FLORIDA SOLAR ENERGY CENTER®

Creating Energy Independence

Partnership for High Performance Housing Draft Final Report

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March 12, 2012

Prepared for
Building America
Building Technologies Program
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy
With Funding from: Pacific Northwest Laboratory

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A Research Institute of the University of Central Florida

Disclaimer

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Definitions

AC	Air conditioning
ACH	Air changes per hour
AHRI	Air-Conditioning, Heating, and Refrigeration Institute
AHU	Air handler unit
AFUE	Annual fuel utilization efficiency
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
BA	Building America
BCQC	Builders Challenge Quality Criteria
CFL	Compact fluorescent light bulbs
COP	Coefficient of performance
CFM	Cubic feet per minute
DC	Direct current
DOE	U.S. Department of Energy
EF	Energy factor
EGUSA	Energy Gauge USA
ERV	Energy recovery ventilator
FSEC	Florida Solar Energy Center
HERS	Home Energy Rating System
HFHI	Habitat for Humanity International
HFHPBC	Habitat for Humanity of Palm Beach County
HSPF	Heating seasonal performance factor
HUD	U.S. Department of Housing and Urban Development

HVAC	Heating, ventilation, and air conditioning
ICAT	Insulation contact, air-tight
kWh	Kilowatt per hour
LEED	Leadership in Energy and Environmental Design
Low-E	Low emissivity
MBtu	Million British thermal units
MERV	Minimum efficiency reporting value
MMBtu	Million metric British thermal units
NSP	Neighborhood Stabilization Program
ORNL	Oak Ridge National Laboratory
Pa	Pascal
POA	Plane of array
PV	Photovoltaic
R-Value	Value denoting thermal resistance
RBS	Radiant barrier system
RESNET	Residential Energy Services Network
RH	Relative humidity
SEER	Seasonal Energy Efficiency Ratio
SHGC	Solar heat gain coefficient
SHIP	State Housing Initiatives Partnership
SHOP	Self-help Homeownership Opportunity Program
U-value	Value denoting thermal transmittance
UCF	University of Central Florida

Executive Summary

This report describes research conducted by the Florida Solar Energy Center (FSEC) under funding from the Pacific Northwest National Laboratory. This work falls under the umbrella of the U.S. Department of Energy's Building America program. High performance goals were set for renovation of existing housing and construction of new affordable housing. Both efforts included monitoring the energy use of several homes.

Partnerships were formed with five organizations in addition to homeowners planning major residential renovation projects. One of the primary research questions included whether or not a 30% projected energy savings could be reached using off-the-shelf products and proven techniques. Under these partnerships, 24 candidate homes received a pre-retrofit energy audit, parametric analysis of potential improvements, recommendations for reaching the 30% goal, and follow up during renovation. Ten (10) renovations were completed by the end of the project. The other homes were either still under renovation or were never started because of financial or logistical hurdles. Each of the completed homes received a post-retrofit audit and final analysis. Based on simulation, nine of the 10 homes achieved 30% or greater savings in predicted annual energy cost. The tenth home achieved a 25% savings even though the mechanical system was not replaced. Because most of the renovations were conducted in foreclosed homes, predicted savings are based on annual energy simulations rather than on actual utility bills. Costs, where available, are provided with economical calculations.

FSEC also provided technical assistance to new construction home builders that were striving for very high performance levels, specifically to Habitat for Humanity International (HFHI) affiliates located in Florida. These affiliates were also striving for Builders Challenge or participating in HFHI's nationwide Partners in Sustainable Building program. Technical assistance included goal setting, preliminary evaluation of the construction process, specifications with recommendations, field support during construction, and final testing upon completion.

Measured data was collected on twelve deep energy retrofit homes and four new homes with a HERS index less than or equal to zero. The twelve (12) retrofit homes were monitored with a novel data collection method to increase the sample size within a limited budget. Retrofit energy use was collected with internet connected home energy feedback devices. Interior temperature and RH were recorded with Hobo dataloggers, while outdoor temperature and dewpoint were taken from National Weather Service stations located at airports in cities near the monitored retrofit homes. The four new homes were monitored using research-grade dataloggers with on-site weather stations and detailed energy sub-metering including photovoltaic (PV) array output.

Post-retrofit cooling energy performance was analyzed on five of the twelve retrofit homes, pre-retrofit monitoring however was not available. An attempt to characterize savings was made by comparing those homes located in the same climate to more recent vintage homes constructed to near minimum-code. These efforts were complicated by the size of most retrofit homes being two to three times smaller than the new construction reference. A utility bill analysis of two homes showed a cooling energy savings of 41 and 54% when comparing pre and post-retrofit cooling months with similar cooling degree-days.

Three of the four new near-zero energy homes monitored under this contract were joined with three other homes monitored by FSEC to provide a comparison of homes with low energy features and various amounts of PV electric power production. Problems with PV systems in two homes were discovered and corrected during the course of the project and improvements documented. Three of the six homes achieved net zero electricity use over a seven month period and were net energy producers during that time. The other three homes fell short of that goal due to shading of the PV panels or high electric usage levels relative to the other sites.

1 Overview

As a nationally recognized research institute of the University of Central Florida (UCF), the Florida Solar Energy Center (FSEC) has over 10 years of significant experience in providing technical support to and conducting research with homebuilding industry stakeholders with an emphasis on the hot-humid climate zone. This activity has focused on achieving high levels of energy efficiency while safe guarding and improving indoor air quality, building durability, and comfort. Projects include field and laboratory studies that quantify energy use impact of individual efficiency measures, such as very high efficiency conditioning and water heating systems, duct sealing, improved windows, reflective roofing, and radiant barriers. FSEC researchers have also conducted field studies to assess the cumulative impact of multiple improvements in both existing and new homes.

Industry partnerships provide FSEC with real world experience, which often brings factors to light that do not surface in controlled experiments. FSEC partnerships cut across many housing sectors including custom and production builders, manufactured housing producers, non-profit housing providers, public housing authorities, and home remodelers. Published reports, papers and data are available online at www.fsec.ucf.edu/en/publications/publist.php?dept=br.

Backed by these experiences, FSEC entered into a Partnership for High Performance Housing with Pacific Northwest National Laboratory (PNNL) in September of 2010 in pursuit of two tasks:

- Task 1 Deep Energy Retrofits -
    - Technical assistance and analysis (Subtask 1A) for 15 candidate deep energy retrofits in Florida (Subtask 1A) with target savings of 30% or more with the expectation that eight (8) or more of the homes will meet the deep retrofit savings goal.
    - Monitoring (Subtask 1B), at PNNL's direction, deep energy retrofits in Florida, Georgia, and Texas.

- Task 2 High Performance New Home Prototypes -
    - Technical assistance and analysis (Subtask 2A) in 6 to 10 new construction high performance homes built by affordable housing partners in Florida. PNNL and FSEC mutually agreed upon efficiency and quality criteria goals related to industry recognized programs such as ENERGY STAR for Homes and the U.S. Department of Energy (DOE) Builders Challenge.
    - Monitoring in four high performance Florida homes with Home Energy Rating System (HERS) Index scores near zero (Subtask 2B).

The industry stakeholders recruited for each task (Table 1) provided access to renovation and construction projects in real world houses. Research conducted in this context exposes factors that do not arise in controlled experiments. The existing conditions challenges, gaps, barriers, and decision making processes involved in achieving these goals will need to be thoroughly understood and addressed in any effort to replicate results on a large scale.

In addition to the partners that ultimately produced study homes, researchers pursed partnership with 20 other organizations and 90 home owners who expressed interest in deep energy retrofits and six additional new construction partners.

Table 1. High Performance Housing Partnership Participants.

	Task 1 Existing Homes	Task 2 New Construction
Owner Occupied Homes	✓	
Brevard County, Housing& Human Services Department	✓	
City of Lakeland, Neighborhood Services Division	✓	
Greater Newtown Housing Trust		✓
Habitat for Humanity of Brevard County	✓	✓
Habitat for Humanity of Lake Sumter	✓	✓
Habitat for Humanity of Palm Beach County	✓	✓
Habitat for Humanity of Hillsborough County		✓

2 Task 1: Deep Energy Retrofits

FSEC researchers worked with PNNL and other PNNL subcontractors to identify partners involved in renovation. Specifically, these partners were interested in improving energy efficiency 30-50% while implementing indoor air quality, durability, and comfort measures. Task 1 consists of 24 deep energy retrofit candidates in Florida (FSEC partnerships with local governments, non-profits, and homeowners) and 12 monitored deep energy retrofits in Florida (FSEC), Texas (partnership with PNNL subcontractor Build San Antonio Green), and Georgia (partnership with Oak Ridge National Laboratory with Southface Energy Institute.)

2.1 FSEC Deep Energy Retrofits Overview

Working with PNNL, local government entities, non-profit housing providers, and private homeowners in Florida, FSEC provided technical assistance for deep energy retrofits candidates with the goal of achieving savings of 30% to 50% or more on a whole house basis. It was expected that eight (8) or more of these homes would meet this savings goal. Activity with private homeowners commenced after the research protocol, which mirrored the PNNL protocol, was approved by the UCF Internal Review Board.

2.1.1 Typical House Characteristics:

The vintage and condition area distribution of the 24 deep energy retrofit candidates is shown in Figure 1.

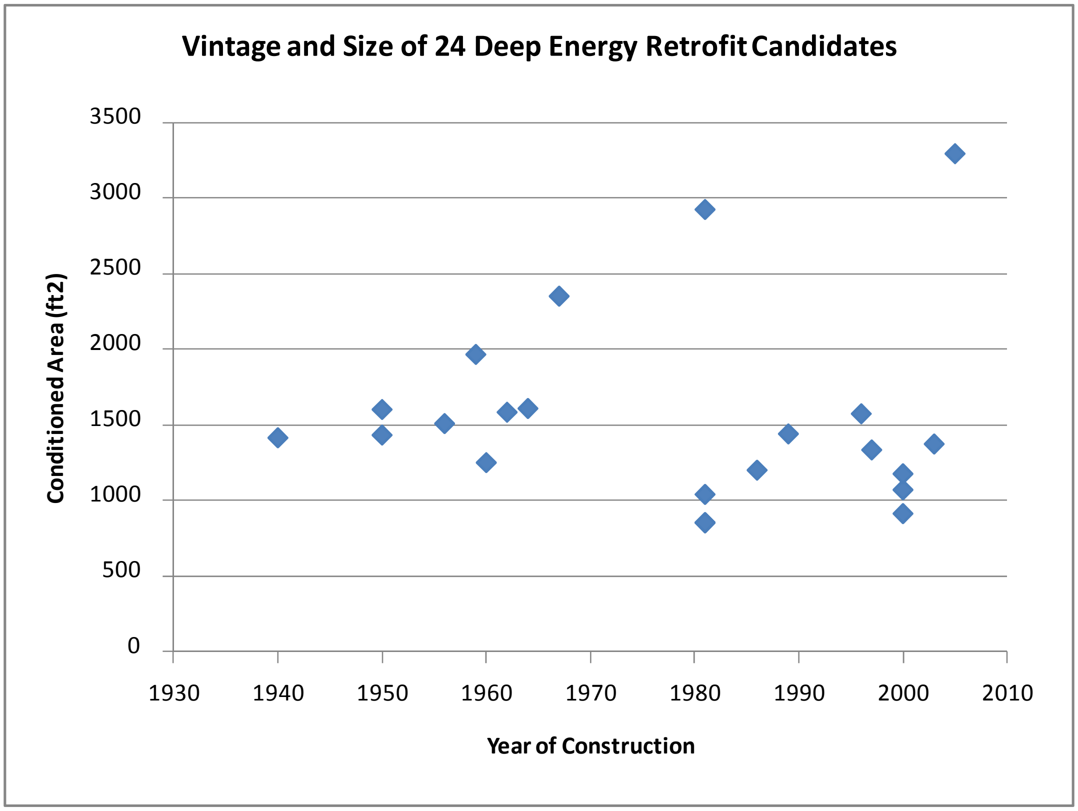


Figure 1. Vintage and conditioned area of deep energy retrofit candidates

The houses in the study are predominately slab-on-grade, single-family homes. Typical roof pitch is very shallow compared to homes in mixed and cold climates, where greater pitches are required to address snow loads. This produces very shallow attics, which do not afford much room for repairing or replacing duct systems, accessing attic eaves to install ventilation baffles, or ensuring that insulation has reached the edge of the attic space. This is a particularly important consideration for unvented attic retrofits.

2.1.2 Hot Humid Climate Implications

Since the deep retrofit candidates were all located in Florida, hot humid climate (Zone 2 of the International Energy Conservation Code definitions), strategies affecting cooling energy use were strong performers. The majority of homes in the study started with older, lower efficiency air conditioning (AC) systems coupled with electric resistance heating. Current new, minimum efficiency heat pumps (in Central Florida) or straight AC (in South Florida) produce considerable improvement in overall efficiency. Even without duct system replacement, significant improvement in duct air tightness was achieved by addressing the typical return plenum configuration, which consists of a wood frame platform formed in the lower portion of an air handler closet that supports an upflow air handler. Often the cavity is open to adjacent interior walls that form the closet. By sealing the cavity or providing a ducted return air path instead, a major portion of the total duct leakage as well as the duct leakage to the outside can be eliminated. This combined with cooling load reduction strategies consistently produce significant improvement. Typically, the key components of the cooling are radiant heat gain through the windows, heat generated by appliances such as the refrigerator, and heat transfer from the attic by conduction through the ceiling assembly. Correspondingly, improvements in those areas were often part of the overall efficiency package.

Based on costs reported by partners in this and other FSEC studies, window replacements cannot be justified on payback from annual energy savings. However, if windows need to be replaced, the energy savings compensate for cost premiums associated with higher performance windows. Window selections among the partners in this study tended to fall short of Energy Star labeling criteria, which was revised by the Environmental Protection Agency for this climate zone during the project period. Even so, the average solar heat gain coefficient (SHGC) for replacement windows was 0.27 and 100% of the projects with window replacements selected double-pane rather than single-pane units, which are typically found in the pre-retrofit homes.

Partners consistently opted for Energy Star refrigerators, which reduces both appliance heat gain as well as annual energy use, and addition of ceiling insulation. Annual conductive heat transfer through the walls tends to be lower in the hot humid climate than in mixed and cold climates because of the relatively low temperature differences between inside and outside. Heat flux across the ceiling plane is a bigger factor in the cooling load because of high attic temperatures compared to conditioned space.

Even though reducing infiltration is not a major savings for homes in the hot humid climate, (again because of the low temperature difference) gaining control over air flow is essential for achieving good indoor air quality, controlling air transported moisture flow, and enhancing comfort. Previous FSEC research (Cummings et al, 1990) has shown that mechanically induced infiltration does draw in heat and humidity even when the drivers of natural infiltration are weak. The ceiling plane tends to be the primary path of infiltration in slab-on-grade, concrete block homes. Drywall holes, recessed lighting, missing plumbing access panels, and unsealed top plate penetrations are all contributors to poor whole house air tightness testing results.

Among the completed houses at the time of this draft report, the estimated natural infiltration rate post-retrofit was 0.31. The mechanical ventilation approach favored in this research is a passive, filtered, dampered duct that provides outside air to the return plenum. Since it is a passive system, outside air only flows in response to a negative pressure event including normal air handler operation (not assisted by a fan cycling control) or depressurization of other space(s) connected to the return plenum, for example when a kitchen exhaust fans is operating. The cumulative effect of this system is to provide a small amount of outside air ventilation while inducing a slight positive pressure, less than 1 pascal (pa), in the conditioned space with respect to outside. The positive pressure is the result of more air being added to the space than is being removed since a portion of the air handler flow is being drawn from the outside. This positive pressure effectively limits flow of outside air through uncontrollable pathways in the walls, ceiling, and the floor. It should be noted that this system does not meet the ventilation intent of American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Standard 62.2 in two ways. First, the system draws a much smaller amount of ventilation air than recommended in Standard 62.2. Second, the outside air is provided only when the air handler operates or in response to other events that depressurize the house, such as operation of exhaust fans. ASHRAE Standard 62.2 levels of ventilation were not incorporated in this study because the anticipated elevation of indoor relative humidity levels has been associated with increased proliferation of biological asthma and allergy triggers (Arlian et al, 2001) as well as changing dew point conditions that may lead to condensation. While researchers acknowledge that supplemental dehumidification can moderate these effects, the nature of the projects in this study, most of which are foreclosed homes that will soon be returned to the market, provide very limited, if any, communication with potential homeowners. Additionally, given budget constraints, it is likely that partner would implement the outside air system but not the dehumidifier. Researchers have no control over those decisions. Even if dehumidifiers could be guaranteed as part of the scope of work, the risk of supplemental dehumidification being turned off or removed must be weighed against the likely benefits of enhanced ventilation. There are also physical challenges of incorporating outside air ventilation system components in the small air handler closets common in older Florida homes.

Regarding the filtration criteria for outside air, we have found partners, in this project as well as others, are reluctant to install filter back grilles in the soffit for the outside air. The filter-back component requires depth at the soffit to accommodate a manufactured or fabricated boot. For low pitched roofs typical of older Florida homes, there is not adequate vertical space to accommodate this component. Additionally, partners are skeptical that residents will replace an outside filter. The reasoning seems to be concern over general awareness of the filter in the long term as well as lack of availability of correct size filters from the retail outlets. Since the outside air must be filtered prior to crossing the cooling coil, the configuration favored in this event is to specify “under cabinet” filter location. This also requires awareness on the mechanical contractor’s part to avoid placing service lines in front of the air handler cabinet preventing placement of the filter.

Retrofits also involved higher performance water heating options including tankless gas water heating and heat pump water heating, ENERGY STAR refrigerators, and extensive compact fluorescent lighting.

The improvements associated with each project are discussed in the individual write ups following this overview. Appendix A includes analysis spreadsheets for 16 the deep retrofit candidates.

2.1.3 Recruitment

Researchers recruited partners for the retrofit home by inviting homeowners and organizations to participate the study.

For recruiting individual homeowners, a procedure was developed collaboratively and subsequently approved through the UCF Internal Review Board. The general strategy was to direct all interested homeowners to PNNL’s website about the study (http://deepenergyretrofits.pnnl.gov/) to download the *Information Request* survey. Applicants returned surveys to the PNNL program manager who reviewed them and forwarded potential Florida candidates for FSEC. Those applicants who met study criteria were provided with a second, more detailed survey that characterized various energy related elements of the potential renovation including condition of heating, cooling, and water heating equipment; envelope changes since the home was built, and operating conditions. Based on this survey, FSEC selected candidates for participation in the study and a pre-retrofit home energy audit was conducted.

FSEC announced the opportunity to participate in the study on web sites and at community:

- Good Morning UCF, an online, daily newsletter distributed to all staff and faculty at the University of Central Florida
- FSEC homepage under "Energy News": http://www.fsec.ucf.edu/en/
- FSEC blog: http://blog.floridaenergycenter.org/echronicle/2011/04/retrofit-study/ The blog entry directed readers to the PNNL recruitment web page about the study where participants could download the information request form to apply for inclusion in the study
- Presented to approximately 75 homeowners and residents of The Villages, a large master planned community in central Florida at their Green Environmental Club meeting

In July 2011, FSEC ended efforts to recruit homeowners based on budget and time constraints. Table 2 summarizes the disposition of the 95 PNNL *Information Request* forms received from Florida homeowners. Of those applicants, only 12 met the criteria for the study as described in the IRB procedure. Five (5) of these 12 candidates opted out or became non-responsive. The remaining seven (7) were included in the study with a test-in, pre-retrofit audit completed. Regrettably, only one of these projects (project identifier EH-14) came to fruition, and unfortunately it was a newly purchased home with no pre-retrofit utility data. Two of seven projects (EH-13 and EH-23) never started. The remaining five (5) projects (EH-05, EH-12, EH-15, EH-16, EH-20, and EH-24) resulting from the homeowner recruitment process were dropped. Table 5 shows these projects in context with the completed projects, and each is discussed individually in Section 2.2.

The low rate of converting interested homeowners into study participants stemmed primarily from applicants not meeting the study criteria. Study criteria and preferences were delineated in the IRB approved protocol. However, only some of the criteria were disclosed on the PNNL website for the study. To avoid bias in the responses to the two surveys, other criteria were were not disclosed. This resulted in a high volume of unqualified applicants: 60 out of 95 in the first survey and 14 out of 26 in the second survey. Examples of characteristics that led to disqualification include conditioned area greater than 3,000 square feet, less than five years, or significantly improved systems (solar water heating, high efficiency heat pump, etc.) or envelop (added ceiling insulation, window tinting, etc.)

The research team originally considered using an online survey structured to only allow qualified candidates to complete the full survey. For example, if the applicant indicated conditioned area greater than 3,000 square feet or a combination of disqualifying characteristics, the survey would terminate and provide guidance to the applicant on sources for information to help with their retrofit planning. This would have saved time and resources spent reviewing and responding to electronic or hand written survey responses. In general, the homeowners interested in the study tended to be more cautious and hesitant to commit to a project because of the capital investment and uncertainty of the current economic conditions; whereas the organizations we contacted were driven more by policy directives to reduce utility costs as a component of overall affordability.

Table 2. Summary of Homeowner Recruitment through the PNNL Website for the Study

Step #	Description	Number of Homeowners	Notes
1	Submit *Information Request*	**95**	60 were disqualified, did not meet criteria
2	Meet study criteria, submit detailed Homeowner	**35**	10 opted out or became non-responsive
3	Submit *Homeowner Questionnaire*	**26**	14 were disqualified, did not meet criteria
4	Meet study criteria	**12**	5 opted out or became non-responsive
5	Complete Homeowner Agreement, pre-retrofit "test-in" energy audit	**7**	2 projects never started, 4 projects were dropped,
6	Complete retrofit, test-out audit	1	

For recruiting organizations, researchers sought partnership with non-profit and local government entities involved in home renovation activities. Because organizations tend to implement similar specifications in many homes, whereas a homeowners is focused on one, researchers took a slightly different approach.

To help potential partners envision what would be needed to achieve the deep energy retrofit goals, researchers drafted an improvement package for achieving 30-50% savings using an example 1970's era Florida home[1]. Reviewing this example in tandem with the typical specifications that the organization uses, provides an immediate snapshot of how much their usual approach would need to change (and therefore cost) to achieve the goals. This review was typically done in person with key decision makers with the authority to implement the needed changes. Table 3 shows the roster of organizations that expressed interest in the study.

Table 3. Task 2 Partnerships with Local Government Housing Agencies and Non-profit Affordable Housing Organizations

Organization	Type	Program Participation	Partnership Formed?	Notes
Habitat for Humanity of Brevard County	Non-profit	NSP	Yes	4 houses total, 2 houses 30%+
Habitat for Humanity - Lake Sumter Florida, Inc,	Non-profit	HFHI Women's Build	Yes	1 house, 30%+
Habitat for Humanity of Palm Beach County	Non-profit	NSP2	Yes	5 houses total, 3 houses, all 30%+
Habitat for Humanity in Seminole County	Non-profit		Yes	0 houses, partner retained green certified; project proceeded.
Habitat for Humanity South Sarasota County, Inc. and CalcsPlus	Non-profit	SHIP	Yes	1 house, 30%+ monitored by FSEC
City of Lakeland	Government	NSP	Yes	2 houses, both 30%+

[1] Based on FSEC work conducted under the Building America Industrialized Housing Partnership.

Organization	Type	Program Participation	Partnership Formed?	Notes
Brevard County Dept of Housing and Human Services	Government	SHIP	Yes	4 houses, all dropped
Florida Green Building Coalition (and Cathy Byrd, Green Heights Development)	Non-profit (For Profit)		Yes	0 houses, data exchange
Community Enterprise Investments, Inc. (Pensacola)	Private, non-profit	NSP, Utility, EDC	No	Timing issues
St. Lucie County Housing and Community Services (Ft. Pierce)	Government	NSP	No	Nonresponsive
City of Winter Park	Government		No	Nonresponsive
St. Johns Partnership, St. Augustine	Private, non-profit	NSP, SHIP, Weatherization, Energy Office	No	Deep retrofit depended on bundling funds from several sources, no guarantee all funds would come in
City of Jacksonville	Government		No	Nonresponsive
City of Cocoa	Government	SHIP, CDBG	No	No deep retrofit projects
City of Boynton Beach	Government		No	Nonresponsive
Tampa Housing Authority	Government		No	Nonresponsive
Central Florida Urban League, Orlando	non-profit		No	Nonresponsive
ServiceSource Network	Non-profit		No	Nonresponsive

FSEC distributed the initial partnership invitation widely by attending and making presentations relevant conferences, sending direct invitations to recipients of state and federal funds for home renovation, contacting allied professionals and real estate investors, and reaching out to high performance new home builders in the affordable housing sector who are also engaged in renovation.

Relevant Housing Conferences: In October of 2010, researchers attended the annual Florida Housing Coalition Conference in Orlando. Subsequently, FSEC e-mailed a partnership invitation to approximately 130 attendees gleaned from conference materials. Ten organizations responded with interest that held potential for partnerships (see Table 2). The City of Lakeland ultimately provided two retrofit homes for the study. Habitat for Humanity of Palm Beach County, also a partner under Task 2, indicated intent to produce up to four deep retrofits.

In March 2011, the Florida Housing Coalition conducted a joint conference with the Institute for Professional and Executive Development (IPED) called Renewable Energy 101 for Housing and Community Development. FSEC researcher, Karen Sutherland, presented our work on a panel with Cathy Byrd of Green Heights Development, chair of the Florida Green Building Coalition's Affordable Housing Committee, and Pierce Jones of the University of Central Florida, co-lead of the Building America team Building Energy Efficient Homes for America. The session included results from work conducted under FSEC's Building America Industrialized Housing Partnership and Building America Partnership for Improved Residential Construction as well as an invitation to participate in current work under FSEC's Partnership for High Performance Houses.

Attendees included a wide variety of public and private housing stakeholders. Also in March of 2011, FSEC attended a meeting with Sarasota affordable housing providers organized by Dwell Green, a company based in Sarasota that provides homeowners with consultation and direction on matters related to energy and environment.

Recipients of DOE Energy Efficient Community Block Grant funding: Brevard County Department of Housing and Human Services received grant money for rehabilitation of homes damaged in Tropical Storm Fay. This partner provided four residences for the study.

FSEC researchers contacted the Energy Efficiency and Conservation Block Grant (EECBG) funded *Orange County Homeowner Energy Efficiency Program* (OCHEEP) in the metro Orlando area for potential partnership. The OCHEEP coordinator provided a contact list of more than 500 program participants. Participation included homeowner training, Florida Class I home energy rating (with up to a $300 rebate), and rebates up to $700 for implemented recommendations. While some of the 500 participants might have been planning to implement deep energy retrofits, resources were not available to reach out to this large dataset to make that determination. However it is interesting to note that this type of database may be an outcome of other EECBG programs and a potential resource for future activity. For example, as 2012 unfolds, all of these participants should have a year of post-retrofit utility data. A direct mail campaign could be launched to see if any participants realized savings of 30% with a follow up effort to learn how they did it.

At the invitation of PNNL project director Subrato Chandra, FSEC researchers discussed collaboration with Dwell Green, Calcs Plus, and the director of Sarasota County's *Get Energy Smart Retrofit Program*. This EECBG program focuses individual, high-priority efficiency measures and not whole house retrofits; however, as participating contractors in this and other Sarasota area initiatives, the two companies were in a position to scout for homes that combined improvements. FSEC provided review to Calcs Plus (also a sub-contractor to PNNL in this study) for a deep retrofit that was underway with South Sarasota Habitat for Humanity near Venice, Florida. That and another home identified by Dwell Green were part of the three monitored retrofits in Florida under Task 2.

Allied Professionals including Home Energy and Green Building Professionals, Remodeling Contractors, and Sub-contractors: FSEC contacted numerous home energy raters, BPI-certified home performance contractors, home inspectors, solar installers, mechanical sub-contractors, remodeling contractors, and insulation installers, primarily in the region surrounding Brevard County where FSEC is located on the east central coast of Florida. The response was consistent with all indicating that they did not have any projects that would be considered deep energy retrofits. Many were not currently working on any privately-funded projects, nor did they have any in the planning stage. The small amount of work that was being done by those companies contacted was restricted to government-funded projects with weatherization or EECBG funding. Although both programs are focused on energy retrofits, neither strives for 30% savings. FSEC also forged a partnership with members of the Florida Green Building Coalition's (FGBC) Affordable Housing Committee. The committee had a task to aggregate cost data from their own projects for energy efficiency (and other green building) improvements in existing homes, and we will exchange data when it becomes available. As we close the project out, we will provide the cost data in aggregate form for the benefit of other practitioners. None of the committee members presented projects for consideration in the study.

Real Estate Investors: FSEC researchers contacted Elliott Perry of Tangelo Park Restoration LLC. Elliot Perry, an innovative builder/broker, had renovated and resold a dozen or so affordable housing properties in the Orlando area using “gut” rehab renovation of houses in disrepair. However, he discontinued this work due to unsold renovated homes. Another investor (also a builder) with a similar business model, except that it converts renovated homes into rental property, was contacted. This builder was interested in partnership; however his current retrofit projects were too far along (equipment had already been replaced, insulation installed, and ducts replaced) for an accurate pre/post analysis to be completed.

High Performance New Home Builders Engaged in Renovation: FSEC has worked extensively with Habitat for Humanity, a non-profit affordable housing organization, throughout Florida. The organization is organized into local chapters called affiliates. There is a movement within that organization toward renovation of existing homes. We offered the partnership opportunity to previous partners as well as affiliates getting into renovation. Several responded affirmatively and a number of partnership houses resulted.

2.1.4 Procedure

A thorough test-in audit was conducted to document pre-retrofit conditions. Researchers characterized efficiency levels with a HERS calculation for each house. The HERS Index was used because most of the partners had already been exposed to it as a metric for whole house energy efficiency. Researchers also produced annual energy use simulations, which allow for modeling characteristics outside the set of “minimum-rated features” defined in the HERS Standard. Calculations are described further below. All of the annual energy use simulations used the thermostat schedules (summer 76F and winter 71F in all days of the week with no setup or setback) defined in the Building America Benchmark procedure. For comparative purposes, the annual energy cost calculations were made using a standard utility rate of $0.13 per kilowatt hour (kWh). The actual utility rates varied both higher and lower than this assumed rate.

Researchers collaborated with partners on a deep energy retrofit package of improvements that took into consideration the budget and overall renovation goals for each house. Relevant building science detailing, potential challenges, and implementation hurdles were also discussed. A final scope of work for a deep energy retrofit was then agreed upon, and researchers provided input as needed while the renovation was in progress. In most cases, adjustments to the scope of work were made during the renovation. After a retrofit was completed, a test-out audit was conducted to determine what measures were implemented with projected savings recalculated. Partners are expected to provide cost data for cost-to-benefit analysis. This proves to be one of the most daunting tasks of the research.

Because most of the homes in the study turned out to be foreclosed properties, pre-retrofit utility data is generally not available. The completed retrofit homes have been occupied, and, researchers will work with partners and the new homeowners to acquire as much post-retrofit utility data if possible.

2.1.5 Calculation of Energy Savings and Improvement Cost

Unless otherwise indicated, all projected annual energy saving calculations were produced using Energy Gauge USA (EGUSA) with the appliance schedules designated by the 2006 Home Energy Rating System standard (HERS 2006) and thermostat schedules defined in the Building America Benchmark procedure. These values, along with improvement package costs where available, are shown in the summary table for each home (throughout this section) and in the analysis spreadsheets provided in Appendix A. For comparative purposes, the annual energy cost calculations were made using a standard utility rate of $0.13 per kilowatt hour (kWh).

Improvement cost is shown in two ways: full cost of the improvement and/or incremental cost of higher efficiency specifications. In some cases, both full cost and incremental cost are available. In other cases, partners have provided only incremental costs, likely based on previous projects.

Incremental cost is the difference between an equal efficiency or performance replacement and a higher efficiency or performance replacement, essentially the premium for higher efficiency equipment or higher performance components. For example, if replacing an "as found" standard efficiency electric water heater with a heat-pump water heater, the incremental cost is the difference between another standard unit and the heat pump unit. In many retrofit candidates, the "as found" mechanical system cannot be replaced with one of equal efficiency because of federal appliance standards. The incremental cost of a higher efficiency mechanical system is calculated in comparison to the minimum available, a Seasonal Energy Efficiency Ratio (SEER) 13 straight air conditioner with electric resistance heating, since no cost cannot be obtained for an "apples to apples" replacement. Likewise, the incremental savings achieved by higher efficiency mechanical system are calculated in comparison to this minimum efficiency scenario. This scenario is indicated as "Minimal Improvement" in the retrofit summaries.

In all cases, the reported costs should be considered representative of a range and not absolute, replicable costs because acquiring accurate cost data is challenging. For example, construction staff within a partnering organization are not involved with actual payments and do not have ready access to invoices for materials and services. Staff in the business office may be reluctant to share sensitive information so cost may be related in the form of an email or simple summary (second source) rather than copies of invoices (primary source). Sub-contractors also are reluctant to share sensitive cost information since that may be valuable to competitors.

Even when primary source material can be acquired, it is not necessarily straight forward. Energy measures that researchers view as individual improvements are grouped together on invoices, sometimes with unrelated charges. The cost of replacing a duct system is combined with the total cost of the mechanical system change out, which may also include cost and installation of bath fans, repair of concrete condenser slabs, etc. The cost of ENERGY STAR ceiling fans may be lumped together with the rest of the lighting package. Partners do regularly acquire estimates for specific houses. However, that is usually done after the scope of work has been set, including design decisions and specifications, diminishing the opportunity for evaluation of design alternatives. Sometimes contractors are paid on the basis of their estimate or quote, regardless of whether the job actually costs more or less to complete. Researchers recognize that some of these challenges have to do with the nature of our public sector partners' requisition and purchasing procedures.

Researchers have worked with costs reported from dozens of renovations conducted under other funding to produce cost estimates for items commonly included in improvement packages. Those numbers are used for estimating payback during the planning phase with partners. Ultimately, however, the actual costs for a particular house may have no resemblance to these estimates because of location, market conditions, characteristics of the house, discounts, and a host of other factors. Where necessary, researchers have exercised professional judgment to assess both full cost and incremental cost for higher efficiency options.

2.2 FSEC Existing Homes (EH) Deep Energy Retrofit Candidates

Ten (10) retrofits were completed, nine (9) of which met or exceed the goal of 30% or more in projected annual energy cost savings . One (EH-03) almost achieved the goal with 26% even without a mechanical system replacement. Table 4 shows the location, pre- and post-retrofit HERS Index, estimated annual energy savings, and the date occupied for the 10 completed homes.

Table 4. Projected Annual Energy Cost Savings for Completed Deep Energy Retrofits

Project ID	Location	Pre-Retrofit HERS Index	Post-Retrofit HERS Index	Projected Annual Energy Cost Savings (%)	Date Occupied
EH-02	Lakeland	177	85	40%	May 2011
EH-03	Green Acres	97	75	26%	June 2011
EH-04	Eustis	132	78	42%	September 2011
EH-06	Melbourne	117	76	35%	August 2011
EH-07	Melbourne	136	85	33%	August 2011
EH-12	Lakeland	146	92	37%	Owner occupied before renovation
EH-14	Indian Harbor Beach	122	70	35%	November 2011
EH-19	West Palm Beach	109	70	40%	October 2011
EH-21	Lake Worth	120	73	39%	November 2011
EH-22	Lake Worth	119	64	48%	November 2011

Table 5 shows the disposition of all 24 deep retrofit candidates in this project.

As described above, ten retrofits were completed. There are six (6) renovations still in progress. Four (4) of these six (6) are single family attached units (EH-08, EH-09, EH-10, and EH-11) and projected to exceed 30% savings; however, the start date was delayed five months, likely pushing the completion date far beyond the end of the contract. The two (2) other projects in progress (EH-17 and EH-18) have progressed slower than anticipated because construction staff were moved to another project after organizational priorities changed. Additionally, the mechanical contractor installed the wrong unit in both houses which will adversely affect whole house efficiency improvement, and the windows in one house were replaced with single pane clear metal frame units.

Six (6) other projects were dropped from the study for the following reasons. The owners of retrofit EH-01 moved out. The owners of EH-05 elected to install a photovoltaic array instead of efficiency improvements. Owners of retrofit EH-15 decided not to add an energy efficiency component to their structural renovation. Testing results and specifications discovered in the test-in audit for retrofit EH-16 revealed that the home had already been improved significantly more than communicated in the pre-audit questionnaire. In retrofit EH-20, the owner and another partnering agency discovered structural deterioration during renovation and postponed completion pending budget revisions. The owner of retrofit EH-24 halted work mid-project for reasons that remain unclear.

In the two projects (EH-13 and EH-23) shown as "Not Started," financing obstacles that arose after test-in prevented commencement of the retrofit work.

Each candidate is described in the sections that follow, and analysis for 19 of the candidates is included in Appendix A.

Table 5. Projected Annual Energy Cost Savings Ranges for 24 Deep Energy Retrofit Candidates

	Occupied	Unoccupied	Total	Candidates
Projected Annual Energy Cost Savings 15-29%		1	1	EH-03 (25% w/o HVAC replacement, occupied after completion)
>30%	1	8	9	EH-02, EH-04, EH-06, EH-07, EH-12, EH-14, EH-19, EH-21, and EH-22 (all occupied after completion, except EH-12 which was owner occupied prior to renovation)
Total Completed Projects	**1**	**9**	**10**	
Still in Progress >30%		**6**	**6**	EH-08, EH-09, EH-10, EH-11, EH-17, and EH-18
Retrofit Did Not Start >30%	**2**		**2**	EH-13 and EH-23
Dropped Projects	**5**	**1**	6	EH-01, EH-05, EH-15, EH-16, EH-20, and EH-24

2.2.1 Deep Energy Retrofit EH-01 (Occupied, Dropped)

Within days of completing the test-in audit of retrofit candidate EH-01, the owners decided to move and withdrew from participation in the project. Table 6 summarizes the pre-retrofit condition of the home.

Table 6. EH-01 Annual Energy Use and Cost Simulation

Parameter	As Found	Recommended
HERS Index	188	Recommendations were not made for this retrofit candidate
Annual Simulation kWh (BABM08)	24810	
Annual Million British Thermal Unit (MBtu) Usage	84.7	
Annual Energy Cost (BABM08)	$2,793	
Project Status: Dropped		

This two bedroom, two bath home built in 1950 (Figures 2-3) is two-story with wood frame walls supported by a masonry pier foundation. The 28" deep open crawl space is skirted with vinyl lattice panels (Figures 4-5). The home has hardwood floors (plank subfloor) throughout, approximately 30% covered with tile finish and 30% with carpet. The dark shingle roof has a 5-

in-12 pitch with dormers that create the living space upstairs. The minimal attic space is vented by four small gable end vents. The original back porch of the house was enclosed to create a laundry room.

Figures 2-3. EH-01 front (east) and side (south) facades of Craftsman style retrofit candidate.

Large double hung windows typical of the Florida vernacular design were designed to promote natural ventilation. The window to floor area ratio is 18.4%. Shading from porches and trees limits direct solar gain; however, the window frames appear to be a large source of infiltration. Specifically, the penetrations in the window frames that allow movement of the corded weights that raise and lower the heavy windows must be left open to facilitate function. During the blower door test, air flow at these points and around electrical switch and outlet plates was the most notable.

Neither the exterior wall cavities nor the attic were accessible at the time of the test-in audit. The walls are assumed to be uninsulated, but the owners report having R-24 insulation installed in the flat attic space and R-11 batt insulation on the knee walls.

The frame floor is uninsulated. The crawlspace created by the open pier foundation has no ground cover, but it is very well ventilated at this time. The skirting around the crawl space is made of vinyl, lattice panels rather than a more solid barrier such as a vented, masonry stem wall or perforated vinyl panels (Figures 4-5).

Figures 4-5. EH-01 pier foundation (left) skirted with vinyl lattice panels (right) provide excellent venting of the open crawl space.

The configuration of the crawl space is an important consideration in deep retrofits because changes related to the whole house air, thermal, and moisture barriers may change the way the conditioned space interacts with adjacent unconditioned spaces such as crawl spaces, attics, and garages. Since this open crawl space is very well connected to the outside, there is less chance of accidentally coupling it to the house as a result of air sealing efforts. Gaining control over air flow needs to be part of any deep energy retrofit, but it carries with it the risk of setting up uncontrolled air flow paths and moisture dynamics.

