 10

Table 5 provides initial metering data for the first 30 homes of the sample when evaluated monthly from September through December 2012 before any retrofits were completed. This results in a consistent sample over the period. "Other" in this case includes plug loads and other loads measured on the Spare 1–4 circuits that vary from the mundane (home offices and freezers) to the exotic (spa-side wine coolers and fish ponds).

Table 5. Early Monitoring Results September—December 2012 Averages, Sites 1–30

House	Refrig (kWh/d)	Refrig 2 Daily (kWh/d)	Pool Daily (kWh/d)	Main TV and Ent. Daily (kWh/d)	Other Daily (kWh/d)	Indoor Temp. (°F)	RH (%)
Sept	2.9	1.8	4.5	2.2	10.7	77.6	56.8
Oct	2.9	2.0	4.1	2.0	10.3	76.9	57.4
Nov	2.4	1.8	3.9	2.0	10.5	73.4	62.6
Dec	2.4	2.6	3.8	2.0	12.9	73.6	64.9

Next to the month in Table 6 are the FPL-estimated monthly average kilowatt-hours per day from its end-use studies (FPL 1999) with estimates for central Florida.

Table 6. Utility-Estimated kWh/day Averages Versus Monitoring Results, September—December

Month	FPL Total (kWh/d)	Whole-House Daily (kWh/d)	A/C Comp Daily (kWh/d)	A/C AHU Daily (kWh/d)	DHW Daily (kWh/d)	Dryer Daily (kWh/d)	Range Daily (kWh/d)	Dishw Daily (kWh/d)
Sept	59.8	55.9	22.5	3.6	4.7	2.1	0.7	0.3
Oct	49.6	47.4	15.3	2.6	5.1	2.0	0.7	0.3
Nov	42.9	34.0	2.5	1.1	6.2	2.4	0.9	0.4
Dec	42.6	38.5	4.1	2.1	6.6	2.5	0.9	0.5

In Table 6 the FPL averages by month agree closely with the monitoring from the PDR project. The preliminary project data reflect the complexity of energy use in modern Florida homes. Although AC use is high in September, no other single end-use load is otherwise dominant. However, homes that have pools show pool pumping to be another very large electricity load. Figure 7 summarizes these end-use data in graphical form.

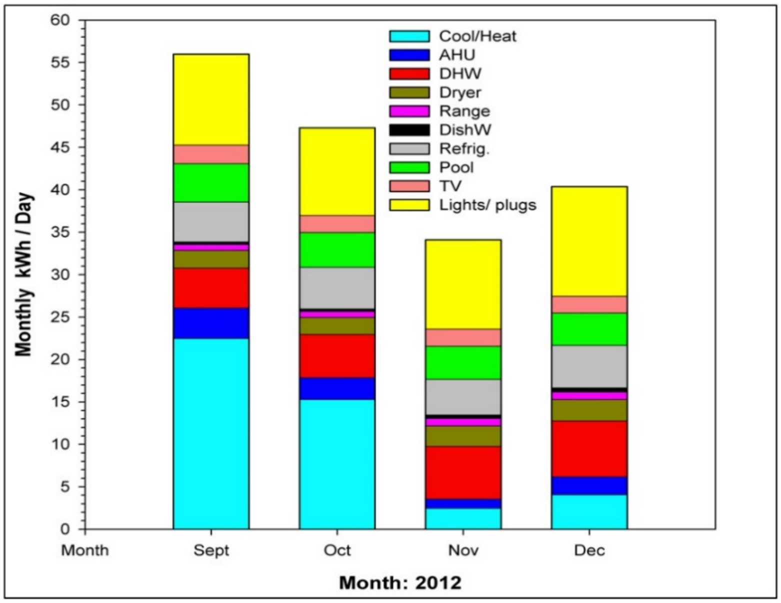

Figure 7. PDR project: End-use monitoring data, September–December 2012

The data reveal how house AC drops with cooler temperatures and the marked seasonal variation in hot water energy use. Cooking energy use is light and somewhat greater over the holidays. Refrigeration is also surprisingly high—nearly equal to the magnitude of water heating when second refrigerators are considered. Clothes dryers also represent a relatively high appliance load, equating to more than 800 kWh if evaluated over the year. Surprisingly, the main television and entertainment center, seldom considered from an energy-efficiency perspective, was also a high load of similar magnitude (approximately 750 kWh/year). Other loads, which include lighting, computers, ceiling fans, and plugs, show a jump in December that is likely related to holiday lighting.

The change in interior temperature from summer to winter reflects the changing need for AC. This also strongly influences interior moisture levels, which increase substantially as mechanical cooling drops and moisture removal from AC falls.

3.1 Annual End-Use Energy Data Summary for 2013

Table 7 and Table 8 show the monitoring results for all of 2013 in the complete sample of homes. Data are given in the average kilowatt-hours per day for the various end uses for the 56 homes with complete monitoring data (four sites withdrew from the project over the year). The temperature and humidity recorded near the home's central thermostat are also shown. Spares 1–4 are used to record computers, freezers, and unusual loads. These data include the pre-retrofit and shallow and deep retrofit periods and thus provide an annual snapshot of energy use over the entire year of the project.

"Other" is the residual loads observed (plugs, fans, lighting) after all end-use loads are subtracted from the building total. It is also important to note that the average pool pump energy is for the entire sample. When confined to sites with operating pool pumps, consumption was about 10 kWh/day.

A graphical summary of each site's energy end uses is shown by the stacked bar presentation in Figure 8 for all of 2013. Figure 9 shows the average end-use makeup for the entire sample as a pie chart. Figure 10 shows the average daily time-of-day demand profile from each site and for each end use over the year. A consistent color-coding is used in all the charts.

Table 7. Measured Energy Use in 60 Homes PDR Sample: December 2012

House	Whole-House Daily (kWh/d)	A/C Comp Daily (kWh/d)	A/C AHU Daily (kWh/d)	DHW Daily (kWh/d)	Dryer Daily (kWh/d)	Range Daily (kWh/d)	Dishw Daily (kWh/d)	Refrig 1 Daily (kWh/d)	Refrig 2 Daily (kWh/d)
1	40.2	12.8	3.1	4.4	2.4	0.2	0.1	2.6	3.3
2	41.3	7.1	1.6	5.3	2.3	0.5	0.7	2.2	1.4
3	47.0	15.0	2.5	2.3	0.4	0.3	0.1	2.0	2.0
4	30.9	9.7	1.3	4.5	3.3	0.4	–	2.5	–
5	71.7	30.2	3.5	7.7	2.0	1.0	0.3	2.1	1.5
6	31.6	2.7	1.2	5.0	0.3	0.9	0.4	2.2	4.6
7	57.3	18.3	3.5	4.8	1.5	1.1	0.4	2	1.4
8	40.1	10.5	1.6	7.2	4.4	1.4	1.7	2.1	2.4
9	37.7	6.9	1.4	7.4	1.5	2.0	0.1	1.7	4.1
10	46.6	18.6	2.7	4.6	1.2	0.7	0.2	2.3	2.1
11	15.7	11.2	1.5	5.0	0.5	1.6	0.0	2.4	–
12	34.6	11.3	2.2	7.1	1.7	0.9	0.3	1.5	–
13	51.1	9.2	–	5.6	2.3	0.7	0.2	2.6	2.1
14	44.0	7.8	1.9	2.8	0.9	0.7	–	2.0	0.0
15	28.4	6.5	1.4	1.7	0.5	0.5	0.0	4.1	–
16	52.2	15.9	4.9	3.7	4.5	0.9	0.8	3.5	2.2
17	35.6	9.3	0.6	5.0	1.4	1.0	0.1	1.7	4.8
18	32.5	10.8	2.0	1.8	0.6	0.4	0.1	1.7	0.1
19	63.3	24.4	7.5	9.6	7.9	0.6	0.9	2.2	1.0
20	46.3	1.6	0.6	9.8	2.7	0.9	0.1	1.9	2.5
21	74.1	17.9	3.7	7.1	2.8	0.7	0.8	2.0	7.4
22	33.2	7.5	1.2	3.4	1.6	0.2	0.3	2.2	1.8
23	49.0	18.4	7.2	4.7	0.8	1.1	0.0	.90	6.2
24	37.7	14.9	3.0	6.0	2.6	0.6	0.7	1.8	–
25	36.0	5.4	1.4	2.4	2.6	0.3	0.2	1.8	0.0
26	52.7	19.8	3.4	7.5	4.8	1.5	0.7	2.8	–
27	52.6	34.5	–	3.2	0.6	0.2	0.1	1.9	2.9
28	43.7	9.4	2.1	3.5	2.7	0.6	0.3	4.3	2.9
29	32.0	12.3	2.1	3.0	2.8	0.6	0.2	2.4	–
30	28.7	7.8	1.1	7.2	2.1	1.1	0.2	2.4	2.9

House	Whole-House Daily (kWh/d)	A/C Comp Daily (kWh/d)	A/C AHU Daily (kWh/d)	DHW Daily (kWh/d)	Dryer Daily (kWh/d)	Range Daily (kWh/d)	Dishw Daily (kWh/d)	Refrig 1 Daily (kWh/d)	Refrig 2 Daily (kWh/d)
31	28.6	8.0	5.8	3.8	1.3	0.2	0.2	1.8	1.2
32	31.0	3.6	1.2	2.0	3.5	0.5	0.2	0.7	2.6
33	55.6	18.8	0.0	3.1	7.6	0.8	0.2	2.2	0.0
34	28.4	11.8	0.0	2.2	1.0	0.5	0.1	1.3	1.3
35	53.3	24.2	2.8	8.4	1.6	0.8	0.3	2.8	3.7
36	29.8	8.8	1.9	2.4	1.3	0.6	0.6	1.2	0.0
37	80.3	20.0	4.1	8.8	3.1	3.0	0.4	2.6	1.0
38	41.3	12.3	4.8	6.1	1.8	1.2	0.2	3.2	3.4
39	38.0	9.8	2.5	4.8	1.0	1.0	0.5	2.7	9.5
40	33.2	13.4	5.1	3.2	1.4	0.6	0.3	1.6	0.3
41	54.4	13.0	3.0	4.0	2.5	0.3	0.4	3.0	0.0
42	49.1	23.2	2.9	4.3	2.3	0.5	0.4	2.3	0.0
43	27.2	10.5	1.7	5.2	2.2	0.6	0.3	2.2	0.1
44	35.5	10.3	3.0	4.4	1.8	0.6	0.1	1.6	0.9
45	31.7	12.7	1.5	2.8	0.4	0.7	0.5	2.0	0.0
46	41.0	7.1	3.2	3.1	1.7	0.3	0.1	1.5	0.0
47	30.2	11.4	1.2	3.7	3.2	0.8	0.0	1.8	0.0
48	63.8	16.4	0.0	8.1	2.5	0.8	0.6	2.2	3.2
49	62.7	20.8	4.8	1.4	1.4	0.3	0.2	2.0	2.4
50	48.1	11.8	3.1	6.4	2.8	1.2	0.3	3.3	0.6
51	38.1	13.7	6.9	2.4	0.9	0.6	0.0	3.0	1.7
52	48.1	7.2	2.0	5.5	2.0	1.3	0.8	2.7	1.1
53	32.5	11.8	0.8	5.1	1.6	0.3	0.2	3.8	0.8
54	52.7	20.2	2.8	8.7	5.2	0.8	0.4	1.8	2.0
55	43.3	9.4	2.0	3.6	1.8	1.1	0.6	1.9	2.1
56	29.7	10.3	3.9	5.2	2.4	1.0	0.6	2.0	0.6
57	20.6	5.9	2.6	4.4	0.7	0.5	0.1	1.5	1.0
58	50.7	12.0	2.1	5.7	1.8	1.4	0.5	3.7	6.3
59	34.6	11.9	1.9	2.8	0.6	0.9	0.2	3.5	1.3
60	30.9	10.2	2.2	2.4	2.9	1.4	0.3	1.6	2.1
Average	**42.2**	**12.8**	**2.5**	**4.8**	**2.2**	**0.8**	**0.3**	**2.3**	**1.8**

Table 8. Measured Energy Use and Interior Conditions in PDR Sample: December 2012

House	Spare 1 Daily (kWh/d)	Spare 2 Daily (kWh/d)	Spare 3 Daily (kWh/d)	Spare 4 Daily (kWh/d)	Pool Daily (kWh/d)	Main Home Ent Daily (kWh/d)	Lights & Other Daily (kWh/d)	Temp Average (°F)	RH Average (%)
1	0.4	–	–	–	–	4.2	6.7	76.6	63.4
2	1.6	0.3	0.0	–	10.5	0.7	7.3	75.9	60.1
3	1.8	1.0	1\1	–	8.5	2.8	7.1	74.0	58.5
4	–	–	–	–	–	3.1	6.4	76.6	57.5
5	1.7	1.1	7.2	–	–	1.9	11.5	76.4	47.6
6	6.4	3.5	1.5	–	–	1.5	1.8	76.0	63.5
7	–	–	–	–	10.2	2.1	12	71.7	59.6
8	–	–	–	–	–	1.1	7.5	77.6	65.2
9	1.6	3.2	–	–	–	1.5	6.3	76.2	63.0
10	3.3	1.7	2.7	–	–	4.4	2.8	73.8	55.5
11	–	–	–	–	–	1.6	1.7	76.5	66.5
12	–	–	–	–	0.5	1.4	7.6	73.1	59.3
13	1.0	2.6	2.2	2.5	9.0	1.6	9.9	76.8	63.1
14	16.2	–	–	–	–	0.5	11.3	74.1	69.6
15	0.4	–	–	–	6.3	1.2	5.7	78.7	62.8
16	–	–	–	0.3	6.1	1.3	8.3	74.9	68.7
17	–	–	–	–	6.6	1.4	3.9	76.7	55.4
18	–	–	–	–	7.2	0.9	7.8	74.0	61.3
19	1.7	–	–	–	–	3.1	4.6	73.8	57.6
20	1.5	0.7	2.8	–	13.5	3.8	4.0	74.1	59.8
21	0.8	5.2	4.2	0.3	12.6	0.9	8.6	76.2	63.7
22	0.4	1.9	3.5	0.8	–	–	8.4	76.0	62.7
23	–	–	–	–	–	2.7	4.3	75.6	52.6
24	–	–	–	–	–	1.1	7.2	74.2	58.9
25	–	–	–	–	8.5	5.7	8.6	78.2	55.6
26	–	–	–	–	–	2.2	10.1	73.3	50.0
27	4.5	–	–	–	–	1.8	3.1	73.6	51.9
28	0.6	0.7	1.9	–	8.8	1.2	4.4	78.3	56.1
29	–	–	–	–	–	1.0	7.7	78.8	64.8
30	–	–	–	–	–	1.2	3.2	76.7	62.6

House	Spare 1 Daily (kWh/d)	Spare 2 Daily (kWh/d)	Spare 3 Daily (kWh/d)	Spare 4 Daily (kWh/d)	Pool Daily (kWh/d)	Main Home Ent Daily (kWh/d)	Lights & Other Daily (kWh/d)	Temp Average (°F)	RH Average (%)
31	0.9	1.0	0.3	–	–	1.4	3.4	74.6	58.7
32	2.7	0.4	0.7	1.7	0.0	0.9	11.7	72.7	57.1
33	0.5	0.0	0.0	4.9	–	1.3	17.2	77.4	55.5
34	2.1	–	–	–	–	2.6	5.3	75.0	60.9
35	1.1	–	–	–	–	2.8	5.0	76.4	55.8
36	–	–	–	–	–	2.0	11.1	73.6	61.8
37	13.1	–	–	–	12.0	–	12.1	76.8	59.0
38	0.3	0.4	1.9	0.8	–	0.3	4.7	77.2	59.1
39	1.3	–	–	–	–	1.1	4.0	77.1	62.2
40	2.0	0.0	0.0	–	–	1.5	4.0	74.9	60.1
41	5.7	1.8	–	–	10.1	–	10.7	74.8	57.6
42	1.7	–	–	–	–	1.7	8.8	74.1	58.2
43	1.0	–	–	–	–	0.5	3.1	76.4	51.3
44	0.2	–	–	–	10.7	1.1	1.3	76.3	60.4
45	0.6	–	–	–	4.5	2.3	4.0	77.4	51.5
46	–	–	–	0.7	9.9	1.5	12.2	77.6	54.8
47	–	–	–	0.3	–	1.9	6.9	77.1	58.4
48	1.1	–	–	–	–	2.3	27.0	75.4	56.5
49	0.4	4.1	2.1	0.0	–	2.2	23.1	71.7	58.8
50	2.9	–	–	–	11.8	1.2	3.0	77.1	60.1
51	0.0	0.0	1.6	0.0	–	1.1	6.4	76.3	62.5
52	1.3	–	–	16.9	–	2.5	5.3	75.9	61.2
53	1.1	–	–	–	–	1.3	5.7	74.0	58.0
54	2.1	0.4	2.4	0.0	0.0	1.0	5.0	74.8	55.6
55	1.1	–	–	–	14.3	0.4	4.9	75.9	61.4
56	–	–	–	–	–	1.1	2.7	77.6	56.7
57	0.7	0.0	0.0	–	0.0	0.7	2.4	76.5	60.0
58	0.1	3.7	2.5	–	–	1.7	9.0	76.3	59.2
59	1.0	–	–	0.3	4.8	0.3	5.2	76.7	59.8
60	1.4	–	–	–	–	3.7	5.1	75.7	57.2
Average	**1.5**	**0.6**	**0.6**	**0.5**	**3.1**	**1.7**	**7.2**	**75.7**	**59.1**

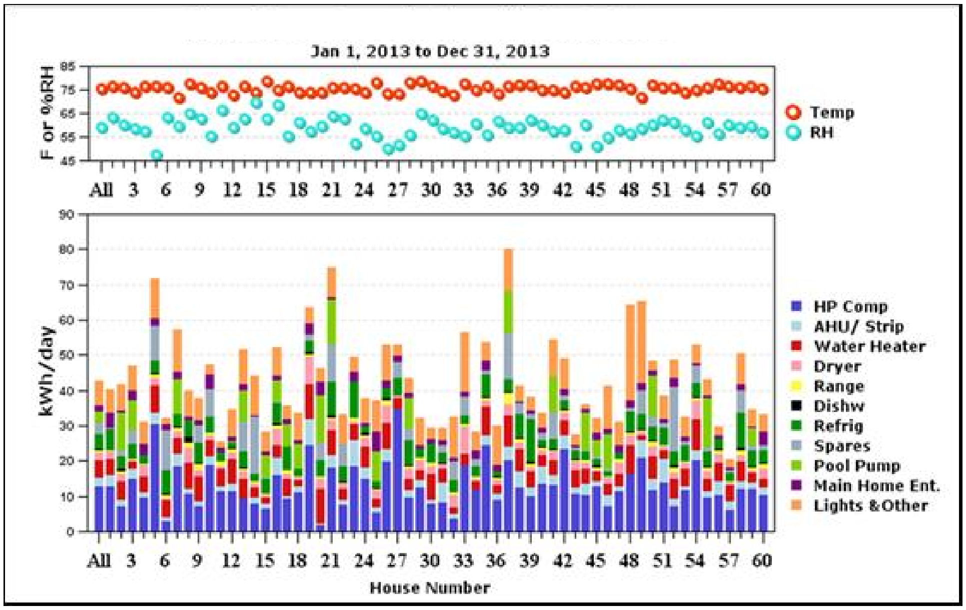

Figure 8. Site energy by end use, and mean temperature and RH for the entire year of 2013 in total PDR sample

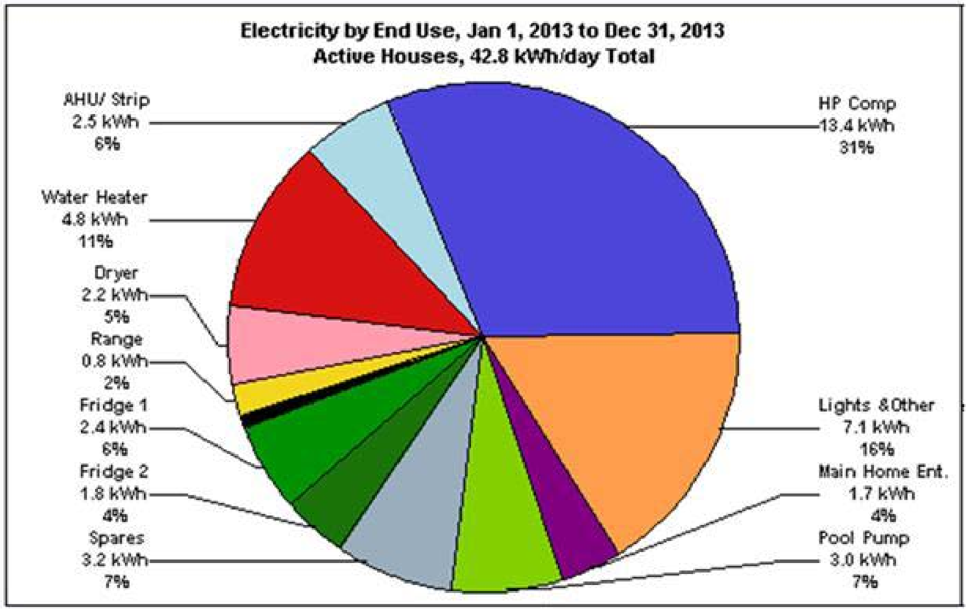

Figure 9. Average energy end-use in the entire year of 2013 in the PDR sample

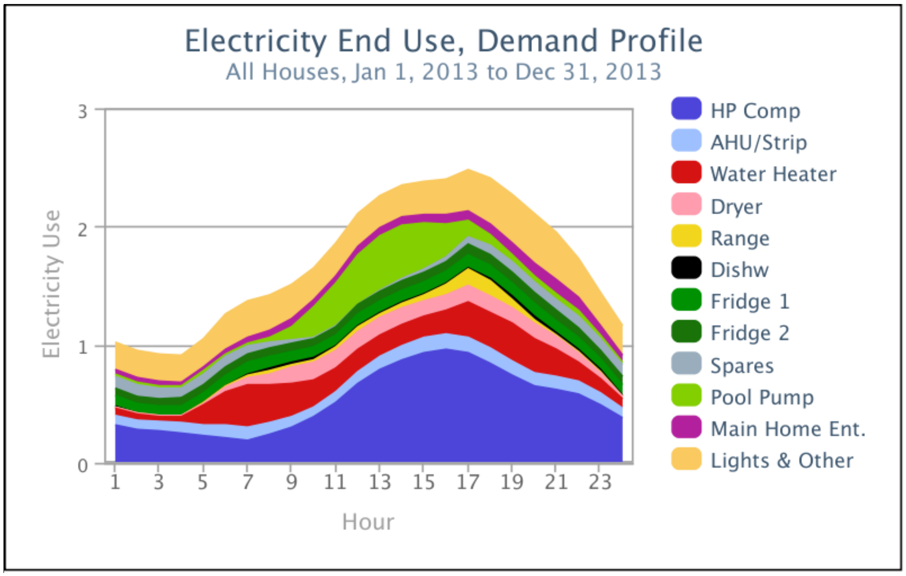

Figure 10. Average daily demand profile in the entire year of 2013 in the PDR sample

Finally, Appendix B shows the average demand profiles by each end use; temperature and humidity are summarized for the entire sample for 2013. Appendix C shows the average end-use load shapes for the 46 homes in the shallow-only retrofit sample for all of 2013 with monthly average 24-hour loads by month. Charts are provided for hourly, daily, and time-of-day load shape averages. Similar load shapes and numerical data can be obtained for each project site at www.infomonitors.com/pdr/.

4 Shallow Retrofits

4.1 Introduction

Each study home had a series of shallow retrofit measures installed between March 2013 and June 2013. An estimation of the pre- and post-retrofit savings for each measure was conducted to compare 30 days pre-retrofit to 30 days post-retrofit against the control group change over the same period. And for a subset of the data set, a year-to-year energy use comparison was made by selecting 1 month pre-retrofit and that same calendar month post-retrofit the following year.

The measures installed in the shallow retrofits at the homeowners' discretion were:

- Changed incandescent and halogen lighting to CFLs or LEDs.
- Added exterior insulation tank wrap to the hot water tank and insulate the hot water pipes.
- Replaced shower fixtures with high-efficiency heads if the measured flow exceeded 2.2 GPM.
- Set pool pump hours to no more than 5 hours/day. (Messenger and Hayes, 1984)
- Cleaned refrigerator coils if soiled.
- Provided APSs to any standby power loads that exceeded 10 watts continuous.

The final measure was seldom installed because equipment standby was often lower than the threshold or could not be shut down (e.g., remote printers, digital video recorders) without loss of functionality. Because of the very small sample size, APSs are independently evaluated.

The installations were discretionary: homeowners were able to choose which measures they did not want to have installed. Thus APSs were often not installed, even where they were applicable. Also, some lighting fixtures were not changed and some showerheads that exceeded the 2.2 GPM limit were not replaced. Still, the audit/retrofit procedure likely replicates what can be achieved in a realistic utility program of a similar type.

Field data recorded on the retrofit particulars include number of lighting fixtures changed, types and wattage, measured flows of showerheads, pool pump runtime, and hot water tank location and insulation status.

To complete the shallow measure energy savings evaluation, the team examined the monitored power for the hot water, pool, refrigerator, and "lighting and other." "Lighting and other" data were obtained by subtracting all the end uses from measured total power and obtaining lighting, ceiling fans, and plug loads. The team also obtained total building power data to see if the shallow retrofits would be visible to homeowners who have only utility bills to observe. And to evaluate the costs associated with retrofit savings, field labor hours were logged and the market value of materials cost documented.

Utility data analysis was conducted to assess the effects of the shallow retrofit on utility bills. This included a disaggregation and evaluation of the shallow retrofit on space heating and cooling. The final investigation characterized the impacts of the shallow retrofit on hourly space heating and cooling energy use to predict utility-coincident peak hour demand.

4.2 Highlight Evaluation of Site 54

Site 54 is shown in detail in Figure 11 and Figure 12 to provide insights about how individual homes were affected by the shallow retrofit performed on May 22, 2013, which included:

- Changing out 95% of bulbs from incandescents to CFLs; the connected lighting load decreased from 2,115 watts to 539 watts
- Replacing one showerhead with a measured flow rate reduction from 2.3 GPM to one with 1.25 GPM turbine spray/1.79 GPM full spray
- Wrapping the garage-located hot water tank with R-3.5 insulation (Figure 11)
- Insulating hot water pipes with an R-value of 3 (R-3) (Figure 11)
- Cleaning fouled refrigerator coils (Figure 12).

Figure 11. Site 54: Uninsulated tank and hot water pipes (left); insulated tank (R-3.5) and hot water pipes (R-3)

Figure 12. Site 54: Refrigerator coils as found (top); refrigerator coils cleaned (bottom)

The retrofit savings estimation methodology was to evaluate power use on each circuit for 1 month before and 1 month after the retrofit. Figure 13 shows the daily power for the affected end uses at Site 54 during this 61-day analysis period. The vertical, dashed, purple line indicates the retrofit date.

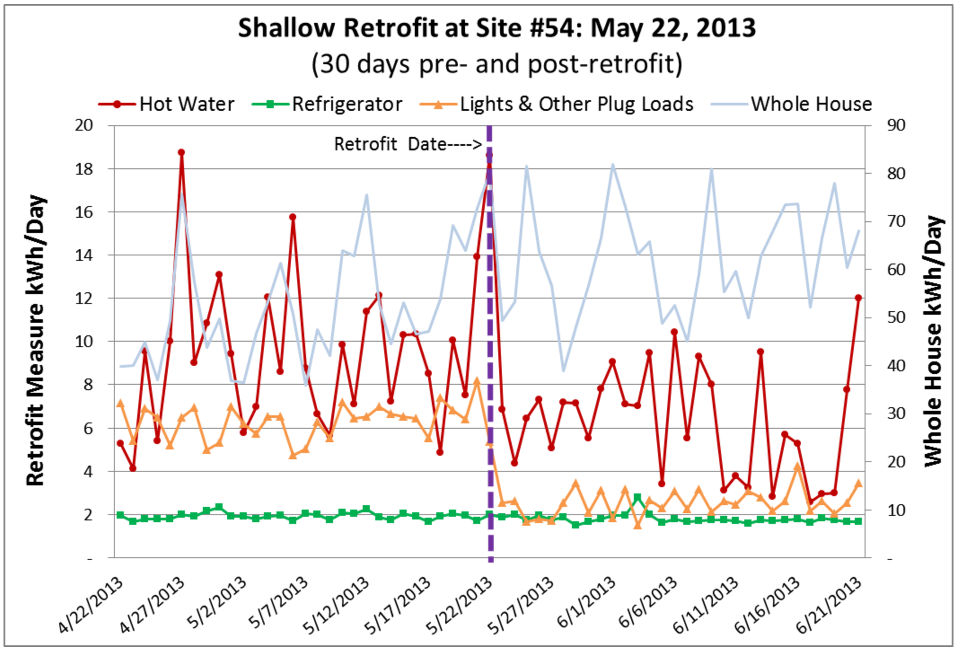

Figure 13. Illustration of evaluation method showing impact of shallow retrofit at PDR Site 54 spanning 2-month period before and after retrofit measures were installed

The plot shows how lighting and domestic water heating retrofit measures produced the greatest monitored energy use reduction (approximately 50% and 31% savings, respectively). Though not visually obvious, refrigerator coil cleaning also generated modest savings (6%). (Reducing pool pump runtime had robust savings for pool homes but was incorporated in only ten homes.)

However, increases to whole-house energy consumption, represented by the faint blue line, more than offset these savings due to natural seasonal variation, because the measurement period spanned the onset of the cooling season. Despite the savings from the retrofit measures, total monitored energy use for Site 54 rose almost 20%.

Also, the examination of the monitored change in each affected end-use load, as well as total house consumption, has limited value given the seasonal changes during the analysis period. Because weather influences many end-use loads, the team normalized savings for each shallow retrofit measure. 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).

For each site the team identified a unique set of control homes that comprised all study homes retrofitted either before or after the site's 61-day analysis period to normalize for seasonal variation. The average change among all the unaffected control homes yielded an average change in the control group's end-use load over the same period. This "average control kWh/day change" was added to or subtracted from the monitored results from each site to account for this seasonal variation. Normalized savings for Site 54 are presented in Table 9.

Table 9. One Month Pre- and Post-Retrofit: Site 54 Measured Savings for Shallow Retrofit

Site #54	Retrofit Measure			Whole-House Total
	Lights and Other	Hot Water	Refrigerator	
Average Monitored kWh/Day Pre	7.0	9.2	1.9	$51.5
Average Monitored kWh/Day Post	3.5	6.3	1.8	$61.7
Average Monitored kWh/Day Savings	3.5	2.9	0.1	–$10.1
Monitored Savings (%)	50.4	31.5	6.2	–19.7
Average Control kWh/Day Pre	6.5	5.5	2.5	$39.8
Average Control kWh/Day Post	6.5	4.4	2.5	$51.6
Average Control kWh/Day Change	0.002	1.053	0.021	-$11.8
Control Change (%)	2.5	17.0	0.9	–31.5
Average Normalized kWh/Day Savings	**3.37**	**1.33**	**0.10**	**6.08**
Normalized Savings (%)	**47.8**	**14.5**	**5.3**	**11.8**

The top four data rows present monitored pre- and post-retrofit energy consumption and savings for each end use that was affected by the shallow retrofit and for the whole house overall. Rows 5 and 6 introduce the average change among the Site 54 control homes during this same period. Normalized savings, the monitored savings less any change observed in the controls, are provided in the last two rows (in bold).

Normalizing the savings had little impact on the lighting and refrigerator circuit; the average savings were 3.4 and 0.1 kWh/day, respectively. However, actual hot water savings was about half of monitored savings, reduced from 2.9 to 1.3 kWh/day. Whole-house total energy use, which was monitored to be –10.1 kWh/day, yielded daily savings of 6.1 kWh (11.8%) once normalized against the control homes, reversing the apparent increase of nearly 20%.

The labor and materials costs associated with the shallow retrofit for Site 54 are provided in Table 10. Because the labor cost varies depending on the program and level of homeowner participation, the hours the field team spent conducting the shallow retrofit at this site are displayed rather than labor cost. The field team spent 6 hours conducting the shallow retrofit at Site 54: 3.5 hours on lighting, 0.75 hours on the showerhead replacement, 1 hour insulating the hot water tank and pipes, 0.25 hours evaluating the entertainment center for standby losses, and 0.5 hours cleaning the refrigerator coils. (Retrofit hours are in bold.)

Table 10. Site 54 Shallow Retrofit Labor and Materials Cost

Site #54	Lighting Change-Out				Showerhead Replacement				DHW Insulation	Smart Power Strip				Refrigerator Coils Cleaned		All Measures		
	# of Bulbs	Total	Research/ Assessment	Retrofit	# of Heads	Total	Research/ Assessment	Retrofit	Retrofit/ Total	# of Strips	Total	Research/ Assessment	Retrofit	# of Refrigerators	Retrofit/ Total	Total	Research/ Assessment	Retrofit
Labor Hours		3.5	1.25	**2.25**		0.75	0.5	**0.25**	1		0.25	0.25	**$0**		**0.5**	6	2	**4**
Materials	42			$166	1			$36	$24	0			$0	1	$0			$240

Not all time logged was for the actual retrofit. Research and assessment often represented a considerable fraction of the documented labor hours. Therefore, where applicable, a distinction is made between total hours (in green text), research and assessment (in red text), and retrofit hours (in bold).

For the lighting retrofit, the disparity between retrofit hours and total hours is large. Researchers documented bulb type and wattage for all old and new bulbs regardless of replacement and the location of each bulb change-out. Researchers regularly assessed showerhead flow rates to determine replacement needs as part of the domestic hot water retrofit. And the home entertainment center standby power loads were nearly always evaluated, although few homes achieved any related savings because APSs were rarely installed. Even though some of the research and assessment hours may be appropriate in a mature utility incentive program, this time would likely be substantially diminished. And in the case of a homeowner retrofit, such labor is arguably inapplicable. For simplicity, the cost/benefit evaluation below considers the labor associated with the actual retrofit.

The materials cost associated with the Site 54 retrofit totaled $240 (Table 10). Materials costs in this report include 6% Florida state sales tax and reflect market cost even though volume discounts were sometimes available. Such costs are conservative given that a mature retrofit program would likely see bulk discounts for some items. Segmented by measure, this includes $166 for 42 CFLs, $36 for one showerhead, and $24 for the thermal tank wrap and pipe insulation.

For the cost/benefit analysis, the team used a hypothetical rate of $30/hour for the retrofit labor (4 × $30 = $120). This brings the total cost for the retrofit to $360. Annual savings are estimated to be $267 assuming an electricity expense rate of $0.12/kWh. Given these assumptions, the shallow retrofit at Site 54 is paid for in a little more than 1 year.

4.3 Shallow Retrofit Summary

Measures were implemented to various degrees, and not all measures were conducted in all homes. The breadth or depth each shallow retrofit measure was applied to the data set is summarized below.

Nineteen pool homes represent 34% of the homes in the data set. Of these, nine homeowners already had their pool pump timers set at or lower than the measure threshold of 5 hours/day. The owner at one site runs the pump only intermittently; e.g., when adding chemicals. Pre-retrofit pool pump electricity use at this site was zero; thus, the home was omitted from pool retrofit savings analysis and was typically unusable as a control home for this end use as well.

- Ten homes had their pool pump timers reduced to ≤6 hours/day. On average, pump time was reduced by 2 hours/day. Although the goal was to reduce time ≤5 hours/day, a compromise was sometimes required. Three timers that were originally set to run 8 or more hours daily were set to 6 hours post-retrofit.

Field staff recorded the number of bulbs and fixtures changed, bulb types, and wattage. Most houses already had some energy-efficient lighting (defined to be CFL or LED types). Indeed, one home already had 100% LEDs, whereas six others had mostly CFLs and needed fewer than 20%

of bulbs changed. Owners sometimes objected to lighting retrofitsfor specific lamps, and those bulbs were not changed. If appropriate LED or CFL models could not be found for particular lamps, incandescent bulbs were replaced with lower wattage incandescent bulbs. Occasionally CFLs were chosen when an LED bulb's color temperature or direction was disagreeable to a homeowner. Those lamps were not changed.

A frequent exchange was a 15-watt CFL in place of a 60-watt incandescent bulb. CFLs were the dominant replacement bulb type. The typical installation bulb was 14–19 watts, though wattage ranged from 7 to 32 watts. Many sites presented ample opportunity for lighting efficiency improvements. For example, Site 7's lighting retrofit included an eight-bulb vanity lamp of incandescents totaling 360 watts to CFLs totaling 72 watts (Figure 14).

Figure 14. Site 7: Eight-bulb retrofit from 360 watts of incandescent bulbs (left) to 72 watts of CFLs (right)

- Fifty-five homes were affected by the lighting retrofit. On average, 54% of bulbs were replaced with CFLs or LEDs (less frequently), ranging from 5% to 96% of the home's total lighting. On average, 64 lamps were audited per household.

Homeowner feedback about quick burnout rates on a specific brand of CFLs points to a vendor control issue. Fortunately, the reseller has readily exchanged the bulbs.

Efforts to reduce domestic hot water energy use were two-pronged: (1) reducing use through low-flow showerheads, and (2) reducing storage thermal losses by insulating tanks and hot or warm pipes. The team examined the impact of changing showerheads versus tank wraps, but the data did not support a statistical determination of specific impacts. Understandably, many homeowners were particular about their showerheads and rejected this measure. For hot water tanks, space limitations generally restricted the application of R-10 thermal blankets, so most homes received smaller R-3.5 or R-3 wraps. Exceptions to tank wrapping include one tank already insulated, one heat pump hybrid, and three partially inaccessible. All accessible hot or warm water pipes were insulated.

- Fifty-three homes had domestic hot water reduction measures installed:
  - Twenty-six homes had at least one showerhead replaced with a low-flow head. (Eighteen sites had one head replaced, seven had two replaced, and one had three replaced.)
  - Fifty-one homes had a hot water tank insulated (Thirty-nine sites with R-3; 6 with R-3.5 and with R-10).

  - Fifty-two homes received R-3 insulation around all accessible hot and warm pipes.

Most homes received refrigerator coil cleaning; however, one homeowner objected to this measure. The refrigerators at five sites were either very new or the coils had recently been cleaned. At sites with multiple refrigerators, generally all coils were cleaned, although some were already clean or inaccessible. Given the mixed loads often picked up for the second refrigerator circuit, only primary refrigerator savings was analyzed.

- Fifty homes had refrigerator coils cleaned. (Forty-one sites had one cleaned, eight had two cleaned, and one had three cleaned.)

APSs can reduce the energy consumption of devices in low power modes. An APS can automatically turn peripheral devices off when they are not being used in response to a master device being powered down to provide energy savings. This measure targeted areas such as entertainment centers and computer stations where low power loads exceeded 10 watts of continuous use. Reaching the 10-watt minimum low power draw was difficult for three reasons: (1) many modern devices have very low power loss in their low power settings, (2) some equipment could not be shut down automatically without functionality loss, and (3) some stations have multiple, independent needs (i.e., television and music) and one function should not control the other. Another APS installation limitation was homeowner objection, often because of unacceptable cable box boot-up time. Further, there were some monitoring limitations. For example, each study home was monitored with one APS monitoring device, but often this location was not where the 10-watt minimum qualifying station was later determined during the shallow retrofit. Also, station device configurations were sometimes altered by homeowners post-retrofit, which invalidated a pre- to post-retrofit energy use comparison.

- Two homes had successful APS installations that were acceptable for evaluation.

4.4 Thirty Days Pre- and Post-Retrofit Savings Evaluation

The team took two approaches to evaluating measure savings:

1. Analyzed savings among the entire data set, labeled “All Homes.” This evaluation is also referred to as *saturation-adjusted*.
2. Analyzed measure savings only among sites that received interventions for that end use, labeled “Homes with Retrofit Measure.” For example, evaluation of hot water end use will comprise the 53 homes that received any of the following: low-flow showerheads, insulation tank wraps, or pipe insulation.

Table 11 presents the average reduction in each affected end-use load of the pre- and post-retrofit groups for all study homes. As described in the highlight of Site 54 (Section 4.2), energy use evaluation required that monitored savings results be normalized to account for naturally increasing or decreasing energy use. However, the seasonal variation was computed for each site and the “average control kWh/day change” in Table 11 represents the average change among all sites’ control groups’ changes.

Table 11. One Month Pre- and Post-Retrofit: Measured Savings in All Homes

All Homes	Retrofit Measure: Pool Pump (n = 18)	Lights and Other (n = 56)	Hot Water (n = 56)	Refrigerator (n = 56)	Whole-House Total (n = 56)
Average Monitored kWh/Day Pre	10.7	7.7	5.6	2.4	40.5
Average Monitored kWh/Day Post	8.1	6.6	4.7	2.4	43.7
Average Monitored kWh/Day Savings	2.6	1.1	0.9	0.0	–3.2
Monitored Savings (%)	24.1	14.2	16.8	1.1	–8.0
Average Control kWh/Day Pre	9.0	7.1	5.2	2.4	38.6
Average Control kWh/Day Post	9.0	7.3	4.6	2.4	44.9
Average Control kWh/Day Change	–0.1	–0.1	0.7	0.0	–6.4
Control Change (%)	–0.9	–1.8	12.8	–2.1	–16.5
Average Normalized kWh/Day Savings	**2.7**	**1.2**	**0.4**	**0.1**	**4.2**
Normalized Savings (%)	**24.9**	**16.2**	**6.8**	**3.5**	**10.3**
Uncertainty @ 95% CI (±)	2.37	0.42	0.24	0.06	1.88
Coefficient of Variation (COVAR)	0.42	0.17	0.32	0.34	0.22

The results are arranged similarly to Table 9 with monitored, control group, and normalized findings (in bold). The team also conducted a t-test of paired mean savings before and after retrofit to establish statistically significant differences. Significance is indicated by t-test results that are lower than the average normalized daily kilowatt-hour savings. The value "uncertainty" indicates the estimated uncertainty, as indicated by the regression, at a 95% confidence interval (CI). The final component in this table, COVAR, provides the variation in savings achieved (standard error divided by mean savings level). Low values of this parameter indicate reliable savings; values higher than 0.5 indicate declining reliability.

With this estimation methodology, the total energy savings in the 56 retrofit homes was 4.2 kWh/day and 10.3% savings on average. Clearly the normalization process has an important impact, because monitored energy use *increased* by 8%. The normalized savings are significant at the 95% CI (1.88 <4.2), and COVAR indicates reliable savings (0.22 <0.42) from the installed retrofit measures—even though these are largely invisible to homeowners—because savings are often swamped by seasonal increases to heating and cooling.

4.4.1 Pool Measure Results

The pool pump timer intervention generated savings of 0.9 kWh/day when weighted among all 56 homes. Because only 19 homes have pools[1] and just 10 showed pump timer reductions, actual savings for this measure were diluted across the whole sample. Considering only pool homes, normalized daily savings rose to 2.7 kWh, or 24.9%. Although the pool pump time reduction had the largest impact, it was also highly variable, because nine homes already operated at 5 hours/day or less and were not changed.

The total whole-house savings in homes with swimming pools averaged 4.5 kWh/day versus 4 kWh/day in homes without pools. The average whole-house savings without the pool pump circuit changes only slightly from 10.3% to 10.2%.[2]

The normalized pool pump measure savings was marginally significant at a 95% CI; likewise, the COVAR value of 0.42 indicates only marginally reliable savings. This means that, although swimming pool pump adjustment had the largest impact, this end use varied the most from one house to the next.

Moving away from the saturation-adjusted evaluation, the team considered only homes that received the pool pump intervention in Table 12, which is structured identically to Table 11; the sample size represents only the homes impacted by the relevant retrofit measure(s).

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[1] One of the 19 pool pumps was used sporadically and was excluded from the analysis in Table 11.

[2] Whole-house savings without the pool pump circuit is calculated by removing the pre-normalized pool circuit change from all pool homes. Because the pool circuit normalization was small, no revision was made to the control group for this estimation.

Table 12. One Month Pre- and Post-Retrofit: Measured Savings in Homes with Retrofit Measure

Homes with Retrofit Measure	Retrofit Measure:				Whole-House Total (n = 56)
	Pool Pump (n = 10)	Lights and Other (n = 55)	Hot Water (n = 53)	Refrigerator (n = 50)	
Average Monitored kWh/Day Pre	13.8	7.7	5.6	2.4	40.5
Average Monitored kWh/Day Post	9.3	6.6	4.7	2.4	43.7
Average Monitored kWh/Day Savings	4.5	1.1	0.9	0.0	–3.2
Monitored Savings (%)	32.8	14.2	15.7	1.3	–8
Average Control kWh/Day Pre	8.8	7.1	5.2	2.4	38.6
Average Control kWh/Day Post	8.9	7.2	4.6	2.4	44.9
Average Control kWh/Day Change	–0.1	–0.1	0.7	0.0	–6.4
Control Change (%)	–0.7	–1.7	12.6	–2.0	–16.5
Average Normalized kWh/Day Savings	**4.6**	**1.3**	**0.4**	**0.1**	**4.2**
Normalized Savings (%)	**33.3**	**16.4**	**6.7**	**3.6**	**10.3**
Uncertainty @ 90% CI (±)	3.25	0.35	0.22	0.05	1.54
Uncertainty @ 95% CI (±)	4.02	0.42	0.26	0.06	1.84
COVAR	0.39	0.16	0.35	0.37	0.22

Isolating the homes that received the pool pump timer reduction, average savings for this measure was 4.6 kWh/day (33.3%). Reporting outside this summary presentation, whole-house savings in these ten homes rose to 7.3 kWh/day, and the average savings was 14.5%.

A major caution must be inserted here for this analysis, because the long-term examination of the reduction of pool pump hours (to be shown later) indicated that this measure was not persistent because many pools were returned, later in the year, to the hours previously used. This may indicate that reducing pool pump hours is only moderately successful for a utility program and that substituting variable-speed pool pumps (shown in Section 5) is likely to yield more reliable energy reductions for this end use.

4.4.2 Lighting Measure Results

Not surprisingly, the lighting retrofit change was the most reliable measure (COVAR = 0.17) and has strong significance at the 95% CI. As lighting/other end-use consumption increased slightly among the control homes, the normalization improved savings slightly. Savings from the lighting retrofit averaged 1.2 kWh/day, or 16.2%. Savings rose to 1.3 kWh/day (16.4%) when the one non-lighting-affected home was dropped (Table 11). Considering only homes in which more than 20% of fixtures were replaced, average savings were 1.5 kWh/day (20.7%).

Despite the highly heterogeneous nature of loads of the lighting/other circuit (ceiling fans and miscellaneous plug loads), a clear connection emerges between the degree of lighting retrofit and the overall circuit savings. This relationship is displayed in the scatterplot below (Figure 15). Moreover, more robust savings would result if the homes with the smallest change-out were removed from the savings analysis.

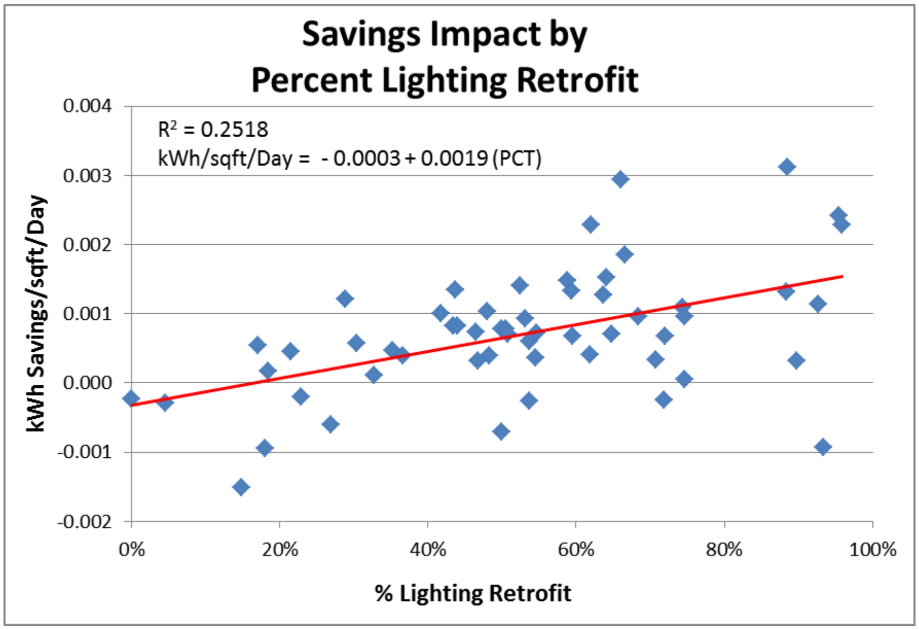

Figure 15. Scatterplot of percentage lighting change-out with predicting savings/ft^2/day

4.4.3 Hot Water Measure Results

Weather-adjusted savings of hot water energy use averaged 0.4 kWh/day or 6.8%. Among the end uses analyzed, seasonal variation in hot water use is most notable, reducing monitored savings by 12.8%. This savings reduction is expected, because the inlet water temperature generally increased between the pre- and post-retrofit periods. The hot water end-use reduction measures were significant at the 95% CI and had reliable savings (COVAR = 0.32).

4.4.4 Refrigerator Measure Results

Weather had the reverse effect on refrigerator coil cleaning savings. The refrigerator circuit, which had essentially no monitored change post-retrofit, yielded 3.5% savings when controlled for seasonal variation. The refrigerator coil cleaning savings were small but reliable and, as shown later in the report, appeared to disappear in a long-term analysis that examined solely those units where coils were cleaned.

Overall, the most important measures that generated savings were pool pumps followed by the lighting retrofit and then water heating. However, with the pool measure savings weighted across the entire 56 study home sample, the lighting retrofit was most impactful. This relationship between total and relative end-use impact is graphically displayed in Figure 16. This chart shows that the savings associated with the individual shallow retrofit measures are only 2.6 kWh of the 4.2 kWh/day whole-house energy savings achieved by the retrofit. The interaction between the shallow retrofit measures and cooling needs are evaluated in Sections 4.7 and 4.8.

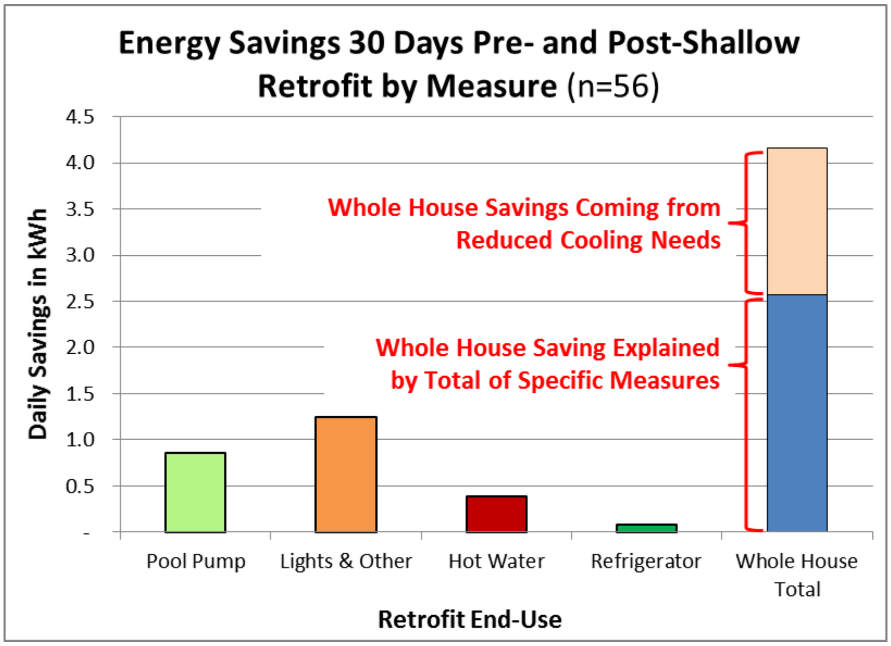

Figure 16. Average energy savings by measure: 30 days pre- and 30 days post-retrofit for all shallow retrofits

4.4.5 Advanced Power Strip Measure Results

Because the APS was installed in so few homes, the savings impact from this measure is presented independently from all other measures. A summary of the savings achieved by the two

APS installations is shown in Table 13. The installation at Site 5 involved a television that served as the master controlling device. It controlled a digital video recorder and a home video game console, for which the low power modes combined drew 4 or 12 watts. (Some devices have multiple low-power modes.) Daily savings at Site 5 averaged 0.21 kWh or 10%. The savings for the Site 10 installation was significantly higher. The master device at this home was an amplifier that controlled a subwoofer with a 20-watt low power mode that yielded an average daily savings of 0.70 kWh (15% over pre-retrofit).

Table 13. Pre- and Post-Retrofit Entertainment Center Energy Use

Site #	Standby Losses (watts)	kWh/Day		Savings		
		Pre-Retrofit	Post-Retrofit	Average Daily kWh	Estimated Annual kWh	%
5	12/4	2.05	1.84	0.21	77	10
10	20	4.82	4.12	0.70	256	15

A more detailed description of the smart strip evaluation is available in a separately published report: *Measured Retrofit Savings from Efficient Lighting and Smart Power Strips* (Sutherland et al. 2014).

