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# Phased Retrofits in Existing Homes in Florida Phase II: Shallow Plus Retrofits

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*Building America Partnership for Improved Residential Construction*

February 2016

Building AMERICA
U.S. Department of Energy

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

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

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

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## Definitions

| | |
|---|---|
| AC | Air Conditioning |
| ACH50 | Air Changes per Hour Measured at a Test Pressure of -50 Pascals with Respect to the Outside, Divided by the Building Volume |
| AHU | Air Handling Unit |
| APS | Advanced Power Strip |
| BAPIRC | Building America Partnership for Residential Construction |
| Btu | British Thermal Unit |
| CFL | Compact Fluorescent Lamp |
| CDD | Cooling Degree Day |
| CMU | Concrete Masonry Unit |
| COP | Coefficient of Performance |
| Delta T | Outdoor Temperature Minus Indoor Temperature, in Degrees Fahrenheit |
| DHW | Domestic Hot Water |
| DOE | U.S. Department of Energy |
| EIFS | Exterior Insulation Finish System |
| FPL | Florida Power & Light Company |
| FSEC | Florida Solar Energy Center |
| HDD | Heating Degree Day |
| HP | Heat Pump |
| HPCD | Heat Pump Clothes Dryer |
| HPWH | Heat Pump Water Heater |
| HSPF | Heating Seasonal Performance Factor |
| HVAC | Heating, Ventilating, and Air Conditioning |
| kWh | Kilowatt-Hour |
| LED | Light-Emitting Diode |
| MSHP | Mini-Split Heat Pump |
| NFRC | National Fenestration Rating Council |
| NWS | National Weather Service |
| PDR | Phased Deep Retrofit |
| Qn,out | Duct Leakage Measured at a Test Pressure of Negative 25 Pascals with Respect to the Outside, Divided by the Building's Conditioned Floor Area |
| $R^2$ | Coefficient of Determination |
| RH | Relative Humidity |
| R-Value (R-*n*) | Thermal Resistance Measure |
| SEER | Seasonal Energy Efficiency Ratio |
| SHGC | Solar Heat Gain Coefficient |

| | |
|---|---|
| Tint | Interior temperature |
| U-Value | Heat Transfer Rate |
| VSPP | Variable Speed Pool Pump |
| W | Watt |
| Wh | Watt-Hour |

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## Executive Summary

The U.S. Department of Energy Building America team— Partnership for Improved Residential Construction (BA-PIRC)—is collaborating with Florida Power & Light (FPL) to conduct a phased residential energy-efficiency retrofit program. This research seeks to determine the impacts on annual energy reductions from the installation of advanced residential technologies. Earlier project work involving the application of two levels of retrofit—shallow and deep—found average savings of 8%–10% and 38%, respectively. Whole-house demand reduction among the deep retrofit homes averaged 39% during the FPL peak summer hour. These savings levels approach the Building America program goals of reducing whole-house energy use of existing homes by 40%.

Phase II of the Phased Deep Retrofit (PDR) project includes single retrofit measures applied to shallow retrofitted homes that could be used to refine the deep retrofit package. This process is also known as "Shallow Plus" retrofitting. Phase II involves the installation of seven energy-efficiency retrofit measures among a subsample of 41 of the larger study's 53 existing all-electric homes. This report summarizes end-use energy savings, economic evaluation results, and supplementary findings from the individual measures.

The central and south Florida homes were built between 1955 and 2006, average about 1,700 $ft^2$ in conditioned area, and have an average occupancy of 2.3 persons. Total house power as well as very detailed energy end-use data are collected to evaluate energy reductions and the economics of each retrofit. All of the studied homes were audited and instrumented during the second half of 2012, and shallow retrofits were conducted from March–June 2013. The retrofit energy reduction measures for the shallow installed measures included those for lighting (compact fluorescent and light-emitting diode lamps), domestic hot water (water heater tank wraps and low-flow showerheads), refrigeration (cleaning of coils), pool pumps (reduction of operating hours), and use of "smart plugs" for home entertainment centers.

To assess new technology and energy savings techniques not previously tested, the following retrofit measures were applied:

- Supplemental mini-split heat pump (MSHP) (6 homes)
- Ducted and space coupled heat pump water heater (8 homes)
- Exterior insulation finish system (EIFS) (1 home)
- Window retrofit (3 homes)
- Smart thermostat (21 homes: 19 Nests; 2 Lyrics)
- Heat pump clothes dryer (HPCD) (8 homes)
- Variable speed pool pump (5 homes).

**Supplemental Mini-Split Heat Pump**
MSHPs have no duct system and often have high efficiency levels that may allow for substantial savings. One-ton high-efficiency 25.5 seasonal energy efficiency ratio ductless MSHPs were

installed in the main living area of six central Florida homes. The supplemental MSHPs were installed with the goal of reducing space heating and cooling energy by reducing runtime of the less-efficient existing central system. Results suggest cooling energy use savings of 37.0% (10.9 kWh/day) and heating energy use savings of 59.0% (13.2 kWh/day at 50°F). In terms of percentages, heating energy reductions were considerably greater than cooling for the four homes with electric resistance central heating. The cost-benefit analysis for this measure appears attractive because of a payback of 12.4 years and an 8.1% annual rate of return. Improved economics are expected as the MSHP market continues to mature. A large added benefit to the consumer is a redundant heating and cooling system—highly desirable given the failure rate of central systems that tend to be replaced every 12 years and serviced even more often.

### Ducted and Space-Coupled Heat Pump Water Heater

In the Phase I project, results showed that heat pump water heaters (HPWHs) saved about 66% of the energy needed to heat water with an electric resistance system. HPWHs create a quantity of cooled and dehumidified air from the compressor section of the unit as a byproduct of their operation. Eight central Florida homes were retrofitted with an HPWH coupled to the conditioned living space to determine its effect on space-conditioning and water heating energy in a cooling-dominated climate. Two different HPWH configurations were evaluated—interior-located (three homes) and attached garage-located with ducting to conditioned space (five homes).

Results for the eight central Florida homes retrofitted with an HPWH coupled to the conditioned living space show median space cooling energy savings of 8.2% (1.1 kWh/day). Meanwhile, space heating energy use increased by 8.9%— although with considerable variation among homes. Among the six homes in which an electric resistance-type tank was replaced with an HPWH coupled to the conditioned space, median Domestic Hot Water (DHW) energy savings were 53.3% (3.2 kWh/day). Data collected from the two sites at which the effect of the coupling on DHW energy use was isolated shows that the coupling reduced potential DHW energy savings from a garage-located HPWH by 0.4 kWh/day or 10.6%. Annual cooling energy savings for the ducted sites yielded a simple payback of about 13 years. An average heating energy penalty that extends payback to nearly the expected 20-year life of the ducting exhibits fairly poor economics for the ducted proposition. This penalty could be reduced or eliminated with a damper system that enables cold HPWH exhaust air to be diverted from the conditioned space during winter. Aside from the premium for the HPWH itself, there is no cost associated with locating an HPWH inside the conditioned space (unless plumbing needs to be rerouted). In this case, net savings on space conditioning and water heating are immediately realized.

### Exterior Insulation Finish System

The idea of heavily insulating walls in the many existing Florida homes of concrete block construction is a very commonly encouraged energy savings measure. However, what are the actual savings? During Phase II, an Exterior Insulated Finish System (EIFS) was evaluated in which insulation with an R-value of 7.7 hr-ft$^2$-$^o$F/Btu was added to the exterior walls of a central Florida home. Space cooling evaluation results predict energy use savings of 18.2% (5.0 kWh/day). Heating energy use was also evaluated and showed slightly negative savings. Little significance can be attached to the results, however, given very poor statistical models resulting from Florida's short and highly variable heating season. At a cost of nearly $20,000, the EIFS retrofit is not a cost-effective retrofit proposition for Florida's climate. Other benefits associated with the measure such as better interior comfort and a stable interior temperature, however, might justify this measure. Given the poor statistical modeling, the EIFS evaluation was bolstered with a simulation analysis to see how occupancy behavior and integral gains influence results. That evaluation also showed marginal economics for Florida's climate.

**Advanced Window Retrofit**

Many Florida homes have standard single-glazed windows with no solar control characteristics. Modern high-performance windows are widely available but not often used. To evaluate potential energy savings, high-efficiency window retrofits were conducted on three central Florida homes with single-pane metal-framed windows. The replacement windows had solar heat gain coefficients ranging from 0.19–0.24 and window thermal conductivity (U-values) ranging from 0.27–0.30 Btu/ft$^2$-°F. Cooling season energy savings ranged from negative 4.8% to positive 27.0% (-0.7–6.9 kWh/day). Heating energy savings of 6.8% (4.2 kWh/day at 50°F) were found at the single home evaluated over a winter. Limited observations for many of these evaluations, however, yield low confidence in the results. Moreover, the cost of the windows retrofits ($8,000–$10,000) does not make this measure a cost-effective energy-efficiency proposition in Florida. However, consumers find the retrofit attractive because of the improvements to house appearance, thermal comfort, and acoustic qualities. Given statistical modeling difficulty, simulation analysis was conducted to help improve understanding of the results.

**Smart Thermostat**

Cooling and heating in Florida are the largest energy end uses—nearly 6,000 kWh/year. Thermostat control is always important to annual energy use. "Smart" thermostats regulate the home temperature by self-programming depending on heuristic evaluation of user control habits as well as sensed homeowner occupancy. Among the 19 Nest thermostats evaluated, the average savings for space cooling was 7.4% (1.6 kWh/day at 80°F)—but with a very high degree of variation. The median savings were 4.8% (1.1 kWh/day). Eight of the 19 sites experienced negative savings, which was largely an artifact of pre-retrofit thermostat habits. However, on average the positive savings were larger in magnitude than the absolute difference in sites experiencing negative savings. Space-heating savings from the Nests were also highly variable—particularly given the very short Florida winter heating season. Average savings were 8.0% (1.1 kWh/day at 50°F) although the median was higher at 15.0% (2.2 kWh/day). Simple payback based on median savings for the Nest is estimated to be 4.6 years with an annual rate of return of 21.9%.

On a site-by-site basis, the study found that pre-installation thermostat behavior and willingness to use available Nest features made a difference. In particular, defeating the occupancy-sensing "away" function appeared to affect savings adversely.

**Heat Pump Clothes Dryer**

Electric clothes dryers represent 5% (790 kWh) of annual energy use in Florida homes. In eight project test sites, electric resistance clothes dryers were replaced with a new unvented Heat Pump Clothes Dryers (HPCD). The estimated median energy savings are 42.0% (312 kWh/year) and average annual savings are 38.5% (359 kWh/year). Cost-effectiveness, which is based on incremental cost over standard resistance models, will depend on consumer preferences;

however, the economics of the HPCD will likely improve as this cost premium falls with market maturity. Although the HPCD uses less electricity than a standard resistance dryer, they still release a significant amount of heat from their operation. The unvented units that were located inside the home led to very high utility room temperatures and increases in space cooling energy that may compromise identified savings; this is an issue the manufacturer is addressing. Given the heat issues, these unvented appliances are only appropriate in Florida if they will be installed outside of the conditioned space—typically in the garage.

**Variable Speed Pool Pump**

Thirty percent of Florida homes have pool pumps, which often use more than 3,500 kWh/year. Replacing standard pool pumps in five central and south Florida homes with variable speed pumps resulted in high energy and demand savings and rapid payback of the measure. Energy savings averaged 68% (7.3 kWh/day) and ranged from 49%–80% (4.9–10.3 kWh/day). Average hourly demand, which often occurred at or near the utility peak period, was typically reduced by about 70%. Annual cost savings amounted to $320—assuming mean savings of 2,665 kWh/year—and allowed for an exceedingly rapid simple payback of 2.7 years.

**Summary**

Among the retrofit technologies evaluated under Phase II, there are several promising measures that might be economically justified as part of a deep retrofit package. The supplemental MSHPs exhibited very favorable economics—especially given a maturing market and the Nest thermostat is an excellent low-cost retrofit measure. Space-coupled HPWHs show space-conditioning savings albeit with a small water heating energy penalty. The internally-located HPWHs have promising net effects; however, the ducted proposition may not be economically justifiable.

Neither the EIFS nor the window retrofit can be justified strictly based on economics. Other benefits may be considered, however, such as increased comfort or improved acoustics in the case of windows. Given the variation seen in the results and savings from both of these building envelope improvement measures, a simulation evaluation was conducted to see how various factors such as occupancy behavior and internal gains might be influencing results. The parametric simulation shows us that installations in Florida will differ considerably depending on interior temperature, internal and external shading, and the magnitude of internal gains.

The HPCD can be a good energy savings proposition depending on the consumer's other options and relative intensity of clothes dryer use. A more mature HPCD market will likely bring more promising economics. These unvented appliances, however, are not recommended in Florida unless installed outside of conditioned space. Other vented HPCDs such as those from LG Electronics may offer more acceptable performance for interior utility room use. Lastly, strengthening findings from Phase I with five new installations to examine, the variable speed pool pumps continue to show very significant savings with exceedingly strong economics. Given Florida's 33% saturation of swimming pools, this measure appears quite desirable because consumers are generally unaware of the large potential savings. The PDR Phase II retrofit (Shallow Plus) study energy savings are summarized in Table E-1. The data are presented graphically in Figure E-1.

**Table ES-1. Phased Deep Retrofit Phase II Measures Evaluation Savings**

| | | Daily Energy Savings (kWh/day) | | | Annual Energy Savings (kWh/year) | | | |
|---|---|---|---|---|---|---|---|---|
| **Option** | **Sample Size** | **Space Cooling** | **Space Heating** | **Non-HVAC** | **Space Cooling** | **Space Heating** | **Non-HVAC** | **Total** |
| **Supplemental MSHP** | 6 | 10.9 | 13.2 | 0.0 | 2,176 | 162 | | 2,337 |
| **Space-Coupled HPWH**[a] | 8 | 1.1 | -0.8 | 3.2 | 131 | (22) | 1,175 | 1,284 |
| **EIFS** | 1 | 5.0 | -1.0 | 0.0 | 1,070 | (34) | | 1,036 |
| **Advanced Windows**[b] | 3 | -0.5 | 4.2 | 0.0 | (118) | 19 | | (99) |
| **Nest Thermostat** | 19 | 1.6 | 1.1 | 0.0 | 435 | 22 | | 457 |
| **HP Clothes Dryer** | 8 | 0.0 | 0.0 | 0.8 | | | 312 | 312 |
| **Var. Speed Pool Pump** | 5 | 0.0 | 0.0 | 7.3 | | | 2,665 | 2,665 |

[a] Non-HVAC savings for the HPWH measure are the average DHW energy savings for the six sites at which electric resistance tank types were replaced with heat pump types—three of which were located inside the home and three of which were located in the garage and coupled to the interior space.

[b] Predicted space cooling savings for the window retrofits ranged from (0.7)–6.9 kWh/day depending on assumptions; the median was (0.5) kWh/day.

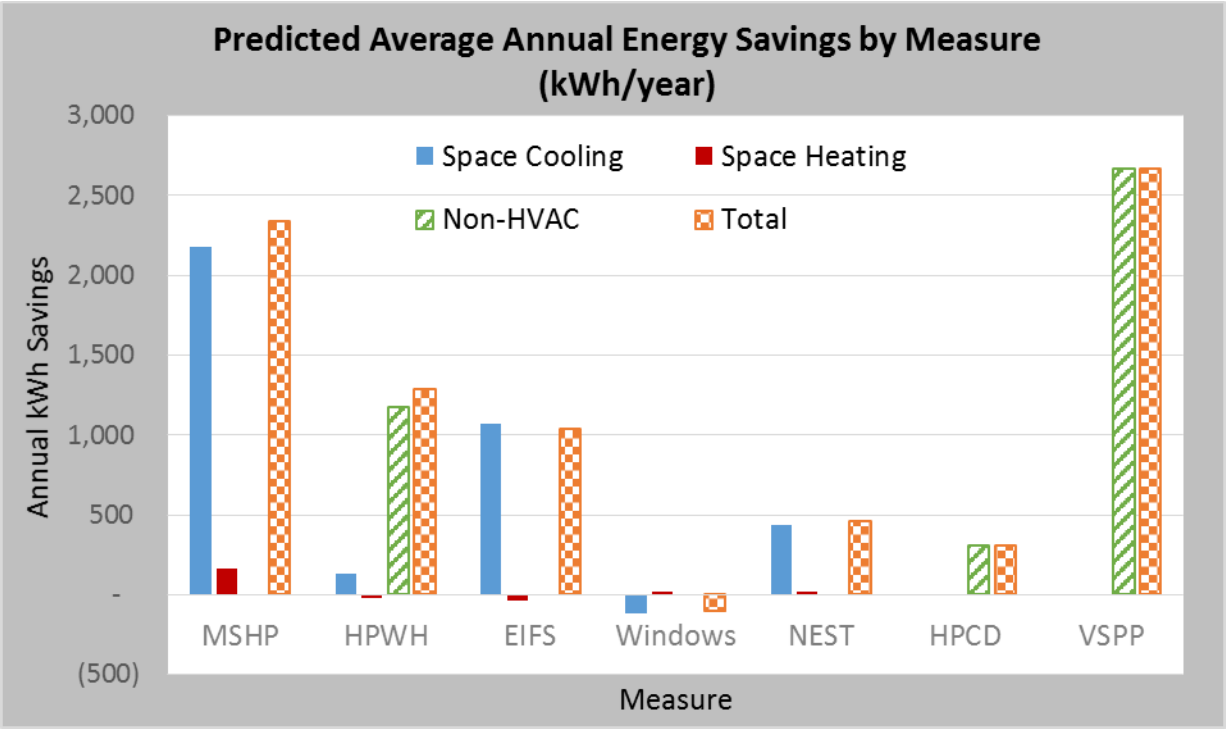

**Figure ES-1. Average annual energy savings for the Phased Deep Retrofit Phase II evaluation measures**

# 1 Introduction

The U.S. Department of Energy (DOE), with the Building America Partnership for Improved Residential Construction (BA-PIRC) team and Florida Power and Light (FPL) electric utility, pursued a pilot phased energy-efficiency retrofit program in Florida by creating detailed data on the energy and economic performance of two levels of retrofit—shallow and deep. For this Phased Deep Retrofit (PDR) project, a total of 56 homes spread across the utility partner's territory in east central Florida, southeast Florida, and southwest Florida were instrumented between August 2012 and January 2013, and received simple pass-through retrofit measures between March 2013 and June 2013. Ten of these homes received a deeper package of retrofits between August 2013 and December 2013. The shallow retrofits are applicable to all homes and provided critical data to the design of "deep retrofits," which make a major impact on whole-house energy use, averaging 39% savings on summer peak hour demand, 60% savings on winter peak hour demand, and 38% annual energy savings. A full account of Phase I of this project, including home details and characterization, "Phased-Retrofits in Existing Homes in Florida Phase I: Shallow and Deep Retrofits", is being drafted concurrent to this report.

Phase II of this project, which is the focus of this report, applied the following additional retrofit measures to select homes that received a shallow retrofit in Phase I:

- Supplemental Mini-Split Heat Pump (MSHP) (six homes)
- Ducted and space-coupled Heat Pump Water Heater (HPWH) (eight homes)
- Exterior Insulation Finish System (EIFS) (one home)
- Window retrofit (three homes)
- Smart thermostat (21 homes: 19 Nests; 2 Lyrics)
- Heat Pump Clothes Dryer (HPCD) (eight homes)
- Variable Speed Pool Pump (VSPP) (five homes)

While some of these retrofit technologies, such as windows and EIFS, have been studied in Florida in the past (Barkaszi and Parker 1995), a detailed evaluation with more modern equipment and costs has not been identified, and were of interest to the utility partner. Technologies such as supplementing an existing central heating and cooling system with an MSHP, and taking advantage of cooling provided by an HPWH with ducting, had not been done in Florida. This report identifies measured energy savings and installation costs of the different technologies, adding to the body of knowledge enabling industry to further the Building America goal of 40% savings in existing housing. Findings also provide utilities with data enabling further optimization and expansion of the shallow and deep retrofit packages piloted in Phase I.

The PDR study sites are all-electric, single-family homes located in central and SouthFlorida. Selected characteristics for all of the homes evaluated in this report are summarized within each section, including location, year built, occupancy, conditioned floor area, HVAC duct and whole house airtightness test results, and measures included in the Phase II retrofit.

# 2 Measurements and Equipment

In Phase I, detailed audit data were obtained from all homes, including house size and geometry, insulation levels, materials, finishes, and equipment. Blower door and duct leakage tests were completed on each home. Detailed photographs were also taken of each home's exterior, appliances and equipment, and thermostat. Shower head flow rate was measured.

Monitoring of house power and the various end uses is accomplished by a 24-channel data logger (SiteSage™). This is supplemented by portable loggers (Point Six and HOBO) to take temperature and Relative Humidity (RH) readings. Data are retrieved daily over the Internet via broadband connection. Data are collected on a 1-hour time step. Ambient temperature and RH are obtained from nearby weather stations. Table 1 summarizes the measurements and equipment used to conduct field testing and data acquisition for the project. A dedicated website[1] has been set up to host the monitored energy data from the project.

**Table 1. Equipment Used for Field Testing**

| Measurement | Equipment Used |
|---|---|
| **Temperature and relative humidity** | HOBO temp & RH logger<br>Point Six temp & humidity logger |
| **Detailed house power (total, HVAC[a], water heating, cooking, clothes drying, refrigeration, pool pump)** | SiteSage by Powerhouse Dynamics |

[a] Heating, ventilating, and air conditioning

## 2.1 Experimental Instrument Accuracies

National Weather Service (NWS) measurements were used for the outdoor temperature, matched to the nearest available weather data, which was typically less than 20 miles away. The stated accuracy of the outdoor temperature measurements by the NWS is ±1°F over the range of interest (NWS 2014).

Interior temperatures in the project are measured near the thermostat using Onset HOBO U-10-003 portable loggers[2] with a stated accuracy of ±0.95°F for temperature and ±3.5% RH for relative humidities up to 85%. Power was measured for the air conditioners, heat pump compressors and air handlers, and strip heat circuits by SiteSage loggers[3] (formerly eMonitor), generally using 50-amp current transformers. These have a stated accuracy of ±1% between 10% and 130% of their rated output. The relative error becomes an artifact of the load itself. For a 3,000-Watt (W) compressor at a given point, this would result in approximately ±30 W in measurement uncertainty for evaluating absolute measurements (Kilowatt-Hours [kWh] for one site versus another). For retrofit measurements (before/after), the measurement equipment-related variation is much lower, such that measurements should be ±0.5% or better. For example, if the air conditioning (AC) in a home was using 25 kWh/day, the average load would be 1,042 W with an absolute uncertainty of 0.5 kWh/day. If the estimate was between pre- and post-retrofit periods (the situation in this evaluation), the uncertainty would be 0.12 kWh/day, although this can be computed for individual cases if the results are in doubt.

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[1] www.infomonitors.com/pdr/

[2] www.onsetcomp.com

[3] http://powerhousedynamics.com

# 3 Evaluation Method

Linear regression analysis was used to project savings for the measures that influence space cooling and space heating energy use—the MSHP, space-coupled HPWH, EIFS, window retrofit, and smart thermostat. The same general model, using the measured cooling and heating electrical power and then modeling this against outdoor weather conditions, was applied for each of these evaluations as described below.

From statistical evaluation, the study shows that the average daily AC and space heating energy had the strongest statistical power to evaluate against weather—much stronger than hourly data because of the time lag posed by temperature on building elements. Averaging the hourly temperatures into daily averages was actually a better statistical predictor of space-conditioning energy than estimating heating degree days (HDD) and cooling degree days (CDD) at a 65°F base for the same periods. The coefficients of determination tended to be much superior, mainly because HDD and CDD periods with zero or negative numbers that were truncated by the degree-day procedure actually influence daily space-conditioning needs. For example, pre-dawn periods with temperatures below 65°F actually reduce the required cooling whereas the degree day calculations assume these hours have a CDD value of zero. As a result, daily average temperatures were used for the analysis. Space-conditioning energy was then plotted against average outdoor temperature and the daily average balance temperature for heating and cooling was determined. In some homes with very tight temperature control these were often the same. The typical daily balance point was approximately 65°F, although this sometimes varied (62°–70°F for cooling and 60°–70°F for heating).

During the process of establishing the most robust statistical formulation to predict space heating and cooling depending on weather, this study found that the same method had been independently identified by Haberl et al. (2005). This is currently recommended in the ASHRAE "toolkit" recommendations on the methods to estimate savings from retrofit measures applied to buildings. This increases confidence in the methods used for this analysis.

The following theoretical model based on suggested ASHRAE protocols (ASHRAE 2002) was applied for predicting energy use:

$$\text{kWh} = A + B(\text{Tamb} - \text{Tint}) + C(\text{Qint}) + D(\text{Solar})$$

Where:

A = regression error or intercept term

B = coefficient for house heat gain (UA)/COP of cooling system (outdoor temperature – indoor temperature; Delta T)

C = 1/COP of cooling system assuming all Qint (internal gains) must be removed

D = fraction of horizontal solar transmitted through windows and exposed building exterior components/COP

An alternative model with a substitute B term was also used.

Where:

B = outdoor temperature

In keeping with the statistical analytical concept of parsimony, this study generally used the simplest model that showed stable and reliable results with strong explanatory power.[4] Outdoor temperature was used rather than the Outdoor Temperature Minus Indoor Temperature, in Degrees Fahrenheit (Delta T) unless the interior temperature profile was altered between the pre- and post-retrofit observation periods.

This was the case for some of the window, EIFS, and space-coupled HPWH evaluations in which the thermostat position was clearly moved. The C term ‘Qint’ and D term ‘Solar’ are included only when significant or needed in models that exhibited poor explanatory power or exhibited contrary results. In a perfectly behaved model, the term for C (internal gains) would be around 0.4, which indicates that the Coefficient of Performance (COP) of the cooling system would be 1/0.4 = 2.5 * 3.412 W = 8.5 British Thermal Units per Watt-Hour (Btu/Wh) for the Seasonal Energy Efficiency Ratio (SEER) (including duct losses).

In the cases of the window and EIFS retrofits, even the best models were often still weak, so these evaluations were bolstered with parametric simulations using BEopt.

Model parameters were collected and compiled in the following ways:

- Hourly energy and interior temperature data were obtained from the PDR database for each particular site and were summarized by day.
- Daily average outdoor temperatures are approximated using ambient temperatures from each site’s nearest NWS station.
- The internal heat gains (Qint) parameter represents the energy use of the kitchen range, dishwasher, lighting, fans and entertainment centers, and other appliances located inside the home that is released to the house interior. If the clothes dryer is indoors, the internal gains parameter includes 20% of its energy use.
- Daily average horizontal solar insolation (W per square meter) data measured at the Florida Solar Energy Center (FSEC) meteorological station in Cocoa, Florida, were used to represent changing sun conditions (Solar).

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

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[4] https://theartofmodelling.wordpress.com/2012/03/14/why-parsimony/

For most of the evaluated measures, the cooling energy estimates are kWh/day for an 80°F day for cooling and a 50°F day for heating. For reference, it might be noted that in Florida's mild winter, the average daily temperature during "winter" when temperatures are lower than 65°F was 58.2°F (2014–2015 winter). Similarly, the average daily temperature in summer from June–September (inclusive) was 80.5°F in 2014. The climatic normal using Orlando, Florida, typical meteorological year 3 data are 79.6°F for summer and 60.8°F for January and February. This indicates that the evaluated values would be appropriate for typical summer conditions and for "colder days" during winter.

The final report will use the established regressions for each site with the relevant typical meteorological year 3 weather data to extrapolate the savings out. However, to facilitate a more rapid evaluation for the interim report, for many of the assessed options the results were applied to the average annual HVAC energy use of the untreated PDR sample reported in the Phase I report—5,880 kWh/year for space cooling and 274 kWh/year for space heating.

# 4 Evaluation of Supplemental Mini-Split Heat Pumps

## 4.1 Site Characteristics and Supplemental Mini-Split Heat Pumps Measure

A major facet of the Phase II segment of the PDR project was the installation of a high-efficiency, supplemental MSHP. Six such systems were installed in central Florida locations from August 27–September 22, 2014. The systems were 1-ton ductless Panasonic XE12PKUA**,** SEER 25.5 Btu/Wh, with the single indoor head located at a central location in the home. The units have a capacity of 11,580 Btu at the 95/80/67 rating condition and a heating capacity of 13,800 Btu/hr at a 47°F outdoor temperature. Maximum power is 800 W at rated conditions.

The homes receiving the supplemental mini-splits were of 1980s and 1990s vintage, with central AC systems of various ages and efficiencies. Duct systems for the existing central system were all flex duct and located in the attic space of each home. Site characteristics for each home are summarized in Table 2. Table 3 provides existing HVAC characteristics.

**Table 2. Supplemental Mini-Split Heat Pump Site Characteristics**

| Site # | City | Year Built | Living Area (ft$^2$) | # of Occu. | Stories | Wall Construction | Ceiling Insula-tion[a] | House Air-tightness (ACH50)[b] |
|---|---|---|---|---|---|---|---|---|
| **3** | Merritt Island | 1993 | 1,856 | 1 | 1 | CMU | R-30 | 7.9 |
| **12** | Port Orange | 1984 | 1,594 | 2 | 1 | CMU | R-19 | 11.3 |
| **16** | Indialantic | 1982 | 2,231 | 3 | 1 | Frame | R-38 | 12.7 |
| **24** | Cocoa | 1986 | 1,978 | 3 | 2 | Frame | R-25 | 9.5 |
| **27** | Palm Bay | 1995 | 2,050 | 2 | 1 | Frame | R-30 | 8.0 |
| **60** | Palm Bay | 1987 | 1,520 | 3 | 1 | Frame | R-25 | 6.6 |

[a] Thermal resistance measure (R-*n*).
[b] Air changes per hour measured at a test pressure of -50 pascals with respect to the outside, divided by the building volume.

**Table 3. Supplemental Mini-Split Heat Pump Site Existing Heating, Ventilating, and Air Conditioning Characteristics**

| Site # | Year of AHU[a] | Year of Comp | AC Size (tons) | AC SEER | Heat Pump or Electric Resistance | Duct Leakage (Qn,out)[b] |
|---|---|---|---|---|---|---|
| **3** | 1993 | 2010 | 3.5 | <13 | Heat Pump | 0.05 |
| **12** | 2000 | 2000 | 3 | 12.0 | Heat Pump | 0.63 |
| **16** | 2002 | 2014 | 4 | 13.0 | Resistance | 0.07 |
| **24** | 2010 | 2010 | 3.5 | 15.0 | Resistance | 0.09 |
| **27** | 2008 Packaged Unit | | 5 | 12.0 | Resistance | 0.05 |
| **60** | 2006 | 2006 | 3 | 15.5 | Resistance | 0.04 |

[a]Air Handling Unit
[b]Duct leakage measured at a test pressure of negative 25 pascals with respect to the outside, divided by the building's conditioned floor area.

It was hoped that the ductless supplemental MSHPs might reduce space cooling and heating energy by reducing the runtime of less efficient, existing central systems subject to duct losses.

However, how this would work out practically was highly speculative because the result was two different systems with potentially competing thermostats serving a single zone. Moreover, no existing simulation model can provide savings estimates because having two HVAC systems serve the same zone violates operation limits for hourly calculations.

In most cases, the indoor unit was located as close as possible to the central return grille of the existing system to help with room-to-room distribution of MSHP air when that unit was operating and the main system was functioning as well. In each house, the cooling set point of the MSHP was set either 2° or 4°F lower than the central system temperature. This was done based on post-retrofit communication with the homeowner as there was no way in advance of the experiments to know how the systems would interact with two independent thermostats. Indoor temperature and RH were measured near the central system thermostat. Although duct leakage was measured, there was no attempt to improve the central system prior to installing the MSHPs. Figure 1 shows examples of the MSHP installation.

**Figure 1. Wall-mounted mini-split heat pump fan coil at Site 3 and Site 24**

## 4.2 Supplemental Mini-Split Heat Pump Evaluation

In order to evaluate how the supplemental MSHP influenced space cooling and heating, the evaluation method described in Section 3 was applied to data for the period from January 1, 2014, to late June or early July 2015 with the pre- and post-retrofit periods clearly delineated. The evaluation periods and MSHP installation dates for each site are:

- Site 24 Evaluation Dates: January 1, 2014–July 1, 2015; Installation August 27, 2014
- Site 3 Evaluation Dates: January 1, 2014–July 1, 2015; Installation September 2, 2014
- Site 16 Evaluation Dates: January 1, 2014–July 1, 2015; Installation September 4, 2014
- Site 60 Evaluation Dates: January 1, 2014–July 7, 2015; Installation September 9, 2014
- Site 12 Evaluation Dates: January 1, 2014–June 22, 2015; Installation September 12, 2014
- Site 27 Evaluation Dates: January 1, 2014–June 25, 2015; Installation September 22, 2014

Tables 4 and 5 show the cooling and heating results from the regressions along with the interior temperature (Tint) and RH before and after the MSHP retrofit. Figure 2 shows the times series data in which electric resistance strip heat is highly visible, as is the reduction to the space cooling in summer and the very low power of the mini-split systems for Site 60.

