U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BUILDING TECHNOLOGIES PROGRAM

Energy Retrofit Field Study and Best Practices in a Hot-Humid Climate

J. McIlvaine, K. Sutherland, and E. Martin
Building America Partnership for Improved Residential Construction

March 2013

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Energy Retrofit Field Study and Best Practices in a Hot-Humid Climate

Prepared for:
The National Renewable Energy Laboratory
On behalf of the U.S. Department of Energy's Building America Program
Office of Energy Efficiency and Renewable Energy
15013 Denver West Parkway
Golden, CO 80401
NREL Contract No. DE-AC36-08GO28308

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Prepared under Subcontract No. KNDJ-0-40339-00

March 2013

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Contents

List of Figures

Unless otherwise noted, all figures were created by BA-PIRC.

List of Tables

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Definitions

AC	Air conditioning
ACH, 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-PIRC	Building America Partnership for Improved Residential Construction
BEopt	Building Energy Optimization
CFL	Compact fluorescent lamp
COP	Coefficient of performance
CFM	Cubic feet of air per minute
DOE	U.S. Department of Energy
EF	Energy factor
EGUSA	Energy Gauge USA
FSEC	Florida Solar Energy Center
HERS	Home Energy Rating System
HSPF	Heating seasonal performance factor
HUD	U.S. Department of Housing and Urban Development
HVAC	Heating, ventilation, and air conditioning
kWh	Kilowatt per hour
NSP	Neighborhood Stabilization Program
Pa	Pascal
R-value	Value denoting thermal resistance
RESNET	Residential Energy Services Network
sd	Standard deviation
SEER	Seasonal energy efficiency ratio
SHGC	Solar heat gain coefficient
U-value	Value denoting thermal conductance

Executive Summary

In the U.S. Census Bureau's Southern region, housing starts ranged from 4.6 to 5.9 million per decade from the 1970s through the 2000s, nearly twice as many as any other region across all decades. The potential for energy savings in these homes is vast, perhaps our most available untapped resource for reducing energy needs. This study was conducted in central Florida, which forms part of the Census Bureau's Southern region. It examines efficiency retrofit opportunities, typical renovation practices, and pathways for achieving U.S. Department of Energy (DOE) goals for existing homes in that region.

Researchers partnered with local government and nonprofit affordable housing entities conducting comprehensive renovations in foreclosed homes. Nearly all of the homes were renovated through the U.S. Department of Housing and Urban Development's (HUD) Neighborhood Stabilization Program (NSP).

DOE's Building America Partnership for Improved Residential Construction (BA-PIRC), based at the Florida Solar Energy Center (FSEC), led the research. Renovation activities were conducted in 70 foreclosed homes built from the 1950s through the 2000s.

Pre-retrofit Home Energy Rating System (HERS) Indices ranged from 95 to 184 (sd = 22), with an average of 129. Post-retrofit HERS Indices range from 65 to 135 (sd = 11), with an average of 83. Projected annual energy savings ranged from $35 to $1,338. All but four homes achieved a HERS Index ≤ 95, which is similar to new Florida homes built in the early 2000s, a remarkable reversal. This may suggest that achieving a HERS Index of 95 is a reasonable goal for energy retrofits in homes with similar characteristics to those in the dataset, though the actual savings will vary depending on house-specific conditions.

The average improvement for the 70-house dataset was a 34% decrease in HERS Index. Average projected annual energy cost savings were 25%. Forty-six of the 70 homes (66%) achieved a 30% reduction in HERS Index with an average projected energy cost savings of 31%. Nineteen fell between 15% and 29%, and only five fell below 15% improvement. A cost effectiveness discussion compares incremental cost for higher performance choices to projected annual energy cost savings for the retrofit meeting or exceeding the 30% improvement goal.

Despite widely disparate pre-retrofit HERS Indices and varying scopes of work, the mean of post-retrofit HERS Indices by decade ranged from 74 to 86, a range of only 12 points compared to a 56-point spread across the decades in pre-retrofit HERS Index (Figure 1).

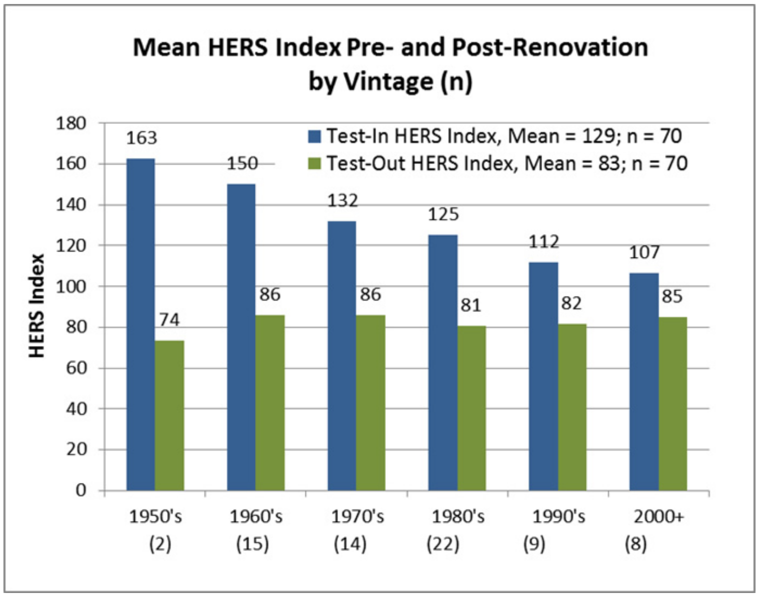


Figure 1. Mean HERS Index at pre- and post-retrofit by decade vintage

To assess the feasibility of replicating these positive results in the general housing stock, researchers examined the mix of improvements associated with the 30% or greater improvement in HERS Index (n = 46). These "deep" retrofits had much in common and were the homes with the most room for improvement, as they all needed multiple energy-related replacements and improvements. Researchers identified 13 key efficiency measures related to equipment, appliance, and lighting efficiency and envelope components. These form the basis of a set of best practices for replacement and in-situ treatment.

The best practices are intended to support program administrators and the general remodeling industry in efforts to enhance energy efficiency of the existing housing stock at the time of major renovation.

Acknowledgments

This work was initially supported by the Florida Energy Systems Consortium (2009) and subsequently sponsored by DOE, Office of Energy Efficiency and Renewable Energy, Building America Program under cooperative agreement number DE-FC26-06NT42767 (2010) and Subcontract No. KNDJ-0-40339-00 (2011-12).

The support and encouragement of past DOE program managers, George James, Terry Logee, Ed Pollock, and William Haslebacher, as well as current DOE program managers, Stacey Rothgeb, Ren Anderson, Eric Werling Sam Rashkin, and David Lee, is gratefully acknowledged. This support does not constitute DOE endorsement of the views expressed in this paper.

We thank Eric Martin, project director of BA-PIRC, for his direction and support. We also thank Rob Vieira and Philip Fairey, both of FSEC, for their advice and support in conducting many aspects of this work. This project would not have been possible without the leadership and vision of the late Subrato Chandra, project manager for the Building America Industrialized Housing Partnership.

Early partnership and participation of Sarasota County and the City of Sarasota were instrumental in launching this study, including collaboration with Nina Powers, Sustainability Outreach Coordinator at Sarasota County Government; Don Hadsell, Director of the Sarasota Office of Housing and Community Development, and Nan Summers (formerly, Director of the Florida House at Sarasota County Government). We are deeply grateful for their participation and that of other local governments who were also recipients of HUD NSP funding, and their partnering nonprofit housing entities, contractors, and home energy raters. Special thanks are also due to:

- Sarasota Office of Housing and Community Development NSP Partners, Sarasota County, Florida:
    - Tanya Lukowiak and Sandy McKitterick of Community Housing Trust of Sarasota County, Inc.
    - Che Barnett of Greater Newtown Community Redevelopment Corporation
    - Dean Shelton of Habitat for Humanity of Sarasota, Inc.
    - Laura Carter Taylor of Goodwill Industries, Manasota
- Ian Golden, Sam Detra, Roy Davis, and Tom Sullivan of Brevard County Housing and Human Services Department, Brevard County, Florida
- Dona DeMarsh, Paula Szabo, and Sue Redstone from Volusia County Community Assistance, Volusia County, Florida
- Mike Byerly, Alachua County Commission, Ken Fonorow, Florida H.E.R.O., and Thomas Webster and Karen Johnson of Alachua County Housing Programs, Alachua County, Florida
- Johnny Roberts of Habitat for Humanity of Greater Birmingham, Birmingham, Alabama
- Brenda Carson Lawless and Josh Shedeck of Habitat for Humanity of Southwest Alabama (formerly Mobile Habitat), Mobile, Alabama
- Mitchell Glasser, Lee Coulter, Dave Tarpley, and Barry Counts of Orange County Housing & Community Development, Orange County, Florida

- Sue Hann, John Rodgers, and Robert Williams of the City of Palm Bay, Florida
- Judy Wilcox and Michael Stollito of Habitat for Humanity, South Sarasota County, Inc. and Dennis Stroer of CalcsPlus, Sarasota, Florida.

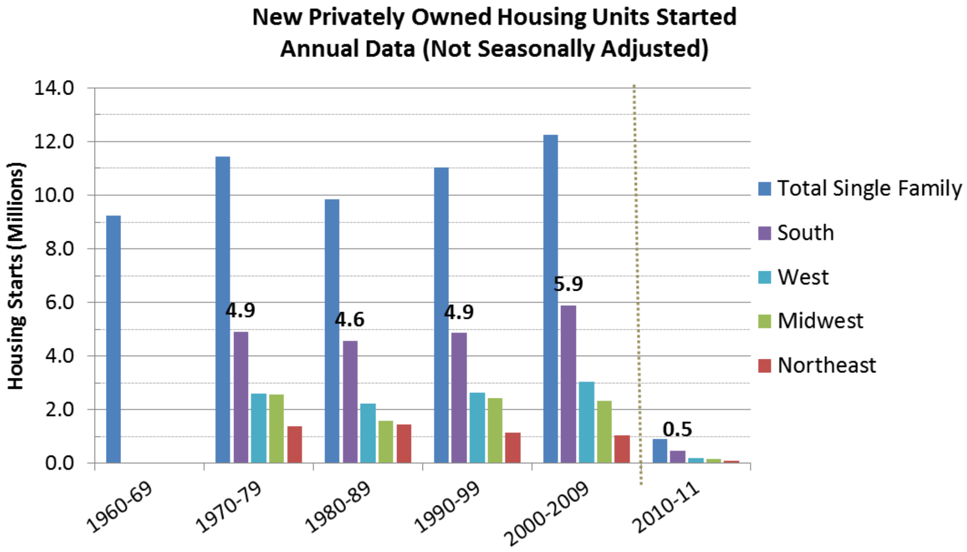
We wish to thank the certified home energy raters who, in addition to author Karen Sutherland, conducted the energy audits and analyses: Kevin Schleith and Patrick Gillis, both formerly of FSEC; David Beal of FSEC; and Tabatha Reyes of Energy Potential, Inc.

We are grateful for the support of other FSEC staff, past and present, including Ian Lahiff, Oscar Toledo, David Hoak, Keith Abbott, Dave Chaser, Stephanie Thomas-Rees, and Jamie Cummings.

We also express great appreciation to FSEC's Billy Bauman for programming expertise and Danielle Daniel and Wanda Dutton for their excellent editorial assistance.

1 Introduction

The U.S. Census Bureau has been collecting data on the construction industry for decades. Figure 2 shows single-family (1 unit) housing starts by decade (from 1960 through 2011) in total and in the four census regions (Figure 3). The potential for energy savings in these homes is vast, perhaps our most available untapped resource for reducing energy needs.



Source: Tablulated from U.S. Census Bureau. New Residential Construction, Historical Data (http://www.census.gov/construction/nrc/historical_data/), "New Housing Units Started", New Privately Owned Housing Units Started, Not Seasonally Adjusted.
Regional data available starting 1964.

Figure 2. U.S. Census Bureau historical housing starts by decade

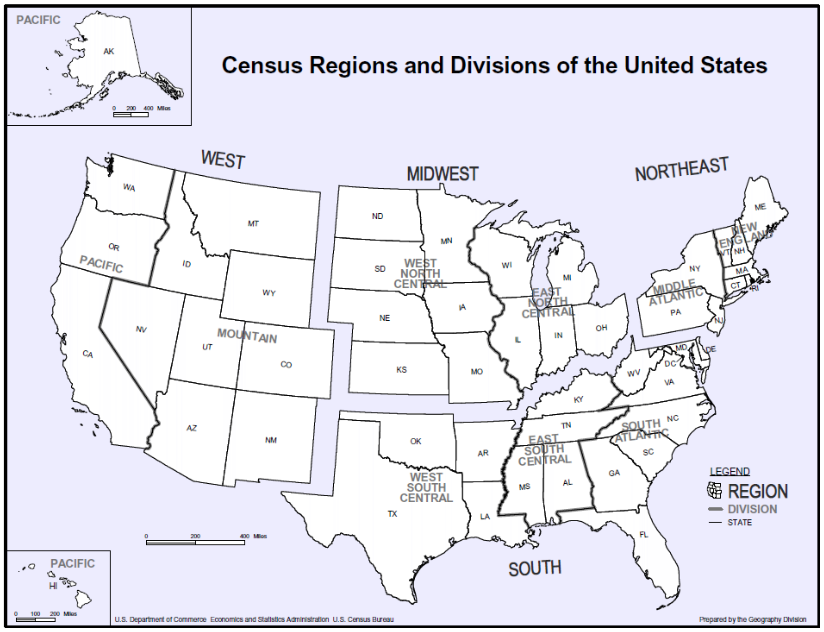


Figure 3. U.S. Census Bureau regions

Regional data collection is available beginning in 1964. Figure 2 shows that at least 1 million homes were built in each region in each full decade. From the 1970s through the 2000s, housing starts were strongest in the "South" census region and ranged from 4.6 to 5.9 million, nearly twice as many starts as any other region across all decades. The South census region covers several Building America climate zones (Best Practices Series 7.1: High Performance Technologies Guide to Determining Climate Regions by County 2010) (see Figure 4).

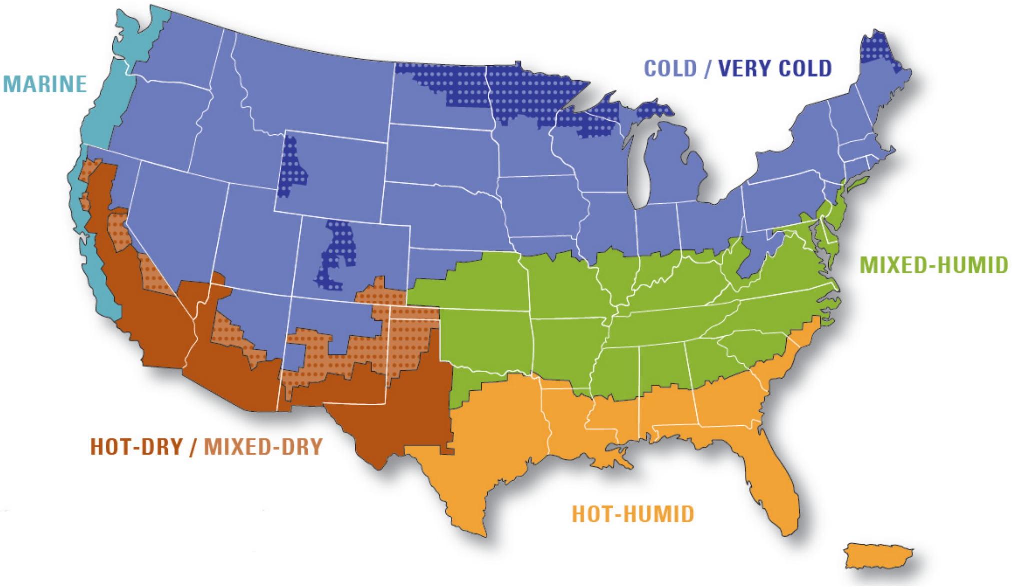


Figure 4. Building America climate zone map

(PNNL 2010)

This study was conducted in Florida, which falls in climate zone 2, commonly referred to as the "hot-humid" climate zone. Building America program goals for existing homes in the hot-humid climate are shown in Table 1 ("Summary of Prioritized Research Opportunities" 2011).

Table 1. Building America Multiyear Energy Savings Goals for Existing Homes (2010)

Energy Savings	Mixed-Dry, Hot-Dry and Marine	Mixed-Humid, Hot Humid	Cold, Very Cold, and Subarctic
Current Best Practice (15% or above)	2011	2011	2011
30%	2012	2013	2014
50%	2015	2016	2017

(NREL and Newport Partners (2011)

Achieving these goals in any particular home is closely linked to the pre-retrofit condition of the home's energy-related characteristics. Older homes that have been well maintained and upgraded over the years may have a higher whole-house efficiency level than newer homes in disrepair. There is no single solution for all existing homes, even within a given climate. However, this study did reveal trends among the improvement packages in houses that achieved these goals, which are now proposed as a set of current best practices, meaning that they can be implemented by the labor force using off-the-shelf materials, components, and equipment. Not all the best practices will be applicable to all homes; however, the partners in this study implemented combinations of them in 70 homes and achieved an average projected energy cost savings of 25%.

1.1 Background

Between the fall of 2009 and the end of 2011, BA-PIRC[1] researchers at the Florida Solar Energy Center (FSEC) worked with affordable housing partners to identify pathways for meeting the goals in Table 2. Researchers participated in renovations of 70 homes in Florida, built between 1957 and 2006 (examples shown in Figure 5).

Figure 5. Study homes of typical character with ranch style floor plans, slab-on-grade foundations, concrete block exterior walls, low sloped roofs, and 8-ft ceiling heights

The nine partnering organizations consisted of local governments and nonprofit organizations. Almost all the partners were awardees under the U.S. Department of Housing and Urban Development’s (HUD) Neighborhood Stabilization Program (NSP). NSP provides funds for the purchase and renovation of unoccupied foreclosed homes with the provision that they will be sold as affordable housing. Partners retained contractors to carry out the renovation work. The 70 homes are located in central (66) and north (4) Florida in the hot-humid climate zone.

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[1] BA-PIRC began this work under a previous Building America contract wherein the team name was the Building America Industrialized Housing Partnership.

Almost all the homes acquired by the partners were distressed, foreclosed homes that each needed comprehensive renovation. The scopes of work often included energy-related elements such as mechanical system and window replacements. However, the potential for additional cost-effective efficiency improvements was evident early in the investigation. Nonenergy-related improvements such as new bathroom and kitchen fixtures, flooring, and rewiring were not included in the energy cost analysis.

All improvements were implemented at once, before resale. Researchers posit that the foreclosed home retrofit findings are relevant to the home-owning public, who has the opportunity to address a package of energy-related improvements as part of a home resale or an equity-drawing home refinance.

1.2 Stakeholder Need

Partners repeatedly requested a standardized approach or cost-effective improvement package that could be adopted program-wide. They preferred this path over conducting in-depth audits and analyses of individual homes, because of the associated time and burdens and because professionals are not readily available in all communities for these activities. Before this study, BA-PIRC did not have such a resource. The best practices proposed in this report are meant to respond to this need and lay out strategies to reach the Building America 30% energy-saving renovation goal for the hot-humid climate.

1.3 Analysis Tools and Methods

Before each renovation, researchers conducted a pre-retrofit “test-in” energy audit, produced modeling analysis, and provided recommendations. Partners determined a scope of work and cost estimate needed to bring a home up to market standards *before submitting an offer to purchase each home*. The number of offers far exceeded the number of actual purchases; therefore, conducting audits and analyses before partners acquired the homes was not practical.

The test-in audit included a sketch of the home; envelope measurements; characteristics of all energy-related equipment, materials, and components; whole-house and duct airtightness testing; interzonal pressure measurements; and extensive photographs.

The audit data were used to build a pre-retrofit simulation model. The partner’s scope of work was modeled parametrically to determine projected savings from each improvement. Then, incremental improvements to each specification and additions to the scope of work were modeled parametrically. Last, researchers calculated annual energy cost savings and cash flow for the partner’s package of improvements and the recommended package. All the modeling results were presented in a spreadsheet and discussed with the partner. Partners selected energy improvements based on what they deemed cost appropriate within the broader scope of renovation work and in the context of local market norms.

The Building America program has standardized methods for calculating projected energy savings which are delineated in the Building America House Simulation Protocols[2] (Hendron and Engebrecht 2010) and the 2012 Addendum (Engebrecht Metzger et al. 2012). For existing homes, comparison of actual energy use before and after renovation would be preferable; however, these homes were unoccupied. In such cases, the protocol calls for comparing whole-

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[2] The Building America benchmark home is used to characterize savings in new construction only.

house annual energy use simulations for the pre- and post-retrofit characteristics using Building Energy Optimization (BEopt) modeling software. At the time this study was conducted, however, BEopt could not model the mechanical equipment frequently present in the subject homes. Therefore, it could not be used for analysis and partner decision making. However, BEopt analysis shows that a package of the eight most common improvements produced 34% source energy savings in a base house that reasonably represents the dataset (with seasonal energy efficiency ratio [SEER] 10 air conditioning [AC]). Results are included in Appendix A.

Because heating, ventilation, and air conditioning (HVAC) equipment efficiency improvement was a central element of whole-house energy savings, researchers used an alternate simulation program, EGUSA, with the same modeling protocols. One caveat to this substitution is that EGUSA does not have detailed occupancy input called for in the protocols. To maintain standardization across multiple analysts, the occupancy, appliance, lighting, and thermostat settings for the 2006 Home Energy Rating System (HERS) Reference home were used.

In addition to annual energy savings targets, researchers targeted a 30% improvement in whole-house energy efficiency using the HERS Index. This metric accounts for differences in fuel mix among the homes, normalizes the effect of conditioned house size, and uses a standardized reference house. It was familiar to many partners because they had already worked with the metric in new construction activities. These characteristics are helpful for interpreting changes across a set of homes. Researchers also promoted the health, durability, and comfort guidelines outlined in DOE’s Builders Challenge Program (Version 1) Quality Criteria (DOE 2009).

