FLORIDA SOLAR ENERGY CENTER®
Creating Energy Independence

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

FSEC-CR-1991-14

Phase I Interim Report
December 4, 2014

Submitted to:

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Work Product Completed Under FPL PO# 2000083685

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Definitions

AC	Air conditioning
AHU	Air handling unit
APS	Advanced power strip
CDD	Cooling degree days
CFL	Compact fluorescent lamp
CMU	Concrete masonry unit
COP	Coefficient of performance
DOE	U.S. Department of Energy
FPL	Florida Power & Light Company
FSEC	Florida Solar Energy Center
HDD	Heating degree days
HP	Heat pump
HPWH	Heat pump water heater
HSPF	Heating seasonal performance factor
HVAC	Heating, ventilation, 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

Acknowledgements

This report describes collaborative research between Florida Power & Light and the U.S. Department of Energy (DOE), Office of Energy Efficient and Renewable Energy, Building America Program, Subcontract Task Order KNDJ-0-40339-04. However, this support does not constitute DOE endorsement of the views expressed herein.

A project such as this one includes many individuals and organizations to make possible meaningful research results. First to thank are the sixty patient homeowners in the project. Also, appreciation to our following collogues who assisted with the audit and data acquisition portion of the project: David Hoak, Jeremy Nelson, David Beal, and Carlos Colon. Special thanks are due to Danielle Daniel and Wanda Dutton for composition.

The following individuals and companies assisted with the retrofit process: Emergency Plumbing, JT Insulation, Able Air Inc., E3 Building Sciences, Lighting Science Group, Fi Foil, Keith Ledford with the Carrier Corporation, Jack Lawrence with G and J Pool Remodeling and Jeff Farlow and Rob Dimare with Pentair Aquatic Systems. For matching homeowner appliance needs: Korey Frericks with Best Buy. Participation with procuring the ENERGY STAR® clothes dryers for the project: Chris Badger (VEIC); Chris Wold (SEDI), My Ton (CLASP), Chris Calwell and Dave Denkenberger (ECOVA). At NEST Labs for assistance with learning thermostat technology assessment: Brian Farhi, Scott McGaraghan and Thomas Hand.

Special thanks to Craig Muccio with Florida Power & Light Company for overall support and assistance with research direction for the project.

Authors also thank Eric Martin, project director of BA-PIRC, for his direction and support.

Executive Summary

The U.S. Department of Energy (DOE) Building America program, in collaboration with Florida Power & Light (FPL), is conducting 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 approaching the Building America program goals of reducing whole-house energy use by 40%.

Under the Phased Deep Retrofit (PDR) project, we have installed phased, energy-efficiency retrofits 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, located in Central and South Florida were built between 1942 and 2006, average 1,777 square feet in conditioned area, and have an average occupancy of 2.6 persons. Data are collected on total house power 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, targeting lighting (CFLs and LED lamps), domestic hot water (wraps and showerheads), refrigeration (cleaning of coils), pool pump (reduction of operating hours), and the home entertainment center ("smart plugs").

Deep retrofits were conducted on a subset of ten PDR 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 learning thermostats. To reduce water heating energy, heat pump water heaters were installed. Pool pumps were changed to variable-speed units, and ceiling insulation was augmented where deficient. Major appliances such as refrigerators and dishwashers were replaced where they were old and inefficient.

Energy Savings of Shallow Retrofits

We 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: 8-9%, or about 4 kWh/day. End-use savings results between the two methodologies differed. 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 and 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 greater in the pre- and post-retrofit October comparison than in the 30-days pre- and post-retrofit evaluation. This may be 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 is reached in two years.

We conducted a longer-term analysis on 41 sites using monthly utility records to confirm our estimation of whole-house savings and to investigate the influence the shallow retrofits had on space conditioning. While the shallow retrofit did not specifically address space condition end-use, results show that cooling energy was reduced by 16% post-retrofit (1,353 kWh annual savings), which we attribute 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 shows net annual savings from the shallow retrofits of 1,356 kWh, or about 8.7%.

The 3.7 kWh/day whole-house, post-retrofit savings projected by the normalized utility analysis substantiates the estimates arising from the preliminary short-term, monitored data. The savings projections are also very similar when the models are applied to Typical Meteorological Year 3 (TMY3) weather data weighted by the FPL service area, confirming the final estimates of 8-9%.

Peak Demand Impact of Shallow Retrofits

The FPL system peak winter hour comparison for the shallow retrofit sites showed a reduction of 0.25 kW between 7 and 8 AM, (identified as largely the impact of the hot water tank wrap and replaced showerheads), but 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- to 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, we were able to compare the sub-sample of 18 homes using the hottest day during local peak hour in October for pre- and post-retrofit years. This showed a whole-house reduction of 0.67 kW between 4 and 5 PM. The energy use reduction for the day was 9%: 52.1 kWh pre- and 47.4 kWh post-retrofit

Preliminary Estimates of Measured Savings of the Deep Energy Retrofits

For the deep retrofits, we conducted a data analysis comparing nearly an entire year using five sites to evaluate energy savings. The results show that post-retrofit annual cooling energy was reduced by 53% (4,129 kWh annual savings), space heating by 55% (737 kWh) and water heating by 69% (1,924 kWh). Whole-house savings were 39% (6,756 kWh/year).

Using incremental costs, simple payback for the improvements was 8.7 years, for an 11.5% simple, after-tax, rate of return. If the retrofits were completed outright as was done in the study, with an added cost of $14,323, the economics are less attractive. The simple payback for the package of measures increases to 17.6 years with a simple rate of return of 5.7%. However, a useful model for a utility "deep retrofit program" would target homes that are in need of having the air conditioning and heating system replaced, at which point all the other improvements would be performed outright. This results in approximately an 11 year payback.

Peak Demand Impact of Deep Retrofits

The plot in Figure E-1 compares pre- to post-retrofit whole-house demand during the FPL system peak summer hour, with a reduction of 1.96 kW between 4 and 5 PM. The energy use reduction for the day was 37%: 76.2 kWh pre- and 48.3 kWh post-retrofit.

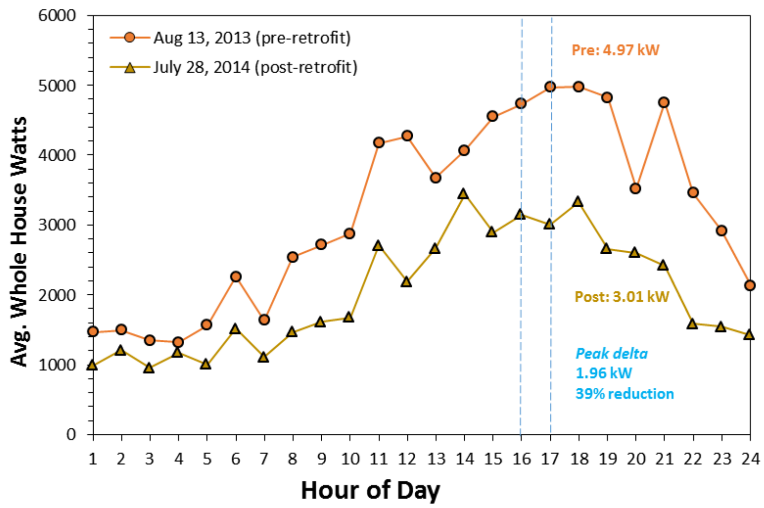

Figure E-1. Comparative analysis between pre- and post-retrofit demand for deep retrofits FPL system peak summer day

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

Estimation of Savings for Specific Measures and End-Uses

The pre/post evaluation of the ten HVAC retrofits showed that the heat pump replacement and duct repair saved an average of 40% of pre-retrofit space conditioning consumption, but that 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.

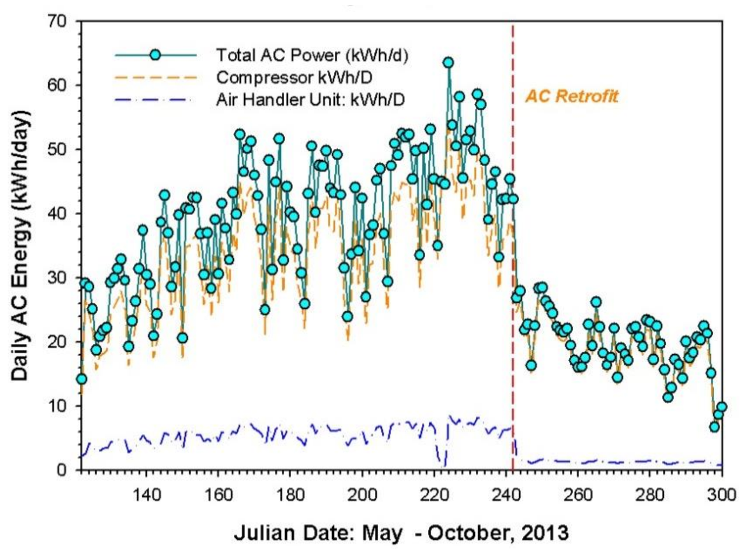

Figure E-2. Site 26 air conditioning energy: pre- and post-retrofit, May – October 2013.

Eight sites replacing 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 savings of 18% (0.6 kWh/day) for the eight homes where installed, although savings were highly variable. Savings from variable-speed pumps installed at three pool sites were very large: 80 to 90% (averaging 12.6 kWh/day). However, we found that 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:

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

Shallow and Deep Retrofit Energy Impacts*	Annual Energy Savings		Summer Peak Hour Reduction**		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 & Other	664	22%	0.24	42%	(0.02)	-6%	$281	$281
Water Heating	179	10%	0.11	26%	0.36	56%	$94	$94
Pool Pump	175	9%	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	4,129	53%	1.92	52%			$8,016	$2,635
Space Heating	737	55%			2.26	80%		
Water Heating***	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****	219	18%	0.04	26%	0.08	39%	$2,620	$1,087
Dishwasher (n=1)	175	32%	(0.27)	n/a	-	n/a	$508	$0
Pool Pump***** (n=3)	4,599	86%	0.89	91%	(0.09)	n/a	$2,035	$1,458
Whole-House	**6,756**	**39%**	**1.96**	**39%**	**2.71**	**60%**	**$14,323**	**$7,074**

* Sample size varies among end-use and metric. End-uses can not be summed for whole-house total. Very small sample sizes noted as "n=*x*"
** Shallow retrofit summer peak is a surrogate October date; deep retrofit summer peak is for the deep retrofit only, thus results are conservative.
*** Water Heating energy savings baseline includes partial post-shallow retrofit, thus results are conservative. Water Heating had no post-retrofit peak summer hour demand in the HPWH segment.
**** Cost includes the clothes washer and dryer as a set.
***** Pool Pump had no pre-retrofit peak winter hour demand.

Conclusions

We find that a much larger-scale deep retrofit program could be favorably designed by targeting efficiency changes at the time that an aging HVAC system is replaced with an efficient one by the homeowner, at which point all the other improvements would be performed outright by contractors. This program model has very favorable economics (payback is approximately 11 years not counting any utility rebates) and has the advantage of engaging the homeowners at the time that large alterations are underway. The large energy savings (nearly 40%) would be highly visible to homeowners and yet would provide even larger reductions to the combined winter and summer coincident peak demand (see Table E-1, above), benefitting the utility.

Next Steps

Future reporting will revise estimates for all deep retrofit sites with long-term utility data analysis. Meanwhile different shallow-plus and deep-plus retrofits are under way 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 smart thermostats.

1 Introduction

The U.S. Department of Energy (DOE), with the Building America Partnership for Improved Residential Construction (BA-PIRC) team, is pursuing a pilot phased energy-efficiency retrofit program in Florida by creating detailed data on the energy and economic performance of two levels of retrofit – simple and deep. A total of 56 homes have been audited and instrumented during the period August 2012 – March 2013.

All homes received simple pass-through retrofit measures. The simple, or "shallow retrofits" are 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. Deep retrofits have been performed 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 then retrofit a large number of occupied homes using a phased approach (pass-through audit/simple measures followed by/coupled with deep retrofits) that would result in significant energy savings. The study identifies measured energy savings and peak demand reductions of the different 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 is 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 et al. 1998). Through incorporating research findings and improved equipment, we have also conducted "deep retrofit" projects where we have profoundly reduced homes' energy use through application of an audit, new technologies, and monitoring. For instance, in one project in an occupied home, FSEC demonstrated a reduction in measured energy use by 45% (Parker et al. 1997). Another occupied home has been progressively retrofit 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

In consultation with FPL, FSEC recruited a total of 56 all-electric homes from within their service territory. Each home was audited, instrumented, and characterized in detail. After monitoring the homes for several months, installed "shallow" retrofit measures were deployed in each home and most often included:

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

Deep retrofits were then conducted on a limited subset of ten of the 56 homes to evaluate what is possible 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. These deep retrofits consisted of installing: ceiling insulation, HVAC equipment, appliances, and smart thermostats. Measures were identified as most productive by reducing data collected in the first phase along with generic results of energy simulations/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 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 & bedroom pressure mapping and pressure relief
- Smart thermostat
- Heat pump water heater
- 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 South Florida. Originally, the sample was to be weighted equally between Central and South 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 location, year built, occupancy, conditioned floor area, and whether there is a pool.

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

Table 1. Selected Site Characteristics of PDR Sample

Site	Town	Yr 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

Site	Town	Yr Built	Occupants	Conditioned Floor Area (ft²)	Pool? (1=Y, 0=N)
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
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%**

2.2 Description of Deep Sites

Table 2 summarizes the ten deep retrofitted sites, providing location, year of construction, occupancy, conditioned floor area, and if the home has a pool. A detailed summary of the deep retrofit homes' characteristics are provided in two tables in Appendix A.

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	2650
8	Grant-Valkaria	32949	1997	2	2	0	2134
10	W. Melbourne	32904	2003	2	0	0	1627
19	Melbourne	32940	1988	3	0	0	2554
26	Palm Bay	32907	1999	2	3	0	1502
30	Merritt Island	32952	1976	2	1	0	1819
37	Cocoa	32927	1993	4	2	1	1654
39	Palm Bay	32907	1981	4	0	0	1559
40	Titusville	32780	1993	3	0	0	1983
51	Cocoa	32926	1994	2	0	0	2233
	Averages:		**1991**	**2.6**	**0.8**	**20%**	**1972**

Following is a description of each deep retrofit home's characteristics including existing systems (i.e. HVAC, hot water heater, etc.) and details on the retrofit measures implemented. All homes had a high-efficiency air-source heat pump HVAC installed. 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.

2.2.1 Site 7

Site 7 is a 2,650 square foot, two-story home built in 1989 with two occupants (2 adults). Construction is slab-on-grade with a combination of a concrete masonry unit (CMU) walls (1st floor) and frame walls (2nd floor). Existing house systems included: a 3.5-ton, single-speed heat pump installed in 2001; programmable thermostat; 40-gallon electric water heater; R-19 fiberglass blown-in ceiling insulation; and a single-speed pool pump. Retrofit measures included: (1) 4 ton, dual speed, 16 seasonal energy efficiency ratio (SEER), 9.0 heating seasonal performance factor (HSPF) heat pump; (2) old/damaged ductwork replacement; (3) duct system sealing; (4) passive air flow pressure relief in all bedrooms; (5) a smart thermostat; (6) 60-gallon heat pump water heater; and (7) ceiling insulation upgrade to R-38 using blown-in fiberglass with knee wall insulation upgrade as appropriate. Retrofit measures began September 24, 2013 with the HVAC system installation and concluded November 9, 2013 with the ceiling insulation upgrade.

2.2.2 Site 8

Site 8 is a 2,134 square foot, single-story home built in 1997 with four occupants (2 adults, 2 children). Construction is slab-on-grade with frame walls. Existing systems included: the original 3.5-ton, single-speed straight cool; manual thermostat; 50-gallon electric water heater; and R-30 fiberglass batt ceiling insulation. This home has no pool. Retrofit measures included: (1) 3-ton, dual-speed, 17 SEER, 9.5 HSPF heat pump; (2) duct system sealing; (3) a smart thermostat; (4) 80-gallon heat pump water heater; and (5) ENERGY STAR dishwasher and clothes washer, and a low-energy clothes dryer. Ceiling insulation upgrades were not necessary as existing levels met the program threshold of R-30 or better. Retrofit measures began August 23, 2013 with the HVAC system installation and concluded October 25, 2013 with appliance installations.

2.2.3 Site 10

Site 10 is a 1,627 square foot, single-story home built in 2003 with two occupants (2 adults). Construction is slab-on-grade with CMU walls. Existing systems included: 3-ton, single-speed heat pump installed in 2003; programmable thermostat; 50-gallon electric water heater; and R-30 (levels) of fiberglass blown-in ceiling insulation in approximately 75% of attic floor with R-8 insulation levels in the remaining 25% of attic floor area. This home has no pool. Retrofit measures included: (1) 3-ton, dual-speed, 18 SEER, 9.2 HSPF heat pump[1]; (2) communicating, programmable thermostat; (3) 60-gallon heat pump water heater; (4) ceiling insulation upgrade to R-38 using blown-in fiberglass with knee wall insulation upgrade as appropriate; and (5) ENERGY STAR clothes washer and low-energy clothes dryer installations. Retrofit measures began May 31, 2013 with the HVAC system installation and concluded December 6, 2013 with the ceiling insulation upgrade.

2.2.4 Site 19

Site 19 is a 2,554 square foot, single-story home built in 1988 with three occupants (3 adults). Construction is slab-on-grade with CMU walls. Existing systems included: 5-ton, single-speed HVAC system with the original 1988 condenser (compressor change-out in 1997) and a 1990 air handler unit; manual thermostat; 50-gallon electric water heater; and R-19 fiberglass batt ceiling insulation. This home has no pool. Retrofit measures included: (1) 5-ton, dual-speed, 16 SEER, 9.0 HSPF heat pump; (2) duct system sealing; (3) passive air flow pressure relief in the master bedroom; (4) a smart thermostat; (5) 80-gallon heat pump water heater; (6) a ceiling insulation upgrade to R-38 using blown-in fiberglass with knee wall insulation upgrade as appropriate; and (7) ENERGY STAR clothes washer and low-energy clothes dryer installations. Retrofit measures began August 26, 2013 with the HVAC system installation and concluded November 18, 2013 with appliance installations.

2.2.5 Site 26

Site 26 is a 1,502 square foot, single-story home built in 1999 with five occupants (2 adults, 3 children). Construction is slab-on-grade with CMU walls. Existing systems included: the original 2.5-ton, single-speed heat pump; manual thermostat; 55-gallon electric water heater; and R-19 fiberglass blown-in ceiling insulation. This home has no pool. Retrofit measures included: (1) 3-ton, dual-speed, 17 SEER, 9.5 HSPF heat pump; (2) duct system sealing; (3) passive air flow pressure relief in all bedrooms; (4) a smart thermostat; (5) 80-gallon heat pump water heater; (6) ceiling insulation upgrade to R-38 using blown-in fiberglass with knee wall insulation upgrade as appropriate; and (7) ENERGY STAR refrigerator, clothes washer, and low-energy clothes dryer installations. Retrofit measures began August 30, 2013 with the HVAC system installation and concluded November 11, 2013 with the insulation upgrade.

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[1] The HVAC installation was independently contracted by the homeowner. The system manufacturer is the same as the other systems installed in the PDR project; however, the unit is a different series with a higher SEER rating. Additionally, the homeowner used a different HVAC contractor for the retrofit.

2.2.6 Site 30

Site 30 is a 1,819 square foot, single-story home built in 1976 with three occupants (2 adults, 1 teen). Construction is slab-on-grade with CMU walls. Existing systems included: a 3.0-ton, single-speed straight cool system that included a 2007 condenser unit and a 2003 air handler; programmable thermostat; 40-gallon electric water heater; and ceiling insulation of approximately an R-8. This home has no pool. Retrofit measures included: (1) 3-ton, dual-speed; 17 SEER, 9.5 HSPF heat pump; (2) duct system sealing; (3) passive air flow pressure relief in all bedrooms; (4) a smart thermostat; (5) ENERGY STAR clothes washer and low-energy clothes dryer installations; and (6) ceiling insulation upgrade to R-38 using blown-in fiberglass. Retrofit measures began September 9, 2013 with the heat pump water heater installation and concluded November 11, 2013 with the insulation upgrade.

2.2.7 Site 37

Site 37 is a 1,654 square foot, single-story home built in 1993 with six occupants (4 adults, 2 teens). Construction is slab-on-grade with frame walls. Existing systems included: 2.5-ton, single-speed heat pump with the original 1992 condenser and a 2004 air handler; manual thermostat; 40-gallon electric water heater; R-19 fiberglass blow in ceiling insulation; and a single-speed pool pump. Retrofit measures included (1) 3-ton, dual-speed, 17 SEER, 9.5 HSPF heat pump; (2) duct system sealing; (3) a smart thermostat; (4) a variable-speed pool pump installation; (5) 50-gallon heat pump water heater; (6) targeted air sealing; (7) ceiling insulation upgrade to R-38 using blown-in fiberglass with knee wall insulation upgrade as appropriate. An ENERGY STAR clothes washer and low-energy clothes dryer installation was targeted for this site; however, the homeowner requested to keep the existing set. Retrofit measures began August 29, 2013 with the HVAC system installation and concluded February 24, 2014 with the insulation upgrade.

2.2.8 Site 39

Site 39 is a 1,559 square foot, single-story home built in 1981 with four occupants (4 adults). Construction is slab-on-grade with CMU walls. Existing systems included: a 3.0-ton, single-speed straight cool system installed in 2006; manual thermostat; 50-gallon heat pump water heater; and R-38 fiberglass blow in ceiling insulation. This home has no pool. Retrofit measures included: (1) 3-ton, dual-speed, 17 SEER, 9.5 HSPF heat pump; (2) duct system sealing; (3) passive air flow pressure relief in the master bedroom; (4) a smart thermostat; and (5) ENERGY STAR refrigerator, clothes washer, and low-energy clothes dryer installations. Ceiling insulation upgrades were not necessary as existing levels met the program threshold of R-30 or better. Installed retrofit measures began September 3, 2013 with the installation of the HVAC system and concluded October 25, 2013 with the appliance installations.

2.2.9 Site 40

Site 40 is a 1,983 square foot, single-story home built in 1993, with three occupants (3 adults). Construction is slab-on-grade with frame walls. Existing systems included: a 3.5-ton, single-speed straight cool system with the original 1993 air handler unit and a 2003 condenser unit; programmable thermostat; 40-gallon electric water heater; and R-19 with a combination of fiberglass blown-in and fiberglass batt ceiling insulation. This home has no pool. Retrofit measures included: (1) 3-ton, dual-speed, 17 SEER, 9.5 HSPF heat pump; (2) new ceiling supply registers; (3) duct system sealing; (4) a smart thermostat, (5) 60-gallon heat pump water heater installation; (6) ceiling insulation upgrade to R-38 using blown-in fiberglass with knee wall insulation upgrade as appropriate; and (7) ENERGY STAR clothes washer and low-energy clothes dryer installations. Retrofit measures began September 13, 2013 with the HVAC system installation and concluded November 22, 2013 with the ceiling insulation upgrade.

2.2.10 Site 51

Site 51 is a 2,233 square foot, two-story home built in 1994 with two occupants (2 adults). Construction includes a crawlspace and frame walls. Existing systems included: a 3.5-ton, single-speed HVAC system installed in 1996; programmable thermostat; 40-gallon electric water heater; and R-19 fiberglass batt ceiling insulation. This home has no pool. Retrofit measures included: (1) 4-ton, dual-speed, 16 SEER, 9.0 HSPF heat pump; (2) duct system sealing; (3) passive air flow pressure relief in all bedrooms; (4) a smart thermostat; (5) 60-gallon heat pump water heater; (6) targeted air sealing; (7) ENERGY STAR refrigerator, clothes washer, and low-energy clothes dryer installations; and (8) ceiling insulation upgrade to R-38 using blow-in fiberglass with knee wall insulation upgrade as appropriate. Retrofit measures began August 27, 2013 with the HVAC system installation and concluded March 26, 2014 with the ceiling insulation upgrade.

2.3 Audit and Instrumentation Installation

Installations and audits began in August 2012. Table 3 shows when sites were audited and instrumented, by month.

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

As the program availability was not widely advertised either by FSEC or FPL, it cannot be determined how well such a program would be received in a much wider program context. It might be noted, however, that a large reason for the high 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.

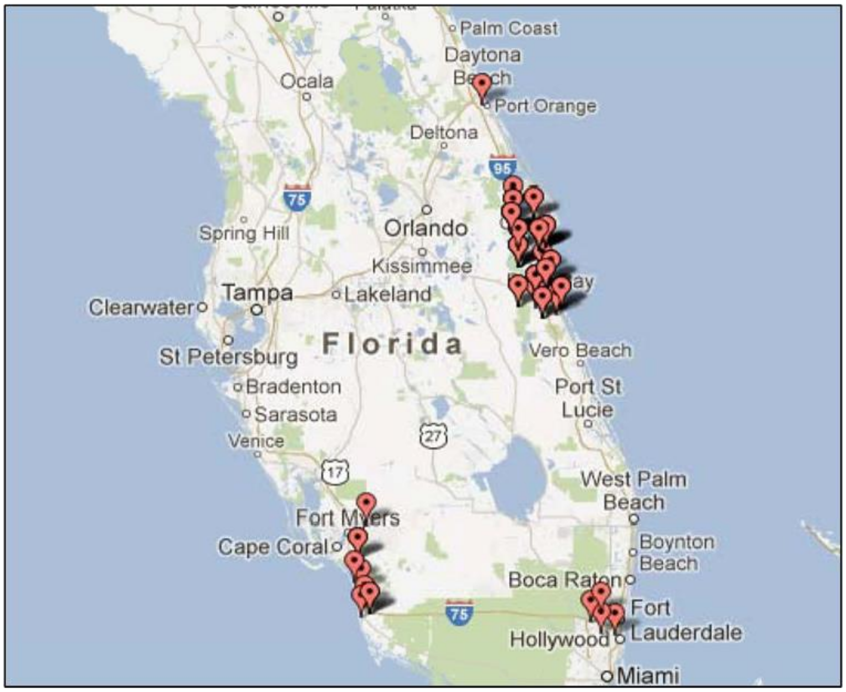

Figure 1. Geographic distribution of the PDR sites in the State of Florida

2.4 Measurements and Equipment

Detailed audit data has been obtained from all homes and includes house size and geometry, insulation levels, materials, finish, and equipment. Blower door and duct leakage tests were completed on each home. Detailed photographs were also made of home exterior, appliances and equipment, and thermostat. Shower head flow rate was measured during the shallow retrofit.

Monitoring of house power and the various end uses is accomplished by a 24-channel data logger (eMonitor™). This is supplemented by portable loggers (LaCrosse® and HOBO) to take temperature and humidity data as well as a portable power logger (Watts up?) to obtain energy use of the main home entertainment center, game systems, and home office/computer workstations. Data is retrieved daily over the internet via broadband connection. Data is being collected on a 1-hour time step. Ambient temperature and relative humidity are obtained from nearby weather stations.

Table 4 summarizes the measurements and equipment utilized to conduct field testing and data acquisition for the project:

Table 4. Equipment Utilized for Field Testing.

Measurement	Equipment Utilized
House envelope airtightness	Blower door and manometer
Duct leakage	duct blaster
Temperature and relative humidity	HOBO temp & RH logger LaCrosse temp & humidity logger
Entertainment centers, game systems, home office/computer workstations	WattsUp.net
Detailed house power (total, HVAC, water heating, cooking, clothes drying, refrigeration, pool pump)	eMonitor by Powerhouse Dynamics

*Heating, ventilation, and air conditioning

3 Pre-retrofit Data

A dedicated website has been setup to host the monitored energy data from the project. It can be found at: http://www.infomonitors.com/pdr/

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 Figures 2 – 6, both as time series over the entire period and as daily end-use load profiles averaged over the 24-hour cycle.

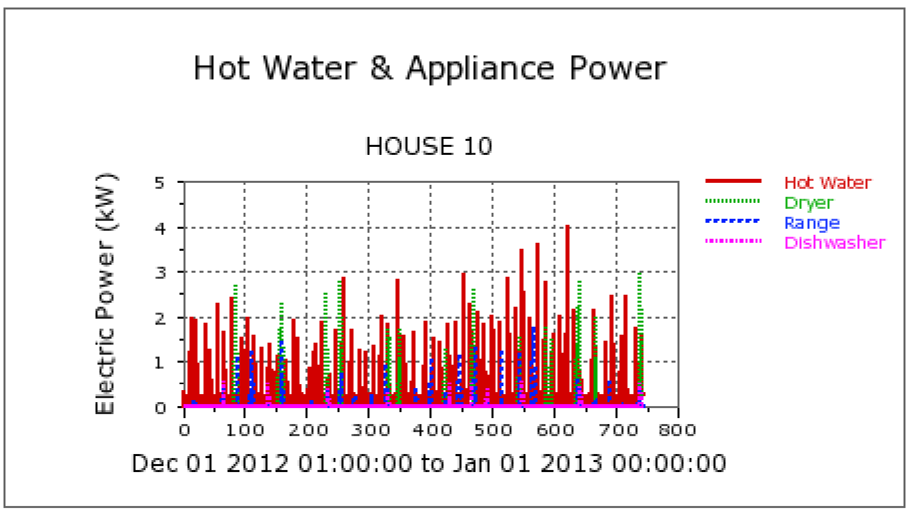

Figure 2. Site 10: Appliance electricity use for the month of December (time series)

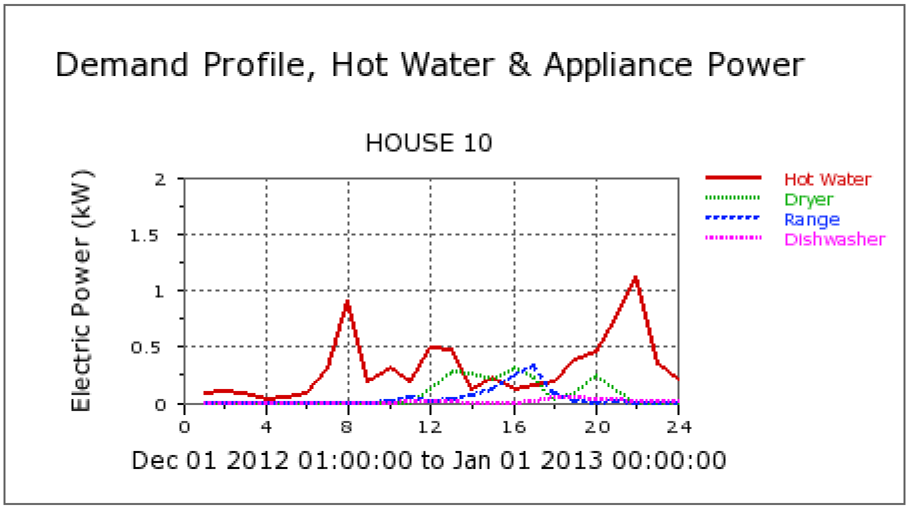

Figure 3. Site 10: Average appliance electricity demand for the month of December (profiles)

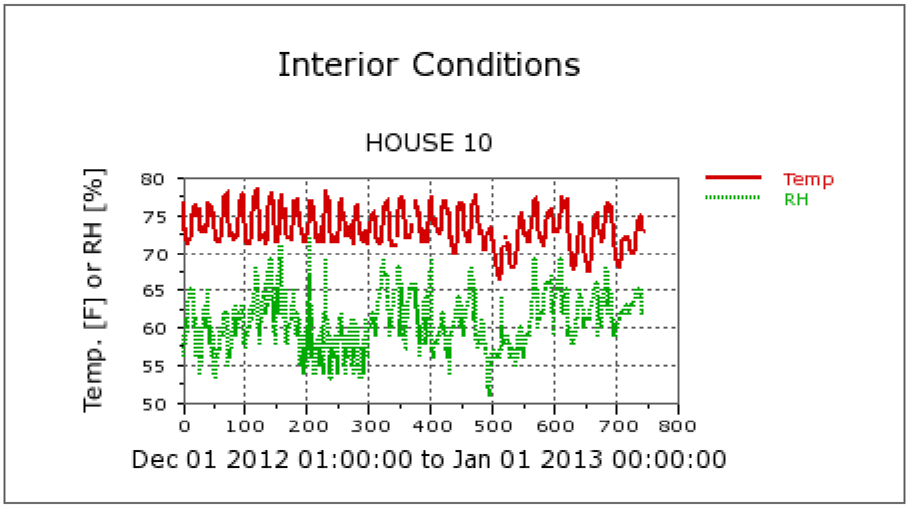

Figure 4. Site 10: Hourly interior temperatures and humidities over the month of December

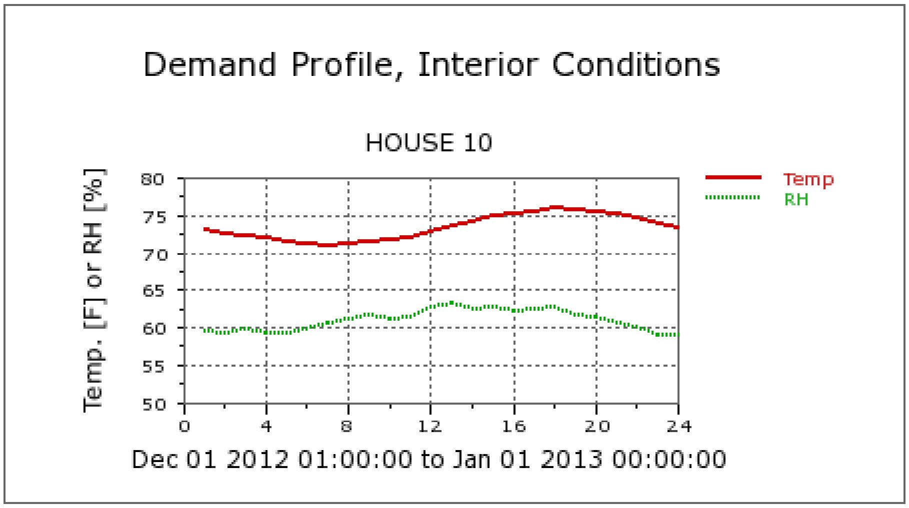

Figure 5. Site 10: Average interior temperatures and humidities over the month of December

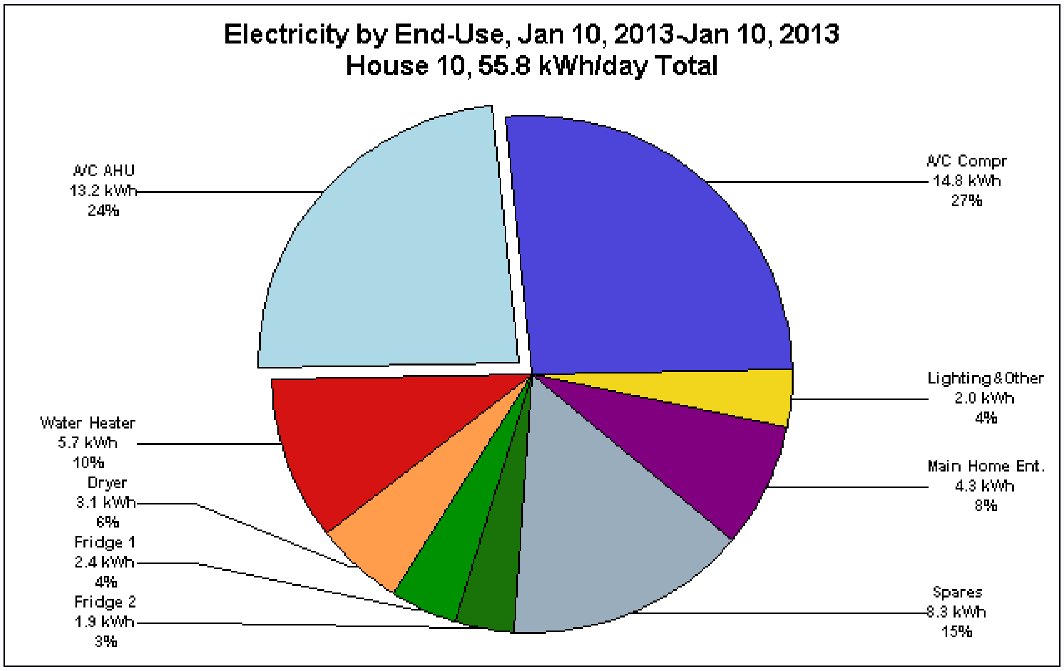

Figure 6. Components of energy end-use loads for January 10, 2013 at Site 10

In Table 5, data are given for the first 30 homes of the sample when evaluated monthly from August – December of 2012 prior to any retrofits. This results in a consistent sample over the period. "Other" in this case includes plug loads as well as other loads measured on the Spare 1 – Spare 4 circuits that vary from the mundane (home offices and freezers) to the exotic (spa-side wine coolers and fish ponds!).

Table 5. Preliminary Monitoring Results August – December of 2012
Averages, Sites 1-30

House	Refrig 1	Refrig 2	Pool	MainTV & Ent.	Other	Indoor Temp	RH
	Daily kWh/d	Daily kWh/d	Daily kWh/d	Daily kWh/d	Daily kWh/d	°F	%
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 is the FPL estimated monthly average kWh/day from their end-use studies (FPL 1999) with estimates for Central Florida.

Table 6. Preliminary Monitoring Results August – December of 2012 Averages, Sites 1-30 (con't)

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

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

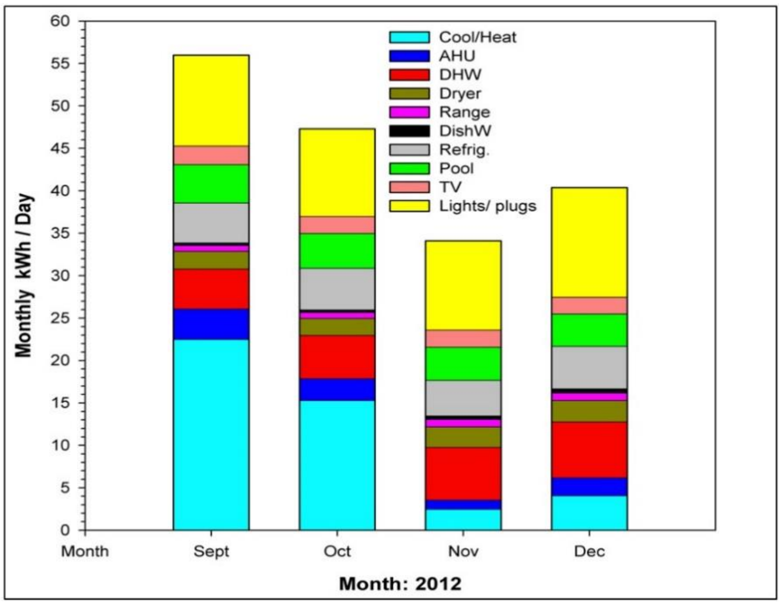

Figure 7. PDR project: End-Use monitoring data, September – December 2012

The data reveal how house air conditioning drops with cooler temperatures and the marked seasonal variation in hot water energy use. Cooking energy use is small 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 are also a relatively large appliance load, equating to over 800 kWh if evaluated over the year. Surprisingly, the main television and entertainment center, seldom considered from an energy-efficiency perspective, was also a large 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 air conditioning. This also is shown to strongly influence interior moisture levels, which increase substantially as mechanical cooling drops and moisture removal from air conditioning falls as well.

3.1 Annual End Use Energy Data Summary for 2013

Tables 7 and 8 show the monitoring results for the entirety of 2013 in the complete sample of homes. Data are given in the average kilowatt hours (kWh) 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. Note that this data includes both the pre-retrofit and shallow and deep retrofit periods and thus, is an annual snapshot of energy use over the entire year of the project.

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

House	Whole-House	A/C Comp	A/C AHU	DHW	Dryer	Range	Dishw	Refrig 1	Refrig 2
	Daily kWh/d	Daily kWh/d	Daily kWh/d	Daily kWh/d	Daily kWh/d	Daily kWh/d	Daily kWh/d	Daily kWh/d	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	2.0	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
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

House	Whole-House	A/C Comp	A/C AHU	DHW	Dryer	Range	Dishw	Refrig 1	Refrig 2
	Daily kWh/d	Daily kWh/d	Daily kWh/d	Daily kWh/d	Daily kWh/d	Daily kWh/d	Daily kWh/d	Daily kWh/d	Daily kWh/d
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 (con't)

House	Spare 1	Spare 2	Spare 3	Spare 4	Pool	Main Home Ent	Lights & Other	Temp	RH
	Daily kWh/d	Daily kWh/d	Daily kWh/d	Daily kWh/d	Daily kWh/d	Daily kWh/d	Daily kWh/d	Average °F	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	1.0\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	12.0	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
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

House	Spare 1	Spare 2	Spare 3	Spare 4	Pool	Main Home Ent	Lights & Other	Temp	RH
	Daily kWh/d	Daily kWh/d	Daily kWh/d	Daily kWh/d	Daily kWh/d	Daily kWh/d	Daily kWh/d	Average °F	Average %
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**

"Other" are 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 those sites with an operating pool pump, consumption was about 10 kWh/day.

A graphical summary of all each site's energy end-uses is shown by the stacked bar presentation in Figure 8 for all of 2013. A second graphic, Figure 9, shows the average end-use make up for the entire sample, rendered as a pie chart. A third graphic, 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 of the charts.

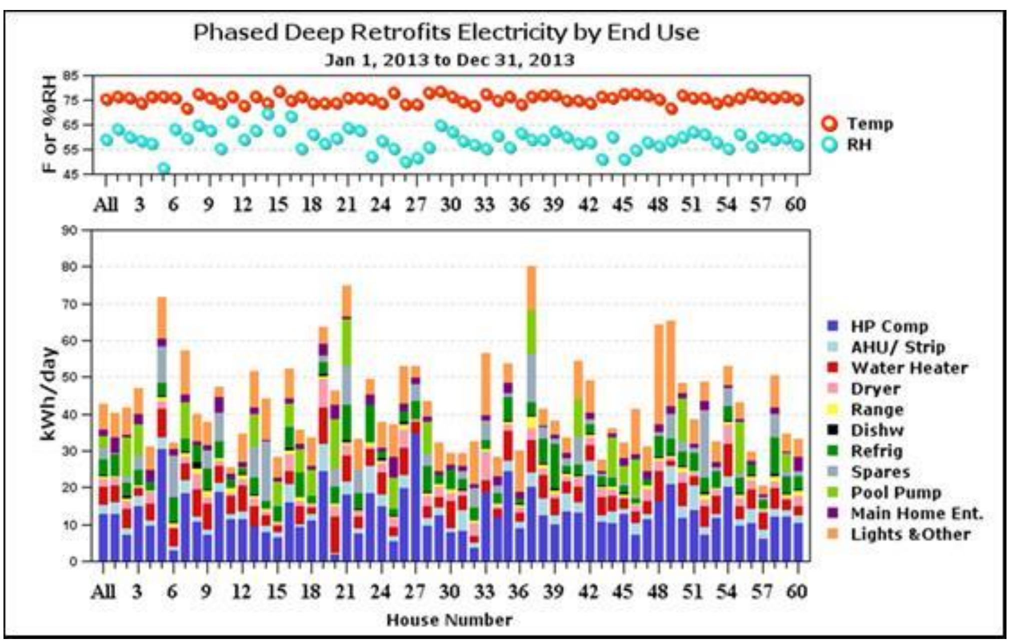

Figure 8. Site energy use in the month of December by end use in total PDR sample

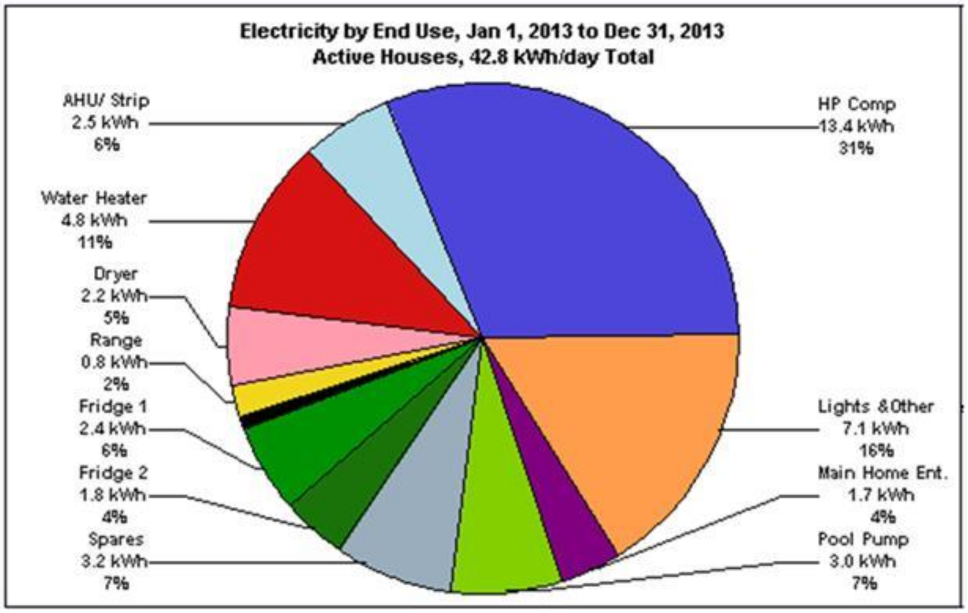

Figure 9. Average energy end-use in the month of December 2012 in the PDR sample

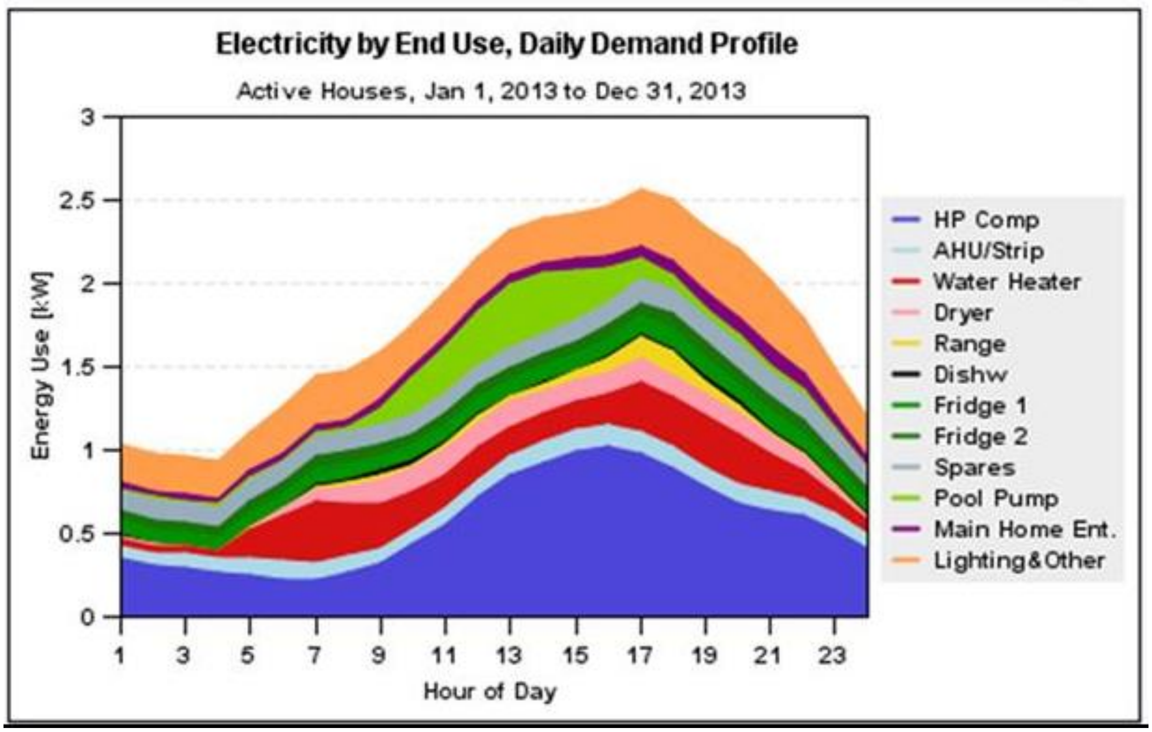

Figure 10. Average daily demand profile in the month of December 2012 in the PDR sample

Finally, Appendix B of the report shows the average demand profiles by each end-use, temperature and humidity summarized for the entire sample for 2013. 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: http://www.infomonitors.com/pdr/.