**Table 4. Cooling Energy Use and Savings Estimates from the Supplemental Mini-Split Sites**

| Site # | Pre-Cooling (kWh/day) | Post-Cooling (kWh/day) | Savings (kWh/day) | % Savings | Cool Bal. T | Tint (pre) | Tint (post) | Delta T | RH (pre) | RH (post) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Site 24** | 31.8 | 30.8 | 1.0 | 3.1% | 65 | 75.4 | 73.9 | 1.5 | 51% | 50% |
| **Site 3** | 36.5 | 23.4 | 13.1 | 35.9% | 67 | 75.0 | 75.2 | -0.2 | 51% | 52% |
| **Site 60** | 22.6 | 14.0 | 8.6 | 38.1% | 65 | 75.9 | 76.3 | -0.4 | 52% | 52% |
| **Site 16** | 33.5 | 26.1 | 7.4 | 22.1% | 68 | 76.9 | 76.4 | 0.5 | 51% | 52% |
| **Site 12** | 34.1 | 16.8 | 17.3 | 50.7% | 65 | 74.8 | 74.5 | 0.3 | 59% | 56% |
| **Site 27** | 54.5 | 30.3 | 24.2 | 44.4% | 70 | 75.5 | 75.0 | 0.5 | 46% | 46% |
| | | | | | | | | | | |
| **Average** | **35.5** | **23.6** | **11.9** | **33.6%** | **66.7** | **75.6** | **75.2** | **0.4** | **52%** | **51%** |
| **Median** | **33.8** | **24.8** | **10.9** | **37.0%** | **66** | **75.5** | **75.1** | **0.4** | **51%** | **52%** |

**Table 5. Heating Energy Use and Savings Estimates from the Supplemental Mini-Split Sites**

| Site # | Pre-Cooling (kWh/day) | Post-Cooling (kWh/day) | Savings (kWh/day) | % Savings | Heat Bal. T | Tint (pre) | Tint (post) | Delta T |
|---|---|---|---|---|---|---|---|---|
| **Site 24** | 4.9 | 4.2 | 0.7 | 14.3% | 65 | 70.2 | 69.7 | -0.5 |
| **Site 3** | 19.9 | 7.7 | 12.2 | 61.3% | 65 | 69.2 | 69.8 | 0.6 |
| **Site 60** | 30.5 | 5.6 | 24.9 | 81.6% | 65 | 73.1 | 73.1 | 0 |
| **Site 16** | 20 | 5.8 | 14.2 | 71.0% | 61 | 69.6 | 70.7 | 1.1 |
| **Site 12** | 14.6 | 13.4 | 1.2 | 8.2% | 65 | 68.7 | 69.9 | 1.2 |
| **Site 27** | 69.7 | 30.2 | 39.5 | 56.7% | 70 | 73.8 | 75.2 | 1.4 |
| | | | | | | | | |
| **Average** | **25.8** | **12.3** | **13.6** | **42.3%** | **65.2** | **70.3** | **71.1** | **0.8** |
| **Median** | **20.0** | **6.8** | **13.2** | **59.0%** | **65** | **69.9** | **70.3** | **0.9** |

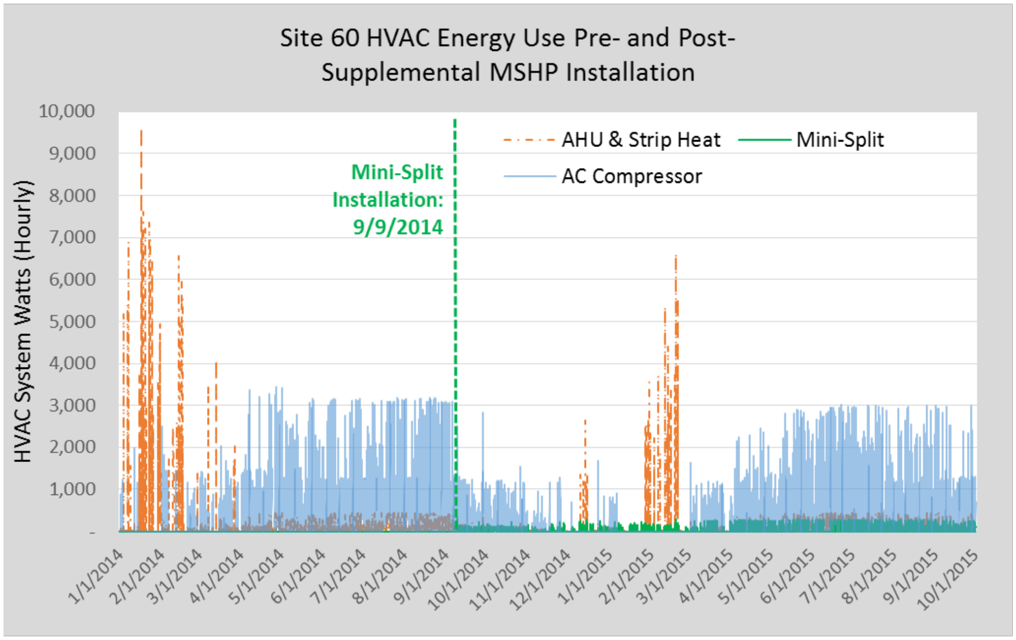

**Figure 2. Time series data showing heating, ventilating, and air-conditioning energy use by air-conditioner compressor (blue), air handler unit and strip heat (orange), and supplemental mini-split (green) for Site 60**

Figures 3 and 4 show an example of the analysis methods used for Site 60 to illustrate how the savings estimates were obtained. Figure 3 shows the regression lines for space cooling, indicating the pronounced impact on daily electricity use. The data show average cooling energy savings of 34% or 11.9 kWh/day (medians are 37% or 10.9 kWh/day) for a summer day with an average daily temperature of 80°F. Interior temperature was 0.4°F cooler than in the pre-retrofit condition. The interior RH conditions were similar pre- and post-retrofit, although significantly lower at Site 12, which has a high degree of duct leakage in the existing central system.

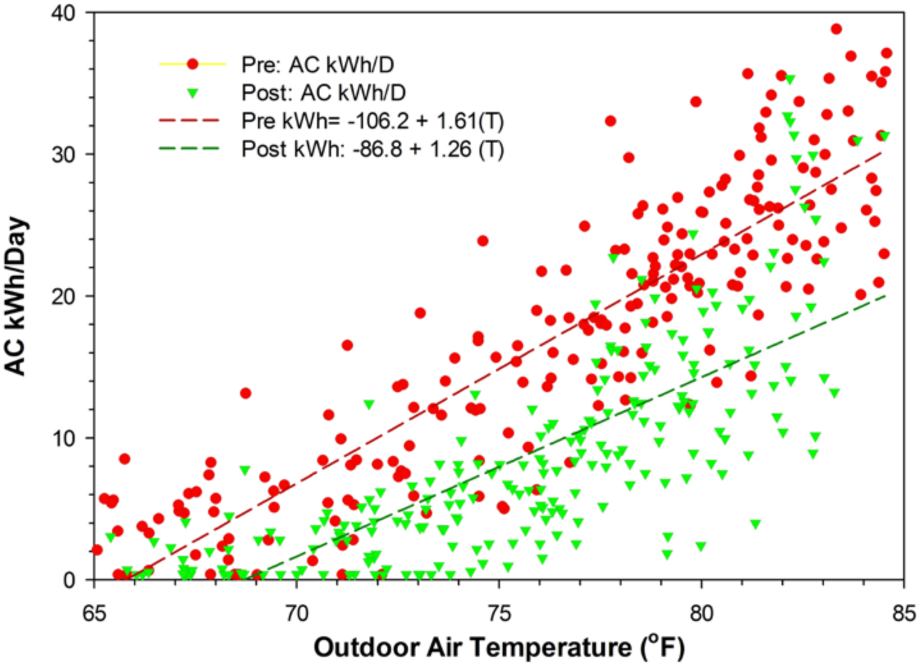

**Figure 3. Computed regression lines for measured daily cooling for Site 60 pre- and post-supplemental mini-split retrofit**

Figure 4 gives a similar presentation for space heating with large differences seen from the switch from primarily electric resistance heat to primarily MSHP heating.

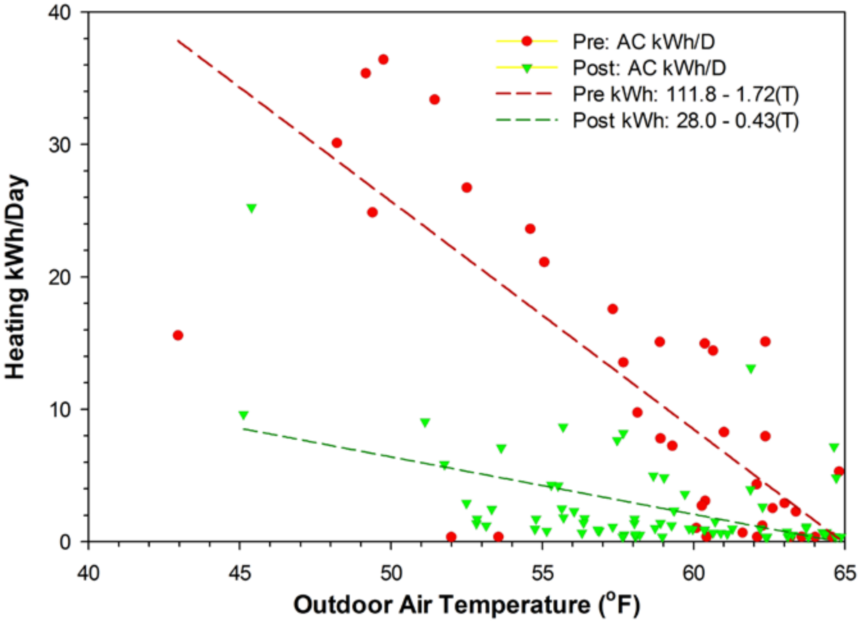

**Figure 4. Regression of daily space heating before and after supplemental mini-split retrofit at Site 60**

The typical heating energy reductions achieved by the supplemental mini-splits were considerably greater than for cooling. These results are because Sites 3, 16, 27, and 60 had electric resistance heating whereas the mini-split uses only a heat pump for producing heat. The median daily space heating savings were 59% or 13.2 kWh/day for a winter day with a 50°F outdoor temperature. Regressions from the analysis of the mini-split installations are provided in Appendix A.

The projected energy savings from the supplemental MSHP measure are impressive, with a median of 37% for cooling energy. Insight into the economics of a supplemental MSHP installation with average predicted savings is provided in the following example.

The full retail cost for the MSHP equipment and the project cost for the installations in 2014 was $4,676 per site. However, in just 1 year, the equipment cost has been significantly reduced, suggesting a current installed price of $3,465, which is the cost used for the economic evaluation in this study. If the median percent cooling energy savings predicted at the average outdoor temperature of 80°F were applied to the average annual HVAC energy of the untreated sample reported in Phase I, the annual savings would be $280 (5,880 kWh/year * 0.37 * $0.12/kWh) + (274kWh/year * 0.59 * $0.12/kWh).

Simple payback for the supplemental MSHP in this example would be 12.4 years with an annual rate of return 8.1%. In a mature market, economics are likely to improve with equipment and labor cost reductions. This cost analysis does not consider one notable benefit to the consumer—the redundant heating and cooling system for the home, which is highly desirable given the failure rate of central AC systems. In Florida’s cooling-dominated climate, where systems are often used continuously, AC systems typically last only about 10–15 years and maintenance needs can often take them off-line temporarily.

# 5 Evaluation of Ducted and Space-Coupled Heat Pump Water Heaters

## 5.1 Site Characteristics and Space-Coupled Heat Pump Water Heater Measure

As a byproduct of their operation, HPWHs create a quantity of cooled and dehumidified air from inlet to the outlet compressor section of the unit. The effect on space-conditioning and water heating energy of coupling an HPWH to the conditioned living space is of particular interest in a cooling-dominated climate such as Florida's. This was investigated in eight homes in the PDR project. Site characteristics for these homes are provided in Table 6.

**Table 6. Heat Pump Water Heater Retrofit Site Characteristics**

| Site # | City | Year Built | Living Area ($ft^2$) | House Airtightness (ACH50) | AC SEER | Heating | Duct Leakage (Qn,out) |
|---|---|---|---|---|---|---|---|
| **1** | Merritt Island | 1961 | 2,028 | 13.7 | 13.0 | Heat Pump | 0.04 |
| **5** | Rockledge | 2006 | 2,328 | 5.6 | 13.0 | Heat Pump | 0.10 |
| **9** | Melbourne | 1984 | 1,013 | 12.9 | < 13 | Resistance | 0.11 |
| **13** | Merritt Island | 1963 | 1,052 | 16.4 | 15.5 | Heat Pump | 0.10 |
| **26** | Palm Bay | 1999 | 1,502 | 4.7 | 17.0 | Heat Pump | 0.04 |
| **50** | Melbourne | 1958 | 2,168 | 5.5 | 17.0 | Resistance | 0.03 |
| **51** | Cocoa | 1994 | 2,233 | 8.3 | 16.0 | Heat Pump | 0.06 |
| **56** | Merritt Island | 1963 | 1,000 | 13.5 | 10.0 | Resistance | 0.16 |

Three different HPWHs were evaluated—the GE 50-Gallon GeoSpring, Airgenerate 66-gallon model ATI66DV, and A.O. Smith Voltex model PHPT-60. FSEC has previously reported on the performance of these units in a laboratory setting at its Hot Water Systems Laboratory (Colon and Parker 2013) (Colon 2015).

Three homes received a GeoSpring unit as a replacement for an electric resistance tank. Two were the newer model GEH50DFEJSR, and one was the original model GEH50DNSRSA. The GE units were located in interior utility rooms in each home. Three additional homes each received an Airgenerate unit as a replacement for an electric resistance tank. This unit comes equipped for ducting air to and from the unit, and each unit was installed in an attached garage.

Two homes had previously received a Voltex as a replacement for an electric resistance tank during an earlier phase of this research ("Phased-Retrofits in Existing Homes in Florida Phase I: Shallow and Deep Retrofits", in draft concurrent to this report). These two units, each located in attached garages, were modified with A.O. Smith's available ducting kit for the Voltex. The Voltex and Airgenerate units were then ducted such that air used for heat pump operation was pulled from, and returned to, the conditioned living environment. A combination of insulated metal and flex duct was used for ducting, and air was pulled from and supplied to the same general location in each home. Figure 5 shows example water heater installations in the project.

**Figure 5. Heat pump water heater configurations: Left, interior GE unit in utility room at Site 13; center, ducted AirGenerate unit at Site 5; right, ducted A.O. Smith unit at Site 26**

The Energy Conservatory Flow Blaster duct blaster attachment was used to measure the airflow entering the conditioned space for all ducted units. Airflow for the GE units was not measured as there is no ducting option. Ducted airflow was in the range of 113–130 CFM for three of the five ducted units. One unit had very low airflow (31 CFM), due to a long duct run. One unit had higher airflow (225 CFM) due to very short duct run. Table 7 provides an installation and commissioning summary with these data.

**Table 7. Space-Coupled Heat Pump Water Heater Installation and Commissioning Summary**

| Site # | Model | Ducted Airflow (CFM) | Location Receiving HPWH Air |
|---|---|---|---|
| **1** | GE | n/a | Utility room |
| **5** | Airgenerate | 130 | Dining Room |
| **9** | Airgenerate | 113 | Office |
| **13** | GE | n/a | Utility room |
| **26** | AO Smith | 115 | Bedroom |
| **50** | Airgenerate | 225 | Dining Room |
| **51** | AO Smith | 31 | Kitchen |
| **56** | GE | n/a | Utility room |

## 5.2 Space-Coupled Heat Pump Water Heater Evaluation

All the HPWHs were installed and/or ducted between July and October 2014. For most sites, data for the period of July 2013–July 2015 were analyzed. For Sites 1, 13, and 51, the pre-retrofit period was censured to shorter periods due to other HVAC installation measures potentially confounding data, and heating analysis was prevented due to lack of pre-retrofit heating data.

The statistical evaluation method is generally described in Section 3. To evaluate the impact of coupled HPWH on space cooling energy, Delta T was used in the regressions as it normalized differences in average indoor temperature between pre- and post-retrofit periods, which exceeded 1°F in some houses. This seemed more appropriate as operation of the ducted HPWH tended to alter the interior temperature profile. Also, rather than evaluating performance at 80°F and 50°F, energy use and savings are evaluated seasonally, using data from the entire pre- and post-retrofit periods evaluated over each day to determine a weighted average daily heating and cooling energy use. Cooling results are provided in Table 8. Regression formulas are provided in Appendix B.

**Table 8. Cooling Analysis Results for Conditioned Space-Coupled Heat Pump Water Heater Retrofits**

| Site # | # of Occupants | Coupling | HPWH Energy Post (kWh/day) | Cooling Energy Pre (kWh/day) | Cooling Energy Post (kWh/day) | Cooling Savings (kWh/day) | Cooling Savings (%) |
|---|---|---|---|---|---|---|---|
| **1** | 4 | Interior | 2.07 | 16.26 | 14.50 | 1.76 | 10.8 |
| **5** | 2 | Ducted | 2.69 | 44.68 | 42.99 | 1.69 | 3.8 |
| **9** | 2 | Ducted | 3.20 | 11.54 | 10.01 | 1.53 | 13.2 |
| **13** | 2 | Interior | 2.64 | 6.81 | 6.08 | 0.73 | 10.7 |
| **26** | 5 | Ducted | 3.53 | 11.48 | 10.07 | 1.41 | 12.3 |
| **50** | 4 | Ducted | 2.65 | 18.50 | 17.78 | 0.72 | 3.9 |
| **51** | 2 | Ducted | 1.25 | 14.99 | 14.16 | 0.83 | 5.6 |
| **56** | 3 | Interior | 3.09 | 18.86 | 18.71 | 0.15 | 2.7 |
| | | | | | | | |
| **Average** | **3** | **N/A** | **2.64** | **17.89** | **16.79** | **1.10** | **7.9** |
| **Median** | **2.5** | **N/A** | **2.67** | **15.63** | **14.33** | **1.12** | **8.2** |

Average cooling savings are similar to those found in a recent side-by-side laboratory study at FSEC’s Flexible Research Test Facility (Colon, Martin, and Parker 2015). The laboratory study found typical daily cooling energy savings in the summer of 2014 to be approximately 0.86 kWh/day or 3.8% with an average HPWH energy use of 1.88 kWh/day and average cooling energy of 22 kWh/day.

Figure 6 shows the regression for Site 9, clearly demonstrating reductions in space cooling energy after coupling the HPWH to the conditioned space. Like Site 9, Sites 1, 13, and 26 also exhibit relatively parallel regression lines indicating cooling savings across a wide range of daily average outdoor temperatures. Each of these sites also exhibits the largest percentage reductions in cooling energy use. Figure 7 is the post-retrofit composite average day’s water heating power for these sites. Notably, Sites 9, 13, and 26 display both a morning and an evening hot water energy use peak (bi-modal), with the evening peak dominating for Sites 13 and 26. Site 1 peaks in the middle of the day, with some evening operation. It is possible that this late day HPWH operation is providing cooling as the house is recovering from load imposed during the hottest part of the day (summer peak demand) when it is needed most.

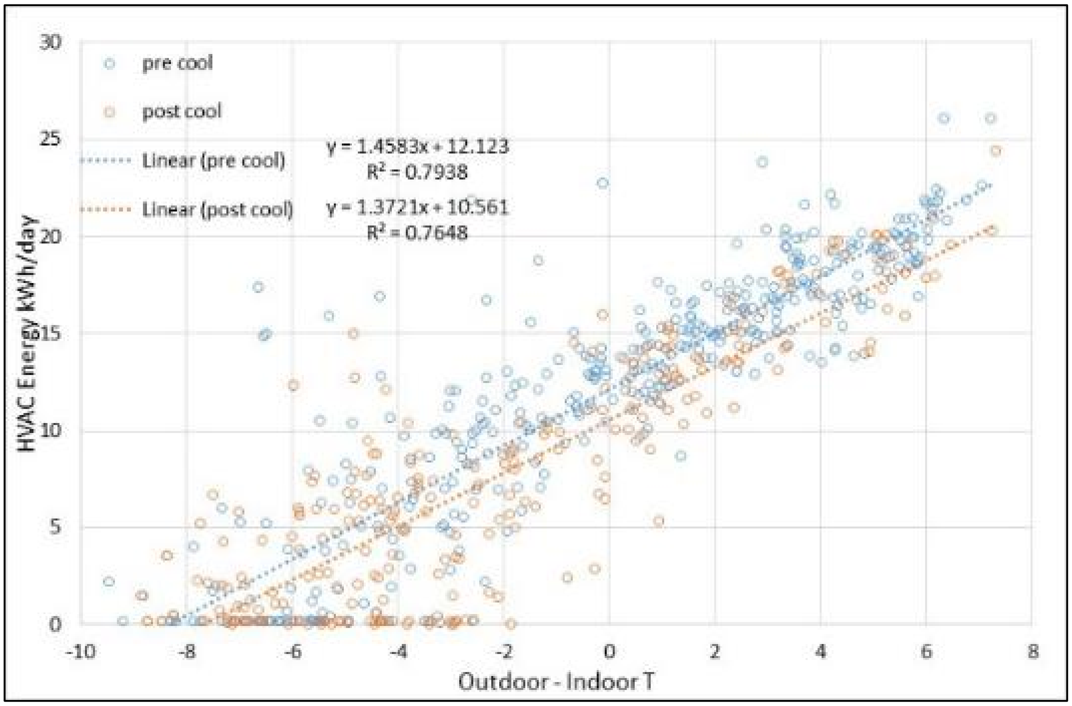

Figure 6. Site 9's parallel regression lines

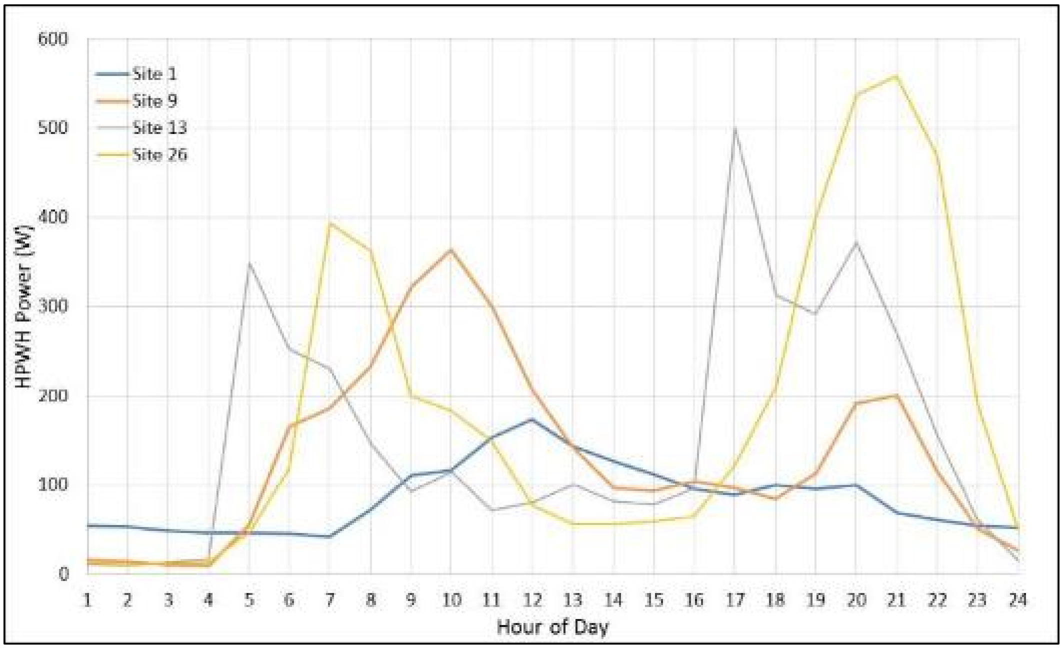

Figure 7. Post-retrofit composite average day's water heating power for Sites 1, 9, 13, and 26

Sites 5, 50, 51, and 56 show lower cooling savings. Regression lines for these sites show savings at low Delta T, but converge at Delta Ts between 2°–4°F. An example regression for Site 5 is shown in Figure 8. Figure 9 is the post-retrofit composite average day's water heating power for Sites 5, 50, 51, and 56.

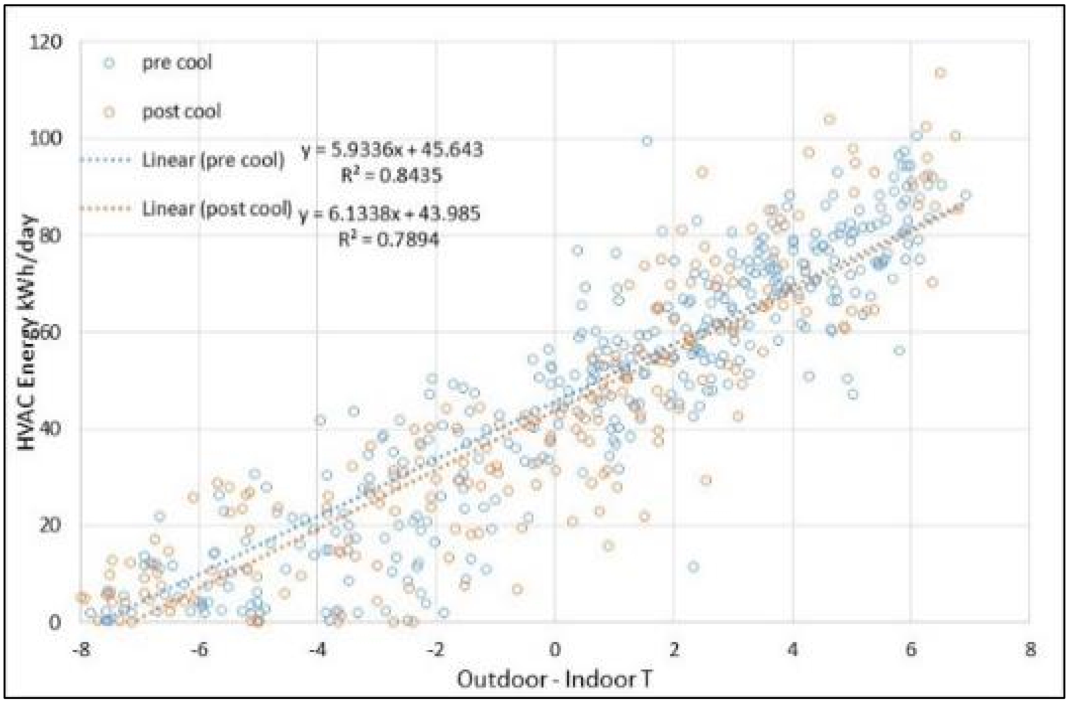

Figure 8. Site 5's cooling regression showing convergence

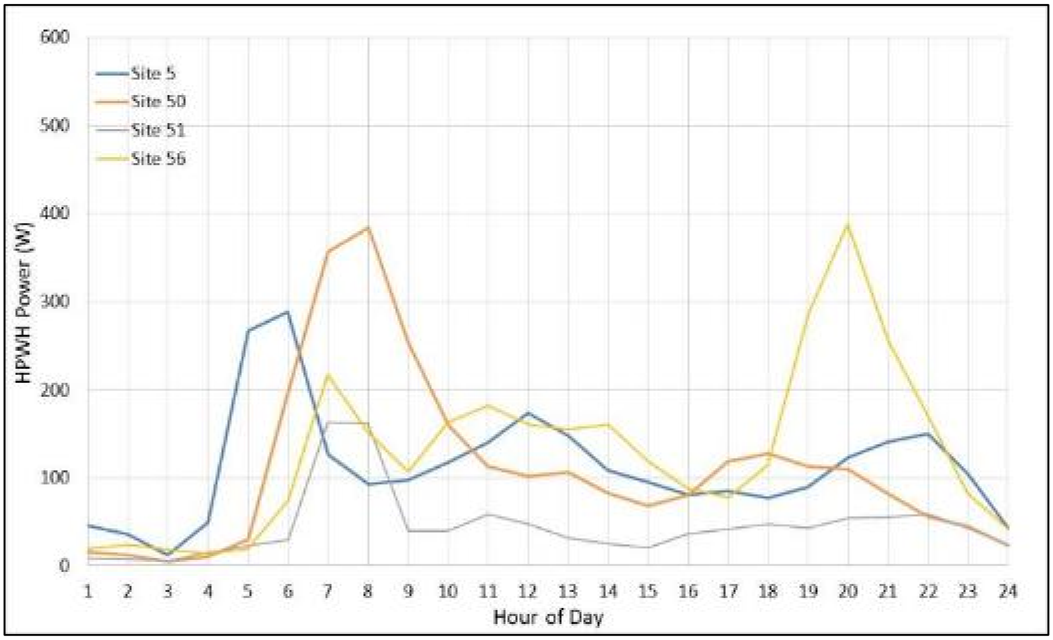

Figure 9. Post-retrofit composite average day's water heating power for Sites 5, 50, 51, and 56

Notably, Sites 5, 50, and 51 exhibit peak HPWH runtime in the early morning hours, with little daytime and evening operation. It is likely that during the early morning, when outdoor temperatures are cooler and less demand is placed on the cooling system, the extra cooling provided by a coupled HPWH is less beneficial. This is because the space temperature is further depressed below the thermostat set point, but without immediate energy savings. While Site 56 has a regression and cooling savings similar to the other homes in this group, it exhibits HPWH runtime similar to the previous group with a similar daily profile that includes an evening peak.

Heating regressions were conducted using outdoor temperature, rather than Delta T and results are provided in Table 9. The need for heating in Florida is variable and sporadic, and changing occupant preferences and tolerances result in variable indoor temperature, as opposed to the relatively consistent thermostat set point used during the cooling season.

**Table 9. Heating Analysis Results for Conditioned Space-Coupled Heat Pump Water Heater Retrofits**

| Site # | # of Occupants | Coupling | HPWH Energy Post (kWh/day) | Heating Energy Pre (kWh/day) | Heating Energy Post (kWh/day) | Heating Savings (kWh/day) | Heating Savings (%) |
|---|---|---|---|---|---|---|---|
| **1** | | | | Insufficient Data | | | |
| **5** | 2 | Ducted | 2.69 | 6.06 | 16.56 | -10.51 | -173.4 |
| **9** | 2 | Ducted | 3.20 | 4.85 | 9.16 | -4.31 | -88.8 |
| **13** | | | | Insufficient Data | | | |
| **26** | 5 | Ducted | 3.53 | 3.71 | 4.03 | -0.33 | -8.9 |
| **50** | 4 | Ducted | 2.65 | 14.83 | 12.85 | 1.98 | 13.4 |
| **51** | | | | Insufficient Data | | | |
| **56** | 3 | Interior | 3.09 | 14.42 | 15.18 | -0.76 | -5.3 |
| | | | | | | | |
| **Average** | **3.2** | **N/A** | **2.64** | **8.77** | **11.56** | **-2.89** | **-24.1** |
| **Median** | **3** | **N/A** | **3.09** | **6.06** | **12.85** | **-0.76** | **-8.9** |

As expected, coupling the HPWH to the conditioned space increases heating energy. This general result matches those found in unoccupied lab homes (Colon, Martin, and Parker 2015). However, the increase in heating energy resulting from coupling the HPWH, with a median of 0.76 kWh/day (8.9%), is greater than the 0.42 kWh/day (5.9%) increase found in lab home studies, with a magnitude of increases in heating energy predicted by the model for sites 5 and 9. Figure 10 shows the regression for Site 5, which has a heat pump. The trend looks similar to the regression for Site 9, which has strip heat. It is clear that there is more heating in the post period, but it is likely that other variables in addition to the HPWH contribute to this trend. The occurrence of some days with relatively low heating energy at average daily outdoor temperatures lower than 55°F is unexplained.

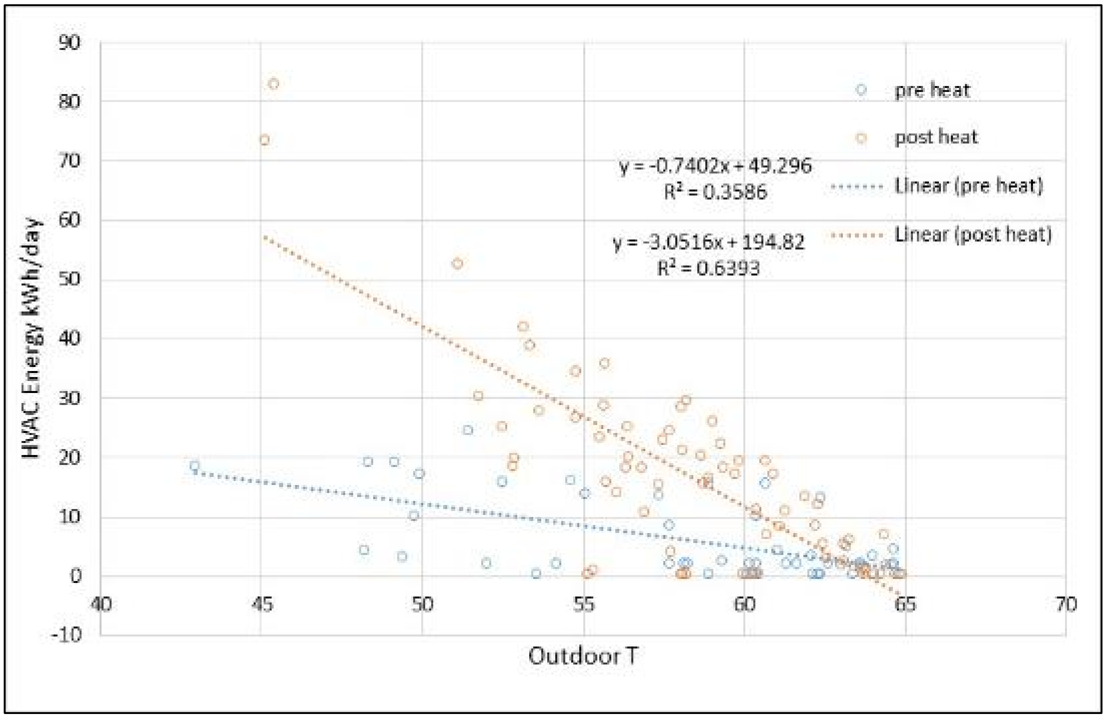

Figure 10. Site 5's heating regression

The regression for Site 56 is shown in Figure 11. Site 56 has strip heat, and the trend looks similar to Site 26, which has a heat pump, and is indicative of more consistent heating behavior.

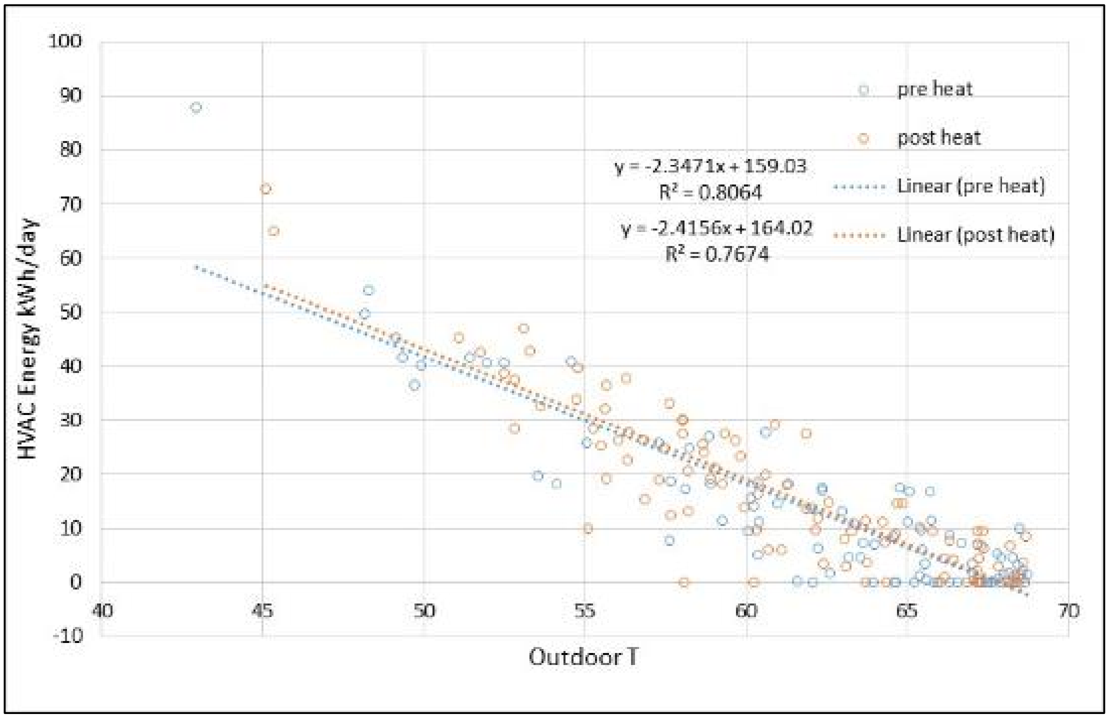

Figure 11. Site 56's heating regression

In any event, it is clear from these results as well as past research that coupling an HPWH to the conditioned space has a negative effect on heating. One way to counter this effect for a ducted HPWH is to install a damper system in the ductwork allowing cold HPWH exhaust air to be diverted from the conditioned space. Many of the ducted installations described in this report were installed with such a damper system, allowing the homeowner to take action if the cold exhaust air became a comfort problem (Figure 12), but findings indicate that none of the homeowners used the system. It is important to note that without a corresponding damper on the HPWH intake allowing air to be drawn from outside of the conditioned space (like that used in Colon, Martin, and Parker 2015), some amount of space depressurization could occur during HPWH operation. The impact of that space depressurization and possible increase in infiltration on space-conditioning energy is not known.

**Figure 12. Y-type ducting arrangement at Site 5 allowing cold exhaust air to be diverted from the conditioned living environment**

The effect of HPWH retrofits on Domestic Hot Water (DHW) energy use was also investigated, again using data for the period of July 2013–July 2015, inclusive of both heating and cooling seasons. As seen in Table 10, the six sites receiving coupled HPWH as replacements to electric resistance tanks had a median savings of 53.3% in DHW energy.