To reiterate, the research objectives were to document typical characteristics and retrofit practices and to identify cost-effective best practices for reaching Building America goals. Typical characteristics and retrofit practices are presented in Section 2. Analysis of homes that achieved 30% improvement follows in Section 3.

2 Dataset Characterization and Retrofit Trends

2.1 Dataset Overview

The final dataset of 70 homes included homes in Alachua, Brevard, Orange, Sarasota, and Volusia Counties, all in Florida (Table 2).

Table 2. Final Disposition of All 70 Study Houses, by Partner

Partner	Homes in Final Dataset
Alachua County Housing Programs	4
City of Palm Bay Housing and Neighborhood Development Services	2
Brevard County Housing and Human Services Department	20
Orange County Housing and Community Development	2
Sarasota Office of Housing and Community Development including:	22
Community Housing Trust of Sarasota County, Inc. (12)	
Greater Newtown Community Redevelopment Corporation (4)	
Habitat for Humanity of Sarasota, Inc. (6)	
Volusia County Community Assistance	20
Total	70

The typical configuration was a three-bedroom, two-bath, concrete block, ranch-style floor plan with shingle roof, and almost exclusively, a slab-on-grade foundation. The dataset is composed of 64 single-family detached homes (91%) and six multifamily dwellings (9%). Two of the multifamily dwellings were single-story duplex units. Two were two-story duplex units, and two were condominiums. Figure 6 and Figure 7 show the year of construction and conditioned area for the dataset.

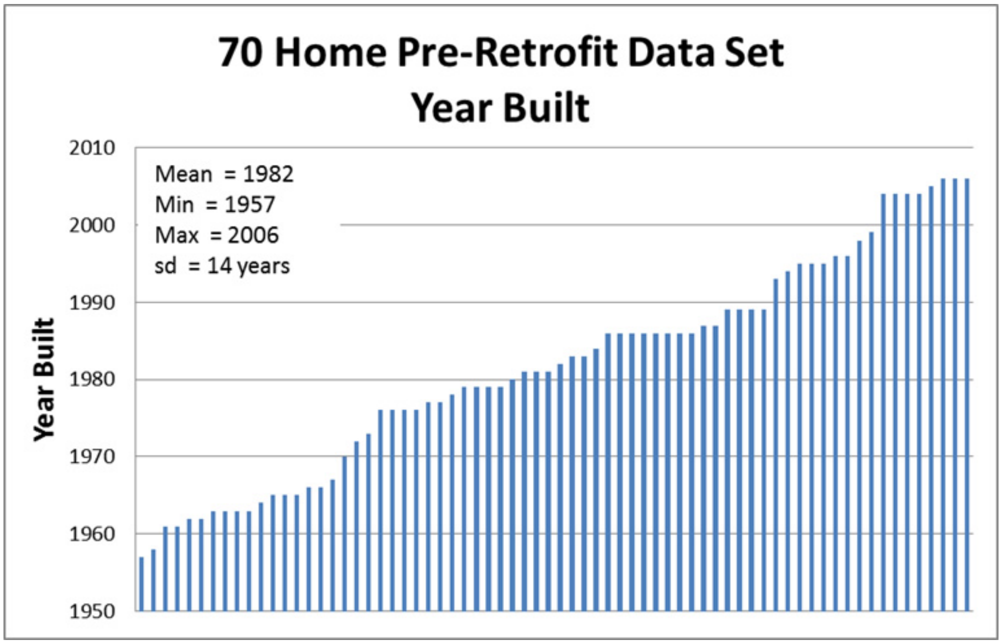

Figure 6. Vintage of the 70 home dataset spanned 49 years

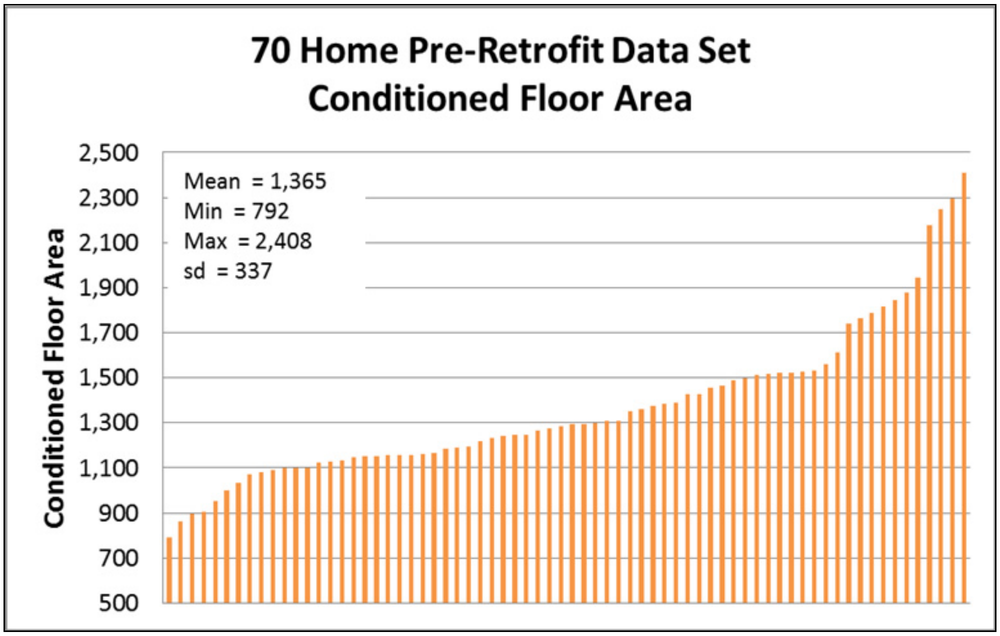

Figure 7. Conditioned floor area for the pre-retrofit dataset

The oldest home was built in 1957 and the most recent in 2006 (Figure 6). The mean year of construction was 1982, with a standard deviation (sd) of 13.8 years. Home size ranged from 792 to 2,408 ft^2, with an average of 1,365 ft^2 (Figure 7).

Pre-retrofit HERS Indices ranged from 95 to 184. There is a general trend for newer homes to have lower (better) HERS Indices because of improvements in the Florida Energy Code, appliance standards, and installation practices. However, some older homes in the study had lower HERS Index scores because of previous efficiency improvements. This is reflected also in the estimated annual energy cost, which ranged from $1,253 to $3,101 for the 70-home dataset.

2.2 Thermal Envelope Components

2.2.1 Exterior Wall Construction and Insulation

Painted stucco over wood frame or concrete block describes the exterior wall finish of nearly every study home, a style typical of the Florida housing stock (Figure 8). A few older study homes were painted concrete block with no stucco, and a few had vinyl siding. Forty-one homes (59%) were constructed entirely with concrete block walls and 22 (31%) were all frame. The remaining seven (10%) were a combination of block and frame (Table 3).

Figure 8. Typical wall construction of light color paint on stucco finish over concrete block

Table 3. Pre-Retrofit Exterior Wall Construction for 70-Home Dataset

Vintage	Concrete Block	2 × 4 Wood Frame	Combination of Block and Frame	Total
1950s	1		1	2
1960s	13	1	1	15
1970s	10	3	1	14
1980s	4	16	2	22
1990s	6	2	1	9
2000s	7		1	8
Total	41	22	7	70
Percent of Total	59%	31%	10%	

Because none of the retrofits in this study was a gut rehab, the wall insulation values could not be assessed visually. Given that conductive wall heat gain is relatively low in this climate, auditors chose to make assumptions about the insulation values based on convention at the time of construction rather than take invasive action.

Older concrete block walls were assumed to be uninsulated; newer ones were assumed to be consistent with the conventional practice of installing a radiant barrier product on furring strips between the block and the drywall. The frame construction homes (predominantly of 1980s or newer vintage) were assumed to have a conventional wall insulation value of R-11. These assumptions were applied respectively in homes with a combination of block and frame, which were primarily block homes with an addition or enclosure of a porch or garage.

Wall R-values were unchanged at post-retrofit for all the homes where the conditioned area was unchanged, except in one home where two uninsulated frame walls were opened and insulated with R-13 fiberglass batts. The latter was included in the best practices for gut rehab or other situations that expose frame wall cavities.

2.2.2 *Exterior Wall Solar Absorptance*

Solar absorptance values of exterior wall color were not measured at either pre- or post-retrofit. Researchers used the EGUSA default values in the modeling software, which are based on a compilation of sources. The default solar absorptance was 0.8 for dark exterior walls, 0.6–0.7 for medium, 0.5 for light, and 0.4 for white. Exterior wall color at pre-retrofit was judged to be dark on 16 houses, medium on 24 houses, light on 27 houses, and white on 3 houses.

For houses being painted, many partners allowed buyer input. Choices included a mixture of buyer and partner preferences. Light or white finishes for exterior walls provide only a modest annual energy savings over medium and dark colors; however, there is no cost associated when a home is slated to be painted. In 20 of the 30 homes that were repainted or received new vinyl siding, a white or light color was selected (Table 4). Light exterior wall finish was chosen for inclusion in the best practices.

Table 4. Exterior Wall Color Pre- Versus Post-Retrofit

	Post-Retrofit			
Pre-Retrofit	**Dark**	**Medium**	**Light**	**White**
Dark	3	2	4	
Medium		2	5	2
Light		2	7	1
White		1	1	
Total Repainted/Resided (n = 30)	3	7	17	3

2.2.3 Windows

Windows were characterized by window type, number of panes (single or double), frame material (wood, metal, insulated metal, or vinyl), window area, horizontal depth of overhang, and vertical separation from overhang. Only six homes had double-pane windows, all with clear glass. Eleven homes had single-pane tinted windows, which were either original or had applied film. The remaining 53 homes had single-pane clear windows. Pre-retrofit windows were almost exclusively metal frame units. Typically, older homes had awning-style operation (Figure 9) or, less frequently, jalousie. Homes built during or since the 1980s were typically single-hung or horizontal slider operation.

Figure 9. Typical awning-style window type

In the hot-humid climate, thermal conduction through windows has much less impact on energy consumption than does the radiant solar heat gain. The solar heat gain coefficient (SHGC) and U-values were unknown in all pre-retrofit cases. Defaults in the modeling software were applied based on the number of panes, presence of tinting, and frame material. For example, a single-pane window with clear glass and a metal frame (the typical pre-retrofit scenario) was assigned an SHGC of 0.80 and a U-value of 1.20. In contrast, post-retrofit window specifications were nearly always known from National Fenestration Rating Council labels. In a few cases, partners did not leave the labels adhered to windows for researchers' post-retrofit observations; in those cases, assumptions were made.

Based on these assumptions, the SHGC was reduced in 49 homes (70%). In 43 homes (61%), the SHGC improvements were achieved with window replacement. In the other six homes with improved SHGC, window film was applied on the glass surface facing the interior of the home. A reduction of 0.42 in SHGC was the overall average for homes with window improvement measures. Generally, all windows in a given home would be upgraded. All newly installed windows would typically have the same—or nearly the same—specifications. In eight cases, the total window area was reduced. In one home, the total window area increased.

Windows were replaced, first and foremost, because they were no longer functional or were not acceptable for some other reason (such as aesthetics) in the current market. Partners could have elected to replace them with new, minimum performance windows. However, they typically chose higher performance units, which reduced heat gain and associated cooling energy use.

In 27 homes, the windows were in good working order or needed only minor repairs. For single- or double-pane clear windows left in place, researchers always recommended installing window film to reduce the solar heat gain. Partners elected not to do so in 21 homes where they deemed the windows to be acceptable in current market conditions. In some cases, site shading reduced the potential benefit of film application. Researchers also found, anecdotally, that the decision was based on use of funds for higher priority elements of the renovation, not necessarily energy-related improvements.

The most common replacement window type was double-pane, low-e, vinyl frame, single-hung with an SHGC of 0.20–0.40 (Table 5). These windows also feature a lower U-value that comes from the insulative quality of double-pane glazing and vinyl frame. The U-value of replacement windows ranged from 0.55 to 0.8 (Table 6). Although the conductive heat gain through windows is largely eclipsed by radiant gain in the hot-humid climate, double-pane windows have nonetheless become the norm in central Florida.

Table 5. SHGC of Replacement Windows

SHGC Ranges*	Houses (Total of 43)	% of Houses
0.40–0.63	11	26%
0.2–0.4	32	74%
*Based on the primary replacement window type in each house (excludes window film)		

Table 6. U-Values of Replacement Windows

U-Value*	Houses (Total of 43)	% of Houses	Description
> 0.80	2	5%	Single pane, metal
0.55–0.80	8	19%	Double pane, metal
< 0.55	33	77%	Double pane, vinyl

*Based on the primary replacement in each house (excludes window film)

Many partners specified ENERGY STAR® windows in their work orders. This is easier for the partners and the contractors than numeric specifications for SHGC and U-value. In the early stages of the project, Version 4 of the ENERGY STAR Window Standard was in effect, supplanted by Version 5 in 2010. For the central Florida region, Version 4 set a maximum allowable SHGC of 0.4 and U-value of 0.65. Replacement windows in 28 homes met the Version 4 requirements. Of the 28, replacement windows in 14 homes met the more stringent requirements of Version 5 that set a maximum SHGC of 0.27 and U-value of 0.60. ENERGY STAR-qualified windows (Version 5) were incorporated into the best practices for replacement windows and application of window film with low SHGC and high visible transmittance to clear windows being left in place.

Based on reported costs, window replacements cannot be justified on payback from annual energy savings. However, if windows need to be replaced for cosmetic or functionality reasons, the incrementally higher cost for double-pane, low-e windows (over minimum replacement) may be justifiable based on projected annual energy cost savings. This depends on the actual incremental cost in the local market and warrants careful consideration aided by projected savings modeling. Regardless of annual cash flow implications, a missed opportunity to choose higher performance replacement windows will likely not arise again for two or more decades. The cost of a high performance window film with a low SHGC or shading coefficient can be justified for clear windows left in place.

As a final note on window replacements, the window type sometimes had great impact on whole-house airtightness. Jalousie and awning windows often did not close completely at pre-retrofit, creating extensive air infiltration paths (see Figure 10). The window in its most closed position is still slightly open. The red line indicates the pitch of the closed pane. If the window closed completely, the frame edge and red line would be vertical rather than pitched. In addition to efficiency gains from reducing solar heat gain and thermal conductance, replacing such poorly closing windows has the added benefit of large infiltration reductions. Air sealing between the window frame and rough opening likewise enhances the infiltration reduction. This third airtightening benefit of window replacement is reflected in the whole-house airtightness testing at the test-out audit (see Section 2.3); however, it is not accounted for in the cost associated with the infiltration reduction measure.

Figure 10. Pre-retrofit awning window in its most closed position is still slightly open, as indicated by the pitch of the red line.

2.2.4 Roof

Florida does not have a snow load that requires the steeper roof pitches found in mixed and cold climates. However, homes in the dataset built in the 1980s or later had steeper roof pitches consistent with changing design preferences (Figure 11). Twenty-six (37%) homes had a shallow roof pitch of ≤ 3.5:12 (Figure 12), 24 (34%) had a roof pitch of 4:12, and the remaining 20 homes had a mixture of steeper pitches (Figure 11).

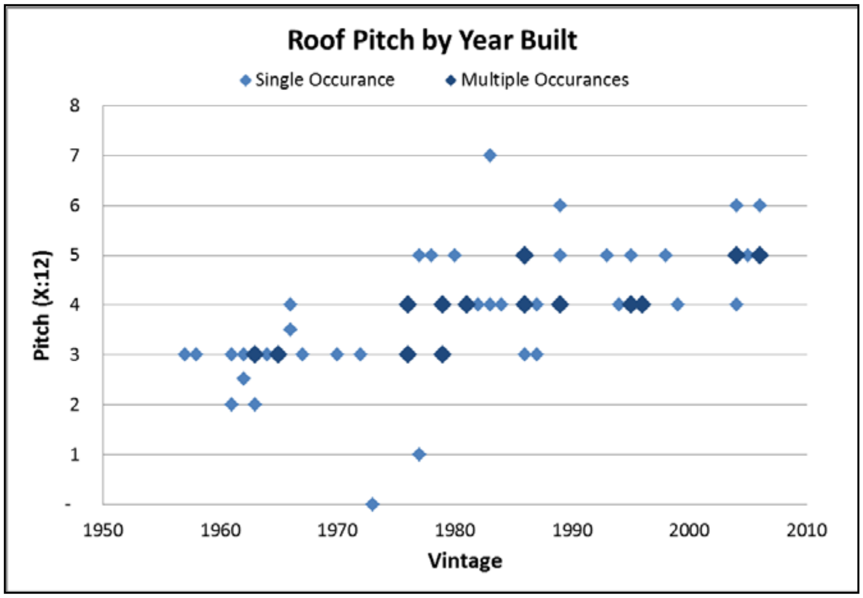

Figure 11. Roof pitch plotted by vintage displays trend of older homes with shallower pitch n = 70

Figure 12. Typical shallow roof pitch of Florida homes built before 1980

The prevalence of shallow roof pitch has implications for potential roof and attic energy improvements. In 58 of the 70 homes, partners elected to add ceiling insulation, and blown-in fiberglass was by far the predominant choice. Attaining the desired R-value throughout the entire attic space was often not possible, given the confined space of shallow roof pitches, presence of air distribution ducts, and truss framing (see Section 2.2.5). The shallow roof pitch and cramped attic also ruled out retrofitting an attic radiant barrier, which was not included in any of the homes. If complete roof deck replacement had been needed, radiant barrier-backed decking would have been recommended; however, the need to replace damaged sheathing would have been determined by the roofing contractor after the exterior roofing material was removed (after the pre-retrofit analysis was completed), rather than specified in the scope of work.

Sixty-eight of the 70 houses had asphalt shingle roof coverings.[3] The solar absorptance was not measured as part of the energy audits. Simulation software defaults were used based on the researchers' observations of shingle color. A qualitative assessment of pre-retrofit roof color reveals that medium colors were predominant in the dataset, followed by dark colors (Table 7).

Table 7. Roof Shingle Color

	Post-Retrofit Color			
Pre-Retrofit Color	**Dark**	**Medium**	**Light**	**White**
Dark	1	6	2	2
Medium	1	12	3	4
Light	1	2	1	0
White	0	0	0	1
Total Replaced (n = 36)	3	20	6	7

Replacement of roof finish was a common part of the retrofits. For the 36 renovations calling for shingle replacement, researchers recommended a light or white color. Compared to the homes'

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[3] One house had a metal roof. It was not replaced. One house had a white tile roof that was replaced with light shingles.

original shingle colors, partners selected a lighter shade for 17 homes, the same shade for 14 homes, and a darker shade for 5 homes. Medium was the predominant choice. The recommended light or white (Table 7) shingles were installed on only 13 homes. Anecdotally, researchers learned this was driven by partner or buyer preference.

There is not a large difference in solar absorptance between dark and white shingles; therefore, this choice does not make a major impact on the simulated cooling load. However, the modest improvement (approximately 1% annual energy cost) from a lighter shade comes at no additional cost when shingles are being replaced. For this reason, researchers elected to retain the recommendation of light or white replacement shingles in the current best practices rather than the color chosen most often.

2.2.5 Ceiling Insulation

With few exceptions, homes had vented attics with some level of batt or blown insulation (Figure 13) applied to the attic floor, except in two cases that had no insulation. The pre-retrofit R-value was not precisely known and had to be estimated based on visual inspection. Typically, a section of the ceiling insulation depth could be measured. Researchers' estimates of pre-retrofit ceiling insulation values ranged from R-0 to R-34 (average R-16), with about 75% between R-9 and R-25. Improving the ceiling insulation level was among the most common retrofit measures included in 58 retrofits (83%) (Table 8).

Figure 13. Typical pre-retrofit ceiling insulation condition

Table 8. Ceiling Insulation R-Values

	< R-19	R-19	R-25	R-30	R-38	> R-38
Did Not Add Insulation (n = 12)	2	4	3	3		0
Added Insulation To Achieve (n = 58)				21	36	1

Achieving R-30 or greater ceiling insulation was recommended for all homes. Over 60% of homes with added insulation achieved R-38, which was incorporated into the best practices.

In 12 homes, however, the partners elected not to add ceiling insulation. Six were built between 2004 and 2006; their insulation values were estimated at R-25–R-30. The expense of adding an insulation was deemed not justifiable for the projected energy savings. The two homes with insulation below R-19 had no accessible attic space. The ceiling finish was formed or attached to single assembly roof or very shallow cathedral style trusses. Of the four R-19 homes, the scope of work in one was limited to equipment replacement and window repair. In the other three, partners prioritized other work over ceiling insulation, but achieved 13%–22% annual energy cost savings and 21%–28% HERS Index improvement through a combination of equipment and window measures.

Typically, ceiling insulation retrofit consisted of blown-in fiberglass on top of existing insulation of various types to achieve the total desired insulation value, rather than removal of existing insulation. Often, researchers observed forced-air ductwork that was not strapped in place above the insulation and was partially buried after insulation was blown into the attic. Although strapping is required by the Florida Residential Mechanical Code for new construction, it is not required for mechanical system change-outs. Where ducts are partially or completely buried under insulation (Figure 14), moisture may condense on the outer surface of the duct if the insulation causes the surface temperature to drop below the dew point of the humid attic air. Duct leakage can increase this risk. Based on these durability concerns, researchers included the mechanical code guidelines for supporting flexible ducts above attic insulation that are required for new construction in the best practices. In other research, the Building America program is investigating the effects and benefits of covering attic-mounted ducts with insulation.

Figure 14. Post-retrofit ducts buried by blown-in fiberglass

Another concern that warrants follow-up investigation concerns attic ventilation. Though recommended, researchers encountered only one contractor who made it standard practice to install ventilation baffles and dams over the exterior wall top plates before blowing in insulation. Other contractors cited roof pitch and attic access issues as the reasons this was not done. No doubt, the labor to install these materials would have increased the ceiling insulation expense, which would need to be factored into the cost analysis. The resulting attic airflow dynamics were pointed out to the partners as an area of concern with potential moisture and thermal performance implications; however, direct investigation was outside the scope of the study.

