BUILDING TECHNOLOGIES PROGRAM

Retrofitting the Southeast: The Cool Energy House

W. Zoeller, C. Shapiro, G. Vijayakumar, and S. Puttagunta
Consortium for Advanced Residential Buildings

February 2013

Available electronically at http://www.osti.gov/bridge
Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov
Available for sale to the public, in paper, from:
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

Retrofitting the Southeast: The Cool Energy House

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

Prepared by:

W. Zoeller, C. Shapiro, G. Vijayakumar, and S. Puttagunta

Steven Winter Associates, Inc.

of the

Consortium for Advanced Residential Buildings (CARB)

61 Washington Street
Norwalk, CT 06854

NREL Technical Monitor: Cheryn Metzger
Prepared under Subcontract No. KNDJ-0-40342-00

February 2013

[This page left blank]

Contents

List of Figures

Unless otherwise noted, all figures were created by CARB.

List of Tables

Unless otherwise noted, all tables were created by CARB.

Definitions

ACH	Air changes per hour
BARA	Building America Retrofit Alliance
BEopt	Building Energy Optimization software
Btu	British thermal unit
CARB	Consortium for Advanced Residential Buildings
CEH	COOL Energy House
CFM	Cubic feet per minute
DOE	U.S. Department of Energy
EF	Energy factor
gal	Gallons
HERS	Home Energy Rating System
HPWH	Heat pump water heater
HSPF	Heating season performance factor
HVAC	Heating, ventilation, and air conditioning
IBS	International Builder Show
IR	Infrared
kWh	Kilowatt hour
NAHB	National Association of Home Builders
NREL	National Renewable Energy Laboratory
o.c.	On center
SEER	Seasonal energy efficiency ratio

Executive Summary

For the third consecutive year, the Consortium for Advanced Residential Buildings has provided the technical engineering and building science support for a highly visible demonstration home in connection with the National Association of Home Builders' International Builders Show. The two previous projects, the Las Vegas net-zero ReVISION House and the 2011 VISION and ReVISION Houses in Orlando, met goals for energy efficiency, cost effectiveness, and information dissemination through multiple web-based venues. This project, which was unveiled at the 2012 International Builders Show in Orlando on February 9, is the deep energy retrofit Cool Energy House (CEH). The CEH began as a mid-1990s two-story traditional specification house of about 4,000 ft^2 in the upscale Orlando suburb of Windermere. The homeowners, who were planning some interior renovations and a small addition, were recruited for this project through their contractor, Southern Traditions, the builder for last year's VISION and ReVISION homes.

The initial objectives of the CEH project included reducing simulated annual energy consumption by 50% compared to the pre-retrofit home. The project team realized from the start that reaching this performance goal in the context of a relatively light (not gut-rehab) renovation was a significant challenge, one that might not be fully accomplished. However, by aggressively pushing the performance level improvements beyond what is typical, and by using the process and the outcomes as teaching and training content for outreach and dissemination, the project team could engage in the research and resource development objectives of the Building America program. Viewed from a whole-house vantage point, and looking at the final predicted performance levels, the numerous integrated energy efficiency measures involved in this project collectively contribute to the 48% reduction in modeled site and source energy use for this all-electric home. Some of those measures were very successful (and contributory); others were less so, yet yielded valuable information on the limits of their benefits.

Nearly all the interior wall surfaces and all the exterior brick veneer remained in place. The two-story insulated frame walls were insulated further by blowing fiberglass from the interior through 6-in. horizontal slots in the gypsum board. The partially occupied attic space was sealed, finished, and encapsulated with R-30 closed-cell spray polyurethane foam at the roof deck. Downsized air-source heat pumps replaced the two older systems, and most of the existing ducts were sealed with mastic and reused. The home also features heat pump water heaters and a whole-house dehumidifier/ventilator, which will be involved in ongoing monitoring to assess performance. These two advanced technologies address two common gaps in this region—high efficiency water heating in all-electric homes and humidity control in the hot-humid climate zone.