Table 10. Heat Pump Water Heater Electrical Energy Savings

| Case | Site # | # of Occupants | DHW Energy Pre (kWh/day) | DHW Energy Post (kWh/day) | DHW Savings (kWh/day) | DHW Savings (%) |
|---|---|---|---|---|---|---|
| Electric Resistance Replaced with Space-Coupled HPWH | 1 | 4 | 3.57 | 2.07 | 1.50 | 42.1 |
| | 5 | 2 | 6.96 | 2.69 | 4.27 | 61.3 |
| | 9 | 2 | 6.99 | 3.20 | 3.79 | 54.3 |
| | 13 | 2 | 6.20 | 2.64 | 3.56 | 57.4 |
| | 50 | 4 | 5.53 | 2.65 | 2.88 | 52.2 |
| | 56 | 3 | 5.89 | 3.09 | 2.80 | 47.6 |
| **Average** | | **2.8** | **5.86** | **2.72** | **3.14** | **53.6** |
| **Median** | | **2.5** | **6.05** | **2.67** | **3.22** | **53.3** |
| Existing HPWH Ducted | 26 | 5 | 2.90 | 3.53 | -0.63 | -21.7 |
| | 51 | 2 | 1.12 | 1.25 | -0.13 | -11.7 |
| **Average** | | **3.5** | **2.01** | **2.39** | **-0.38** | **-15.9** |

As expected, the two sites that had HPWHs for more than 1 year prior to having them ducted showed slight increases in DHW energy use after the HPWHs were coupled to the conditioned space (0.38 kWh/day). This study estimates that the coupling reduced potential DHW energy savings from a garage-located HPWH by 10.6% (0.38/3.60 kWh/day, where 3.60 = 3.22 kWh/day saving for electric resistance replacements + 0.38 kWh/day loss for existing ducting). While the lab home results presented in Colon, Martin, and Parker 2015 found a negligible change in COP when using air from the conditioned space as a heat source versus using air from the garage, Colon 2015 did find a higher COP when testing unducted versions of the AO Smith unit in a garage environment. In Florida, using garage air as a heat source is beneficial for HPWH water heating operation because garage temperatures are high for much of the year. Changing to a room temperature heat source can be expected to impact water heating efficiency. Analysis of the seven Phase I sites at which the HPWHs were not ducted was conducted to act as a control group for this measure. While the results varied among sites ranging from a 13% reduction in DHW heating energy to a 26% increase, an average of a 6.5% increase in DHW energy for this control group is less than the 16% found for the ducted sites. Therefore, DHW energy savings when replacing an electric resistance tank with an HPWH is expected to be greater if the unit is coupled to the garage rather than the conditioned space. In Phase I of this research ("Phased-Retrofits in Existing Homes in Florida Phase I: Shallow and Deep Retrofits", in draft concurrent to this report). DHW energy savings from replacing an electric resistance water heater with an uncoupled HPWH was found to average 68.5% (5.27 kWh/day). Phase I percent savings for uncoupled HPWH matches well with the Phase II results if the 15.9% savings loss from coupling is added to the observed 53.3% savings for the coupled units (53.3% + 15.9% = 69.2%). Absolute savings from uncoupled units in Phase I (5.27 kWh/day) are greater than what can be extracted from Phase II (3.22 kWh/day newly installed HPWH + negative 0.38 kWh/day existing HPWH = 3.60 kWh/day), because Phase I targeted households with the highest DHW energy consumption had a mix of 60- and 80-gallon HPWH retrofits. Phase II homes used less DHW on average, and retrofits only included 60-gallon HPWHs.

The cost to install the ducting to couple the HPWH to the conditioned space, inclusive of materials and labor, was $620. While details of each installation varied, the contractor charged a flat rate for each job. In hindsight, the contractor felt they underbid the jobs, and is likely to charge more in the future. Median annual cooling savings for the ducted sites was $49/year, assuming $0.12/kWh, yielding a simple payback of 12.6 years. A median heating energy penalty of $16 cut these savings by a third, yielding a simple payback of 18.4 years, nearly the ducting's 20-year expected life. Therefore, due to the cost of ducting, it is not cost-effective to couple an HPWH installed in a garage to the conditioned space. However, there is a small benefit to installing an HPWH in a location inside the conditioned space versus a garage location. One could expect a small (~$17/year) penalty on water heating energy savings due to the relatively cooler indoor air versus garage air, but the overall savings on space-conditioning energy (~$34/year) outweighs this penalty. These savings, however, may not adequately cover the cost of rerouting plumbing to accommodate an interior location if the water heater was originally designed to be located somewhere else.

# 6 Evaluation of Exterior Insulation Finish System

Another measure investigated under the Phase II PDR project was the installation of an EIFS, conducted on a single site. Prior research on energy savings resulting from exterior insulation shows that the interior thermostat set point in a cooling-dominated climate has a large impact on potential savings.

A field test conducted by FSEC and Oak Ridge National Laboratory evaluated changes in space cooling energy use associated with EIFS applied to two central Florida homes (Barkaszi and Parker 1995). The space-conditioning energy use evaluations showed post-retrofit cooling energy savings from 9%–14% at one site with an average daily interior temperature of 73°F, and -1% at the second home, because the occupants maintained a much higher interior temperature of 79°F. A fundamental finding of this study was that the EIFS retrofit generates little cooling energy savings with higher thermostat settings. The PDR study involved evaluating the impacts of a home with an EIFS as well as an advanced window retrofit. The EIFS retrofit was the first of these two measures installed at the subject site and is evaluated in this section in a case-wise manner. The impact from the window retrofit and combination of measures is discussed in Section 7.

## 6.1 Site 54 Characteristics and Exterior Insulation Finish System Retrofit Measure

The site chosen for this measure, pictured in Figure 13, is a two-person occupancy, single-story home with 1,390 ft$^2$ of living space located in Palm Bay, Florida. This home, built in 1999 has concrete masonry unit (CMU) walls with a stucco finish, a concrete slab foundation, an asphalt shingle roof, and R-19 fiberglass insulation at the attic floor and knee walls.

Figure 13. Site 54 Prior to EIFS and window retrofit

The living space adjacent to the garage wall consists of framed 2x4 construction with a drywall finish. The home has ten windows and a single sliding glass door. With a pre-retrofit tested Air Changes per Hour (measured at a test pressure of -50 Pascals with respect to the outside and divided by the building volume) (ACH50) of 5.38, this home has good airtightness for its vintage. The existing AC system is the original, manufacturer-rated 10 SEER heat pump. A single, centrally-located return feeds into the interior-located air handler. Supply air is distributed through R-6 insulated flex ducts with limited duct leakage (Qn,out = 0.03) running through the vented attic. General characteristics for Site 54 are provided in Table 11. Table 12 provides a detailed description of wall area by façade.

**Table 11. Site 54 General Characteristics**

| Characteristic | |
|---|---|
| **City** | Palm Bay |
| **Year Built** | 1999 |
| **Living Area (ft$^2$)** | 1,390 |
| **Number of Occupants** | 2 |
| **Stories** | 1 |
| **Wall Construction** | CMU |
| **Ceiling Insulation** | R-19 |
| **House Airtightness (ACH50)** | 5.3 |
| **Year of HVAC** | 1999 |
| **AC Size (tons)** | 2.5 |
| **AC SEER** | 10 |
| **Heating** | Heat Pump |
| **Duct Leakage (Qn,out)** | 0.03 |

**Table 12. Site 54 Gross and Net Wall Area by Façade**

| Site # | Wall Construction | Wall Color | Gross Wall Area (ft$^2$) | Net Wall Area (ft$^2$) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Total | East | South | West | North | NE | SE |
| **54** | CMU | Off-White | 1,347 | 1,143 | 285 | 251 | 348 | 230 | 15 | 15 |

An EIFS was applied consisting of 2-in. Type I expanded polystyrene (XPS) insulation with an R-value specification of 3.85 per inch. The total added R-value of 7.7 hr-ft$^2$-°F/Btu was installed between November 1 and December 16, 2014. (For evaluation purposes, the insulation was complete on November 13 with final finish work delayed, in part, due to rain.) Before installing the EIFS, all items attached or close to the exterior wall were moved or removed. The exterior walls were pressure-washed and a pull test was conducted to ensure the fully cured insulation adhered to the wall.

The EIFS installation process consisted of the following steps:

- A primer was applied to the exterior wall to support adhesion of the insulation.
- Adhesive was applied to the 2-in. insulation sheets and the insulation was adhered to the exterior wall.
- The installed insulation was rasped to provide a level finish.
- A reinforced base coat and final finish textured coat were next applied, as seen in Figure 14.
- In lieu of painting, the chosen wall color (off-white, similar to pre-retrofit) was premixed with a finish coat, allowing the final texture and color to be applied in one step.

**With no change in exterior finish color, the building has similarly low solar absorptance pre- and post-retrofit.**

**Figure 14. Site 54 attachment of 2-inch polystyrene insulation (top left), final textured coat application (top right), completed exterior insulation finish system retrofit (bottom)**

## 6.2 Exterior Insulation Finish System Space Cooling Energy Evaluation

The pre-retrofit EIFS space cooling observations were drawn from November 2013 through May 2014, and post-retrofit observations were drawn from November 2014 through April 2015, before the window retrofit began. The evaluation method used for predicting energy use savings is presented in Section 3.

Pre- and post-retrofit average daily exterior and interior temperatures, internal gains, and solar insolation are provided in Table 13. It is noteworthy that the post-retrofit daily average interior temperature is cooler by about 1.5°F post-retrofit in both of the season evaluations. This is perhaps an artifact of the better-insulated home causing nighttime float temperature to rise, inspiring occupants to select a lower temperature setting. Note also, the internal gains are much higher during the pre-retrofit periods, dropping by 26% between cooling periods and 32%

between heating periods. Regressions from the analysis of the EIFS installation are provided in Appendix C.

**Table 13. Average Daily Interior Temperatures, Internal Gains, and Solar Insolation Pre- and Post-Retrofit Evaluation Periods**

| Evaluation Season | Pre T Outdoor (°F) | Post T Outdoor (°F) | Pre T Indoor (°F) | Post T Indoor (°F) | Pre Internal Heat Gains (kWh/day) | Post Internal Heat Gains (kWh/day) | Pre Solar Insol. (kWh/m$^2$/day) | Post Solar Insol. (kWh/m$^2$/ day) |
|---|---|---|---|---|---|---|---|---|
| **Cooling** | 72.1 | 72.4 | 76.4 | 74.7 | 14.1 | 10.4 | 4.5 | 4.1 |
| **Heating** | 55.7 | 56.9 | 71.9 | 70.5 | 14.3 | 9.7 | 4.3 | 4.2 |

Observations for each period include when the daily average ambient temperature exceeded 63°F, the point at which space cooling energy is evident at this particular site. The scatterplot in Figure 15 demonstrates the trend of cooling energy use by outdoor temperature for the pre- and post-retrofit periods. The pre-retrofit observations and trend line are orange, the post-retrofit are blue. The trend lines portray post-retrofit energy savings as the outdoor temperature increases.

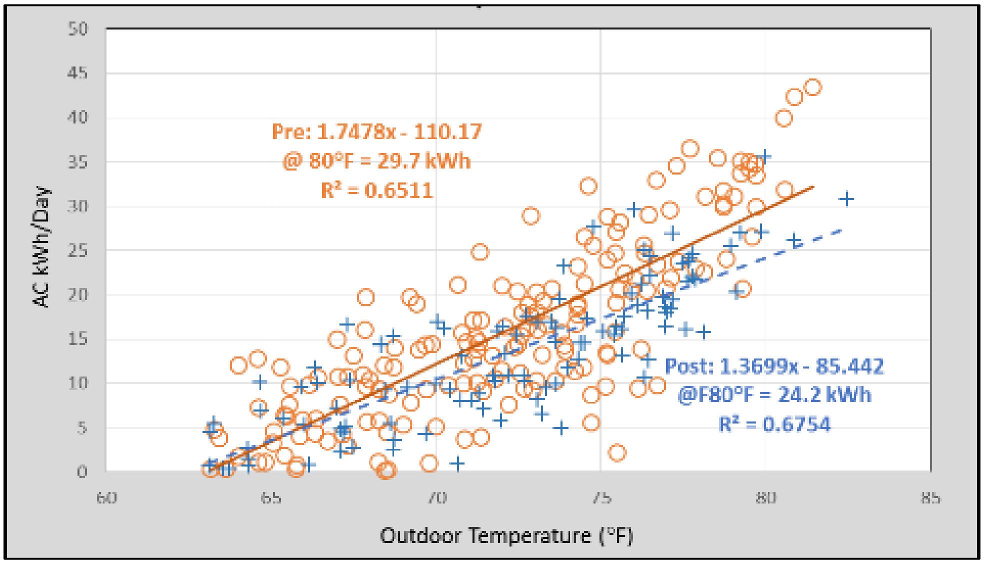

**Figure 15. Site 54 pre- and post-exterior insulation finish system daily average space cooling consumption versus outdoor temperature**

Although the scatter in the data is very large, a general trend of lower cooling consumption in the post period (blue) can be observed. Moreover, the Site 54 occupants maintained a much cooler average daily interior temperature during the post-retrofit (74.7°F) than the pre-retrofit period (76.4°F). This temperature difference is consistent through the day, as can be seen in the daily temperature profile plotted in Figure 16. The hourly interior (solid line labeled “Tint”) and ambient (dashed line labeled “Tamb”) temperature profiles are red for the pre-retrofit period and green for the post-retrofit period.

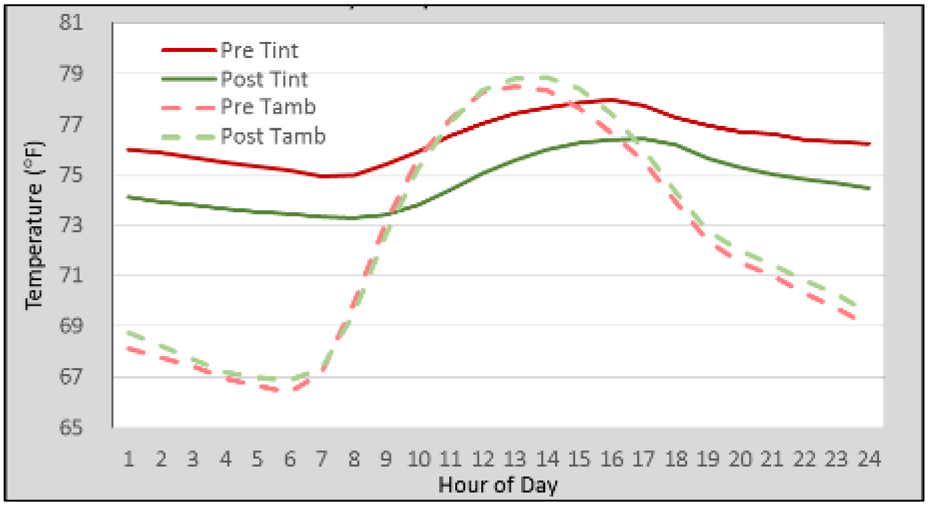

**Figure 16. Site 54 Daily indoor and outdoor temperature profiles, pre- and post-exterior insulation finish system retrofit for cooling season observations**

With fairly similar ambient temperatures among periods, the interior temperature was consistently lower post-retrofit. This indicates a change in occupant preferences rather than the building's thermal performance as influenced by the added wall insulation. The occupants have apparently taken back some of the savings for improved comfort. Savings were therefore evaluated based on the Delta T.

Solar insolation and internal gains, which were both greater during the pre-retrofit period (internal gains: 14.1 versus 10.4 kWh; solar insolation 4.3 versus 4.1 kWh/m$^2$), were both significant in each model ($p$ <0.01). Both pre- and post-retrofit regression results show stronger model fits than using outdoor temperature alone. ($R^2$ = 0.76 pre; 0.72 post). Using these models, and assuming an average outdoor temperature of 80°F, daily cooling energy needs are likely to be reduced during the warmest summer months from 27.2 to 22.2, a savings of 5.0 kWh/day (18.2%) as a result of the EIFS retrofit. These findings are somewhat higher than expected given the 3–5 kWh/day (9%–14%) savings found for the home with an interior temperature setting of 73°F (Barkaszi and Parker 1995).

For insight into the impact of internal gains, the savings projection is 25.9% assuming the pre-retrofit internal gains of 14.1 kWh/day and post-retrofit internal gains of 10.4 kWh/day. To ignore the change in internal gains inflates the savings projection by 7.7%. Also, if the analysis was confined to using the outdoor temperature and not accounting for the lower interior temperatures, the indicated savings drop to approximately 10% or 2.8 kWh/day at an 80°F outdoor temperature.

## 6.3 Exterior Insulation Finish System Space Heating Energy Evaluation

Space heating is limited in Florida's climate as evidenced by the zero recorded heating energy uses shown below in Figure 17. However, it is also evident at Site 54 that when the daily average outdoor temperature falls below 62°F, the occupants begin to heat. Thus, days with average temperatures below 62°F were used as the threshold for model inclusion.

The pre-retrofit observations were drawn from November 1, 2013, through March 2014 and post-retrofit from November 14, 2014, through March 2015. The scatterplot in Figure 17 displays pre- and post-retrofit space heating use versus outdoor temperature, and reveals higher space heating energy use post-EIFS retrofit.

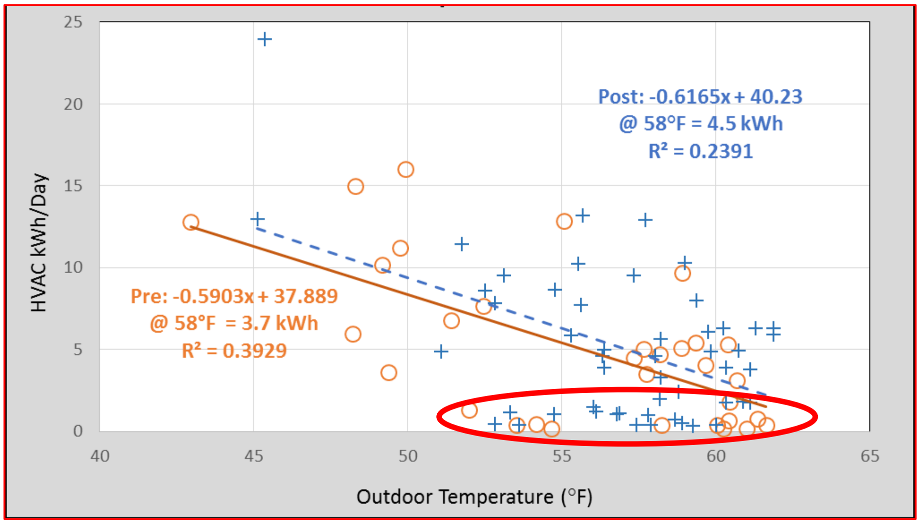

**Figure 17. Site 54 pre- and post-exterior insulation finish system daily average space heating consumption versus outdoor temperature**

The limited and sporadic heating needs in central Florida limit statistical modeling for space heating use predictions. First, there are few observation-days with significant heating loads. For example, there were only 32 days during the 2013–2014 winter and 51 days during the 2014–2015 winter in which the average daily ambient temperature fell below 62°F. Secondly, the timing and duration of the cold fronts that pass through the area impact heating needs greatly. The great amount of scatter in Figure 17 demonstrates this point. Circled in red is the wide distribution of temperatures from 52°–62°F, for which sometimes little or no space heating is used. Other observations show considerable space heating energy use (up to 13 kWh/day) at these same temperatures.

While neither internal gains nor solar insolation were significant for modeling with the very limited sample set, each of these parameters was greater during the pre-retrofit period. Internal heat gains were particularly dissimilar—14.3 kWh/day pre-retrofit, 9.7 kWh/day post-retrofit. This is important, because the pre-retrofit conditions were more favorable for reducing space heating energy needs. On the other hand, the savings model does not consider the change in interior temperature, which was cooler post-retrofit (71.9°F pre versus 70.5°F post).The plot in Figure 18 shows that the post-retrofit interior temperature was consistently lower throughout the day.

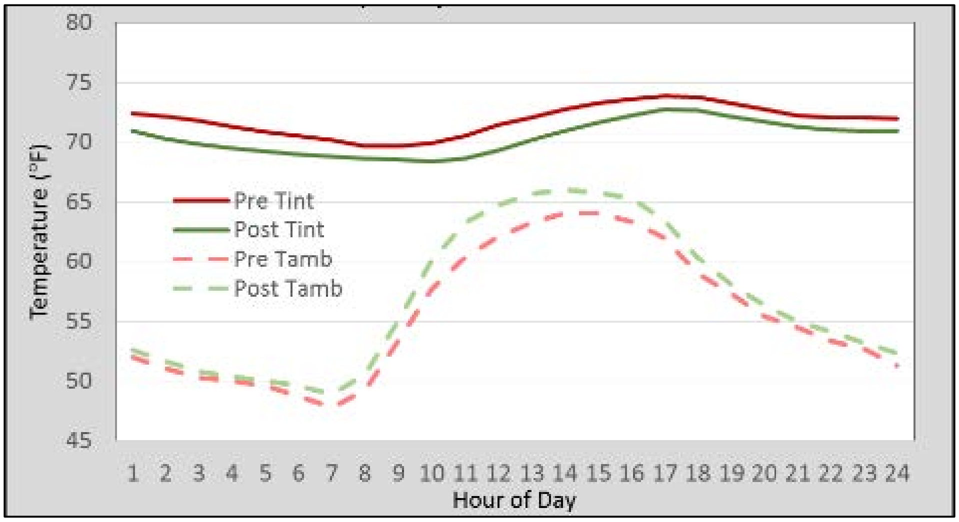

**Figure 18. Site 54 daily indoor and outdoor temperature profiles, pre- and post-exterior insulation finish system retrofit for heating season observations**

Given the consistently lower interior temperature, it is arguable that savings should be evaluated based on the Delta T. However, the poorly-fitting outdoor temperature regression models (pre: $R^2 = 0.39$; post: $R^2 = 0.24$) deteriorated further as a whole with Delta T (pre: $R^2 = 0.28$; post: $R^2 = 0.28$) and were not suitable for characterizing heating performance. Solar insolation and internal heat gains parameters were also considered, but were not significant.

Predicting space heating energy savings in response to outdoor temperature for a cold day with an average outdoor temperature of 50°F, the models suggest energy use increases from 8.4 kWh to 9.4 kWh, suggesting negative savings of 1.0 kWh/day (-12.3%). However, given the very poor statistical models, which explain less than 30% of the variation in post-retrofit heating, not much significance can be attached to these results.

As noted above, the climate in central Florida, and particularly the coastal regions, requires limited annual space heating. Given the limited statistical power of the found relationships, the heating effects should be re-evaluated in 2016 when there are more post-retrofit data for the site that may allow better characterization of heating performance.

## 6.4 Exterior Insulation Finish System Retrofit Savings Summary

In the evaluation of the EIFS at Site 54, seasonal space cooling energy savings was 5.0 kWh/day (18.2%) for an average day among the warmer summer months. However, space heating indicated negative savings of 1.0 kWh (-12.3%) on a cold central Florida day, but with unreliable statistical models from a limited sample of heating days. A summary of the EIFS energy savings results are provided in Table 14.

**Table 14. Exterior Insulation Finish System Site 54 Space-conditioning Energy Savings Summary**

| Evaluation Season | Pre (kWh/day) | Post (kWh/day) | Daily Savings (kWh) | % Savings Cooling @ 80 °F Heating @ 50 °F |
|---|---|---|---|---|
| **Cooling** | 27.2 | 22.2 | 5.0 | 18.2% |
| **Heating** | 8.4 | 9.4 | -1.0 | -12.3% |

Costs incurred for the EIFS retrofit measure, including modifications to electrical outlets and plumbing fixtures, were $19,438. In terms of a cost benefit alone, the EIFS measure is not an energy-efficiency measure. If the HVAC energy savings results are applied to the average annual HVAC energy use of the untreated PDR sample reported in Phase I, the annual savings are $124 with $128/year cooling energy savings (5,880 kWh/year * 0.182 * $0.12/kWh) and -$4/year heating energy savings (274 kWh/year * -0.123 * $0.12/kWh).With little space-conditioning impact during the swing seasons and unknown savings for the coldest winter days, it is clear that EIFS retrofit at Site 54 is not a cost-effective energy-efficiency proposition for Florida's climate. Other benefits associated with the measure, such as better interior comfort and a stable interior temperature, however, might justify the EIFS measure, but this is beyond the scope of this evaluation.

The evaluation of the EIFS retrofit is a heavily examined case study. Given the considerable variance in the regressions, variations in occupancy behavior and internal gains, the savings from EIFS in Florida will differ considerably for individual homes and will likely depend on:

- Average interior temperature maintained (the lower the temperature, the greater the savings)
- The pre-existing shading from outdoor features (buildings, setback shading, vegetation) and indoor shading (blinds and drapes and insect screening)
- The magnitude of internal gains (the greater the internal gains, the lower the savings from insulation as internal heat cannot be lost to the outdoors during the evening hours when it is cooler outside than inside)
- Exterior wall color (with white or light wall color, such as in this case study, solar radiation is reflected and the savings are reduced).

To investigate the sensitivity of these influences on the energy saving results, a detailed parametric evaluation was conducted using the BEopt hourly energy simulation running EnergyPlus.

## 6.5 Parametric Evaluation of Factors Affecting Wall Insulation Savings in Florida Homes

The analyzed results of the single wall retrofit experiment in the PDR Phase II retrofit showed mixed results, with 18% space cooling savings and inconclusive heating savings. As described in the narrative, it is likely that the negative heating energy savings come from the fact that internal gains were higher in the pre-retrofit heating period than in the post period. However, the interior temperature was lower post-retrofit. Given the single case study nature of the monitoring effort in Phase II, a simulation evaluation was conducted to see how various factors might be influencing results.

The expectation coming into the evaluation was that savings would likely be fairly low as seen earlier in testing in Cocoa, Florida (Barkaszi and Parker 1995). That study found annual cooling energy savings of 9%–14% with a 73°F set point, but negative savings (-1%) at 79°F for a building with white walls.

The BEopt simulation software running EnergyPlus was used to evaluate the influences. A prototype 1,790 ft$^2$ building, portrayed in Figure 19, was produced with characteristics similar to what would be found in a typical home in the PDR project, but with several specifics similar to those at Site 54, the home that received the EIFS retrofit. This included insulation (R-4 walls, R-19 ceiling, uninsulated slab floor, 8 ACH50), AC systems, and heating. For BEopt rendering for windows, the base case windows were single-glazed with aluminum frames (U-value = 1.16 Btu/hr-ft$^2$-°F, Solar Heat Gain Coefficient [SHGC] = 0.76). A SEER 10/Heating Seasonal Performance Factor (HSPF) 6.8 heat pump was assumed with base thermostat set points of 75°F for cooling and 71°F for heating and R-4 ducts with 15% duct leakage. Site 54 effectively had no neighboring houses as assumed in the baseline analysis.

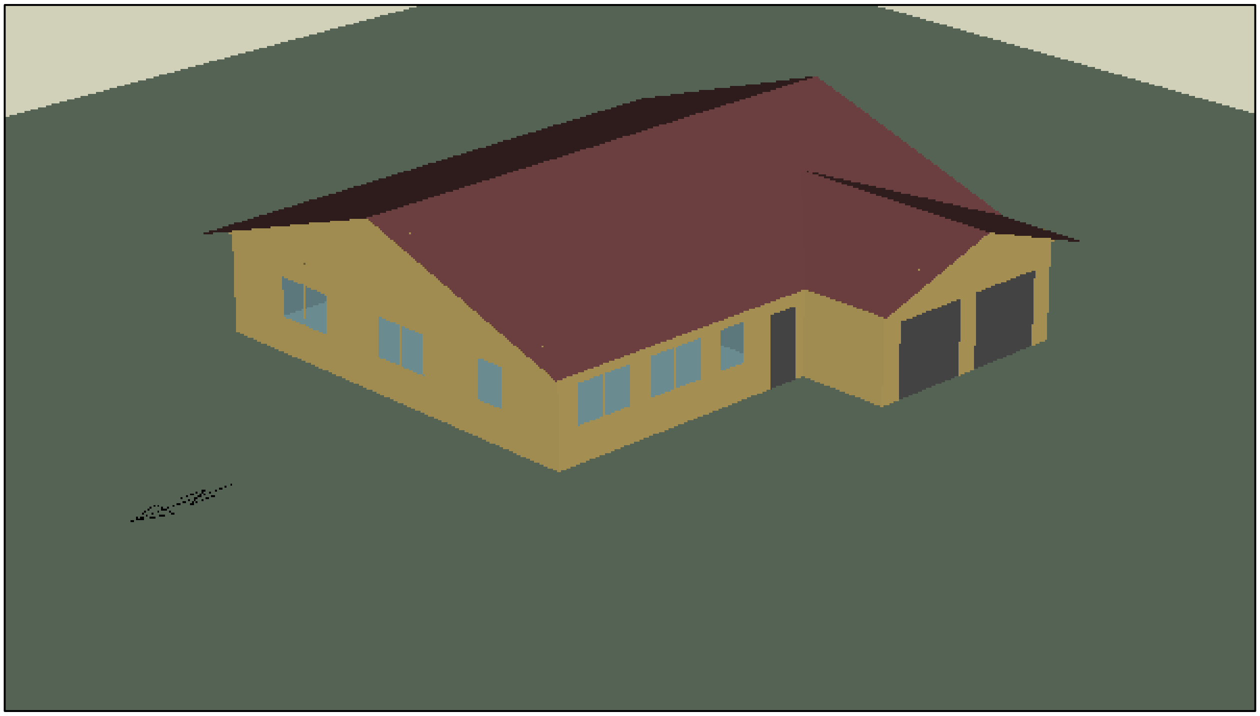

**Figure 19. Prototypical Phased Deep Retrofit residence rendered in BEopt with no adjacent home as at Site 54**

The standard 8-in. hollow-core concrete block wall (medium density concrete aggregate) was used as the base case with a light-colored exterior finish with a solar absorptance of 0.5. The 2-

in. XPS insulation had a measured R-value of 7.7 hr- ft$^2$-°F/Btu and this was simulated along with the other factors expected to influence space cooling savings from walls.

The Site 54 savings evaluation assessed cooling and heating energy. However, the focus here was on the cooling energy savings in particular. High levels of internal and window heat gain lead to overheating in spring and fall season and BEopt has the potential to simulate year-round venting, although in the project natural ventilation was fairly uncommon except during the Florida winter season. This operational capability was then subjected to evaluation.

Other parameters that can be expected to influence wall savings include wall color, interior thermostat temperature, and internal heat gain rate. The higher the temperature set point, the lower the savings from the lower U-factor of walls. Moreover, at some point the lower heat loss from the walls at night will begin to exert a negative influence on savings.

Similarly, with high levels of internal heat gain from greater appliance and interior plug loads, the home's interior temperature will tend to be elevated such that greater heat loss at night from less-insulated walls and single-glazed windows is actually desirable. For Site 54, this study found that assuming 50% greater than normal plug loads (1.5) worked fairly well to match pre-retrofit data.

Figure 20 shows the results for a case similar to Site 54 with 50% greater plug loads and a cooling set point of 75°F. The predicted cooling energy savings from the exterior wall insulation amounts to only 349 kWh/year if the building takes advantage of natural ventilation—a 6% cooling energy savings. The results are shown in Table 15 below in the form of an analysis result table from BEopt.

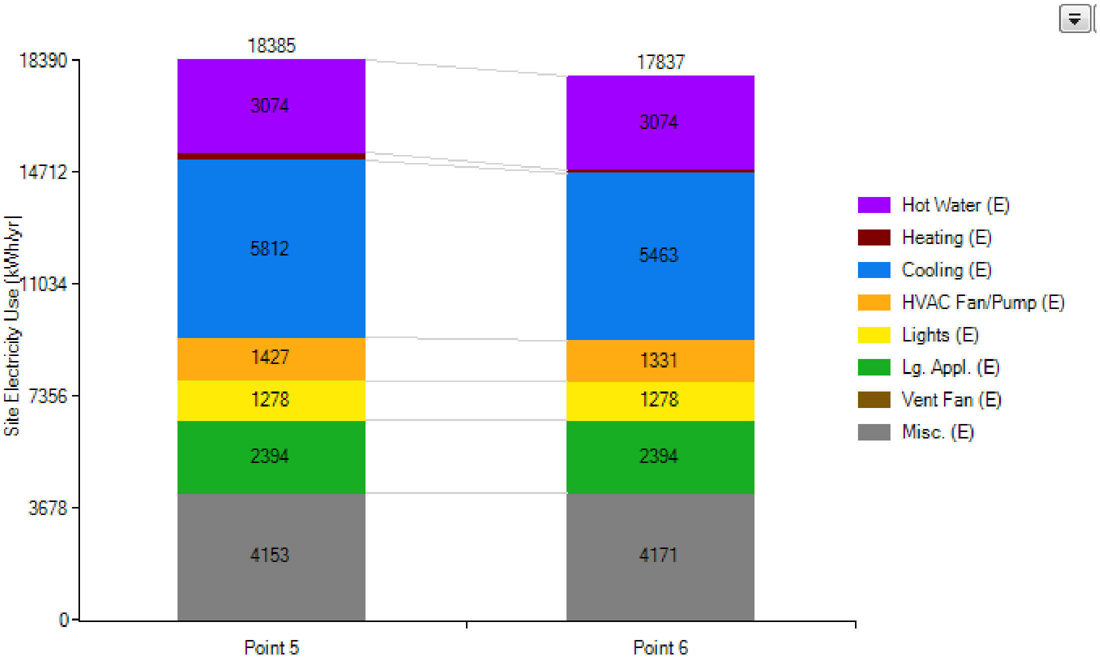

**Figure 20. Estimated savings from standard uninsulated block walls (Point 5) versus addition of R-7.7 expanded polystyrene on exterior; 75°F set point with 1.5x normal plug loads**

### Table 15. Sensitivity of Wall Savings to Parameters

| | No Ventilation | | | | With Year-Round Ventilation | | | |
|---|---|---|---|---|---|---|---|---|
| Set Point Degrees Fahrenheit | Uninsulated 8-in. Block (kWh) | 8-in. Block w/R7.7 XPS (kWh) | Savings (kWh) | Savings % | Single Glazed (kWh) | Double LowE_Solar (kWh) | Savings (kWh) | Savings (kWh) |
| 72° | 7753 | 7271 | 482 | 6.2% | 7770 | 7268 | 502 | 6.5% |
| 73° | 7151 | 6720 | 431 | 6.0% | 7110 | 6659 | 451 | 6.3% |
| 74° | 6537 | 6169 | 370 | 5.7% | 6454 | 6052 | 402 | 6.2% |
| **75°[a]** | **5932** | **5624** | **308** | **5.2%** | **5812** | **5463** | **349** | **6.0%** |
| 76° | 5340 | 5088 | 252 | 4.7% | 5205 | 4906 | 299 | 5.7% |
| 77° | 4766 | 4563 | 203 | 4.3% | 4625 | 4379 | 246 | 5.3% |
| 78° | 4209 | 4053 | 156 | 3.7% | 4077 | 3880 | 197 | 4.8% |
| 79° | 3678 | 3567 | 111 | 3.0% | 3564 | 3414 | 150 | 4.2% |
| 80° | 3174 | 3101 | 73 | 2.3% | 3077 | 2972 | 105 | 3.4% |
| 81° | 2699 | 2664 | 35 | 1.3% | 2623 | 2556 | 67 | 2.6% |
| 82° | 2260 | 2254 | 6 | 0.3% | 2201 | 2169 | 32 | 1.5% |
| Internal Gains | | | | | | | | |
| 0.5 x PL | 5390 | 5029 | 361 | 6.7% | 5290 | 4903 | 387 | 7.3% |
| 1 x PL | 5659 | 5325 | 334 | 5.9% | 5548 | 5182 | 366 | 6.6% |
| **1.5 x PL** | **5932** | **5624** | **308** | **5.2%** | **5812** | **5463** | **349** | **6.0%** |
| 2 x PL | 6208 | 5923 | 285 | 4.6% | 6079 | 5750 | 329 | 5.4% |
| 3 x PL | 6773 | 6523 | 250 | 3.7% | 6621 | 6334 | 287 | 4.3% |
| 4 x PL | 7345 | 7145 | 200 | 2.7% | 7175 | 6926 | 249 | 3.5% |
| External & Internal Shade | | | | | | | | |
| Hvy int shade, w/nhbrs | 5604 | 5322 | 282 | 5.0% | 5522 | 5205 | 317 | 5.7% |
| **Hvy int shade, no nhbrs** | **5932** | **5624** | **308** | **5.2%** | **5812** | **5463** | **349** | **6.0%** |
| Less int shade, w/nhbrs | 6079 | 5835 | 244 | 4.0% | 5988 | 5709 | 279 | 4.7% |
| Less int Shade; no nhors | 6468 | 6202 | 266 | 4.1% | 6331 | 6020 | 311 | 4.9% |
| Wall Color & Solar Reflectance | | | | | | | | |
| Med/Dark Stucco (ABS = 0.75) | 6401 | 5832 | 569 | 8.9% | 6266 | 5665 | 601 | 9.6% |
| **Light Stucco (ABS = 0.5)** | **5932** | **5624** | **308** | **5.2%** | **5812** | **5463** | **349** | **6.0%** |
| White Stucco (ABS = 0.3) | 5557 | 5454 | 103 | 1.9% | 5448 | 5302 | 146 | 2.7% |

[a] Bolded rows represent parameter selected for the general model used in the remaining parameters' sensitivity runs.