Post-retrofit, insulation thickness usually varied throughout the attic space. The shallow roof pitch and typical truss configuration of older homes often limit access in the attic and restrict space for insulation over the exterior wall top plates to only a few inches. Insulation was generally deeper under the ridges of the attics. Rather than estimating an effective insulation level, the full purchased insulation value was used in the simulations. For example, if the partner paid the contractor to bring the insulation up to R-30, this value was used in the post-retrofit simulations based on the assumption that the deep and shallow portions averaged out to the specified R-value. Steeper pitched roofs typically afforded adequate room for the desired depth of insulation throughout the attic, extending to the exterior wall top plates.

Attic access was typically through a hatch in a central hallway, closet, or garage ceiling. Researchers recommended gluing rigid insulation or stapling a fiberglass batt to the back of the hatch cover. The audit procedure did not specifically track this detail; however, auditors agree that it was rarely, if ever, executed. When contractors are primarily or exclusively installing blown-in insulation, neither rigid nor batt insulation is commonly on hand.

2.3 Building Infiltration

Even though reducing infiltration is not a major savings for homes in the hot-humid climate, (because of the low temperature difference between indoors and out) gaining control over airflow is essential for achieving good indoor air quality, controlling air-transported moisture, and enhancing comfort. Cummings et al. (1990; 2012) showed that mechanically induced infiltration introduces heat and moisture, even when the drivers of natural infiltration are weak. The ceiling plane tends to be the primary infiltration path in slab-on-grade, concrete block homes.

The pre- and post-retrofit retrofit audits included a standard test for estimating whole-house airtightness and infiltration (RESNET 2006). Whole-house airtightness (ACH50) is calculated as air changes per hour measured at a test pressure of negative 50 Pa with respect to the outside, divided by the building volume. By using a measurement that is normalized by conditioned volume, the relative airtightness of different size homes can be compared. Researchers recommended a target maximum ACH50 of 6, which is similar to minimum code, new construction homes in Florida.

Researchers were able to conduct whole-house airtightness tests in 60 homes at pre-retrofit and in 69 homes at post-retrofit. In 10 homes, it was not possible to conduct pre-retrofit whole-house testing because of health concerns or large missing sections of drywall. The overlap of pre- and post-retrofit testing created a set of 59 homes. Whole-house airtightness test results are plotted in Figure 15 by vintage for pre- and post-retrofit.

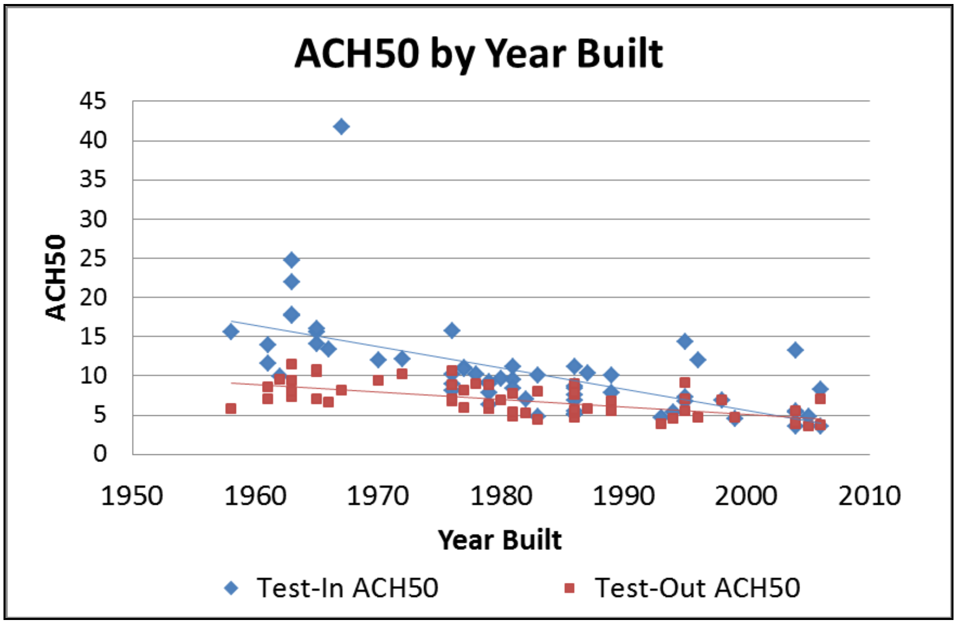

Figure 15. Scatter plot for whole-house airtightness test results (ACH50) by vintage for homes tested pre- and post-retrofit (n = 59)

For the 59 homes, pre-retrofit ACH50 ranged from 3.6 to 41.8 with an average of 10.5. All but one home had ACH50 < 25. When test-in results were high, auditors identified airflow pathways and provided that information to the partner. In Florida's hot-humid climate, high infiltration rates are less detrimental than they are in climates with larger temperature differentials between outside and conditioned spaces. It is less beneficial and less cost effective to expend labor on *extensive* air sealing efforts in the hot-humid climate. Air sealing efforts necessary to achieve the target ACH50 test result include sealing around drywall penetrations (for supply and return registers, dryer vents, wiring, lighting and fan fixtures, and plumbing), replacing missing plumbing access panels, correcting poor window and door closure, eliminating recessed lighting, and installing gaskets at attic access panels in the conditioned space (Figure 10 and Figure 16).

Figure 16. Pre-retrofit drywall penetrations: The ceiling fixture was removed, but penetration to the attic was unsealed (left); plumbing access in the wall covered with a return grille rather than a solid cover or patch (center); large opening beneath the bathroom vanity where block and drywall were removed as part of an incomplete renovation (right).

A list of important infiltration points to investigate was developed for the pre-retrofit audit process. Identified problem areas were provided to partners to ensure air sealing efforts addressed the highest priorities. Researchers found that these leakage points were not common knowledge to partners. Therefore, a list of the most important air sealing sites is included in the best practices (see Appendix C) to guide air sealing efforts to the most likely sources of uncontrolled airflow.

Whole-house airtightness was improved in 51 cases by 35% on average (Table 9). Post-retrofit ACH50 ranged from 3.5 to 11.5. All but five homes achieved ACH50 < 10.0, and 30 achieved the target ACH50 of 6.0. The highest reductions were seen in the 13 homes built in the 1950s and 1960s (Table 9), in which the mean ACH50 was reduced by more than half but still tended to be higher at post-retrofit than houses of newer vintage. Whether looking at pre- or post-retrofit, newer homes tend to be more airtight, though the tendency is much more subtle post-retrofit. Note the low post-retrofit sd within each decade and the similarity of post-retrofit ACH50 across the decades. This suggests that, with this building type, whole-house airtightness levels similar to new construction (ACH50 ≤ 6.0) can be achieved in vintages newer than the 1960s, regardless of pre-retrofit degree of airtightness. Among the 1960s homes (and one 1958 home), ACH50 ranged from 5.8 to 11.5, suggesting that the target ACH50 is possible but may require more diligence for homes of this age. Based on these finding, a target ACH50 ≤ 6.0 is included in the best practices.

Table 9. Pre- and Post-Retrofit Whole-House Airtightness (ACH50) and Improvement by Decade

59 Homes Tested at Pre- and Post-Retrofit		Pre-Retrofit ACH50		Post-Retrofit ACH50		Airtightness Improvement	
Decade	Number of Houses	Average	sd	Average	sd	Average	Percent
1950s	1	15.6	–	5.8	–	9.8	63%
1960s	12	18.2	8.5	8.7	1.6	9.5	52%
1970s	13	10.1	2.4	7.9	1.7	2.2	22%
1980s	18	8.2	2.1	6.2	1.3	2.0	24%
1990s	8	7.7	3.6	5.8	1.7	1.9	25%
2000+	7	6.3	3.4	4.5	1.3	1.8	29%
Average		10.5	6.0	6.8	2.0	3.7	35%

The home with pre-retrofit ACH50 of 41.8 was built in 1967 and had severe window closure and drywall penetration issues (Figure 10). After a window change-out and other improvements, the ACH50 dropped to 8.1.

A common infiltration path that sometimes remained post-retrofit was located at the ceiling of the air handler unit (AHU) closet (Figure 17). Contractors often did not seal the gap around the supply plenum at the ceiling drywall. Access to this gap is complicated by closets that were designed for smaller AHUs.

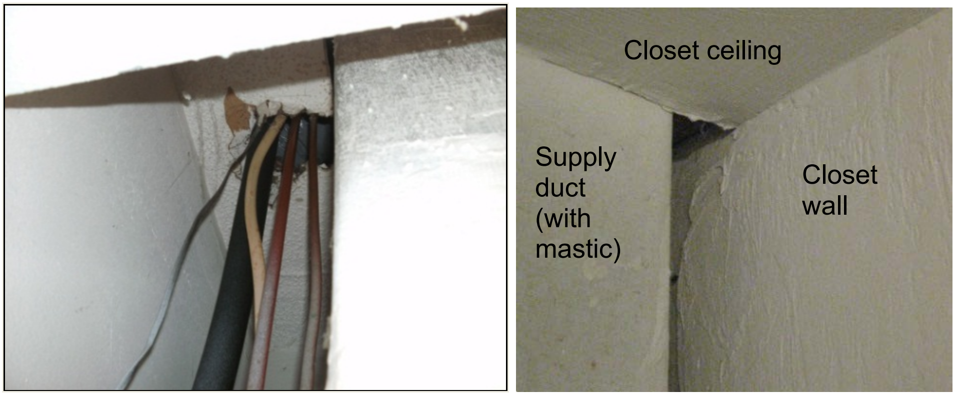

Figure 17. Gaps or holes at ceiling of AHU closet

In two cases where whole-house airtightness was not improved it was virtually unchanged. In five cases, the leakage was marginally increased (≤ 6%); however, in one home the leakage nearly doubled. The airflow paths included unsealed penetrations near the new bathroom vanity and the kitchen exhaust hood (Figure 18).

Figure 18. Post-retrofit: Unsealed range hood penetration through top of cabinet into the attic

Although post-retrofit airtightness could not be precisely predicted, researchers anticipated that ACH50 test results might be very low given that duct and air barrier sealing measures were likely in all homes. Therefore, whole-house, outside air ventilation was recommended for every house (see Section 2.4.6) and included in the best practices.

2.4 Mechanical Space Conditioning Systems

At pre-retrofit, all 70 homes in the dataset had forced-air, central AC systems with single, centrally located returns. The heating fuel in 64 of the homes was electricity, either heat pump or an electric resistance coil integrated into the central AHU. The remainder had naturally aspirated gas furnaces. AHUs were located in the main living space in 40 (57%) homes, the garage in 21 (30%) homes, the attic in 6 (9%) homes, and outside in 3 homes (4%). None of the homes had more than one mechanical system. Mechanical equipment efficiency and size, AHU configuration, duct heat transfer, duct airtightness, outside air ventilation, and thermostats are detailed in Sections 2.4.1–2.4.7.

2.4.1 Mechanical Equipment Efficiency, Pre-Retrofit

With few exceptions, the mechanical systems' rated heating and cooling efficiencies were identifiable at pre-retrofit by looking up model numbers in the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) Directory of Certified Product Performance. However, occasionally name plate labels were too worn to read, and in a few cases the compressor had been stolen. In those cases, researchers made assumptions based on the rated efficiencies of the AHUs or furnaces, partially identifiable model numbers, and estimating the age of the systems and using the minimum efficiencies available at that time.

The Building America House Simulation protocols call for adjusting rated efficiency for equipment age and maintenance level. Neither was known for these homes. Rather than make assumptions, researchers did not derate equipment efficiencies. The rated cooling and heating efficiencies, when known, were consistently modeled in all 70 homes.

By assuming rated efficiency for pre-retrofit simulations, we ensure that savings projections from equipment replacement are conservative and that savings across the dataset are not influenced by variance in auditor assessment. Researches commonly observed conditioning equipment with combinations of significant corrosion, rust, clogged coils, crimped or punctured condensate lines, missing access panels, and tangled wiring (Figure 19). Pre-retrofit cooling and heating efficiencies for the 70-home dataset are plotted in Figure 20 and Figure 21.

Figure 19. Looking up at pre-retrofit clogged, dirty cooling coils in the AHU (left); corroded and clogged cooling coil (right)

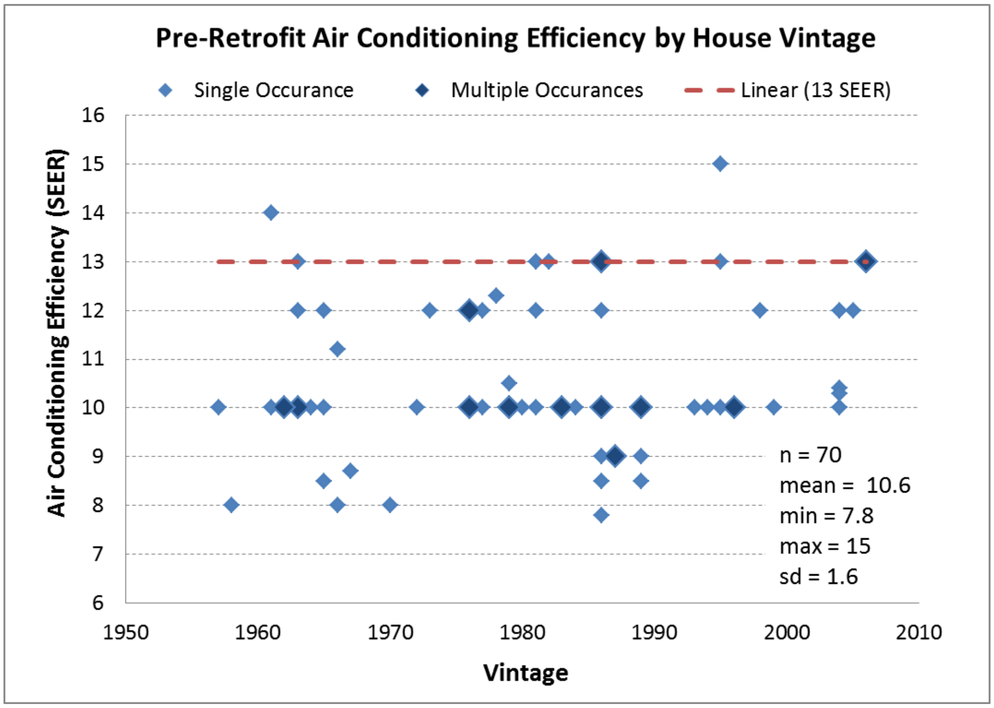

Figure 20. Pre-retrofit AC efficiencies (SEER) by house vintage (n = 70)

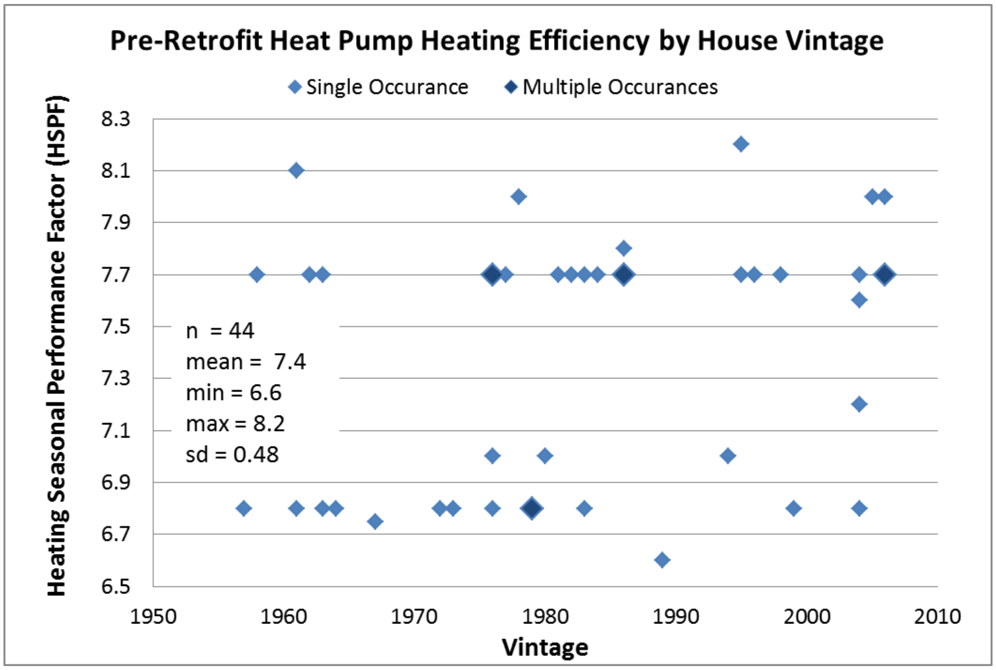

Figure 21. Pre-retrofit heat pump heating efficiencies by house vintage (n = 70)

The pre-retrofit cooling efficiencies, including some estimates as described above, ranged from SEER 7.8 to 15, with a mean of SEER 10.6, and an sd of 1.6 (Figure 20). Only 10% met or exceeded SEER 13, the current federal minimum efficiency allowed for AC manufacture and sale, denoted by the red line in Figure 20. Over 60% of the AC equipment (43 units) was SEER 10 or lower efficiency. For many of these homes, installing an air conditioner with a SEER of 13 would have been a dramatic improvement. Note that savings (and costs) for higher SEER AC replacements are quantified in comparison to this federal minimum, because nothing lower could have been installed. For example, annual energy cost for a SEER 15 replacement was compared to the annual energy cost for a SEER 13 replacement, rather than the original SEER 8 equipment. For more detailed discussion of this concept, see Appendix B.

Heating systems were predominantly electric. Twenty homes had central electric resistance heating systems (coefficient of performance [COP] of 1), which is sometimes referred to as an electric furnace. The remaining 44 homes had air source electric heat pumps. Figure 21 shows that pre-retrofit heat pump heating efficiencies ranged from 6.6 to 8.2 heating seasonal performance factor (HSPF), with a mean of 7.4 (sd = 0.48). Six homes had gas furnaces at pre-retrofit with efficiencies ranging from 0.76 to 0.80 annual fuel utilization efficiency (AFUE).

Mechanical equipment was replaced in 61 homes (87%). In 40 cases, a central air source electric heat pump was replaced with one of higher efficiency. Partners replaced 18 of the 20 electric resistance systems with heat pumps. In three homes, a naturally aspirated gas furnace with straight AC was replaced with like equipment. Post-retrofit, the mechanical systems' rated efficiencies were always determined using the AHRI directory. Table 10 and Figure 22 show pre- and post-cooling efficiency.

Table 10. Pre-Renovation and Post-Renovation AC Efficiencies

		Replacement SEER Rating			
		13–13.9	**14–14.9**	**15–15.9**	**16–16.2**
Pre-Retrofit SEER Rating	<10	1		7	4
	10–10.9	4	2	16	9
	11–11.9				1
	12–12.9		2	4	4
	13–13.9			4	2
	14–14.9			1	
Total Replaced (n = 61)		5	4	32	20

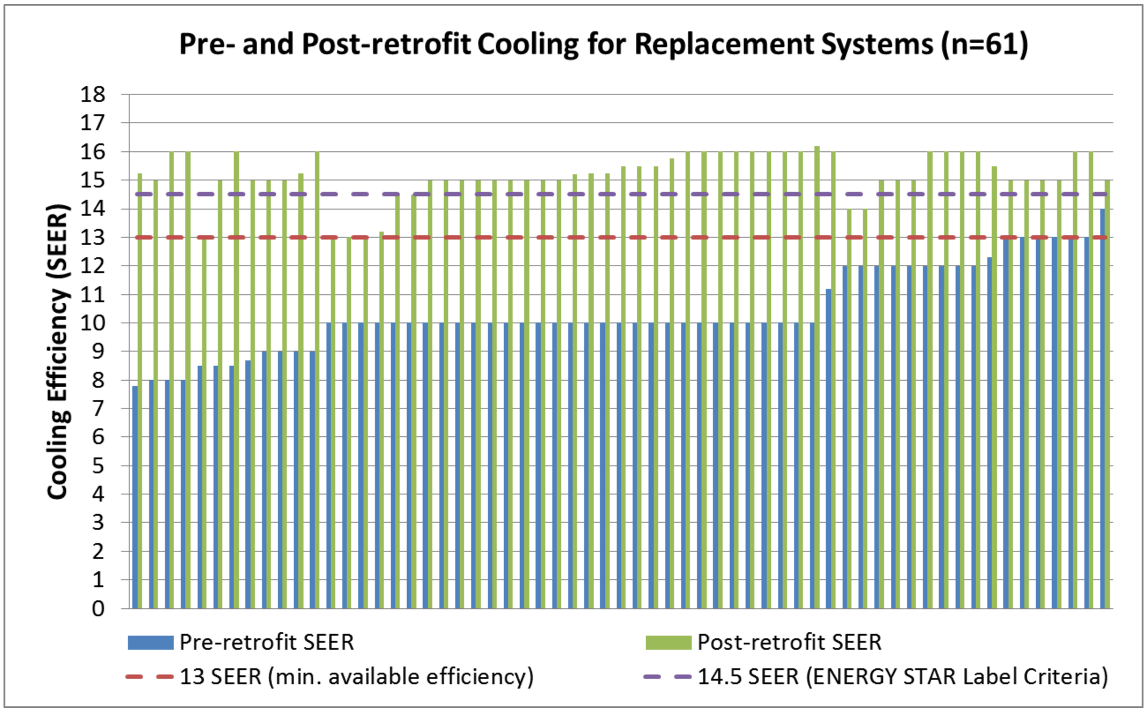

Figure 22. Mechanical system cooling efficiency at pre- and post-retrofit audit

Average SEER improvement was 49%. All the SEER 10 and lower units were replaced. One home had its compressor replaced with a like kind. Only five of the 61 replacements were SEER 13 units, the current federal minimum efficiency. Only two others fell below 14.5, the current specification for ENERGY STAR-labeled air conditioners (dashed purple line on Figure 22). The rest were SEER 15 or higher with a maximum of 16.2. In two cases, cooling efficiency doubled from SEER 8 to SEER 16.