Assessing the presence of pressure dynamics before, during, and after retrofit activity is essential if atmospheric combustion equipment such as standard efficiency gas water heaters and furnaces are involved in the project. In these cases, risks may be deadly. Even in the absence of combustion equipment, unanticipated pressure imbalances may create indoor air quality, durability, and comfort issues. Retrofit activities potentially contributing to creation of these dynamics include, but are not limited to:

- air sealing floors, ceilings, or exterior walls
- duct replacement, sealing, or relocation
- relocation of interior doors and walls
- addition or removal of insulation
- change in floor, wall, or roof finishes
- removal or addition of exhaust fans
- enclosure of previously unconditioned space

Pressure mapping, a standard component of our post-retrofit, test-out audit procedure can be used to assess the connectedness of conditioned and unconditioned spaces under normal operating conditions as well as "worst case" scenarios.

2.2.2 Deep Energy Retrofit EH-02 (Occupied after completion in April)

This unoccupied, single-family detached home in Lakeland, Florida is the first of two renovations completed in 2011 by the City of Lakeland, Community Development Department, Neighborhood Services Division (www.lakelandgov.net/commdev/Housing.aspx). Table 7 summarizes the projected annual energy use and cost savings for deep energy retrofit candidate EH-02. Table 8 relates the anticipated financing and payback associated with the whole package of improvements. Appendix A includes analysis for this project.

Table 7. EH-02 Annual Energy Use and Cost Simulation

Parameter	As Found	Minimal Improvement	Actual Retrofit
HERS Index	177	160	85
Annual Simulation kWh (BABM08)	18,412	17,116	10,998
Annual MBtu Usage (BABM08)	62.8	58.4	37.5
Annual Energy Cost (BABM08)	$2,393	$2,225	$1,431
Project Status: Completed 4/30/11			
"Minimal Improvement" reflects improvement for replacing the mechanical system with a SEER 13 air conditioner with electric resistance heating, the minimum efficiency system available.			

Table 8. EH-02 Annual Energy Savings Analysis

	Preliminary and Estimated Full Cost & Savings (As Found vs. Actual)	Preliminary and Estimated Incremental Cost & Savings (Minimal vs. Actual)
HERS Index Improvement (%)	52%	47%
Annual Energy Cost Savings ($)	$962	$794
Annual Energy Cost Savings (%)	40%	36%
Improvement Costs	$19,097	$2,761
Monthly Mortgage	$128	$19
Monthly Energy Cost Savings	$80	$66
Monthly Cash Flow	-$48	$48
Simple Payback (years)	20	3

Built in 1960, this three bedroom, two bath home (Figure 6) has 1,250 square feet of conditioned space. The slab-on-grade, primarily concrete block home had a white block exterior and dark asphalt single roof. By the time a partnership was in place with the City, deconstruction had already occurred. Some wall and ceiling cavities were exposed, and many appliances had been removed.

The thermal envelope included a 338 ft^2 section with a shallow pitch, which restricted the level of ceiling insulation. The ceiling for this section was composed of acoustical tiles, and its exterior walls were frame. Ceiling insulation for the entire ceiling consisted of a mixture of batt fiberglass and blown-in cellulous and was estimated to be an average of R-9. The existing windows, a mixture of awning style, single hung, and one jalousie-type, were all single-pane, clear, with metal frame. A few were broken, and replacement was slated for all. Appliances and lighting included an older 50-gallon electric hot water heater and 100% incandescent lighting.

Figure 6. EH-02 pre-retrofit (Post-retrofit exterior unchanged)

The air heating and conditioning systems (Figures 7-9) included:

- a forced air, SEER 10, package unit central air conditioner with electric resistance heating,
- two older air conditioner window units, and
- an old abandoned furnace built into an interior wall.

Figures 7-9. EH-02 pre-retrofit package unit (left), wall unit (center), abandoned furnace (right)

Partial deconstruction, broken windows, large exterior wall penetrations, and the appearance of mold prevented whole house air tightness tests. In order to model the home, an ACH50 of 22 was used, an estimate made using pre-retrofit test results from prior research. Duct leakage testing was limited to total leakage given the inability to depressurize the home, and the distribution system was found to be exceptionally leaky (Qn,total = 0.30).

Among several efficiency measure recommendations, researchers presented the concept of bringing outside air into the mechanical system. Citing a lack of funding on this project, however, the partner was unable to incorporate the outside air detail as part of the retrofit process. Additional efficiency recommendations the partner did not implement were insulating the attic to R-38, installing slightly more efficient windows, wrapping the hot water tank and insulating pipes, and installing a programmable thermostat.

The renovation, completed April 30, 2011, was considerable. The measures with the greatest impact on projected energy cost savings (in order of contribution) were the installation of a forced air, central heat pump (SEER 15), significant reduction in duct leakage, almost exclusive use of efficient lighting, reduction in whole house infiltration, insulation of the attic to R-30, and installation of double-pane, low-E (emissivity), vinyl frame windows. Figures 10-12 show the pre- and post-retrofit windows and new lighting. The entire package of improvements, listed in Table 9, is estimated to produce $962 in annual energy cost savings.

Figures 10-12. EH-02 pre-retrofit awning window (left), post-retrofit Low-E (center), post-retrofit fan with compact fluorescent light bulbs (CFLs) (right).

Table 9. EH-02 Key Energy Efficiency Measures

Component	Pre- and Post-Retrofit Characteristics
Roof	From dark (solar absp = 0.92) to white asphalt shingles (solar absp = 0.75)
Ceiling Insulation	From 1250 ft^2 R-9 to 912 ft^2 blown-in fiberglass, R-30
Exterior Walls	From R-0 to R-11 in 3 frame walls
Windows	From single pane, clear, metal frame U = 1.20; SHGC = 0.80 to double pane, low-E U = 0.65; SHGC = 0.35
Doors	From 2 wood & 1 wood with jalousie windows to 3 insulated metal, 1 with storm
Floors	From 100% concrete to 30% carpet 60% laminate 10% tile
Whole House Infiltration	From ACH50 = 22 (est.) to ACH50 = 12.2
Heating and Cooling System	From SEER 10 with integral electric resistance heat to SEER 15 heat pump; heating seasonal performance factor (HSPF) = 8.7
Air Distribution System	From Qn,out = 0.30 to Qn,out = 0.10
Water Heating System	From 50 gal, electric, energy factor (EF) = 0.88 (est.) to 40 gal, electric; EF = 0.92
Refrigerator	From default to Energy Guide label of 416 kWh/yr
Lighting	From 0 CFLs to 80% CFLs
Fans	From no fans to ENERGY STAR fans

The removal of the old furnace (Figure 13, left) provided the space for the new split system air handler unit. As noted in Table 9, a highly efficient mechanical system was chosen. However, the mechanical closet was poorly designed, with an open return in the closet and airflow-restricting door allowing air passage only though the bottom grille (Figures 14-15, center and right).

Figures 13-15. EH-02 pre-retrofit abandoned heater (left), post-retrofit closet (center), post-retrofit open return with airflow-restricted louvered doors (right)

The post-retrofit duct leakage test results were poor (Qn,out = 0.10), though markedly improved from the pre-retrofit condition. Sources of leakage identified by researchers included a bathroom supply register, the unsealed seam at the floor of the air handler closet, and the condensate line entering the closet ceiling. The whole house leakage test results were also poor (ACH50 = 12.2), especially considering the installation of new windows and doors as well as drywall repair. The poorly sealed air handler closet and electrical panel were determined to be the primary sources of infiltration. These findings and the implications were shared with the partner, and at the partner's request, researchers met with the contractor to identify the above referenced infiltration and duct leakage issues that needed repair. Researchers offered to conduct testing after repairs to ensure issues were resolved, but the partner declined. This partner's interest in participation dwindled. During the post-retrofit audit, pressure mapping was performed to test the balance of mechanical system air flow though the house. Researchers created a "worst case" scenario by running the air handler and exhaust fans, and shutting all bedroom doors. Operating in "worst case" the home was depressurized to -4.3 pa, and there was excessive positive pressure in all bedrooms. Citing budgetary constraints, the partner was unwilling to install the above door transfer grilles into the plaster walls to correct the mechanically induced house pressure imbalances, opting instead to create a larger gap between the bottom of the bedroom doors and the floor, which did not provide adequate return air pathways. Post-retrofit pressure mapping results are presented in Table 10.

Table 10. EH-02 Post-Retrofit Pressure Mapping

Location	Pressure (Pa)
House WRT Out	-4.3
Master WRT House	9.0
Bedroom 2 WRT House	7.1
Bedroom 3 WRT House	11.1
Back Room WRT House	3.8
Air Handler Closet WRT House	-17.0

In summary, the pre-retrofit condition of this house provided ample opportunity for a deep energy retrofit. The projected energy cost savings of 40% was achieved through the installation of a forced air, central air conditioner (SEER 15) with heat pump, significant reduction in duct leakage, almost exclusive use of efficient lighting, reduction in whole house infiltration, insulation of the attic to R-30, and installation of double-pane, low-E, vinyl frame windows. There were two issues with this project: 1) The design and construction of the mechanical closet resulted in high duct leakage and whole house infiltration, and 2) return airflow restriction from bedrooms. Because the interior walls were plaster, the partner was unwilling to incorporate researchers' recommended correction to the house pressure imbalances - the installation of above door transfer grilles.

Total costs for the energy-related portion of the renovation equaled $19,097. The projected annual energy cost savings was $962, for a projected monthly loss of $48 per year and a 20-year simple payback. However, considering the incremental cost of higher efficiency options for replacement of worn out equipment and components, the monthly net is a positive $48, with a 3-year simple payback.

2.2.3 Deep Energy Retrofit EH-03 (Occupied after completion in May)

This, unoccupied, foreclosed, single-family detached home in Lake Worth, Florida is the first of five renovations initiated in 2011 by Habitat for Humanity Palm Beach County, Inc. (www.habitatpbc.org), a non-profit, affordable housing organization. Table 11 summarizes the projected annual energy use and cost savings for deep energy retrofit project EH-03. Table 12 relates the anticipated financing and payback associated with the whole package of improvements. Appendix A includes analysis for this project.

Table 11. EH-03 Annual Energy Use and Cost Simulation

Parameter	As Found	Minimal Improvement	Actual Retrofit
HERS Index	97	97	75
Annual Simulation kWh (BABM08)	12,773	12,773	9,421
Annual MBtu Usage (BABM08)	43.6	43.6	32.2
Annual Energy Cost (BABM08)	$1,656	$1,656	$1,225
Project Status: Completed 5/26/11			
"Minimal Improvement" reflects improvement for replacing the mechanical system with a SEER 13 air conditioner with electric resistance heating, the minimum efficiency system available.			

Table 12. EH-03 Annual Energy Savings Analysis

	Full Cost & Full Savings (As Found vs. Actual)	Incremental Cost & Incremental Savings (Minimal vs. Actual)
HERS Index Improvement (%)	23%	23%
Annual Energy Cost Savings ($)	$431	$431
Annual Energy Cost Savings (%)	26%	26%
Improvement Costs	$3,246	$2,246
Monthly Mortgage	$22	$15
Monthly Energy Cost Savings	$36	$36
Monthly Cash Flow	$14	$21
Simple Payback (years)	8	5

Built in 2003, this three bedroom, two bath, frame construction home has 1,373 square feet of conditioned space. In February 2011, a test-in audit was conducted to document the home's pre-retrofit characteristics, which served as the retrofit base case model. The eight-year-old home (Figure 16) had many energy efficient elements incorporated into its original construction. The existing home characteristics were a light-colored exterior, a white shingle roof, R-19 attic insulation, above bedroom door transfer grilles, and extensive shading of the large, east-facing window. Windows were single-pane, metal frame, with clear glazing. Appliances and lighting in place included an ENERGY STAR labeled refrigerator, a few CFLs, a minimally efficient electric water heater, and a central, forced air heating and cooling system. The mechanical system, a SEER 12 air conditioner with a heat pump, exceeded the minimal efficiency available at the time.

Figure 16. EH-03 pre-retrofit with hurricane shutters in place (Exterior unchanged during retrofit)

The whole house was tight (ACH50 = 5.9) and duct leakage was low (Qn,out = 0.047). Pressure pan diagnostics were performed to highlight potential areas of concern within the supply duct system, and none were found. Findings are presented in Table 13.

Table 13. EH-03 Pre-Retrofit Pressure Pan Diagnostics

Register Location	Pressure (Pa)
Kitchen 1	0.3
Kitchen 2	0.8
Kitchen 3	0.1
Living Room	0.5
Bedroom 1	0.4
Bedroom 2	0.2
Bedroom 3	0.3

Our partner decided the mechanical system, only eight years old, had enough useful life to be retained. The partner was willing, however, to incorporate a passive outside air ventilation system. The package of improvements included replacing the domestic hot water heater with a hybrid heat pump water heater (coefficient of performance (COP) = 2.35), insulating the attic to R -38, insulating one wall found to be without insulation to R-13, replacing the outdated ENERGY STAR refrigerator with a currently qualified model, and an extensive use of compact fluorescent light bulbs.

This retrofit, completed May 26, 2011, was comprised of a package of measures (Table 14) that resulted in an estimated $431 in annual energy cost savings. Based on the partner provided renovation costs of $3,246, these savings outweigh the added mortgage cost by an average of $14 per month. In addition, researchers analyzed the incremental first costs for the higher efficiency options. The monthly cash flow increased to $21 with a 5-year simple payback.

The estimated annual energy savings, added mortgage costs, and anticipated positive cash flow are presented in Table 12.

Table 14. EH-03 Key Energy Efficiency Measures

Component	Pre- and Post-Retrofit Characteristics
Ceiling Insulation	From R-19 to R-38, blown-in fiberglass
Exterior Walls	Insulated one non-insulated wall with R-13 fiberglass batts
Whole House Infiltration	From ACH50=5.9 to ACH50 = 6.26, installation of passive runtime outside air ventilation system
Water Heating System	From 50 gal, electric, EF = 0.88 to 50 gal, electric heat pump hybrid water heater, COP = 2.35
Refrigerator	From default to Energy Guide label of 378 kWh/yr
Lighting	From 10% CFLs to 80% CFLs

The slight increase in the whole house infiltration can likely be attributed to the installation of the passive runtime ventilation system into the return plenum, as there were no other penetrations into the envelope during the renovation. This passive run-time ventilation strategy also produces a slight positive pressure in the house with respect to the outside while the air handler is running, a building durability feature to ensure that infiltration of hot humid outdoor air will not occur under normal operating conditions and that any house depressurization will be neutralized with air from a known, clean path rather than through envelope infiltration points. Although auditors attempted to block the fresh air intake for the air tightness tests, duct mask did not adhere well to the boot or surrounding plywood.

The duct leakage-to-out was essentially unchanged between test-in and test-out; however, there was a worsening of the total duct leakage. The air handler and single, central return system were interior, with supply distribution running through the attic. With the house depressurized to -50pa, the attic registered at +47pa with reference to the main body of the house. This result indicated good separation between the conditioned space and the attic. Neither the mechanical system nor its duct work was replaced as part of this retrofit. Predictably, duct leakage to the outside (Qn,out = 0.05) was essentially unchanged at test-out; however Qn,total increased from 0.09 to 0.12. Again, researchers attribute this finding to the outside air ventilation installation. Duct leakage test results are presented in Table 15.

Table 15. EH-03 Pre-Retrofit vs. Post-Retrofit Duct Leakage

Duct Testing	Pre-Retrofit	Post-Retrofit
Cubic feet per minute (CFM) 25, total:		
Return	118	153
Supply	129	174
Qn,total	0.09	0.12
CFM 25,out:		
Return	56	55
Supply	72	81
Qn,out	0.047	0.05

During the post-retrofit audit, pressure mapping was performed to assess whole house system pressure boundaries. Auditors induced a “worst case” scenario by running the air handler and exhaust fans and shutting all bedroom doors. Operating in “worst case” the home was only slightly depressurized (-0.5 pa), and there was not excessive pressure built up in any of the bedrooms. Therefore, the existing above door transfer grilles are doing an adequate job of balancing mechanically induced house pressures. See Table 16 for a summary of the post-retrofit pressure mapping results. Figure 17 is a picture of above door transfer grilles.

Table 16. EH-03 Post-Retrofit Pressure Mapping

Location	Pressure (Pa)
House WRT Out	-0.5
Master WRT House	0.7
Bedroom 2 WRT House	0.4
Bedroom 3 WRT House	0.7

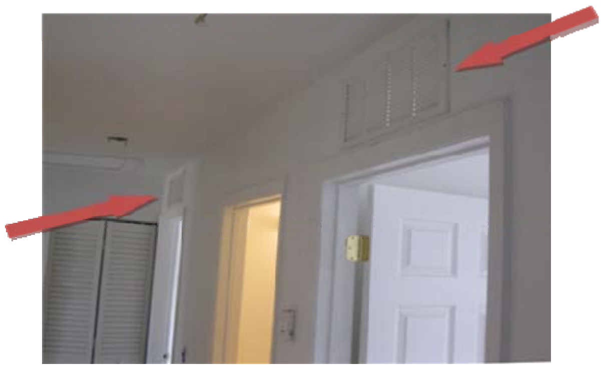


Figure 17. Retrofit EH-03. Above door transfer grilles.

The retrofit components responsible for the bulk of the projected energy cost savings are the hybrid heat pump water heater, added ceiling insulation and extensive use of CFLs. These measures, in addition to the installation of the mechanical runtime ventilation system, are highlighted in the following discussion.

As noted earlier, the existing mechanical system was determined to have several years of useful life and was not slated for replacement. The partner agreed to work with researchers, however, to bring fresh air into the home via the mechanical system. Our recommended passive, runtime ventilation strategy involves connecting duct work from the outside into the return plenum near the air handler where it is mixed with house air when the system is running. The outside air is drawn through an inlet mounted in the soffit. In this design, the outside air is being filtered at the entry to the air handler rather than at the soffit. We have found partners, in general, are reluctant to install filter back grilles in the soffit for the outside air. The filter-back component requires depth at the soffit to accommodate a manufactured or fabricated boot. For low pitch, there is not adequate vertical space to accommodate this component. Additionally, partners are skeptical that residents will replace an outside filter. The reasoning seems to be concern over general awareness of the filter in the long term as well as lack of availability of correct size filters from the retail outlets. Since the outside air must be filtered prior to crossing the cooling coil, the configuration implemented in this house has been accepted. An insect screen however was provided at the intake. Figures 18-20 show images of this installation.

Figures 18-20. EH-03 pre-retrofit return plenum (left), outside air ducted into the post-retrofit return plenum (middle), soffit retrofit for the air intake (right)

The attached, unconditioned storage room measuring 7’x 8’x 9’, was large enough to house a heat pump water heater. The installation of the hybrid water heater with heat pump (Figures 21-22) in this location has the added benefit of dehumidifying and cooling this storage area and the attic, which the room is open to.

Figures 21-22. EH-03 pre-retrofit electric tank water heater, EF = 0.88 (left), hybrid heat pump water heater, COP = 2.35 (right)

The existing ceiling insulation was comprised of R-19 fiberglass batts laid on top of the ceiling drywall. Blown-in fiberglass insulation was added to the existing batt, yielding R-38 total. Figures 23-24 illustrate the pre- and post-retrofit ceiling insulation.

Figures 23-24. EH-03 pre-retrofit (left) and post-retrofit (right) ceiling insulation

The final significant retrofit measure was the installation of approximately 80% compact fluorescent light bulbs.

Several low-cost, energy saving recommendations not incorporated into the retrofit may have enabled this home to reach the 30% energy cost savings threshold. Our suggestions were to install a programmable thermostat, apply window film to the east and west facing windows, select ENERGY STAR qualified ceiling fans, and insulate the hot water system pipes.

In summary, had the mechanical system been at or near the end of its life and replaced, or if some of the lower cost suggestions above had been incorporated into the renovation, this project would have easily achieved or exceeded the 30% energy cost savings goal. As noted in Tables 11 and 12, this retrofit attained a 26% projected energy cost savings with a projected annual energy cost of $1,225 and a projected annual cost savings of $431. This includes the slight energy use increase from the passive ventilation system. Using costs provided by our partner to address the cost-effectiveness of this retrofit, we see a monthly cash flow of $14 and a simple payback of 8 years. Considering incremental first costs only, the monthly cash flow is increased to $21 with a 5-year simple payback. Although this retrofit fell short of our savings goal it is an impressive example of energy efficiency gains that can be cost-effectively achieved in a newer home.

2.2.4 Deep Energy Retrofit EH-04 (Occupied after completion in August)

This home was unoccupied at the time of renovation which was completed in August of 2011. In the fall, a new owner purchased and occupied the premises. Table 17 summarizes the projected annual energy use and cost savings for deep energy retrofit project EH-04. Table 18 relates the anticipated financing and payback associated with the whole package of improvements. This project has been selected for monitoring, described in Section 2.2.3. Appendix A includes analysis for this project.

Table 17. EH-04 Annual Energy Use and Cost Simulation

Home Components	As Found	Minimal Improvement	Actual Retrofit
HERS Index	132	Same as “Actual”	78
Annual kWh	11,920		7,750
Annual Therms	106		0
Annual MBtu Usage	51.3		26.5
Annual Energy Cost	$1,733		$1,008
Project Status: Completed			
“Minimal Improvement” reflects improvement for replacing the mechanical system with a SEER 13 air conditioner with electric resistance heating, the minimum efficiency system available. In this house, that was the specification in the Actual Retrofit so there is no difference between the two scenarios.			

Table 18. EH-04 Annual Energy Savings Analysis

	Full Cost & Savings (As Found vs. Actual)	Incremental Cost & Savings (Minimal vs. Actual)
HERS Index Improvement (%)	Full First Cost Not Available	41%
Annual Energy Cost Savings ($)		$725
Annual Energy Cost Savings (%)		42%
Improvement Costs		$5,310
Monthly Mortgage		$36
Monthly Energy Cost Savings		$60
Monthly Cash Flow		$25
Simple Payback (years)		7

This slab-on-grade, single-family, ranch style home located in Eustis, Florida was purchased and renovated by Lake-Sumter Habitat for Humanity for resale as affordable housing. The house was built in 1981 with concrete block construction, 1,040 ft^2 of conditioned space, three bedrooms and two baths. Figures 25-26 show the pre- and post-retrofit condition of the exterior finishes. The home had been vacant for a significant period of time and underwent substantial renovations including both energy and non-energy related upgrades.

A pre-retrofit audit was conducted on February 24, 2011. Data collected during the audit was used to generate a HERS Index of 132. Annual energy consumption was calculated at 51.2 million metric British thermal units (MMBtu) resulting in a total energy cost of $1,733 annually at $0.13 kWh. The heating, ventilation, and air conditioning (HVAC) system consisted of an air handler installed in an interior closet, a SEER 9 air conditioner, and a gas furnace estimated at 0.68 annual fuel utilization efficiency (AFUE) coupled with a remarkably leaky duct system (Qn,out=0.32). The attic was insulated with R-19 fiberglass batts, and the exterior block walls were insulated with ½" of expanded polystyrene board insulation. The windows were metal frame with a combination of single and double-pane clear and frosted glass.

Figures 25-26. EH-04 pre-retrofit (left) and post-retrofit (right)

Using Energy Gauge USA® and the Building America bench mark 2008 thermostat schedules, the predicted annual savings attributed to efficiency measures was $725, a 42% reduction from the "as found" building. The greatest reduction in energy use was attained by replacing the old SEER 9 air conditioner and gas furnace, with a SEER 13 heat pump (Figures 27-28). Another significant measure that considerably improved the homes efficiency was the reduction of duct leakage, both total leakage and leakage to outside. Window replacement, attic insulation, installation of CFLs, and refrigerator replacement also contributed to increased efficiency. Table

19 summarizes the project's energy efficiency measures. A detailed analysis of this project can be found in Appendix A.

Table 19. EH-04 Key Energy Efficiency Measures

Component	Pre- and Post-Retrofit Characteristics
Ceiling Insulation	From R-19 to R-38, RESNET Grade I
Windows	Installed new double-pane from (5) single, clear, metal (U=1.20; SHGC = 0.80); (3) double, tinted, metal to ENERGY STAR windows (U = 0.51; SHGC = 0.25)
Heating and Cooling System	From 2-ton SEER 9; gas furnace AFUE = 0.68 to SEER 13; 2-ton A/C heat pump; HSPF 7.7
Air Distribution System	Reduced Duct Leakage trom Qn Out = 0.32 to Qn out = 0.046
Refrigerator	From standard model to ENERGY STAR refrigerator
Lighting	From 8 fixtures; 2 CFL to 9 fixtures; 9 CFS 100%

The mechanical contractor did not itemize the cost for duct sealing and construction of the air handler closet and return plenum from the total HVAC replacement cost, which included a two ton SEER 13 heat pump (Figures 27-28). Duct leakage was the second most significant repair, reducing the HERS Index by 16 points and saving an estimated $207 in annual energy costs.

Figures 27-28. EH-04. Replacing the 9 SEER air conditioner and gas furnace with a 13 SEER heat pump accounted for the greatest reduction in estimated annual energy cost ($277) of any single measure in this project.

In order to install the new air handler, the closet was reconfigured, and a new return plenum with a ducted plenum was constructed. When the return grille and filter were removed for the duct leakage test during the post retrofit audit, fiberglass insulation from the attic was observed in the return plenum. Further investigation led to the discovery that the interior wall cavity forming the front of the air handler closet was not sealed (Figure 29, left). Attic air and insulation were being pulled through this leakage pathway when the air handler was operating. The project manager left the site and returned with fiberglass insulation and a can of expanding foam insulation to seal the opening (Figure 30, right).

Figures 29-30. EH-04. An open wall cavity connecting the return plenum to the attic was discovered during the test out (left photo with arrow marking air pathway). The opening was sealed using a combination of fiberglass (filler) and expandable foam sealant/insulation (photo right). The excess foam was trimmed before reinstalling the air handler filter and grille.

The fiberglass batt ceiling insulation was matted and compressed throughout the attic and completely missing in many areas (Figure 31, left). The insulation contractor did an excellent job of ensuring the new insulation was evenly distributed and at the depth required to attain R-38 thermal performance (Figure 32, right).

Figures 31-32. EH-04 pre-retrofit compressed fiberglass insulation (left) was improved to R-38 with blown-in fiberglass.

Several of the windows in the pre-retrofit house were broken, and others did not lock. Windows were replaced for security and functionality reasons as opposed to concerns of energy consumption. If the window replacement was removed from the post-retrofit energy analysis, there would still be a 38% reduction in annual energy cost and a 36% reduction in HERS Index, which reduces the project's simple payback from seven to six years. This emphasizes that a 30-year-old home with air conditioning efficiency and duct system typical of the early 1990's can achieve 30% improvement with relatively moderate improvements in HVAC, ceiling insulation, appliances (ENERGY STAR refrigerator), and lighting. In addition, this home had a gas heating pre-retrofit, which the partner chose to replace with a minimum efficiency electric heat pump. The majority of homes in this and other FSEC studies of similarly aged houses have electric rather than gas heating where air conditioning is typically paired with electric resistance heating rather than heat pump units. Such a configuration in the "as found" condition of this home would have produced higher estimated pre-retrofit annual energy cost and similarly larger estimated energy savings for the minimum efficiency heat pump replacement.

Adding outside air to the return system was recommended and discussed with the partner. When the low-pitched roof and lack of access was considered along with the house's relatively high

ACH50 of 9.27, the partner decided that cost and installation difficulty outweighed the benefit. A passive run-time ventilation strategy was recommended because it produces a slight positive pressure in the house with respect to the outside while the air handler is running, a building durability feature, exfiltrating conditioned air as opposed to infiltrating hot humid outdoor air. When the air handler is not running, this system also provides a more controllable path for vent-fan make-up air to enter the house as opposed to infiltration through the walls.

Pressure relief transfer grilles were installed in all of the bedrooms. Table 20 details the results of pressure mapping conducted during the test out.

Table 20. EH-04 Post-Retrofit Pressure Mapping

Location	Pressure (Pa)
House WRT Out	0.8
Master (including bath) WRT House	3.0
Bedroom 2 WRT House	0.2
Bedroom 3 WRT House	0.3

The total annual energy consumption in the post-retrofit house is estimated at $1,012, down from $1,733 at test in. This represents a 42% reduction in annual energy costs to the homeowner, $60 per month in savings, and an estimated simple payback of 7 years. These figures clearly show that the potential for cost-effective energy use reductions of 30% or greater are possible with homes of similar size and condition in the hot humid climate. To verify the savings predictions, this project has been selected for post-retrofit monitoring. More information on the specifics on the monitoring of this home is available in the monitored homes section of this report.

2.2.5 Deep Energy Retrofit EH-05 (Occupied, Dropped)

The homeowners of Retrofit Candidate EH-05 elected to install photovoltaic (PV) instead of efficiency improvements at this time, ending partnership activity. The utility bills of this three person family are high. When the home was built in 2005, it was certified Energy Star. Given the age and original effort to incorporate energy efficiency, none of the measures analyzed produced sufficient savings to justify the first cost. Researchers provided recommendations for HVAC specification at the time of replacement and some guidance on pool pump operation.

2.2.6 Deep Energy Retrofit EH-06 (Occupied after completion in August)

This unoccupied, foreclosed, single-family detached home in Melbourne, Florida is the second of four renovations initiated in 2011 by Habitat for Humanity of Brevard County, Inc. (http://brevardhabitat.com), a non-profit, affordable housing organization. Table 21 summarizes the projected annual energy use and cost savings for deep energy retrofit project EH-06. Table 22 relates the anticipated financing and payback associated with the whole package of improvements. Appendix A includes analysis for this project.

Table 21. EH-06 Annual Energy Use and Cost Simulation.

Home Components	As Found	Minimal Improvement	Actual Retrofit
HERS Index	117	117	76
Annual Simulation kWh (BABM08)	16,077	16,077	10,450
Annual MBtu Usage (BABM08)	54.9	54.9	35.7
Annual Energy Cost (BABM08)	$2,091	$2,091	$1,360
Project Status: Completed 8/13/11			
"Minimal Improvement" reflects improvement for replacing the mechanical system with a SEER 13 air conditioner with electric resistance heating, the minimum efficiency system available.			

Table 22. EH-06 Annual Energy Savings Analysis

Parameter	Full Cost & Savings (As Found vs. Actual)	Incremental Cost & Savings (Minimal vs. Actual)
HERS Index Improvement (%)	35%	35%
Annual Energy Cost Savings ($)	$731	$731
Annual Energy Cost Savings (%)	35%	35%
Improvement Costs	$7,867	$3,459
Monthly Mortgage	$53	$23
Monthly Energy Cost Savings	$61	$61
Monthly Cash Flow	$8	$38
Simple Payback (years)	11	5

Built in 1962, this three bedroom, two bath home (Figures 33-34) has 1,583 square feet of conditioned space.

Figures 33-34. EH-06 pre-retrofit (left) and post-retrofit (right).

Nearly 50 years old, this slab-on-grade, concrete block home had a light colored exterior and light asphalt single roof. The thermal envelope included a 285ft^2 enclosed porch with a shallow pitch, which restricted the level of ceiling insulation. Ceiling insulation consisted of a mixture of batt and blown-in fiberglass and was estimated to be an average of R-11 for the entire ceiling. The existing windows, a mixture of awning style and single hung, were all single-pane, clear, with metal frame, and all were planned for replacement. The mechanical system was a forced air, SEER 12, central air conditioner with a heat pump. Appliances and lighting in place included an older 40-gallon electric hot water heater, no refrigerator, and 100% incandescent lighting.

The home was exceptionally leaky (ACH50 = 16.3). The predominant causes of infiltration included several wall penetrations, an abandoned mechanical system return drop creating an open pathway to the attic, and a previously retrofitted bathroom lighting fixture. The air handler closet design consisted of a stand, no platform return, and was installed behind airflow-restricting louvered doors. The resulting dust build-up in the closet prevented researchers from performing duct leakage tests. A Qn,out of 0.13 was used as a default, the average pre-retrofit duct leakage found in prior research.

The retrofit was completed on August 13, 2011. Measures with the most significant contribution to projected energy cost savings were the almost exclusive use of efficient lighting, the installation of low-E windows, the reduction in house and duct leakage, and the installation of R-38 ceiling insulation, respectively. The entire package of improvements, listed in Table 23, is estimated to produce $731 in annual energy cost savings. The partner has reported the costs for all of these measures to be $7,867. Based on these costs, projected savings outweigh the added mortgage cost by an average of $8 per month for an 11-year simple payback. Researchers also analyzed the incremental first costs for the higher efficiency options. Considering only incremental costs, monthly cash flow is increased to $38, and simple payback is reduced to 5 years. The estimated annual energy cost savings, added mortgage costs, and anticipated positive cash flow are presented in Table 22.

Table 23. EH-06 Key Energy Efficiency Measures

Component	Pre- and Post-Retrofit Characteristics
Roof	Light asphalt shingles, same as pre-retrofit
Ceiling Insulation	From R-11 to R-38 in accessible section (1298sf)
Exterior Walls	New paint, light color, same as pre-retrofit
Windows	From single pane, clear, metal frame (U = 1.20; SHGC = 0.80) to double-pane, low-E, vinyl frame (U = 0.30; SHGC = 0.29)
Doors	From wood to insulated (1 door)
Whole House Infiltration	From ACH 50 – 16.3 to ACH50 = 6.23
Heating and Cooling System	From SEER 12 with heat pump; HSPF 6.8 (est.) to SEER 14 with integral electric resistance heat
Air Distribution System	From Qn,out = 0.13 (est.) to Qn,out 0.033
Water Heating System	From 40 gal, electric, EF = 0.92 to 40 gal, electric, EF = 0.92
Refrigerator	From default to Energy Guide label of 383 kWh/yr
Lighting	From 0 CFLs to 12 of 14 fixtures with CFLs

The partner's election to install an air conditioner with integral electric resistance heat rather than with a heat pump was a missed energy-savings opportunity. The projected annual energy cost savings of the resistance heat system installed was only $15, whereas the heat pump had a projected annual energy cost savings of $174, a difference of $159 annually.

As previously mentioned, the existing mechanical closet was poorly designed with an open return in a closet with airflow-restricting louvered doors. Such a design allowed for uncontrolled airflow and resulted in dust build-up. The mechanical system retrofit included constructing a ducted return and bringing filter access to the wall plane (Figure 35-36). Outside air ventilation via a runtime vent was not incorporated into this mechanical system retrofit. Although the deep retrofit package proposed to the partner recommended outside air, researchers prioritized efficiency measures at this early stage in the partnership. Post-retrofit duct leakage tests confirmed that the contractor performed a good job with respect to sealing the supply plenum and return plenum. If post-retrofit whole house air tightness testing had revealed an extremely tight envelope, researchers would have re-visited the issue with the partner.

Figures 35-36. Retrofit EH-06. Air Handler Closet: Pre-retrofit without return plenum and installed behind airflow-restricting louvered doors (left), Post-retrofit platform return plenum with filter access on same plane as wall (right).

During the post-retrofit audit, pressure mapping was performed to assess whole house system pressure boundaries. Auditors induced a “worst case” scenario by running the air handler and exhaust fans and shutting all bedroom doors. Operating in “worst case” the home was depressurized to -2.5 pa. Bedrooms were moderately pressurized. Table 24 shows a summary of the post-retrofit pressure mapping results.

Table 24. EH-06 Post-Retrofit Pressure Mapping

Location	Pressure (Pa)
House WRT Out	-2.5
Master WRT House	2.7
Bedroom 2 WRT House	3.2
Bedroom 3 WRT House	3.3

During the test-out audit, researchers observed no change in the attic insulation, which was previously estimated to be an average of R-11 (Figures 37-38). Our partner understood the insulation contractor had completed this work before scheduling our post-retrofit audit. Ultimately, fiberglass was blown-in to achieve R-38. However, this measure would have potentially been skipped had it not been for our involvement in this retrofit.

Figures 37-38. EH-06 ceiling insulation: Pre-retrofit estimated average of R-11 (left), post-retrofit no additional insulation (right)

In summary, a combination of low-cost and high-cost measures helped this project exceed its deep energy retrofit goal, for a projected energy cost savings of 35%. Savings were achieved primarily through the installation of efficient lighting, low-E windows, R-38 ceiling insulation, and a drastic reduction in whole house leakage, and tight duct work. There were two shortcomings of this project, however:

The mechanical system chosen for this retrofit was suboptimal. An air conditioner with a heat pump rather than an integral resistance heat is the preferred system for this location.

The partner failed to confirm the completion of all subcontractor work. This lapse in communication and lack of central oversight indicate a gap in the contracting paradigm.

Despite the issues noted above, the project cost-effectively achieved its deep retrofit goal. With total costs of $7,867 for the energy-related retrofit measures and projected annual energy cost savings of $731, the projected monthly cash flow is $8 for an 11-year simple payback. Monthly cash flow is increased to $38 for a 5-year simple payback when only the incremental first costs are considered.

2.2.7 Deep Energy Retrofit EH-07(Occupied after completion in July)

This unoccupied, foreclosed, single-family detached home in Melbourne, Florida is the first of four renovations completed in 2011 by Habitat for Humanity of Brevard County, Inc. (http://brevardhabitat.com), a non-profit, affordable housing organization. Table 25 summarizes the projected annual energy use and cost savings for deep energy retrofit project EH-07. Table 26 relates the anticipated financing and payback associated with the whole package of improvements. Appendix A includes analysis for this project.

Table 25. EH-07 Annual Energy Use and Cost Simulation

Home Components	As Found	Minimal Improvement	Actual Retrofit
HERS Index	136	121	85
Annual Simulation kWh (BABM08)	17,386	15,870	11,628
Annual MBtu Usage (BABM08)	59.3	54.2	39.7
Annual Energy Cost (BABM08)	$2,260	$2,063	$1,511
Project Status: Completed 7/30/11			
"Minimal Improvement" reflects improvement for replacing the mechanical system with a SEER 13 air conditioner with electric resistance heating, the minimum efficiency system available.			

Table 26. EH-07 Annual Energy Savings Analysis

	Full Cost & Savings (As Found vs. Actual)	Incremental Cost & Savings (Minimal vs. Actual)
HERS Index Improvement (%)	38%	30%
Annual Energy Cost Savings ($)	$749	$552
Annual Energy Cost Savings (%)	33%	27%
Improvement Costs	$7,923	$2,567
Monthly Mortgage	$53	$17
Monthly Energy Cost Savings	$62	$46
Monthly Cash Flow	$9	$29
Simple Payback (years)	11	5

Built in 1964, this four bedroom, two bath home (Figures 39-40) has 1,608 square feet of conditioned space. Renovations to this home were underway by the time a partnership was in place with this Habitat affiliate. The test-in audit was conducted to document as much as possible of the pre-retrofit character of the home as possible. Additional information was gathered from project staff. Pre-retrofit, the home was conditioned by a central, forced air heating and cooling system with a SEER 10 air conditioner and electric resistance heating. The foundation is slab-on-grade with concrete block walls. The thermal envelope included a 276 ft^2 enclosed porch with a shallow pitch, restricting potential ceiling insulation levels and cramping supply duct work. The remaining ceiling insulation was also very poor, and an R-9 average was estimated for the entire ceiling. Worn out single-pane, clear, metal frame windows were slated for replacement.

Figures 39-40. EH-07 pre-retrofit (left) and post-retrofit (right).

At the time a partnership was formed with this Habitat affiliate, renovations were already underway, including installation of a new, forced air, central air conditioner (SEER 13) with electric resistance heating. Since the mechanical closet had already been rebuilt, there was no discussion of incorporating outside air. The partner was willing, however, to incorporate recommendations including installing double-pane, low-E, vinyl frame windows, insulating the attic to R-38, and selecting higher efficiency appliances and lighting. The package of improvements (Table 27) is estimated to produce $749 in annual energy savings. Based on the partner provided renovation costs of $7,923, these savings outweigh the added mortgage cost by an average of $9 per month.

In further analysis, researchers assumed some minimum efficiency upgrades along with the incremental costs for higher efficiency options. Allowing for the fact that the mechanical system could not have been replaced with a less efficient unit, the projected energy cost savings over the minimal replacement is reduced to $552. This in consideration with incremental first costs only, the monthly cash flow is increased to $29 with a 5 year simple payback. The estimated annual energy savings, added mortgage costs, and anticipated positive cash flow are presented in Table 26.