The 49% simulated reduction in energy consumption over the previous conditions translates to approximately 12,687 kWh/yr or $1,500 in anticipated annual electricity bill savings. The retrofit also improved indoor air quality by providing whole-house and local ventilation, as well as dehumidification, and improved thermal comfort by air sealing, duct sealing, and reducing solar heat gain through windows. The costs associated with upgrades that contributed to reported energy savings amounted to $47,550, for a simple payback of about 31 years.

1 Introduction and Background

The objective of test house research evaluations is to demonstrate and document on a test home the viability of market-ready systems that improve the energy efficiency of existing homes to levels that are 30%–50% better than the pre-retrofit performance based on the Building America House Simulation Protocols (Hendron and Engebrecht 2010). Through these demonstrations, important information is obtained on the costs to implement, and gaps requiring additional research are often identified. These projects also provide valuable data on the commercial viability of "best in class" residential energy efficiency solution packages.

Working with a builder partner on a test home allows whole-house building strategies to be vetted to ensure that there are no unintended consequences before these strategies are implemented at a production scale. These test homes also provide an opportunity to work with the builder and contractors to formalize scopes of work, trade sequencing, and guidance documentation. This information is critical before moving to a production scale, because community buildouts can have multiple supervisors and contractors who need to have clearly defined roles and expectations before construction begins.

For the third consecutive year, the Consortium for Advanced Residential Buildings (CARB) provided the technical engineering and building science support for a highly visible demonstration home in connection with the National Association of Home Builders' (NAHB) International Builders Show (IBS). The two previous projects, the Las Vegas net-zero ReVISION House and the 2011 VISION (new construction) and ReVISION (retrofit) Houses in Orlando set and met goals for energy efficiency, cost effectiveness, and information dissemination through multiple Web-based venues. This project, which was unveiled at the 2012 IBS in Orlando on February 9 (though construction was not complete), is the deep energy retrofit Cool Energy House (CEH). The CEH began as a 16-year-old two-story traditional specification house of about 4,000 ft^2 in the upscale Orlando suburb of Windermere. The homeowners, who were planning some interior renovations and a small addition, were recruited for this project through their contractor, Southern Traditions, the builder for the VISION and ReVISION Homes (EDU 2012).

Working in collaboration with fellow Building America Team's Building America Retrofit Alliance (BARA), CARB provided the test-in energy-audit base-lining; the performance optimization analysis through BEopt (Building Energy Optimization) to determine upgrade selections, technical installation support, and the mechanical systems engineering. After the project was completed, CARB conducted the final test-out and systems commissioning, and initiated long-term field monitoring. Compared to a pre-retrofit Home Energy Rating System HERS Index of 141, a final post-retrofit Home Energy Rating System Index of 61 was achieved. Using the Building America House Simulation Protocols and BEopt, the completed retrofit is projected to reduce overall energy use by 49%, close to the initial target of 50%.

The challenge in meeting these targets was amplified by this not being a gut-rehab, but a rather modest renovation effort. Nearly all the interior wall surfaces and all the exterior brick veneer remained in place. Additional insulation was added to the insulated two-story frame walls by blowing fiberglass from the interior using horizontal 6-in. slots in the gypsum board, an experimental process developed by the team. During final testing, infrared (IR) thermal imaging will be compared to initial images to qualitatively assess the airtightness improvement of the wall insulation to determine if this novel approach should be further examined for potential wider market dissemination. The partially occupied attic space was sealed and encapsulated with R-30 closed-cell spray polyurethane foam at the roof deck. Downsized air-source heat pumps replaced the two older systems, and most of the existing ducts were sealed and reused. Windows were replaced, two 50-gal heat pump water heaters (HPWHs) replaced the two 50-gal electric resistance storage tanks, and a whole-house ventilation/dehumidification system was installed with its own distribution system.

Figure 1. Front (west) and rear (east) elevations, pre-retrofit

Figure 2. Front (west) and rear (east) elevations, post-retrofit

Figure 3. Rendering, post-retrofit [Image courtesy of Winter Park Design]

2 Research Methods

BARA and CARB began the project in the summer of 2011 with a goal for the deep energy retrofit of 50% source energy savings over the existing all-electric home, while being as non-intrusive as possible to exterior and interior finishes. The teams divided the work into three main phases: auditing and testing (pre- and post-construction), BEopt analysis, and implementation. After identifying the primary barriers to reaching that performance target, cost-benefit analyses of various measures took place using BEopt software.