Replacement heat pump heating efficiencies ranged from 7.7 to 9.5 HSPF with an average of 8.6. Only five fell below the ENERGY STAR equipment HSPF requirement of 8.2. HSPF ratings are tied directly to heat pump cooling efficiency, which is the primary equipment selection driver in the hot-humid climate. As heat pump cooling efficiency rises, so does heating efficiency.

The best practices call for ENERGY STAR-labeled replacement equipment.

For the nine homes where equipment was not replaced, researchers recommended that it be serviced and that other HVAC system improvements such as duct tightening be implemented. In six of these cases, the equipment left in place had a SEER of 13 or higher. Five were heat pumps; one was electric resistance. In three homes, equipment with a SEER slightly over 10 was left in place (two heat pumps and one electric resistance). In each of these homes, the equipment was functional and deemed by partners as acceptable for market conditions.

2.4.2 Mechanical Equipment Size

During the course of this study, mechanical equipment sizing calculations were required for new construction in Florida but not for replacements. In 2012, the Florida Energy Code changed to require sizing calculations for replacements. Regardless of requirements, researchers recommended that conditioning equipment be sized using ACCA Manual J calculations or equivalent. Matching equipment size to load improves humidity control compared to oversized equipment. Table 11 shows change in cooling capacity.

Table 11. Change in Cooling Capacity Post-Retrofit

	Number of Systems (Total = 61)
24 kBtu Smaller (12 kBtu = 1 ton)	1
~12 kBtu Smaller	5
~6 kBtu Smaller	11
No or Minor Change (± 2 kBtu)	30
~6 kBtu Larger	11
~12 kBtu Larger	3

The test-out audit procedure did not include collecting sizing calculations. Anecdotally, it did not appear that mechanical contractors were providing them to the partners, whether or not they were doing calculations. AHRI data, when available, were used to determine equipment capacity pre- and post-retrofit. Half the replacement cooling equipment (30 homes) was within ±2 kBtu of the original equipment capacity. Twenty-two systems were approximately ±6 kBtu (0.5 tons) smaller or larger. Three systems were essentially 12 kBtu (1 ton) larger and five were one ton smaller. One replacement system was 24 kBtu (2 tons) smaller than the original equipment.

2.4.3 Air Handler Unit Location and Configuration

The AHU, the heart of the air distribution system, was located in the conditioned space (“interior”) in 40 cases (57%), in the garage in 21 cases (30%), in the attic in six cases (9%), and outdoors in three cases (4%). The dataset shows a clear trend toward interior AHU closets in homes built before the 1990s (Figure 23). In only four retrofits were the AHUs relocated; all four were moved to locations with lower heat gain. In three houses, the AHU was moved into conditioned space, and in the other, it was moved from the attic into the garage.

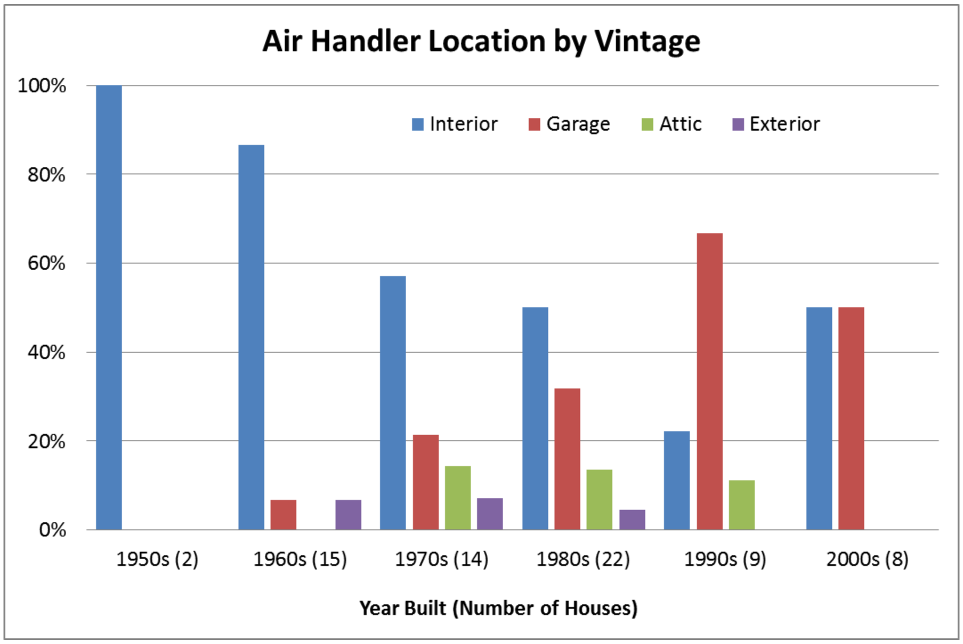

Figure 23. Pre-retrofit, 40 homes had AHUs in the conditioned space, with greater prevalence in homes built before the 1990s (n = 70)

Researchers observed five basic air distribution system configurations:

- **Forty homes.** Upflow AHU in conditioned space, usually in a dedicated closet (Figure 24), mounted on either:
  - A framed AHU platform with a wall-mounted filter-back return grille (Figure 24) and a central return plenum formed by a cavity under the platform. In many homes, the cavity was unfinished (Figure 25, left). Finished cavities were formed by sealed duct board (Figure 25, right) or drywall.
  - A metal AHU stand or framed platform with the filter at the bottom of the AHU and the whole closet constituting the return plenum. The return air path was usually through a louvered door or a grille in the closet door (Figure 26).
- **Nineteen homes.** Upflow AHU on a framed platform in the garage (Figure 27) with plywood or drywall exterior finish and duct board or open framing inside platform forming a return plenum underneath. This is the typical configuration for new Florida homes with garages (except the return plenum must have a sealed interior finish). The return air path is through:
  - A wall-mounted filter-back grille ducted directly into the platform cavity.
  - A ceiling-mounted filter-back grille connected to a flex duct running through the attic to the top of framed platform in the garage.
- **Two homes.** Horizontal flow AHU in the garage (Figure 28, left) with duct board supply and return plenums. The return air path is through a wall- or ceiling-mounted filter-back grille.

- **Six homes.** Attic-mounted horizontal flow AHU (Figure 28, right) with duct board supply and return plenums. The return air path is through a ceiling-mounted filter-back grille.
- **Three homes.** Package unit exterior to house with return air path through a wall-mounted filter-back grille. Two were units typical of manufactured housing (Figure 29, left) and one unit was typical of portable classrooms (Figure 29, right). In all three homes, systems were put together haphazardly with ill-fitting parts, which makes airtight assembly challenging.

Figure 24. Upflow AHUs in conditioned space in a dedicated closet. Interior AHU closets with returns formed by platforms had wall-mounted return grilles with a full door on an adjacent wall (left) or a partial door above (right).

Figure 25. Return plenums were formed by either unfinished, open framing (left) or sealed duct board (right) or drywall.

Figure 26. Interior closets that served as return plenums had louvered doors or door-mounted return grilles.

Figure 27. Upflow AHUs on framed platforms in garage with a wall-mounted filter-back grille were ducted directly into the platform cavity.

Figure 28. Horizontal flow AHUs mounted at ceiling of garage (left) and in the attic (right)

Figure 29. Exterior package units with return air path through a wall-mounted filter-back grille. Ground mounted unit with metal shroud housing main return and supply ducts (left) and wall-hung unit with attic-mounted ducts (right).

The best practices related to AHU replacement are modeled after the Florida Residential Mechanical Code requirements for new homes. These include finished and sealed return air plenum, mechanically fastened and sealed supply plenum connection to the AHU, finished closet walls and ceiling (when applicable), provision of 4-in. clearance around the AHU. Additional best practices not related to new construction code include ACCA Manual D return sizing, sealing the gap between the supply plenum and ceiling drywall, and sealing the gap between the return plenum and the AHU platform.

2.4.4 Duct Heat Transfer

Only two houses had supply ducts in the conditioned space, which is the most desirable location because it minimizes duct heat gain and loss and keeps any duct leakage in the conditioned space. One was a two-story home with a single assembly roof; the supply ducts were located in the floor cavity. The other was a one-story home with exposed roof rafters. It had a supply trunk in a soffit above the central hallway. The remaining 68 homes had attic-mounted supply ducts. Typically, supply duct runs (flex) branch off the main supply plenum (duct board) or a smaller junction box (duct board). In addition to this “spider” style system, which is very common in Florida new construction, researchers observed a smaller number of systems where supply ducts branched off a central supply trunk. Some metal ductwork was observed.

The audit procedure did not specifically track it, but few, if any, homes had fully ducted return air systems that served bedrooms or passive return air pathways from bedrooms. The Florida Residential Mechanical Code has required passive return air pathways for new construction since the 2001 edition; however, the requirement does not apply to replacement systems.

Researchers made efforts to determine the rated insulation value for the mechanical distribution systems pre-retrofit. However, access to duct systems was limited by the shallow, crowded attic conditions described in Sections 2.2.4 and 2.2.5. In some cases where ducts were accessible, material degradation had obscured insulation value labeling. When the insulation value could not be determined, auditors assumed a value based on the estimated age of the material and the convention at that time. The same insulation value was assumed for the entire distribution system.

Supply duct insulation was improved in 21 homes with R-6 duct insulation replacing insulation ranging from R-2 to R-4.3. In the remaining 49 houses, the pre- and post-retrofit duct insulation was the same with 24 at R-6 and 25 lower than that. Florida residential mechanical code has required R-6 duct insulation for new homes since 1991. Although the code does not mandate R-6 for replacement ducts, R-6 has become the norm driven by product availability and was adopted as part of the best practices.

2.4.5 Duct Airtightness

Even without replacing the duct system, duct airtightness improved significantly when the typical return plenum configuration was addressed. This consists of a wood frame platform formed in the lower portion of an AHU closet that supports an upflow AHU. The space below the platform forms a central return plenum. Often the plenum is open to adjacent wall cavities that form the closet. By finishing and sealing the wall cavities or constructing a ducted return air path instead, much of the total duct leakage as well as the duct leakage to the outside can be eliminated. For example, open framing under the AHU platform creates an unintentional airflow path between the attic (via surrounding wall cavities) and the return air plenum. This dynamic is taken to an extreme when the upper portion of the closet is partially or completely open to the attic. This was observed in closets with the above platform configuration as well as in closets where the AHU was mounted on a metal stand instead of a wood platform. In the latter, the whole closet functions as the return plenum, usually connected to the house by through a louvered door.

Pre- and post-retrofit duct airtightness was measured by depressurizing the duct system using a calibrated “duct blaster” fan in accordance with a standard test procedure (RESNET 2006). Duct tightness is expressed in terms of airflow required to achieve a standard test pressure (25 Pa) in the duct system, measured in cubic feet per minute or CFM25.

The test procedure measured both the total leakage (CFM25,total) and leakage involving air outside the conditioned space (CFM25,out). For comparison among different size houses, the CFM25 results are normalized by conditioned floor area of the house yielding Qn,total and Qn,out.

The target maximum Qn,out for the retrofits was 0.06 or 6 CFM/100 ft^2 of conditioned floor area at the standard test pressure. Researchers chose the target as a practical expectation based on extensive experience in both new construction (McIlvaine et. al 2003; Chandra 2004) and in repair of existing houses (Moyer et al. 2001).

A pre-retrofit duct leakage test was conducted in 54 of the homes (77%); it was not performed in 14 homes, generally because the ductwork was visually assessed to be too leaky to test or where depressurization posed health risks. In one case, the AC coils were coated with paint ingested into the system during spray painting (apparently with the AHU running), which blocked airflow. Two homes had problems with the whole-house air barriers, which prevented depressurizing of the whole house and precluded testing for leakage to the outside. Post-retrofit auditing included duct testing in 69 homes. The overlap created a set of 53 homes tested before and after renovation.

Pre-retrofit Qn,out ranged from 0.015 to 0.398 with an average of 0.123 (sd = 0.098). At pre-retrofit, 16 homes met the duct airtightness target of Qn,out ≤ 0.06, ranging in vintage from 1958 to 2004. At the post-retrofit audit, two of those were found to be leakier, but an additional 24 homes met the target, including 18 with Qn,out ≤ 0.03. This level of duct tightness is exemplary. It meets the requirements of new construction above-code programs such as ENERGY STAR and the Builders Challenge. Table 12 presents average duct airtightness results by decade for the set of 53 homes tested before and after renovation.

Table 12. Average Pre- and Post-Retrofit Duct Test Results (Qn,out) by Decade

		Pre-Retrofit		Post-Retrofit	
Decade	**n**	**Qn,out**	**sd**	**Qn,out**	**sd**
1950s	1	0.04	NA	0.07	NA
1960s	11	0.15	0.10	0.06	0.03
1970s	12	0.20	0.13	0.11	0.09
1980s	15	0.09	0.04	0.07	0.04
1990s	7	0.09	0.07	0.06	0.04
2000+	7	0.07	0.05	0.03	0.03
Overall	53	0.12	0.10	0.07	0.06

Of the 53 houses tested before and after retrofit, duct leakage was reduced in 42 (79%) and stayed the same in one (2%). In 10 homes, ducts were leakier after renovation. In three of those, new ductwork had been installed. Six had a noticeable lack of return plenum sealing (Figure 30, left). Five had no dedicated return plenum; rather, the whole AHU closet with a louvered door (Figure 30, center) or door-mounted return grille served as the return plenum surrounding an AHU mounted on a metal stand (Figure 30, right).

Figure 30. Return air plenum lined with duct board without sealant at edges and seams (left). Narrow AHU closet functioning as return with uncontrolled airflow (center). Attempt to make a sealed return plenum around a metal AHU stand (right), with noticeable unsealed gap at bottom edge of duct board.

Contractors were often challenged by existing conditions. Figure 30, right, shows an attempt to create a sealed return air plenum around a metal stand supporting an AHU. The contractor had good intent, as evidenced by the extensive use of mastic sealant; however, the bottom edge of the material is notably unsealed and constitutes a major leakage point. To address some of the concerns related to air distribution system leakage, the best practices call for ducted return plenums, sealed with mesh and mastic, with a wall-mounted, filter-back return grilles. As of March 2012, the Florida Residential Energy Code requires contractors to seal accessible ducts, defined as 30 in. of work space. Building America has produced a relevant guideline titled "Sealing and Insulating Ducts in Existing Homes," which provides guidance and drawings for a number of typical scenarios (Aldrich and Puttagunta 2011).

Four houses were retested after additional duct repairs were made. In one, duct leakage was reduced from 0.13 to 0.05, and was negligibly improved in the other three. Given the number of retrofits that resulted in higher duct leakage, we recommended that partners define a clear chain of action and responsibility as part of the scope of work to measure and correct duct leakage that exceeds the target, including establishing financially responsibility for repairs and retesting. We also added a list of typical duct leakage points to the best practices to draw attention to common problem areas contractors can address to improve odds of achieving the target.

One problem encountered in many homes was that an AHU was being replaced with a larger one in a relatively small AHU closet (Figure 31). The larger AHUs are coincident with higher efficiency equipment, even within the same or smaller capacity. Contractors had a difficult time reaching the areas that needed to be sealed, including the return plenum (construction joints and connection to the AHU), the supply plenum connection to the AHU, and the gap around the supply plenum in the closet ceiling.

Figure 31. Crowded AHU closet with little room to access and seal duct connections to cabinet

2.4.6 Outside Air Ventilation

As discussed in Section 2.3, the target infiltration post-retrofit was an ACH50 of 6.0. Although partners did not plan extensive air sealing to achieve the target, some of the homes were already below the target pre-retrofit and researchers anticipated others would be at post-retrofit. Infiltration was reduced primarily by replacing windows and doors and repairing drywall, but partners did not include special measures (such as gasketed electrical cover plates) to achieve super tight homes.

Because the eventual level of whole-house airtightness was impossible to predict, researchers recommended a passive, supply-only outside air ventilation strategy. This approach provides additional air exchange and controls the outside air pathway. Supply-only ventilation induces a small positive air pressure (< 1 Pa positive with respect to outside) in the house that reduces infiltration through unintended paths.

The strategy includes an outside air duct with a filtered intake and balancing damper to allow adjustment of outside airflow. The duct terminates in the return plenum. The recommended duct sizing is based on ASHRAE Standard 62.2-2010 flow rate for continuous ventilation. However, the outside air flows during normal AHU operation only. The recommended passive system design has been successfully implemented in hundreds of BA-PIRC research homes in central and northern Florida with no reports of adverse moisture impacts (Fonorow et al. 2007).

Researchers successfully worked with a partner to incorporate the recommended passive outside air ventilation approach in one retrofit of the 70. Partners who did not include ventilation reported factors such as lack of room to accommodate the outside air duct in already cramped AHU closets, difficulty of accommodating an outside air inlet in small soffits (typically 1-in. overhangs), skepticism about occupant/owner awareness of maintenance requirements, and skepticism about the likelihood of post-retrofit need for ventilation. The measure was never included in any scope of work. It was incorporated into the one house using a change order. Clearly, more education and outreach are required for partners to understand implications related to mechanical ventilation.

2.4.7 Thermostats

Only nine homes (13%) had programmable thermostats during the pre-retrofit audit. Five were either unchanged or replaced with similar units; however, four (6%) were replaced with non-programmable models. Programmable thermostats were installed in 32 (46%) of the 51 homes that did not previously have them. Although the expense of upgrading to a programmable control was minimal (typically around $100), partners who did not incorporate this recommended measure cited unlikely occupant use because of programming complexity.

2.5 Domestic Hot Water

The fuel type for the water heaters at test-in was electric in 62 cases (89%), natural gas in seven cases (10%), and propane in one case. All the gas systems were 40-gal tank-type units. Electric tank sizes ranged from 28 to 80 gal, averaging 43 gal. There were five 40-gal and ten 50-gal units.

Researchers determined the energy factor (EF) using model numbers and manufacturers' published technical specifications. In a few cases, the pre-retrofit rated efficiency could not be determined, and researchers made assumptions based on rated efficiencies of similar equipment. The average EF, including a few assumed values, at test-in was 0.88 for electric units and 0.59 for combustion units. Table 13 provides a summary of the pre-retrofit EFs by fuel type.

Table 13. Pre-Retrofit Domestic Hot Water Efficiency by Fuel Type

Fuel Type	Number of Homes	Efficiency		
		EF Mean	EF Range	EF sd
Electric	62	0.88	0.80 – 0.92	0.03
Natural Gas/Propane	8	0.59	n/a	n/a

Twenty-eight electric tank-type units were replaced with more efficient units of the same type; many were only marginally better. In total, the electric tank units at the post-retrofit audits (including units that were not replaced) had an average EF of 0.91. Four of the electric tank-type units were replaced with heat pump water heaters units with average COP of 2.3, and two were replaced with tankless electric systems (EF 0.99).

Two of the eight gas water heaters were replaced with tankless gas units (EF 0.82), and the remaining six combustion units were replaced with electric tank units. All these replacement units had an EF of 0.92.

2.6 Appliances

Before renovation, appliances were typically missing, old, or in poor condition (Figure 32). Many of the homes were not equipped with dishwashers. Researchers attempted to use manufacturers' rated efficiencies; however, often model numbers were illegible or the equipment had been removed before the pre-retrofit audit. Thus, to define efficiencies for the appliances at pre-retrofit, researchers relied almost exclusively on estimates which likely overestimated the efficiencies, making improvement projections conservative.

Figure 32. Typical pre-retrofit appliance condition for range (left) and refrigerator (right)

Refrigerator replacement was the only appliance change-out that had meaningful impact on modeled energy savings. Three refrigerators found at the pre-retrofit audits were equivalent to ENERGY STAR efficiency (at or below 479 kWh/yr). Under the program guidelines for NSP funds, when replacing refrigerators, partners were encouraged by HUD to install ENERGY STAR equipment. Fifty-two homes (74%) were retrofitted with more efficient ENERGY STAR refrigerators, with an average rating of 451 kWh/yr.

2.7 Lighting and Ceiling Fans

Lighting characteristics were audited for the pre- and the post-retrofit homes using a count of fluorescent tube and compact fluorescent lamp (CFL)-equipped fixtures compared to the total fixture count. Forty-four homes (63%) had no fluorescent lighting at test-in. The other 26 homes had on average 13% of their fixtures fitted with CFLs or fluorescent tubes. In 46 cases (66%), the retrofit included the addition of fluorescent lighting with an average 53% increase in the number of fixtures using fluorescent bulbs. In 22 cases (31%) there was no change in lighting, and in two cases there was a decrease in fluorescent lighting at post retrofit.

Ceiling fans are very common in Florida homes. At least one fan was present pre-retrofit in 59 homes; however, model numbers were never available at the pre-retrofit audit. Researchers relied exclusively on estimates for fan efficiency. As with the appliances, the fans, often old, were probably less efficient than the estimates; hence, researchers deemed this to be a conservative approach. In 10 cases (14%), ENERGY STAR ceiling fans were installed as part of the retrofit. The typical efficient unit was rated at 130 cfm/Watt at medium speed. In several cases new units were installed but the partner was unable to provide documentation specifying the efficiency of the new equipment. In such cases, no efficiency gains were assumed.

2.8 Conditioned Area Reductions

During pre-retrofit audits, researchers found that many homes had porches and garages enclosed and made part of the conditioned space (Figure 33). These were retained as part of the conditioned space in all but five homes. Returning those spaces to their original use reduced conditioned floor area, volume, and thermal envelope area. Conditioned floor area reductions ranged from 140 ft^2 to 696 ft^2 and were, with one exception, coincident with a reduced window area (Table 14). Rather than include this envelope change in every energy-saving measure, researchers adjusted the pre-retrofit simulation model to reflect the change. This effectively focuses savings on efficiency improvements rather than on size adjustments that are relevant to a small number of renovations. The analysis reflects the savings from the package of improvements if the house had been the same size at pre-retrofit. From a homeowner perspective, though, reducing the size of a home would likely produce annual savings.