Note that the results suggest the following influences to AC savings from wall insulation in a cooling-dominated climate:

- Annual savings from EIFS varies strongly by the interior thermostat setting. For example, a home maintaining 80°F versus 75°F would see 77% less savings. At an 82°F set point (which some project participants did select), with no ventilation used, savings effectively disappear. On the other hand, a home maintaining 72°F inside would see 56% greater savings from the added insulation compared to one maintaining a set point of 75°F.

- Wall color has a large impact on potential EIFS cooling energy savings. White walls have savings one-third those of medium/dark-colored stucco walls.
- Pre-existing shading from adjacent buildings and porches has some impact on wall insulation savings, but these are modest with light-colored walls. The influence is greater with darker walls.
- Greater internal heat gains from appliance and plug loads reduce the savings from better wall insulation, particularly for cooling. For example, a home with low plug loads will see savings nearly double that of a home with very high internal heat gains.
- There was an interaction between window and wall insulation savings. For example, with less interior blind shading of windows, there is greater window heat gain, reducing the advantage of wall insulation.
- Natural ventilation has only modest influences on savings, but using natural ventilation to control overheating was shown to boost savings for wall insulation in all cases.

Although not analyzed, the savings from two-story buildings with EIFSs would almost certainly be greater given the much larger area and the lower likelihood of shading of the second story vertical sections.

While 10%–15% cooling savings are possible with the right combination of factors (darker walls, low internal gains, low existing shading, and low set points), the opposite is true as well. A very high set point with high internal gains with light or white walls mostly shaded by other buildings, vegetation, porches, or blinds would see negligible savings from an EIFS. In particular, light-colored walls with pre-existing shading in existing Florida homes is likely to limit savings in many applications. Indeed, savings would be unlikely in homes that maintain higher interior temperature in summer and already have light-colored walls.

# 7 Evaluation of Advanced Window Retrofits

Under Phase II of the PDR study, window retrofits were conducted in three occupied homes to evaluate the impact of advanced windows on space-conditioning energy consumption. One of these homes received an EIFS installation prior to the window retrofit. In past research, FSEC evaluated the impact of energy-efficient windows on HVAC energy use comparing two identically-constructed central Florida homes, one with clear, single-pane, aluminum framed windows and the other with advanced windows (Anello et al. 2000). Cooling energy consumption during a 17-day, unoccupied summer period indicated 15% savings for the home with energy-efficient windows. Space heating energy savings of 36% were shown in the home with advanced windows during one very cold day (relative to the central Florida climate) after the homes were occupied. Unlike the Anello et al. window study in 2000, however, the current research is conducted on occupied homes. The current research is also unique in that it looks at the effects of multiple thermal improvement measures on one home.

The window retrofit homes are single-story homes with about 1,400 to 2,000 $ft^2$ of living space. General characteristics for these three homes are provided in Table 16. More detailed site descriptions are provided within the evaluation sections for each site.

### Table 16. Windows Retrofit Sites General and Heating, Ventilating, and Air-Conditioning Characteristics

| Site # | 23 | 25 | 54 |
|---|---|---|---|
| **City** | Palm Bay | Melbourne | Palm Bay |
| **Year Built** | 1980 | 2000 | 1999 |
| **Living Area (ft$^2$)** | 1,946 | 1,788 | 1,390 |
| **# of Occupants** | 3 | 2 | 2 |
| **Stories** | 1 | 1 | 1 |
| **Wall Construction** | CMU | CMU | CMU |
| **Ceiling Insulation** | R-19 | R-30 | R-19 |
| **House Airtightness (ACH50)** | 8.4 | 4.6 | 5.3 |
| **Year of HVAC** | 2001/02 | 2010 | 1999 |
| **AC Size (tons)** | 3.5 | 3.5 | 2.5 |
| **AC SEER** | 14 | 15.5 | 10 |
| **Heating** | Resistance | Heat Pump | Heat Pump |
| **Duct Leakage (Qn,out)** | 0.05 | 0.06 | 0.03 |

This evaluation assesses the window retrofits' impact on the home's HVAC energy consumption using measured end-use space-conditioning energy with regression modeling techniques, as described in Section 3, to evaluate impacts from exterior temperature, internal heat gains, and solar insolation on HVAC energy. The regression model used outdoor temperature in place of Delta T unless an interior temperature change between pre- and post-retrofit observation periods was apparently behavioral and not a change in the thermal characteristics of the home.

Pre- and post-retrofit average daily external and interior temperatures, internal gains, and solar insolation are summarized in Table 17. Regressions from the analysis of the advanced window retrofits are provided in Appendix D.

### Table 17. Average Daily Interior Temperatures, Internal Gains, and Solar Insolation Pre- and Post-Retrofit Evaluation Periods

| Site # | Evaluation Season | Pre Outdoor Temp (°F) | Post Outdoor Temp (°F) | Pre Indoor Temp (°F) | Post Indoor Temp (°F) | Pre Internal Heat Gains (kWh/day) | Post Internal Heat Gains (kWh/day) | Pre Solar Insol. (kWh/m$^2$/day) | Post Solar Insol. (kWh/m$^2$/day) |
|---|---|---|---|---|---|---|---|---|---|
| **23** | Cooling | 74.4 | 73.5 | 75.2 | 74.8 | 10.9 | 12.7 | 5.0 | 3.3 |
| **23** | Heating | 58.0 | 58.3 | 73.8 | 73.4 | 10.4 | 12.0 | 4.1 | 4.1 |
| **25** | Cooling | 79.9 | 80.4 | 81.3 | 80.8 | 16.3 | 14.4 | 5.9 | 6.7 |
| **54** | Cooling (Windows) | 76.9 | 77.1 | 76.4 | 76.8 | 10.0 | 9.8 | 5.5 | 6.6 |
| **54** | Cooling (EIFS & Windows) | 78.3 | 79.1 | 77.3 | 76.5 | 14.0 | 10.5 | 6.3 | 6.6 |

To evaluate the impact of a window retrofit on space-conditioning energy use, it is important to note the presence and position of shading, both external and internal. This is because the advanced windows being evaluated have a large influence on solar heat gain transmittance with the potential significantly altered by the conditions before and after the glazing is installed. In addition to exterior shading from trees or adjacent buildings, drawn blinds/drapes and insect screening on the pre-existing windows may significantly reduce the impact of the SHGC on the solar radiation because there is less solar radiation than without such shading. Work at NREL (Farrar-Nagy et al. 2000) has shown that architectural shading and site shading have a major impact on measured building cooling needs. Based on this work and much preceding ASHRAE fenestration research over decades, it appears that conventional blinds and curtains on the interior part of buildings have a major influence on space cooling as well—particularly because many are drawn. Insect screening is also relevant in the assessment of window retrofit energy savings. For single- or double-hung windows with insect screening on the lower part, solar transmission is reduced. A study (Kotey et al. 2009) found that insect screening decreases solar transmission by 40% for the window section covered. As such, detailed accounts of the interior and exterior shading characteristics are provided in the evaluation section of each window retrofit.

Space cooling energy savings is projected using an assumed average cooling season outdoor temperature of 80°F and space heating with an average outdoor temperature of 50°F. It is noteworthy that the post-retrofit daily average interior temperatures (Table 17) were observed to typically be cooler. As described in the EIFS section, changes in interior temperature may be the result of changed thermal characteristics of the home, a rising nighttime float temperature for example, influencing occupants to set thermosets lower. To help determine if a change in indoor temperature is a byproduct of the window retrofit, the daily temperature profiles for the pre-and post-retrofit periods were evaluated. If a behavioral change between evaluation periods is evident, the savings predictions consider Delta T rather than outdoor temperature alone. The evaluation of each of these retrofits is described below in a case study fashion.

## 7.1 Window Retrofit Site 23

### *7.1.1 Site 23 Characteristics*

Site 23 is two-person-occupied, single-story home with 1,946 ft$^2$ of living space located in Palm Bay, Florida. This 1980 home has CMU walls on a concrete slab foundation and an asphalt shingle roof. The attic floor is insulated with blown fiberglass with an approximate R-value of 19. The pre-retrofit airtightness test reveals moderate whole house air leakage for the building's age (ACH50 = 8.4). The home has 10 windows and two sliding glass doors. The original windows and glass doors are single-pane clear glass with metal frames. The building's front façade faces north and the back porch roof shades most of the south-facing glazing. Adjacent buildings partially shade the few east- and west-facing windows. In numerous visits to this home, all bedroom and north-facing blinds were typically closed. Only the blinds to the windows shaded by the back porch were typically open. An account of glazing area and shading by façade is provided in Table 18.

**Table 18. Site 23 as Found Glazing and Shading Characteristics**

| Site # | Existing Type | | Single, Clear w/Metal Frame | |
|---|---|---|---|---|
| | Total Window Area (ft$^2$) | | 197 | |
| | Window to Floor Area (%) | | 10% | |
| **Glazing by Face** | **East** | **South** | **West** | **North** |
| **Net Window Area (ft$^2$)** | 18 | 104 | 41 | 34 |
| **Interior Drapes or Blinds** | White Blinds | White Blinds | White Blinds | White Blinds |
| **Exterior Screening** | 50% | 35% w/50% screen<br>65% w/100% screen | 52% w/50% screen<br>48% w/100% screen | 50% |
| **Overhang Avg./Width (ft)** | 1.5 | 10.0 | 70 | 20 |
| **Exterior Shading** | Moderate | Moderate | Moderate | None |
| **Shading Type** | Adj. Bldg. | Trees,<br>65% Porch | Adj. Bldg., Trees,<br>48% Porch | |
| **Distance to Adj. Bldg. (ft)** | 20 | None | 20 | None |

The existing space-conditioning system is a 2002 14 SEER air conditioner with electric resistance heating. A single, centrally-located return feeds into the garage-located air handler. Supply air is distributed through R-4.4 insulated flex ducts with moderate duct leakage (Qn,out = 0.05) running through the vented attic.

All exterior glass and frames were replaced October 29–30, 2014. The replacement double-glazed solar control windows have SHGCs ranging from 0.20–0.24 and U-factors from 0.28–0.30 Btu/ft$^2$-°F. Figure 21 shows Site 23 before and after the window retrofit. The timing of this retrofit enabled both space heating and space cooling evaluations. The evaluation period for Site 23 is November 2013–June 2015.

**Figure 21. Site 23 window retrofit, pre-retrofit with existing single-pane, metal-framed windows (left), post-retrofit with double-pane, vinyl-frame windows (right)**

### 7.1.2 Site 23 Window Retrofit Space Cooling Energy Evaluation

From examination of the end-use metered data, the occupants of Site 23 use space cooling when the daily average exterior temperature rises above 69°F. The initial investigation into space cooling energy savings showed the internal temperate averaged about 2°F cooler post-retrofit (75°F) than it did during the pre-retrofit cooling period (77°F). HVAC energy use increased coincidently with this internal temperature change. The homeowner confirmed a temporary occupancy increase for the first six months of 2015 and reported that the new occupant preferred a lower thermostat set point than is typically maintained in the home. In an attempt to isolate the occupancy change from the impact of the window retrofit, a shorter, milder period prior to the occupancy change was analyzed. This spans October 2014 to early December 2014, including only observations when the daily average ambient temperature exceeded 69°F, and excludes the warmest pre-retrofit days so to compare periods of alike average daily ambient temperatures (pre: October 4, 2014–October 28, 2014; post: October 31, 2014–December 6, 2014).

The scatterplot in Figure 22 of this limited period with consistent occupancy demonstrates the cooling energy use trend to outdoor temperature for the pre- and post-retrofit periods. The pre-retrofit observations and trend line are in orange, the post-retrofit are in blue, and both show a high degree of scatter.

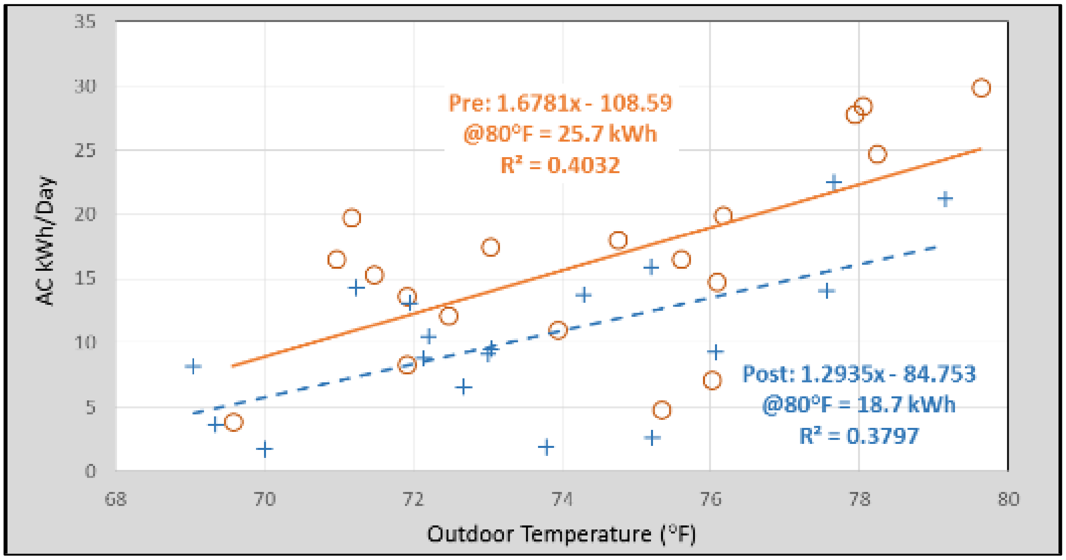

**Figure 22. Site 23 pre- and post-window retrofit daily average space cooling consumption versus outdoor temperature**

Avoiding the occupancy change and large coincident behavior change provides us evaluation periods with few observations (19 pre, 18 post) and at a time of year with less extreme high temperatures and limited space cooling. These factors had negative impacts on the model strength ($R^2$ = 0.40 and 0.38), and thus the strength of the savings projections.

The daily average interior temperatures were fairly consistent over the evaluation period (75.2°F pre-retrofit, 74.8°F post-retrofit). In Figure 23 shows the daily interior (solid line labeled “Tint”) and ambient (dashed line labeled “Tamb”) temperature profiles for the pre-retrofit (red) and post-retrofit (green) periods. The plot reveals a more evenly-maintained interior temperature post-retrofit. The difference between pre- and post-retrofit interior temperatures does not appear to be a change in thermostat preferences (as evidenced by the similar nighttime profiles), but rather a difference in the building’s thermal qualities. Thus, Delta T was not a parameter used in this evaluation.

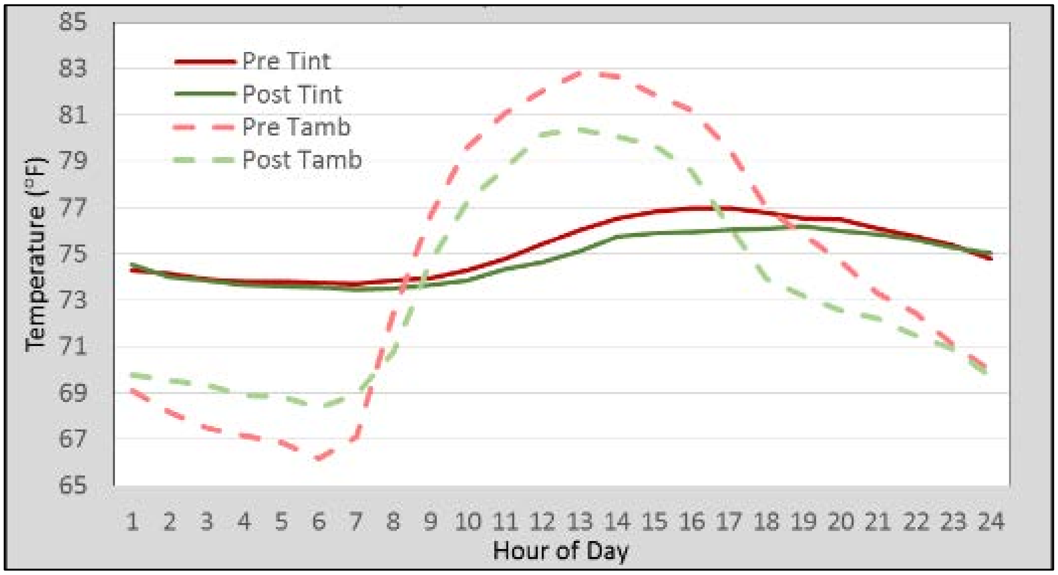

**Figure 23. Site 23 daily indoor and outdoor temperature profiles, pre- and post-window retrofit for cooling season observations**

The energy use prediction models also considered solar insolation and internal heat gains, but neither parameter was significant in either period and was not used.

The post-retrofit daily cooling energy for this internally and externally well-shaded home, with a set point of approximately 75°F, is reduced from 25.7 to 18.7 kWh at an average outdoor temperature of 80°F, a savings of 6.9 kWh/day or 27.0%. This projection is weak, however, given the poor R-squared values and few observations at the average summertime temperature used for the savings prediction. Thus, the standard error on the regression is quite large and while the savings appear real, the result has a considerable uncertainty in the exact magnitude. This home has recently had a return to pre-retrofit occupancy and a re-evaluation of the cooling energy savings will be a subject of the final PDR Phase II report.

### *7.1.3 Site 23 Window Retrofit Space Heating Energy Evaluation*

Plotting HVAC energy use against exterior temperature indicated that the Site 23 occupants begin space heating when the daily average exterior temperature drops below 65°F. The demand for space heating is limited in this hot-humid climate, although heating energy consumption is high at this home with electric resistance heating. Pre-retrofit observations were drawn from November 2013 through March 2014 and post-retrofit from November 2014 through March 2015 and when the average ambient temperature was below 65°F and the daily compressor power was less than 2.5 kWh.

Figure 24 displays the pre- and post-retrofit daily average space heating versus outdoor temperature. Note that on the coolest days, space heating energy consumption exceeds 90 kWh/day. Again, there is large scatter in the limited heating energy data set. The trendlines convergence at 59°F demonstrates slightly greater post-retrofit heating energy savings as the outdoor temperature becomes lower. This is expected because the advanced windows save more when the temperature is lower. The solar control glazing, however, transfers less of the sun's heat, potentially limiting heating savings, particularly at higher temperatures at which the window thermal conductance becomes less important.

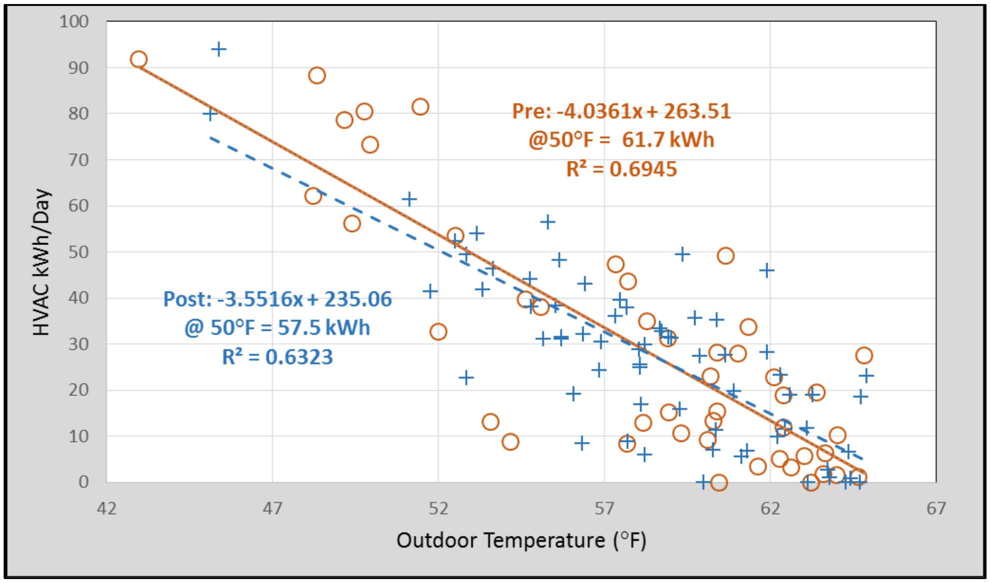

**Figure 24. Site 23 pre- and post-window retrofit daily average space heating consumption versus outdoor temperature**

Daily average interior temperature was slightly cooler post-retrofit (73.8°F pre, 73.4°F post). In the daily temperature profile in Figure 25 shows that, for both periods, the building maintains the same temperature during the morning hours. However, post-window retrofit the home maintains a lower temperature after the warmest hours, despite having higher internal gains (12.7 kWh/day post versus 10.9 kWh/day pre) and slightly warmer daytime ambient temperatures. This afternoon difference likely comes from the lower solar heat gain transmission characteristics of the windows.

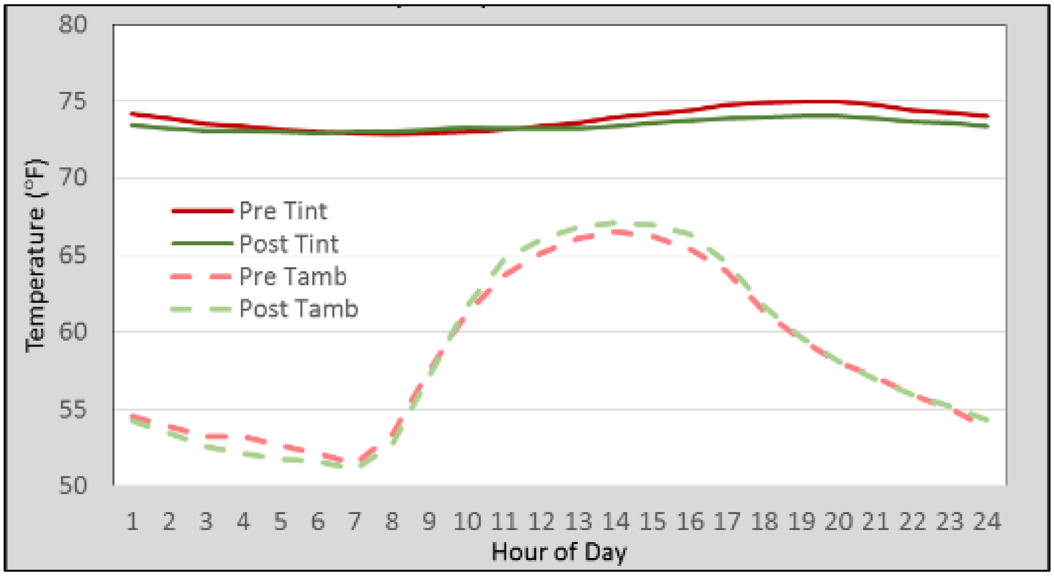

**Figure 25. Site 23 Daily indoor and outdoor temperature profiles, pre- and post-window retrofit for heating season observations**

Because the difference between pre- and post-retrofit interior temperature appears to be a change in the building's thermal properties, the Delta T was not a parameter used for the savings projection. Internal gains and solar insolation parameters were also considered for modeling, but were not significant. However, internal gains were slightly higher post-retrofit (pre 10.4 kWh/day, post 12.0 kWh/day). Using the simple regression based on ambient temperature, this home with an interior set point of 73°–74°F shows savings of 4.2 kWh/day or 6.8% at an average outdoor temperature of 50°F. Note that during periods with milder temperatures, the high-efficiency windows show slightly negative heating energy savings. Given higher internal gains during the post-retrofit period, this savings projection may be overstated.

## 7.2 Window Retrofit Site 25

### *7.2.1 Site 25 Characteristics*

Site 25, pictured in Figure 26, is a two-person occupied, single-story home with 1,788 ft$^2$ of living space located in Melbourne, Florida. The home, built in 2000, has CMU walls on a concrete slab foundation and an asphalt shingle roof. R-30 fiberglass insulation covers the attic knee walls and most of the attic floor, but is missing from some of the attic perimeter, a common windstorm result found in some Florida homes. Pre-retrofit whole-house airtightness testing shows moderately tight construction (ACH50 = 4.6).

Figure 26. Site 25 in Melbourne, Florida

Site 25 has 10 windows and one sliding glass door. Prior to the window retrofit, all of the glazing units were single-pane clear glass with metal frames. The home faces southwest with a front porch roof shading one large window. A deep back porch shades the northwest-facing sliding glass door and the two southeast-facing windows are partially shaded by vegetation. The remaining southwest- and northwest-facing glazing receives little shading. Bedroom blinds were observed to be drawn, with living room and kitchen blinds open. An account of glazing area and shading by façade is summarized in Table 19.

Table 19. Site 25 Glazing and Shading Characteristics

| Site # 25 | Existing Type | | Single, Clear w/Metal Frame | |
|---|---|---|---|---|
| | Total Window Area (ft$^2$) | | 243 | |
| | Window to Floor Area (%) | | 14% | |
| **Glazing by Face** | **SE** | **SW** | **NW** | **NE** |
| **Net Window Area (ft$^2$)** | 61 | 67 | 20 | 95 |
| **Interior Drapes or Blinds** | White Blinds | White Blinds | White Blinds | White Blinds |
| **Exterior Screening** | 50% | 50% | 36% w/50% screen<br>64% w/100% screen | 69% w/50% screen<br>31% w/100% screen |
| **Exterior Shading** | Moderate | Moderate | Moderate | Moderate |
| **Shading Type** | Adj. Bldg., Trees | Trees, 52% Porch | Adj. Bldg., 64% Porch | Trees, 31% Porch |
| **Overhang Avg./Width (ft)** | 1.3 | 4.5 | 9 | 3.7 |
| **Distance to Adj. Bldg. (ft)** | 20 | None | 20 | None |

The AC system is a 2010 vintage, 15.5 SEER heat pump. A single, centrally-located return feeds into the interior-located air handler. Supply air is distributed through R-6 insulated flex ducts with moderate duct leakage ($Qn_{,out} = 0.06$) running through the vented attic.

The window retrofit was conducted between April 22 and May 28, 2015 and included the replacement of all exterior glass and frames (with the exception of one small, well-shaded, decorative, southwest-facing window). The replacement glazing units are insulated double-pane windows with vinyl frames. The SHGC ranges from 0.19–0.21 and all the windows have a U-factor of 0.29 Btu/ft$^2$-°F.

### *7.2.2 Site 25 Window Retrofit Space Cooling Energy Evaluation*

The timing of the Site 25 window retrofit allows for an evaluation of its space cooling only for this report. Because there was little space cooling called for prior to April 22, 2015, when the window installation began, the pre-retrofit period consists of observations in 2014. For each year (2014 for pre-retrofit and 2015 for post-retrofit), observations were pulled from the end of May into July (pre: May 23, 2014–July 31, 2014; post: May 29, 2015–July 13, 2015).

Based on examination of the data, Site 25 occupants use space cooling when the daily average exterior temperature rises above 73°F. The scatter plot in Figure 27 displays daily average space cooling consumption versus outdoor temperature along with a fitted regression model on the data for the pre- and post-retrofit periods.

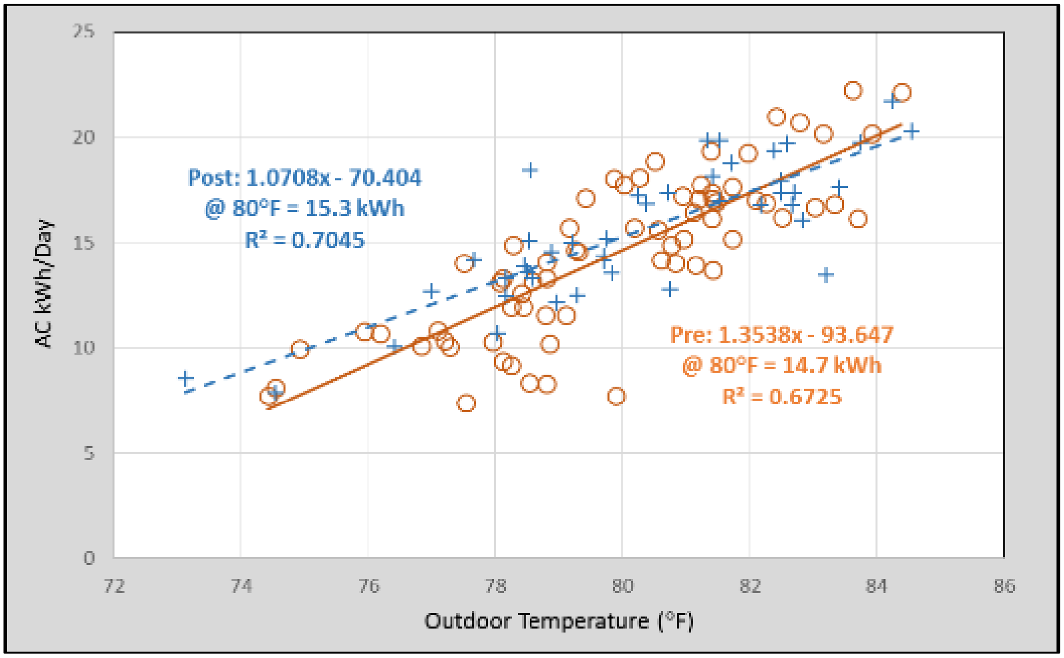

**Figure 27. Site 25 pre- and post-window retrofit daily average space cooling consumption versus outdoor temperature**

The occupants of Site 25 prefer a warm home. On average, the interior temperature was maintained 0.4°F cooler post-retrofit (81.3°F pre versus 80.8°F post). The daily indoor and outdoor temperature profiles for the pre- and post-retrofit periods are plotted in Figure 28. The daily average Delta T is negative for both periods; that is, over the course and for most of the hours of the day, it is cooler outside than inside. Note the post-retrofit indoor temperature maintains a level temperature throughout the day, despite the higher outdoor temperatures. Post-retrofit, the home appears to be better at maintaining comfort, helping explain the lower average indoor temperature which appears to be the result of a change in the building's thermal properties rather than a behavioral change. Thus, the saving projection ignores the difference in indoor temperature.

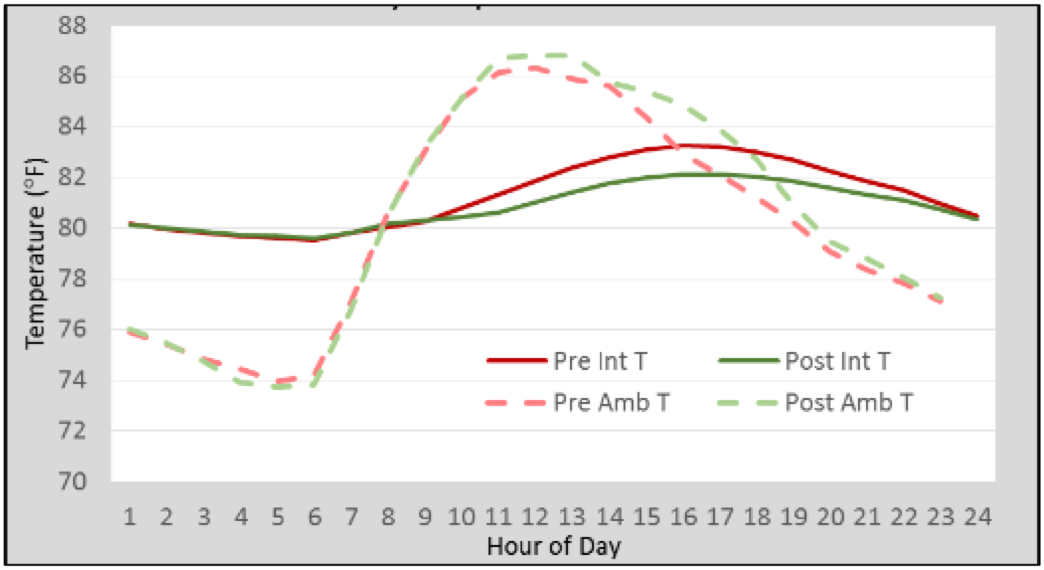

**Figure 28. Site 25 Daily indoor and outdoor temperature profiles, pre- and post-window retrofit for cooling season observations**

Next, the analysis considered the internal heat gains and solar insolation parameters. The internal gains calculation changed between pre- and post-retrofit as the timing of the window retrofit coincided with the installation of an unvented HPCD. As presented in section 8.1, the utility room is much warmer during operation of the new unvented appliance. To account for this lack of hot air venting, the post-retrofit internal heat gains calculation assumes 90% of the dryer energy. Still, the internal gains parameter is lower post-retrofit (16.3 kWh/day pre versus 14.4 kWh/day post). Solar insolation also varied between periods, but moved in the reverse direction, from 5.9 kWh/m$^2$/day pre to 6.7 kWh/m$^2$/day post.

Solar insolation and internal gains were each significant in the pre-retrofit model ($p < 0.01$), but less so in the post-retrofit model (solar insolation $p < 0.05$; internal gains $p < 0.10$). The resulting model fits improved ($R^2$ improved from 0.70 to 0.77 pre and from 0.67 to 0.75 post). Using an average cooling season ambient temperature of 80°F and assuming an average of the daily internal gains and solar insolation of both periods, the savings prediction is slightly negative in this well-shaded home with a high thermostat set point of about 81°F. Post-retrofit, the daily cooling energy consumption increased from 14.6 kWh to 15.3 kWh, for negative savings of 0.7 kWh/day (-4.8%) assuming an average outdoor temperature of 80°F. In any case, as seen above in Figure 28, the home has improved comfort in the cooling season with smaller differences in the amplitude of the interior temperature.

## 7.3 Window Retrofit Site 54

### *7.3.1 Site 54 Characteristics*

Site 54 is a two-person occupied single-story home with 1,390 ft$^2$ of living space located in Palm Bay, Florida. This home, built in 1999, has CMU walls with a stucco finish, a concrete slab foundation, an asphalt shingle roof, and R-19 fiberglass insulation at the attic floor and attic knee walls. The garage wall adjacent to living space consists of framed 2x4 construction with a drywall finish, and, after the EIFS retrofit, all walls had exterior insulation of R-value of 7.7 hr-ft$^2$-°F/Btu added. The home has 10 windows and one sliding glass door. With a pre-retrofit

ACH50 = 5.38, this home has good airtightness for its vintage. The existing AC system is the original, 10 SEER rated heat pump. A single, centrally-located return feeds into the interior-located air handler. Supply air is distributed through R-6 insulated flex ducts with limited duct leakage ($Qn_{,out}$ = 0.03) running through the vented attic.

The existing windows and glass doors at the home were single-pane clear glass with metal frames. The home faces west, with most of the wall area and all of the glazing (except one small window on the north side) on the building's east and west sides. The home's fenestration has little shading apart from the east-facing sliding glass door, which is shaded by a porch. Researchers observed bedroom blinds drawn and main living area blinds partially drawn. An account of glazing area and shading by façade is provided in Table 20.