4.5 Year-to-Year Savings Evaluation

To gain insight into savings persistence and the savings a homeowner would observe by comparing utility bills, the team evaluated the month of October before and after the shallow retrofit. Figure 17 shows the average load profiles for all end uses on a 17 PDR home sample for October 2012 versus October 2013. The sample size was limited to homes that were fully monitored by Oct. 1, 2012 and excludes deep retrofit sites. October was selected from the few months with many homes monitored by Oct. 1, 2012 and for its typical Florida weather behavior. In using the same calendar month for each period, this investigation essentially excluded space-conditioning changes. Thus the evaluation is quite different than the 30-day pre- to post-retrofit described above, which occurred between spring and summer. The shallow retrofit's impact on space heating and cooling is evaluated in Sections 4.7 and 4.8.

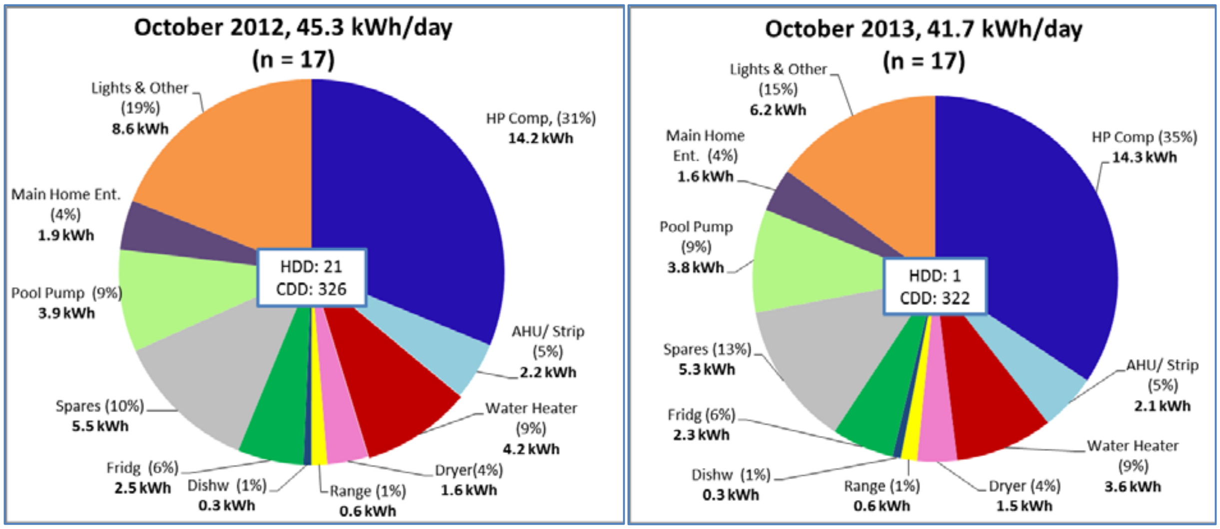

Figure 17. Average end-use load profile in shallow retrofit sample, October 2012 versus October 2013

Average end-use savings between the 2 years vary from the normalized 30-day pre- and post-retrofit methodology; total savings for this period was slightly lower, averaging 3.6 kWh/day or 7.9%. Weather differences between the months were subtle; therefore, weather normalization would impact results minimally. (Note the similar heating degree days and cooling degree days [HDDs and CDDs] within each pie chart.)

Notice the large difference in lighting and plug-load energy use in the sample between years, 2.4 kWh/day (27.7% savings); more than twice the 1.2 kWh/day savings than in the normalized 30-day pre- and post-retrofit methodology. Refrigeration and water heating savings, 0.2 kWh/day for 8.6% and 0.6 kWh/day for 14.3% savings, respectively, are also greater than in the 30-day pre- and post-retrofit evaluation. Further investigation revealed that the apparent refrigeration savings was not attributed to sites that had coils cleaned. No savings were found among those sites.

The average daily savings for water heating is similar in both analyses. However, pre-retrofit water heating is significantly higher in the previous analysis, as expected given the general time of year, which dilutes the percentage savings. Average daily savings are expected to increase with a higher pre-retrofit period end use. The pool pump circuit savings of October 2012 versus October 2013 was substantially lower: 0.1 kWh/day (2.6%). This is quite different from the preliminary analysis, which showed 2.7 kWh/day savings (15.9%). This is likely due to lack of persistence with adjustments to pool pump timers.

One large caution with this presentation concerns the small sample: only 17 homes versus the 56 evaluated in the larger analysis. Thus, the uncertainties are likely much larger than they were in the month pre- and post-evaluation methodology.

The relationship between total and relative end-use impact is graphically displayed in Figure 18. The summing of the measure savings is 3.4 kWh, which is approximately equal to whole-house savings of 3.6 kWh. This chart differs notably from Figure 16.

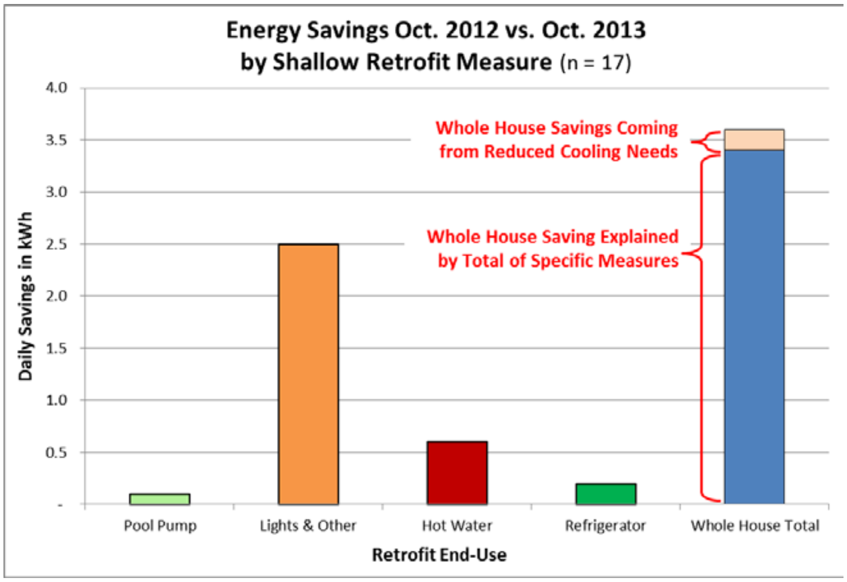

Figure 18. Average energy savings by measure, 17 shallow retrofit homes, October 2012 versus October 2013

4.6 Cost Evaluation

A summary of labor and materials costs associated with the shallow retrofits for all 56 homes are provided in Table 14. As in the highlight of Site 54 above, total hours (in green text) have been segmented to distinguish between research and assessment (in red text) and retrofit hours (in bold) for the lighting, showerhead, and smart strip measures. The averages, minimum, maximum, and standard deviations (std) relate to all sites where the measures were implemented.

Table 14. Shallow Retrofit Labor and Materials Costs for All Sites

		Lighting Change-Out				Showerhead Replacement				DHW Ins.	Smart Power Strip (n = 10)				Refrigerator Coils Cleaned (n = 50)		Pool Pump Timer (n-10)	All Measures (n = 56)		
		# of Bulbs	Total	Research/ Assessment	Retrofit	# of Heads	Total	Research/ Assessment	Retrofit	Retrofit/Total	# of Strips	Total	Research/ Assessment	Retrofit	# of Refrigerators	Retrofit/Total	Retrofit/Total	Total	Research/ Assessment	Retrofit
Labor	Total		256	133	123		37	29	8	58		26	23	3		31	3	411	184	226
	Avg/Site		4.57	2.37	2.24		0.69	0.53	0.29	1.04		0.47	0.42	0.28		0.63	0.25	7.33	3.29	4.04
	Minimum		1	0.5	0.25		0.25	0.25	0.25	0		0.25	0.25	0.25		0.5	0.25	2	1	1
	Maximum		12	5.5	8		1.5	1.5	0.5	1.5		1.25	1	0.5		1.5	0.25	15	6.25	9.5
	std		1.96	1.12	1.17		0.26	0.21	0.1	0.38		0.26	0.21	0.08		0.23	0	2.23	1.19	1.36
Materials	Total	1,920			$11,758	35			$803	$1,193	12			$423	60	$0	$0			$14,178
	Avg/Site				$214				$31	$23				$42						$253
	Minimum	1			$3	1			$9	$6	1			$32	1					$10
	Maximum	81			$611	3			$72	$39	2			$74	3					$690
	std				143				18	9				17						154

The shallow retrofits were completed in 4 hours, on average, ranging from 1 to 9.5 hours. Including research and assessment time, the average field time is nearly double. Materials costs associated with the retrofits only and averaged over all sites were $253. Segmented by measure and spread among only sites that were given the specific measure, averages were $214 for lighting, $31 for showerheads, $23 for the thermal tank wrap and pipe insulation, and $42 for the APS.

For the cost/benefit analysis a rate of $30/hour is assumed for the retrofit labor and energy costs of $0.12/kWh. Assessing the cost-effectiveness of the retrofit package, labor costs are $121 (44 hours × $30). Adding this to the average materials costs of $253, the average total cost for the retrofit was $374. Using the 30-day pre- and post-retrofit analysis savings estimation (4.2 kWh/day), simple payback is 2 years; using the more conservative savings reported in the October 2012 versus October 2013 evaluation (3.6 kWh/day) simple payback is 2.4 years.

Applying the same energy and labor cost assumptions, total cost and simple payback for each end use is provided below using the savings estimations from each methodology above, the 30 days pre- and post-retrofit followed by the October analysis:

- Lighting: $281 total cost, 4.9- and 2.7-year simple payback
- Hot water: $94 total cost, 5.4- and 3.6-year simple payback
- Refrigerator: $19 total cost, 4.3-year simple payback, using the first analysis only
- Pool pump: $8 total cost, 2 weeks and 1.8-year simple payback
- APS: $32 per site cost, 1- and 3.5-year simple payback for each installation.[3]

4.7 Pre- and Post-Retrofit Utility Data Analysis

Given their modest nature, the shallow retrofits may not provide enough savings to be visible to homeowners as they examine the monthly utility bills. Moreover, potential savings may also be obscured by differing post-retrofit weather.

Utility data for the 41 study homes were disaggregated to characterize heating, cooling, and baseload energy use before and after the shallow retrofit.[4] Weather-adjusted savings projections were estimated in two ways:

- Adjusting post-retrofit energy use for each home with its pre-retrofit weather
- Normalizing pre- and post-retrofit energy use for each home to Typical Meteorological Year (TMY3) weather for four FPL service territories, weighted by service area.

The approach and results are described briefly in the following sections.

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[3] Although the total cost for all APS installations is included in the whole-house cost evaluation, the costs and savings for this measure are necessarily limited to the two installations evaluated using the 30 days pre- and post-retrofit savings evaluation.

[4] Of the 56 homes remaining in the study post-retrofit, two more were lost before enough post-retrofit bills could be collected; ten received deep retrofits and were therefore not candidates for the shallow evaluation; two homes had photovoltaic installations; and the energy use patterns in one home could not be modeled adequately.

4.7.1 Utility Data Weather Normalization and Disaggregation

The team first projected energy uses for cooling, heating, and baseload—the amount of energy consumed for all other end uses—to weather-normalize utility data. A simple linear regression based on the best fit between total monthly energy use and concurrent weather data was applied to disaggregate consumption related to heating, cooling, and baseload needs for the pre- and post-retrofit periods for each home (Agnew and Goldberg 2013).

Model results provided an intercept, interpreted as the baseload energy use, and coefficients for each of the model's independent variables. Regression models based on different behavioral characteristics were developed to find the strongest model for each home and period.

FPL provided several years of homeowner-released utility data from which the team selected 12 months preceding and 12 months following each study home's retrofit. HDDs, CDDs, and a *holiday dummy variable* were the independent variables matched to the utility bill periods.

To create HDD and CDD scenarios for each home, hourly dry bulb temperatures were collected from the National Oceanic and Atmospheric Administration's "Hourly/Sub-Hourly Observational Data" for four airports that are geographically close to the study homes.[5] Typically, HDDs and CDDs calculated in degrees Fahrenheit are the delta between average daily exterior temperatures and a base temperature of 65°F (relating to an interior set point). The team used hourly rather than daily exterior dry bulb temperature to generate HDD and CDD data for precise projections. To further improve the models, the team attempted several combinations of the base temperatures used to generate HDDs and CDDs to match the characteristics of each home and for each 12-month period. When 65°F was not the best base temperature, it often indicated that interior thermostat set points higher or lower than typical were maintained. Not surprisingly, some study occupants liked warmer temperatures and others preferred cooler temperatures throughout the year. Still others tended to be conservative by using little space conditioning year round. Often, behaviors changed between pre- and post-retrofit. In cooling-dominated climates, the HDD variable is not always appropriate, because some occupants do little space heating in Florida's mild winters. For these cases, HDD was excluded when it weakened the model.

Allowing for heightened holiday lighting and cooking, a dichotomous holiday variable was included in some models. If on the edge of significance (t-statistic ≥ 1.3; p-value ≤ 0.15), the holiday variable was considered for the final model choice if it did not reduce the overall model-fit. Sometimes the strongest model had an unacceptable intercept coefficient that provided an impracticable baseload. When this coefficient either exceeded the actual lowest monthly bill or was unrealistically low (~ <400), the next-strongest model was considered. Monthly pre-retrofit heating and cooling energy uses were then projected by multiplying the corresponding HDD and CDD inputs by their respective coefficients.

Figure 19 provides an example for Site 9 that characterizes pre-retrofit space heating and cooling and baseload electricity. The shallow retrofit at Site 9 included a 71% lighting retrofit for a 50%

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[5] NOAA Hourly/Sub-Hourly Observational Data for Melbourne International Airport, Naples Municipal Airport, Fort Lauderdale/Hollywood International Airport, and Daytona Beach International Airport.

connected lighting kilowatt reduction as well as hot water tank wrap and refrigerator coil cleaning. Site 9 is fairly representative of the 41-home sample in terms of post-retrofit energy use changes. Typical set points appear to be favored in this home pre- and post-retrofit. The strong fit of the model (adjusted coefficient of determination [R^2] = 0.95) is evident from the close alignment between "predicted" monthly use (green diamonds) and the monthly utility data ("FPL," orange circles). Projected space-cooling and space-heating energy uses are the solid-fill sections in blue and red, respectively. The monthly baseload prediction is the flat purple line.

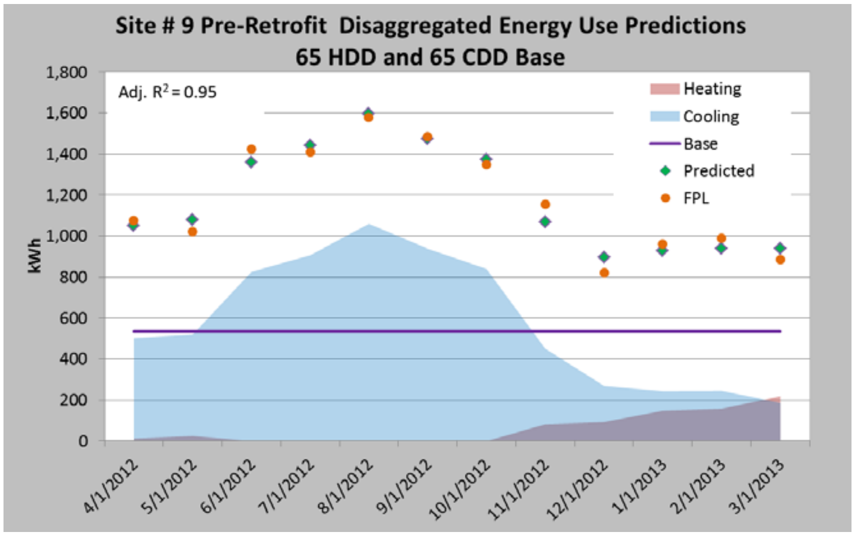

Figure 19. Site 9 Pre-retrofit space heating and cooling and baseload characterization

Once the best pre- and post-retrofit models were chosen, the post-retrofit HDD and CDD coefficients were applied to the pre-retrofit degree days (calculated according to post-retrofit building characteristics) to project post-retrofit energy consumption. The post-retrofit end-use characterization plot for Site 9 is shown in Figure 20. The fit of the model (adjusted R^2 = 0.90) is slightly lower than that for pre-retrofit but is still very strong. The space cooling energy is noticeably lower throughout the year, especially during summer. Conversely, the space-heating energy use is slightly higher post-retrofit. These changes are likely because reductions in internal gains from the lighting retrofit reduced the need for space cooling and increased the need for space heating. A comparison of Figure 19 and Figure 20 reveals that baseload energy use is also noticeably reduced by the shallow retrofit.

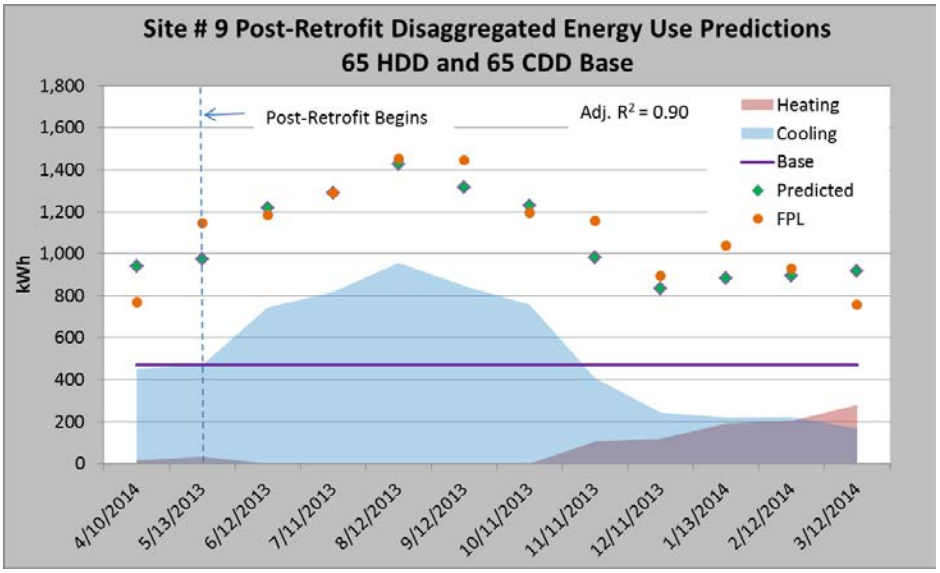

Figure 20. Site 9: Post-retrofit space heating and cooling, and baseload characterization

Table 15 summarizes the total and end-use energy projections for the shallow retrofits in Site 9. The annual post-retrofit reduction in baseload energy use is representative of the 41-home sample: 775 kWh (2.1 kWh/day; 12%). The increase in post-retrofit heating energy use shown at this site is typical of the whole data set. Space-cooling energy use was reduced by 682 kWh (1.9 kWh/day; 10%). Utility bills presented a savings of 6% between years, but actual post-retrofit whole-house savings at Site 9 was 9% or about 1,247 kWh/year (3.4 kWh/day) when normalized to weather-related differences.

Table 15. Site 9 Shallow Retrofit: Pre- and Post-Retrofit Heating, Cooling, and Baseload Projections Normalized to Pre-Retrofit Weather

Annual Energy Use Site # 9	Utility Bill	Normalized Projection			
	Total	Total	Base	Heating	Cooling
Pre-Retrofit kWh	14,148	14,148	6,425	738	6,985
Post-Retrofit kWh	12,481	12,901	5,651	948	6,303
Savings (kWh)	1,667	1,247	775	(210)	682
Savings (%)	12	9	12	–28	10

Table 16 shows the evaluation of the entire sample, which is a summary of the results for all 41 shallow retrofit homes analyzed. Overall, the more severe post-retrofit weather eroded 25% of the actual whole-house energy savings. The average annual post-retrofit energy bill reduction was 1,030 kWh (2.8 kWh/day; 7%); the weather-normalized annual post-retrofit energy savings was 1,356 kWh (3.7 kWh/day; 9%). This becomes the best estimate of the shallow retrofit savings, which includes large interactions with space heating and cooling. In particular, annual cooling energy appears to be strongly affected, likely from changed internal gains from the lighting retrofit.

Table 16. Shallow Retrofit: Pre- and Post-Retrofit Heating, Cooling, and Baseload Projections Normalized to Pre-Retrofit Weather

Annual Energy Use Averages (n = 41)	Utility Bill Total	Normalized Projection			
		Total	Base	Heating	Cooling
Pre-Retrofit kWh	15,559	15,559	6,481	811	8,267
Post-Retrofit kWh	14,511	14,203	5,850	1,440	6,914
kWh Savings	1,049	1,356	632	(629)	1,353
Savings Overall (%)	7	9	10	–78	16
Uncertainty @ 95% CI (±)	680	684	704/587 @ 90% CI	229	698
COVAR	0.32	0.25	0.55	–0.18	0.26

Weather-normalized analysis of the total whole-house post-retrofit savings also provides improved insight into the actual magnitude of influences and corrects for the more modest visible savings.

However, the year-to-year differences in the disaggregated end uses are especially intriguing. The shallow retrofit measures targeted energy used for lighting, water heating, refrigeration, plug loads, and pool pumps. Space-heating and space-cooling energy were not directly addressed. Yet the results show robust post-retrofit cooling energy reduction and a clear heating energy increase. The annual space-cooling energy savings projection was 1,353 kWh (3.7 kWh/day; 16%); the annual space heating energy loss projection was 629 kWh (–1.7 kWh/day; –78%).

These changes were most likely effects of the lighting retrofit; a large number of incandescent lamps (~ 60 watts or 200 Btu/h) were replaced with either CFLs (~15 watts or 50 Btu/h) or LEDs (~9 watts or 30 Btu/h). An average of 35 lamps (56%) were changed per home; the connected lighting load changed from 2.68 kW to 1.28 kW. If during the evening hours one-third of the lamps were on, the reduction in released internal heat gains might be about 1,580 Btu/h—a significant change in the level of heat released to the interior.[6]

In this sample, the post-retrofit annual cooling energy use savings average (1,353 kWh) was equal to the entire savings average (1,356 kWh). And about half of the annual cooling energy reduction or the entire baseload savings projection (632 kWh/year) was lost by the increased post-retrofit space heating energy (629 kWh/year). This occurred because the heat previously released from incandescent fixtures being reduced led to lower cooling needs but higher heating demand. The heating impact was particularly high for two reasons: (1) some of the study homes have straight cool AC with strip electric resistance heat, and (2) the lighting waste heat actually delivers space heating more efficiently than the heating system with duct losses. Also the coefficient of performance (COP) of the heat pumps operating in heating mode is significantly lower than the COP of the cooling system in operation, and many systems use resistance strip

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[6] Connected lighting load was reduced by 1.4 kW post-retrofit: 1.4 kW × 3412 * 33% = 1,580 Btu/h.

heat with heat pump operation, particularly on startup during mornings after a nighttime temperature setback.[7]

The total utility bill and the total normalized savings projections are significant at the 95% CI (680 <1,049 and 684 <1,356 for bill and normalized savings, respectively); COVAR indicates reliable savings. The COVAR for the total savings improves from 0.32 given utility bills to 25 when normalized, which improves the robustness of the estimates. Heating and cooling savings projections are also reliable and significant at the 95% CI. The base-load savings projection is not significant at the 95% CI, but it is significant at the 90% CI (587 <632). Ninety percent is reasonable to use in energy use evaluation, because it allows some independent variables of strong influence into the regression that would otherwise be statistically passed by due to the natural variance. This variance arises given that the data source is energy use from occupied homes and because the weather data are from the general area rather than for each specific site.

4.7.2 Typical Meteorological Year 3 Weather Normalization

The final element of the shallow retrofit utility data analysis was to evaluate total, space heating and cooling, and baseload end-use savings under TMY3 weather data.[8] This allows the savings estimates to be extended to the various climate zones that FPL typically uses for forecasting purposes.

The pre- and post-retrofit regression results from the weather-normalization evaluation were applied to TMY3 weather data to predict space-heating and space-cooling energy use for the pre- and post-retrofit periods. As before, hourly dry bulb temperature data (from TMY3) were used to create HDDs and CDDs. The degree day base temperature matched that used in each original model. For example, if the original model's base was 60°F for CDD, 60°F was used to calculate CDD with the TMY3 temperatures. Baseload is presumed to be unchanged from the previous analysis. Table 17 provides the average savings using TMY3 weather for four of FPL's service areas: Miami, West Palm Beach, Fort Myers, and Daytona.

Table 17. Shallow Retrofit: Pre- and Post-Retrofit Heating, Cooling, and Baseload Projections Normalized to TMY3 Weather, Weighted by FPL Service Area

Annual Savings		Hourly TMY3 HDD CDD Averages				FPL Service Area Weight
		Total	Base	Heating	Cooling	
Miami	**%**	11	10	–114	15	0.4319
	kWh	1,854	632	(350)	1,573	
West Palm Beach	**%**	9	10	–97	16	0.2243
	kWh	1,505	632	(622)	1,495	
Fort Myers	**%**	9	10	–107	15	0.1921
	kWh	1,525	632	(575)	1,469	
Daytona	**%**	3	10	–92	18	0.1517
	kWh	441	632	(1,405)	1,215	

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[7] For instance a SEER 12 heat pump (COP = 3.5) might have a heating seasonal performance factor of 7.5 (COP = 2.2). In reality, the COPs are degraded by the duct system leakage and conduction such that the operating COP for such a system might be only 2.8 cooling and 1.8 heating—still a very large difference between heating and cooling.

[8] http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/

Annual Savings		Hourly TMY3 HDD CDD Averages				FPL Service Area Weight
		Total	Base	Heating	Cooling	
Weighted	**%**	**9**	**10**	**–105**	**16**	
	kWh	1,498	632	(614)	1,481	

Again, heating and cooling interact strongly because of the lighting retrofit. The warmer service areas benefits slightly more from the reduced cooling energy needs than does Daytona.

The space-heating energy use is significantly higher in Daytona, where the increase in post-retrofit space heating needs (1,405 kWh/year) erode all the space-cooling savings (1,215 kWh/year), leaving a net post-retrofit savings of only 3%. Miami, on the other hand, with very little heating demand, has little to lose from the lighting retrofit. Projected savings from the shallow retrofit package is 11% in Miami; the package savings in West Palm Beach and Fort Myers is 9%.

Weighted to weather-adjusted results across the FPL service area, annual space-heating energy use increased by 614 kWh—which almost negated annual baseload savings (632 kWh)—but annual space-cooling energy was significantly reduced (1,481 kWh). Overall, characterized with TMY3 weather and weighted across the FPL service areas, annual shallow retrofit savings of 1,498 kWh (9%) with large interactions between heating and cooling is projected.[9]

4.8 Hourly Space-Conditioning End Use Analysis

This section presents the method and results of the monitored space-heating and space-cooling energy use evaluation. Findings for the shallow retrofit analysis are presented below. The deep retrofit results are discussed in Section 5.6.3.

The initial space-conditioning characterization approach was to predict hourly space-heating and space-cooling energy given the linear relationship between energy used and the difference between indoor and outdoor temperatures (delta-T). However, the resulting linear regression models were weak with very low R^2. A time-lag function improved the models slightly; however, delta-T was still a poor predictor of space-conditioning energy use. Exterior temperature given hour of the day provided better predictions. To delineate AC use for heating versus cooling, condenser and air handling unit (AHU) energy use coincident with outdoor temperatures higher than 65°F was assumed to be cooling energy; space conditioning when outdoor temperatures were lower than 60°F was interpreted as heating energy.

Monitored pre- and post-retrofit hourly energy use for the condenser and AHU were aligned with hourly outdoor temperatures for each site analyzed. The team created linear regression models for each hour of the day (24) and each period (pre- and post-retrofit). Resulting regression statistics were applied to hourly outdoor temperatures to predict hourly space-conditioning energy use in the following manner:

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[9] The effort was duplicated with daily TMY3 weather, which yielded slightly higher overall savings (10.6%). However, the hourly data are probably more accurate.

$$kW_{ni} = (M_{ni}\ T_{pi}) + Y_{ni}$$

Where:

kW = space conditioning energy

$_n$ = site number

$_i$ = hour

M = coefficient for the exterior temperature (°F)

T = exterior temperature (°F)

$_p$ = temperature profile

Y = non-weather-dependent fraction of space conditioning (constant)

Four temperature profiles were used to predict savings:

- Normalizing post-retrofit models to the average outdoor temperature in the pre-retrofit analysis period
- Normalizing pre-retrofit models to the average outdoor temperature in the post-retrofit analysis period
- Applying the hourly average heating and cooling season TMY3 temperature data for Miami, West Palm Beach, Fort Myers, and Daytona, weighted by FPL service area to the pre- and post-retrofit models [10]
- Applying the hourly temperatures for the peak TMY3 heating and cooling day for Miami, West Palm Beach, Fort Myers, and Daytona, weighted by FPL service area to the pre- and post-retrofit models.

When observations were plentiful, hourly predictions for each site were created then averaged for final predictions. When the numbers of observations were limited, per-site modeling was not feasible (e.g., negative energy use predictions). In these cases observations for all sites were consolidated for the hourly predictions.

The shallow retrofit did not directly target space-conditioning energy reductions; however, utility data analysis results point to increased heating energy use and reduced cooling energy use as impacts of the shallow retrofit. The lighting retrofit is the probable cause, because it substantially reduces the amount of heat generated in the home. (Recall the example from Section 4.7.1 proposed reductions in heat gains of 1,580 Btu/h.[11]) To investigate this effect further, the team analyzed the space-heating and space-cooling energy use impacts of the shallow retrofits using monitored data. The end-use monitoring data provide more specific insight to the space-conditioning changes that were coincident with the shallow retrofits.

The degree of lighting retrofit varied greatly by site, so for consistency the team evaluated the same study homes for space-heating and space-cooling energy use changes. The number of

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[10] Heating season is defined as December through March; cooling season is defined as May through October.

[11] Connected lighting load was reduced by 1.4 kW post-retrofit. 1.4 kW × 3,412/33% = 1,580 Btu/h.

acceptable sites for space-cooling energy use modeling was limited by the lack of cooling season between instrumentation and the shallow retrofit. The pre-retrofit monitoring period completely excluded summer data for most shallow-only retrofitted homes. Twelve sites were monitored by early September 2012, during which outdoor temperatures reached 89°–90°F, a threshold warm enough for modeling to represent hours with significant cooling needs. Two of the 12 sites were not candidates for the space-heating analysis because of apparent plug-in portable space-heating energy use rather than central heating. Plugged space heating was not monitored independently and would have skewed the results. Ultimately nine homes were suitable for evaluation.

The pre-retrofit cooling period was limited to 7 weeks of monitored data, including part of September and all of October 2012; these same weeks in 2013 were used for the post-retrofit modeling. Space-cooling needs during this moist time of year vary from early summer when an AC has a smaller latent load to control. Consequently, including the earlier summer data for the post-retrofit modeling would invite bias. Space-heating observations were limited only by the lack of heating in the hot-humid climate. Pre-retrofit heating observations were drawn from December 2012 through March 2013; these same months the following year were used for post-retrofit modeling.

4.8.1 Space-Cooling Results

The analysis for space cooling using monitored end use data confirms the utility data disaggregation results: The shallow retrofits measurably reduced space-cooling energy use. This evaluation of cooling energy use is limited to the most humid summer days and more moderate exterior temperatures. Given the restricted number of observations per site, the team consolidated observations from all sites for each hourly model.

Space-cooling energy use was evaluated for the following temperature profiles: pre-retrofit normalized to post-retrofit weather, post-retrofit normalized to pre-retrofit weather, and both periods normalized to the average TMY3 cooling season profile. Because the hourly prediction models were designed with only a few observations of very hot (and no extreme) temperatures, they were not applicable to the peak TMY3 cooling day temperature profile.

Table 18 shows the results for the projected shallow retrofit space-cooling energy savings using nine sites. The projected daily AC energy use savings normalized to the TMY3 profile is 2.7 kWh (13%). This compares well with the annual utility data analysis, which predicted cooling energy savings of 3.7 kWh/day when pre-retrofit weather-normalized, and 4.1 kWh/day when TMY3 weather-normalized. (The cooling energy use savings prediction from the shallow retrofit for these analyses were 16% and 17%, respectively.)

Table 18. Shallow Retrofit: Pre-Retrofit versus Post-Retrofit Daily and Peak Hourly Cooling Energy Savings Evaluation Summary

Shallow Retrofit Cooling Analysis Normalization Weather Profile	Daily				Peak Hour (3–4 p.m. EST)			
	kWh			Savings (%)	kW			Savings (%)
	Pre	Post	Delta		Pre	Post	Delta	
Pre-Retrofit Weather					1.27	0.99	0.28	22
Post-Retrofit Weather					1.49	1.30	0.19	13
TMY3 Average, Weighted	20.9	18.2	2.7	13	1.52	1.34	0.18	12

Shallow Retrofit Cooling Analysis Normalization Weather Profile	Daily				Peak Hour (3–4 p.m. EST)			
	kWh			Savings (%)	kW			Savings (%)
	Pre	Post	Delta		Pre	Post	Delta	
TMY3 Peak, Weighted	N/A[a]							

[a] Analysis was limited to late summer data. Modeling is not applicable to peak temperatures.

The section on the right side of Table 18 presents projections for the peak hour (3–4 p.m.) for each temperature profile. Peak hour savings projections range from 0.18 to 0.28 kWh (12%–22%). Figure 21 is a plot of the daily space cooling energy use profile for pre- and post-retrofit normalized to the pre-retrofit weather. The post-retrofit daily cooling profile (dark blue) is much lower than the pre-retrofit daily cooling profile (light blue) for many hours of the day. The red, vertical, dotted lines represent the peak space-cooling hour.

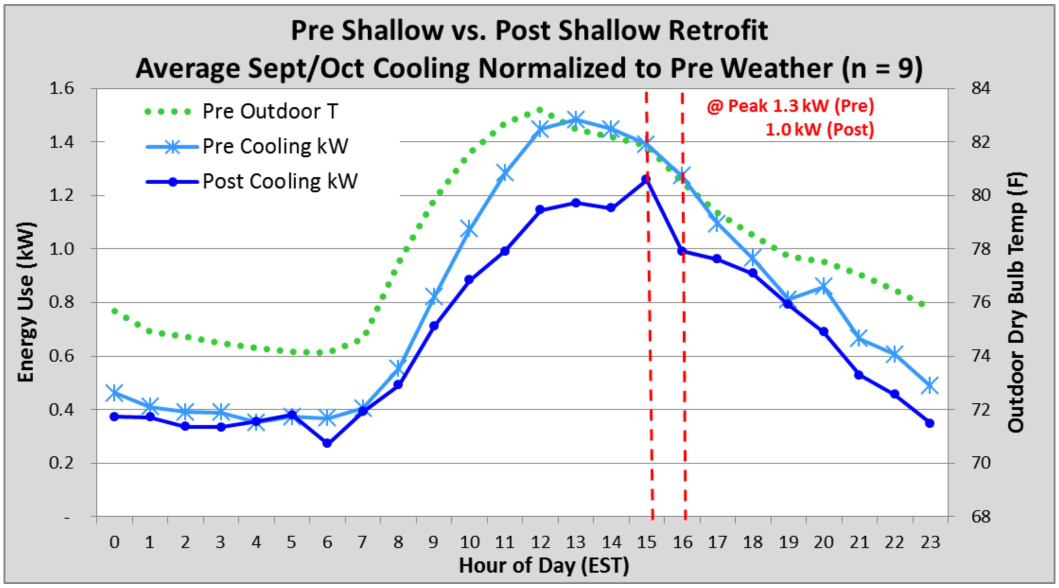

Figure 21. Pre-retrofit versus post-retrofit hourly space-cooling profile, pre-retrofit weather-normalized

Without weather normalization no savings are observed due to the more severe post-retrofit weather. The non-weather-normalized daily space-cooling energy use profile is plotted in Figure 22 to demonstrate the significance of weather normalization. The figure shows essentially no difference in cooling energy use between pre- and post-retrofit throughout the day, but the hotter post-retrofit weather (indicated in green stars) is obvious. See Appendix D for the shallow retrofit cooling energy use projection plots for all temperature profiles.

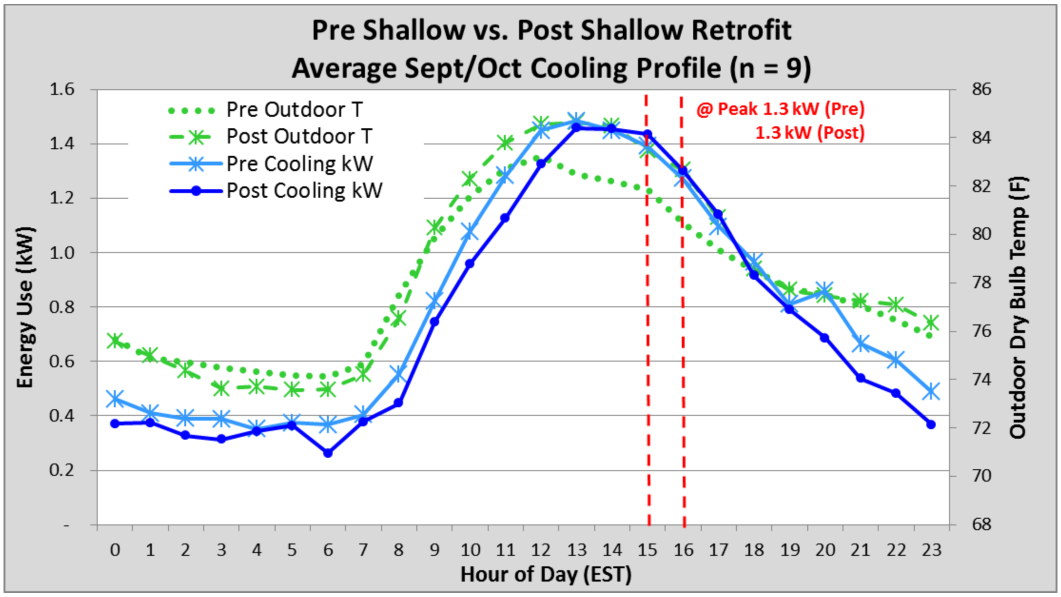

Figure 22. Pre-retrofit versus post-retrofit hourly space-cooling profile, non-weather-normalized

In the end, given two very different analysis methods, the shallow retrofits caused cooling energy to be reduced by 14%–16% and had a similar impact on peak demand.

4.8.1.1 Whole-House Summer Peak Demand Reduction

In a separate investigation of the shallow retrofit's impact on peak summer hour, the team compared the whole-house power demand at peak hour in October 2012 to that of 2013. This is a surrogate for the FPL system summer peaks during those years, because the study homes were not monitored in time for that comparison. Figure 23 compares the average demand of 18 sites during the peak hour in October 2012 (pre-retrofit) to the peak hour in October 2013 (post-retrofit), which shows a reduction of 0.67 kW between 4 and 5 p.m. The energy use reduction for the day was 9%: 52.1 kWh pre-retrofit and 47.4 kWh post-retrofit. This is significant in that the estimate is quite close to the separate estimates reported in Table 18. Both days had comparable outdoor temperatures; the average daily temperature and peak hour temperature were about 79°F. However, the hours preceding peak were warmer post-retrofit.

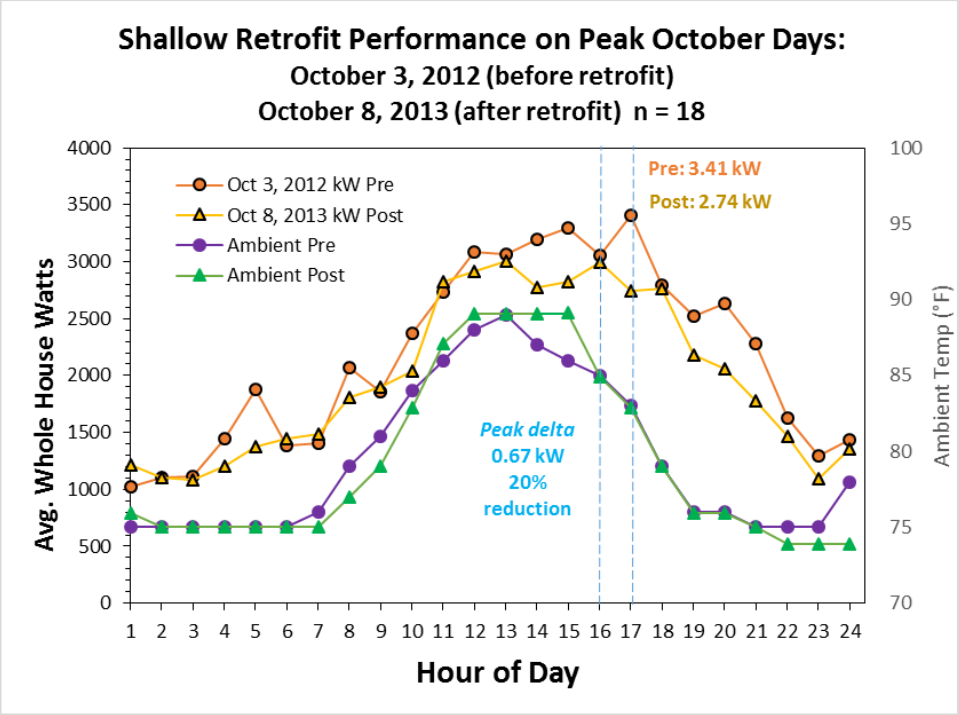

Figure 23. Comparative analysis between pre- and post-retrofit demand at peak day in October

4.8.2 Space-Heating Results

Space-heating energy evaluations are inherently limited in the hot-humid climate; the relatively warm winters provide few days with significant heating needs, and subtle changes in outdoor temperatures affect occupants differently. Some hours of the day had as few as three observations during the entire heating period from December through March. In several cases, the per-site modeling inaccurately predicted negative energy; therefore, as with the space-cooling energy analysis, the team consolidated observations from all nine sites to develop each hourly model. Consolidating the sites improved the modeling, but a handful of negative energy predictions still needed to be corrected. (These occurred only when the models were applied to peak TMY3 temperatures.) Modeling limitations aside, the evaluation for space-heating energy with hourly monitored end-use data confirms the utility data analysis finding that the shallow retrofits measurably increased space-heating energy use.

Space-heating energy use was evaluated for the following temperature profiles: pre-retrofit normalized to post-retrofit weather, post-retrofit normalized to pre-retrofit weather, and both periods normalized to the peak TMY3 heating day profile. Averaging the TMY3 heating season weather is not applicable, because the average nearly cancels out all space heating in this climate.

Table 19 summarizes the projected shallow retrofit impact on space-heating energy use for each temperature profile. With projections weather-normalized to the peak TMY3 heating season profile, daily space-heating energy use increases 8.1 kWh (39%). In the right-hand section of Table 19 are the peak hour (7–8 a.m.) projections. The negative savings at the peak hour is approximately 0.3 kW when models are normalized to either pre- or post-retrofit weather.

Applying the peak TMY3 heating day temperatures, space-heating energy increases by 0.63 kW at the peak hour.

Table 19. Shallow Retrofit: Pre-Retrofit versus Post-Retrofit Daily and Peak Hourly Heating Energy Savings Evaluation Summary

Shallow Retrofit Heating Analysis Normalization Weather Profile	Daily				Peak Hour (7–8 a.m. EST)			
	kWh			Savings (%)	kW			Savings (%)
	Pre	Post	Delta		Pre	Post	Delta	
Pre-Retrofit Weather					0.89	1.20	(0.31)	–35
Post-Retrofit Weather					0.80	1.09	(0.29)	–36
TMY3 Average, Weighted	N/A[a]							
TMY3 Peak, Weighted	20.6	28.7	(8.1)	–39	2.04	2.67	(0.63)	–31

[a] Averaging the TMY3 heating season removes the need for heating in this climate.

The utility data disaggregation and hourly end-use model projections agree that space-heating energy use increased after the shallow retrofit; however, they disagree about the extent of change. This limited-sample analysis is probably inherently less reliable, because the utility disaggregation evaluated 41 homes, and this analysis used only nine. A small number of study homes combined with few space-heating observations and pronounced differences in homeowner heating season behaviors during mild winters likely weaken the space-heating energy use predictions of the monitored end use analysis. Still, lighting retrofits will have strong impacts on space-heating needs—a fact predicted by analysis using the Building Energy Optimization energy simulation for Orlando.

Figure 24 shows a plot of the daily pre- and post-retrofit space-heating use projections normalized to post-retrofit weather. In comparison to pre-retrofit (deep red), all post-retrofit (bright red) morning hours (when it is coldest outdoors) require more energy. Moreover, the energy use in the late afternoon and early evening increased discernably, generally when occupants returned home and turned lights on. The negative savings at the peak hour (red, vertical, dotted lines) is relatively small. See Appendix D for the shallow retrofit heating energy use projection plots for all temperature profiles.

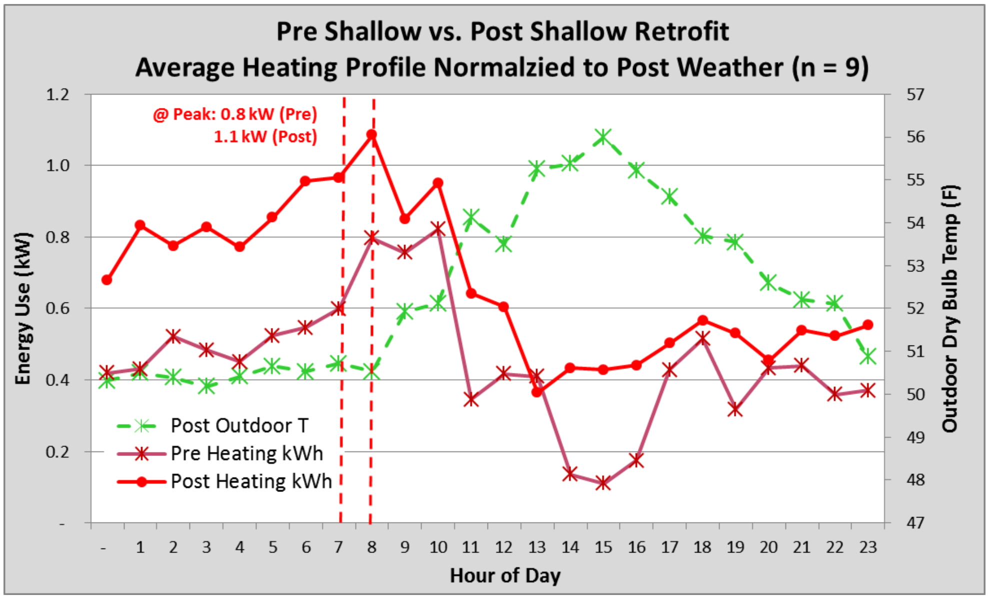

Figure 24. Pre-retrofit versus post-retrofit hourly space-heating profile, post-retrofit weather-normalized

4.8.2.1.1 Whole-House Winter Peak Demand Reduction

In a separate investigation of the shallow retrofit's impact on peak winter hour, the team compared the average whole-house power at the FPL system peak hour in 2013 (Mar. 4) to that of 2014 (Jan. 23). Figure 25 compares the average whole-house demand of 18 sites during the peak winter hour, which shows a small reduction between 7 and 8 a.m. of 0.25 Wh. However, post-retrofit energy demand increased significantly in the hours before and after the peak. Also, the average daily temperature was slightly cooler on the post-retrofit peak (48.8°F pre-retrofit versus 48.3°F post-retrofit), and the peak hour temperature was much colder post-retrofit (40°F pre-retrofit versus 36°F post-retrofit), though the preceding morning hours were not consistently colder post-retrofit. Daily energy use increased 8% (49.7 kWh pre-retrofit, 53.6 kWh post-retrofit), which substantiates earlier findings that the post-retrofit space-heating energy use increased after the shallow retrofit.

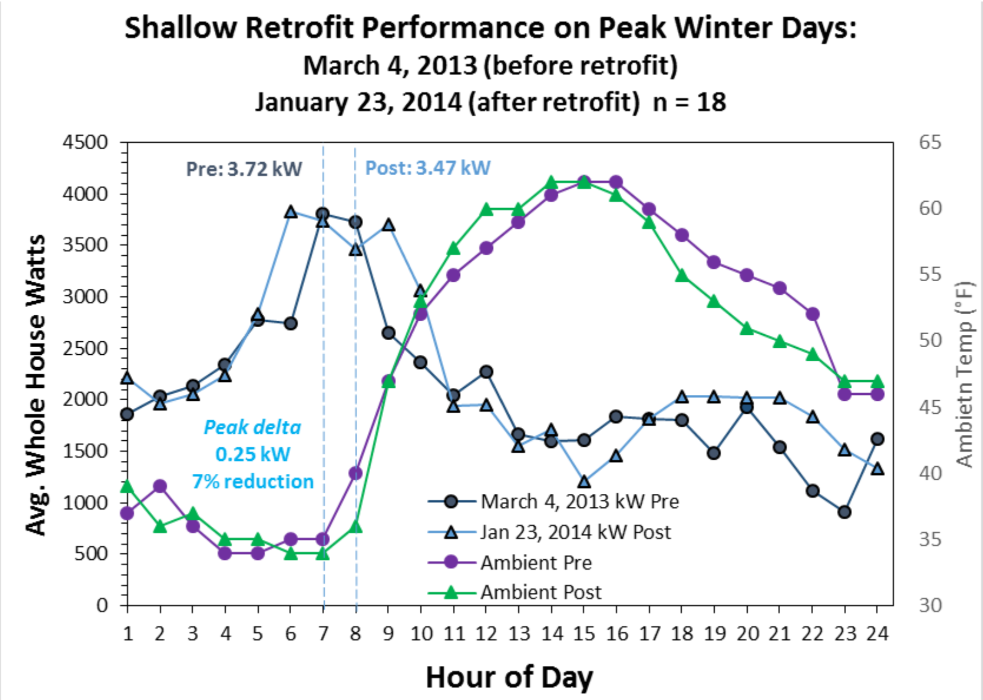

Figure 25. Comparative analysis between pre-retrofit and post-retrofit demand for FPL system peak winter day

The simple tank and pipe insulation wraps and showerhead replacements substantially reduced the domestic hot water energy demand in the morning and evening hours, as shown in Figure 26.

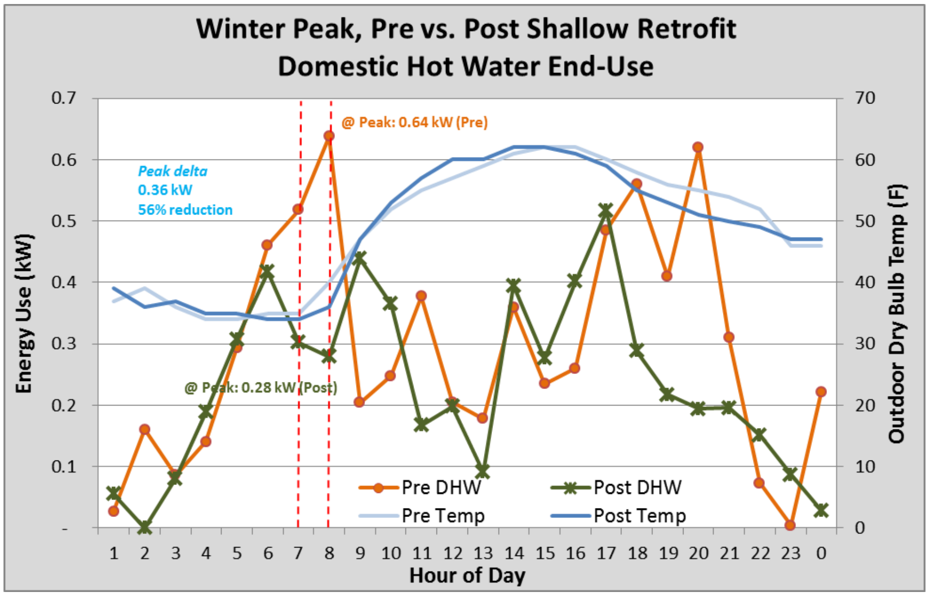

Figure 26. Pre-retrofit versus post-retrofit domestic hot water demand for FPL system peak winter day

4.9 Shallow Retrofit Discussion

One issue regarding customer expectations with the shallow retrofits is illustrated in Table 9, Table 11, and Table 16. In Table 11, for example, the whole-house savings level is low enough (9.2% of pre-retrofit consumption) that focusing on the overall billing data before and after the retrofits, which rose 9.3% during this period, will not reliably reveal the savings. The average total monitored consumption was 3.2 kWh higher in the month post-retrofit than the one before it, because the retrofits in this pilot were being completed in spring or early summer when AC use increased. The rising level of space cooling in the post-retrofit period generally overmatched the generated savings, which instead appeared as a lower-than-expected increase to the added consumption in the post-retrofit month. (Among the control groups, the consumption was 6.4 kWh higher in the post-retrofit month). The team conducted two pre- to post-retrofit evaluations to consider this effect:

- Examined 12 months of utility records, disaggregated by space heating, space cooling, and baseload
- Analyzed hourly space-heating and space-cooling end use data as they related to exterior temperatures.

For a subset of homes, the team compared the same calendar month of different years, 1 pre-retrofit and 1 post-retrofit. Such an evaluation minimizes seasonal variation effects on energy use by comparing the same part of the calendar each year although with the caution that large weather-related influences can still alter results—particularly in winter. However, by moving the post-retrofit analysis period forward in time, the team has better confidence about the long-term impacts of a retrofit measure.

The pool pump timer intervention showed pronounced evidence of return to pre-retrofit energy use over the long-term. Pump timers were likely moved back to pre-retrofit settings, and professional pushback on the timer adjustment from the pool maintenance industry has been reported in multiple cases. Also, the pump runtime is not static throughout the year; therefore, owners are relied on to continue the savings strategy as the timer is changed throughout the year. Further, the summertime pre- to post-retrofit delta may represent a bigger change in operational hours than in October. Thus, although changing pool pump hours can reduce pool pump energy substantially over the short term, this measure is not persistent because hours often return to preintervention levels. To effectively reduce pool pump energy use, variable-speed pool pumps, described in Section 5, are a superior option.