Figure 33. Pre-retrofit exterior wall of porch converted into conditioned space

Table 14. Pre- and Post-Retrofit Conditioned Area and Removed Floor, Ceiling, and Window Area

Removed Enclosure Type	Pre-Retrofit House Conditioned Area (ft^2)	Post-Retrofit House Conditioned Area (ft^2)	Resulting Reduction in Floor Area (ft^2)	Change in Window Area (ft^2)
Garage	1,499	1,145	354	-9
Porch	1,275	952	323	+12
Porch	1,158	1,018	140	–98
Porch	2,178	1,482	696	–75
Porch	1,944	1,683	261	–57

3 Whole-House Improvement and Cost Effectiveness

3.1 HERS Index Improvement

The primary metric researchers used in partner communications, and to evaluate whole-house improvements, was percent change in HERS Index pre- and post-retrofit. This is similar to a percent change in projected annual energy use and cost. Nuances in the HERS Index calculation procedure account for differences among the homes in fuel mix and conditioned area. Most partners were familiar with the metric from new construction activities. In all cases, researchers also provided partners with projected annual energy cost savings and cash flow analysis for each efficiency improvement when measure cost was provided. Additionally, BEopt analysis description and results are included in Appendix A.

Pre-retrofit HERS Indices ranged from 95 to 184 (sd = 22), with an average of 129. Post-retrofit HERS Indices range from 65 to 135 (sd = 11), with an average of 83 (Figure 34). Projected annual energy savings ranged from $35 to $1,338. All but four homes achieved a HERS Index ≤ 95, which is similar to new Florida homes built in the early 2000s, a remarkable reversal. This may suggest that achieving a HERS Index of 95 is a reasonable goal for energy retrofits in homes with similar characteristics to those in the dataset, though the actual savings achieved will vary depending on house specific conditions.

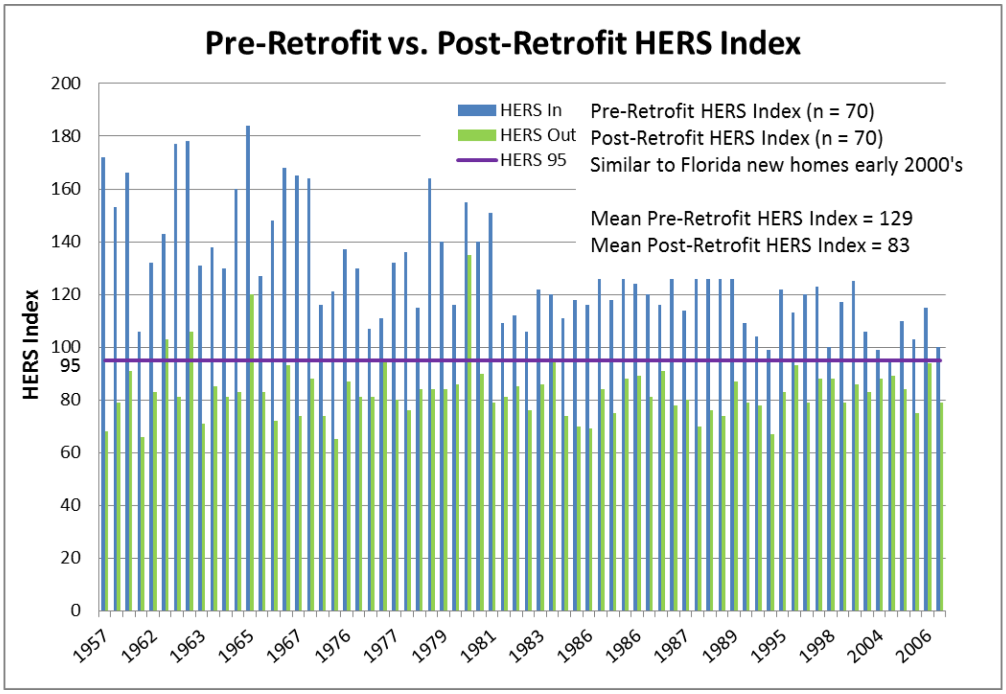

Figure 34. Pre-retrofit HERS Indices (blue) by vintage paired with post-retrofit HERS Indices (green)

The average improvement in HERS Index for the 70-house dataset was 34%. Average projected annual energy cost savings were 25%. Forty-six homes (66%) achieved a 30% improvement in

HERS Index (above the yellow line in Figure 35) with an average projected energy cost savings of 31%. Nineteen had 15% and 29% HERS Index improvement and only five fell below 15%.

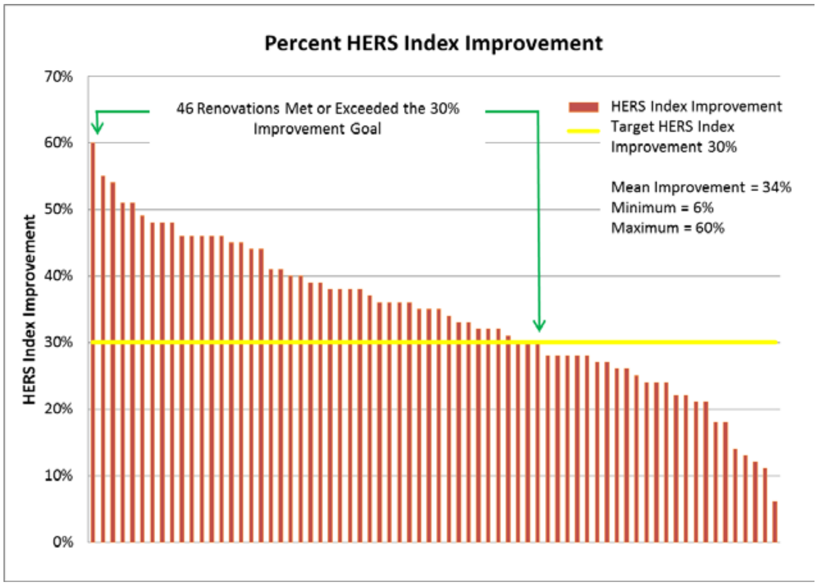

Figure 35. HERS Index improvement goal (30%, yellow line) was met in 46 deep retrofits.

Mean HERS Index improvement among houses built in the same decade ranged from 21% to 55% with a trend of higher improvement levels in older homes (Figure 36). Despite widely disparate pre-retrofit HERS Indices and varying scopes of work, the mean of post-retrofit HERS Indices by decade ranged from 74 to 86, a range of only 12 points compared to a 56-point spread across the decades in pre-retrofit HERS Index (Figure 36).

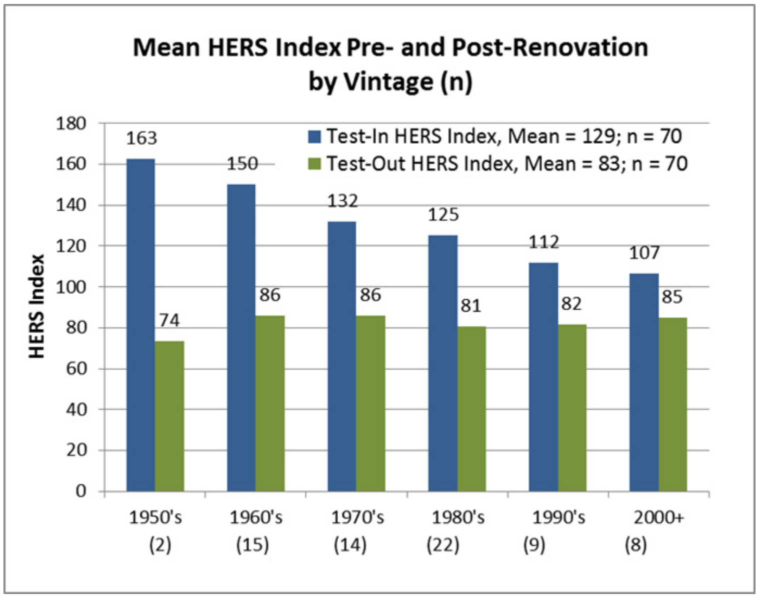

Figure 36. Mean HERS Index at pre-and post-retrofit by decade vintage

Researchers investigated the relationship among these comprehensive renovations between the HERS Index improvement and numerous other factors. Beyond a few slight trends detected, there is a correlation between pre-retrofit HERS Index and HERS Index improvement *($r = 0.7$, $P < 0.001$)*. The linear regression line in Figure 37 displays the fit between these variables for the whole 70-house dataset *($R2 = 0.4994$)*. All but two homes (red diamonds) with pre-retrofit HERS Indices above 124 met the 30% improvement threshold.

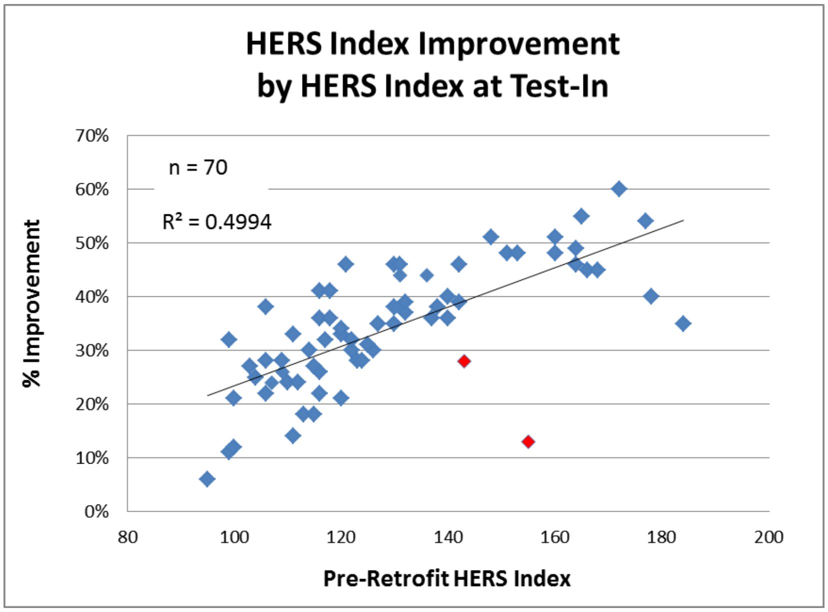

Figure 37. HERS Index improvement compared to the pre-retrofit HERS Index for the whole 70-house dataset

Table 15 shows that among the three most active partners similar average improvement levels were achieved in homes of similar age. The overall average savings (bottom row) among the partners was consistent (34%–36%).

Table 15. Average HERS Index Improvement for Top Partners by Vintage

Vintage	Partner A (n = 20)	Partner B (n = 22)	Partner C (n = 20)	Overall Mean (n = 70)
1950s	48%	60%		54%
1960s	40%	48%	42%	42%
1970s	38%	28%	37%	34%
1980s	36%	36%	33%	35%
1990s	25%	29%	33%	28%
2000s	18%	9%	26%	20%
Overall Mean	**36%**	**34%**	**34%**	**34%**

3.2 Composition of Deep Energy Retrofit Improvement Packages

To assess the feasibility of replicating these positive results in housing of similar pre-retrofit character, researchers looked more closely at the mix of improvements associated with the houses that had ≥ 30% improvement in HERS Index (n = 46), hereafter referred to as “deep” retrofits. The deep retrofits had much in common and were the homes with the most room for improvement, as they all needed multiple energy-related replacements and improvements.

Table 16 shows the prevalence of 13 key efficiency measures in three groups: deep retrofits (n = 46, 66%), less than deep retrofits (n = 24, 34%), and the whole dataset (n = 70).

Table 16. Prevalence of 13 Key Efficiency Strategies Implemented

Category	13 Key Efficiency Strategies	≥ 30% HERS Improvement (n = 46)	< 30% HERS Improvement (n = 24)	All Houses (n = 70)
Mechanical System Equipment	1. Installed equipment with higher cooling and/or heating efficiency	96%	71%	87%
Thermal Envelope, Ceiling	2. Added ceiling insulation	93%	63%	83%
Whole-House Airtightness	3. Improved ACH50 test results	92%	77%	88%
Air Distribution System Airtightness	4. Improved Qn,out test results	86%	68%	80%
Windows	5. Applied window film or installed replacement windows with lower SHGC and/or U-value (based on primary retrofit window type in each home)	80%	46%	67%
Appliances	6. ENERGY STAR-labeled refrigerator	76%	71%	74%
Water Heating	7. Replaced existing with higher efficiency unit	70%	38%	59%
Lighting	8. Efficient lighting increase by at least 30% (number of fluorescent fixtures)	52%	42%	49%
Mechanical System Controls	9. Replaced non-programmable thermostat with programmable thermostat	48%	42%	46%
Air Distribution System, Thermal Barrier	10. New ducts with higher R-value	39%	13%	30%
Thermal Envelope, Exterior Wall	11. Lighter color exterior wall paint (lower solar absorptance)	30%	8%	23%
Thermal Envelope, Roof	12. Lighter shingle color (lower solar absorptance)	30%	13%	24%
Ceiling Fans	13. Fan(s) with improved efficiency	15%	13%	14%

As shown in Table 16, 96% of deep retrofits included a mechanical system replacement, 93% included additional ceiling insulation, and 92% included infiltration reduction. Most also included duct tightening (86%) and window replacement or film (80%). All these measures are related to cooling energy savings with additional heating season benefits. Additional cooling load reduction strategies were less prevalent. They include R-6 replacement ductwork (39% of deep retrofits), light color exterior paint (30%), and light color shingles (30%). Although the latter two improvements provide relatively small energy savings, they are usually free at the time of replacement as long as choices are made within the same line of paint or shingles.

In addition to measures chosen to reduce space conditioning energy use, partners incorporated appliance, water heating, and lighting improvements: 67% of the deep retrofits included an ENERGY STAR refrigerator and 70% included a higher efficiency water heater. Typically, the water heating efficiency gains were modest (e.g., 0.88–0.92).

About half the retrofits increased the number of fluorescent lighting fixtures by 30% or more and a similar number added programmable thermostats. ENERGY STAR-labeled ceiling fans were incorporated into only 15% of the deep retrofits.

These key efficiency measures were also present in large percentages of the non-deep retrofits (Table 16). Window improvements were nearly twice as prevalent in the deep retrofits as in the non-deep. If any given one of the non-deep houses had needed a window replacement, it would likely have resulted in another deep retrofit. The important conclusion is that the deep retrofits included a combination of major improvements supplemented with multiple minor improvements. The mechanical system efficiency improvement was particularly important; however, two homes without conditioning equipment replacement did achieve a deep retrofit through an expanded package of other improvements. The retrofit package for one of these homes included nine of the 13 key strategies, including significant improvement in ceiling insulation, duct leakage, and numbers of CFLs. The second home realized significant savings from a heat pump water heater.

These trends taken together with the cost data discussed in the next section formed the basis for developing the best practices document for Part 2 of the research. Reference Appendix B for a detailed look at the 13 key energy efficiency strategies incorporated into each deep retrofit.

3.3 Cost Effectiveness of Energy Retrofit Improvement Packages

To assess cost effectiveness, projected annual energy cost savings were weighed against the reported cost of improvements. Projected annual cost savings are used in lieu of actual utility bills or monitored data because these were unoccupied, foreclosed homes. All references to annual energy cost and cost savings are based on simulation projections. A more detailed discussion of cost-effectiveness calculations is provided in Appendix B.

Partners did not, and in some cases could not, provide complete cost information in all 70 retrofit cases. Habitat for Humanity affiliates, for instance, often received donated time and materials and were not able to submit the true costs associated with a particular measure and therefore the complete retrofit package. Similarly, mechanical contractors generally billed for the whole job without showing line item costs. Costs for all work, for instance to replace a heat pump and seal ductwork, were combined into one invoice. A final challenge in collecting cost data related to retrofits that had multiple benefits. Typically the costs identified for whole-house leakage were often under-reported, because they fell into other measures. A classic example of this is a window replacement; it improves the efficiency of the window and typically reduces the whole-house leakage.

Preference for one cost-effectiveness metric over another may vary depending on the finance mechanisms and interests of the owner. Almost all the homes in this research were being sold to qualifying affordable housing buyers after renovation. In this scenario, the cost associated with the deep retrofit package is assumed to be rolled into a mortgage, slightly increasing the homeowner's annual mortgage burden. When the annual savings exceed this incrementally higher annual debt burden, it creates a net positive annual cash flow for the owner.

Researchers used financing terms of 7% for a 30-year mortgage as delineated in the House Simulation Protocols—high compared to current rates, but typical of a number of years ago when this research began. The cost-effectiveness calculation does not consider life cycle cost, return on investment, or other metrics that may be important in some situations; however, it is a simple metric that provides partners with a snapshot of the immediate projected cash flow, which is extremely important to sustainable ownership in affordable housing. This metric provides a concrete, though hypothetical, indication of the financial difference between making and not making the energy improvements. And although the annual cost of the debt will remain the same year after year, the utility cost (and consequently savings) will likely rise, creating greater cash flow in future years.

In some cases, cost-effectiveness calculations used the full cost of a measure; others used the incremental cost, which is defined as the cost premium for higher performance or efficiency at replacement. When the incremental cost was used, it was compared to the incremental energy cost savings beyond replacement with an item of like performance. In the case of mechanical equipment replacement, however, a like efficiency unit is not always available because of federal minimum efficiency standards. Then, incremental savings are calculated in comparison to savings achieved beyond a SEER 13 replacement. For example, if SEER 8 cooling equipment were being replaced for functional reasons, the minimum efficiency replacement would be a SEER 13 unit, which would certainly produce savings. However, if a higher efficiency SEER 15 unit were selected instead, the cost effectiveness of that choice would be calculated using incremental cost (over the SEER 13) compared to the incremental savings (over the SEER 13).

For some measures, the incremental cost was deemed to be zero. No cost premium was associated with a higher performance choice at the time of replacement. These include:

- When roof was replaced, a lighter color was chosen.
- When exterior walls were painted, a lighter color was chosen.
- When electric tank type water heaters were replaced, a slightly more efficient unit of the same type was chosen.

For other measures, the full cost was compared to the full energy savings in cost analysis because they were implemented in absence of functionality needs, purely for energy efficiency improvement. These include:

- Whole-house air sealing measures that were not part of other measures (caulk, foam, etc., estimated by partners)
- Servicing or sealing HVAC equipment and air distribution system components (in the absence of HVAC replacement)
- CFLs
- Outside air runtime vent for indoor air quality and durability (one house)
- Programmable thermostat
- Ceiling insulation.

In a perfect world, partners would have provided the cost for the higher performance replacement item as well as the cost for replacing an item with an item of the same (or minimum available) efficiency. However, partners do not usually catalog prices for items they do not buy, so researchers typically had to estimate the incremental costs for these measures based on other partner activity, price checking, and other research.

In the 42 deep retrofits for which we have cost information, total retrofit cost, including incremental cost over replacement with like efficiency where applied, ranged from $780 to $8,382 and averaged $3,854 (sd = 1,687). The scatter plot in Figure 38 displays incremental costs compared to percentage improvement in the HERS Index for the 42 houses.

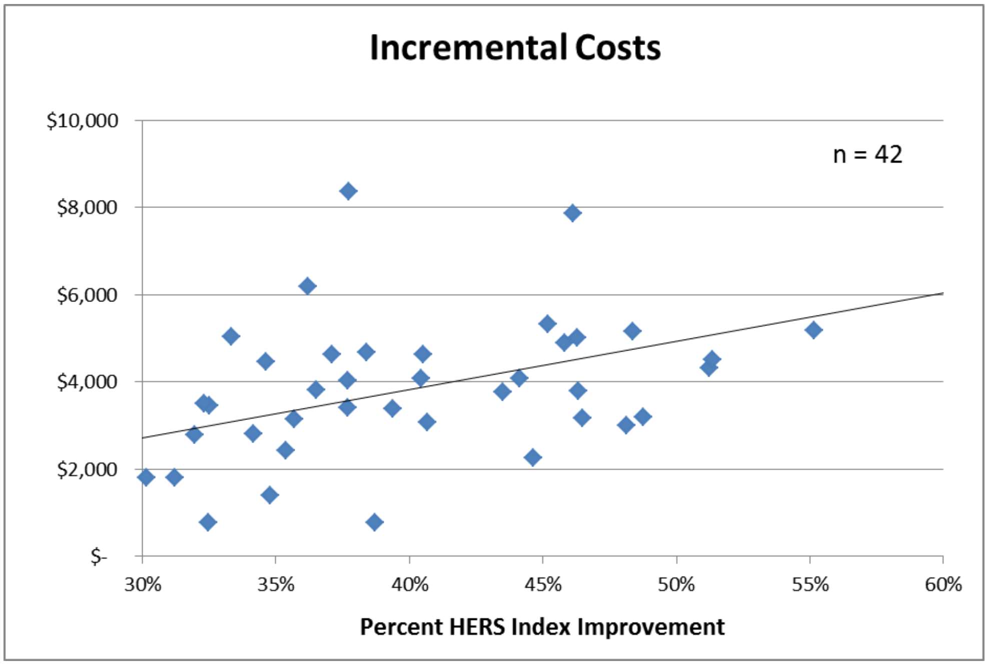

Figure 38. Incremental costs by percent HERS Index improvement for 42 deep retrofits with cost data

To allow comparison among the retrofits, the annual energy cost calculations were made using a standard utility rate of \$0.13/kWh, \$1.72/therm of natural gas, and \$1.40/gal of propane (one home). This is a known bias in the study, in that local utility rates may be higher or lower; however, in the interest of studying the whole dataset, utility rates needed to be standardized. Although using the annual energy *use* rather than the annual energy *cost* would have allowed comparability without this complication, it would not have provided a path for the cost-effectiveness calculations. Where utility rates were higher or lower than the standardized rate, resulting annual cash flow would have been higher or lower, respectively.

A scatter plot of the incremental annual cash flow compared to HERS Index improvement is provided in Figure 39. Incremental annual cash flow ranged from –\$79 to \$626 and averaged \$169 (sd = 158). Cash flow was positive in all but six cases (86% were positive).