2.1 Energy Audit

An energy audit of the CEH was conducted on a peak cooling-load day for Florida, August 2, 2011, and included a blower door test, a duct-blaster test, and IR photography to evaluate thermal deficiencies in the envelope. A visual inspection revealed that exterior walls had Kraft-faced fiberglass batts installed as insulation, which was evaluated as Grade III, with many gaps and voids. Although existing insulation was nominally rated as R-19 and R-13, respectively, the first floor 2 × 6 walls were estimated to have a de-rated R-value between 10 and 12, and the second and third floor 2 × 4 walls were estimated to have de-rated R-values between 7 and 9.

The attic floor had 5–8 in. of blown fiberglass insulation, resulting in an overall R-value of about 19. Air infiltration was calculated using a blower door; the infiltration rate was measured at 3,650 CFM50, or 6 ACH50 (air changes per hour at 50 Pascal). Though this rate meets current ENERGY STAR® Version 3 (EPA 2012). National Program requirements for homes following the prescriptive path in this climate zone, this still provides considerable room for improvement in building tightness. With the blower door test in progress, an IR camera was used to document thermal deficiencies and air leakage, as shown in Figure 4. Potential areas for envelope improvements identified in this 16-year-old house were air leakage, poorly installed insulation, and the lack of an effective air barrier separating the finished attic space from the vented attic.

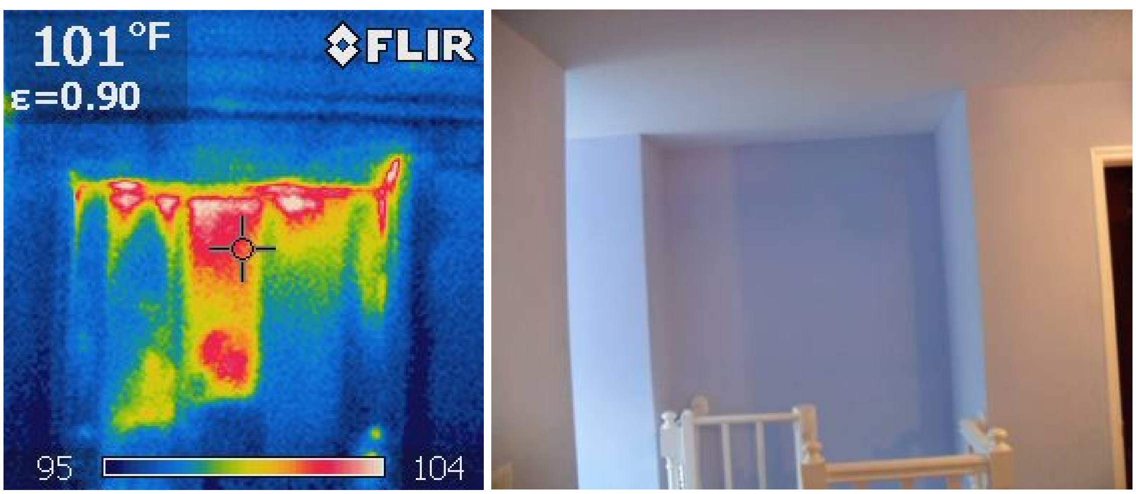

Figure 4. Thermal losses caused by poor wall insulation installation and air leakage, pre-retrofit

Heating and cooling were provided by two 2.5-ton air-source heat pumps. One heat pump serviced the first floor. Its air handler, located in the vented attic, was manufactured in 1995 (the year the house was originally built); the original compressor had been replaced with a seasonal energy efficiency ratio (SEER) 10 unit manufactured in 2002. Though the 2002 compressor has the capacity for an efficiency to reach SEER 10, actual efficiency is unknown because of the older coil. The air handler for the second heat pump, also located in the vented attic, serviced the second floor and partially finished attic space. Both that air handler and its compressor had been replaced in 2008 (increasing to a SEER 13).