Table 27. EH-07 Key Energy Efficiency Measures

Component	Pre- and Post-Retrofit Characteristics
Ceiling Insulation	From R-11 to R-38 in 1320ft^2 of accessible section (single assembly ceiling over enclosed porch inaccessible)
Exterior Walls	From light colored exterior to light colored exterior
Windows	From single pane, metal frame, clear windows (U = 1.20; SHGC = 0.80) to Double-pane, low-E, vinyl frame (U = 0.30; SHGC = 0.29)
Doors	From wood to– insulated (2 doors–)–
Floors	From 70% Carpet, 20% Tile, 10% Vinyl to 80% Vinyl, 20% Tile
Whole House Infiltration	From ACH50=11(est.) to ACH50 = 7.22
Heating and Cooling System	From SEER 10 with integral electric resistance heat to SEER 13 with integral electric resistance heat
Air Distribution System	From R-4.2 (est.) flex ducts; Qn,out = 0.13 (est.) to R-6 flex ducts; Qn,out = 0.57 and duct board return air plenum
Water Heating System	From 40 gal, electric, EF = 0.88 (est.) to 40 gal, electric; EF = 0.92
Refrigerator	From default to Energy Guide label of 383 kWh/yr
Lighting	From 0 CFLs to 80% CFLs
Ceiling Fans	From no fans to Non-ENERGY STAR fans

Most of the energy cost savings for this renovation, completed July 30, 2011, resulted from installing high efficiency windows, using efficient lighting almost exclusively, and increasing ceiling insulation to R-38. Replacement of the mechanical distribution system was also fairly significant in its contribution to energy cost savings.

Working with limited air-handler closet space proved to be a challenge for the mechanical contractor. Unsealed holes in the ceiling of the air handler closet resulted in ceiling insulation to being pulled into the air handler closet when the mechanical system was running (Figures 41-42). Leaving a large hole in the closet is a result of poor quality assurance. Although researchers offered to retest the home, the partner declined post-corrective testing. The subcontractor returned to correct this installation. In contrast, the new return air plenum was notably well constructed by reversing the duct board (shiny side in) and sealing all seams well with mastic (Figure 43). This achieves an adequately sealed plenum; however, when researchers discussed this approach with engineering staff at one manufacturer and no known problems with this installation were in evidence; however, two concerns were raised. First, this approach is not consistent with manufacturer guidance on product use and therefore would likely not be supported in the case of a dispute involving the product in this configuration. Second, the foil side is a vapor flow retarder which should not be on the cold side of the assembly. This installation is inside the conditioned space so that the temperature and moisture conditions on both sides of the material are similar; however, if this were in an unconditioned space it would warrant a more thorough review.

Figures 41-42. EH-07. White attic insulation around air handler (left) fell through spaces in the closet ceiling (right, looking up at closet ceiling framing).

Figure 43. EH-07. New return air plenum constructed of foil faced duct board, shiny side facing in.

Testing of the new duct work found higher than expected leakage, especially considering the apparently well sealed return plenum. Researchers performed pressure pan diagnostics. The results of this test pointed to leakage at the small, cramped supply registers at the entrance into the enclosed porch. Inadequate work space prevented the contractor from addressing the problems near this register. Findings are presented in Table 28.

Table 28. EH-07 Pre-Retrofit Pressure Pan Diagnostics

Register Location	Pressure (Pa)
Kitchen	0.2
Utility Room	1.5
Living Room 1	0.3
Living Room 2	0.4
Florida Room 1	0.8
Florida Room 2	0.4
Florida Room 3	3.5
Bedroom 1	0.4
Bedroom 2	0.4
Bedroom 3	0.4
Bedroom 4	0.3
Bathroom 1	0.8
Bathroom 2	0.0

During the post-retrofit audit, pressure mapping was performed to assess whole house system pressure boundaries. Auditors induced a "worst case" scenario by running the air handler and exhaust fans and shutting all bedroom doors. Operating in "worst case" the home was depressurized only slightly, -0.5 pa. All bedrooms were moderately pressurized. The home had no passive air transfer grilles or jump ducts from the bedrooms. Table 29 shows a summary of the post-retrofit pressure mapping results.

Table 29. EH-07 Post-Retrofit Pressure Mapping

Location	Pressure (Pa)
House WRT Out	-0.5
Master WRT House	3.4
Bedroom 2 WRT House	3.8
Bedroom 3 WRT House	2.2
Bedroom 4 WRT House	5.1

Researchers informed the partner of the pressure pan and the pressure mapping results and recommended correction action. Citing inaccessibility to the problem registers and plans for immediate occupancy of the home, the partner was unable to address either issue.

In summary, this retrofit highlights two retrofit challenges:

Lack of quality assurance – The missing ceiling in the air handler closet points to a need for better quality assurance processes. Although the construction manager was aware of the need for this detail, it did not get implemented. The construction did not identify it under regular quality assurance procedures. Integrating new details into the existing framework of subcontractor communications remains a major challenge to achieving high performance in the retrofit arena.

Confined work spaces – Performing an adequate job requires sufficient work space. An air distribution system housed within the attic of a shallow pitched roof continues to be a challenge for existing home retrofits.

Despite the issues during the retrofit and considering that the mechanical equipment installed was of minimal efficiency, the project easily met its goal of a deep energy retrofit with 33% projected energy cost savings, projected energy costs of $1,511, and a projected annual cost savings of $749. Using costs provided by our partner to address the cost-effectiveness of this retrofit, we see a monthly cash flow of $9 and a simple payback of 11 years.

2.2.8 Deep Energy Retrofit EH-08,-09,-10,-11 (Unoccupied, In Progress)

Table 30 summarizes the projected annual energy use and cost savings for deep energy retrofit projects EH-08-11, four single-family attached units in a single building. Table 31 relates the anticipated financing and payback associated with the whole package of improvements. Appendix A includes analysis representative of the four units.

Table 30. EH-08, EH-09, EH-10, and-EH-11 Annual Energy Use and Cost Simulation.

Parameter	As Found	Projected Post-Retrofit
HERS Index	166 (range of 117 to 190)	73 (range of 65 to 73)
Annual Simulation kWh (BABM08)	14,044	6,721
Annual Energy Cost (BABM08)	$1,827	$875
Project Status: In Progress, completion likely Spring 2012		

Table 31. EH-08, EH-09, EH-10, and-EH-11 Annual Energy Savings Analysis

	As Found vs. Predicted
HERS Index Improvement (%)	56%
Annual Energy Cost Savings ($)	$952
Annual Energy Cost Savings (%)	52%
Improvement Costs	NA
Monthly Mortgage	NA
Monthly Energy Cost Savings	$79
Monthly Cash Flow	NA
Simple Payback (years)	NA

Brevard County Department of Housing and Human Services invited Building America to work with their rehab project in Titusville FL, a deep energy retrofit of a quad-plex building. The 1981 built slab-on-grade, two story, four-unit building has two units on each floor. The upper floor is frame, and the lower floor is of block construction. Each two bedroom, one bath unit is 853 ft^2. (Figure 44).

Figure 44. EH-08-11 pre-retrofit, renovation is still in progress

A test-in survey revealed a building with three antiquated, SEER 8 central air conditioners with electric resistance heating combined with extremely leaky duct systems (Qn out > 0.25), and one replacement unit with a SEER 13 heat pump and new, fairly tight duct work. An older, 30-gallon electric water heater was installed on the interior of the units. There was shingle roof clearly at the end of its useful life. Attic insulation levels were assumed to be R-19 based on construction date because there was no attic access. Block was modeled as uninsulated, and frame walls were R-11. There were single-pane metal windows, and the ground floor units had rear-located sliding glass doors. In addition, the lighting was predominantly incandescent, and there were old, standard refrigerators in the units. The floors were wall-to-wall carpet with vinyl in the baths and kitchens.

The partner's scope of work specified high-efficiency heat pumps (SEER 16) including new ducts, a metal roof, new ENERGY STAR windows, increased attic insulation, tile flooring, and appliance replacement. Building America analysis highlighted several areas of the partner's specifications that needed refinement. Sliding glass door specifications were not called out. Furthermore, the color of the metal roof, the appliance efficiencies, and the tightness of the duct system were not specified. Building America (BA) recommendations are reflected in Table 32. Implementation of these measures is expected to reduce energy costs between $509 and $1,385, depending on the condition during test-in and which floor the unit is on.

Table 32. EH-08-11 Key Energy Efficiency Measures

Component	BA Proposed Retrofit Characteristics
Roof	White metal
Attic	R-30
Windows	ENERGY STAR, including sliding glass door
HVAC	SEER 16 heat pump
Duct System	Leak-free (Qn out<0.031)
Lighting	ENERGY STAR Certified
Refrigerator	ENERGY STAR Certified
Water Heater	40-gallon electric tank.
Flooring	100% tile
Ceiling Fans	ENERGY STAR Certified

The partner agreed to adopt all of the Building America (BA) recommendations. The metal roof is not white, but Galvalume. As of yet, this project is not finished. A five-month delay in the start of this renovation has pushed likely completion into the spring of 2012.

2.2.9 Deep Energy Retrofit EH-12 (Occupied after completion in November)

This single-family detached home in Lakeland, Florida is the second of two renovations completed in 2011 by the City of Lakeland, Community Development Department, Neighborhood Services Division (www.lakelandgov.net/commdev/Housing.aspx). Built in 1950, this 3 bedroom, 2 bath home (Figures 45-46) had 1,432 square feet of conditioned space at test-in. After rehab, the house was a 4 bedroom, 2 bath house with a conditioned footprint of 1,756 square feet.

The thermal envelope included a 542 square foot section with a shallow pitch cathedral roof. This could not be inspected and was assumed to house R-11 insulation. The ceiling for this section was tongue-in-groove wood, and it was found to be very leaky during testing. This roof/ceiling was not addressed by the rehab and remained as the major source of infiltration after rehab. The existing windows were older single pane with metal frames. All were replaced. Appliances and lighting included an older 30-gallon electric hot water heater, 80% fluorescent lighting, and seven old ceiling fans. Table 33 and 34 show the annual energy use and savings analysis for this home.

Table 33. EH-12 Annual Energy Use and Cost Simulation

Home Components	As Found	Minimal Improvement	Actual Retrofit
HERS Index	146	155	92
Annual Simulation kWh (BABM08)	21,789	23,966	15,212
Annual MBtu Usage (BABM08)	77.4	88.1	51.9
Annual Energy Cost (BABM08)	$2,832	$3,166	$1,978
"Minimal Improvement" reflects improvement for replacing the mechanical system with a SEER 13 air conditioner with electric resistance heating, the minimum efficiency system available.			

Table 34. EH-12 Annual Energy Savings Analysis

	Full Cost & Savings (As Found vs. Actual)	Incremental Cost & Savings (Minimal vs. Actual)
HERS Index Improvement (%)	37%	41%
Annual Energy Cost Savings ($)	$854	$1,138
Annual Energy Cost Savings (%)	30%	37%
Improvement Costs	Not available	Not available
Monthly Mortgage	Not available	Not available
Monthly Energy Cost Savings	$71	$95
Monthly Cash Flow	Not available	Not available
Simple Payback (years)	Not available	Not available


Figures 45-46. EH-12 pre-retrofit and post-retrofit exterior.

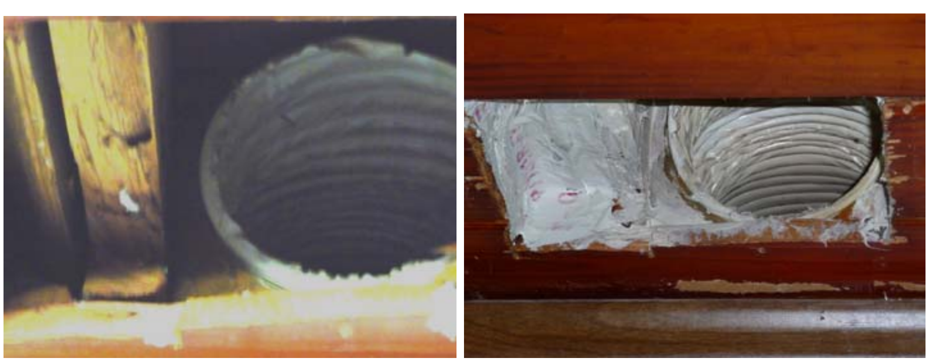
The air heating and conditioning system consisted of three portable electric resistance heaters (an abandoned oil furnace was present in the crawlspace but unusable) and three fairly recent window air conditioners (an unusable, abandoned air handler was found in the main attic).

The renovation to this home was considerable. The measures (shown in Table 35) with the greatest impact to projected energy cost savings (in order of contribution) were the addition of one bedroom and 324 square feet of conditioned space, the installation of a forced air, central air conditioner (SEER 15) with heat pump, significant reduction in duct leakage, almost exclusive use of efficient lighting, ENERGY STAR ceiling fans, reduction in whole house infiltration, insulation of the accessible attic to R-30, and installation of double pane, low-E, vinyl frame windows. The entire package of improvements (Table 34) is estimated to produce $854 in annual energy cost savings.

Table 35. EH-12 Key Energy Efficiency Measures

Component	Pre- and Post- Retrofit Characteristics
Roof	New roofing, no change to color or material
Ceiling Insulation	From R-19 to R-30 in main body of house, no change to cathedral ceiling
Exterior Walls	Repaint block walls, no change to solar adsorptivity.
Windows	From single pane metal frame to low-E (U = 0.51; SHGC = 0.25)
Doors	Replace jalousie wood door with insulated metal door
Floors	No change
Whole House Infiltration	From ACH50 of 34 to ACH50 of 16; Still quite leaky
Heating and Cooling System	From window A/C and portable space heater to SEER 15 HSPF 8.7 heat pump
Air Distribution System	Reused and replaced as needed, Qn out = 0.05 after rehab
Supply/Return/AHU Locations	Attic/interior/interior
Water Heating System	From 30-gallon interior to 40-gallon exterior, electric; EF = 0.93
Refrigerator	No change
Lighting	From 80% CFL to 100% CFL
Fans	From standard to ENERGY STAR fans
Controls	Standard

One remaining problem after rehab was the leaky cathedral roof. This area was converted from a porch to part of the living space. The soffits are vented, allowing outside air to infiltrate into the roof cavity with ease. The ACH50 post-rehab was still very high, although the rehab resulted in the ACH50 being reduced by more than half (from 34 to 16). Additional problems with this area were found in the duct system. Three supply ducts run to this area and were reused from the old, in-place duct system. These supplies were installed without using traditional “boots”. The duct was merely pulled into the ceiling cavity and allowed to blow cool air in the general direction of the porch space. Mid-point testing found this problem (Figure 47, left). The HVAC contractor repaired these three supplies by slathering mastic around the area (Figure 48, right), which created a better seal and resulted in a Qn out of 0.05.



Figures 47-48. Pre and post rehab porch supply registers

In summary, the pre-retrofit condition of this house provided ample opportunity for a "deep energy retrofit." The projected energy cost savings of 37% over as-found was achieved through the installation of a forced air, central air conditioner (SEER 15) with heat pump, significant reduction in duct leakage, almost exclusive use of efficient lighting, reduction in whole house infiltration, insulation of the attic to R-30, and installation of double pane, low-E, vinyl frame windows. This savings was achieved while adding 324 ft^2 of conditioned space to the house - a full bedroom, and installing an Energy Star rated dishwasher.

2.2.10 Deep Energy Retrofit EH-13 (Occupied, renovation not started)

This project has not started because of a structural issue discovered in the bid process. Structural repair are complete, however the expense requires that scope of work be heavily revised. It is possible that the project might be carried out in December and January; however, researchers are getting divergent reports from the owner and local government agency financing the renovation. The start date could be significantly delayed or even canceled. We expect to know more by the end of November.

2.2.11 Deep Energy Retrofit EH-14 (Occupied after completion in October)

This single-story, concrete block house (Figures 49-50) located in Indian Harbor Beach, Florida was renovated by the homeowner, who also served as the general contractor. The homeowner’s goal was to make the existing house energy efficient and attractive and to use the house as a model to showcase his remodeling workmanship. The house was newly purchased and remained unoccupied during renovation. The renovation was completed in October, and the owners moved in immediately. Table 36 summarizes the projected annual energy use and cost savings for deep energy retrofit project EH-14. Table 37 relates the anticipated financing and payback associated with the whole package of improvements. Details of the analysis are included in Appendix A.

Table 36. EH-14 Annual Energy Use and Cost Simulation

Home Components	As Found	Minimal Improvement	Actual Retrofit
HERS Index	122	Same as Actual	70
Annual kWh	19,661		12,690
Annual Therms	231		151
Annual MBtu Usage	90.2		58.4
Annual Energy Cost	$3,045		$1,969
Project Status Completed			
“Minimal Improvement” reflects improvement for replacing the mechanical system with a SEER 13 air conditioner with electric resistance heating, the minimum efficiency system available. In this house, that was the specification in the Actual Retrofit so there is no difference between the two scenarios.			

Table 37. EH-14 Annual Energy Savings Analysis

	Full Cost & Savings (As Found vs. Actual)	Incremental Cost & Savings (Minimal vs. Actual)
HERS Index Improvement (%)	Cost Data Not Available	43%
Annual Energy Cost Savings ($)		$1,076
Annual Energy Cost Savings (%)		35%
Improvement Costs		NA
Monthly Mortgage		NA
Monthly Energy Cost Savings		$90
Monthly Cash Flow		NA
Simple Payback (years)		NA

Figures 49-50. EH-14 pre-retrofit with deconstruction already in progress (left) and post-retrofit (right).

The house is single-story, slab-on-grade, with a low pitch (3/12) gable roof, 1,962 ft2 of conditioned space, four (4) bedrooms, three (3) baths and a detached garage. On May 18, 2011, a pre-retrofit audit was conducted. Default values for infiltration and total duct leakage were used because some deconstruction of the envelope and HVAC system had begun at the time of the test. The heating and cooling system is a ground water heat pump with a cooling capacity of 58,000 GWHP (18.0 energy efficiency ratio (EER)) and a heating capacity of 48,000 GWHP (4.0 COP) rated at entering water temperatures of 59°F during the cooling season and 50°F during the heating season. The windows were metal, clear, single-pane, and the block walls were uninsulated. The attic was vented, and the ceiling was insulated with a combination of fiberglass batts and blown-in insulation (estimated R value of 12).

The water heater was a 50-gallon natural gas storage tank (EF 0.58) located in the detached garage (Figures 51-52). A complete list of the test-in conditions for this house is available in the analysis spreadsheet (see Appendix A). The HERS Index of the "as found" house was 122, with an estimated annual energy cost of $3,045.


Figures 51-52. EH-14. Switching from an exterior located gas hot water tank (left photo) to an interior mounted instantaneous tank reduced the HERS Index by 7 points and saved an estimated $491/yr in energy use.

During the retrofit, the thermal boundary was realigned by removing the ceiling insulation and applying five and a half inches (5 ½”) of open cell spray foam to the underside of the roof deck. Prior to installing the foam insulation, the soffits were blocked at the top wall plate. This unvented attic configuration effectively places the attic mounted duct system inside the thermal envelope and air barrier. After moving in, the owner intends to install transfer ducts with fireproof dampers to connect the attic and conditioned space, reducing the temperature difference between the two spaces.

A single layer of radiant barrier was installed on the interior side of all exterior walls, and the block cores were filled with injected foam insulation. The exterior was finished with an elastomeric white paint. The single-pane windows and sliding glass doors were replaced with vinyl ENERGY STAR rated double-pane glass with a U value of 0.28 and SHGC of 0.21. The gas water heater was removed from the garage and replaced with an interior mounted-on instantaneous gas water heater rated at 0.82 EF.

The old duct system (Figure 53, left) was replaced with R-6 flex duct, and the location of the supply ducts was brought inside by the realignment of the thermal boundary with foam (Figure 54, right). These combined renovations reduced duct leakage to Qn out = 0.006. Window replacement and insulation of the roof deck helped substantially tighten the house. Air infiltration was reduced from an estimated ACH50 of 22 (based on results of audits conducted in a different study) to an ACH50 of 1.99, well below the threshold that outside air would be recommended. However, no outside air provisions were implemented.


Figures 53-54. EH-14. Old duct work with blown-in ceiling insulation pre-retrofit (Left Photo). Looking up at insulated roof deck with new ductwork inspected prior to hanging sheetrock ceiling (Right photo).

CFLs were installed in 63 % of hardwired fixtures, and a new programmable thermostat was also installed. The combined benefit of these measures reduced the HERS Index at test out to 70, resulting in an estimated reduction in annual energy consumption of 35%. The partner has not supplied cost data for the efficiency measures. Table 38 lists the key energy efficiency measures of this home. Information related to savings estimates, reduction in annual energy consumption, and payback are listed in Table 37.

Table 38. EH-14 Key Energy Efficiency Measures

Component	Pre- and Post-Retrofit Characteristics
Roof	From ceiling insulation, R-12 to roof deck insulated with open cell foam to R-20
Exterior Walls	From no insulation to Fi Foil installed on interior side R-4.2
Exterior Walls	From standard un-insulated block to foam fill block core U = 0.204
Exterior Walls	From mixed color block walls; (solar absp. 0.40 and 0.75) to elastomeric finish (White) (solar absp. 0.40)
Windows	From double pane, clear, metal (U = 0.80; SHGC = 0.70) to ENERGY STAR double-pane, low-E, vinyl frame (U = 0.28, SHGC = 0.21)
Infiltration	From ACH50 = 22 to ACH50 = 1.99
Air Distribution	From attic located supply ducts, Qn out = 0.17 to interior duct system Qn out = 0.006
Supply/Return/Air Handler Unit (AHU) location	From attic/interior/interior to all interior
Water Heating System	From 50 gal. gas (EF = 0.58) located in garage to interior tankless gas system (EF = 0.82)
Lighting	From 31% CFL's to 63% CFL's
Controls	From non-programmable thermostat to programmable thermostat

Despite numerous discussions of building science conflicts that did not lead to resolutions, the research team decided to conduct a test-out audit at this location that was previously reported as "dropped". Many aspects of this retrofit are commendable, and it has attained an estimated annual energy savings of 35% and a HERS Index of 70 at test-out. However, it is not exemplary in several respects.

The principal area of concern is indoor humidity, and researchers have advised the homeowner to carefully observe or measure indoor humidity levels over the course of the first year of occupancy. The whole house air tightness test result post-retrofit indicates an extremely tight air barrier (ACH50 = 1.99), greatly in excess of the threshold for recommending outside air ventilation. Unfortunately, the owner opted not to include that recommendation. Granted, the configuration of the air handler and the air handler closet would have made the design challenging but possible. Very little local exhaust has been provided to handle internally generated moisture. Significant moisture from the roof assembly is a high possibility. The unvented attic was created by applying open cell spray foam to the underside of the existing roof decking. The roof finish was not replaced, so the typical tar paper underlayment is assumed for this roof assembly. Based on pressure difference measures during blower door testing, the attic appears to be fully coupled with the conditioned space, likely through ceiling penetrations.

Recent field experiment data collected by FSEC has raised concerns about absolute moisture content in unvented attics, even with newer underlayment. The combined effect of a moisture gain from this attic and moisture gains from household activity may exceed the capacity of the HVAC system, especially in this home, where a conscious effort to reduce the heating and cooling loads has been made. This effort will, in turn, reduce HVAC run time.

A second area of concern arises from pressure dynamics associated with inadequate return air pathways. During previous site visits, the owner was advised to correct the duct compression (Figure 55). When the foam insulation (applied to the underside of the roof decking) in a very shallow pitch roof expanded, compressing some of the ducts. Some of these were jump ducts, and, at test out, researchers did find unexpectedly high pressure differences in two bedrooms under normal operating conditions. We again advised repair of the compressed ducts. This, combined with the very low infiltration level, may result in severe discomfort. Table 39 details pressure mapping data collected during the test out.

Table 39. EH-14 Post-Retrofit Pressure Mapping

Location	Pressure (Pa)
House WRT Out, at rest	0.8
House WRT Out, Worst Case	-6.4
Master WRT House	6.9
Bedroom 2 WRT House	7.9
Bedroom 3 WRT House	4.9
Bedroom 4 WRT House	5.5
AHU WRT House	-3.0

Figure 55. EH-14. A very shallow unvented attic with foam insulation at roof deck resulting in duct compression and an area of thinner insulation.

A third concern, as reported in August, is that the homeowner applied spray foam insulation into the cores of his exterior block walls against our recommendation. At the test-out, insufficient temperature differences prevented characterizing the thermal signature of this insulation. The cost of this improvement vastly outweighs the benefit; however, the homeowner made this final decision.

A final concern arose over code official objections to providing a small amount of conditioned air to the unvented attic with an appropriate draw of return air. Researchers advised this partner in preliminary discussions that any unusual details should be discussed with the code official prior to implementation. This was not done. In essence, the fire code does not allow the space to be designated as "occupiable" because it does not have a fire retardant coating applied to the exposed surface of the foam; therefore, it cannot be conditioned. These coatings are expensive and impractical once the house is completed due to poor access to the eave area. Researchers advised the need to minimize the temperature difference across the ceiling plane. This typically implies direct supply and return to the space or passive air flow pathways to allow mixing of house and attic air. Neither solution was acceptable to the local code body. At test-out, this appears to be less of an issue than anticipated because no pressure difference was measured between the attic and main body of the house under operating or under test conditions suggesting that house air and attic will be able to circulate freely in response to temperature driven air movement and likely pressure driven air movement also in response to depressurization of the main space when the air handler is operating with bedroom doors closed. As always, a planned, controlled air flow pathway would be preferable.

While this project does incorporate high performance windows, a high efficiency tankless gas water heater, and other efficiency measures, it does not successfully meet the other criteria for our project including a moisture management plan, pressure balance, and a proactive approach with code officials when implementing unfamiliar details.

2.2.12 Deep Energy Retrofit EH-15 (Occupied, Dropped)

The owners (and occupants) of this 1940 home were implementing structural improvements at the time of the test-in audit and considering adding energy improvements to the scope of work. The energy retrofit, however, did not come to fruition and the project was dropped from consideration. The as-found condition of retrofit candidate EH-15 evidenced significant uncontrolled air flow and a crawl space with no ground cover. The moisture movement associated with this combination of conditions warrants more thorough investigation beyond the scope of technical assistance provided through this study.

Researchers recommended that the homeowners retain a qualified professional to develop a whole house strategy and assist with implementation. The owners of the home were willing to consider investment in a deep energy retrofit; however, development of a strategy for controlling air, heat, and moisture flow is a clear imperative prior to implementing the package of improvements recommended for the home. Since none of the major energy users are in need of replacement, improvements include measures recommended solely for energy improvement. Hence, the full first cost is used for the financial calculations.

Table 40 summarizes the projected annual energy use and cost savings for the recommended package for deep retrofit candidate EH-15. Table 41 relates the estimated financing and payback associated with the whole package of improvements based on estimated incremental first cost. In addition, Appendix A includes analysis for this project.

Table 40. EH-15 Annual Energy Use and Cost Simulation

Home Components	As Found	Recommended	Actual Retrofit
HERS Index	125	101	Retrofit was not Implemented
Annual Simulation kWh (BABM08)	15,222	11,506.0	
Annual MBtu Usage	52.0	39.3	
Annual Energy Cost (BABM08)	$1,704	$1,288	
Project Status: Dropped			

Table 41. EH-15 Annual Energy Savings Analysis

	Full Cost & Full Savings (As Found vs. Recommended)	Incremental Cost and Incremental Savings (As Found vs. Recommended)
HERS Index Improvement (%)	19%	No measures in this package relate to replacements. All are done for energy improvement only.
Annual Energy Cost Savings ($)	$416	
Annual Energy Cost Savings (%)	24%	
Improvement Costs	$2,325	
Monthly Mortgage	$16	
Monthly Energy Cost Savings	$35	
Monthly Cash Flow	$19	
Simple Payback (years)	6	

This two bedroom, one bath single family home (Figure 56, left) is built on a concrete block foundation forming a vented crawl space, a wood frame floor with 30% tile covering, and block exterior walls with vinyl siding. The shingle roof and exterior vinyl siding are both medium colored. As with many homes of this vintage, a porch on the back (north) side of the home was previously enclosed to create additional living space.

The 1,414 ft^2 home has an electric air source heat pump (SEER 13, HSPF 7.7 - installed in 2004) with an interior air handler closet, an electric 40-gallon water heater (<10 years old) outside the conditioned space, standard efficiency refrigerator (2002), and six ceiling fans. Approximately 10% of the lighting fixtures were outfitted with compact fluorescent bulbs. The thermal envelope is composed of a minimal ceiling insulation (estimated to be R-12, Figure 57, right), uninsulated frame floor over a vented crawl space with no ground cover, uninsulated block exterior walls, and single-pane, clear, uninsulated metal frame windows.

The home is well shaded on the east, south, and west faces, though the homeowner reports some discomfort on the south side of the house in the summer months and some general dissatisfaction with overall comfort. Average electric bills reported by the owners indicate $160 to $300 monthly for two occupants. This appears to be somewhat higher than the simulation, which includes three occupants (number of bedrooms plus one). However, the owners have not provided utility bills, so an annual total is not available. Researchers suspect that the uncontrolled air flow described below may be spurring energy use to maintain comfort conditions.

Figures 56-57. EH-15. As found home (left). Attic insulation, head room, and roof framing (right).

Measures influencing energy efficiency would reduce the annual energy use and cost for this home. Measures recommended at this time (Table 42) include installing R-38 (total) ceiling insulation, replacing recessed lighting fixtures with ICAT rated units (must be done prior to ceiling insulation addition), converting 80% of lighting fixtures to fluorescent bulbs, repairing damaged ducts, elevating duct runs above anticipated ceiling insulation height, and reducing infiltration by 50%. Caveats regarding the duct repair and air sealing are discussed below.

This home is a better candidate for duct repair than many Florida homes of newer vintage, which commonly have a 3-in-12 roof pitch. The 4-in-12 roof pitch coupled with rafter framing (as opposed to trusses) provide more room for working in the attic, where duct systems are typically located in Florida homes,

As shown in Table 41, the package of recommendations saves an estimated $416, 24%, in annual energy cost. At a full first cost of $2,325, these savings result in a six (6) year payback. In addition to these improvements, researchers recommend general maintenance steps such as cleaning the refrigerator coils and servicing the seven-year-old mechanical system. The cost associated with those and the cost of a full pre-retrofit diagnostic energy audit have been omitted from the cost calculations.

Table 42. EH-15 Key Recommended Energy Efficiency Measures

Component	Recommended Characteristics
Moisture, Air, and Heat Flow Dynamics	Prerequisite: Full pre-retrofit diagnostic energy audit to identify heat, moisture, and air flow pathways and drivers
Ceiling Insulation	Increase to Grade I, R-38 (recessed fixtures must be replaced first)
Whole House Infiltration1	Reduce by 50%, ACH50=10
Heating and Cooling System	HVAC Service - Not part of simulation
Air Distribution System3	Repair existing duct system, achieve air tightness testing in line with typical new construction (Qn,out = 0.03), strap duct runs above anticipated ceiling insulation level
Water Heating System	R-5 Insulation blanket
Refrigerator	Clean Coils - Not part of simulation
Lighting	Replace recessed lighting fixtures with new insulation contact, air-tight (ICAT) rated units, install fluorescent bulbs in 80% of fixtures

In a questionnaire administered prior to the test-in audit, the owners indicated willingness to spend $7,000 to $10,000 on energy improvements, which would also cover the costs of a major equipment improvement. The recommended improvements coupled with a high efficiency heat pump water heater or a SEER 16+ heat pump would likely surpass the 30% savings goal. However, it was revealed during the test-in audit that none of the major energy use equipment is in need of immediate replacement. The HVAC equipment and the refrigerator will likely need replacement within a few years. Researchers recommend waiting until then and making a higher efficiency choice at that time. The incremental cost of both heat pump water heaters and SEER 16 equipment may be then be lower due to deeper market penetration. Within that time span, other options may be more readily available, such as ductless mini splits.

Regardless of insulation, equipment, and maintenance recommendations, the single most important recommendation for this home is to address the moisture source of the vented crawl space, which has no ground cover, and address the uncontrolled air flow drivers and pathways.

To reiterate, it would be inadvisable to make the air flow related improvements prior to conducting a thorough moisture flow evaluation and devising a moisture control strategy. Implementing the infiltration and duct sealing improvements without doing so could inadvertently introduce an unexpected moisture load to the conditioned space or to components of the building. Specifically, the vented crawl space does not currently include any ground cover. The whole house air tightness test result does indicate excessive air exchange across the whole envelope. The CFM50 for the house was 3,999, which converts to an ACH50 of 21. While this number is large, it is not unheard of among the approximately 120 existing homes that FSEC has audited. Numerous visible openings in the ceiling were identified (Figure 58, left), and there is an extenuating circumstance that cannot be eliminated in normal operating conditions of this home. The owners have three dogs that come and go through a continuously open dog-sized opening in the back door.

Figures 58-59. EH-15. Air flow pathway from the attic into conditioned space along the fireplace wall (left) and through and around numerous recessed lighting fixtures (right).

Sealing the envelope appears to be a cost-effective and obvious improvement for this home with an estimated simple payback of seven years, particularly the obvious openings in the air handler closet (Figure 59, above right) which connect it to the attic and adjacent interior wall cavities.

However, the air handler closet also plays a role in the air distribution system leakage that cannot be disregarded. Although the magnitude of duct test results are not out of line, qn,out of 0.11, the role of the air handler closet in overall air flow dynamics needs more detailed investigation.

Essentially, the air handler is located in an interior closet where a filter back return air grille in good repair is connected to a simple return duct directly below the up-flow air handler (Figures 60-61). The closet door has a perforated panel. The free area of the panel would be inadequate to supply the system with return air.

Figures 60-61. EH-15. Air handler located in the central hallway has a door with a small perforated panel for return air (left). Inside the closet (right) is a filter back grille connected to a small return air duct below an up-flow air handler.

There appear to be other, deliberate passive return air flow pathways into the closet, probably from a previous mechanical system installation. These air flow pathways are apparent from adjacent rooms as wall mounted registers. Registers in rooms further away may be connected to the closet via a furred down duct chase in the hall (Figures 62-63). It is unclear how much of this passive return system is still fully connected to the rooms, though it is clearly visible from some rooms. During operation of the air handler, it is likely that depressurization of the closet is drawing air through this passive return system not only from the connected rooms but also from the adjacent attic and the interior wall cavities.

Figures 62-63. EH-15. This wall-mounted passive return air register (left) is connected to a furred down duct chase on the other side of the wall. The bottom of the chase, indicated by the dashed line, forms the ceiling of the adjacent hallway (right).

Figures 64-65. EH-15. Uncontrolled air flow pathways in wall and floor (left) and ceiling (of closet surrounding return air plenum.

The closet (Figures 64-65 above) also has visible air flow pathways into the attic that are not part of the passive return configuration. These pathways, as well as the passive return air system, seem to be obvious targets for improving the integrity of the house's air barrier. The practicality of identifying and eliminating the complex air flow paths would require further investigation.

Making these repairs may seem to be the most obvious improvement, but doing so could effectively switch change the air and moisture flow dynamics of the house in unanticipated ways. But air sealing measures could result in moisture problems if care has not been taken. This may be especially true for any connections to or moisture dynamics within the vented crawl space. Creating a durable, continuous air barrier separating the conditioned space from the vented crawl space below may prove the most difficult element of the envelope to address. A house of this vintage is likely to have a plank sub-floor. Extensive, closely-spaced floor joists will make it difficult to seal that entire expanse. Furthermore, the floor of the crawl space is not currently covered, meaning that the ground, a significant source of moisture, could be coupled to the house.

This is a complex dynamic that requires careful assessment and planning. Since the test-in audit procedure is not designed to be a full diagnostic assessment, researchers did not characterize the pressure or air flow boundary condition between the crawl space and the conditioned space. Nor have researchers recommended a course of action to address these dynamics. That would be an important investigation to undertake before any changes affecting air flow, temperature conditions, pressure balance, or moisture dynamics are made to the house. This would include everything on the recommended list of improvements with the possible exception of the hot water tank wrap, since the unit is not in the conditioned space.

The primary lesson from this candidate retrofit is that a house of this vintage may offer a large opportunity for energy savings if improvements have not been done over time, but also that it may be inadvisable to approach a deep energy retrofit in such a home without a detailed, diagnostic audit and planning process. The risk of potential moisture damage may not have been recognized by an insulation, HVAC, or general contractor without building science training.

2.2.13 Deep Energy Retrofit EH-16 (Occupied, Dropped)

The owners (and occupants) of this 2,350 ft2 house expressed interest in a deep retrofit. Researchers pursued this candidate based on preliminary survey responses. Table 43 summarizes the as-found efficiency of the home. The home was found to be in much better condition than anticipated with a HERS Index of 79 and the candidate was dropped from consideration because major energy efficiency retrofits had been executed in the past five years. Minor recommendations were made for deep energy retrofit candidate EH-16.

Table 43. EH-16 Annual Energy Use and Cost Simulation

Home Components	As Found
HERS Index	79
Annual kWh	17,263
Annual Therms	0
Annual MBtu Usage	58.9
Annual Energy Cost	$2,021
Project Status: Dropped	

A test-in audit of this 2,350 ft^2 house, located in Cocoa Beach, Florida, was conducted on June 6, 2011. The HERS Index score was 79, and annual energy costs were calculated at $2,021 using $0.13/kWh. The initial survey completed by the homeowner showed both a willingness to participate in the program and a desire to significantly improve their home's efficiency. Key energy efficiency measures incorporated by the homeowner and at the time of construction included: exterior concrete block walls insulated with 1" of rigid foam insulation (interior side), low-E window replacements, window shades, solar domestic hot water system, ENERGY STAR appliances, HVAC upgrade, and code compliant ceiling and kneewall insulation (Figures 66-68).

Figures 66-68. EH-16. A number of energy efficiency measures had been incorporated into the home including window shades (middle photo) and a solar hot water system (right photo)

After reviewing the test-in data, it was determined that the house was not a good candidate for the deep energy retrofit study due to the unlikelihood that cost-effective measures would yield the required 30% minimum savings.

2.2.14 Deep Energy Retrofit EH-17 (Unoccupied, In Progress as of 12/31)

Table 44 summarizes the projected annual energy use and cost savings for deep energy retrofit project EH-17. Table 45 relates the anticipated financing and payback associated with the whole package of improvements. Appendix A includes analysis for this project.

Table 44. EH-17 Annual Energy Use and Cost Simulation

Home Components	As Found	Projected Minimal Improvement	Projected Deep Retrofit
HERS Index	107	103	59
Annual kWh	11,796	11,515	6,267
Annual Therms	0	0	0
Annual MBtu Usage	40.3	39.3	21.4
Annual Energy Cost	$1,535	$1,498	$815
Project Status: In Progress			
"Minimal Improvement" reflects improvement for replacing the mechanical system with a SEER 13 air conditioner with electric resistance heating, the minimum efficiency system available.			

Table 45. EH-17 Annual Energy Savings Analysis

	Full Cost & Savings (As Found vs. Projected Deep)	Incremental Cost & Savings (Minimal vs. Projected Deep)
HERS Index Improvement (%)	Cost Not Available	40%
Annual Energy Cost Savings ($)		$683
Annual Energy Cost Savings (%)		46%
Improvement Costs		$0
Monthly Mortgage		$0
Monthly Energy Cost Savings		$36
Monthly Cash Flow		$36
Simple Payback (years)		$0

This home is 1,070 ft^2 with three bedrooms and one bath. It is a wood frame, slab-on-grade; single-story house that was constructed in 2000 and is located in Brevard County, FL. The home had been unoccupied for an extended period of time and was purchased by the partner for renovation and resale as affordable housing. Figures 69-71 illustrate the pre-retrofit and mid-point progress.

At the time of test-in, sheetrock had been removed from the lower half of all exterior walls exposing the fiberglass insulation. Mold was observed along the bottom wall plate and in the lower half of the stud bays. As a result, a blower door test was not conducted, and BA default values for infiltration were used to formulate the initial HERS Index of 107. The outside HVAC compressor was missing at the time of test-in, but was reported to be a SEER 12, 2-ton unit with interior air handler and electric resistance heating. Windows are single-pane, clear glass. The walls are insulated with R-13 fiberglass batts, and the ceiling is insulated with blown-in fiberglass insulation to R-19. The distribution system consisted of a single return with supply ducts (R-6 flex ducts) located in the vented attic. The duct system was dismantled during test-in and default values were used for duct tightness calculations. Domestic hot water is supplied by a 40-gallon electric water heater with an EF = 0.92. More detail on the "as found", minimal improvement and deep energy retrofit measures is available in Table 46.

Figures 69-71. EH-17 pre-retrofit (left) midpoint-retrofit (center), December progress (right)

Measures recommended in the deep energy retrofit package include increasing attic insulation to R-38, replacing exterior doors with insulated doors (U=0.21), installing a SEER 14 HVAC heat pump (HSPF 8.5), reducing duct leakage - Qn out = 0.04, installing an ENERGY STAR heat pump water heater with COP of 2.3, and installing a minimum of 80% CFL lighting. Implementation of these measures would result in a HERS Index of 62, a 42% reduction, and a projected savings in annual energy costs of $683/yr. A detailed list of the improvement measures can be found in Table 46. Saving and HERS reduction of the individual improvements are located in Appendix A of this report.