End-use savings for the remaining shallow retrofit measures; i.e., lighting and other plug loads, refrigeration, and water heating, appear greater in the pre- and post-retrofit October comparison than in the 30-days pre- and post-retrofit evaluation. Yet the whole-house savings were higher in the 30 days pre- and post-retrofit evaluation. Insight into the whole-house savings was provided by the utility data analysis and hourly space-conditioning evaluation. These very different investigations agree that the shallow retrofit provides substantial cooling energy savings in the summer and increases heating energy needs in the winter. For Florida’s cooling-dominated climate, this provides a significant net savings. The utility data analysis predicted that the study homes would experience an annual net space-conditioning energy reduction of 724 kWh, averaging 2 kWh/day savings.

The hourly space-conditioning analysis provides an understanding of the shallow retrofit's impact on space heating and cooling at peak hour. This evaluation confirms that the shallow retrofit provided space-cooling energy savings and an energy penalty for space heating. This analysis also demonstrated the importance of weather-normalization, where Figure 21 and Figure 22 were compared to show post-retrofit cooling savings entirely eroded by warmer post-retrofit weather. If customers only compare utility bills, they may believe (erroneously) that they are not achieving savings.

4.10 Summary and Potential Improvements to Shallow Retrofits

A summary of the impact of installed shallow retrofit results in the Florida sample of existing homes follows:

- Adjusting for weather-related changes over the 30 days before and after the shallow retrofits, savings of the overall shallow retrofits 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. Simple payback for the shallow retrofit averaged 2 years given the savings estimate from the initial savings evaluation. Payback is 2.4 years given the more conservative savings of the October analysis.
- Whole-house energy demand during the FPL system peak hour was reduced 0.67 in summer and 0.25 in winter.
- The lighting retrofit measure is 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 averaged 4.9 and 2.7 years, depending on which saving evaluation was used.
- The shallow retrofit caused significant changes to space-heating and space-cooling energy use. Strong evidence indicated that the lighting retrofit's reduction in heat gains was the cause. The utility data disaggregation, which evaluated 41 of the shallow retrofit homes, showed that annual space cooling decreased by 1,353 kWh (16%) when normalized to pre-retrofit weather. Meanwhile, the evaluation predicted that post-retrofit annual space heating would nearly double, with 629 kWh negative savings. The predicted annual baseload savings of 632 kWh is about half the space-cooling energy savings. Normalized to TMY3 and weighted by FLP service areas, the annual predictions are 1,481 kWh for space-cooling energy savings and negative savings of 614 kWh for space-heating energy.
- The space-heating and space-cooling evaluation of hourly monitored data on nine study homes confirms the impact of the shallow retrofit on space-conditioning energy use. Space-cooling peak hour savings ranged from 0.18 to 0.28 kW, depending on the temperature profile used. Negative space-heating savings ranged from 0.29 to 0.63 kW.
- Potential savings from reducing pool pumping hours appears significant but in practice is difficult to achieve. In the 19 sample pool homes, nine were already operating less than 5 hours/day and were not altered. Each of the 10 homes in which hours were reduced saved an average of 4.6 kWh/day. However, the intervention was short-lived for many homes.

The savings observed during the immediate post-retrofit analysis for this end use was markedly diminished in an evaluation that used a post-retrofit period months after the intervention. Homeowner information may be useful, because most do not know that pumps are costing $50 a month when operated 8 hours/day. Variable-speed pool pumps offer a better option to reduce pool pump energy use.

- The domestic hot water retrofit produced relatively large and dependable winter day peak demand reductions. And water-heating energy savings are large enough to continue to emphasize tank wraps and showerhead change-outs (139 and 219 kWh/year as reported in the earlier and later analyses). Depending on which savings evaluation was used, simple payback for the hot water retrofit averaged 5.4 and 3.6 years.
- Savings from refrigerator coil cleaning were small in the initial analysis and mostly disappeared in the later October comparison when confined to refrigerators with cleaned coils and good data. Simple payback for the refrigerator coil cleaning averaged roughly 4.3 years using the more reliable 30-day pre-post method, which is likely longer than the effective life of the measure. The team recommends excluding coil cleaning from future programs; however, short-term monitoring of refrigerators should be conducted to determine whether they should be replaced (see Section 5.4.1).
- Finding good candidate sites for the APS installation proved difficult, because candidates with large standby losses were equipment such as digital video recorders that could not be interrupted. However, given an electronics equipment station with enough low power losses among devices that can be shut down without loss of functionality (>10 watts continuous), the savings justifies the small price of the APS. The small sample indicates 0.21 and 0.70 kWh daily energy savings.
- Savings from a shallow retrofit program in Florida are effective; however, reductions are small in magnitude, and customers may not see their impact by comparing monthly utility bills.

5 Deep Retrofits

5.1 Background

Pre-retrofit planning was required before retrofit measures were implemented. This included choosing equipment, materials, and contractors and defining work scopes and performance metrics to guide proper implementation. Proper retrofit staging was essential to minimize rework and avoid delays to the PDR project. The deep measures were implemented mostly between August and December 2013; the project's final deep retrofit measure was completed in March 2014.[12] The installation details for the high-efficiency heat pump ACs, learning thermostats, HPWHs, ceiling insulation, and ductwork repair are described in Appendix E.

5.2 Preliminary Space Heating and Cooling

Several deep retrofit measures have the potential to impact the space-heating and space-cooling energy used by the study homes. A preliminary analysis of cooling energy savings is described in this section.

The HVAC analysis consists of a site-by-site evaluation of how the combination of the following measures affected cooling:

- Replacement of heating and cooling heat pump
- Installation of Nest learning thermostat
- Testing and sealing of the ductwork system.

Only cooling is evaluated in this preliminary analysis, which was conducted before central Florida's short winter. At the time of analysis, most insulation retrofits were not yet installed; thus, the evaluated savings did not include this measure. Cooling-related efficiency improvements were evaluated by examining pre- and post-retrofit cooling energy use and interior temperature and weather conditions. Subsequent analyses in Sections 5.6.2 and 5.6.3 investigate space-heating and space-cooling energy use.

A standard format was used to describe each home; the effects of the AC replacement and duct repair on measured cooling were then analyzed. The team used regression techniques against the average daily air temperature and AC use and the measured interior temperature by the thermostat. The statistical analysis can separate results from the AC retrofit and learning thermostat. Data and data analysis are graphically displayed for three sites. One site shows small savings and negative savings from the learning thermostat (Site 7); another shows large savings and savings from the learning thermostat (Site 19). Finally, Site 10 is shown where a more efficient AC (but no learning thermostat) was installed.

Key findings are summarized from each site in tabular form to show regression results and estimated summer cooling savings from the retrofits.

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[12] Site 10's HVAC install was installed in May 2013, earlier than the other deep homes, and by a different HVAC contractor.

5.2.1 Site 7

Site 7 is a larger home (2,650 ft^2). It had a relatively efficient 3.5-ton heat pump (2001 vintage) with an estimated SEER of 14. The home's 2011 electricity consumption was 25,211 kWh. The heat pump was replaced with a 4-ton, 2-speed SEER 16 Carrier 25HCB6 heat pump on Sept. 24, 2013. This was matched with a variable-speed FV4CNB006 AHU. At the same time, damaged segments of the duct system were replaced and the overall duct system sealed; the duct leakage of Qn,out =0.126 was decreased to 0.063. A Nest learning thermostat replaced the programmable thermostat in the upstairs hallway. As seen from earlier monitoring, the two occupants preferred low interior temperatures during the cooling season.

The AC energy use had been measured at Site 7 since project inception. From May 1 to Sept. 23, 2013, average AC energy use averaged 28.7 kWh/day (4,200 kWh), and the average house interior temperature was maintained at 72.2°F (RH averaged 61.6%). In the month immediately preceding the retrofit, the average values were 38.5 kWh/day and 72.5°F maintained inside. Figure 27 shows the period at the end of summer when the retrofit was installed. AHU, compressor, and total AC system energy are plotted. Energy use appears to fall after the retrofit (26.1 kWh/day post-retrofit), although the reduction in AHU energy is much more consistent than the compressor energy. Given the timing of the retrofit at the end of summer, it was important to examine how weather in the pre- and post-retrofit periods influenced the evaluated savings.

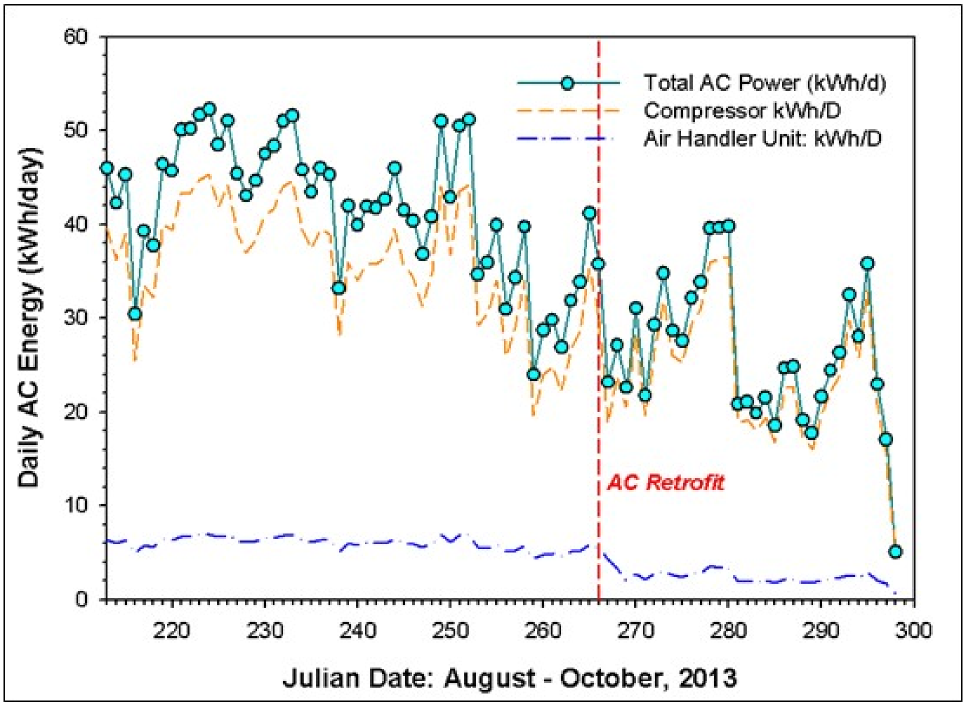

Figure 27. Site 7 AC energy; pre- and post-retrofit August–October 2013

Figure 28 shows that most of the changes seen in the weeks after the retrofit on Sept. 24, 2013 are associated with a lower average outdoor temperature. Also, the occupants with the Nest learning thermostat maintained a lower temperature by about 1.4°F (71.1°F).

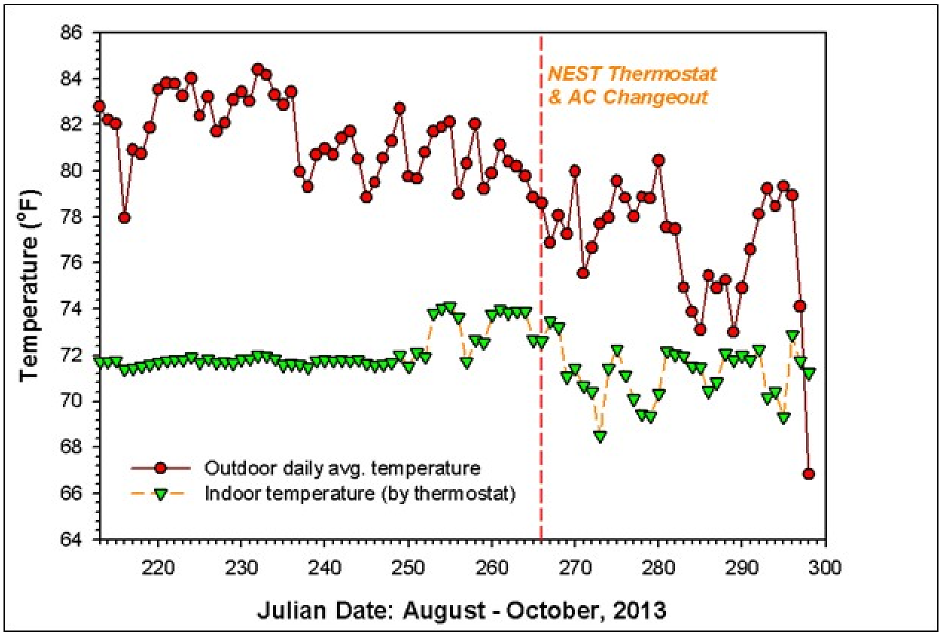

Figure 28. Site 7 average indoor and outdoor temperatures August–October 2013

To sort out the weather-related influences, the team assembled the summer pre- and post-retrofit daily AC use and regressed daily AC use pre- and post-retrofit against the average daily air temperature. Figure 29 shows the results. Although the data show considerable scatter, the weather-related increases to cooling in hotter weather were expected.[13] However, the retrofit produced only about 2.6 kWh/day energy savings (about 7%) at 80°F. Although not shown, examination of data showed similar compressor energy but much lower AHU electricity use post-retrofit.

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[13] The differences in cooling energy use that were not attributable to indoor and outdoor temperatures were due to other important influences: solar heat gains through windows and on building surfaces and internal heat gains produced by varied use of interior appliances. The latter in particular can create large day-to-day cooling loads.

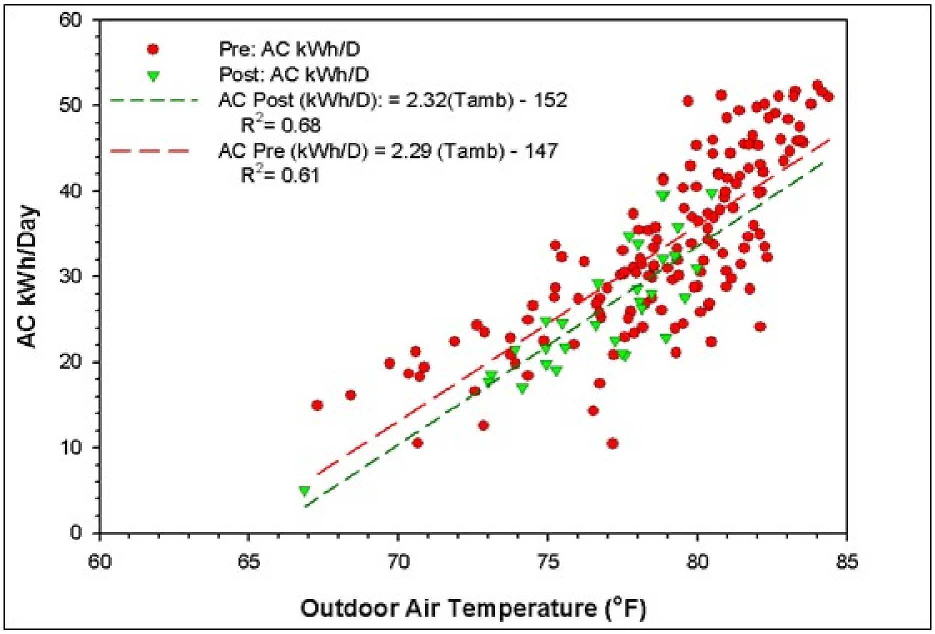

Figure 29. Site 7 average AC versus outdoor temperature July–October 2013

Because the interior temperature varied from pre-retrofit to post-retrofit, the team further examined the energy reduction with AC plotted against interior to exterior temperature difference. The regression prediction significantly improved, in particular for the pre-retrofit period. Figure 30 shows that the new AC system and ductwork repair reduced cooling energy use by about 18% at a given interior temperature. However, most of this was lost with lower maintained interior temperatures; pre-retrofit, at an average ambient temperature of 80°F, the temperature difference from inside to outside was 8°F; afterward, the difference was 9°F.

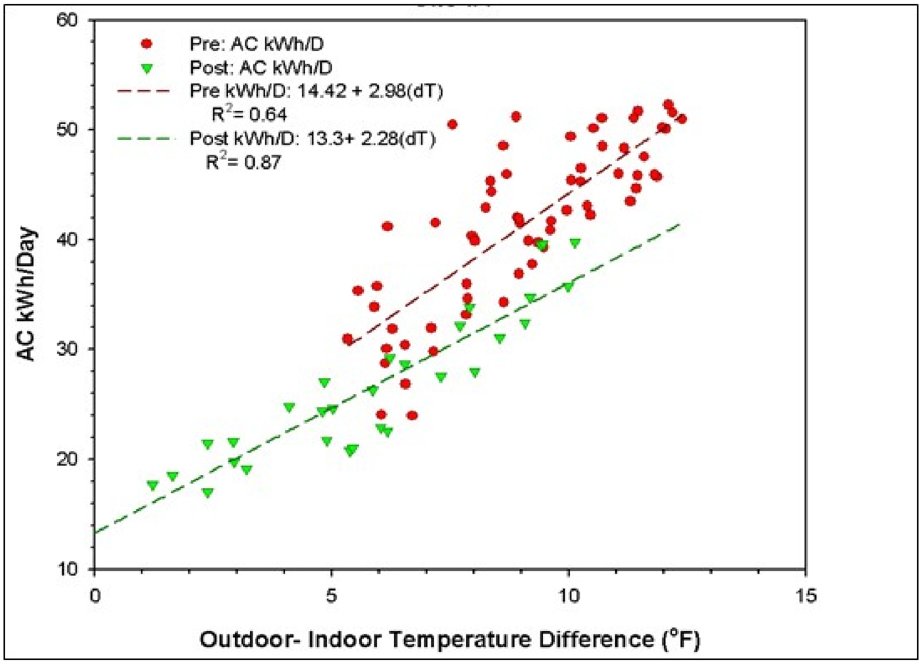

Figure 30. Site 7 average AC versus temperature difference July–October 2013

The temperature-corrected difference suggests that the daily cooling energy use of 38.3 kWh/day for the old system and 33.8 kWh for the new system, a savings of 4.5 kWh/day or about 12%, which mostly came from the more efficient variable-speed AHU blower. However, had temperatures been maintained the same pre- and post-retrofit, the regression-indicated savings would have been 6.8 kWh/day (38.3 versus 31.5 kWh/day) or 18%.Although savings of the AC retrofit cannot be separated from the duct-sealing segment, the regression allows evaluation of how the learning thermostat influenced savings. In this specific case, the result is not positive; the learning thermostat appeared to adversely influence potential savings:

- The occupants appeared to prefer an indoor temperature of approximately 72°F. However, after the Nest thermostat was installed, they chose to lower the average temperature by about 1°F, which reduced indicated AC savings by about 6% (differences in the regressions above).
- The programmable thermostat in place before the retrofit maintained a very constant and predictable temperature that averaged about 72°F per day. After the learning thermostat was installed, the daily interior temperature trended lower but became much more variable and less predictable. After the learning thermostat was installed, the occupants selected a lower temperature, which likely compensated for its attempts to elevate the interior temperature to produce savings.
- Because the learning thermostat was placed in an upstairs hallway, the occupants frequently went upstairs to change its operation during the first weeks of use (they specifically did not want the thermostat downstairs where its occupancy-related function would have been used). Moreover, the occupants opted to defeat its “auto-away” function, which deprived the thermostat of a means of achieving savings.

In summary, no savings could be attributed to the learning thermostat. In fact, the opposite appears to have been true (the learning thermostat had negative savings), because the occupants maintained a lower average temperature inside after it was installed. When controlling for temperatures maintained, the heat pump replacement and duct repair saved about 18% of cooling. However, with the thermostat influence, this dropped to only a 12% savings. These conclusions, however, are based on month-long data. Additional analysis of a much larger sample of learning thermostats installed in 2014 is planned under PDR Phase II.

5.2.2 Site 10

Site 10 is a 1,727-ft^2 home in West Melbourne, Florida, built concrete block construction. It had the original 3-ton, 12 SEER, AC unit from when the house was built in 2003. The home’s electricity consumption in 2011 was 19,130 kWh, which is slightly higher than average.

The original heat pump system was replaced with a 3-ton variable-speed SEER 18 Carrier Infinity Model 25HNB936A310 heat pump with a Carrier Infinity Model variable-speed van coil (FE4ANF003) on May 31, 2013. The duct system was fairly tight when evaluated with a normalized leakage of Qn,out = 0.049 and was reduced as the duct system was sealed with a test-out duct leakage was Qn,out = 0.043. A learning thermostat was not installed, because the variable-speed Carrier unit uses its own special thermostat. The two adult occupants maintained average cooling temperatures but mentioned needing to achieve cooler temperatures than the old system could achieve.

The AC energy use had been measured at Site 10 since project inception. From Apr. 1 to May 31, 2013, AC energy use averaged 41.9 kWh/day with the house interior temperature maintained at an average 76.1°F. Figure 31 shows the cooling system energy use over the summer when the retrofit was installed. AHU, compressor, and total AC system energy use are plotted. Energy use was dramatically reduced after the retrofit (24.6 kWh/day post-retrofit), even though the weather was much warmer in the post-retrofit period.

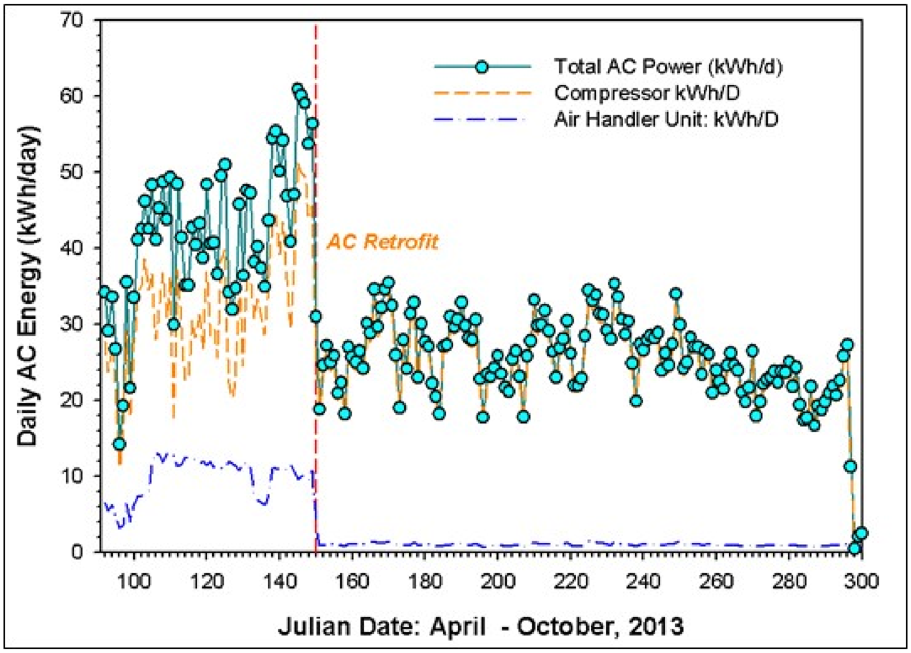

Figure 31. Site 10 AC energy; pre- and post-retrofit April–October 2013

Figure 32 shows the average temperatures over the summer of monitoring. The occupants also maintained a much lower indoor air temperature (73.8°F) after the AC retrofit was done, which indicates considerable take-back for comfort. The cooler interior temperatures are apparent after the retrofit.

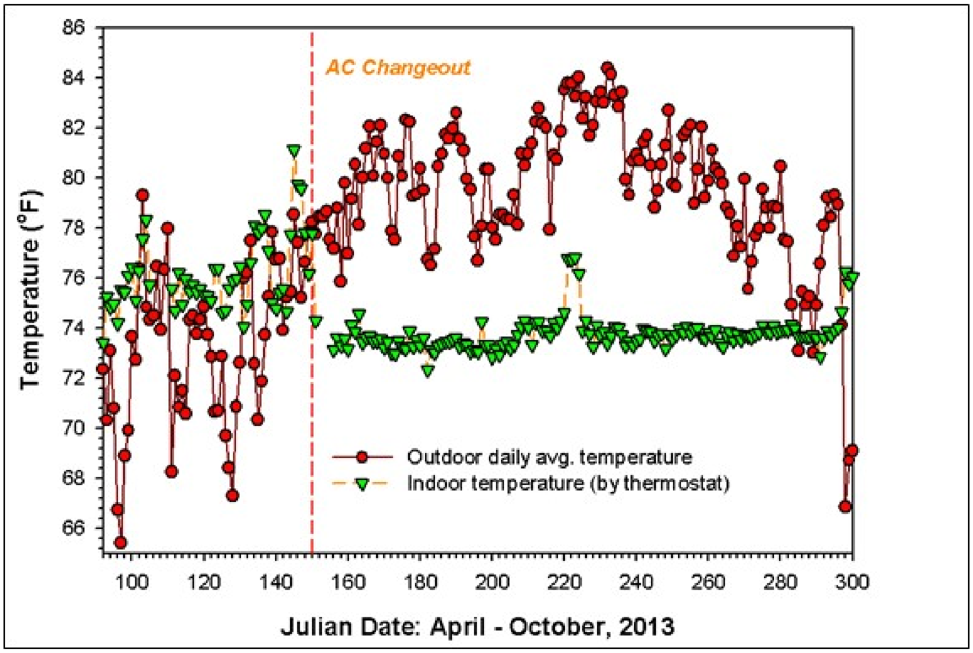

Figure 32. Site 10 average indoor and outdoor temperature April–October 2013

Figure 33 shows the energy use for the old system versus that of the new heat pump. At an average daily outdoor temperature of 80°F an apparent savings of 31.6 kWh/day (57.7 kWh versus 25.9 kWh/day) or about 55% was achieved.

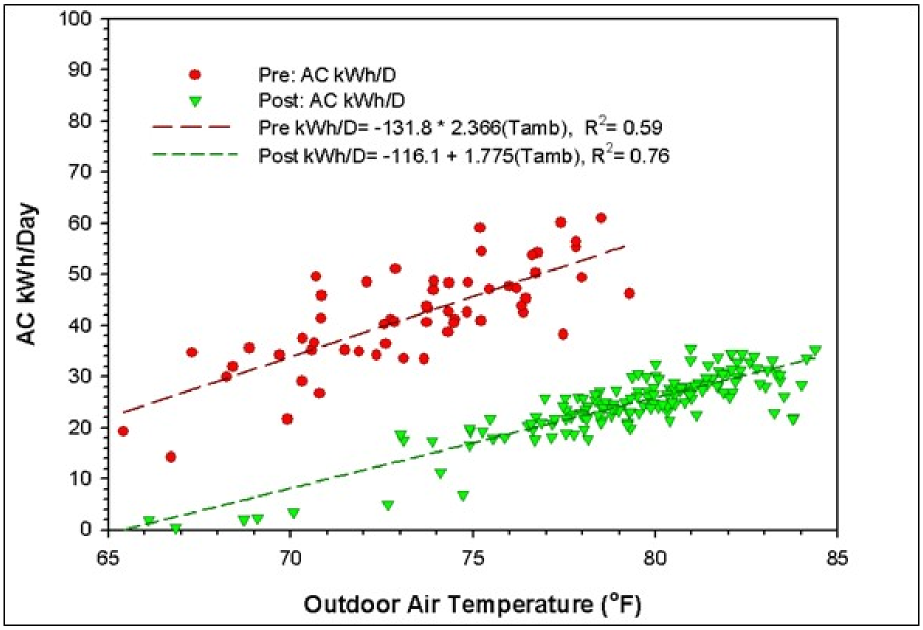

Figure 33. Site 10 average AC versus outdoor temperature April–October 2013

Figure 34 regresses cooling energy consumption against average interior to exterior temperature difference. At an 80°F outdoor temperature, the average interior to exterior temperature difference was approximately 6.5°F after the retrofit and 2.5°F before the retrofit. Average temperatures maintained were very different pre- and post-retrofit. At the temperatures maintained, the difference estimated by the regressions pre- and post-retrofit indicates a savings of 50%.

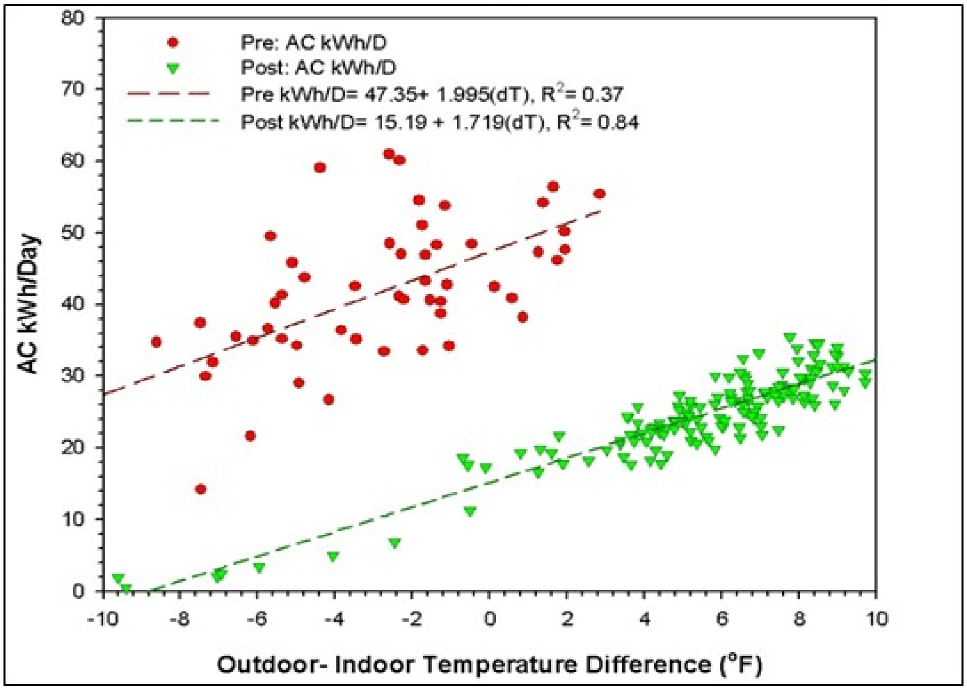

Figure 34. Site 10 average AC versus temperature difference April–October 2013

The same regression suggests that if the temperature inside had been the same as it was before the HVAC retrofit, an additional 6.9 kWh/day would have been saved. This indicates savings would have been 63% had occupant temperature take-back not taken place. This suggests the degree of take-back may have been more modest with a learning thermostat in place.

5.2.3 Site 19

Site 19 is a 2,554-ft^2 home in Melbourne, Florida, built in 1988 of concrete block construction. It had an aging 5-ton York AC unit with mismatched components. The AHU is of 1990 vintage; the compressor was replaced in 1997. Given the mismatch, it has no nameplate SEER, but its efficiency is likely less than 10 Btu/Wh. This home's energy use was among the highest in the overall PDR sample. Total electricity consumption in 2011 was 26,691 kWh.

The original heat pump system was replaced with a 5-ton, 2-speed SEER 16 Carrier 25HCB6 heat pump on Aug. 26, 2013. This is matched with a variable-speed FV4CNB006 AHU.

The duct system was fairly leaky when evaluated. The original normalized leakage of Qn,out = 092 and was reduced as the duct system was sealed with a test-out duct leakage was Qn,out = 054. A Nest l earning thermostat replaced the programmable thermostat in the single-story home. The three adult occupants preferred slightly lower-than-average cooling temperatures.

The AC energy use had been measured at Site 19 since project inception. From May 1 to Aug. 26, 2013, AC energy use averaged 59.4 kWh/day with the house interior temperature maintained at an average of 74.7°F. In the month immediately preceding the retrofit, the average values were 73.9 kWh/day and 75.4°F maintained inside.

Figure 35 shows the cooling system energy use over the summer when the retrofit was installed. AHU, compressor, and total AC system energy use are plotted. Energy use is dramatically reduced (26.5 kWh/day post-retrofit).

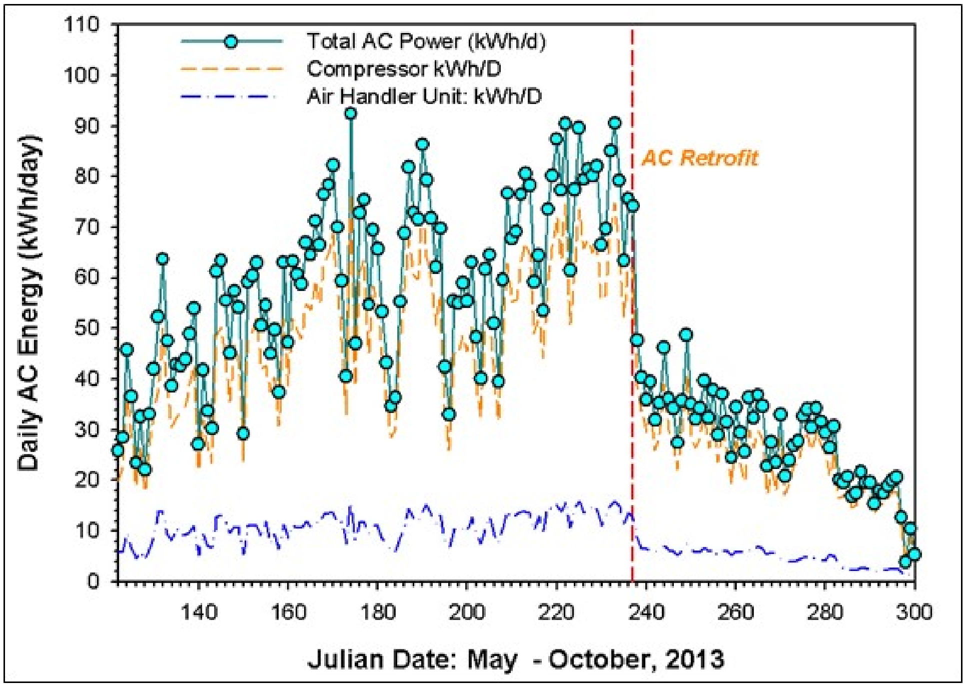

Figure 35. Site 19 AC energy; pre- and post-retrofit May–October 2013

Cooling energy use seemed to decrease significantly from the week before to the week after (76.8 kWh to 37.9 kWh/day). However, as before, the post-retrofit period weather was much cooler. Figure 36 shows that some of the changes seen in the weeks after the retrofit on Aug. 26, 2013 are associated with a lower average outdoor temperature. Also, the occupants with the Nest learning thermostat maintained a slightly higher temperature than before the retrofit.

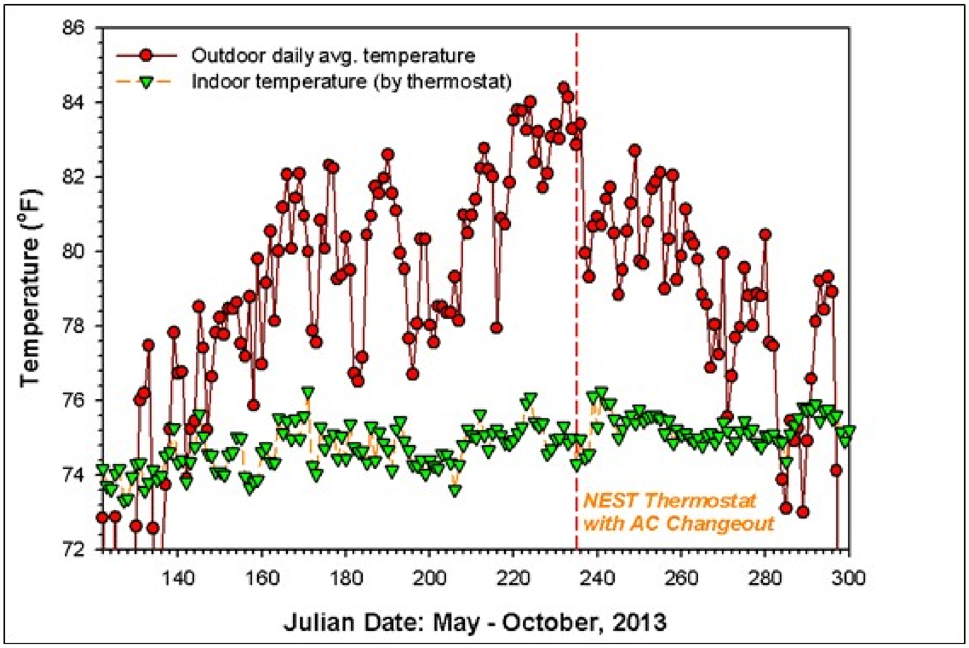

Figure 36. Site 19 average indoor and outdoor temperature May–October 2013

To evaluate weather-related influences, the team used the summer pre- and post-retrofit daily AC data and then regressed daily cooling kilowatt-hours pre- and post-retrofit against the average daily air temperature (Figure 37).

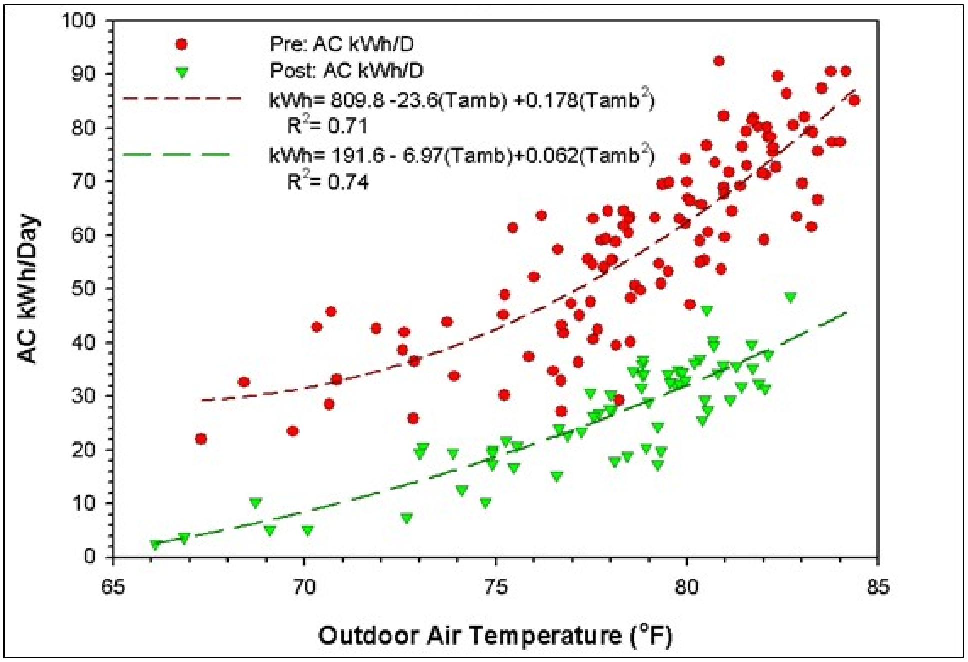

Figure 37. Site 19 average AC versus outdoor temperature May–October 2013

The team used quadratic regressions to estimate the daily pre- and post-retrofit AC and how it varied with outdoor temperature. At 80°F, the regressions indicated 61 kWh pre-retrofit and 30.8

kWh post-retrofit—30.2 kWh/day savings or a 47% reduction. This represents the HVAC retrofit overall savings includes all elements: AC change-out, duct sealing, and Nest learning thermostat. However, the team examined pre- and post-retrofit interior temperatures to separate out the savings that were attributable to the learning thermostat. In the month before the retrofit, the occupants maintained an average temperature 75.1°F; in the month after the retrofit, the interior temperature rose to an average of 75.4°F.

The regression differences between Figure 37 and Figure 38 allow evaluation of how the learning thermostat influenced savings. At an average daily outdoor temperature of 80°F, the average outdoor to indoor temperature difference for the regression in Figure 38 was 5.3°F (pre-retrofit) and 4.7°F (post-retrofit). The predicted consumption is 32.1 kWh/day for the post-retrofit condition for a savings of 47%.

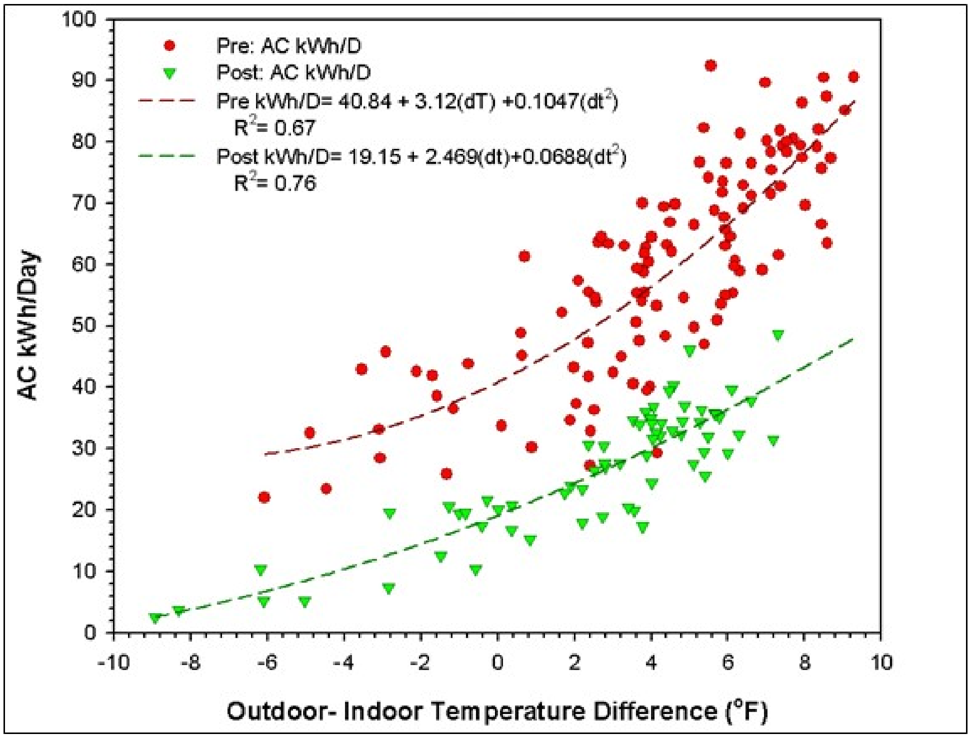

Figure 38. Site 19 average AC versus temperature difference May–October 2013

If pre- and post-retrofit energy consumption is evaluated at the post-Nest temperature difference, the predicted pre-retrofit consumption falls to 58.4 kWh/day. This shows that when controlling for changes to indoor-to-outdoor temperature the AC retrofit and duct repair reduced consumption by 26.3 kWh/day (58.4 – 32.1 kWh) or 45%.

The remainder of the savings (2.1 kWh/day) comes from the learning thermostat, which appears to have produced a cooling energy savings of approximately 4%.

5.2.4 Summary of Cooling Energy Savings by Site

Table 20 shows the measured AC retrofit savings by site. In all but one case, the AC unit or heat pump was replaced with a 3- or 4-ton, 2-speed SEER 16 or 17 Carrier heat pump. (These units were chosen for Nest thermostat compatibility.) Ducts were also tested and sealed at each site and a Nest learning thermostat was installed except at Site 10. At Site 10 a 3-ton variable-speed SEER 18 Carrier Infinity Model 25HNB936A310 heat pump with a Carrier Infinity Model variable-speed van coil (FE4ANF003) was installed.

Table 20. PDR Cooling Energy Savings Analysis

Site	Pre (kWh)	Post (kWh)	Savings (kWh)	Savings (%)	HVAC Saved (%)	Thermostat (°F)		Temperature-Related	
						Pre	Post	Savings (%)	Learning Thermostat Savings (%)
7	38.3	33.8	4.5	12	18%	72.1	71.1	–6	–6
8	35.4	14.7	20.7	58	54%	77.9	78.5	4	4
10	57.7	25.9	31.8	55	63%	77.8	73.8	–13	[a]
19	61.0	30.8	30.2	50	47%	75.1	75.4	3	3
26	41.2	21.8	19.4	47	48%	75.1	73.6	–1	–1
30	19.3	16.5	2.8	15	23%	77.8	76.9	–8	–8
37	40.0	33.6	6.4	16	28%	78.3	75.8	–12	[b]
39	23.2	15.0	8.2	35	31%	78.3	79.1	4	4
40	32.4	20.6	11.8	36	35%	75.4	75.7	1	1
51	39.7	21.5	18.2	46	48%	80.5	79.2	–2	–2
Avg.	38.8	23.4	15.4	37	39.5	76.8	75.9	–1.9	–0.6

[a] No learning thermostat installed

[b] Received improper instruction relative to learning thermostat operation

Measured average savings for a typical summer day in central Florida with an average temperature of 80°F were 15.4 kWh/day or 37% of pre-retrofit consumption from the combination AC replacement/duct repair and learning thermostat installation. The team used regression techniques with the outdoor weather and temperature maintained indoors to separate out the influences of the AC retrofit and duct repair from the learning thermostat installation. The AC and duct repair saved an average of 40% of pre-retrofit consumption, but lower temperatures were generally chosen—even with a learning thermostat—so the average final savings were about 37%.

In the single site without a learning thermostat, the interior temperature maintained post-retrofit was 4°F cooler. With the learning thermostat, it was still about 0.7°F cooler post-retrofit. Four of the nine Nest sites achieved post-retrofit savings from the learning thermostat of 1%–4%. However, these were marred by others with negative savings.

The team does not know why occupants chose lower temperatures post-retrofit—although with Site 37 this behavior resulted from improper instruction about learning thermostat operation (this site was eliminated from the computed averages). The households may have chosen a lower temperature to compensate for the learning thermostat attempts to raise the interior temperature. Occupant-reported feedback also revealed that Site 7 defeated the “auto-away” feature to prevent the thermostat from raising the interior temperature while the occupants were not home.

This study faced significant limitations relative to evaluating learning thermostats. The team could not determine what learning thermostats would do to systems in which the AC system was not being changed. AC retrofit may very well alter occupant expectations, and the high degree of temperature take-back seen at Site 10 may be typical. A previous study that replaced five AC units with high-efficiency units in 2001 showed an average temperature-related take-back of 1°F (Masiello et al. 2004). This cannot be known without further research, which a series of Nest-only retrofits may enable for some of the shallow retrofit group, installed as part of PDR Phase II.

5.3 Heat Pump Water Heaters

Based on FSEC's previous research experience with HPWS, deep home retrofit HPWS were selected based upon occupancy, installed location (i.e., garage or home interior), and cost. Systems selected were the A.O. Smith Voltex hybrid electric heat pump 80- and 60-gal units and the 50-gal capacity General Electric GeoSpring hybrid water heater.

Electric resistance water heaters were replaced with new HPWHs in eight of the deep-retrofit PDR homes in central Florida during September and October 2013. A comparison of 1 year pre-retrofit and 1 year post-retrofit energy use was conducted, although some homes were lacking a full year of pre-retrofit data. Assuming comparable groundwater temperatures between years, the measured average savings for the eight homes was 68.5% (5.27 kWh).

Table 21 lists individual annual savings from the eight sites, which were chosen from the complete set of 55 homes[14] to create a representative sample that included varying hot water end-use loads. The range of hot water loads within this sample was determined only through measured energy use, because hot water flow rates were not measured as part of the study. An A.O. Smith Voltex HPWH with either a 60- or 80-gal capacity was chosen for each retrofit according to occupancy and observed electricity demand.

Table 21. Measured Annual HPWH Retrofit Savings at Eight Sites

Site	Savings (kWh/d)	Savings (%)	Pre-Retrofit Analysis (days)	Post-Retrofit Analysis (days)	Pre-Retrofit Capacity (gal)	HPWH Capacity (gal)
Site 7	3.28	54.8	358	365	40	60
Site 10	4.02	67.1	342	365	50	60
Site 40	2.30	59.6	234	365	40	60
Site 51	2.28	71.1	275	365	40	60
60-Gal Average	2.97	63.1				
Site 08	6.24	70.5	365	343	50	80
Site 19	9.55	76.5	365	365	50	80
Site 26	6.76	69.9	364	365	55	80
Site 30	7.72	78.3	347	365	40	80
80-Gal Average	7.57	73.8				
Overall Average	5.27	68.5				

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[14] One of the 56 sites had been dropped by the time of this analysis.

Four homes received a 60-gal HPWH and the other four received 80-gal units. Savings were generally higher with the 80-gal units (which were installed in homes with higher water heating loads) averaging 73.8% with energy use reduced on average by 7.57 kWh/day. The 60-gal units installed in homes with relatively lower hot water loads averaged 63.1% savings and 2.97 kWh/day of reduced energy use.

A shorter analysis period comparing 30 days of pre- and post-retrofit energy at each site showed similar average savings of 65.5% (3.77 kWh) after adjusting for the influence of weather. Table 22 lists individual savings from eight sites in order of installation date. A group of 47 homes in which electric resistance water heaters were unchanged serves as a control for normalizing to seasonal changes. Average energy use in the control group increased 4.4% compared to the same 30-day period before and after the retrofit at each site. The increase in pre/post energy use accelerated from 0.9% to 7% over the 6-week period from early September to mid-October. Savings for the 80-gal units averaged 69.5% (5.16 kWh/day); the 60-gal units averaged 61.4% savings (28 kWh/day).

Table 22. Measured HPWH Retrofit Savings at Eight Sites (30 days pre- and post-retrofit)

Site	Install Date	Savings (kWh/d)	Raw Savings (%)	Control Group Change (kWh/d)	Control Group Change n = 47 (%)	Normalized Savings (%)	Pre-Retrofit Equipment Capacity (gal)	HPWH Equipment Capacity (gal)
Site 51	09/04/13	1.39	68.1	0.03	0.9	68.4	40	60
Site 10	09/05/13	2.67	60.2	0.07	1.9	61.0	50	60
Site 30	09/09/13	4.41	68.7	0.13	3.6	69.8	40	80
Site 26	09/12/13	5.53	70.7	0.16	4.7	72.1	55	80
Site 40	09/13/13	1.94	59.8	0.19	5.3	61.9	40	60
Site 19	09/19/13	5.76	64.8	0.22	6.5	67.1	50	80
Site 7	09/24/13	2.30	52.0	0.17	4.9	54.4	40	60
Site 08	10/16/13	4.96	66.8	0.26	7.0	69.1	50	80
60-Gal Average		2.08	61.4	0.12	3.3	61.4		
80-Gal Average		5.16	69.5	0.19	5.4	69.5		
Overall Average		3.62	63.9	0.15	4.4	65.5		

Figure 39 and Figure 40 show the impact on daily electric energy use 30 days before and after the retrofit. Energy data from the day of retrofit, when the HPWH was installed, were removed from the analysis and the graphs. In most cases all data were included for analysis; however, extremely low energy use during pre-retrofit periods in three homes signaled a clear period of vacancy that lasted 3–4 days. These days were removed and substituted with an equivalent number of days taken just before the 30-day pre-retrofit span. All electric resistance water heaters in this analysis had tank wraps and piping insulation installed as part of the shallow retrofit measures in spring 2013. This includes the eight pre-retrofit units replaced with HPWHs and the entire group of 47 control homes. Thus, savings in a pristine sample of homes without any efforts to reduce water heating energy use could be expected to be slightly higher than shown in this analysis.

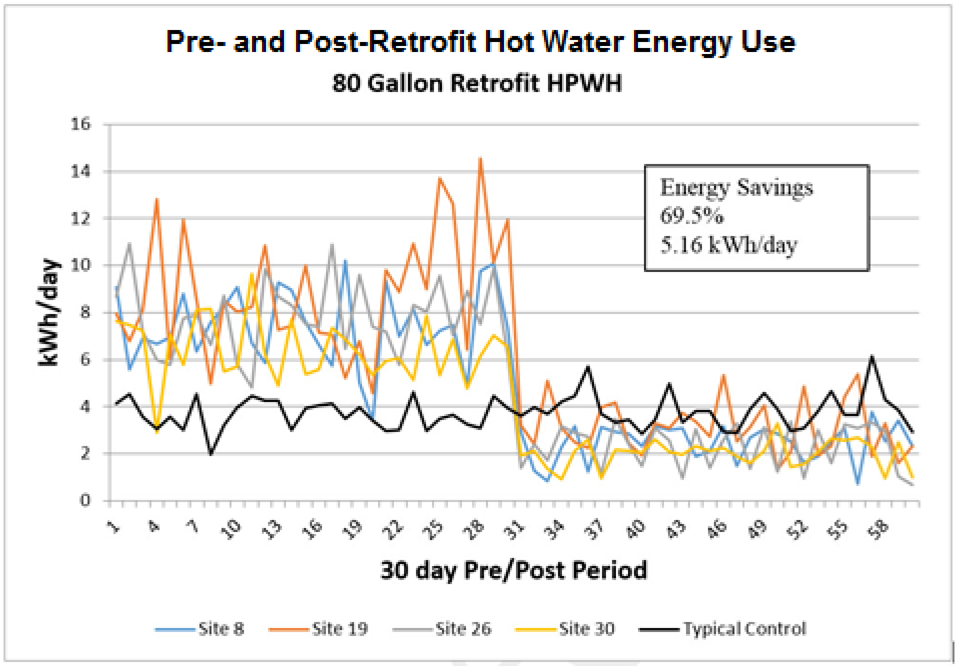

Figure 39. Pre- and post-retrofit hot water energy use for homes that received 80-gal HPWHs

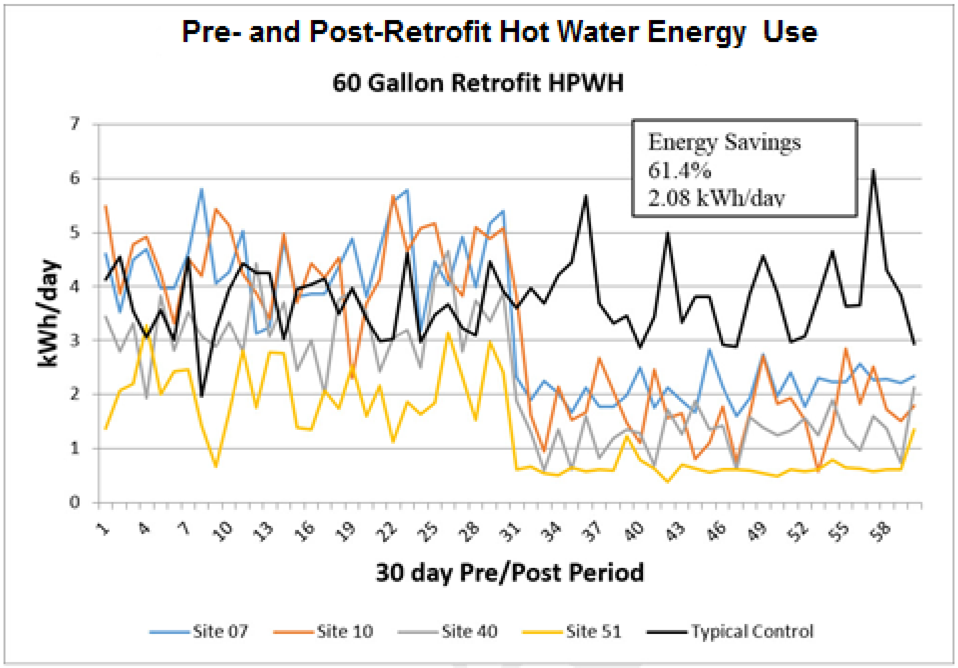

Figure 40. Pre- and post-retrofit hot water energy use for homes that received 60-gal HPWHs

5.4 Appliances

Within the ten deep retrofit homes, some appliances were changed if measured consumption was high. Generally, an ENERGY STAR model was offered to replace any refrigerators that used 2.5 kWh/day or more. Also, any older dishwashers that used more than 1 kWh/day were considered for replacement.[15]

Finally, a first-of-its-kind, low-energy clothes dryer became available from Samsung Corporation. Any homeowners who were willing to consider that choice were offered these as replacements so the team could assess potential savings.