4 Shallow Retrofits

4.1 Introduction

Each study home had a series of simple retrofit measures installed from March 2013 through June 2013. An estimation of the pre- and post-retrofit savings for each measure has been conducted comparing 30 days pre-retrofit to 30 days post-retrofit against the control group change over the same period. And for a subset of the dataset, a year-to-year energy use comparison has been made by selecting one 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:

- Change incandescent and halogen lighting to CFL or LED lighting
- Add exterior insulation tank wrap to hot water tank and insulate hot water pipes
- Replace shower fixtures with hi-efficiency head if measured flow is greater than 2.2 gpm
- Set pool pump hours to no more than five hours/day
- Clean refrigerator coils if soiled
- Provide advanced smart power strips (APS) to any standby power loads greater than 10 watts continuous

The latter measure was very seldom installed because equipment standby was often below the threshold or could not be shut down (e.g. remote printers, HDVRs) without loss of functionality. Because of the very small sample size, smart strips are independently evaluated.

It should also be pointed out that the installations were discretionary: homeowners were able to choose which measures they did not want to have installed. Thus, even where applicable, often APSs were not installed. Also, some lighting fixtures were not changed and some showerheads (over the 2.2 gpm limit), 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 run-time, and hot water tank location and insulation status.

To complete the shallow measure energy savings evaluation, we examined the monitored power for the hot water, pool, refrigerator, and "lighting and other." "Lighting and other" was obtained by subtracting all of the end-uses from measured total power and obtaining lighting, ceiling fans, and plug loads. We also obtained total building power to see if the shallow retrofits would be visible to homeowners who solely have 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

To provide insight on how individual homes were affected by the shallow retrofit, Site 54 is shown in detail below. The shallow retrofit performed on May 22, 2013 included:

- Changing out 95% of bulbs from incandescent to CFLs, with a reduction in the connected lighting load 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-3.0)

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 one month before and one month after the retrofit. Figure 13 shows what was observed in daily power for the affected end-uses at Site 54 during this sixty-one day analysis period. The vertical, dashed, purple line indicates the retrofit date.

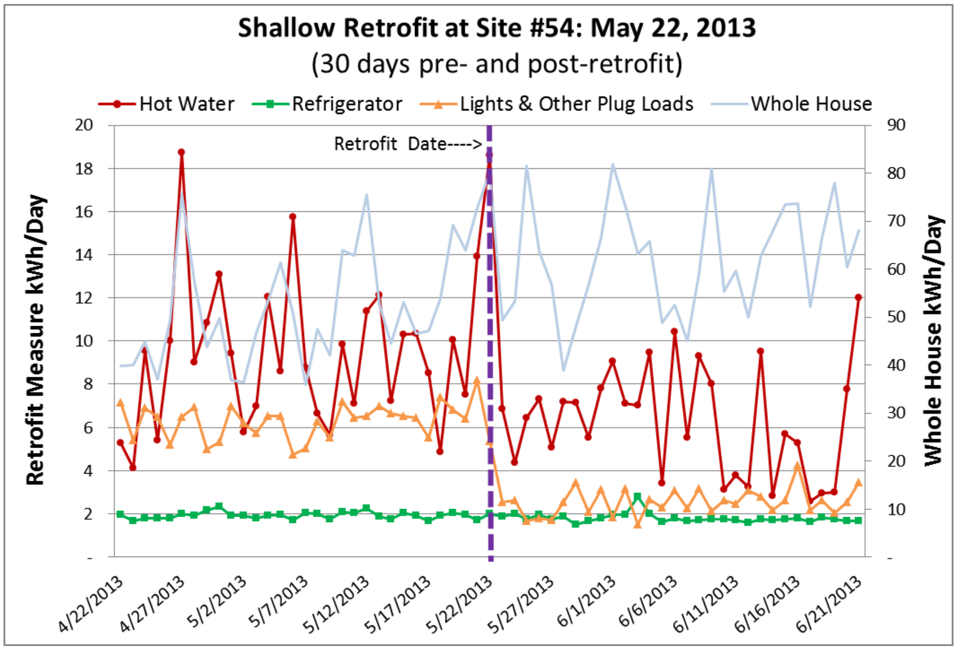

Figure 13. Illustration of evaluation method showing impact of shallow retrofit at PDR Site 54 spanning two-month period before and after installed retrofit measures

The plot shows how lighting and domestic hot 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 time had robust savings among pool homes, but was incorporated in only 10 homes.)

However, increases to whole-house energy consumption, represented by the faint blue line, more than offset these savings due to natural seasonal variation as 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, we normalized savings for each shallow retrofit measure. This is necessary so as to not underestimate savings for measures where energy use is naturally increasing with higher seasonal temperature (e.g. refrigerators) or to overestimate savings from others that are naturally dropping (water heating).

To normalize for seasonal variation, for each site we identified a unique set of control homes comprised of all study homes retrofitted either before or after the site's 61-day analysis period. Monitored results from each site were adjusted to account for the average change in the control group's end-use load over the same period. 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

	Retrofit Measure:			
Site #54	Lights & Other	Hot Water	Refrigerator	Whole House Total
Avg. Monitored kWh/Day Pre	7.0	9.2	1.9	51.5
Avg. Monitored kWh/Day Post	3.5	6.3	1.8	61.7
Avg. Monitored kWh/Day Savings	3.5	2.9	0.1	-10.1
Percent Monitored Savings	50.4%	31.5%	6.2%	-19.7%
Avg. Control kWh/Day Change	<0.0	1.1	<0.0	-11.8
Percent Control Change	2.5%	17.0%	0.9%	-31.5%
Avg. Normalized kWh/Day Savings	**3.4**	**1.3**	**0.1**	**6.1**
Percent 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 affected by the shallow retrofit, and then for the whole-house overall. Rows five and six 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 lighting and refrigerator circuit, with average savings of 3.4 and 0.1 kWh/day, respectively. However, actual hot water savings is 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, yields daily savings of 6.1 kWh, or 11.8% once normalized against the control homes, reversing the apparent increase of nearly 20%.

The labor and materials cost associated with the shallow retrofit for Site 54 are provided in Table 10. As the labor cost will vary depending on the program and level of homeowner participation, we display the hours our field team spent conducting the shallow retrofit at this site rather than labor cost. Our field team spent six 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 entertaining center for standby losses, and 0.5 hours cleaning the refrigerator coils. (Retrofit hours are in bold, black text.)

Table 10. Site 54 Shallow Retrofit Labor and Materials Cost

Site #54	Lighting Change-out				Showerhead Replacement				DHW Insul.	Smart Power Strip				Fridg 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 Referigerators	**Retrofit/ Total**	Total	Research/ Assessment	**Retrofit**
Labor Hours		3.50	1.25	**2.25**		0.75	0.50	**0.25**	**1.00**		0.25	0.25	**0**		**0.50**	6.00	2.00	**4.00**
Materials	42			**$166**	1			**$36**	**$24**	0			**$0**	1	**$0**			**$240**

Note not all time logged was for the actual retrofit. Research and assessment often represented a considerable portion of the documented labor hours. Therefore, where applicable, we make a distinction between total hours (in green text), research and assessment (in red text), and retrofit hours (in black text).

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. As part of the domestic hot water retrofit, researchers regularly assessed showerhead flow rates to determine replacement needs. And the home entertainment center standby power loads were nearly always evaluated, while few homes received any related savings because smart strips were rarely installed. While a portion of the research and assessment hours may be appropriate in a mature utility incentive program, research and assessment 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). Martials cost 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 a mature retrofit program would likely see bulk discounts for some items. Segmented by measure, this includes $166 for 42 CFL bulbs, $36 for one showerhead, and $24 for the thermal tank wrap and pipe insulation.

For the sake of cost/benefit analysis, we will suppose a rate of $30/hour for the retrofit labor (4 x $30 = $120). This brings the total cost for the retrofit to $360. If we estimate $0.12/kWh at 6.1 kWh/day savings, savings are $267/year. Given these assumptions, the shallow retrofit at Site 54 is paid for in just over one 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 dataset is summarized below.

Pool homes represent 34% of the homes in the dataset. Of these 19 pool homes, nine homeowners already had their pool pump timer set at or below the measure threshold of five hours/day. The owner at one site runs the pump only intermittently, e.g. when adding chemicals. Pre-retrofit pool pump electric 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.

- 10 homes had their pool pump timers reduced to ≤ six hours/day. On average, pump time was reduced by two hours/day. While the goal was to reduce time ≤ five hours/day, a compromise was sometimes required. Three timers originally set to run eight or more hours daily were set to six hours post-retrofit.

The number of bulbs and fixtures changed, bulb types, and wattage were recorded by field staff. Most houses already had some energy efficient lighting (defined to be CFL or LED types). Indeed, one home already had 100% LED lighting, whereas six others had mostly CFLs and needed fewer than 20% of bulbs changed. Owners sometimes objected to lighting retrofits in particular lamps and those bulbs were not changed. In lamps where an appropriate LED or CFL could not be found, 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)

- 55 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 regarding quick burnout rates on a specific brand of CFLs points to a vendor control issue. Thankfully, we have also received reports that the reseller has exchanged the bulbs without reluctance.

Efforts to reduce domestic hot water energy used were two-pronged; (a) reducing use through low-flow showerheads and (b) reducing storage thermal losses by insulating tanks and hot or warm pipes. We examined the impact of changing showerheads versus tank wraps, but the data did not support statistical determination of specific impacts. Understandably, many homeowners were particular about their showerhead and rejected this measure. Regarding hot water tanks, space limitations generally restricted the application of R-10 thermal blankets, so most homes received a smaller R-3.5 or R-3 wrap. 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.

- 53 homes had domestic hot water reduction measures installed:
    - 26 homes had at least one showerhead replaced with a low-flow head. (18 sites had 1 head replaced; 7 had 2 replaced; 1 had 3 replaced)
    - 51 homes had a hot water tank insulated. (39 sites with R-3; 6 with R-3.5 and with R-10)
    - 52 homes received R-3 insulation around all accessible hot and warm pipes.

Most homes received refrigerator coil cleaning; however, one homeowner objected to having them cleaned. 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 is analyzed.

- 50 homes had refrigerator coils cleaned. (41 sites had 1 cleaned; 8 had 2 cleaned; 1 had 3 cleaned)

Advanced Power Strips (APS) are a way to 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, thereby providing 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 smart plug 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, invalidating a pre- to post-retrofit energy use comparison.

- 2 homes had successful APS installations acceptable for evaluation.

4.4 30 Days Pre- and Post-Retrofit Savings Evaluation

We took two approaches to evaluating measure savings. The first method presented analyzes savings among the entire dataset, labeled "All Homes." This evaluation is also referred to as saturation-adjusted. The second approach analyzes measure savings only among sites receiving an intervention for that end-use, labeled "Homes with Retrofit Measure." For example, evaluation of hot water end-use will be comprised of the 53 homes that received any of the following: a low flow showerhead, an insulation tank wrap, 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, energy use evaluation required that monitored savings results be normalized to account for naturally increasing or decreasing energy use.

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

	Retrofit Measure:				
All Homes	**Pool Pump (n=18)**	**Lights & Other (n=56)**	**Hot Water (n=56)**	**Refrigerator (n=56)**	**Whole House Total**
Avg. Monitored kWh/Day Pre	10.7	7.7	5.6	2.4	40.5
Avg. Monitored kWh/Day Post	8.1	6.6	4.7	2.4	43.7
Avg. Monitored kWh/Day Savings	2.6	1.1	0.9	0.0	-3.2
Percent Monitored Savings	14.2%	15.3%	13.9%	0.6%	-9.3%
Avg. Control kWh/Day Change	-0.1	-0.1	0.7	0.0	-6.4
Percent Control Change	-1.4%	-1.7%	10.1%	-2.6%	-18.5%
Avg. Normalized kWh/Day Savings	**2.7**	**1.2**	**0.4**	**0.1**	**4.2**
Percent Normalized Savings	**15.9%**	**16.9%**	**3.8%**	**3.2%**	**9.2%**
Uncertainty* (+/-)	1.9	0.3	0.2	<0.0	1.6
COVAR	0.42	0.17	0.32	0.34	0.22

* Statistically significant @ 90% confidence interval

The results are arranged similarly to Table 9, with monitored, control group, and normalized findings (in bold). Additionally, we conducted a t-test of paired mean savings before and after retrofit, used to establish statistically significant differences. Significance is indicated by t-test results lower than the average normalized daily kWh savings. The value "uncertainty" indicates the estimated uncertainty at a 90% confidence interval. The final component in this table, "COVAR" (coefficient of variation), provides the variation in savings achieved (standard error divided by mean savings level). Low values of this parameter indicate reliable savings, while values above 0.5 indicate declining reliability.

With this estimation methodology, the total energy savings in the 56 retrofit homes was 4.2 kWh/day and 9.2% savings on average. Clearly the normalization process has an important impact, as monitored energy use increased by almost 10%, rather than show any savings. The normalized savings are significant at the 90% confidence interval (1.6 < 4.2) and COVAR indicates reliable savings (0. 17 < 0.46) from the installed retrofit measures, even though largely invisible to homeowners due to savings being 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, or 5.1%, when weighted among all 56 homes. As there are only 19 pool homes[2] and just 10 received pump timer reductions; actual savings for this measure are diluted across the whole sample. Considering only pool homes, normalized daily savings is rises to 2.7 kWh. Although the pool pump time reduction had the largest impact, it was also highly variable, as nine homes already operated at five hours/day or less and were not changed.

The total savings in homes with swimming pools averaged 4.5 kWh/day versus 4.0 kWh/day in homes without pools. The average whole-house savings without the pool pump circuit changes drops from 9.2% to 8.2%.[3]

The normalized pool pump measure savings are significant; however the COVAR value of 0.46 indicates only marginally reliable savings. This means that, while 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, we consider only homes that received the pool pump intervention in Table 12. Table 12 is structured identically to Table 11, only the sample size represents only the homes impacted by the relevant retrofit measure(s).

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

	Retrofit Measure:				
Homes with Retrofit Measure	**Pool Pump (n=10)**	**Lights & Other (n=55)**	**Hot Water (n=53)**	**Refrigerator (n=50)**	**Whole House Total (n=56)**
Avg. Monitored kWh/Day Pre	13.8	7.7	5.6	2.4	40.5
Avg. Monitored kWh/Day Post	9.3	6.6	4.7	2.4	43.7
Avg. Monitored kWh/Day Savings	4.5	1.1	0.9	0.0	-3.2
Percent Monitored Savings	26.3%	15.7%	13.5%	0.9%	-9.3%
Avg. Control kWh/Day Change	-0.1	-0.1	0.7	0.0	-6.4
Percent Control Change	-1.3%	-1.7%	10.0%	-2.5%	-18.5%
Avg. Normalized kWh/Day Savings	**4.6**	**1.3**	**0.4**	**0.1**	**4.2**
Percent Normalized Savings	**27.6%**	**17.4%**	**3.5%**	**3.3%**	**9.2%**
Uncertainty* (+/-)	3.3	0.3	0.2	0.1	1.6
COVAR	0.39	0.16	0.35	0.37	0.22

* Statistically significant @ 90% confidence interval

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

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

Isolating the homes receiving the pool pump timer reduction, average savings for this measure was 4.6 kWh/day, or 27.6%. Reporting outside of this summary presentation, whole-house savings in these ten homes rise to 7.3 kWh/day, and average savings was 11.6%.
A major caution must be inserted here for this analysis as the long term examination of the reduction of pool pump hours (to be shown later), indicated that this measure was not persistent as 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 the deep retrofit analysis section) 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 was highly significant at the 90% confidence interval. As lighting/other end-use increased slightly among the control homes, the normalization improved saving slightly. Savings from the lightning retrofit averaged 1.2 kWh/day, or 16.9%. Savings rises to 1.3 kWh/day (17.4%) when the one, non-lighting affected home is dropped (Table 11). Considering only homes where more than 20% of fixtures were replaced, average savings were 1.5 kWh/day (19.9%).

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

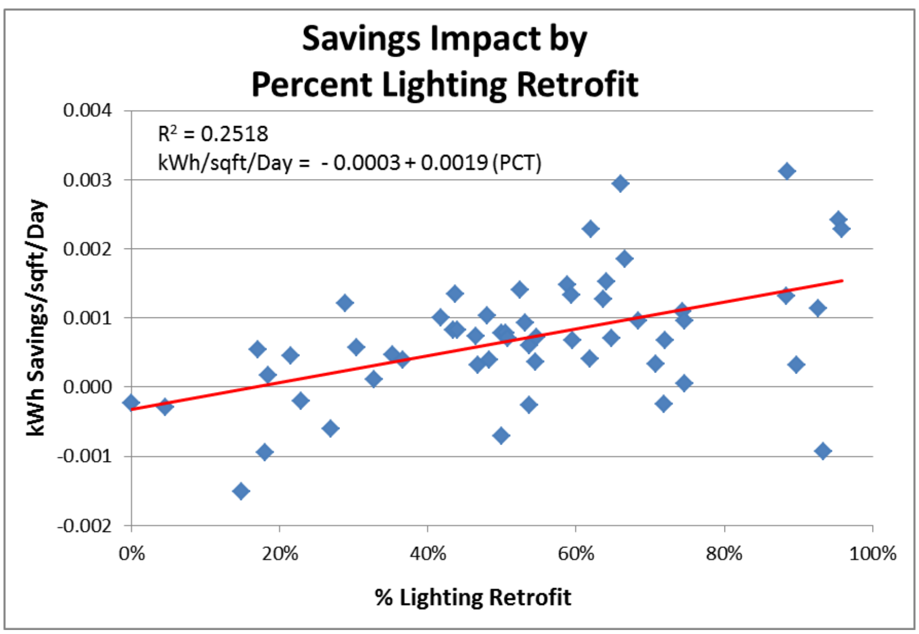

Figure 15. Scatterplot of percentage lighting change-out with predicting savings/sqft/day

4.4.3 Hot Water Measure Results

Weather-adjusted savings of hot water energy use averaged 0.4 kWh/day, or 3.8%. Among the end-uses analyzed, seasonal variation in hot water use is most notable, reducing monitored savings by 10.1%. This savings reduction is expected as the inlet water temperature generally increased between pre- and post-retrofit periods. The hot water end-use reduction measures were significant at the 90% confidence interval 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 3.2% 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 generate savings are 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 is most impactful. This relationship of total and relative end-use impact is graphically displayed in Figure 16. This chart shows us that the savings associated with the individual shallow retrofit measures are only about half of the whole-house savings achieved by the retrofit. The interaction between the shallow retrofit measures and other end uses are evaluated in sections 4.7 and 4.8.

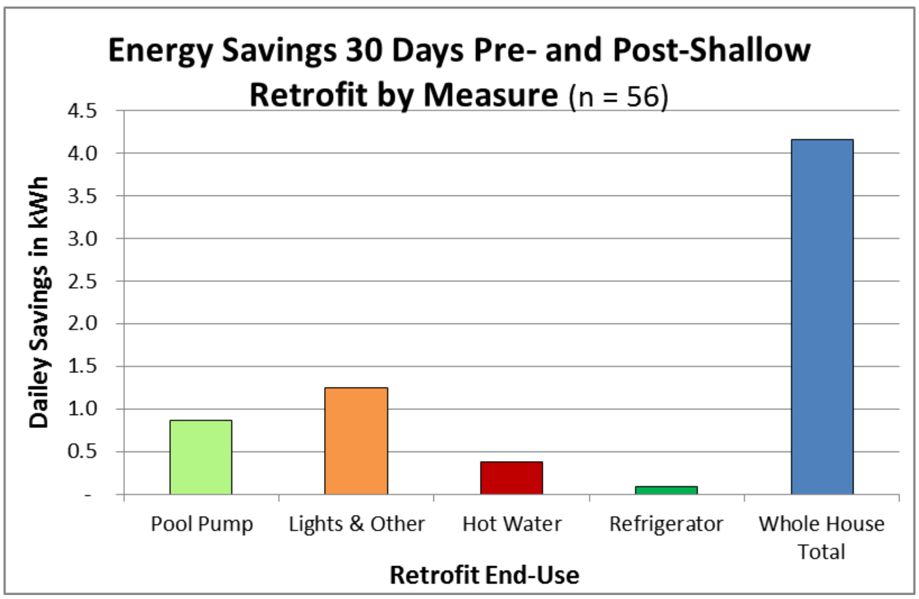

Figure 16. Average energy savings by measure: 30 days pre- and 30 days post-retrofit for all shallow retrofits

4.4.5 Smart Power Strip Measure Results

Because the APS was installed in so few homes, we present the savings impact from this measure independently from all other measures. A summary of the savings achieved by the two smart power strip installations are shown in Table 13. The installation at Site 5 involved a television serving as the master device, controlling a DVD and a home video game console which combined had low power modes between 4 and 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 controlling a subwoofer with a 20 watt low power mode, which yielded an average daily savings of 0.70 kWh, or 15% over pre-retrofit.

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

Site Number	Standby Losses (watts)	kWh/Day Pre-Retrofit	kWh/Day Post-Retrofit	Savings Avgerage Daily kWh	Savings Estimated Annual kWh	Savings %
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 the 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 comparing their bills, we evaluated the month of October, prior to 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 vs. October 2013. The sample size was limited to homes fully monitored by October 1, 2012 and excludes deep retrofit sites. October has been selected among the few months with many homes monitored by October 1, 2012 and for its typical Florida weather behavior. With little cooling and no heating in October, this investigation essentially excludes 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.

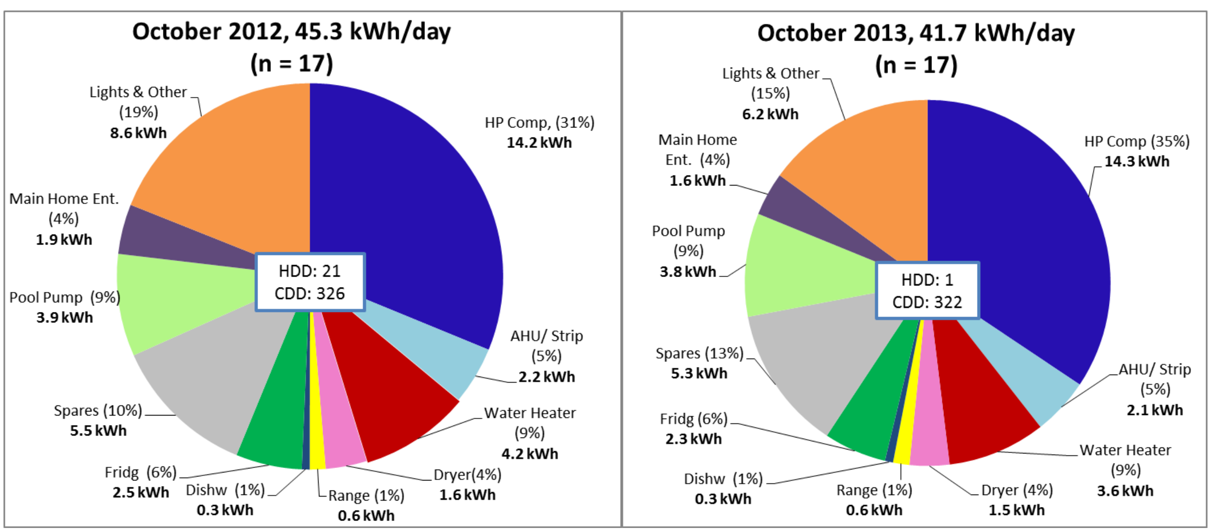

Figure 17. Average end-use load profile in shallow retrofit sample, October 2012 versus October 2013

Average end-use savings between the two years vary from our normalized 30-day pre- and post-retrofit methodology above; 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 and cooling degree days (HDD and CDD) within each pie chart.)

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

While the average daily savings for water heating is similar in both analyses, pre-retrofit water heating is significantly higher in the previous analysis, as expected given the general time of year, diluting the percentage savings. We would expect, however, average daily savings to increase with a larger pre-retrofit period end-use. Meanwhile, the pool pump circuit savings comparing October 2012 to October 2013 was substantially lower, with 0.1 kWh/day, or 2.6%. This is quite different from the preliminary analysis showing 2.7 kWh/day savings, or 15.9%. This may be due to lack of persistence to 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 of total and relative end-use impact is graphically displayed in Figure 18. Summing the measure savings is approximately equal to whole-house savings, a notable difference between this chart and Figure 16.

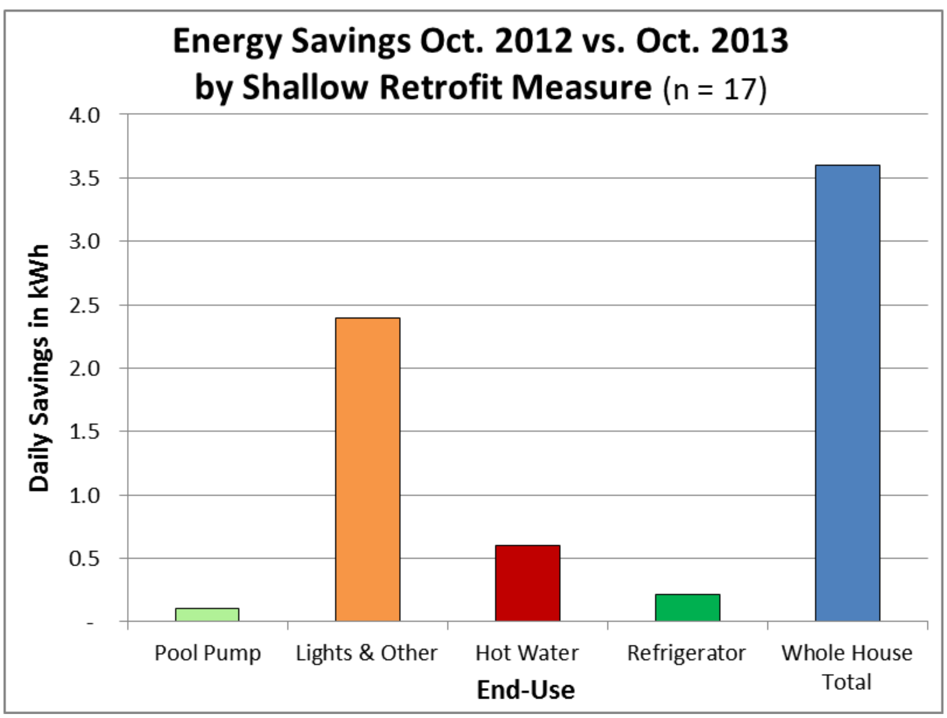

Figure 18. Average energy savings by measure, October 2012 vs. October 2013, for 17 shallow retrofit homes

4.6 Cost Evaluation

A summary of labor and materials cost associated with the shallow retrofit 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, black text) for the lighting, showerhead, and smart strip measures. The averages, minimum, maximum, and standard deviations (std) relate to all sites where the measure were conducted.

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

		Lighting Change-out (n = 55)				Showerhead Replacement (n = 26)				DHW Insul. (n = 52)	Smart Power Strip (n = 10)				Fridg 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 Hours	**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**
	Min		1.00	0.50	**0.25**		0.25	0.25	**0.25**	**0.00**		0.25	0.25	**0.25**		**0.50**	**0.25**	2.00	1.00	**1.00**
	Max		12.00	5.50	**8.00**		1.50	1.50	**0.50**	**1.50**		1.25	1.00	**0.50**		**1.50**	**0.25**	15.00	6.25	**9.50**
	std		1.96	1.12	**1.17**		0.26	0.21	**0.10**	**0.38**		0.26	0.21	**0.08**		**0.23**	**0.00**	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**
	Min	1			**$3**	1			**$9**	**$6**	1			**$32**	1					**$10**
	Max	81			**$611**	3			**$72**	**$39**	2			**$74**	3					**$690**
	std				**143**				**18**	**9**				**17**						**154**

The shallow retrofits were completed in four hours, on average, ranging from 1.0 to 9.5 hours. Including research and assessment time, the average field time is nearly double. Materials cost associated with the retrofits only, averaged over all sites, were $253. Segmented by measure, spread among only sites given the specific measure, averages are $214 for lighting, $31 for showerheads, $23 for the thermal tank wrap and pipe insulation, and $42 for the smart power strip.

For the sake of cost/benefit analysis, we again assume a rate of $30/hour for the retrofit labor and energy costs of $0.12/kWh. Assessing the cost-effectiveness of the retrofit package, labor costs are $121 (4.04 hours x $30). Adding this to the average materials costs of $253, the average total cost for the retrofit is $374. Using the 30-day pre- and post- retrofit analysis savings estimation (4.2 kWh/day), simple payback is 2.0 years; while 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, 2.0 weeks and 1.8 year simple payback
- Smart Strip: $32 per site cost, 1 and 3.5 year simple payback for each installation[4]

4.7 Pre- and Post-Retrofit Utility Data Analysis

Given their modest nature, the shallow retrofits may not provide savings large enough to be visible to homeowners examining 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.[5] Weather-adjusted savings projections were estimated in two ways:

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

We briefly describe our approach and results.

4.7.1 Utility Data Weather Normalization and Disaggregation

To weather-normalize utility data, we first projected energy uses for cooling, heating, and baseload – the amount of energy consumed for all other end uses. 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 both pre and post-retrofit periods for each home (Agnew and Goldberg 2013).

Model results provide 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.

Several years of homeowner-released utility data were provided by FPL, from which we selected 12 months preceding and 12 months following each study home's retrofit. Heating Degree Days (HDD), Cooling Degree Days (CDD), and a *holiday dummy variable* were the independent variables matched to the utility bill periods, and are described next.

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 geographically close to the study homes (National Oceanic and Atmospheric Administration 2014). Typically, HDD and CDD calculated in °F are the delta between average daily exterior temperature and a base temperature of 65°F (relating to an

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

[5] Of the 56 homes remaining in the study post-retrofit, two more were lost before a sufficient number of post-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.

interior set point). We generated HDD and CDD using hourly rather than daily exterior dry bulb temperature for more precise projections. Aiming to improve our models further, we varied the base temperatures for HDD and CDD from 60° to 70°F, attempting several combinations, to match the characteristics of each home and for each 12-month period. When 65°F is not the best base temperature, it often indicates interior thermostat set points higher or lower than typical were maintained. Not surprisingly, we found, some study occupants like it warmer both in summer and winter while others prefer cooler temperatures throughout the year. Finally, still others tend to be conservative, 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 as some homes hardly do any space heating in Florida's mild winters. For these cases, HDD was excluded when it weakened the model.

Allowing for heighted 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 ≥ 0.85), 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, providing 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, characterizing pre-retrofit space heating and cooling, and baseload electricity. The shallow retrofit at Site 9 included a 71% lighting retrofit for a 50% connected lighting kW 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 $R^2 = 0.95$) is evident from the close alignment between 'Predicted' monthly use (green diamonds) and the monthly utility data ("FPL", orange circles). Projected space cooling and heating energy use are the solid-fill sections in blue and red, respectively. The monthly baseload prediction is the flat purple line.

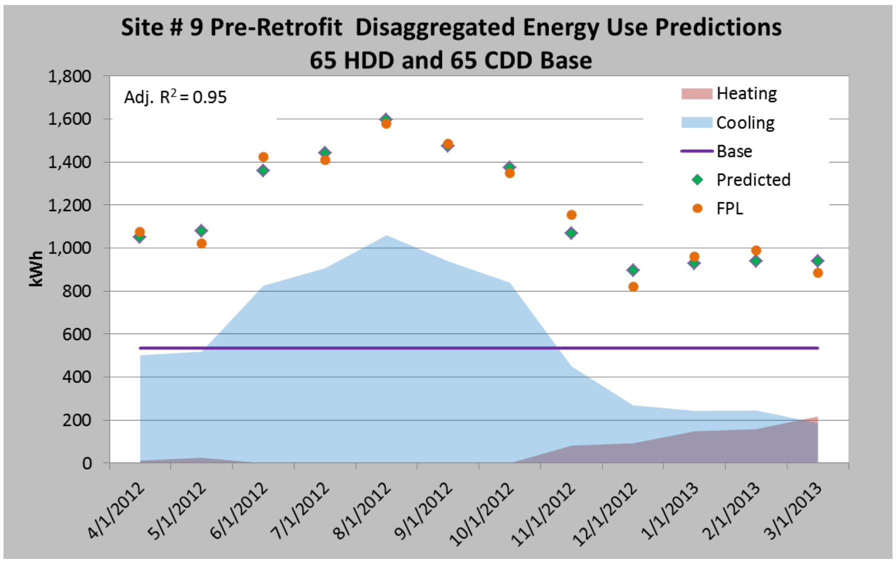

Figure 19. Site 9 Pre-retrofit space heating and cooling, and baseload characterization

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 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. Comparing Figures 19 and 20 we see baseload energy use is also noticeably reduced by the shallow retrofit.

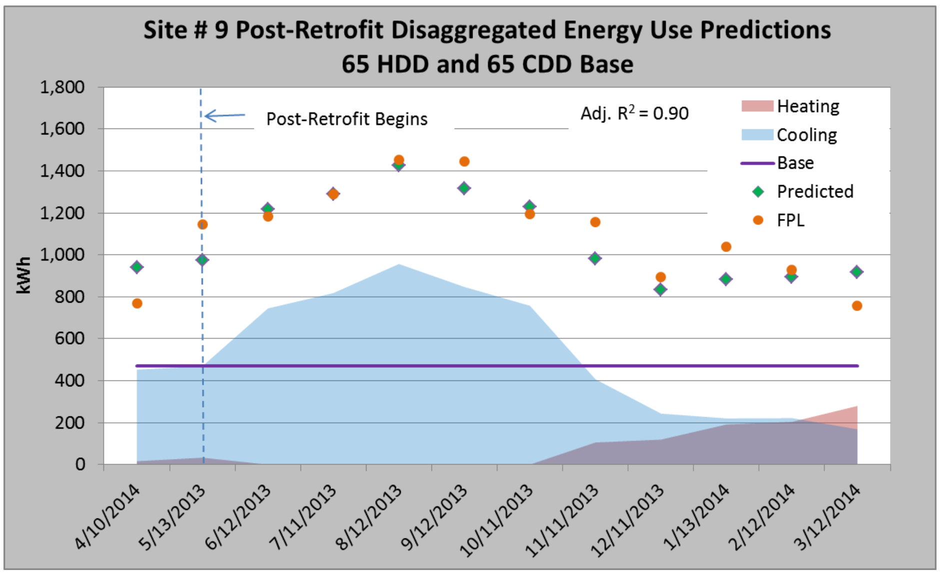

Figure 20. Site 9 Post-retrofit space heating and cooling, and baseload characterization.

A summary of the total and end use energy projections for the shallow retrofits in Site 9 are given in Table 15. The annual post-retrofit reduction in baseload energy use is representative of our 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 dataset as discussed below. Space cooling energy use was reduced by 682 kWh (1.9 kWh/day; 10%). While utility bills presented a savings of 6% between years, 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 Pre- and Post-Retrofit Heating, Cooling, and Baseload Projections Normalized to Pre-Retrofit Weather

Annual Energy Use	Utility Bill	Normalized Projection			
Site 9	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
kWh Savings	1,667	1,247	775	(210)	682
Percentage Savings	12%	9%	12%	-28%	10%

Our evaluation of the entire sample is shown in Table 16, a summary of the results for all 41 shallow-retrofitted homes analyzed. Overall, the more severe post-retrofit weather eroded one-fourth of the actual whole-house energy savings; the average annual post-retrofit energy bill reduction was 1,030 kWh (2.8 kWh/day; 7%), while the weather-normalized annual post-retrofit energy savings was 1,356 kWh (3.7 kWh/day; 9%). This becomes our 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.

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

Annual Energy Use Averages	Utility Bill	Normalized Projection			
(n = 41)	Total	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
Percent Savings Overall	7%	9%	10%	-78%	16%

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. Recall the shallow retrofit measures targeted energy used for lighting, water heating, refrigeration, plug loads, and pool pumps. Space heating and cooling energy were not directly addressed. Yet, our results show robust post-retrofit cooling energy reduction as well as a clear heating energy increase. The annual space cooling energy savings projection is 1,353 kWh (3.7 kWh/day; 16%), and annual space heating energy loss 629kWh (-1.7k Wh/day; -78%).

These changes are most likely effects of the lighting retrofit, where a large number of incandescent bulbs (~ 60 watts or 200 Btu/hr) were replaced with either CFLs (~15 watts or 50 Btu/hr) or LEDs (~9 watts or 30 Btu/hr). We changed an average of 35 lamps (56%) per home, with the connected lighting load changing 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/hr – a large change in the level of heat released to the interior.[6] In our sample, the post-retrofit annual cooling energy use savings average (1,353 kWh) is 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/yr) is lost by the increased post-retrofit space heating energy (629 kWh/yr). This occurs because the heat previously released from incandescent fixtures being reduced leads to lower cooling needs, but higher heating demand. The heating impact is particularly large for two reasons: some of the study homes have straight cool AC with strip electric resistance heat and 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 less than the COP of the cooling

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

system in operation and many systems use resistance strip heat with heat pump operation, particularly on start up during mornings after a nighttime temperature setback.[7]

4.7.2 TMY3 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 Typical Meteorological Year 3 (TMY3) weather data.[8] This allows extension of the savings estimates to the various climate zones typically used by FPL for forecasting purposes.

The pre- and post-retrofit regression results from the weather-normalization evaluation above were applied to TMY3 weather to predict space heating and cooling energy use for both the pre- and post-retrofit periods. As before, hourly dry bulb temperature data (from TMY3) were used to create HDD and CDD. 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 prior 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. 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	%	10%	10%	-155%	16%	
	kWh	1,985	632	(231)	1,584	0.4319
W Palm	%	9%	10%	-109%	17%	
	kWh	1,693	632	(451)	1,512	0.2243
Ft Myers	%	10%	10%	-124%	17%	
	kWh	1,802	632	(356)	1,526	0.1921
Daytona	%	3%	10%	-100%	19%	
	kWh	717	632	(1,137)	1,222	0.1517
Weighted	**%**	**9%**	**10%**	**-130%**	**17%**	
	kWh	**1,692**	**632**	**(442)**	**1,502**	

Again, we see the large interaction effects 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 larger in Daytona where the increase in post-retrofit space heating needs (1,137 kWh/yr) nearly erodes all the space cooling savings (1,222 kWh/yr), 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 heat loss. Projected savings from the shallow

[7] For instance a SEER 12 Heat Pump (COP= 3.5) might have an HSPF 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/

retrofit package is 10% in Miami and Fort Myers; while package savings in West Palm Beach is slightly lower, at 9%.

Weighted to weather-adjust results across the FPL service area, annual space heating energy use is increased by 442 kWh – almost negating annual baseload savings (632 kWh) – but annual space cooling energy is significantly reduced (1,502 kWh). Overall, characterized with TMY3 weather and weighted across the FPL service areas, we project annual shallow retrofit savings of 1,692 kWh, or 9% with large interactions with heating and cooling.[9]

4.8 Hourly Space Conditioning End Use Analysis

In this section we discuss the method and results of the monitored space heating and 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 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 coefficients of determination (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 air conditioning use for heating versus cooling, condenser and air handler energy use coincident with outdoor temperatures above 65° F was assumed to be cooling energy, while space conditioning when outdoor temperatures were below 60° F was interpreted as heating energy.

Monitored pre- and post-retrofit hourly energy use for the condenser and air handler were aligned with hourly outdoor temperatures for each site analyzed. We 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:

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

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 portion of space conditioning (constant)

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

Four temperature profiles were used to predict savings:

1. Normalizing post-retrofit models to the average outdoor temperature in the pre-retrofit analysis period.

2. Normalizing pre-retrofit models to the average outdoor temperature in the post-retrofit analysis period.

3. 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 both the pre- and post-retrofit models. [10]

4. 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 both pre- and post-retrofit models.

When observations were plentiful, hourly predictions for each site were created then averaged for final predictions. Where 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.

While the shallow retrofit did not directly target space conditioning energy reductions, utility data analysis results point to increased heating energy use and reduced cooling energy use as impacts of the shallow retrofit. The probable cause of these effects is the lighting retrofit which 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/hr.[11]) To investigate this effect further, we analyzed the space heating and cooling energy use impacts of the shallow retrofits using monitored data. The end use monitoring data allows more specific insight to the space conditioning changes coincident with the shallow retrofits.

The degree of lighting retrofit varied greatly by site so for consistency we evaluated the same study homes for space heating and space cooling energy changes. The number of 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 time outdoor temperatures reached 89-90°F, a threshold warm enough for modeling to represent hours with significant cooling needs. Two of the twelve 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 skew results. Ultimately nine homes were suitable for evaluation.

The pre-retrofit cooling period was limited to seven 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 varies from early summer when an

[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 X 3412 / 33% = 1,580 Btu/hr.

air conditioner has less latent load to control. Consequently, including the earlier summer data for the post-retrofit modeling would invite bias. Space heating observations were only limited 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. We emphasize that 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, we 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 average TMY3 cooling season profile. Since 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.

Results for the projected shallow retrofit space cooling energy savings using nine sites are in Table 18. The projected daily air conditioning 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 was 16% and 17%, respectively.)

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

Shallow Retrofit Cooling Analysis Normalization Weather	Daily				Peak Hour (15:00 - 16:00 EST)			
	kWh			%	kW			%
	Pre	Post	Delta	Savings	Pre	Post	Delta	Savings
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%
TMY3 Peak, Weighted	N/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 (15:00-16:00) 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. Note the post-retrofit daily cooling profile (dark blue) is well below 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.

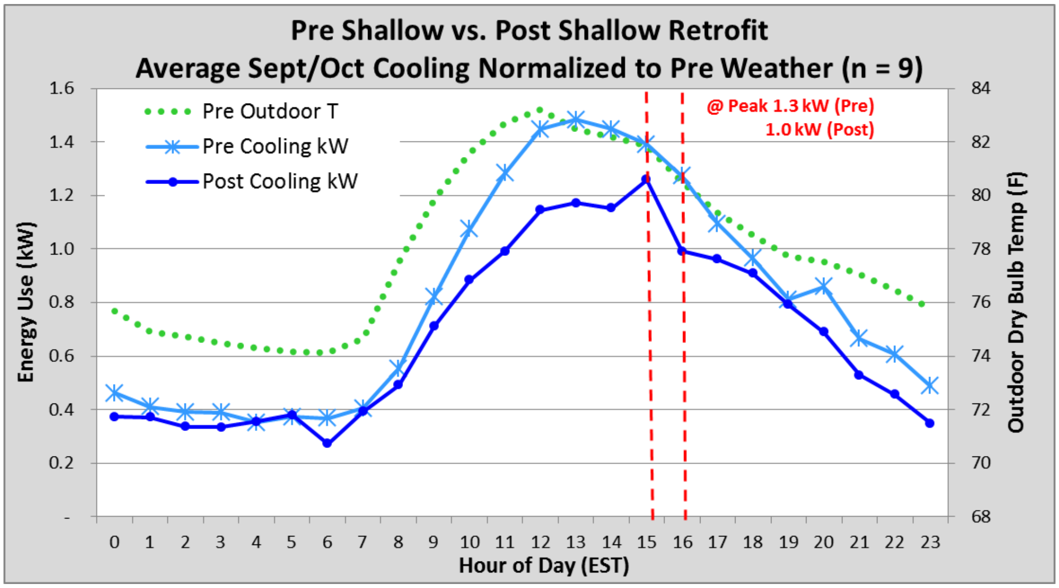

Figure 21. Pre shallow retrofit vs. post shallow retrofit hourly space cooling profile, pre-retrofit weather-normalized

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

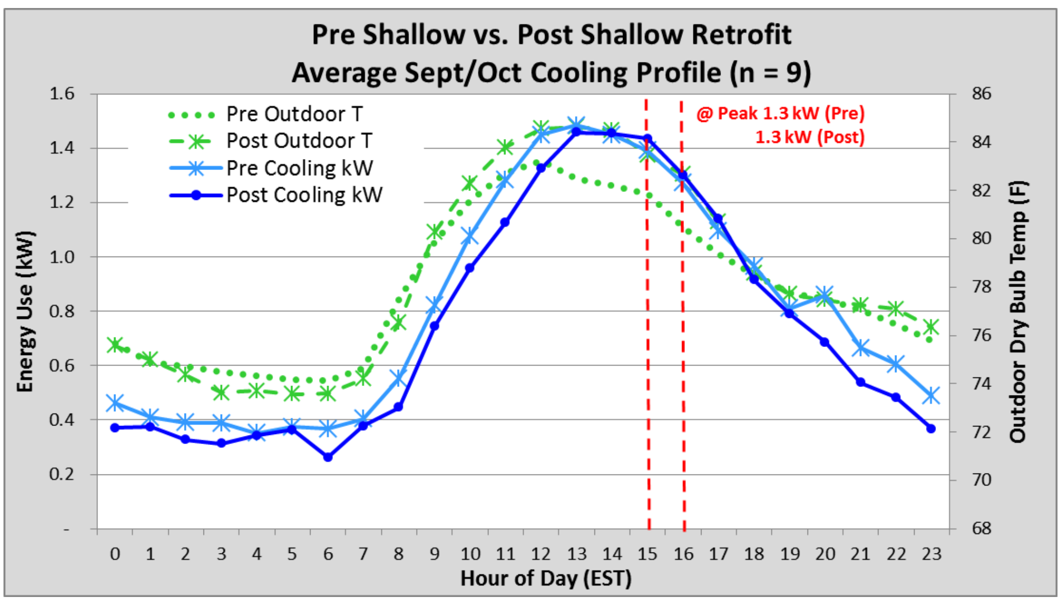

Figure 22. Pre shallow retrofit vs. post shallow retrofit hourly space cooling profile, non- weather-normalized

In the end, we note that given two very different analysis methods, we find that the shallow retrofits caused cooling energy to be reduced by 14-16% with 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, we compare 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 those years, as 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 PM. The energy use reduction for the day was 9%: 52.1 kWh pre and 47.4 kWh post.