**Table 20. Site 54 as Found Glazing and Shading Characteristics**

| Site # 54 | Existing Type | | | Single, Clear w/Metal Frame | | |
|---|---|---|---|---|---|---|
| | Total Window Area (ft$^2$)<br>Window to Floor Area (%) | | | 167<br>12% | | |
| **Glazing by Face** | **East** | **South** | **West** | **North** | **NE** | **SE** |
| **Net Window Area (ft$^2$)** | 91 | 0 | 56 | 3 | 9 | 9 |
| **Interior Drapes or Blinds** | White Blinds | | White Blinds | | White Blinds | White Blinds |
| **Exterior Screening** | 56% w/50% screening<br>44% w/100% screening | | 50% | 50% | 50% | 50% |
| **Exterior Shading** | Moderate | | None | 100% | None | Light |
| **Shading Type** | Trees,<br>44% Porch | | | Hurricane Shutter | | Partially shaded by adjacent porch |
| **Overhang Avg./Width (ft)** | 8.2 | | 1 | 1.2 | 1 | 1 |
| **Distance to Adj. Bldg. (ft)** | None | 25 | None | None | None | None |

All windows and the sliding glass door were replaced on April 29–30, 2015 with insulated double-pane glazing units with vinyl frames. The new components have an SHGC ranging from 0.21–0.24 and a U-factor ranging from 0.27–0.29 Btu/ft$^2$-°F. A picture of the home after the completion of the EIFS and window retrofits is shown in Figure 30.

**Figure 30. Site 54 after the exterior insulation finish system and window retrofit**

The following section includes analysis for the window retrofit and the window and EIFS retrofit measures combined. The timing of the windows measure allows us to examine only the cooling season at this time.

### *7.3.2 Site 54 Window Retrofit Space Cooling Energy Evaluation*

As the second of the two building envelope retrofit measures, the window retrofit cannot be measured in isolation from the EIFS application. That is, the pre-window retrofit period came after the EIFS installation. The pre-retrofit observations are drawn from April 2015 and the post-retrofit observations are from May 2015, and for each period in which the average daily ambient temperature exceeds 63°F. The scatterplot in Figure 31 displays energy savings as the outdoor temperature increases. At milder temperatures, the window retrofit shows no impact on cooling energy consumption. However, negative cooling energy savings seem apparent with warmer ambient conditions. Unfortunately, there are limited data available for evaluation of the energy savings until further data is collected.

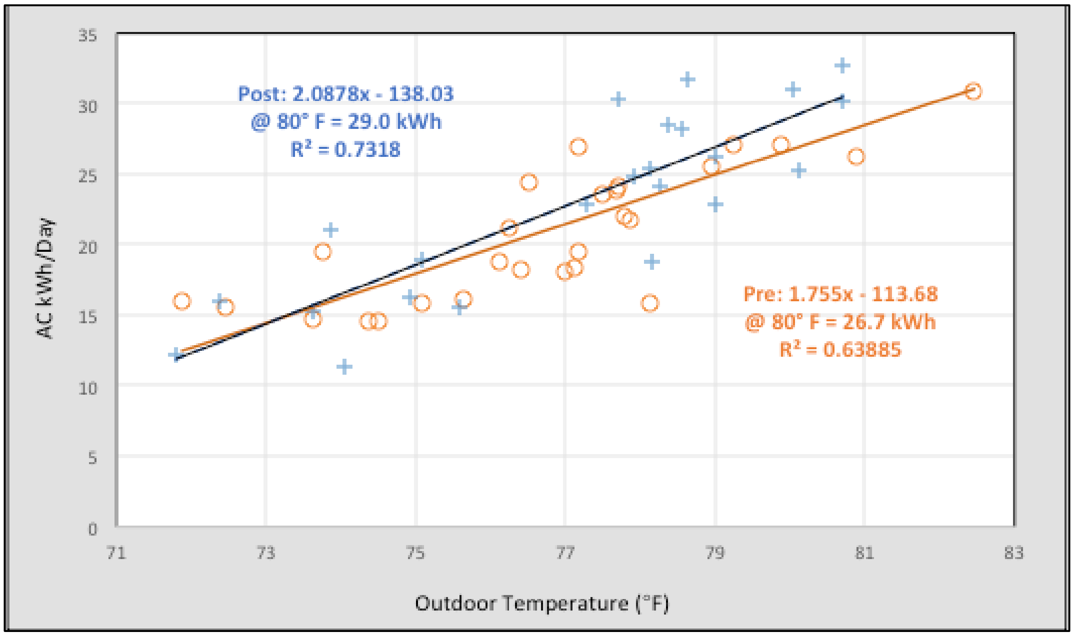

**Figure 31. Site 54 pre- and post-window retrofit daily average space heating consumption versus outdoor temperature**

The daily average interior temperature was similar between evaluation periods, 76.4°F pre-retrofit versus 76.8°F post-retrofit, yet there is a difference in the interior temperature profiles. Figure 32 shows that both periods have consistent ambient temperature profiles and attain a similar interior temperature during the afternoon. However, during the evening and into mid-morning, the post-retrofit building maintains a higher temperature. This warmer temperature indicates a change in the building’s thermal qualities, a byproduct of the retrofit rather than a behavioral change. Thus interior temperature is excluded from the modeling projection. The warmer nighttime temperature conditions likely come from the lower thermal conductance of the building after the retrofit.

This takes place because higher interior temperatures result from internal heat gains when the temperature outdoors is lower than the indoor temperature. Put another way, the post-retrofit building loses heat to the outdoors at a lower rate.

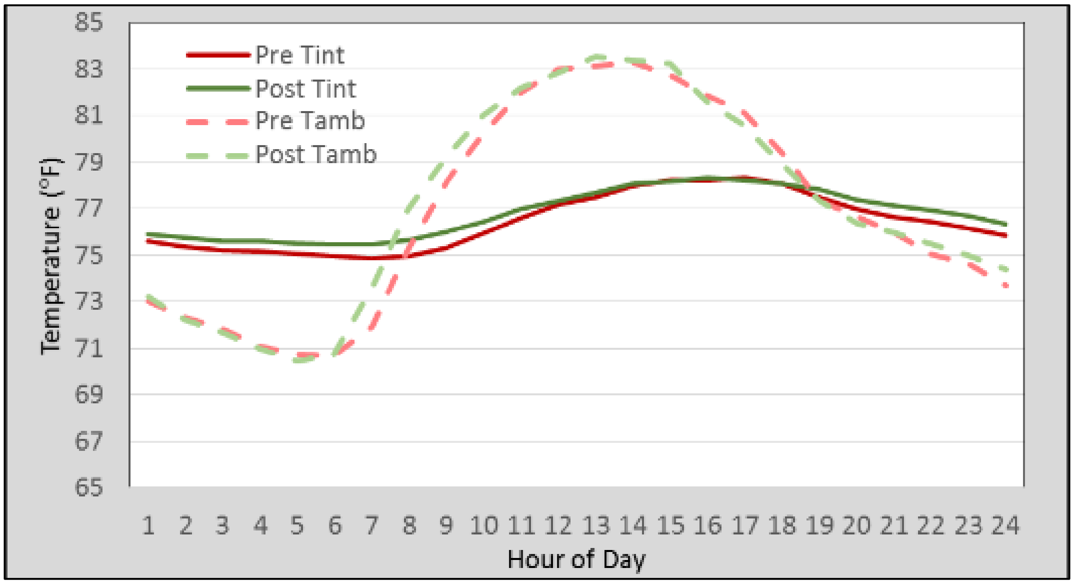

**Figure 32. Site 54 Daily indoor and outdoor temperature profiles, pre- and post-window retrofit for cooling season observations.**

While internal heat gains varied little between the pre- and post-window retrofit periods, daily average solar insolation was greater during the post-retrofit period (5.5 kWh/m$^2$ pre, 6.6 kWh/m$^2$ post). The solar insolation and internal gains parameters varied in their significance in each model. The internal heat gains variable is significant in the pre-retrofit model ($p<0.05$), but has a low level of significance in the post-retrofit model ($p<0.15$). Solar insolation has a low level of significance in the pre-retrofit model ($p<0.15$), but is highly significant in the post-retrofit model ($p<0.01$). These added parameters improve the model strength (pre $R^2 = 0.72$, post $R^2 = 0.87$).

Projected daily space cooling energy for this moderately-shaded home with a thermostat set point of 76°–77°F is 26.8 kWh pre-retrofit and 27.4 kWh post-retrofit, for negative savings of 0.5 kWh/day (-2.0%), assuming an average outdoor temperature of 80°F. Thus, some of the 5.0 kWh/day space cooling savings from the EIFS installation appears lost after the advanced window retrofit. However, while the windows cooling energy savings model appears statistically strong, there are few observations with an average daily summer temperature near the 80°F used for the savings prediction. Thus, while this evaluation seems to indicate no savings from the combination of measures, the data set used to create the models is quite limited and the conclusions must remain suspect until further data is accumulated to allow a more conclusive evaluation.

### *7.3.3 Preliminary Exterior Insulation Finish System and Window Retrofit Space Cooling Energy Evaluation*

For the EIFS and window retrofit evaluation, pre- and post-retrofit analysis periods are necessarily discontinuous. To capture a similar part of the cooling season before and after both the measures, observations were drawn from May through mid-July 2014 for pre-retrofit and May through mid-July 2015 for post-retrofit. At first glance, the combined measures appear to improve space cooling energy consumption. The scatterplot in Figure 33 displays slight space cooling energy savings, with shrinking savings as the outdoor temperature rises.

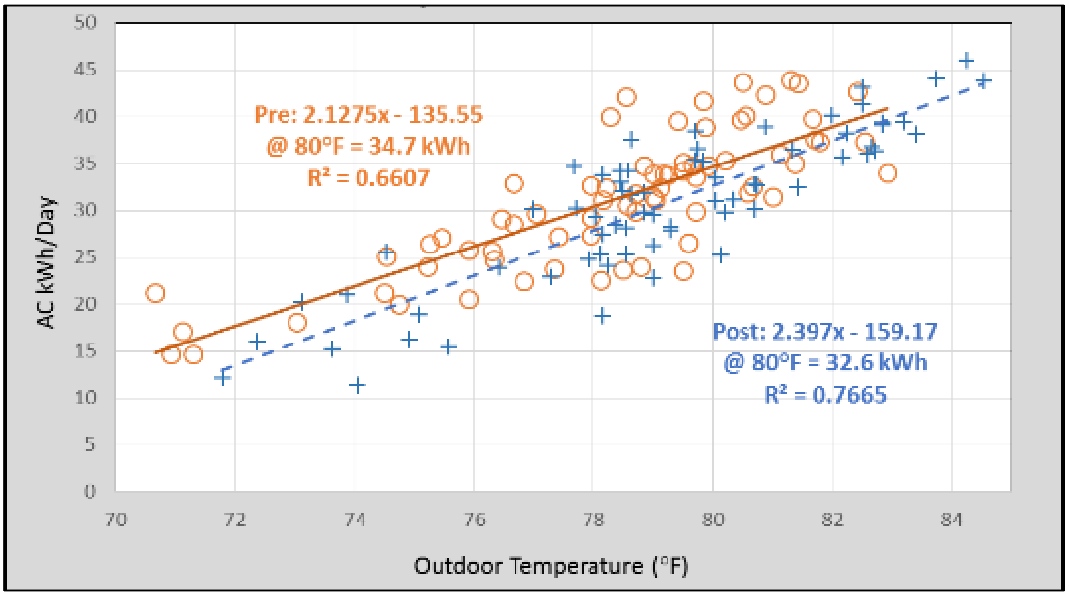

**Figure 33. Site 54 pre- and post-exterior insulation finish system and window retrofit daily average space cooling consumption versus outdoor temperature**

The daily average interior temperatures were again cooler post-retrofit—77.3°F pre-retrofit versus 76.5°F post-retrofit. The plot in Figure 34 displays ambient and indoor temperatures for both evaluation periods. Evening indoor temperatures are similar between periods, though post-retrofit has warmer afternoons. Meanwhile, the building maintains a lower temperature from the early hours through mid-day. The period of time during which the post-retrofit building remains cooler than the pre-retrofit building is indicative of behavioral change with a different thermostat setting. Thus, Delta T was included in the savings evaluation.

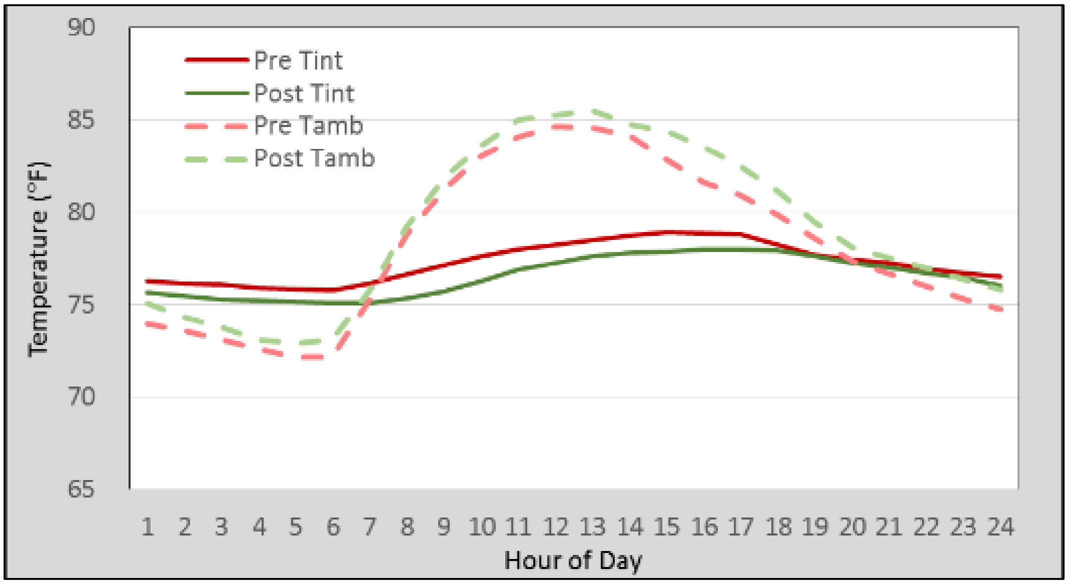

**Figure 34. Site 54 daily indoor and outdoor temperature profiles, pre- and post-exterior insulation finish system and window retrofit for cooling season observations**

There were large differences in average daily internal heat gains among analysis periods (pre: 14.0 kWh; post: 10.5 kWh). The internal gains parameter was significant in both models (*p* <0.01) and solar insolation moderately so (pre: *p* <0.10; post: *p* <0.01). The three-term regression models have relatively strong fits (pre: $R^2$ = 0.70; post: $R^2$ = 0.87).

The resulting cooling energy savings projection for the combined EIFS and window retrofit measures is 1.9 kWh/day (pre: 34.9 kWh/day; post: 33.0 kWh/day) or 5.4%, at an average summer temperature of 80°F. The savings are lower than expected, given the 5.0-kWh/day (18.2%) cooling energy use savings experienced after the EIFS measure, and -1.0-kWh/day (-2.0%) savings post-window retrofit. Also, it is noteworthy that the daily space cooling energy consumption prediction is much higher (pre: ~33 kWh; post: ~35 kWh) than that for the EIFS only (pre: ~22 kWh; post: ~27 kWh) and windows only (~27 kWh pre and post) evaluations. However, there is reason to believe that some models are potentially biased and of limited value for the assessment. These differences may be attributed to modeling with observations among the three different evaluations unavoidably taken from different times of the calendar year, and sometimes lacking observations representing typical summer days. This creates considerable bias in the data and the models that result from using them. Another complication is that internal gains and solar insolation parameters were not always significant, and could not be used consistently for modeling. A re-evaluation of the combined EIFS and window retrofit measures using a longer time series will be examined for the final PDR report.

## 7.4 Window Retrofit and Site 54 Savings Summary

As summarized in Table 21 for the three window retrofits and Table 22 for Site 54 wall and window measures, the impact of these measures on space-conditioning energy are mixed. Seasonal space cooling energy savings for the window retrofit ranged from -0.7 kWh/day (-4.8%) to 6.9 kWh/day (27.0%), and the single projection for space heating savings is 4.2 kWh/day (6.8%) on a cold central Florida day averaging 50°F. Given the timing of this report, this study cannot evaluate the impacts on space heating at two sites. The space heating impacts reported here can be bolstered once data from the post-retrofit heating season has been collected in late 2015 and early 2016.

**Table 21. Windows Space-Conditioning Energy Savings Summary**

| Site # | Evaluation Season | Pre (kWh/day) | Post (kWh/day) | Daily kWh Savings | % Savings Cooling @ 80°F Heating @ 50°F |
|---|---|---|---|---|---|
| **23** | Cooling | 25.7 | 18.7 | 6.9 | 27.0% [a] |
| **23** | Heating | 61.7 | 57.5 | 4.2 | 6.8% |
| **25** | Cooling | 14.6 | 15.3 | -0.7 | -4.8% |
| **54** | Cooling (Windows Only) | 26.8 | 27.4 | -0.5 | -2.0% [a] |

[a] Limited observations and period bias in the pre- and post-retrofit periods makes these estimates suspect.

**Table 22. Site 54 Space Cooling Energy Savings Summary**

| Evaluation Measure | Pre (kWh/day) | Post (kWh/day) | Daily kWh Savings | % Savings Cooling @ 80°F |
|---|---|---|---|---|
| **EIFS** | 27.2 | 22.2 | 5.0 | 18.2% |
| **EIFS & Windows** | 34.9 | 33.0 | 1.9 | 5.4% |

The cost of the window retrofits at Sites 23 and 54 were $9,943 and $8,383, respectively.[5] If the HVAC energy savings results at Site 23 are applied to the average annual HVAC energy use of the untreated PDR sample reported in Phase I, the annual savings are $193, with $191/year cooling energy savings (5,880 kWh/year * 0.27 * $0.12/kWh) and $2/year heating energy savings (274 kWh/year * 0.68 * $0.12/kWh). Extrapolating using the site that revealed the greatest savings, the window retrofit is not a cost-effective energy retrofit proposition. This evaluation, however, demonstrates the potential for a window retrofit to improve comfort in each case with more stable indoor temperatures. Comfort, acoustic, and aesthetic improvements could also be part of the justification for an advanced window retrofit.

The space cooling energy savings for the EIFS measure at Site 54 was 5.0 kWh/day (18.2%) as presented in Section 5.3. The windows-only savings could not be conclusively established because of the limitation in the available monitoring periods with consistent conditions. As this

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[5] The actual costs for the window retrofits included impact resistant windows that were necessary project expenses resulting from government code changes. The premium for non-energy window performance has been removed from these costs. The retrofit at Site 25 was conducted by the homeowner with no installation cost.

evaluation period lacks the warmest summer weather, the collective impact of these measures (windows and EIFS) will be re-evaluated in a subsequent report when more data are available. However, given the total cost of $27,821, the Site 54 EIFS and window retrofit measures cannot be justified solely on energy-related cost-effectiveness.

The three window retrofits amount to a series of heavily examined case studies. Given the variation seen in the results, savings from advanced windows in Florida will differ considerably for individual homes and will likely depend on:

- Average interior temperature maintained (the lower the temperature, the greater the savings)
- The pre-existing shading from outdoor features (buildings, setback shading, vegetation) and indoor shading (blinds and drapes and insect screening)
- The magnitude of internal gains. The greater the internal gains, the lower the savings from either advanced windows or insulation because internal heat cannot be lost to the outdoors during the evening hours when it is cooler outside than inside.

## 7.5 Parametric Evaluation of Factors Affecting Window Savings in Florida Homes

The measured and analyzed results of the three window retrofit experiments in the PDR Phase II project were decidedly mixed, with savings estimates ranging from negative savings to positive savings of 27%. Given the case study nature of the monitoring effort, a simulation evaluation was conducted to see how various factors might be influencing results in a more controlled fashion.

The expectation coming into the evaluation was that savings would likely be around 15% as seen earlier in testing in Melbourne, Florida (Anello et al. 2000). However, these results were obtained with unoccupied buildings with lower internal gain levels than would be seen in real occupied homes. As the Melbourne homes in Anello's study were new construction, there was little in the way of vegetative shading, which is very common in established Florida homes.

The BEopt simulation software running EnergyPlus was used to evaluate the influences. A prototype 1,790 ft$^2$ building, shown in Figure 35, was modeled with characteristics similar to what would be found in a typical home in the PDR project relative to insulation (R-4 walls, R-19 ceiling, uninsulated slab floor, 8 ACH50), AC systems, and heating. A SEER 13/HSPF 7.7 heat pump was assumed, with base thermostat set points of 77°F for cooling and 72°F for heating and R4 ducts with 15% duct leakage.

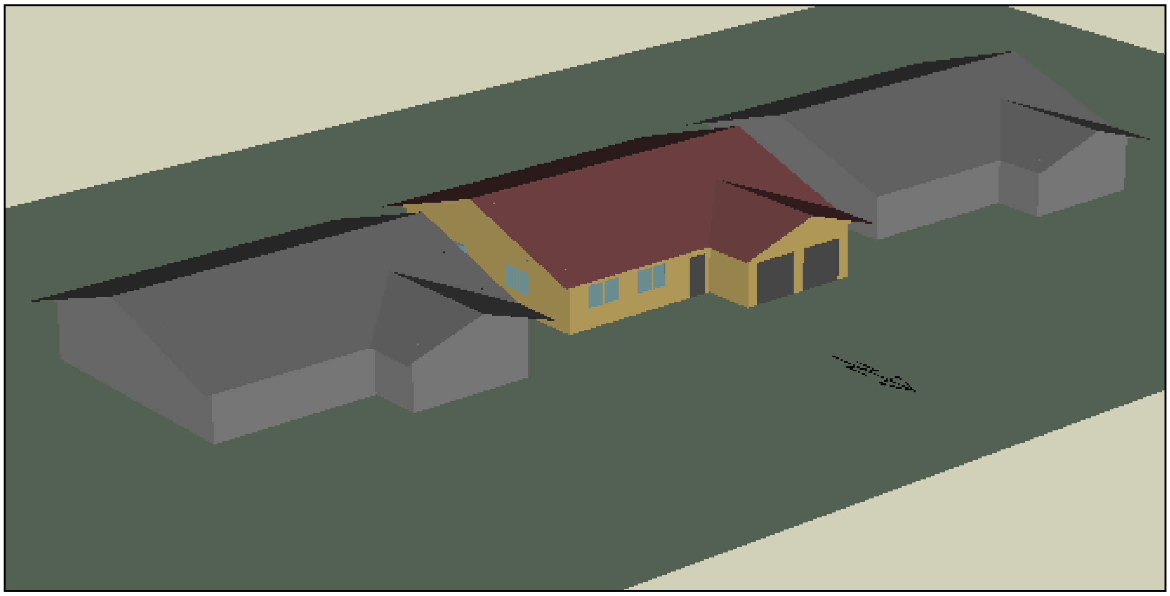

**Figure 35: Prototypical Phased Deep Retrofit residence rendered in BEopt with adjacent home on either side**

For the BEopt rendering for windows, the model assumed single-glazed, aluminum-framed base case windows (U = 1.16 Btu/hr-ft$^2$-°F, SHGC = 0.76) and then simulated high-performance windows similar to those used in the project (U=0.28; SHGC = 0.22). It also assumed there were adjacent homes as commonly seen in the suburbs and in the cases we encountered, and 3-ft. overhangs to approximate the high degree of shading seen from porches (see Table 19). Further, based on the characterization shown in Table 19, the model included the assumption that interior shading was extensive from observed blind position and also from 50% of the windows commonly being covered by insect screening that has been shown to reduce solar transmittance by nearly 40%. In addition, the effective solar transmittance was assumed to be 30% of the fully exposed value in the cooling season and 50% of the value in winter. These values contrast with the BEopt standard values of 50% in the cooling season and 70% in winter, which would reflect different blind management than was observed in the project homes. High levels of window heat gain can lead to overheating in spring and fall and BEopt has the potential to simulate year-round venting, although in this project natural ventilation was fairly uncommon except during the Florida winter season.

Other parameters that can be expected to influence window savings include interior thermostat temperature and internal heat gain rate. The higher the temperature set point, the lower the savings from the lower U-factor of windows. Moreover, at some point the lower heat loss from the windows at night will begin to exert a negative influence on savings.

Similarly, with high levels of internal heat gain from greater appliance and interior plug loads, the home's interior temperature will tend to be elevated such that greater heat loss at night from single-glazed windows is actually desirable. This is clearly shown in Figure 28 for Site 25, which has a cooling set point of nearly 82°F and has very high plug loads with daily home entertainment power of 5.7 kWh/day. Based on modeling, it appears that assuming twice the normal plug loads worked fairly well in many cases.

Figure 36 shows the results for a case similar to Site 25 with twice the normal plug loads and a cooling set point of 81°F. The predicted cooling energy savings from the advanced windows amounts to only 202 kWh/year. Note that the measured cooling energy at Site 25 during the entire year of 2013 was 2,227 kWh, which corresponds well to the 2,172 kWh predicted. The results are shown below in the form of an analysis result table (Table 23) from BEopt.

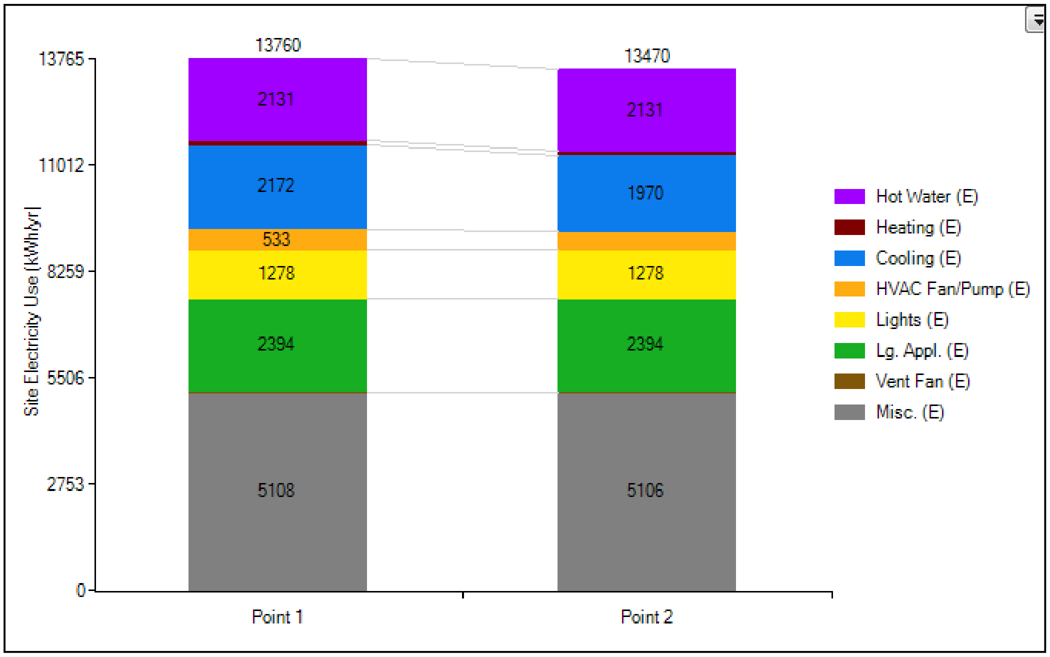

**Figure 36: Estimated savings from single-glazed windows (Point 1) versus double-glazed low-e solar control windows, with a 81°F set point and 2X normal plug loads**

**Table 23. Parametric Evaluation of Influences to Savings from Advanced Windows in Florida**

| | No Ventilation | | | | With Year-Round Ventilation | | | |
|---|---|---|---|---|---|---|---|---|
| **Set Point °F** | Single Glazed (kWh) | Double Low-e Solar (kWh) | Savings (kWh) | Savings % | Single Glazed kWh | Double Low-e Solar (kWh) | Savings (kWh) | Savings % |
| **72°** | 6413 | 5891 | 522 | 8.1% | 6413 | 5888 | 525 | 8.2% |
| **73°** | 5888 | 5404 | 484 | 8.2% | 5888 | 5404 | 484 | 8.2% |
| **74°** | 5372 | 4927 | 445 | 8.3% | 5349 | 4903 | 446 | 8.3% |
| **75°** | 4865 | 4458 | 407 | 8.4% | 4804 | 4396 | 408 | 8.5% |
| **76°** | 4367 | 3998 | 369 | 8.4% | 4282 | 3916 | 366 | 8.5% |
| **77°** | **3883** | **3549** | **334** | **8.6%** | **3790** | **3458** | **332** | **8.8%** |
| **78°** | 3420 | 3118 | 302 | 8.8% | 3326 | 3030 | 296 | 8.9% |
| **79°** | 2978 | 2708 | 270 | 9.1% | 2896 | 2629 | 267 | 9.2% |
| **80°** | 2562 | 2327 | 235 | 9.2% | 2491 | 2257 | 234 | 9.4% |
| **81°** | 2172 | 1970 | 202 | 9.3% | 2113 | 1914 | 199 | 9.4% |
| **82°** | 1805 | 1638 | 167 | 9.3% | 1761 | 1591 | 170 | 9.7% |
| **Internal Gains** | | | | | | | | |
| **0.5 x PL** | 3086 | 2729 | 357 | 11.6% | 3033 | 2679 | 354 | 11.7% |
| **1 x PL** | 3344 | 2989 | 355 | 10.6% | 3277 | 2931 | 346 | 10.6% |
| **2 x PL** | **3883** | **3549** | **334** | **8.6%** | **3790** | **3458** | **332** | **8.8%** |
| **3 x PL** | 4449 | 4135 | 314 | 7.1% | 4356 | 4015 | 341 | 7.8% |
| **4 x PL** | 5029 | 4733 | 296 | 5.9% | 4880 | 4584 | 296 | 6.1% |
| **External & Internal Shade** | | | | | | | | |
| **Hvy int & ext shade, w/nhbrs** | **3883** | **3549** | **334** | **8.6%** | **3790** | **3458** | **332** | **8.8%** |
| **Less Int Shade** | 4124 | 3631 | 493 | 12.0% | 4015 | 3538 | 477 | 11.9% |
| **Hvy int & ext shade, no nhbrs** | 4528 | 3913 | 615 | 13.6% | 4390 | 3801 | 589 | 13.4% |
| **Less int shade, no nhbrs** | 4938 | 4050 | 888 | 18.0% | 4774 | 3927 | 847 | 17.7% |

[a] Bolded rows represent parameter selected for the general model used in the remaining parameters' sensitivity runs.

Note that the results suggest the following influences on AC savings from windows in a cooling-dominated climate:

- Pre-existing shading from adjacent buildings, porches, blinds, and insect screens has a very large impact on savings, reducing them by more than 50% relative to standard assumptions (which also includes interior shading).
- Greater internal gains from appliance and plug loads reduce the cooling energy savings from advanced windows because interior temperatures tend to be higher during nighttime hours when ambient temperatures are lower and heat loss is beneficial. For example, a home with low plug loads will see savings nearly double that of a home with very high internal heat gains.

- The annual savings of advanced windows varies significantly by the interior thermostat setting. For example, a home maintaining 81°F versus 77°F would see 40% less savings. On the other hand, a home maintaining a 73°F inside temperature would see 56% greater savings from the better windows.
- Natural ventilation has only modest influences on produced savings, at least according to the algorithms in BEopt.

While 20%–30% savings are possible with the right combination of factors (low internal gains, minimal existing shading, and low set points), the opposite is true as well. A very high set point with high internal gains with windows mostly shaded by other buildings, vegetation, porches, or blinds would see negligible savings from advanced windows. In particular, pre-existing shading in existing Florida homes is likely to limit savings in many applications.

# 8 Evaluation of Smart Thermostats

## 8.1 Background

As thermostats are the central switch that controls the operation of heating and cooling systems—commonly the largest energy loads in homes—it follows that understanding how the occupants and thermostat interact is key to achieving potential energy savings. However, this potential is complex, made up of the control hardware and how homeowners use it (behavior).[6] That this technique has potential for energy savings has been demonstrated in well-controlled laboratory measurements. For example, experimental work by Levins at Oak Ridge National Laboratory (Levins 1988) showed 20% measured heating savings from thermostat setback in the highly instrumented and unoccupied Karns homes versus the use of a constant thermostat setting. More recently, detailed National Research Council Canada test homes in Canada (Manning et al. 2007) showed that both thermostat setback (winter) and setup (summer) reliably produce savings of 13% and 11% respectively. However, until the advent of smart thermostats, such savings levels have depended on the willingness of occupants to manage their thermostats and make effective control decisions. Somewhat lower energy savings in occupied homes are well-documented. For example, Blasnik as cited by Bailes (2012) has shown heating savings of 5%-8% in multiple studies in many occupied homes in the northeastern United States from 1998–2008. Also, Roberts and Lay (2013) showed that in 20 homes in New York, the measured interior nighttime temperatures were only about 3°F lower than midday temperatures and, in a similar sample of Florida homes, the same differences were only about 2°F during the day. This appears substantially lower than the potential, however, based on the laboratory experiments.

### *8.1.1 Unrealized Potential with Standard Programmable Thermostats*

From 1999–2001, a large monitoring project in central Florida for Florida Power Corporation evaluated 150 submetered homes and found that homes with programmable thermostats actually used more space cooling than those with manual slide thermostats because homeowners were more likely to change the daily settings on the manual thermostats (Nevius 2000).[7] Verifying this finding, the influence of thermostats and load controls has been evaluated in Florida homes by utilities that want to enhance load control. The utilities' findings also showed that programmable thermostats increased cooling consumption (Lopes and Agnew 2010). The problems were not confined to Florida, as data from Minnesota showed much the same contrary result from programmable thermostats (Nevius and Pigg 2000). Other efforts (Vastamaki, Sinkkonen, and Leinonen 2005) (Meier et al. 2011) showed that much of the problem emerged from the user interface of programmable thermostat for homeowners was too complicated, and only one in four households with programmable thermostats had been programming them.

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[6] www.energyvanguard.com/blog-building-science-HERS-BPI/bid/50152/If-You-Think-Thermostat-Setbacks-Don't-Save-Energy-You're-Wrong

[7] Part of the problem identified during occupant interviews as part of the Florida Power Corporation monitoring project had to do with complexity (e.g., "technological nuisance factor"), which kept many from programming devices. Manual thermostats are easy to operate and set back, whereas homeowners with programmable thermostats tended to leave them at a constant "Hold" setting.

Figure 37. The Nest learning thermostat

Newer "smart" thermostats get around these problems by self-programming depending on heuristic evaluation of user control habits as well as sensed homeowner occupancy. Such smart thermostats include Nest (see Figure 37), Lyric, and Ecobee. These modern devices use a combination of data on occupancy, weather, and thermostat-setting preference to help consumers with automated setback/setup schedules. These devices have also been shown in other studies in other regions to produce cooling energy savings. For example, the Nest thermostats have been shown to provide savings of 1.16 kWh/day or 11.3% in a very large sample of homes in Southern California (Nest 2014). There are reasons to believe savings may differ in Florida, however, with different demographics, construction practices, and intense cooling consumption.

## 8.2 Installation Campaign

A total of 44 PDR sites were considered for installation of the Nest or Lyric "smart" thermostat Phase II evaluation. The installation sites were chosen based on homeowner acceptance, compatibility, and no confounding measures being installed in the home (nine sites received a Nest in 2013 as part of the deep retrofit):

- Two sites already had a Nest
- Five sites had incompatible AC systems—typically very high-efficiency systems
- Four sites were not appropriate because of the need to not confound other measures being installed
- Four sites rejected the offer of a smart thermostat
- One site is delaying installation of a Lyric until 1 year from the installation of their new AC system.

Within the PDR Phase II evaluation, 28 sites received a Nest or Lyric thermostat (two Lyrics and 26 Nests). A third Lyric installation was subsequently traded for one of the 26 Nests. Of the Nest installs, six were just installed in the summer of 2015, leaving 20 for the current evaluation, although one site (46) is still not included in the analysis due to uncertainty about the timing of the installation and removal.

Among the 38 smart thermostats installed as part of the PDR program (nine sites received Nest within the deep retrofit evaluation, 22 sites received a Nest or Lyric in 2014, and seven sites a Nest or Lyric in 2015), 19 Nest and two Lyric thermostat installations are evaluated below. The nine homes that had Nest thermostats installed in the summer of 2013 as part of the deep retrofits are not included in this analysis because the thermostats were installed as a part of a much larger group of retrofit measures. The multiple measures made it difficult to reliably split apart the impact of the thermostats from other changes made at the same time. (Performance data for the six Nest and one Lyric installation in the summer of 2015 will not be available until the winter of 2015–2016).