Table 46. EH-17 Key Energy Efficiency Measures

Component	Pre Retrofit and BA Proposed Retrofit Characteristics
Roof	From: R-19 to R = 38 Grade 1
Windows	From: Single pane, clear, metal to ENERGY STAR, low-E (U ≤ 0.60; SHGC ≤ 0.27)
Doors	From: Uninsulated to insulated, U <= 0.21
Whole House Infiltration	From: ACH50 = 16.12 to Estimated ACH50 = 6 and install runtime vent
Heating and Cooling System	From: 12 SEER; 2 ton, Electric Resistance Heat to 14 SEER; 2 ton, Heat Pump, 8.5 HSPF, with programmable thermostat
Air Distribution System	From: Qn, out = 0.88 to estimated Qn, out = 0.04
Water Heating System	From: 40 gal., (0.92 EF) to Heat Pump Water Heater (COP -2.3)
Lighting	From 0/15 CFL to 12/15 (80%) CFL

The renovation plans for this house include adding a one car attached garage to the front/west side of the house. This addition has been included in the analysis and savings calculations for the project.

The original completion date for this renovation was pushed back by the partner in order to meet deadlines on other projects. The partner’s new completion time frame is March, after the end of the research project.

2.2.15 Deep Energy Retrofit EH-18 (Unoccupied, In Progress as of Dec 5)

Table 47 summarizes the projected annual energy use and cost savings for deep energy retrofit project EH-18. Table 48 relates the anticipated financing and payback associated with the whole package of improvements. Appendix A includes analysis for this project.

Table 47. EH-18 Annual Energy Use and Cost Simulation

Home Components	As Found	Minimal Improvement	Deep Retrofit
HERS Index	97	94	59
Annual kWh	9,286	9085	5,231
Annual Therms	0	0	0
Annual MBtu Usage	31.7	31.0	18
Annual Energy Cost	$1,044	$1,021	$679
Project Status: In Progress			

Table 48. EH-18 Annual Energy Savings Analysis

	Full Cost & Savings (As Found vs. Projected Deep)	Incremental Cost & Savings (Minimal vs. Projected Deep)
HERS Index Improvement (%)	Cost Not Available	37%
Annual Energy Cost Savings ($)		$342
Annual Energy Cost Savings (%)		33%
Improvement Costs		$0
Monthly Mortgage		$0
Monthly Energy Cost Savings		$29
Monthly Cash Flow		$29
Simple Payback (years)		$0

This is a 913 ft^2 two bed, one bath home. Located in Brevard County, Florida, this single story building is also slab-on-grade and of stick frame construction. The home had been unoccupied for an extended period of time and was purchased by the partner for renovation and resale as affordable housing. Figures 72-73 illustrate the pre-retrofit and mid-point progress.

The initial HERS Index for this house was 97. The outside HVAC compressor was missing at the time of test in; however, it was reported to be a SEER 12, 2-ton unit with interior air handler and electric resistance heating. Windows are single-pane clear glass, walls are insulated with R -13 fiberglass batts, and the ceiling is insulated with blown-in fiberglass insulation to R-24. The distribution system consisted of a single return with supply ducts (R-6 flex ducts) located in the vented attic. Total duct leakage (Qn, total) measured 0.125, and leakage to outside (Qn, out) was 0.065. Domestic hot water is supplied by a 40-gallon electric water heater with an EF = 0.92. More detail on the "as found", minimal improvement and deep energy retrofit measures is shown in Table 49.

Figures 72-73. EH-18 pre-retrofit (left) and midpoint-retrofit (right).

Measures recommended in the deep energy retrofit package include R-38 ceiling insulation, reduced whole house infiltration to ACH50 </= 6.0, installation of a SEER 14 HVAC system with 8.5 HSPF heat pump, window replacement with ENERGY STAR, low-E windows, U = < 0.60, SHGC = < 0.27, and installation of an ENERGY STAR heat pump water heater with a COP of 2.3. Implementation of these measures would result in a HERS Index of 59, a 37% reduction, and save an estimated $342 on annual energy costs from minimal improvements required by Florida building code. Table 48 details the anticipated savings of the recommended improvement measures.

Table 49. EH-18 Key Energy Efficiency Measures

Component	Pre-Retrofit and BA Proposed Retrofit Characteristics
Roof	From R-24 to R = 38 blown-in
Windows	From single pane, clear, metal to ENERGY STAR, low-E ($U \leq 0.60$; $SHGC \leq 0.27$)
Whole House Infiltration	From ACH50 = 7.21 to estimated ACH50 = 6 and install runtime vent
Heating and Cooling System	From SEER 12; 2 ton, electric resistance heat to SEER 14; 2 ton, heat pump, 8.5 HSPF, with programmable thermostat
Air Distribution System	From Qn, out = 0.065 to estimated Qn,out = 0.04
Water Heating System	From 40 gal. (0.92 EF) to heat pump water heater (COP -2.3)

The renovation plans for this house include the addition of a one car, attached garage to the north side of the house as well as a small addition on the rear of the house. These items have been included in the analysis and savings calculations for the project.

In order to meet deadlines on other projects, the partner moved the original completion date of this renovation to a later time. The partner's new completion time frame is March, after the completion of the research.

2.2.16 Deep Energy Retrofit EH-19 (Occupied after completion in September)

This unoccupied, foreclosed home is being renovated by Brevard County Habitat for Humanity. Table 50 summarizes the projected annual energy use and cost savings for deep energy retrofit project EH-19. Table 51 relates the anticipated financing and payback associated with the whole package of improvements. Appendix A includes analysis for this project.

Table 50. EH-19 Annual Energy Use and Cost Simulation

Home Components	As Found	Minimal Improvement	Actual Retrofit
HERS Index	109	105	70
Annual Simulation kWh (BABM08)	13,061	12,719	7,856
Annual MBtu Usage (BABM08)	44.6	43.4	26.8
Annual Energy Cost (BABM08)	$1,698	$1,653	$1,022
Project Status: Completed 9/10/2011			
"Minimal Improvement" reflects improvement for replacing the mechanical system with a SEER 13 air conditioner with electric resistance heating, the minimum efficiency system available.			

Table 51. EH-19 Annual Energy Savings Analysis

	Full Cost & Savings (As Found vs. Actual)	Incremental Cost & Savings (Minimal vs. Actual)
HERS Index Improvement (%)	36%	33%
Annual Energy Cost Savings ($)	$676	$631
Annual Energy Cost Savings (%)	40%	38%
Improvement Costs	NA	NA
Monthly Mortgage	NA	NA
Monthly Energy Cost Savings	$56	$53
Monthly Cash Flow	NA	NA
Simple Payback (years)	NA	NA

This unoccupied, foreclosed, single-family detached home in West Palm Beach, Florida was the second of five renovations initiated in 2011 by Habitat for Humanity of Palm Beach County, Inc. (www.habitatpbc.org), a non-profit, affordable housing organization. Built in 2000, this three bedroom, two bath home (Figures 74-75) has 1,176 square feet of conditioned space.

The slab-on-grade home with concrete block walls had a light-colored exterior, a white asphalt single roof, and an attached shed. Ceiling insulation was R-19 fiberglass batts. The windows were single hung, single-pane, clear, with metal frame. Appliances and lighting included a 40-gallon electric hot water heater, a non-ENERGY STAR refrigerator, and 100% incandescent lighting.

Figures 74-75. EH-19 pre-retrofit (left) and post-retrofit (right)

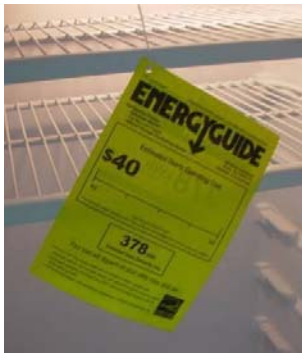
The air heating and conditioning system was a central, forced air system with a SEER 12 air conditioner and electric resistance heating (Figures 76-77). The property had been vandalized and some materials stolen (Figure 78). Both the air handler and the compressor had been gutted, and the bathrooms and the laundry area had large wall penetrations where plumbing lines had been removed. Since the envelope was compromised and the air hander was not intact, researchers were unable to conduct whole house leakage and duct leakage tests. In order to perform energy modeling, averages from prior research were used for pre-retrofit whole house air leakage (ACH50 = 11) and duct leakage (Qn,out = 0.13).

Figures 76-78. EH-19 pre-retrofit air handler (left), compressor (center), interior wall destruction (right)

The scope of work for this renovation was hefty for this 11-year-old home; however, much of the work was non-energy related. The measures with the greatest impact to projected energy cost savings (in order of contribution) were the installation of a hybrid heat pump water heater (COP = 2.35), almost exclusive use of efficient lighting, installation of a central, forced air conditioner (SEER 15) with heat pump, installation of an ENERGY STAR refrigerator, and the increasing of the ceiling insulation level to R-38. Figures 79-81 present post-retrofit pictures, including lighting and appliances. The entire package of improvements for this retrofit was completed on September 10, 2011 (Table 52) and is estimated to produce $676 in annual energy cost savings.

The attached shed, measuring 12’x 5’x 8’, was large enough to house a heat pump water heater. The installation of the hybrid water heater with heat pump in this location has the added benefit of dehumidifying and cooling the utility shed and the attic, which the shed is open to.



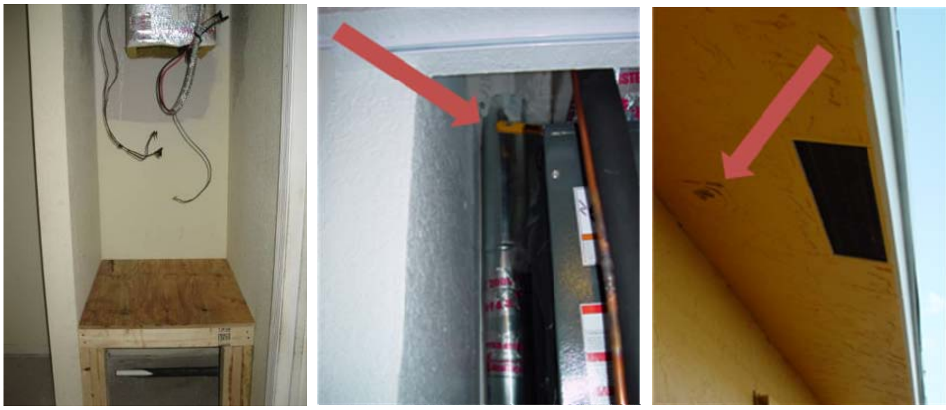
 

Figures 79-81. EH-19 post-retrofit ENERGY STAR refrigerator (left), post-retrofit CFL fixture (center), post-retrofit heat pump water heater

Table 52. EH-19 Key Energy Efficiency Measures

Component	Pre- and Post-Retrofit Characteristics
Ceiling Insulation	From R-9 to R-38, blown-in fiberglass
Exterior Walls	From light (solar absp. = 0.45) to dark color (solar absp. = 0.60)
Whole House Infiltration	From ACH50 = 11 (est.) to ACH50 = 6.86; Installed a mechanical runtime vent
Heating and Cooling System	From SEER 12 with integral electric resistance heat to SEER 15 with integral electric resistance heat
Air Distribution System	From Qn,out = 0.13 (est.) to Qn,out = 0.052
Water Heating System	From 40 gal, electric, EF = 0.88 (est.) to 50 gal, electric tank with heat pump, COP = 2.35
Refrigerator	From default to Energy Guide label of 378 kWh/yr
Lighting	From 0 CFLs to 80% CFLs
Fans	From fans with default efficiency to 100 CFM @ medium speed
Controls	From no programmable thermostat to a programmable thermostat

Confined by limited space, the mechanical contractor performed a fair job of retrofitting the air handler cabinet with a platform return, installing the new, larger air hander, and incorporating the outside air runtime ventilation detail. The post-retrofit duct leakage test result was Qn,out = 0.052; therefore, the newly constructed platform return was fairly well sealed. However, the access to the plenum remained behind the airflow-restricting louvered doors rather than on the same plane as the hallway wall. The partner incorporated an existing attic ventilation duct into the outside air runtime ventilation scheme. This did not allow filtering at the intake, and the opening was ignored by the painting contractor who painted over it, leaving it partially obstructed. Post-retrofit pictures of the air handler closet and return plenum are shown in Figures 82-84.



Figures 82-84. EH-19 mid-point construction of air handler closet (left), post-retrofit incorporation of outside air ventilation into air handler closet (center), post-retrofit return air intake at soffit (right)

Among the improvement to the house envelope was the replacement of one broken window and the reconstruction of several wall cavities. The whole house leakage test result (ACH50 = 6.86) suggests a moderately low level of infiltration.

During the post-retrofit audit, pressure mapping was performed to test the balance of mechanical system air flow though the house. Researchers created a "worst case" scenario by running the air handler and exhaust fans, and shutting all bedroom doors. Operating in "worst case" the home was depressurized slightly (-3.0 pa), and there was excessive positive pressure in one bedroom. Researchers suggested the partner install an above door transfer grille between this bedroom and the main body to allow passive air transfer out of the bedroom. Post-retrofit pressure mapping results are presented in Table 53.

Table 53. EH-19 Post-Retrofit Pressure Mapping

Location	Pressure (Pa)
House WRT Out	-3.0
Master WRT House	4.1
Bedroom 2 WRT House	1.1
Bedroom 3 WRT House	2.0

In summary, the partner successfully achieved a deep energy retrofit with projected annual energy cost savings of 40%. The estimated savings was accomplished primarily through installing a hybrid heat pump water heater (COP = 2.35), almost exclusive use of efficient lighting, installing a central, forced air conditioner (SEER 15) with heat pump, installing an ENERGY STAR refrigerator, and brining the ceiling insulation level up to R-38.

Researchers found a couple of problems with this retrofit. The design of the mechanical closet was lacking in that the well-constructed return platform was blocked by airflow-restricting louvered doors, and a lack of central oversight was exemplified by the painting over of the outside air intake.

When the partner provides cost data for the energy-related elements of the renovation, researches will complete the economic calculations.

2.2.17 Deep Energy Retrofit EH-20 (Unoccupied, Dropped)

This unoccupied, foreclosed home was dropped from the study after the partner halted work because of unanticipated problems that exceeded the available budget. Table 54 summarizes the projected annual energy use and cost savings for deep energy retrofit project EH-20. Table 55 relates the anticipated financing and payback associated with the whole package of improvements. Appendix A includes analysis for this project.

Table 54. EH-20 Annual Energy Use and Cost Simulation

Home Components	As Found	Minimal Improvement	Proposed Retrofit
HERS Index	142	117	59
Annual Simulation kWh (BABM08)	15,646	12,985	4,969
Annual Simulation Therms (BABM08)	142	142	88
Annual MBtu Usage (BABM08)	334.7	304.1	153.1
Annual Energy Cost (BABM08)	$2,291	$1,945	$832
Project Status: Dropped			

“Minimal Improvement” reflects improvement for replacing the mechanical system with a SEER 13 air conditioner with electric resistance heating, the minimum efficiency system available.

Table 55. EH-20 Annual Energy Savings Analysis

	Full Cost & Full Savings (As Found vs. Proposed Deep Retrofit)	Incremental Cost & Incremental Savings (Proposed Minimal vs. Proposed Deep Retrofit)
HERS Index Improvement (%)	58%	50%
Annual Energy Cost Savings ($)	$1,459	$1,113
Annual Energy Cost Savings (%)	64%	57%
Improvement Costs	NA	NA
Monthly Mortgage	NA	NA
Monthly Energy Cost Savings	$122	$93
Monthly Cash Flow	NA	NA
Simple Payback (years)	NA	NA

This unoccupied, foreclosed, single-family detached home in West Palm Beach, Florida was the third of five renovations initiated in 2011 by Habitat for Humanity of Palm Beach County, Inc. (www.habitatpbc.org), a non-profit, affordable housing organization. Built in 1989, this three bedroom, two bath home (Figures 85-86) has 1,440 square feet of conditioned space. The partner put this renovation on hold; subsequently, the project was dropped from this study.

The home is slab-on-grade with frame walls and had a light colored exterior, a white asphalt single roof, and a small built-in shed. Ceiling insulation was R-15 fiberglass batts. The windows were almost all broken, if not fully removed. What did remain of the windows was awning-style, clear, single-pane glass with metal frame. The kitchen was gutted, and all appliances were missing except for the air handler located in the attic. The floor was comprised of approximately 50% tile and 50% vinyl.

Figures 85-86. EH-20 pre-retrofit

The air heating and conditioning system was a central, forced air system estimated to be a SEER 9 air conditioner with electric resistance eating. The water heater was a natural gas, 40-gallon tank located in the attached shed. In addition, the property had been vandalized, and much of the equipment and some materials stolen. There were large wall openings where plumbing lines had been removed. Researchers were unable to conduct whole house leakage and duct leakage tests due to the compromised envelope and the filthy conditions. In order to perform energy modeling, averages from prior research were used for pre-retrofit whole house air leakage (ACH50 = 11) and duct leakage (Qn,out = 0.13). Figures 87-91 show the pre-retrofit condition of the home.

Figures 87-88. Retrofit EH-20 pre-retrofit sight of missing compressor (left), pre-retrofit kitchen missing appliances (right)

Figures 89-91. EH-20 pre-retrofit vandalized walls (left & center), broken sliding glass door (right)

As the renovation was underway, the property was found to be rat-infested. Interior walls were removed. Shortly thereafter, the partner reported the project to be on an indefinite hold, citing budgetary reasons. Lacking an actual retrofit to report for this project, researchers' proposed the deep energy retrofit package presented in Table 56.

Table 56. EH-20 Proposed Energy Efficiency Measures

Component	Proposed Deep-Retrofit Characteristics
Ceiling Insulation	From R-15 to R-38
Windows	From Single-pane, metal frame, clear (U = 1.20; SHGC = 0.80) to Double-pane, low-E, vinyl frame (U = 0.60; SHGC = 0.27)
Whole House Infiltration	From ACH50 = 11 (est.) to ACH50 = 6; Install a mechanical runtime vent
Heating and Cooling System	From SEER 9 with integral electric resistance heat to SEER 15 with integral electric resistance heat
Air Distribution System	From R-4.2 flex ducts, Qn,out = 0.13 (est.) to R-6 flex ducts, Qn,out = 0.05

Return/AHU Locations	From air handler and return in attic to conditioned space
Water Heating System	From 40 gal, gas, EF = 0.56 (est.) to tankless gas; EF = 0.82
Refrigerator	From default to ENERGY STAR labeled
Lighting	From 0 CFLs to 80% CFLs
Fans	From no fans to ENERGY STAR fans
Controls	From no programmable thermostat to a programmable thermostat

With the incorporation of the measures summarized above, this project could easily meet its goal of a deep energy retrofit with 64% projected energy cost savings and projected annual energy cost savings of $1,459.

2.2.18 Deep Energy Retrofit EH-21 (Occupied after completion in October)

The renovation of this unoccupied, foreclosed home was completed in October. Table 57 summarizes the projected annual energy use and cost savings for deep energy retrofit project EH-21. Table 58 relates the anticipated financing and payback associated with the whole package of improvements. Appendix A includes analysis for this project.

Table 57. EH-21 Annual Energy Use and Cost Simulation

Home Components	As Found	Minimal Improvement	Actual Retrofit
HERS Index	120	107	73
Annual Simulation kWh (BABM08)	17,386	16,021	10,688
Annual MBtu Usage (BABM08)	59.3	54.7	36.5
Annual Energy Cost (BABM08)	$2,260	2,083	1,388
Project Status: Completed 10/22/2011			
"Minimal Improvement" reflects improvement for replacing the mechanical system with a SEER 13 air conditioner with electric resistance heating, the minimum efficiency system available.			

Table 58. EH-21 Annual Energy Savings Analysis

	Full Cost & Savings (As Found vs. Actual)	Incremental Cost & Savings (Minimal vs. Actual)
HERS Index Improvement (%)	39%	32%
Annual Energy Cost Savings ($)	$872	$695
Annual Energy Cost Savings (%)	39%	33%
Improvement Costs	NA	NA
Monthly Mortgage	NA	NA
Monthly Energy Cost Savings	$77	$58
Monthly Cash Flow	NA	NA
Simple Payback (years)	NA	NA

This unoccupied, foreclosed, single-family detached home in Lake Worth, Florida is the fourth of five renovations initiated in 2011 by Habitat for Humanity of Palm Beach County, Inc. (www.habitatpbc.org), a non-profit, affordable housing organization. Built in 1996, this three bedroom, two bath home (Figure 92) has 1,573 square feet of conditioned space.

The slab-on-grade, concrete block, two-story home had a light colored exterior and a medium-dark clay, barrel tile roof. Ceiling insulation was R-19 batt fiberglass. The existing windows were single-hung, single-pane, clear, with metal frame; all were in good shape. Appliances and lighting included an older, 30-gallon electric hot water heater and 100% incandescent lighting.

Figure 92. EH-21 post-retrofit (exterior unchanged between pre-retrofit and post-retrofit)

The air heating and conditioning systems included a window air conditioning unit and a forced air, SEER 10, central air conditioner with electric resistance heating. The air handler was in a narrow interior closet (Figures 93-95).

Figures 93-95. Retrofit EH-21 pre-retrofit wall unit (left), Pre-retrofit condenser (center), pre-retrofit air handler (right)

Results from the whole house air tightness test were high (ACH50 of 15.05).The air handler closet was a primary source of leakage. Other sources were the small storage compartment under the stairwell and a pocket door into the upstairs bathroom.

Given the design of the air handler closet, researchers were unable to include the closet in the duct leakage tests. Even with the closet excluded from the test, leakage was high ($Q_{n,out}$ = 0.10). Given the air movement between the attic and the closet under the house depressurization test, true duct leakage has been underrepresented.

The renovation, completed on October 22, 2011, was limited; however, a few combined measures had a big impact on the overall projected energy cost savings. The most significant measures (in order of contribution) were the installation of an electric hybrid water heater with heat pump, almost exclusive use of efficient lighting, reduction in whole house infiltration, and installation of a forced air, central air conditioner (SEER 14.5) with integral resistance heat. The existing R-19 ceiling insulation was supplemented to achieve R-38. Figures 96-97 show the pre- and post-retrofit domestic water heaters. The entire package of improvements, listed in Table 59, is estimated to produce $872 in annual energy cost savings.

Figures 96-97. EH-21 pre-retrofit electric tank water heater (left), post-retrofit electric hybrid water heater with heat pump (right)

Table 59. EH-21 Key Energy Efficiency Measures

Component	Pre- and Post-Retrofit Characteristics
Ceiling Insulation	From R-19 to R-38 with blown-in fiberglass
Whole House Infiltration	From ACH50 = 15.05 to ACH50 = 6.15
Heating and Cooling System	From SEER 10 with integral electric resistance heat to SEER 14.5 with integral electric resistance heat
Air Distribution System	From Qn,out = 0.10 to Qn,out = 0.065
Water Heating System	From 30 gal, electric, EF = 0.89 to 50 gal, electric tank with heat pump, COP = 2.35
Refrigerator	From default to Energy Guide label of 378 kWh/yr
Lighting	From 0 CFLs to 80% CFLs
Controls	From no programmable thermostat to a programmable thermostat

The new air handler was installed into the existing, narrow air handler closet, and it proved to be challenging. The mechanical contractor left a hole, roughly 4"x15", between the closet ceiling and the attic. After several failed attempts, the partner successfully patched the gap with a piece of drywall and caulk to seal the seams. The confined space did not allow the partner to incorporate outside air ventilation, a detail they have been incorporating into the other retrofits we partnered on. The mechanical distribution system was poorly designed, with a supply trunk running through the platform return, and this was sealed with caulk, rather than mastic. Access to the return plenum was behind airflow-restricting louvered doors, rather than on the same plane as the hallway wall. Figures 98-100 show post-retrofit pictures of the air handler closet.

Figures 98-100. EH-21 post-retrofit air handler closet (left), post-retrofit closet (center), post-retrofit open return with airflow-restricted louvered doors (right)

The post-retrofit duct leakage test results were much improved (Qn,out = 0.065), with room for improvement, nonetheless. Researchers suggested that mastic be used to better seal the seams of the return plenum. The whole house leakage (ACH50 = 6.15) was drastically improved over the pre-retrofit condition.

During the post-retrofit audit, pressure mapping was performed to test the balance of mechanical system airflow though the house. Researchers created a "worst case" scenario by running the air handler and exhaust fans, in addition to shutting all bedroom doors. Operating in "worst case" the home was depressurized only slightly (-1.6 pa), and there was excessive positive pressure in one bedroom. The partner installed an above door transfer grille between this bedroom and the main body to allow passive air transfer out of the bedroom. Post-retrofit pressure mapping results are presented in Table 60.

Table 60. EH-21 Post-Retrofit Pressure Mapping

Location	Pressure (Pa)
House WRT Out	-1.6
Master WRT House	1.3
Bedroom 2 WRT House	2.2
Bedroom 3 WRT House	4.6

In summary, the partner successfully retrofitted this home to accomplish a deep energy retrofit with only a handful of renovation measures. The projected energy cost savings of 39% was achieved through the installation of an electric hybrid water heater with heat pump, almost exclusive use of efficient lighting, reduction in whole house infiltration, and installation of a forced air, central air conditioner (SEER 14.5) with integral resistance heat.

There were two issues with this retrofit project:

The air hander was built into a confined space, and the mechanical contactor failed to patch a large hole leading from mechanical closet ceiling into the attic. Furthermore, a supply trunk running through the return platform and lack of mastic used to seal the plenum seams resulted in some avoidable duct leakage. This lack of quality assurance and central oversight indicated a gap in the retrofit contracting paradigm.

The design of the closet creates airflow restriction, as the return plenum access is housed behind the air handler closet louvered doors.

When the partner provides cost data for the energy-related elements of the renovation, researches will complete the economic calculations.

2.2.19 Deep Energy Retrofit EH-22 (Occupied after completion in November)

Renovation activity in this unoccupied, foreclosed home was completed in November. Table 61 summarizes the projected annual energy use and cost savings for deep energy retrofit project EH-22. Table 62 relates the anticipated financing and payback associated with the whole package of improvements. Appendix A includes analysis for this project.

Table 61. EH-22 Annual Energy Use and Cost Simulation

Home Components	As Found	Minimal Improvement	Actual Retrofit
HERS Index	119	105	64
Annual Simulation kWh (BABM08)	15,516	14,075	8,139
Annual MBtu Usage (BABM08)	53.0	48.0	27.8
Annual Energy Cost (BABM08)	$2,019	$1,831	$1,059
Project Status: Completed 11/12/2011			
"Minimal Improvement" reflects improvement for replacing the mechanical system with a SEER 13 air conditioner with electric resistance heating, the minimum efficiency system available.			

Table 62. EH-22 Annual Energy Savings Analysis

	Full Cost & Savings (As Found vs. Actual)	Incremental Cost & Savings (Minimal vs. Actual)
HERS Index Improvement (%)	46%	39%
Annual Energy Cost Savings ($)	$960	$772
Annual Energy Cost Savings (%)	48%	42%
Improvement Costs	NA	NA
Monthly Mortgage	NA	NA
Monthly Energy Cost Savings	$168	$153
Monthly Cash Flow	NA	NA
Simple Payback (years)	NA	NA

This unoccupied, foreclosed, single-family detached home in Lake Worth, Florida was the final of five renovations initiated in 2011 by Habitat for Humanity of Palm Beach County, Inc. (www.habitatpbc.org), a non-profit, affordable housing organization. Built in 1997, this three bedroom, two bath home (Figures 101-102) has 1,334 square feet of conditioned space.

The slab-on-grade home had medium-colored concrete block exterior walls and a white asphalt single roof. Ceiling insulation was compressed R-19 fiberglass batts; researchers degraded to R-17 for modeling purposes. Three knee walls totaling 68 ft^2 were wrapped with R-19 fiberglass batts, and the attic access (8 ft^2) was void of insulation. The windows were single hung, single-pane, tinted, with metal frame. Appliances and lighting included a 30-gallon electric hot water heater (Figure 103), a non-ENERGY STAR refrigerator, and 100% incandescent lighting.

Figure 101-102. EH-22 pre-retrofit (left) and post-retrofit (right)

The air heating and conditioning system was a central, forced air system that researchers estimated to be a SEER 10 air conditioner with electric resistance heating. The compressor had been stolen (Figure 104). In addition, the air handler had been disassembled (Figure 105-106) by the partner prior to the house being selected for the study. Broken windows and a missing front door compromised the house envelope. Researchers were unable to conduct whole house leakage and duct leakage tests for the above stated reasons; thus, averages from prior research for pre-retrofit whole house air leakage (ACH50 = 11) and duct leakage (Qn,out = 0.13) were used for modeling purposes.

Figures 103-106. EH-22 pre-retrofit water heater (left), missing compressor (center left), dismantled air handler (center right), air handler closet (right)

The renovation on this home was completed on November 12, 2011, and the initial test-out audit was conducted on November 16, 2011. The first of two post-retrofit tests identified the following three problems that the partner subsequently worked to correct:

An attempt to incorporate outside air via runtime ventilation failed on three accounts, enumerated below.

ACH50 was 7.02, a higher result than expected given the scope of the retrofit. The primary source identified for this leakage was around the pull-down attic stairs, which did not close properly and was without a gasket.

There was excessive pressure built up in the bedrooms during mechanical system runtime.

The mechanical system retrofit was this project's most challenging measure. The location of the existing air hander was too small to house the new unit. To keep the air handler in the interior space, the partner used a pedestal area created where the cathedral ceiling meets two knee walls, installing the unit for horizontal air flow. The confined space was not large enough to incorporate a return; rather a single return was installed in the adjacent attic space. (Figure 107) Despite a difficult configuration, the partner attempted to incorporate outside air via runtime ventilation. The system design failed in three areas, however: First, the outside air damper worked in reverse pulling shut during system run time. Second, no interior occupant control was present, nor was installing one aesthetically feasible since the outside air duct never entered the interior space. Third, the outside air entered the system unfiltered since there was no filter at intake, and the outside air duct entered the return plenum, downstream of the return filter.

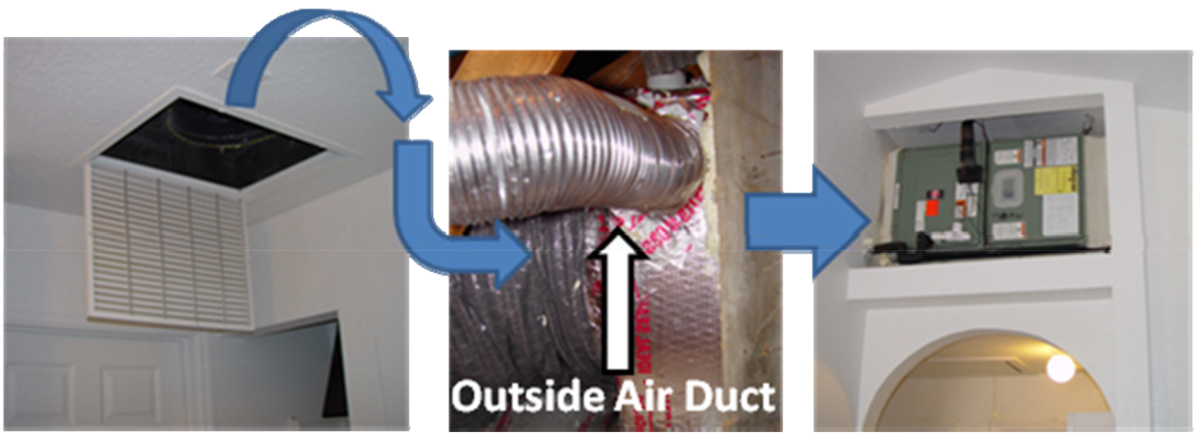


Figure 107. EH-22 post-retrofit central return (left) outside air intake ducted directly into air handler plenum upstream of return filter (center), air handler mounted internally, adjacent knee wall, with horizontal air flow (right)

Since the house was not exceptionally tight, and because an aesthetically pleasing solution was unlikely, researchers decided the best course of action was to abandon the attempt to incorporate outside air. With partner agreement, researchers assisted the partner with a method for disabling the outside air, which included removing the duct at the entrance into the plenum and at the intake. The plenum was patched with a snugly fitting piece of duct board cut the same dimensions as the hole; seams were then sealed with mesh and mastic. The intake collar was taped over with UL 181 rated tape.

To address the infiltration problem, a gasket was installed around the edge of the pull-down attic stair. Although this measure did restrict some attic air from flowing into the home, the hatch was warped and would not lay flat with the ceiling plane when closed. The partner reported they were going to attempt a better seal by installing fasteners that could manually lock the hatch flush with the ceiling. Meanwhile, the partial correction provided a small reduction to whole house leakage.

The second post-retrofit test result for whole house leakage was ACH50 = 5.76, improved from the previous result of ACH50 = 7.02.

During each post-retrofit audit, pressure mapping was performed to test the balance of mechanical system airflow though the house. Researchers created a "worst case" scenario by running the air handler and exhaust fans, in addition to shutting all bedroom doors. During the initial test-out, operating in "worst case" the home was depressurized (-5.7 pa), and there was excessive positive pressure in all bedrooms. There were no returns or jump ducts installed in the bedrooms. The partner took corrective action by installing above door transfer grilles between all bedrooms and the main body to allow passive air transfer out of the bedrooms. However, the penetrations through the walls were left open to the internal wall cavities. In a previous discussion, researchers had described the transfer grille sealing needs to the partner; unfortunately, the communication was not translated to the field worker. The partner agreed to seal the access to the interior wall. Meanwhile, post-retrofit pressure mapping for Test #2 was conducted with transfer grilles open to the wall cavities. Post-retrofit pressure mapping results for Test #1 and Test #2 are presented in Table 63.

Table 63. EH-22 Post-Retrofit Pressure Mapping

Location	Post-Retrofit Test #1 Pressure (Pa)	Post-Retrofit Test #2 Pressure (Pa)
House WRT Out	-5.7	-6.6
Master WRT House	21.9	8.5
Bedroom 2 WRT House	13.5	3.5
Bedroom 3 WRT House	9.7	2.8

Pressure was greatly reduced in all bedrooms; however, pressure in the master bedroom, which had two supply registers, was still high at +8.5pa. Regardless, the overall house pressure to outside, the "worst case" scenario, was slightly more depressurized (from - 5.7pa to -6.6pa). Differences in test conditions should be considered when comparing the results from the post-retrofit tests; the second post-retrofit test was conducted under windier conditions, after the outside air had been sealed off, and after house leakage from the attic hatch had been reduced.

The retrofit measures with the most significance (in order of contribution) were the installation of an electric hybrid water heater with heat pump, almost exclusive use of efficient lighting, the installation of a forced air, central air conditioner (SEER 14.5) with integral resistance heat, and the installation of Low-E windows with vinyl frame were tied in their contribution to efficiency improvement. The existing attic insulation, comprised of compressed R-19 fiberglass batts, was supplemented to achieve R-38; although the knee walls and attic hatch area remained at R-19 and R-1, respectively. Energy efficiency losses were incurred with this retrofit by relocating the mechanical system return from the interior into the attic and by changing flooring composition, which was initially 100% tile. The entire package of improvements, listed in Table 64, is estimated to produce $960 in annual energy cost savings.

Table 64. EH-22 Key Energy Efficiency Measures

Component	Pre- and Post-Retrofit Characteristics
Ceiling Insulation	From R-17 to R-38 with blown-in fiberglass
Windows	From Single-pane, metal frame, tinted (U = 1.20; SHGC = 0.70) to Double-pane, low-E, vinyl frame (U = 0.34; SHGC = 0.26)
Floors	From 100% Tile to 50% Vinyl, 10% Tile, 40% Carpet
Whole House Infiltration	From ACH50 = 11 (est.) to ACH50 = 5.76
Heating and Cooling System	From SEER 10 (est.) with integral electric resistance heat to SEER 14.5 with integral electric resistance heat
Air Distribution System	From Qn,out = 0.13 (est.) with R-4.2 to Qn,out = 0.054 with R-6
Return Location	From interior to attic
Water Heating System	From 30 gal, electric, EF = 0.89 to 50 gal, electric tank with heat pump, COP = 2.35
Refrigerator	From default to Energy Guide label of 378 kWh/yr
Lighting	From 0 CFLs to 80% CFLs
Fans	From fans with default efficiency to 100 CFM @ medium speed
Controls	From no programmable thermostat to a programmable thermostat

In summary, this project achieved the greatest estimated energy cost savings of all the retrofit homes within this study to date, 48%, despite a couple of efficiency losses. The versatile floor plan allowed for relocation of the air hander within conditioned space when the exiting air handler closet was insufficient in size. However, the unique configuration presented challenges for incorporation of a mechanical runtime ventilation system, which was ultimately abandoned. Finally, a lack of detailed instruction from the researcher's contact to his field worker yielded improperly installed transfer grilles.

2.2.20 Deep Energy Retrofit EH-23 (Occupied, Not Started as of Dec 5)

Table 65 summarizes the projected annual energy use and cost savings for deep energy retrofit project EH-23. Table 66 relates the anticipated financing and payback associated with the whole package of improvements. Appendix A includes analysis for this project.

Table 65. EH-23 Annual Energy Use and Cost Simulation

Home Components	As Found	Recommended Deep Retrofit
HERS Index	100	64
Annual kWh	23,893	17,807
Annual Therms	0	0
Annual MBtu Usage	66.5	46.5
Annual Energy Cost	$2,998	$2,238
Status: Start delayed indefinitely because of financing issues		

Table 66. EH-23 Annual Energy Savings Analysis Based on Estimated Costs

	Full Cost & Savings (As Found vs. Actual)	Incremental Cost & Savings (Minimal vs. Actual)
HERS Index Improvement (%)	Cost Not Available Renovation has not Begun	
Annual Energy Cost Savings ($)		
Annual Energy Cost Savings (%)		
Improvement Costs		
Monthly Mortgage		
Monthly Energy Cost Savings		
Monthly Cash Flow		
Simple Payback (years)		

This two-story, four bedroom, three bath, single-family residence is located in Jacksonville, Florida on a well-shaded lot (Figures 108-109). Constructed in 1981, there is 2,923 ft^2 of conditioned space. The house is stick-frame constructed, slab-on-grade, with a vented flat attic above the single-story sections. In addition, the house has cathedral ceilings with knee walls on the second floor and a heated pool in the backyard.

An initial test-in audit was conducted on August 8, 2011. The HVAC system consisted of a 4-ton SEER 11 heat pump, interior-located air handler, and returns with supply ducts running through the attic. The second floor had several supply registers and a portable window unit air conditioner to supplement cooling needs. Attic insulation varied from R-19 to R-30, knee walls were insulated with R-30 batts that, in places, had fallen down or pulled away from the drywall. The cathedral ceiling was insulated with R-19 fiberglass batts that completely filled the 2"x6" truss cavity, essentially blocking the vent pathway. The exterior walls were insulated with R-11 fiberglass.

The supply ducts in the attic varied between R-4.2 and R-6 flex duct. Total duct leakage and leakage to out measured Qn total = 0.155, Qn out = 0.065. The screened pool was heated by a heat pump, which was running during the time of test-in.

The pre-retrofit test in resulted in a HERS index of 100,   and annual energy use of 66.5 MMbtu's estimated at a cost of $2,998 per year at $0.13kWh. Details of the test in results and anticipated savings from efficiency measures contained in the final analysis can be found in Table 67.

Figures 108-109. EH-23 pre-retrofit

Table 67. EH-23 Key Energy Efficiency Measures

Component	Pre-Retrofit and BA Proposed Retrofit Characteristics
Roof	From dark asphalt shingles to white asphalt shingles (Solar absp. = 0.75)
Roof	From no radiant barrier to radiant barrier system
Ceiling Insulation	From R-19 to R-38, repair knee wall insulation to Grade 1
Windows	From no window tinting to window tinting , east and west walls (SHGC 0.35)
Whole House Infiltration	From ACH50 = 9.26 to ACH50 = 6.0; install runtime vent (60 cfm)
Heating and Cooling System	From SEER 11; 4 ton, heat pump, 7.7 HSPF to geothermal heat pump system; EER = 13.44, COP = 2.47
Air Distribution System	From R-4 ducts, Qn, out = 0.065 to estimated Qn out ≤ 0.04), replace all ducts, R-6
Water Heating System	From 40 gal, electric (0.92 EF) to heat pump water heater; COP = 2.35
Lighting	From 14/22 CFL (63%) to 18/22 CFL (80%)
Controls	Programmable thermostat

This project was more time consuming and complicated than anticipated. The homeowner received advice from several different contractors, as well as the PNNL team, on energy efficiency improvement measures. Efficiency measures were to be paid for with a low interest loan through a local utility. All measures needed to meet the programs loan criteria, which further complicated the project. Numerous efficiency measures including various SEER heat pump systems, solar augmented heat pump systems, and ground source heat pumps were analyzed. Several different roof measures including a galvanized roof, white asphalt shingles, radiant barrier, and roof deck insulation were also analyzed. Despite advice from the PNNL team, the homeowner chose a ground source heat pump to replace his old SEER 11 heat pump unit.