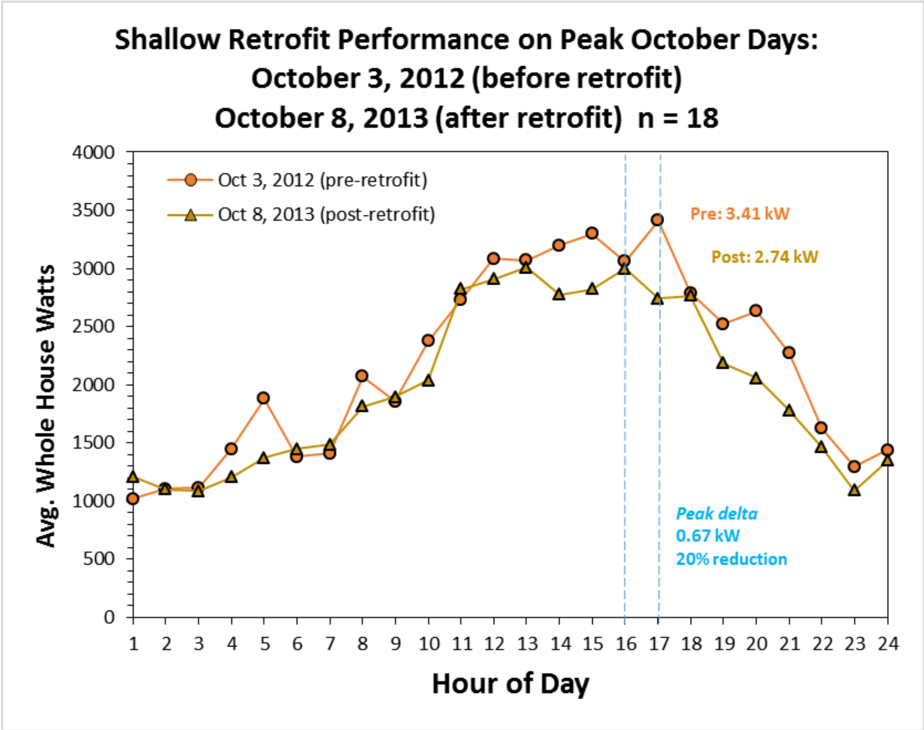

Figure 23. Comparative analysis between pre- and post-retrofit demand at peak day in October

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 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, we consolidated observations from all nine sites to develop each hourly model. While consolidating the sites improved the modeling, there remained a handful of negative energy predictions to correct. (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 end 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 as the average nearly cancels out all space heating in this climate.

Table 19 is a summary of 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, or 39%. In the right-hand section of Table 19 are the peak hour (7:00-8:00) 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. Pre Shallow vs. Post Shallow Retrofit Daily and Peak Hourly Heating Energy Savings Evaluation Summary

Deep Retrofit Heating Analysis Normalization Weather Profile:	Daily				Peak Hour (7:00 - 8:00 EST)			
	kWh			%	kW			%
	Pre	Post	Delta	Savings	Pre	Post	Delta	Savings
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*							
TMY3 Peak, Weighted	20.6	28.7	(8.1)	-39%	2.04	2.67	(0.63)	-31%

* Averaging the TMY3 heating season removes the need for heating in this climate.

While the utility data disaggregation and hourly end use model projections agree that space heating energy use increased after the shallow retrofit, they disagree on the extent of change. However, we believe this limited-sample analysis is inherently less reliable since the utility disaggregation evaluated 41 homes, while 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, we do conclude that lighting retrofits will have strong impacts on space heating needs—a fact predicted by analysis using the BEopt 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, there is a discernable increase in the energy used in the late afternoon and early evening, generally when occupants are returning home and lights are turned on. The negative savings at the peak hour (red, vertical, dotted lines) is relatively small. Reference Appendix C for the shallow retrofit heating energy use projection plots for all temperature profiles.

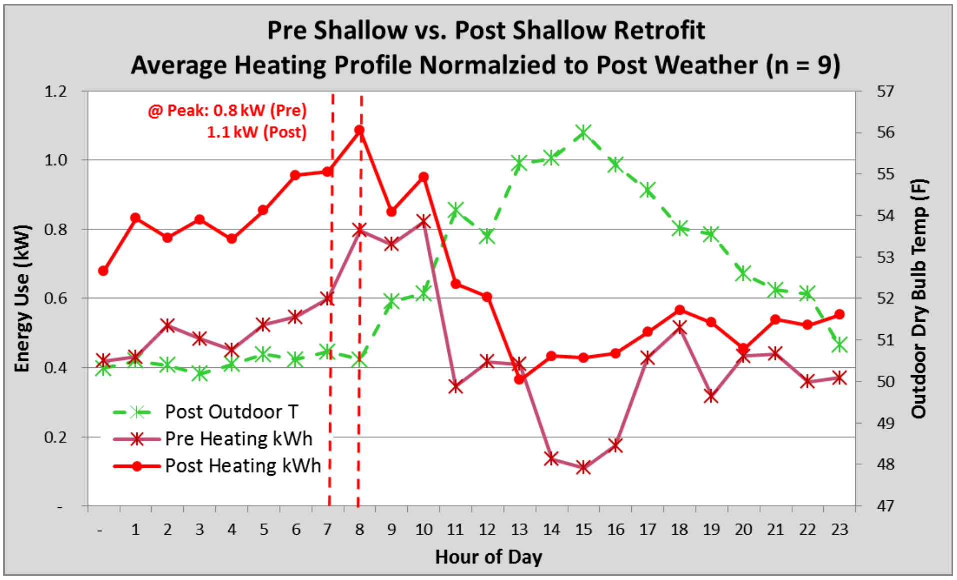

Figure 24. Pre shallow retrofit vs. post shallow retrofit hourly space heating profile, post-retrofit weather-normalized

4.8.2.1 Whole-House Winter Peak Demand Reduction

In a separate investigation of the shallow retrofit's impact on peak winter hour, we compare the average whole-house power at the FPL system peak hour in 2013 (March 4th) to that of 2014 (January 23rd). 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 AM of 0.25 Wh. However, there are larger, distinct post-retrofit energy demand increases in the hours before and after the peak. Daily energy use increased 8% (49.7 kWh pre, 53.6 kWh post), which substantiates earlier findings that the post-retrofit space heating energy use increased after the shallow retrofit.

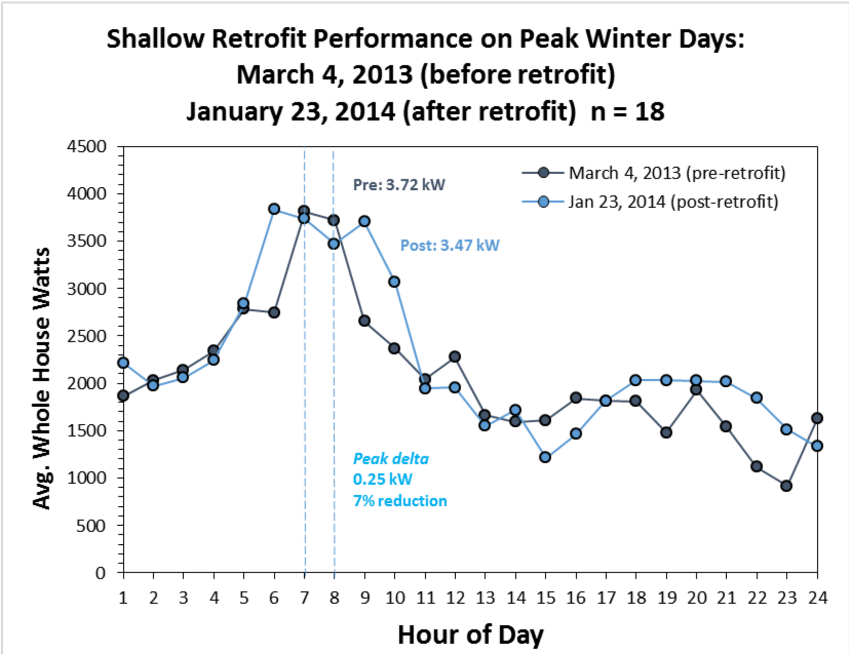

Figure 25. Comparative analysis between pre- and post-retrofit demand for FPL system peak winter day

The simple tank and pipe insulation wraps and shower head replacements created large domestic hot water energy demand reduction in the morning and evening hours, as shown in Figure 26.

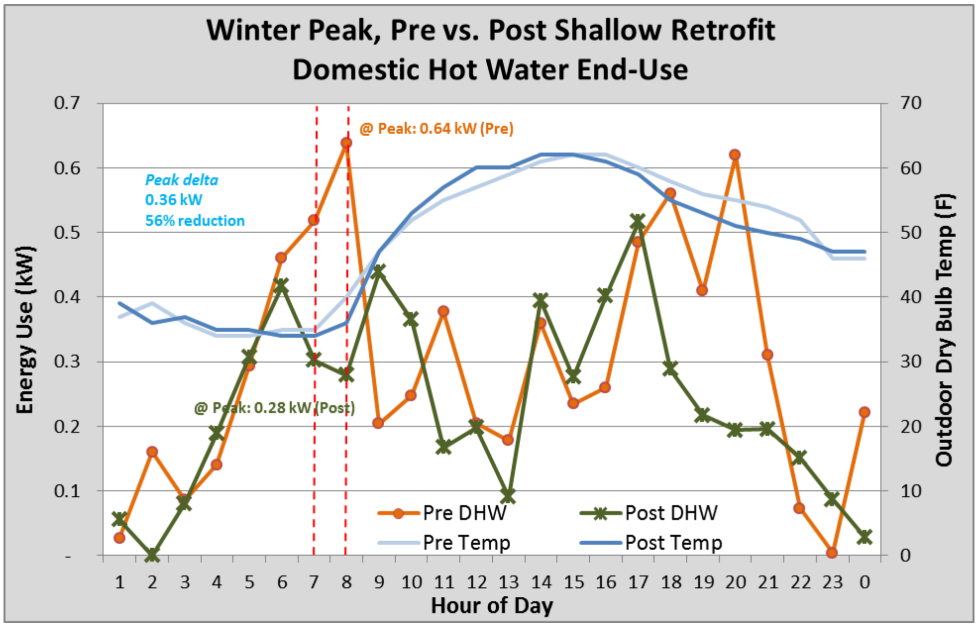

Figure 26. Pre- vs. post-retrofit domestic hot water demand for FPL system peak winter day

4.9 Shallow Retrofit Discussion

One issue regarding customer expectations with the shallow retrofits is illustrated in Tables 9, 11 and 16. In Table 11, for example, the whole-house savings level is small enough (9.2% of pre-retrofit consumption) that focus on the overall billing data before and after the retrofits, which rose 9.3% during this period, will not reliably reveal the savings. Note that the average total monitored consumption was 3.2 kWh higher in the month post-retrofit than the one before it. This is because the retrofits in this pilot were being completed in spring or early summer, when air conditioning is increasing. The rising level of space cooling in the post-retrofit period generally over matched 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 month). We conducted two pre- to post-retrofit evaluations to consider this effect:

1. We examined 12 months of utility records, disaggregated by space heating, space cooling, and baseload.

2. We analyzed hourly space heating and cooling end use data as it related to exterior temperatures.

For a subset of homes, we compared the same calendar month of different years, one pre- and one 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, we have better confidence regarding long-term impacts of a retrofit measure.

For the pool pump timer intervention, we found pronounced evidence of return back to pre-retrofit energy use over the long-term. Likely pump timers have been 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 run-time 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. We conclude that while changing pool pump hours can reduce pool pump energy substantially over the short-term, that this measure is not persistent as hours will often return to pre-intervention levels. For effective reduction of pool pump energy, we suggest that substitution of variable-speed pool pumps, described in the deep retrofit section of the report, is 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 is providing substantial cooling energy savings in the summer, while also increasing heating energy needs in the winter. For Florida's cooling-dominated climate, this provides a significant net savings. The utility data analysis predicts that the study homes experienced an annual net space conditioning energy reduction of 724 kWh, averaging 2.0 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. We also used this analysis to demonstrate the importance of weather-normalization, where we compared Figure 21 to Figure 22 to show post-retrofit cooling savings entirely eroded by warmer post-retrofit weather. If only comparing utility bills, customers may not believe they are achieving savings when real savings actually exist.

4.10 Summary and Potential Improvements

Following is a summary of the impact of installed shallow retrofit results in our Florida sample of existing homes:

- Adjusting for weather-related changes over the 30 days prior to and after the shallow retrofit, savings of the overall shallow retrofits in homes averaged 4.2 kWh/day or 9.2% of pre-retrofit monthly consumption. Comparing pre-retrofit October to post-retrofit October for a subset of the dataset, savings averaged 3.6 kWh/day or 7.9% of pre-retrofit monthly consumption. Simple payback for the shallow retrofit averaged 2.0 years given the savings estimate from the initial savings evaluation, while 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, while in the 2012 vs. 2013 October analysis reported even

greater savings, 2.4 kWh/day (453 and 874 kWh/yr, respectively). Simple payback for the lighting averaged 4.9 and 2.7 years, depending on which saving evaluation is used.

- The shallow retrofit caused significant changes to space heating and cooling energy use. We presented strong evidence that the lighting retrofit's reduction in heat gains is the cause. The utility data disaggregation, evaluating 41 of the shallow retrofit homes, found annual space cooling decreased by 1,353 kWh (16%) when normalized to pre-retrofit weather. Meanwhile, the evaluation predicts that post-retrofit annual space heating nearly doubled, with 629 kWh negative savings. The predicted annual baseload savings of 632 kWh are about half the space cooling energy savings. Normalized to TMY3 and weighted by FLP service areas, the annual predictions are 1,502 kWh for space cooling energy savings and negative savings of 442 kWh for space heating energy.

- The space heating and 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. Meanwhile, negative space heating savings ranged from 0.29 to 0.63 kW.

- Potential savings from reducing pool pumping hours appears large, but may be difficult in practice to achieve. In the 19 pool homes in our sample, nine were already operating less than five hours/day and were not altered. Savings in the 10 homes where hours were reduced each saved an average of 4.6 kWh/day. However, the intervention appears to have been short-lived for many homes. The savings observed during the immediate post-retrofit analysis for this end-use was markedly diminished in an evaluation using a post-retrofit period months after the intervention. Homeowner information may be useful, as most do not know that pumps are costing $50 a month when operated eight hours/day. We find that variable-speed pool pumps offer a better option to reduce pool pump energy.

- 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/yr, as reported in the prior and later analyses). Depending on which savings evaluation is 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, while largely disappearing 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. This is likely longer than the effective life of the measure, however.

- Finding good candidates sites for the smart power strip installation proved difficult. 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. In our small sample, we estimate 0.21 and 0.70 kWh daily energy savings.

- While savings from a shallow retrofit program in Florida are effective, reductions are small in magnitude, and customers may not see their impact when comparing month-to-month billing data.

5 Deep Retrofits

5.1 Background

Prior to measure implementation, pre-retrofit planning was required. 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. Implementation of the deep measures occurred largely between August and December 2013, while the project's final deep retrofit measure was completed in March of 2014.[12] The installation details for the high-efficiency heat pump air conditioners, smart thermostats, heat pump water heaters, ceiling insulation, and ductwork repair are described in Appendix D.

5.2 Space Heating and Cooling

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

The Heating, Ventilation and Cooling (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
- Test and sealing of duct work system

Only cooling is evaluated in this preliminary analysis which was conducted prior to Central Florida's short winter. At the time of analysis, the insulation retrofits were not yet installed in most cases, 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 cooling energy use.

Below, we used a standard format for describing each home and then analyzing the effect of the AC replacement and duct repair on measured cooling. We use regression techniques against the average daily air temperature and air conditioning use as well as the measured interior temperature by the thermostat. The statistical analysis is able to separate results from the AC retrofit and learning thermostat. Data and data analysis are graphically displayed. We show evaluation of three sites. One site shows small savings and negative savings from the learning thermostat (Site 7); another shows large savings and also savings from the learning thermostat (Site 19). Finally, we show Site 10 where a more efficient AC was installed, but no learning thermostat.

We then summarize key findings from each site in tabular form showing 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 square feet) with a relatively efficient existing 3.5 ton heat pump (2001 vintage) with an estimated SEER of 14. Their 2011 electricity consumption was 25,211 kWh. The existing heat pump was replaced with a 4 ton two speed SEER 16 Carrier 25HCB6 heat pump on September 24th, 2013. This was matched with a variable-speed FV4CNB006 air handler unit (AHU). At the same time, damaged segments of the duct system were replaced and the overall duct system sealed with a change in observed duct leakage with a Qn of 0.126 to 0.063. A learning NEST thermostat replaced the existing programmable thermostat located in the upstairs hallway of the home. As seen from earlier monitoring, the two occupants in the home prefer low interior temperatures during the cooling season.

The air conditioning energy use had been measured at Site 7 since project inception. From May 1 to September 23, 2013, average air conditioning energy use averaged 28.7 kWh per day (4,200 kWh) with the average house interior temperature maintained at 72.2°F (relative humidity averaging 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. Air handler, 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 air handler 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.

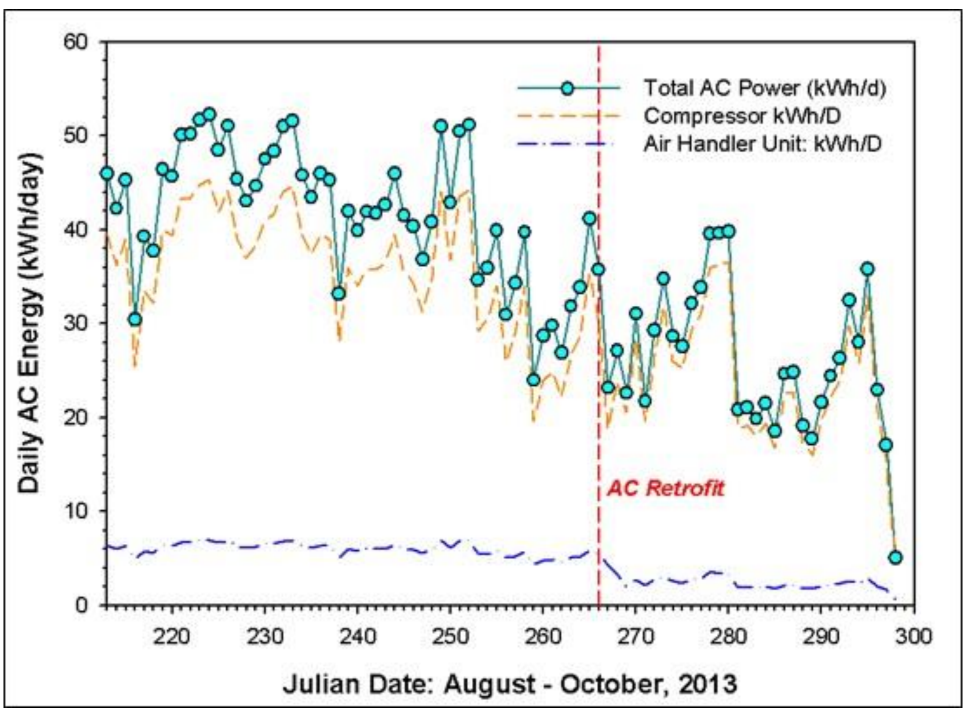


Figure 27. Site 7 air conditioning energy; pre & post retrofit July – October, 2013

Figure 28 shows that most of the changes seen in the weeks after the retrofit on September 24th, 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 degrees F (71.1°F).

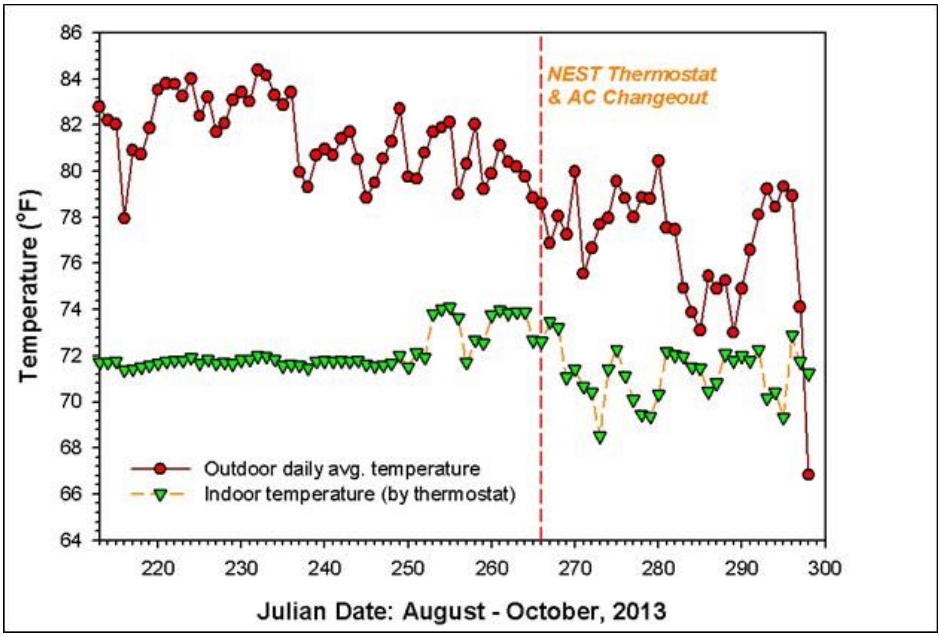


Figure 28. Site 7 average indoor and outdoor temperature July – October, 2013

To sort out the weather related influences, we assembled the summer pre- and post-retrofit daily air conditioning and then regressed daily air conditioning pre- and post-retrofit against the average daily air temperature. Figure 29 shows the results. Although with considerable scatter, the data show the expected weather related increases to cooling in hotter weather.[13] However, there is a relatively low indicated savings from the retrofit – about 2.6 kWh/day at 80°F – about 7%. Although not shown, examination of data showed similar compressor energy, but much lower air handler unit (AHU) electricity post retrofit.

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

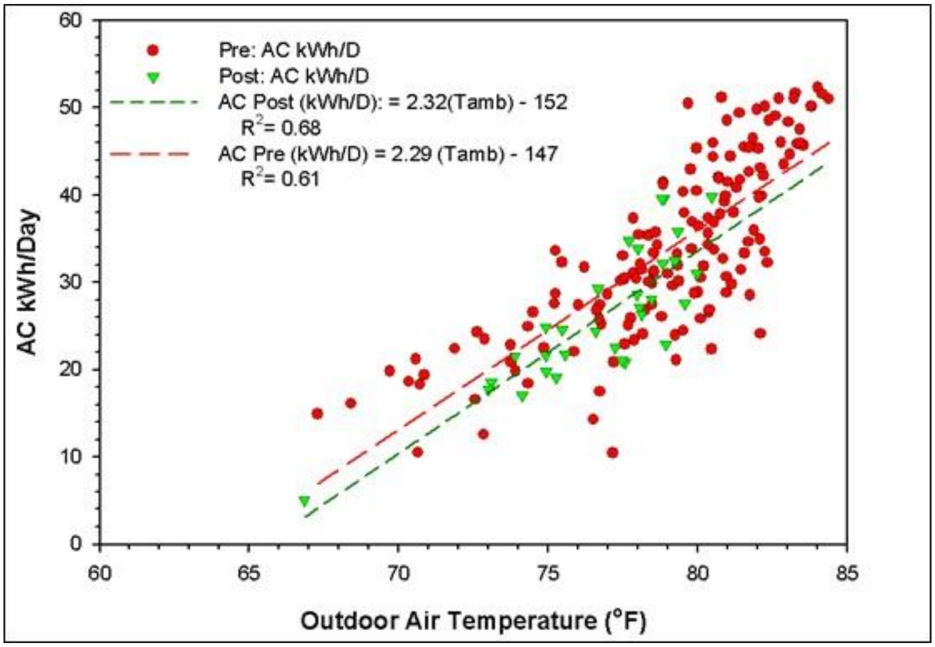


Figure 29. Site 7 average air conditioning vs. outdoor temperature July – October, 2013

As the interior temperature varied from pre to post period, we further examined the energy reduction with air conditioning plotted against interior to exterior temperature difference. The regression prediction is significantly improved, in particular for the pre-retrofit period. Figure 30 shows the new air conditioning system and ductwork repair is reducing cooling energy use by about 18% at a given interior temperature. However, most of this is being lost with lower maintained interior temperatures; pre- retrofit, at an average ambient temperature of 80°F, the temperature difference from inside to outside was 8.0°F; afterwards, the difference was 9.0°F.

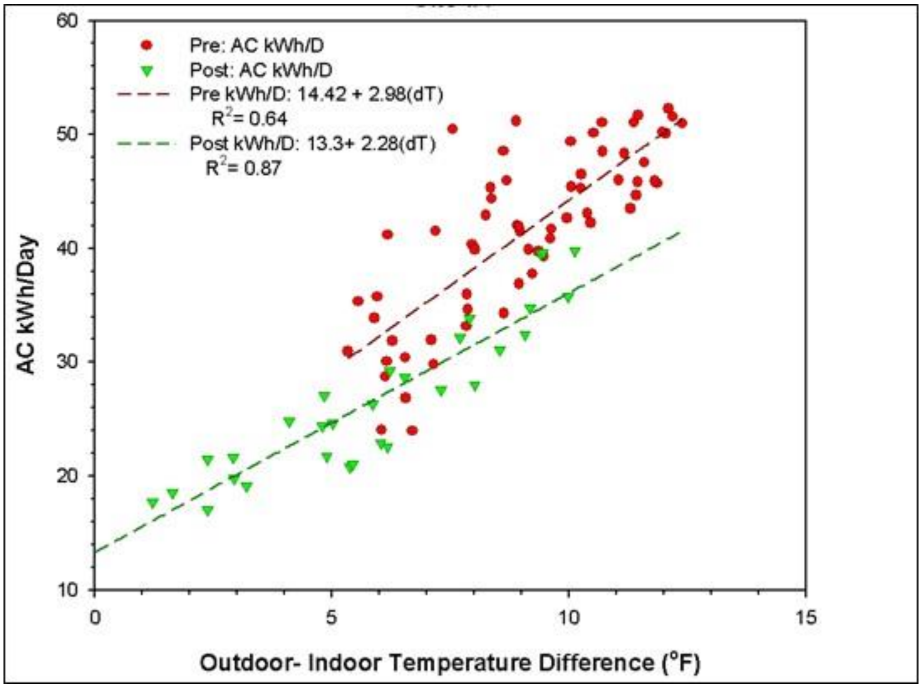


Figure 30. Site 7 average air conditioning vs. temperature difference July – October, 2013

The temperature corrected difference suggests 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% mostly coming from the more efficient variable-speed air handler blower. However, had temperatures been maintained the same pre and post, the regression indicated savings would have been 6.8 kWh/day (38.3 vs. 31.5 kWh/day) or 18%.While 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 appear to prefer an indoor temperature of approximately 72°F. However, after the NEST was installed, they chose to lower the average temperature by about 1.0°F which reduced indicated AC savings by about 6% (differences in the regressions above).
- The programmable thermostat in place prior to retrofit maintained a very constant and predictable temperature averaging 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, likely to compensate for its attempts to elevate the interior temperature to produce savings.
- As the learning thermostat was located in an upstairs hallway, the occupants frequently went upstairs to change its operation during the first weeks of use (the occupants specifically did not want the thermostat located downstairs where its occupancy related function would have been used). Moreover, the occupants opted to defeat its “auto-away” function, depriving the thermostat of a means of achieving savings.

In summary, there were no savings that could be attributed to the learning thermostat. In fact, the opposite appears to have been true (learning thermostat had negative savings) as 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 on 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 square foot home in W. Melbourne, FL built concrete block construction. It had the original 3-ton air conditioner from when the house was built in 2003 with a 12 SEER. The home’s electricity consumption in 2011 was 19,130 kWh, slightly higher than average.

The original heat pump system were 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 31st, 2013. The duct system was found to be 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 since the variable-speed Carrier unit uses its own special thermostat. The two adult occupants in the home maintain average cooling temperatures, but mentioned needing to achieve cooler temperatures than the old system could achieve.

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

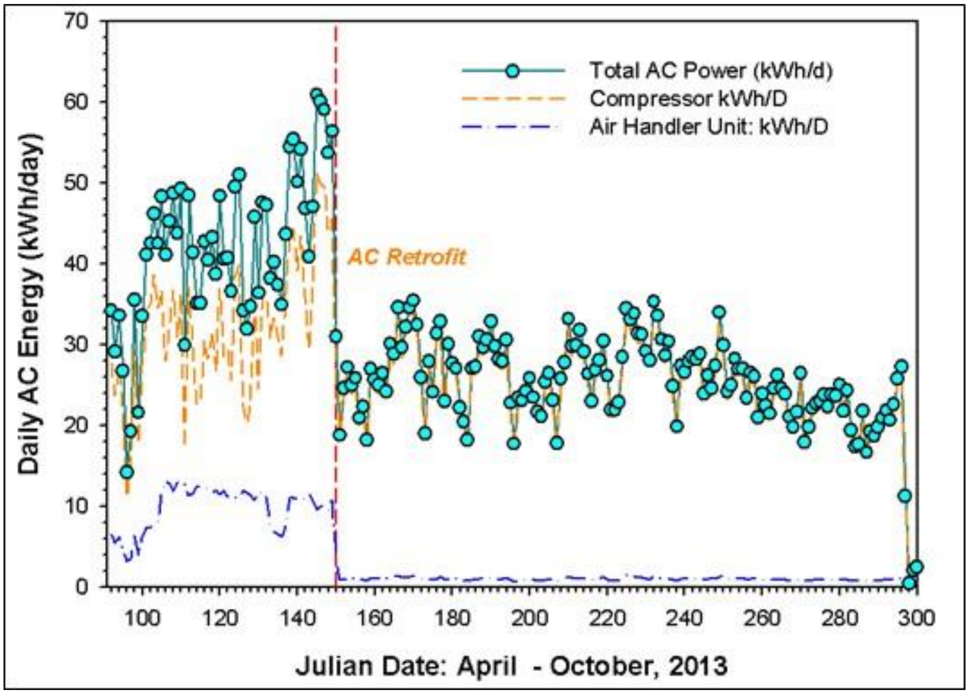


Figure 31. Site 10 air conditioning energy; pre & post retrofit April – October, 2013

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 indicating considerable take-back for comfort. The cooler interior temperatures are apparent after the retrofit.

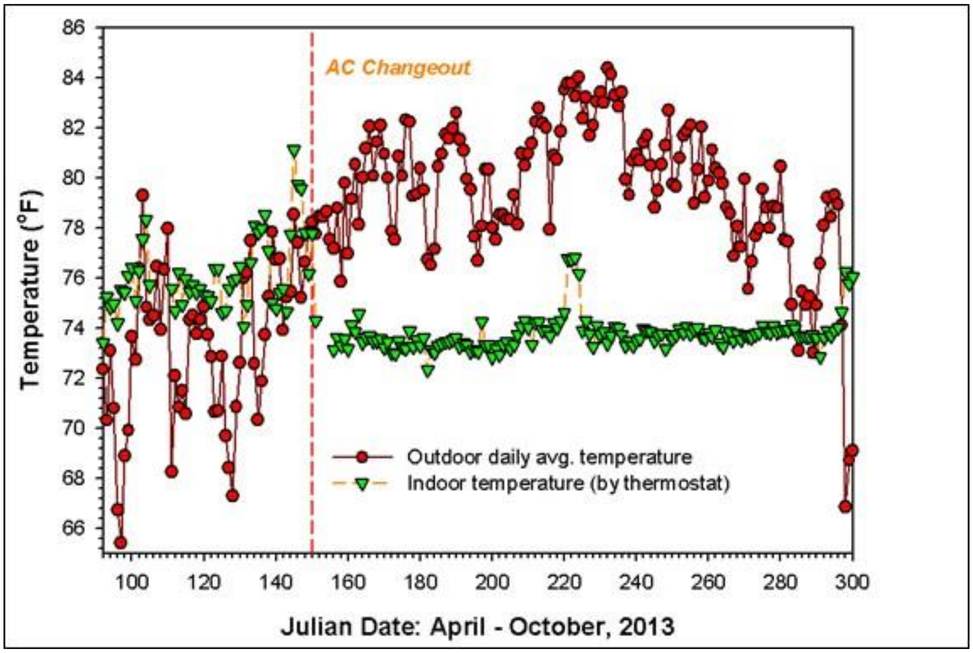


Figure 32. Site 10 average indoor and outdoor temperature April – October, 2013

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 there was an apparent savings of 31.6 kWh per day (57.7 kWh vs. 25.9 kWh/D) or about 55%.

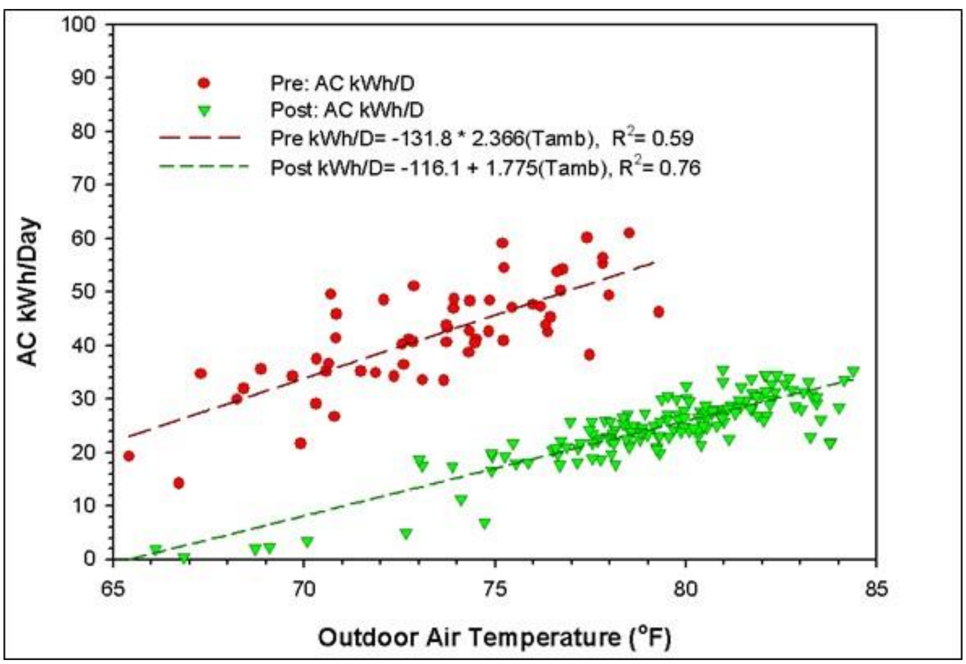


Figure 33. Site 10 average air conditioning vs. outdoor temperature April – October, 2013

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%.

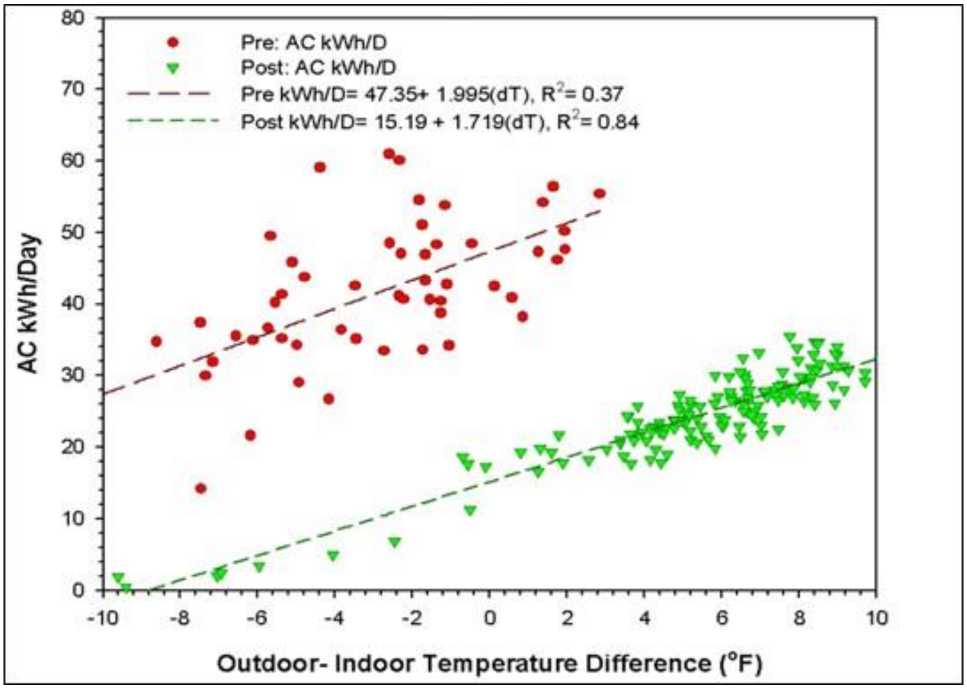


Figure 34. Site 19 average air conditioning vs. temperature difference April – October, 2013

However, the same regression suggests that if the temperature inside had been the same as it was before the HVAC retrofit, there would be 6.9 kWh additional savings per day. This indicates savings would have been 63% had occupant temperature take-back not taken place.

This specific case may suggest 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 square foot home in Melbourne, FL built in 1988 of concrete block construction. It had an aging 5 ton York air conditioner with mismatched components. The air handler unit is of 1990 vintage while the compressor was replaced in 1997. Given the mismatch, there is no nameplate SEER, but its efficiency is likely less than 10 Btu/Wh. The home's energy use is 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 two speed SEER 16 Carrier 25HCB6 heat pump on August 26, 2013. This is matched with a variable-speed FV4CNB006 air handler unit (AHU).

The duct system was found to be fairly leaky when evaluated. The original normalized leakage of Qn 0.092 and was reduced as the duct system was sealed with a test-out duct leakage was Qn,out = 0.054. A learning NEST thermostat replaced the existing programmable thermostat in the single story home. The three adult occupants in the home prefer slightly lower than average cooling temperatures.

The air conditioning energy use had been measured at Site 19 since project inception. From May 1to August 26, 2013, average air conditioning energy use averaged 59.4 kWh per day with the average house interior temperature maintained at 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. Air handler, compressor and total AC system energy are plotted. Energy use is dramatically reduced after the retrofit (26.5 kWh/day post retrofit).

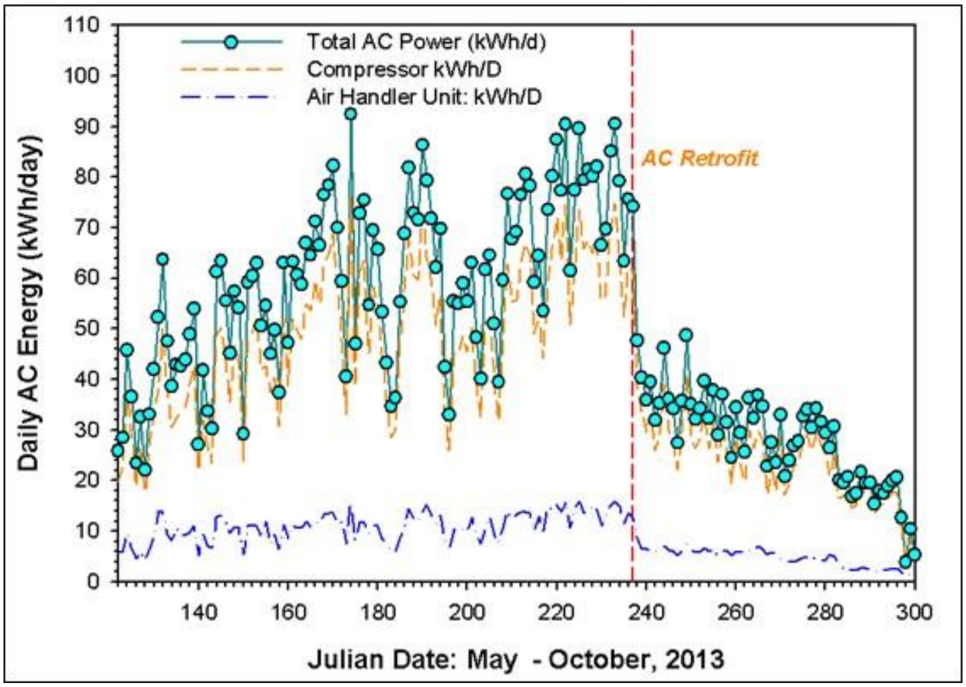


Figure 35. Site 19 air conditioning energy; pre & post retrofit May – October, 2013

There is a large apparent reduction in cooling energy use from week before to 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 August 26, 2013 are associated with a lower average outdoor temperature. Also, the occupants with the NEST learning thermostat maintained a very slightly higher temperature than before the retrofit.

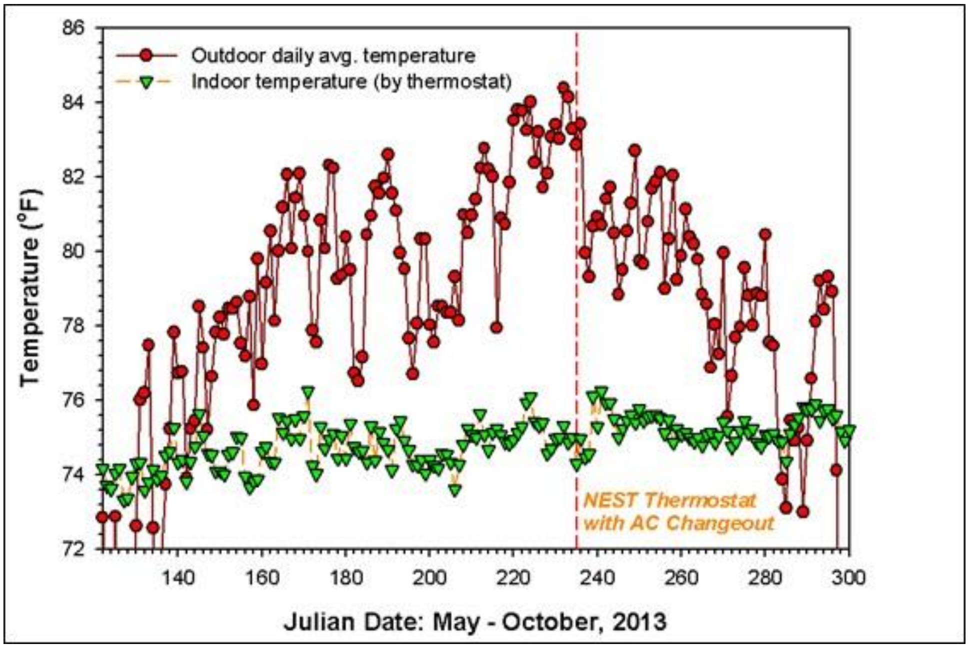


Figure 36. Site 19 average indoor and outdoor temperature May – October, 2013

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

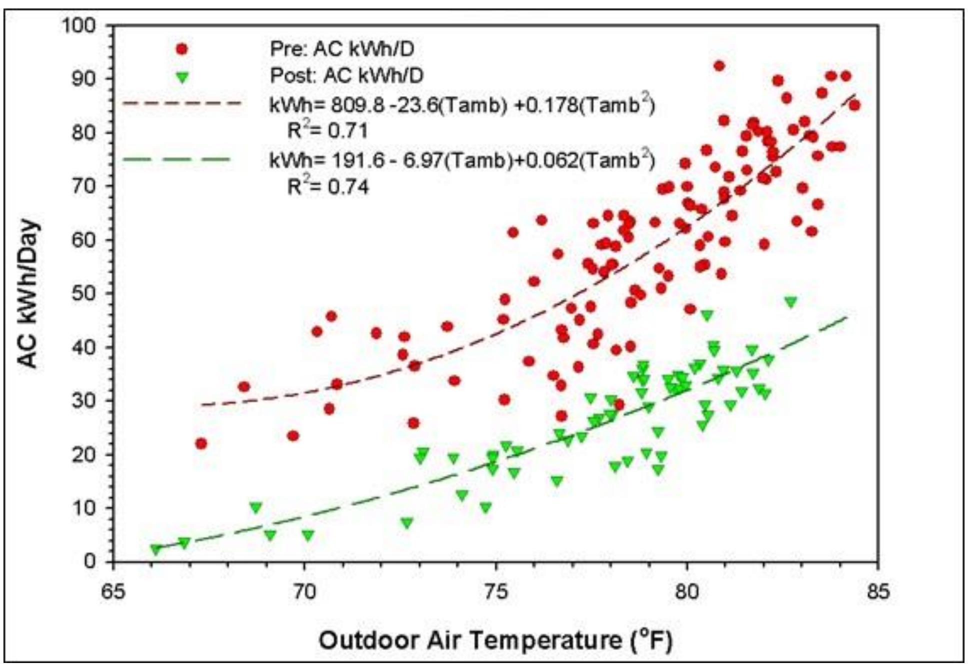


Figure 37. Site 19 average air conditioning vs. outdoor temperature May – October, 2013

We used quadratic regressions to estimate the daily pre- and post-retrofit air conditioning and how it varied with outdoor temperature. At 80°F, the regressions indicated 61.0 kWh pre-retrofit and 30.8 kWh after – 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, through examination of pre- and post-retrofit interior temperatures we attempted to separate out the savings attributable to the learning thermostat. In the month before the retrofit, the occupants maintained an average temperature 75.1°F; in the month average the retrofit, the interior temperature rose to an average of 75.4°F.

The regression differences between Figure 37 and 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 5.34°F (Pre) and 4.66°F (Post). The predicted consumption is 32.1 kWh/day for the post retrofit condition for a savings of 47%.