Site characteristics for the 19 Nest and two Lyric installations are summarized in Table 24, HVAC characteristics for these sites are provided in Table 25, and serial numbers for the Nest installations are in Appendix E.

**Table 24. Smart Thermostat General Site Characteristics**

| Site # | City | Year Built | Living Area (ft²) | No. of Occu. | Stories | Ceiling Insulation | Wall Construction | House Air-tightness (ACH50) | Year of AHU | Year of Comp | AC Size (tons) | AC SEER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **4** | Melbourne | 1971 | 1,166 | 2 | 1 | R-19 | CMU | 11.5 | 2000 | 2000 | 2.5 | 14.0 |
| **6** | Palm Bay | 1981 | 1,542 | 2 | 1 | R-25 | CMU | 8.9 | 2006 | 2006 | 3 | 13.0 |
| **11** | Cocoa Beach | 1958 | 1,672 | 3 | 1 | R-6 | CMU | 10.9 | 1998 | 2002 | 3 | < 12 |
| **15** | Melbourne Beach | 1975 | 1,359 | 2 | 1 | R-15 | CMU | 8.2 | 1997 | 1997 | 3 | 13.5 |
| **17** | Indialantic | 1964 | 1,456 | 2 | 1 | R-30 | CMU | 8.4 | 2002 | 2002 | 3 | 19.0 |
| **18** | Cocoa | 1995 | 1,802 | 2 | 1 | R-21 | CMU | 6.2 | 2008 | 2008 | 3 | 14.0 |
| **21** | Cocoa Beach | 1981 | 1,628 | 2 | 1 | R-30 | CMU | 6.9 | 2013 | 2013 | 3.5 | 13.0 |
| **22** | Cocoa Beach | 1955 | 1,743 | 2 | 1 | R-19 | CMU | 11.0 | 2001 | 2001 | 2.5 | 12.0 |
| **28** | Merritt Island | 1966 | 2,622 | 2 | 1 | R-16 | CMU | 8.9 | 1999 | 1999 | 5 | 10.0 |
| **29** | Cocoa | 1985 | 1,215 | 2 | 1 | R-30 | Frame | 10.2 | 1985 | 1985 | 2.5 | < 10 |
| **34** | Pembroke Pines | 1978 | 1,651 | 2 | 1 | R-8 | CMU | 9.3 | 2011 Packaged Unit | | 3 | 15.0 |
| **35** | Plantation | 1993 | 1,625 | 2 | 2 | R-19 | CMU/Frm | 6.6 | 1993 | 1998 | 3.5 | < 10 |
| **42** | Naples | 2001 | 1,666 | 3 | 2 | R-30 | Frame | 6.1 | 2002 | 2002 | 3 | 10.0 |
| **45** | Davie | 1987 | 1,299 | 2 | 1 | R-19 | CMU | 9.1 | 2006 | 2006 | 2.5 | 13.0 |
| **47** | Fort Myers | 1990 | 1,088 | 4 | 1 | R-15 | Frame | 5.5 | 1999 | 2004 | 2.5 | < 10 |
| **48** | Naples | 1973 | 1,436 | 4 | 1 | R-38 | CMU | 13.2 | 2006 Packaged Unit | | 3 | 13.0 |
| **52** | Cocoa | 2000 | 1,696 | 2 | 1 | R-30 | Frame | 7.0 | 2012 | 2012 | 3 | 13.0 |
| **58** | Rockledge | 1979 | 2,020 | 2 | 1 | R13 | CMU | 13.3 | 2003 | 2003 | 3.5 | 13.0 |
| **59** | Melbourne Beach | 1985 | 2,298 | 2 | 1 | R-19 | Frame | 7.1 | 2005 | 2005 | 4 | 14.0 |
| **43** | Fort Myers | 2000 | 1,383 | 2 | 1 | R-25 | CMU | 6.5 | 1999 | 1999 | 2.5 | 10.0 |
| **44** | Naples | 1998 | 1,627 | 2 | 1 | R-19 | CMU | 4.7 | 1998 | 1998 | 4 | 10.0 |

**Table 25. Thermostat Replacement Site HVAC Characteristics**

| Site # | Heating | Duct Leakage (Qn, out) | Existing T-Stat Make | Existing Technology | As Found Program Setting | T-Stat Installed | Install Date |
|---|---|---|---|---|---|---|---|
| **4** | Heat Pump | 0.17 | Robertshaw | Non-programmable | N/A | NEST | Sept 3, 2014 |
| **6** | Resistance | 0.10 | Honeywell | Non-programmable | N/A | NEST | Aug 27, 2014 |
| **11** | Heat Pump | 0.13 | Honeywell | Non-programmable | N/A | NEST | Sept 5, 2014 |
| **15** | Heat Pump | 0.13 | White Rogers | Non-programmable | N/A | NEST | Oct 10, 2014 |
| **17** | Heat Pump | 0.12 | Trane (XT500C) | Programmable | 'Hold' | NEST | Sept 10, 2014 |
| **18** | Heat Pump | 0.05 | Honeywell | Programmable | 'Hold' | NEST | Sept 11, 2014 |
| **21** | Heat Pump | 0.12 | White Rogers | Programmable | Program Running | NEST | July 24, 2014 |
| **22** | Resistance | 0.08 | White Rogers (1F82 -261) | Programmable | Program Running | NEST | Sept 4, 2014 |
| **28** | Heat Pump | 0.06 | Robertshaw analog | Non-programmable | N/A | NEST | Sept 12, 2014 |
| **29** | Resistance | 0.07 | Honeywell | Non-programmable | N/A | NEST | Aug 20, 2014 |
| **34** | Resistance | 0.06 | Trane | Programmable | 'Hold' | NEST | Nov 20, 2014 |
| **35** | Resistance | 0.08 | Filtrete | Programmable | Program Running | NEST | Nov 22, 2014 |
| **42** | Resistance | 0.04 | White Rodgers (1F86-344) | Non-programmable | N/A | NEST | Oct 29, 2014 |
| **45** | Resistance | 0.09 | Climate Technology | Non-programmable | N/A | NEST | Nov 20, 2014 |
| **47** | Resistance | 0.03 | not recorded | Programmable | Program Running | NEST | Oct 30, 2014 |
| **48** | Resistance | 0.20 | White Rogers (IF86-344) | Non-programmable | N/A | NEST | Oct 29, 2014 |
| **52** | Heat Pump | 0.06 | Honeywell | Programmable | 'Hold' | NEST | Aug 27, 2014 |
| **58** | Heat Pump | --- | Honeywell | Programmable | Program Running | NEST | Aug 25, 2014 |
| **59** | Resistance | 0.10 | Honeywell | Programmable | 'Hold' | NEST | Sept 12, 2014 |
| **43** | Resistance | 0.03 | Honeywell | Non-programmable | N/A | Lyric | Oct 28, 2014 |
| **44** | Resistance | 0.07 | Honeywell | Non-programmable | N/A | Lyric | Nov 19, 2014 |

For the Phase II research evaluation, the thermostats were installed in PDR homes that had not received other retrofits between July 24, 2014, and November 22, 2014. The pre-retrofit evaluation periods generally ran from July 2013 through the installation date at each site and the post-retrofit period from installation through July 2015. The installations were primarily in the central and south Florida areas. These had no other retrofits that were coincident with the thermostat installation other than pool pumps, which were not expected to alter interior HVAC needs. No specific instruction or programming was provided to occupants, who were free to alter the thermostats as they pleased. Default Nest and Lyric settings were used. For each home, a full year of pre-installation data was available including AC, heating, and air handler use as well as indoor temperatures and RH.

## 8.3 Smart Thermostat Evaluation and Example Analysis

The analysis method used to evaluate the performance of each Nest or Lyric installation was to summarize the pre-year data and compare daily measured space-conditioning energy to outdoor temperature according to the evaluation method described in Section 3. Regressions from the analysis of the smart thermostats are provided in Appendix F.

To help understand how energy use changed before and after the smart thermostat installation, the indoor temperatures being maintained were also compared to the outdoor temperatures in an attempt to identify specific thermostat control effects. These changes were explored extensively for cases in which energy use actually increased.

Below is an example of how the analysis method was done for each site. The example uses Site 28, selected because the results from the site were very close to what was seen on average in the Nest evaluation. Site 28 is a 2,622 ft$^2$ home built in 1966 in Merritt Island, Florida, with two working adults in the household. The concrete masonry home is poorly insulated—R-16 attic insulation, no wall insulation, single-pane glass, and a blower door tested leakage of 8.9 ACH50. The heat pump system is an older 1999 vintage 4-ton machine. The existing thermostat was a TRANE XT500C programmable thermostat (Figure 38).

**Figure 38: Site 28 existing thermostat, a Trane XT500C programmable model**

Data from July 2013 to the present are presented in Figure 39 below, both for indoor and outdoor temperature and for the HVAC time series. The Nest was installed September 12, 2014. The interior temperature data recorded by the portable HOBO loggers (red) was continuous, showing the expected dip in response to winter outdoor conditions. Outdoor ambient temperature is light blue.

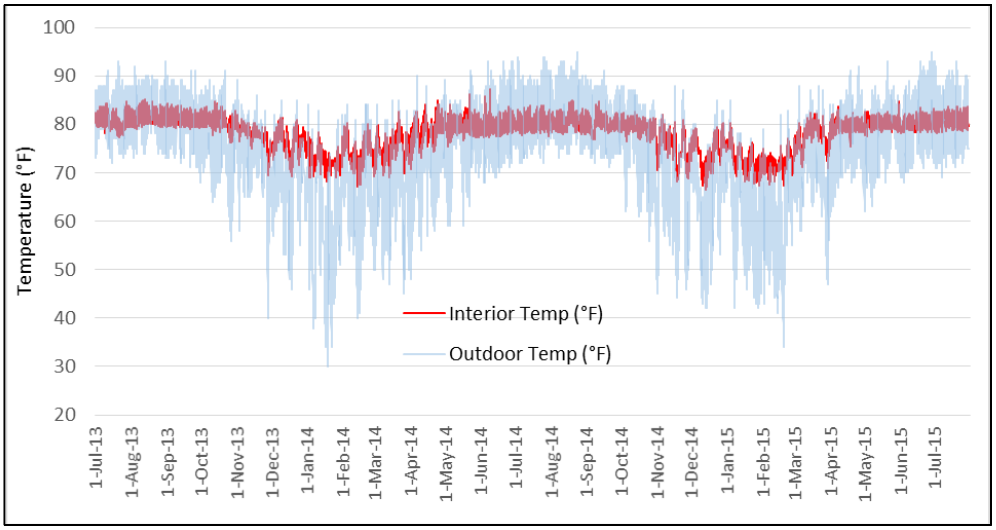


**Figure 39. Site 28 interior temperature versus local National Weather Service outdoor temperature July 2013–July 2015**

Daily HVAC data over this same period are plotted in Figure 40 below. Orange represents the compressor power and green is the air handler.

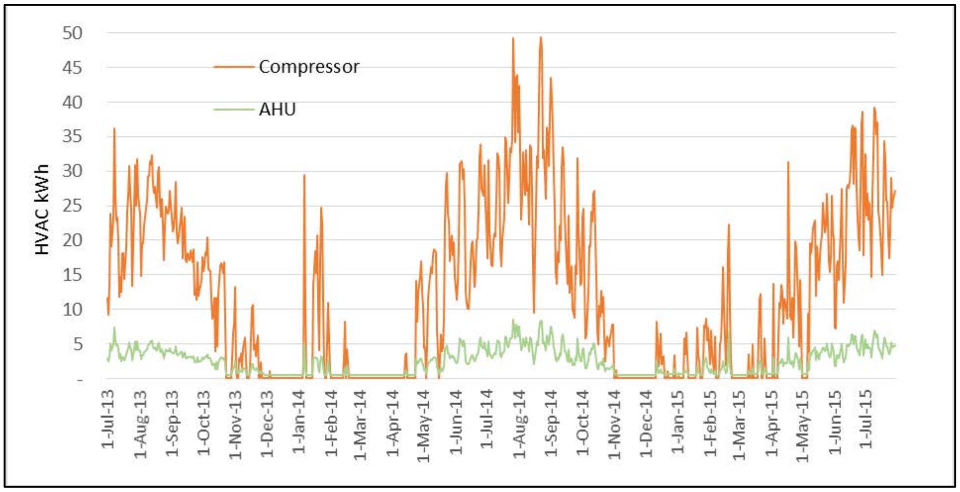


**Figure 40. Site 28 compressor and air handler power July 2013–July 2015**

As this household maintains a temperature of about 78°–80°F during hottest days, the data for HVAC suggest a poorly functioning 4-ton air conditioner or a very large cooling load.

### *8.3.1 Visual Plot of Cooling and Heating versus Outdoor Temperature over the Length of the Pre- and Post-Retrofit Periods and Regression Results*

Examination of plotted daily HVAC over the 700-day period against outdoor temperature (see Figure 41 suggests both winter and summer savings. Zeros are prior to the retrofit and 1s indicates post retrofit observations. Air handler power is plotted at the bottom of the chart in brown triangles. The data also indicate an approximate 67°F balance point for the building.

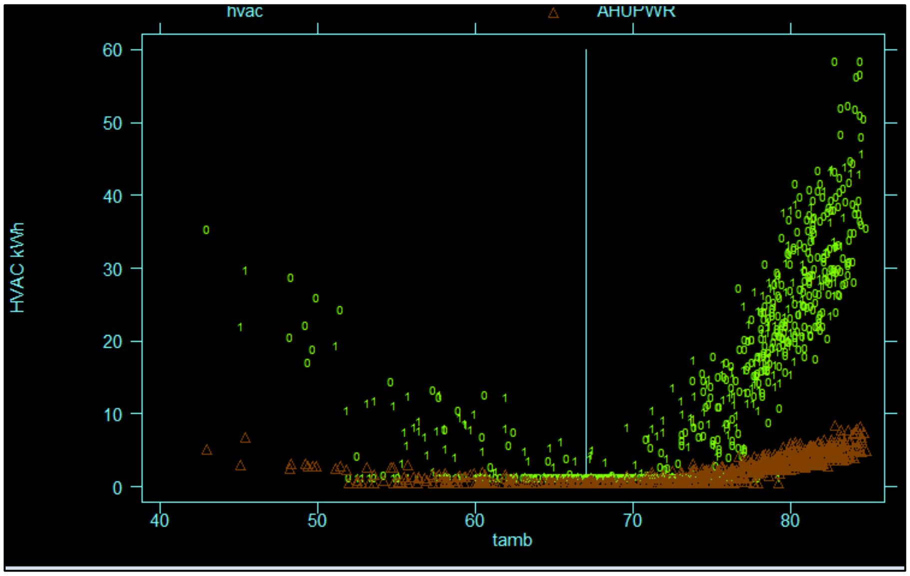
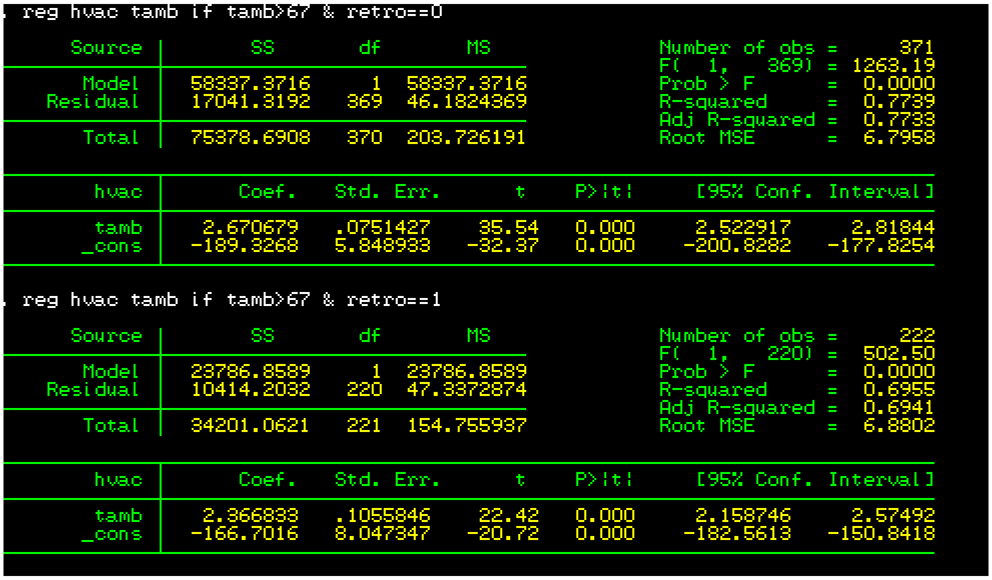


Figure 41. Site 28 daily HVAC kWh over the 700 day period plotted against outdoor temperature; zeros are pre-retrofit period; 1s are post. Brown triangle show air handler unit power

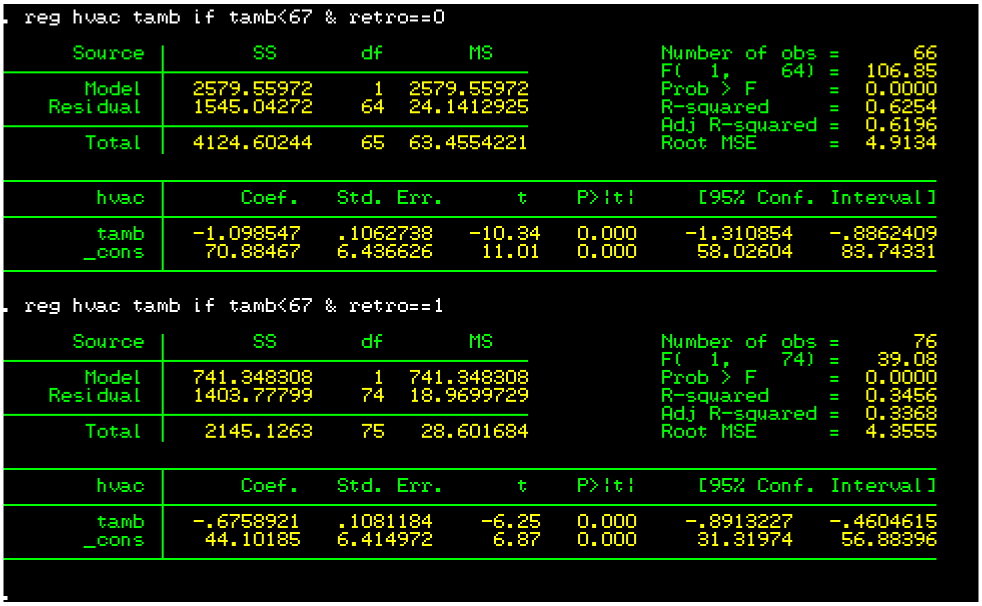
Site 28 cooling and heating regression results are provided in Figures 42 and 43 below, respectively.



```
. reg hvac tamb if tamb>67 & retro==0

      Source |       SS       df       MS              Number of obs =     371
-------------+------------------------------           F(  1,   369) = 1263.19
       Model |  58337.3716     1  58337.3716           Prob > F      =  0.0000
    Residual |  17041.3192   369  46.1824369           R-squared     =  0.7739
-------------+------------------------------           Adj R-squared =  0.7733
       Total |  75378.6908   370  203.726191           Root MSE      =  6.7958

------------------------------------------------------------------------------
        hvac |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        tamb |   2.670679   .0751427    35.54   0.000     2.522917     2.81844
       _cons |  -189.3268   5.848933   -32.37   0.000    -200.8282   -177.8254
------------------------------------------------------------------------------

. reg hvac tamb if tamb>67 & retro==1

      Source |       SS       df       MS              Number of obs =     222
-------------+------------------------------           F(  1,   220) =  502.50
       Model |  23786.8589     1  23786.8589           Prob > F      =  0.0000
    Residual |  10414.2032   220  47.3372874           R-squared     =  0.6955
-------------+------------------------------           Adj R-squared =  0.6941
       Total |  34201.0621   221  154.755937           Root MSE      =  6.8802

------------------------------------------------------------------------------
        hvac |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        tamb |   2.366833   .1055846    22.42   0.000     2.158746     2.57492
       _cons |  -166.7016   8.047347   -20.72   0.000    -182.5613   -150.8418
------------------------------------------------------------------------------
```

Figure 42. Site 28 cooling regression analysis

Cooling for an 80°F summer day with the 67°F balance point was 24.3 kWh/day pre-Nest installation and 22.7 kWh post-Nest installation, for a 7% savings.



```
. reg hvac tamb if tamb<67 & retro==0

      Source |       SS       df       MS              Number of obs =      66
-------------+------------------------------           F(  1,    64) =  106.85
       Model |  2579.55972     1  2579.55972           Prob > F      =  0.0000
    Residual |  1545.04272    64  24.1412925           R-squared     =  0.6254
-------------+------------------------------           Adj R-squared =  0.6196
       Total |  4124.60244    65  63.4554221           Root MSE      =  4.9134

------------------------------------------------------------------------------
        hvac |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        tamb |  -1.098547   .1062738   -10.34   0.000    -1.310854   -.8862409
       _cons |   70.88467   6.436626    11.01   0.000     58.02604    83.74331
------------------------------------------------------------------------------

. reg hvac tamb if tamb<67 & retro==1

      Source |       SS       df       MS              Number of obs =      76
-------------+------------------------------           F(  1,    74) =   39.08
       Model |  741.348308     1  741.348308           Prob > F      =  0.0000
    Residual |  1403.77799    74  18.9699729           R-squared     =  0.3456
-------------+------------------------------           Adj R-squared =  0.3368
       Total |   2145.1263    75   28.601684           Root MSE      =  4.3555

------------------------------------------------------------------------------
        hvac |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        tamb |  -.6758921   .1081184    -6.25   0.000    -.8913227   -.4604615
       _cons |   44.10185   6.414972     6.87   0.000     31.31974    56.88396
------------------------------------------------------------------------------

.
```

Figure 43. Site 28 heating regression analysis

For the heat pump (which only shows modest strip heat use on cold days) the regression analysis indicated the following savings: Pre-Nest installation 15.9 kWh @ 50° F; post-nest installation 10.3 kWh, for 5.6 kWh or 35% savings.

### 8.3.2 Evaluation of Changes to Indoor Temperatures

Figure 44 is a plot of interior temperatures against outdoor ambient temperature pre- (green circles) and post-retrofit (brown triangles) for cooling.

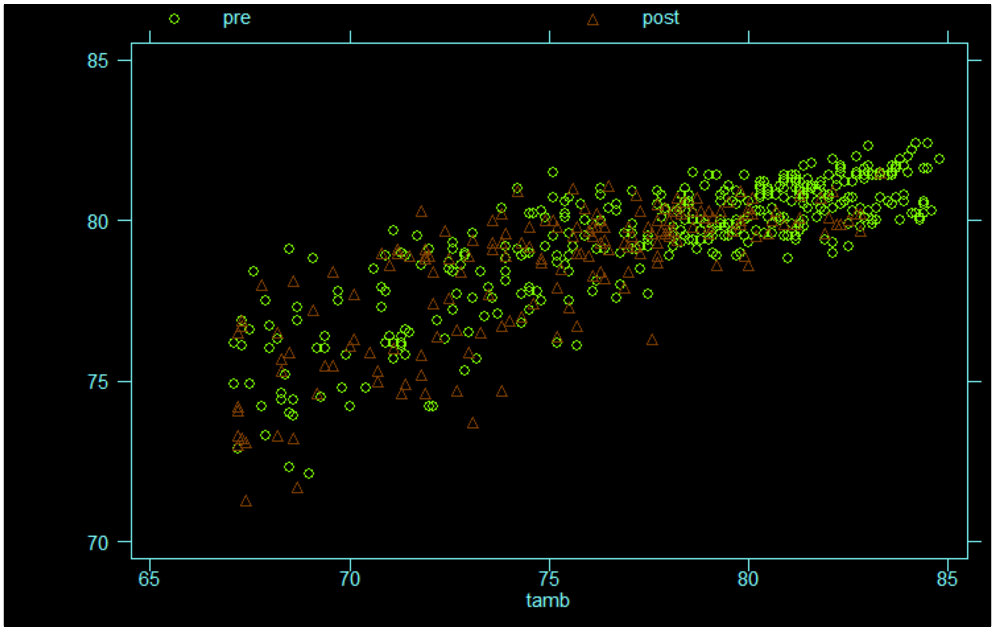


Figure 44. Site 28 cooling season interior temperatures versus outdoor temperatures pre- and post-retrofit

A similar presentation of the data for heating in Figure 45 shows the Nest typically maintaining a lower interior daily temperature compared with the interior temperature in the pre-retrofit condition, which accounts for the savings.

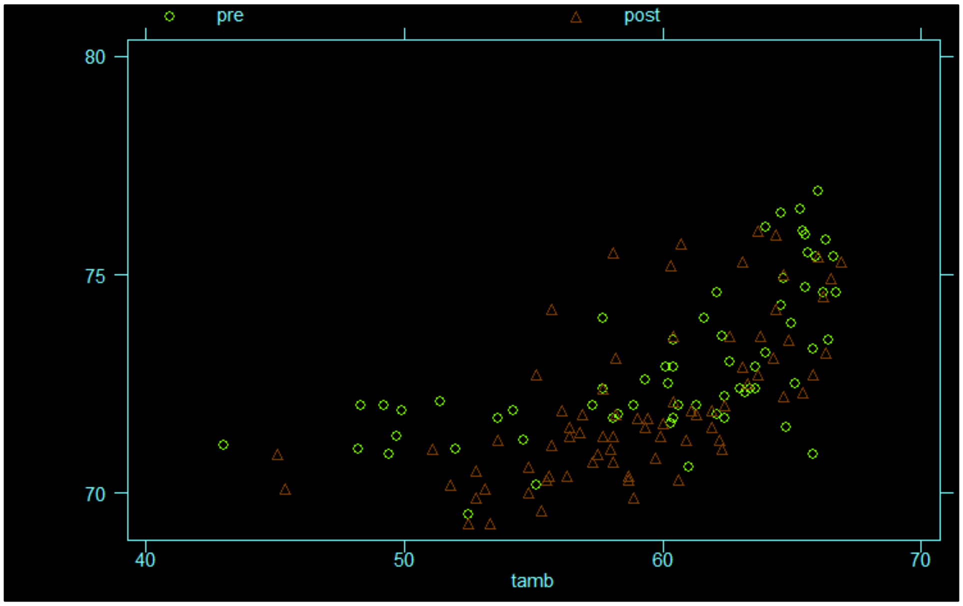


**Figure 45. Site 28 heating season interior temperatures versus outdoor temperatures pre- and post-retrofit**

## 8.4 Summary of Home-by-Home Analysis

After completing the analysis for all 19 homes and two homes with the Lyric, the results were summarized and combined into Table 26. The data for the Lyric—two cases studies—cannot be evaluated in any meaningful fashion. However, the 19 Nest sites lend themselves to summary. Here, the average savings for cooling (1.6 kWh/day at an outdoor daily temperature of 80°F) was 7.4%, but with a very high degree of variation. The median savings were 1.1 kWh/day or 4.8%. The standard deviation of the savings was 3.3 kWh/day—higher than the savings themselves. Indeed, the analysis showed that eight out of 19 sites experienced negative savings, which was largely an artifact of pre-retrofit thermostat habits. On average, at the sites that had positive savings, those savings were larger in magnitude than the absolute difference in sites that experienced negative savings. Not surprisingly, analysis of pre- and post-retrofit interior temperatures versus outdoor temperatures revealed that sites without savings often maintained lower indoor temperatures in the post-Nest installation period.

### Table 26. Nest Thermostat Evaluations: Florida Phased Deep Retrofit Project 2013–2015 (Preliminary)

| Site # | Install | Balance T | Pre (kWh/day) | Post (kWh/ day) | Delta (kWh /day) | Cool reduction % | Pre (kWh/ day) | Post (kWh/ day) | Delta (kWh/ day) | Heat reduction % |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | **Cooling** | | | | **Heating** | | | |
| **4** | Sept 3, 2014 | 65/65 | 16.0 | 16.8 | -0.8 | -5.0% | 9.0 | 8.2 | 0.8 | 8.9% |
| **6** | Aug 27, 2014 | 72/69 | 7.7 | 7.5 | 0.2 | 2.6% | 11.7 | 9.5 | 2.2 | 18.8% |
| **11** | Sept 5, 2014 | 68/68 | 23.0 | 24.0 | -1.0 | -4.3% | 22.0 | 19.1 | 2.9 | 13.2% |
| **15** | Oct 10, 2014 | 70/70 | 15.2 | 16.6 | -1.4 | -9.2% | 14.7 | 9.3 | 5.4 | 36.7% |
| **17** | Sept 10, 2014 | 65/67 | 15.1 | 16.4 | -1.3 | -8.6% | 7.8 | 6.9 | 0.9 | 11.5% |
| **18** | Sept 11, 2014 | NA/66 | 24.1 | 17.7 | 6.4 | 26.6% | 0.0 | 0.0 | 0.0 | 0.0% |
| **21** | July 24, 2014 | 66/66 | 29.0 | 20.4 | 8.6 | 29.7% | 19.9 | 33.2 | -13.3 | -66.8% |
| **22** | Sept 6, 2014 | NA/70 | 25.1 | 23.2 | 1.9 | 7.6% | 0.0 | 0.0 | 0.0 | 0.0% |
| **28** | Sept 12, 2014 | 67/67 | 24.3 | 22.7 | 1.6 | 6.6% | 15.9 | 10.3 | 5.6 | 35.2% |
| **29** | Aug 20, 2014 | 68/68 | 27.3 | 30.4 | -3.1 | -11.4% | 16.7 | 10.7 | 6.0 | 35.9% |
| **34** | Nov 20, 2014 | 64/64 | 15.8 | 13.6 | 2.2 | 13.9% | 0.0 | 0.0 | 0.0 | 0.0% |
| **35** | Nov 22, 2014 | 67/67 | 34.7 | 36.4 | -1.7 | -4.9% | 10.4 | 11.7 | -1.3 | -12.5% |
| **42** | Oct 29, 2014 | 65/65 | 17.2 | 13.9 | 3.3 | 19.2% | 23.2 | 14.0 | 9.2 | 39.7% |
| **45** | Nov 20, 2014 | 65/65 | 17.3 | 15.2 | 2.1 | 12.1% | 0.0 | 0.0 | 0.0 | 0.0% |
| **47** | Oct 30, 2014 | 64/64 | 21.0 | 21.9 | -0.9 | -4.3% | 0.0 | 0.0 | 0.0 | 0.0% |
| **48** | Oct 29, 2014 | 65/67 | 25.0 | 25.1 | -0.1 | -0.4% | 14.7 | 11.5 | 3.2 | 21.8% |
| **52** | Aug 27, 2014 | 68/68 | 8.5 | 3.4 | 5.1 | 60% | 5.5 | 18.4 | -12.9 | -234.5% |
| **58** | Aug 25, 2014 | 63/69 | 25.8 | 24.7 | 1.1 | 4.3% | 23.1 | 11.6 | 11.5 | 49.8% |
| **59** | Sept 12, 2014 | 63/68 | 27.9 | 20.4 | 7.5 | 26.9% | 21.2 | 24.2 | -3.0 | -14.2% |
| | | | | | | | | | | |
| ***Average*** | | | **21.1** | **19.5** | **1.6** | **7.4%** | **14.4** | **13.2** | **1.1** | **8.0%** |
| **Std Deviation** | | | 7.1 | | 3.3 | | 7.0 | | 6.9 | |
| **Median** | | | **23.0** | | **1.1** | **4.8%** | **14.7** | | **2.2** | **15.0%** |
| | | | | | | | | | | |
| **Lyric Thermostat Evaluations** | | | | | | | | | | |
| **43** | Oct 28, 2014 | 67/67 | 20.6 | 24.0 | -3.4 | -16.5% | 0.0 | 0.0 | 0.0 | 0.0% |
| **44** | Nov 19, 2014 | 67/67 | 21.2 | 17.1 | 4.1 | 19.3% | 43.6 | 33 | 10.6 | 24.3% |

On a site-by-site basis, the study found that pre-installation thermostat behavior and willingness to use available Nest features made a difference. For example, a site with a programmable thermostat that was not used cannot be expected to show savings, and those with low levels of vacancy cannot be expected to achieve much savings from the occupancy-sensing "away" function.

Heating savings from the Nest were also highly variable, particularly given the very short winter heating season in Florida. Average savings were 8.0% (1.1 kWh/day at 50°F), although the median was higher: 2.2 kWh/day or 15.0%. Savings were even more variable than for cooling, because some homes had heat pumps and others had electric resistance heating with higher savings associated with thermostatic control.

While there was great range in predicted savings among the Nest sites analyzed (-3.1– 8.6 kWh/day for cooling energy and -13.3–11.5 kWh/day for heating energy), the average predicted savings for the Nests was considered to gain insight into the economics of smart thermostat installation. Given its easy installation, the study assumed the Nest's retail cost of $250 and no labor cost.

To compute the Nest savings, the estimated pre-intervention end-use cooling and heating in the overall PDR sample was used. As seen in the Phase I report, "Phased-Retrofits in Existing Homes in Florida Phase I: Shallow and Deep Retrofits", is being drafted concurrent to this report, the average annual cooling consumption in the untreated PDR sample was 5,880 kWh. The average estimated annual heating was 274 kWh. For estimating savings, using the PDR evaluation averages appears to be more representative than the median. This is justified by three factors:

- The sample was carefully examined for each case to remove outliers, which resulted in the exclusion of two sites that received but did not use the smart thermostats.
- The space cooling and heating consumption does not have a normal distribution, rather is strongly log-normal with a long tail of a small group of high users that skew cooling and heating consumption.
- The small Nest sample may not be representative of typical cooling and heating consumption in the larger sample of homes that likely better represent the FPL population.

Thus, cooling savings are 5,880 kWh * 0.074 = 435 kWh and heating savings are 274 * 0.08 = 22 kWh for a total annual savings of 457 kWh or $55 at $0.12/kWh. Simple payback for the Nest installation in this example would be about 4.6 years with an annual rate of return 21.9%. This is excellent for a low-cost retrofit measure. It is also attractive enough that future projects should consider installing smart thermostats as part of the simple utility shallow retrofit measures.

The savings in the PDR project were somewhat lower than found in Nest evaluations in other locations. Whereas Nest evaluations in other locations showed savings of about 11%–15% (Nest 2015), about half of this savings level was found in this study of Florida single-family homes. This likely a result of two reasons:

- Florida homes tend to have high thermal capacitance, with slab-on-grade floors and concrete masonry walls that respond slowly to thermostat changes. Seasonal residents (about 4% of the state population) were specifically excluded from the PDR sample. Such residents, due to long vacancy periods, would likely experience higher savings rates.
- Florida single-family homeowners are older than average (many retirees) and have higher occupancy rates (spend more time at home). These circumstances result in less savings from thermostat changes compared with other demographic groups in other parts of the United States.

That said, attached homes and rental homes in Florida have vacancy rates much higher (13.2%) than other single-family homes (3.8%) in this study (Mazur and Wilson 2011). This is at least partly due to older Florida residents who migrate seasonally—so called "snowbirds"—and inflate the winter population by nearly 800,000 people, but are largely gone during the AC-intensive summer season (Smith and House 2006). These snowbirds may experience higher savings levels from smart thermostats even though they were not part of the evaluation. These higher savings levels could be expected because during the single-family analysis it was clear from visual examination of the data that the Nest thermostat achieved significant savings during vacation or longer periods of vacancy as seen in Figure 46.