Total airflow through both heating, ventilation, and air conditioning (HVAC) distribution systems was measured. Airflow in the upstairs unit was 788 CFM and in the downstairs unit was 710 CFM. Total duct leakage (leakage to both inside and outside) and leakage to outside only were also tested. The upstairs unit had a total leakage of 145 CFM25; the downstairs unit had a total leakage of 130 CFM25. Together, this corresponded to a leakage rate of 7 CFM/100 ft^2, or 18% of total measured system airflow. Leakage to outside on the upstairs unit was 70 CFM25, and 42 CFM25 on the downstairs unit. This corresponded to a leakage rate of 3 CFM/100 ft^2, or 7% of total airflow. Notable areas of leakage occurred around junction boxes, boot connections, and the duct board at the air handlers, but the leakage for these two systems was low enough to even beat ENERGY STAR Version 3 requirements (EPA 2012).

Domestic hot water was provided by two 50-gal electric resistance storage water heaters, both installed in 1995. An occupant-operated local exhaust ventilation fan was installed in each of the four bathrooms. Fourteen percent of the lighting was fluorescent lamps; the remaining lighting was incandescent. One ENERGY STAR-qualified refrigerator was installed.

2.2 Energy Use Modeling

To model the energy use of the existing building and the proposed retrofit, CARB initially used BEopt 1.1. Upon completion of the building, the model was updated to BEoptE+ 1.2 (NREL 2012a), which enabled better modeling of the HPWHs and dehumidifier. CARB entered the data from the energy audit and analyzed the modeled energy use of the existing home to identify areas with the greatest opportunities for savings. Various energy saving measures were modeled relative to the pre-retrofit conditions, to determine a package that could come as close to 50% energy savings as practical. Although the renovated home does include a two-story 700-ft^2 addition on the north side where the garage once was and a new detached garage with living space above, for consistency, both the pre-retrofit and post-retrofit have been modeled without those new spaces, using the pre-retrofit conditioned floor area, wall area, and ceiling area.