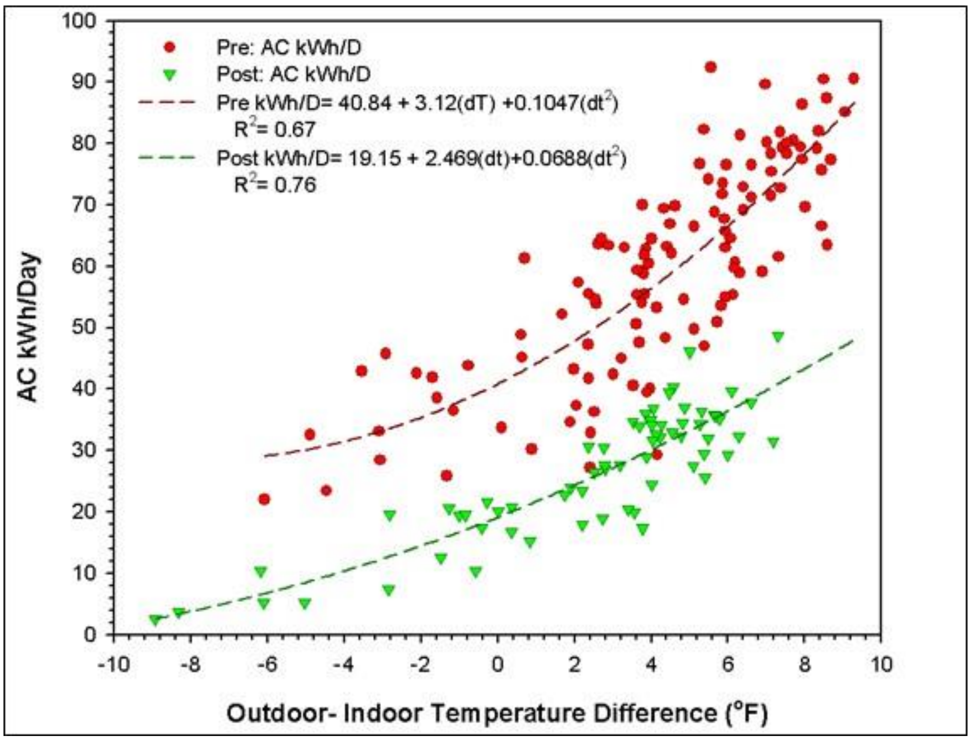


Figure 38. Site 19 average air conditioning vs. temperature difference May – October, 2013

If we evaluate both pre- and post-retrofit consumption at the post NEST temperature difference, the predicted pre 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 existing air conditioner or heat pump was replaced with a 3 or 4 ton two-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	Percent Savings (%)	HVAC Saved (%)	Thermostat (°F)		Temperature-Related	
						Pre-Retrofit	Post-Retrofit	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%	*
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%	**
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	37.0	39.5	76.8	75.9	-1.9%	-0.6%

* No learning thermostat installed
** 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. Using regression techniques with the outdoor weather and temperature maintained indoors we were able to separate out the influences of the AC retrofit and duct repair from the learning thermostat installation. We saw that the AC and duct repair saved an average of 40% of pre-retrofit consumption, but that lower temperatures were generally chosen, even with a learning thermostat so that 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. There were four of the nine NEST sites where there were post retrofit savings from the learning thermostat of 1 – 4%. However, these were marred by others with negative savings.

We do not know why sites chose lower temperatures post retrofit—although with Site 37 this came from improper instruction on learning thermostat operation (this site was eliminated from the computed averages). It is possible that the households chose a lower temperature to compensate for the learning thermostat attempts to raise the interior temperature. It is also known from occupant reported feedback, that Site 7 defeated the “auto-away” feature to prevent the thermostat from raising the interior temperature while they were not home.

It is important to understand the large limitations of this study relative to learning thermostats. A key limitation is that we cannot evaluate what learning thermostats will do to systems where the AC system is not being changed. AC retrofit may very well alter occupant expectations as with the large degree of temperature take-back seen at Site 10 may be typical. A previous study replacing five air conditioners with high efficiency units in 2001 showed an average temperature related take-back of 1.0°F (Masiello et al. 2004). This cannot known without further research – which we anticipate being able to attempt by a series of NEST-only retrofits to 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 heat pump hot water systems (HPWS), deep home retrofit HPWS were selected based upon occupancy of home, installed location (i.e. garage or home interior), and cost. Systems selected were the AO Smith Voltex® Hybrid Electric Heat Pump 80 and 60 gallon units, and the 50 gallon capacity GE GeoSpring Hybrid Water Heater.

Existing electric resistance water heaters were replaced with new heat pump water heaters in eight of the deep-retrofit PDR homes in Central Florida during September and October of 2013. A comparison of one year pre-retrofit and one 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, measured average savings for the eight homes was 68.5% (5.27 kWh).

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

Table 21. Measured Annual Heat Pump Water Heater Retrofit Savings at 8 Sites

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

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

Four homes received a 60 gallon HPWH and the other four 80 gallon units. Savings were generally higher with the 80 gallon units (which were installed in homes with higher water heating loads) averaging 73.8% with energy use reduced on averaged by 7.57 kWh/day. The 60 gallon 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 thirty 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 where resistance water heaters were unchanged serves as a control for normalizing to seasonal changes. Average energy use in the control group increased 4.4% when comparing the same thirty day period before and after the retrofit at each site. The increase in pre/post energy use accelerated from 0.9% to 7.0% over the six week period from early September to mid-October. Savings for the 80 gallon units averaged 69.5% (5.16 kWh/day) and the 60 gallon units averaged 61.4% savings (2.08 kWh/day).

Table 22. Measured Heat Pump Water Heater Retrofit Savings at 8 Sites (30 days pre and post)

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

Figures 39 and 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 but extremely low-energy use observed during pre-retrofit periods in three homes signaling a clear period of vacancy lasting from three to four days. These days were removed and substituted with an equivalent number of days taken just prior to the 30-day span before retrofit. It should be noted that all electric resistance water heaters in this analysis had a tank wrap and piping insulation installed as part of the shallow retrofit measures in the spring of 2013. This includes the eight pre-retrofit units replaced with HPWHs as well as the entire group of 47 control homes. Thus savings in a pristine sample of home without any efforts to reduce water heating energy use could be expected to be slightly higher than shown in this analysis.

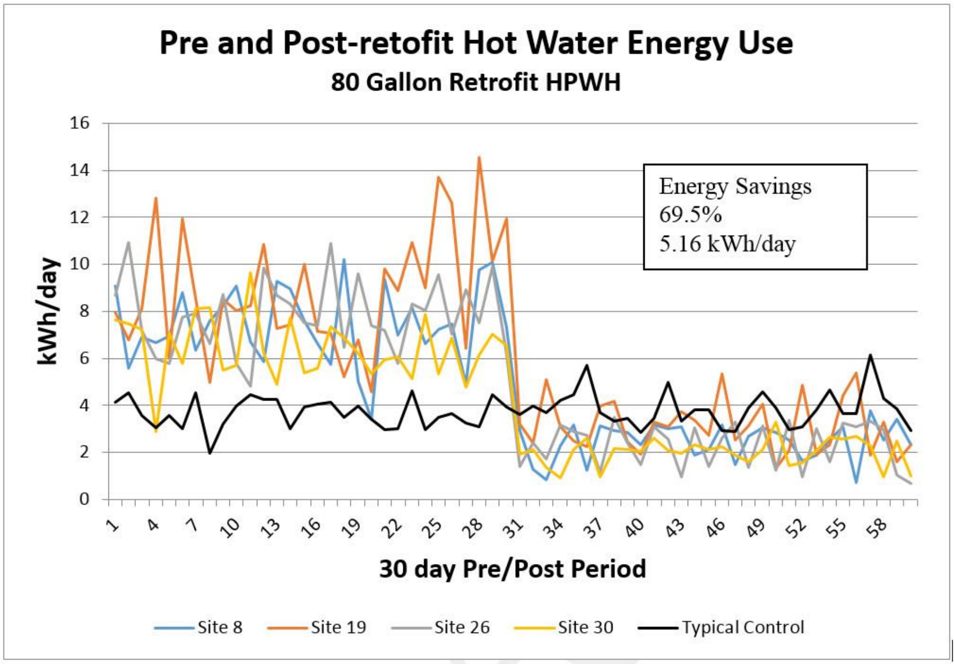


Figure 39. Pre and Post-retrofit Hot Water Energy Use for Homes Receiving 80 Gallon HPWHs

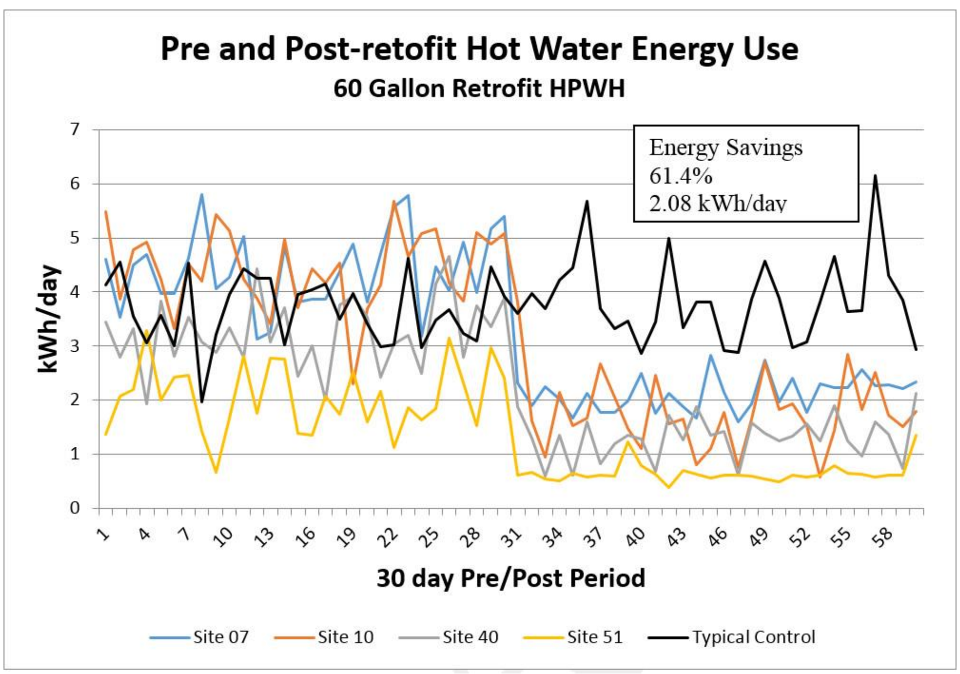


Figure 40. Pre and Post-retrofit Hot Water Energy Use for Homes Receiving 60 Gallon HPWHs

5.4 Appliances

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

Finally, a new, first of its kind, low-energy clothes dryer became available from Samsung Corporation and we decided to replace both the washer and dryer pair in any homes that would consider that choice in order to obtain an assessment of potential savings.

A total of three primary refrigerators, a single dishwasher, and eight clothes washer/dryers sets were replaced. Table 23 shows the sites and date where the appliances were changed out. Later, we include a preliminary energy savings analysis, by each appliance, which was accomplished by comparing a period of sixty days before and after the retrofit for each site.

Table 23. Appliance Retrofits in PDR Project

Site #	Installation Date	DW Make	DW Model #	Frig Make	Frig Model #	Washer Make	Washer Model #	Dryer Make	Dryer Model #
8	10/25/2013	Bosch	SHE3AR52UC			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	WA50F9A6D	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: 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).

Figures 41 and 42 show the large reduction seen (in hourly and daily power in) in a refrigerator retrofit at Site 26 that is well pre-qualified (auditors have measured high consumption). As shown below, consumption is cut for the end use by nearly 50%.

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

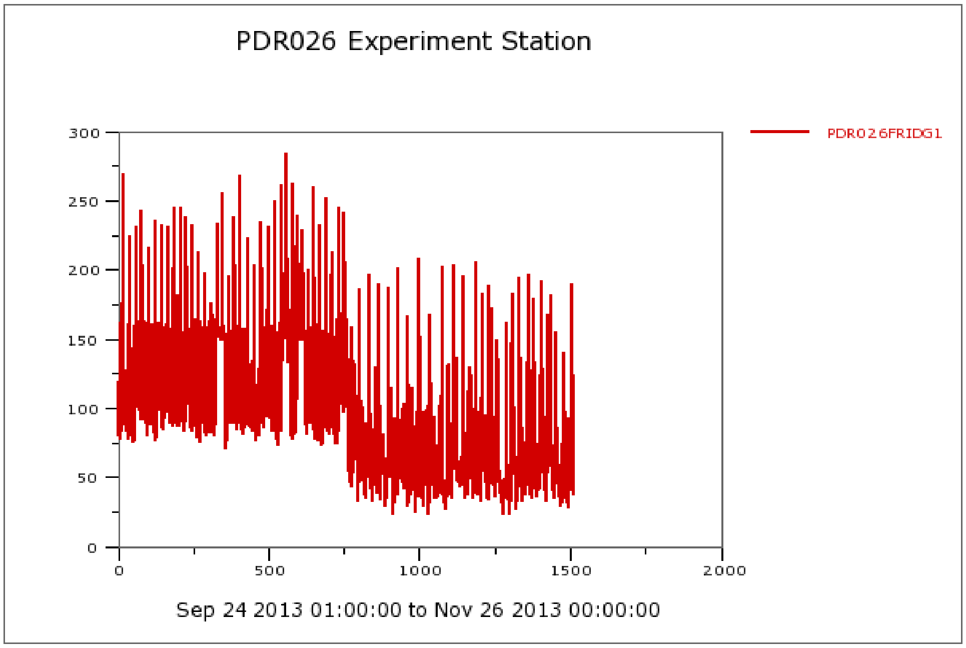


Figure 41. Measured change in hourly refrigerator power a month before and after refrigerator replacement at Site 26 on October 25, 2013 (Y-axis: watts, x-axis, elapsed hours).

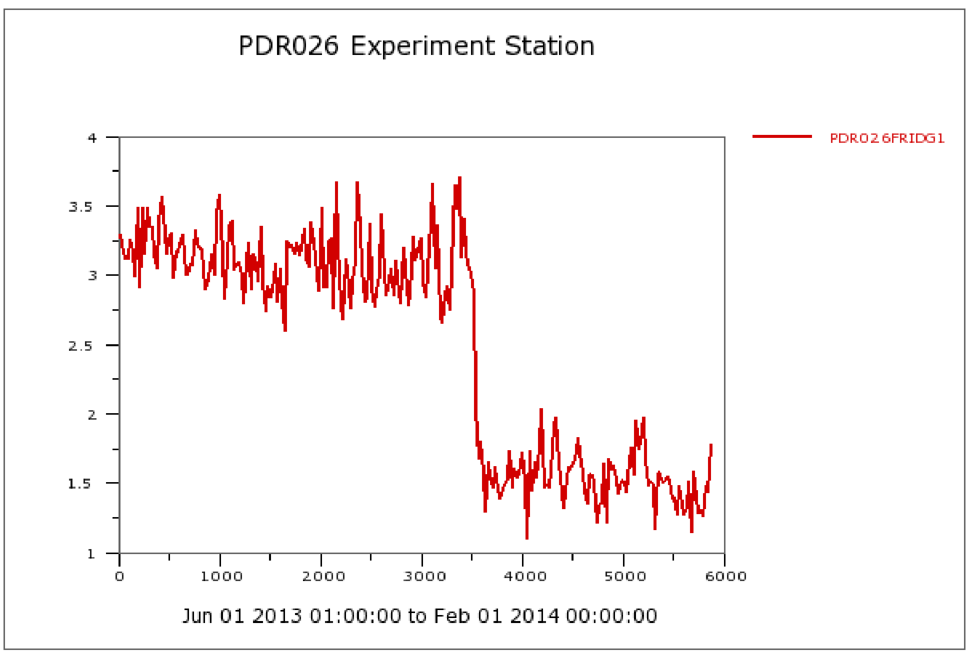


Figure 42. Measured change in daily refrigerator power after refrigerator replacement on October 25, 2013. Data for June 1 2013 – February 1, 2014 (Y-axis is kWh/Day; X-axis is elapsed hours)

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

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

Site	Pre kWh/D	Post 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 label, but this is expected since refrigerator energy use in warmer climates is often about 25% greater than test values due to higher room temperatures (Parker and Stedman 1990). Our results indicate measuring refrigerator power as audited over a multi-day 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 the new Samsung DV457 model. Seven of these homes received a matched Samsung washer/dryer pair. The standard matched clothes washer was a Samsung Model WF457 with a Modified Energy Factor (MEF) of 3.42. However, Site 26, objected to the front load washer because of room constraints and selected instead, an ENERGY STAR top-load washer (Samsung WA50F9A60). Table 25 shows the measured dryer energy in the nine homes receiving the first of its kind, high-efficiency dryer. As clothes washer machine energy was not measured, it was not possible to examine its relative contribution to energy loads. However from previous monitoring, we know that clothes washer energy is minor (typically less than 0.5 kWh/day) with the energy use of the clothes dryer as the major energy-related impact of laundry cycles[16].

Table 25. Washer/Dryer Replacement Energy Savings (60% days before/after)

Site	Dryer (Pre)	Dryer (Post)	Δ kWh	% Savings
8	6.40	2.65	3.75	59%
26	4.39	6.38	-1.99	-45%
39	0.73*	1.69*	-0.96*	*
51	0.82	0.65	0.17	21%
30	1.81	2.28	-0.47	-26%
19	7.48	5.51	1.97	26%
40	1.39	1.23	0.16	12%
10	1.46	0.80	0.66	45%
Average	3.39	2.79	0.60	18%

★ Did partial line-dry before retrofit. Not included in averages.

[16] In future work, we will attempt to examine how the clothes washer replacement in the retrofit may have reduced hot 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, it became apparent that in at least one site (Site 19), a hot water wash is used and replacement of the washer was associated with a decreased water heating load.

The data analysis in Table 25 above shows that achieved energy savings of the clothes dryer was highly variable, but averaged 0.60 kWh/day or 18%. Site 39 was eliminated from analysis since this home owner did a partial line dry prior to receiving the new washer and dryer and afterwards reported using the dryer more and line drying less. Even so, there were two sites where negative pre/post savings were seen highlighted above. Site 26 (-2 kWh/day) was the site which did not receive the matched washer/dryer pair, although they did receive a top loading ENERGY STAR washer showing excellent clothing residual moisture removal characteristics (MEF= 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, often selecting faster cycles. Also, Site 30 showed a modestly negative savings (~0.5 kWh/day increase with the new unit). In any case, the dryer was not particularly well received by homeowners, being very complex to operate and with long drying times in the ECO mode.

The site with the largest clothes dryer use (Site 19 at 7.5 kWh/day), showed a savings of 26% (2 kWh/day) in the sixty-day period after the installation of the new unit. Figure 43 shows the running weekly average kWh/day at the site over the period of the retrofit extending to the end of 2013.

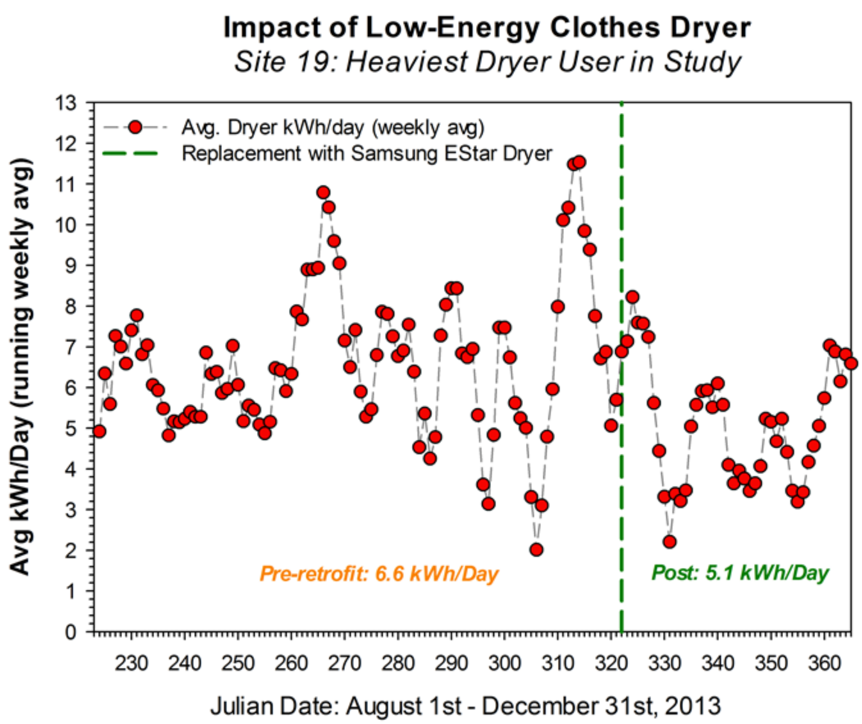


Figure 43. Measured savings of the high-efficiency clothes dryer at Site 19 from August – December, 2013.

Again, it must be emphasized that the savings seen the project on clothes dryers is preliminary and six months of data will allow a more definitive assessment. Also, the savings seen, such as those at Site 10, were a 45% savings (0.7 kWh/day) likely include impact of the new washer with less residual moisture than the original unit.

5.4.3 Dishwasher

A single dishwasher was retrofit at Site 8 on October 27, 2013. While average dishwasher power in the overall PDR sample is only about 0.4 kWh/day, it was approximately 1.5 kWh/day at Site 8 which appears to be heavily used. An ENERGY STAR Bosch dishwasher (Energy Factor (EF) = 0.77) was chosen and installed in cooperation with the homeowner. Figure 44 shows the reduction in measured power from August 27th – December 27, 2013 on the dishwasher circuit at this home.

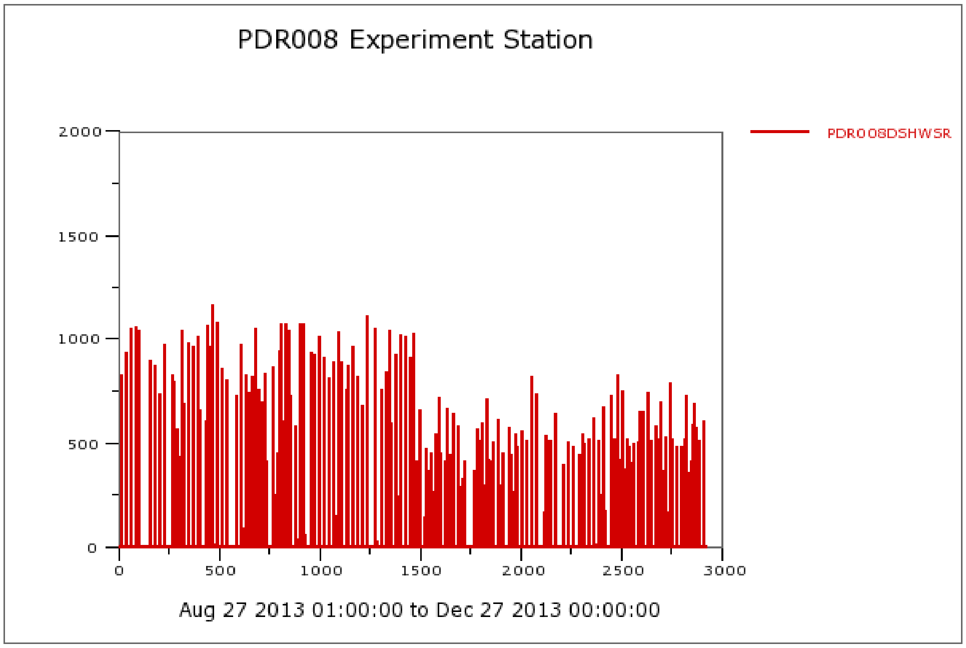


Figure 44. Measured hourly power of dishwasher at Site 8 (watts on the Y-axis) which was replaced with an ENERGY STAR model on October 27th (around hour 1500)

In the sixty-day period prior to retrofit, the dishwasher power averaged 1.48 kWh per day. In the sixty-day period after replacement with an ENERGY STAR model by Bosch, on October 27th, the dishwasher energy use averaged 1.00 kWh per day. This represents a savings of 0.48 kWh/day or 32% in the end use energy. This is perhaps more impressive in spite of this being a holiday period when dishwasher energy may greater in many homes.

5.5 Pool Pumps

Existing single speed pool pumps were replaced with variable-speed pumps in two deep retrofit homes resulting in energy savings of 80 to 90%. Another study home had a similar pump replacement performed by the homeowner, early-on in the study, but 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% was measured in all three cases with variations attributed to differences in system hydraulics and runtime deviations as required by different chlorination systems. Average hourly demand was also reduced by 80 to 90%. Energy and demand savings at all sites have persisted with little variation for more than one year.

5.5.1 Deep Site 7

Pre-retrofit monitoring of the 1.5 heat pump (HP) single-speed pump was conducted for 203 days from September 6, 2012 to March 27, 2013. Runtime during this period averaged 9.3 hours per day with an average draw of 2.01 kW for an average daily energy use of 18.7 kWh. Runtime of the single speed pump was reduced to 5.5 hours per day during the shallow retrofit resulting 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 September 24, 2013 resulting in a 90% reduction in measured energy use and average hourly demand over the pre-retrofit scenario as shown in Figure 45. Energy savings have continued throughout the 13 month post retrofit period. The 3 HP *Pentair* variable-speed pump runs for 11.0 hours per day with an average draw of 0.17 kW and measured average energy use of 1.9 kWh per day. A summary of the pre- and post-retrofit energy use are shown in Table 26.

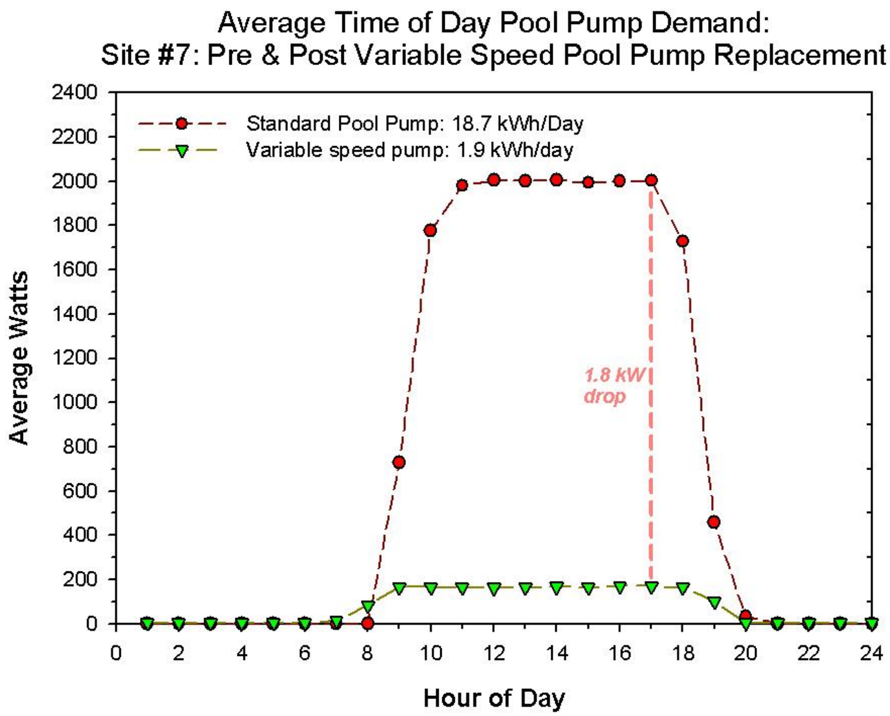


Figure 45. Average Time of Day Pool Pump Demand at Site 7 as originally found (red) and after variable-speed pump retrofit (green)

Table 26. Measured Pool Pump Energy for Site 7

	Monitored Days	Runtime Hours/day	Average kWh/day	Energy Savings	Average kW draw	Demand Savings
1.5HP pump, as found	203	9.3	18.7		2.01	
Adjusted Schedule	181	5.5	10.7	43%	1.94	3%
New VS Pump	413	11.0	1.9	90%	0.17	92%

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

5.5.2 Deep Site 37

Energy savings at site 37, shown in Table 27, were less clear-cut than those seen at site 7. The pool water was found to be in exceedingly poor condition at the beginning of data collection on December 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 prior to 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 found to be concentrated mainly during the nighttime hours. The erratic schedule was counterproductive to pool health and very likely contributed to the poor quality pool conditions.

The shallow retrofit at site 37 was conducted on April 18, 2013 when pool pump runtime was reduced to 4 hours/ day during mid-day. While such a short runtime can be sufficient for pool health in some situations, it was later found that this pool used a salt water chlorination system which 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 resulting in a confusing period of collected energy data for several months. In an effort to establish a fixed baseline for measured savings, a new runtime schedule was set on October 11, 2013 and data collected for 26 days. The single speed 1.5 HP pump was set to run for 8.7 hours during midday during which time pool health noticeably improved. Measured energy use during this period was 14.8 kWh/ day with an average draw of 1.70 kW.

A variable-speed pump and new filter were installed on November 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 has averaged 2.6 kWh/ day through November 11, 2014.

Table 27. Measured Pool Pump Energy for Site 37

	Monitored Days	Runtime Hours/day	Average kWh/day	Energy Savings	Average kW draw	Demand Savings
1.5HP 1-speed pump	N/A	variable	variable			
Fixed Baseline	26	8.7	14.8		1.70	
New VS Pump	370	8.1	2.6	82%	0.32	81%

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

5.5.3 Shallow Site 59

This site was only targeted for shallow energy retrofits, but later found to have a new variable-speed pool pump installed by the homeowner in place of the original single speed 1HP documented at the initial audit on 12/03/12. 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 1HP pump prior to replacement on 12/24/12 with a 3HP *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, as shown in Table 28.

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 a total of 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, either for pool maintenance or for best energy savings.

Accordingly, the variable-speed pump was then reprogrammed by a pool contractor on 10/23/13 to operate a total of 8.5 hours/day, 4.5 hours during midday at high-speed and 4 hours at low speed. The new settings for both high- and low-speed drew considerably less energy than the previous pumping program resulting in average daily energy use of 1.8 kWh. This resulted in measured savings of 83% over the original single-speed pool pump with no reported water quality problems over the last year.

Table 28. Measured Pool Pump Energy for Site 59

	Monitored Days	Runtime Hours/day	Average kWh/day	Energy Savings	Average kW draw	Demand Savings
1HP, 1-speed pump	19	6.8	10.6		1.57	
New VS Pump	254	11.1	5.5	48%	0.50	68%
Adjusted VS Pump	385	8.5	1.8	83%	0.21	87%

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

5.6 Deep Retrofit Savings Evaluations

In the prior analyses, we detailed the savings seen for particular end-uses. To investigate overall and peak hour savings, we conducted evaluations in three ways:

1. A preliminary assessment comparing four months of pre-retrofit to four months of post-retrofit using measured data from six evaluation sites.
2. A utility data analysis of five sites, disaggregating space heating, space cooling, and baseload energy use for comparison between 12 months pre- and 12 months post-retrofit.
3. 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). The sample size is limited to the six deep retrofit homes fully monitored by October 1, 2012. Total savings for the post-retrofit period averaged 16.5 kWh/day, or 34.4%.

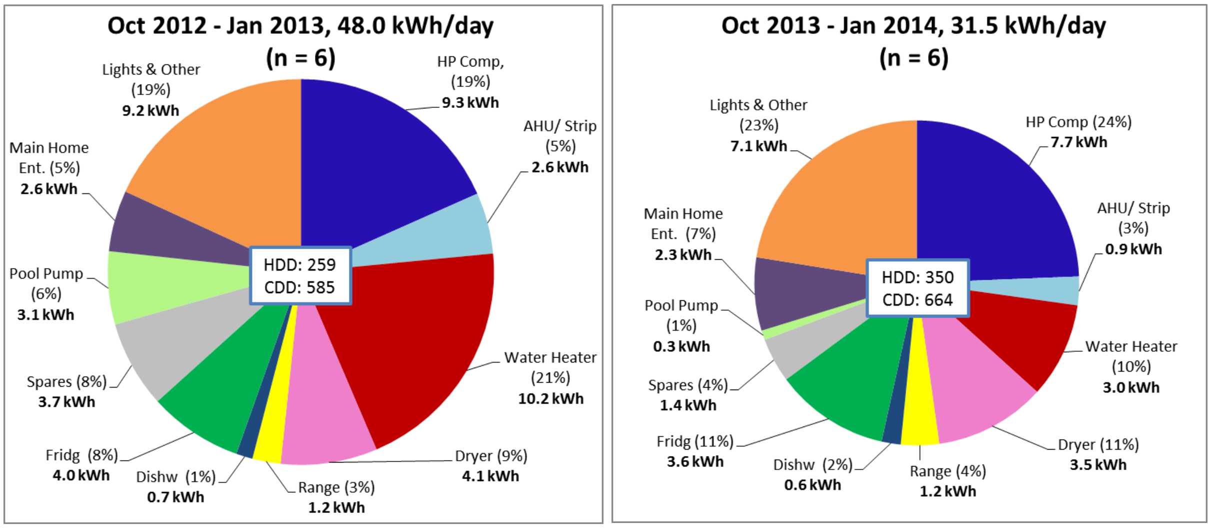


Figure 46. Average end-use load profile in limited deep retrofit sample, October 2012 – January 2013 versus October 2013 – January 2014.

Savings were spread across end uses. However, water heating energy showed dramatic reductions (7 kWh/day) as did pools (3 kWh/Day). Space heating and cooling energy was reduced by about 3 kWh/day or about 30%. The energy savings from the earlier shallow lighting retrofit are also in evidence at approximately 2 kWh/day.

While total savings over this quarter year are quite good, a longer-term analysis will likely reveal larger savings. We cite three reasons:

1. The full effect from the HVAC load-reduction measures are not realized because the available analysis period excludes the prime cooling season which was most substantially altered by the AC retrofit, duct repair, and learning thermostat changes.
2. The post-retrofit period includes some pre-retrofit conditions as several retrofit measures were not fully completed until after December 2013. This was particularly the case for additions to ceiling insulation as well as some of the replaced appliances.
3. Both heating degree days (HDD) and cooling degree days (CDD) were higher during the post-retrofit period likely biasing towards greater post-retrofit heating and cooling. (HDD and CDD calculated at a 65 F base are provided in the center of each pie chart.)[17]

Conversely, hot water savings will somewhat diminish with a full year of analysis as it will include summer, when the inlet water temperature are highest and water heating loads are reduced.

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 the heat pump water heater followed by the HVAC load reduction measures (considering both AHU and heat pump savings) and then the pool pump replacement (affecting only one site).

[17] Averaged Metar (NOAA) Reports for Melbourne, Florida.

Table 29. Average Savings for Six Deep Retrofit Sites

	Average Daily kWh Savings by Site: October 2012 through January 2013 versus October 2013 through January 2014											
Site #	Whole House	HP Comp	AHU/ Strip	Water Heater	Dryer	Range	Dishw	Fridg	Spares	Pool Pump	Main Home Ent.	Lights & 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
Avg. kWh Savings	**16.5**	**1.6**	**1.7**	**7.2**	**0.6**	**-**	**0.1**	**0.4**	**0.5**	**2.8**	**0.3**	**2.1**
Avg. % 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 heat pump water heater 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 heat pump water heater. Savings to 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. Meanwhile the HVAC energy use (heat pump compressor and air handler unit (AHU) were even at Site 7 and somewhat increased at Site 8. Such results are not unexpected given both HDD and CDD 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 to the HVAC, domestic hot 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 existing into the post-retrofit period, note that the high-efficiency dryer was not installed until 12/5/2013, halfway into the post-retrofit period.

This preliminary evaluation of end use savings provides us 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. The following section analyses utility records for a year before and 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 the five deep-retrofit study homes with available data were disaggregated to characterize space heating and cooling, and baseload energy use before the shallow retrofit and again after the deep retrofit. Weather-adjusted savings projections were estimated in two ways:

1. Adjusting post-retrofit energy use for each home with its pre-retrofit weather, and

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

Reference section 4.7 for a description of the normalization and disaggregation approach used for both the shallow and deep retrofit utility data analyses. We briefly describe our results for the deep retrofit utility data analysis below.

5.6.2.1 Utility Data Weather Normalization and Disaggregation

This deep retrofit utility data analysis is incomplete; not enough time has lapsed since the completion of all deep retrofit measures. However, five study homes have at least 10 months of post-retrofit utility data which will allow preliminary insight into savings results. Once a full 12 months of post-retrofit utility data are available for all 10 deep-retrofit homes (in April 2015) we will conduct the final evaluation.

Figure 47 shows the pre-retrofit space heating and cooling, and baseload energy use prediction for Site 19. The pre-retrofit period is the 12 months billed preceding the 4/17/2013 shallow retrofit. Warmer heating set points and milder cooling set points were favored in this home during pre-retrofit than a 65°F degree day base temperature would project. The fairly robust fit of the model (adjusted $R^2 = 0.89$) is evident from the close alignment between 'Predicted' monthly use (green diamonds) and the monthly "FPL" utility data (orange circles). Projected space cooling and heating energy use are the solid-fill sections in blue and red, respectively. The baseload prediction is the flat purple line.

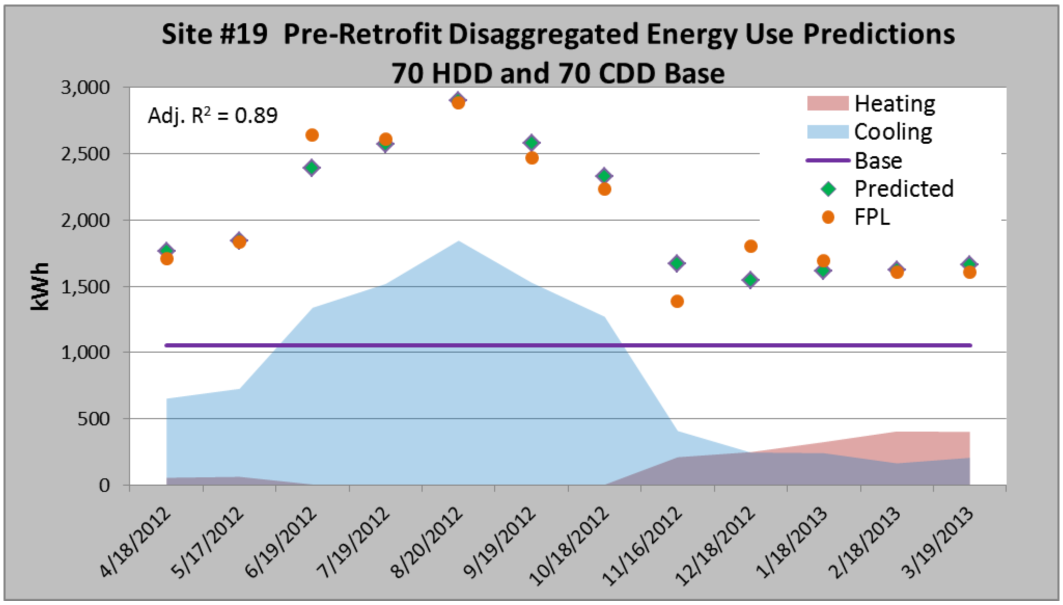


Figure 47. Site 19 Pre-retrofit space heating and cooling, and baseload characterization

The shallow retrofit at Site 19 included a 72% lighting retrofit for a 55% connected lighting kW reduction as well as hot water tank wrap, low-flow shower head installation, and refrigerator coil cleaning. The deep retrofit at Site 19 was conducted between 7/10/2013 and 11/18/2013 and included a high-efficiency heat pump air conditioner, duct system sealing, a smart thermostat, a heat pump water heater, high-efficiency washer and dryer, 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 and cooling, and baseload energy use prediction normalized to pre-retrofit weather for Site 19.

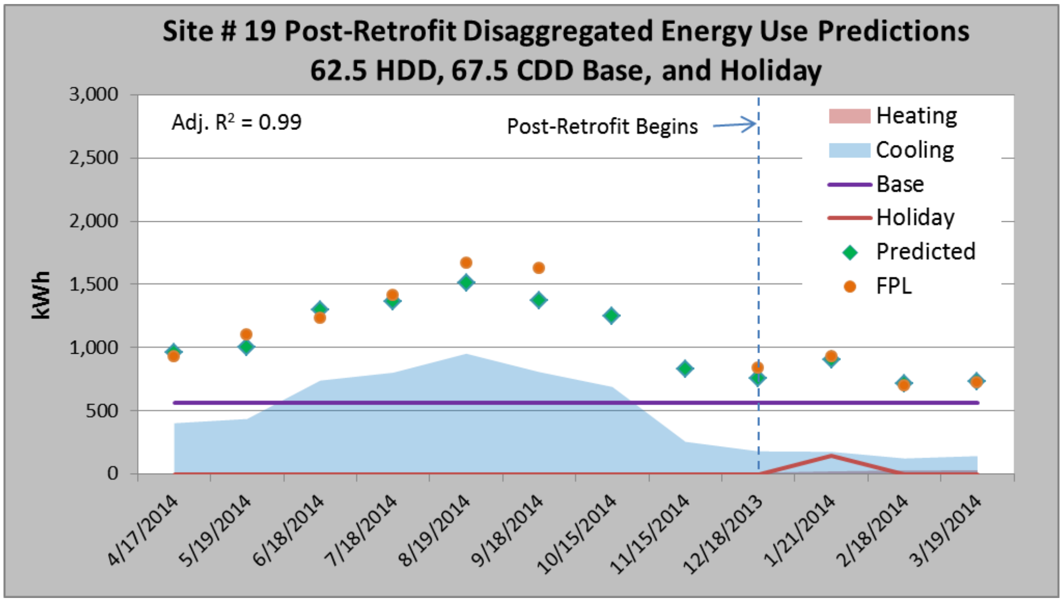


Figure 48. Site 19 Post-retrofit space heating and cooling, and baseload characterization

A much lower heating set point was evident post-retrofit (HDD base of 62.5°F vs. 70°F chosen pre-retrofit) which may be a reflection of the greater ceiling insulation added to the home. Conversely, the owners appear to be keeping the home slightly cooler in the summer (CDD base of 67.5°F vs. 70°F chosen pre-retrofit), contrary to 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 an exceptionally strong fit with an adjusted R^2 = 0.99. Meanwhile the slight misalignment between the prediction using pre-retrofit weather and the post-retrofit billing during 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 1,850 kWh in August, is under 1,000 kWh post-retrofit, and baseload has similarly been reduced by half. The small amount of post-retrofit space heating is nearly invisible in this plot.

A summary of annual total and space conditioning end use deep retrofit energy projections for Site 19 are given in Table 30. When combined, the shallow and deep retrofits reduced annual cooling energy use by 4,424 kWh, a 44% savings over pre-retrofit. Baseload savings are equally impressive: 5,754 kWh/year or 46%. The drastic reduction in annual space heating from 1,713 to 111 kWh supports a transition from electric resistance to the highly efficient heat pump. Note we have estimated that the lighting retrofit has increased post-retrofit heating needs at the same time, but with the result of still very low heating needs post-retrofit. Whole-house annual energy use was reduced from 24,483 to 12,704 kWh, a savings of 48%.

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

Annual Energy Use Site 19	Utility Bill Total	Normalized Projection Total	Base	Heating	Cooling
Pre-Retrofit kWh	24,483	24,483	12,632	1,713	10,138
Post-Retrofit kWh	Incomplete	12,704	6,878	111	5,715
kWh Savings	N/A	11,779	5,754	1,602	4,424
Percent Savings Overall	N/A	48%	46%	94%	44%

Looking next to the results for all five homes, a summary of the annual predicted savings is presented in Table 31. The predicted average annual space cooling savings is 4,129 kWh (53%), 737 kWh (55%) for space heating, and 1,890 kWh (24%) for baseload. Overall the whole-house annual savings prediction is 6,756 kWh, a 39% energy use reduction from pre-retrofit.

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

Annual Energy Use Averages (n = 5)	Utility Bill Total	Normalized Projection Total	Base	Heating	Cooling
Pre-Retrofit kWh	17,171	17,171	7,973	1,344	7,854
Post-Retrofit kWh	Incomplete	10,415	6,083	607	3,725
kWh Savings	N/A	6,756	1,890	737	4,129
Percent Savings Overall	N/A	39%	24%	55%	53%

The savings results for each individaul site are summarized in Table 32. Total energy savings ranged from 26% to 48%. The post-retrofit model for Site 39 had an exceptionally poor model fit (Adjusted R^2 = 0.50) and the negative savings for baseload energy use and relatively large cooling savings are supsect. The post-retrofit model fit was much better for all other homes. We reiterate these results are preliminry and expect model improvments once 12 months of data are available for analysis. Still, they reflect a very impressive whole-house electricity savings rate of nearly 40%.

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

Site	Annual Energy Use: Pre-Retrofit	Annual Energy Use: Post-Retrofit	Annual Energy Savings: Base	Heating	Cooling	Total % Savings
8	15,285	9,939	1,366	188	3,792	35%
19	24,483	12,704	5,754	1,602	4,424	48%
26	20,004	11,938	3,614	316	4,136	40%
39	13,961	10,290	(1,790)	340	5,121	26%
40	12,124	7,206	505	1,241	3,173	41%

Annual space cooling energy use was comparably large for all sites, ranging from about 3,000 to 5,000 kWh. The space heating impact 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 operating with significantly higher COPs; while other homes may have had marginally efficient heat pumps before retrofit.

5.6.2.2 TMY3 Weather Normalization

The last component of the utility data analysis was to evaluate total, space heating and 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 above were applied to TMY3 weather to predict space heating and cooling energy use for both the pre- and post-retrofit periods. Reference 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				Service Area Weight
		Total	Base	Heating	Cooling	
Miami	%	39%	24%	57%	54%	
	kWh	7,905	1,890	329	5,686	0.4319
W Palm	%	36%	24%	52%	53%	
	kWh	7,280	1,890	517	4,873	0.2243
Ft Myers	%	38%	24%	56%	54%	
	kWh	7,694	1,890	524	5,281	0.1921
Daytona	%	31%	24%	49%	53%	
	kWh	6,518	1,890	1,100	3,529	0.1517
Weighted	**%**	**37%**	**24%**	**55%**	**54%**	
	kWh	**7,514**	**1,890**	**526**	**5,099**	

The percentage space cooling energy savings is essentially unchanged among locations, 53% to 54%, with the smallest energy use reduction in the northern-most location, Daytona. And, also as expected, Daytona achieves the highest space heating savings -- 1,100 kWh/year, two to three times the savings of the other locations.

Weighted across the FPL service areas, annual heating energy savings are 526 kWh (55%) and the annual cooling energy savings are 5,099 kWh (54%). Overall, we project annual shallow retrofit savings of 7,514 kWh (37%) with two thirds of the total savings generated by space cooling reductions.

5.6.3 Hourly Space Conditioning End Use Analysis

In this section we discuss the results of the monitored space heating and 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 impact space heating and cooling energy. These include high-efficiency heat pump air conditioners, duct system sealing, and upgraded ceiling insulation. To investigate the hourly impact of these measures on space conditioning, we analyzed monitored space heating and cooling energy data as they related to hourly outdoor temperatures.

All 10 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 instrumentation and the shallow retrofit. Therefore, rather than compare the pre shallow retrofit to the post deep retrofit condition, the space cooling evaluation compares the energy use of the post shallow/pre deep period to a post deep retrofit period. One must consider the savings from both the shallow and deep retrofits 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 we only captured observations between the shallow and deep retrofits. 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 plugged-in portable space heating rather than central heating during the pre-retrofit period. To use data from this site would skew results as the plugged-in space heating 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 characterized is prior to the shallow retrofit. Also, there was a space heating energy penalty 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 heat pump water heater in one. We chose to keep these sites in the analysis as we deem the measures to have relatively minor impacts on heating energy savings – yielding slightly conservative savings projection for the missing insulation and slightly inflated energy savings for the home that later received an interior heat pump water heater. (The heat pump water heater’s cold air byproduct would likely have increase space heating energy use.)

5.6.3.1 Space Cooling Results

The evaluation of end use space cooling confirms the substantial energy savings projected with the preliminary 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 are 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.