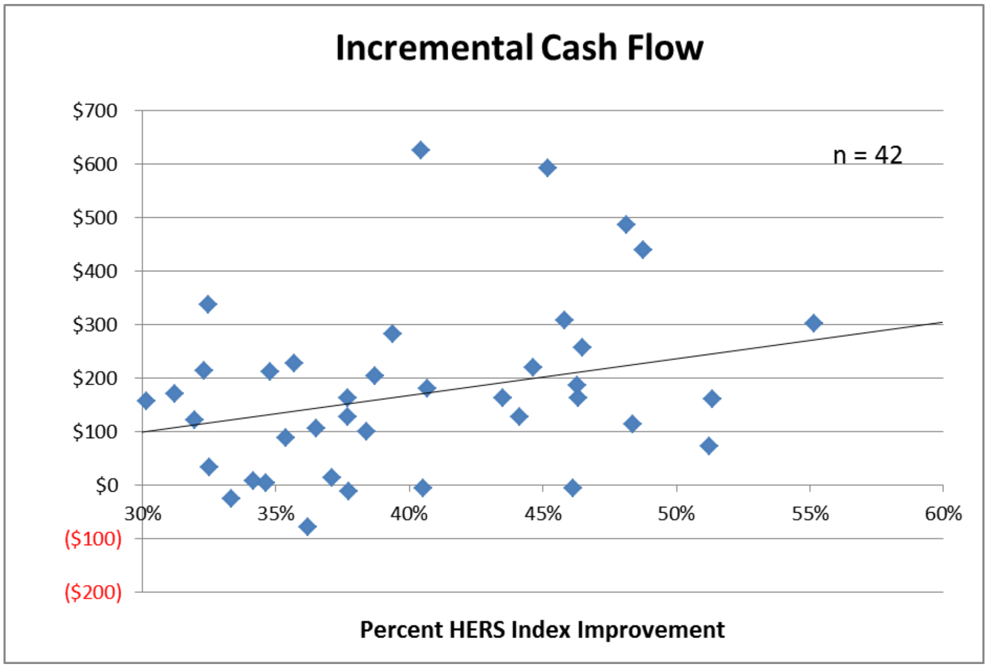

Figure 39. Incremental annual cash flow by percent HERS Index improvement for 42 deep retrofits with cost data

Five of the six negative cash flow retrofits were marginal, –\$7 to –\$26 annually, which might have been positive under less conservative financing terms or local utility rates. In two cases, expensive window retrofits had a major impact on incremental costs. In one home the window specifications were unknown and, to be conservative, software program defaults were used to calculate savings even though the actual specifications were likely better. In two other cases very high efficiency mechanical systems were installed that generated only modestly higher incremental savings that were heavily outweighed by incremental cost. In the one remaining case with an annual cash flow of –\$79, the retrofit included an expensive electric tankless water heater (which researchers recommended against) that saved little energy. For a more detailed discussion on energy costs and savings, improvement costs, and cash flow for deep retrofits, see Appendix B.

4 Gaps and Challenges

Similar to researchers' experience in new construction, a major barrier to widespread implementation of high efficiency, high performance specifications is lack of building science and energy efficiency awareness among contractors, buyers, code officials, and subcontractors. The best practices include retaining a certified home energy rater or other building science support to provide the guidance, analysis, and quality assurance that researchers provided to the partners during the study.

We have also included specific material to help contractors meet the targets in three areas where problems occurred: duct and whole-house airtightness and passive return air pathways. In addition to target metrics, the best practices include checklists of typical leakage points to seal and direct contractors to sections of the Florida Residential Mechanical Code that apply to new construction for further information. These criteria are particularly important in renovation projects to identify unanticipated pressure differentials that can have a negative impact on health and building durability, including moisture degradation and back drafting combustion exhaust into the conditioned space. These serious potential risks are addressed in multiple elements of the best practices, including post-retrofit testing and assessment by a Class I certified home energy rater, regardless of rater involvement before or during renovation. After partnering on this study, the Sarasota Office of Housing and Community Development integrated this practice into the standard specifications for all NSP renovations (Appendix D) with successful implementation in many homes.

In addition to these criteria, other parts of the best practices cover items required by the Florida Residential Mechanical Code for new construction but not for existing homes. These items specifically address system design, quality installation, duct integrity, durability issues, and system accessibility:

- Mechanical system sizing using ACCA Manual J
- Matching indoor and outdoor mechanical system components
- Duct system components mechanically attached and sealed with fiberglass mesh and mastic or code approved alternative
- Sealed return air plenums
- Abandonment of building cavities used as ducts
- 4-in. allowance between AHUs and surrounding walls
- Flexible ductwork to be supported above attic insulation.

5 Best Practices

Researchers evaluated trends in the 46 deep retrofits to identify the most commonly implemented measures. They developed a standardized set of best practices to be used in combination as a viable approach to achieving 30%–50% HERS Index improvement in homes similar to those in the study.

The best practices are intended as general guidance for organizations that want to develop consistent energy-related specifications for a standard “Community Wide Improvement Package.” The overall best practices list is expected to be customized by organizations, and a subset of the overall list will be implemented. The best practice includes health and safety criteria, which are greatly influenced by Building America new construction research and the Quality Criteria for DOE’s Builders Challenge (Version 1).[4] Some of these criteria, such as moisture control and combustion safety, are mandatory measures that apply to every home regardless of specific replacements. Others, such as performing room-by-room ACCA Manual D calculations to size ducts, are recommended

The measures incorporated into the best practices were regularly implemented in the deep retrofits. In some cases, a less common specification was chosen. For example, the best practice for shingle color is “white” even though “light” was more prevalent in the dataset based on partners’ aesthetic preferences.

The best practices include measures that address house characteristics such as recessed lighting, crawlspaces, and pools, that are not well represented in the study. Other measures are included that were recommended but not widely implemented. These known opportunities included ducted kitchen and bath exhaust fans to the outside, more thorough return plenum sealing, Residential Energy Services Network (RESNET) Class I knee wall insulation, maximum CFL installation, and ENERGY STAR ceiling fans.

Depending on initial conditions, replacement specifications in the best practices may not be applicable in a given house. In those cases, the best practices often include improvements that can be made in-situ to existing equipment and components. This dynamic means that not every home will achieve deep energy savings with a standard approach; however, homes that need a combination of replacements will likely reach the 30% improvement mark and across a community an average of 30% improvement can probably be reached (Table 15).

The best practices are divided into in the following 16 categories:

- Combustion safety
- Mechanical equipment and air distribution
- Ventilation
- Infiltration
- Roof
- Ceiling insulation

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[4] This program is now called the DOE Challenge Home and has many more required elements than the Builders Challenge, Version 1.

- Knee walls
- Windows
- Exterior walls
- Floors
- Water heating
- Appliances
- Lighting
- Fans
- Moisture
- Pool.

Even if a home needs no replacements, the in-situ strategies should improve its overall performance at some level. In addition to replacement specifications, there are a variety of performance criteria to raise awareness about whole-house and duct airtightness. Researchers provide a list of typical locations that often need to be sealed. This is not a comprehensive prescriptive approach, but it will help contractors meet the performance targets. A simplified version of the best practices is presented in Table 17. An expanded version is included in Appendix C.

Table 17. Summary of Current Best Practices (Appendix C)

Components and Strategies	Replacement Measure Specifications	Additional Requirements and Recommendations for All Projects and Maintenance/Repair Measures for Components Not Being Replaced
Combustion Safety	Locate combustion appliances in unconditioned space when feasible; if combustion appliances are in conditioned space or attached unconditioned space, perform combustion zone safety procedures to ensure an adequate supply of combustion air and install carbon monoxide detectors.	
Mechanical Equipment and Air Distribution	A three-part guideline details specifications for replacing mechanical equipment. The guideline is segmented into the following sections: 1. HVAC Assessment, Design, and Specifications 2. HVAC Installation 3. Post-retrofit HVAC Testing and Verification Key components addressed within the sections of the guideline include: • ENERGY STAR (minimum SEER 14.5) qualified conditioning equipment • Ensure ducted returns • Ensure flex duct collars are fully insulated • Seal off all joints and edges (preferably with mastic) in supply ducts, return plenum, and connections to air handler • Ensure duct leakage to the outside ≤ 6% (Qn,out ≤ 0.06) • Ensure new ductwork is strapped to trusses to achieve clearance over anticipated ceiling insulation • Ensure any new ducts are insulated to R-value ≥ 6 • Perform ACCA Manual J load calculation and	A four-part guideline details specifications when keeping an existing mechanical system. The guideline is segmented into the following sections: 1. HVAC Return Plenum and Passive Return Air Pathways 2. HVAC Service Mechanical Equipment 3. HVAC Test Duct System Airtightness Pre-retrofit 4. Post-retrofit HVAC Duct Testing and Verification Key components addressed within the sections of the guideline include: • For existing atmospheric combustion furnaces, provide adequate supply of combustion air • When feasible, retrofit a duct board plenum into platform returns, otherwise fully seal platform return • When feasible, replace louvered doors on AHU closets with a correctly sized central return grille mounted in the wall (if adjacent to a living space) or in a solid door. • When feasible, replace AHU stands with

Components and Strategies	Replacement Measure Specifications	Additional Requirements and Recommendations for All Projects and Maintenance/Repair Measures for Components Not Being Replaced
	size the system accordingly • When feasible, install a dampered, passive mechanical ventilation duct to provide outside air to return plenum • Ensure pressure balance between main body of the house and each bedroom	ducted return plenum • Ensure servicing by HVAC contractor • If measured duct leakage exceeds 6% ($Q_{n,out} \geq 0.06$), identify and seal leakage points • Ensure pressure balance between main body of the house and each bedroom
Ventilation	In addition to the passive mechanical ventilation system in the HVAC section, install kitchen and bathroom exhaust fan ducted to outdoors.	Install kitchen and bathroom exhaust fans ducted to outdoors.
Infiltration	Conduct pre- and post-retrofit blower door test to assess whole-house airtightness and identify leakage points. Target test result is ACH50 ≤ 6.0. Measure combustion zone pressure differences. Identify and repair duct and/or whole-house infiltration points if necessary to achieve proper balance. A list of common infiltration points is provided.	
Roof	Achieve solar reflectance ≥ 0.25 with asphalt shingles, ensure proper installation of flashing, and install drip edge.	
Ceiling Insulation	Before installing insulation, complete mechanical, electrical, and plumbing rough-in and replace “can” lights and fluorescent tube figures with insulation contact and airtight rated units. Support ducts above ceiling insulation. Insulate vented ceiling to achieve RESNET Grade I R-38. Insulate any interior attic hatch.	
Knee Walls	Ensure RESNET Grade I installation to R-13 or greater insulation.	
Windows	Install ENERGY STAR-labeled windows with U-value ≤ 0.6 and SHGC ≤ 0.27. Ensure proper flashing installation, ensure proper cutting and wrapping of any house wrap, replace any rotted materials, air seal around opening, and caulk edges.	Ensure proper flashing installation, replace any rotted materials, air seal around opening, and caulk edges.
Exterior Walls	If replacing drywall in frame construction, install RESNET Grade I R-13 insulation. Select light or	

Components and Strategies	Replacement Measure Specifications	Additional Requirements and Recommendations for All Projects and Maintenance/Repair Measures for Components Not Being Replaced
	white paint.	
Floors	If crawlspace, repair or install ground cover for vented areas, lapping joints 6 in., and continuing up stem wall 2 ft.	
Water Heating	Wrap tank with R-5 blanket and insulate accessible hot water pipes.	
Appliances	Install ENERGY STAR-rated refrigerator, dishwasher, washing machine, and vent dryer to outdoors.	Vent clothes dryer to outdoors.
Lighting	Install screw-in or pin-based CFLs where feasible.	
Fans	Select ENERGY STAR ceiling fans.	
Moisture	Remove moisture loading at walls and foundation.	
Pool	Add pool cover to existing or newly installed pool.	

6 Conclusions

Based on the *incremental cash flow* available for 42 of the 46 deep retrofits in the hot-humid climate zone, the study fundamentally finds that cost-neutral deep energy retrofits of 30% or more improvement can be done, even under the more conservative finance terms described above. The emphasis here is that most of the key efficiency improvement strategies were applied *at the time of replacement when higher performance items can be implemented for a relatively low incremental cost.*

In general terms, this means that the incremental cost of higher performance components, equipment, and materials can often be justified at the time of natural replacement, based on the incremental savings over a comparable item of minimum performance. This is true also for the improvements made for energy efficiency reasons alone, such as ceiling insulation and duct sealing when existing conditions are poor. However, considering the renovation projects in this study, we find no evidence to suggest that the total cost of replacing equipment, components, materials, and systems in good working condition can be justified on the sole basis of anticipated energy savings, with the possible exception of CFLs.

As expected, there was not a one-size, or one-package, fits-all solution for deep energy retrofits. The diversity of packages manifest in the 46 deep retrofits (Appendix B) plainly illustrates multiple paths to 30% savings within a core group of key strategies, depending on the condition of the house. In essence, the cost effectiveness (and therefore applicability) of any one of the key efficiency strategies in a particular house will depend on whether the existing condition justifies replacement.

Revisiting Table 15, we are reminded that an average savings of more than 30% was achieved by the most active partners in samples of houses with widely diverging characteristics producing a great range of post-retrofit HERS Indices. This bodes well for the concept of applying a common set of best practices across a community-wide renovation program where each house receives the best practice treatment in all replacement selections as well as a number of universally applicable measures such as combustion safety, duct and whole-house air sealing, and high efficiency lighting. Further research is needed to refine the best practices and research their implementation on a community scale.

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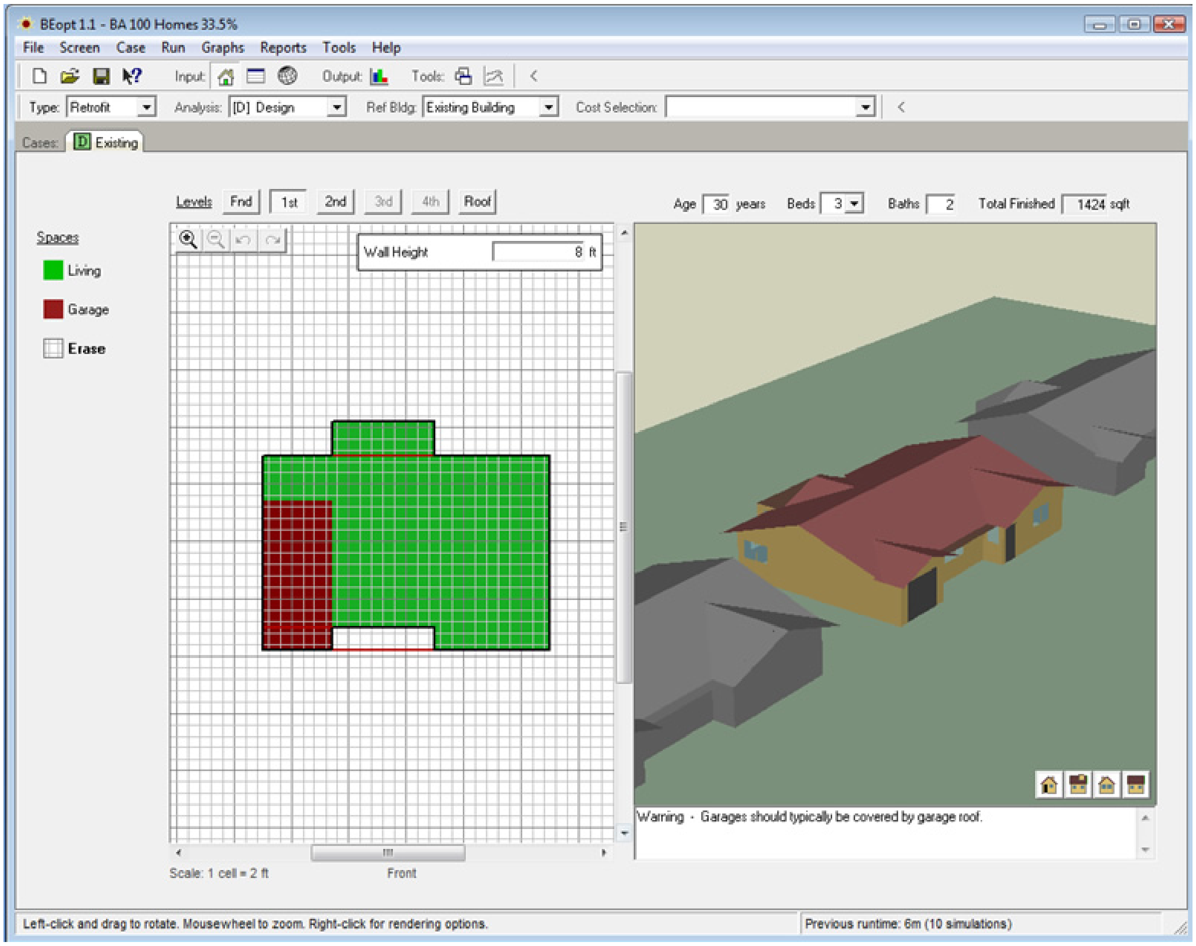
Appendix A: 30% Energy Efficiency Solution Package

The 30% energy efficiency solution package described results from data collected from the retrofits of more than 70 homes studied under BA-PIRC. The study was conducted in central and north Florida, in the hot-humid climate zone. The characteristics of the base house were either the average (where appropriate) or most frequently occurring in the dataset.

Although the base house represents the typical characteristics found in the BA-PIRC research, it does not necessarily represent the average building in the hot-humid climate region. Most buildings analyzed in the study group were previously foreclosed properties that were purchased and placed in community rehabilitation programs. In most cases, HUD NSP funds were used to purchase and renovate the homes. Community partners provided cost data based on actual expenditures; however, these costs could not be broken down into labor and materials categories.

A model of the base house was created in BEopt version 1.1 (Figure 40), an annual energy use simulation and optimization software. Envelope and equipment characteristics are shown in Table 18.



Type: Retrofit
Analysis: [D] Design
Ref Bldg: Existing Building
Cost Selection:

Age 30 years
Beds 3
Baths 2
Total Finished 1424 sqft

Wall Height 8 ft

Scale: 1 cell = 2 ft

Warning - Garages should typically be covered by garage roof.

Left-click and drag to rotate. Mousewheel to zoom. Right-click for rendering options.

Previous runtime: 6m (10 simulations)

Figure 40. BEopt screen shot of base house

Table 18. Basic House Characteristics

House Characteristics	Base House	Improved House
Foundation Type	Slab on grade	Same
Exterior Wall Type	Concrete block, R-0	Same
Attic/Roof/Ceiling Insulation	Vented/shingle/R-19	Vented/shingle/R-38
Location of Ducts/Air Handler	Attic/interior	same
Window Type	Single pane, metal frame, awning	Double pane, low-e, vinyl frame
Lighting/Appliances	10% fluorescent/standard reference	80% fluorescent/ENERGY STAR reference
Heating	Electric resistance	Heat pump HSPF = 8.8

Conditioned area of the base house is 1,424 ft^2. This single-story, concrete block, single-family home has three bedrooms and two bathrooms. It is located in Orlando, Florida and is approximately 30 years old.

The 30% improvement package includes equipment, appliance, lighting, and envelope elements consistent with the trends in the 70 retrofits in the BA-PIRC field study. The package is composed of the eight most prevalent improvements in the field study data (Table 19).

Table 19. Prevalence of Key Efficiency Strategies in 70 Retrofit Field Study Homes

13 Key Efficiency Strategies	All Houses (n = 70)
1. Higher efficiency cooling and/or heating equipment	87%
2. Added ceiling insulation	83%
3. Reduced infiltration (ACH50 test results)	88%
4. Improved duct airtightness (Qn,out test results)	80%
5. Window film or windows with lower SHGC and/or U-value	67%
6. ENERGY STAR labeled refrigerator	74%
7. Higher efficiency water heater	59%
8. 30% more fluorescent lighting	49%
9. Programmable thermostat	46%
10. New ducts with higher R-value	30%
11. Lighter color exterior wall finish	23%
12. Lighter color roof finish	24%
13. Efficient ceiling fans	14%

Table 20 shows the “as found” and “replacement” characteristics for individual components of the package, as well as estimated costs, projected cost savings, and projected annual cash flow.

Table 20. Projected Energy Savings and Economics Calculations for 30% Improvement Package

As Found Annual Source Energy Use (MBtu)[1]	**191**
As Found Annual Energy Cost ($)[1,2]	**$2,929**

Home Component	**As Found**	**Replacement or Improvement**	**Full First Cost**	**Incremental First Cost for Higher Efficiency at Replacement**	**Cost Used for Economic Calcs[8]**	**Annual Source Energy Savings (MBtu)[1,4]**	**Annual Energy Cost Savings ($)[1,2,4]**	**Simple Payback (years)[4]**	**Annual Finance Cost for Retrofit at Resale ($) [3]**	**Annual Cash Flow if Financed ($)[3,4]**
Heating and Cooling	Straight Central AC, SEER 10, Electric Resistance Heating, 3 Ton, Non Programmable Thermostat	Central Heat Pump, SEER 15, HSPF 8.8, 3 Ton, Programmable Thermostat	$4,252		$4,252	44	$637	6.7	$343	$294
Windows	(21) Single, clear, metal frame (U = 1.20; SHGC = 0.80)	Double Pane, Low-E, Vinyl frame, U value <= 0.5, SHGC <= 0.35	$6,825	$3,150	$3,150	11	$154	20.5	$254	($100)
Air Distribution System[5]	Older R-4 rigid ducts with leakage of 15%, central return	New R-6 ducts with leakage of 7.5%, central return	$1,196	--	$1,196	11	$157	7.6	$96	$61
Infiltration[6,7]	ACH50 = 12	ACH50 <= 6.0	$459	--	$459	8	$116	4.0	$37	$79
Lighting	20 fixtures; 2 CFL's (10%)	80% CFL's	$56	--	$56	9	$132	0.4	$5	$127
Ceiling Insulation	R-19 Fiberglass Batt	Add Blown-In Fiberglass to achieve R-38	$1,082	--	$1,082	7	$92	11.8	$87	$5
Refrigerator	Default, 18.5 cubic inch	Energy Star, 18.5 cubic inch	$750	$0	$0	4	$56	0.0	$0	$56
Water Heating	50 Gallon, electric (EF=0.88)	50 Gallon, electric (EF=0.92)	$750	$0	$0	2	$31	0.0	$0	$31
Total for Package of Energy Improvements and Higher Efficiency Replacement Specifications[4]					$10,195	64	$928	11	$822	$106
Annual Savings (%)						34%	32%			

[1] Annual energy use and energy cost calculations made with BEOpt version 1.1. Remaining economic analysis completed outside of BEopt.