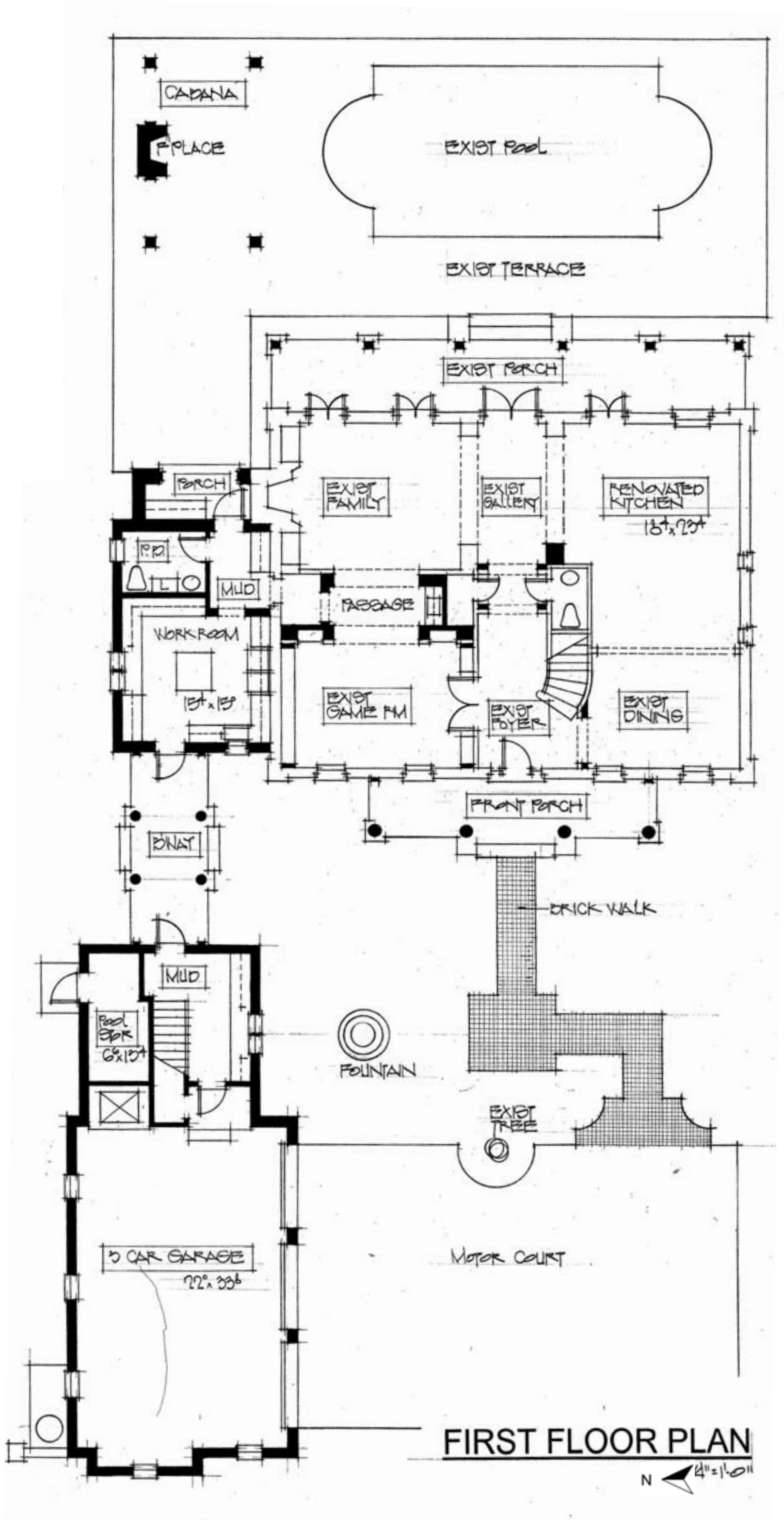

Figure 5. First floor plans, post-retrofit [Image courtesy of Winter Park Design]