Three primary refrigerators, a single dishwasher, and eight clothes washer/dryers sets were replaced. Table 23 shows the site numbers and dates of the appliance change-outs. An energy savings analysis, by each appliance, was conducted by comparing a period of 60 days before and after the retrofit for each site.

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[15] Practically, auditors would have to measure refrigerator energy use for a few days, determine frequency of dishwasher use from homeowners, and determine if the current model was at least 10 years and a non-ENERGY STAR unit.

Table 23. Appliance Retrofits in PDR Project

Site #	Installation Date	Dishwasher Make	Dishwasher Model #	Refrigerator Make	Refrigerator Model #	Washer Make	Washer Model #	Dryer Make	Dryer Model #
8	10/25/2013	Bosch	SHE3AR 52UC			Samsung	WF457	Samsung	DV457
10	12/5/2013					Samsung	WF457	Samsung	DV457
19	11/18/2013					Samsung	WF457	Samsung	DV457
26	10/25/2013			Whirlpool	GB2FHDX	Samsung	WA50 F9A6D	Samsung	DV457
39	10/25/2013			Samsung	RS265TD	Samsung	WF457	Samsung	DV457
40	11/19/2013					Samsung	WF457	Samsung	DV457
51	10/29/2013			Samsung	RS265TD	Samsung	WF457	Samsung	DV457

5.4.1 Refrigerators

Two models of ENERGY STAR refrigerators were selected for the retrofits: a Samsung RS265TD and a Whirlpool GB2FHDX with Energy Guide estimated annual electricity use of 502 and 403 kWh, respectively (or 1.4 and 1.1 kWh/day).

Figure 41 and Figure 42 show the large reduction (in hourly and daily power use) of a refrigerator retrofit at Site 26 that was well prequalified (the team measured high consumption). Consumption was cut for this end use by nearly 50%.

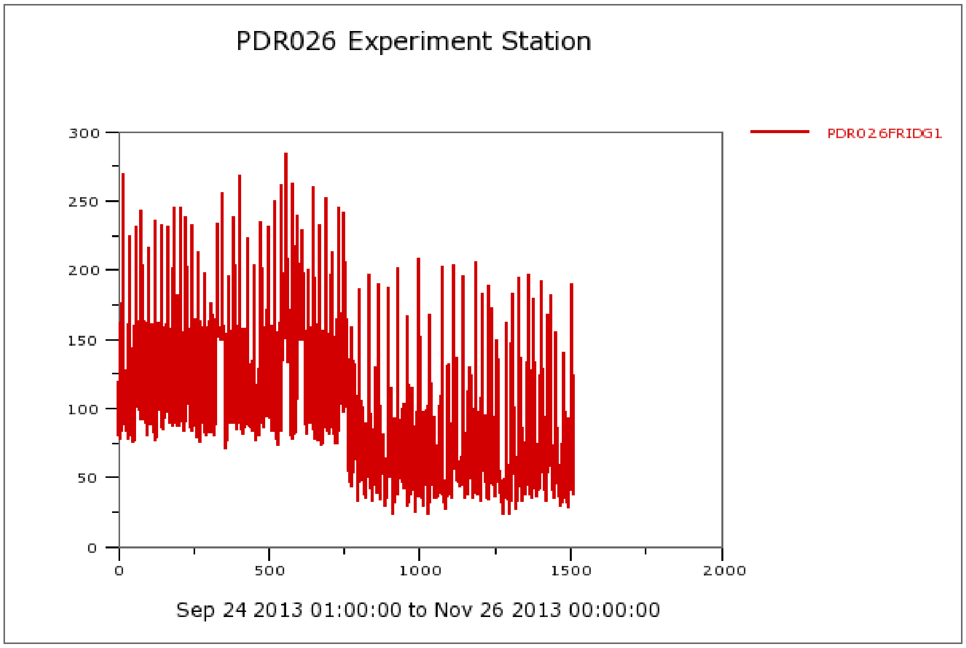

Figure 41. Measured change in hourly refrigerator power a month before and after refrigerator replacement at Site 26 on Oct. 25, 2013 (y-axis: watts, x-axis, elapsed hours)

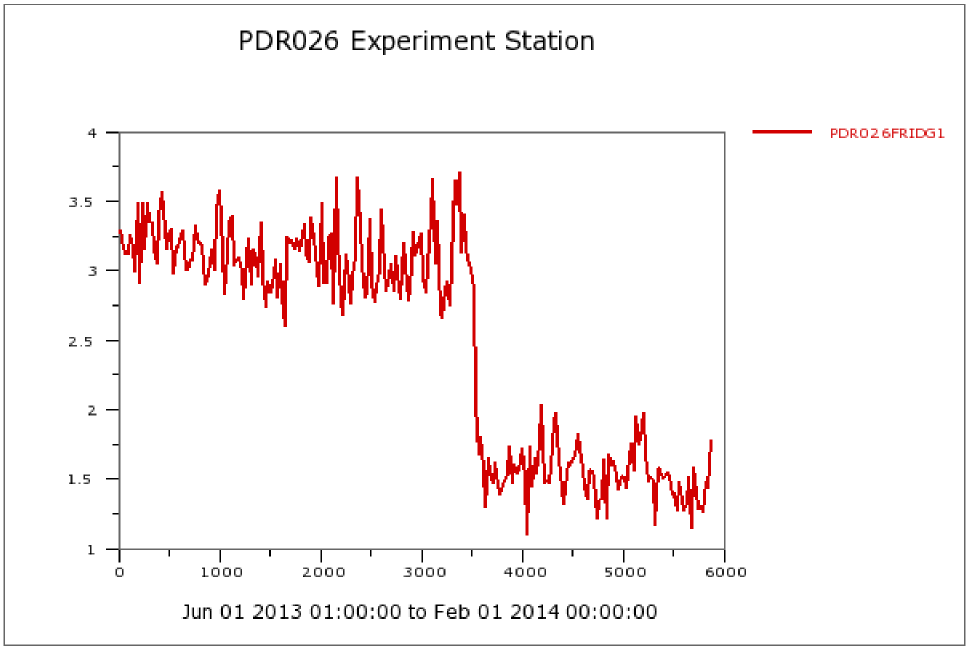

Figure 42. Measured change in daily refrigerator power after refrigerator replacement on Oct. 25, 2013. Data are for June 1, 2013–Feb. 1, 2014 (y-axis is kWh/day; x-axis is elapsed hours).

Table 24 shows the estimated savings of each of the three refrigerators that were replaced. Pre-retrofit refrigerators' electricity consumption was about 3 kWh/day, which dropped to about 1.8 kWh afterward for a reliable savings of about 1.3 kWh/day or 42%. The pre-retrofit condition includes the post-retrofit shallow measure (coil cleaning). The pre-retrofit analysis suggests that savings would be slightly greater using the soiled coils as a baseline.

Table 24. Refrigerator Replacement Savings (60 days before/after)

Site	Pre-Retrofit (kWh/d)	Post-Retrofit (kWh/d)	Δ kWh (kWh/d)	Percent (%)
26	3.07	1.56	1.51	49
39	2.89	2.11	0.78	27
51	3.18	1.62	1.56	49
Average	3.05	1.76	1.28	42

Measured post-retrofit energy use of the refrigerators was greater than that on the EnergyGuide. This was expected, because refrigerator energy use in warmer climates is often about 25% greater than test values due to higher room temperatures (Parker and Stedman 1990). The results indicate that measuring refrigerator power as audited over a multiday period can provide a reliable means to determine whether an ENERGY STAR replacement is warranted. Moreover, the three case study results suggest robust savings from refrigerator replacement.

5.4.2 Clothes Dryers

The electric resistance clothes dryers in eight homes were replaced with new Samsung DV457 models that were designed to be more efficient than standard units. The homes also received high-efficiency washers. Seven of these homes received matched Samsung washer/dryer pairs.

The standard matched clothes washer was a Samsung Model WF457 with a modified energy factor of 3.42. However, the owners of Site 26 objected to the front-load washer because of space constraints and selected instead an ENERGY STAR top-load washer (Samsung WA50F9A60). Table 25 shows the measured dryer energy in the eight homes that received the first-of-its-kind, high-efficiency dryer. Because clothes washer energy was not measured, its relative contribution to energy loads could not be examined. However, previous monitoring showed that clothes washer energy use is minor (typically less than 0.5 kWh/day); the energy use of the clothes dryer is the major energy-related impact of laundry cycles.[16]

Table 25. Washer/Dryer Replacement Energy Savings (1 year before and after)

Site	Average kWh/d		Δ kWh	Savings (%)
	Pre-Retrofit	Post-Retrofit		
8	3.78	3.15	0.63	17
10	1.56	0.84	0.72	46
19	10.05	6.30	3.75	37
26	3.82	4.58	–0.75	–20
30	2.50	2.03	0.48	19
39[a]	0.65	1.11	–0.46	–70
40	1.10	0.65	0.45	41
51	0.68	0.84	–0.16	–24
Average	**3.36**	**2.63**	**0.73**	**22**

[a] Did partial line-dry before retrofit. Not included in averages.

The data analysis in Table 25 shows that achieved energy savings of the clothes dryer was highly variable but averaged 0.73 kWh/day or 22%. Site 39 was eliminated from analysis, because this homeowner did a partial line dry before receiving the new washer and dryer and afterward reported using the dryer more and line drying less. Even so, at two sites negative pre/post savings were seen (highlighted in yellow in Table 25). Site 26 (–0.75 kWh/day) did not receive the matched washer/dryer pair, although it did receive a top-load ENERGY STAR washer that shows excellent residual moisture removal characteristics (modified energy factor = 2.7).

A much more likely factor for the negative savings was the homeowner’s reported dissatisfaction with the longer drying times of the new dryer; thus, faster cycles were often used. Also, Site 51 showed a slightly negative savings (–0.16 kWh/day increase with the new unit). In any case, the dryer was not particularly well received by some homeowners, because it was very complex to operate and had long drying times in the eco mode.

The site with the highest clothes dryer use (Site 19 at 10.05 kWh/day pre-retrofit) showed a savings of 37% (3.75 kWh/day) in the 1-year period after the new unit was installed. Figure 43

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[16] In future work, the team will attempt to examine how the clothes washer replacement in the retrofit may have reduced water heating loads, which largely depends on the degree to which hot/warm water wash is done in applicable homes. When the washer was replaced at one site (Site 19), a hot water wash was used and replacement of the washer was associated with a decreased water-heating load.

shows the running weekly average kWh/day at the site over the period of the retrofit extending from November 2012 to November 2014.

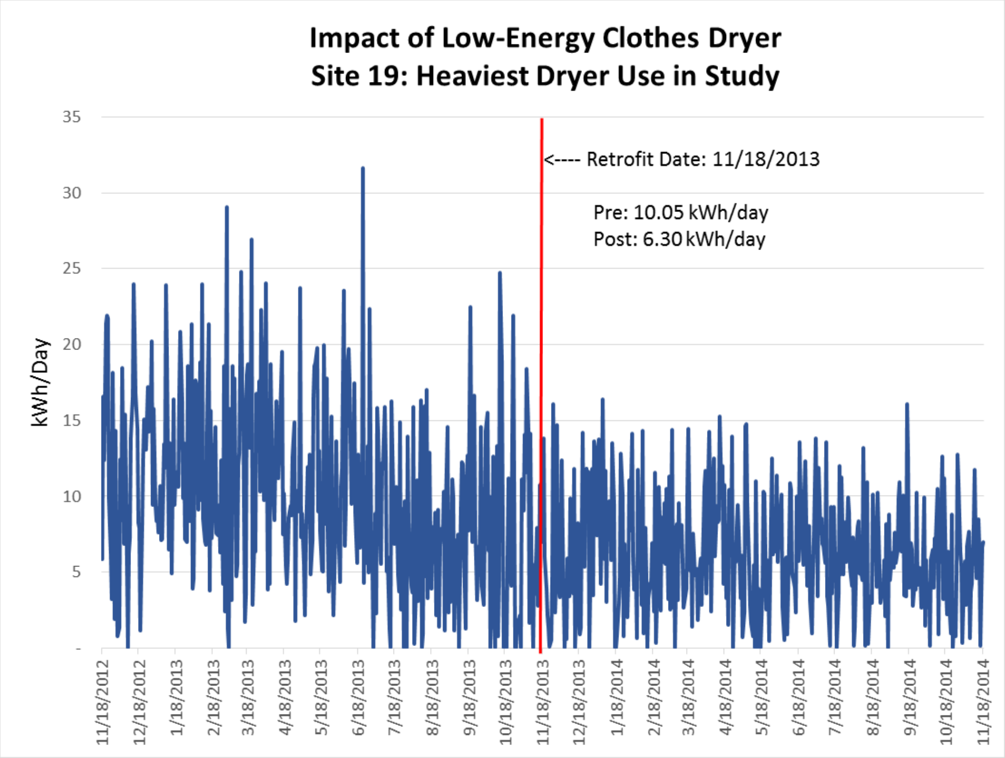

Figure 43. Measured savings of the high-efficiency clothes dryer at Site 19 from November 2012–November 2014

The 46% savings at Site 10 (0.72 kWh/day) likely included the impact of the new washer with less residual moisture than the original unit.

5.4.3 Dishwasher

A single dishwasher was retrofitted at Site 8 on Oct. 27, 2013. Although the average dishwasher power in the overall PDR sample was only about 0.4 kWh/day, it was approximately 1.5 kWh/day at Site 8, which appeared to be heavily used. An ENERGY STAR Bosch dishwasher (energy factor = 0.77) was chosen and installed in cooperation with the homeowner. Figure 44 shows the reduction in measured power from Aug. 27–Dec. 27, 2013 on the dishwasher circuit at this home.

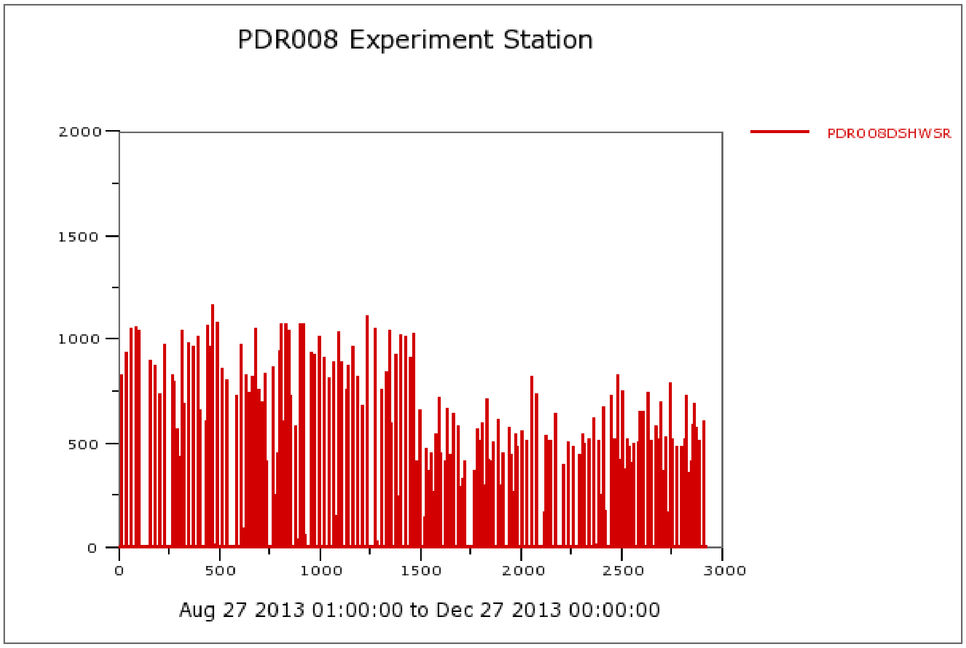

Figure 44. Measured hourly power of dishwasher at Site 8 (watts on the Y-axis) which was replaced with an ENERGY STAR model on Oct. 27 (about 3 p.m.)

In the 60-day period pre-retrofit, the dishwasher power averaged 1.48 kWh/day. In the 60-day period after replacement with an ENERGY STAR model by Bosch, on Oct. 27, the dishwasher energy use averaged 10 kWh/day. This represents a savings of 0.48 kWh/day or 32% in the end-use energy. This is perhaps more impressive, given this was a holiday period when dishwasher energy use may be higher in many homes.

5.5 Pool Pumps

The single-speed pool pumps were replaced with variable-speed pumps in two deep retrofit homes and resulted in energy savings of 80%–90%. The owner of another study home had a similar pump replacement performed early in the study, but it exhibited a much lower 48% savings level until pump programming was modified to take full advantage of the variable-speed pump.

Excellent energy savings of at least 80% were measured in all three cases; variations were attributed to differences in system hydraulics and runtime deviations as required by different chlorination systems. Average hourly demand was also reduced by 80%–90%. Energy and demand savings at all sites have persisted with little variation for more than 1 year.

5.5.1 Deep Site 7

Pre-retrofit monitoring of the 1.5-hp single-speed pump was conducted for 203 days from Sept. 6, 2012 to Mar. 27, 2013. Runtime during this period averaged 9.3 hours/day with an average draw of 21 kW for an average daily energy use of 18.7 kWh. Runtime of the single-speed pump was reduced to 5.5 hours/day during the shallow retrofit and resulted in a 43% measured savings with average daily energy use reduced to 10.7 kWh over a period of 181 days. Acceptable water quality was maintained during the period of reduced pump runtime.

A variable-speed pump and new filter were installed on Sept. 24, 2013 and resulted in a 90% reduction in measured energy use and average hourly demand over the pre-retrofit scenario (Figure 45). Energy savings continued throughout the 13-month post-retrofit period. The 3-hp Pentair variable-speed pump runs for 11 hours/day with an average draw of 0.17 kW and measured average energy use of 1.9 kWh/day. Table 26 summarizes the pre- and post-retrofit energy use.

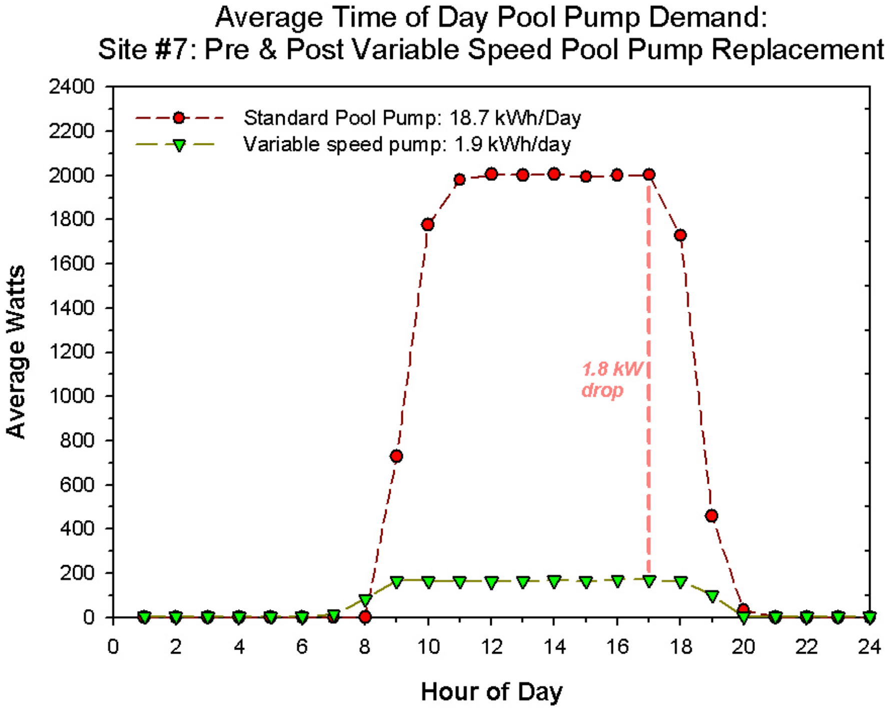

Figure 45. Average time of day pool pump demand at Site 7 as originally found (red) and after variable-speed pump retrofit (green)

Table 26. Measured Pool Pump Energy for Site 7

	Monitored Days	Runtime (h/d)	Average (kWh/d)	Energy Savings (%)	Average Draw (kW)	Demand Savings (%)
1.5-hp Pump, as Found	203	9.3	18.7		2.01	
Adjusted Schedule	181	5.5	10.7	43	1.94	3
New Variable-Speed Pump	413	11	1.9	90	0.17	92

Note: Electricity demand values are based on hourly energy use measurements and are determined here by dividing average kWh/day by runtime hours.

5.5.2 Deep Site 37

Energy savings at site 37 (Table 27) were less clear-cut than those at site 7. The pool water was in exceedingly poor condition at the beginning of data collection on Dec. 11, 2012. The first month of monitored data showed brief, sporadic pump use averaging less than 1 kWh/day followed by 3 weeks of fluctuating operation averaging 17 kWh/day. The remaining 10 weeks of data taken before the shallow retrofit showed regular pump use of 15 hours/day with an average draw of 1.8 kW averaging 26 kWh/day. The homeowner experienced a pump failure during this time and replaced the 1.5-hp single-speed pump with a similar unit. The pre-retrofit pump runtime was concentrated mainly during the nighttime hours. The erratic schedule was counterproductive to pool health and very likely contributed to the poor conditions.

The shallow retrofit at Site 37 was conducted on Apr. 18, 2013 when pool pump runtime was reduced to 4 hours/ day during midday. Such a short runtime can be sufficient for pool health in some situations; however, this pool used a saltwater chlorination system that requires much longer runtimes to maintain adequate chlorine levels for proper pool health.

Likely as a result, many adjustments to pump runtime and schedule were noted during this time and resulted in a confusing period of collected energy data for several months. In an effort to establish a fixed baseline for measured savings, the team set a new runtime schedule on Oct. 11, 2013, and data were collected for 26 days. The single-speed 1.5-hp pump was set to run for 8.7 hours during midday, when the pool health noticeably improved. Measured energy use during this period was 14.8 kWh/ day with an average draw of 1.70 kW (Table 27).

Table 27. Measured Pool Pump Energy for Site 37

	Monitored Days	Runtime (h/d)	Average (kWh/d)	Energy Savings (%)	Average Draw (kW)	Demand Savings (%)
1.5-h Single-Speed Pump	N/A	Variable	Variable			
Fixed Baseline	26	8.7	14.8		1.70	
New Variable-Speed Pump	370	8.1	2.6	82	0.32	81

Note: Electricity demand values are based on hourly energy use measurements and determined here by dividing average kilowatt-hours per day by runtime hours.

A variable-speed pump and new filter were installed on Nov. 6, 2013. Data collected over the last year show an 82% average reduction in measured energy use and demand over the 26-day fixed baseline scenario. The 3-hp Pentair variable-speed pump runs for an average of 8.1 hours/day with an average draw of 0.32 kW. Measured energy use of the variable-speed pump averaged 2.6 kWh/day through Nov. 11, 2014.

5.5.3 Shallow Site 59

This site was targeted for shallow energy retrofits only; however, the team later learned that the homeowner installed a new variable-speed pool pump in place of the original single-speed 1-hp pump that was documented at the initial audit on Dec. 13, 2012. A homeowner interview revealed a lack of expected savings from the new pump. Measured data included 19 full days of energy use by the single-speed 1-hp pump before it was replaced on Dec. 24, 2012 with a 3-hp Pentair variable-speed pump. The original pump operated for an average of 6.8 hours/day with an average draw of 1.57 kW totaling 10.6 kWh of measured daily energy use (Table 28).

Table 28. Measured Pool Pump Energy for Site 59

	Monitored Days	Runtime (h/d)	Average (kWh/d)	Energy Savings (%)	Average Draw (kW)	Demand Savings (%)
1-hp Single-Speed Pump	19	6.8	10.6		1.57	
New Variable-Speed Pump	254	11.1	5.5	48	0.50	68
Adjusted Variable-Speed Pump	385	8.5	1.8	83	0.21	87

Note: Electricity demand values are based on hourly energy use measurements and determined here by dividing average kilowatt-hours per day by runtime hours.

Several months of data (254 days) were collected for the new variable-speed pump showing a 48% savings over the single-speed unit. Measured data indicated the pump was scheduled to operate 11.1 hours/day, 4.1 hours at high speed and the remaining 7 hours at a much lower speed for a total of 5.5 kWh/day. However, Pentair specialists indicated that the programming of their variable-speed pump was not optimal for pool maintenance or for best energy savings.

Accordingly, a pool contractor reprogrammed the variable-speed pump on Oct. 23, 2013 to operate 8.5 hours/day: 4.5 hours during midday at high-speed and 4 hours at low speed. The new settings for high- and low-speed operation drew considerably less energy than the previous pumping program and resulted in average daily energy use of 1.8 kWh. This resulted in measured savings of 83% over the original single-speed pool pump. No water quality problems were reported over the last year.

5.6 Deep Retrofit Savings Evaluations

The previous analyses detailed the savings for particular end uses. To investigate overall and peak hour savings, the team conducted evaluations in three ways:

- A preliminary assessment comparing 4 months of pre-retrofit to 4 months of post-retrofit using measured data from six evaluation sites
- A utility data analysis of all ten sites, disaggregating space-heating, space-cooling, and baseload energy use for comparison between 12 months pre- and 12 months post-retrofit
- Hourly space-conditioning energy modeling of all ten study homes, regressing energy against outdoor temperature to assess peak hour implications.

5.6.1 Preliminary Deep Retrofit Savings Evaluation

Figure 46 shows the average load profiles for all end uses on a deep retrofit sample for October 2012 through January 2013 (pre-retrofit) versus October 2013 through January 2014 (post-retrofit). At that time the sample size was limited to the six deep retrofit homes that were fully monitored by Oct. 1, 2012. Total savings for the post-retrofit period averaged 16.5 kWh/day or 34.4%.

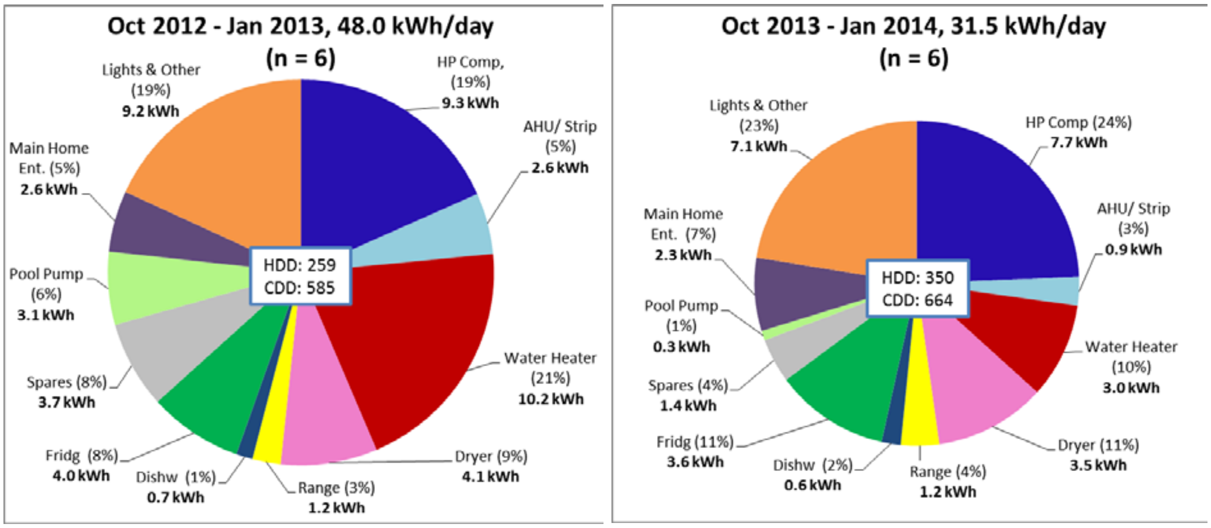

Figure 46. Average end-use load profile in limited deep retrofit sample, October 2012–January 2013 versus October 2013–January 2014

Savings were spread across end uses. However, water-heating energy use showed dramatic reductions (7 kWh/day) as did pool energy use (3 kWh/day). Space-heating and space-cooling energy use was reduced by about 3 kWh/day (30%). The energy savings from the earlier shallow lighting retrofit are also in evidence at approximately 2 kWh/day. Although total savings over this quarter were quite good, a longer-term analysis is expected to reveal greater savings.

Whole-house and end-use savings by site and average savings overall are provided in Table 29. The most important savings-generating deep retrofit measures are (1) the HPWH, (2) the HVAC load reduction measures (considering AHU and heat pump savings), and (3) the pool pump replacement (which affected only one site).

Table 29. Average Savings for Six Deep Retrofit Sites

Site #	Average Daily Kilowatt Savings by Site: October 2012–January 2013 versus October 2013–January 2014											
	Whole House	Heat Pump Comp	AHU/ Strip	Water Heater	Dryer	Range	Dishwasher	Refrigerator	Spares	Pool Pump	Main Home Entertainment	Lights and Other
7	26.2	(0.6)	0.6	4.5	0.2	0.1	(0.2)	0.1	–	16.7	(0.3)	4.8
8	9.0	(1.1)	(0.1)	6.8	0.6	(0.1)	0.6	0.4	–	N/A	1.2	0.4
10	16.1	3.8	3.3	4.4	0.3	(0.1)	–	0.2	3.4	N/A	0.7	4.7
19	25.6	5.9	3.6	10.9	3.4	0.5	0.4	0.6	(0.1)	N/A	(0.1)	1.5
26	12.9	3.4	2.8	7.5	(1.3)	(0.6)	(0.1)	1.2	–	N/A	0.1	0.1
30	9.5	(1.8)	–	9.2	0.4	0.1	–	0.4	–	N/A	0.1	1.1
Average Savings (kWh)	16.5	1.6	1.7	7.2	0.6	–	0.1	0.4	0.5	2.8	0.3	2.1
Average Savings (%)	34.4	17.2	65.4	70.6	14.6	0.0	14.3	10.0	26.3	90.3	11.5	22.8

Sites 7 and 19 saw the greatest savings, about 26 kWh/day each. The pool pump and the HPWH are particularly impressive measures for Site 7. Site 19, one of the highest consumption sites in the pre-retrofit monitoring, also had considerable savings from the HPWH. Savings for the HVAC and dryer end uses were also very large.

Sites 8 and 30 display the poorest savings of about 9 kWh/day each. Regardless, domestic hot water savings remained reliable at both sites. The HVAC energy use (heat pump compressor and AHU were even at Site 7 and somewhat increased at Site 8. Such results are not unexpected, given that HDDs and CDDs increased during the post-retrofit period. These are clear examples of the need for a longer-term analysis, including summer, as well as an argument to conduct weather normalization.

Site 10 may represent the most typical site with notable savings for the HVAC, domestic water heater, and dryer end uses. Average daily savings of 16 kWh represents 33% savings over pre-retrofit energy use at this site. As an example of pre-retrofit conditions into the post-retrofit period, the high-efficiency dryer was not installed until Dec. 5, 2013, halfway into the post-retrofit period.

This preliminary evaluation of end-use savings provides only a partial view of the deep retrofit energy savings. A complete understanding of energy use changes coincident with the retrofits must include the summer, especially in Florida’s cooling-dominated climate. Section 5.6.2 analyses utility records for 1 year before and 1 year after the phased retrofits to assess the full energy savings impact of all measures combined.

5.6.2 Pre- and Post-Retrofit Utility Data Analysis

Utility data for all ten deep-retrofit study homes were disaggregated to characterize space-heating, space-cooling, and baseload energy use before the shallow retrofits and again after the deep retrofits. Weather-adjusted savings projections were estimated in two ways:

- Adjusting post-retrofit energy use for each home with its pre-retrofit weather
- Normalizing pre- and post-retrofit energy use for each home to TMY3 weather for four FPL service territories weighted by service area.

See Section 4.7 for a description of the normalization and disaggregation approach used for the shallow and deep retrofit utility data analyses. Descriptions of the results for the deep retrofit utility data analysis follow.

5.6.2.1 Utility Data Weather Normalization and Disaggregation

Figure 47 shows the pre-retrofit space heating, space-cooling, and baseload energy use predictions for Site 19. The pre-retrofit period is the 12 months billed before the Apr. 17, 2013 shallow retrofit. A 65°F degree day base temperature was indicated for the pre-retrofit period. The fairly robust fit of the model (adjusted $R^2 = 0.91$) is evident from the close alignment between “predicted” monthly use (green diamonds) and the monthly “FPL” utility data (orange circles). Projected space-cooling and space-heating energy uses are the solid-fill sections in blue and red, respectively. The baseload prediction is represented by the flat purple line.

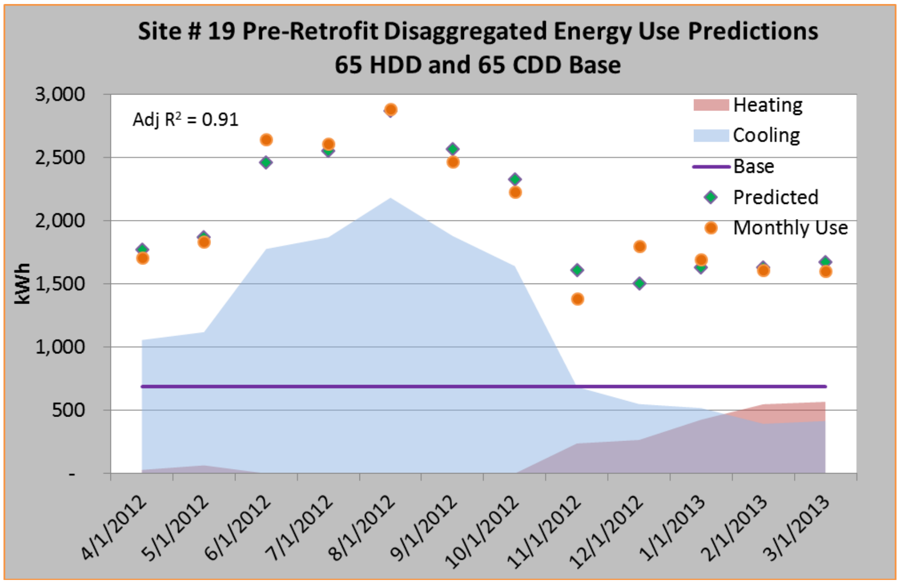

Figure 47. Site 19 Pre-retrofit space-heating, space-cooling, and baseload characterization

The shallow retrofit at Site 19 included a 72% lighting retrofit for a 55% connected lighting kilowatt reduction as well as hot water tank wrap, low-flow showerhead installation, and refrigerator coil cleaning. The deep retrofit at Site 19 was conducted between July 10, 2013 and Nov. 18, 2013 and included a high-efficiency heat pump AC, duct system sealing, a learning thermostat, an HPWH, a high-efficiency washer and dryer set, and upgraded ceiling insulation.

Once the best pre- and post-retrofit models were chosen, the post-retrofit HDD and CDD coefficients were applied to the pre-retrofit degree days (calculated according to post-retrofit building characteristics) to project post-retrofit energy consumption. Figure 48 shows the post-retrofit space-heating, space-cooling, and baseload energy use predictions normalized to pre-retrofit weather for Site 19.

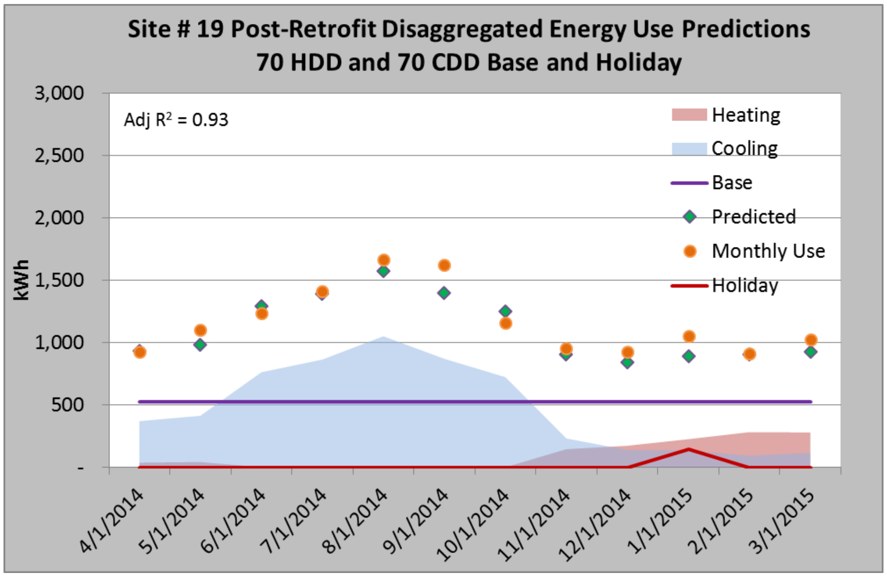

Figure 48. Site 19 Post-retrofit space-heating, space-cooling, and baseload characterization

The models suggest higher heating and cooling set points post-retrofit (HDD and CDD base of 70°F versus 65°F chosen pre-retrofit). The apparent warmer summer set point is in agreement with the short-term analysis finding for space cooling for this site. The holiday dummy variable's t-statistic was strong, indicating heightened non-weather-related electricity use over the holiday (red line). The post-retrofit model has a strong fit with an adjusted $R^2 = 0.93$. The slight misalignment between the prediction using pre-retrofit weather and the post-retrofit billing during the hottest summer months demonstrates a warmer post-retrofit period.

Energy reductions are clear in every month and for each end use: Monthly space cooling, which peaked during pre-retrofit around 2,200 kWh in August, is about 1,000 kWh post-retrofit. Post-retrofit space-heating energy use savings is similarly high; energy use was reduced by about half during the coldest month despite the apparent warmer post-retrofit heating set point.

Table 30 summarizes the annual total and space-conditioning end use deep retrofit energy projections for Site 19. When combined, the shallow and deep retrofits reduced annual cooling energy use by 5,788 kWh, a 41% savings over pre-retrofit. Baseload savings were also impressive: 1,778 kWh/year or 22%. The reduction in annual space heating energy use from 2,141 to 1,201kWh, a 44% savings, supports a transition from electric resistance to the highly efficient heat pump. The lighting retrofit increased post-retrofit heating needs at the same time but with the result of still lower heating needs post-retrofit. Whole-house annual energy use was reduced from 24,483 to 13,453 kWh, a savings of 45%.

Table 30. Site 19 Pre- and Post-Retrofit Space-Heating, Space-Cooling, and Baseload Projections Normalized to Pre-Retrofit Weather

Annual Energy Use Site 19	Utility Bill	Normalized Projection			
	Total	Total	Base	Heating	Cooling
Pre-Retrofit (kWh)	24,483	24,483	8,242	2,141	14,100
Post-Retrofit (kWh)	14,027	13,453	6,464	1,201	8,312
Savings (kWh)	10,456	11,030	1,778	941	5,788
Savings Overall (%)	**43**	**45**	**22**	**44**	**41**

Table 31summarizes the annual predicted savings results for all ten homes. The predicted average annual space-cooling savings is 4,336 kWh (48%), 854 kWh (56%) for space heating, and 1,878 kWh (23%) for baseload. Overall the whole-house annual savings prediction is 7,067 kWh, a 38% energy use reduction from pre-retrofit.

Table 31. Deep Retrofit Space Heating and Cooling, and Baseload Projections Normalized to Pre-Retrofit Weather

Annual Energy Use Averages (n = 10)	Utility Bill	Normalized Projection			
	Total	Total	Base	Heating	Cooling
Pre-Retrofit (kWh)	18,643	18,643	8,102	1,532	9,009
Post-Retrofit (kWh)	12,094	11,575	6,225	678	4,672
Savings (kWh)	6,549	7,067	1,878	854	4,336
Savings Overall (%)	**35**	**38**	**23**	**56**	**48**

The savings results for each site are summarized in Table 32. Total energy savings ranged from 22% to 52%. The original post-retrofit regressions for Site 39—coincidentally the home with the lowest energy-use savings—produced inflated and unrealistic disaggreted energy-use savings predictions. Consulting end-use metered data, consistently high "lighting and other" end use during the post-retrofit period concealed the interaction between weather and utility data. In this case, predictions were based on measured heating and cooling energy use regressed against weather data to determine realistic HDD and CDD coefficents. This resulted in a very strong model with an adjusted $R^2 = 0.99$ and credible savings results. Table 32 reflects impressive whole-house electricity savings rates that averaged 38%.

Table 32. Deep Retrofit Space-Heating, Space-Cooling, and Baseload Projections by Site

Site	Annual Energy Use (kWh)		Projected Annual Energy Savings (kWh)			Total Savings (%)
	Pre-Retrofit	Post-Retrofit	Baseload	Heating	Cooling	
7	24,686	11,924	8,658	–	4,104	52
8	15,285	10,174	1,945	5	3,161	33
10	19,329	11,912	5,234	–	2,183	38
19	24,483	13,453	1,778	941	8,312	45
26	20,004	11,447	1,576	909	6,072	43
30	13,890	8,926	4,427	(371)	909	36
37	27,167	21,267	(3,710)	3,615	5,994	22
39	13,961	9,489	334	281	3,857	32
40	12,124	7,641	(78)	1,124	3,438	37
51	15,499	9,521	(1,387)	2,033	5,332	39
n = 10	**18,643**	**11,575**	**1,878**	**854**	**4,336**	**38**

Annual space-cooling energy use was high for all sites but varied greatly from about 1,000 to 8,000 kWh. This is not surprising in that the homes have different constructions, thermal characteristics, and AC efficiency levels. In particular, thermostat preference has a significant impact on space cooling: each degree lower than 79°F increases space cooling by about 10%. The relatively small cooling energy savings for Site 30 is supported by the measured cooling savings analysis (see Table 20), which presented Site 30 with the least cooling energy savings and negative savings associated with the learning thermostat. The high cooling energy savings predicted for Site 19 is similarly supported by the findings reported in Table 20.

The space-heating impact also varied substantially from site to site. This is explained by some of the study homes moving from electric resistance strip heat to high-efficiency heat pumps that operate with significantly higher COPs; other homes may have had marginally efficient heat pumps pre-retrofit.

Changes to the baseload were most varied, ranging from annual negative savings of about 3,700 kWh to 8,700 kWh positive savings. Site 37 had the most notable negative baseload savings. Part of this is explained by a very strong holiday variable detected post-retrofit with no detectable holiday-coincident energy use increase during the pre-retrofit period. Regression predictions are also supported by metered data, which show a sustained post-retrofit increase in the “lighting and other” end uses. A high-watt device may have been introduced to the home during the post-retrofit period.

5.6.2.2 Typical Meteorological Year 3 Weather Normalization

The last component of the utility data analysis was to evaluate total, space-heating, space-cooling, and baseload end-use savings under TMY3 weather data to extend the savings estimates to those expected across the FPL geographic service territory.

The pre- and post-retrofit regression results from the weather-normalization evaluation were applied to TMY3 weather to predict space-heating and space-cooling energy use for the pre- and post-retrofit periods. See Section 4.7.2 for a description of the evaluation method. Table 33 provides the average savings using TMY3 weather for four of FPL’s service areas: Miami, West Palm Beach, Fort Myers, and Daytona.

Table 33. Pre- and Post-Retrofit Space Heating, Cooling, and Baseload Projections Normalized to TMY3 Weather, Weighted by FPL Service Area

Annual Savings		Hourly TMY3 HDD CDD Averages				FPL Service Area Weight
		Total	Base	Heating	Cooling	
Miami	**%**	38	23	47	48	0.4319
	kWh	7,456	1,878	124	5,455	
West Palm Beach	**%**	37	23	34	48	0.2243
	kWh	7,008	1,878	361	4,769	
Fort Myers	**%**	37	23	50	48	0.1921
	kWh	7,009	1,878	244	4,887	
Daytona	**%**	37	23	52	48	0.1517
	kWh	6,324	1,878	1,002	3,444	
Weighted	**%**	**38**	**23**	**45**	**48**	
	kWh	**7,098**	**1,878**	**333**	**4,887**	

The percentage space-cooling energy savings remained essentially unchanged among locations (48%). The smallest energy-use reduction occurred in the northernmost location, Daytona. And, also as expected, Daytona achieved the highest space-heating savings—1,002 kWh/year, many times the savings of the other locations.

Weighted across the FPL service areas, annual heating energy savings were 333 kWh (45%), and the annual cooling energy savings were 4,887 kWh (48%). Overall, annual deep retrofit savings were 7,098 kWh (38%); two-thirds of the total savings were generated by space-cooling reductions.

5.6.3 Hourly Space-Conditioning End-Use Analysis

This section presents the results of the monitored space-heating and space-cooling energy-use evaluation for the deep retrofit homes. Section 4.8 describes the evaluation model used for this analysis.

The deep retrofit involved several measures that directly impacted space-heating and space-cooling energy use. These included high-efficiency heat pump AC units, duct system sealing, and upgraded ceiling insulation. To investigate the hourly impacts of these measures on space conditioning, the team analyzed monitored space-heating and space-cooling energy data as they related to hourly outdoor temperatures.

All ten deep retrofit homes were evaluated for the hourly space cooling analysis. As with the shallow retrofit homes, few sites had a sufficiently long cooling season between the instrumentation and the shallow retrofit. Therefore, rather than compare the pre- retrofit (shallow) to the post-retrofit (deep) condition, the space-cooling evaluation compared the energy use of the post-retrofit (shallow)/pre-retrofit (deep) period to a post-retrofit (deep) period. The savings from the shallow and deep retrofits must be considered for the full impact of the phased retrofit measures on space-cooling energy.

The pre-retrofit space-cooling analysis period necessarily varied by site to ensure that only observations between the shallow and deep retrofits were captured. Generally, observations were drawn from April through August 2013. For each site, post-retrofit observations were drawn from the same dates in 2014 to ensure no time-of-year bias.

For the space-heating evaluation, however, one site was dropped due to the apparent use of a plugged-in portable space heater rather than central heating during the pre-retrofit period. To use data from this site would have skewed the results, because the plugged-in space heater was not monitored. Thus, nine homes were used to characterize the change in space-heating energy. The heating season baseline is unavoidably different than that for cooling: Because the shallow and deep retrofits occurred in quick succession between two heating seasons, the pre-retrofit period occurred before the shallow retrofit. Also, a space-heating energy penalty was associated with the shallow retrofits, so ignoring the shallow retrofit would effectively inflate the total project space-heating energy savings.

Pre-retrofit heating season observations were drawn from December 2012 into March 2013; these same months the following year were used for post-retrofit modeling. The retrofits at three homes were incomplete during the post-retrofit period. This included the insulation measure in three homes and an interior HPWH in one. The team chose to keep these sites in the analysis, because the measures have relatively minor impacts on heating energy savings. These measures yielded a slightly conservative savings projection for the missing insulation and slightly inflated energy savings for the home that later received an interior HPWH. (The HPWH's cold air byproduct would likely have increased space-heating energy use.)

5.6.3.1 Space-Cooling Results

The evaluation of end-use space cooling confirmed the substantial energy savings projected with the utility data analysis. With a robust number of observations for modeling, each site was evaluated independently and then models for each hour were averaged over all sites. Thus, the results were compiled differently than for either of the shallow retrofit space conditioning end-use evaluations, which necessarily combined hourly observations for all homes.

Space-cooling energy use was assessed for the following temperature profiles: pre-retrofit normalized to post-retrofit weather, post-retrofit normalized to pre-retrofit weather, both periods normalized to the average TMY3 cooling season profile, and both periods normalized to the peak TMY3 cooling day temperature profile.

Table 34 is a summary of the projected space cooling energy savings for all weather-normalized profiles. Daily space-cooling energy use is the total daily projection for each site given average TMY3 cooling season temperatures and peak TMY3 temperatures, averaged among all sites then weighted by FPL service area. The daily percent savings illustrates the differences between these averages rather than the average savings per site. Per-site savings are also presented in this section.

Table 34. Post-Retrofit (Shallow)/Pre-Retrofit (Deep) versus Post-Retrofit (Deep) Daily and Peak Hour Cooling Energy Savings Evaluation Summary

Deep Retrofit Cooling Analysis Normalization Weather Profile	Daily				Peak Hour (3–4 p.m. EST)			
	kWh			Savings (%)	kW			Savings (%)
	Pre	Post	Delta		Pre	Post	Delta	
Pre-Retrofit Weather					2.33	1.31	1.02	44
Post-Retrofit Weather					2.33	1.31	1.02	44
TMY3 Average, Weighted	35.9	18.5	17.4	48	2.55	1.43	1.12	44
TMY3 Peak, Weighted	48.5	25.4	23.2	48	4.13	2.24	1.89	46

The indicated average daily savings was 17.4 kWh with the average TMY3 profile and 23.2 kWh with the TMY3 peak weather profile; each represented 48% post-retrofit energy use reduction. The daily savings projections were slightly higher than the cooling energy savings projected with utility data evaluation, which was 13.4 kWh normalized to TMY3. The differences between the two analyses are even greater considering the baseline for the utility data analysis was pre-retrofit (shallow), whereas the current analysis excludes the shallow retrofit savings. These differences can be expected given the limited sample size.

Adding the average daily space cooling energy savings of 48% to the average shallow retrofit daily space-cooling savings (13%) predicts 62% space-cooling energy savings for both phases of the shallow and deep retrofits.

The right-hand section of Table 34 presents the site average energy use at the peak hour. For all temperature profiles, post-retrofit peak hour cooling energy savings is about 45%. All models project savings of approximately 1 kW at peak hour except for the peak TMY3 cooling day profile, when savings nearly double to 1.89 kW. Figure 49 shows the daily space-cooling energy load plot normalized to pre-retrofit weather. The figure shows significant post-retrofit (dark blue) energy savings over pre-retrofit energy use (light blue) throughout the day, primarily at the peak of the day when savings are about 1 kW for several continuous hours. Peak hour is identified by the red, vertical, dotted lines. See Appendix D for the deep retrofit space-cooling energy-use projection plots for all temperature profiles.