The final measures decided upon by the homeowner are shown in Table 67. Once the analysis was finalized and submitted to the local utility for approval, the homeowner stopped responding to communication from the PNNL team. It is unclear whether this project progressed beyond the analysis stage. After numerous failed attempts to communicate with the partner, the PNNL team discontinued this project.

2.2.21 Deep Energy Retrofit EH-24 (Occupied, Dropped)

Renovation progress in this occupied home was insufficient to reach completion before the end date of the contract and was dropped from consideration. Table 68 summarizes the projected annual energy use and cost savings for deep energy retrofit project EH-24.

Table 68. EH-24 Annual Energy Use and Cost Simulation

Home Components	As Found
HERS Index	164
Annual kWh	19,184
Annual Therms	0
Annual MBtu Usage	65.5
Annual Energy Cost	$2,493
Status: Dropped	

A site visit was conducted on the 1,200 ft^2 two-section manufactured home (Figure 110, left) in Brevard County on August 16, 2011. Due to significant deconstruction of the interior air and thermal barrier, a blower door test and duct tightness test were not performed. Field measurements were taken including documentation of the mechanical systems (Figure 111, right) and measurements of the thermal shell. Discussion with the homeowner and designer during the test-in audit revealed that financing and logistical issues would likely interfere with progress on this renovation. Informal site visits in September and October found no progress.

Figures 110-111. EH-24 pre-retrofit manufactured home (left) with central, forced air package unit mechanical system

Nonetheless, the test-in data was used to create an energy model to predict the buildings annual energy use and relative efficiency, and basic recommendations were provided to the homeowner. Because whole house air tightness and duct tightness tests were not conducted, estimates were used based on previous research under the Building America Industrialized Housing program.

The as-found house has a HERS Index score of 164 and an estimated annual energy consumption of $2,493/yr. Major building characteristics impacting the energy rating were an old HVAC package system with the air handler located outside, and the return system located in the crawlspace. The house also has low insulation levels in the walls, floor system, and attic areas.

Renovation plans include significant upgrades to the overall energy efficiency of the home, which if implemented will substantially reduce the buildings energy load and will significantly improve comfort for the buildings occupants. After careful review of the building's existing conditions including the renovation plans, FSEC provided basic recommendations for the homeonwer's consideration even though the project was not included in the study. These recommendations related to air, thermal, and moisture barriers as well as specifications for the mechanical system, appliances, and lighting.

2.3 Deep Retrofit Monitoring: Measured Energy Performance Analysis

Energy and interior temperature and relative humidity (RH) were monitored in twelve deep energy retrofit homes. Two home energy feedback devices (TED and eMonitor) were used to collect total and sub-metered electrical end uses. Many of the homes had natural gas appliances, but gas monitoring was not performed. Larger electrical end uses, such as space heating and cooling as well as water heating were sub-metered. Smaller electrical branch circuits were also monitored including refrigerator, dishwasher and various plug loads. Please see Appendix B for details on the energy feedback devices used and tests of their relative accuracies.

Measured energy data was collected from the two feedback devices in different ways. TED data was collected on a weekly basis by directly contacting the internet-connected device through a browser interface. Collected data was reviewed on a monthly basis to verify data quality and review home performance. Problems with two TED devices prevented data collection during the first month (June) but were corrected by early July. Uninterrupted data has been collected since July 9 on all three TED-monitored homes, which were all located in San Antonio, Texas.

Data collection from the eMonitors proved less troublesome and labor-intensive than with TED. The eMonitor feedback device is also internet-connected, but in contrast to TED the data is not stored locally (except for a 1-day buffer) and is continually pushed to a remote site where it can be accessed and downloaded periodically. A server at FSEC retrieved the eMonitor data on a daily basis and stored it locally. This data was reviewed periodically for overall quality and brief analysis. The nine homes with eMonitors were located in Central Florida (3) and Metro Atlanta (6).

Interior temperature and RH readings were recorded in all homes by Hobo dataloggers on an hourly basis to match the hourly energy data. The loggers were downloaded on one to two month intervals. Outdoor temperature and dewpoint were collected and stored on FSEC servers from National Weather Service stations located at airports in cities near the monitored homes.

2.3.1 Atlanta Retrofit Homes

Six retrofit homes located in Metro Atlanta were the first to receive monitoring equipment beginning in early May, 2011. These homes were recruited and retrofit assistance provided by Oak Ridge National Laboratory (ORNL), which is under separate contract with DOE. The original ORNL project plan did not include monitoring but was added through a partnership with FSEC under this contract. Measured energy data has been continuously collected and stored at FSEC since April, 2011. The data has been periodically reviewed for gross errors but has otherwise only been stored for ready-access by ORNL.

2.3.2 San Antonio Retrofit Homes

Three retrofit homes in San Antonio, Texas have been monitored since July 9, 2011. FSEC provided only monitoring assistance for these homes with retrofit support provided by Build San Antonio Green (BSAG) and home performance measurements performed by Calcs-Plus. These small homes (683 to 940 square feet) received extensive envelope and moderate equipment improvements, greatly increasing comfort and overall livability. Some of the homes were upgraded from window-unit air conditioners to central air and heat.

Figure 112 shows area-adjusted cooling performance of the three homes in comparison to two new homes constructed in 2009. The new homes, built by Woodside Homes in San Antonio, had identical 1,979 ft^2 floor plans and were evaluated in a recent research publication (Chasar 2010). The two dashed regression lines represent measured data from the new homes collected during the summer of 2009. The standard practice new home (control) was constructed with a few components above the minimum building code requirements including a SEER 14 air conditioner (similar to that used in the retrofits).

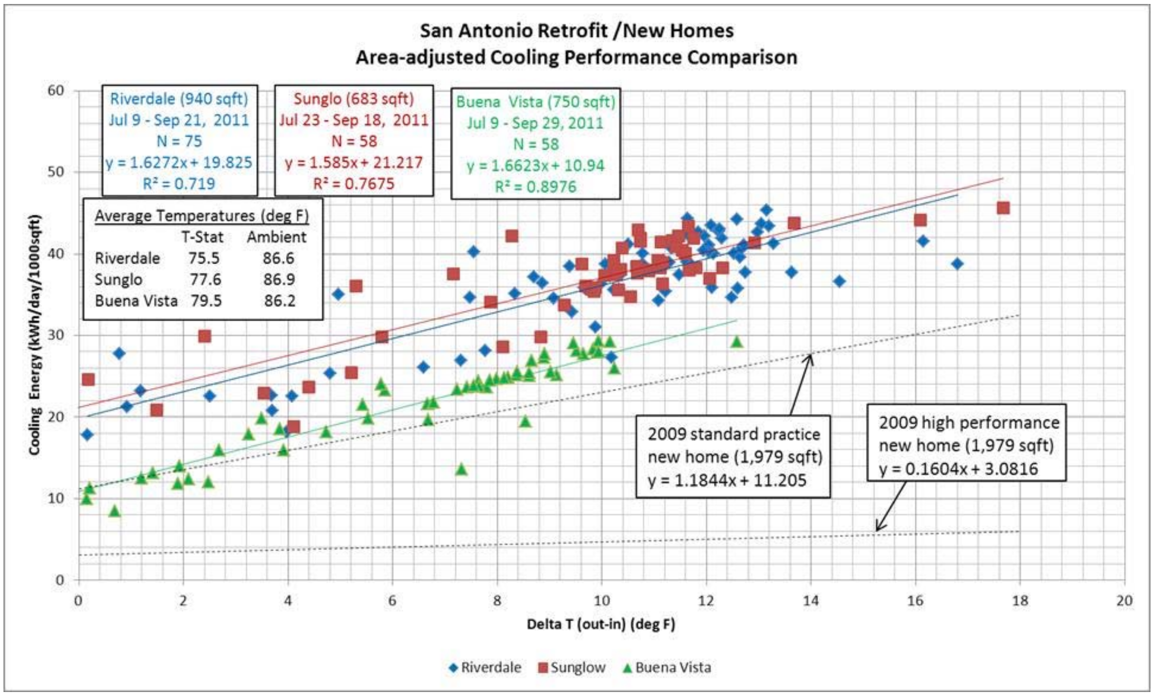


Figure 112. San Antonio retrofit cooling performance comparison.

The level of cooling performance in the retrofit homes, while not on par with the standard practice new home, exhibited a considerable degree of efficiency. The new homes are two to three times larger than the retrofits, making direct comparisons of cooling performance difficult. The smaller retrofit homes tend toward a higher level of interior loads from appliances and occupant activity common in homes of all sizes. This leads to higher cooling energy use on a square foot basis. Table 69 compares retrofit cooling performance to the Woodside standard practice (Control) home and includes Woodside's highest performing (Improved) home as a best case reference. Savings are derived from comparing areas under the linear regression lines over the Delta T (x-axis) values from 0 to 18°F. One retrofit home (Buena Vista) used 18.5% more area-adjusted cooling energy than the Woodside Control. The other retrofits used roughly 60% more energy.

Table 69. San Antonio Measured Cooling Performance Comparison

Home	Year Built	HERS Index Pre-Post	Area / Size Factor	Area Under Regression Line	Savings Relative to Control
Woodside Control	2009	n/a-86	1,979 / 1x	394	
Woodside Improved	2009	n/a-37	1,979 / 1x	81	79.3%
Sunglo Retrofit	1955	Not available at this time	683 / -2.9x	639	-62.3%
Riverdale Retrofit	1949	161-93	940 / -2.1x	620	-57.7%
Buena Vista Retrofit	1950	150-88	750 / -2.6x	466	-18.5%

Utility bills were acquired for the San Antonio homes from both pre and post-retrofit periods. The collected TED data and utility electric readings were compared over the same post-retrofit billing periods to validate the home energy monitor against utility data. Results from two billing periods from each home showed a difference of -2% to +6% in total billed kWhs with an average difference of 3%.

Electric billing data was also used to assess post-retrofit cooling performance improvements. Cooling energy was estimated by averaging the electric use from the three lowest bills and subtracting that value from each of the June through September bills. This method assumes that the lowest bills over the year approximate the non-cooling electric use, and further assuming this level to be constant throughout the year yields estimated cooling energy when subtracted from the total monthly energy use during the cooling months. In addition, cooling degree days were obtained for the equivalent billing cycle and plotted against estimated cooling energy for each month. Linear regression analysis showed reasonably well-fit data on two homes with R^2 values between 0.78 and 0.99 and cooling energy savings estimates of 41 and 54%. Pre-retrofit billing data from the third home was far more scattered ($R^2 = 0.22$) and did not yield a meaningful comparison.

2.3.3 Florida Retrofit Homes

Three retrofit homes in Venice, Eustis and Sarasota, Florida have been monitored since the late summer of 2011. Retrofit design assistance and performance testing was provided by FSEC on one home (Eustis, retrofit project EH-04) and was provided by Calcs-Plus on the remaining two homes.

Limited summer data was collected from two Florida retrofit homes (Venice - 47 days and Eustis – 12 days). Figure 113 shows a cooling performance comparison of these homes with data from two 1998, Central Florida homes used as benchmarks in a recent research publication (Chasar 2006). Table 70 further compares the houses. The benchmark homes are identical 2,400 ft^2 floor plans, one built to 1998 standard practice with a SEER 10 cooling system, and the other, a near-net-zero energy home with a SEER 14.4 system. These homes were originally detailed in a previous publication (Parker 1999).

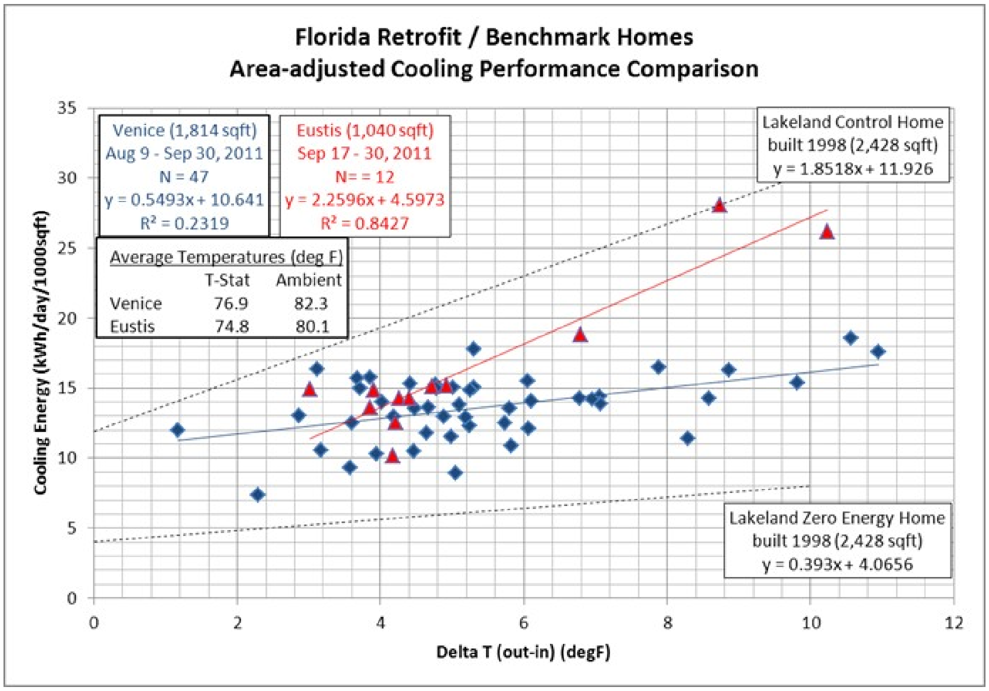


Figure 113. Florida retrofit cooling performance comparison.

The Venice home provided nearly seven (7) weeks of cooling data showing a trend of cooling energy savings over the 1998 control home (37%) with significant scatter. The small sample size of the Eustis home (12 days) provided a limited assessment showing cooling energy savings of 25% over the 1998 control home. Data from the 1998 near-ZEH home continues to set the bar for area-adjusted cooling performance efficiency even when compared to more recent vintage homes with higher efficiency equipment (Chasar 2006). Additional retrofit data collection is planned for the summer of 2012 to enhance the cooling performance evaluation.

Table 70. Florida Measured Cooling Performance Comparison

Home	Year Built	HERS Index Pre-Post	Area	A/C SEER	Area Under Regression Line	Savings Relative to Control
Lakeland Control	1998	n/a	2,428	10	212	
Lakeland NZEH	1998	n/a	2,428	14.4	60	71.5%
Venice Retrofit	1978	185-57	1,800	16.3	135	36.8%
Eustis Retrofit	1981	132-78	1,040	13	159	25.0%

2.3.4 Conclusion

Measured data was collected on twelve deep energy retrofit homes, five of which were evaluated for cooling energy performance during the summer of 2011. A novel data collection method was employed to increase the sample size within a limited budget. Accuracy of the collected energy readings was below the level typically found with research-grade monitoring equipment but deemed acceptable at no more the 11%. Interior temperature and RH were provided by Hobo dataloggers, while outdoor temperature and dewpoint were taken from National Weather Service stations located at airports in cities near the monitored homes. Measured energy data was provided by two types of home energy feedback devices.

Cooling energy performance was compared between three San Antonio 1950-era retrofits and two recent vintage homes (2009) from a previous study. A comparison of the new and retrofit homes is complicated by the difference in size (680 - 940 ft^2 versus 1,980 ft^2). Area-adjusted results show one retrofit using 19% more cooling energy than the 2009 reference home and the other two using roughly 60% more cooling energy. These results are thought to be somewhat inflated due to the compact homes having more concentrated internal loads from equipment and occupant activity that would occur fairly equally in all homes.

The cooling performance comparison of two Florida retrofits was benchmarked against two newer homes with previously documented performance. Again, the benchmark homes are larger than the retrofits (2,430 versus 1,810 and 1,040), but assessments were made on an area-adjusted basis. One retrofit with a SEER 16 air conditioner achieved a 37% savings over the 1998 benchmark home (with SEER 10 equipment). The other retrofit showed a 25% improvement with SEER 13 equipment.

3 Task 2: New Construction High Performance Prototypes

3.1 Overview of New Construction High Performance Affordable Housing

FSEC provided technical assistance to new construction home builders striving for very high performance levels, specifically to Habitat for Humanity International (HFHI) affiliates located in Florida striving for Builders Challenge or participating in HFHI's nationwide Partners in Sustainable Building program. Three partner affiliates built eleven prototypes.

3.1.1 Typical House Characteristics

Typical houses are all electric and of wood frame construction with attics under 1,300 ft^2. In addition, the houses have three bedrooms with one or two baths, 8' flat ceilings (no trays, etc. or soffits), and are typically without garages unless code mandated. One affiliate built garages. All of the FSEC prototypes under the task are located in Florida in the hot-humid climate zone.

3.1.2 Recruitment

To recruit partners, FSEC built on existing relationships with leadership and local affiliates of HFHI. Working with motivated partners is a fundamental element of FSEC's strategy for this project. FSEC recruited partners at the Florida Habitat for Humanity Conference in September 2010. Researchers also worked with the program managers of HFHI's Partners in Sustainability program to select affiliates for building a certified home under a green home or advanced building science program, including the Builders Challenge. In addition, recruitment was carried out among HFHI's recipients of the U.S. Department of Housing and Urban Development (HUD)'s Self-help Homeownership Opportunity Program (SHOP) funding.

The Partners in Sustainable Building program sponsors homes in more than 135 Habitat affiliates across 42 states. The participating affiliates will be granted $3,000 for each home built to ENERGY STAR standards or up to $5,000 for each home built to Builders Challenge (BC). The selected Habitat affiliates are expected to build 2,400 homes in 2010–2011. Launched in 2009, this $30 million efficient building initiative is a five-year program aimed at helping Habitat affiliates in the United States incorporate sustainable building practices in 5,000 homes.

SHOP provides funds for eligible national and regional non-profit organizations and consortia to purchase home sites and develop or improve the infrastructure needed to set the stage for sweat equity and volunteer-based homeownership programs for low-income persons and families. Houses built on land financed by SHOP must meet ENERGY STAR standards as a minimum, with each year's funding requiring stricter energy and green conservation measures.

3.1.3 Technical Assistance Procedure

After recruiting partners interested in pursuing this goal, FSEC provided technical assistance to each qualifying candidate. Specifically, FSEC worked with each partner to bring their standard practices in line with those needed to achieve our mutual goals through the technical assistance. This process included an introductory period of building science training followed by partnership on several trial houses, each with the goal of achieving Builders Challenge level. Once the partner had achieved the Builders Challenge goal in a trial house, FSEC pursued two or more additional prototypes that met the goal.

Important Caveat to Task 2: One of the primary anticipated challenges of this task is the Builders Challenge requirement of incorporating the building science details (Builders Challenge Quality Criteria 1 and 2 - energy features and moisture protection) in the construction drawings. This requirement has been an insurmountable hurdle to certification under the Builders Challenge in previous FSEC projects with affordable housing entities. They do not want to spend their limited funding revising standardized plans as many of these details are not required for permitting. The time constraints of the contract did not provide adequate time for these changes to be made as most of the houses were already permitted at the time a partnership was formed. Energy Star does not require that details be incorporated into the plans.

An additional road-block was the change in the ENERGY STAR program. ENERGY STAR certification is a major criteria for both of HFHI's grant monies, HUD SHOP funding ($15K) and Partners in Sustainability program ($3K). In order to facilitate partnerships, an alternative path for program compliance was devised based on ENERGY STAR 2.5.

ENERGY STAR Version 2.5 qualified houses incorporate the following additional ENERGY STAR Version 3.0 Checklist requirements, which duplicate the Builders Challenge Quality Criteria (BCQC):

- Minimal Duct leakage (Builders Challenge Quality Criteria - Qn total 0.10, Qn out 0.05).
- ENERGY STAR Labeled windows
- Whole Building mechanical ventilation (BCQC 11,). We will not advocate ASHRAE 62.2-2010 at this time.
- Kitchen Exhaust vented outside (BCQC 12, HVAC System Quality Rater Checklist 8.1)
- Bath Exhaust vented outside (BCQC 13, HVAC Rater Checklist 8.2)
- Clothes Dryer vented outside (BCQC 14, HVAC Rater Checklist 8.5)
- Minimum efficiency reporting value (MERV) 8 filter (BCQC 17, HVAC Rater checklist 11.1 says MERV 6)

We do not allow naturally aspirated combustion appliances in the conditioned space.

This method allows recruited partners to concentrate on bringing their houses in-line with both programs prior to committing to the expense of updating their plans to reflect changes that may or may not be adopted.

3.1.4 Training/Preliminary Field Testing

To begin our process after recruitment, researchers provide introductory training on key concepts and performance targets (duct leakage, detailing, specifications, etc.) necessary for success. This is pursued in tandem with detailed energy analysis of two or three of the partner's current projects. Researchers conduct a thorough audit of the partner's current building techniques and generate a HERS Index. Researchers also provide a projected HERS Index for the home based on the partner's proposed new package. This exercise helps partners understand both the analysis process used to identify a package of improvements and the building science concepts necessary for success. Partners gain an understanding of what they are already doing well and where improvements are needed. In this initial process, partners find out how close they are to meeting the goal and gain an understanding of steps needed to reach the goal.

3.1.5 Package Selection

Partners then select a package of improvements, and researchers provide technical assistance as needed during implementation. These houses give partners a chance to practice unfamiliar details, locate vendors, and bring sub-contractors up to speed. Partners will generally be striving toward their goal in several houses concurrently. Researchers anticipate that some partners will achieve the overall goal in one or two houses, while others will fall short.

The small-size houses mandated by Habitat's internal policies, coupled with Florida's benign climate reduce the impact of envelope enhancements. Since cooling and heating loads in a small, well-built Florida house are correspondingly small, dramatic increases in conditioning equipment efficiency were not warranted. Energy consumers that are not size dependant provide exaggerated savings in these small houses. Building America recommendations took these factors into consideration, stressing appliances and lighting efficiencies followed by hot water heating efficiency measures. Simple "no brainer" envelope improvements were then suggested, including radiant barrier decking and R-38 (in place of R-30) attic insulation. Looking ahead to the launch of the ENERGY STAR for New Homes, Version 3.0, higher efficiency HVAC equipment was recommended.

3.1.6 Construction of Prototype

Following package selection, partners implement the package as soon as possible on their next new home. Partners are encouraged to amend their plans to reflect the energy upgrades selected, and add moisture control details. Researchers conduct a mid-point inspection, carrying out the ENERGY STAR 3.0 Thermal Enclosure System Raters Checklist and as much of the rater's HVAC System Quality Installation Raters Checklist as practical. More training and contractor interface to achieve package goals are carried out as indicated at this time.

If all is well at this point, the next step is final testing and energy ratings. Standard blower door and duct blaster testing are carried out, and when practical, (power to house, AHU functioning) pressure mapping and exhaust fan flow measurements are carried out.

3.1.7 Calculation of Energy Savings

Unless otherwise indicated, all projected annual energy saving calculations were produced using EGUSA with the appliances schedules designated by the 2006 Home Energy Rating System standard (HERS 2006) and thermostat schedules defined in the Building America 2008 Benchmark (BABM08).

3.1.8 Calculation of Cost

Costs are calculated using information provided by the partners on material costs. When available, costs are expressed as incremental costs, the increment being the added cost over code-complaint, or regional standard practice. All houses in this portion of the project are all-electric, Therefore, gas prices are irrelevant. In addition, electric costs are assumed to be $0.13/kWh. Mortgage costs are based on a 30-year, 7% mortgage and are calculated by using the Microsoft Office Excel Payment function. Habitat for Humanity does not charge interest for their homes, and in light of this, results are also shown for a 20 year, 0% mortgage. Detailed calculations are included in Appendix A.

3.2 FSEC New Construction High Performance Affordable Housing Partners

FSEC worked with three partners to build eleven new homes for this project. The results of the eleven homes are summarized in Table 71. The HERS Index achieved by the home and if it was registered under ENERGY STAR Version 2.0 or 2.5 are detailed in the first column. The second column reports the house size; the third column describes the house by number of bedrooms, bathrooms, and size of the garage. If “0 car” is specified, there is no garage.

The time the house was registered determined if the house was verified under ENERGY STAR Version 2.0 or 2.5, but all houses met the modified Version 2.5 criteria outlined in Section 3.1.3, and would have been verifiable under ENERGY STAR 2.5 Guidelines. Two of the homes built additionally qualified for the US DOE’s Builders Challenge.

Table 71. Summary of Completed High Performance New Houses

Habitat for Humanity of Palm Beach County, West Palm Beach, FL		
HERS V2 = 57	1340 ft^2	3 bed, 2 bath, 0 car*
HERS V2.5 = 58	1084 ft^2	3 bed, 2 bath, 0 car
HERS V2.5 = 58	1084 ft^2	3 bed, 2 bath, 0 car
Habitat for Humanity of Hillsborough County, Tampa, FL		
HERS V2 = 67	1164 ft^2	3 bed, 2 bath, 0 car
HERS V2.5 = 67	1164 ft^2	3 bed, 2 bath, 0 car
HERS V2.5 = 64	1164 ft^2	3 bed, 2 bath, 0 car
HERS V2.5 = 64	1164 ft^2	3 bed, 2 bath, 0 car
Habitat for Humanity of Lake-Sumter, Florida, Inc., Eustis FL		
HERS V2 = 66 – Builders Challenge	1100 ft^2	3 bed, 2 bath, 1 car
HERS V2 = 65 – Builders Challenge	946 ft^2	2 bed, 1 bath, 1 car
HERS V2 = 71**	1152 ft^2	3 bed, 1.5 bath, 1 car
HERS V2 = 71**	954 ft^2	2 bed, 1 bath, 1 car

*Floor plan can be built as a 4 bed, 2 bath house
** HERS V2.5 = 67 and 68

3.2.1 Habitat for Humanity of Lake-Sumter Counties. (NC-1,-2,-3,-4)

Serving two counties, Lake and Sumter, in rural North-Central Florida, Lake-Sumter Habitat for Humanity was formed in 1989 and has built over 180 affordable houses. In 2010, the affiliate built 17 houses. Home sizes vary from a 900 ft^2 two bedroom, one bath house to a four bedroom, two bath 1,300 ft^2 home. When the houses are built in the city of Eustis, a garage is required by code. Table 72 provides a snap shot of typical annual energy use, cost, and savings for this partner.

Table 72. Habitat for Humanity of Lake-Sumter Counties, Typical Annual Energy Use, Cost, and Savings for New Construction House NC-1, -2, -3, and -4

HERS Index	78 pre-BA;
Total Cost of Energy Efficiency Measures	$1644
Projected Annual Savings	$177 @ $0.13/kWh
Projected Annual Mortgage Cost	$132 @ 30 years and 7% interest
Projected Annual Mortgage Cost	$82 @ 20 years and 0% interest
Projected Annual Cash Flow	$45 @ 30 Years and 7% interest
Projected Annual Cash Flow	$95 @ 20 Years and 0% interest
Number of Houses	4 out of 6 houses met the criteria for this research
Project Status: Completed	

Six (6) high-performance houses were built during the project time period of fall/winter 2010 to 2011 spring building season. Researchers were not called in time to do a Thermal Bypass inspection on the first two (2) of the six homes built during the project, but the remaining four (4) homes all met the project's criteria (Figures 114-117).

Of the four (4) qualifying houses, two (2) met the Builders Challenge criteria including updated plans reflecting the energy improvements and moisture protection details. These houses were a three bedroom, two bath, 1,100 ft^2 house and a two bedroom, two bath, 946 ft^2 house. The remaining two qualifying houses met the enhanced ENERGY STAR 2.5 criteria and were a two bedroom, one bath, 954 ft^2 house and a three bedroom, one and half bath, 1,152 ft^2 house.

Prior to working with the Building America team, the affiliate built houses that had a SEER 13, HSPF 7.7 heat pump, an electric water heater, no use of CFL or other fluorescent lighting except a fixture in the kitchen, standard ceiling fans, and the donated ENERGY STAR refrigerator. The houses had radiant barrier system (RBS) decking, R-30 attic insulation, R-13 wall insulation, and Version 2.0 ENERGY STAR double-pane windows (SHGC=0.35, U=0.35). The houses had no provision for outside air and did not vent the kitchen range hoods to the outside.

Figures 114-117. Four prototype houses built by HFH of Lake-Sumter counties in Eustis, FL

Working with Building America researchers, the affiliate agreed on a package (shown in Table 73) that increased the attic insulation from R-30 to R-38 while keeping the RBS decking, installing the wall insulation to Residential Energy Services Network (RESNET) Grade I standards, using at least 90% fluorescent lighting, ENERGY STAR ceiling fans, and an ENERGY STAR heat pump (SEER 15.25 HSPF 8.7). The reported costs for these simple changes for the 1,100 ft^2 home were $1640, for an annual mortgage increase (30 years at 7%) of $82/year and a projected energy savings of $291, using $0.13 kWh costs. The net positive yearly cash flow to the homeowner was $209. These changes resulted in the HERS Index going from 83 to 66 (other homes in the project ranged from HERS 68 to HERS 65).

Table 73. Lake Sumter Habitat for Humanity Key Energy Efficiency Measures

Component	Pre- and Post Characteristics
Roof	RBS decking, from a medium roof color to a light color
Attic	From R-30 uninspected to R-38 Grade 1
Cooling/heating	From SEER 13/HSPF 7.7 to SEER 15.25/HSPF 8.7
Windows	From U = 0.35; SHGC = 0.35 to U = 0.34; SHGC = 0.26
Lighting	Default 10% fluorescent to 100% fluorescent
Ceiling fans	From standard to ENERGY STAR
Ducts	From Qn out=0.06 to Qn out=0.03, Qn total = 0.08
Infiltration	From ACH50=6.4/ACH=0.25 to ACH50=5.2/ACH=0.2
Ventilation	From none to return side run-time ventilation (42 CFM)
Spot ventilation	From unvented range hood to vented range hood

The gaps and lessons learned with this partner include:

- The climate in Florida emphasizes an increase in roof and attic insulation over wall insulation.
- Since cooling and heating loads in a small, well-built Florida house are correspondingly small, dramatic increases in conditioning equipment efficiency were not warranted.
- The HFH affiliate was able to achieve the required HERS Index of 70 using relative few, off-the-shelf components and building materials.
- Improved hot water heating was discussed, but the lack of natural gas infrastructure combined with the high cost of solar hot water heating and the unavailability of the new "hybrid" heat pump hot water heaters during the permitting process led to exclusion of efficient hot water heating.

When discussing the results of the project with the construction director of the affiliate, he concluded that in light of the availability of "hybrid" hot water heat pumps, the money spent upgrading his HVAC would have been better spent on a hybrid hot water heater as far as payback to the homeowner. Future new construction undertaken by the affiliate will involve the use of hybrid heat pump water heaters when they cannot take advantage of a recent utility program providing substantial funding for non-profit builders to install solar hot water heating.

This program is dependent on the utility serving the area (Lake and Sumter counties have several utilities, not all are participating in the program).

Local code officials did not allow the affiliate to place the fresh air inlet in the soffit. Instead, the affiliate placed the inlet at the roof deck and did not include an extension on the inlet to raise it above the deck. When a riser was suggested to the affiliate, it was rejected on the grounds of aesthetics. This installation is sub-optimal; the out-gassing of the shingles defeats the purpose of the fresh air inlet by introducing polluted air to the house.

Quoting Construction Manager Sean del Castillo of HFH of Lake-Sumter CO, "Builders Challenge gave me insight into better construction and better practices. Builders Challenge is a good way to make homes more efficient. If you can bring down monthly payments for utilities, that home becomes much more affordable for the homeowner."

3.2.2 Habitat for Humanity of Hillsborough CO, Inc.:(NC-8,-9,-10,-11)

Habitat for Humanity of Hillsborough County, Florida is located in Tampa, Florida and builds houses throughout the Hillsborough County area. Established in 1987, the affiliate has completed over 135 new houses and many retrofits. The affiliate builds several sizes of houses, but all project houses were 3 bedroom/2 bath 1164 ft^2 frame houses with no garages. The affiliate is receiving funding from the HUD's SHOP Program, mandating ENERGY STAR construction on all houses receiving funding. Four houses were built in conjunction with the Building America sponsored project. Two of the four houses are shown in Figures 118-119.


Figures 118-119. Typical Hillsborough HFH homes.

Prior to working with Building America the Hillsborough County Affiliate built houses with R-19 attics, R-13 walls (RESNET Grade 3), Double pane clear vinyl windows (SHGC=0.7, U=0.5), an SEER 13 air conditioner with electric resistance heating, no deliberate use of compact or pin based fluorescent lighting, no fresh air ventilation, combined with a fairly leaky house (ACH50=8.2 ACH=0.36) and moderately tight duct system (Qn out=0.05), with a projected HERS Index of 87 and an annual estimated electric cost of $1223 with electric costs of $0.13/kWh.

Presented with Building America's results from analysis the affiliate agreed on a package of energy improvements including a SEER 14 heat pump (a problem, see lessons/gaps below), R-38 attic insulation, ENERGY STAR windows (problem, see lessons/gaps below), R-15 RESNET Grade I wall insulation with donated R-3 insulated sheathing, over 90% fluorescent lighting, and a donated ENERGY STAR refrigerator. The affiliate opted against RBS decking, and does not install ceiling fans. These details are outlined in Table 74.

Table 74. HFH of Hillsborough CO. Key Energy Efficiency Measures

Component	Pre- and Post Characteristics
Roof	From Medium colored shingles to light or white
Attic	From R-19 to R-38
Walls	From R-13 grade 3 to R-15 Grade 1 and R-3 sheathing
Windows	From U = 0.5; SHGC = 0.7 to U = 0.32; SHGC = 0.28
HVAC	From SEER 13A/C with electric resistance heating to SEER 14 heat pump
Ventilation	From no fresh air to run-time fresh air.
Spot Ventilation	From re-circulating kitchen range hood to range hood vent outdoors.
Ducts	From Qn out=0.05 to Qn out=0.03/Qn total=0.07
Infiltration	From ACH50=8.2, ACH=0.36 to ACH50=5.6, ACH=0.25
Lighting	Over 90% fluorescent
Appliances	No dishwasher, no washer yet, ENERGY STAR refrigerator

These improvements resulted in an estimated energy savings of $346/year for electric costs of $0.13/kWh, and a HERS index of 65. Improvement costs are $2500 (Construction Manager estimate), including $1000 for 100% tile floor, and the cost of the donated R-3 sheathing and ENERGY STAR refrigerator (Table 75). The positive cash flow to the homeowner is estimated to be $145 per year.

Table 75. Habitat for Humanity of Hillsborough County, Typical Annual Energy Use, Cost, and Savings for New Construction House NC8, -9, -10, -11

HERS Index	Pre-BA HERS=87 SEER 13 Prototype HERS=67 and 68 SEER 14 Prototype HERS=64
Total Cost of Energy Efficiency Measures	$2500 SEER 14 (includes $1000 for tile floor)
Projected Annual Savings (HERS 64)	$387 for SEER 13 $421 for SEER 14
Projected Annual Mortgage Cost	$201 for SEER 14 with a 30 year, 7% mortgage
Projected Annual Mortgage Cost	$125 for SEER 14 with a 20 year, 0% mortgage
Projected Annual Cash Flow with 30 year, 7% mortgage	$186 for SEER 13 $220 for SEER 14
Projected Annual Cash Flow with 20 year, 0% mortgage	$262 for SEER 13 $296 for SEER 14

Gaps/Lessons Learned:

- The climate in Florida emphasizes increases in roof and attic insulation over wall insulation.
- Since cooling and heating loads in a small, well-built Florida house are correspondingly small, dramatic increases in conditioning equipment efficiency were not warranted.
- The HFH affiliate was able to achieve the required HERS Index of 70 using relative few, off-the-shelf components and building materials.
- Merely specifying ENERGY STAR components does not insure that buyers and suppliers will follow through. Buyers and suppliers MUST be clear on what specifications are necessary to comply with design requirements. See next paragraph for details.

The original intent of the affiliate was to qualify the houses in the DOE's Builders Challenge program, including updating their house plans to indicate the energy and moisture protection features incorporated into the houses. However, when the affiliate purchased windows for the upcoming year, they specified ENRGY STAR, as per Builders Challenge requirements, but their suppler provided windows that were not ENERGY STAR for the southern climate (supplied windows had SHGC=0.28, requirements for southern climate SHGC=0.27 or lower). This oversight eliminated the affiliate from the Builders Challenge, and it was decided to pursue the enhanced ENERGY STAR 2.5 package outlined in the introduction.

The affiliate also specified SEER 14 heat pumps for all its houses going forward, but when the installed equipment found in the first two houses was examined, and the model numbers were entered into the Air-Conditioning, Heat, and Refrigeration Institute (AHRI) database, it was found that SEER 13 heat pumps were installed. The contractor refused to fill out the HVAC Contractor's Quality Installation Checklist as per ENREGY STAR 2.5, and would not respond to calls from the affiliate. One house was completed and occupied prior to this discovery, yet still met the program's goal of a HERS Index below 70, achieving a HERS Index of 68. The second house built to this specification achieved a HERS Index of 67. The estimated energy savings with this package is $387, with a positive cash flow to the homeowner of $262 using HFH's 20 year, 0% mortgage rate. The houses that used the SEER 14 heat pump achieved a HERS Index of 64, with a projected annual energy savings of $421 and a cash flow to the homeowner of $296

3.2.3 Habitat for Humanity of Palm Beach County: NC-5,-6,-7

Habitat for Humanity of Palm Beach County, FL (HFHPBC), located in West Palm Beach, FL, was formed in 1986 and has since built more than 111 affordable houses. This affiliate has also served an additional 125 families worldwide through their affiliation with HFH International. Despite the very difficult housing market in south Florida, HFHPBC has, over the past three years, increased its housing production from six homes per year to an average of fifteen homes per year and is projecting to serve thirty families per year by the end of 2011 through a combination of new construction and rehabilitation. During the 2011 building season, HFHPBC built three (3) prototype homes in conjunction with Building America. Table 76 shows the typical estimated annual energy use, cost, and savings for these homes.

Table 76. NC-5,-6-7 Energy Use, Cost, and Savings Projections

HERS Index	Pre-BA HERS=84, Prototypes HERS=57
Total Cost of Energy Efficiency Measures	\$1500 (Construction director estimate)
Projected Annual Savings	\$434 @ \$0.13/kWh
Projected Annual Mortgage Cost	\$121 @ 30 years and 7% interest
Projected Annual Mortgage Cost	\$75 @ 20 years and 0% interest
Projected Annual Cash Flow	\$313 @ 30 years and 7% interest
Projected Annual Cash Flow	\$359 @ 20 years and 0% interest

Two different standard designs were built. The larger of the two has 1,340 ft^2 of conditioned space, three bedrooms with a fourth bedroom converted into a den. The other design is a 1,084 ft^2, three bedroom, two bath home. These homes do not have garages; however, they do include an attached unconditioned storage room that also houses the water heater. Figures 120-121 shows these homes.

Figures 120-121. Habitat for Humanity of Palm Beach Co. three bedroom/two bath house.

Prior to partnering with Building America, HFHPBC was building houses with R-30 attics and medium colored shingles, R-13 walls with RESNET Grade II insulation, standard double-pane windows (U=0.48/SHGC=0.64), a SEER 13 A/C with electric resistance heating, tight ducts (Qn out=0.02), a tight shell (ACH50=7.4/ACH=0.19), a standard electric water heater, an ENERGY STAR refrigerator (donation from Whirlpool), approximately 40% fluorescent lighting, and standard ceiling fans.

Based on Building America analysis, the affiliate decided to go forward with a package that included R-38 attic and R-13 wall insulation, RESNET Grade I, ENERGY STAR windows (U=0.34/SHGC=0.26) a SEER 14 A/C with electric resistance heating, tight ducts, a very tight shell (ACH50=2.5/ACH=0.06 due to ENERGY STAR 2.5 sealing details), a hybrid heat pump hot water heater (COP 2.3), over 90% fluorescent lighting, an ENERGY STAR refrigerator, ceiling fans, and a washing machine. Table 77 illustrates these improvements.