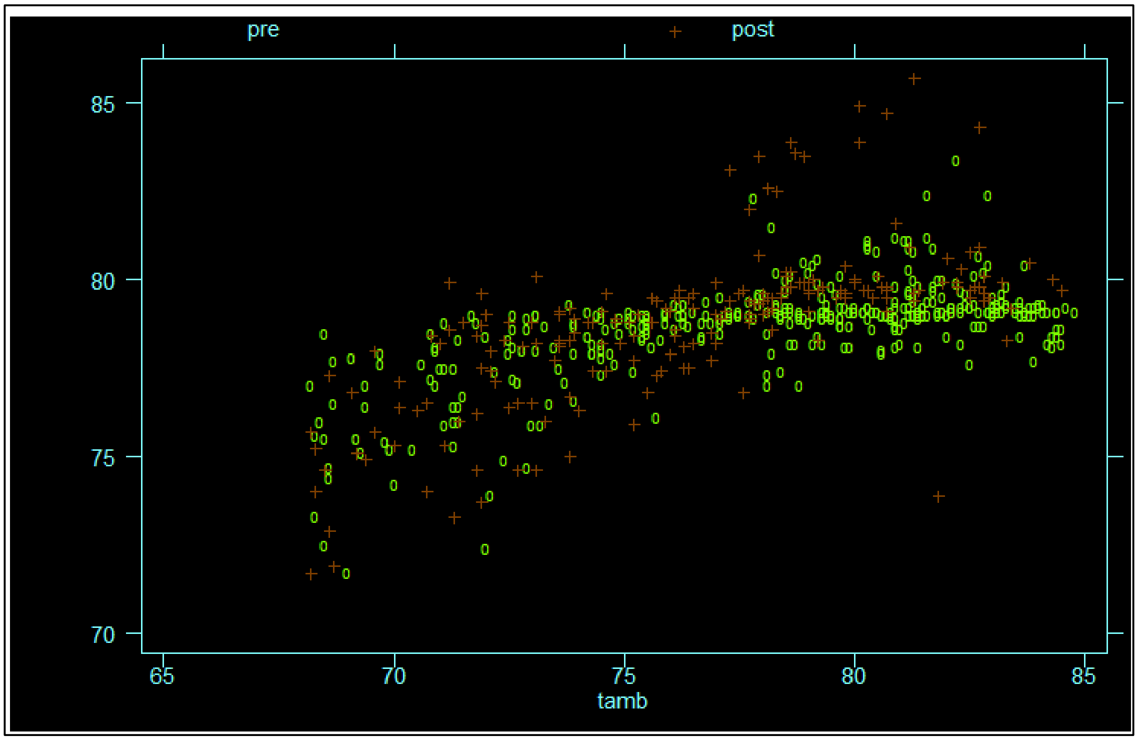


**Figure 46: Pre (green) and post (brown) temperatures at Site 59 plotted against the daily outdoor temperature; note two-week period with higher set points with Nest in the upper right**

The results above will be updated in the Phase II final report, with data from longer time periods as well as an evaluation of RH impacts and evaluation of the effects of summer and winter peaks. Also, in the summer of 2015, a further six Nest thermostats were installed, and that data analysis will be included in the final report.

# 9 Preliminary Evaluation of Heat Pump Clothes Dryers

The electric resistance clothes dryers in eight homes were replaced with new Whirlpool HPCDs. The dryer model (WED99HED) is designed to be approximately 40% more efficient than standard units and was awarded ENERGY STAR®'s Emerging Technology Award.[8] Occupancy and existing washer and dryer makes and models are provide in Table 27.

**Table 27. Heat Pump Clothes Dryer Site Characteristics**

| Site ID | City | # of Occupants | Existing Washer Make | Existing Washer Model | Existing Dryer Make | Existing Dryer Model | Appliance Location |
|---|---|---|---|---|---|---|---|
| **19** | Melbourne | 3 | Whirlpool Cabrio | WTW6200SW2 | Samsung | DV457 | Interior |
| **22** | Cocoa Beach | 2 | Kenmore | 11020712990 | Whirlpool | 4WED5790SQ | Interior |
| **25** | Melbourne | 2 | GE | S2100G2WW | Alliance Speed Queen | ADE30RGS171 TW01 | Interior |
| **28** | Merritt Island | 2 | Whirlpool Duet | WFW9470WR01 | Whirlpool Duet | WED9750WR0 | Exterior |
| **52** | Cocoa | 2 | GE | WHRE5550K2WW | Kenmore | 96284100 | Interior |
| **53** | Melbourne | 1 | GE | WWSR3090T2WW | GE | DWXR473ET2 WW | Interior |
| **58** | Rockledge | 2 | GE | HW, low water, 5600W 24A | GE | GTDN500EM0 WS | Interior |
| **61** | Cocoa Beach | 2 | LG | WM2016CW | Whirlpool | WED9200SQ | Exterior |

The dryers were matched with a Whirlpool 4.5 cubic foot clothes washer (WFW95HED) that had an Energy Guide estimated annual electricity use of 109 kWh/year (shown below in Figure 47) and a modified energy factor of 3.2.

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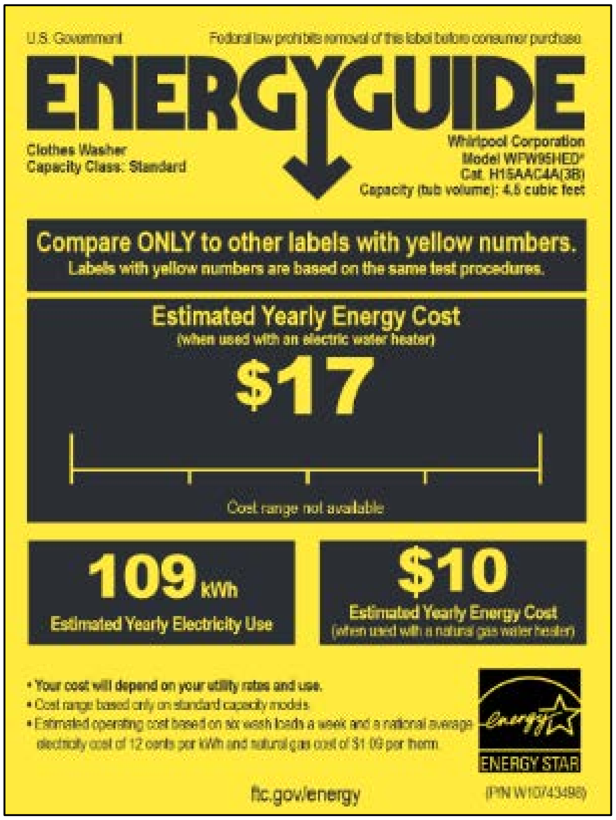
[8] www.startribune.com/energy-guzzling-clothes-dryers-finally-get-more-eco-friendly/292379401/



U.S. Government

Federal law prohibits removal of this label before consumer purchase

ENERGYGUIDE

Clothes Washer
Capacity Class: Standard

Whirlpool Corporation
Model WFW95HED*
Cat. H15AAC4A(3B)
Capacity (tub volume): 4.5 cubic feet

Compare ONLY to other labels with yellow numbers.
Labels with yellow numbers are based on the same test procedures.

Estimated Yearly Energy Cost
(when used with an electric water heater)

$17

Cost range not available

109 kWh
Estimated Yearly Electricity Use

$10
Estimated Yearly Energy Cost
(when used with a natural gas water heater)

- Your cost will depend on your utility rates and use.
- Cost range based only on standard capacity models.
- Estimated operating cost based on six wash loads a week and a national average electricity cost of 12 cents per kWh and natural gas cost of $1.09 per therm.

ENERGY STAR

ftc.gov/energy

(PN W10743498)

Figure 47. Energy Guide label for WFW95HED washer

The HPCD is a 7.3 cubic foot condensing clothes dryer and is unvented, similar to high-efficiency European models. It has both a heat pump section and a supplemental electric heating element. There are three primary modes of dryer operation—eco mode, which mainly uses the heat pump, but with longer drying times; balanced, which uses both heat pump and element operation to achieve faster drying times; and speed mode, which uses both the heat pump and electric resistance elements to dry in the fastest possible time.

The new clothes dryers and washers were installed in late May and early June 2015 in cooperation with the homeowners. Instructions were provide on efficient appliance operation. Seven of the PDR homes had conventional clothes washers and dryers that were then replaced by the efficient Whirlpool models (Figure 48). Site 19 had started the PDR project with a standard washer and dryer, but then had participated in the Phase I retrofits, which included the more efficient Samsung DV457 clothes dryer that was shown to reduce consumption by 26% at this home. Significantly, the occupants of Site 19 do a very large volume of laundry, with baseline dryer energy use of about 8 kWh/day (~3,000 kWh/year). The new HPCD dryer was expected to further reduce their clothes drying energy.

Figure 48. BA-PIRC team member Bryan Amos awaits shipment to one of the heat pump clothes dryer retrofit homes in the Phased Deep Retrofit Project in May 2015

Measured baseline data were from January 1, 2014, to the install date for each washer/dryer pair. The post-installation period data were from the installation date through mid-July 2015, a much shorter period of 30–60 days. This analysis method was deemed acceptable because evaluation of plotted clothes dryer data at each site revealed little in the way of time-of-year seasonality (there was a strong time-of-day element for clothes drying at each site) and each household also showed periodicity relative to the preferred time to do laundry—once every other day, each weekend or even every day. Figure 49 shows the time series data for Site 25 from January 2014 to present with the daily clothes dryer demand plotted as well as the monthly summed clothes dryer energy. The timing and effect of the HPCD retrofit is clear in the data with measured clothes dryer electricity falling by more than half.

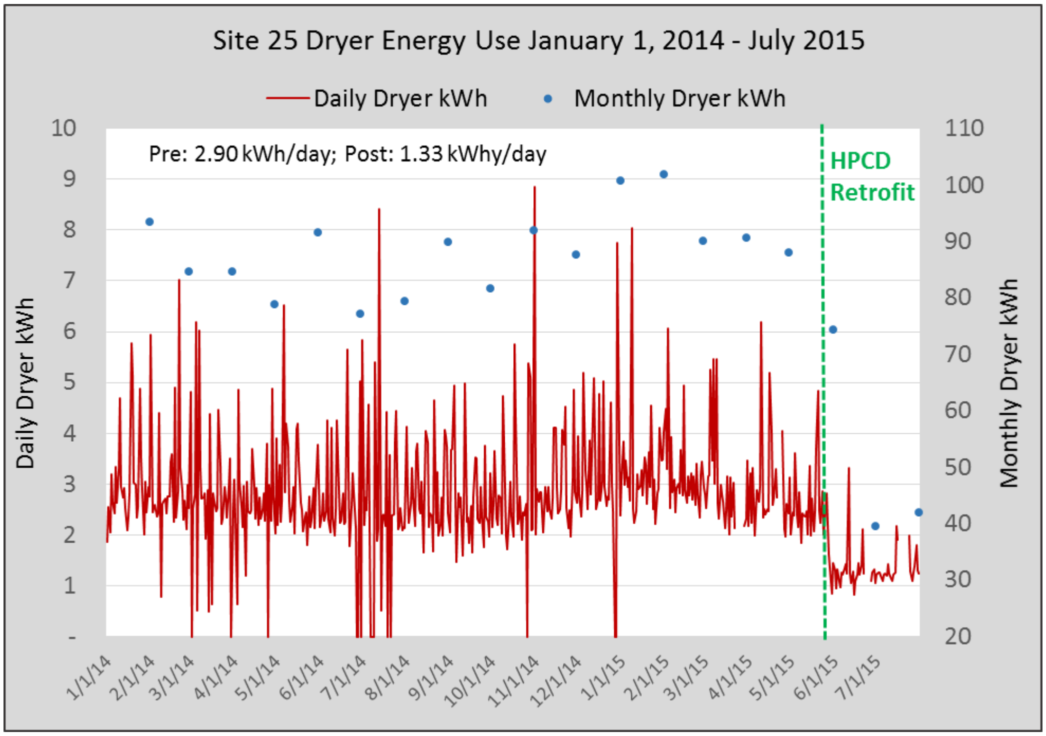


**Figure 49. Time series for clothes dryer energy at Site 25.**

Table 28 shows the measured data in the pre- and post-installation periods as of mid-July 2015 for each site as well as the averages. Washer energy (which is typically quite modest) was not collected in the baseline period, and therefore not evaluated. It should be noted, too, that the savings level for clothes drying may not only reflect the efficiency of the clothes dryer, but also of the clothes washer in reducing the amount of moisture left in the clothes to be dried.

**Table 28. Summary Heat Pump Clothes Dryer Retrofits**

| Interior | Site # | Install Date | Pre- (2014-15) | | Post- (2015) | | Savings | | People |
|---|---|---|---|---|---|---|---|---|---|
| | | | Daily kWh | Annual kWh | Daily kWh | Annual kWh | Annual kWh | % | |
| Y | 58 | May 14 | 1.47 | 537 | 1.02 | 373 | 164 | 30.5% | 2 |
| Y | 52 | May 26 | 1.46 | 533 | 0.85 | 310 | 223 | 41.8% | 2 |
| Y | 25 | May 27 | 2.90 | 1,057 | 1.33 | 484 | 573 | 54.2% | 2 |
| N | 61 | May 28 | 1.28 | 467 | 0.74 | 270 | 197 | 42.2% | 2 |
| N | 28 | June 1 | 2.45 | 894 | 1.53 | 559 | 335 | 37.5% | 2 |
| Y | 53 | June 1 | 2.20 | 803 | 0.83 | 303 | 500 | 62.3% | 2 |
| Y | 19[a] | June 3 | 7 | 2,555 | 5.38 | 1,964 | 591 | 23.1% | 4 |
| Y | 22 | June 5 | 1.67 | 610 | 0.88 | 321 | 289 | 47.4% | 2 |
| **Average** | | | **2.56** | **932** | **1.57** | **573** | **359** | **38.5%** | **2.3** |
| **Median** | | | **1.94** | **707** | **1.11** | **403** | **312** | **42.0%** | **2** |

[a] 2013—November 17, 2013, standard dryer used 8.30 kWh/day

Median energy savings in the pilot demonstration were estimated at 312 kWh/year or 42.0% of median baseline consumption and average savings of 359 kWh/year or 38.5%. Savings results at two sites are noteworthy. The savings for Site 19 would be 35% if based on the baseline unit, rather than more efficient Samsung DV457 unit in operation in 2014, and the owners at Site 58 reported they were not interested in using the eco mode and preferred the speed mode, which resulted in lower savings.

With predicted median annual savings of 312 kWh ($37 at 0.12/kWh), the Whirlpool HPCD, model WED99HED, is not a cost-effective measure at its full cost of $1,328—a current retail price for the appliance including delivery and installation. However, based on the assumption that consumers will only purchase the HPCD if they are in the market for a new appliance, this economic evaluation considers only the incremental cost for the HPCD—the increase in cost for this HPCD model over the consumer's forsaken choice (dryer #2). Because the cost of dryer #2 can vary greatly from consumer to consumer, and the price of dryer #2 dictates economics, this cost-benefit analysis is based on the cost of dryer #2. Supposing dryer #2 costs about $800, the incremental cost of $528 will be paid back in about 14.1 years with a 7.1% annual rate of return. The payback and rate of return for the HPCD option improve with a more costly dryer #2 and can be cost-effectively justified. If, however, dryer #2 costs only $500, simple payback exceeds 20 years, arguably beyond the appliance's life. This rough example of HPCD measure economics suffers from the following assumptions:

- The dryer is paired with a low residual moisture content washing machine, with no additional cost.
- No savings were generated by the paired clothes washing machine.
- The baseline dryer energy in the sample is equal to that of a new electric resistance model.

While there will always be a significant premium on HPCD over resistance models, the incremental cost premium is expected to fall by perhaps one-third based on the European experience.

## 9.1 Homeowner Complaints and Acceptability Issues

Within the operation of the unvented HPCD, the condensed moisture from clothes is passed down a drain and the waste heat from the heat pump and electric resistance elements of the system operation is released into the space. Although the amount of sensible heat released into the space from the non-venting HPCD was expected to be modest given the increased efficiency of the unit, the actual experience showed a very significant quantity of sensible heat was released—more than the comparable amount of heat released to the interior from the conventional electric resistance vented clothes dryer. Figure 50 plots the temperature measured inside the laundry room at Site 25 a few weeks before and after the installation of the new unvented HPCD, installed May 27, 2015. Site 25 provides a particularly telling illustration of the issue given their regular, daily clothes washing. Pre-retrofit, the temperature during appliance operation rises from about 80°F to 83–84°F. However, post-HPCD dryer installation, the utility room temperature frequently exceeded 95°F and nearly approached 100°F. This is exceedingly uncomfortable, particularly because many clothes dryers in Florida are located in utility rooms in an effort to make the laundry operation a less onerous duty.

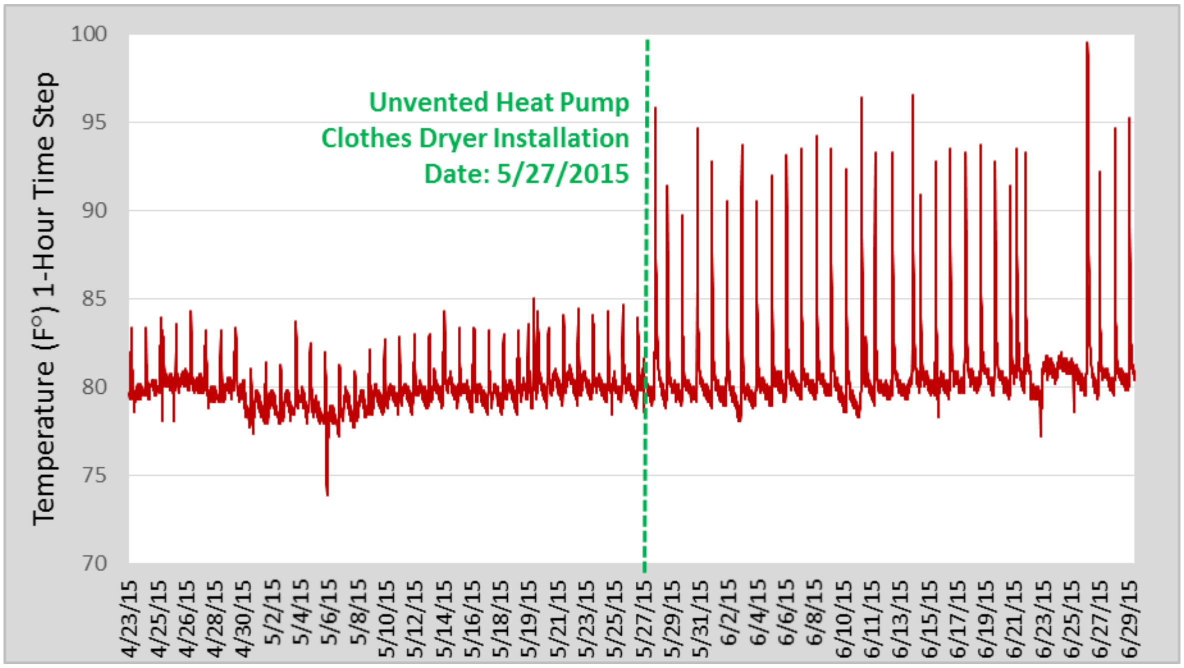


**Figure 50. Site 25 laundry room temperature pre- and post-unvented heat pump clothes dryer installation**

Approximately half of clothes dryers in the state are contained in utility rooms that are either conditioned or semi-conditioned. Six of the eight HPCDs in the Phase II project research were located in utility rooms. It is also likely that operation of the interior HPCD may have led to increased space cooling energy at the homes although time did not allow this analysis, which will be performed at a later date.

Notably, four other sites complained of both noise and excessive heat during system operation (19, 53, 58, and 61). Such issues, particularly excess heat release, could limit adoption of the technology in hot and humid Florida where homeowners are very much heat-adverse. A HPCD vented to the outside is much more likely to be popular in this climate. Meanwhile, the researchers shared the findings with Whirlpool and the manufacturer is reportedly looking into several modifications to mitigate the excessive heat issue.

# 10 Evaluation of Variable Speed Pool Pump

Existing pool pumps were replaced with VSPPs in five retrofit homes (Table 29). Energy and demand savings were calculated using 6 months of post-retrofit data and are evaluated for each site below.

**Table 29. Variable Speed Pool Pump Site Characteristics**

| Site # | City | # of Occupants | Pool Size (gals) | Original Pump (horsepower) |
|---|---|---|---|---|
| **13** | Merritt Island | 2 | 15,000 | 1 |
| **28** | Merritt Island | 2 | 18,000 | 1 |
| **41** | Bonita Springs | 2 | 12,000 | 2 |
| **44** | Naples | 2 | 14,000 | 1.5 |
| **50** | Melbourne | 4 | 14,000 | 0.25/1.5 (2-speed) |

The tables and figures for each site include all measured energy data over the entire pre- and post-retrofit periods. Plots represent an "average" daily energy profile over the entire measurement period rather than an actual day. Runtime hours/day are averages calculated over each period to provide a comparison of equivalent runtime at the average peak power draw, essentially the actual runtimes for single speed pumps and a representation of equivalent runtime (at peak) for the VSPPs. Actual runtimes of the VSPPs (at all speeds) are noted in the narrative.

## 10.1 Site 13 Evaluation

Pre-retrofit monitoring of the 1-horsepower single-speed pump was conducted for 275 days (August 22, 2012–May 23, 2013). Runtime during this period averaged 5.6 hours per day with an average draw of 1.66 kW for an average daily energy use of 9.3 kWh as shown in Table 30. Runtime of the single speed pump was reduced to 5.5 hours per day during the shallow retrofit resulting in a 5% measured savings with average daily energy use reduced to 8.8 kWh over a period of 598 days (May 25, 2013–January 12, 2015).

**Table 30. Measured Pool Pump Energy for Site 13**

| | Monitored (days) | Runtime (hours/day) | Average (kWh/day) | Energy Savings | Average kW Draw | Demand Savings |
|---|---|---|---|---|---|---|
| **1-Horsepower, 1-Speed Pump** | 275 | 5.6 | 9.3 | | 1.66 | |
| **Adjusted Schedule** | 598 | 5.5 | 8.8 | 5% | 1.60 | 3% |
| **New VS Pump** | 175 | 5.9 | 3.0 | 68% | 0.51 | 69% |

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

A VSPP and new filter were installed on January 13, 2015. The post-retrofit evaluation period ending July 7, 2015, showed a 68% reduction in measured energy use and average hourly demand over the pre-retrofit scenario as shown in Figure 51. The 3-hp Pentair VSPP ran an equivalent of 5.9 hours per day at the average peak draw of 0.51 kW with an average energy use of 3.0 kWh/day over the 6-month post-retrofit period. When all hours of runtime are included, the pump was active at various speeds for roughly 9 hours per day.

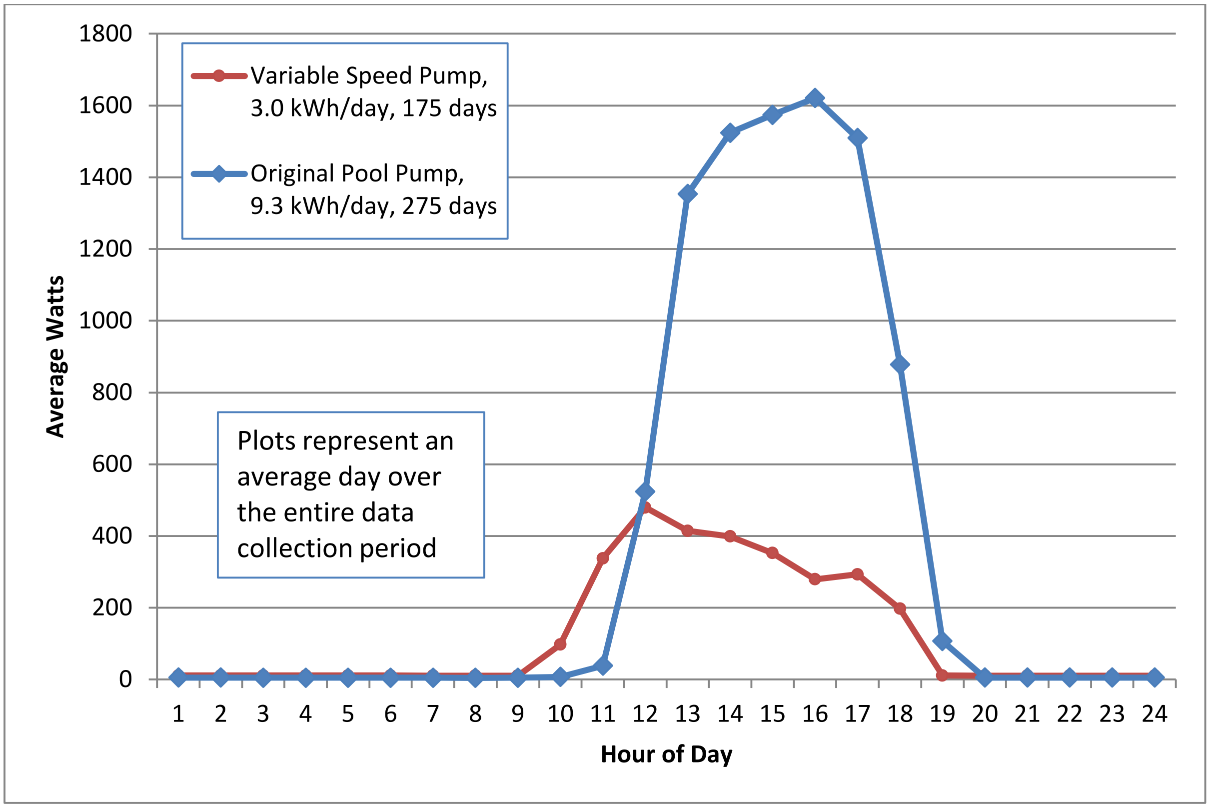


**Figure 51. Average time-of-day pool pump demand at Site 13 as originally found (blue) and after variable speed pump retrofit (red)**

## 10.2 Site 28 Evaluation

Energy savings at Site 28 were significantly less than at the four other retrofit sites. This site had a different electrical configuration, with the pump powered by a single-phase 120V circuit rather than the typical 240V circuit. Pre-retrofit monitoring of the 1-hp single-speed pump was conducted for 255 days (September 18, 2012–May 30, 2013). Runtime during this period averaged 6.6 hours per day with an average draw of 1.52 kW for an average daily energy use of 10.0 kWh (Table 31). Runtime of the single-speed pump was reduced to 5.8 hours per day during the shallow retrofit, resulting in a 9% measured savings with average daily energy use reduced to 9.1 kWh over a period of 591 days (June 1, 2013–January 12, 2015).

**Table 31. Measured Pool Pump Energy for Site 28**

| | Monitored (days) | Runtime (hours/day) | Average (kWh/day) | Energy Savings | Average kW Draw | Demand Savings |
|---|---|---|---|---|---|---|
| **1 Horsepower, 1-speed pump** | 255 | 6.6 | 10.0 | | 1.52 | |
| **Adjusted Schedule** | 591 | 5.8 | 9.1 | 9% | 1.56 | -3% |
| **New, VS Pump** | 165 | 4.0 | 5.1 | 49% | 1.30 | 14% |

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

A VSPP and new filter were installed on January 23, 2015. Six months of data collection ending July 7, 2015, show a 49% average reduction in measured energy use compared to the pre-retrofit condition (Figure 52). The 1.5-hp Pentair VSPP ran the equivalent of 4.0 hours per day at the average peak draw of 1.30 kW with an average energy use of 5.1 kWh/day over the 6-month post-retrofit period. When all hours of runtime are included, the pump was active at various speeds for roughly 9 hours per day.

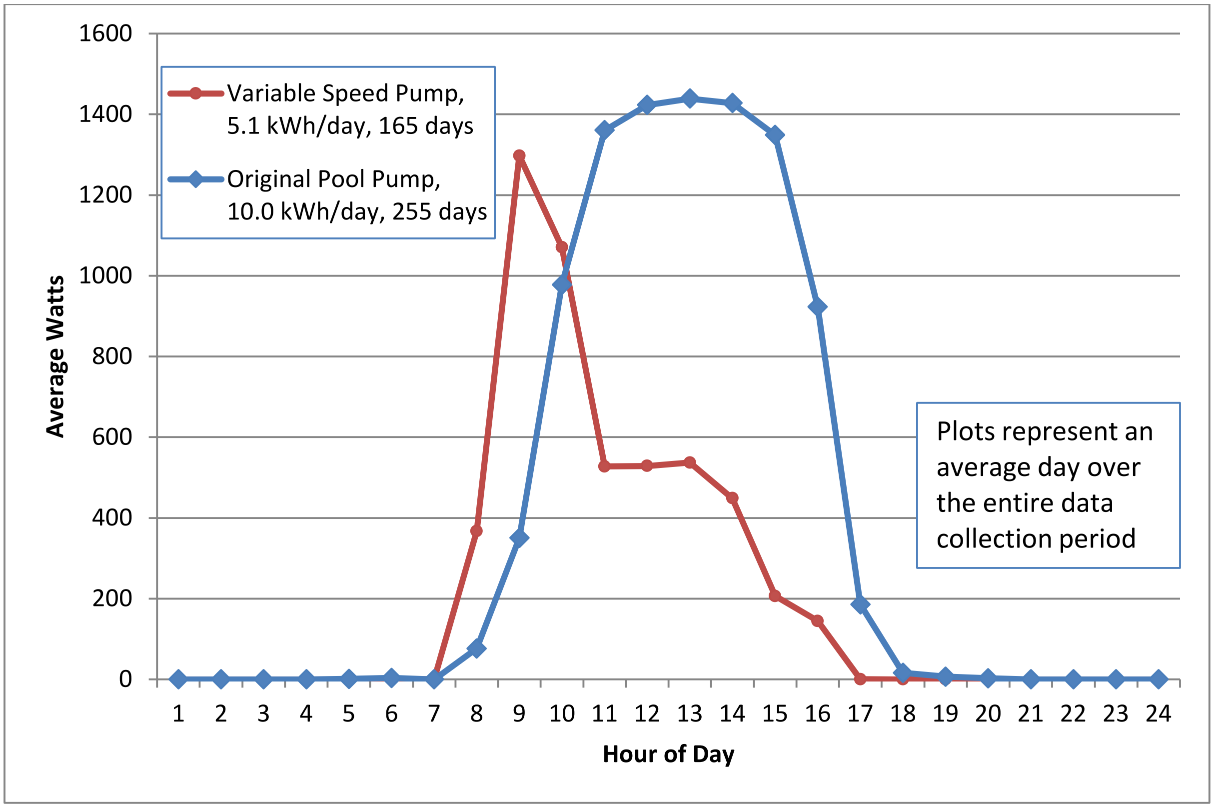


**Figure 52. Average time-of-day pool pump demand at Site 28 as originally found (blue) and after variable speed pump retrofit (red)**

## 10.3 Site 50 Evaluation

Pre-retrofit equipment at this site was a 2-speed pump running at either 0.25 or 1.5 hp. This pump was monitored for 161 days from December 13, 2012–May 22, 2013, with an average runtime of 7.3 hours per day primarily in high-speed mode and an average peak draw of 1.82 kW

(Table 32). Average daily energy use was 13.3 kWh. Average runtime of the 2-speed pump was reduced to 7.2 hours per day during the shallow retrofit period, resulting in a 16% measured savings with average daily energy use reduced to 11.1 kWh over a period of 599 days (May 24, 2013–January 12, 2015).

**Table 32. Measured Pool Pump Energy for Site 50**

| | Monitored (days) | Runtime (hours/day) | Average (kWh/day) | Energy Savings | Average kW Draw | Demand Savings |
|---|---|---|---|---|---|---|
| **0.25-1.5 Horsepower 2-Speed Original Pump** | 161 | 7.3 | 13.3 | | 1.82 | |
| **Adjusted Schedule** | 599 | 7.2 | 11.1 | 16% | 1.54 | 15% |
| **New VS Pump** | 175 | 5.9 | 3.1 | 77% | 0.52 | 71% |

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

A VSPP and new filter were installed on January 13, 2015. Data collected during the post-retrofit period ending July 7, 2015, showed a 77% reduction in measured energy use and 71% less average hourly demand over the pre-retrofit scenario as shown in Figure 53. The 3-horsepower Pentair VSPP ran the equivalent of 5.9 hours per day at the average peak draw of 0.52 kW with an average energy use of 3.1 kWh/day over the 6-month post-retrofit period. When including all hours of runtime the pump was active at various speeds for roughly 12 hours per day.

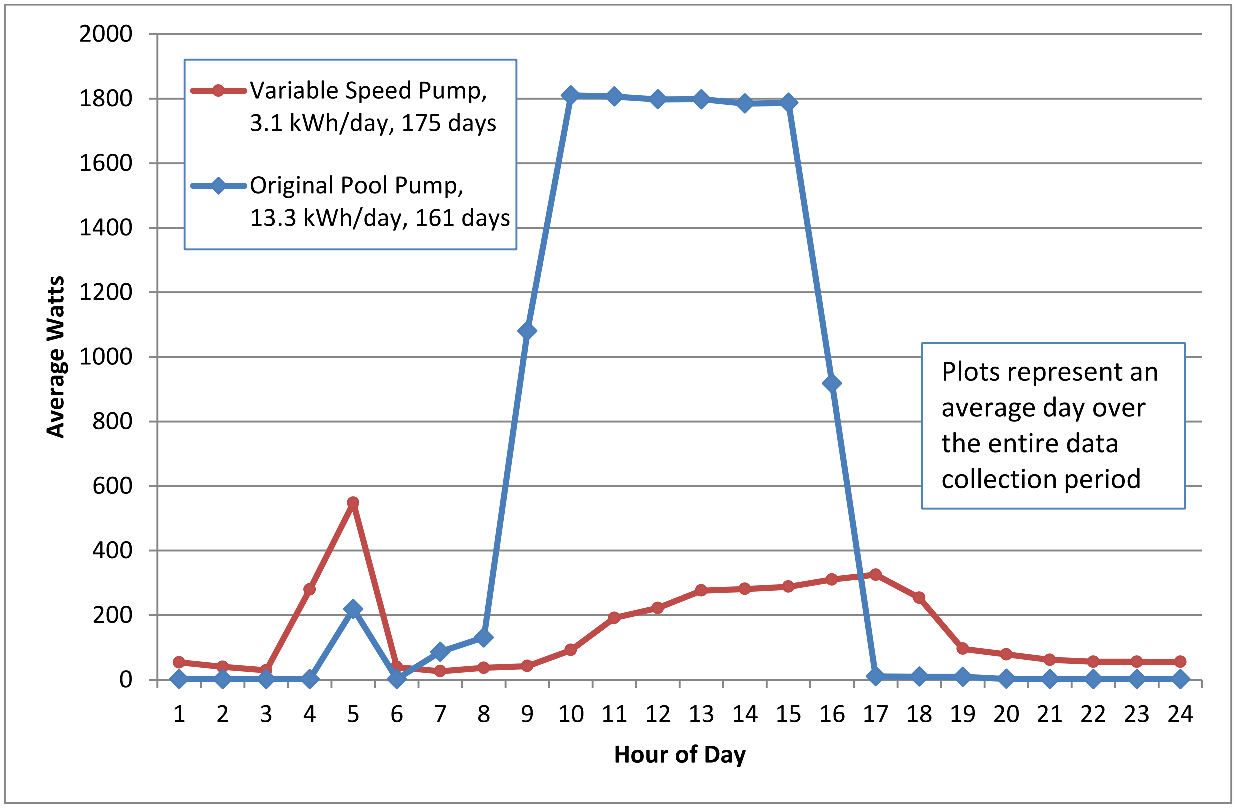


Figure 53. Average time-of-day pool pump demand at Site 50 as originally found (blue) and after variable speed pump retrofit (red)

## 10.4 Site 41 Evaluation

Pre-retrofit monitoring of the 2-horsepower single-speed pump was conducted for 219 days (November 11, 2012–June 17, 2013). Runtime during this period averaged 4.5 hours per day with an average peak draw of 2.35 kW resulting in an average daily energy use of 10.7 kWh (Table 33). Measurements show a slight increase in runtime during the 574-day shallow retrofit period (June 18, 2013–January 13, 2015) and almost identical energy use resulting in no (0%) measured savings.