Table 35. Post-Retrofit (Shallow)/Pre-Retrofit (Deep) versus Post-Retrofit (Deep) Daily Cooling Energy Savings by Site

Daily Space Cooling Energy Savings Projections per Deep Retrofit Site								
Site	TMY3 Average, Weighted				TMY3 Peak, Weighted			
	Pre (kWh)	Post (kWh)	Savings (kWh)	Savings (%)	Pre (kWh)	Post (kWh)	Savings (kWh)	Savings (%)
7	34.3	24.0	10.4	30	45.7	32.0	13.7	30
8	25.4	14.5	11.0	43	36.8	21.4	15.4	42
10	55.6	22.4	33.2	60	67.5	28.4	39.1	58
19	60.9	25.6	35.3	58	81.2	36.8	44.4	55
26	40.1	16.6	23.5	59	51.3	22.3	29.0	57
30	16.5	12.8	3.8	23	25.4	17.9	7.5	30
37	38.0	22.0	16.0	42	49.4	27.8	21.6	44
39	21.9	13.5	8.4	38	31.4	19.6	11.8	38
40	31.9	15.6	16.3	51	42.9	21.9	21.1	49
51	34.6	18.5	16.1	47	53.5	25.6	27.9	52
Average Savings				48				48

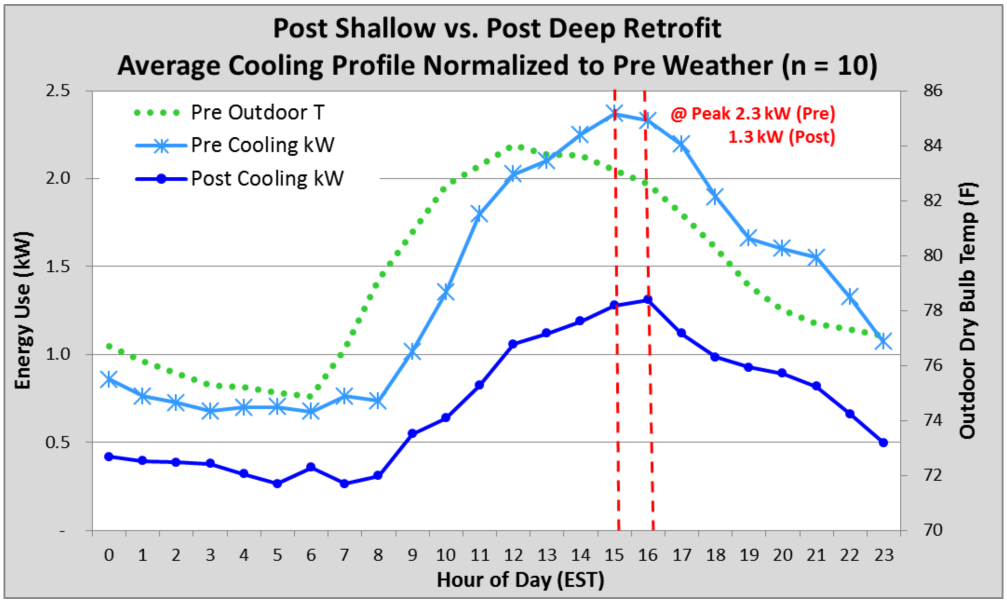

Figure 49. Post-retrofit (shallow)/pre-retrofit (deep) versus post-retrofit (deep) hourly space cooling profile, pre-retrofit weather-normalized

Given robust monitored end-use data, the team could assess space-cooling energy savings for each deep retrofit site. Table 35 provides the daily energy savings projections for each site. Daily space-cooling energy savings under the average TMY3 profile ranged from 3.8 to 35.3 kWh. As expected from previous space-cooling energy analyses, Site 30 is an outlier with relatively slight energy savings. Daily space-cooling energy savings for five homes is 16 kWh or more. Applied to the TMY3 peak day, savings ranged from 7.5 to 44.4 kWh. Sites 10, 19, and 26 (circled in red) had the most significant drop in post-retrofit energy use, though these savings were relatively muted in terms of per-site percentages. This evaluation of monitored cooling energy use confirms that very significant space-cooling energy savings are achieved from the high-efficiency heat pump AC units, duct system sealing, and upgraded ceiling insulation.

5.6.3.1.1 Whole-House Summer Peak Demand Reduction

For an independent investigation of the deep retrofit's impact on peak summer hour, the team compared the power demand for the FPL system summer peak day in 2013 (Aug. 13) to that in 2014 (July 28). As with the cooling analysis above, the pre-retrofit period came after the shallow retrofit, so this evaluation excludes any shallow-retrofit demand reductions. Figure 50 shows the average daily load plot for each period for nine deep retrofit homes on these peak days. (Site 10 was excluded because the high-efficiency AC unit was installed before Aug. 13, 2013.) The nine deep retrofit homes included several that had very high pre-retrofit energy consumption before they received the comprehensive measures in the fall of 2013. The results are a 39% coincident peak reduction or almost 2 kW between 4 and 5 p.m. Reduction to energy is similar: 76.2 kWh (pre) and 48.3 kWh (post).

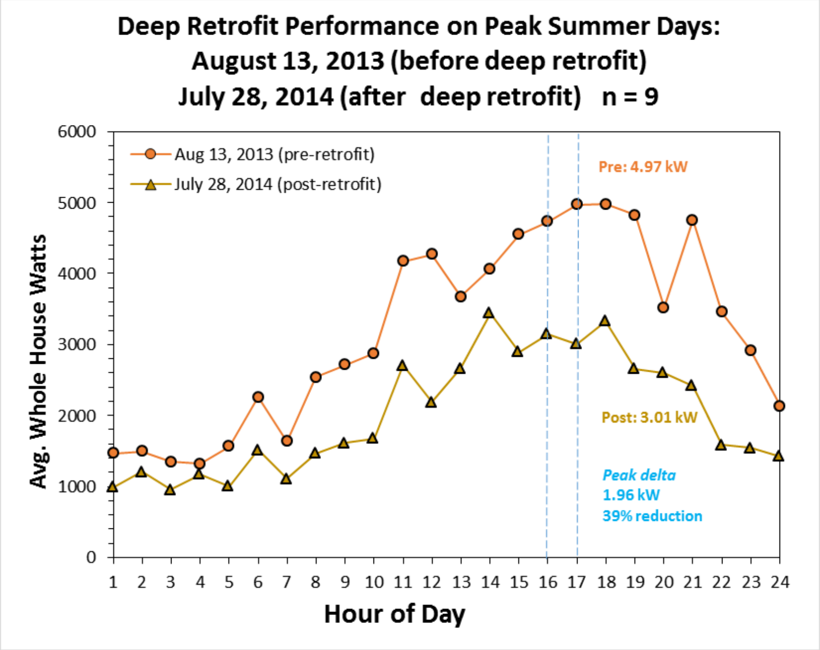

Figure 50. Comparative analysis between pre- and post-retrofit demand for FPL system peak summer day

5.6.3.1.2 Space-Heating Results

The space-heating energy-savings evaluation confirms utility regression analysis findings: The negative space-heating savings associated with the lighting retrofit were outweighed by the deep retrofit measure savings.

As with the shallow retrofit space-heating end-use evaluation, some hours of the day had as few as three observations during the entire heating period from December into March. Thus, readings were consolidated from all sites for each hourly model.

Space-heating energy use was evaluated for the following temperature profiles: pre-retrofit normalized to post-retrofit weather, post-retrofit normalized to pre-retrofit weather, and both periods normalized to the peak TMY3 heating day profile. Averaging the TMY3 heating season weather is not applicable, because the average nearly cancels out all space heating in the four service areas considered.

Projected daily space-heating energy savings and peak hour energy reduction results are presented in Table 36. The daily savings projection using the peak TMY3 day is 20.3 kWh. The peak hour section on the right side of Table 36 compares well with the pre- and post-retrofit average of all sites at the peak hour. The space heating energy peak hour savings projection is 0.44 kW normalized to pre-retrofit weather, 0.35 kW normalized to post-retrofit weather, and 1.39 kW for the peak day profile.

Table 36. Pre-Retrofit (Shallow) versus Post-Retrofit (Deep) Daily and Peak Hour Heating Energy Savings Evaluation Summary

Deep Retrofit Heating Analysis Normalization Weather Profile	Daily				Peak Hour (7–8 a.m. EST)			
	kWh			%	kW			%
	Pre	Post	Delta	Savings	Pre	Post	Delta	Savings
Pre-Retrofit Weather					0.90	0.45	0.44	49
Post-Retrofit Weather					0.76	0.41	0.35	46
TMY3 Average, Weighted	N/A[a]							
TMY3 Peak, Weighted	35.7	15.4	20.3	57	2.34	0.95	1.39	59

[a] A typical day in the heating season in this climate has few or no hours for modeling.

Figure 51 shows the daily load shape for pre-retrofit (shallow) and post-retrofit (deep) space-heating energy use predictions when normalized to pre-retrofit weather. This 24-hour plot represents the average heating energy use when temperatures were lower than 60°F and does not represent a typical day. The energy savings were significantly large through the modeled day, as one compares the pre-retrofit energy use (dark red) to the post-retrofit energy use (bright red). The high-use hour varied among sites pre-retrofit, causing a bimodal appearance in the projection; peak hour demand reduction is unexpectedly small, 0.45 kW. Savings from 6–7 a.m. (0.69 kW) are much larger than at peak hour, which is identified by the red, vertical, dotted lines.

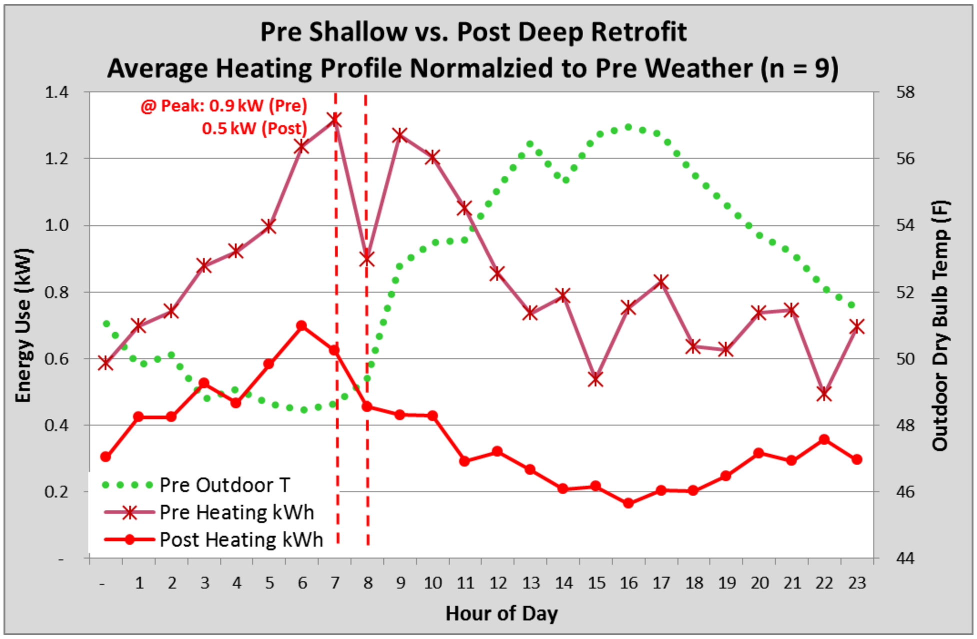

Figure 51. Pre- retrofit (shallow) versus post-retrofit (deep) hourly space heating profile, pre-retrofit weather-normalized

The pre-retrofit condition occurred before the shallow retrofit. An obvious decrease in the pre-retrofit space-heating energy use occurred in the late afternoon, presumably when occupants returned home and turned on the lights. Post-retrofit, this pattern is essentially gone. See Appendix D for all deep retrofit space-heating temperature profile projection plots.

Although Florida's heating season is mild, the deep retrofit measures reduce space-heating energy enough to provide a net savings, even when combined with the negative savings associated with the lighting retrofit.

5.6.3.1.3 Whole-House Winter Peak Demand Reduction

In the investigation of the deep and shallow retrofit's complete impact on peak summer hour, the team compared the power demand for the FPL system winter peak day in 2013 (Mar. 4) to that in 2014 (Jan. 23). Like the space-heating analysis above, the pre-retrofit period precedes the shallow retrofit. This is unlike the space-cooling analysis, which used the post-retrofit (shallow) as the baseline. Figure 52 shows the average daily load plot for pre- and post-retrofit for nine deep retrofit homes on these peak days. (One home was excluded because the deep retrofit was incomplete by Jan. 23, 2014.) The results are a 60% coincident peak reduction (2.7 kW) between 7 and 8 a.m. Energy use was reduced by 44%: 73.7 kWh (pre) and 41.4 kWh (post).

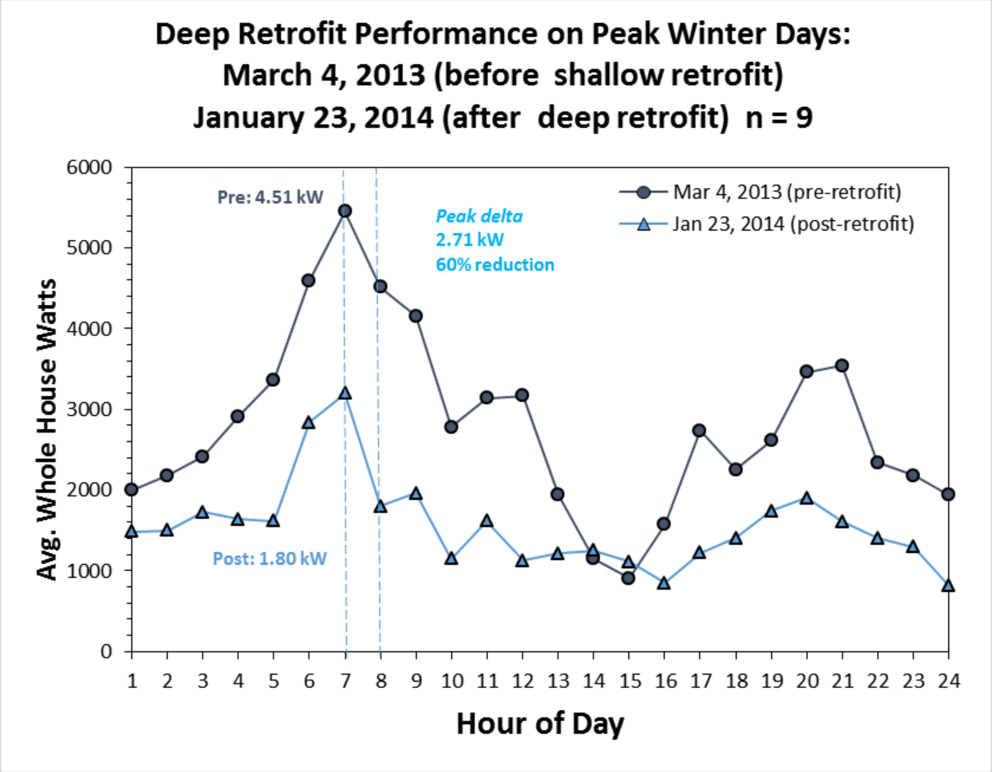

Figure 52. Comparative analysis between pre- and post-retrofit demand for FPL system peak winter day

5.7 Cost Evaluation

To investigate the deep retrofit cost-effectiveness, the team compared the average full and incremental installation costs to savings. In this evaluation, the team assessed the whole-house costs and benefits using the utility data analysis predicted whole-house savings, which considers a full year pre-retrofit to a nearly full year post-retrofit. The shallow retrofit cost is included, because the utility data analysis uses the pre-shallow retrofit period as its baseline. Table 37 is a summary of the average costs for each measure. Costs include tax and exclude any high-volume discounts the project received.

Table 37. Deep Retrofit Measures Full and Incremental Costs

Deep Retrofit Measure Cost Summary		
Measure	Average Full Cost	Average Incremental Cost
HVAC System Installation (10)	$8,016	$2,635
HPWHs (9)	$2,274	$1,478
ENERGY STAR Washer/Dryer Sets (8)	$2,620	$1,087
ENERGY STAR Refrigerators (3)	$1,208	$0
ENERGY STAR Dishwasher (1)	$508	$0
Variable-Speed Pool Pumps and Filters (2)	$2,035	$1,458
Insulation (2)	$1,120	$1,120

Deep Retrofit Measure Cost Summary		
Measure	**Average Full Cost**	**Average Incremental Cost**
Infiltration Reductions (5)	$170	$170
Average Retrofit Cost Per Site (10)	**$13,960**	**$6,711**
Shallow Retrofit (average for deep retrofits only)	$363	$363
Total for Shallow and Deep Retrofits	**$14,323**	**$7,074**

The estimated savings for the whole-house consumption averaged 38%, ranging from 22% to 52%. As described in the preceding analysis, the energy reductions averaged 7,067 kWh/year or approximately 590 kWh/month. The impact on utility bills was highly visible and averaged $71/month or $848/year at $0.12/kWh (including applicable taxes).

The incremental costs of these measures show the average cost to choose the more efficient options if they were completed at the time the equipment or appliance was at the end of its useful life ($7,074). The simple payback for the improvements in the deep retrofits evaluated on an incremental basis was 8.3 years, reflecting a 12% simple after-tax rate of return. This shows that replacing the equipment and options changed in the deep retrofit program to more efficient ones at the end of their useful service life would be highly cost-effective. The resulting economics would exhibit a rate of return that is considerably higher than conventional competing investments such as stocks or bonds.

If the retrofits were completed outright (as in this study) with a full cost of $14,323, the economics are less attractive. The simple payback for the package of measures increases to 16.9 years with a simple rate of return of 5.9%. However, a very useful model for a utility "deep retrofit program" might be conducted for homes that need new HVAC systems, at which point all the other improvements would be performed outright. The added incremental and outright costs at that point for such a program would be $8,942 against the same energy reduction. This would produce a simple payback of just 10.5 years and a simple after-tax rate of return of 9.5%—much higher than any conventional investment.

5.8 Lessons Learned

Many of the project lessons were developed from deep retrofit measure implementation. Appendix E provides a detailed description of deep retrofit measure installation experiences, including system and contractor selections, performance criteria, and installation issues.

5.8.1 Heating, Ventilating, and Air Conditioning

- Control wiring and thermostat setup need to be emphasized within HVAC system commissioning, particularly for high-efficiency systems. For instance, single-speed units retrofitted with two-stage systems may require new control wiring if the original wiring lacks necessary leadership.

- Full functionality of two-stage heat pumps (heating and cooling) at high and low stages needs to be carefully verified at the time of installation. Otherwise, efficiency and dehumidification performance will be adversely affected.
- The HVAC contractor's installation team and service team had different skill sets (i.e., the installation team was less technically savvy than the service team). For future Nest thermostat installations, a service team member might serve as a member of the installation team.
- Using an authorized manufacturer/dealer/contractor to properly size, install, and commission equipment (even with the strong recommendation of the manufacturer) does not guarantee the job will be done properly. Oversight is required.
- The HVAC contractor did not own some of the equipment needed for proper degassing/dehydration/charging of the system and did not use best practices when charging a system until so directed.

5.8.2 Learning Thermostat

- The installation of the Nest thermostat may dictate a professional installation and/or modification to the installation guide.
- The location of the learning thermostat is important for best function. Upstairs locations are not preferred, and the best installation point will be one where the device often senses the occupants. This requirement may necessitate relocation of the thermostat for best performance.
- Homeowners need to be educated about using the learning thermostat. They should be encouraged not to defeat the "auto-away" feature. Occupants should also be alerted that if they choose aggressive heating and cooling, such a thermostat will not produce savings.
- For the learning thermostat to save energy, homeowners need to teach it their preferences. For instance, in summer this might include turning it up before leaving home.
- The "heat pump balance" feature needs to be carefully set up to provide best performance of heat pumps to avoid auxiliary heating.
- Encourage use of the "reminder" feature to help homeowners remember when to change system air filters.
- Although the "airwave" feature does not often provide benefits in Florida, it should be selected so that the AC unit can operate most efficiently when it is sufficiently dry inside.
- Homeowners should be encouraged to "follow the leaf" display on the Nest thermostat to achieve best savings.

5.8.3 Insulation

- This project followed FPL program standards that pertain to installation of insulation. The consumer is responsible to verify that the contractor complies with applicable codes and ordinances and that all applicable permits are obtained. The verification FPL conducts of customers' installations only confirms that the installations were qualified for FPL incentives; proper inspection was still necessary.

- To gauge overall ceiling insulation R-value, a core sample or total insulation bag count should be used to obtain density.
- Confirm the insulation contractor is aware that R-value is not necessarily additive, based simply on printed R-values for instance, particularly if installation results in compression.
- Confirm the use of attic eave baffles with blown insulation to maintain perimeter insulation levels and mitigate soffit vent blockage.
- Use techniques to limit or negate knee wall insulation (e.g., batts) from falling off over time.

5.8.4 Heat Pump Water Heater

- Noise can be an issue with HPWHs and varies between manufacturers. Locations outside occupied zones such as the garage are recommended.
- Installation should seek to minimize transferred noise and vibration due to mechanical connections between HPWHs and adjacent space. If such a scenario cannot be avoided, sound-damping materials may help minimize noise and vibration transfer.
- Water heater locations may lack the minimum unobstructed space required by the HPWH manufacturer for optimal efficiency. Plumbing may need to be modified and obstructions moved to maximize airflow and performance.
- The homeowner must be educated about the proper care of installed equipment per the manufacturer to maintain long-term efficiency.

5.8.5 Low-Energy Clothes Dryer

- The first-of-its-kind clothes dryer used in the project is complicated to operate. Homeowners should be coached on how to use it effectively.
- Homeowners should be encouraged to use the "eco" setting to provide best savings when appropriate. However, they should be made aware that this drying cycle takes about twice as long as that in conventional dryers.

5.8.6 Pool Pump

- Replacing a single-speed pool pump with a variable-speed pump can reduce overall energy use by 80%–90%, but other accessible parts (filter, piping, etc.) may need to be optimized.
- Variable-speed pool pumps need to be programmed by knowledgeable installers. In one case about half the achieved savings were lost when the variable-speed pump was not properly programmed.
- Variable-speed pool pumps need to be maintained by knowledgeable service providers.

5.8.7 General

- A useful business model might be one that makes evaluation and combination retrofits available through HVAC or water-heating contractors so all the services are done at the same time and subcontractors coordinated. Bundling all the options in this fashion would likely improve cost-effectiveness and convenience for the homeowner. This idea was not evaluated, however.

- Feedback from homeowners about overall satisfaction (or lack thereof) with retrofit measures is a critical takeaway piece of this study. Homeowners do not always speak up if they are having issues or are not completely comfortable or satisfied with retrofit change-outs. The team plans to collect feedback over time from the deep retrofit homeowners via a survey to help ascertain the level of satisfaction.
- Although a piece of equipment may be energy efficient, some or most of the efficiency gains can be lost if the equipment is too complicated to operate or its energy efficiency is based on an optional mode that does not align with the user's lifestyle.
- Simply focusing on energy efficiency without understanding the retrofit impacts and preferences of the end user can undermine success. Communication with the homeowners and occupants before, during, and after each retrofit measure is critical for a positive outcome.

6 Conclusions

6.1 Shallow Retrofit Results

Shallow retrofit savings in the PDR project were evaluated in several ways to improve confidence in final estimates and to investigate utility-coincident peak hour demand reductions.

Predicted whole-house savings were similar regardless of analysis methods, finding 8%–10% annual electricity savings, although the distribution across end uses varied between short- and longer-term assessments. For instance, the average daily savings of 0.9 kWh from readjusting pool pump hours disappeared long-term post-retrofit. Many pump timers were likely moved back to pre-retrofit settings. Also, pool maintenance pushback on the timer adjustment was reported. Savings from refrigerator coil cleaning in the shallow retrofits were measurable but very modest and could likely be replaced with an audit to measure 24-hour refrigerator energy use with an eye to replace if consumption exceeds 4 kWh/day).

The lighting retrofit produced significant and persistent savings. End-use savings for lighting and other plug loads, refrigeration, and water heating appear greater in one evaluation, though the whole-house savings were similar.

The two methods for evaluating space conditioning agree that the shallow retrofit decreased cooling energy use and increased heating energy use, an expected dynamic that was attributed to the reduction in internal heat gains from the lighting retrofit. The magnitude of the effect is much larger for cooling on an annual basis, however, given Florida's warm climate. The team predicts annual post-retrofit space-cooling energy savings of 1,353 kWh and negative savings of 629 kWh for space-heating energy. Baseload savings were 632 kWh, for a net annual energy savings of 1,356 kWh.

The analysis for the utility-coincident peak hour predicts space-conditioning demand reductions of 0.19 to 0.28 kW between 4 and 5 p.m. in summer against increases of 0.29 to 0.31 kW between 7 and 8 a.m. in winter. However, Florida has few heating days, whereas space cooling is needed during much of the year.

The whole-house pre- to post-retrofit demand change during the FPL system summer and winter peaks were 0.67 and 0.25 kW, respectively. However, energy use for the peak winter day increased by 8%, which was consistent with other findings. The hot water tank and pipe wrap and showerhead replacement measure produced a relatively large and dependable winter day peak reduction (approximately 0.36 kW or 56%) as well as good consumer economics. Insulation wraps and showerhead replacements should be emphasized in a utility shallow retrofit program with better-performing hot water tank wraps (some are under development by FSEC) and a larger choice of lower-flow shower fixtures than used in this study.

One possible issue with the shallow retrofit, confirmed by the utility billing data analysis, is that its low savings levels may be hidden from consumers by weather changes between years, but this should not be a limitation to such a program.

6.1.1 Shallow Retrofit Cost-Effectiveness

The cost-effectiveness of the shallow retrofit outcome looks very promising for more extensive 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 is exceedingly positive (higher than 42%). Programmatically, the largest challenge of an expansive shallow retrofit program is that trained crews must be available to make the changes.

6.2 Deep Retrofit Results

The team assessed deep retrofit annual energy savings in the PDR project in different ways to improve the estimation certainty and then evaluated reductions to household electricity demand at the utility-coincident peak hour.

Whole-house savings for the post-retrofit period using a long-term utility data analysis showed savings of 19.4 kWh/day or 38%. Daily space-cooling savings associated with the deep retrofit measures, as predicted by the utility bill analysis, showed a savings of 11.9 kWh/day or 46%. This energy use reduction includes the impact of the shallow retrofit, which also reduces cooling. The space-heating utility data evaluation, which included the negative savings from the shallow retrofit lighting measures, still indicated a savings of 2.3 kWh/day or 33% on cold days for deep retrofits.

In the space-conditioning end-use energy demand evaluation that uses monitored data, the team found peak summer hour (4–5 p.m.) demand reductions of 12 kW (44% savings) and peak winter hour (7–8 a.m.) reductions between 0.35 and 0.44 kW (46%–49% savings). The average whole-house demand reduction at FPL system peak hours was 1.96 kW (39% savings) during summer, and 2.71 kW (60% savings) during winter.

The pre- to post-retrofit evaluation of the ten HVAC retrofits showed that the heat pump replacement and duct repair saved an average of 40% of pre-retrofit consumption, but that lower interior temperatures were generally chosen (by an average of ~1°F) even with the learning thermostat. Final cooling savings were about 15.4 kWh/day (37%) in summer.

The eight sites that replaced electric resistance water heaters with HPWHs had consistently large energy use reductions and yielded weather-normalized pre/post average savings of 69% (5.3 kWh/day).

A first-of-its-kind, low-energy clothes dryer produced average pre/post savings of 22% (0.7 kWh/day) for the eight homes in which they were installed. However, savings from this measure were highly variable; the home with the highest use showed a 37% reduction; some sites had negative savings. A homeowner will find unattractive economics given the small energy savings coupled with the high cost of this measure. In Phase II of this study the team will investigate the energy impacts and cost-effectiveness of clothes dryers that incorporate heat pump technology.

Refrigerator replacement in three homes showed average savings of 42% (1.3 kWh/day). Post-retrofit energy savings for the single dishwasher change-out were 32% (0.5 kWh/day), excluding likely hot water use reductions.

Savings from variable-speed pumps installed at three pool sites were very large in fraction and magnitude: 80%–90% (averaging 12.6 kWh/day). However, only about half the potential savings were achieved unless the variable-speed units were properly programmed by an experienced installer. Pool maintenance contractors who are unfamiliar with the technology may reprogram the pump and erode savings.

6.2.1 Deep Retrofit Cost-Effectiveness

The results from the utility data analysis were used to conduct a cost/benefit evaluation for the deep retrofits (which include the shallow retrofits before them). Using the incremental costs, excluding utility rebates, the simple payback for the improvements was 8.3 years, reflecting a 12% simple after-tax rate of return. This shows that replacing the equipment and options at the end of their useful service life with the more efficient ones (as in the deep retrofit program) is highly cost-effective.

If the retrofits were completed immediately instead of at the normal time of replacement, as in this study, with a full cost of $14,323, the economics are less attractive. The simple payback for the package of measures increases to 16.9 years with a simple rate of return of 5.9%.

One important finding arises directly from this experience: a much larger-scale deep retrofit program could be favorably constructed by targeting efficiency changes at the time that an aging HVAC system is replaced. Such a utility "deep retrofit program" might target homeowners who need to replace their HVAC systems, at which point all the other improvements would be performed outright by contractors coordinated by the HVAC contractor. This program model has very favorable economics (payback drops to approximately 10.5 years without utility rebates) and has the advantage of engaging the homeowners at the time that major household alterations will be underway. The resulting annual energy reduction of 38% would be highly visible to homeowners and yet would result in large reductions to winter and summer peak demands that would benefit the utility.

A summary of the energy savings and peak hour reduction results for the shallow and deep retrofits by end use is provided in Table 38.

Table 38. Shallow and Deep Retrofit Energy Impact Results Summary

Shallow and Deep Retrofit Energy Impacts[a]	Annual Energy Savings		Summer Peak Hour Reduction[b]		Winter Peak Hour Reduction		Cost	
	kWh	%	kW	%	kW	%	Total	Incremental
Shallow Retrofits								
Space Cooling	1,353	16	0.42	24%			$0	$0
Space Heating	(629)	–78			(0.11)	–6	$0	$0
Lighting and Other	664	22	0.24	42%	(0.02)	–6	$281	$281
Water Heating	180	11	0.11	26%	0.36	56	$94	$94
Pool Pump	175	14	0.05	28%	0.00	7	$8	$8
Whole-House	**1,356**	**9**	**0.67**	**20%**	**0.25**	**7**	**$374**	**$374**
Deep Retrofits (shallow and deep retrofit impacts are presented, unless otherwise noted)								
Space Cooling	4,336	46	1.92	52%			$8,016	$2,635
Space Heating	854	33			2.26	80		
Water Heating[c]	1,924	69	0.26	100%	0.32	34	$2,274	$1,478
Refrigerator (n = 3)	471	42	0.06	48%	0.02	19	$1,208	$0
Clothes Dryer[d]	267	22	0.04	26%	0.08	39	$2,620	$1,087
Dishwasher[e] (n = 1)	175	32	(0.27)	N/A	–	N/A	$508	$0
Pool Pump[e] (n = 3)	4,599	86	0.89	91%	(0.09)	N/A	$2,035	$1,458
Whole-House	**7,067**	**38**	**1.96**	**39%**	**2.71**	**60**	**$14,323**	**$7,074**

[a] Sample size varies by end use and metric. End uses cannot be summed for whole-house total. Very small sample sizes are noted as "n = *x*."

[b] Shallow retrofit summer peak is a surrogate October date; deep retrofit summer peak is for the deep retrofit only, so results are conservative.

[c] Water heating energy savings baseline includes partial post-retrofit (shallow), so results are conservative. Water heating had no post-retrofit peak summer hour demand in the HPWH segment.

[d] Cost includes the clothes washer and dryer as a set.

[e] No pre-retrofit peak winter hour demand for the dishwasher or pool pump; no post-retrofit peak winter hour demand for the dishwasher.

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Appendix A: Deep Retrofit Site Characteristics

Table 39. Pre-Retrofit Site Characteristics

Site	Year Built	Conditioned Floor Area (ft^2)	# of Floors	Foundation Type	Wall Type	HVAC	T-Stat	DHW	Ceiling Insulation	Pool Pump
7	1989	2,650	2	SOG	CMU and stick	14 SEER	P	40-gal electric tank	R-19	single speed
8	1997	2,134	1	SOG	Stick	10 SEER	M	50-gal electric tank	R-30	N/A
10	2003	1,627	1	SOG	CMU	12 SEER	M	50-gal electric tank	R-30	N/A
19	1988	2,554	1	SOG	CMU	<10 SEER	P	50-gal electric tank	R-19	N/A
26	1999	1,502	1	SOG	CMU	10 SEER	M	55-gal electric tank	R-19	N/A
30	1976	1,819	1	SOG	CMU	13 SEER	P	40-gal electric tank	R-8	N/A
37	1993	1,654	1	SOG	Stick	Less than 10 SEER	M	40-gal electric tank	R-19	single speed
39	1981	1,559	1	SOG	CMU	14 SEER	M	50-gal HPWH	R-38	N/A
40	1993	1,983	1	SOG	Stick	Less than 12 SEER	P	40-gal electric tank	R-19	N/A
51	1994	2,233	2	Crawlspace	Stick	10 SEER	P	40-gal electric tank	R-19	N/A

Table 40. Installed Deep Retrofit Measures by Site

Site	High-Efficiency Heat Pump	Bedroom Pressure Relief	Nest T-Stat	HPWH	Ceiling Insulation	ENERGY STAR Refrigerator	ENERGY STAR Washer	Low-Energy Dryer	ENERGY STAR Dishwasher	Variable-Speed Pool Pump
7	4-ton, 16 SEER, 9 HSPF, new ductwork	x	x	60 gal	R-38			Rejected		x
8	3-ton, 17 SEER, 9.5 HSPF, system sealing		x	80 gal	Existing R-38		x	x	x	No pool
10	3-ton, 18 SEER, 9.2 HSPF, system sealing[a]			60 gal	R-38		x	x		No pool
19	3-ton, 16 SEER, 9 HSPF, system sealing	x	x	80 gal	R-38		x	x		No pool
26	3-ton, 17 SEER, 9.5 HSPF, system sealing	x	x	80 gal	R-38	x	x	x		No pool
30	3-ton, 17 SEER, 9.5 HSPF, system sealing	x	x	80 gal	R-38		x	x		No pool
37	3-ton, 17 SEER, 9.5 HSPF, system sealing		x	50 gal	R-38			Rejected		x
39	3-ton, 17 SEER, 9.5 HSPF, system sealing	x	x	Existing 50 gal	Existing R-38	x	x	x		No pool
40	3-ton, 17 SEER, 9.5 HSPF, system sealing		x	60 gal	R-38		x	x		No pool
51	4-ton, 16 SEER, 9 HSPF, system sealing	x	x	60 gal	R-38	x	x	x		No pool

[a] Site 10: The homeowner installed the HVAC of his own accord and although the system is made by the same manufacturer as the rest of the deep retrofit systems, it is a different series and higher SEER rating. Also, the homeowner used a different HVAC contractor for all HVAC related retrofit work.

Appendix B: Plots for End-Use Loads in Phased Deep Retrofit Project: 2013

Summary End-use Plots [17]

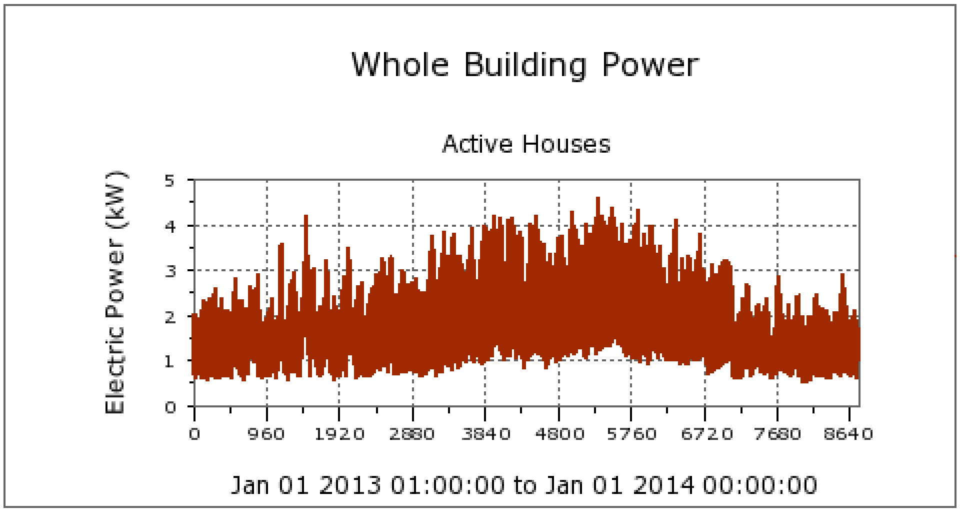

Figure 53. Hourly total electricity load for all 56 homes during 2013

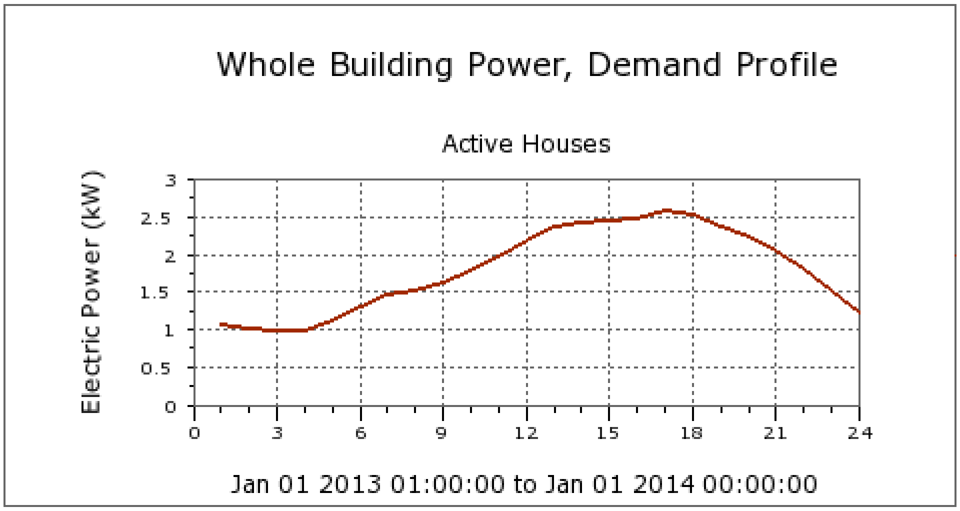

Figure 54. Average total electricity load shape during 2013

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[17] Data creating these plots can be downloaded at the site data domain: http://www.infomonitors.com/pdr/

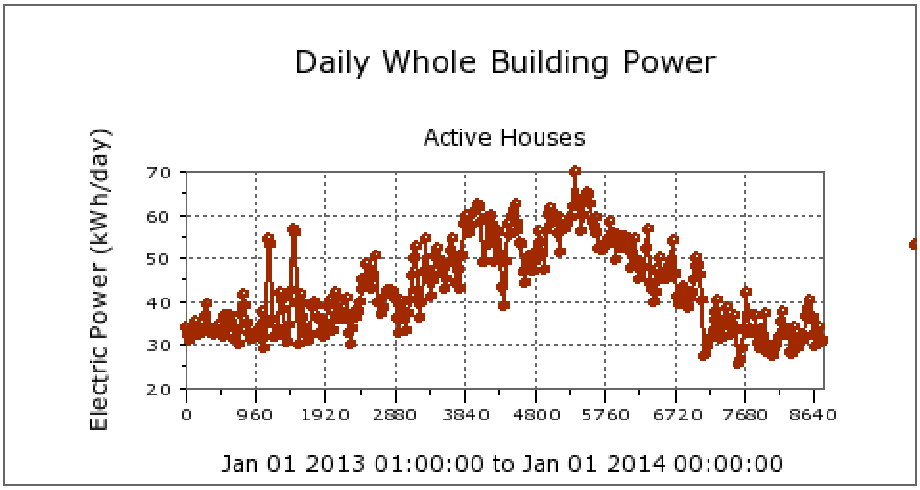

Figure 55. Average daily electricity use (kWh/day) for total electricity in overall sample

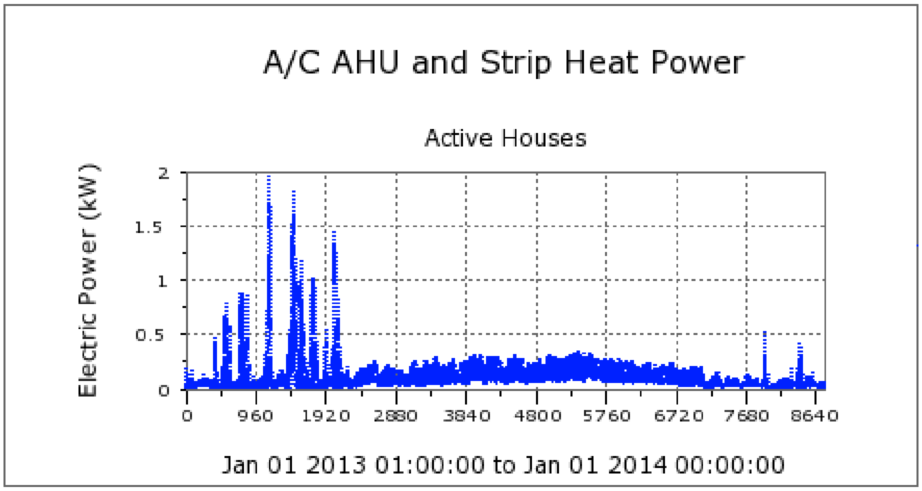

Figure 56. Average hourly AHU and strip heat power in overall sample

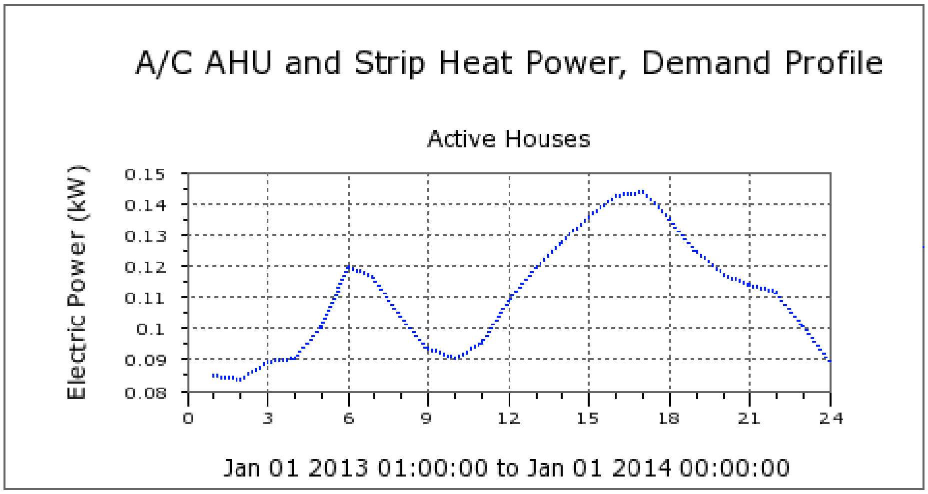

Figure 57. Average AHU and strip heat electricity load shape during 2013

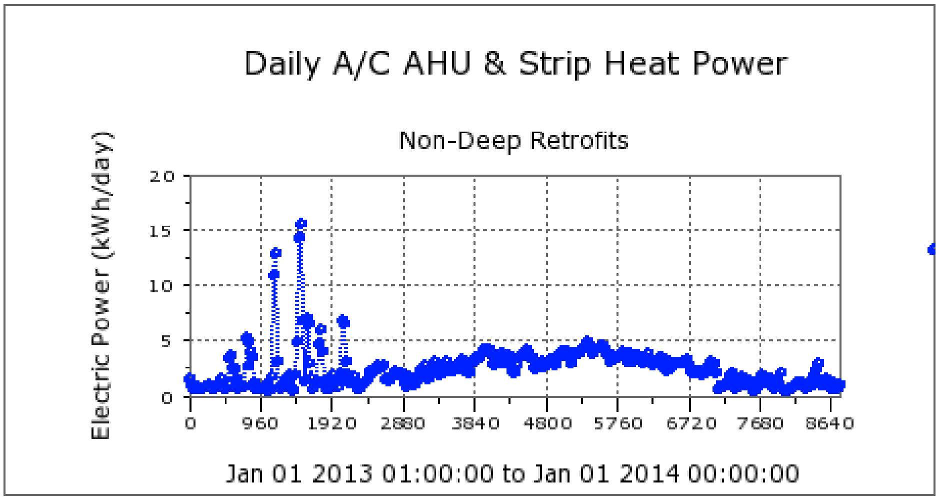

Figure 58. Average daily electricity use (kWh/day) for AHU/strip heat electricity in overall sample

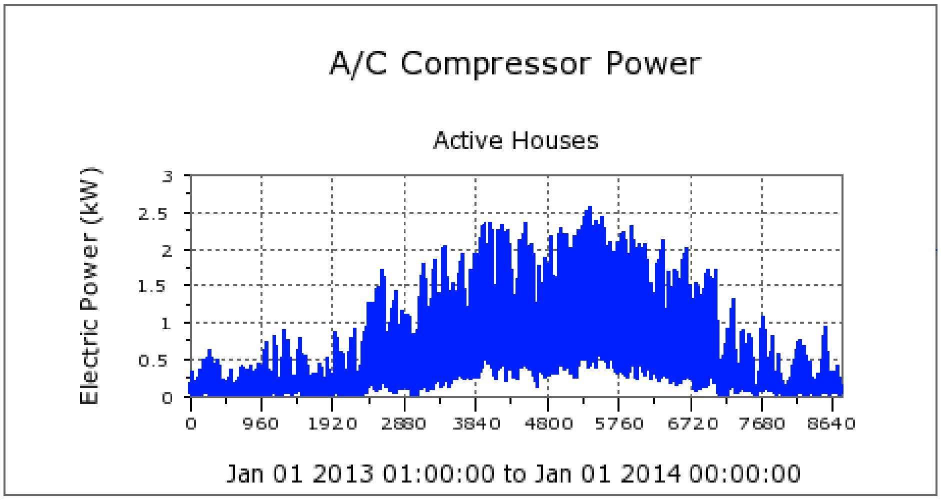

Figure 59. Average hourly compressor power (heat pump and AC unit) in overall sample

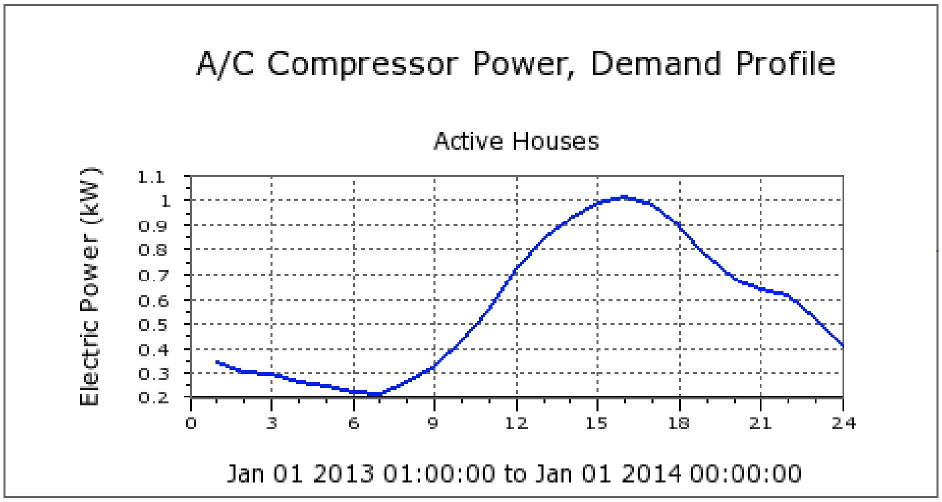

Figure 60. Average compressor load shape during 2013

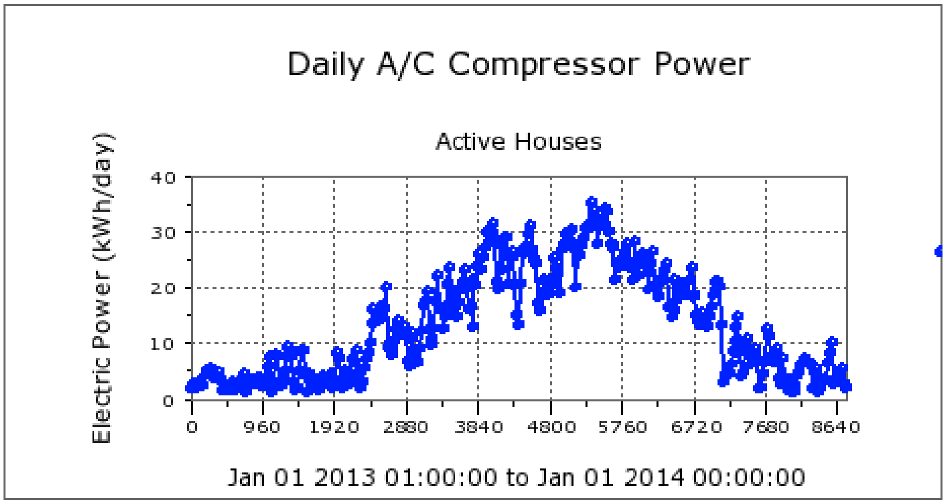

Figure 61. Average daily electricity use (kWh/day) for compressor electricity in overall sample

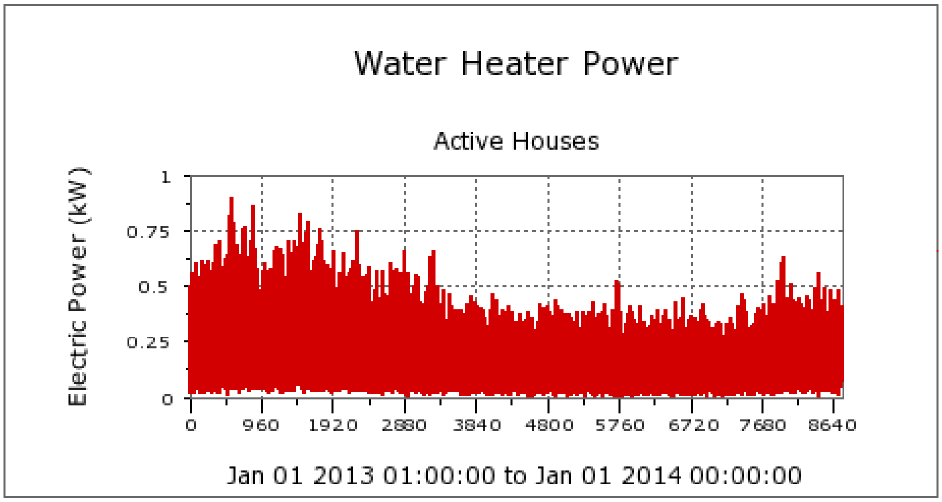

Figure 62. Average hourly water heating electricity in overall sample

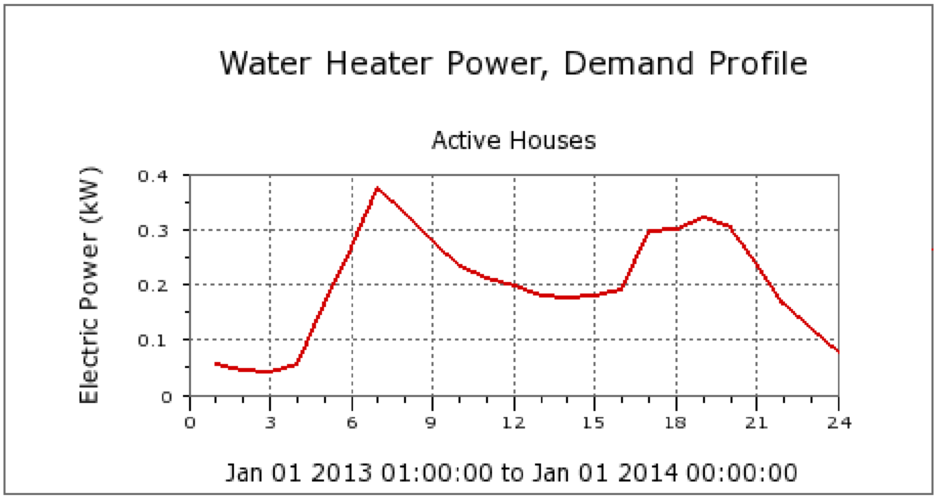

Figure 63. Average water heater load shape during 2013

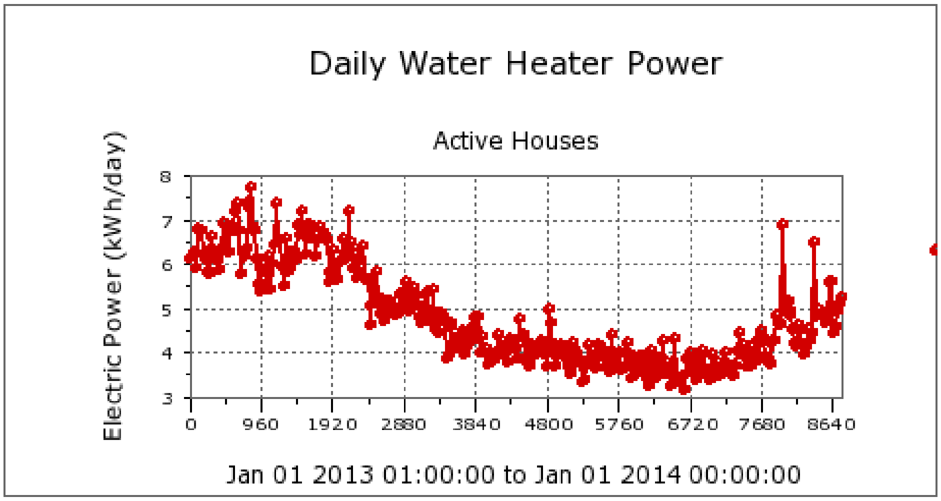

Figure 64. Average daily electricity use (kWh/day) for water heating in overall sample