Builders Challenge was not pursued, as there was no opportunity to refine the house plans to reflect the required energy and moisture enhancements. The enhanced ENERGY STAR 2.5 path was followed to comply with the Building America program.

Table 77. Project NC5, NC-6, and NC-7 Key Energy Efficiency Measures

Component	Pre- and Post-Retrofit Characteristics
Roof	From medium shingles to light shingles, no RBS
Attic	From R-30 to R-38
Walls	From R-13 Grade 2 to R-13 Grade 1
Windows	From U = 0.48; SHGC = 0.64 to U = 0.34; SHGC = 0.26
HVAC	From SEER 13/electric resistance heating to SEER 14/electric resistance heating
Ducts	No Change, Qn out =0.02
Infiltration	From ACH50=7.4/ACH=0.19 to ACH50=2.5/ACH=0.06
Ventilation	From none to Run-time return fresh air ventilation
Spot Ventilation	From re-circulating kitchen range hood to vented outside
Water Heating	From Standard electric tank to Hybrid Heat Pump Hot Water heater
Lighting	From 45% fluorescent to at least 95% fluorescent
Ceiling Fans	From standard to ENERGY STAR

This affiliate was the only participant in the new construction portion of the project that addressed water heating. Since there was no natural gas available and due to the exorbitant cost of solar hot water heaters, the affiliate chose to use hybrid heat pump hot water heaters (HPHW) (Figure 122, left). The specifications of these units define a certain amount of warm free air space to provide heat for the unit to use. The affiliate builds a small storage space (Figure 123, center) attached to the home that also houses hot water heater. However, these storage spaces are smaller than the required 800 to 1,000 ft^3 that the HPWHs need. To remedy this, the affiliate sheet rocked only a portion of the ceiling in the storage space (Figure 124, right). This construction detail couples the air in the storage unit with the attic to provide access to the required volume of warm air necessary for proper function of the heat pump water heater.

Figures 122-124. The heat pump water heater, HPWH (left) is located inside a small unconditioned room (center) which is connected to the hot attic (right) to provide adequate free air for the proper operation of the HPWH.

The gaps and lessons learned with this partner include:

- For energy efficiency, the climate in Florida responds better to increases in roof reflectance and attic insulation over wall insulation.
- Because cooling and heating loads in small, well-built Florida houses are correspondingly small, dramatic increases in conditioning equipment efficiency were not warranted.
- The HFH affiliate was able to achieve the low HERS Index of 57 using relatively few, off-the-shelf components and building materials.
- Air sealing around the window and door frames and air sealing the top plate to the wallboard with a foam gasket (ENERGY STAR 2.5 requirements) significantly improved the overall air tightness of the home.
- The benign climate of south Florida does not justify a heat pump, as the heating loads are trivial, and the added cost cannot be justified.

3.2.4 Habitat for Humanity of Brevard County, Inc.

Habitat for Humanity (HFH) of Brevard County, Inc., FL was established in 2005 when two affiliates, South Brevard HFH and Space Coast HFH, merged organizations. Up to that point, the two affiliates successfully provided homeownership opportunities to nearly 150 families. Over the first five years as a merged affiliate, Habitat for Humanity of Brevard County, Inc. has provided an additional 120 families housing. The only new construction house that the affiliate was able to start during the project period was located in Cocoa, FL. This four bedroom, two bath, one-car garage, 1,262 ft^2 slab-on-grade frame house is one of many floor plans the affiliate intended to build. Table 78 shows the energy use, cost, and savings anticipated from the improvement package.

Table 78. Estimated Energy Use, Cost, and Savings

Location	Melbourne, FL, serving Brevard Co., FL
Partner	Habitat for Humanity of Brevard County, Inc.
HERS Index	Est. Pre test HERS=85, BA package HERS=55
Total Cost of Energy Efficiency Measures	N/A
Projected Annual Savings	$592 @ $0.13/kWh
Projected Annual Mortgage Cost	N/A
Projected Annual Cash Flow	N/A
Number of Houses	1
Status: Did not implement package	

After several delays and false starts, HFH of Brevard County, Inc. did not appear to be on track to implement any of the efficiency enhancements from the Building America package at project's end. The baseline, as-found specifications are what the affiliate actually built, combined with reasonable estimates of test results. Table 79 enumerates what the affiliate is building and what improvements the BA Package contained.

Table 79. Project Key Energy Efficiency Measures

Component	From As-built to BA Package
Roof	From medium shingles and RBS to light shingles RBS
Attic	From R-30 to R-38
Walls	From R-13 Grade 2 to R-13 Grade 1
Windows	From U = 0.48; SHGC = 0.64 to U = 0.34; SHGC = 0.26
HVAC	From SEER 13/electric resistance heating to SEER 14/HSPF 8.2
Ducts	From Qn out=0.06 to Qn out=0.03
Infiltration	From ACH50=8.3/ACH=0.35 to ACH50=4.8/ACH=0.2
Ventilation	From none to Run-time return fresh air ventilation
Spot Ventilation	From re-circulating kitchen range hood to vented outside
Water Heating	From Standard electric tank to Hybrid Heat Pump Hot Water heater
Lighting	From Default Fluorescent to at least 95% fluorescent
Ceiling Fans	From standard to ENERGY STAR

The gaps and lessons learned with this partner include:

- This affiliate had no grant money or other financial incentive to change what they built.
- Initial analysis results were presented to partners based on $0.12/kWh and used costs generated by Energy Gauge USA's ENERGY STAR Guide. The project results morphed into Energy Gauge USA's Annual Simulation combined with thermostat set-points defined by Building America Benchmark 2008. This change had a profound effect on the results; BA packages now showed significantly higher savings. Sharing these "better" results with the partner during the first analysis may have influenced the affiliate to build a more aggressive package.

3.2.5 Habitat for Humanity in Seminole Co.

This Habitat affiliate came to Building America's attention during their search for assistance with Leadership in Energy and Environmental Design (LEED) certification of a house they were building in conjunction with Seminole State College students. Analysis of the intended design and specifications indicated that the homes would have HERS Index scores in the low 60's and that many of the details of interest in this research would be implemented. When the affiliate discovered that Building America would not provide LEED Certification, a HERS Rater/LEED Certifier was found who would donate these services for publicity received, and Building America's participation in the project ended.

3.3 Analysis of Near Zero Energy New Construction Homes

FSEC tracked the energy use of six new low-energy homes for the period of January - October 2011– a ten month period. Data collection was maintained on three of the homes as part of this project including TW1 and TW2 in Gainesville as well as the KB Home site in Orlando (KBH). Three other homes, NZG and ZEG also in Gainesville, as well as DPR in Cocoa Beach are part of another FSEC project but included here for reference. All of the homes have low energy features and include various amounts of solar PV electric power production. The energy features have been described in previously available reports. Relevant information will be provided below in our depiction of comparative performance.

Within the analysis of incoming data, we were able to see that two of the homes, TW1 in Gainesville and KBH in Orlando, had some trouble with their PV systems. This became obvious by examining the rated PV direct current (DC) system sizes with the output seen from the inverter from other monitored projects which showed better performance. In both projects, we found problems resulting in one PV array string not operating. These were repaired on May 5th, 2011 at TW1 and July 12th at KBH.

Performance over the entire period from April 1 - November 15th, 2011 (Table 80) shows that the TW1, TW2 and DPR sites achieved net zero electricity use over the period – all were net producers.

Table 80. Comparative Performance of Six Monitored Low Energy Homes with Photovoltaics

Total Period: April 1 - November 15, 2011

Parameter	NZG	ZEG	TW1	TW2	KBH	DPR
Use: kWh/d	14.27	30.12	26.25	16.54	56.02	18.04
PV kWh/d	8.91	13.71	28.13	22.56	32.53	21.46
Net kWh/d	1.18	16.41	-1.88	-6.02	23.49	-2.42
Pct Solar%	88%	46%	107%	136%	58%	113%
kWdc (rated)	3.15	4.20	6.75	5.40	8.60	4.92
kWday/kWdc	2.83	3.26	4.17	4.18	3.78	4.36

Table 81 shows the energy end-uses for total, cooling, water heating and other at the six sites.

Table 81. Comparative Energy End Use of Six Monitored Low Energy Homes with Photovoltaics. Total Period: April 1 - November 15, 2011

Parameter	NZG	ZEG	TW1	TW2	KBH	DPR
Total: kWh/d	14.27	30.12	26.25	16.54	56.02	18.04
Cooling: kWh/d	5.85	16.95	14.63	7.82	27.97	5.07
DHW: kWh/d	0.27*	0.07*	0.01*	0.02*	8.80*	3.33*
Other: kWh/d	8.15	13.10	11.61	8.70	18.25	12.97

* Solar primary system

** Gas auxiliary for solar system: 3.33 ft^3/day

The KBH site showed substantially higher electricity loads than the other sites, with only about a 60% solar contribution in spite of having two PV arrays totaling 8.6 kW. Cooling energy use was elevated due to high cooling loads, which averaged 28 kWh per day at this site. The home also had a dedicated energy recovery ventilator (ERV) and dehumidification system that used about 1.0 and 2.5 kWh/day respectively (not included in cooling energy total). During this period, the ERV has operated constantly with the fan on high speed providing an estimated 73 CFM of ventilation air. Water heating loads were also high at KBH at 8.80 kWh/day, given that a solar water heating system is present; this may be due to the water recirculation system, which should perhaps be further examined.

The NZG site in Gainesville showed very low consumption and nearly a 90% solar fraction with a small 3.1 kW west facing PV array.The ZEG site in Gainesville showed the poorest performance, in large part due to a poorly functioning ground source heat pump that is slated for replacement in the summer of 2012.

A closer look at the repair of the disabled Inverter 2 string at the KB Home on July 12th and another inverter string at the TW1 home on May 5th is apparent in the collected data of Figures 125 and 126, respectively.

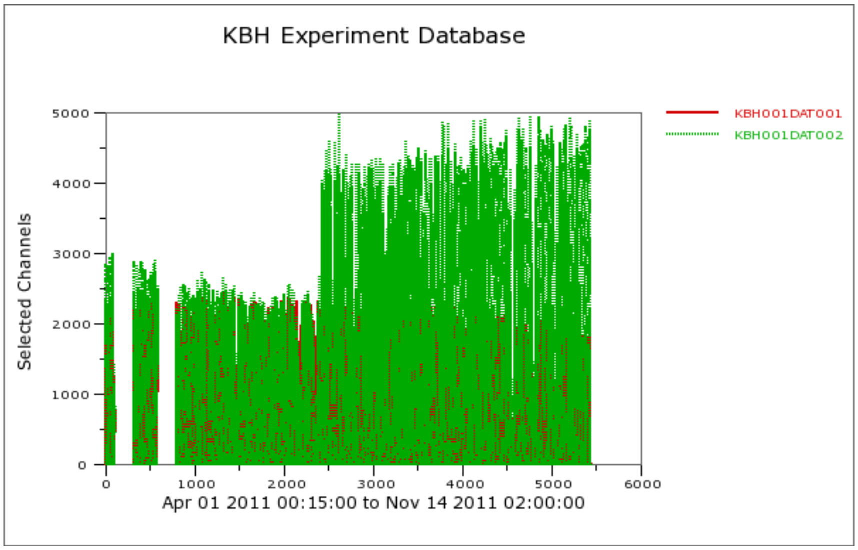


Figure 125. Measured inverter 1 (red) and inverter2 (green) output at KB Home site showing the impact of the string repair on July 12th. Some missing data is seen in April and May.

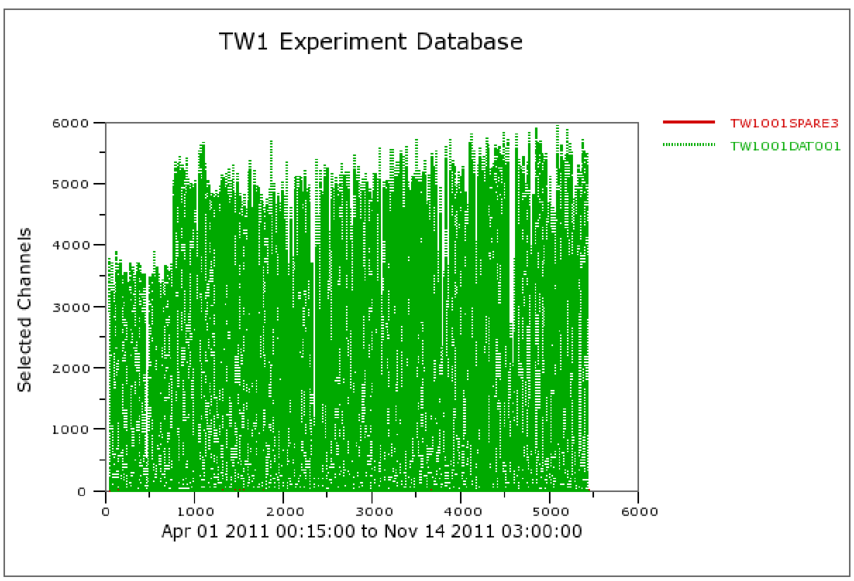


Figure 126. TW1 showing the impact of repairing an inoperable string on May 5th.

Table 82 shows the numbers before the PV system repair for April of 2011 in all six sites.

Table 82. Comparative Performance of Six Monitored Low Energy Homes with Photovoltaics

Total Period: April, 2011

Parameter	NZG	ZEG	TW1	TW2	KBH	DPR
Consumed kWh/d	9.58	21.89	21.78	13.37	39.15	14.10
PV kWh/Day	9.95	15.91	23.32	25.27	32.62	24.77
Net kWh/Day	-0.37	5.98	-1.54	-12.20	6.53	3.51
Percent Solar	104	73	107	192	83	176
kWdc (rated)	3.15*	4.20*	6.75	5.40	8.60	4.92
kWday/kWdc	3.16	3.79	3.45	4.68	3.79	5.03
kWh/day, POA	22.28	23.58	21.18	23.35	25.67	25.82

The data for April is interesting, as it shows a month where space conditioning loads are minimized in Central Florida. The plane of array (POA) irradiances indicate some issue with the NZG and ZEG sites unless the pyranometer is not well representing array shading from trees (likely given site evaluation). The POA irradiance for the KBH site (with east and south facing PV arrays) is the average of the east and south pyranometers. The Cocoa Beach and KBH sites had particularly greater solar irradiance in April. In Table 83, we show the same comparative indexes for August 2011 after TW1 and KBH were repaired with data for the hottest summer month of the year:

Table 83. Comparative Performance of Six Monitored Low Energy Homes with Photovoltaics

Total Period: August, 2011

Parameter	NZG	ZEG	TW1	TW2	KBH	DPR
Consumed kWh/d	18.33	38.67	36.43	26.44	56.45	23.21
PV kWh/Day	9.00	13.99	29.13	21.61	34.20	19.70
Net kWh/Day	4.40	24.68	7.30	4.83	22.25	3.51
Percent Solar	49	36	80	82	61	85
kWdc (rated)	3.15*	4.20*	6.75	5.40	8.60	4.92
kWday/kWdc	2.85	3.33	4.31	4.00	3.98	4.00
kWhday, POA	19.41	19.53	17.43	20.60	19.82	20.37

Note the improvement in the August data seen for the TW1 and KBH sites in terms of kWh per kWdc nominal installed capacity. The other sites show lower output in August, as expected, given the impact of higher temperatures on PV system performance. Localized cloud cover and roof tilt and orientation also figure into these values, as April was more clear than August, and the all sites had considerably greater irradiance.

Note that the TW1 home now has the highest output in kWh/day against the installed DC-rated nominal wattage of the system. The NZG and ZEG sites are also in Gainesville but are west facing arrays with some site shading showing a 20-30% reduction to output relative to the south facing arrays. The DPR site in Cocoa Beach showed the lowest electrical loads, mainly due to a high efficiency mini-split heat pump being used for cooling.

The regression analysis of Figure 127 shows collected data for three of the homes. The KBH site has large measured space cooling that suggests large loads due in part to the dedicated ERV and dehumidification system given that consumption barely drops in response to cooler outdoor temperatures. TW1 and TW2 show roughly comparable cooling efficiencies with TW1 looking to be about 10% lower. However, both sites show cooling levels that are low and quite good compared with conventional practice homes.

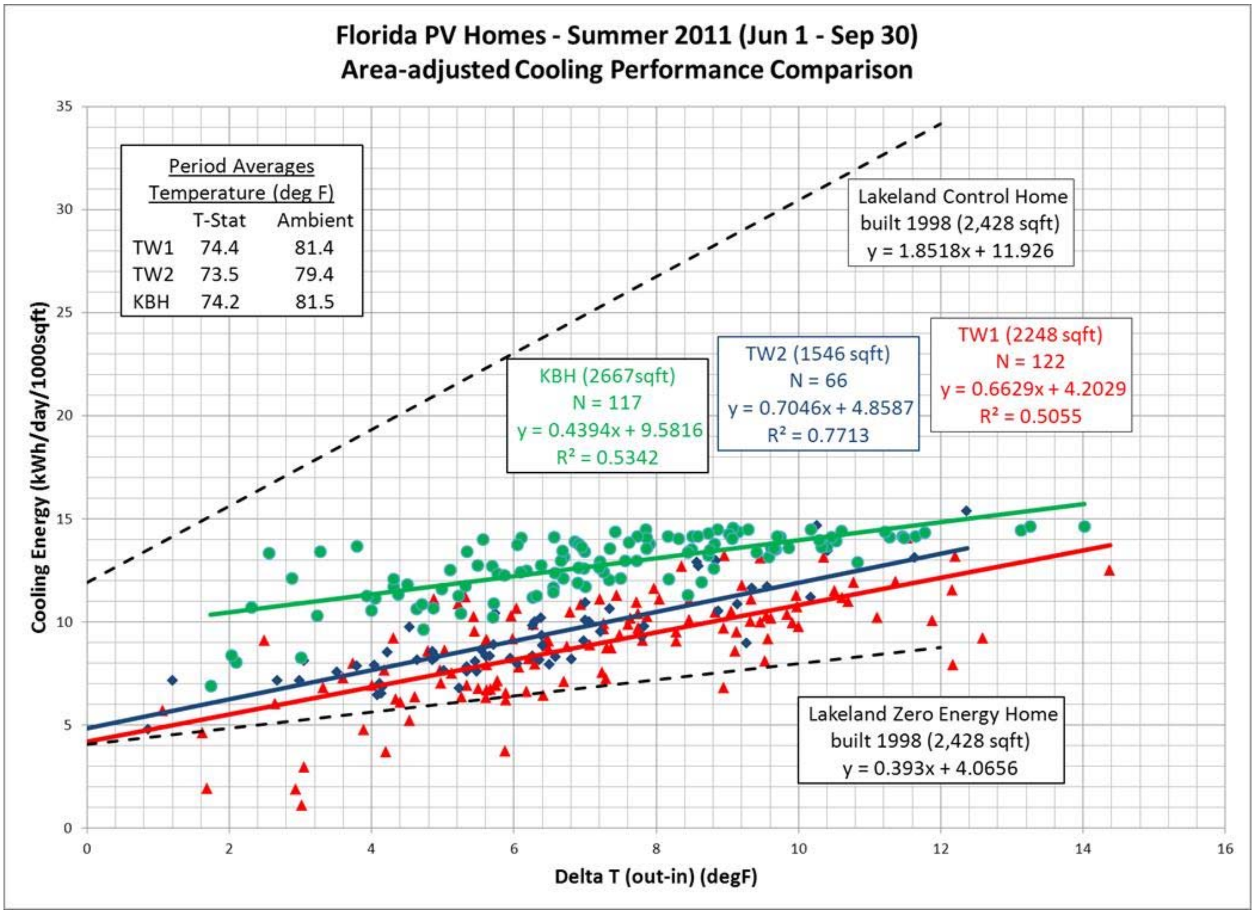


Figure 127. Area-adjusted cooling performance comparison of TW1, TW2 and KBH homes

Lakeland data is all during occupied periods, the same as referenced in the 2006 BA paper.

4 Task 3: Analysis Support

This task was added to the scope of work in November, 2011 to provide data analysis assistance of indoor air conditions in 13 homes as well as utility billing data collected by FSEC and other PNNL subcontractors. Indoor temperature and relative humidity data was collected in ten Builder's Challenge homes in Gainesville, Florida. Fifteen minute readings were collected from these homes with Hobo dataloggers from March of 2011 and summarized into plots showing the range and mean on a monthly basis. The three zero energy homes (TW1, TW2, KBH) analyzed in task 2 were also included. Plots for all homes can be found in Appendix C.

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Appendix A – Parametric Analysis for Deep Retrofit Candidates

After a detailed pre-retrofit energy audit, researchers create an annual energy use simulation model for the purpose of evaluating efficiency improvement measures. Analysis for 18 of the deep energy retrofit candidates are included here.

The characteristics and condition of the as-found home heavily influence the potential impact of each improvement. Characteristics of energy related components of the house are shown in the first column of each table in Appendix A. The second column lists the individual measures that make up the whole house efficiency improvement package.

The analysis process begins with evaluation of each measure individually. To accomplish this, researchers run the annual energy use simulation many times, each time changing only one element (each one listed in the second column). The simulation results for each alternative specification are compiled and compared to those for the as-found house. The comparative results for each measure are shown in the set of columns starting in the third column and moving to the right. These results help partners compare the value of competing improvements. For example, the results can be used to compare the relative impact of higher performance windows compared to the addition of wall insulation.

Initially, the analysis includes a longer list than presented in these analysis tables which include only the measures in the mutually agreed upon package of improvements. These individual results cannot be combined in an algebraic fashion because of interactions among the measures. For example, a higher efficiency refrigerator generates less heat which reduces the cooling load but increases the heating load. The change in conditioning loads affects the impact of higher efficiency air conditioning and heating equipment. The implemented (for completed projects) or recommended (for all other projects) improvement measures are combined into a single, improved version of the as-found house. The results of the whole package simulation are compared to the original as-found condition of the house.

The cost and savings of improvements are shown in two ways: full cost of the improvement and/or incremental cost of higher efficiency specifications. Incremental cost is the difference between replacement of an item with the same thing. For example, if replacing a standard efficiency electric water heater with a heat-pump water heater, the incremental cost is the difference between another standard unit and the heat pump unit. In the case of mechanical systems, the incremental cost of a higher efficiency specification is calculated in comparison to a SEER 13 system since an equal replacement for units with efficiency lower than that is not available.

In 2011, the Residential Energy Services Network (RESNET) amended the *2006 Mortgage Industry National Home Energy Rating Systems Standards* (RESNET, 2011) to use the full cost and full savings for evaluating the finance of energy improvements through mortgage instruments. This approach readily applies to improvements made at the time of sale. For other situations, such as making a higher efficiency choice t the time of equipment replacement, the incremental cost and savings approach has more relevance. Both are included here when possible.

In some cases, both full cost and incremental are available. In other cases, partners have provided only incremental costs. Partner provided cost data originates from several types of sources. Some of our local government housing authority partners, contractor payment is based on the bid selected for the job, regardless of the contractors actual cost to do the work. Non-profit housing providers may receive discounts, donations, or other consideration that would not be a reflection of the general market. Additionally, the Habitat for Humanity projects may involve volunteer labor that reduces the cost of implementation.

In all cases, the reported costs should be considered representative of a range and not absolute, replicable costs. In addition to these issues, simply acquiring cost data from partners is challenging. For example, construction staff within a partnering organization are not involved with actual payments and do not have ready access to invoices for materials and services. Staff in the business office may be reluctant to share sensitive information so cost may be related in the form of an email or simple summary (second source) rather than copies of invoices (primary source). Sub-contractors also are reluctant to share sensitive cost information since that may be valuable to competitors.

Even when primary source material can be acquired, it is not necessarily straight forward. Energy measures that researchers view as individual improvements are grouped together on invoices, sometimes with unrelated charges. The cost of replacing a duct system is combined with the total cost of the mechanical system change out, which may also include cost and installation of bath fans, repair of concrete condenser slabs, etc. The cost of ENERGY STAR ceiling fans may be lumped together with the rest of the lighting package. Partners do regularly acquire estimates for specific houses. However, that is usually done after the scope of work has been set, including design decisions and specifications, diminishing the opportunity for evaluation of design alternatives. Sometimes contractors are paid on the basis of their estimate or quote, regardless of whether the job actually costs more or less to complete. Researchers recognize that some of these challenges have to do with the nature of our public sector partners' requisition and purchasing procedures.

Researchers have worked with costs reported from dozens of renovations conducted under other funding to produce cost estimates for items commonly included in improvement packages. Those numbers are used for estimating payback during the planning phase with partners. Ultimately, however, the actual costs for a particular house may have no resemblance to these estimates because of location, market conditions, characteristics of the house, discounts, and a host of other factors. Where necessary, researchers have exercised professional judgment to assess both full cost and incremental cost for higher efficiency options.

To facilitate comparison of projects, the annual energy cost calculations were made using a standard utility rate of $0.13 per kWh. The actual utility rates varied both higher and lower than this assumed rate. Unless otherwise indicated, all projected annual energy saving calculations were produced using EGUSA with the appliance schedules designated by the 2006 Home Energy Rating System standard (HERS 2006) and thermostat schedules defined in the Building America Benchmark procedure.

Retrofit Candidate EH-02 - 1250 ft², 1960 Built, 3 bed, 2 bath, Block construction; $0.11.5/kWh

Home Components	As Found	Minimal Improvement	Actual Retrofit	Total First Costs	Incremental First Costs for Higher Efficiency	Change in HERS Index over Minimal	Annual Incre-mental Savings over
Roof	Dark colored asphalt shingles (Solar absp = 0.92)		Replaced with white asphalt (Solar absp = 0.75)	$6,200	$0	-3	$19
Ceiling Insulation	Batt insulation; R-9		912 ft² blown, R-30	$456	$456	-9	$93
Exterior Walls	White colored block walls (Solar absp = 0.40); 3 frame walls, no insulation		R-11 in 3 frame walls	$67	$67	-5	$57
Windows	(10) Single, clear, metal frame (U = 1.20; SHGC = 0.80)		Replaced with low-E (U = 0.65; SHGC = 0.35)	$3,600	$1,080	-7	$78
Doors	(2) Wood doors; (1) jalousie; Front storm		(3) Insulated doors; (1) Front storm	$930	$0	-1	$3
Floors	100% concrete (flooring removed)		30% Carpet/60% Laminate/ 10% Tile			2	-$30
Whole House Infiltration[1]	Large holes in envelope (Default ACH50 = 22); No ventilation system		Improved home infiltration (ACH50 = 12.2); Still quite leaky	$1,614	$0	-10	$117
Heating and Cooling System	Older unit, Efficiency Est. 10 SEER; 3 ton Strip Heat	13 SEER Strip Heat COP = 1	Installed 15 SEER , 3 ton Heat Pump; HSPF = 8.7	$4,275	$1,000	-37	$436
Air Distribution System	Qn,out = Qn,tot (no depressurizing) 0.30; Ducts Est. R-4.2		High duct leakage (Qn,out = 0.10)	$0	$0	-12	$175
Supply/Return/AHU Locations	Attic/Interior/Interior						
Water Heating System	50 gal, electric, 10+years (Est. EF = 0.88)		40 gal, electric; EF = 0.92	$598	$0	-1	$10
Refrigerator	Kitchen torn out. Defaulted appliances		Replaced with 416 kWh/yr	$749	$50	-3	$47
Lighting	15 fixtures; 0 CFLs		80% + CFLs	$108	$108	-5	$124
Fans	No fans		Installed non ENERGY STAR fans	$500	$0	-4	-$35
Controls	No programmable thermostat						
Costs Totals				$19,097	$2,761	No Sum[2]	No Sum[2]
HERS Index	177	160	85				
Annual Simulation kWh (BABM08)	18,412	17,116	10,998				
Annual MBtu Usage (BABM08)	62.8	58.4	37.5				
Annual Energy Cost (BABM08)	$2,393	$2,225	$1,431				

Actual Retrofit Costs & Savings	Full Cost & Full Savings (As Found vs. Actual)	Incremental Cost & Incremental Savings (Minimal vs. Actual)
HERS Index Improvement (%)	52%	47%
Annual Energy Cost Savings ($)	$962	$794
Annual Energy Cost Savings (%)	40%	36%
Improvement Costs	$19,097	$2,761
Monthly Mortgage	$128	$19
Monthly Energy Cost Savings	$80	$66
Monthly Cash Flow	-$48	$48
Simple Payback (years)	20	3

Footnotes:

[1] Installation of a runtime vent is a health/safety/durability measure that does not improve energy efficiency.

[2] The incremental changes are interrelated and can not be summed to determine the overall HERS index improvements.

Retrofit Candidate EH-03 - 1373 ft^2, 2003 Built, 3 bed, 2 bath, Frame construction; $0.13/kWh

Home Components	As Found	Minimal Improvement	Actual Retrofit	Total First Costs	Incremental First Costs for Higher Efficiency	Change in HERS Index over Minimal	Annual Incre-mental Savings over Minimal
Roof	White colored asphalt shingles (Solar absp = 0.75)						
Ceiling Insulation	Batt insulation; R = 19		R = 38	$391	$391	-5	$54
Exterior Walls	Medium color (Solar absp = 0.60); R = 11; (1) wall R = 1		One insulated wall insulated R = 13	$30	$30	-1	$4
Windows	(10) Single, clear, metal frame (U = 1.20; SHGC = 0.80)						
Doors	(2) Insulated doors						
Floors	100% laminate						
Whole House Infiltration[1]	Moderate infiltration (ACH50 = 5.9); No ventilation system		Essentially unchanged (ACH50 = 6.26); Installed 44CFM runtime vent	$250	$250	0	-$14
Heating and Cooling System	12 SEER; 2.5 ton Heat pump; HSPF est. 6.8	No Change					
Air Distribution System	Qn,out = 0.047; Ducts R = 6						
Supply/Return/AHU Locations	Attic/Interior/Interior						
Water Heating System	50 gal, electric (EF = 0.88)		Heat pump water heater (COP = 2.35)	$1,500	$1,100	-7	$183
Refrigerator	Default efficiency (old ENERGY STAR, no longer listed)		ENERGY STAR (378 kWh/yr)	$650	$50	-4	$66
Lighting	10% CFLs		80 %CFLs	$425	$425	-6	$145
Fans	5 ceiling fans						
Controls	No programmable thermostat						
Total Improvement Cost				$3,246	$2,246	No Sum[2]	No Sum[2]
HERS Index	**97**	**97**	**75**				
Annual Simulation kWh	**12,773**	**12,773**	**9,421**				
Annual MBtu Usage	**43.6**	**43.6**	**32.2**				
Annual Energy Cost (BABM08)	**$1,656**	**$1,656**	**$1,225**				

Actual Retrofit Costs & Savings	Full Cost & Full Savings (As Found vs. Actual)	Incremental Cost & Incremental Savings (Minimal vs. Actual)
HERS Index Improvement (%)	**23%**	**23%**
Annual Energy Cost Savings ($)	**$431**	**$431**
Annual Energy Cost Savings (%)	**26%**	**26%**
Improvement Costs	**$3,246**	**$2,246**
Monthly Mortgage	**$22**	**$15**
Monthly Energy Cost Savings	**$36**	**$36**
Monthly Cash Flow	**$14**	**$21**
Simple Payback (years)	**8**	**5**

Footnotes:

[1] Installation of a runtime vent is a health/safety/durability measure that does not improve energy efficiency.

[2] The incremental changes are interrelated and can not be summed to determine the overall HERS index improvements.

Retrofit Candidate EH-04, 1040 sqft, 1981 Built, 3 bed, 2 bath, Block construction; $0.13/kWh

Home Components	As Found	Actual Retrofit	Incremental Costs for Energy Improve-ments	Change in HERS Index over As Found	Annual Incre-mental Savings over Minimal
Roof	Light colored asphalt shingles (Solar absp = 0.80)				
Ceiling Insulation	Batt insulation; R = 19	Installed 14+ Inches of Loose Fill F.G. Grade 1	$702	-8	$82
Exterior Walls	Light colored block walls (Solar absp = 0.50); 4 Block walls R-3; 1 Frame wall R-11				
Windows	(5) Single, clear, metal (U = 1.20; SHGC = 0.80); (3) Double, tinted, metal (U = 0.65; SHGC = 0.67)	Installed new Energy Star windows (U = 0.51; SHGC = 0.25)	$1,283	-10	$97
Doors	(3) Insulated doors				
	(2) storm doors				
Floors	100% concrete (flooring removed)				
Whole House Infiltration[1]	Default ACH50 = 11; No ventilation system	Reduced ACH50 = 9.27; No ventilation system	n/a	0	$16
Heating and Cooling System	Older unit, Est. 9 SEER; 2 ton	Installed 13 SEER; 2 ton A/C	$2,597		
	Gas Furnace AFUE = 0.68	Heat Pump HSPF 7.7		-20	$277
Air Distribution System	Qn,out 0.32; Ducts Est. R = 4.2	Reduced Duct Leakage; Qn out = 0.046	n/a	-16	$207
Supply/Return/AHU Locations	Attic/Interior/Interior				
Water Heating System	40 gal, electric (Est. EF = 0.88)				
Refrigerator	Kitchen torn out. Defaulted appliances	Installed Energy Star Refrigerator	$719	-5	$57
Lighting	8 fixtures; 2 CFLs	9 fixtures; 100% CFL's	$9	-7	$113
Fans	2 fans; default efficiency	Installed 2 new fans for a total of 4; default efficiency			
Controls	No programmable thermostat				
Costs Totals			$5,310	No Sum[2]	No Sum[2]
HERS Index	**132**	**78**			
Annual kWh	**11,920**	**7,750**			
Annual Therms	**106**	**0**			
Annual MBtu Usage	**51.3**	**26.5**			
Annual Energy Cost	**$1,733**	**$1,008**			
Costs and Cash flow changes..	**As Found vs. Actual Retrofit - Full cost**	**As Found vs. Actual Retrofit - Incremental Cost**			
% HERS Index Improvement		**41%**			
Annual Energy Cost Savings		**$725**			
% Energy Cost Savings		**42%**			
Improvement Costs	Full Costs Not Available for this project	**$5,310**			
Monthly Mortgage		**$36**			
Monthly Energy Savings		**$60**			
Monthly Cash Flow		**$25**			
Simple Payback (years)		**7**			

Footnotes:

[1] Installation of a runtime vent is a health/safety/durability measure that does not improve energy efficiency.

[2] The incremental changes are interrelated and can not be summed to determine the overall HERS index improvements.

Retrofit Candidate EH-06 - 1583 sqft, 1962 Built, 3 bed, 2 bath, Block construction with Frame Enclosure; $0.13/kWh

Home Components	As Found	Minimal Improvement	Actual Retrofit	Total First Costs	Incremental First Costs for Higher Efficiency	Change in HERS Index over Minimal	Annual Incre-mental Savings
Roof	Light colored asphalt shingles (Solar absp = 0.80)						
Ceiling Insulation	Batt & Blown insulation; R-11		Blown fiberglass flat section (1298sf) R-38	$450	$450	-6	$74
Exterior Walls	Light colored block walls (Solar absp = 0.50); Block walls R-1; 1 Frame wall R-11						
Windows	(10) Single, clear, metal (U = 1.20; SHGC = 0.80); (1) Single, tinted, metal (U = 1.20; SHGC = 0.70)		Replaced with ENERGY STAR (U = 0.30; SHGC = 0.29)	$3,459	$1,155	-9	$160
Doors	(1) Insulated door; (2) Wood doors		Installed Insulated door	$167	$0	0	$0
Floors	100% Tile						
Whole House Infiltration[1]	ACH50 = 16.3; No ventilation system		Reduced infiltration ACH50 = 6.23	$32	$32	-6	$115
Heating and Cooling System	12 SEER; 3 ton	Worse than existing, no change	14 SEER; 2.5 ton	$1,345	$680	-5	$174
	Heat Pump; est. 6.8 HSPF		Strip Heat (COP = 1)				
Air Distribution System	Est. Qn,out 0.13; Ducts Est. R = 6.0		Tight duct system; Qn,out 0.033	$782	$782	-5	$82
Supply/Return/AHU Locations	Attic/Interior/Interior						
Water Heating System	40 gal, electric (Est. EF = 0.88)		40 gal, electric (EF = 0.92)	$475	$0	-1	$19
Refrigerator	Default efficiency		ENERGY STAR 383 kWh/yr	$847	$50	-2	$62
Lighting	11 fixtures; 0 CFLs		12 of 14 fixtures with CFLs	$310	$310	-7	$193
Fans	fans; default efficiency						
Controls	No programmable thermostat						
Costs Totals				$7,867	$3,459	No Sum[2]	No Sum[2]
HERS Index	**117**	**117**	**76**				
Annual Simulation kWh (BABM08)	**16,077**	**16,077**	**10,450**				
Annual MBtu Usage (BABM08)	**54.9**	**54.9**	**35.7**				
Annual Energy Cost (BABM08)	**$2,091**	**$2,091**	**$1,360**				

Actual Retrofit Costs & Savings	Full Cost & Full Savings (As Found vs. Actual)	Incremental Cost & Incremental Savings (Minimal vs. Actual)
HERS Index Improvement (%)	**35%**	**35%**
Annual Energy Cost Savings ($)	**$731**	**$731**
Annual Energy Cost Savings (%)	**35%**	**35%**
Improvement Costs	**$7,867**	**$3,459**
Monthly Mortgage	**$53**	**$23**
Monthly Energy Cost Savings	**$61**	**$61**
Monthly Cash Flow	**$8**	**$38**
Simple Payback (years)	**11**	**5**

Footnotes:

[1] Installation of a runtime vent is a health/safety/durability measure that does not improve energy efficiency.

[2] The incremental changes are interrelated and can not be summed to determine the overall HERS index improvements.

Retrofit Candidate EH-07 - 1608 ft^2, 1964 Built, 4 bed, 2 bath, Block construction; $0.13/kWh

Home Components	As Found	Minimal Improvement	Actual Retrofit	Total First Costs	Incremental First Costs for Higher Efficiency	Change in HERS Index over Minimal	Annual Incre-mental Savings
Roof	Light colored asphalt shingles (Solar absp = 0.80)						
Ceiling Insulation	Batt insulation; degraded R-11 (R-9)		Blown fiberglass flat section (1320sf) R-38	$450	$450	-9	$119
Exterior Walls	Light colored block walls (Solar absp = 0.50); R-1						
Windows	(17) Single, clear, metal (U = 1.20; SHGC = 0.80)		Replaced with EnergyStar (U = 0.30; SHGC = 0.29)	$3,555	$1,187	-13	$172
Doors	(3) Wood doors		Replaced (2) doors - Insulated	$330	$0	0	$1
Floors	70% Carpet/20%Tile/10% Vinyl		20% Tile/ 80% Vinyl	$1,313	$0	-1	$6
Whole House Infiltration[1]	Default ACH50 = 11.5; No ventilation system		Reduced infiltration ACH50 = 7.22	$21	$21	-2	$58
Heating and Cooling System	10 SEER; 3.5 ton Strip Heat; COP = 1	13 SEER; 24 ton Strip Heat; COP = 1	No improvement over minimal				
Air Distribution System	Default Qn,out 0.13; Ducts Est. R-4.2		Replaced ducts; Qn,out 0.057; R-6	$640	$640	-6	$78
Supply/Return/AHU Locations	Attic/Interior/Interior						
Water Heating System	40 gal, electric (Est. EF = 0.89)		40 gal, electric; EF = 0.92	$475	$0	-1	$15
Refrigerator	Default efficiency		EnergyStar 383 kWh/yr	$847	$50	-3	$56
Lighting	13 fixtures; 0 CFLs		80% CFLs	$219	$219	-6	$170
Fans	None		Non EnergyStar fans	$73	$0	-2	-$92
Controls	No programmable thermostat						
Costs Totals				$7,923	$2,567	No Sum[2]	No Sum[2]
HERS Index	**136**	**121**	**85**				
Annual Simulation kWh (BABM08)	**17,386**	**15,870**	**11,628**				
Annual MBtu Usage (BABM08)	**59.3**	**54.2**	**39.7**				
Annual Energy Cost (BABM08)	**$2,260**	**$2,063**	**$1,511**				

Actual Retrofit Costs & Savings	Full Cost & Full Savings (As Found vs. Actual)	Incremental Cost & Incremental Savings (Minimal vs. Actual)
HERS Index Improvement (%)	38%	30%
Annual Energy Cost Savings ($)	$749	$552
Annual Energy Cost Savings (%)	33%	27%
Improvement Costs	$7,923	$2,567
Monthly Mortgage	$53	$17
Monthly Energy Cost Savings	$62	$46
Monthly Cash Flow	$9	$29
Simple Payback (years)	11	5

Footnotes:

[1] Installation of a runtime vent is a health/safety/durability measure that does not improve energy efficiency.