[2] Utility rate used for annual energy cost calculations was $0.1165 per kWh chosen from the BEopt utility library, Florida average.

[3] Finance terms at time of resale assumed to be 30 year mortgage at 7% interest.

[4] Values in some columns can not be added to arrive at a total because of interaction among the measures. Values in the "Total for Package…" row are for the package of improvements considered all together.

[5] Air distribution system leakage is shown as a percentage of air handler flow.

[6] Whole house air tightness testing results shown in air changes per hour at a test pressure in the house of 50 pascals with respect to the outdoors.

[7] A portion of the infiltration improvement results from the window replacement. The cost associated with that improvement is included in the incremental window cost.

[8] The economic calculations use the *Full First Cost* when a measure is chosen strictly for efficiency improvement (e.g. ceiling insulation). Total first cost was used for Heating and Cooling system because we are counting total savings. The *Incremental First Cost for Higher Efficiency at Replacement* is used when a component is in need of replacement. For example, for Windows, incremental cost over replacement with single clear is used.

The base home had an annual source energy use of 191 MBtu. At a utility rate of $0.1165/kWh (BEopt library Florida average), the estimated annual energy cost was $2,929.

The annual finance cost (column 10) for financing the cost of these efficiency improvements is compared to annual energy cost savings (column 8) to estimate annual cash flow (last column). Positive cash flow indicates that energy cost savings exceed the finance costs. For the whole improvement package, the modeling showed annual source energy savings of 34% (64 MBtu) and annual energy cost savings of 32% ($928).

The cost estimate for the improvement package was $10,195. Financed over a 30-year period at 7% interest, the annual finance cost was estimated to be $822. This results in a calculated $106 of annual positive cash flow.

The economic calculations use the full first cost when a measure is chosen strictly for efficiency improvement (e.g., ceiling insulation). The incremental first cost is used for a higher efficiency or performance choice at the time of replacement. Replacement might be needed for functionality or to meet market standards. For example, when windows are replaced for functionality or market standards, higher than minimum performance windows could be chosen. Those would likely carry a cost premium. The economic calculations in Table 20 show a $3,150 premium for choosing double-pane, low-e, vinyl frame windows instead of single-pane clear windows.

In this example, all individual improvements created positive annual cash flow except for the high performance windows, which were the second largest improvement package expense. The annual finance cost of $254 for the window retrofit exceeded the projected annual energy cost savings of $154, for a negative annual cash flow of $100. Note that the energy cost savings associated with the reduced infiltration of new windows are not captured in this measure's savings. Also, the estimated incremental cost of the windows is purposely on the high side of the cost range to avoid overstating potential annual cash flow. During the field study, partners were given analysis showing the projected annual energy savings from higher performance replacement windows. Then the partner decided whether to make that upgrade. In some cases, the higher cost of more efficient windows may have created negative cash flow (for that single measure, not the whole package). Despite this, they installed the higher performance units in 41 homes. They generally selected double-pane, low-e windows, even though they could have chosen basic replacement windows at a significantly lower cost. Anecdotally, partners point out, and researchers agree, that a missed opportunity for window replacement might not arise again for two or more decades. The higher performance window makes a significant contribution to overall energy savings, and there was net positive annual cash flow from the combined effect of the other improvements of $106.

Equipment and envelope conditions in existing homes vary widely, as do the costs for some of these components. Rather than a specific set of improvements, the 30% package proposed here should be considered as an example. In general, the field study showed that a combination of measures that address the efficiency of major end-use equipment and conditioning loads is needed to reach the 30% target.

Appendix B: Deep Energy Retrofit Packages

Composition of Improvement Packages

Table 21 provides more detail for all 46 deep retrofits, including HERS Index and a representation of which of the 13 key energy efficiency strategies are incorporated in each deep retrofit. The houses are ranked in descending order of improvement (column 4). Each of the 13 key strategies is shown as a column heading. A green cell with a “Y” for “yes” indicates inclusion of that measure in that house. “N” indicates “no” for measures not included. Because airtightness improvements are variable, ranges indicate improvement level in percentage reduction in ACH50 and Qn,out using the ranges 1%–25%, 26%–50%, 51%–75%, and > 75%. As discussed in Section 2.3 and Section 2.4.5 of this report, airtightness testing results were worse post-retrofit in some houses. This is indicated by the term “worse” in those columns. The term “untested” indicates that the house was not tested prior to renovation or in one case after renovation for reasons described in Section 3 and Section 2.4.5, respectively. In the domestic hot water column, the brighter green cells indicate much greater efficiency gains realized with a heat pump water heater (4) or tankless gas (1) over the much smaller efficiency improvement seen with tank-type and electric tankless units. The bottom row shows the prevalence of each key strategy in the deep retrofit dataset in descending order, exactly as shown in Table 19.

Table 21. Composition of Deep Energy Retrofit Packages

House Count	Improvement			13 Key Efficiency Strategies												
	Test-In	Test-Out	% Change	#1 HVAC	#2 Ceiling Insulation	#3 House Leakage	#4 Duct Leakage	#5 Window	#6 Refrigerator	#7 Domestic Hot Water	#8 30% + More CFLs	#9 Programable T-stat	#10 Duct R-Value	#11 Exterior Wall Color	#12 Roof Color	#13 Efficient Fans
1	172	68	60%	Y	Y	Untested	Untested	Y	N	HP	Y	Y	Y	N	Y	N
2	165	74	55%	Y	Y	>75%	51-75%	Y	Y	Y	Y	N	N	Y	N	N
3	177	81	54%	Y	Y	51-75%	51-75%	Y	Y	Y	N	N	Y	N	N	N
4	148	72	51%	Y	Y	Untested	Untested	Y	Y	Y	Y	Y	Y	Y	Y	N
5	160	78	51%	Y	Y	Untested	Untested	Y	Y	Y	Y	N	N	Y	N	N
6	164	84	49%	Y	Y	26-50%	>75%	Y	N	N	N	Y	N	N	Y	N
7	153	79	48%	Y	Y	51-75%	Worse	Y	Y	Y	Y	N	N	N	Y	N
8	160	83	48%	Y	Y	51-75%	>75%	Y	Y	TG	N	N	Y	N	N	N
9	151	79	48%	Y	Y	51-75%	51-75%	Y	Y	N	Y	N	N	Y	N	N
10	142	76	46%	Y	Y	Untested	Untested	Y	Y	Y	N	Y	N	Y	N	N
11	164	88	46%	Y	Y	1-25%	26-50%	N	Y	N	N	N	N	N	Y	N
12	121	65	46%	Y	Y	Untested	>75%	Y	Y	Y	Y	Y	Y	N	Y	Y
13	130	70	46%	Y	Y	Untested	Untested	Y	Y	Y	Y	Y	Y	Y	N	N
14	131	71	46%	Y	Y	51-75%	51-75%	N	Y	HP	Y	Y	N	N	N	Y
15	166	91	45%	Y	Y	26-50%	Worse	Y	N	Y	N	Y	N	N	Y	N
16	168	93	45%	Y	N	51-75%	51-75%	Y	Y	N	N	N	N	Y	Y	N
17	136	76	44%	Y	Y	26-50%	26-50%	Y	N	Y	Y	Y	Y	N	N	Y
18	131	74	44%	Y	Y	1-25%	Untested	Y	Y	N	Y	Y	Y	N	N	N
19	118	70	41%	Y	Y	1-25%	Worse	Y	Y	Y	Y	Y	Y	N	N	Y
20	116	69	41%	Y	Y	1-25%	26-50%	Y	Y	Y	Y	N	N	Y	N	N
21	178	106	40%	Y	Y	26-50%	26-50%	Y	N	N	N	N	Y	N	N	N
22	140	84	40%	Y	Y	26-50%	26-50%	Y	Y	Y	Y	N	N	N	N	N
23	132	80	39%	N	Y	26-50%	51-75%	Y	Y	Y	Y	Y	N	Y	N	N
24	142	87	39%	Y	Y	26-50%	26-50%	Y	N	N	N	N	N	N	N	N
25	138	85	38%	Y	Y	51-75%	>75%	Y	Y	Y	N	N	Y	Y	N	N
26	106	66	38%	Y	Y	26-50%	51-75%	Y	Y	HP	Y	N	N	N	Y	N
27	130	81	38%	Y	Y	Untested	>75%	N	N	Y	Y	Y	N	Y	N	N
28	130	81	38%	Y	Y	26-50%	Untested	N	N	Y	N	N	Y	N	Y	N
29	132	83	37%	Y	Y	1-25%	1-25%	Y	Y	Y	N	N	Y	Y	N	N
30	137	87	37%	Y	Y	1-25%	1-25%	Y	Y	N	N	Y	N	N	N	N
31	118	75	36%	Y	Y	26-50%	1-25%	Y	Y	Y	Y	Y	Y	Y	N	N
32	116	74	36%	Y	Y	1-25%	Worse	Y	Y	Y	Y	N	N	N	N	Y
33	140	90	36%	Y	Y	26-50%	51-75%	Y	Y	Y	N	Y	N	N	N	N
34	130	84	35%	Y	Y	Worse	26-50%	N	Y	N	N	N	N	N	Y	N
35	184	120	35%	Y	N	26-50%	26-50%	Y	N	N	N	N	Y	N	N	N
36	127	83	35%	Y	Y	26-50%	51-75%	Y	Y	Y	Y	N	Y	N	N	N
37	120	79	34%	Y	Y	Untested	Untested	Y	N	Y	N	Y	N	N	N	N
38	111	74	33%	Y	Y	Untested	Untested	Y	Y	N	Y	N	N	N	N	N
39	120	81	33%	Y	Y	26-50%	51-75%	Y	Y	Y	Y	N	Y	N	N	Y
40	117	79	32%	Y	Y	Worse	26-50%	Y	Y	N	N	N	N	N	Y	N
41	99	67	32%	N	Y	1-25%	26-50%	N	Y	HP	Y	Y	N	Y	Y	Y
42	122	83	32%	Y	N	26-50%	51-75%	N	N	Y	Y	Y	Y	N	N	N
43	125	86	31%	Y	Y	Worse	26-50%	Y	Y	N	N	Y	N	N	N	N
44	126	88	30%	Y	Y	1-25%	Worse	N	Y	Y	N	Y	N	N	N	N
45	114	80	30%	Y	Y	26-50%	26-50%	Y	Y	N	N	Y	N	N	Y	N
46	122	86	30%	Y	Y	1-25%	Untested	N	Y	Y	N	N	N	N	N	N
% Deep Retrofits w/Measure:				96%	93%	92%	86%	80%	76%	70%	52%	48%	39%	30%	30%	15%

Energy Costs and Savings, Improvement Costs, and Cash Flow for Deep Retrofits

Cost-effectiveness information for each of the 46 deep retrofits is presented in Table 22. The first four columns show house count, HERS Index pre- and post-retrofit, and the improvements percentage. The table is sorted by HERS Index improvement (column 4) in descending order. The remaining columns show factors involved in the cost-effectiveness calculations, specifically:

- House count (column 1)
- HERS Index improvement (columns 2–4)
- Test-in projected annual energy cost (column 5)
- Test-out projected annual energy cost savings (column 6)
- Test-out projected annual energy cost savings over minimum (column 7)
- Total improvement costs (column 8)
- Incremental improvement costs (column 9)
- Incremental annual cash flow (column 10).

Columns 2 through 4 related to HERS Index improvement are discussed in Section 3.1. The factors in columns 5 through 10 are discussed after the table.

Table 22. Energy Costs and Savings, Improvement Costs, and Cash Flow for Deep Retrofits (n = 46)

Deep Retrofits (30% HERS Reduction or more): Energy Costs, Savings, Improvement Costs, & Incremental Cash Flow									
Column 1	Columns 2-4			Column 5	Column 6	Column 7	Column 8	Column 9	Column 10
House Count	HERS Index Improvement Test-In	Test-Out	% Change	Test-In Projected Annual Energy Cost	Test-Out Projected Annual Energy Cost Savings[1]	Test-Out Projected Annual Energy Cost Savings Over Minimum[2]	Total Improvement Costs	Incremental Improvement Costs	Incremental Annual Cash Flow
1	172	68	60%	$2,036	$1,087	$764	$31,882	$7,433	$165
2	165	74	55%	$1,983	$863	$719	$18,571	$5,181	$301
3	177	81	54%	$2,445	$999	$999	n/a	n/a	n/a
4	148	72	51%	$2,669	$1,338	$525	$25,975	$4,520	$161
5	160	78	51%	$2,020	$980	$420	$18,488	$4,326	$71
6	164	84	49%	$2,030	$697	$697	$16,250	$3,204	$439
7	153	79	48%	$1,817	$659	$530	$18,955	$5,167	$114
8	160	83	48%	$1,880	$728	$728	$17,595	$3,011	$485
9	151	79	48%	$2,561	$1,092	$902	n/a	n/a	n/a
10	142	76	46%	$1,981	$674	$511	$11,496	$3,171	$255
11	164	88	46%	$2,854	$814	$468	$22,648	$3,793	$162
12	121	65	46%	$1,666	$595	$590	$24,384	$5,013	$186
13	130	70	46%	$2,179	$785	$626	$45,326	$7,856	*$7*
14	131	71	46%	$2,331	$702	$702	$13,103	$4,891	$308
15	166	91	45%	$3,101	$1,055	$1,021	$19,152	$5,321	$592
16	168	93	45%	$1,939	$639	$401	$19,146	$2,271	$218
17	136	76	44%	$1,894	$578	$455	$21,430	$4,080	$126
18	131	74	44%	$1,887	$599	$465	$9,570	$3,759	$162
19	118	70	41%	$1,637	$536	$428	$8,385	$3,072	$180
20	116	69	41%	$1,600	$475	$366	$22,623	$4,633	*$7*
21	178	106	40%	$2,761	$955	$955	$21,200	$4,088	$626
22	140	84	40%	$1,811	$567	$567	n/a	n/a	n/a
23	132	80	39%	$1,746	$555	$555	$9,835	$3,386	$282
24	142	87	39%	$1,923	$514	$266	$8,394	$781	$203
25	138	85	38%	$2,106	$477	$477	$22,210	$4,693	$99
26	106	66	38%	$1,946	$662	$662	$36,905	$8,382	*$13*
27	130	81	38%	$1,739	$488	$487	$11,165	$4,040	$161
28	130	81	38%	$1,592	$396	$400	$14,500	$3,400	$126
29	132	83	37%	$1,558	$414	$386	$17,535	$4,623	$13
30	137	87	37%	$1,727	$436	$414	$10,300	$3,821	$106
31	118	75	36%	$1,617	$387	$387	n/a	n/a	n/a
32	116	74	36%	$2,296	$711	$419	$39,308	$6,180	*$79*
33	140	90	36%	$1,783	$509	$481	$8,974	$3,155	$227
34	130	84	35%	$1,712	$414	$283	$14,029	$2,418	$88
35	184	120	35%	$2,289	$593	$324	$7,580	$1,399	$211
36	127	83	35%	$1,746	$364	$364	$14,835	$4,470	$4
37	120	79	34%	$1,614	$316	$234	$8,085	$2,822	$7
38	111	74	33%	$1,721	$410	$380	$14,325	$5,042	*$26*
39	120	81	33%	$1,624	$312	$312	$11,600	$3,468	$33
40	117	79	32%	$1,826	$399	$399	$4,536	$780	$336
41	99	67	32%	$1,496	$495	$495	$12,156	$3,506	$212
42	122	83	32%	$1,688	$462	$345	$9,055	$2,780	$121
43	125	86	31%	$1,642	$349	$315	$6,195	$1,800	$170
44	126	88	30%	$1,963	$453	$302	$5,053	$1,813	$156
45	114	80	30%	$1,437	$277	$177	$11,573	$2,448	*$20*
46	122	86	30%	$1,766	$359	$287	$5,488	$1,868	$136
Min:	99	65	30%	$1,437	$277	$177	$4,536	$780	-$79
Max:	184	120	60%	$3,101	$1,338	$1,021	$45,326	$8,382	$626
Average:	138	81	41%	$1,949	$612	$500	$16,424	$3,854	$169

[1] The change in HERS Index is not necessarily equivalent to the change in projected annual energy cost . This relates to the calculation procedures outlined in the RESNET Home Energy Rating System Standard.

[2] The "Minimum" is a revision to the 'test-in' scenario to include: 1) the federal minimum efficiency standard for air conditioner replacement (SEER 13), if the system was replaced, and 2) test-out house envelope size alterations (with normalized test-in leakage results). Associated improvement costs and energy cost savings for both have been removed from the cash flow calculation.

Test-In Projected Annual Energy Cost (column 5)

Projected annual energy cost for the pre-retrofit homes ranged from $1,437 to $3,101, and averaged $1,949 (sd = $376).

Projected annual energy calculations were produced using EGUSA with the operating and thermostat schedules designated by the 2006 HERS Standard (RESNET 2006). Because of calculation procedures in the HERS Rating Standard, the percent change in HERS Index does not match the percent change in projected energy costs. To allow comparison among the retrofits, the annual energy cost calculations were made using a standard utility rate of $0.13/kWh, $1.72/therm of natural gas, and $1.40/gal of propane (one home). This is a known bias in the study in that local utility rates may be higher or lower; however, in the interest of studying the whole dataset, utility rates needed to be standardized. Although using the annual energy *use* rather than the annual energy *cost* would have allowed comparability without this complication, it would not have provided a path for the cost-effectiveness calculations. Where utility rates were higher or lower than the standardized rate, resulting annual cash flow would have been higher or lower, respectively.

Test-Out Projected Annual Energy Cost Savings and Savings Over Minimum (columns 6 and 7)

Projected annual energy cost savings for each deep retrofit are presented in two ways. The first (column 6) is a straightforward difference between projected pre- and post-retrofit annual energy costs. Projected annual savings over the as-found condition ranged from $277 to $1,338, with an average of $612 (sd = $244, column 6).

The second (column 7, Test-Out Projected Annual Energy Cost Saving Over Minimum) addresses a nuance of retrofit savings calculations that is important in relation to calculating incremental cost.

In some cases, an item could not be replaced with one of equal efficiency or specification. This complicates calculating incremental cost in some scenarios, such as when a SEER 10 heat pump is being replaced with a SEER 15 unit, because SEER 10 units cannot be purchased. In these cases, cost cannot be obtained for an “apples to apples” replacement. Incremental savings and costs are calculated instead in comparison to the pre-retrofit house with a SEER 13 central, split system air conditioner paired with either an integral electric resistance heating element (COP = 1) or a naturally aspirated gas furnace (0.78 AFUE) depending on the pre-retrofit heating fuel. One exception to this is when an as-found unit with SEER 12 heat pump would have lower annual energy cost than SEER 13 with electric resistance heating. To create a less efficient basis of comparison would effectively overstate the savings; thus, comparisons in these cases are made to the original system.

These issues arise also when conditioned area is reduced. For example, comparing R-38 over a 1,500 ft^2 (post-retrofit area) to R-9 over 2,000 ft^2 (pre-retrofit area) would exaggerate the project cost energy savings.

These few items are combined into a modified version of the pre-retrofit house called “Minimum Improvement,” which represents the pre-retrofit house with adjusted size (five houses) and minimum efficiency or specification replacements. Annual savings compared to this scenario are shown as “Projected Annual Energy Cost Savings Over Minimum” (column 7). Excluding the savings from any reduction in conditioned area and cooling efficiency improvement up to SEER 13, the savings over minimum ranged from $177 to $1,092, with an average of $500 (sd = $201).In retrofits where there was no change to the conditioned area and the air conditioner was not replaced or was replaced with a SEER 13, there is no difference between column 6 and column 7. For examples, see houses 6 and 8.

Total and Incremental Improvement Costs (columns 8 and 9)

Improvement costs are characterized in two ways: total cost and incremental cost. Many of these homes needed extensive repair to bring them up to local market standards, costing tens of thousands of dollars. Only costs associated with energy-related elements of the renovation are being reported here in Total Improvement Costs (column 8). For example, costs for cabinets, interior painting, electrical system repairs, and other nonenergy-related items are not reported.

Researchers requested that partners provide costs for individual energy-related improvements in each house. Partners provided costs for 42 of the 46 deep retrofits (as well as 21 of the other homes). Total improvement costs (column 8) ranged from $4,536 to $45,326 and averaged $16,424 (sd = $9,262).

When labor and materials were donated or heavily discounted, partners were unable to provide meaningful costs. In several cases, the partner was unable to provide cost information for all the elements of the improvement package. In these cases, researchers estimated costs, relying on reported costs for the same or similar items in a different home or bid documents, which are often identical to actual invoices in these projects. There are four deep retrofits for which researchers received no cost information. Accounting for the costs associated with improving the envelope leakage measure was also not possible in any of the houses. Typically, this improvement was simultaneous with other improvements such as window replacement, drywall repair, and lighting and plumbing fixture replacements, rather than an extensive air sealing campaign.

Researchers found no evidence that the total cost for replacing functional equipment and components in good condition could be offset by projected annual energy cost savings. However, when an energy-related item needs to be replaced, the incremental cost of choosing higher performance options can often be offset by the incremental savings. Incremental cost (column 9) is the portion of total cost related to higher performance specifications when energy-related items needed to be replaced. For example, when a water heater is worn out and must be replaced, it could be replaced with a unit of the same (or nearly the same) efficiency; a higher performance unit can be purchased for a slightly higher cost. That cost difference is the incremental cost that would be added to the mortgage for higher performance. This accounting strategy parallels the decision-making process. It responds to the question, “If the water heater needs to be replaced, is a higher performance specification worth the money?” As described previously incremental costs and savings were sometimes calculated in comparison to a modified version of the pre-retrofit home when equipment cannot be replaced with models of like efficiency.