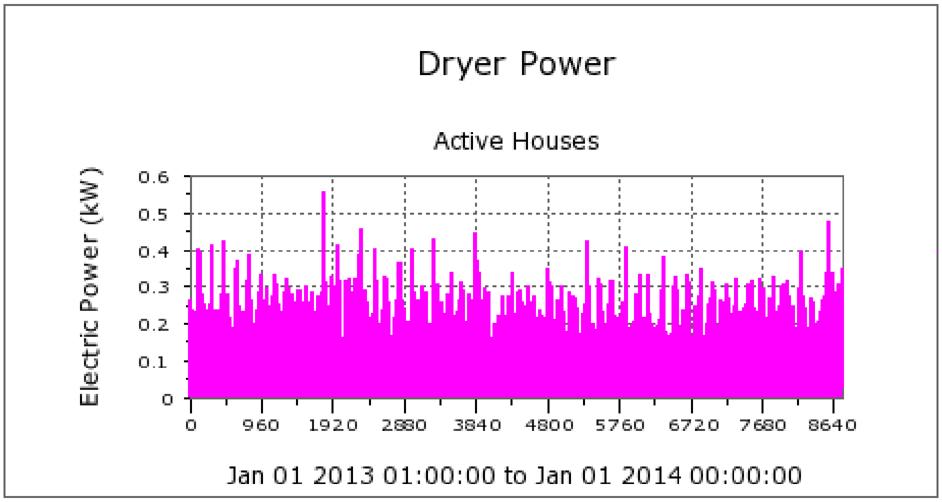

Figure 65. Average hourly clothes dryer electricity in overall sample

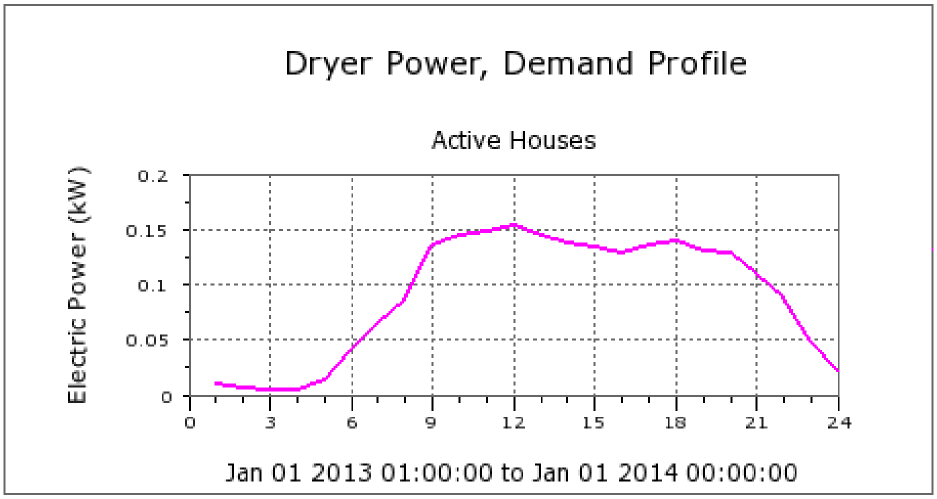

Figure 66. Average clothes dryer load shape during 2013

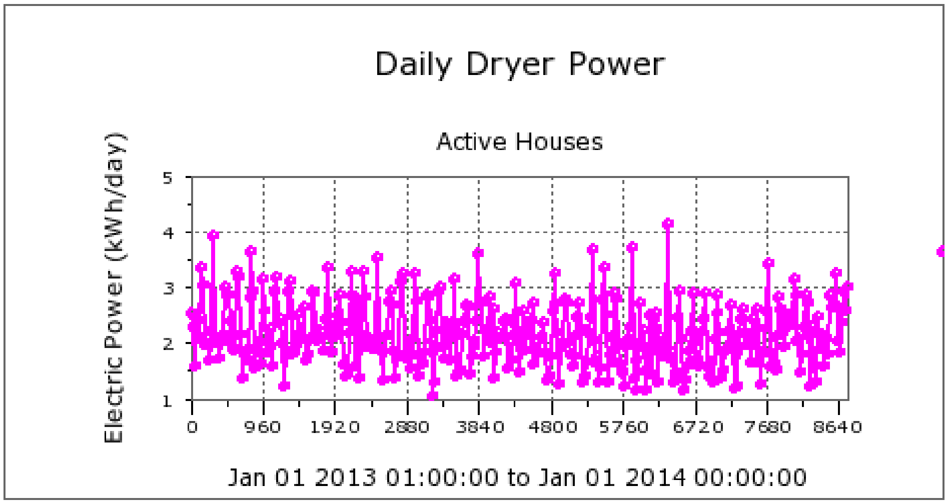

Figure 67. Average daily electricity use (kWh/day) for clothes drying in overall sample

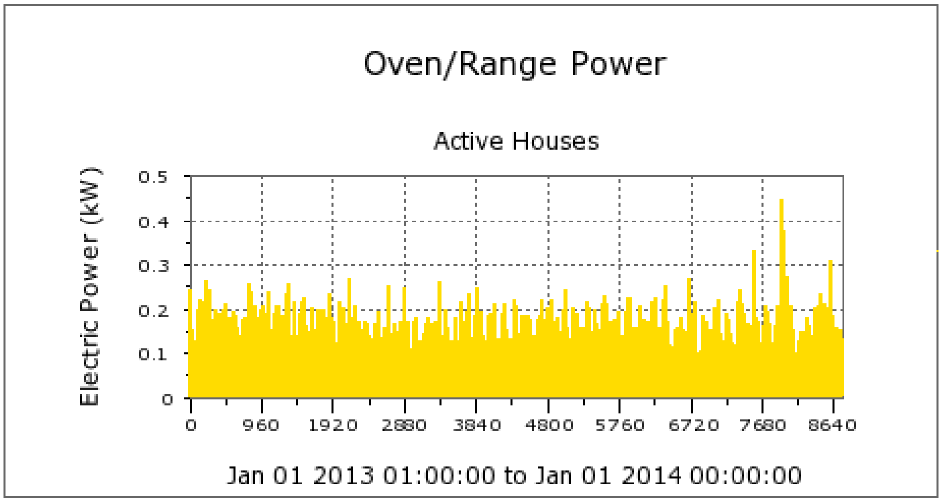

Figure 68. Average hourly oven/range electricity in overall sample

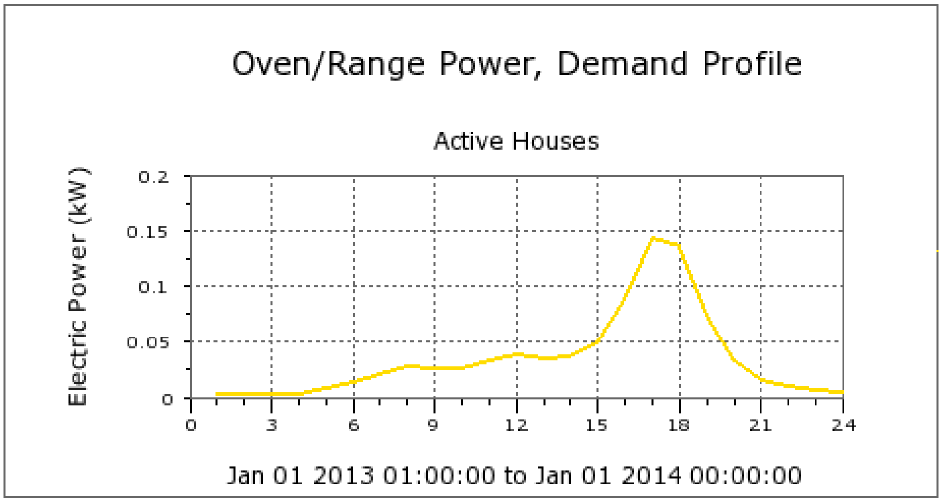

Figure 69. Average range/oven load shape during 2013

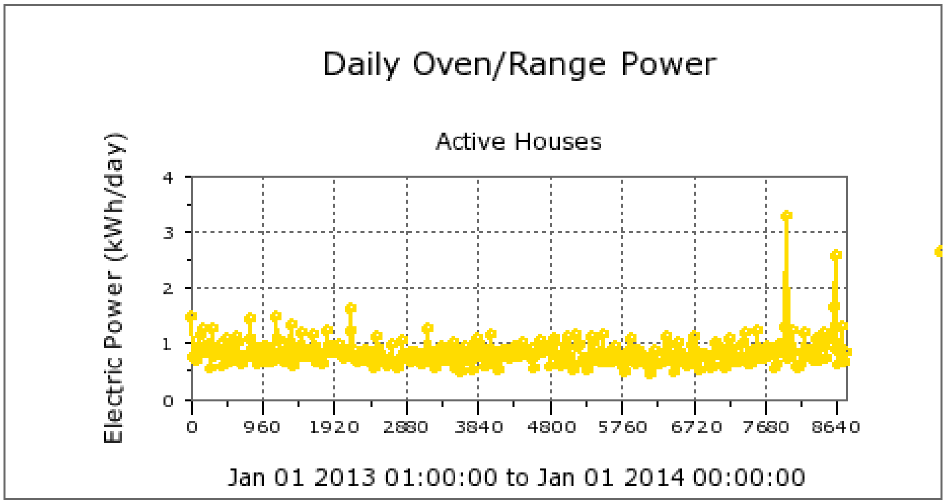

Figure 70. Average daily electricity use (kWh/day) for range/oven in overall sample

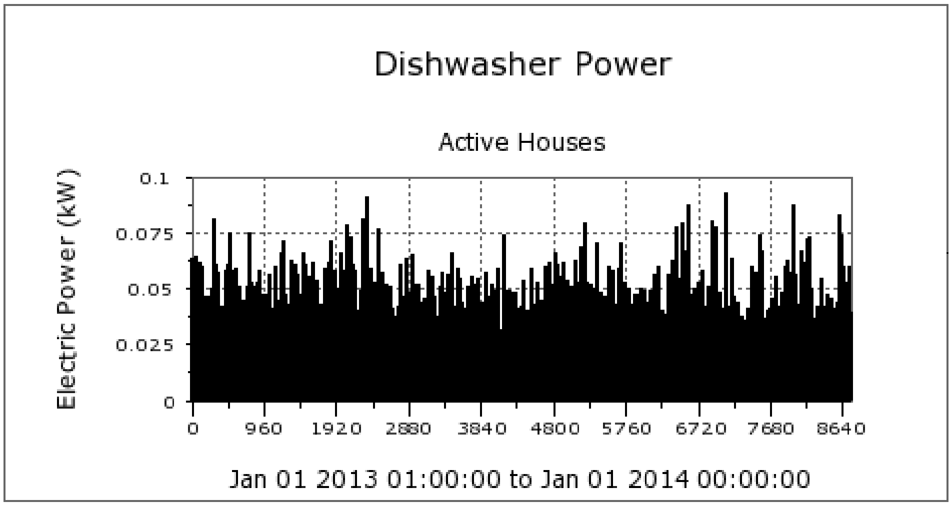

Figure 71. Average hourly dishwasher electricity in overall sample

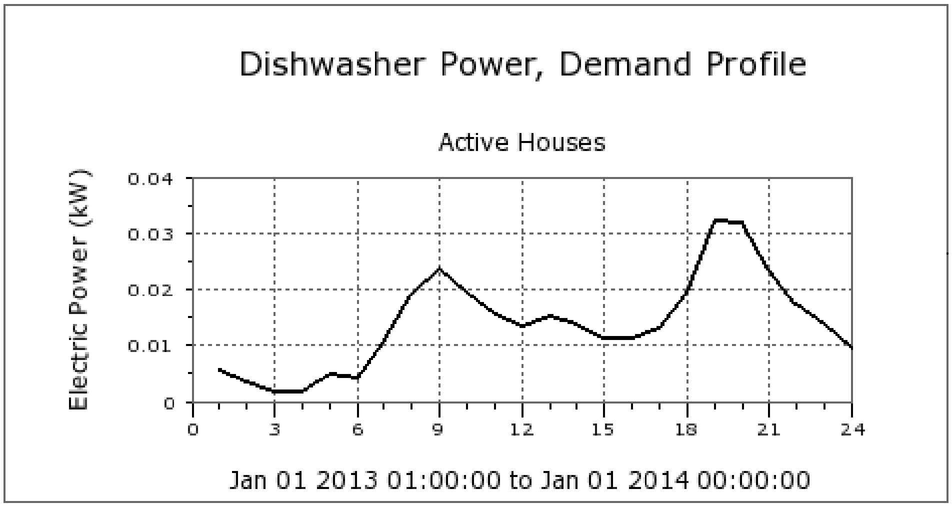

Figure 72. Average dishwasher load shape during 2013

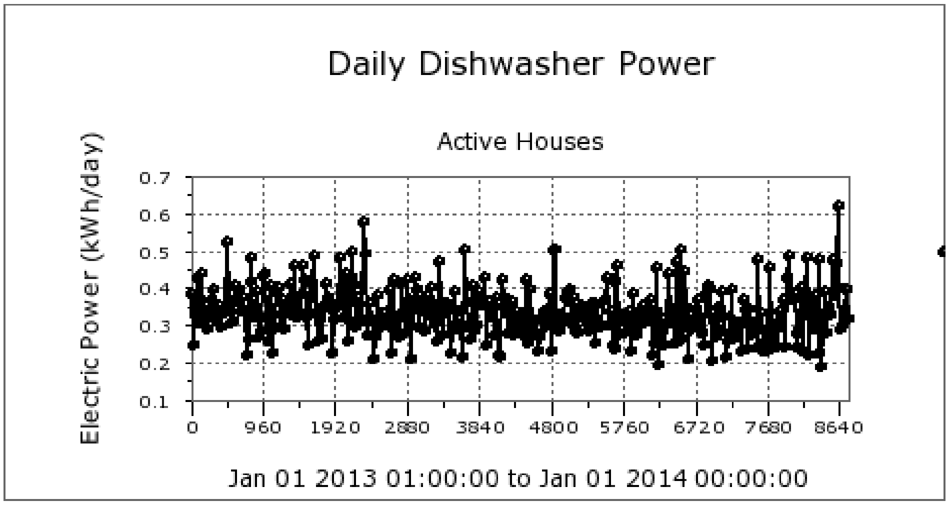

Figure 73. Average daily electricity use (kWh/day) for dishwasher in overall sample

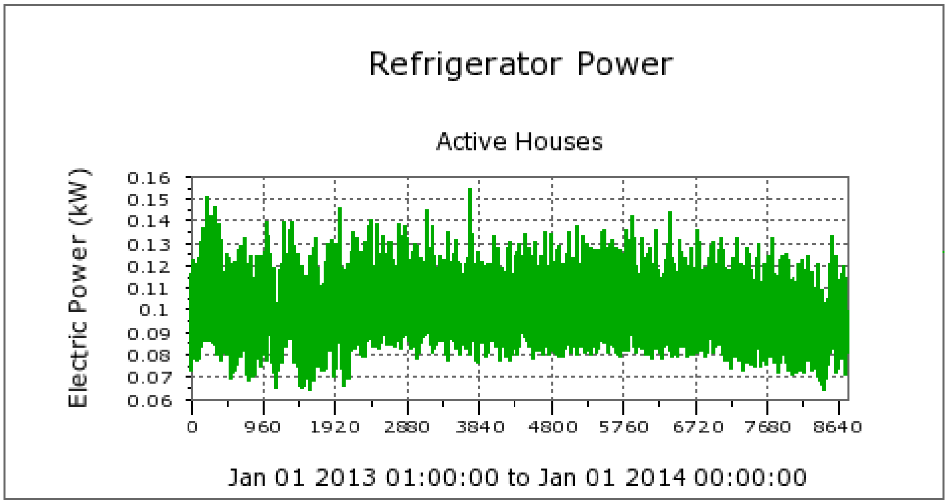

Figure 74. Average hourly refrigerator electricity in overall sample

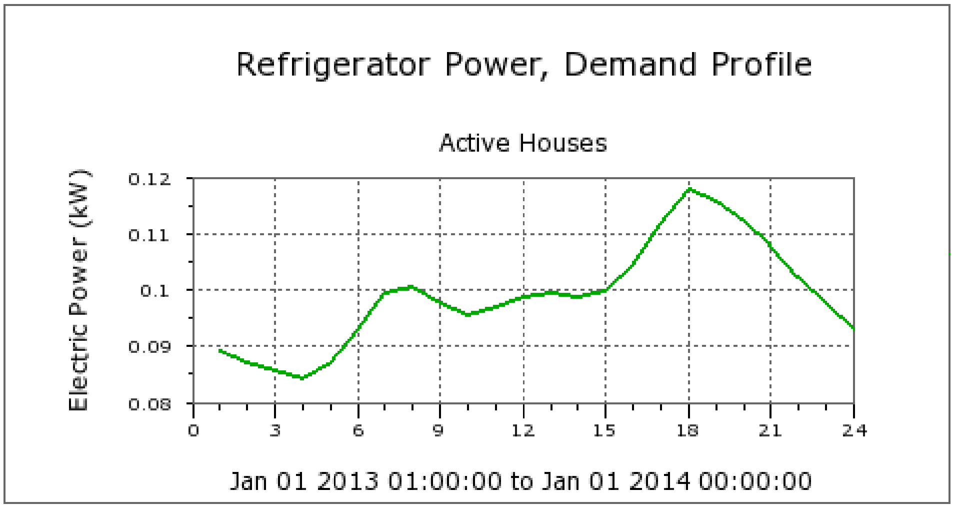

Figure 75. Average refrigerator load shape during 2013

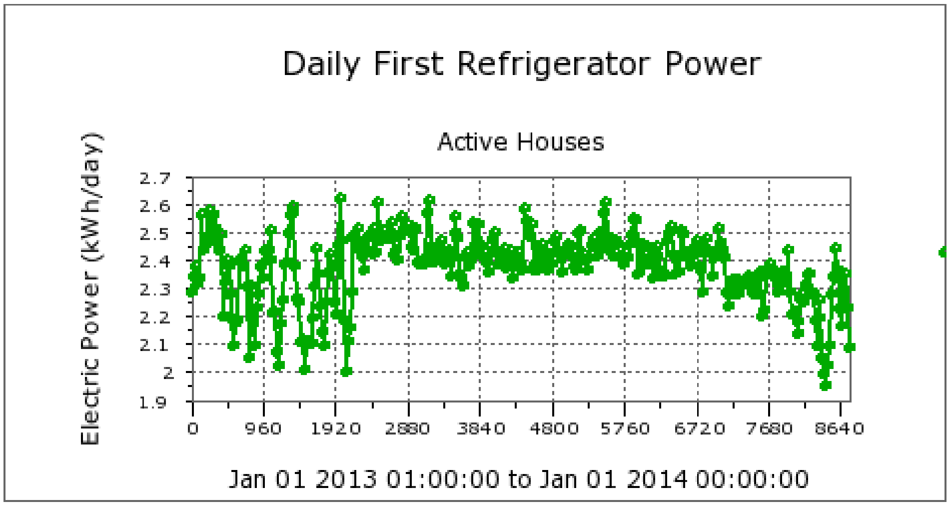

Figure 76. Average daily electricity use (kWh/day) for refrigerator in overall sample

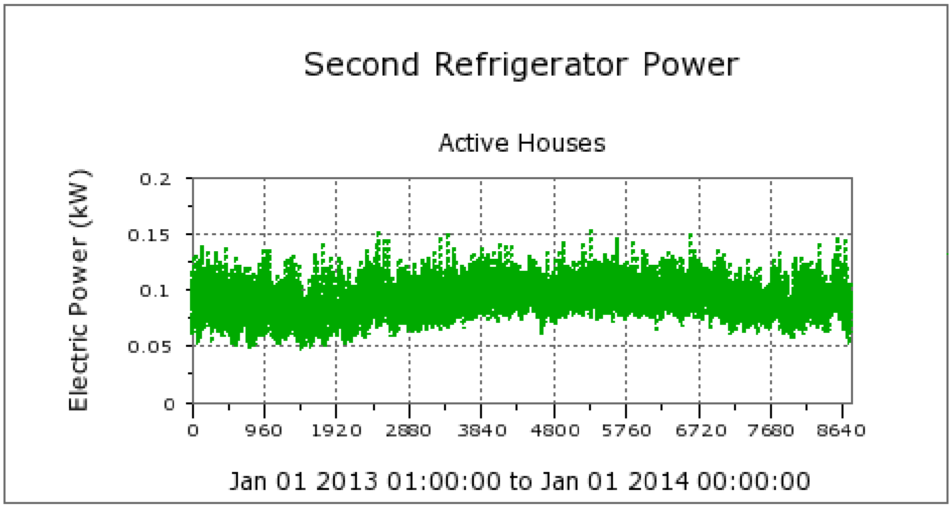

Figure 77. Average hourly second refrigerator electricity in overall sample

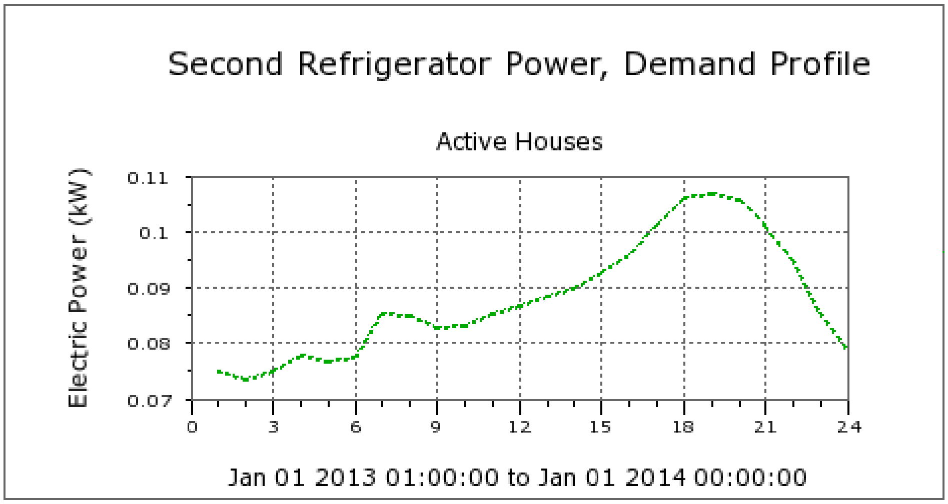

Figure 78. Average second refrigerator load shape during 2013

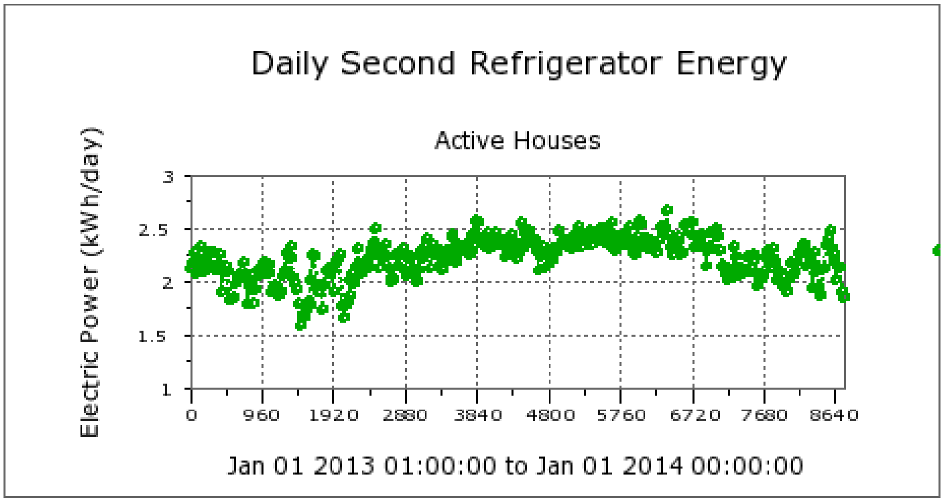

Figure 79. Average daily electricity use (kWh/day) for second refrigerator in overall sample

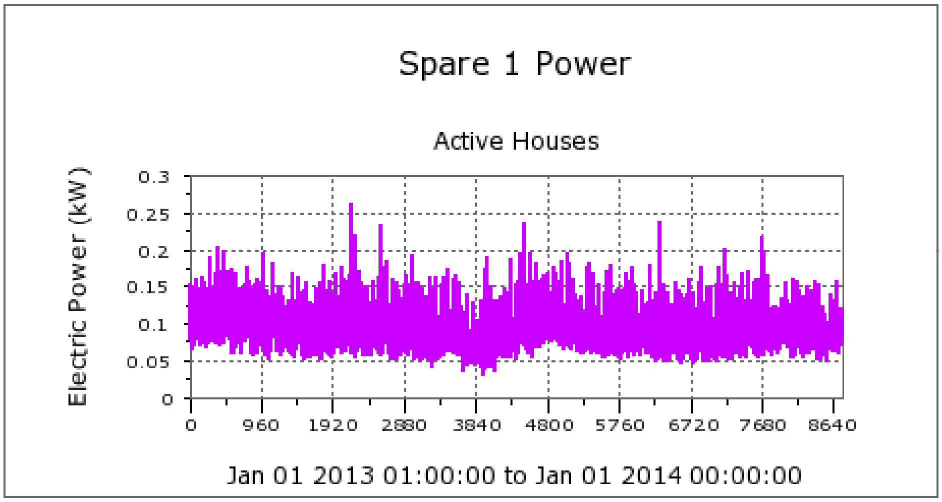

Figure 80. Average hourly Spare 1 electricity in overall sample

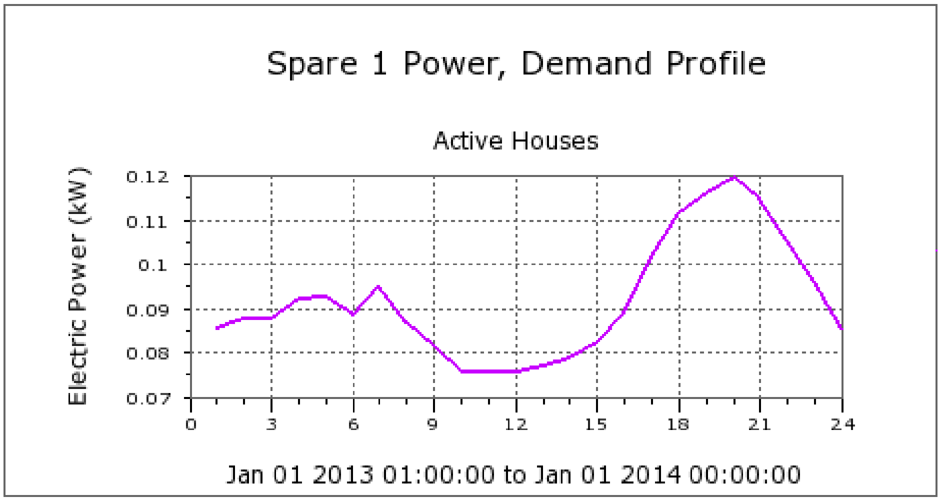

Figure 81. Average Spare 1 load shape over 2013 (Spare 1 included many home offices)

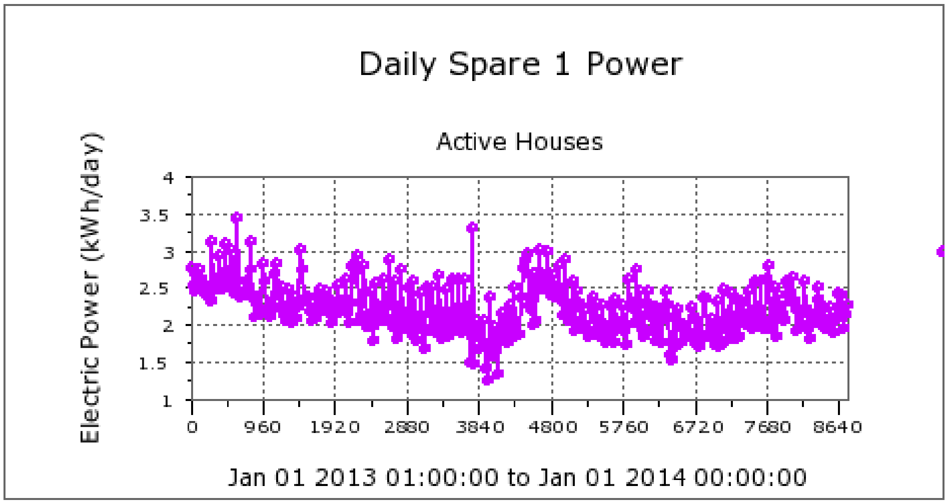

Figure 82. Average daily electricity use (kWh/day) for Spare 1 in overall sample

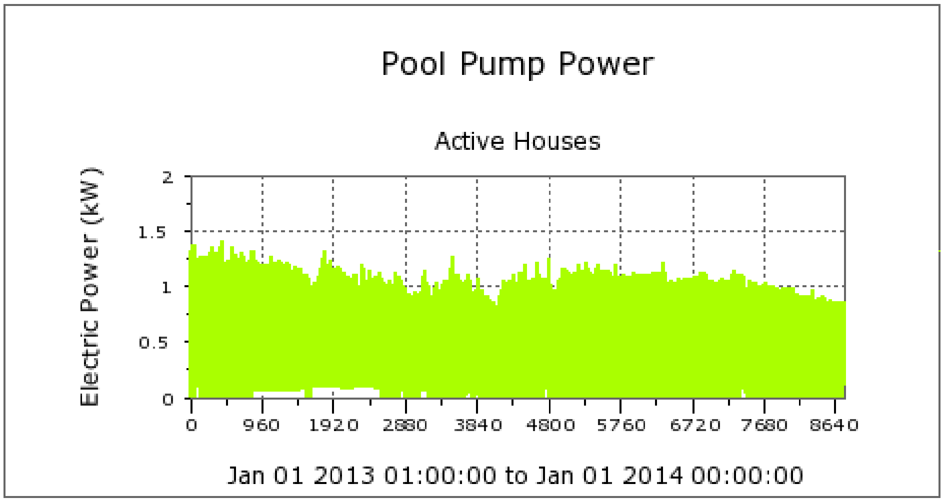

Figure 83. Average hourly pool pump electricity in overall sample

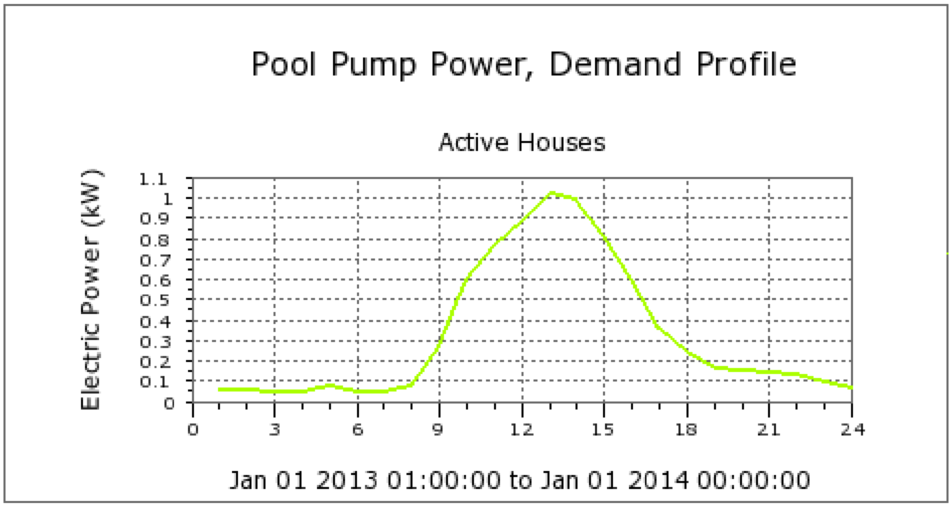

Figure 84. Average swimming pool pump shape during 2013

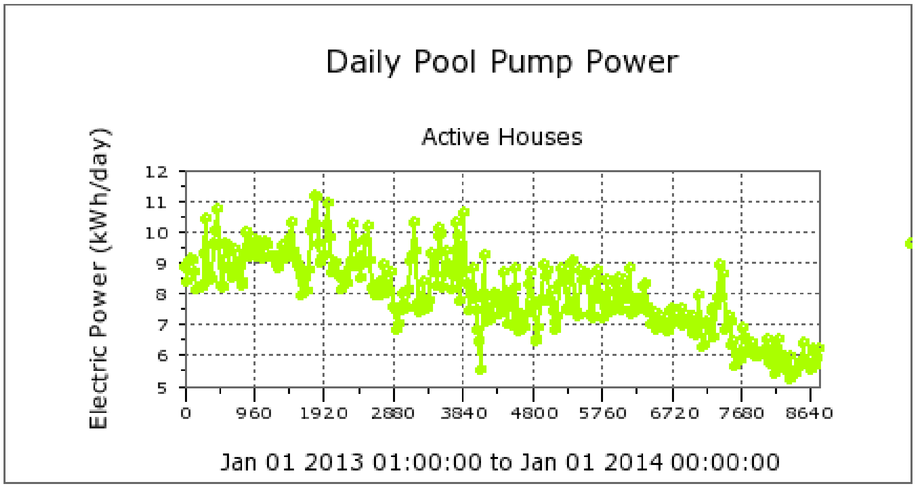

Figure 85. Average daily electricity use (kWh/day) for swimming pools in overall sample. Reductions seen beginning hour 2000 reflect shallow retrofits, then deep retrofits ~hour 6000

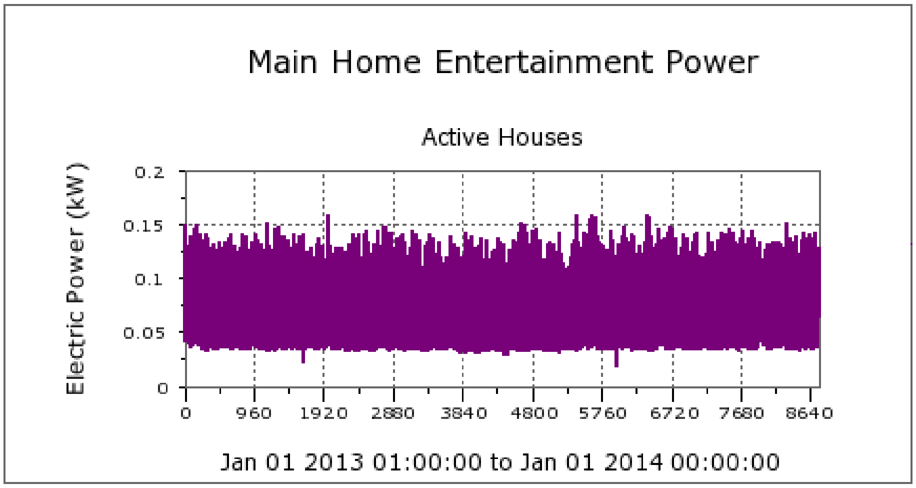

Figure 86. Average hourly home entertainment electricity in overall sample

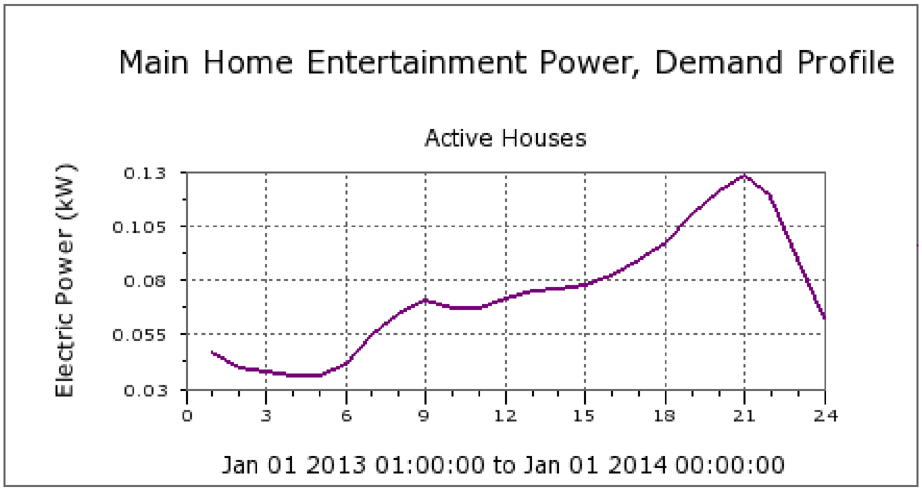

Figure 87. Average home entertainment load shape during 2013

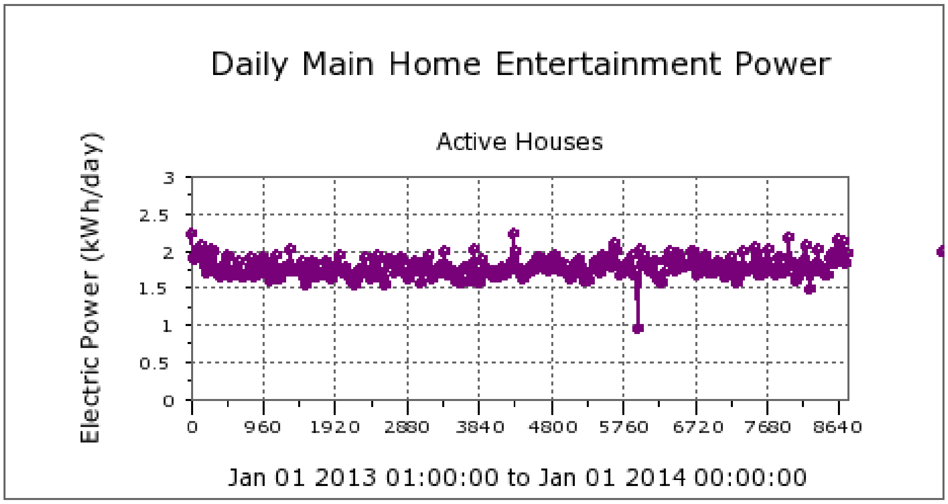

Figure 88. Average daily electricity use (kWh/day) for home entertainment in overall sample

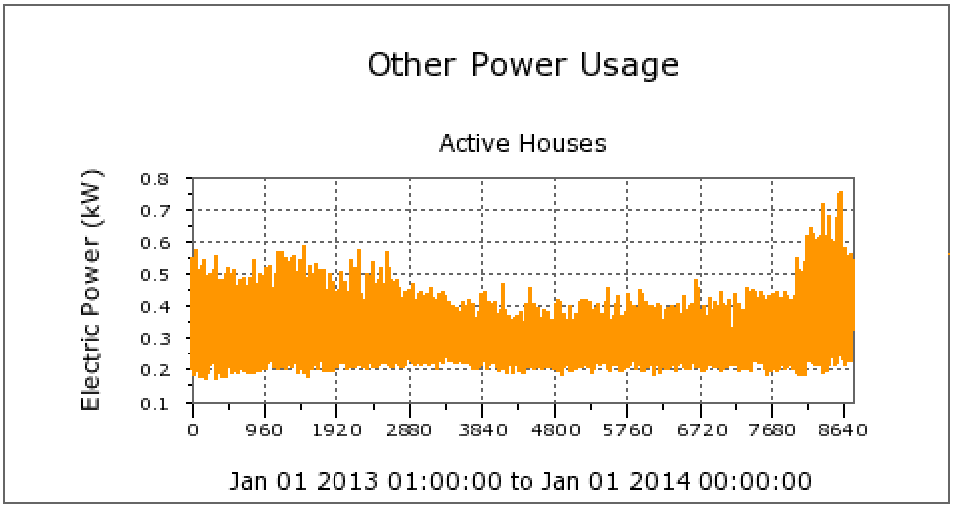

Figure 89. Average hourly lighting and plug load electricity in overall sample

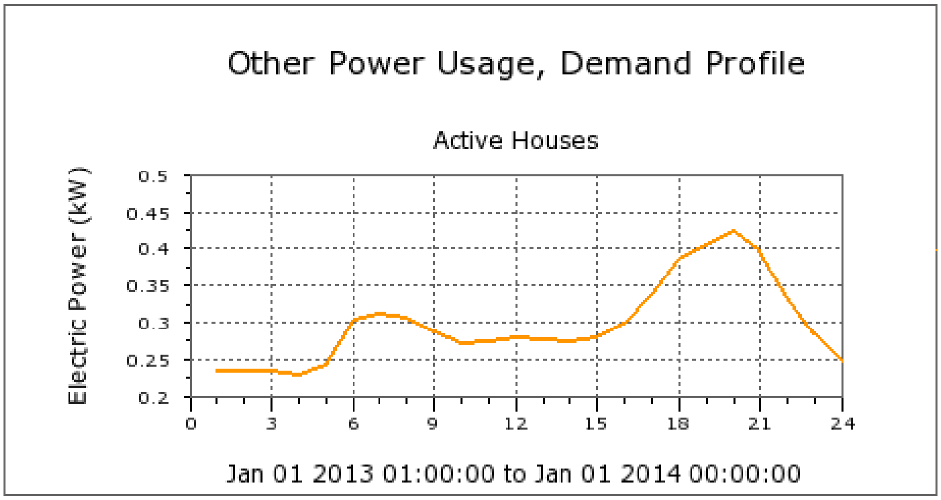

Figure 90. Average lighting and plug load shape during 2013

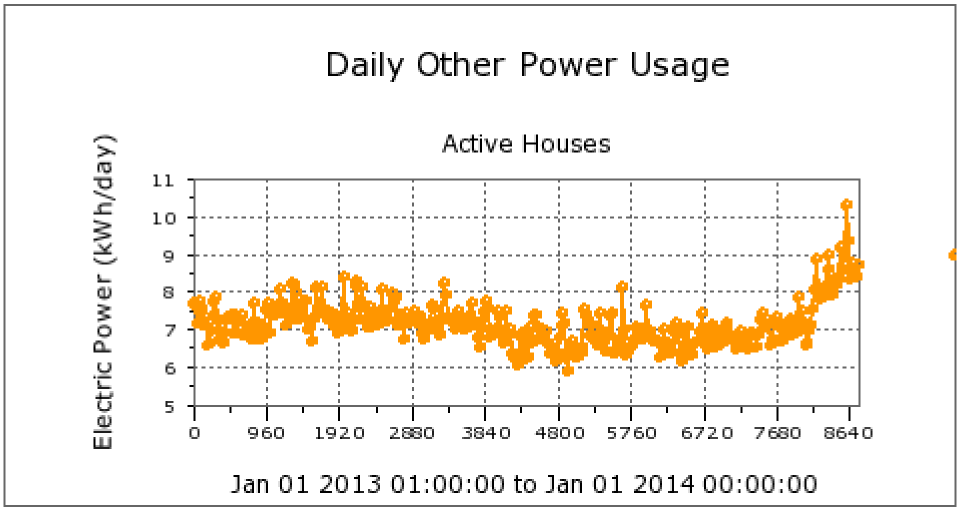

Figure 91. Average daily electricity use (kWh/day) for lighting and plug loads in overall sample. Increases at the end of the year represent holiday lighting.