Indicated average daily savings is 17.4 kWh with the average TMY3 profile and 23 kWh with the TMY3 peak weather profile, each representing 48% post-retrofit energy use reduction. The daily savings projections are slightly higher than the cooling energy savings projected with utility data evaluation, which was 14 kWh normalized to TMY3. The differences between the two analyses are even larger considering the baseline for the utility data analysis was pre shallow retrofit, whereas the current analysis excludes the shallow retrofit savings. These differences can be expected given the limited sample size and incomplete nature of the utility data comparison.

Table 34. Post Shallow/Pre Deep vs. Post Deep Retrofit Daily and Peak Hour Cooling Energy Savings Evaluation Summary

Deep Retrofit Cooling Analysis Normalization Weather Profile:	Daily				Peak Hour (15:00 - 16:00 EST)			
	kWh			%	kW			%
	Pre	Post	Delta	Savings	Pre	Post	Delta	Savings
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%

Adding the average daily savings of 48% to the average shallow retrofit daily savings (13%), gives us a prediction of 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 where savings nearly doubles to1.89 kW. Figure 49 shows the daily space cooling energy load plot normalized to pre-retrofit weather. Here, we see significant post-retrofit (dark blue) energy savings over pre-retrofit energy use (light blue) throughout the day, primarily at the peak of the day where savings are about 1 kW for several continuous hours. Peak hour is identified by the red, vertical, dotted lines. Reference Appendix C for the deep retrofit space cooling energy use projection plots for all temperature profiles.

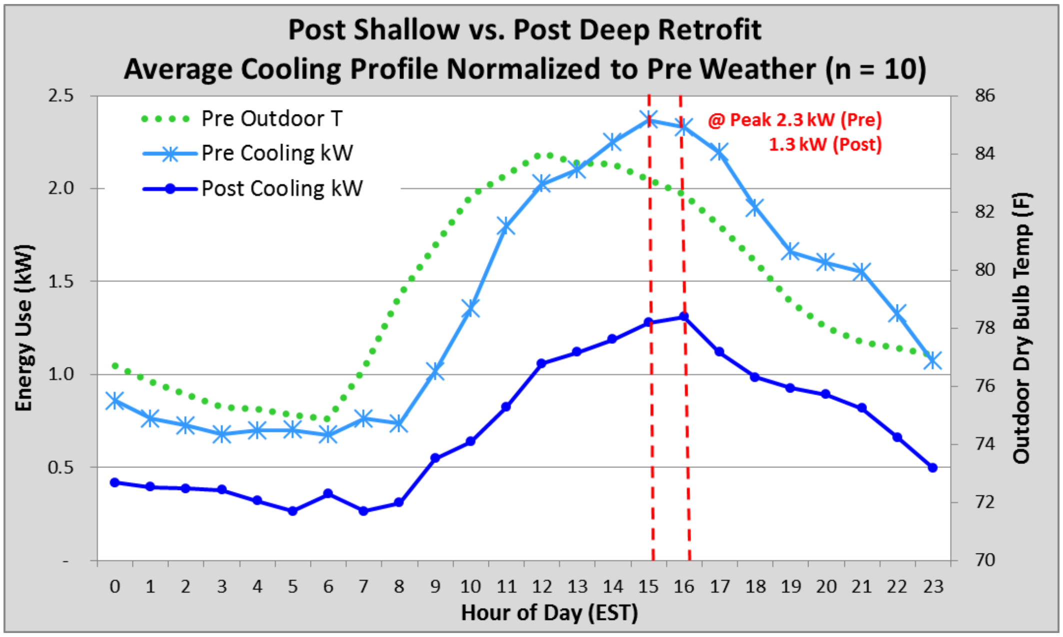


Figure 49. Post shallow/pre deep vs. post deep retrofit hourly space cooling profile, pre-retrofit weather-normalized

Given robust monitored end-use data, we are able to 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 ranges from 3.8 to 35.3 kWh. As expected from prior space cooling energy analyses, Site 30 is an outlier with relatively little 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.

The average savings by site (45%) is slightly lower than the savings reported in the utility bill analysis (48%), the percent change in energy use of all sites combined. This is because the sites with the largest pre-retrofit energy use (10, 19 and 26, circled in red) had the most significant drop in post-retrofit energy use, but these savings were relatively muted in terms of per-site percentages. Given the end-use monitoring, the 48% savings projection is a more accurate description of the overall space cooling energy savings achieved by the deep retrofits. Regardless, we conclude very significant space cooling energy savings are achieved from the high-efficiency heat pump air conditioners, duct system sealing, and upgraded ceiling insulation.

Table 35. Post Shallow/Pre Deep vs. Post Deep Retrofit Daily Cooling Energy Savings by Site

Daily Space Cooling Energy Savings Projections Per Deep Retrofit Site								
Site	TMY3 Average, Weighted				TMY3 Peak, Weighted			
	kWh	kWh	Savings	Savings	kWh	kWh	Savings	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 Per Site:				45%				45%

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, we compare the power demand for the FPL system summer peak day in 2013 (August 13th) to that in 2014 (July 28th). As with the cooling analysis above, the pre-retrofit period comes after the shallow retrofit, thus 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 air conditioner was installed before August 13, 2013.) The nine deep homes included several that had very high pre-retrofit consumption before they received the comprehensive measures in the fall of 2013. The results are a 39% coincident peak reduction or just under 2 kW between 4 and 5 PM. Reduction to energy is similar: 76.2 kWh (pre) and 48.3kWh post.

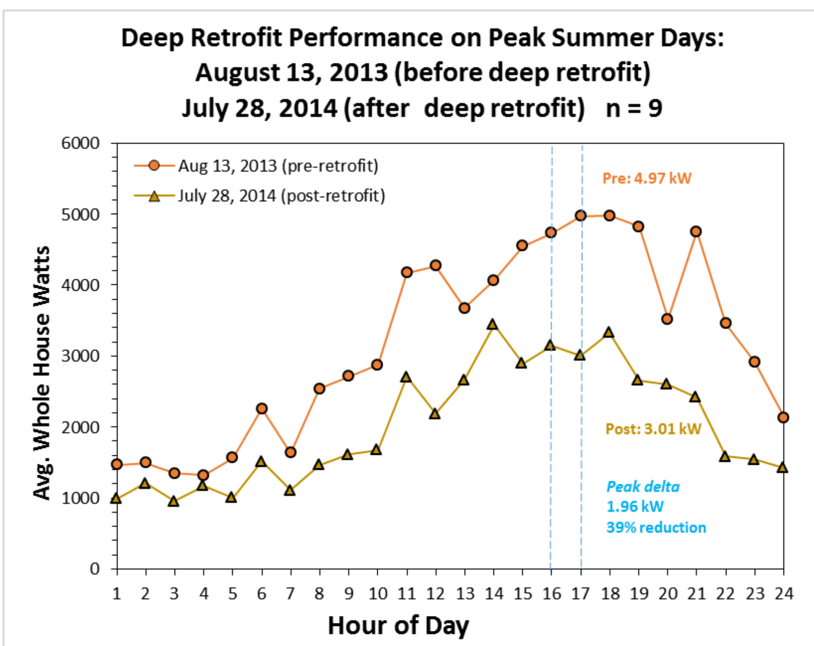


Figure 50. Comparative analysis between pre- and post-retrofit demand for FPL system peak summer day

5.6.3.2 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. Given the low number of observations, again we consolidated readings 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 as 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 Shallow vs. Post Deep Retrofit Daily and Peak Hour Heating Energy Savings Evaluation Summary

Deep Retrofit Heating Analysis Normalization Weather Profile:	Daily				Peak Hour (7:00 - 8:00 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*							
TMY3 Peak, Weighted	35.7	15.4	20.3	57%	2.34	0.95	1.39	59%

* 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 shallow and post deep retrofit space heating energy use predictions when normalized to pre-retrofit weather. This 24 hour plot represents the average heating energy use when temperatures were below 60 and does not represent a typical day. The energy savings are 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 bi-modal appearance in our projection; peak hour demand reduction is unexpectedly small, 0.45 kW. Savings from 6:00-7:00 (0.69 kW) are much larger than at peak hour, which is identified by the red, vertical, dotted lines.

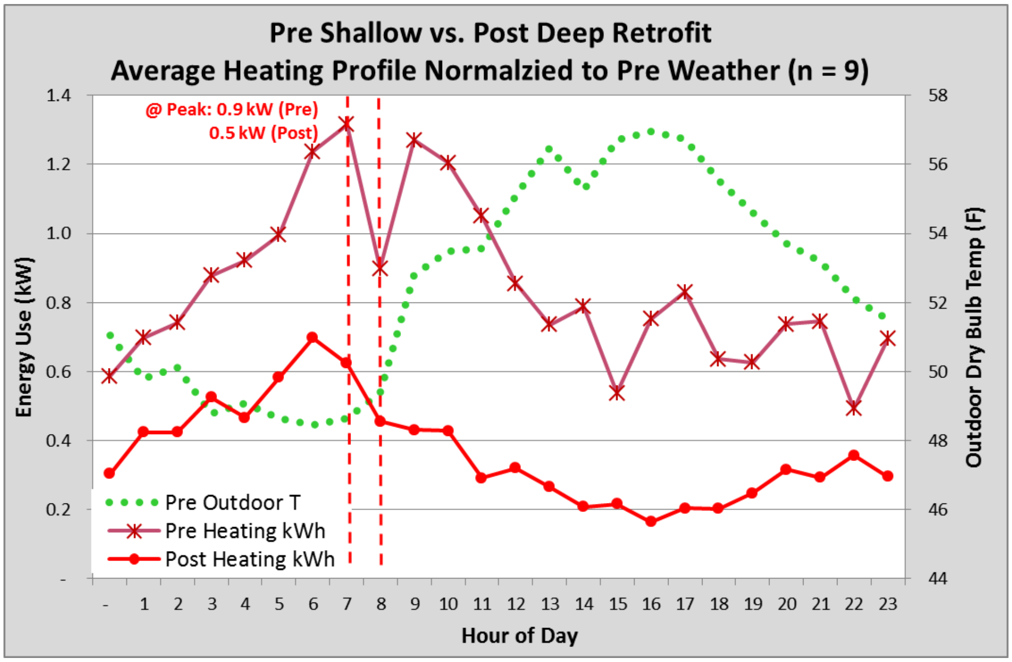


Figure 51. Pre shallow retrofit vs. post deep retrofit hourly space heating profile, pre-retrofit weather-normalized

We reiterate that the pre-retrofit condition is before the shallow retrofit. Note that, as with the shallow evaluation, we again see an obvious decrease in the pre-retrofit space heating energy use in the late afternoon, presumably when occupants are returning home and lights are turned on. Post-retrofit, this pattern is essentially gone. Reference Appendix C for all deep retrofit space heating temperature profile projection plots.

While the heating season is mild in Florida's climate, we conclude that the deep retrofit measures had a large influence on space heating energy, reducing energy use significantly enough to provide a net savings, even when combined with the negative savings associated with the lighting retrofit.

5.6.3.2.1 Whole-House Winter Peak Demand Reduction

In our investigation of the deep and shallow retrofit's complete impact on peak summer hour, we compare the power demand for the FPL system winter peak day in 2013 (March 4th) to that in 2014 (January 23rd). Like the space heating analysis above, the pre-retrofit period precedes the shallow retrofit, unlike the space cooling analysis which used the post shallow retrofit 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 January 23, 2014.) The results are a 60% coincident peak reduction or 2.7 kW between 7 and 8 AM. Reduction to energy was 44%: 73.7 kWh (pre) and 41.4 kWh post.

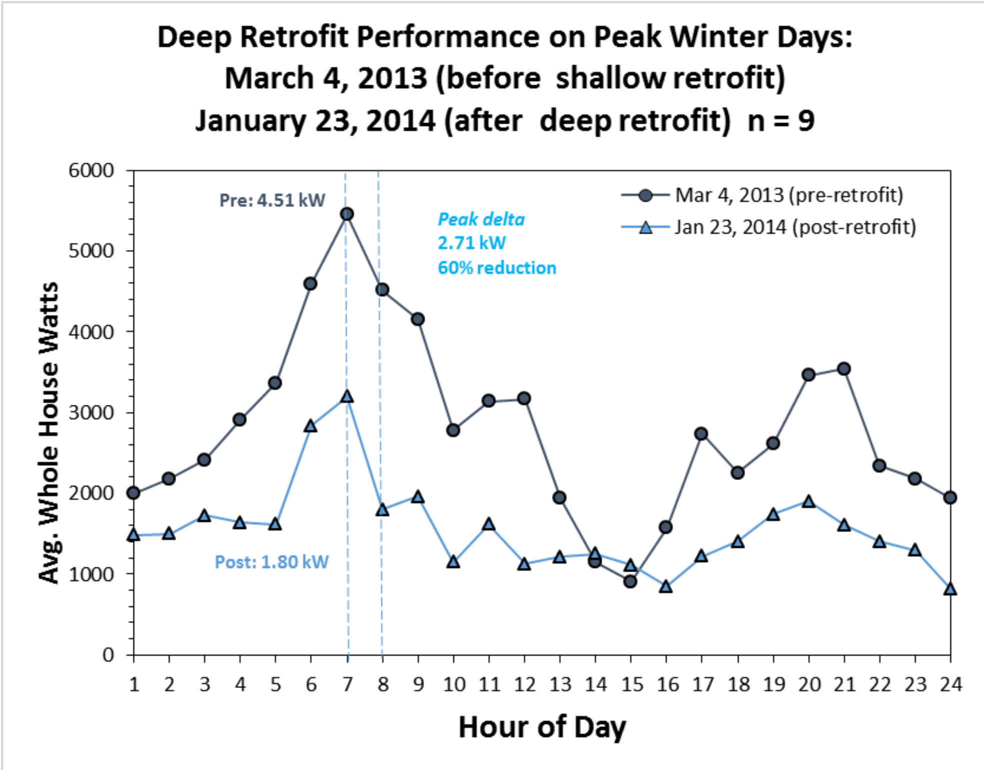


Figure 52. Comparative analysis between pre- and post-retrofit demand for FPL system peak winter day

5.7 Cost Evaluation

To investigate the preliminary deep retrofit cost-effectiveness, the average full and incremental installation costs were compared to savings. In this early evaluation, we assess the whole-house cost/benefits using the utility data analysis predicted whole-house savings, which considers a full year pre-retrofit to a nearly full year post-retrofit (projected to a full year). The shallow retrofit cost is included, as 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
Heat Pump Water Heater (9)	$2,274	$1,478
ES Washer/Dryer Sets (8)	$2,620	$1,087
ES Refrigerator (3)	$1,208	$0
ES Dishwasher (1)	$508	$0
Variable Speed Pool Pump & Filter (2)	$2,035	$1,458
Insulation (2)	$1,120	$1,120
Infiltration Reduction (5)	$170	$170
Average Retrofit Cost Per Site (10)	**$13,960**	**$6,711**
Shallow Retrofit (Avg. for Deeps Only)	$363	$363
Total for Shallow and Deep Retrofit	**$14,323**	**$7,074**

The estimated savings for the whole-house consumption averaged 39% (ranging from 26% to 48% for the evaluated sites). As described in our preceding analysis, the energy reductions averaged 6,756 kWh/year or approximately 560 kWh/month. The impact on utility bills was highly visible to the consumer averaging $68/month or $811 a year at $0.12/kWh (including applicable taxes).

The incremental cost of the above options shows the average cost to choose the more efficient options if completed at the time the equipment or appliance was at the end of its useful life. The simple payback for the improvements in the deep retrofits evaluated on an incremental basis was 8.6 years, reflecting an 11.7% simple after-tax rate of return. This shows that replacing the equipment and options changed in our 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 considerably better than conventional competing investments such as stocks or bonds.

If the retrofits were completed outright as was done in the study, with an added cost of $14,323, the economics are less attractive. The simple payback for the package of measures increases to 17.6 years with a simple rate of return of 5.7%. However, a very useful model for utility "deep retrofit program" might be conducted for homes which were in need of having the HVAC system replaced in the home 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 11.0 years and a simple after-tax rate of return of 9.1%-- much better than any conventional investment.

5.8 Lessons Learned

Many of the project lessons developed from deep retrofit measure implementation. Appendix D is a detailed description of deep retrofit measure installation experiences, including system and contractor selection, performance criterion, and installation issues.

5.8.1 HVAC

- Control wiring and thermostat set up needs 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 original wiring lacks necessary leadership.
- Full functionality of two-stage heat pumps (both heating and cooling) <u>at both high and low stages</u> need to be carefully verified at the time of installation. Otherwise, both 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 not as technically savvy as the service team). For future NEST thermostat installations, it may be appropriate to use a service team member as part of the installation team.
- Utilizing 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.
- Location of the learning thermostat is important for best function. Upstairs locations are not preferred and best installation point will be one where occupants are often seen by the device. This requirement may necessitate relocation of the thermostat from its current location for best performance.
- Education of homeowners relative to using the learning thermostat is important. They should be encouraged not to defeat the "Auto-Away" feature. Occupants should also be alerted that having such a thermostat will not produce savings by occupants choosing more aggressive heating and cooling.
- 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.
- Careful set up of the "Heat Pump Balance" feature is needed 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 will not often provide benefits in Florida, it should be selected so that the air conditioner 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 pertaining to installation of insulation. It is the responsibility of the consumer to verify that the contractor complies with applicable codes and ordinances, and that all applicable permits are obtained. The verification conducted by FPL of customer's installations is only to confirm the installation qualifies for FPL incentives and does not substitute for proper inspection.
- To gauge overall ceiling insulation R-value, a core sample or total insulation bag count should be utilized to obtain density.
- Confirm the insulation contractor is aware that R-value is not necessarily additive, based simply upon 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.
- Utilize techniques to limit or negate knee wall insulation (e.g. batts) from falling off over time.

5.8.4 Heat Pump Water Heater (HPWH)

- Noise can be an issue with HPWHs and will vary between manufacturers. Locations outside of occupied zones such as the garage are recommended.
- Installation should seek to minimize transferred noise/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.
- Existing water heater locations may lack the minimum required unobstructed space called out by the HPWH manufacturer for optimal efficiency. Modification to existing plumbing and moving away obstructions may be needed to maximize airflow and performance of the HPHW system.
- Educating the homeowner on proper care of installed equipment per the manufacturer is critical for maintaining long-term efficiency.

5.8.5 Low Energy Clothes Dryer

- The new, first of its kind, clothes dryer used in the project is very complicated to operate. Homeowners should be coached on how to use it effectively after installation.
- 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

- Retrofitting a single speed pool pump with a variable-speed pump can reduce overall energy use by 80-90% but may require optimizing other accessible parts (i.e. filter, piping, etc.).
- Variable-speed pool pumps need to be programmed by knowledgeable installers. We saw in one case that about half the achieved savings were lost when the variable-speed pump was not properly programmed.

5.8.7 General

- Feedback from homeowner regarding overall satisfaction or lack thereof with retrofit measures is a critical take away piece of this study. Homeowners do not always speak up if they are having an issue or are not completely comfortable or satisfied with a retrofit change out. We plan to collect feedback over time from the deep retrofit homeowners via survey to help ascertain overall homeowner 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 homeowner/occupant before, during, and after each retrofit measure is critical for a positive outcome.

6 Follow-Up Work

The savings analysis for the deep retrofits was limited given the timing of this report. The utility data disaggregation used only a subset of the deep retrofit sample, and with an incomplete post-retrofit period for those sites. By April 2015 researchers will be able to complete the utility data evaluation for all homes, assessing the deep retrofit impacts on space conditioning, baseload, and whole-house. This analysis will include TMY3 energy savings predictions weighted by FPL service area.

Future reporting will include an evaluation of end use energy impacts from the PDR Phase II measures, which were installed in 2014.

7 Conclusions

7.1 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 8-9% 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 re-adjusting 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 measureable, 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 was greater than 4 kWh/day).

Meanwhile, the lighting retrofit produced savings that were large and persistent. 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 evaluating space conditioning agree that the shallow retrofit decreased cooling energy use and increased heating energy use, an expected dynamic 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. We predict 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 PM in summer against increases of 0.29 to 0.31 kW between 7 and 8 AM in winter. However, the number of heating days in Florida is few whereas space cooling occurs 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%, consistent with our other findings. The hot water tank and pipe wrap and showerhead replacement measure produced relatively large and dependable winter day peak reduction (approximately 0.36 kW or 56%) as well as good consumer economics. We suggest that insulation wraps and showerhead replacements should be emphasized in a utility shallow retrofit program with better performing hot water tank wraps (some 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 the small savings levels of a shallow retrofit may be hidden to consumers by weather changes between years, but this should not be a limitation to such a program.

7.1.1 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/yr at a per-site average cost of $374, a simple payback is reached in about two years, all measures included. The corresponding rate of return on investment is exceedingly positive – greater than 42%. Programmatically, the largest challenge of an expansive shallow retrofit program is that trained crews be available to make the changes.

7.2 Preliminary Deep Retrofit Results

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

Whole-house savings for the post-retrofit period using a long-term utility data analysis showed savings of 18.5 kWh/day, or 39%. Daily space cooling savings associated with the deep retrofit measures, as predicted by the utility bill analysis, showed a savings of 11.3 kWh/day, or 53%. This energy use reduction includes the impact of the shallow retrofit, which has been shown to also reduce cooling. The space heating utility data evaluation, which included the negative savings from the shallow retrofit lighting measures, still indicated a savings of 2.0 kWh/day on cold days for deep retrofits, or 55%.

In the space conditioning end-use energy demand evaluation using monitored data, we found peak summer hour (4-5 PM) demand reductions of 1.02 kW (44% savings) and peak winter hour (7-8 AM) reductions between 0.35 and 0.44 kW (46-49% savings). Meanwhile, 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 in summer or 37%.

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

A new, first-of-its-kind, low-energy clothes dryer produced average pre/post savings of 18% (0.6 kWh/day) for the eight homes where they were installed. However, savings from this measure were highly variable; the home with the largest use showed a 26% reduction, while 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 we will investigate the energy impacts and cost-effectiveness of clothes dryers incorporating 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, we found that only about half of the potential savings were achieved unless the variable-speed units were properly programmed by an experienced installer.

7.2.1 Deep Retrofit Cost-Effectiveness

We used the results from the utility data analysis to conduct a preliminary 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 8.7 years, reflecting an 11.5% 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 our deep retrofit program is highly cost-effective.

If the retrofits were completed immediately instead of at the normal time of replacement, as was done in the study, with an added cost of $14,323, the economics are less attractive. The simple payback for the package of measures increases to 17.6 years with a simple rate of return of 5.7%.

One important finding arises directly from our 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 homes that are in need of having the heating and cooling system replaced in the home by the home owner, 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 11 years not counting any utility rebates) and has the advantage of engaging the homeowners at the time that large household alterations will be underway. The resulting annual energy reduction (approximately 40%) 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 XX.

Table XX. Shallow and Deep Retrofit Energy Impact Results Summary

Shallow and Deep Retrofit Energy Impacts*	Annual Energy Savings		Summer Peak Hour Reduction**		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 & Other	664	22%	0.24	42%	(0.02)	-6%	$281	$281
Water Heating	179	10%	0.11	26%	0.36	56%	$94	$94
Pool Pump	175	9%	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	4,129	53%	1.92	52%			$8,016	$2,635
Space Heating	737	55%			2.26	80%		
Water Heating* **	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******	219	18%	0.04	26%	0.08	39%	$2,620	$1,087
Dishwasher***** (n=1)	175	32%	(0.27)	n/a	-	n/a	$508	$0
Pool Pump***** (n=3)	4,599	86%	0.89	91%	(0.09)	n/a	$2,035	$1,458
Whole-House	**6,756**	**39%**	**1.96**	**39%**	**2.71**	**60%**	**$14,323**	**$7,074**

* Sample size varies among end-use and metric. End-uses can not be summed for whole-house total. Very small sample sizes noted as "n=*x*"

** Shallow retrofit summer peak is a surrogate October date; deep retrofit summer peak is for the deep retrofit only, thus results are conservative.

*** Water Heating energy savings baseline includes partial post-shallow retrofit, thus results are conservative. Water Heating had no post-retrofit peak summer hour demand in the HPWH segment.

**** Cost includes the clothes washer and dryer as a set.

***** No pre-retrofit peak winter hour demand for Dishwasher or Pool Pump; No post-retrofit peak winter hour demand for dishwasher.

References

Agnew, K.; Goldberg, M. (2013). Chapter 8: Whole-Building Retrofit with Consumption Data Analysis Evaluation Protocol. NREL/SR-7A30-53827. Accessed November 2014: http://energy.gov/sites/prod/files/2013/11/f5/53827-8.pdf

AO Smith. (2011). Service Handbook. "Residential Hybrid Electric Heat Pump Water Heater, For Models: PHPT-60, PHPT-80." Accessed November 2014: http://www.hotwater.com/water-heaters/residential/conventional/electric/voltex-hybrid-electric/voltex-hybrid-electric-heat-pump-water-heater-phpt-80/

Chasar, D.; Withers, C. (2013). *Measured Cooling Performance and Potential for Buried Duct Condensation in a 1991 Central Florida Retrofit Home.* FSEC-CR-1946-13. Cocoa, FL: Florida Solar Energy Center. Accessed November 2014: http://www.fsec.ucf.edu/en/publications/pdf/FSEC-CR-1946-13.pdf

FPL (1999). "Gas Hot Water Research Project." Craig Muccio. Florida Power & Light Company: Miami, FL.

Hirst, E.; Trumble, D. (1989). "Effects of the Hood River Conservation Project on Electricity Use and Savings in Single-Family Homes." *Applied Economics*. (21:8); pp. 1020-1042.

Masiello, J. A.; Bouchelle, M. P.; Parker, D. S.; Sherwin, J. R. (2004). "Measured Energy and Peak Demand Reduction from High Efficiency Air Conditioner Replacement." *2004 ACEEE Summer Study on Energy Efficiency in Buildings*; August 2004, Washington, D.C. American Council for an Energy Efficient Economy.

Messenger, R.; Hayes, S. (1984). *Swimming Pool Circulation System Energy Efficiency Optimization Study*. Boca Raton, FL: Florida Atlantic University. Accessed November 2014: http://consensus.fsu.edu/FBC/Pool-Efficiency/FAU-FPL-NSPI_1984_study-efficiency_of_circulation_systems.pdf

National Oceanic and Atmospheric Administration. (2014). Accessed October 2014: http://gis.ncdc.noaa.gov/map/viewer/#app=cdo&cfg=cdo&theme=hourly&layers=00000001&extent=-139.2:12.7:-50.4:57.8&node=gis

Parker, D.; J. Sherwin. (2012). Achieving Very High Efficiency and Net Zero Energy in an Existing Home in a Hot-Humid Climate: Long-Term Utility and Monitoring Data. FSEC-RR-383-12. Cocoa, FL: Florida Solar Energy Center. Accessed 2013: http://www.fsec.ucf.edu/en/publications/pdf/FSEC-RR-383-12.pdf

Parker, D.; Sherwin, J.; Floyd, D. (1998). *Measured Energy Savings from Retrofits Installed in Low-Income Housing in a Hot and Humid Climate*. FSEC-PF-339-98. Cocoa, FL: Florida Solar Energy Center. Accessed 2013: http://www.fsec.ucf.edu/en/publications/html/FSEC-pf-339-98/index.htm

Parker, D.; Sherwin, J.; Sonne, J.; Barkaszi, S.; Floyd, D.; Withers, Jr., C. (1997). *Measured Energy Savings of a Comprehensive Retrofit in an Existing Florida Residence*. FSEC-CR-978-

97. Cocoa, FL: Florida Solar Energy Center. Accessed 2013: http://www.fsec.ucf.edu/en/publications/html/FSEC-CR-978-97/

Parker, D. S.; Stedman, T. C. (1990). "Measured Electricity Savings of Refrigerator Replacement: Case Study and Analysis." *1992 ACEEE Summer Study on Energy Efficiency in Buildings*. American Council for an Energy Efficient Economy. Washington D.C., Vol. 3; p. 199.

Shapiro, C.; Zoeller, W.; Mantha, P. (2013). *Measure Guideline: Buried and/or Encapsulated Ducts.* Prepared by the Consortium for Advanced Residential Buildings for the Department of Energy Building America program. Accessed 2013: http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/measure_guide_buried_encap_ducts.pdf

Sutherland, K.; Parker, D.; Chasar, D.; Hoak, D. (2014). “Measured Retrofit Savings from Efficient Lighting and Smart Power Strips.” Presented at 2014 ACEEE Summer Study on Energy Efficiency in Buildings; August 20, 2014, Pacific Grove, California. Cocoa, FL: Florida Solar Energy Center. Accessed November 2014: http://fsec.ucf.edu/en/publications/pdf/FSEC-RR-508-14.pdf

Appendix A: Deep Retrofit Site Characteristics

Pre-Retrofit Site Characteristics

Site	Yr Built	Conditioned Floor Area (ft^2)	# of Floors	Foundation Type	Wall Type	HVAC	T-Stat	DHW	Ceiling Insulation	Pool Pump
7	1989	2650	2	SOG	CMU & Stick	14 SEER	P	40gal electric tank	R-19	single speed
8	1997	2134	1	SOG	Stick	10 SEER	M	50gal electric tank	R-30	N/A
10	2003	1627	1	SOG	CMU	12 SEER	M	50gal electric tank	R-30	N/A
19	1988	2554	1	SOG	CMU	Less than 10 SEER	P	50gal electric tank	R-19	N/A
26	1999	1502	1	SOG	CMU	10 SEER	M	55gal electric tank	R-19	N/A
30	1976	1819	1	SOG	CMU	13 SEER	P	40gal electric tank	R-8	N/A
37	1993	1654	1	SOG	Stick	Less than 10 SEER	M	40gal electric tank	R-19	single speed
39	1981	1559	1	SOG	CMU	14 SEER	M	50 gallon HPWH	R-38	N/A
40	1993	1983	1	SOG	Stick	Less than 12 SEER	P	40gal electric tank	R-19	N/A
51	1994	2233	2	Crawlspace	Stick	10 SEER	P	40gal electric tank	R-19	N/A

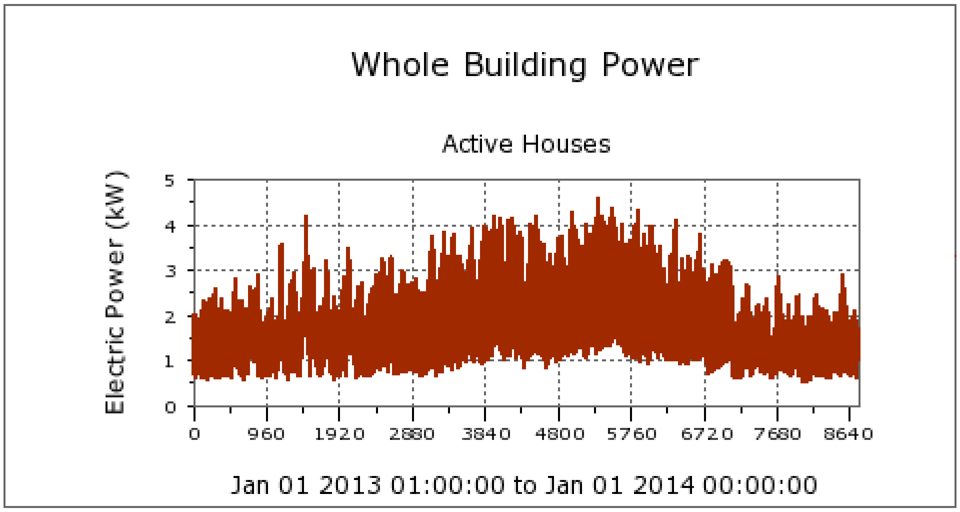
Installed Deep Retrofit Measures by Site

Site	High Efficiency Heat Pump	Duct System Testing & Sealing	Bedroom Pressure Relief	NEST T-Stat	Heat Pump Water Heater	Ceiling Insulation	E-STAR Frig	E-STAR Washer	E-STAR Dryer	E-STAR Dish-washer	Variable-Speed Pool Pump
7	x	x	x	x	x	x					x
8	x	x		x	x			x	x	x	
10	x	x			x	x		x	x		
19	x	x	x	x	x	x		x	x		
26	x	x	x	x	x	x	x	x	x		
30	x	x	x	x	x	x		x	x		
37	x	x		x	x	x					x
39	x	x	x	x	x		x	x	x		
40	x	x		x	x	x		x	x		
51	x	x	x	x	x	x	x	x	x		

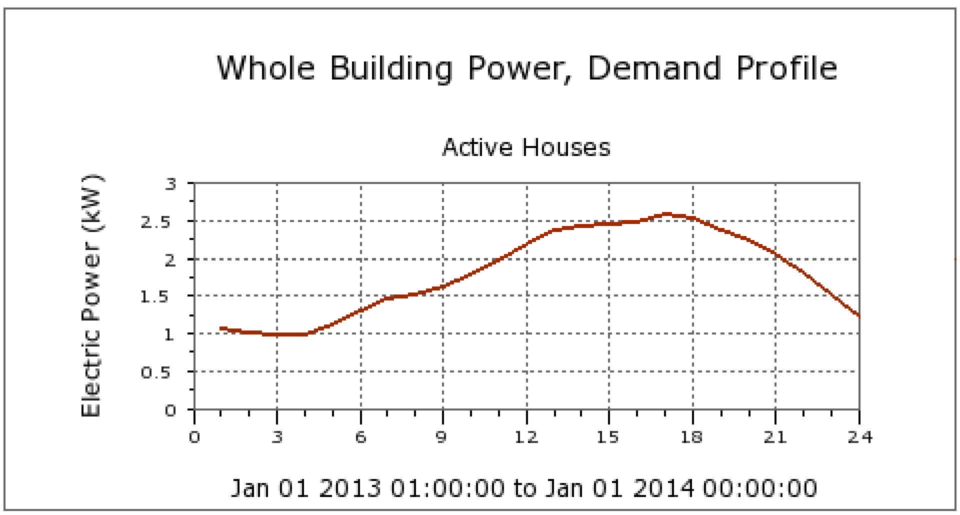
[1] Site 10: The homeowner installed the HVAC of his own accord and although the system is made by the same manufacturer as the rest of the deep retrofit systems, it is a different series and higher SEER rating. Additionally, the homeowner used a different HVAC contractor for all HVAC related retrofit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

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

Summary End-use Plots [18]

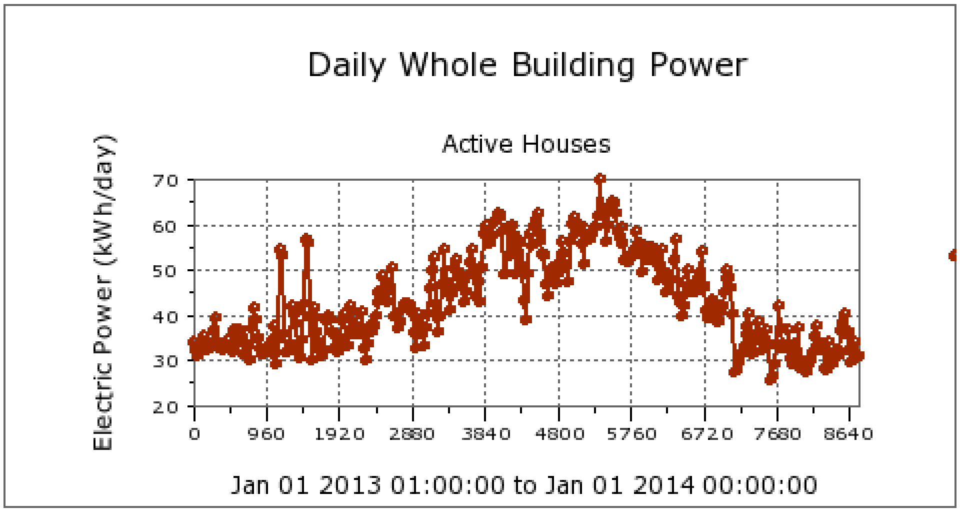


Hourly total electrical load for all 56 homes over the year

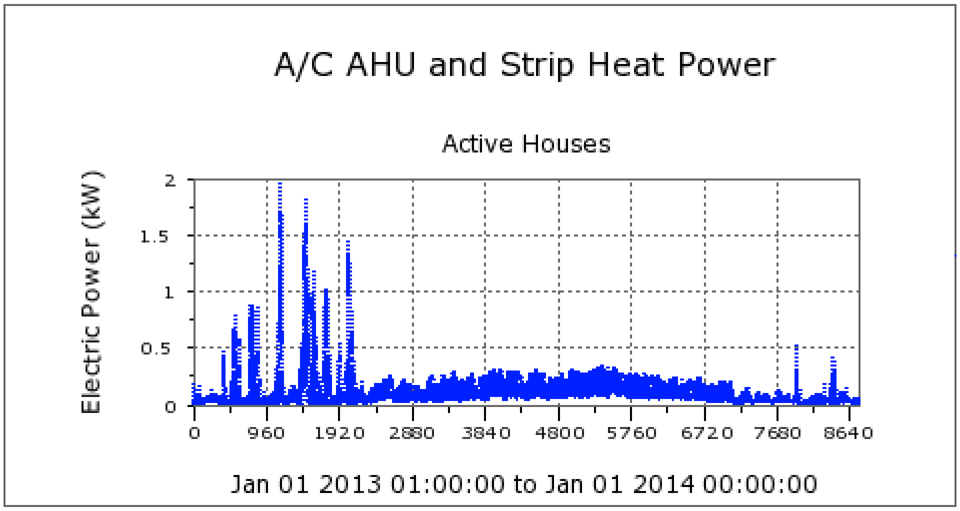


Average total electrical load shape over 2013

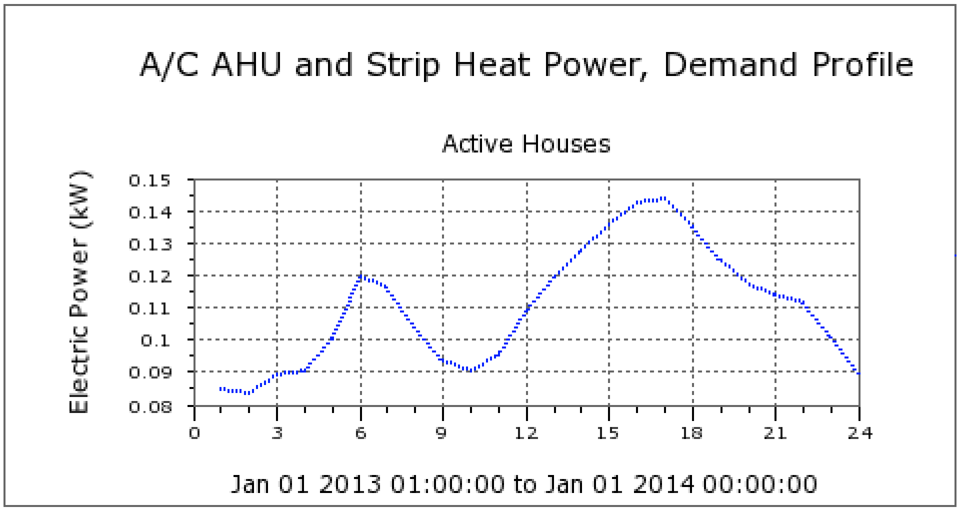
[18] Data creating these plots can be downloaded at the site data domain: http://www.infomonitors.com/pdr/



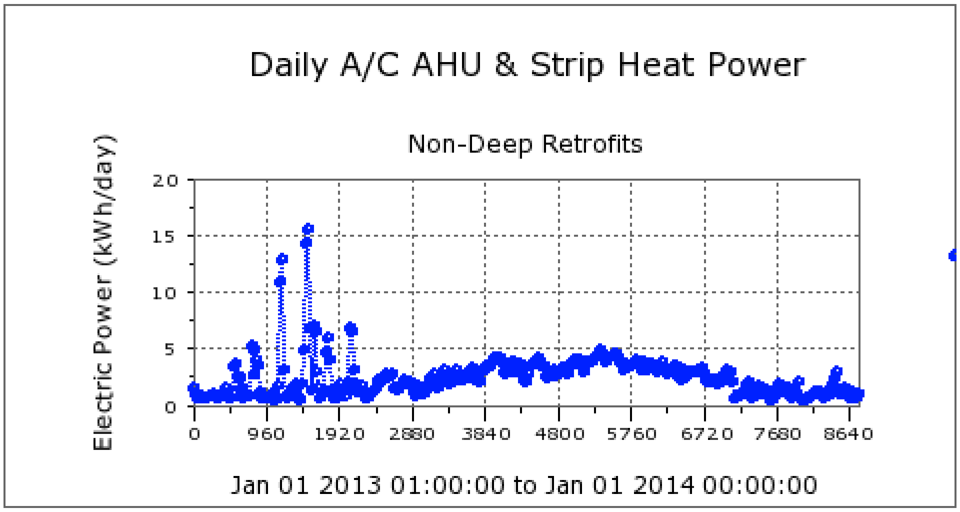
Average daily electricity use (kWh/day) for total electricity in overall sample



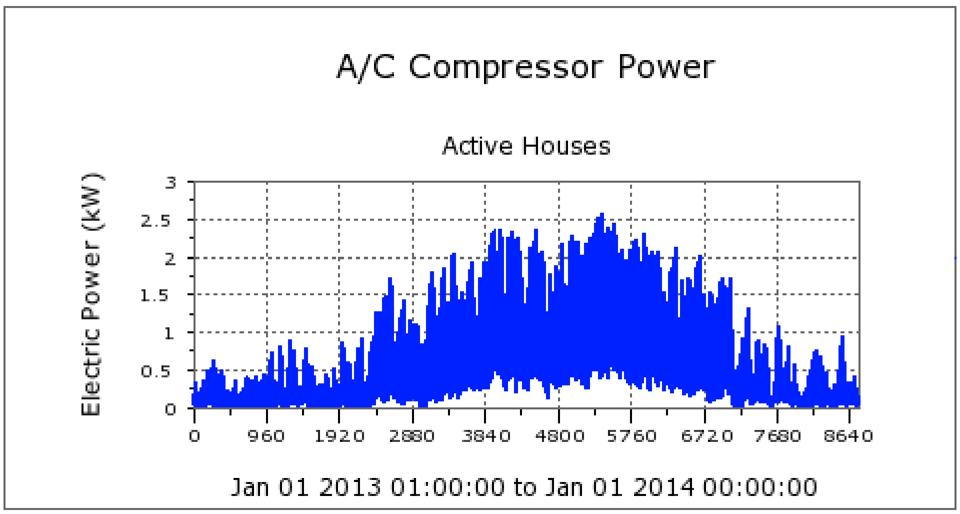
Average hourly air handler and strip heat power in overall sample



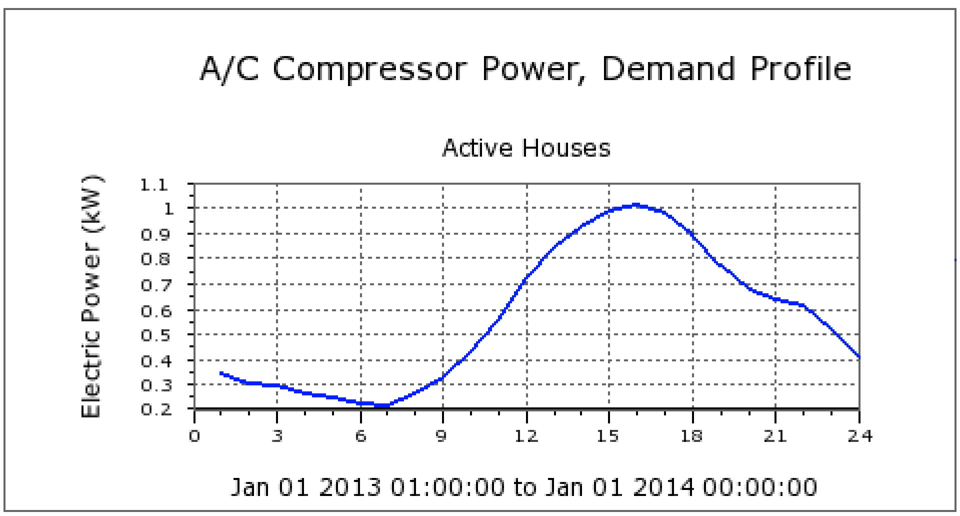
Average air handler and strip heat electrical load shape over 2013



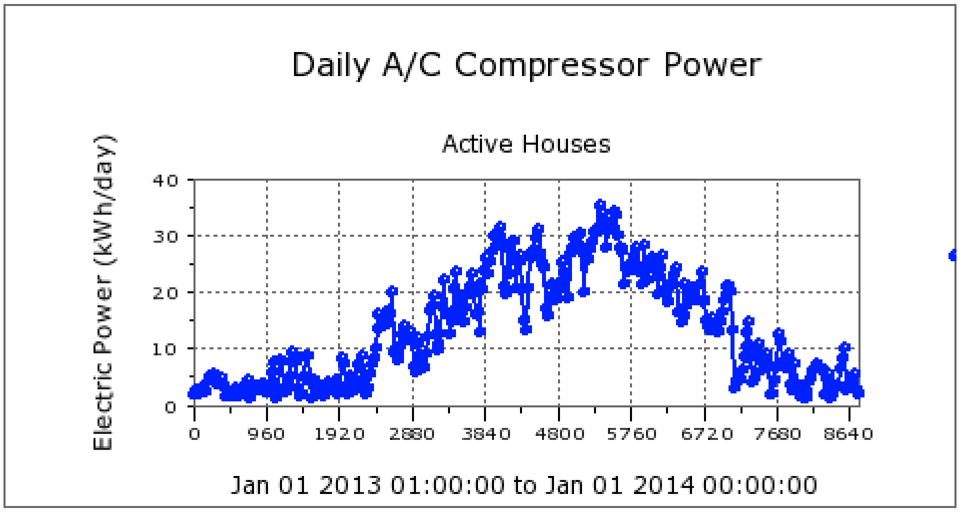
Average daily electricity use (kWh/day) for AHU/strip heat electricity in overall sample