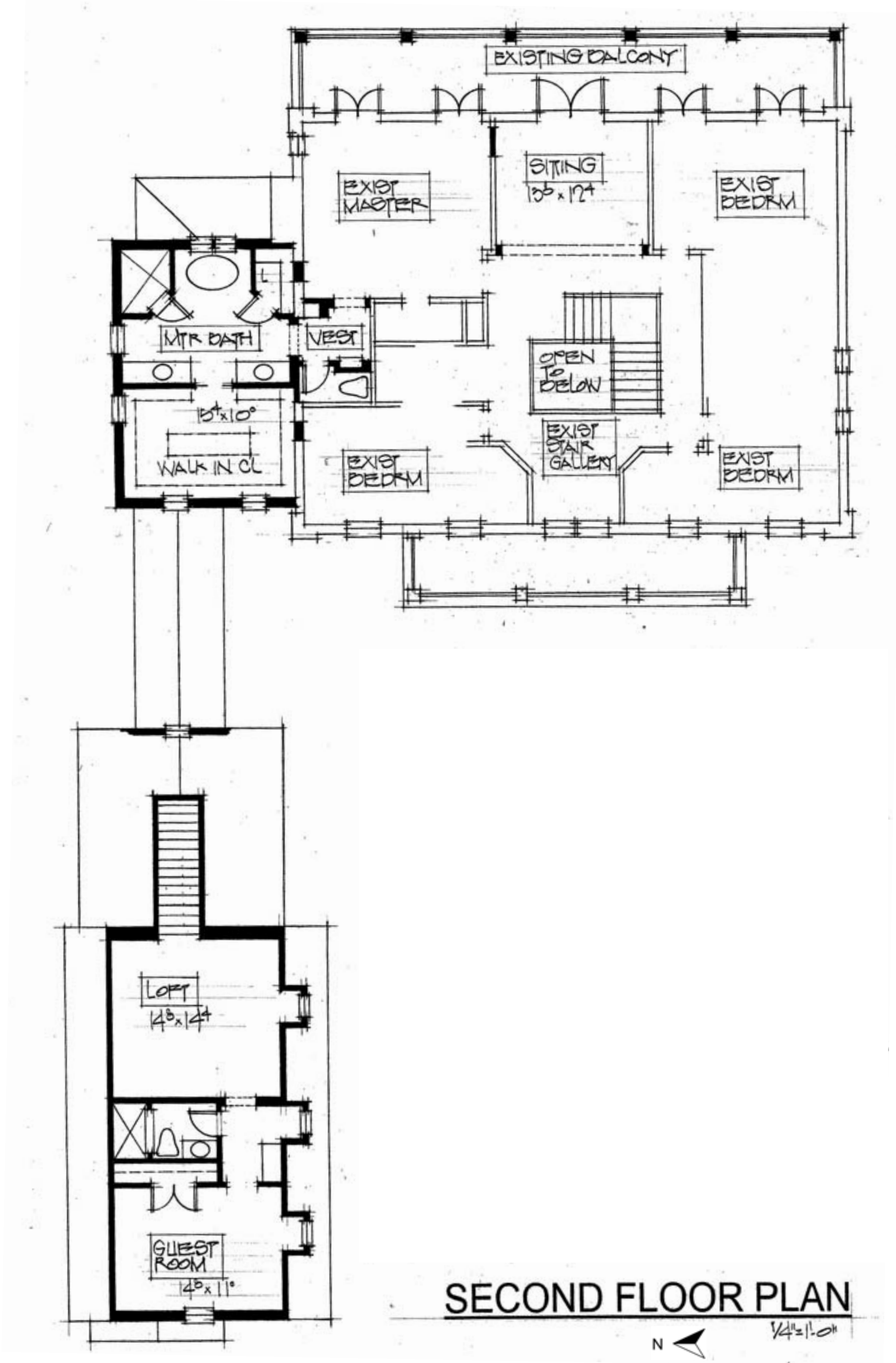

Figure 6. Second floor plans, post-retrofit [Image courtesy of Winter Park Design]

2.3 CARB-Recommended Specifications

Final energy efficiency measures implemented, shown in Table 1, were recommended by CARB based on past experience with retrofit projects and best-practice approaches for retrofits, bearing in mind the project objectives and limitations. The desire to preserve existing brick façade and minimize impact to interior finishes figured prominently in the recommendations. The first column represents building components in the existing home based on findings from the energy audit. Equipment efficiencies were estimated based on the age of the equipment and U-values and solar heat gain coefficients (SHGCs) were estimated using windows of similar construction.

Table 1. Existing, Proposed, and Post-Retrofit Specifications

Component	Existing	Proposed	Post-Retrofit
Foundation Assembly	Uninsulated	Same as existing	Same as existing
Above Grade Wall Assembly	1st floor: R-19, Grade III, 2 × 6 16-in. o.c. 2nd floor: R-13, Grade III, 2 × 4 16-in. o.c.	1st floor: R-21, Grade I, 2 × 6 16-in. o.c. 2nd floor: R-15, Grade I, 2 × 4 16-in. o.c.	1st floor: R-21, Grade I, 2 × 6 16-in. o.c. 2nd floor: R-15, Grade I, 2 × 4 16-in. o.c.
Ceiling/Attic Assembly	R-19 blown-in fiberglass, 2 × 8 at ceiling, vented attic	R-30 at roof, 5-in. closed-cell spray foam, unvented attic	R-30 at roof, 5-in. closed-cell spray foam, unvented attic
Window Glazing	Rear (east): single pane, U = 0.869, SHGC = 0.619 Elsewhere: double pane, U = 0.447, SHGC = 0.547 wood, aluminum	All: low-e, double pane, U = 0.28, SHGC = 0.21 vinyl	All: low-e, double pane, U = 0.28, SHGC = 0.21 vinyl
Building Infiltration	Measured 6 ACH50	Target 4.0 ACH50	Measured 4.8 ACH50
Space Conditioning System	Two 2.5 ton ~SEER 10, HSPF* 6.2 heat pumps	Two 2-ton SEER 17.5, HSPF 9.5 heat pumps, whole-house dehumidifier (150 pints/day; 2.02 L/kWh)	Two 2 ton SEER 17.5, HSPF 9.5 heat pumps, whole-house dehumidifier (150 pints/day; 2.02 L/kWh)
Ductwork	R-4 insulation, measured 7% leakage to outside	Ducts in conditioned space, sealed with mastic	Ducts in conditioned space, sealed with mastic
Whole House Ventilation	None	Whole-house supply-only ventilation, minimum ASHRAE 62.2 (part of whole-house dehumidifier)	Whole-house supply-only ventilation controlled by humidistat (part of whole-house dehumidifier)
Local Ventilation	Spot vent only	spot vent with delay off timers	Spot vent with delay off timers
Water Heating	Two electric resistance, 50-gal, EF = 0.91	Two HPWHs, 50 gal, EF = 2.4	Two HPWHs, 50 gal, EF = 2.4
Lighting	14% fluorescent lighting	75% high efficacy lighting	75% high efficacy lighting
Roofing Material	dark asphalt shingles, abs = 0.92, e = 0.91	Same as existing	Same as existing
Appliances	ENERGY STAR refrigerator, standard dishwasher	New ENERGY STAR refrigerator and dishwasher, induction stove	New ENERGY STAR refrigerator and dishwasher, induction stove