In the 42 deep retrofits for which we have cost information, total incremental cost, or cost over replacement with like efficiency, ranged from $780 to $8,382 and averaged $3,854 (sd = 1,687).

Incremental Annual Cash Flow (column 10)

In all cases, the incremental mortgage burden is compared to the "Projected Energy Savings Over Minimum" scenario (column 7) for the whole package of improvements to generate the Incremental Annual Cash Flow (column 10). Numbers in black indicate positive cash flow in 36 of the 42 deep retrofits with improvement cost data. "n/a" indicates that the partner did not provide cost data. Incremental annual cash flow ranged from –$79 to $626 and averaged $169 (sd = 158). Cash flow was positive in all but six cases (86% were positive).

The six retrofits with negative cash flow are discussed in Section 3.3.

Appendix C: Draft Current Best Practices

Preliminary Standard Building Science and Energy Efficiency Guidelines

Items italicized and in red indicate required measures.

Components and Strategies	**Replacement Measure Specifications**	**Additional Requirements and Recommendations for All Projects and Maintenance/Repair Measures for Components not being replaced**
Combustion Safety (If any combustion appliances exist within home)	☐ *When feasible, locate all atmospheric combustion water heaters and furnaces in unconditioned space.* ☐ *Install CO detectors near all combustion appliances and all bedrooms.* ☐ *Supply adequate combustion air per Gas Code and manufacturer specifications.* ☐ *For fireplaces, install a glass door.* ☐ *Install return air pathways and pressure relief as necessary to avoid depressurization.* ☐ *If not replacing existing gas water heaters or furnaces, implement the guidance in HVAC, water heating, infiltration, and insulation sections.*	
HVAC & Mechanical Distribution	When replacing mechanical equipment, observe the following guidelines: Part 1 – HVAC Assessment, Design, and Specifications: ☐ *Ensure ENERGY STAR (min. SEER 14.5) qualified air conditioner with heat pump (North and Central FL), straight cool (South FL).* ☐ *No atmospheric combustion furnaces in conditioned space.* ☐ Ensure matched equipment. ☐ When conceivable, bring air hander and/or ducts into interior space. ☐ *Ensure ducted return.* ☐ *Duct leakage to the outside ≤ 6% (Qn,out ≤ 0.06).* ☐ *Include testing in the mechanical contractor scope of work.* ☐ *Ensure ducts insulated to R-Value ≥ 6 or higher.* ☐ Consider installing a MERV 8 air handler filter or higher. (System air flow design must account for the increased pressure drop associated with this type of filter.) ☐ In bedrooms that do not have a ducted return air pathway, provide "jump ducts" or "high-low" passive return air pathways to achieve balanced return air. Size per guidelines in the Florida Mechanical Code section 601.4. ☐ Perform ACCA Manual J load calculation and size system accordingly. ☐ Perform room-by-room ACCA Manual D calculations and size ducts accordingly. ☐ Produce a schematic duct design showing sizes for each component. ☐ *When feasible, install a dampered, passive mechanical ventilation duct to provide outside air to the return plenum. Note that the system must be*	When keeping an existing mechanical system, observe the following guidelines: Part 1 – HVAC Return Plenum and Passive Return Air Pathways: ☐ When feasible, retrofit a duct board plenum into platform returns. ☐ When feasible, replace louvered doors on air handler closets with a correctly sized central return grille mounted in the wall (if adjacent to a living space) or in a solid door. ☐ When feasible, replace air handler stands with ducted return plenum. For example, a correctly sized central return grille mounted in a wall in the main living space of the house, a duct board plenum (sealed at the edges and seams with mesh and mastic), under a new framed platform. ☐ In bedrooms that do not have a ducted return air pathway, provide "jump ducts" or "high-low" passive return air pathways to achieve balanced return air. Size per guidelines in the Florida Mechanical Code section 601.4. Part 2 – HVAC Service Mechanical Equipment: ☐ *If an atmospheric combustion furnace exists, provide adequate supply of combustion air per National Gas Code and manufacturer specifications.* ☐ HVAC contractor service call including checking air conditioning/heat pump charge, cleaning inside and outside coils of AC/heat pump, cleaning gas furnace components, checking gas lines for leaks, cleaning condensate drain lines of air conditioners, and conducting any other recommended maintenance.

Components and Strategies	**Replacement Measure Specifications**	**Additional Requirements and Recommendations for All Projects and Maintenance/Repair Measures for Components not being replaced**
	designed so that the outside air passes through a filter before entering the air handler. Part 2 - HVAC Installation: ☐ *New duct work must be strapped to trusses to achieve clearance over anticipated ceiling insulation. Ideal location is midway between roof deck and top of insulation* ☐ Duct sizes specified on design are installed. ☐ *Ensure flex duct collars are fully insulated.* ☐ *Seal all joints and edges in supply ducts, return plenum, and connections to air handler. Mesh and mastic seal preferred.* Part 3 – Post-retrofit HVAC Testing and Verification (after all renovation activity in the house has been completed.): ☐ Acquire documentation from mechanical contractor that equipment and systems have been tested and are operating as designed. ☐ *Test to ensure duct leakage to the outside ≤ 6% (Qn,out ≤ 0.06).* ☐ *Test to ensure pressure difference between main body of the house and each bedroom of <=2.5 pascals when air handler is operating at maximum capacity and with all interior doors closed. If in excess of 2.5 pascals, add passive air pathways from pressurized bedroom to main body of home.* ☐ *For homes with an atmospheric gas furnace in an attached unconditioned space, conduct a combustion zone depressurization test under worst case operating conditions. After all other changes and repairs to the mechanical system have been made; take steps necessary to ensure that the combustion zone (e.g. laundry room) is not depressurized below -3 pascals with respect to the main living area.*	Part 3 – HVAC Test Duct System Air Tightness Pre-retrofit. If measured leakage exceeds 6% (Qn,out ≥ 0.06), identify and seal leakage points. Likely leakage points are addressed below. ☐ If air handler stand, all edges and seams in closet drywall. ☐ If central ducted return, return grille connection to framing; return plenum (e.g. duct board) connection to framing and connection to air handler. ☐ If open platform, all edges and seams. ☐ If supply registers are being pulled, seal between drywall and boot. ☐ Seal any loose connections. ☐ Ensure flex duct collars are fully insulated. Part 4 – Post-retrofit HVAC Testing and Verification (after all renovation activity in the house has been completed.): ☐ *Duct System Air Tightness Post-retrofit. Apply same criteria and strategies as the first item under "Part 3" above.* ☐ With all interior doors closed and air handler operating at maximum capacity, measure pressure difference between main body of the house and each bedroom. For rooms depressurized more than 2.5 pascals (reading at or below negative 2.5), add passive air pathways to main body of home. ☐ *For homes with an atmospheric gas furnace in the conditioned space or in an attached unconditioned space, conduct a combustion zone depressurization test under worst case operating conditions. After all other changes and repairs to the mechanical system have been made; take steps necessary to ensure that the combustion zone (e.g. laundry room) is not depressurized below -3 pascals with respect to the main living area.*
Ventilation	☐ *Install passive outside air ventilation system, see Part 1 of HVAC section.* ☐ *Kitchen exhaust fan ducted to outdoors (CFM 100)* ☐ *Bathroom exhaust fans ducted to outdoors (CFM 50)* ☐ Consider bath fan timer.	☐ Install passive outside air ventilation system, see Part 1 of HVAC section ☐ *If possible, install new kitchen exhaust fan ducted to outdoors (CFM 100)* ☐ *If possible, install new bathroom exhaust fans ducted to outdoors (CFM 50)*

Components and Strategies	Replacement Measure Specifications	Additional Requirements and Recommendations for All Projects and Maintenance/Repair Measures for Components not being replaced
Infiltration	☐ Pre-retrofit, conduct blower door test to assess whole house air tightness and identify leakage points (see list below). Target test result is 6 or less air changes per hour at the test pressure of 50 pascals (ACH50 ≤ 6.0).	

	☐ *Repeat test post-retrofit. If test result exceeds target of ACH50 ≤ 6.0, check and repair the following common leakage points (particularly important if there are atmospheric combustion water heaters or furnaces in the home):*
	o Windows
	o Doors – replace weather stripping if missing or degraded
	o Electrical panel service entrance
	o Lighting fixtures and can lights
	o Fan fixtures – if replacing, seal to drywall
	o Kitchen exhaust fan chase
	o Switches and outlets – if replacing covers, seal boxes to drywall
	o Plumbing penetrations through interior and exterior walls (e.g. under sinks)
	o Plumbing access panels – secure tightly and/or weather strip
	o Attic hatch – weather strip
	o Top of interior air handler closet – seal all edges and seams
	o Soffits over cabinets housing lighting – add air barrier above
	  o Holes in drywall
	  o Top plates where accessible
	  o In frame floors, bottom plate penetrations
	  ☐ *Post-retrofit, measure whole house pressure difference in the main body of the house and in the combustion zone with respect to outside while all interior doors are closed, exhaust fans and dryer are on, and air handler is off. Repeat test with air handler on. If pressure exceeds, - 5 pascals in either test in the main body of the house, or -3 pascals in the combustion zone, identify and repair duct and/or whole house infiltration points.*	

Roof	☐ *If asphalt shingle, light or white colored finish, Solar Reflectance ≥ 0.25.* ☐ *Ensure proper installation of flashing.* ☐ *Install drip edge.*	
Ceiling Insulation	☐ Complete mechanical, electrical, and plumbing rough-in prior to ceiling insulation. ☐ *All recessed lighting fixtures including "can" lights and fluorescent tube fixtures should be boxed in to prevent insulation contact or replaced with units rated for insulation contact and air tightness (ICAT) prior to ceiling insulation.* ☐ *Ducts shall be supported above ceiling insulation with hanger supports no more than 5 feet apart.* ☐ *Insulate any interior attic hatch with rigid foam or batt insulation to R-19 and weather-strip.* ☐ *If ceiling insulation is in poor condition, add insulation to achieve RESNET Grade I R-38 throughout.* ☐ Where attic or other unconditioned space (such as floor cavities) extend over porches, provide insulation damn and an air barrier to prevent insulation spillage onto porch ceiling and air infiltration into attic or floor cavity. ☐ If multi-story home, assure floor cavity between stories are properly insulated such that uncontrolled attic air is not allowed to influence interior space. (Reference Withers, C., Cummings, J., Opportunities for Energy Conservation and Improved Comfort From Wind Washing Retrofits in Two-Story Homes – Part I and Part 2, Florida Solar Energy Center, Sept. 2010.) ☐ If attic insulation is at the roof deck, additional factors need to be addressed.	
Knee Walls (vertical attic surfaces)	☐ *Ensure RESNET Grade I installation to R-13 or greater insulation.*	

Components and Strategies	**Replacement Measure Specifications**	**Additional Requirements and Recommendations for All Projects and Maintenance/Repair Measures for Components not being replaced**
Windows	☐ *Install ENERGY STAR labeled windows with U-value ≤ 0.6 and SHGC ≤ 0.27.* ☐ *Ensure proper flashing installation* ☐ *If installing house wrap, follow manufacturer instructions for cutting and wrapping at window openings.* ☐ *Replace any rotted materials.* ☐ *Air seal between window frame and rough opening.* ☐ *Caulk between edges of window frame and exterior finish.* ☐ Plant shade trees near east and west facing windows (Deciduous trees in North Florida).	☐ If un-tinted, apply window tint to achieve combined (glass + tint) SHGC ≤ 0.5 and preferably visible transmittance ≥ 0.5. ☐ *Caulk between edges of window frame and exterior finish.* ☐ *Ensure proper head flashing (above top of window) with wood siding, install if necessary.* ☐ *Check for and replace any rotted materials around window (e.g. studs, sheathing.)* ☐ Plant shade trees in east and west facing windows (Deciduous trees in North Fl).
Exterior Walls	☐ If painting, use light or white color. ☐ *If replacing drywall in frame construction, install RESNET Grade I installation to R-13.* ☐ If replacing drywall in block construction, install continuous rigid insulation under furring strips. ☐ If replacing siding, check for and replace rotted materials, install and integrate continuous drainage plane with window and door flashing.	
Floors	☐ If frame, consider R-19 insulation. If using spray foam, ensure coverage of framing members (at least ½”) to reduce thermal bridging. ☐ *If crawl space, repair or install ground cover for vented areas, lapping joints 6”, and continuing up stem wall 2’.*	☐ *If crawl space, repair or install ground cover for vented areas, lapping joints 6”, and continuing up stem wall 2’.*
Water Heating	☐ *No atmospheric combustion water heaters in the conditioned space.* ☐ *If an atmospheric combustion water heater is installed in an attached unconditioned space, ensure that the combustion zone (e.g. laundry room) is not depressurized below -3 pascals with respect to the main living area under worst case operating conditions, post-retrofit. Provide make up air if necessary.* ☐ Wrap tank with R-5 blanket, for gas units, read instructions carefully. ☐ Insulate accessible hot water pipes. ☐ Evaluate solar access and cost of solar water heating. ☐ Gas: Tankless, EF>0.80. ☐ Electric: Integrated Heat Pump Water Heater, COP >= 2.0 or standard tank type unit, EF >=0.92.	☐ *If an atmospheric combustion water heater exists, provide adequate supply of combustion air per National Gas Code and manufacturer specifications.* ☐ *If an atmospheric combustion water heater is in the conditioned space or in an attached unconditioned space, ensure that the combustion zone (e.g. laundry room) is not depressurized below -3 pascals with respect to the main living area under worst case operating conditions, post-retrofit. Provide make up air if necessary.* ☐ Wrap tank with R-5 blanket, for gas units, read instructions carefully. ☐ Insulate accessible hot water pipes.

Components and Strategies	**Replacement Measure Specifications**	**Additional Requirements and Recommendations for All Projects and Maintenance/Repair Measures for Components not being replaced**
Appliances (Refrigerator, Dish Washer, Washing Machine)	☐ *Install ENERGY STAR rated appliances.* ☐ *Clothes dryer vented to outdoors.*	☐ Clean refrigerator coils. ☐ *Clothes dryer vented to outdoors.*
Lighting	☐ *Install screw in or pin based CFL when feasible.* ☐ *Recessed "can" lights to be eliminated or replaced with Insulation Contact Rated Airtight Fixtures (ICAT).* ☐ Install air barrier above soffit mounted light fixtures.	
Fans	☐ *Select ENERGY STAR rated ceiling fans.*	
Moisture	☐ Implement improvements per guidance in sections above - passive outside air ventilation system (HVAC), install ducted exhaust fans (Ventilation), reduce whole house infiltration (Infiltration), reduce duct leakage (HVAC), and ensure continuous ground cover in vented crawl spaces (Floors). ☐ Remove moisture loading at walls and foundation (e.g. irrigation system, roof runoff, soil contact).	
Pool	☐ Add pool cover to existing or newly installed pool.	

Appendix D: Sarasota NSP Energy Conservation Standards

After participating in Part 1 of this Building America research, the Sarasota Office of Housing and Community Development (Sarasota County and City of Sarasota, Florida) developed this set of standard specifications in consultation with BA-PIRC, HERS raters in the Sarasota region, non-profit housing providers in the community, and staff.

NEIGHBORHOOD STABILIZATION PROGRAM 2
ENERGY CONSERVATION STANDARDS

Exterior Standards

Exterior Siding and Trim – All siding and trim must be intact, waterproof and free of deterioration. Replacement of damaged sections may include up to 25% of sound surfaces. If more than 25% of the section is damaged, the entire section must be replaced. All exterior surfaces must have a continuous coat of paint or bonded finish with an expected life of at least 5 years.

> Replacement standard – All siding that is replaced must be sensitive to the historic nature of the home. All exterior painting must be light color or white with low or no Volatile Organic Compounds (VOCs).

Roofs – All roofs must be weather tight. Shingles must be in good shape and show no signs of blistering or curling. Missing shingles and flashing must be repaired or replaced. Broken antennas must be removed. All roofs must have at least a ten-year minimum expected useful life and be installed after March 1, 2001.

> Replacement standard – Flat roofs will be replaced with 10-year rated material and any roof coating must be ENERGY STAR qualified. Pitched roofs will be replaced with an ENERGY STAR minimum 25 year rated shingle. If an ENERGY STAR shingle is not available, the shingle must be a light color. The entire roof deck must be re-nailed in compliance with the hurricane mitigation manual section 201.1 and a secondary water barrier shall be provided as required by section 201.2. Roof to wall connections will be installed and facilitated as deemed appropriate by OHCD inspector.

Insulation – Attics must be insulated to R-30. Exterior walls only need to be insulated if the plaster or drywall is removed.

> Replacement standard – All new insulation must use formaldehyde-free recycled content materials such as fiberglass or cellulose and if new or additional insulation is being installed, it must be brought to R-38.

Windows – Each habitable room, excluding the kitchen, bathroom and interior rooms must have at least one window. All windows must be weather tight and those accessible from the ground must have locking hardware. If the existing windows will remain, the OHCD inspector is to consider the use of solar window film on windows facing the south or west.

Replacement standard – Replacement windows will be dual pane ENERGY STAR insulated window for our climate zone with impact glass. Bathrooms windows must be opaque or have a window covering if viewable from the outside.

Window protection – All openings must have hurricane protection by either having hurricane resistant glass or shutters.

Replacement standard – If windows are not being replaced, each opening must have shutters installed that meet the Florida Building Code for newly constructed housing in the area.

Caulking and weather stripping – All windows and doors must be caulked and/or weather striped and in an excellent condition.

Replacement standard - Caulk and weather-strip doors and windows, using foam sealant for larger gaps. Install foam gaskets behind outlet and switch plates on walls. Replace leaky door thresholds with ones that have pliable sealing gaskets.

Weatherization-

Where accessible all areas where plumbing, ducting, or electrical penetrates through walls, floors, ceiling must be sealed. All attic leaks where walls meet attic floor, dropped soffits, behind kneewalls, attic hatch or door, etc must be sealed.

HVAC

Heating plant – Each unit must have a heating system capable of heating the unit to 68 degrees when the outside temperature is 40 degrees. All HVAC systems must have a SEER rating of at least 13 and be less than 8 years old. If the existing HVAC unit is not replaced, the following services must be performed: inspect condensate drain while in cooling mode; Inspect, clean, and/ or change air filter; clean indoor and outdoor coils; check central AC refrigerant charge and charge if needed.

Replacement standard – An ENERGY STAR unit with a SEER rating of 16 or greater will be installed. In cases where the existing space does not permit the installation of a 16 SEER rated unit, an ENERGY STAR unit with a minimum SEER rating of 15 may be installed. A Manual J form must be submitted to OHCD prior to specification and purchase of unit.

Ducts –All ducts must be deemed to be in an excellent condition. If the ducts are not being replaced, a Duct Test must be all and all joints and connections must be sealed with duct mastic with a goal of 6% or less leakage. Where the duct meets floor, wall, or ceiling, the gaps must be sealed.

Replacement standard –All ductboard must have a minimum insulation of R-6. Flexible Ducts shall be class 1. All systems shall be designed to minimize ductboard lengths and all plenums shall be sealed and constructed in accordance with the Florida Mechanical Code.

Thermostats – All units must have a programmable thermostat controlling the HVAC unit.

Replacement standard – An ENERGY STAR 7-day programmable thermostat that controls each zone must be installed.

Vent Fans

Replacement Standard- All newly installed kitchen and bathroom fans must be ENERGY STAR.

Appliances and Equipment

Hot Water Heater – All units must have a water heater capable of producing 100 degree F at the faucet and must not be more than 8 years old.

Replacement Standard – All new hot water heaters must be an ENERGY STAR qualified model.

Refrigerators – All units must have a working refrigerator that is less than 10 years old that is appropriately sized for the home and capable of keeping food cold.

Replacement standard – An ENERGY STAR labeled model.

Dishwasher - Units are not required, but may have dishwashers.

Replacement standard – An ENERGYSTAR unit must be installed The unit must be a CEE tier 2 with a minimum energy factor of 0.68 or greater, have a maximum annual energy use of 325 kWh or less and have a water factor of 6.5 or less.

Ceiling fans-

Replacement Standard – All new ceiling fans must be ENERGY STAR labeled. New ceiling fan light kits must be ENERGY STAR.

Lighting

Fixtures – Eighty Percent of all light fixtures must have ENERGY STAR LED or CFL or fluorescent light bulbs installed in the fixtures.

Replacement standard – All replaced lighting and lightning fixtures must use ENERGY STAR LED or CFL light bulbs.

Plumbing

Toilet – All units must have a working toilet with a maximum 1.6 gallons.

Replacement standard – All units must be WaterSense labeled (1.28 gallons or less per flush).

Shower heads – All shower heads must be WaterSense labeled (2 gallons or less per minute)

Bathroom Faucets – All bathroom faucets must be WaterSense labeled (1.5 gallons or less per minute) or retrofitted with a WaterSense labeled faucet aerator.

Kitchen Faucets – All kitchen faucets must have flows of 2.2 gallons or less per minute

Landscaping – All exterior downspouts that are not on the front of the home must be connected to a rain barrel or cistern to reduce runoff and provide rainwater harvesting for landscape purposes. All renovated landscaping shall follow the guidelines of the SWFWMD Florida Water Star Program for existing homes to conserve water.

Shut off valves

Replacement Standard- All shut off valves shall be replaced with quarter turn or push/pull turn offs. All supply lines shall be reinforced or armored.

Well – All wells will be inspected to insure that they are safe.

Indoor Environmental Quality (IEQ)

The existing specifications will be changed to only use LOW OR NO VOC paints, glues, adhesives, solvents, cleaners and finishes to minimize occupant exposure to chemicals.

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U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

DOE/GO-102013-3896 ▪ March 2013

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