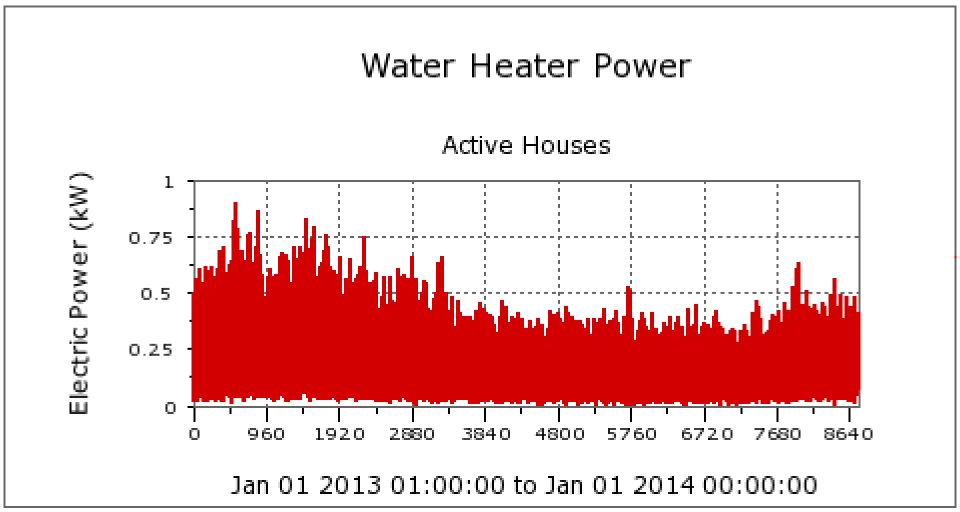
Average hourly compressor power (heat pump & air conditioning) in overall sample



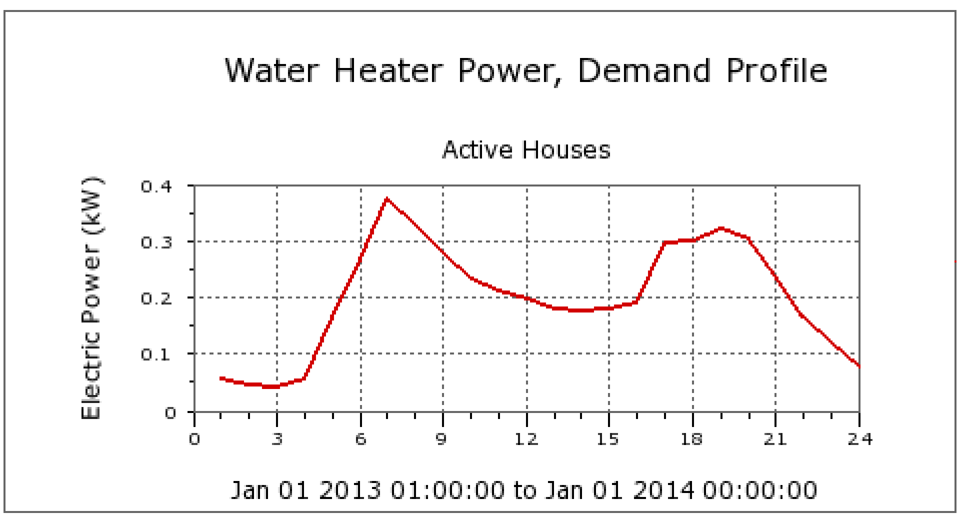
Average compressor load shape over 2013



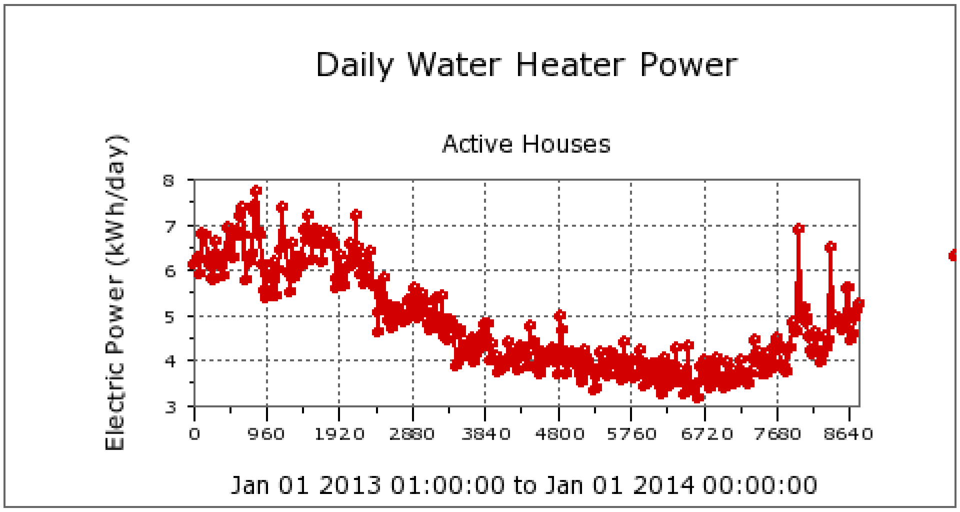
Average daily electricity use (kWh/day) for compressor electricity in overall sample



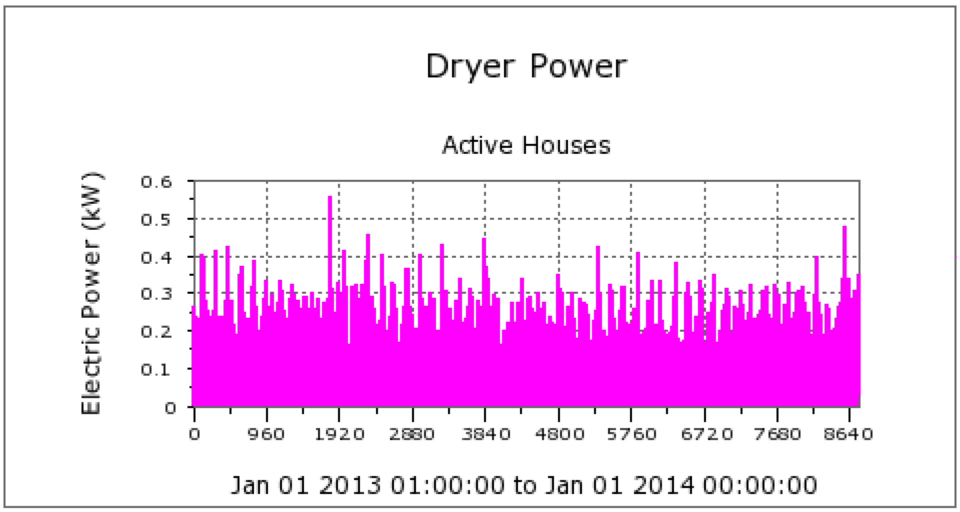
Average hourly water heating electricity in overall sample



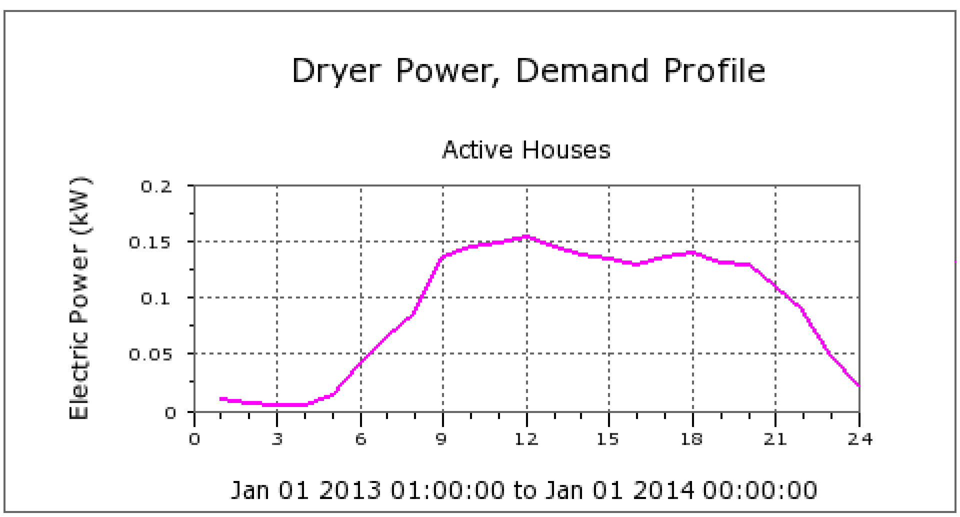
Average water heater load shape over 2013



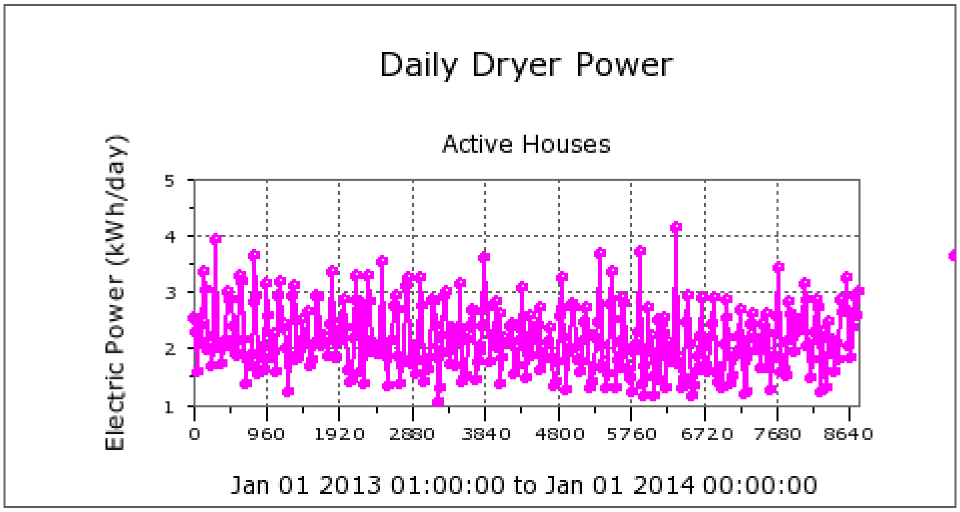
Average daily electricity use (kWh/day) for water heating in overall sample



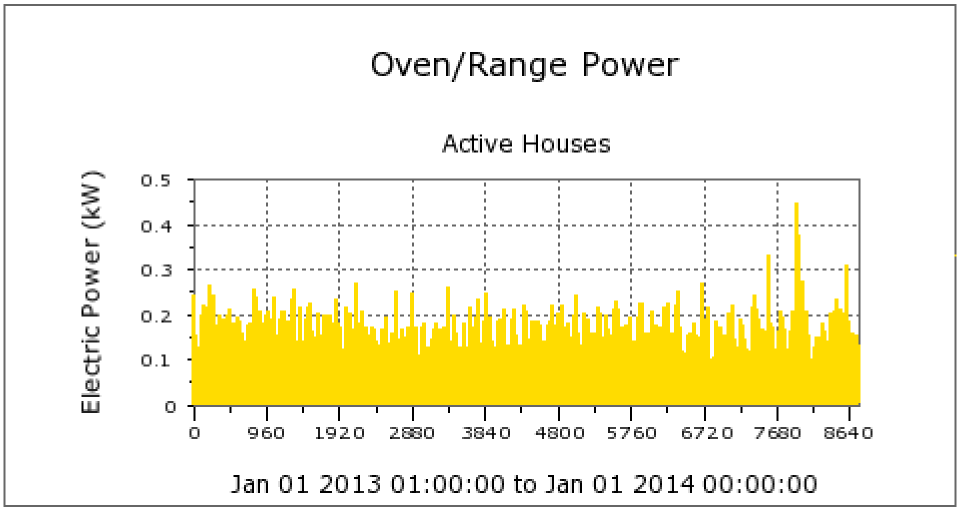
Average hourly clothes dryer electricity in overall sample



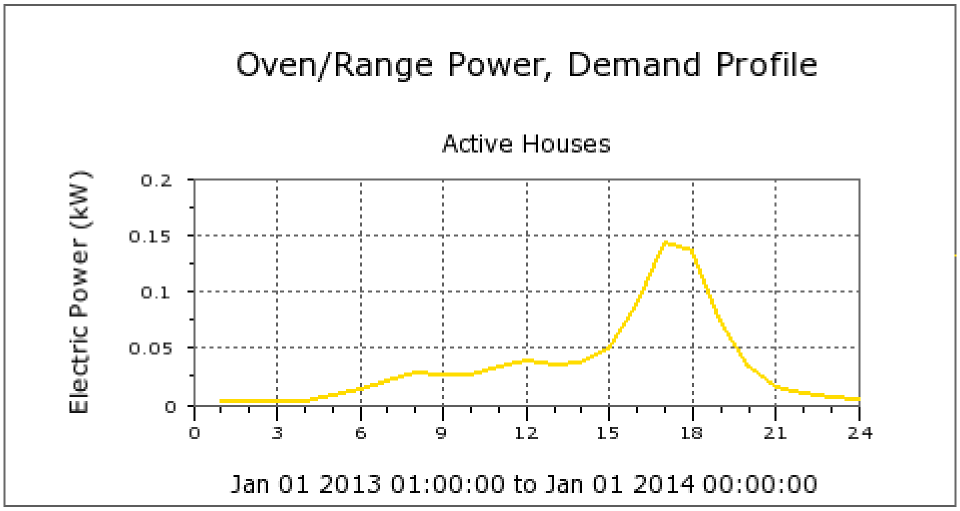
Average clothes dryer load shape over 2013



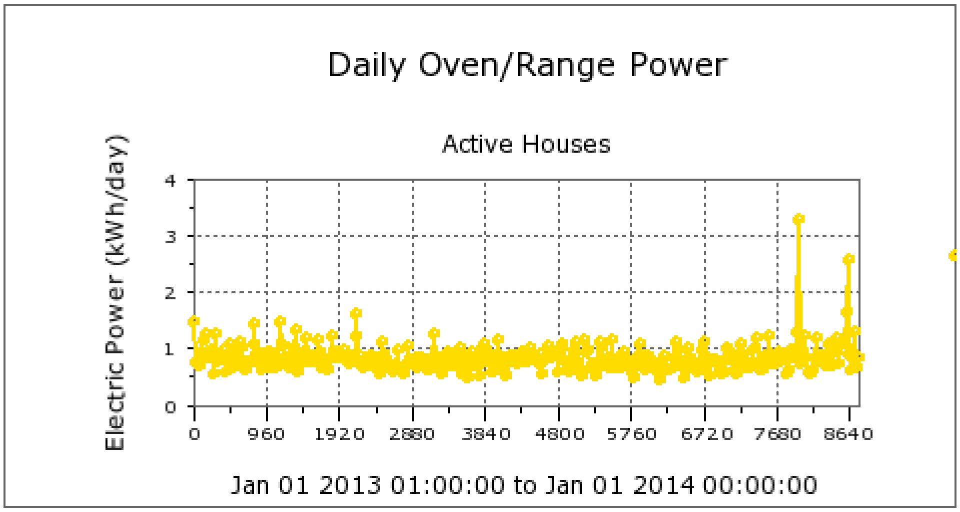
Average daily electricity use (kWh/day) for clothes drying in overall sample



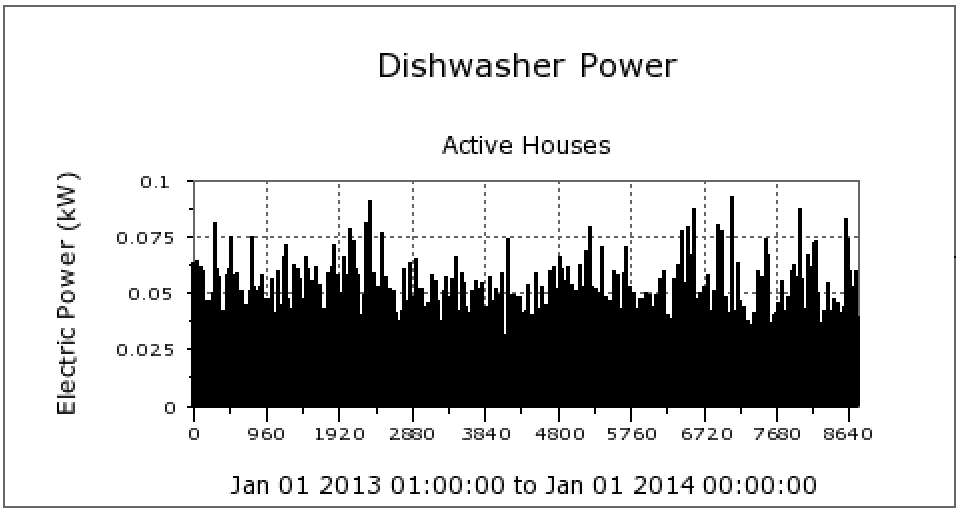
Average hourly oven/range electricity in overall sample



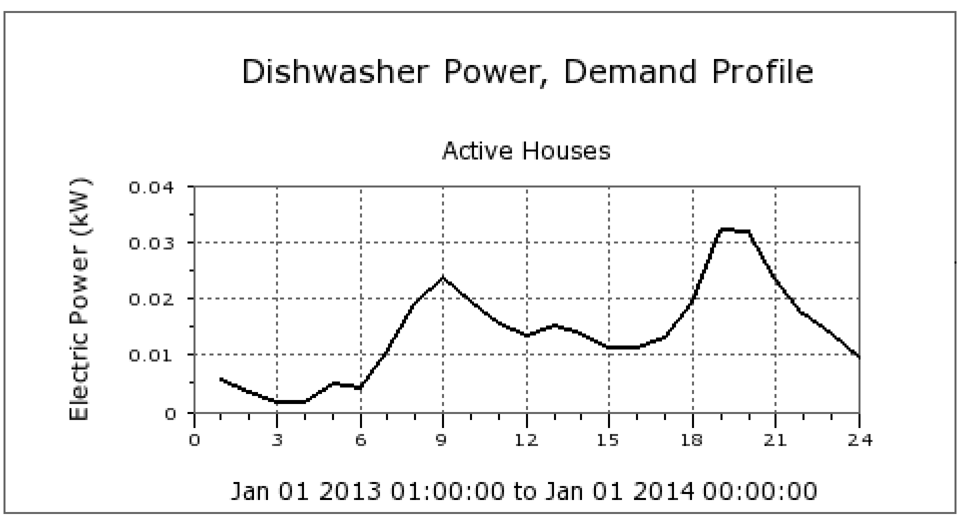
Average range/oven load shape over 2013



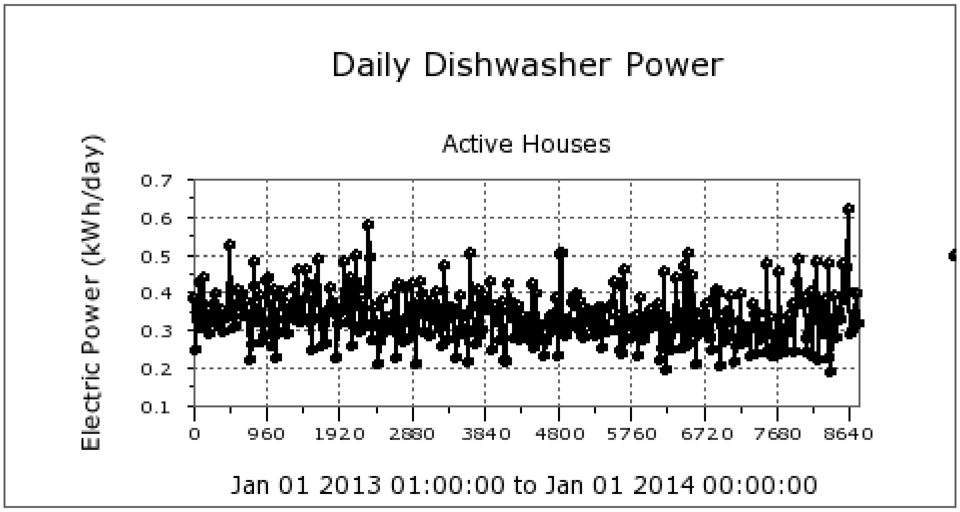
Average daily electricity use (kWh/day) for range/oven in overall sample



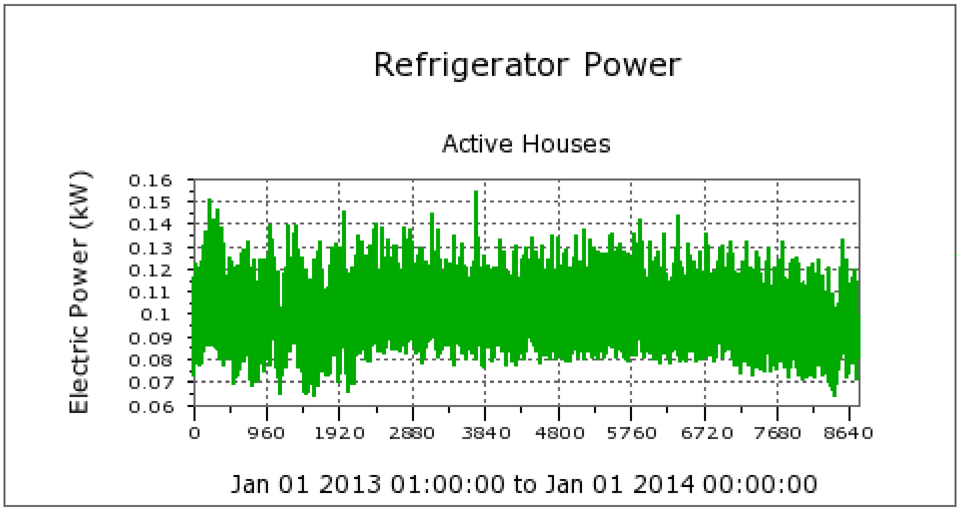
Average hourly dishwasher electricity in overall sample



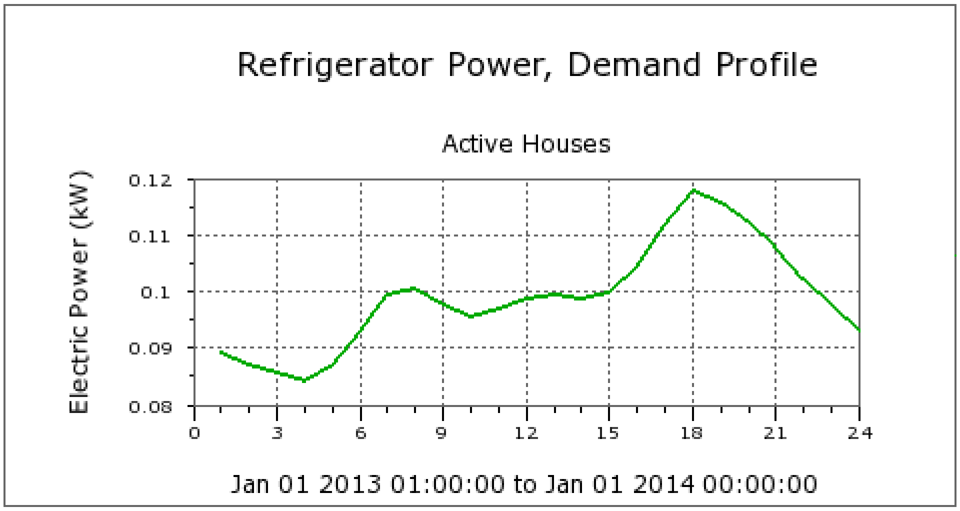
Average dishwasher load shape over 2013



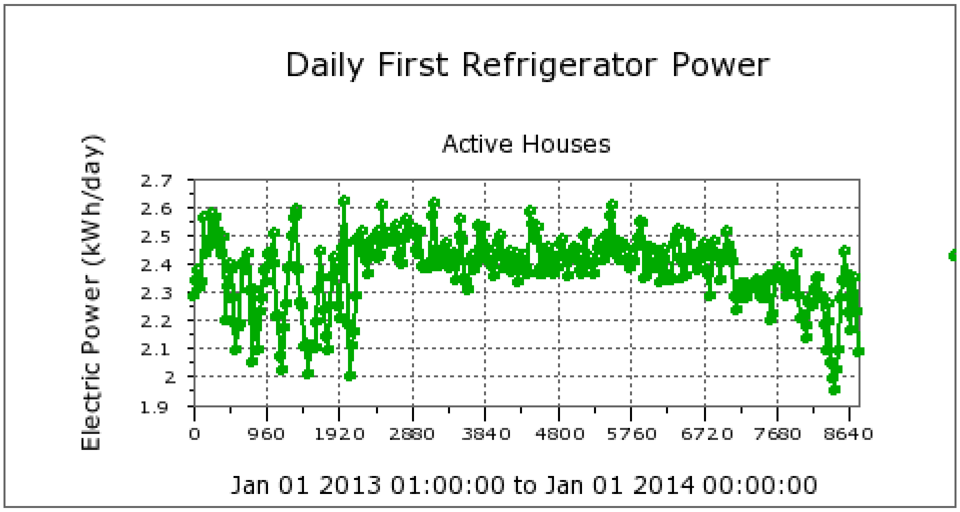
Average daily electricity use (kWh/day) for dishwasher in overall sample



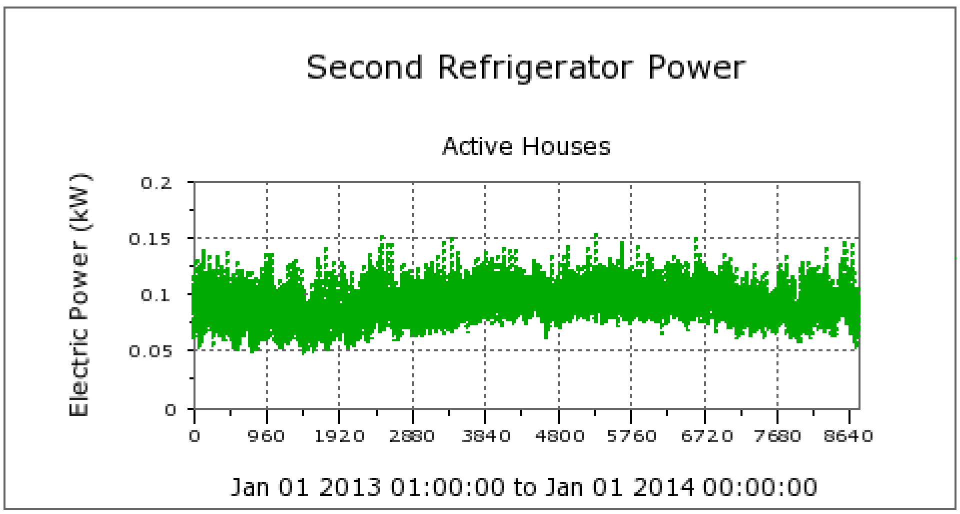
Average hourly refrigerator electricity in overall sample



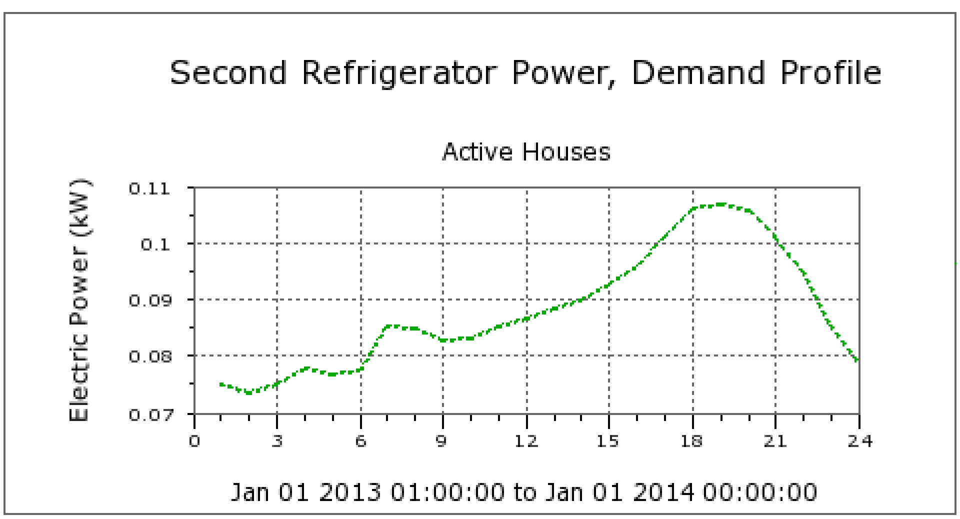
Average refrigerator load shape over 2013



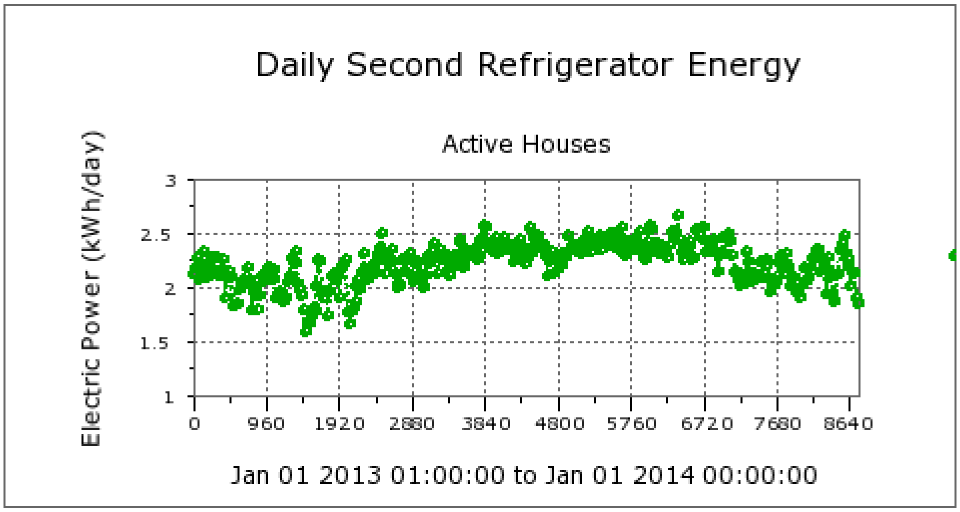
Average daily electricity use (kWh/day) for refrigerator in overall sample



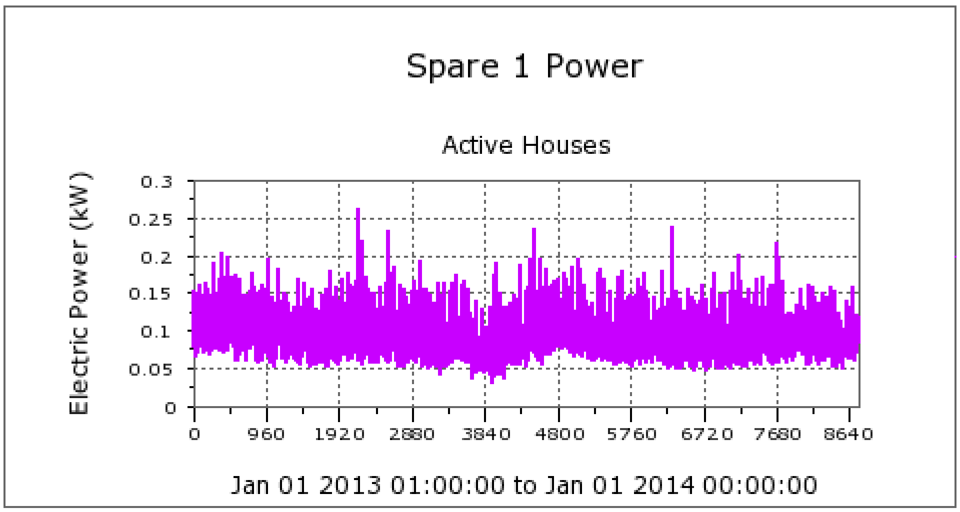
Average hourly 2nd refrigerator electricity in overall sample



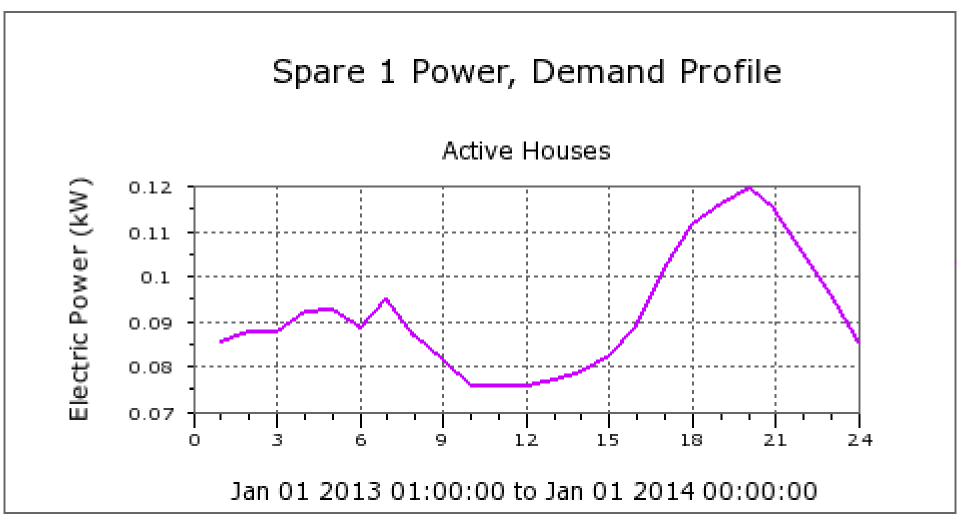
Average 2nd refrigerator load shape over 2013



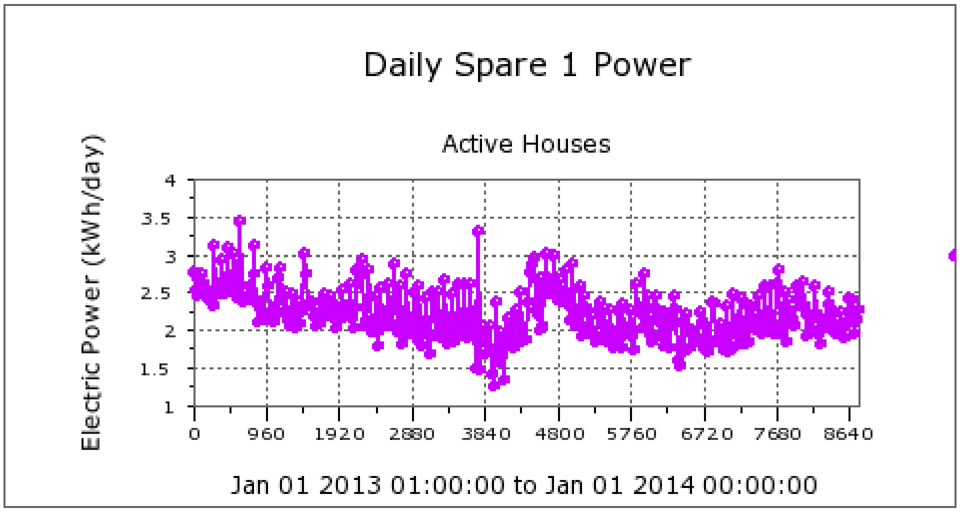
Average daily electricity use (kWh/day) for 2nd refrigerator in overall sample



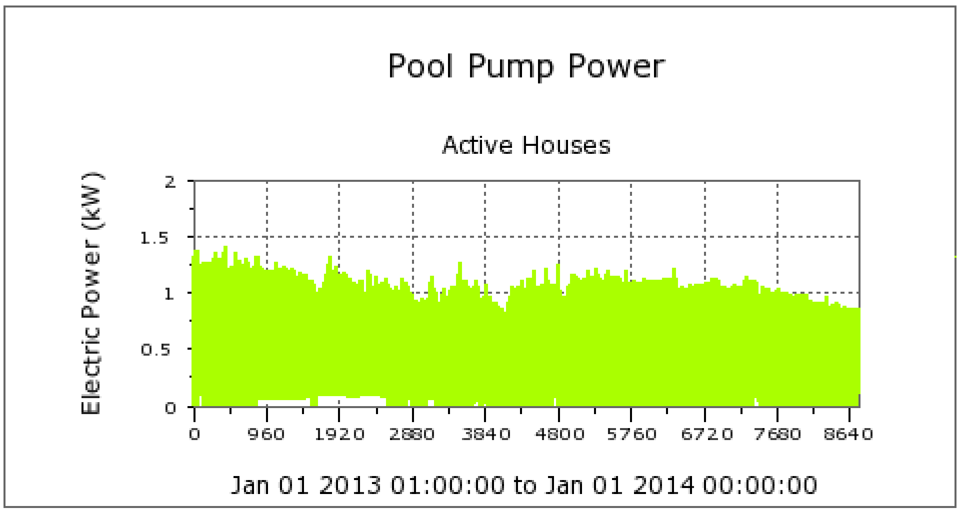
Average hourly Spare 1 electricity in overall sample



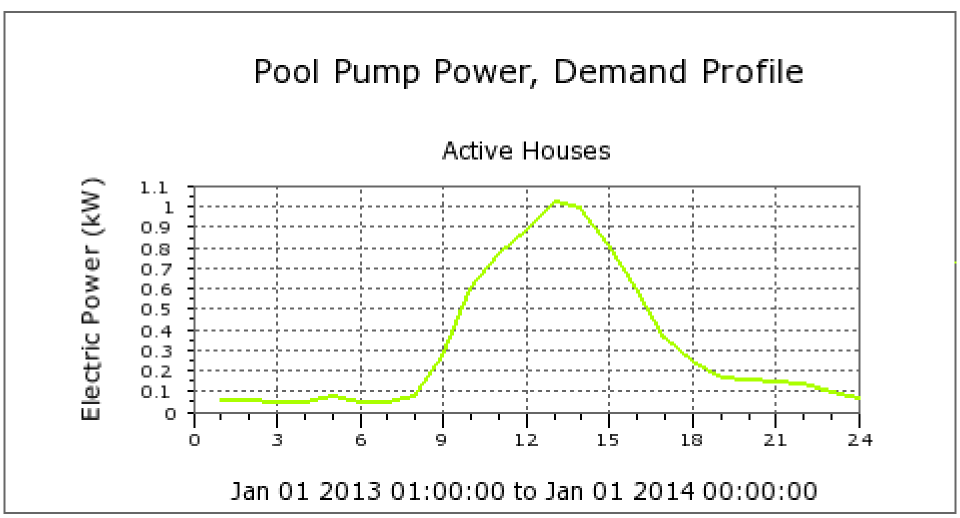
Average Spare 1 load shape over 2013 (Spare 1 included many home offices)



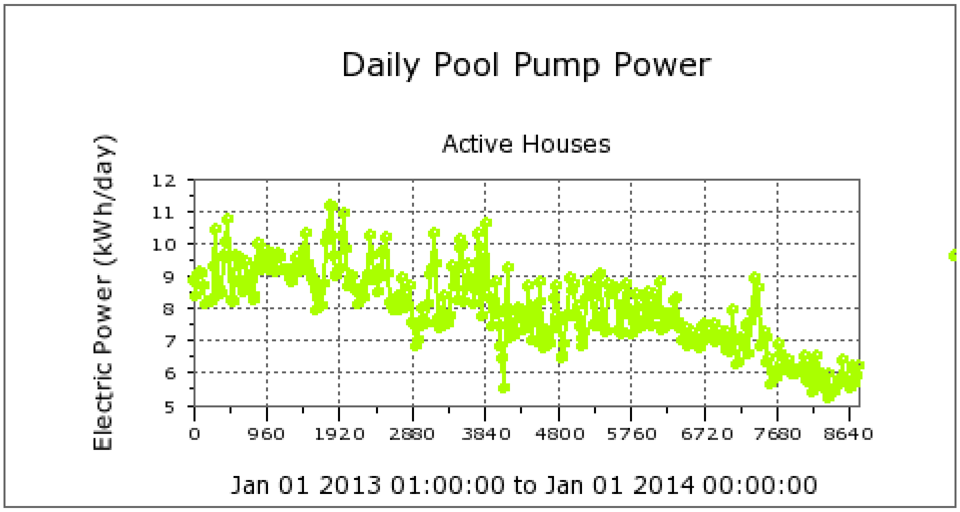
Average daily electricity use (kWh/day) for Spare 1 in overall sample



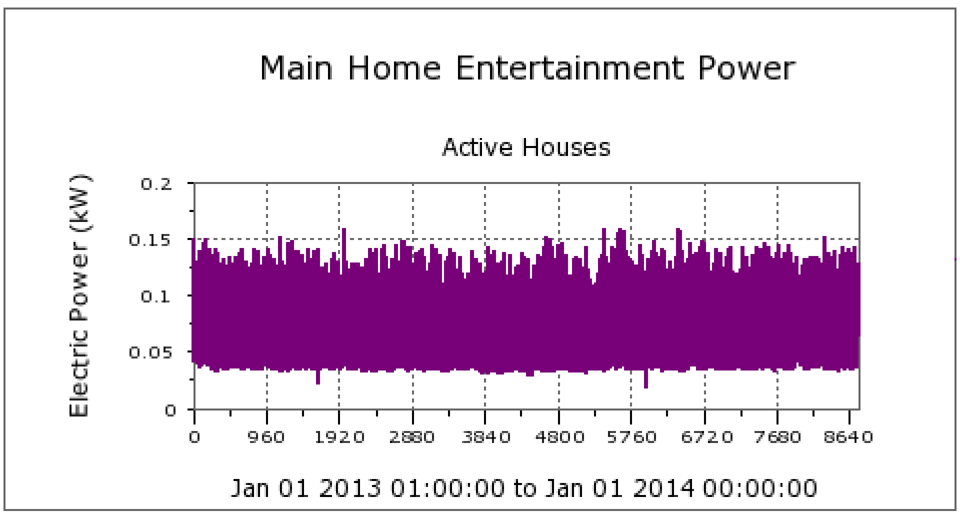
Average hourly pool pump electricity in overall sample



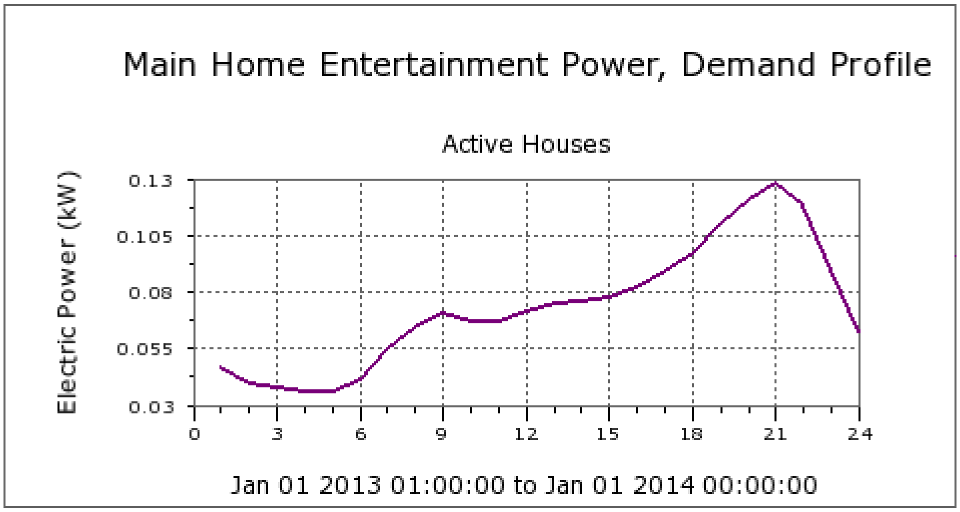
Average swimming pool pump shape over 2013



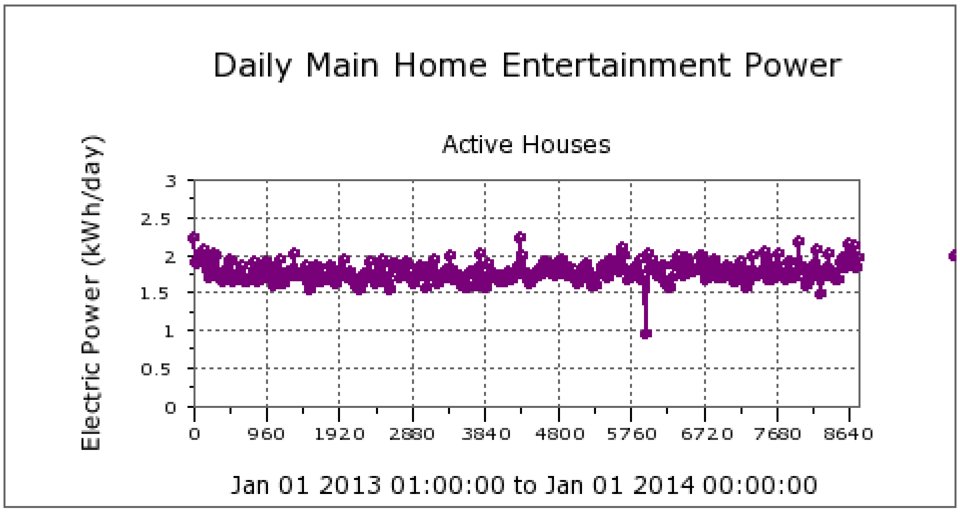
Average daily electricity use (kWh/day) for swimming pools in overall sample. Reductions seen beginning `hour 2000 reflect shallow retrofits, then deep retrofits ~hr 6000



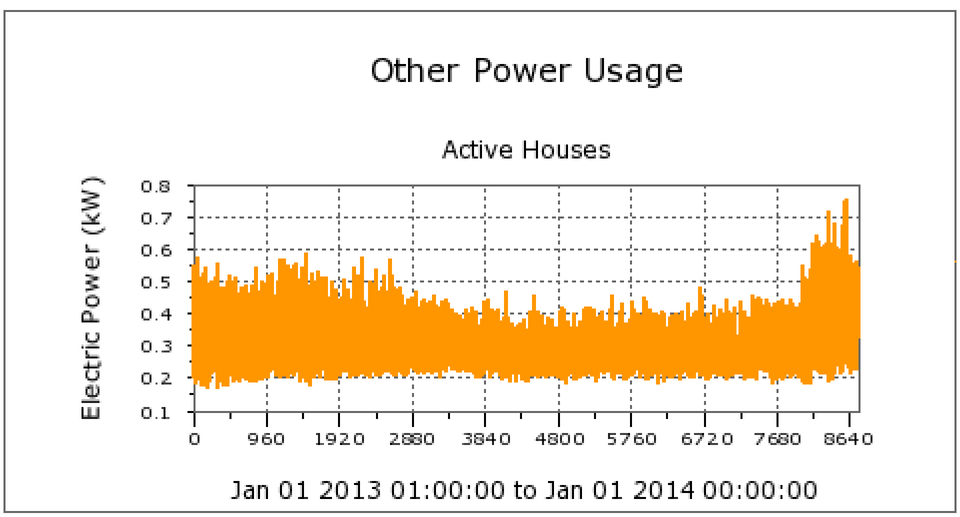
Average hourly home entertainment electricity in overall sample



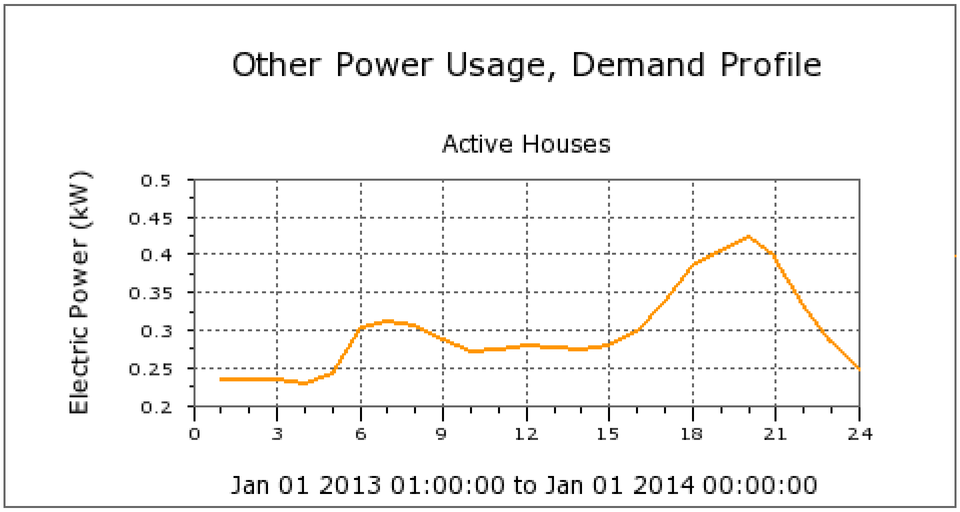
Average home entertainment load shape over 2013