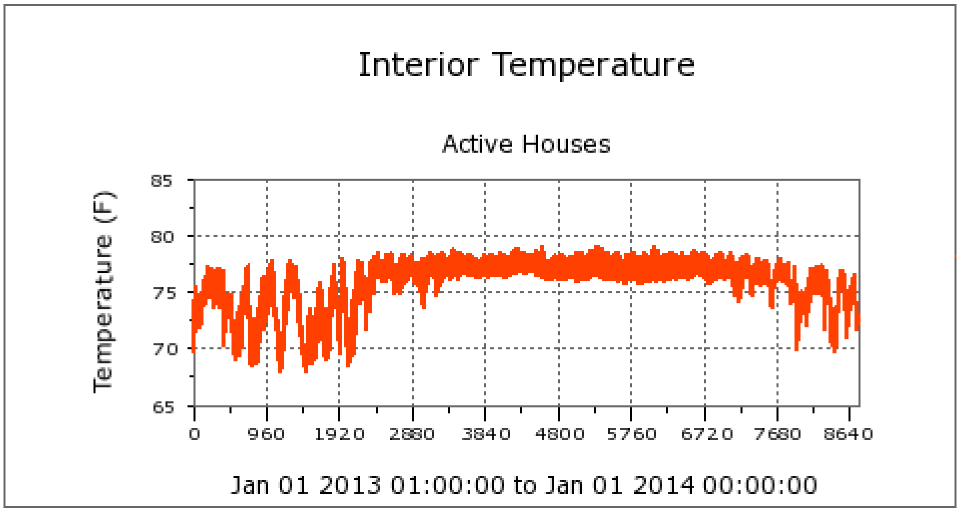

Figure 92. Hourly average temperature in homes during 2013

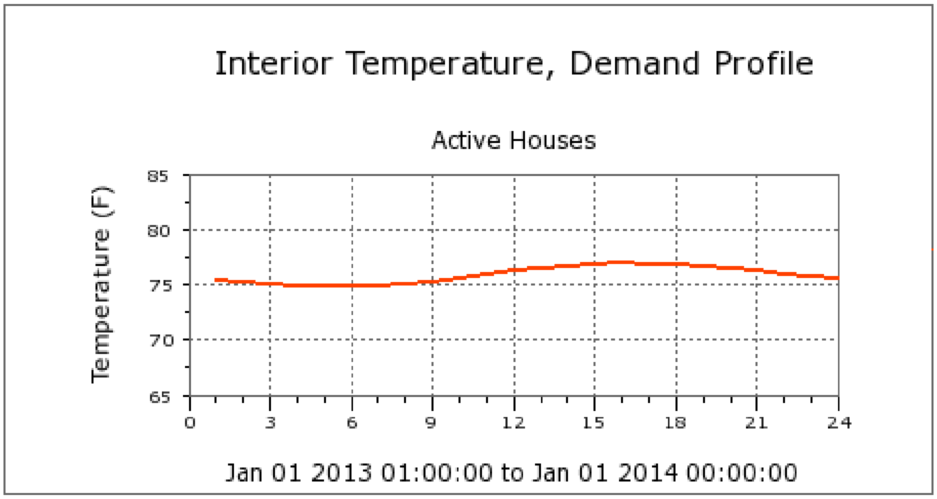

Figure 93. Average interior temperature profile during 2013

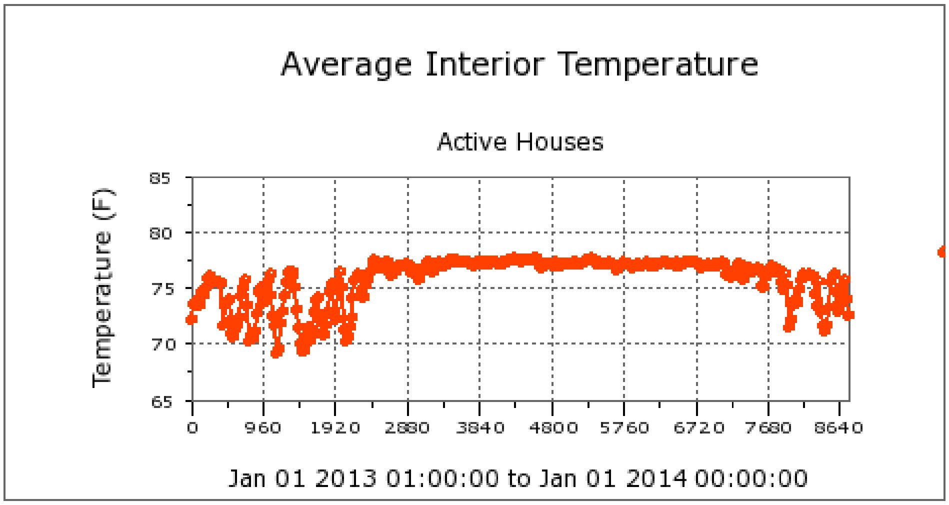

Figure 94. Daily average temperature during 2013

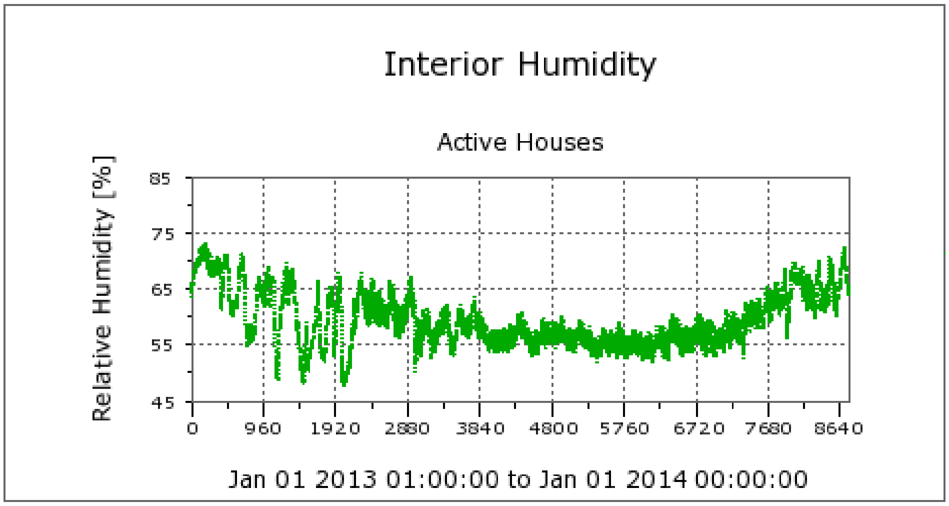

Figure 95. Average hourly interior humidity in homes during 2013

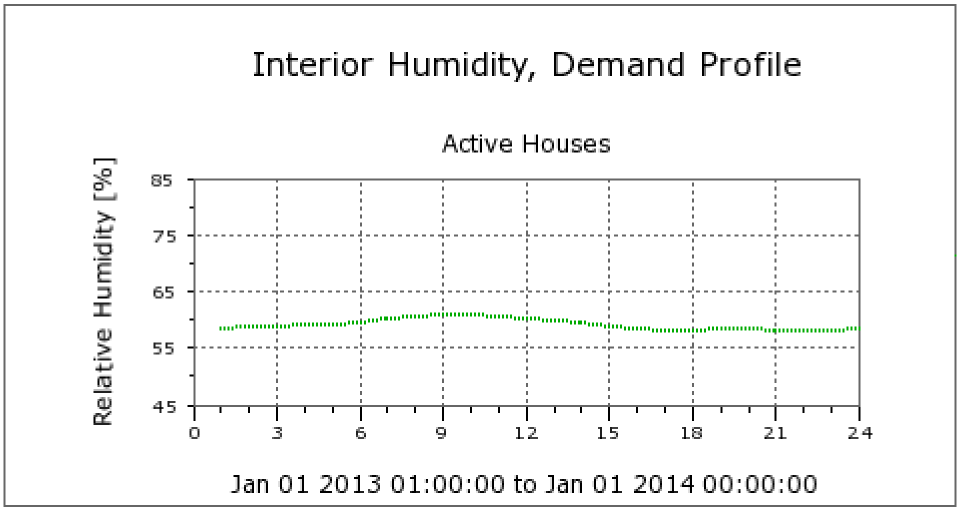

Figure 96. Average interior humidity profile over 2013

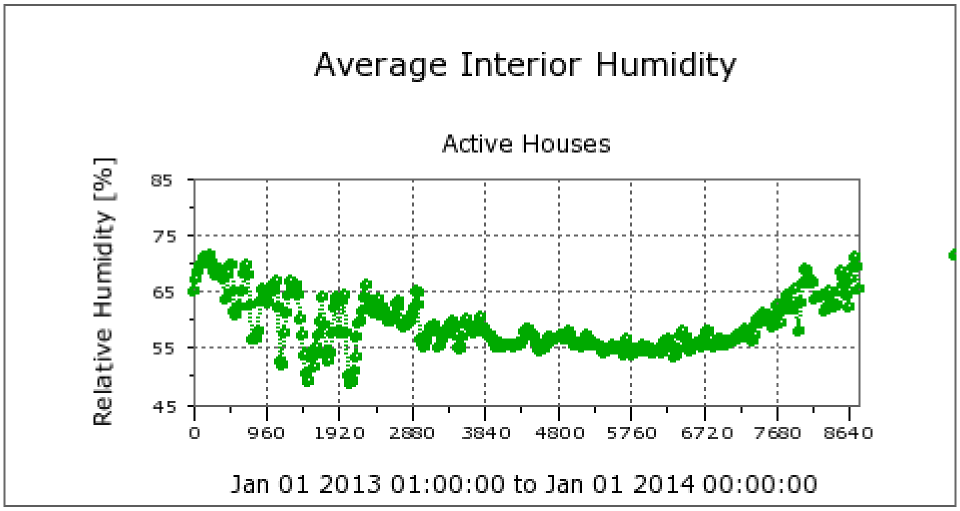

Figure 97. Average daily interior humidity level during 2013

Appendix C: 2013 Monthly Load Shapes

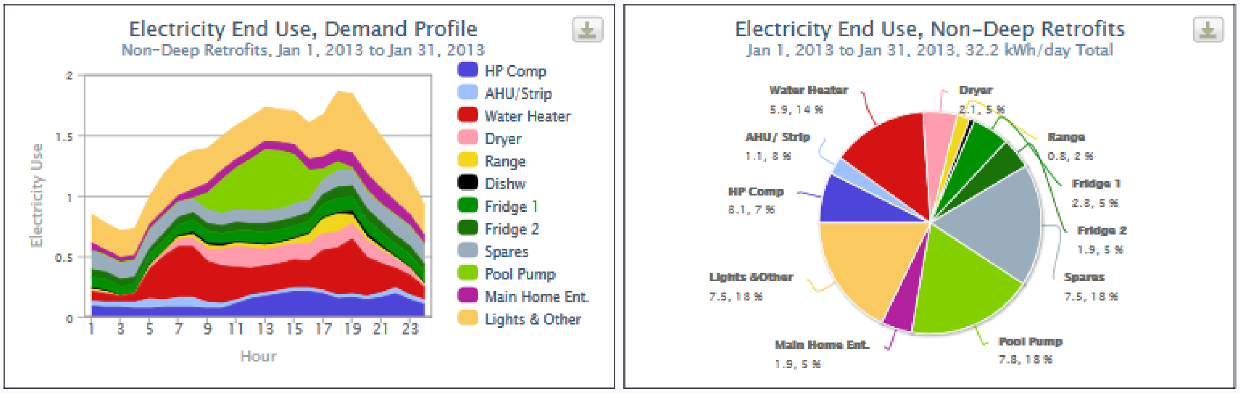

Figure 98. Electricity end uses, January loads

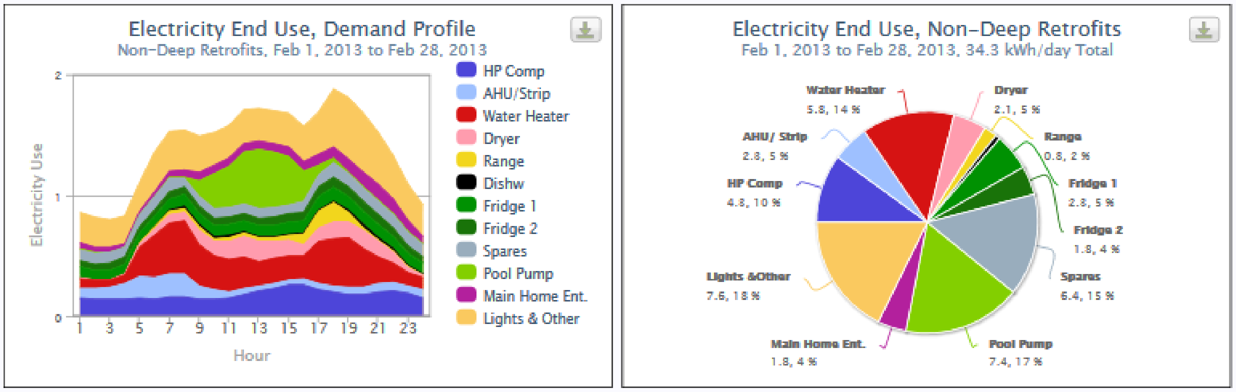

Figure 99. Electricity end uses, February loads

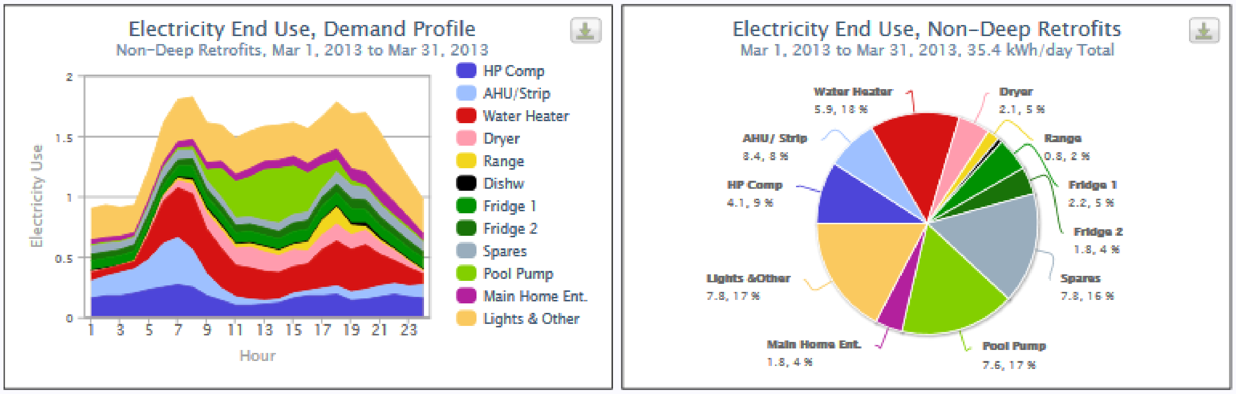

Figure 100. Electricity end uses, March loads

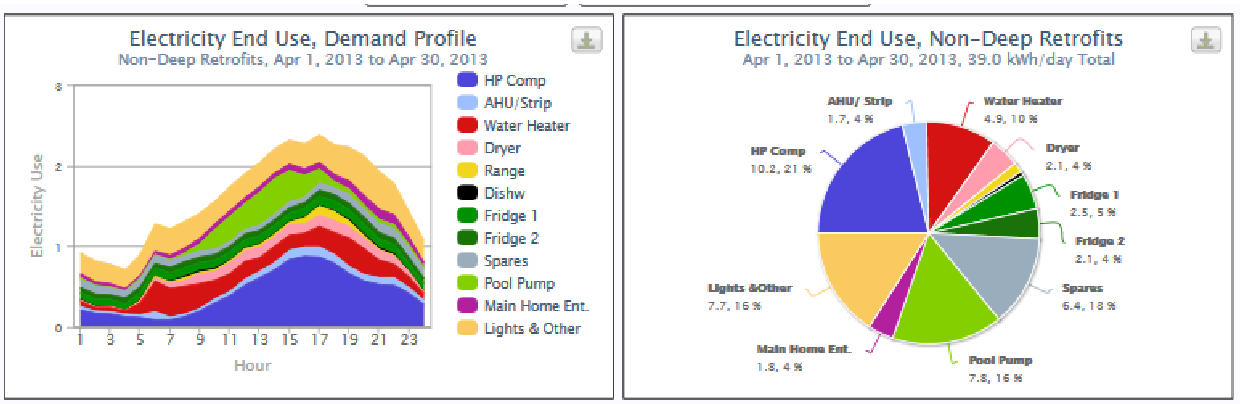

Figure 101. Electricity end uses, April loads

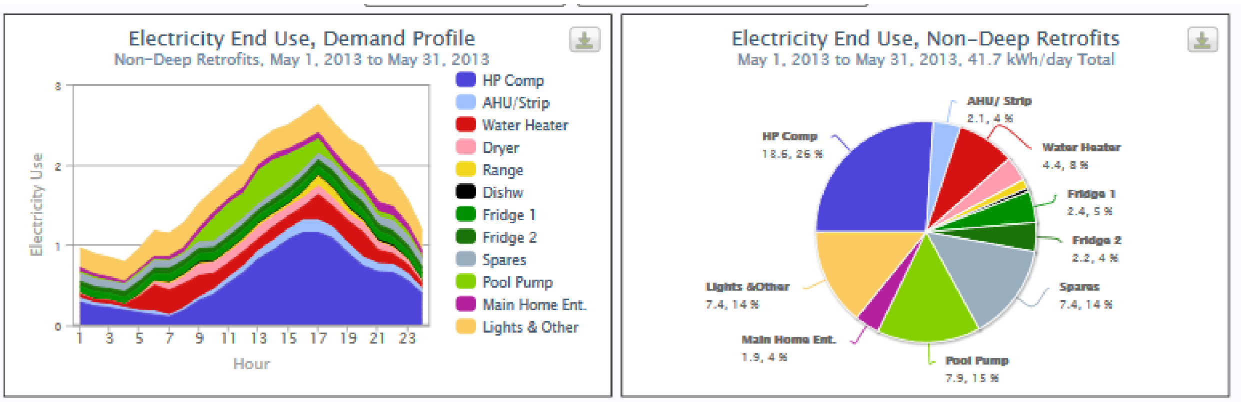

Figure 102. Electricity end uses, May loads

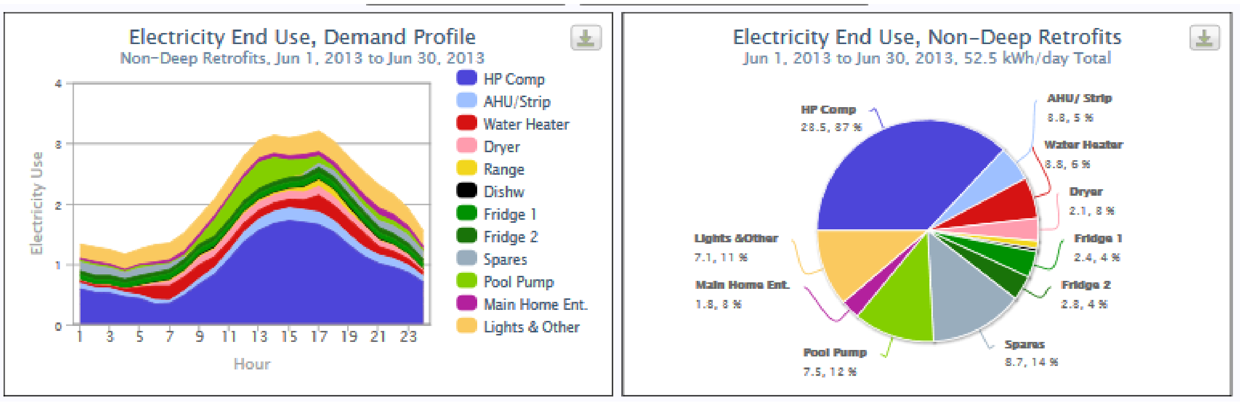

Figure 103. Electricity end uses, June loads

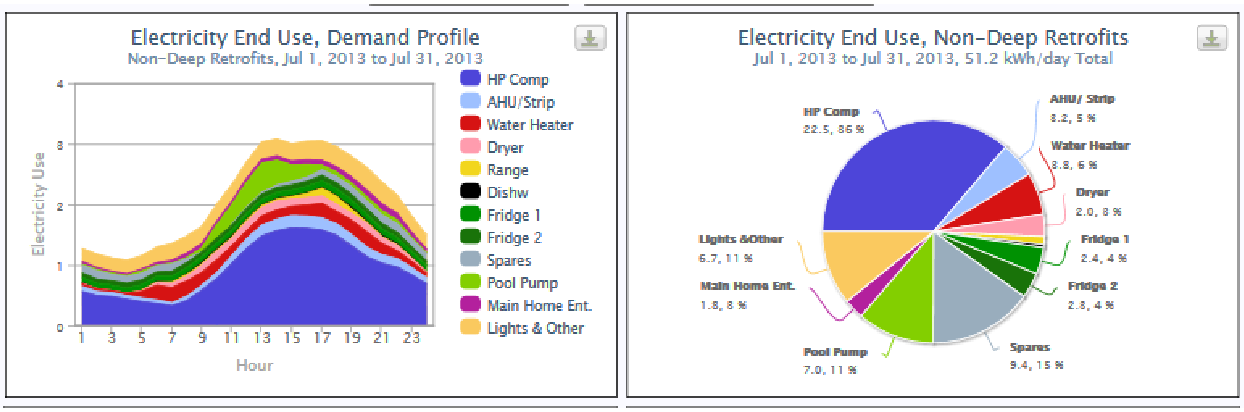

Figure 104. Electricity end uses, July loads

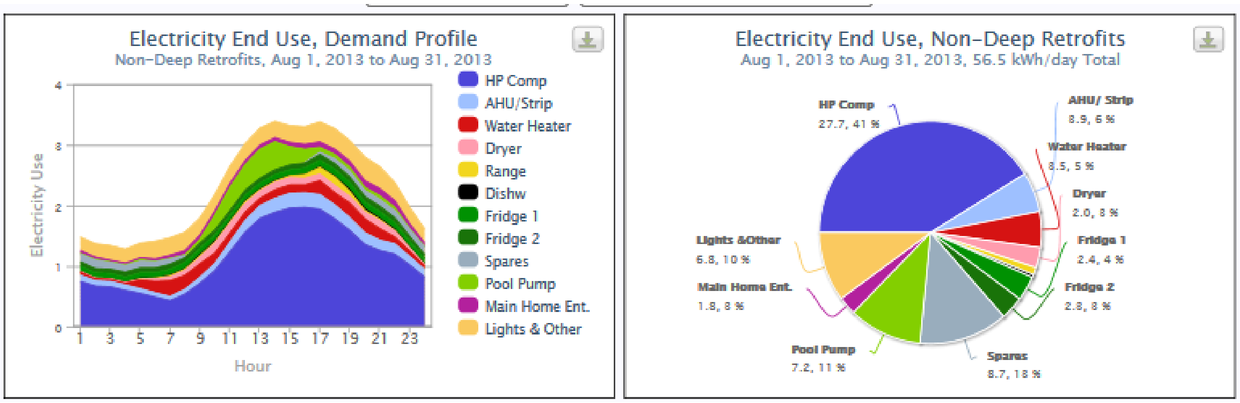

Figure 105. Electricity end uses, August loads

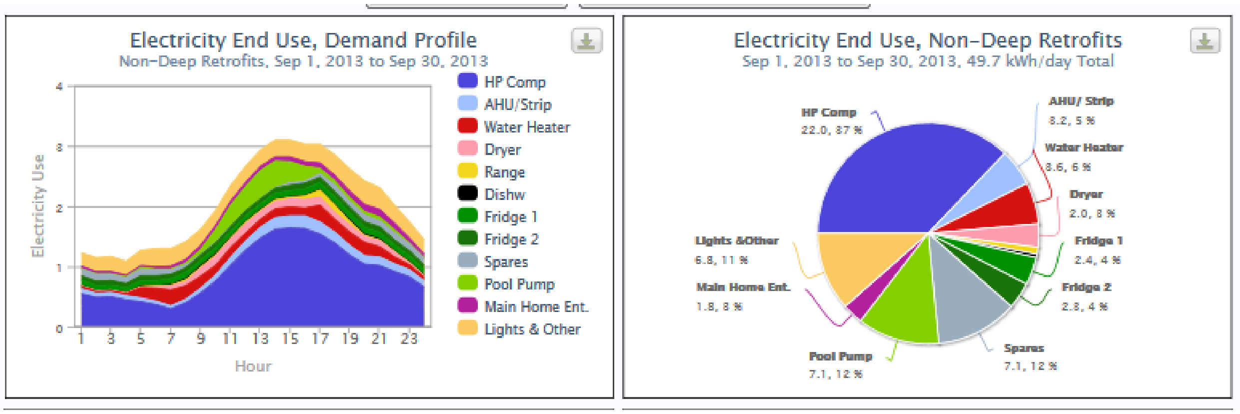

Figure 106. Electricity end uses, September loads

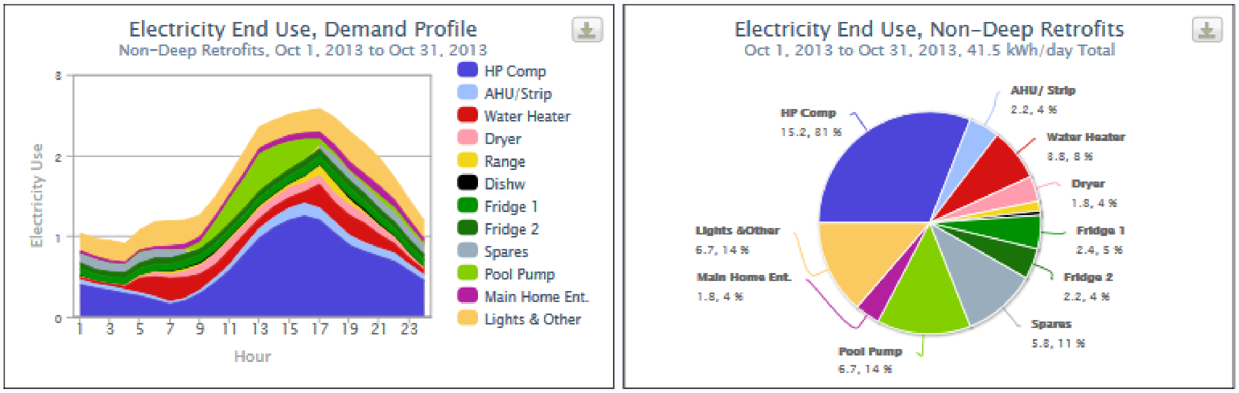

Figure 107. Electricity end uses, October loads

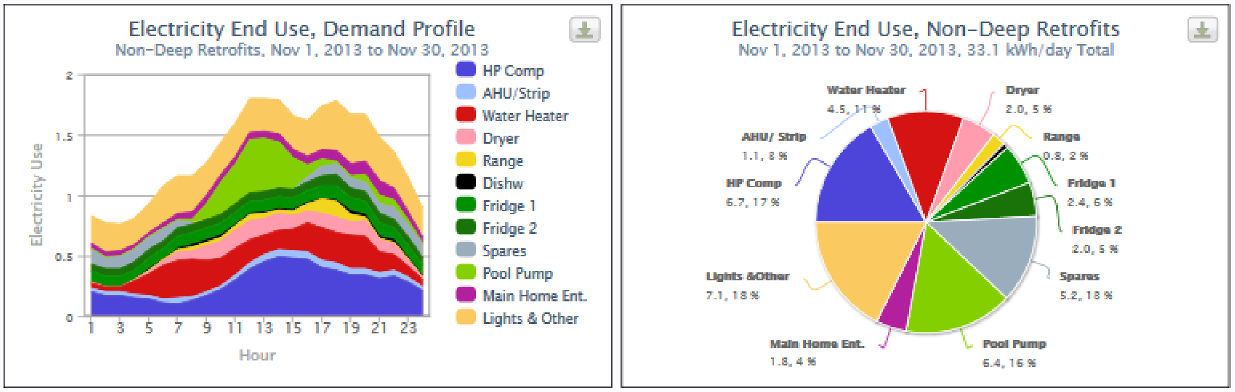

Figure 108. Electricity end uses, November loads

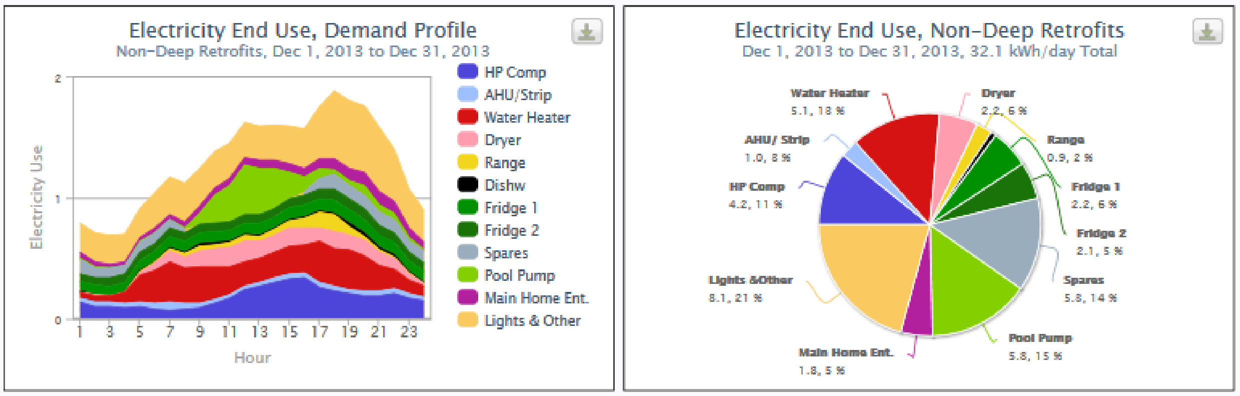

Figure 109. Electricity end uses, December loads

Appendix D: Hourly Power Plots

Shallow Cooling Plots

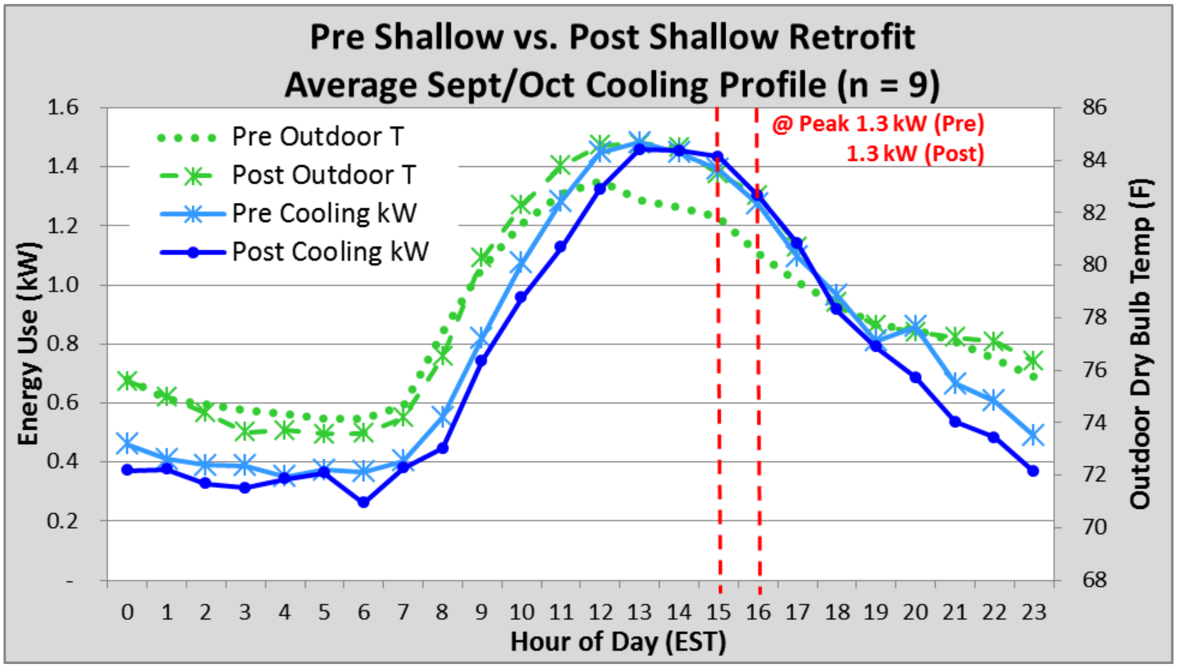

Figure 110. Pre-retrofit (shallow) versus post-retrofit (shallow) average September/October cooling profile

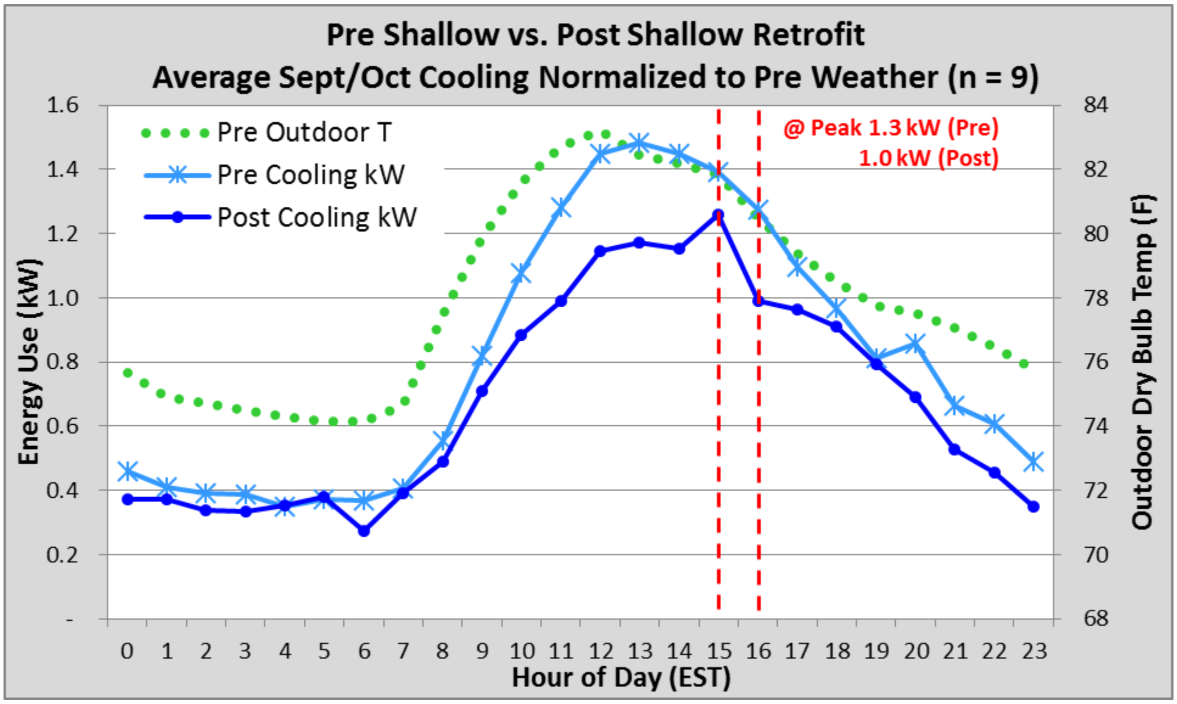

Figure 111. Pre-retrofit (shallow) versus post-retrofit (shallow) average September/October cooling normalized to pre-retrofit weather

Shallow Cooling Plots (cont.)

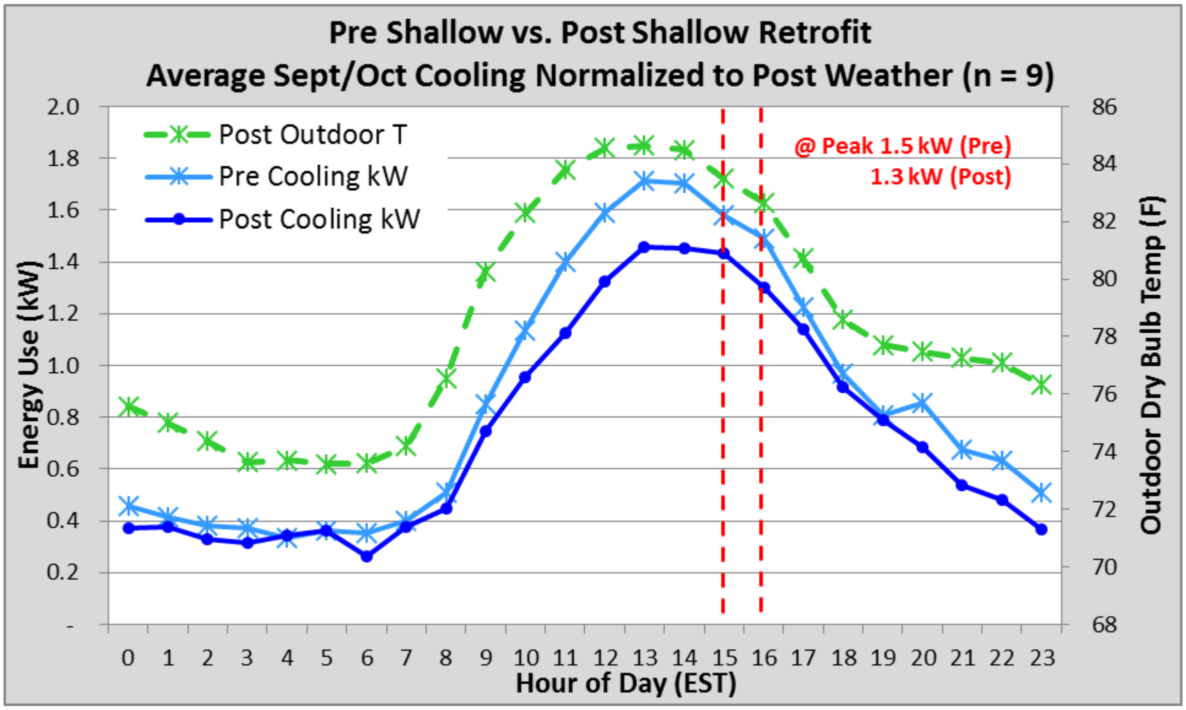

Figure 112. Pre-retrofit (shallow) versus post-retrofit (shallow) average September/October cooling normalized to post-retrofit weather

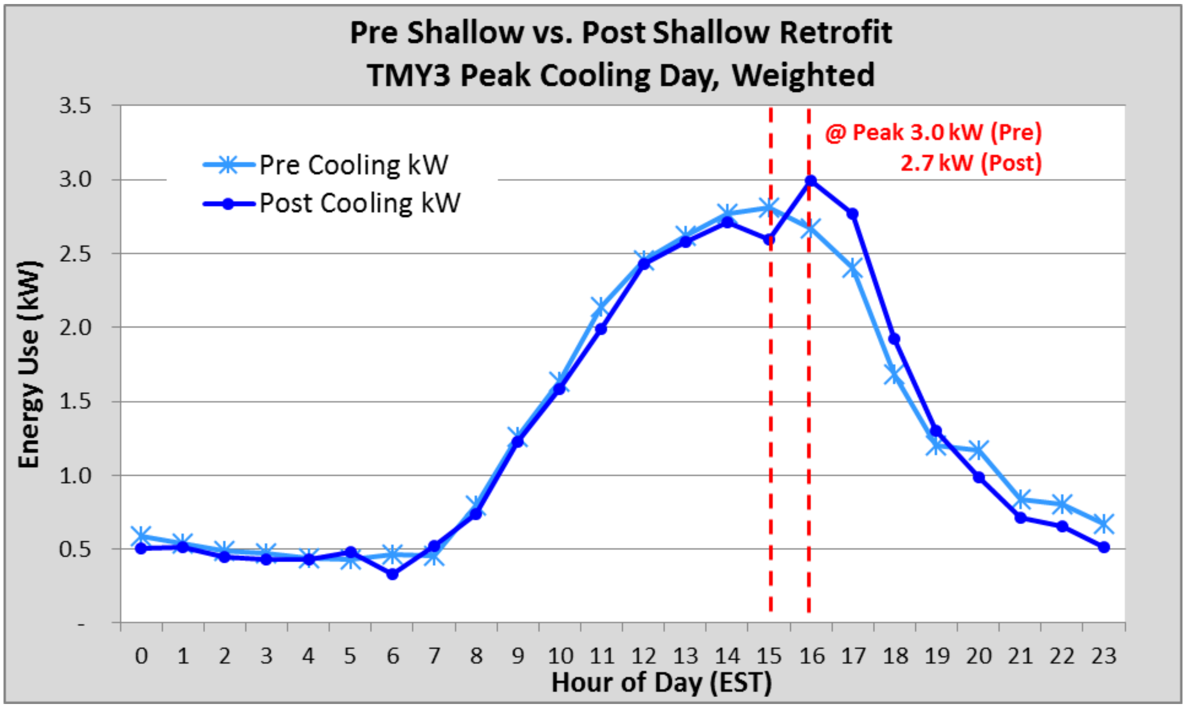

Figure 113. Pre-retrofit (shallow) versus post-retrofit (shallow) TMY3 peak cooling day, weighted

Shallow Cooling Plots (cont..)

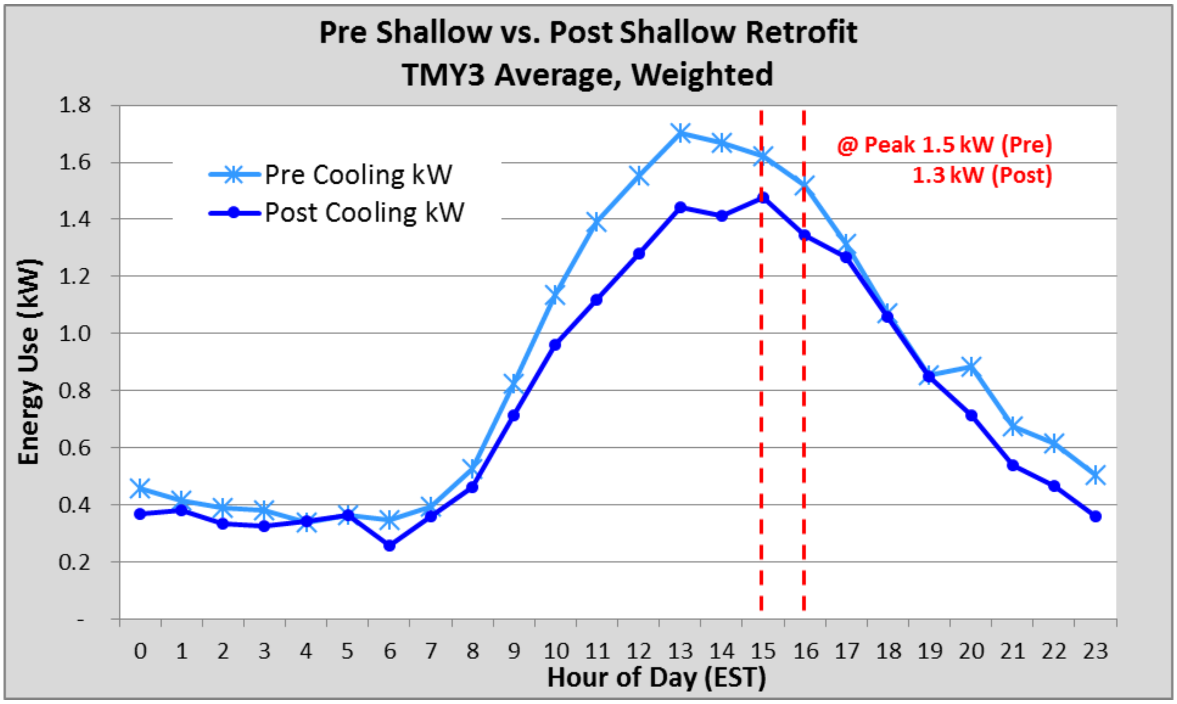

Figure 114. Pre-retrofit (shallow) versus post-retrofit (shallow) TMY3 average, weighted by FPL service area

Shallow Heating Plots

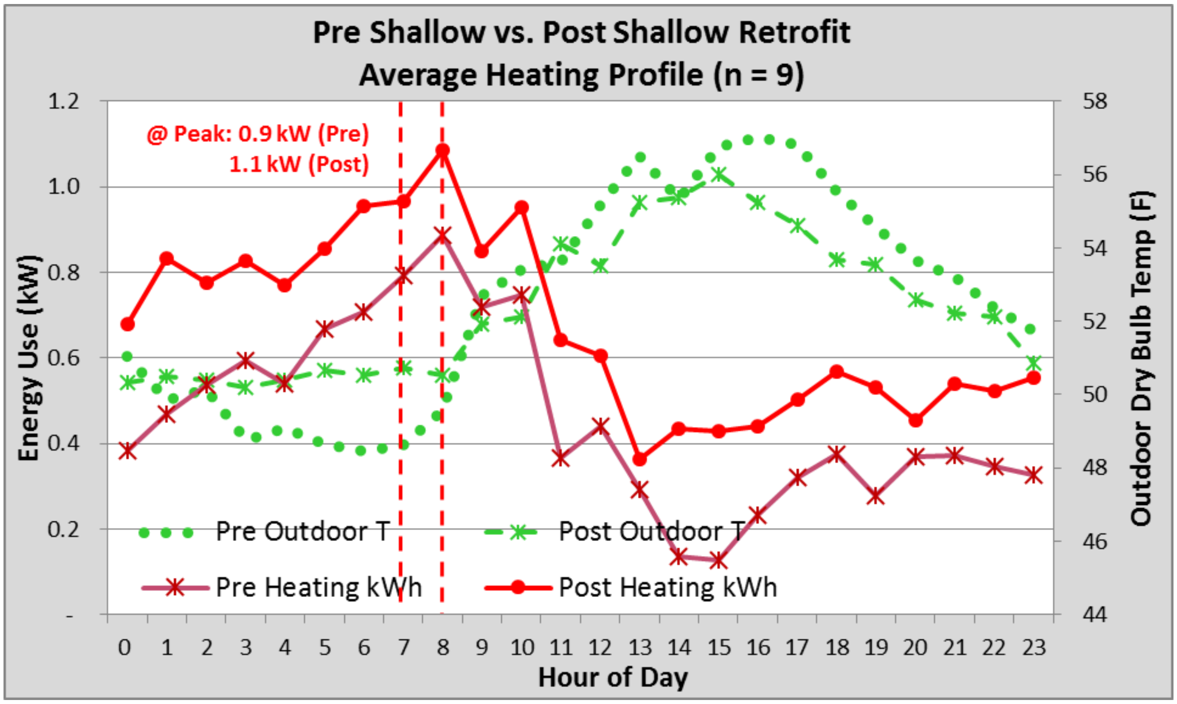

Figure 115. Pre-retrofit (shallow) versus post-retrofit (shallow) average heating profile

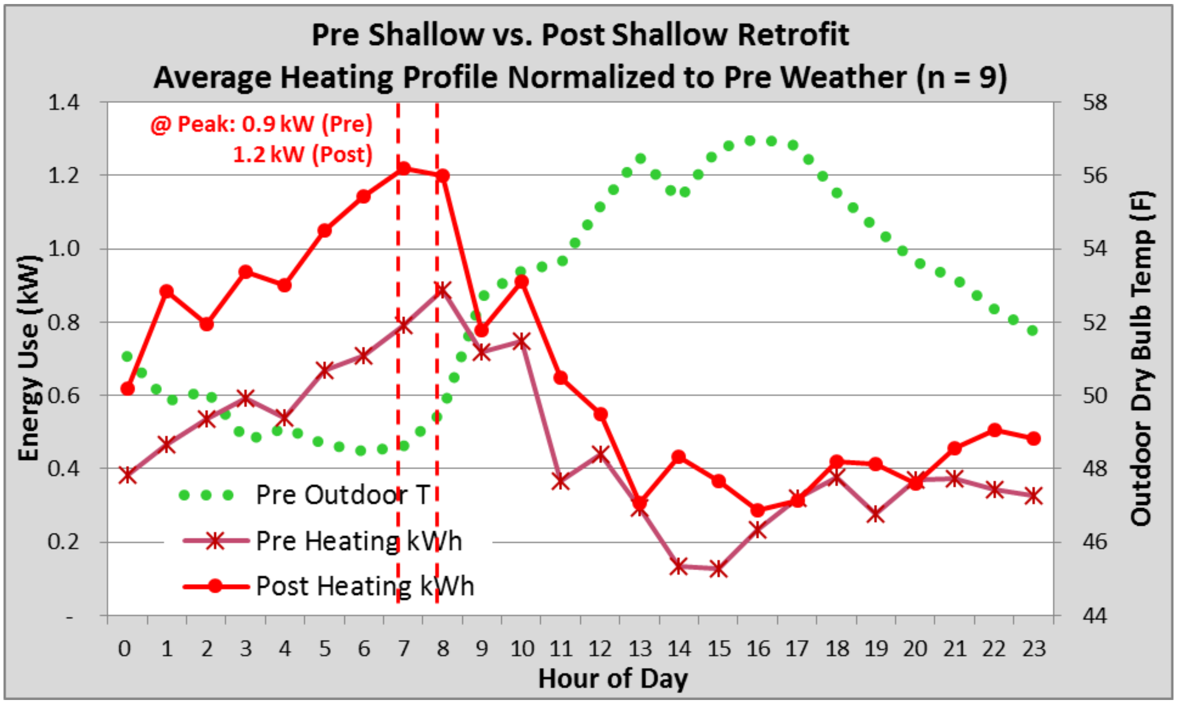

Figure 116. Pre-retrofit (shallow) versus post-retrofit (shallow) average heating profile normalized to pre-retrofit weather

Shallow Heating Plots (cont.)

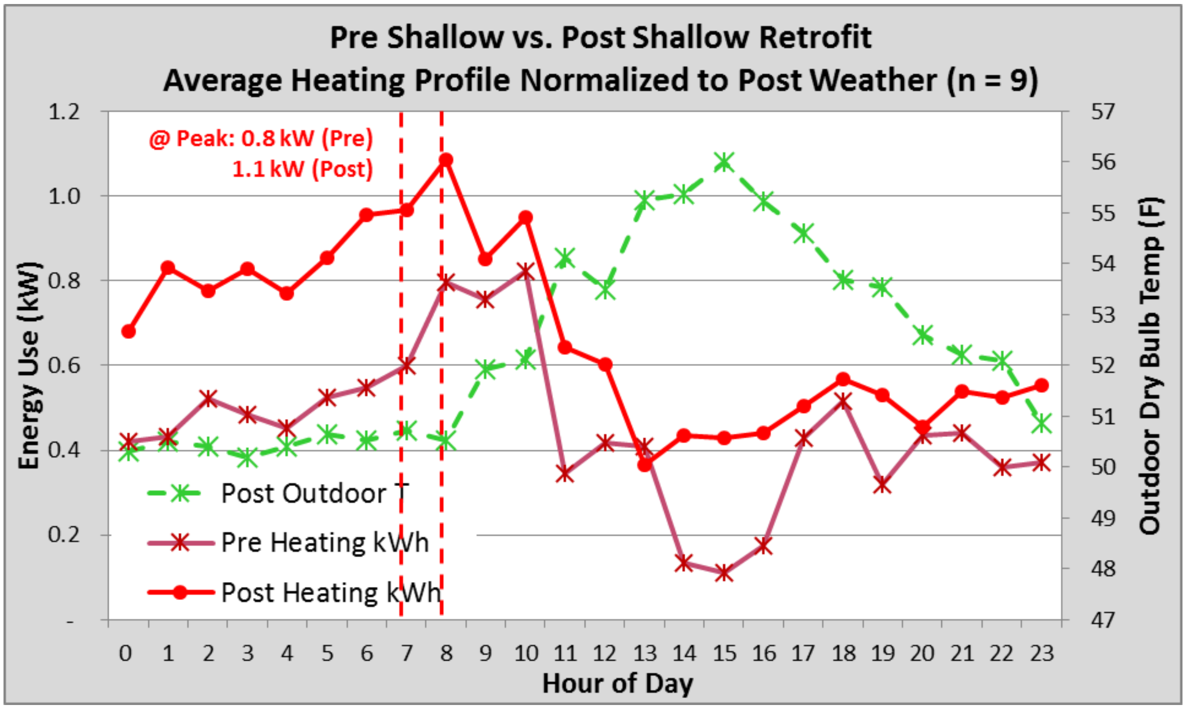

Figure 117. Pre-retrofit (shallow) versus post-retrofit (shallow) average heating profile normalized to post-retrofit weather

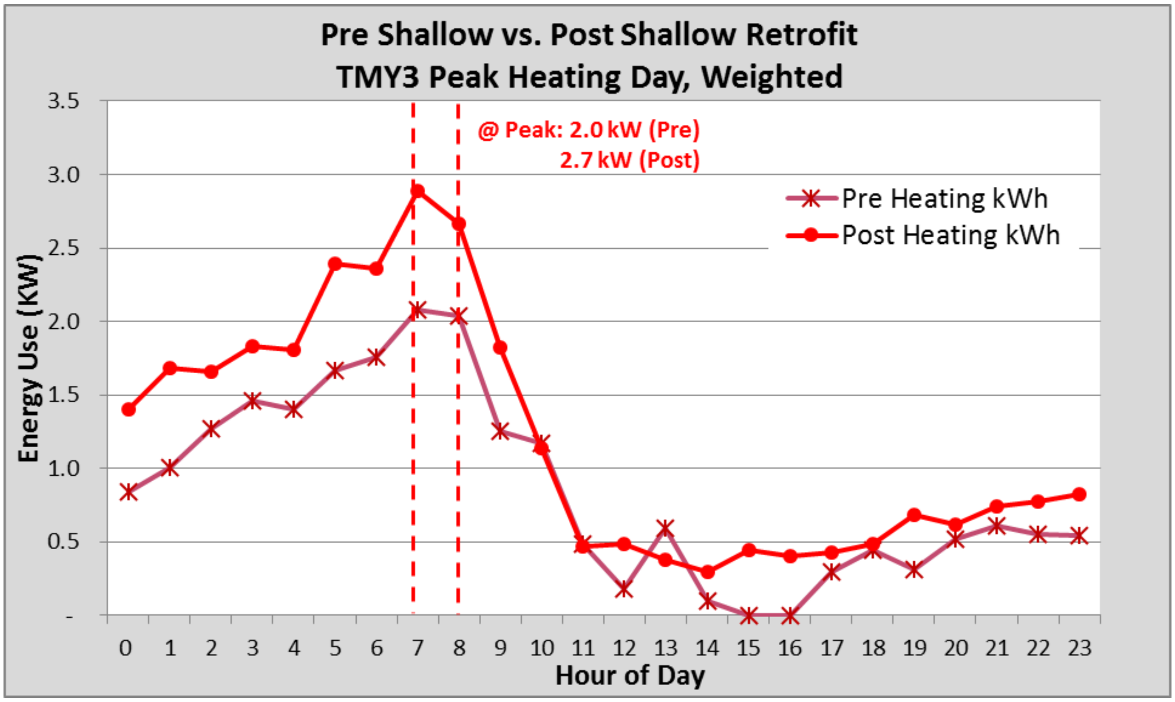

Figure 118. Pre-retrofit (shallow) versus post-retrofit (shallow) TMY3 peak heating day, weighted by FPL service area

Deep Cooling Plots

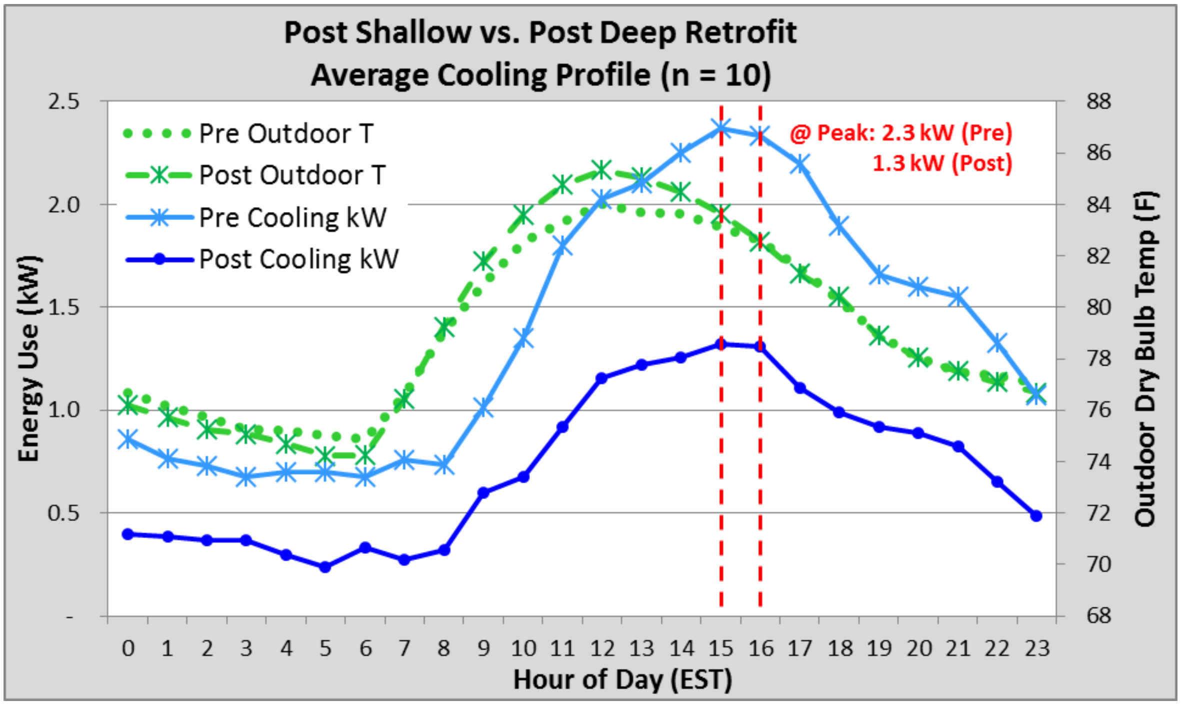

Figure 119. Post-retrofit (shallow) versus post-retrofit (deep) average cooling profile

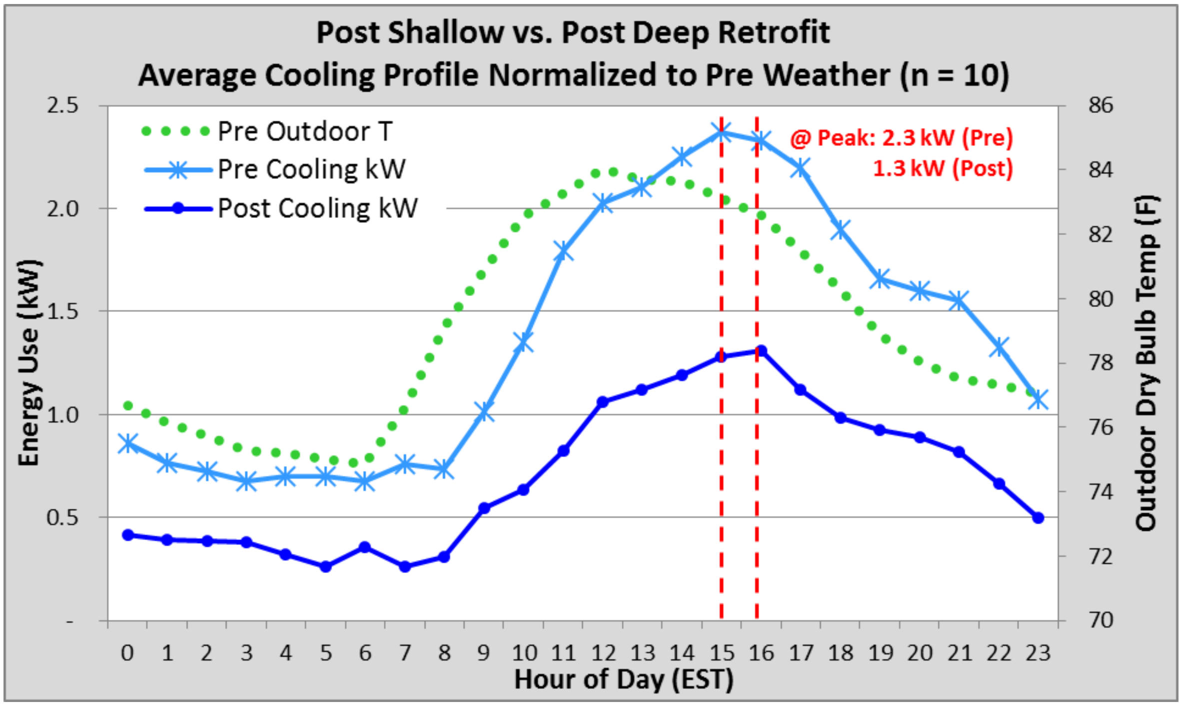

Figure 120. Post-retrofit (shallow) versus post-retrofit (deep) average cooling profile normalized to pre-retrofit weather

Deep Cooling Plots (cont.)

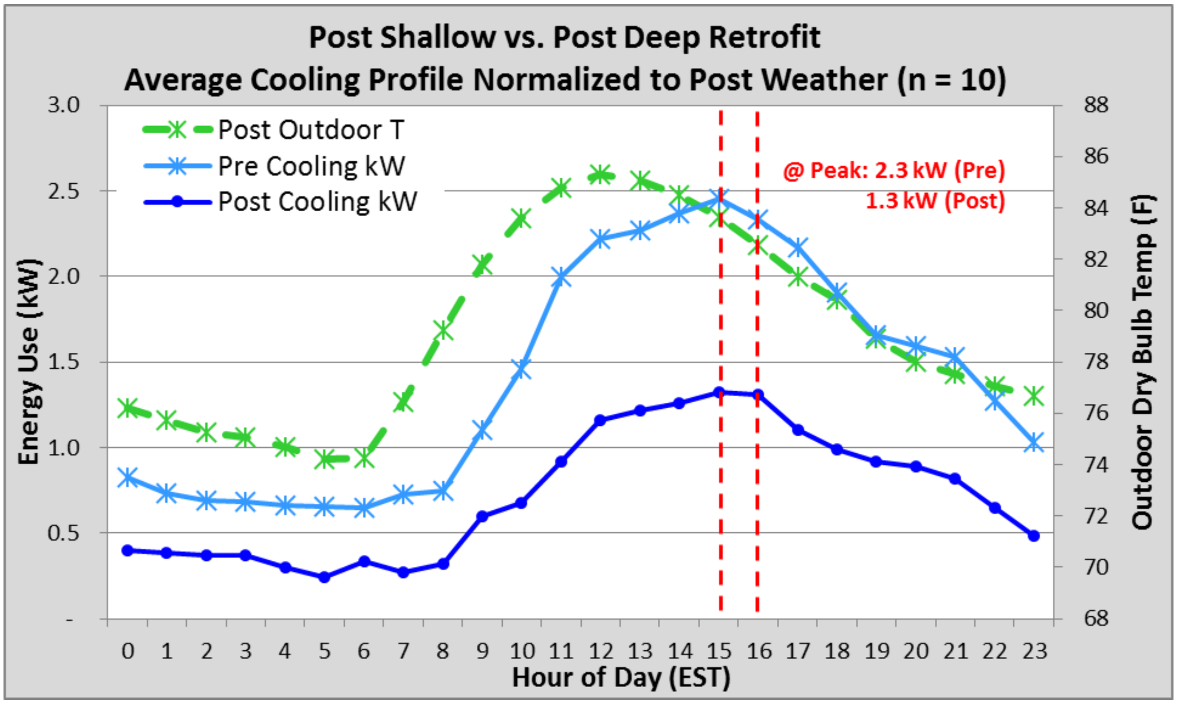

Figure 121. Post-retrofit (shallow) versus post-retrofit (deep) average cooling profile normalized to post-retrofit weather

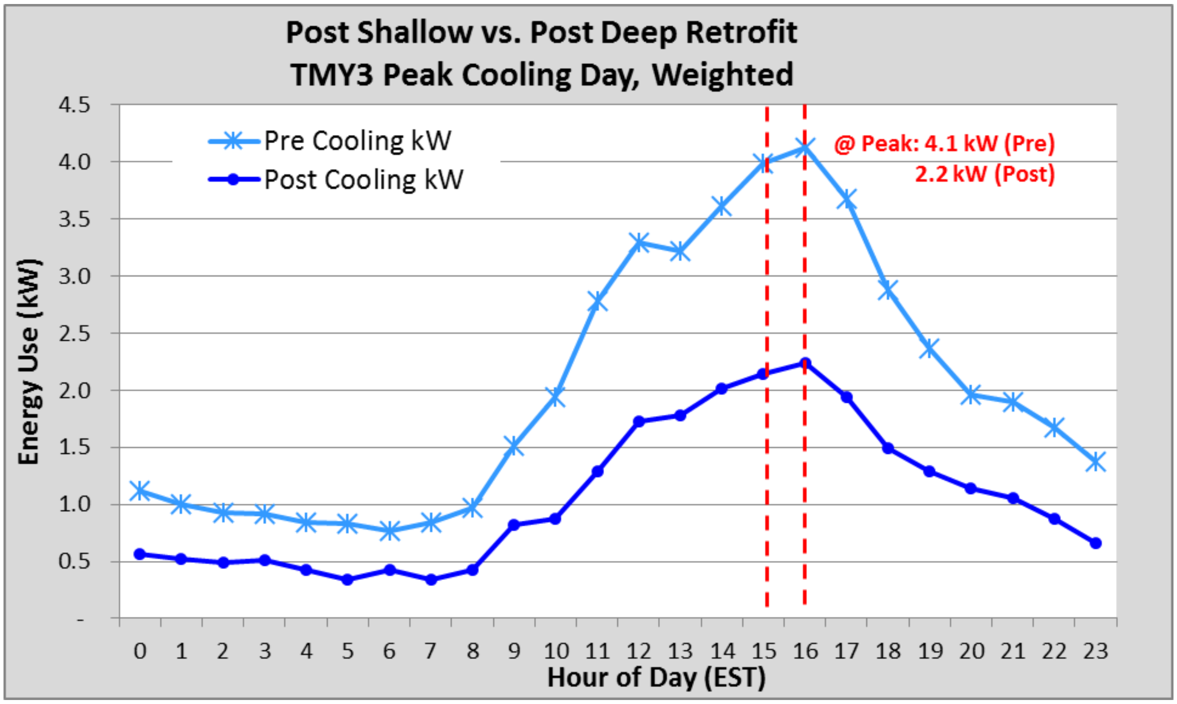

Figure 122. Post-retrofit (shallow) versus post-retrofit (deep) TMY3 peak cooling day, weighted by FPL service area

Deep Cooling Plots (cont..)