Table 33. Measured Pool Pump Energy for Site 41

| | Monitored (days) | Runtime (hours/day) | Average (kWh/day) | Energy Savings | Average kW Draw | Demand Savings |
|---|---|---|---|---|---|---|
| **2-Horsepower, 1-Speed Pump** | 219 | 4.5 | 10.7 | | 2.35 | |
| **Adjusted Schedule** | 574 | 4.7 | 10.6 | 0% | 2.24 | 5% |
| **New VS Pump** | 174 | 4.7 | 3.4 | 68% | 0.72 | 70% |

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

A VSPP and new filter were installed on January 14, 2015. The post-retrofit evaluation period, ending July 7, 2015, resulted in a 68% reduction in measured energy use and average hourly demand over the pre-retrofit scenario as shown in Figure 54. The 3-horsepower Pentair VSPP ran the equivalent of 4.7 hours per day at the average peak draw of 0.72 kW with an average energy use of 3.4 kWh/day over the 6-month post-retrofit period. When hours of runtime are included, the pump was active at various speeds for roughly 7 hours per day.

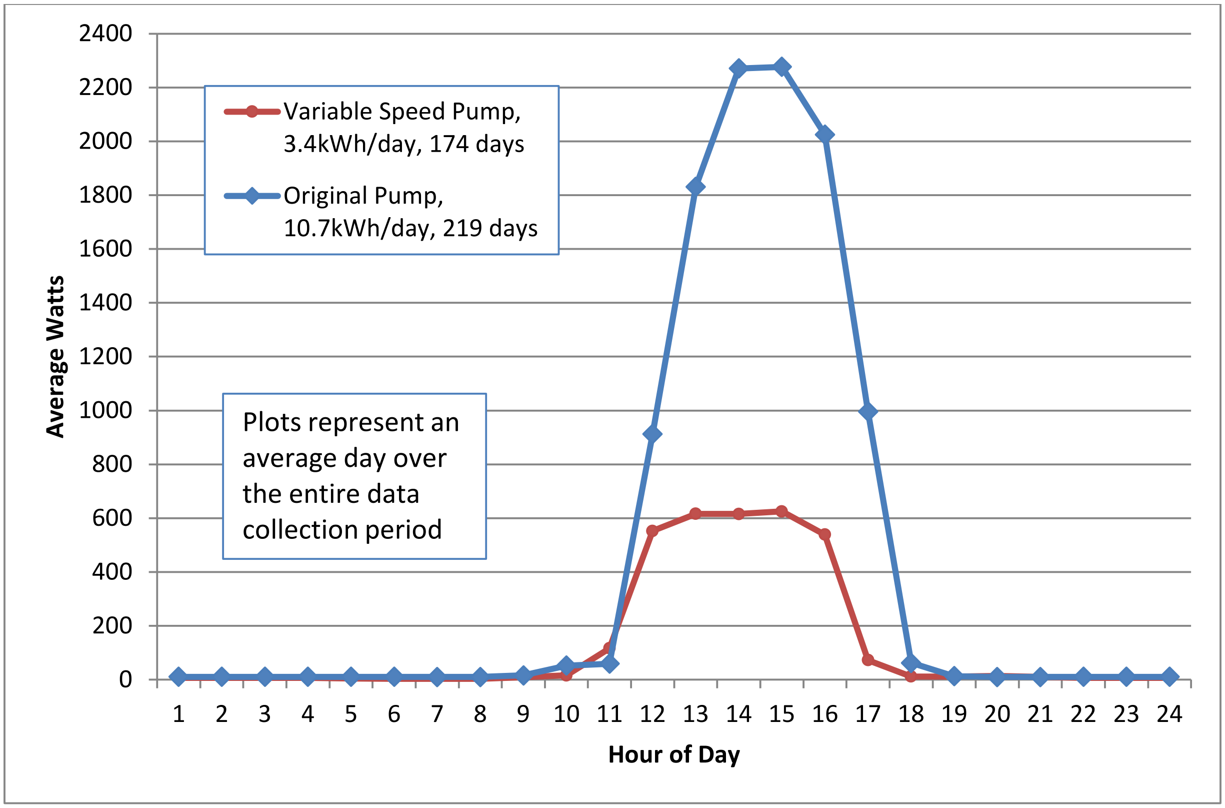


**Figure 54. Average time-of-day pool pump demand at Site 41 as originally found (blue) and after variable speed pump retrofit (red)**

## 10.5 Site 44 Evaluation

Pre-retrofit monitoring of the 1.5-hp single-speed pump was conducted for 214 days (November 15, 2012–June 16, 2013). Runtime during this period averaged 7.3 hours per day with an average peak draw of 1.78 kW resulting in an average daily energy use of 12.9 kWh (Table 34). Runtime of the single-speed pump was reduced to 5.6 hours per day during the shallow retrofit period resulting in a 24% measured savings with average daily energy use reduced to 9.9 kWh over a period of 575 days (June 18, 2013–January 13, 2015).

**Table 34. Measured Pool Pump Energy for Site 44**

| | Monitored (days) | Runtime (hours/day | Average (kWh/day) | Energy Savings | Average kW Draw | Demand Savings |
|---|---|---|---|---|---|---|
| **1.5-Horsepower 1-Speed Pump** | 214 | 7.3 | 12.9 | | 1.78 | |
| **Adjusted Schedule** | 575 | 5.6 | 9.9 | 24% | 1.77 | -1% |
| **New VS Pump** | 174 | 6.2 | 2.6 | 80% | 0.42 | 76% |

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

A VSPP and new filter were installed on January 14, 2015. The post-retrofit evaluation period, ending July 7, 2015, resulted in an 80% reduction in measured energy use and 76% lower average hourly demand compared with the pre-retrofit scenario as shown in Figure 55. The 3-horsepower Pentair VSPP ran the equivalent of 6.2 hours per day at the average peak draw of 0.42 kW with an average energy use of 2.6 kWh/day during the 6-month post-retrofit period. When all hours of runtime are included, the pump was active at various speeds for roughly 8 hours per day.

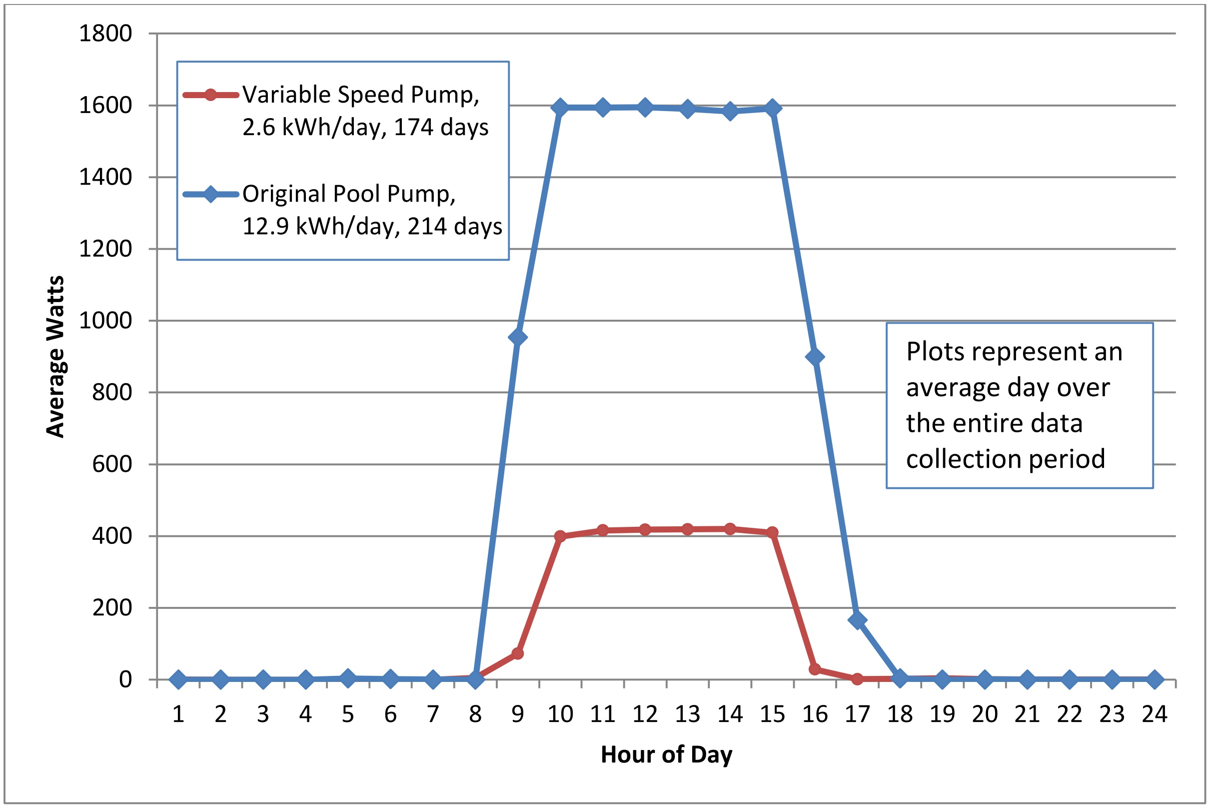


**Figure 55. Average time-of-day pool pump demand at Site 44 as originally found (blue) and after variable speed pump retrofit (red)**

## 10.6 Summary Savings and Cost Analysis

The energy use savings among the five VSPP installations ranged from 49%–80% and 4.9–10.3 kWh/day. Average hourly demand was typically reduced by about 70%, except for one home with a 120V (rather than typical 240V) pump in which demand was reduced by only 14%.

Total costs of equipment and installation of each VSPP in central Florida was $1,500. The installer quoted a standard single-speed pool pump replacement at $650 for a 1-horsepower unit. With a median savings from the 5 homes of 7.3 kWh/day (68%), annual cost savings at $0.12/kWh amounts to $320. Assuming the incremental cost above the single-speed unit, this results in a rapid simple payback of 2.7 years and an annual rate of return of 38%. While worst-case payback was 4.0 years at site 28, sites 50 and 44 exhibited payback periods of less than 2 years.

# 11 Conclusions

Seven innovative technology energy-efficiency measures were installed in a subsample of the PDR project test sites under Phase II of the project. End-use savings and economics revealed several promising measures for inclusion into a refined deep-retrofit package. However, other measures, such as the EIFS and window retrofit, may only be justifiable based on increased comfort, acoustical advantages, or aesthetics. Findings for each energy-efficiency measure are summarized below.

**Supplemental Mini-Split Heat Pump**
The project involved the evaluation of 25.5 SEER, 1-ton, ductless MSHPs installed in the main living areas of six study homes as a supplemental system to the main central cooling air conditioner or heat pump. Results suggest cooling energy use savings of 37.0% (10.9 kWh/day at 80°F average ambient temperature), and heating energy use savings of 59.0% (13.2 kWh/day at 50°F average ambient temperature). In terms of percentages, heating energy reductions were significantly greater than cooling savings in the four homes with electric resistance central heating.

Measure economics, assuming a current installation price of about $3,500, are potentially attractive, with a suggested payback of 12.4 years and 8.1% annual rate of return. As the MSHP market continues to mature, the economics will likely further improve. A large added benefit to the consumer is a redundant heating and cooling system—highly desirable given the failure rate of central AC systems.

**Space-Coupled Heat Pump Water Heater**
The results from evaluations of eight homes retrofitted with an HPWH coupled to the conditioned living space show a median of 8.2% (1.1 kWh/day) space cooling energy savings. Meanwhile, space heating energy use showed negative savings of 8.9% (0.8 kWh/day), with considerable variation among homes.

The effect of space-coupled HPWH retrofits on DHW energy use was also evaluated. Among the six homes in which an electric resistance-type tank was replaced with HPWH coupled to the conditioned space, average DHW energy savings were 53.3% (3.2 kWh/day). Two of the sites had HPWHs operating for a substantial amount of time prior to ducting, enabling the effect of the coupling on DHW energy use to be isolated. As expected, due to changing the HPWH heat source from warmer garage air to room temperature air and somewhat reducing system airflow, the coupling slightly reduced potential DHW energy savings from an uncoupled, garage-located HPWH by 0.4 kWh/day. The DHW energy penalty is estimated to be 10.6%.

The cost to install the ducting to couple the HPWH to the conditioned space, inclusive of materials and labor, was $620. Median annual cooling savings for the ducted sites was 412 kWh or $49/year, yielding a simple payback of about 13 years. An average heating energy penalty of 79 kWh or $16 cut these savings by one-third, yielding a simple payback about the length of the expected 20-year life of the ducting. This penalty could be reduced or eliminated with a damper system enabling cold HPWH exhaust air to be diverted from the conditioned space during winter. Aside from the premium for the HPWH itself, there is no cost associated with locating an

HPWH inside the conditioned space such as a utility room. In this case, net savings on space-conditioning and water heating are immediately realized. DHW energy savings for an interior-coupled HPWH in Florida is slightly less than for a garage-located HPWH due to a lower temperature heat source, but the space-conditioning energy savings outweighs the slight DHW energy loss.

**Exterior Insulation Finish System**

Space cooling evaluation results for the single home receiving R-7.7 hr-ft$^2$-°F/Btu exterior wall insulation show cooling energy use reductions of 18.2% (5.0 kWh/day at 80°F). Heating energy use was projected to increase by 12.3% (-1.0 kWh/day at 50°F), however little significance can be attached to the results given the poor statistical models resulting from Florida's short and highly variable heating season. At a cost approaching $20,000, the EIFS retrofit is not cost-effective for Florida homes. However, the measure may be justified by other benefits such as better interior comfort and a more stable interior temperature.

Given the variations in occupancy behavior and internal gains, the savings from EIFS in Florida will differ considerably for individual homes. With considerable variance in the regression analysis, a simulation evaluation was conducted to see how these varying factors might influence results and found:

- Annual savings from EIFS vary substantially depending on the interior thermostat setting.
- Exterior wall color has a very large impact on potential EIFS cooling energy savings.
- Pre-existing shading from adjacent buildings, porches, blinds, and insect screens impacts EIFS savings, but these impacts are modest with light-colored walls.
- Greater internal heat gains from appliance and plug loads reduce the savings from better wall insulation, particularly for cooling.

**Advanced Windows**

Advanced solar control windows were installed in three homes (SHGC: 0.19–0.24; U-values 0.27–0.30 Btu/ft$^2$-ºF). Analysis showed cooling season energy savings ranged from -4.8%–27% (-0.7 to 6.9 kWh/day at 80°F) and heating energy savings of 6.8% (4.2 kWh at 50°F) for the one home with heating season data available. The cost, $8,000–$10,000, means window retrofits are not cost-effective energy-efficiency strategies for Florida homes. This evaluation, however, did demonstrate the potential for a window retrofit to improve comfort with more stable indoor temperatures. Moreover, consumers overwhelmingly favor the measure based on improvements to house appearance, thermal comfort, and acoustic qualities.

Limited observations for the few case studies yielded suspect results and re-evaluations are planned for a subsequent report based on a greater quantity of post-retrofit data. A range in results is not unexpected given that the buildings varied in their degree of internal and external window shading, internal set points, and internal heat gains. A simulation evaluation was conducted to see how various factors such as occupancy behavior might be influencing results, and the findings include:

- Pre-existing shading from adjacent buildings, porches, blinds, and insect screens has a very large impact on potential savings, reducing them by more than 50% relative to standard assumptions (which also includes interior shading).
- Greater internal gains from appliance and plug loads reduce the cooling energy savings from advanced windows as interior temperatures tend to be higher during nighttime hours when ambient temperatures are lower and heat loss is beneficial.
- The annual savings of advanced windows varies very significantly by the interior thermostat setting. Low cooling temperatures produce savings; temperatures higher than 78$^o$F yield very low savings levels.

**Smart Thermostat**

Evaluations of the 19 Nest thermostats installed as part of Phase II show average cooling energy savings of 7.4% (1.6 kWh/day at 80°F), but with a very high degree of variation. The median savings were 4.8% (1.1 kWh/day). The analysis showed that eight out of 19 sites experienced negative savings, which was largely an artifact of pre-retrofit thermostat habits. On average, the positive savings were larger in magnitude than the absolute difference at sites that experienced negative savings. Space heating savings from the Nest were also highly variable, particularly given the very short Florida winter heating season. Average savings were 8.0% (1.1 kWh/day at 50°F) although the median was higher, at 15.0% (2.2 kWh/day).

The economics reveal the Nest thermostat to be an excellent low-cost retrofit measure. Simple payback for the installation of the $250 Nest is estimated to be 4.6 years with an annual rate of return 21.9%. The evaluations of two Lyric installations had highly disparate findings with no conclusive results, although consumer acceptance of the technology appeared more limited.

On a site-by-site basis, pre-installation thermostat behavior and willingness to use available Nest features made a difference for individual homes. For example, a site with a programmable thermostat that was effectively used prior to the retrofit cannot be expected to experience much savings. On the other hand, those with low levels of vacancy cannot be expected to achieve much energy reduction and, in particular, defeating the “away” function appeared to affect savings adversely.

**Heat Pump Clothes Dryer**

Energy use savings were achieved among all eight homes that received an unvented condensing (HPCD). The estimated median energy savings are 42.0% (312 kWh/year) and average annual savings are 38.5% (359 kWh/year). ENERGY STAR washing machines were installed along with the clothes dryer. The energy-efficient washing machines are likely removing more moisture from the laundry loads than the replaced washers, thus also contributing to these savings.

With a current retail cost of $1,328 for the dryer, there is a significant premium on the HPCD compared with standard resistance models. Cost-effectiveness assumes incremental cost only, but varies with consumer preferences and will depend on the cost of the standard model. Meanwhile, the incremental cost premium will likely fall as the market matures with increased competition, thus improving the economics of the HPCD measure.

Although the HPCD use less electricity than a standard resistance dryer, they still release a significant amount of heat from their operation. The unvented units that were located inside the home led to very high utility room temperatures and increases in cooling that may compromise identified savings. Thus, these unvented clothes dryers are only appropriate in Florida if they will be installed outside of the conditioned space, typically in the garage.

### Variable Speed Pool Pump

Evaluation of the VSPPs installed in five homes showed 68% median savings (7.3 kWh/day), ranging from 49% to 80% (4.9–10.3 kWh/day). Average hourly demand often occurring at or near the utility peak period was typically reduced by about 70%.

Annual cost savings amounted to $320 assuming the 2,665 kWh/year median savings of the five homes. Even given the high VSPP cost ($1,500 installed), this made for an exceedingly rapid simple payback of 2.7 years and a 38% annual rate of return. Three similar retrofits analyzed under Phase I of the study showed even greater savings (85%, 12.6 kWh/day), so the Phase II result is likely conservative. This appears to be a particularly important measure given Florida's 33% saturation of homes with swimming pools.

A summary of the PDR Phase II retrofit study energy savings results are provided in Table 35. Annual savings for space cooling, space heating, and non-HVAC energy are provided graphically in Figure 56.

**Table 35. Phased Deep Retrofit Phase II Measures Evaluation Savings Summary**

| | | Daily Energy Savings (kWh/day) | | | Annual Energy Savings (kWh/year) | | | |
|---|---|---|---|---|---|---|---|---|
| **Option** | **Sample Size** | **Space Cooling** | **Space Heating** | **Non-HVAC** | **Space Cooling** | **Space Heating** | **Non-HVAC** | **Total** |
| **Supplemental MSHP** | 6 | 10.9 | 13.2 | 0.0 | 2,176 | 162 | - | 2,337 |
| **SpaceCoupled HPWH**[a] | 8 | 1.1 | -0.8 | 3.2 | 131 | (22) | 1,175 | 1,284 |
| **EIFS** | 1 | 5.0 | -1.0 | 0.0 | 1,070 | (34) | - | 1,036 |
| **Advanced Windows**[b] | 3 | -0.5 | 4.2 | 0.0 | (118) | 19 | - | (99) |
| **Nest Thermostat** | 19 | 1.6 | 1.1 | 0.0 | 435 | 22 | - | 457 |
| **HP Clothes Dryer** | 8 | 0.0 | 0.0 | 0.8 | - | - | 312 | 312 |
| **Var. Speed Pool Pump** | 5 | 0.0 | 0.0 | 7.3 | - | - | 2,665 | 2,665 |

[a] Non-HVAC savings for the HPWH measure is the average DHW energy savings for the six sites at which electric resistance tank types were replaced with heat pump types, three of which were located inside the home and three in the garage coupled to the interior space.

[b] Predicted space cooling savings for the window retrofits ranged from (0.7) to 6.9 kWh/day, depending on assumptions, and the median was (0.5) kWh/day.

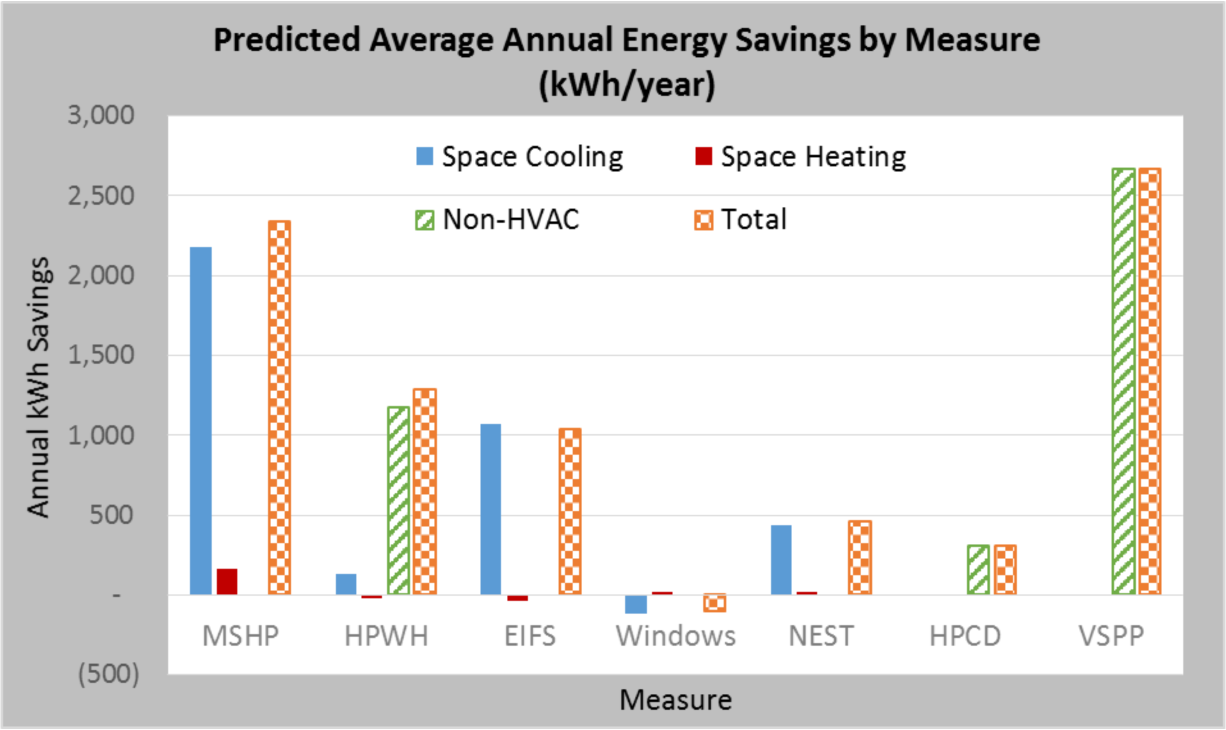


**Figure 56. Average annual energy savings for the Phased Deep Retrofit Phase II evaluation measures**

## Looking Forward

Future reporting will include revised savings results for the supplemental MSHPs and smart thermostats based on data monitored over a longer period than was possible for this report. The future report will also include data from recent additional installations of these two measures. There will be an evaluation of two replacement MSHPs—one a single-coil ducted installation, the other with a multi-split configuration.

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# **Appendix A:** Regressions from Analysis of Mini-Split Heat Pump Installations

Coefficients are in kWh/day.

Site 24: Balance point: 65°F for cooling and heating
Cooling: Pre: -149.8 + 2.22(Tamb); Post: -126.8 + 1.97(Tamb)
Heating: Pre: 94.9–1.50 (Tamb); Post: 27.2–0.39 (Tamb)

Site 3: Balance point: 67°F cooling; 65°F heating
Cooling: Pre: -193.9 + 2.88 (Tamb); Post: -133.4 + 1.96(Tamb)
Heating: Pre: 17.4–0.25 (Tamb); Post: 17.7–0.27(Tamb)

Site 16: Balance point: 68°F cooling; 68°F heating
Cooling: Pre: -234.9 + 3.35(Tamb); Post: -187.2 + 2.67(Tamb)
Heating: Pre: 76.5–1.13(Tamb); Post: 48.8–0.86(Tamb)

Site 12: Balance point: 65°F cooling and heating
Cooling: Pre: -190 + 2.80(Tamb); Post: -93 + 1.37(Tamb)
Heating: Pre: 68.–1.08(Tamb); Post: 62.4–0.98 (Tamb)

Site 27: Balance point: 70°F cooling and heating
Cooling: Pre: -305.5 + 4.50(Tamb); Post: -134.5 + 2.06(Tamb)
Heating: Pre: 210.2–2.81 (Tamb); Post: 95.2–1.30(Tamb)

Site 60: Balance point: 65°F for cooling and heating
Cooling: Pre: -106.2 + 1.61(Tamb); Post: -86.8 + 1.26(Tamb)
Heating: Pre: 111.8–1.72 (Tamb): Post: 28–0.43 (Tamb)

# **Appendix B:** Regressions from Analysis of Coupled Heat Pump Water Heaters

Coefficients are in kWh/day.

Site 1: Balance point: 68°F for cooling
Cooling: Pre: 17.1 + 2.39(Tamb-Tint); Post: 15.2 + 2.23(Tamb-Tint)
Heating: N/A

Site 5: Balance point: 65°F for cooling; 65°F for heating
Cooling: Pre: 45.6 + 5.93(Tamb-Tint); Post: 44 + 6.13(Tamb-Tint)
Heating: Pre: 49.3–0.74(Tamb); Post: 194.8–3.05(Tamb)

Site 9: Balance point: 68°F for cooling; 64°F for heating
Cooling: Pre: 12.1 + 1.46 (Tamb-Tint); Post: 10.6 + 1.37(Tamb-Tint)
Heating: Pre: 48.5–0.76(Tamb); Post: 99.3–1.56(Tamb)

Site 13: Balance point: 70°F cooling
Cooling: Pre: 7.4 + 1.42(Tamb-Tint); Post: 6.6 + 1.32(Tamb-Tint)
Heating: N/A

Site 26: Balance point: 62°F for cooling; 60°F for heating
Cooling: Pre: 10.5 + 1.20(Tamb-Tint); Post: 9.1 + 1.16(Tamb-Tint)
Heating: Pre: 37.8–0.62(Tamb); Post: 32.6–0.52(Tamb)

Site 50: Balance point: 65°F for cooling; 64°F for heating
Cooling: Pre: 21.4 + 2.47(Tamb-Tint); Post: 20.8 + 2.65(Tamb-Tint)
Heating: Pre: 153.89–2.42(Tamb); Post: 164.97–2.65(Tamb)

Site 51: Balance point: 70°F for cooling
Cooling: Pre: 15.8 + 2.35(Tamb-Tint); Post: 15 + 2.57(Tamb-Tint)
Heating: N/A

Site 56: Balance point: 69°F for cooling; 69°F for heating
Cooling: Pre: 21.8 + 3.06(Tamb-Tint); Post: 21.7 + 3.50(Tamb-Tint)
Heating: Pre: 159–2.35(Tamb); Post: 164.02–2.42(Tamb)

# **Appendix C:** Regressions from Analysis of Exterior Insulation Finish Systems

Coefficients are in kWh/day.

Balance point: 63°F for cooling; 62°F for heating

Cooling: Pre: 10.9 + 1.8(Tamb-Tint) + 0.5(Qint) + 1.3(Solar)
Post: 2.6 + 1.4(Tamb-Tint) + 0.8(Qint) + 1.6(Solar)

Heating: Pre: 37.9–0.6(Tamb); Post: 40.2–0.6(Tamb)

## **Appendix D:** Regressions from Analysis of Advanced Windows

Coefficients are in kWh/day.

Site 23:

Balance point: 69°F for cooling; 65°F for heating
Cooling: Pre: -108.6 + 1.7(Tamb); Post: -84.8 + 1.3(Tamb)
Heating: Pre: 263.5 - 4.0(Tamb); Post: 235.1 - 3.6(Tamb)

Site 25:

Balance point: Evaluation period low temperature = 73°F
Cooling: Pre: -98.0 + 1.3(Tamb) + 0.3(Qint) + 0.6(Solar)
Cooling: Post: -56.4 + 0.8(Tamb) + 0.3(Qint) + 0.8(Solar)

Site 54 (Advanced Windows Only):

Balance point: 63°F for cooling
Cooling: Pre: -118.9 + 1.7(Tamb) + 0.7(Qint) + 0.7(Solar)
Cooling: Post: -142.7 + 1.9(Tamb) + 0.6(Qint) + 2.0(Solar)

Site 54 (EIFS & Advanced Windows):

Balance point: 63°F for cooling
Cooling: Pre: 16.6 + 2.4(Tamb-Tint) + 0.6(Qint) + 0.6(Solar)
Cooling: Post: 7.7 + 2.4(Tamb-Tint) + 01.0(Qint) + 0.9(Solar)

# **Appendix E:** Installed Nest Serial and Base Numbers

| **Site #** | **Seral Number** | **Base Number** |
|---|---|---|
| **4** | 02AA01AC011406UJ | 02BA03AC021400NB |
| **6** | 02AA01AC011405S9 | 02BA03AC521306DQ |
| **11** | 02AA01AC251405SG | 02BA03AC251401UN |
| **15** | 02AA01AC251407HO | 02BA03AC2514021D |
| **17** | 02AA01AC251405NV | 02BA03AC231405F6 |
| **18** | 02AA01AC25140A9A | 02BA03AC23140A1L |
| **21** | 02AA01AC0114077S | 02BA03AC521304TX |
| **22** | 02AA01AC251407L3 | 02BA03AC231409ZL |
| **28** | 02AA01AC251408NU | 02BA03AC241403lD |
| **29** | 02AA01AC011406X1 | 02BA03AC511308Q2 |
| **34** | 02AA01AC231406E2 | 02BA03AC221401JY |
| **35** | 02AA01AC281404R1 | 02BA03AC271400MC |
| **42** | 02AA01AC22140C37 | 02BA03AC01140569 |
| **45** | 02AA01AC2814022N | 02BA03AC281401E5 |
| **47** | Not recorded | Not recorded |
| **48** | 02AA01AC221409U4 | Not recorded |
| **52** | 02AA01AC011404NC | 02BA03AC5213060R |
| **58** | 02AA01AC0114034J | 02BA03AC011400PS |
| **59** | 02SS01AC25140A8Z | 02BA03AC25140500 |

# **Appendix F:** Regressions from Analysis of Smart Thermostats

## Nest

Coefficients are in kWh/day.

Site 4:
Balance point: 65°F for cooling and heating
Cooling: Pre: -760 + 1.2(Tamb); Post: -92.0 + 1.4(Tamb);
Heating: Pre: 38.7 – –0.6(Tamb); Post: 38.9–0.6(Tamb)

Site 6:
Balance point: 72°F cooling; 69°F heating;
Cooling: Pre: -105.6 + 1.4(Tamb); Post: -92.2 + 1.2(Tamb);
Heating: Pre: 47.7–0.7(Tamb); Post: 39.3–0.6(Tamb)

Site 11:
Balance point: 68°F for cooling and heating
Cooling: Pre: -176.2 + 2.5(Tamb); Post: -184.0 + 2.6(Tamb);
Heating: Pre: 87.5–1.3(Tamb); Post: 73.6–1.1(Tamb)

Site 15:
Balance point: 70°F for cooling and heating
Cooling: Pre: -1480 + 2.0(Tamb); Post: -156.2 + 2.2(Tamb);
Heating: Pre: 55.2 – 0.8(Tamb); Post: 34.8 – 0.5(Tamb)

Site 17:
Balance point: 67°F cooling; 65°F heating;
Cooling: Pre: -79.1 + 1.2(Tamb); Post: -94.0 + 1.4(Tamb);
Heating: Pre: 25.3 – 0.4(Tamb); Post: 22.8 – 0.3(Tamb)

Site 18:
Balance point: 66°F cooling
Cooling: Pre: -169.5 + 2.4(Tamb); Post: -125.5 + 1.8(Tamb);

Site 21:
Balance point: 66°F for cooling and heating
Cooling: Pre: -178.2 + 2.7(Tamb); Post: -103.4+ 1.5(Tamb);
Heating: Pre: 86.9 – 1.3(Tamb); Post: 156.7 – 2.5(Tamb)

Site 22:
Balance point: 70°F for cooling
Cooling: Pre: -206.9 + 2.9(Tamb); Post: -176.0 + 2.5(Tamb);

Site 28:
Balance point: 67°F for cooling and heating

Cooling: Pre: -189.3 + 2.6(Tamb); Post: -103.4 + 1.5(Tamb);
Heating: Pre: 70.9– 1.1(Tamb); Post: 44.1 – 0.7(Tamb)

Site 29:
Balance point: 68°F for cooling and heating
Cooling: Pre: -92.2 + 1.3(Tamb); Post: -84.8 + 1.2(Tamb);
Heating: Pre: 69.7– 1.1(Tamb); Post: 44.0 – –0.7(Tamb)

Site 34:
Balance point: 64°F for cooling
Cooling: Pre: -219.4 + 3.1(Tamb); Post: -240.0 + 3.4(Tamb);

Site 35:
Balance point: 67°F for cooling and heating
Cooling: Pre: -214.1 + 3.1(Tamb); Post: -235.6 + 3.4(Tamb);
Heating: Pre: 97.4–1.4(Tamb); Post: 110.1–1.6(Tamb)

Site 42:
Balance point: 65°F for cooling and heating
Cooling: Pre: -77.4 + 1.2(Tamb); Post: -70.8 + 1.1(Tamb);
Heating: Pre: 163.2–2.5(Tamb); Post: 77.8–1.2(Tamb)

Site 45:
Balance point: 65°F for cooling
Cooling: Pre: -108.4 + 1.6(Tamb); Post: -96.0 + 1.4(Tamb);

Site 47:
Balance point: 64°F for cooling
Cooling: Pre: -105.4 + 1.6(Tamb); Post: -106.0 + 1.6(Tamb);

Site 48:
Balance point: 66°F cooling; 64°F heating
Cooling: Pre: -177.6 + 2.5(Tamb); Post: -167.7 + 2.4(Tamb);
Heating: Pre: 110.4–1.7(Tamb); Post: 80.3–1.2(Tamb)

Site 52:
Balance point: 70°F cooling; 68°F heating
Cooling: Pre: -83.1 + 1.1(Tamb); Post: -23.3 + 0.3(Tamb);
Heating: Pre: 20.7–0.3(Tamb); Post: 80.7–1.2(Tamb)

Site 58:
Balance point: 69°F cooling; 63°F heating
Cooling: Pre: -222.7 + 3.1(Tamb); Post: -206.5 + 2.9(Tamb);
Heating: Pre: 130.6–2.2(Tamb); Post: 65.1–1.1(Tamb)

Site 59:

Balance point: 68°F cooling; 63°F heating
Cooling: Pre: -207.3 + 2.9(Tamb); Post: -154.8 + 2.2(Tamb);
Heating: Pre: 116.7–1.9(Tamb); Post: 148.2–2.5(Tamb)

### Lyric

Site 43:
Balance point: 62°F for cooling
Cooling: Pre: -112.2 + 1.7(Tamb); Post: -107.2 + 1.6(Tamb);

Site 44:
Balance point: 67°F for cooling and heating
Cooling: Pre: -154.0 + 2.2(Tamb); Post: -103.7+ 1.5(Tamb);
Heating: Pre: 259.2–3.9(Tamb); Post: 204.9–3.1(Tamb)

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