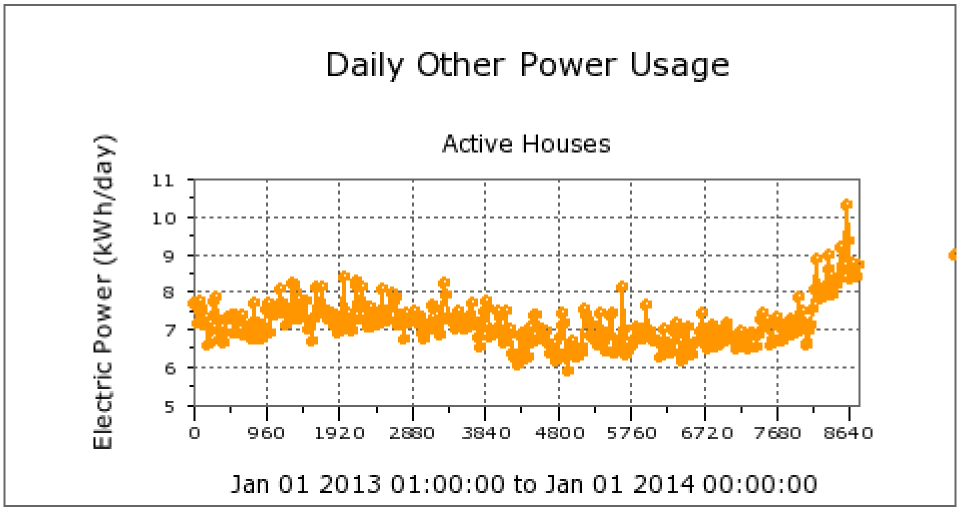
Average daily electricity use (kWh/day) for home entertainment in overall sample



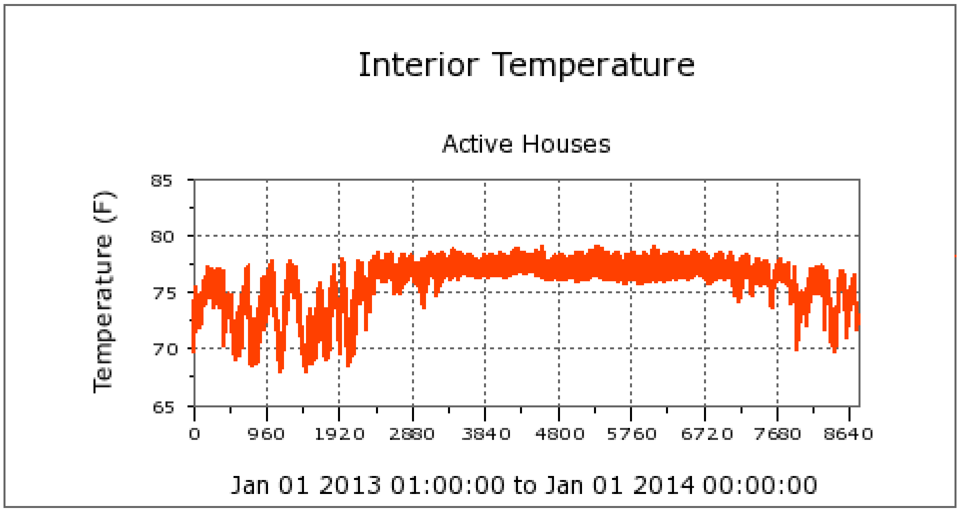
Average hourly lighting and plug load electricity in overall sample



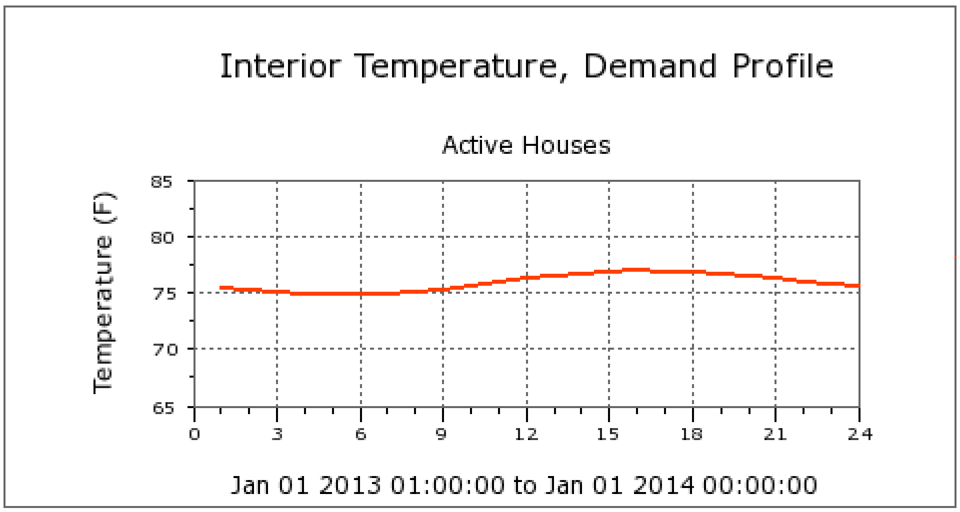
Average lighting and plug load shape over 2013



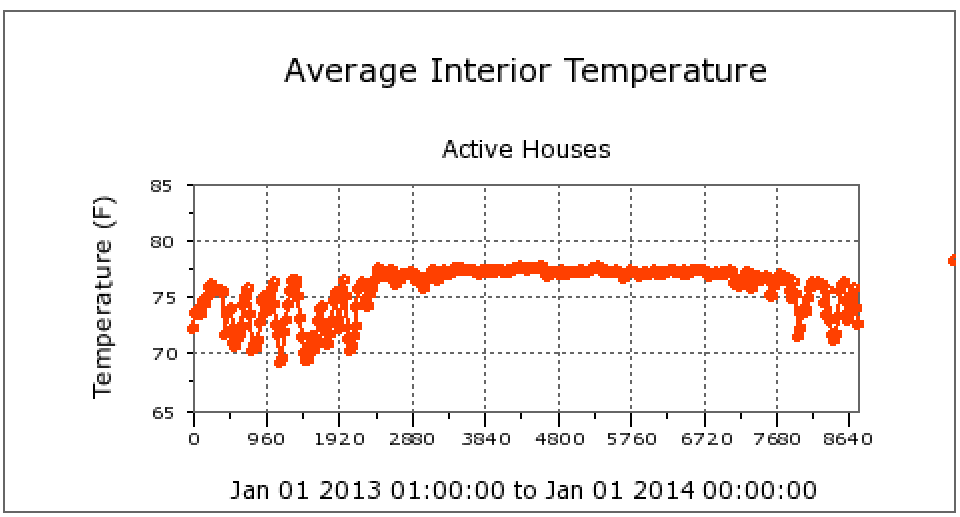
Average daily electricity use (kWh/day) for lighting and plug loads in overall sample. Increases at the end of the year represent holiday lighting.



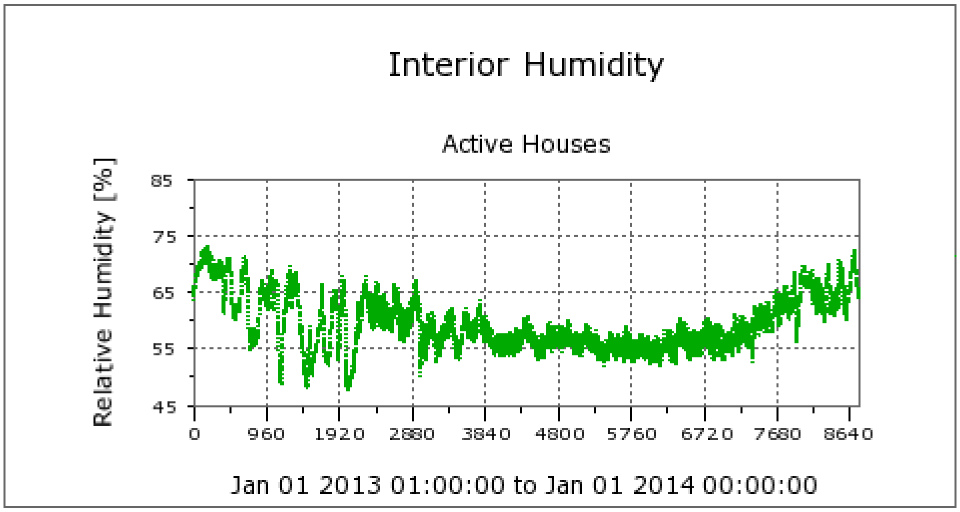
Hourly average temperature in homes over 2013



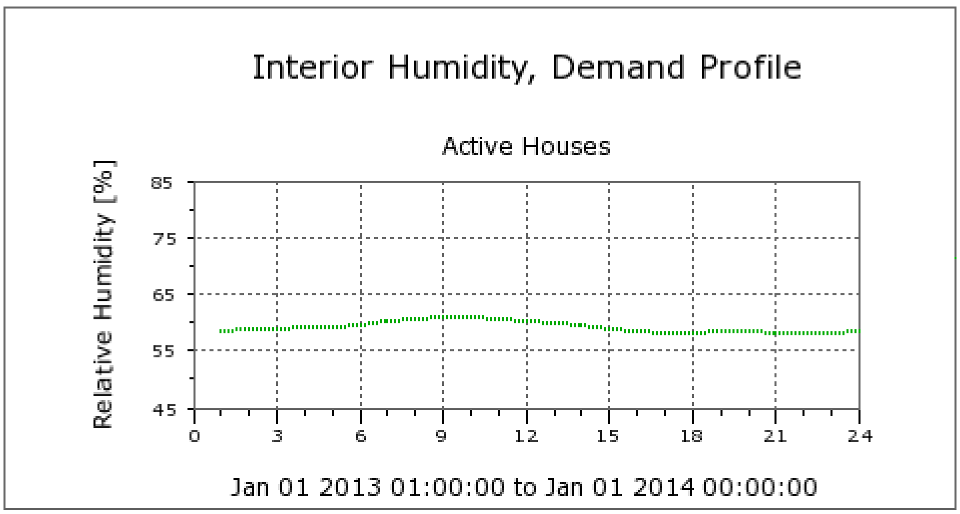
Average interior temperature profile over 2013



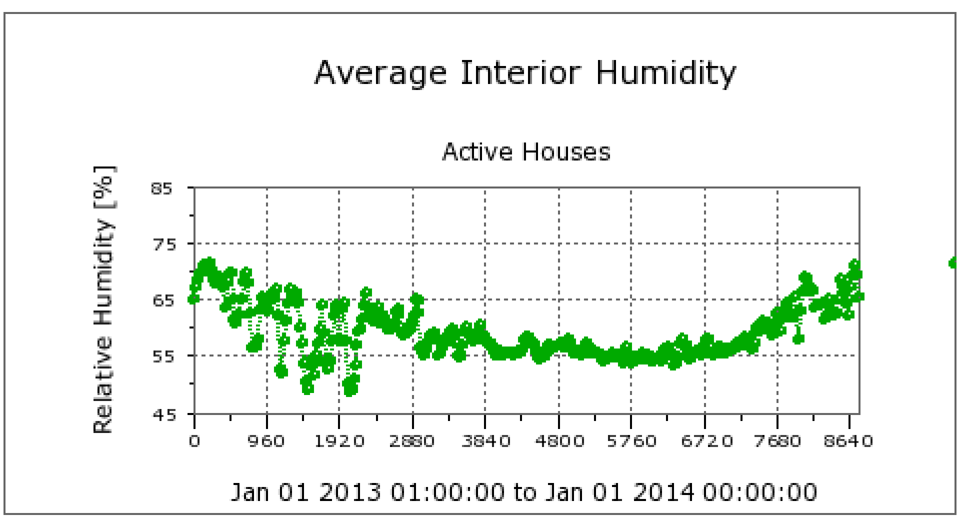
Daily average temperature over 2013



Average hourly interior humidity in homes over 2013



Average interior humidity profile over 2013

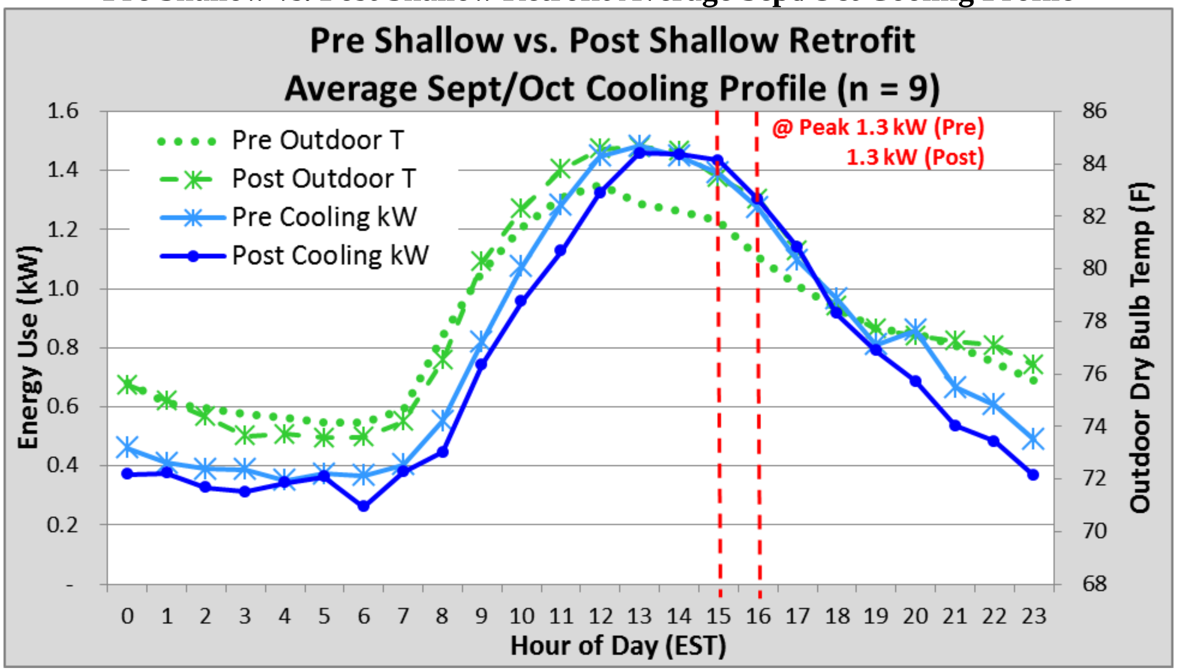


Average daily interior humidity level over 2013

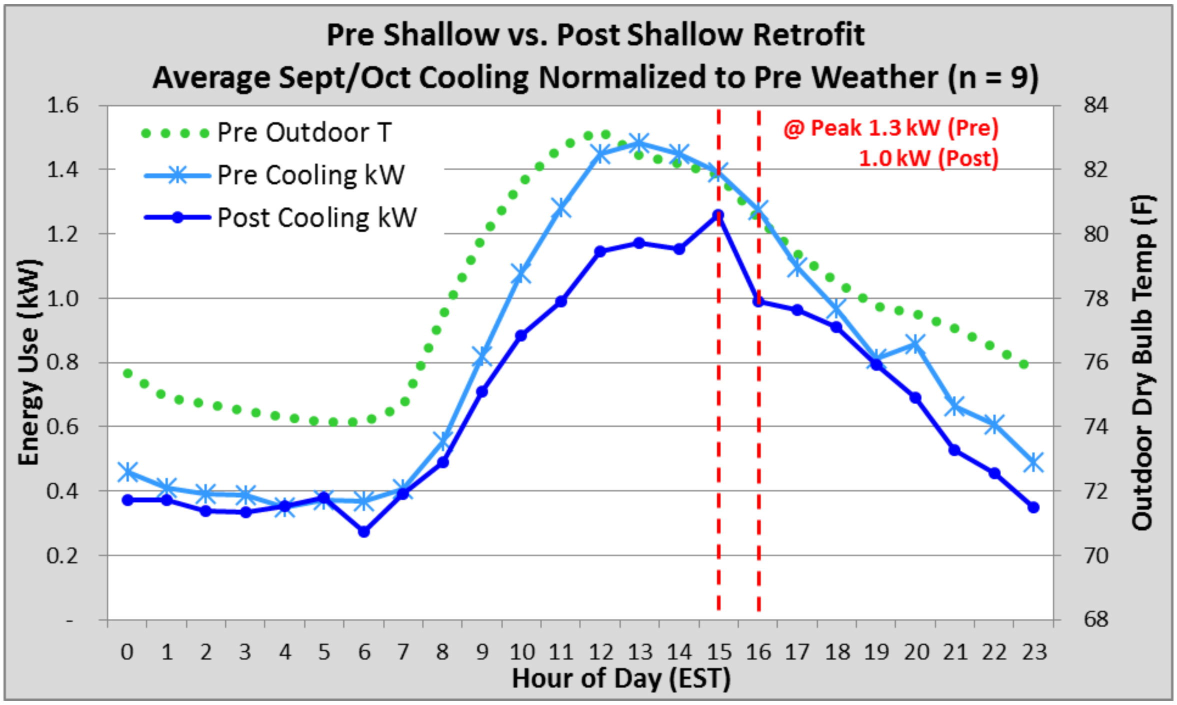
Appendix C: Hourly Power Plots

<u>Shallow Cooling Plots</u>

Pre Shallow vs. Post Shallow Retrofit Average Sept/Oct Cooling Profile

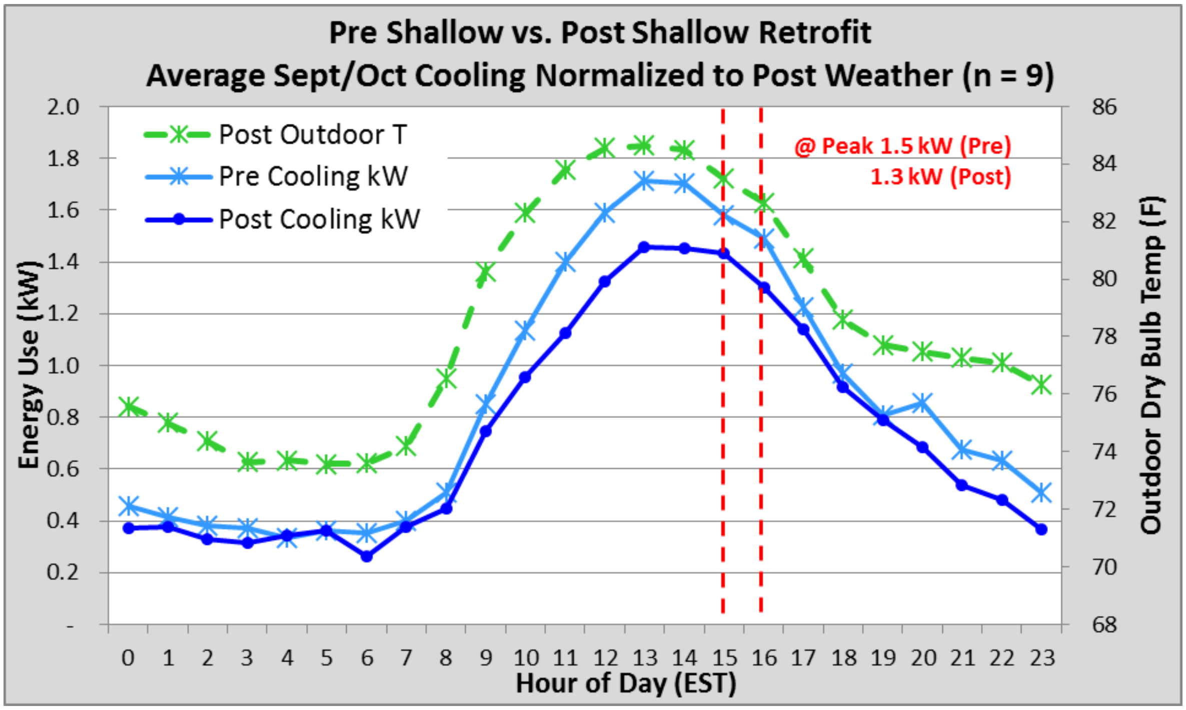


Pre Shallow vs. Post Shallow Retrofit Average Sept/Oct Cooling Normalized to Pre Weather

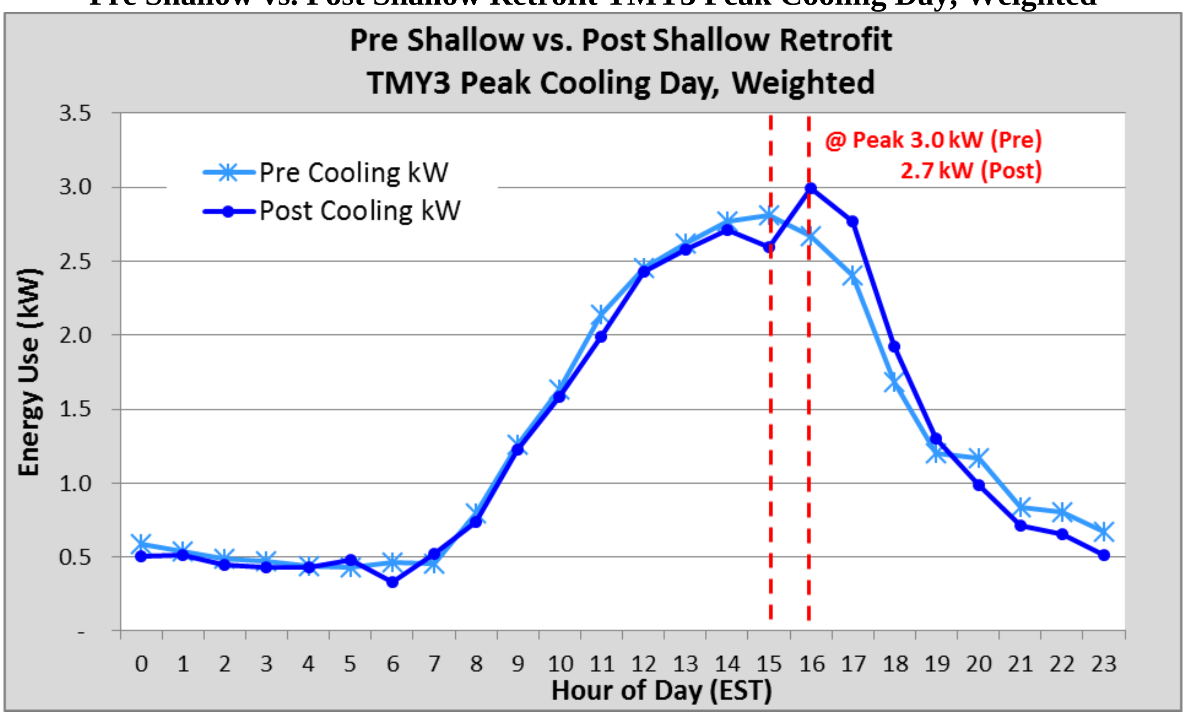


Shallow Cooling Plots (cont.)

Pre Shallow vs. Post Shallow Retrofit Average Sept/Oct Cooling Normalized to Post Weather

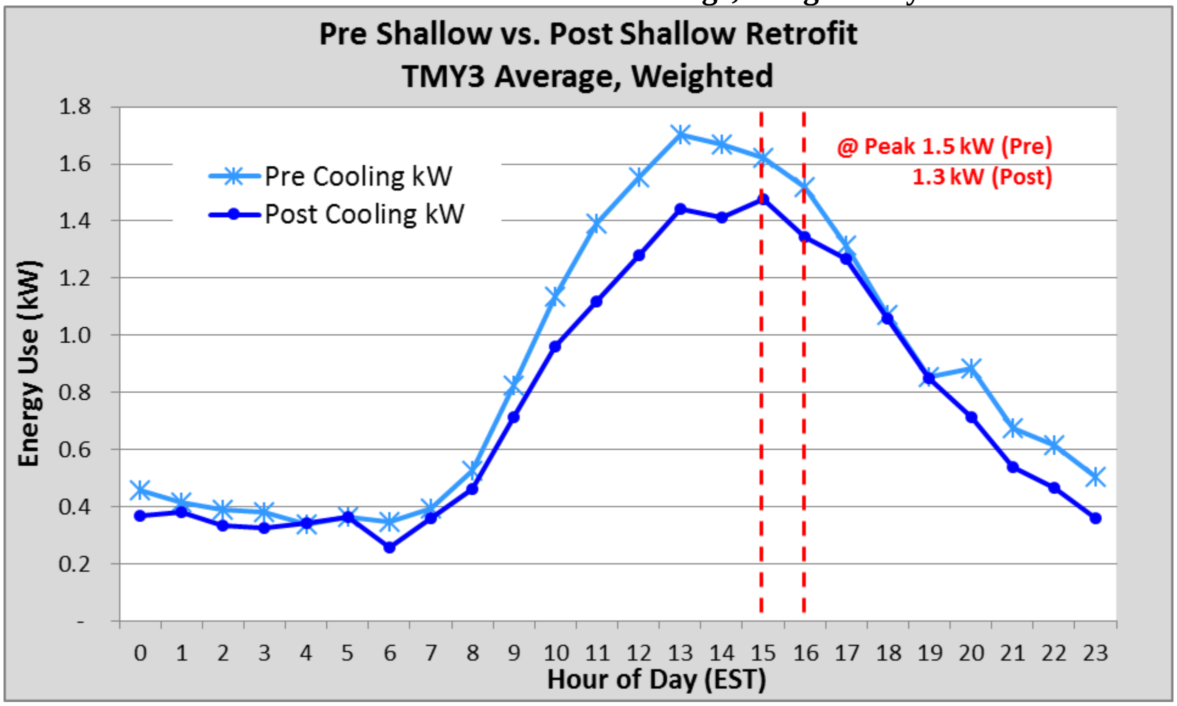


Pre Shallow vs. Post Shallow Retrofit TMY3 Peak Cooling Day, Weighted



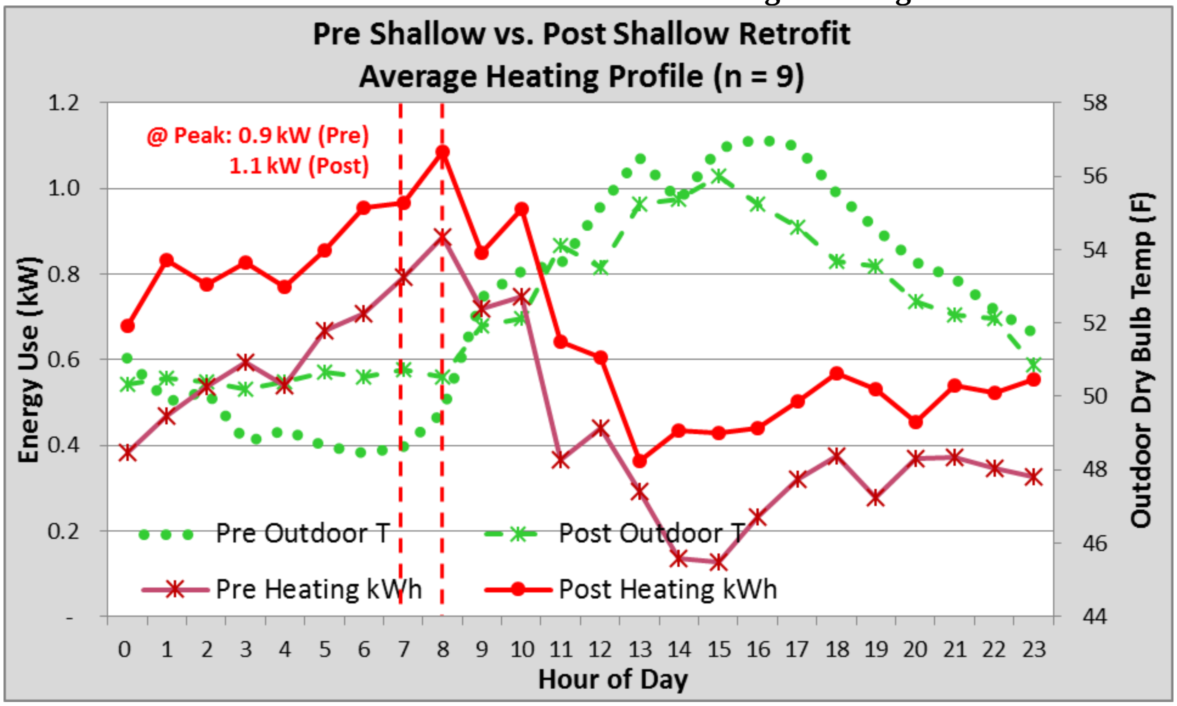
Shallow Cooling Plots (cont..)

Pre Shallow vs. Post Shallow Retrofit TMY3 Average, Weighted by FPL Service Area

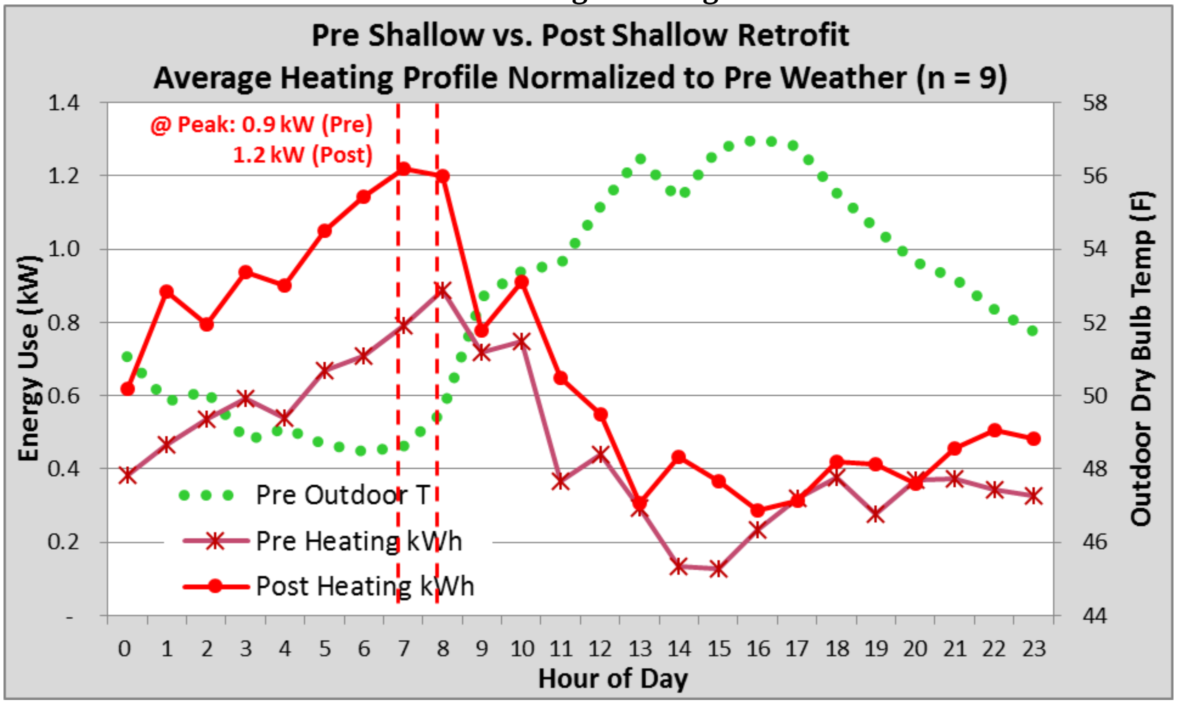


Shallow Heating Plots

Pre Shallow vs. Post Shallow Retrofit Average Heating Profile

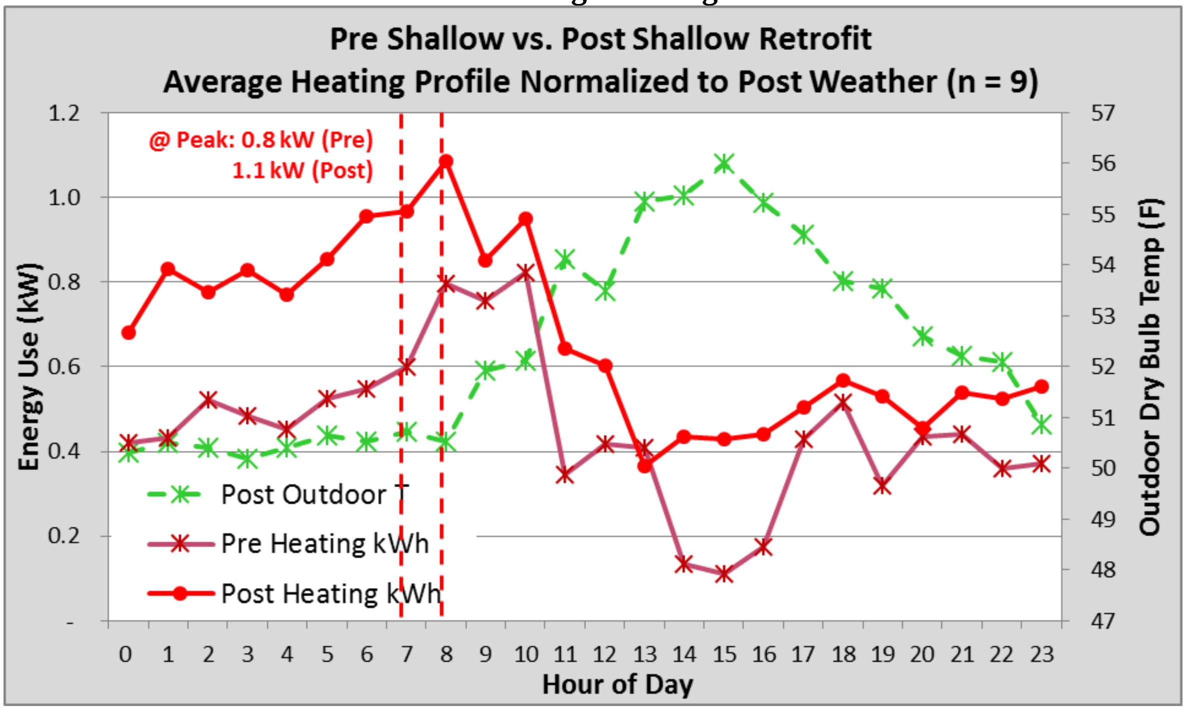


Pre Shallow vs. Post Shallow Retrofit Average Heating Profile Normalized to Pre Weather

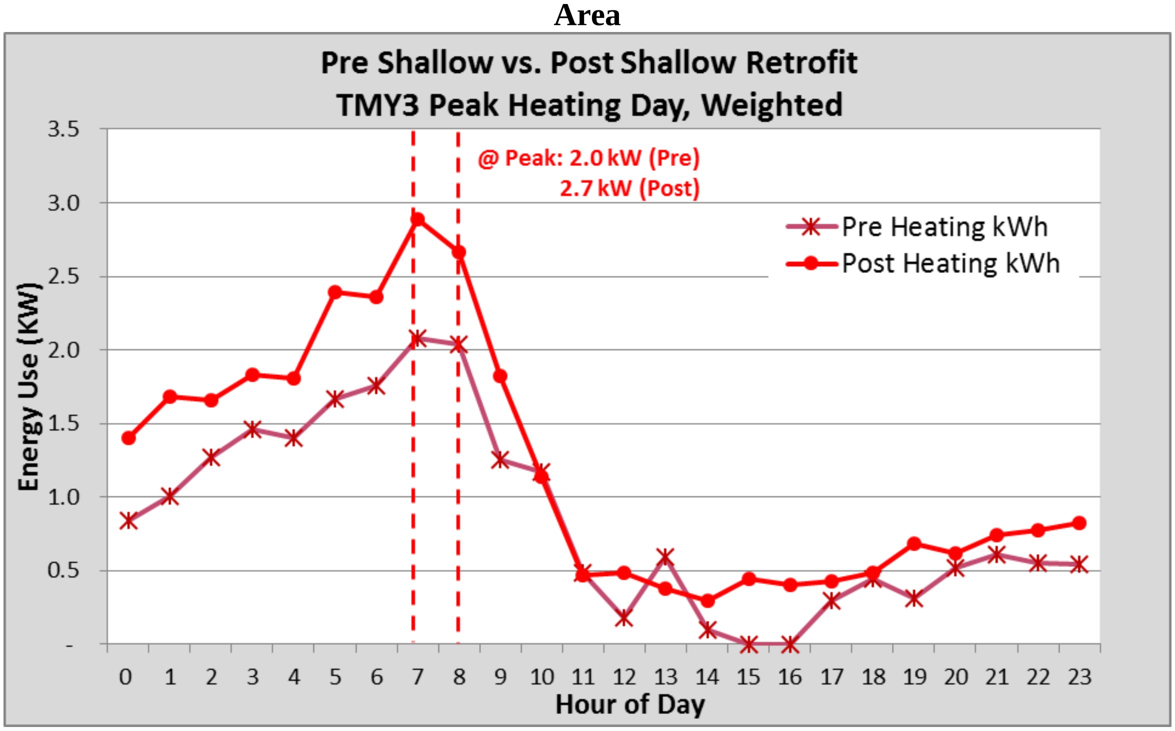


Shallow Heating Plots (cont.)

Pre Shallow vs. Post Shallow Retrofit Average Heating Profile Normalized to Post Weather

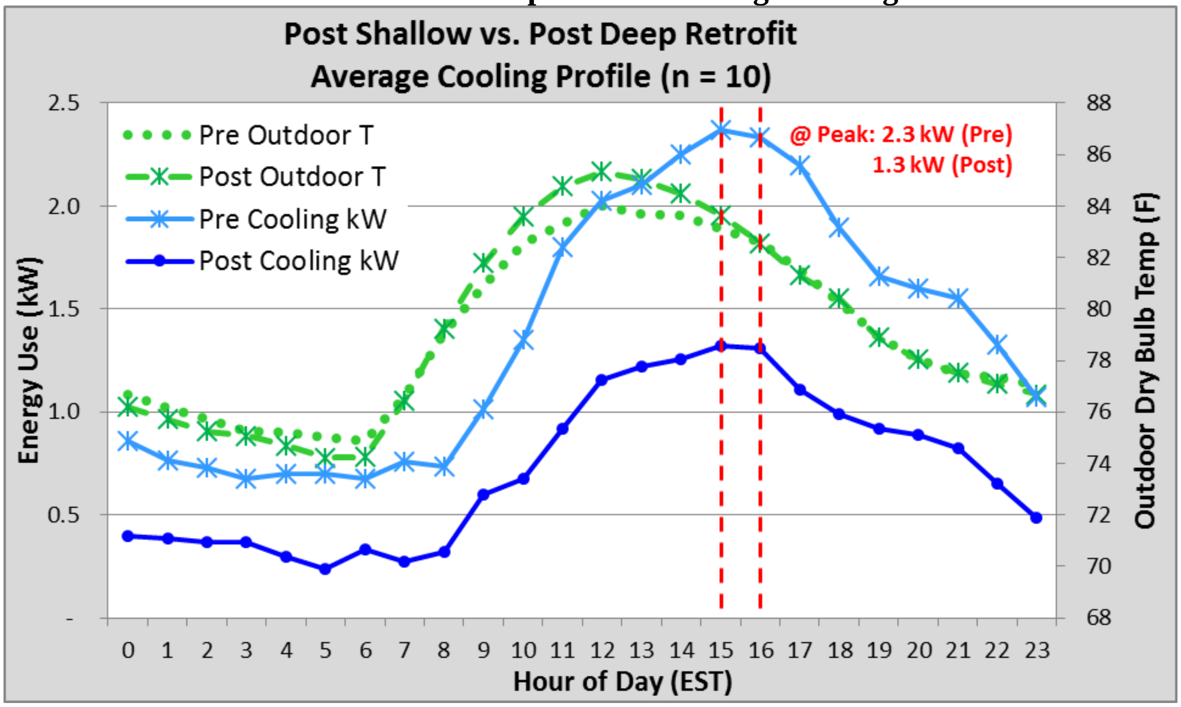


Pre Shallow vs. Post Shallow Retrofit TMY3 Peak Heating Day, Weighted by FPL Service Area

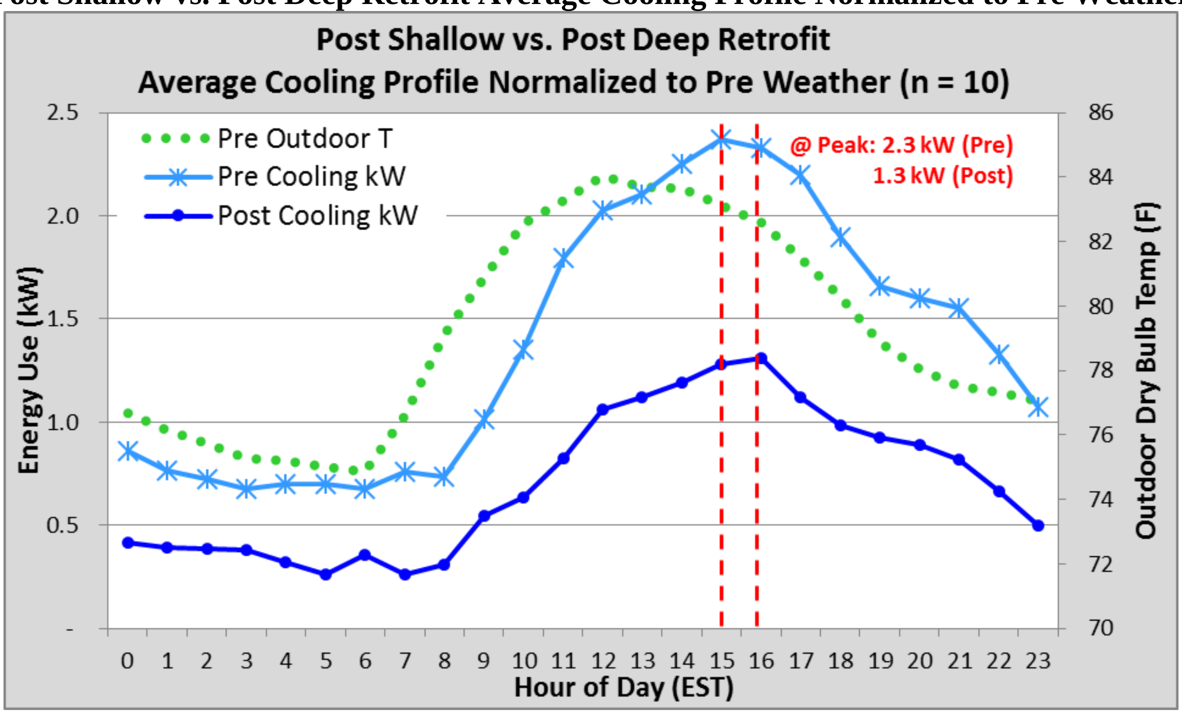


<u>Deep Cooling Plots</u>

Post Shallow vs. Post Deep Retrofit Average Cooling Profile

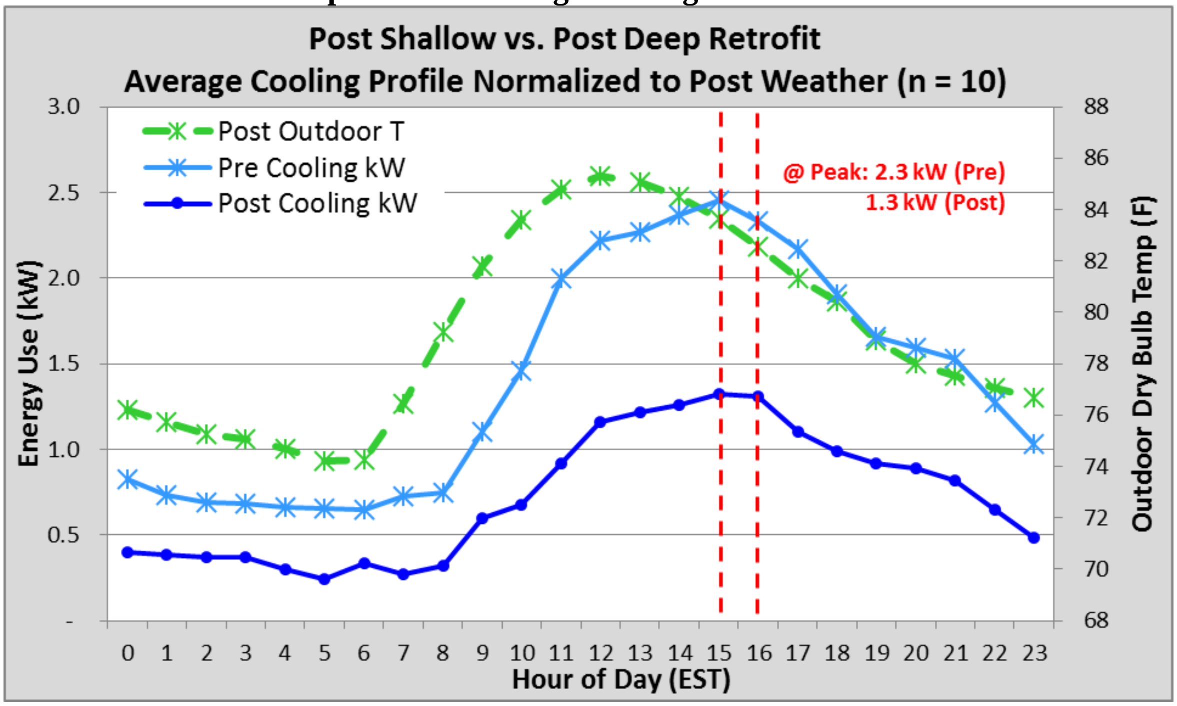


Post Shallow vs. Post Deep Retrofit Average Cooling Profile Normalized to Pre Weather

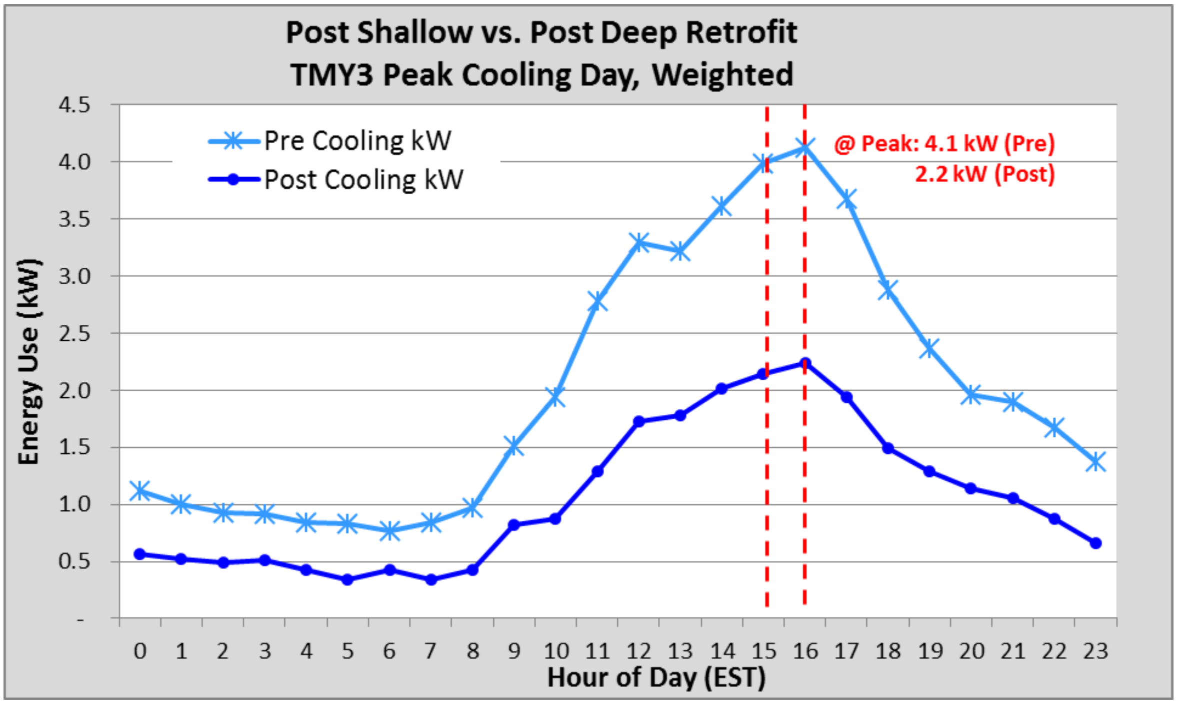


Deep Cooling Plots (cont.)