[2] The incremental changes are interrelated and can not be summed to determine the overall HERS index improvements.

Retrofit Candidates EH-08, EH-09, EH-10, and EH-11, 853 ft^2, 2 bed/1 bath, quad-plex

Home Components	As Found	Proposed	Change in HERS	Annual Energy Cost Savings BABM08
Roof	N/A	N/A		
Ceiling Insulation	N/A	N/A		
Exterior Walls	Light colored block walls (Solar absp = 0.50); Block walls R-1; 1 Frame wall R-11	repair stucco, paint		
Windows	(4) Single, clear, metal (U = 1.20; SHGC = 0.80);	Replace windows with ENERGY STAR glass (U=0.6/SHGC=0.27)	-14	$115
Doors	(1) Insulated door; (1) Sliding Glass Door (SHGC=0.8, U=1.2)	ENERGY STAR SGD	-11	$86
Floors	Wall-to-wall except bath and kitchen vinyl	100% tile	-10	$59
Whole House Infiltration[1]	CFM50 = 1033 ACH(est.)=0.36	reduced ACH(est)=0.25	-1	$31
Heating and Cooling System	Old A/C, SEER 8	SEER 16	-52	$469
	Strip heat	HSPF 8.8		
Air Distribution System	old, leaky, Qn = 0.30 or higher	Qn=0.03	-21	$265
Supply/Return/AHU Locations	All interior due to construction	same		
Water Heating System	30 Gal electric tank,interior	40 gal ef = 0.93	-1	$10
Refrigerator	Standard	ENERGY STAR(400kWh/YR)	-6	$64
Lighting	Incandesent	ENERGY STAR	-11	$138
Fans	N/A	3 ENERGY STAR	-8	-$51
Controls	Standard	Standard		
Costs Totals		$0	No Sum[2]	No Sum[2]

HERS and Annual Energy Changes over As Found

	As Found	Proposed
HERS Index	**166**	**73**
HERS Index Improvement	**93**	
% HERS Index Improvement		
Annual MBtu Usage		
Annual Simulation kWh (BABM08)	**14044**	**6721**
Annual Energy Cost (BABM08)	**$1,827**	**$875**
Annual Energy Cost Savings	**$952**	
% Energy Cost Savings	**52%**	

EH-12 Lakehurst St., Lakeland, Fl.

1432 sqft (test-in) 1756 sqft (test-out), 1950 Built, 3 bed, 2 bath, Block construction; $0.13/kWh

Home Components	As Found	Minimal Improvement	Actual Retrofit	Partner Reported Costs	Costs for Energy Improve-ments	Change in HERS Index over Minimal
Roof	Light colored asphalt shingles (Solar absp = 0.8)		New roofing, including modified bitumen flat roofing, no color specified			
Ceiling Insulation	Uninspected; 542sf est. R = 11; 890sf est. R = 19		R-30			-3
Exterior Walls	Light colored block walls (Solar absp = 0.55); Block walls R-1		Paint			
Windows	(12 + Jalousie window in door) Single, clear, metal (U = 1.20; SHGC = 0.80)		Low-E (SHGC=0.25, U=0.51)			-9
Doors	(1) Wood door; (1) Jalousie		Metal insulated w storm door			-1
Floors	90% Wood or Vinyl; 10% Tile		Same			
Whole House Infiltration[1]	Exceptionally leaky; ACH50 = 33.9; No ventilation system		Tighten ACH50 =16.4			-19
Heating and Cooling System	3 A/C Room units; 12 kBtu/hr; EER ~ 9	13 SEER	SEER 15			-34
	3 Portable resistance heaters; 5 kBtu/hr	Strip Heat; COP = 1	HSPF 8.7			
Air Distribution System	Ductless	Default leakage	Qn = 0.054			-6
Supply/Return/AHU Locations	N/A	Attic/Interior/Interior	Attic/Interior/Interior			
Water Heating System	30 gal; EF = 0.88		40 Gal; EF = 0.93			-1
Refrigerator	2 @ Default efficiency		Same			
Lighting	15 fixtures; 80% CFLs		100% CFL			-1
Fans	fans; default efficiency		ENERGY STAR			-1
Controls	N/A		Standard			
Add 324 sqft conditioned area (1 bedroom)		Add 1 bedroom	Add 1 bedroom			
Costs Totals						No Sum[2]
HERS Index	146	155	92			
Annual Simulation kWh (BABM08)	21,789	23,966	15,212			
Annual MBtu Usage (BABM08)	74.4	81.8	51.9			
Annual Energy Cost @ $0.13 kWh	$2,832	$3,116	$1,978			

Actual Retrofit Costs & Savings	Full Cost & Full Savings (As Found vs. Actual)	Incremental Cost & Incremental Savings (Minimal vs. Actual)
HERS Index Improvement (%)	37%	41%
Annual Energy Cost Savings ($)	$854	$1,138
Annual Energy Cost Savings (%)	30%	37%
Improvement Costs	$0	$0
Monthly Mortgage	$0	$0
Monthly Energy Cost Savings	$71	$95
Monthly Cash Flow	$71	$95
	0	0

Footnotes:

[1] Installation of a runtime vent is a health/safety/durability measure that does not improve energy efficiency.

[2] The incremental changes are interrelated and can not be summed to determine the overall HERS index improvements.

EH-14 1962 sq ft, Year Built 1951, 4 bed, 3 bath, block construction; $0.13/kWh

Home Components	As Found	Actual Retrofit	First Cost	Change in HERS	Annual Energy Cost Savings
Roof	Medium colored asphalt shingles (Solar absp = 0.85)	No change			
Ceiling Insulation	Batt & Blown insulation; Est. R 12	Roof deck insulation R 20[3]		-8	$89
Exterior Walls	No cavity insulation	Install Fi Foil on interior R 4.2		-4	$47
Exterior Walls	Standard Block Wall	Foam fill block core (U=0.204)		-3	$34
Exterior Walls	White colored block walls (Solar absp = 0.40 and 0.75)	Elastomeric finish (white) on ext. (Solar absp = 0.40)		-1	$9
Windows	(11) Double, clear, metal (U = 0.8; SHGC = 0.70)	Replace with ENERGY STAR (U = 0.29; SHGC = 0.21)		-15	$170
Glazing Area	Glass/Floor Area = 0.191	No change			
Doors	(2) Insulated doors w/windows; (1) Wood	No change			
Floors	30% Carpet/ 44% Tile/ 26% Vinyl	15% Carpet/ 85% Tile		-1	$9
Whole House Infiltration	Est. worst case: ACH50 = 22; No ventilation system	Improved infiltration, new windows and attic enclosure (ACH50 = 1.99)		-7	$85
Heating and Cooling System	10.2 EER; 4 ton	No change			
	COP = 4.0				
Air Distribution System	Qn,out 0.17[2]; Ducts Est. R = 4.2	Internal duct system Qn,out = 0.006		-12	$143
Supply/Return/AHU Locations	Attic/Interior/Interior	Interior/Interior/Interior			
Water Heating System	50 gal, gas (EF = 0.58); Garage	Tankless gas system (EF = 0.82)		-7	$262
Refrigerator	Default efficiency	No change			
Lighting	16 fixtures; 5 CFLs	61.3% CFL's		-3	$65
Fans	5 fans; default efficiency	6 Fans; default efficiency			
Controls	No programmable thermostat	Programmagle Thermostat		-4	$44
Costs Totals			$0	No Sum[1]	No Sum[1]

HERS and Annual Energy Changes over As Found

	As Found	Actual Retrofit
HERS Index	**122**	**70**
HERS Index Improvement		**52**
% HERS Index Improvement		**43%**
Annual MBtu Usage	**72.0**	**44.9**
Annual Energy Cost	**$2,816**	**$1,996**
Annual Energy Cost Savings		**$820**
% Energy Cost Savings		**29%**

Costs and Cash flow changes... **Between As Found and Actual Retrofit**

		Between As Found and Actual Retrofit	
% HERS Index Improvement		**43%**	
Improvement Costs		**--**	Automatically calculated
Monthly Mortgage		**--**	from costs entered above
Monthly Energy Savings		**$68**	
Monthly Cash Flow		**--**	
Simple Payback (years)		**#VALUE!**	

Footnotes:

[1] The incremental changes are interrelated and can not be summed to determine the overall HERS index improvements.

[3] CFM 25 to out of 327 was run on supply only as interior closet was already dismantled.

[3] Measure only, does not include distribution benefits and/or infiltration reduction

For homes built prior to 1979, EPA lead abatement

Retrofit Candidate EH-15, 1414 sqft, 1940 Built, 2 bed, 1 bath, Block construction; $0.13/kWh

Home Components	As Found	Recommended	Estimated Incremental Cost	Change in HERS	Annual Energy Cost Savings[1]	Simple Payback
Roof	Medium colored asphalt shingles (default solar absp = 0.85)					
Ceiling Insulation	Batt & Blown insulation; Grade III, R-12	Increase to Grade I, R-38	$500	-8	$76	6.6
Crawl Space	No frame floor or crawl space wall insluation					
Exterior Walls	Medium colored block walls (default solar absp = 0.6)					
Windows	(13) Single, clear, metal (U = 1.20; SHGC = 0.80)					
Doors	(3) Insulated door; (2) Wood doors					
Floors	30% Tile 70% Wood					
Whole House Infiltration[1]	ACH50 = 21; No ventilation system	Reduce by 50% (seal ceiling), ACH50=10	$700	-7	$99	7.1
Heating and Cooling System	13 SEER; 3 ton	(HVAC Service - Not part of simulation)				
	Heat Pump; est. 7.7 HSPF					
Air Distribution System[3]	Qn,out = 0.11; R = 4.2	Repair duct system (Qn,out = 0.06), strap duct runs above anticipated ceiling insulation height	$500	-2	$34	14.7
Thermostat Setting Schedule	BA Benchmark 2008					
Supply/Return/AHU Locations	Attic/Interior/Interior					
Water Heating System	40 gal, electric (Est. EF = 0.88)	R-5 Insulation blanket	$25	0	$10	2.5
Refrigerator	Default efficiency	(Clean Coils - Not part of simulation)				
Lighting	10% CFLs	New ICAT Recessed Fixtures (by electrician), 80% CFLs	$600	-5	$115	5.2
Fans	6 fans; default efficiency					
Costs Totals			$2,325	No Sum[2]	No Sum[2]	No Sum[2]

HERS Index	**125**	**101**
Annual Simulation kWh (BABM08)	**15,222**	**11,506.0**
Annual MBtu Usage (BABM08)	**52.0**	**39.3**
Annual Energy Cost (BABM08)	**$1,704**	**$1,288**

Actual Retrofit Costs & Savings	Full Cost & Full Savings (As Found vs. Recommended)	As Found vs. Recommended Retrofit - Incremental Cost
HERS Index Improvement (%)	**19%**	No measures in this package relate to replacements. All are done for energy improvement only.
Annual Energy Cost Savings ($)	**$416**	
Annual Energy Cost Savings (%)	**24%**	
Improvement Costs	**$2,325**	
Monthly Mortgage	**$16**	
Monthly Energy Cost Savings	**$35**	
Monthly Cash Flow	**$19**	
Simple Payback (years)	**6**	

For homes built prior to 1979, EPA lead abatement rules apply (see http://www.epa.gov/lead /pubs/renovation.htm) and may affect the total cost of painting, drywall repair and related activities. Further, the cost of complying with this rule lies outside the scope of this analysis.

Footnotes:

[1] Based on output of EnergyGuage "Annual Energy Use" calculation with Building America Benchmark 2008 thermostat settings and schedules.

[2] The incremental changes are interrelated and can not be summed to determine the overall HERS index improvements.

[3] Duct leakage testing excluded leakage of return plenum formed by the surrounding air handler closet due to physical limitations of testing equipment. Although significant savings may be garnered from devising a ducted return air pathway, it would require significant reconfigurationation.

Retrofit Candidate EH-17, 1070 sqft, 2000 Built, 3 bed, 1 bath, conventional framed construction ; $0.13/kWh

Home Components	As Found	Minimal Improvement	Deep Retrofit	Incre-mental Cost	Change in HERS	Annual Energy Cost Savings
Roof	Med. colored asphalt shingles (Solar absp = 0.96)					
Ceiling Insulation	Blown Fiberglass R-19 Gr.3		Blown in to R = 38 Grade 1		-1	$10
Exterior Walls	Med. Colored Vinyl siding 2x4 framed walls (solar asb. 0.6, R-13)					
Windows	(7) Single, clear, metal (U = 1.20; SHGC = 0.80);		Replace with ENERGY STAR, Low-e (U =<0.60; SHGC =<0.27)		-1	$8
Doors	(2) Insulated doors		Replace with insulated, U <= 0.21		0	$2
Floors	100% Vinyl					
Whole House Infiltration[1]	Estimated ACH50 = 16.12; No ventilation system		Improved infiltration (Est. ACH50 = 6); Install runtime vent - 40 cfm		0	$2
Heating and Cooling System	12 SEER; 2 ton Strip Heat COP = 1	13 SEER; 2 ton Strip Heat COP = 1	14 SEER; 2 ton Heat Pump, 8.5 HSPF		-4	$38
Air Distribution System	Duct Dist Eff. Est. .88 ; Ducts . R = 6.0 (total leakage tested = 175)		Improved leakage, Qn,out = 0.04		-1	$3
Supply/Return/AHU Locations	Attic/Interior/Interior					
Water Heating System	40 gal, electric (Est. EF = 092)		40 gal heat pump COP 2.3		-8	$175
Refrigerator	Default efficiency					
Lighting	15 fixtures; 0 CFLs		Install 80% CFL's = 12/15		-6	$90
Fans	4 -fans; default efficiency		Replace with ENERGY STAR		0	-$1
Controls	programmable thermostat					
Costs Totals				$0	No Sum[2]	No Sum[2]
HERS Index	**107**	**103**	**62**			
Annual kWh	**11,796**	**11,515**	**6,267**			
Annual MBtu Usage	**40.3**	**39.3**	**21.4**			
Annual Energy Cost	**$1,535**	**$1,498**	**$815**			
Costs and Cash flow changes…		**Between As Found and Minimal Improvement**	**Between Mimimal Improvment and Deep Retrofit**			
% HERS Index Improvement		**4%**	**40%**			
Annual Energy Cost Savings		**$37**	**$683**			
% Energy Cost Savings		**2%**	**46%**			
Improvement Costs						
Monthly Mortgage						
Monthly Energy Savings		**$3.08**	**$36**			
Monthly Cash Flow			**#REF!**			
Simple Payback (years)			**#REF!**			

Footnotes:

[1] Installation of a runtime vent is a health/safety/durability measure that does not improve energy efficiency.

[2] The incremental changes are interrelated and can not be summed to determine the overall HERS index improvements.

[3] Simulation estimates that a 15 SEER Heat Pump would yield additional savings of 2 HERS points and $16/year.

For homes built prior to 1979, EPA lead abatement rules apply (see http://www.epa.gov/lead /pubs/renovation.htm) and may affect the total cost of painting, drywall repair and related activities. Further, the cost of complying with this rule lies outside the scope of this analysis.

Retrofit Candidate EH-18, 913 sqft, ~2000 Built, 2 bed,1 bath, conventional framed; $0.13/kWh

Home Components	As Found	Minimal Improvement	Deep Retrofit	Incre-mental Cost	Change in HERS	Annual Energy Cost Savings
Roof	Med. Light colored asphalt shingles (Solar absp = 0.96)					
Ceiling Insulation	F.G. Blown insulation; R = 24		Blown in to R = 38		-1	$10
Exterior Walls	Light colored vinyl walls (Solar absp = 0.50); R-13					
Windows	(5) Single, clear, metal (U = 1.20; SHGC = 0.80); (1) Single, tinted, metal (U = 1.20; SHGC = 0.70)		Replace with ENERGY STAR, Low-e (U =<0.60; SHGC =<0.27)		-1	$9
Doors	(2) Insulated door		Replace with insulated, U <= 0.21		-1	$5
Floors	100% Vinyl					
Whole House Infiltration[1]	ACH50 = 7.21; No ventilation system		Improved infiltration (Est. ACH50 = 6); Install runtime vent		0	$0
Heating and Cooling System	12 SEER;2 ton	13 SEER; 2 ton	14 SEER; 2 ton		-5	$32
	Strip Heat COP-1	Strip Heat COP-1	Heat Pump, 8.5 HSPF			
Air Distribution System	Qn,out 0.065; Ducts R = 6.0		Improved leakage, Qn,out = 0.04		0	$4
Supply/Return/AHU Locations	Attic/Interior/Interior					
Water Heating System	40 gal, electric (Est. EF = 0.92)		Hybrid (COP -2.3)		-8	$126
Refrigerator	Default efficiency					
Lighting	11 fixtures; 0 CFLs					
Fans						
Controls	Programmable thermostat					
Costs Totals				$0	No Sum[2]	No Sum[2]
HERS Index	**97**	**94**	**59**			
Annual kWh	**9,286**	**9085**	**5231**			
Annual MBtu Usage	**31.7**	**31.0**	**18**			
Annual Energy Cost	**$1,044**	**$1,021**	**$679**			
Costs and Cash flow changes…		**Between Minimal and Actual**	**Between Minimal Improvment and Deep Retrofit**			
% HERS Index Improvement		**3%**	**37%**			
Annual Energy Cost Savings		**$23**	**$342**			
% Energy Cost Savings		**2%**	**33%**			
Improvement Costs			**$0**			
Monthly Mortgage			**$0**			
Monthly Energy Savings		**$ 1.92**	**$29**			
Monthly Cash Flow		**$ 1.92**	**$29**			
Simple Payback (years)			**0**			

Footnotes:

[1] Installation of a runtime vent is a health/safety/durability measure that does not improve energy efficiency.

[2] The incremental changes are interrelated and can not be summed to determine the overall HERS index improvements.

[3] Simulation estimates that a 15 SEER Heat Pump would yield additional savings of 2 HERS points and $16/year.

For homes built prior to 1979, EPA lead abatement rules apply (see http://www.epa.gov/lead /pubs/renovation.htm) and may affect the total cost of painting, drywall repair and related activities. Further, the cost of complying with this rule lies outside the scope of this analysis.

Retrofit Candidate EH-19 - 1176 sqft, 2000 Built, 3 bed, 2 bath, Block Construction; $0.13/kWh

Home Components	As Found	Minimal Improvement	Actual Retrofit	Partner Reported Costs	Costs for Energy Improvements	Change in HERS Index over Minimal	Annual Incre-mental Savings
Roof	Whit asphalt shingles (Solar absp = 0.75)						
Ceiling Insulation	Batt insulation; R-19		Blown-in Fiberglass to R-38			-6	$59
Exterior Walls	Light colored block walls (R = 4.5;Solar absp = 0.45)		Walls painted medium (Solar absp = 0.60)			2	-$14
Windows	(10) Single, clear, metal (U = 1.20; SHGC = 0.80)						
Doors	(2) Insulated doors						
Floors	100% Vinyl						
Whole House Infiltration[1]	Est. ACH50 = 11; No ventilation system		ACH50 = 6.86; Runtime Vent			0	$35
Heating and Cooling System	12 SEER; 2.5 ton	13 SEER	15 SEER; 2.5 ton			-9	$106
	Strip Heat; COP 1	Strip Heat; COP 1	Strip Heat; COP 1				
Air Distribution System	Est. Qn,out = 0.13; Ducts R-6		Qn,out = 0.052; Ducts R-6			-4	$48
Supply/Return/AHU Locations	Attic/Interior/Interior						
Water Heating System	40 gal, electric (Est. EF = 0.88)		Electric heat pump (COP = 2.35); 50 gal			-8	$182
Refrigerator	Default efficiency		ENERGY STAR 378kWh/year			-4	$62
Lighting	18 fixtures; 0 CFLs		80% + CFLs			-6	$140
Fans	5 fans; default efficiency		5 fans; 100 CFM @ medium sped			-2	$27
Controls	No programmable thermostat		Programmable thermostat			-3	$0
Costs Totals				$0	$0	No Sum[2]	No Sum[2]
HERS Index	109	105	70				
Annual Simulation kWh (BABM08)	13,061	12,719	7,856				
Annual MBtu Usage (BABM08)	44.6	43.4	26.8				
Annual Energy Cost (BABM08)	$1,698	$1,653	$1,022				

Actual Retrofit Costs & Savings	Full Cost & Full Savings (As Found vs. Actual)	Incremental Cost & Incremental Savings (Minimal vs. Actual)
HERS Index Improvement (%)	36%	33%
Annual Energy Cost Savings ($)	$676	$631
Annual Energy Cost Savings (%)	40%	38%
Improvement Costs	$0	$0
Monthly Mortgage	$0	$0
Monthly Energy Cost Savings	$56	$53
Monthly Cash Flow	$56	$53
Simple Payback (years)	0	0

Retrofit Candidate EH-20 - 1440 ft^2, 1989 Built, 3 bed, 2 bath, Frame construction; $0.13/kWh

Home Components	As Found	Minimal Improvement	Deep Retrofit	Estimated Total First Costs	Estimated Incremental First Costs for Higher Efficiency	Change in HERS Index	Annual Incre-mental Savings over Minimal
Roof	Whit asphalt shingles (Solar absp = 0.75)						
Ceiling Insulation	Batt insulation; R-15 (compressed R-19)		Insulate to R-38; Grade I Installation		$400	-7	$91
Exterior Walls	Light colored frame walls (Solar absp =						
Windows	(10) Single, clear, metal (U = 1.20; SHGC = 0.80)		ENERGY STAR (U = 0.60; SHGC = 0.27)		$2,000	-13	$196
Doors	(3) Insulated (1) wood						
Floors	50% Vinyl 50% Tile						
Whole House Infiltration	Est ACH50 = 11; No ventilation system		Improved air tightness (ACH50 = 6); Runtime vent (42CFM)		$250	-1	$67
Heating and Cooling System	9 SEER; 3 ton Strip Heat; COP 1	13 SEER Strip Heat (COP = 1)	15 SEER; Right sized Strip Heat; COP 1		$500	-12	$156
Air Distribution System	Est. Qn,out = 0.13; Ducts R 4.2		Replace ducts R 6; Improved leakage (Qn,out = 0.05)		$1,200	-9	$120
Supply/Return/AHU Locations	Attic/Attic/Attic		Attic/Interior/Interior[3]		$500	-8	$107
Water Heating System	40 gal, gas (Est. EF = 0.56)		Tankless Gas (EF = 0.82)		$500	-8	$98
Refrigerator	Default efficiency		ENERGY STAR		$50	-4	$61
Lighting	15 fixtures; 0 CFLs		80% or more CFLs		$72	-6	$163
Fans	None		If installing fans, ENERGY STAR				
Controls	No programmable thermostat		Programmable Thermostat		$125	-4	$0
Costs Totals					$5,597	No Sum[2]	No Sum[2]
HERS Index	**142**	**117**	**59**				
Annual Simulation kWh (BABM08)	**15,646**	**12,985**	**4,969**				
Annual Simulation Therms (BABM08)	**142**	**142**	**88**				
Annual MBtu Usage (BABM08)	**334.7**	**304.1**	**153.1**				
Annual Energy Cost (BABM08)	**$2,291**	**$1,945**	**$832**				

Actual Retrofit Costs & Savings	Full Cost & Full Savings (As Found vs. Proposed Deep Retrofit)	Incremental Cost & Incremental Savings (Proposed Minimal vs. Proposed Deep Retrofit)
HERS Index Improvement (%)	**58%**	**50%**
Annual Energy Cost Savings ($)	**$1,459**	**$1,113**
Annual Energy Cost Savings (%)	**64%**	**57%**
Improvement Costs	**$0**	**$5,597**
Monthly Mortgage	**$0**	**$38**
Monthly Energy Cost Savings	**$15**	**$93**
Monthly Cash Flow	**$15**	**$55**
Simple Payback (years)	**0**	**5**

For homes built prior to 1979, EPA lead abatement rules apply (see http://www.epa.gov/lead/pubs/renovation.htm) and may affect the total cost of painting, drywall repair and related activities. Further, the cost of complying with this rule lies outside the scope of this analysis.

Footnotes:

[1] Installation of a runtime vent is a health/safety/durability measure that does not improve energy efficiency.

[2] The incremental changes are interrelated and can not be summed to determine the overall HERS index improvements.

[3] Relocate air handler and return to interior space.

Retrofit Candidate EH-21 - 1573sqft, 1996 Built, 3 bed, 2 bath, Block Construction; $0.13/kWh

Home Components	As Found	Minimal Improvement	Actual Retrofit	Partner Reported Costs	Costs for Energy Improve-ments	Change in HERS Index over Minimal	Annual Incre-mental Savings over Minimal
Roof	Med/Dark barrel tile (Solar absp = 0.80)						
Ceiling Insulation	Batt: Ceiling (1031 sf) R-19; Knee wall R-15		Ceiling blown-in fiberglass to R-38	$281	$281	-2	$33
Exterior Walls	Medium-Light colored block walls (Solar absp = 0.55); Block walls R-4.2						
Windows	(15) Single, clear, metal (U = 1.20; SHGC = 0.80)						
Doors	(1) Insulated; (1) wood						
Floors	93% tile (slab); 7% carpet (raised floor)						
Whole House Infiltration	ACH50 = 15.05; No ventilation system		ACH50 = 6.15; No ventilation system	$0		-6	$141
Heating and Cooling System	10 SEER, 4 ton; Window unit EER 10.7 Strip Heat; COP = 1	13 SEER Strip Heat; COP = 1	14.5 SEER Strip Heat; COP = 1	$3,610	$900	-8	$109
Air Distribution System	Qn,out 0.10; Duct insulation R-6		Improved leakage, Qn,out = 0.065			-1	$22
Supply/Return/AHU Locations	Attic(66%)& Interior(34%)/Interior/Interior						
Water Heating System	30 gal, electric; EF = 0.89		Heat Pump, 50 gal; EF = 2.35	$1,360	$860	-6	$182
Refrigerator	Default efficiency		ENERGY STAR 378 kWh/yr	$0	$50	-3	$60
Lighting	18 fixtures; 0 CFLs		80%+ CFLs	$150	$150	-6	$177
Fans	fans; default efficiency						
Controls	No programmable thermostat		Programmable thermostat	$0	$125	-3	$0
Costs Totals				$5,401	$2,241	No Sum[1]	No Sum[1]
HERS Index	**120**	**107**	**73**				
Annual Simulation kWh (BABM08)	**17,386**	**16,021**	**10,688**				
Annual MBtu Usage (BABM08)	**59.3**	**54.7**	**36.5**				
Annual Energy Cost (BABM08)	**$2,260**	**2,083**	**1,388**				

Actual Retrofit Costs & Savings	Full Cost & Full Savings (As Found vs. Actual)	Incremental Cost & Incremental Savings (Minimal vs. Actual)
HERS Index Improvement (%)	**39%**	**32%**
Annual Energy Cost Savings ($)	**$872**	**$695**
Annual Energy Cost Savings (%)	**39%**	**33%**
Improvement Costs	**$5,401**	**$2,241**
Monthly Mortgage	**$36**	**$15**
Monthly Energy Cost Savings	**$73**	**$58**
Monthly Cash Flow	**$36**	**$43**
Simple Payback (years)	**2**	**1**

Footnotes:

[1] The incremental changes are interrelated and can not be summed to determine the overall HERS index improvements.

Retrofit Candidate EH-22 - 1334ft^2, 1997 Built, 3 bed, 2 bath, Block Construction; $0.13/kWh

Home Components	As Found	Minimal Improvement	Actual Retrofit	Partner Reported Costs	Costs for Energy Improve-ments	Change in HERS Index over Minimal	Annual Incre-mental Savings over Minimal
Roof	White colored asphalt shingles (Solar absp = 0.75)						
Ceiling Insulation	Batt insulation; 1360sf attic compressed to R-17; 68sf kneewall R-19; 8sf R-1		Attic insulation brought to R-38; 8sf R-1			-5	$73
Exterior Walls	Medium colored block walls (Solar absp = 0.60); Block walls R-4.2		Painted stucco, medium color, no change				
Windows	(10) Single, tinted, metal (U = 1.20; SHGC = 0.70)		LowE, U = 0.34; SHGC = 0.26			-8	$106
Doors	(2) Insulated door						
Floors	100% Tile		50% Vinyl; 10% Tile; 40% Carpet			2	-$15
Whole House Infiltration[1]	Untested, Est. ACH50 = 11; No ventilation system		ACH50 = 5.76; Abandoned attempted runtime vent			-2	$75
Heating and Cooling System	Missing; Default to 10 SEER; 3 ton Strip Heat; COP = 1	13 SEER Strip Heat; COP = 1	14.5 SEER Strip Heat; COP = 1			-8	$106
Air Distribution System	Est. Qn,out = 0.13; Ducts Est. R 4.2		Qn,out = 0.054; Ducts R-6			-5	$76
Supply/Return/AHU Locations	Attic/Interior/Interior		Attic/Attic/Interior			3	-$59
Water Heating System	30 gal, electric; EF = 0.89		50 gal, electric heat pump; EF = 2.35			-7	$178
Refrigerator	Default efficiency		Energy Guide label 378 kWh/yr			-3	$63
Lighting	14 fixtures; 0 CFLs		80% CFLs			-6	$157
Fans	fans; default efficiency		New fans, 100 CFM @ medium sped			-1	$29
Controls	No programmable thermostat		Programmable thermostat			-3	$0
Costs Totals						No Sum[2]	No Sum[2]
HERS Index	119	105	64				
Annual Simulation kWh (BABM08)	15,516	14,075	8,139				
Annual MBtu Usage (BABM08)	53.0	48.0	27.8				
Annual Energy Cost (BABM08)	$2,019	$1,831	$1,059				

Actual Retrofit Costs & Savings	Full Cost & Full Savings (As Found vs. Actual)	Incremental Cost & Incremental Savings (Minimal vs. Actual)
HERS Index Improvement (%)	46%	39%
Annual Energy Cost Savings ($)	$960	$772
Annual Energy Cost Savings (%)	48%	42%
Improvement Costs	$0	$0
Monthly Mortgage	$0	$0
Monthly Energy Cost Savings	$168	$153
Monthly Cash Flow	$168	$153
	0	0

Footnotes:

[1] Installation of a runtime vent is a health/safety/durability measure that does not improve energy efficiency.

[2] The incremental changes are interrelated and can not be summed to determine the overall HERS index improvements.

Retrofit Candidate EH-23, 2923 sq.ft.,1981,4 bed,3 bath, stick frame construction; $0.13/kWh					
Home Components	**As Found**	**Deep Retrofit**	**Incre-mental Cost**	**Change in HERS**	**Annual Energy Cost Savings**
Roof	Dark colored asphalt shingles (Solar absp = 0.95)	Install white asphalt shingles (Solar absp. = 0.75), Install radiant barrier system		-2	$33
	No Radiant Barrier System	Install Radiant Barrier System		-6	$104
Ceiling Insulation	Batt insulation; 1332 sq.ft. R-19, 415.6 sq.ft. R-30, Cathedral 697.5 sq.ft. R-19, Knee wall 285.35 sq.ft. R-19	Install loose fill insulation to flat attic, R-38, Repair kneewall insulation to Grade 1		-5	$85
Exterior Walls	Med. colored framed and stuccoed walls (Solar absp = 0.75); R-11				
Windows	(11) Single, clear, metal (U = 1.20; SHGC = 0.80); (1) Single, ckear, vinyl (U = 0.95; SHGC = 0.80)	Install window tinting , east and west walls (SHGC 0.35)		-4	$67
Doors	(2) Insulated doors; (2) Wood doors				
Floors	50% carpet, 50% tile first floor, second fl. 100% carpet				
Whole House Infiltration[1]	ACH50 = 9.26; No ventilation system	Reduce infiltration to ACH50 = 6.0; install runtime vent (60 cfm)		0	$18
Heating and Cooling System	11 SEER; 4 ton	Geothermal System; EER = 13.44		-28	$472
	Heat Pump; est.7.7 HSPF	Geothermal Heat Pump; COP = 2.47			
Air Distribution System	Qn,out .065; Ducts average est. R = 4.8	Improve Qn out = 0.04), Replace all ducts, R-6		-2	$48
Supply/Return/AHU Locations	Attic/Interior/Interior				
Water Heating System	40 gal, electric (EF =0.92)	Heat Pump Water Heater; COP = 2.35		-5	$224
Refrigerator	Default efficiency				
Lighting	22 fixtures; 14 CFLs	Install 80% CFL's (18/22)		-1	$45
Fans	7 fans; default efficiency				
Controls	No programmable thermostat	Programmable Thermostat		-3	$54
Costs Totals			$0	No Sum[2]	No Sum[2]
HERS and Annual Energy Changes over As Found					
HERS Index	**100**	**64**			
HERS Index Improvement		**36**			
% HERS Index Improvement		**36%**			
Annual MBtu Usage	**66.5**	**46.5**			
Annual Simulation kWh (HERS)	**21,355**	**16,256**	**24%**		
Annual Simulation kWh (BABM08)	**23,893**	**17,807**	**25%**		
Annual Energy Cost	**$2,998**	**$2,238**			
Annual Energy Cost Savings		**$760**			
% Energy Cost Savings		**25%**			
Costs and Cash flow changes…		**Between Partner Package and Deep Retrofit**			
% HERS Index Improvement		**36%**			
Improvement Costs		**$0**			
Monthly Mortgage		**$0**			
Monthly Energy Savings		**$63**			
Monthly Cash Flow		**$63**			
Simple Payback (years)		**0**			

Footnotes:

[1] Installation of a runtime vent is a health/safety/durability measure that does not improve energy efficiency. Reduced infiltration incorporates new Bath and kitchen fans

[2] The incremental changes are interrelated and can not be summed to determine the overall HERS index improvements.

Appendix B – Data Monitoring Equipment

Introduction

The Florida Solar Energy Center (FSEC) supports many Building America projects with long-term monitoring of building energy use and environmental conditions to verify savings projections. Homes are typically monitored for at least one year using 15 to 50 channels of data to measure indoor and outdoor environmental conditions as well as the energy use of heating, cooling, water heating, whole house, and other points (e.g. Solar PV or Solar DHW) as needed. Fully-automated data collection, verification, archiving and management ensure the accurate logging of large amounts of data simultaneously from numerous field sites prior to being made available for analysis and display via the internet.

FSEC typically uses high-accuracy equipment based on Campbell Scientific data loggers for collecting field data. While highly customizable and robust, such systems are expensive and cost often limits the number of instrumented sites. This project sought to increase available data by using home energy monitors to collect reasonably accurate electric energy use. As part of this project, hourly and cumulative outputs from TED and eMonitor devices were compared to established reference devices and found to be within 2% to 11% of the reference.

Florida and metro-Atlanta Retrofit Homes

Two eMonitor models, eMonitor-12 and eMonitor-24, were chosen for these homes. The eMonitor system (http://www.powerhousedynamics.com/) includes an online interface with graphical display of all monitored circuits in near real time and stored historical data (Figure B-1). Historical energy data is also available for download to spreadsheets. For this project FSEC developed an automated download routine to independently archive hourly energy data and provide additional analysis functions.

In addition to electric energy monitoring, interior temperature and relative humidity will be recorded with Hobo dataloggers manufactured by Onset Computer Corporation. These standalone loggers will record average hourly interior conditions and will be downloaded periodically. This data, along with ambient data from local National Weather Service stations, will provide a means of determining cooling (and/or heating) performance when integrated with energy data collected via eMonitor.

Figure B-1. Components of the eMonitor system

San Antonio Retrofit Homes

These small homes (2-3 bedroom, 1 bath) had limited space for energy monitors and had electric breakers located in separate panels (240V at exterior panel, 120V at interior panel). The TED energy monitor, which uses power line carrier (PLC) technology, was an ideal choice as circuit monitors can be placed in separate panels. Although limited to four circuits, this device provided the mandatory house and space conditioning measurements needed for the study. The TED 5004C (http://www.theenergydetective.com) was purchased with a countertop LCD display to provide energy feedback to occupants. Data is stored in the TED "gateway" device at the home.

In addition to electric energy monitoring, interior temperature and relative humidity will be recorded with Hobo dataloggers manufactured by Onset Computer Corporation. These standalone loggers will record average hourly interior conditions and will be downloaded periodically. This data, along with ambient data collected from local National Weather Service stations, will provide a means of determining cooling (and/or heating) performance when integrated with energy data collected via TED.

TED and eMonitor Output Error Comparison

As part of this project, hourly and cumulative outputs over several days from TED and eMonitor were compared to established reference devices. A Fluke 435 Power Analyzer provided the primary reference readings for whole house energy use. A Wattnode WNB-3D-240-P power meter, manufactured by Continental Control Systems, was used as a reference point for end use measurements (AC condenser, air hander and water heater). The following tables show cumulative energy totals over several days and how eMonitor and TED compare to the reference devices.

TED total home energy readings (Table B-1) were generally very close to reference values except during one period when interference over the home power lines caused a high error level. The cause of this error was addressed by relocating the TED gateway to a location directly adjacent to the main breaker panel. Errors were higher in end use energy readings (Table B-2) with TED ranging from -2% to +1% for domestic hot water and from -4% to +8% for the air conditioning equipment.

Total home energy readings (Table B-1) with eMonitor consistently ranged from -9 to -11%. End use energy readings (Table B-2) ranged more widely from -8% to +8% for water heater and air conditioning equipment.