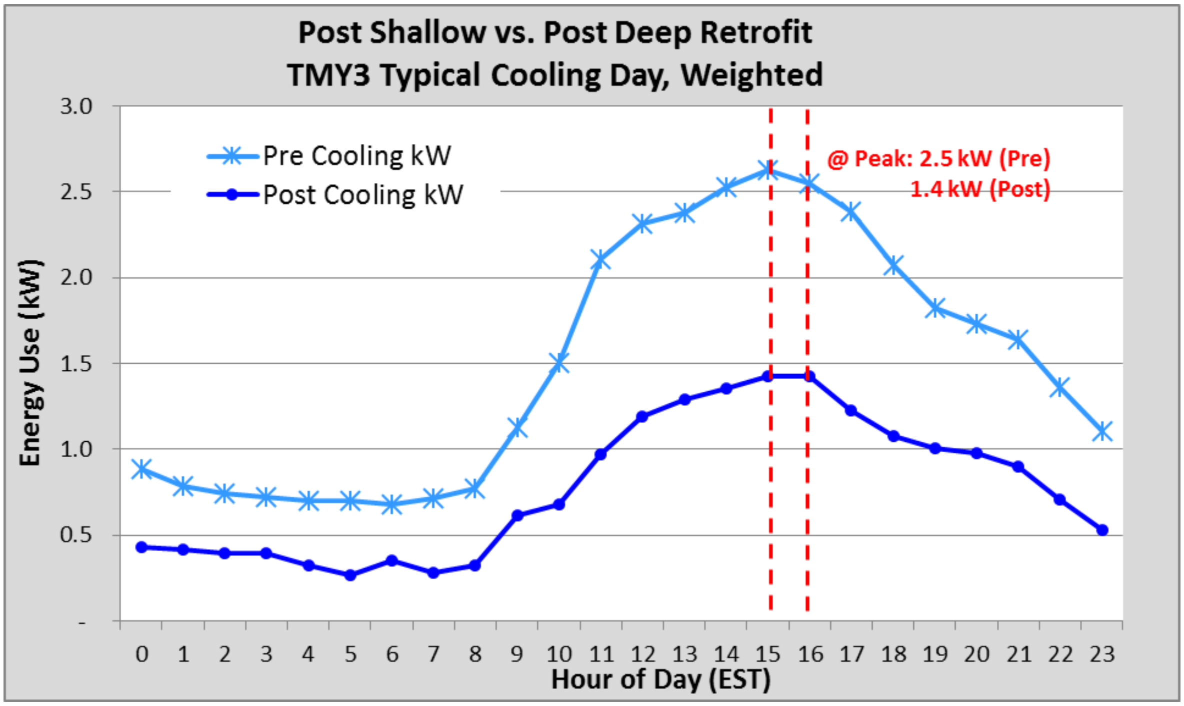

Figure 123. Post-retrofit (shallow) versus post-retrofit (deep) TMY3 typical cooling day, weighted by FPL service area

Deep Heating Plots

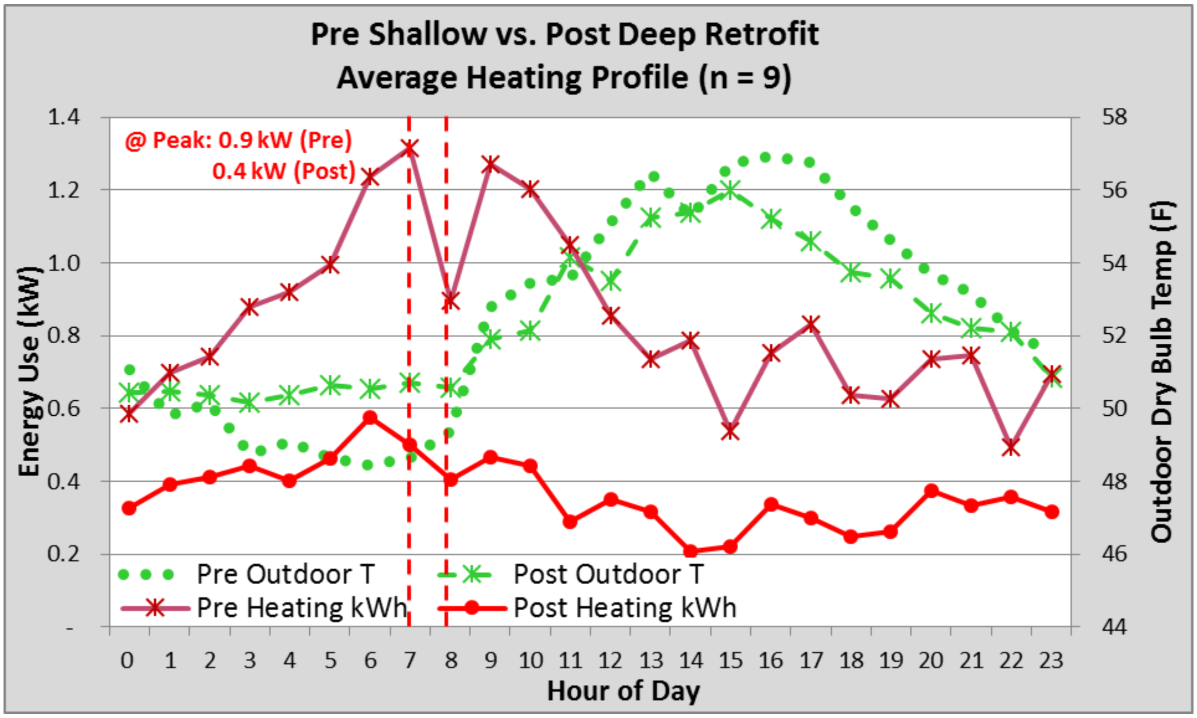

Figure 124. Pre-retrofit (shallow) versus post-retrofit (deep) average heating profile

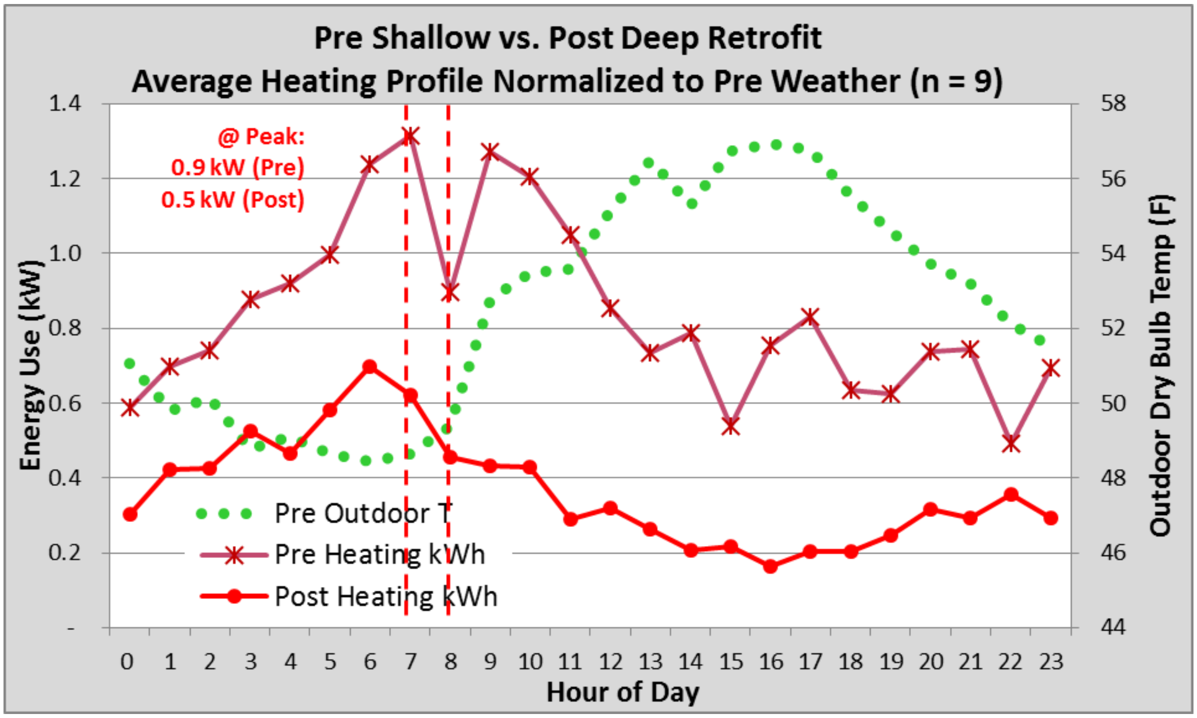

Figure 125. Pre-retrofit (shallow) versus post-retrofit (deep) average heating profile normalized to pre-retrofit weather

Deep Heating Plots (cont.)

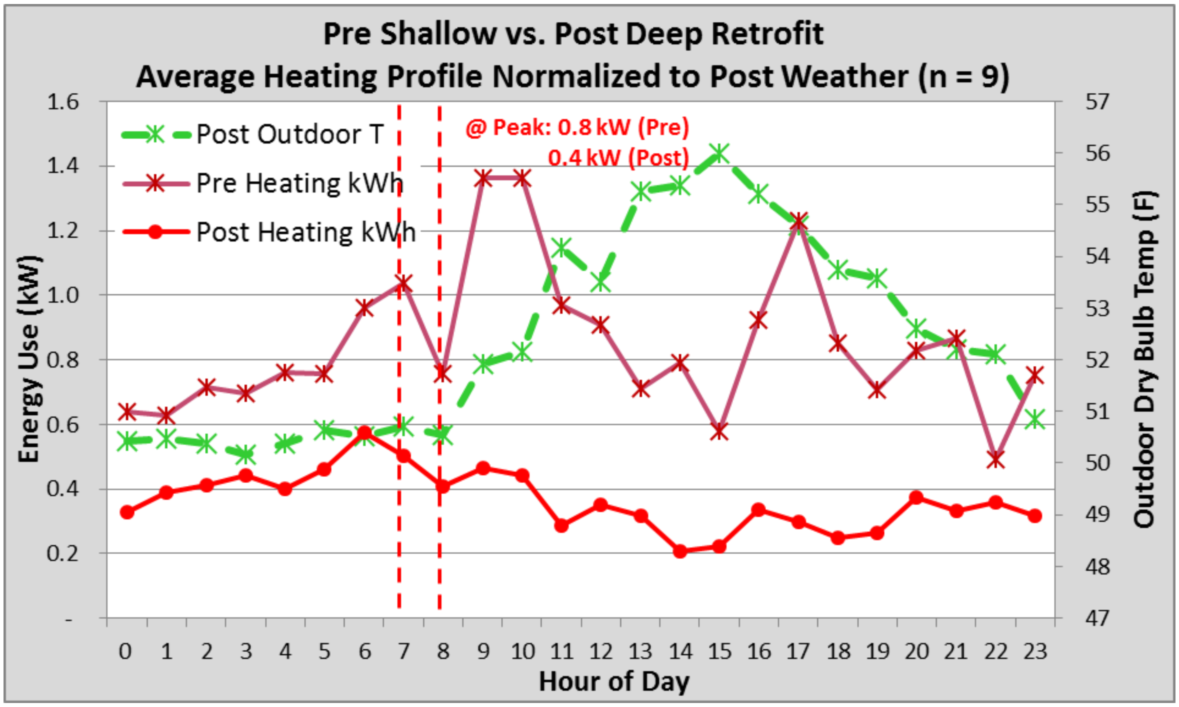

Figure 126. Pre-retrofit (shallow) versus post-retrofit (deep) average heating profile normalized to post-retrofit weather

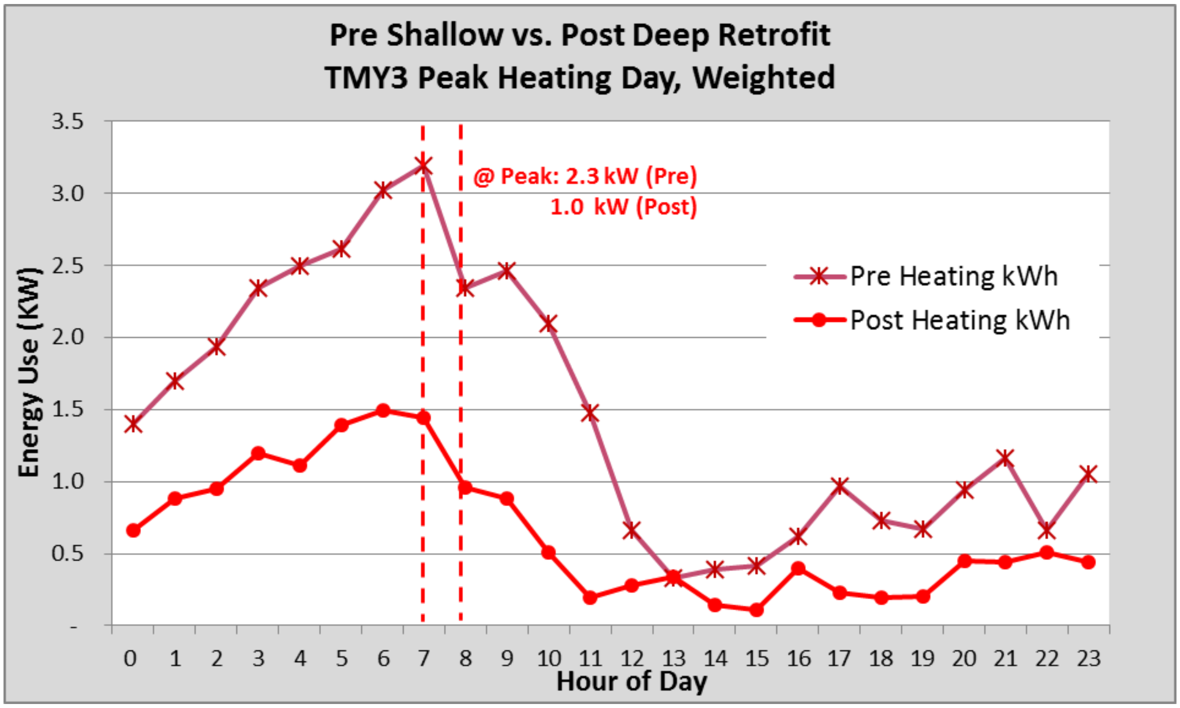

Figure 127. Pre-retrofit (shallow) versus post-retrofit (deep) TMY3 peak heating day, weighted by FPL service area

Appendix E: Deep Retrofit Installations Details

Heating, Ventilating, and Air-Conditioning Measures

System and Contractor Selection

Carrier's Performance Series air-source heat pump was the chosen HVAC product line. This choice was based on system performance, compatibility with the chosen learning thermostat, and price.[18] The installed systems were either a 16 SEER with a 9 heating seasonal performance factor or a 17 SEER with a 9.5 heating seasonal performance factor.

The team chose a local mechanical contractor from Carrier's recommended licensed installers. This company is a large, regional residential and commercial mechanical contractor that has been in business since 1980. The team met with the contractor to discuss project parameters, the company's installation protocols and standards, project completion time frame, and the company's ability to meet the installation standards and performance metrics.

The team initially requested the following installation standards: (1) perform a Manual J and Manual D; (2) replace refrigerant and condensate lines (not reuse); (3) follow proper degassing/dehydration/charging procedures (offering that a researcher would be at each installation to provide guidance); (4) provide a completed ENERGY STAR for Homes, Version 3 (Revision 07) HVAC System Quality Installation Contractor Checklist,[19] and (4) install a Nest second-generation learning thermostat.

The contractor stated that the Manual D should have been conducted when the system was originally installed and is not typically calculated when systems are replaced. The Florida Building Code does not require a Manual D (or equivalent) with system replacements. However, Florida Code does require that all accessible (with a minimum of 30 inches clearance) joints and seams in the air distribution system be inspected and sealed where needed using reinforced mastic or a code approved equivalent. The team subsequently removed the Manual D requirement from the work scope. The contractor agreed to meet the remaining installation requests, in addition to the performance metrics for duct leakage and bedroom pressure balancing.

Internally, system load calculations were conducted with EnergyGauge USA[20] simulation software and system size results were compared to the contractor's recommendations. Sizing compared well for most systems, though there were cases of discrepancies by a ton or more. After internal review of both load calculation sets and more discussion with the mechanical contractor, system size was determined for each site.

The company's large size meant it had the ability to deploy a dedicated crew to the project. This ability was attractive because it was mid-August and systems needed to be installed as quickly as possible to capture the cooling season.

The team provided the HVAC contractor with a work scope for each site to identify unique issues and provide guidance about expectations with each installation. This also helped

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[18] The HVAC system was the only measure homeowners were partially financially responsible for.

[19] www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/Inspection_Checklists.pdf

[20] www.energygauge.com/

streamline the HVAC contactor's efforts on specific tasks, most notably duct sealing. Because the contractor used visual inspection of the air distribution system to gauge its tightness, the team identified each site's air distribution system as "tight," "leaky," or "very leaky" based on our duct leakage test results. This potentially saved contractor time sealing ductwork that was already meeting the performance metrics.

Performance Criteria

Performance tests conducted before the deep retrofit measures were implemented included whole-house airtightness, duct system leakage, and pressure deltas between each bedroom and the main living area. The threshold for duct leakage was ≤6 CFM to outdoors/100 ft^2 of conditioned floor area (Qn,out ≤06). The threshold for bedroom pressure deltas was 6 Pascals (with bedroom door closed and HVAC running). If this threshold was exceeded, passive relief was installed via a jump duct or above-door transfer grille. In some cases additional work addressed performance or comfort. As examples, supply grilles were replaced at Site 40 to optimize flow and throw, and at Site 30, a small bedroom supply duct was replaced with larger-diameter ductwork. The increased volume of supply air into the Site 30 bedroom created a need for pressure relief in additional bedrooms.

Five of the nine homes required subsequent contractor visits to address performance criteria failures (i.e., high duct leakage and missing bedroom air pressure relief). The time needed to schedule, correct, and retest these sites delayed the attic insulation measure in some homes by several weeks.

Nest Thermostat Integration

The Nest second-generation learning thermostat was selected for this project to investigate the technology's impact on energy efficiency. The contractor reportedly had installed a few Nest controllers previously. The Nest thermostat is unique in its ability to "learn" and make adjustments over time based on the user's interaction and behavior. Typical programmable thermostats allow a user-defined program to adjust temperature; however, they cannot change with atypical occupancy patterns unless they are manually overridden. The Nest can do this. For example, it can determine that the home is unoccupied and adjust itself accordingly, which may save energy. See Appendix F for more information about the Nest installation.

Improper Installations

A follow-up call to Site 19 indicated comfort issues. The owner needed to reduce the evening cooling thermostat set point 1°–2°F lower than pre-retrofit settings to achieve comfort. The monitored data clearly revealed interior RH issues. The green line in Figure 128 shows RH increased more than 10% immediately following the HVAC installation (just after 996 on the x-axis); temperature (red line) remained fairly constant.

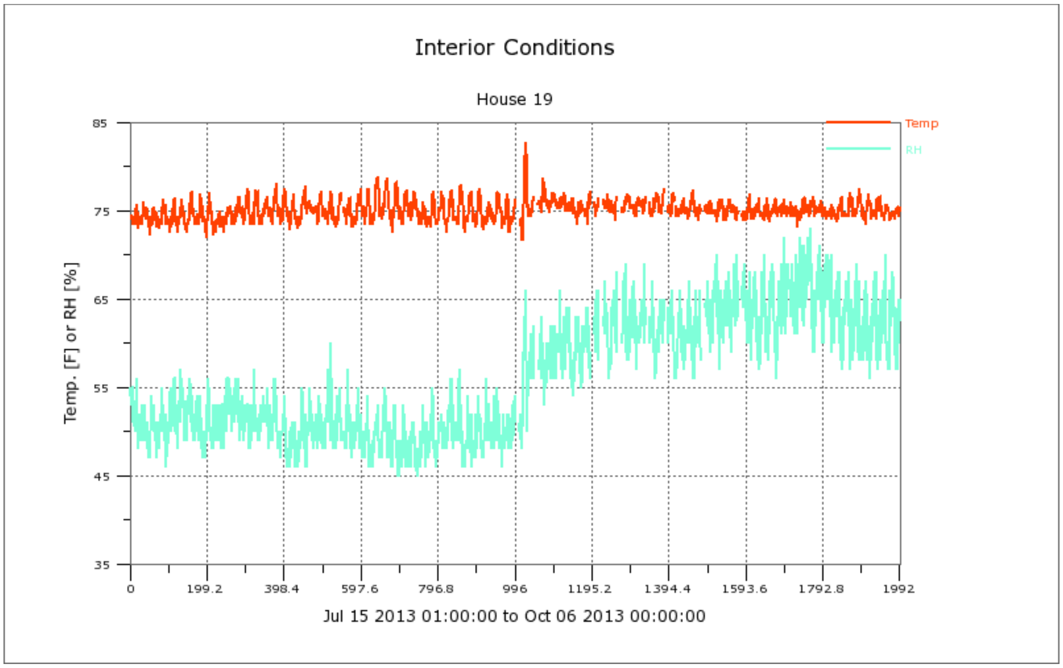

Figure 128. Interior temperature and RH of Site 19 before and after HVAC installation

The initial contractor service call to fix the system yielded no improvement to the RH level. Not until the contractor was provided with the RH readings was a senior technician deployed. The technician found that miswiring of the Nest thermostat caused the first stage of the two-stage compressor to be bypassed so that only the second stage ran. Once rewired, RH returned to acceptable limits and comfort was restored. The lesson learned from the Site 19 issue was that monitored data had to be more heavily scrutinized when HVAC systems were installed. Post-retrofit RH levels for subsequent installations appeared consistent with pre-retrofit levels; however, HVAC runtime was waning as the swing season approached, which may have influenced the comparisons.

During post-retrofit performance testing at Site 40 field staff found that the compressor was not operating while the AHU was running. Even though the homeowner reported being very happy with the new system, he said the system ran “colder” than his previous system and appears to have caused him to increase the thermostat cooling set point 1°–2°F to feel comfortable. The team confirmed that Site 40’s HVAC system was operating exclusively in Stage 2, just as at Site 19.

Figure 129 and Figure 130 from the eMonitor[21] website show the operation runtime and the condenser and AHU end-use consumption at Site 40 spanning 1 day. Figure 131 and Figure 132 show these same plots for Site 8 where the same system was wired properly. The blue and red circles in Figure 131 highlight Stage-1 and Stage-2 condenser operations, respectively. Figure 132 shows how the AHU operation aligns with the condenser stage during normal operation.

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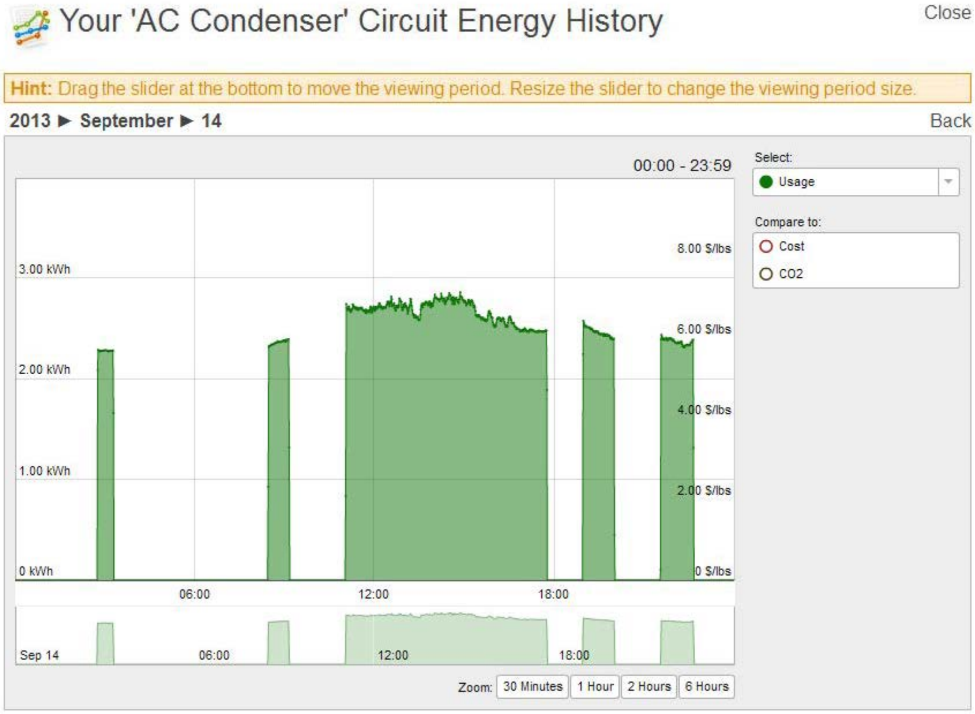
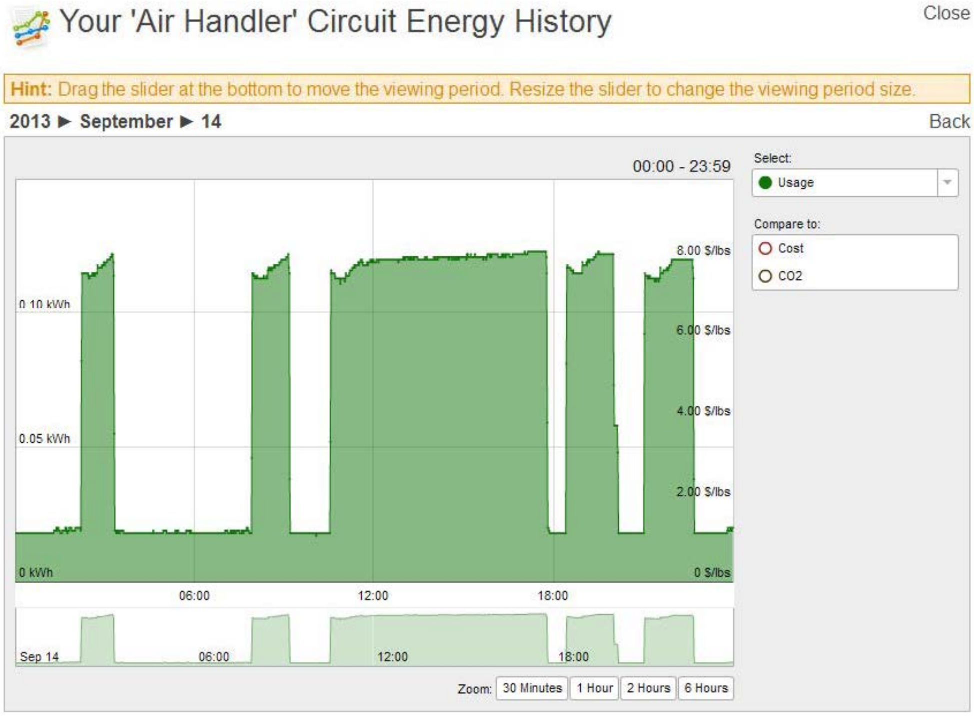
[21] www.emonitor.us/


Your 'AC Condenser' Circuit Energy History

Hint: Drag the slider at the bottom to move the viewing period. Resize the slider to change the viewing period size.

2013 ▶ September ▶ 14

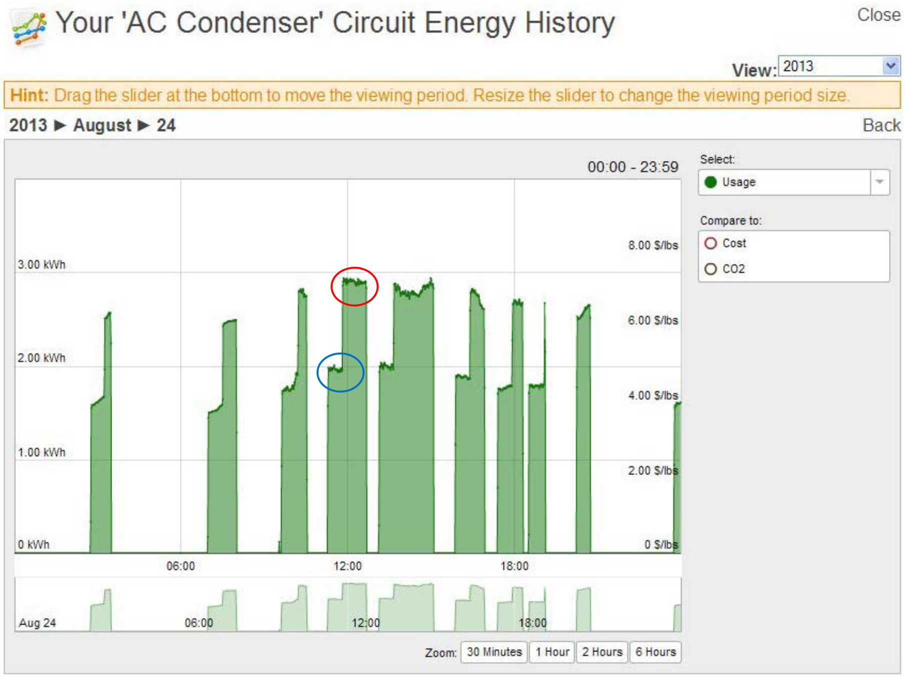
Figure 129. Site 40 condenser Stage 2 only operation


Your 'Air Handler' Circuit Energy History

Hint: Drag the slider at the bottom to move the viewing period. Resize the slider to change the viewing period size.

2013 ▶ September ▶ 14

Figure 130. Site 40 AHU operation reflecting Stage 2 only condition



Your 'AC Condenser' Circuit Energy History

View: 2013

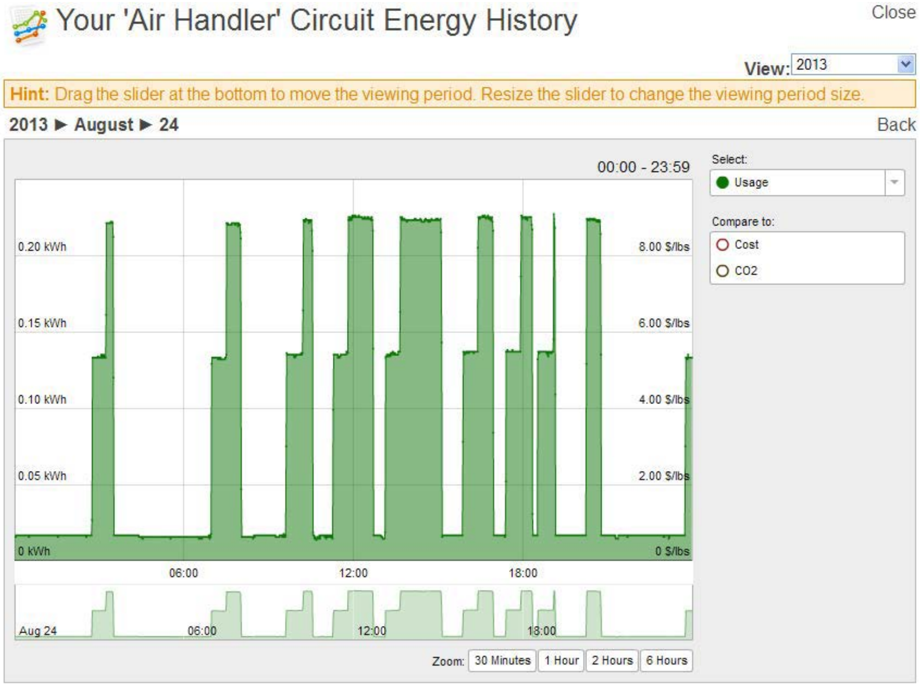
Hint: Drag the slider at the bottom to move the viewing period. Resize the slider to change the viewing period size.

2013 ▶ August ▶ 24

Select: ● Usage

Compare to: ○ Cost ○ CO2

Figure 131. Site 8 condenser Stage 1 and Stage 2 normal operation



Your 'Air Handler' Circuit Energy History

View: 2013

Hint: Drag the slider at the bottom to move the viewing period. Resize the slider to change the viewing period size.

2013 ▶ August ▶ 24

Select: ● Usage

Compare to: ○ Cost ○ CO2

Figure 132. Site 8 AHU normal operation alignment with Stage 1 and Stage 2 conditions

Review of monitored data and field testing revealed that the systems at three other sites were also operating at a single stage. One was running in Stage 2 only; two others were operating exclusively in Stage 1. Homeowners with the Stage 2 only operation had comfort issues;

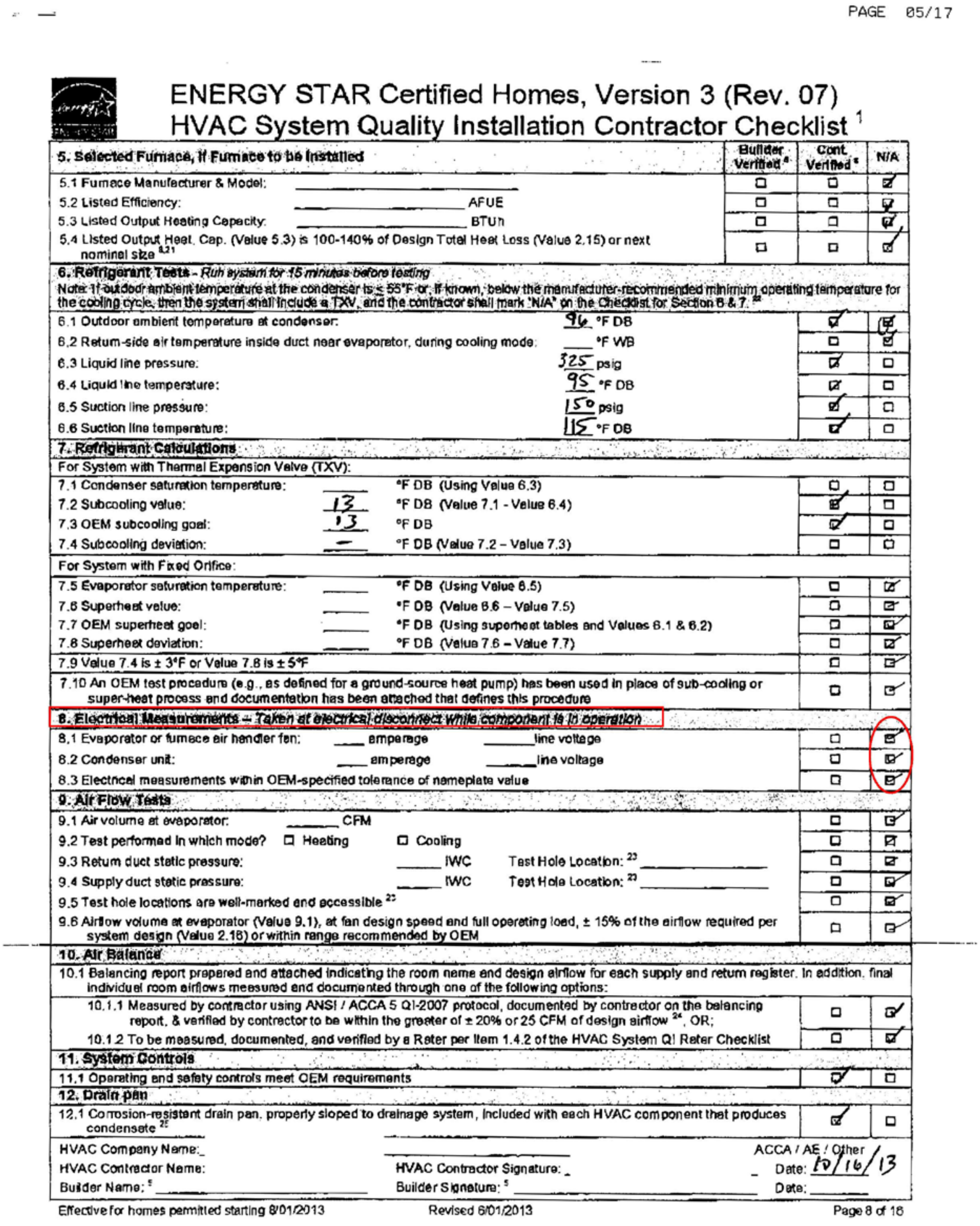
homeowners with the Stage 1 only homes had no comfort complaints. Five of the nine installations were incorrectly wired and caused the two stage compressors to operate in a single stage. This high failure rate, which may have gone undetected outside of this study, is concerning.

The initial system refrigerant charging at the Stage 1 only homes was not performed while the systems were running at high capacity. Therefore, the team directed the mechanical contractor to confirm proper refrigerant charge once the systems were operating properly at these two sites.

Evaluating Installation Issues

The mechanical contractor's work scope for each site required: (1) installation of the Nest learning thermostat, and (2) completion of the ENERGY STAR for Homes Version 3 (Revision 7) HVAC System Quality Installation Contractor Checklist. The contractor was a Carrier factory-authorized dealer familiar the two-stage compressors being installed and reported it had installed Nest thermostats. Nest touts ease of installation claiming "three out of four customers install Nest in 30 minutes or less" but also provides a list of Nest-certified professional installers on its website.

The first HVAC System Quality Installation Contractor Checklist returned lacked (among other items) electrical measurement data. Figure 133 shows that Section 8 was marked "N/A." Electrical measurements were one way the team confirmed the stage at which the compressor was operating and the operation alignment of the AHU.



PAGE 05/17

ENERGY STAR Certified Homes, Version 3 (Rev. 07)
HVAC System Quality Installation Contractor Checklist [1]

5. Selected Furnace, if Furnace to be Installed	Builder Verified [4]	Cont. Verified [5]	N/A
5.1 Furnace Manufacturer & Model: ________	☐	☐	☑
5.2 Listed Efficiency: ________ AFUE	☐	☐	☑
5.3 Listed Output Heating Capacity: ________ BTUh	☐	☐	☑
5.4 Listed Output Heat. Cap. (Value 5.3) is 100-140% of Design Total Heat Loss (Value 2.15) or next nominal size [8,21]	☐	☐	☑
6. Refrigerant Tests - *Run system for 15 minutes before testing* Note: If outdoor ambient temperature at the condenser is ≤ 55°F or, if known, below the manufacturer-recommended minimum operating temperature for the cooling cycle, then the system shall include a TXV, and the contractor shall mark 'N/A' on the Checklist for Section 6 & 7. [22]			
6.1 Outdoor ambient temperature at condenser: 96 °F DB		☑	☑
6.2 Return-side air temperature inside duct near evaporator, during cooling mode: ____ °F WB		☐	☑
6.3 Liquid line pressure: 325 psig		☑	☐
6.4 Liquid line temperature: 95 °F DB		☑	☐
6.5 Suction line pressure: 150 psig		☑	☐
6.6 Suction line temperature: 115 °F DB		☑	☐
7. Refrigerant Calculations			
For System with Thermal Expansion Valve (TXV):			
7.1 Condenser saturation temperature: ____ °F DB (Using Value 6.3)		☐	☐
7.2 Subcooling value: 13 °F DB (Value 7.1 - Value 6.4)		☑	☐
7.3 OEM subcooling goal: 13 °F DB		☑	☐
7.4 Subcooling deviation: – °F DB (Value 7.2 – Value 7.3)		☐	☐
For System with Fixed Orifice:			
7.5 Evaporator saturation temperature: ____ °F DB (Using Value 6.5)		☐	☑
7.6 Superheat value: ____ °F DB (Value 6.6 – Value 7.5)		☐	☑
7.7 OEM superheat goal: ____ °F DB (Using superheat tables and Values 6.1 & 6.2)		☐	☑
7.8 Superheat deviation: ____ °F DB (Value 7.6 – Value 7.7)		☐	☑
7.9 Value 7.4 is ± 3°F or Value 7.8 is ± 5°F		☐	☑
7.10 An OEM test procedure (e.g., as defined for a ground-source heat pump) has been used in place of sub-cooling or super-heat process and documentation has been attached that defines this procedure		☐	☑
8. Electrical Measurements – *Taken at electrical disconnect while component is in operation*			
8.1 Evaporator or furnace air handler fan: ____ amperage ____ line voltage		☐	☑
8.2 Condenser unit: ____ amperage ____ line voltage		☐	☑
8.3 Electrical measurements within OEM-specified tolerance of nameplate value		☐	☑
9. Air Flow Tests			
9.1 Air volume at evaporator: ____ CFM		☐	☑
9.2 Test performed in which mode? ☐ Heating ☐ Cooling		☐	☑
9.3 Return duct static pressure: ____ IWC Test Hole Location: [23] ____		☐	☑
9.4 Supply duct static pressure: ____ IWC Test Hole Location: [23] ____		☐	☑
9.5 Test hole locations are well-marked and accessible [23]		☐	☑
9.6 Airflow volume at evaporator (Value 9.1), at fan design speed and full operating load, ± 15% of the airflow required per system design (Value 2.16) or within range recommended by OEM		☐	☑
10. Air Balance			
10.1 Balancing report prepared and attached indicating the room name and design airflow for each supply and return register. In addition, final individual room airflows measured and documented through one of the following options:			
10.1.1 Measured by contractor using ANSI / ACCA 5 QI-2007 protocol, documented by contractor on the balancing report, & verified by contractor to be within the greater of ± 20% or 25 CFM of design airflow [24], OR;		☐	☑
10.1.2 To be measured, documented, and verified by a Rater per Item 1.4.2 of the HVAC System QI Rater Checklist		☐	☑
11. System Controls			
11.1 Operating and safety controls meet OEM requirements		☑	☐
12. Drain pan			
12.1 Corrosion-resistant drain pan, properly sloped to drainage system, included with each HVAC component that produces condensate [25]		☑	☐

HVAC Company Name: ________ ACCA / AE / Other

HVAC Contractor Name: HVAC Contractor Signature: ________ Date: 10/16/13

Builder Name: [5] ________ Builder Signature: [5] ________ Date: ________

Effective for homes permitted starting 8/01/2013 Revised 6/01/2013 Page 8 of 16

Figure 133. Second page of a completed ENERGY STAR for Homes (V3 Rev. 7) HVAC System Quality Installation Contractor Checklist

The installed thermostat does not have a test mode to test stage operation and dehumidify configurations, unlike some programmable thermostats. A test mode may have helped the contractor install the Nest. The contractor reported insufficient system setup and wiring instructions provided by the installation guild; however, the contractor took responsibility for the failed system installations. Fully functional HVAC system operation was unverified by the installation team. Installation issues led to heating operation concerns, because the focus had thus far been on system cooling. In response, the contractor revisited all sites to confirm proper overall HVAC operation.

On a side note, some homeowners have adapted well to the new thermostats, optimizing their comfort and integrating features into their lifestyle.

Insulation

Contractor and Material Selections

FPL has many residential rebate and incentive programs, including a Residential Ceiling Insulation program,[22] which offers a rebate for attic insulation based on the thermal value. FPL has a list of participating independent contractors who comply with FPL's program standards, although FPL did not make contractor recommendations.

The team sought a contractor who had experience and knowledge installing multiple insulation types; e.g., blown-in, batt, or foam products; and one large enough to complete the installations at all sites quickly. A contractor from FPL's list of participating contractors was chosen based on experience, installation criteria, and pricing. The team followed FPL insulation program installation standards during the development of contractor work scopes for each site; R-38 was the target at the ceiling deck and knee wall insulation upgrades as needed.

Site Criteria and Implementation

Eight homes were selected for ceiling insulation upgrades; the maximum average thermal value was R-19. Thermal values at the remaining two sites were R-30 and R-38. Savings generated for an R-30 to R-38 ceiling insulation upgrade is not cost-justified in Climate Zone 2. A third site had R-30 originally installed, but about 25% was compressed to the top of the bottom chords. With the contractor onsite to upgrade the compressed areas to R-38, the cost to have the entire ceiling upgraded to R-38 was justified.

The insulation retrofit generally consisted of blown-in fiberglass insulation at the ceiling deck and fiberglass batt insulation at knee walls where appropriate. The team specified all attic access panels to conditioned space be fully gasketed and insulated to R-38 and additional attic rulers be installed to simplify the verification of insulation depth (Figure 134). The ceiling insulation retrofits for Sites 30 and 51 were relatively complex and required more planning and attention than the other, straightforward installations. Each is discussed below.

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[22] www.fpl.com//residential/energy_saving/programs/index.shtml?cid

Figure 134. Attic rulers

Site 30

Upgrading the ceiling insulation at Site 30, the oldest home in the deep sample (built in 1976), posed potential moisture issues. Most of the original duct system was exposed and sections rest directly on the bottom chords of the roof truss. The duct system is primarily rigid, round metal, with R-2 or R-3 insulation on the main trunk line and an aged vapor barrier sealed with a tar-like product and duct tape (Figure 135). The team was concerned that adding R-38 blown-in insulation would partially or completely bury the ductwork (Figure 136)—and perhaps alter the dew point at the duct surface—to create condensation.

Figure 135. Site 30 ductwork

Figure 136. Buried ductwork

Removing the insulation to see under the ductwork exposed water marks, most likely from duct condensation drips (see Figure 137). These pictures were taken during a site visit in December, a time of generally cooler weather when AC is less frequently needed. No moisture was found on ducts or drywall, and all the insulation moved from under the ductwork was dry.

Figure 137. Historical moisture issues in attic under ductwork

Living room ceiling paint was peeling near the location of concern (Figure 138). Although the homeowner did not have specific interior moisture concerns, the location of ceiling paint peeling was reportedly in this condition ever since the home was purchased.

Figure 138. Ceiling damage close to room's supply duct

Figure 139 shows a furring strip (blue arrow) running perpendicularly under the living room ductwork to the left, and perpendicularly under (and in contact with) the bottom roof truss chord (green arrow) to the right. Water staining was evident on the ceiling drywall where the living room duct, roof, and ceiling members converged (red arrows). The moisture source was unclear, because the attic was dry at the time.

Figure 139. Past water stains observed in ceiling drywall directly above living room

A number of retrofit options were discussed based on prior research (Chasar and Withers 2013; Shapiro, Zoeller, and Mantha 2013). The team considered encapsulating the ductwork in closed-cell foam and then burying most of the duct system with blown-in insulation. Ultimately R-38 blown-in fiberglass was installed— the same approach used at the other sites.

To monitor this retrofit, the team applied several moisture sensor strips to duct sections where the drywall below showed signs of wetting (see Figure 140). The sensor strips register moisture levels. Moisture sensor strip remote monitoring is a project consideration, but currently strips are read on site. Depending on the ductwork moisture results at Site 30, the home may be a candidate for future research planned on duct encapsulation.

Figure 140. Moisture sensor strip adhered to bottom of ductwork

Site 51

Site 51 is a two-story home and the only deep study home with a crawl space. A partially finished, walk-in closet off a second-floor bedroom located directly over the attached garage was being used as the master bedroom closet. Issues of concern were:

- The closet was outside the thermal boundary of the home and substantially connected to the garage (Figure 141).
- The closet supply vent (with an open damper) was directly connected to the master bedroom supply vent (Figure 142).
- The closet had a working solar roof fan drawing air out when operational.
- A non-weather-stripped interior door separated the closet from the bedroom.

Figure 141. Second-floor closet

Figure 142. Second-floor closet with shared supply ducting and open damper

The following were concerns in other areas of the home:

- The second-floor bathroom's knee wall behind the tub had no interior barrier.
- Ceiling insulation was missing from part of the attic floor.
- There was no blocking between floors at interstitial space boundary (not all accessible).
- The knee walls and ceiling had a mixed vapor retarder (i.e., kraft paper) facing.
- The crawl space had:
    - No insulation
    - No ground cover
    - Unsealed floor transition areas.

Even though major modifications to study homes are not within the scope of the PDR project, several issues had to be addressed before the ceiling insulation could be upgraded. The bedroom closet described above was a top concern. After considering various approaches to modify the closet, the owners decided to stop using the closet as internal space. This decision narrowed the resolution to isolating the closet from the house. This included: (1) fully gasketing the closet door, (2) aligning the thermal barrier adjacent to the closet, and (3) sealing off the closet supply vent.

The last item to be addressed was to install an air barrier on the knee wall behind the second-floor bathroom tub. The tub wall cavity's fiberglass insulation was reinstalled and an air barrier was mechanically fastened and sealed with foam as shown in Figure 143 to Figure 145.

Figure 143. Missing air barrier behind tub

Figure 144. Insulation replaced

Figure 145. Air barrier installed

The attic insulation was found in various configurations—some of the batt insulation kraft paper was facing inward; some outward (Figure 146 a, b, and c). The insulation retrofit included the vapor retarder uniformly facing the interior.

Figure 146. (a) Attic knee wall exposed kraft (top left), (b) knee wall with cardboard covering exposed insulation (top right), and (c) batt insulation with kraft paper exposed (bottom)

The crawl space at Site 51 was dry, showed no visible signs of moisture issues, was passively vented, and was moderately sloped. The home had three transition points (stair steps) to maintain level flooring. Testing revealed these transition areas were not well sealed and represented a 2-ft^2 hole in the floor that the insulation contract fully sealed with foam (Figure 147).

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Figure 147. Crawl space floor transition areas unsealed (left) and sealed (right)

Heat Pump Water Heaters

Capacity

The 80-gal capacity Voltex HPWH was installed in all deep home sites that had four or more occupants to help support the HPWH running the heat pump for most or all the hot water needs and minimize the need for electric heat while running in the hybrid mode. The exception to this was Site 37, which had six occupants: the 50-gal General Electric GeoSpring hybrid water heater.

The 60-gal capacity Voltex HPWH was to be installed in all deep home sites that had three or fewer occupants. The exception to this was Site 39, which had a Rheem Model HP50 HPWH installed before the site participated in the PDR study.

Noise and Location

Work undertaken in FSEC's Hot Water System Laboratory helped determine appropriate HPWH system selection based on retrofit location and cost. It was decided that the A.O. Smith Voltex hybrid electric heat pump 80- and 60-gal units would be installed in the eight deep homes with hot water systems in the garage. The 50-gal capacity General Electric GeoSpring hybrid water heater was selected for the single deep interior HPWH retrofit at Site 37 due to its cost and reduced noise potential.

Correct placement is still critical when installing an HPWH in an exterior location (e.g., garage) to minimize potential noise issues. At Site 19, part of the HPWH's plumbing was mechanically fastened to the garage wall, which is directly adjacent to the master bedroom. During HPWH operation, noise vibration was transferred to the master bedroom. Also, the HPWH's outlet fan was directed at the garage/master bedroom wall. During HPHW operation, the homeowners noticed noise in the master bedroom. Modifications were done post-retrofit to minimize the noise and discomfort caused by the HPWH by (1) installing sound attenuation material on the garage wall and between accessible mechanical connections, and (2) installing an output duct kit to cover the fan outlet and redirect air away from the garage/master bedroom wall.

Figure 148 shows initial installation of the HPWH of a mechanical plumbing connection and outlet HPWH fan and the associated sound attenuation board and duct kit retrofit installation.

Figure 148. Site 19 HPWH initial installation (left) and noise attenuation retrofit (right)

Similar to Site 19, Site 40 had a garage wall that was adjacent to the master bedroom. However, the HPWH install at Site 40 used a CMU garage wall (not adjacent to any home wall) for the mechanical plumbing connections. The HPWH's outlet air was directed away from the shared garage/master bedroom wall. In this case, the homeowners at Site 40 reported no noise issues during HPWH operation.

Figure 149 shows the HPWH installed in a corner of the garage with the shared garage/master bedroom wall on the left and the CMU wall to the right.

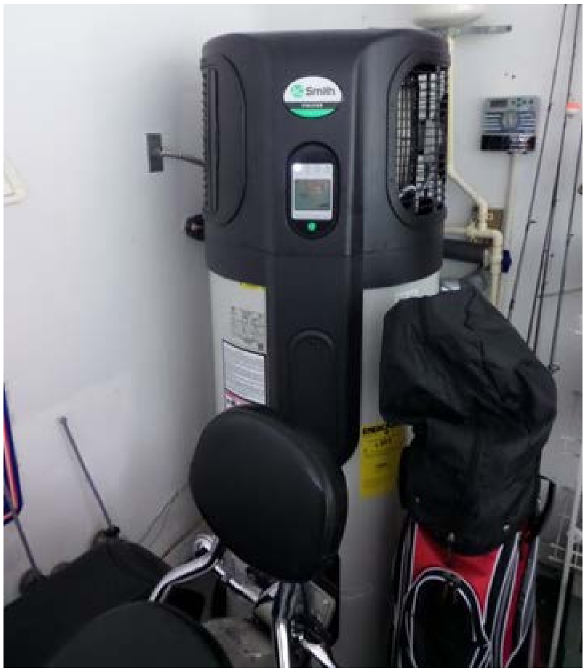

Figure 149. Site 40 HPWH

The post-HPWH installation follow-up site visits revealed that many of the HPWH retrofits did not have the minimal clearances specified by the manufacturer. For example, on page 6 of the Service Handbook for A.O. Smith HPWH models PHPT-60 and PHPT-80 (A.O. Smith 2011) it states: *"For optimal efficiency, the following minimum clearances should be maintained: 3 feet on the air inlet side, 6 feet on the air outlet side and 2 feet front and back."*

At times, meeting the manufacturers' minimal clearances for retrofit HPHW system installation proved difficult due to plumbing and hot water system locations and obstructions such as shelving and workbenches, as shown in Figure 150.

Figure 150. HPWH retrofit existing conditions

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