Post Shallow vs. Post Deep Retrofit Average Cooling Profile Normalized to Post Weather

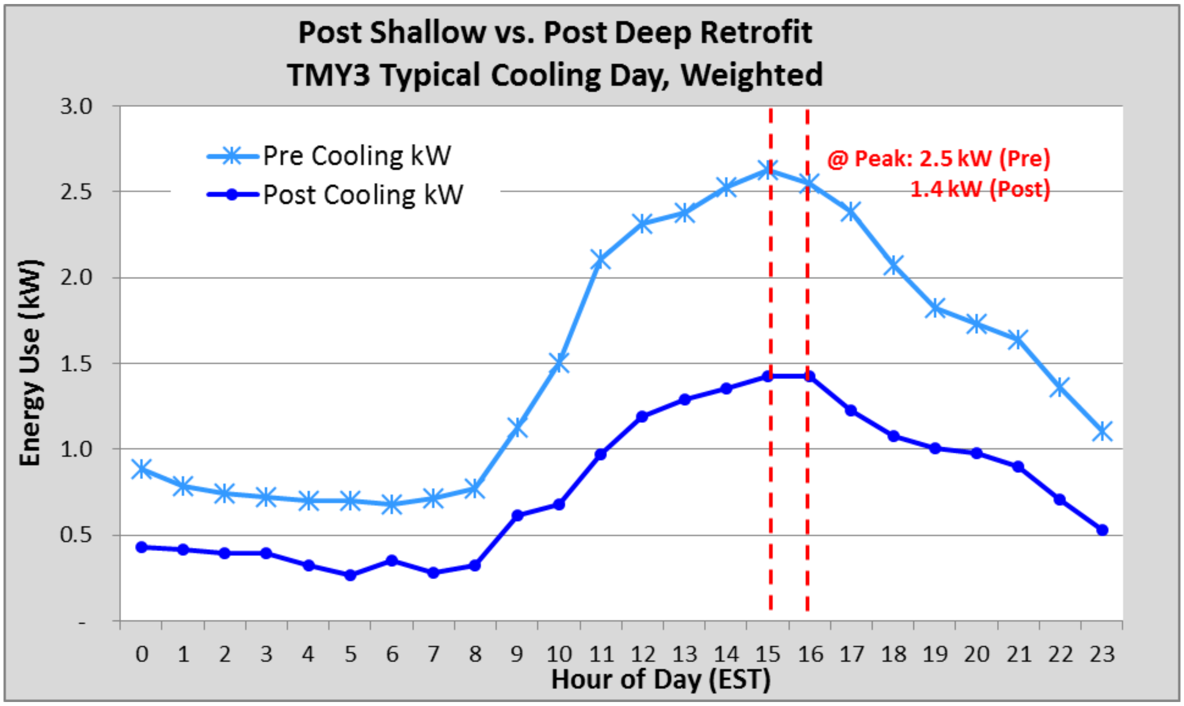


Post Shallow vs. Post Deep Retrofit TMY3 Peak Cooling Day, Weighted by FPL Service Area



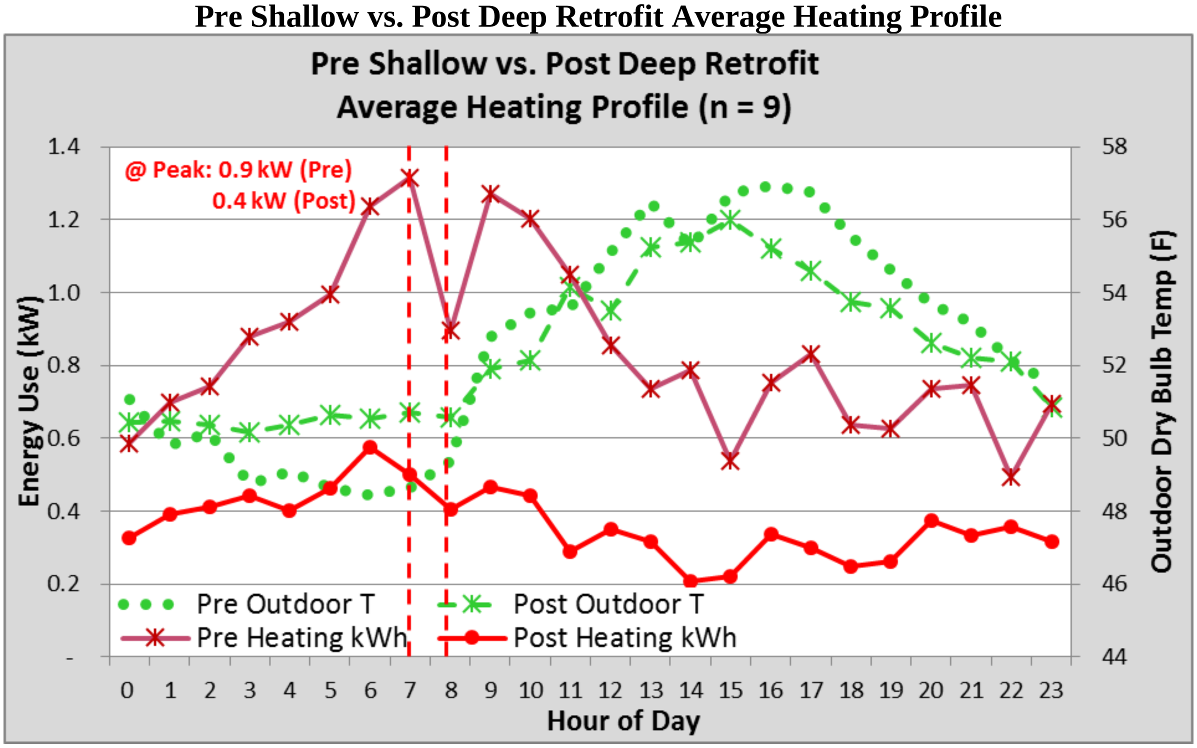
Deep Cooling Plots (cont..)

Post Shallow vs. Post Deep Retrofit TMY3 Typical Cooling Day, Weighted by FPL Service Area



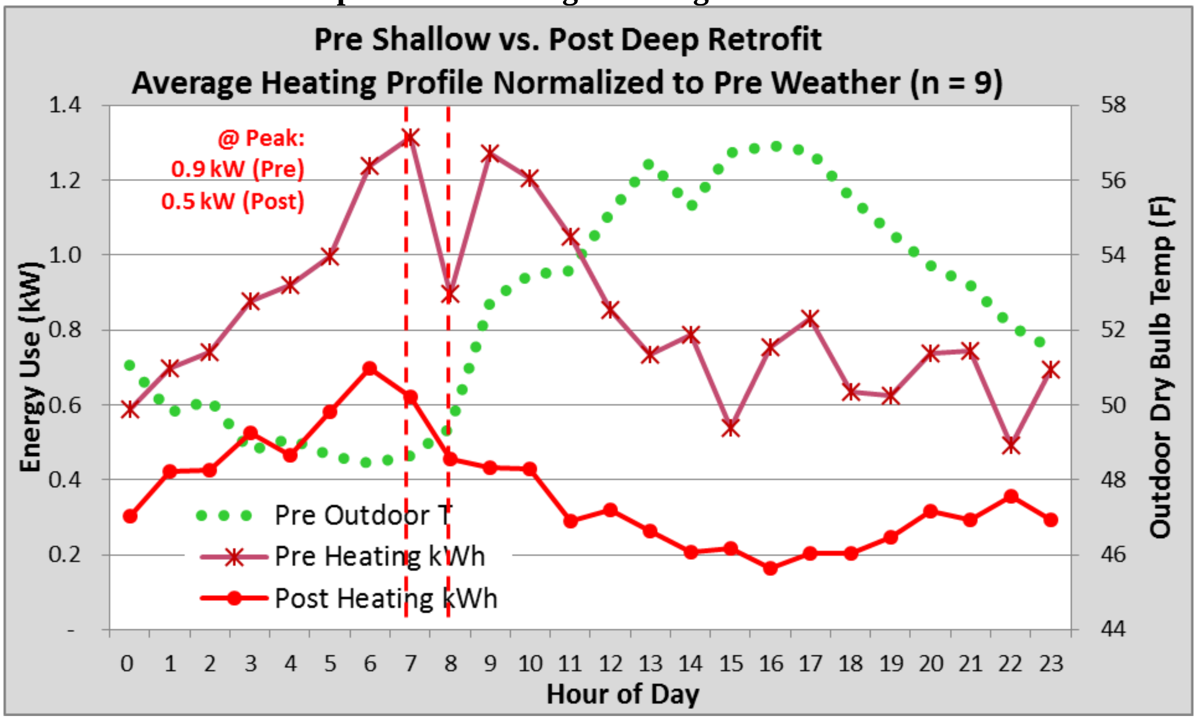
Deep Heating Plots

Pre Shallow vs. Post Deep Retrofit Average Heating Profile

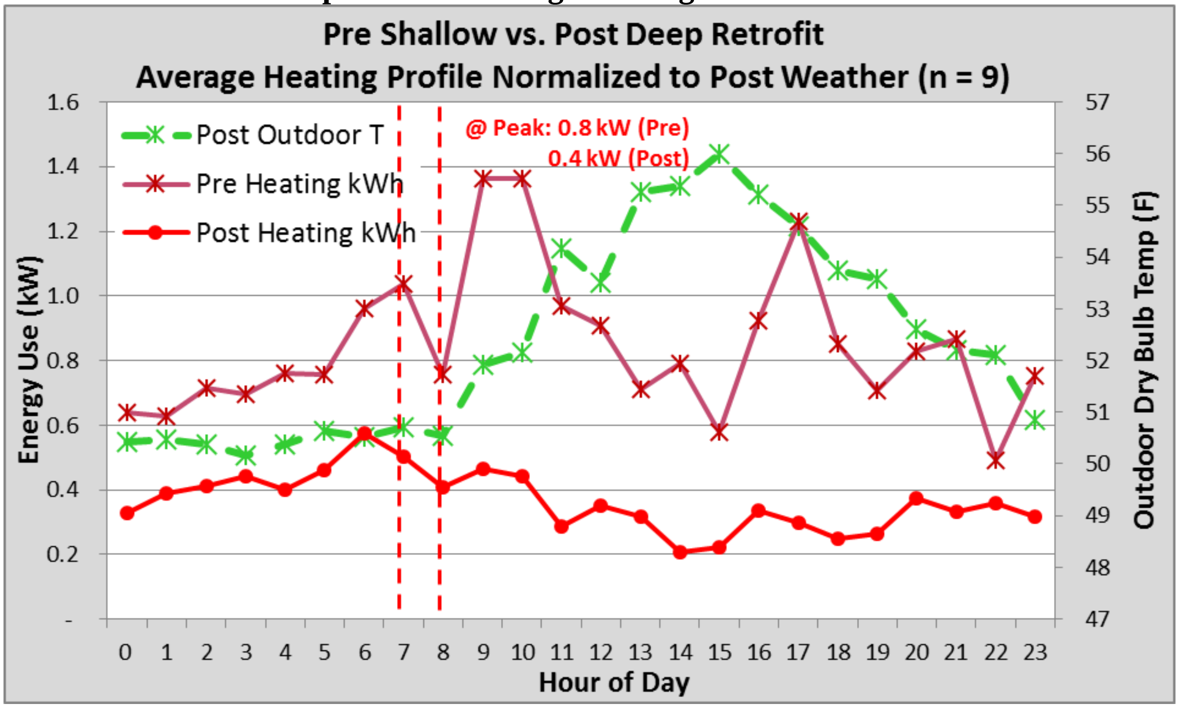


Deep Heating Plots (cont.)

Pre Shallow vs. Post Deep Retrofit Average Heating Profile Normalized to Pre Weather

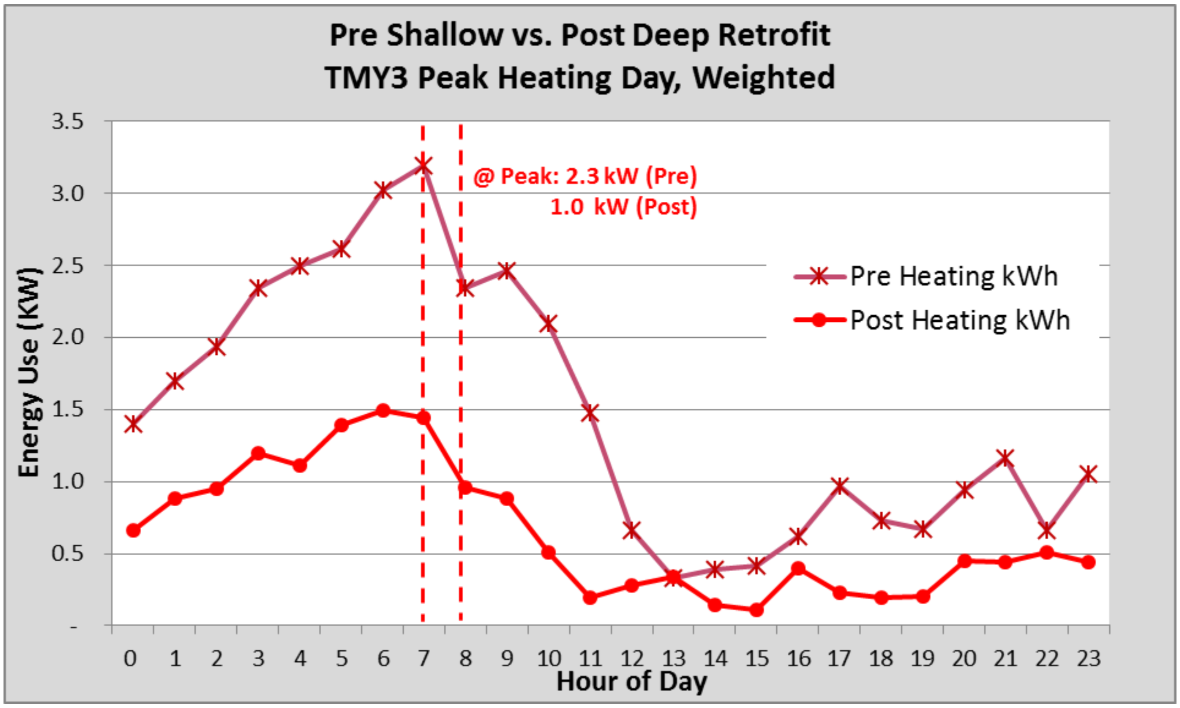


Pre Shallow vs. Post Deep Retrofit Average Heating Profile Normalized to Post Weather



Deep Heating Plots (cont.)

Pre Shallow vs. Post Deep Retrofit TMY3 Peak Heating Day, Weighted by FPL Service Area



Appendix D: Deep Retrofit Installations Details

HVAC Measures

System and Contractor Selection

Carrier's Performance Series air-source heat pump was the chosen HVAC product line. Our choice was based on system performance, compatibility with the chosen smart thermostat, and price.[19] The installed systems were either a 16 SEER with a 9.0 HSPF or a 17 SEER with a 9.5 HSPF.

We chose a local mechanical contractor among Carrier's recommended licensed installers. The selected company is a large, regional residential and commercial mechanical contractor, in business since 1980. We met with the contractor to discuss project parameters, the company's installation protocols/standards, project completion time-frame, and their ability to meet our installation standards and performance metrics.

We initially requested the following installation standards: (1) perform a Manual J & Manual D; (2) replace both existing 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,[20] and (4) install a NEST 2nd 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. We subsequently removed the Manual D requirement from the work scope. The contractor agreed to meet our remaining installation requests, in addition to our performance metrics for duct leakage and bedroom pressure balancing.

Internally, system load calculations were conducted with EnergyGauge USA[21] simulation software. We compared our system size results 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 our project. This ability was attractive to us because it was mid-August and systems needed to be installed as quickly as possible to capture the cooling season.

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

[20] http://www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/Inspection_Checklists.pdf

[21] http://www.energygauge.com/

We provided the HVAC contractor with a work scope for each site to identify unique issues and provide guidance on what was expected with each installation. This also helped streamline the HVAC contactor's efforts on specific tasks, most notably duct sealing. Since the contractor used visual inspection of the air distribution system to gauge its tightness, we 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 our performance metrics.

Performance Criteria

Performance tests conducted prior to deep retrofit measures included whole-house air-tightness, 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 square foot of conditioned floor area (Qn,out ≤ 0.06). 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 grill. In some cases additional work addressed performance or comfort. As examples, supply grills 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 2nd Generation learning thermostat was selected for our 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. While typical programmable thermostats allow a user-defined program to adjust temperature, they are not able to change with atypical occupancy patterns unless manually overridden. The NEST, however, does. For example, it can detect that the home is unoccupied and adjust itself accordingly, potentially saving energy. See Appendix E for more information on the NEST installation.

Improper Installations

A post system installation follow-up call to Site 19 indicated comfort issues. The owner needed to reduce the evening cooling thermostat set-point a degree or two below pre-retrofit settings to achieve comfort. Our monitored data clearly revealed interior relative humidity (RH) issues. The green line in Figure 1 shows RH increased more than 10% immediately following the HVAC installation (just after 996 on the x-axis) while temperature (red line) remained fairly constant.

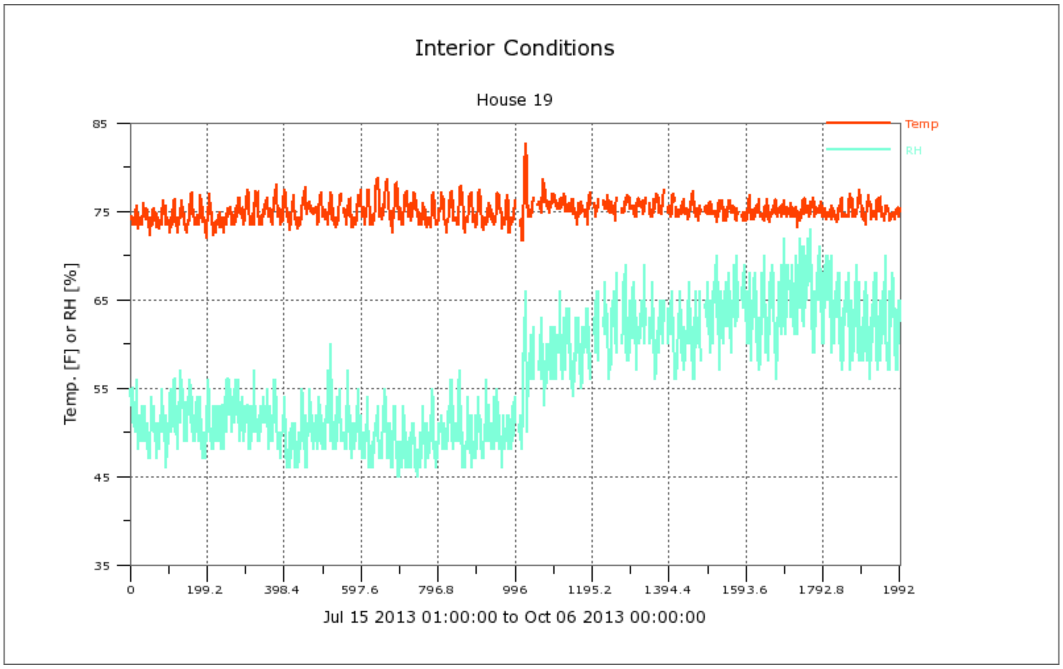


Figure 1. Interior temperature and RH of Site 19 before and after HVAC install

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, restoring comfort. Learning from the Site 19 issue monitored data were more heavily scrutinized upon HVAC installations. Post-retrofit RH levels for subsequent installations appeared consistent with pre-retrofit levels; however HVAC run time 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 air handler unit was running. While the homeowner reported being very happy with the new system, he said the system ran “colder” than his previous system causing him to increase the thermostat cooling set-point a degree or two to feel comfortable. We confirmed that Site 40’s HVAC system was operating exclusively in stage two, just as at Site 19.

Figures 2 and 3 taken from the eMonitor™[22] website show the operation run time and the condenser and AHU end-use consumption at Site 40 spanning one day. Figures 4 and 5 show these same plots for Site 8 where the same system was wired properly. The blue and red circles in Figure 4 highlight stage-one and stage-two condenser operations respectively. Figure 5 shows how the AHU operation aligns with the condenser stage during normal operation.

[22]https://www.emonitor.us/

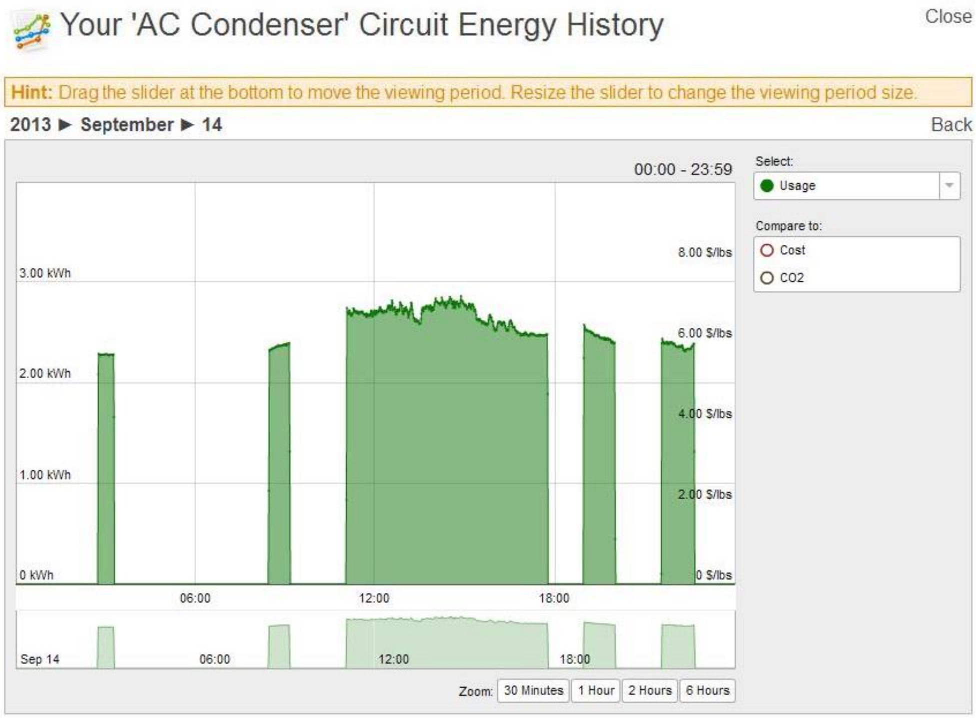


Figure 2. Site 40 Condenser Stage 2 only operation

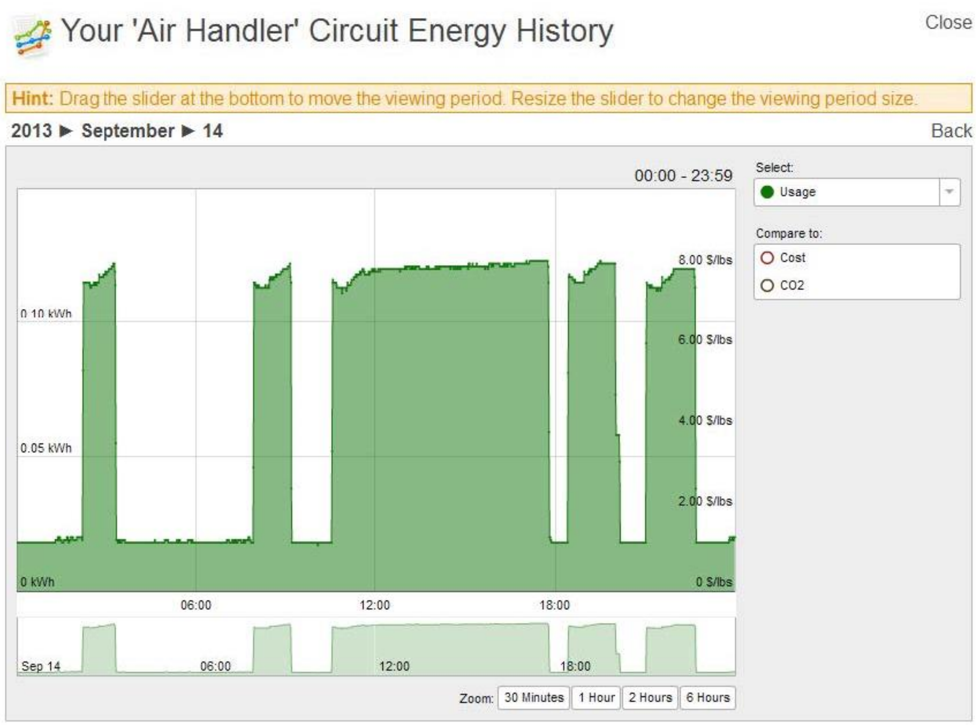


Figure 3. Site 40 AHU operation reflecting Stage 2 only condition

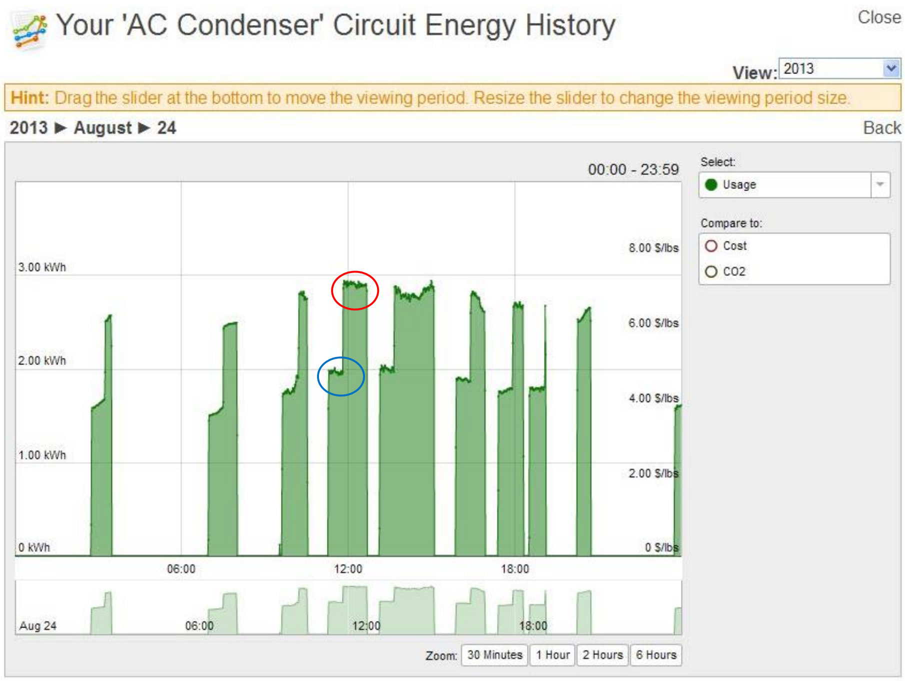


Figure 4. Site 8 Condenser Stage 1 and Stage 2 normal operation

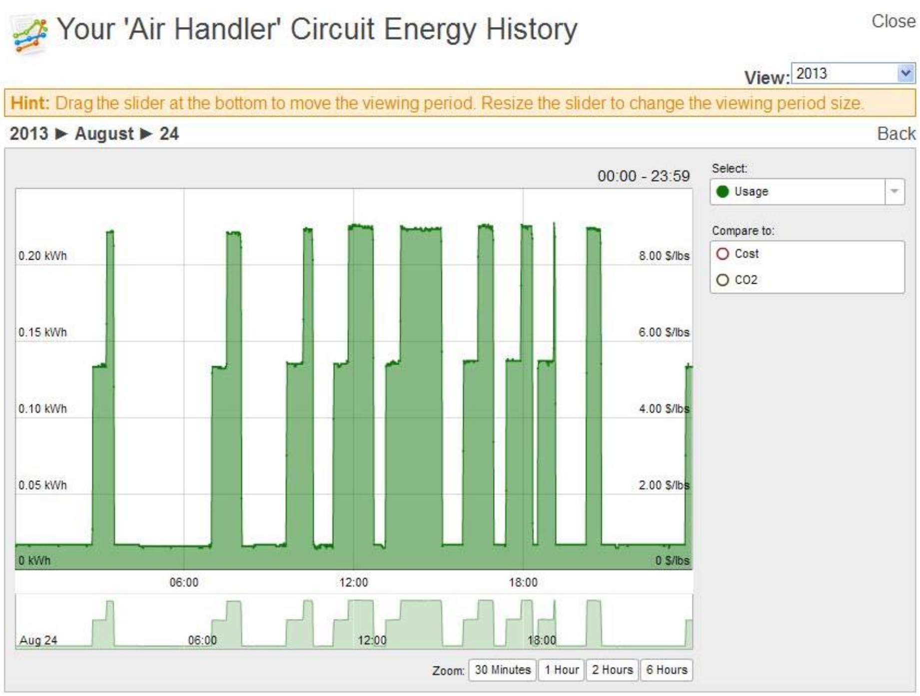


Figure 5. Site 8 AHU normal operation alignment with Stage 1 and Stage 2 conditions

Review of monitored data and field testing revealed that the systems at three other sites were also operating at a single stage. One was found to be running in stage-two only, while two others were operating exclusively in stage-one. While homeowners with the stage-two only operation had comfort issues, homeowners of the stage-one only homes had no comfort complaints. In total, five of the nine installations were incorrectly wired causing 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-one only homes were not performed while the systems were running at high capacity. Therefore we 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 they 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 6 shows Section 8 was marked "N/A". Electrical measurements were one way we confirmed what stage the compressor was operating along with operation alignment of the AHU.

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: ______

Figure 6. 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 installation of the NEST. The contactor reported insufficient system set up and wiring instructions provided by the installation guild, however they took responsibility for the failed system installations. Fully functional HVAC system operation was unverified by the installation team. Installation issues led us to heating operation concerns, as 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 adopted well to the new thermostat, optimizing their comfort and integrating features into their lifestyle.

Insulation

Contractor and Material Selection

Our partner in the project and the local utility, FPL, has many residential rebate and incentive programs, including a Residential Ceiling Insulation program.[23] The program offers a rebate for attic insulation based on the existing thermal value. FPL has a list of participating independent contractors who comply with FPL’s program standards, although FPL did not make contractor recommendations.

For our program we 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. We selected a contractor from FPL’s list of participating contractors based on experience, our installation criteria, and pricing. We followed FPL insulation program installation standards as we developed contractor work scopes for each site, targeting R-38 at the ceiling deck and knee wall insulation upgrades as needed.

Site Criteria & Implementation

Eight homes were selected for ceiling insulation upgrades, with maximum average thermal values of R-19. Existing thermal values in 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 on site to upgrade the compressed areas to R-38, it was cost-justified to have the entire ceiling upgraded to R-38.

The insulation retrofit generally consisted of blown-in fiberglass insulation at the ceiling deck and fiberglass batt insulation at knee walls where appropriate. We specified all attic access panels to conditioned space be fully gasketed and insulated to R-38 and additional attic rulers be installed to simplify our verification of insulation depth (Figure 7). The ceiling insulation retrofits for Sites 30 and 51 were relatively complex, requiring more planning and attention than the other, straight-forward installations. Each is discussed below.

[23] http://www.fpl.com//residential/energy_saving/programs/index.shtml?cid=aliasprograms

Figure 7. 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 8). We were concerned that adding R-38 blown-in insulation would partially or completely bury the duct work (Figure 9), potentially altering the dew point at the duct surface, creating condensation.

Figure 8. Site 30 ductwork

Figure 9. Buried ductwork

Removing the existing insulation to see under the ductwork exposed water marks, most likely from duct condensation drips (see Figure 10). These pictures were taken during a site visit in December, a time of generally cooler weather when air conditioning is less frequently needed. No moisture was found on ducts or drywall and all the insulation moved from under the duct work was dry.

Figure 10. Historical moisture issues in attic under duct work

We observed living room ceiling paint peeling near the location of concern (Figure 11). While the homeowner did not have specific interior moisture concerns, the location of ceiling paint peeling was reported to have been in this condition ever since the home was purchased.

Figure 11. Ceiling damage close to room's supply duct

Figure 12 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 since the attic was dry at the time.

Figure 12. 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 et al. 2013). We considered encapsulating the ductwork in closed cell foam and then burying most of the duct system with blown-in insulation. Ultimately we installed R-38 blown-in fiberglass, the same approach used at the other sites, and will observe the impact.

To monitor this retrofit, we applied several moisture sensor strips to ducts sections where the drywall below showed signs of wetting (see Figure 13). The sensor strips will 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 13. 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 crawlspace. 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, substantially connected to the garage (Figure 14)
- The closet supply vent (with an open damper) was directly connected to the master bedroom supply vent (Figure 15)
- 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 14. 2nd floor closet

Figure 15. Second floor closet with shared supply ducting and open damper

The following were concerns in other areas of the home:

- No interior air barrier on second floor bathroom's knee wall behind tub
- Missing ceiling insulation in part of attic floor
- No blocking between floors at interstitial space boundary (not all accessible)
- Mixed vapor retarder (i.e. kraft paper) facing on knee walls and ceiling
- Crawlspace had:
    - No insulation
    - No ground cover
    - Unsealed floor transition areas

While major modifications to study homes are not within the scope of the PDR project, we had several issues to address prior to the ceiling insulation upgrade. 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 prior to the insulation upgrade was to install an air barrier on the knee wall behind the second floor bathroom tub. The tub wall cavity's fiberglass insulation was re-installed and an air barrier was mechanically fastened and sealed with foam as shown in Figures 16 – 18.

Figure 16. Missing air barrier behind tub

Figure 17. Insulation replaced

Figure 18. Air barrier installed

The attic insulation was found in various configurations – some of the batt insulation kraft paper was facing inward; some outward (Figure 19 a, b, and c). The insulation retrofit included the vapor retarder uniformly facing the interior.

Figure 19. (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 crawlspace at Site 51 was dry, showing no visible signs of moisture issues, was passively vented, and 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 two square foot hole in the floor that the insulation contract fully sealed with foam (Figure 20).

Figure 20. Crawlspace floor transition areas unsealed (left) and sealed (right)

Heat Pump Water Heaters

Capacity

The 80 gallon capacity Voltex HPWH was installed in all deep home sites that had an occupancy of four or more in the home to help support the HPWH running the heat pump for most or all the hot water needs while minimizing the need for electric heat while running in the hybrid mode. The exception to this was Site 37 with an occupancy of six, the 50 gallon GE GeoSpring Hybrid Water Heater was chosen largely due to its installation location.

The 60 gallon capacity Voltex HPWH was to be installed in all deep home sites that had occupancy of three or less. The exception to this was Site 39 which had an existing RHEEM Model HP50 Heat Pump Water Heater installed prior to participation in the Phased Deep Retrofit study.

Noise & 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 AO Smith Voltex® Hybrid Electric Heat Pump 80 and 60 gallon units would be installed in the eight deep homes with hot water systems located in the garage. The 50 gallon capacity GE GeoSpring Hybrid Water Heater was selected for the single deep interior HPWH retrofit at Site 37 due to its reduced noise potential to home occupants and cost.

Correct placement is still critical when installing a HPWH in an exterior location (i.e. 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. Additionally, the HPWH's outlet fan was directed at the garage/master bedroom wall. Needless to say during HPHW operation, noise was apparent to the homeowners 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 fan outlet and redirect air away from the garage/master bedroom wall.

Figure 21 shows initial install of the HPWH of a mechanical plumbing connection and outlet HPWH fan and the associated sound attenuation board and duct kit retrofit install.

Figure 21. Site 19 HPWH initial install (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 utilized 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 issues of noise during HPWH operation.

Figure 22 shows the HPWH installed in a corner of the garage with the shared garage/master bedroom wall located on the left and the CMU wall to the right.

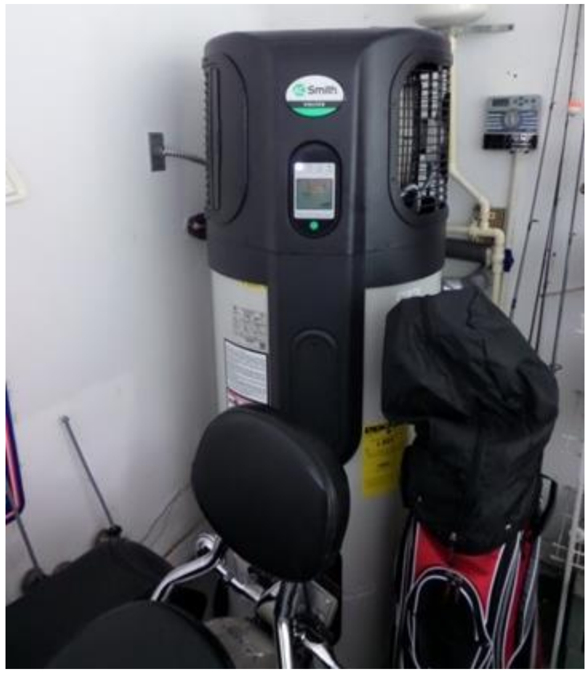


Figure 22. Site 40 HPWH

During the post HPWH install follow up site visits it was noted 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 AO Smith HPWH models PHPT-60 and PHPT-80 (AO 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 existing plumbing and hot water system locations and obstructions like shelving, workbenches, etc. as shown in Figure 23.

Figure 23. HPWH retrofit existing conditions

Appendix E: NEST Installation Guide

12. Setup and Nest Account

Nest will turn on and walk you through setup. Turn the ring and press to select.

Connect Nest to Wi-Fi during setup, then visit nest.com/account to create a Nest Account so you can control Nest from anywhere.

For more information visit nest.com or call 855-4MY-NEST (855-469-6378).

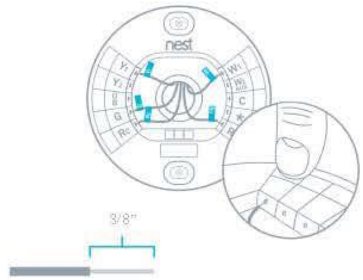
Recycle your old thermostat: see nest.com/responsibility

Please recycle Nest's 100% recyclable packaging.

8. Attach base

9. Connect wires

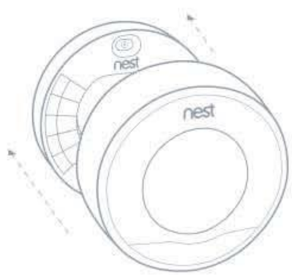
After all the wires are connected, make sure they're flush with the wall.



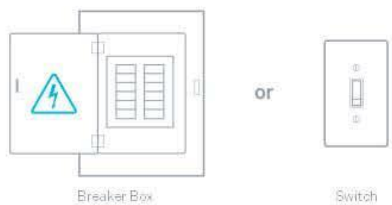
The exposed wire should be straight.

10. Attach display

Press the display until it clicks into place.



11. Switch power back on



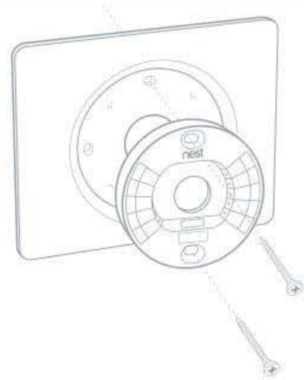
Optional in most homes

Use trim plate if needed

You can cover up holes or marks left by your old thermostat with the optional trim plate.

Place the trim plate on the wall and put the base on top so they snap together, then screw them both to the wall.

The trim plate can be found in the bottom of the Nest box.

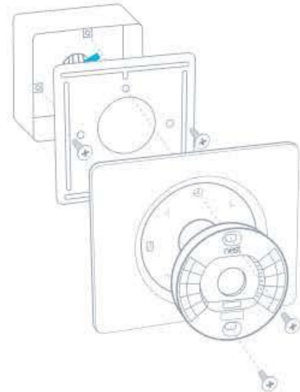


Optional in most homes

Mounting Nest on an electrical box

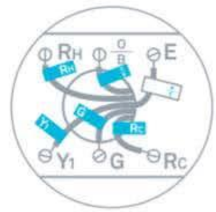
Electrical boxes aren't common, but if you have one, secure the steel plate to the electrical box with two of the short steel plate screws. Insert the screws into the long slots on the steel plate.

Use the other two short screws to attach the Nest base and trim plate to the steel plate.



5. Label wires

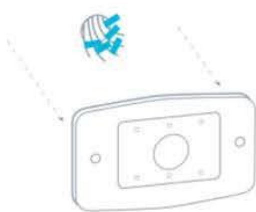
Peel off the blue labels and attach them to your wires. Use the white labels if you have a E, W3, HUM or DEHUM wire. You can connect only one of these wires to Nest's ⋆ connector.



HUM and DEHUM wires may require a professional. Check at nest.com/works

Tip: Take a picture of the wires on your old thermostat to help you remember.

6. Disconnect wires and remove base



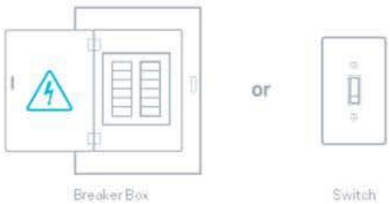
Tip: Wrap the wires around a pencil to keep them from falling into the wall.

7. Mark where screws will go

Use the bubble level to make sure Nest is level.

1. Switch off power

This protects you and avoids blowing a fuse. Adjust the temperature on your old thermostat to make sure your system is off.



2. Remove cover

Some covers pop off, while others need to be unscrewed.

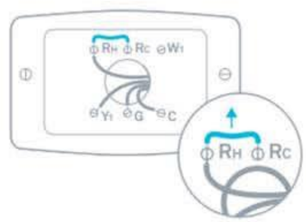
3. Check your system

If your old thermostat is labeled 120V or 240V or has thick wires with wire nuts, your system is high voltage. Not sure? Contact support.

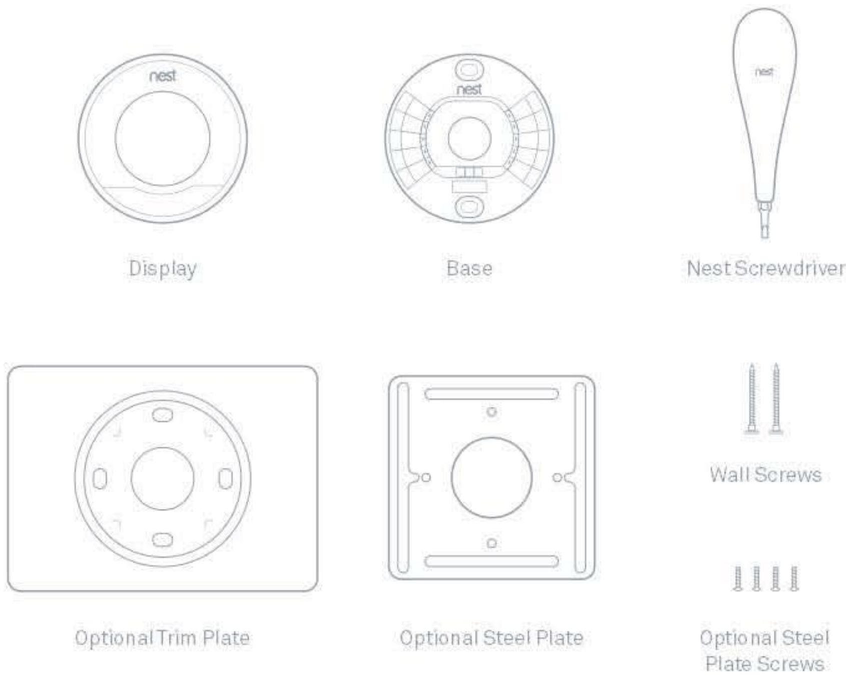
⚠ **CAUTION:** Do not connect Nest to high voltage wires.

4. Remove any jumper wires

Jumper wires are short wires between two connectors. Nest doesn't need them. An R wire can go into either Rc or Rh.



Contents


Display
Base
Nest Screwdriver
Optional Trim Plate
Optional Steel Plate
Wall Screws
Optional Steel Plate Screws

Compatibility

Nest works with over 95% of 24V heating and cooling systems, including gas, electric, oil, solar, hot water, geothermal, forced air, heat pump and radiant. It can control:

- Heating: one, two and three stages (W1, W2, W3)
- Cooling: one and two stages (Y1, Y2)
- Heat pump: with auxiliary and emergency heat (O/B, AUX, E)
- Fan (G)
- Power (C, Rh, Rc)
- Humidifier or dehumidifier (HUM, DEHUM)

Nest's ★ connector can accept only one of these wires: W3, E, HUM or DEHUM.

Adding a common C wire is not required in 99% of installations.

Professional installation recommended for:

- Dual fuel systems (heat pump with furnace)
- Whole-home humidifiers and dehumidifiers

Go to nest.com/works to make sure Nest will work in your home and find out if you'll need Nest Concierge professional installation.

Watch the video

Before you install Nest, watch the installation video at nest.com/support

Questions? Visit support or give us a call at 855-4MY-NEST.

nest

Learning Thermostat
Installation Guide

FLORIDA SOLAR ENERGY CENTER®

Creating Energy Independence