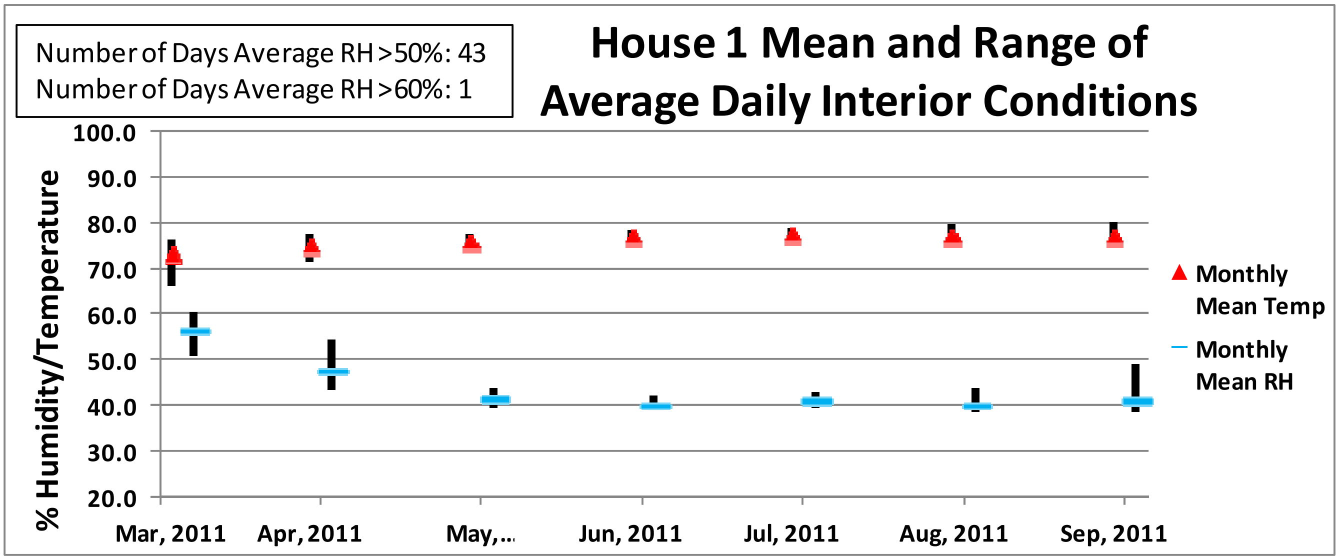
Table B-1. Total Home Energy Use Comparison

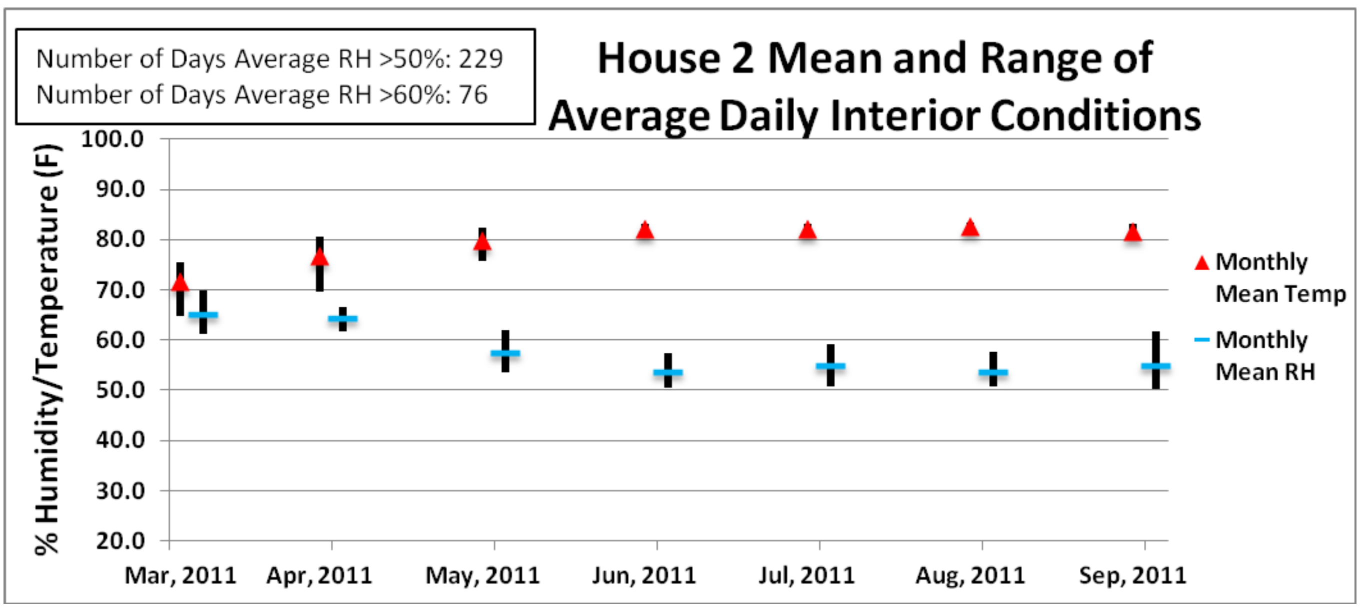
Total Hours	Fluke 435	Wattnode (Whrs)	% diff	tot diff	eMonitor (Whrs)	% diff	tot diff	TED (Whrs)	% diff	tot diff
76	132667	129830	-2.1%	-2837	120434	-9.2%	-12233	133699	0.8%	1032
52	64533	62703	-2.8%	-1830	58267	-9.7%	-6266	64597	0.1%	64
105	186667	182667	-2.1%	-3999	169456	-9.2%	-17211	580647	211.1%	393980
241	340933	345890	1.5%	4957	309261	-9.3%	-31672	343688	0.8%	2755
276	459973	445872	-3.1%	-14101	382339	-10.4%	-77634	460434	0.1%	461
144	311307	303244	-2.6%	-8063	278516	-10.5%	-32791	313006	0.5%	1699
168	389267	377378	-3.1%	-11889	348682	-10.4%	-40585	392918	0.9%	3651

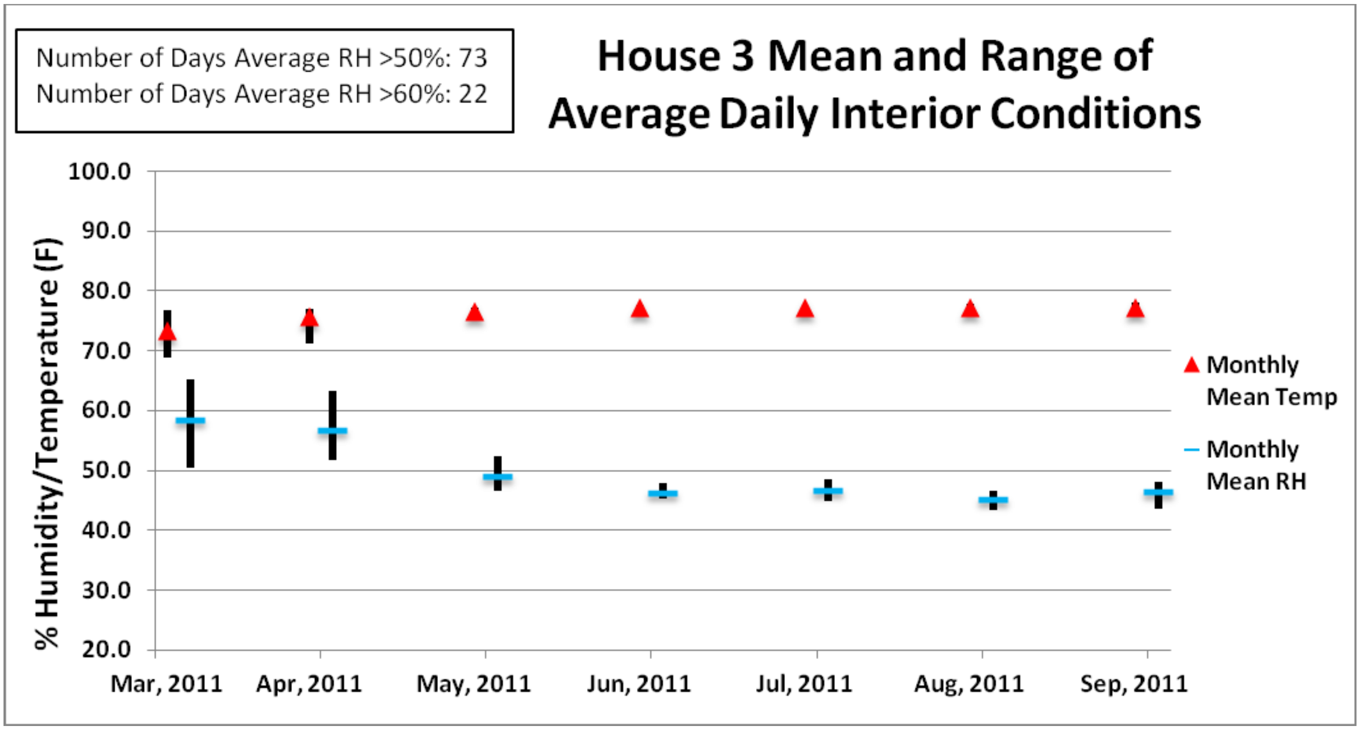
Table B-2. End Use Energy Comparison

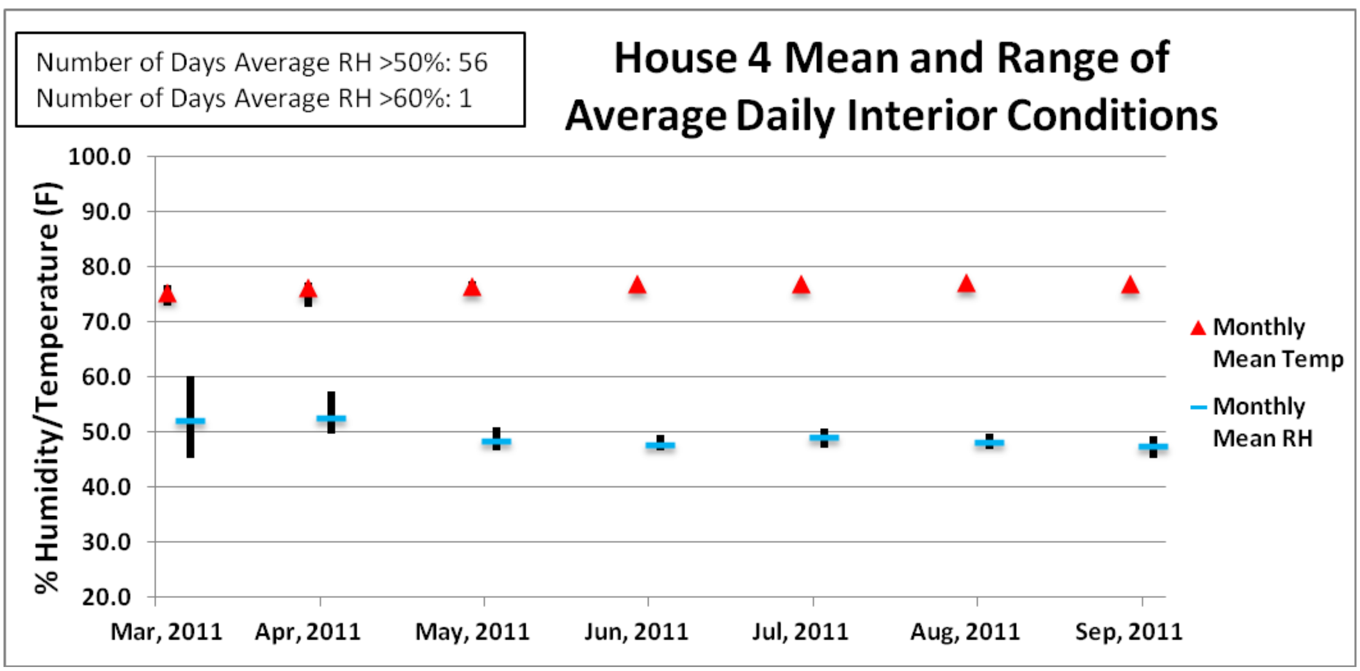
	Wattnode (Wh)	eMonitor (Wh)	% diff	tot diff	TED (Wh)	% diff	tot diff
AHU	2419	2588	7.0%	169			
AHU	3485	3764	8.0%	279	CTs improperly installed		
Compressor	14510	14634	0.9%	124	15332	5.7%	822.30
AHU	8666	9322	7.6%	656	CTs improperly installed		
Compressor	34561	34386	-0.5%	-174.6	36378	5.3%	1817.4
DHW	81655	78285	-4.1%	-3370	82656	1.2%	1001
AHU	14384	13844	-3.8%	-540	CTs improperly installed		
Compressor	41959	38562	-8.1%	-3397	40431	-3.6%	-1528
DHW	71285	68414	-4.0%	-2871	69568	-2.4%	-1717
AHU	15949	16202	1.6%	253	CTs improperly installed		
Compressor	71212	72695	2.1%	1482.6	75478	6.0%	4265.6
DHW	73679	65469	-4.6%	-8209.6	71956	-2.3%	-1722.6
AHU	22919	22619	-1.3%	-299.9	11473	4.0%	437.2
Compressor	222925	229867	3.1%	6942.2	240073	7.7%	17148.2
DHW	56575	53987	-4.6%	-2587.9	55383	-2.1%	-1191.9

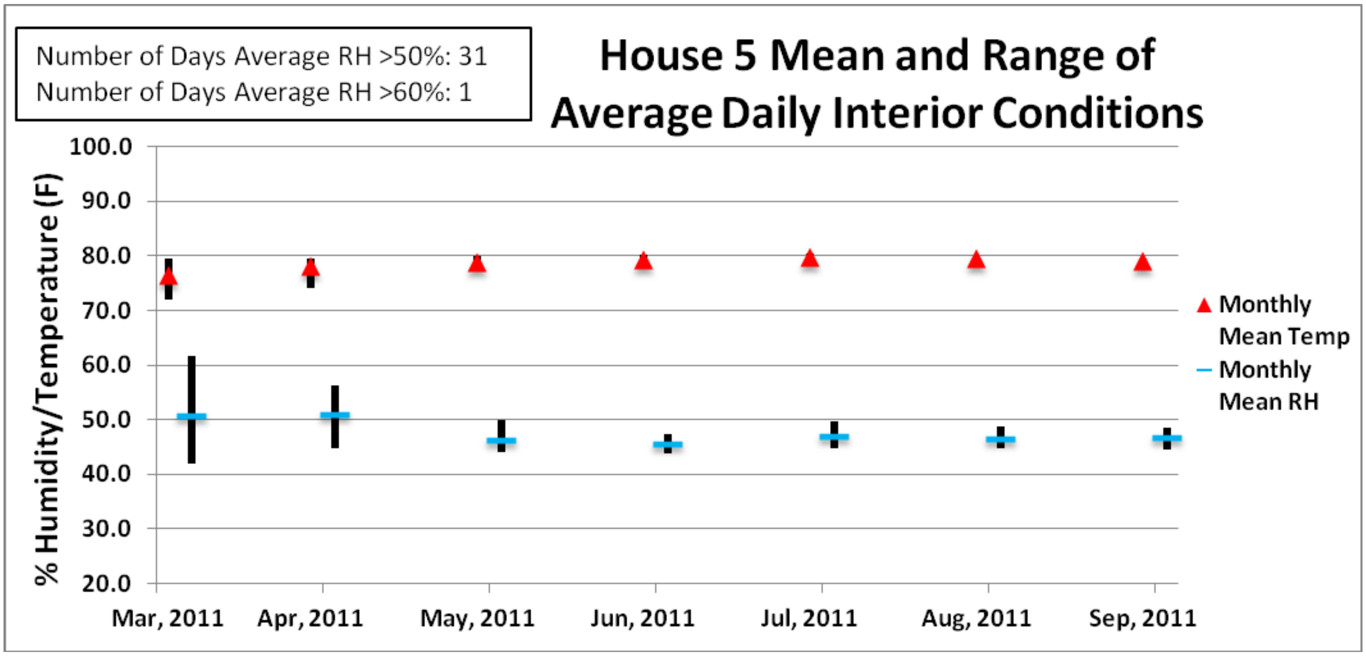
Appendix C – Analysis Support

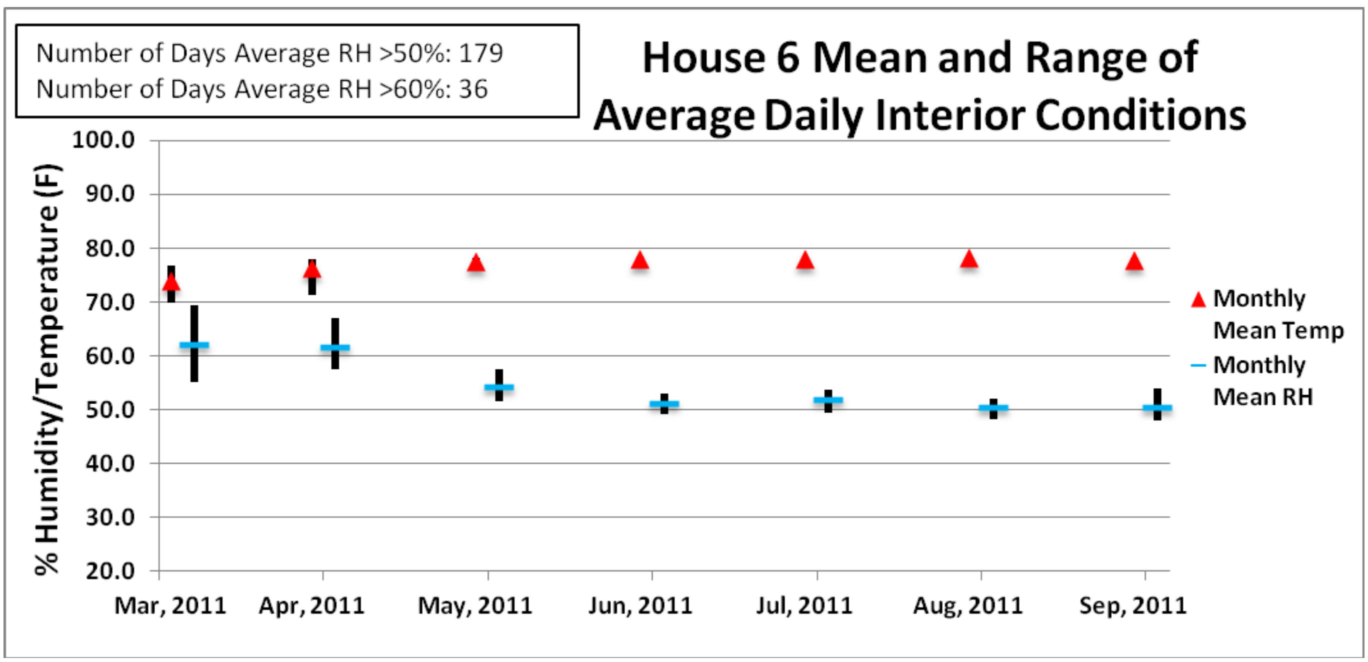


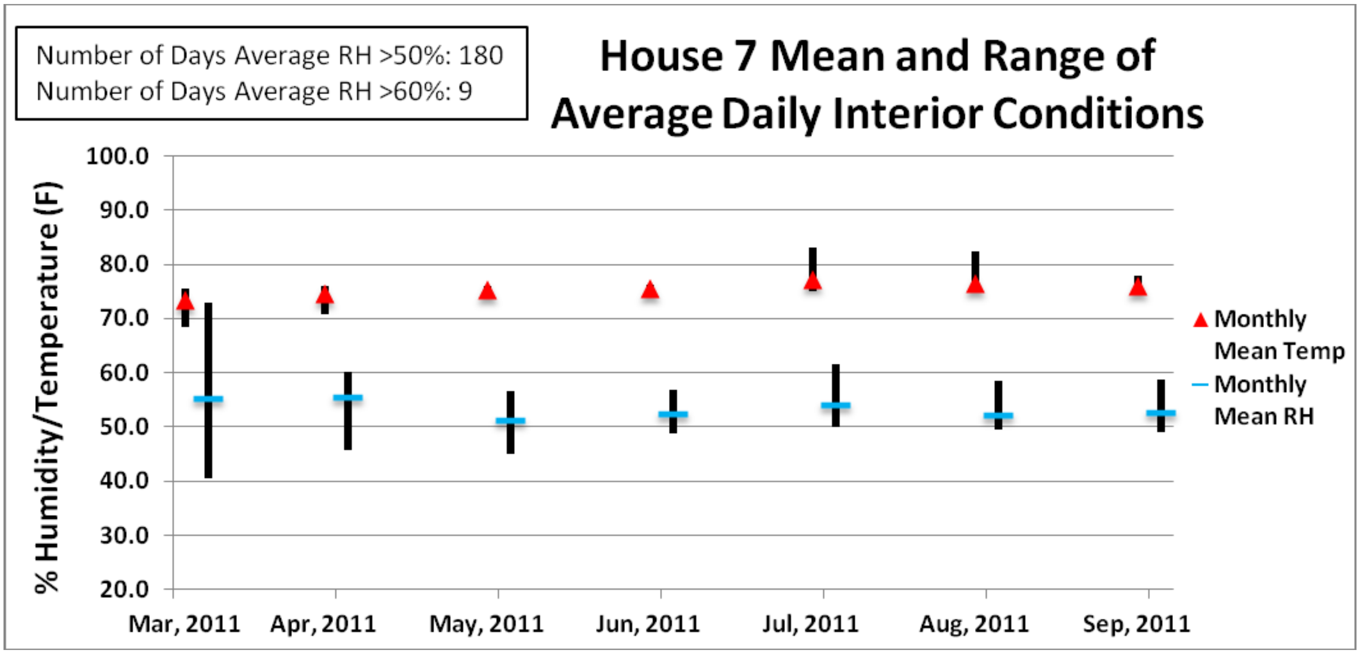


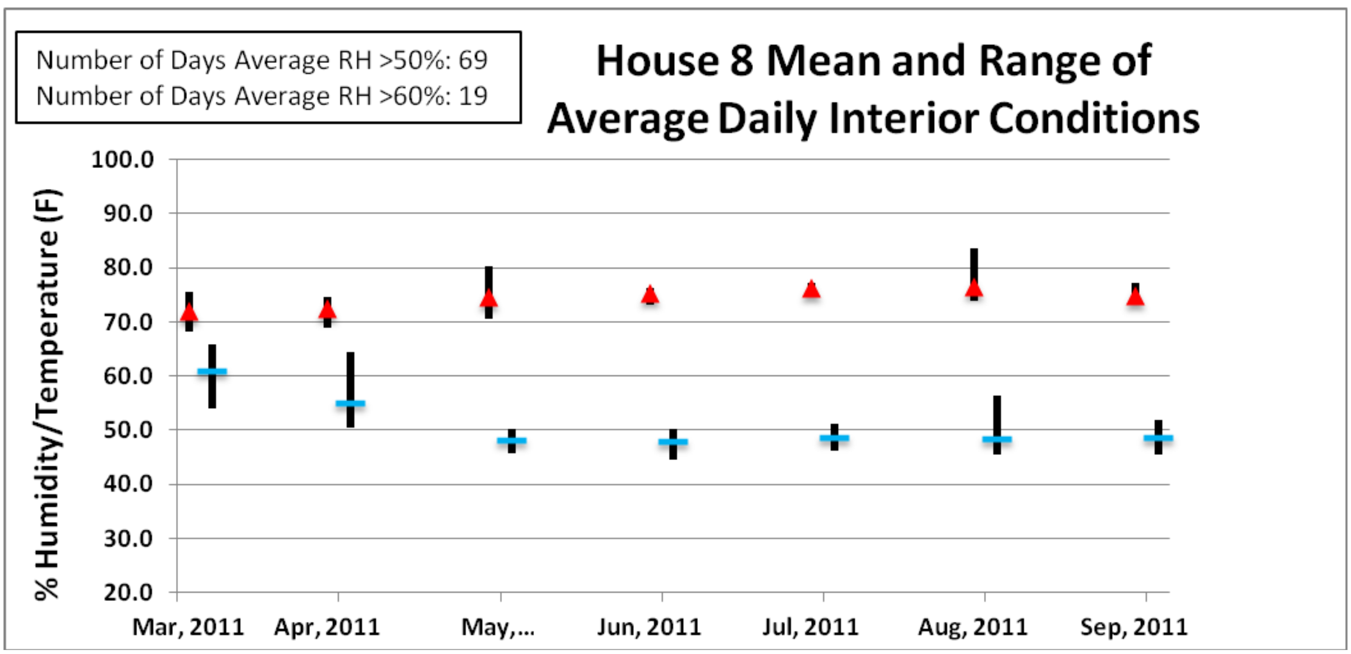

Number of Days Average RH >50%: 73
Number of Days Average RH >60%: 22
House 3 Mean and Range of Average Daily Interior Conditions
% Humidity/Temperature (F)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
Mar, 2011
Apr, 2011
May, 2011
Jun, 2011
Jul, 2011
Aug, 2011
Sep, 2011
Monthly Mean Temp
Monthly Mean RH


Number of Days Average RH >50%: 56
Number of Days Average RH >60%: 1
House 4 Mean and Range of Average Daily Interior Conditions
% Humidity/Temperature (F)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
Mar, 2011
Apr, 2011
May, 2011
Jun, 2011
Jul, 2011
Aug, 2011
Sep, 2011
Monthly Mean Temp
Monthly Mean RH


Number of Days Average RH >50%: 31
Number of Days Average RH >60%: 1
House 5 Mean and Range of Average Daily Interior Conditions
% Humidity/Temperature (F)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
Mar, 2011
Apr, 2011
May, 2011
Jun, 2011
Jul, 2011
Aug, 2011
Sep, 2011
Monthly Mean Temp
Monthly Mean RH


Number of Days Average RH >50%: 179
Number of Days Average RH >60%: 36
House 6 Mean and Range of Average Daily Interior Conditions
% Humidity/Temperature (F)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
Mar, 2011
Apr, 2011
May, 2011
Jun, 2011
Jul, 2011
Aug, 2011
Sep, 2011
Monthly Mean Temp
Monthly Mean RH


Number of Days Average RH >50%: 180
Number of Days Average RH >60%: 9
House 7 Mean and Range of Average Daily Interior Conditions
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
% Humidity/Temperature (F)
Mar, 2011
Apr, 2011
May, 2011
Jun, 2011
Jul, 2011
Aug, 2011
Sep, 2011
Monthly Mean Temp
Monthly Mean RH


Number of Days Average RH >50%: 69
Number of Days Average RH >60%: 19
House 8 Mean and Range of Average Daily Interior Conditions
100.0
90.0
80.0
70.0
60.0
50.0
40.0
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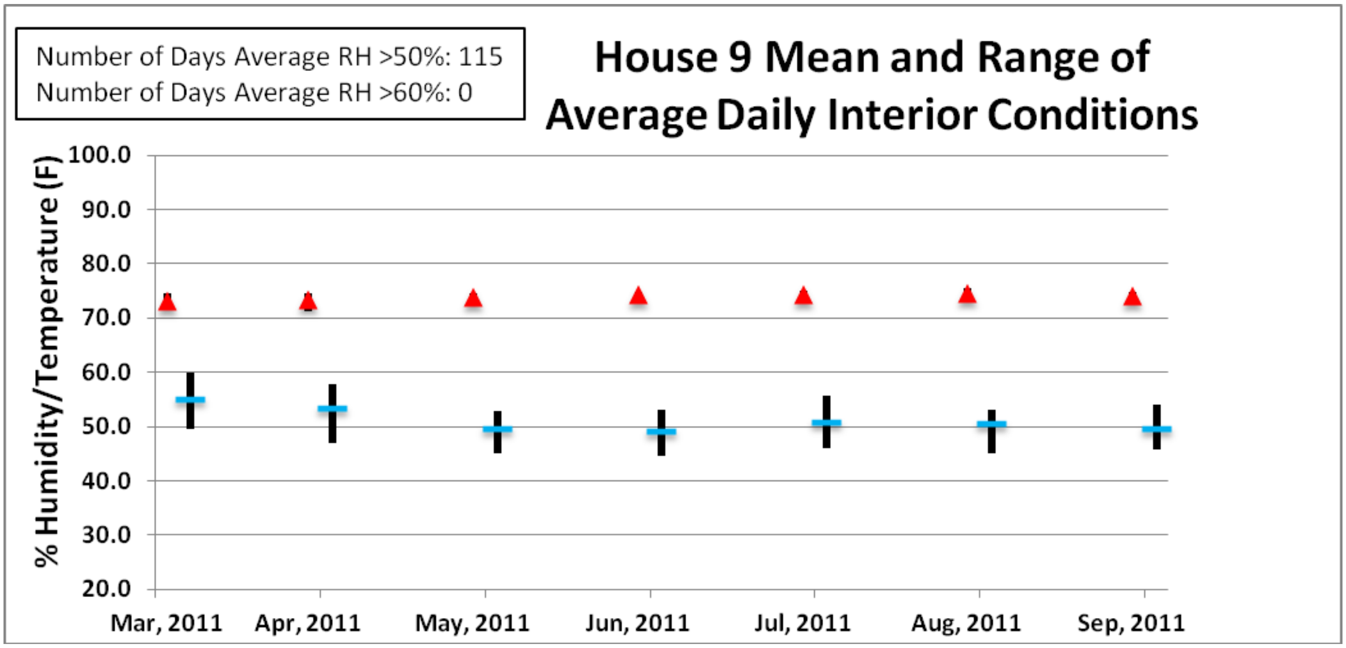
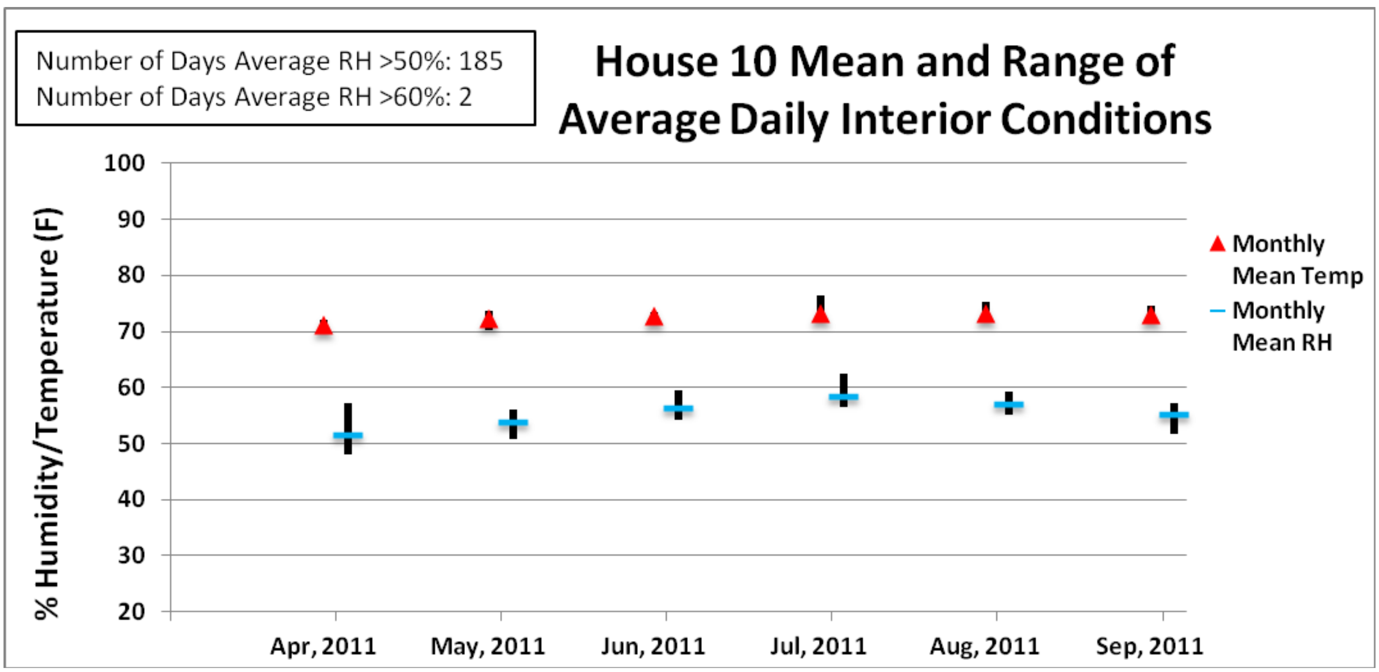
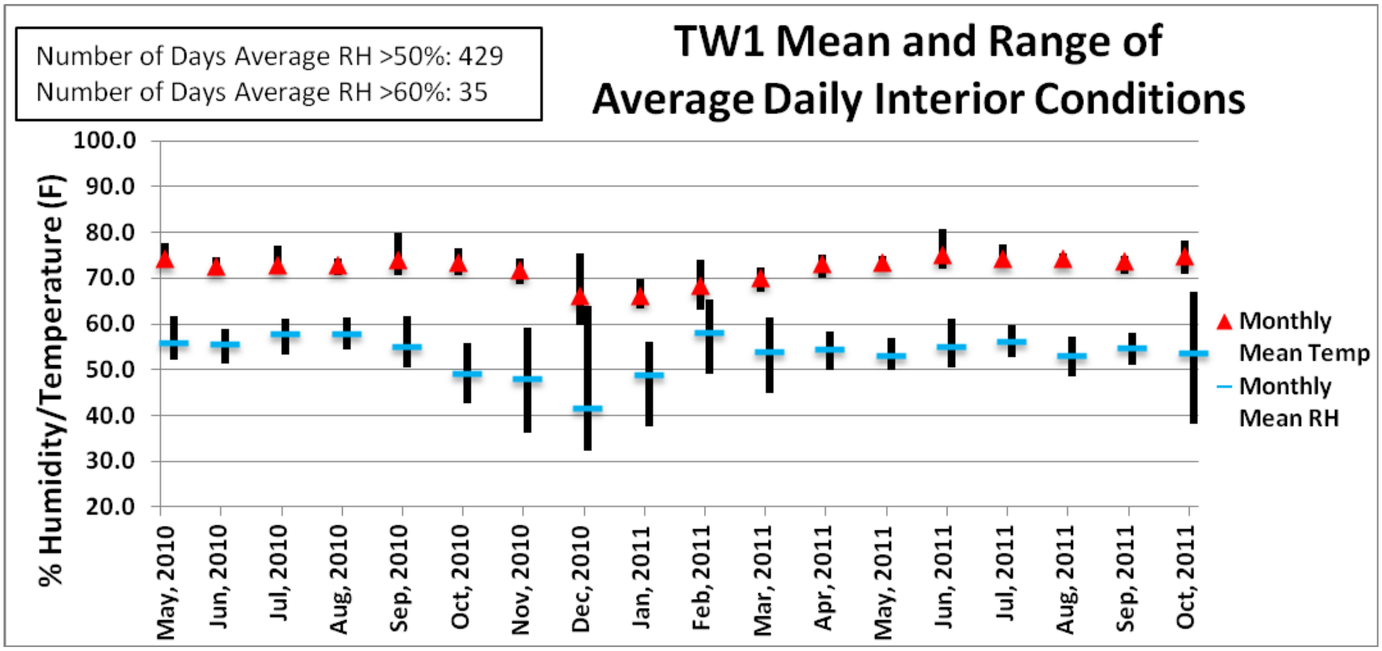
% Humidity/Temperature (F)
Mar, 2011
Apr, 2011
May,...
Jun, 2011
Jul, 2011
Aug, 2011
Sep, 2011


Number of Days Average RH >50%: 115
Number of Days Average RH >60%: 0
House 9 Mean and Range of Average Daily Interior Conditions
% Humidity/Temperature (F)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
Mar, 2011
Apr, 2011
May, 2011
Jun, 2011
Jul, 2011
Aug, 2011
Sep, 2011


Number of Days Average RH >50%: 185
Number of Days Average RH >60%: 2
House 10 Mean and Range of Average Daily Interior Conditions
% Humidity/Temperature (F)
100
90
80
70
60
50
40
30
20
Apr, 2011
May, 2011
Jun, 2011
Jul, 2011
Aug, 2011
Sep, 2011
Monthly Mean Temp
Monthly Mean RH


Number of Days Average RH >50%: 429
Number of Days Average RH >60%: 35
TW1 Mean and Range of
Average Daily Interior Conditions
% Humidity/Temperature (F)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
May, 2010
Jun, 2010
Jul, 2010
Aug, 2010
Sep, 2010
Oct, 2010
Nov, 2010
Dec, 2010
Jan, 2011
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Apr, 2011
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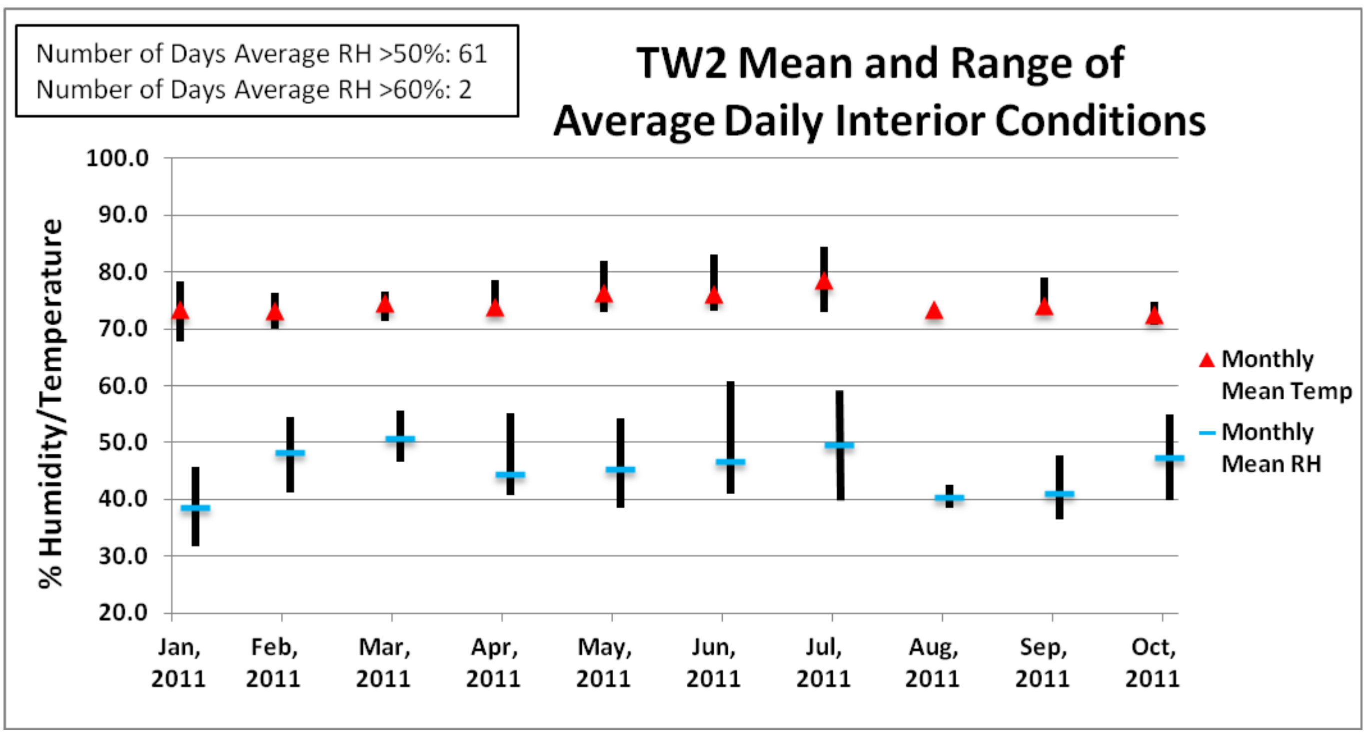
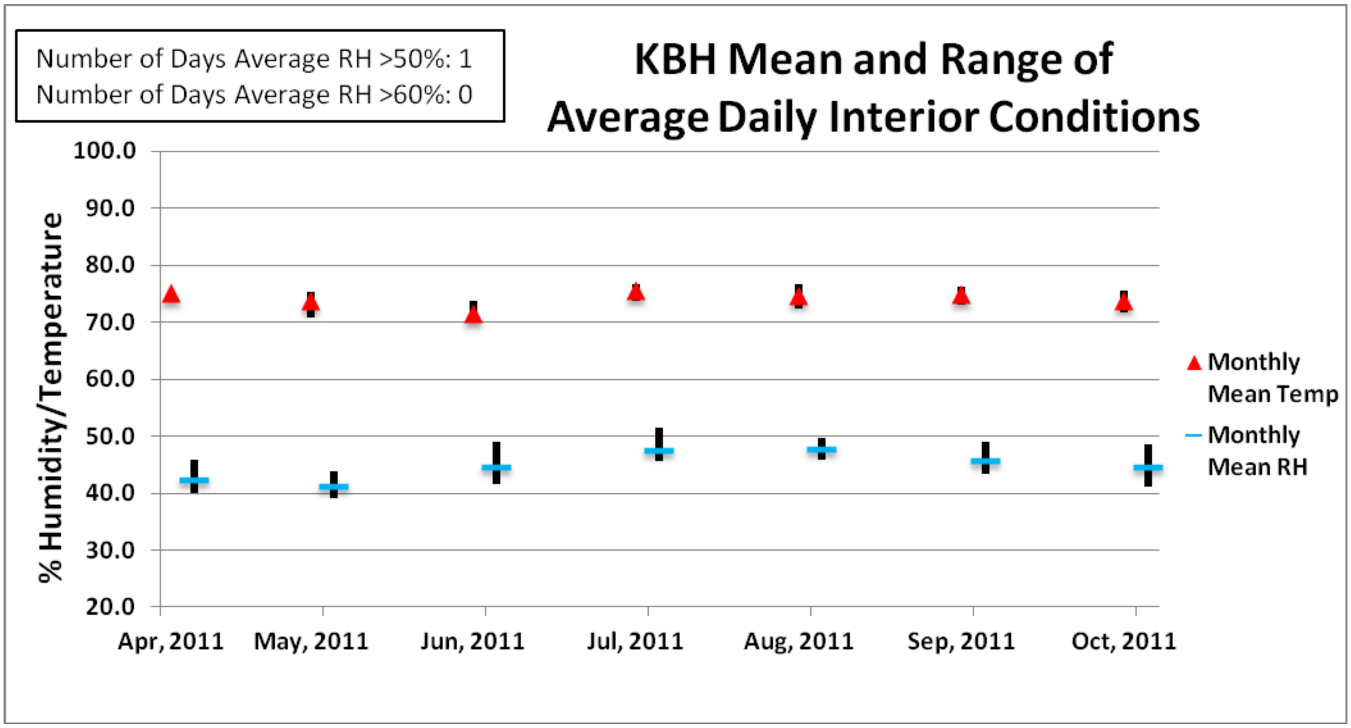
Aug, 2011
Sep, 2011
Oct, 2011
Monthly Mean Temp
Monthly Mean RH


Number of Days Average RH >50%: 61
Number of Days Average RH >60%: 2
TW2 Mean and Range of
Average Daily Interior Conditions
% Humidity/Temperature
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
Jan, 2011
Feb, 2011
Mar, 2011
Apr, 2011
May, 2011
Jun, 2011
Jul, 2011
Aug, 2011
Sep, 2011
Oct, 2011
Monthly Mean Temp
Monthly Mean RH


Number of Days Average RH >50%: 1
Number of Days Average RH >60%: 0
KBH Mean and Range of
Average Daily Interior Conditions
% Humidity/Temperature
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
Apr, 2011
May, 2011
Jun, 2011
Jul, 2011
Aug, 2011
Sep, 2011
Oct, 2011
Monthly Mean Temp
Monthly Mean RH

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