* HSPF = heating season performance factor

2.4 Energy Analysis Relative to Previous Conditions

CARB's recommendations were based on analyzing the existing energy use, as estimated from an energy model of the existing home. As shown in Table 2, the highest modeled end use was cooling, and offered the largest opportunity for savings. Therefore, recommendations were prioritized that reduced the cooling load. Although existing insulation was relatively decent for this hot-humid climate zone, the first goal was to increase insulation quality and decrease infiltration with the same measure, and bring the equipment and ducts into conditioned spaces by insulating at the roof deck, rather than at the attic floor. To further improve the envelope, high performance windows were selected, with good U-values and very low SHGCs. Internal gains were reduced by installing high efficacy lighting, and even with the 700-ft^2 addition, the cooling load decreased from 5 tons to 4 tons. Upgrading to SEER 17.5 heat pumps to meet this reduced load resulted in combined simulated savings of 68% in cooling energy use, and contributed to 27% of the 49% simulated whole-house energy savings.

Although heating in Florida is one of the smallest loads, the simulation showed that the high efficiency heat pumps (9.5 HSPF) could decrease that end use of 75% or 3% of the 49% simulated whole-house energy savings, and decrease the air handler energy use from the electrically commutated motors. Based on the simulation, the next end use to target was the lights, followed by the hot water system. Upgrading lights contributed to 5% of the 49% simulated whole-house energy savings and hot water energy use decreased by 67% in the simulation by switching from 16-year-old traditional electric resistance water heaters to HPWHs.

The introduction of fresh air incurred an energy penalty in the simulation, reducing the project savings from 50.3% to 49.2%. However, this system also provides dehumidification, so the improvement to indoor air quality was worth the small penalty. The dehumidifier may enable occupants to use a higher cooling set point that will offset the energy penalty with cooling savings. This will be evaluated during monitoring. Table 2 shows the simulated energy consumption by end use for the existing and post-retrofit home.

Table 2. Simulated Energy Use Distribution

	Existing		Post-Retrofit		Savings
Loads	Site Energy (kWh)	Source Energy (MMBtu)	Site Energy (kWh)	Source Energy (MMBtu)	Percent (%)
Cooling	10,295	118	3,337	38	68%
Heating	1,148	13	292	3	75%
Hot Water	2,116	24	699	8	67%
HVAC Fan	2,524	29	340	4	87%
Lights	3,813	44	2,512	29	34%
Appliances	1,257	14	1,220	14	3%
Ventilation	33	0	98	1	-198%
Miscellaneous Electric Loads	4,622	53	4,622	53	0%
Total	25,807	296	13,120	151	49%

Figure 7 shows the cumulative energy savings by measure and their individual impacts on the whole-house energy savings. The new air-source heat pumps contributed the most; the unvented "conditioned" attic and HPWHs came in second and third, respectively. Improvements to lighting and windows contributed a little more than 5% each to the total 49% savings.

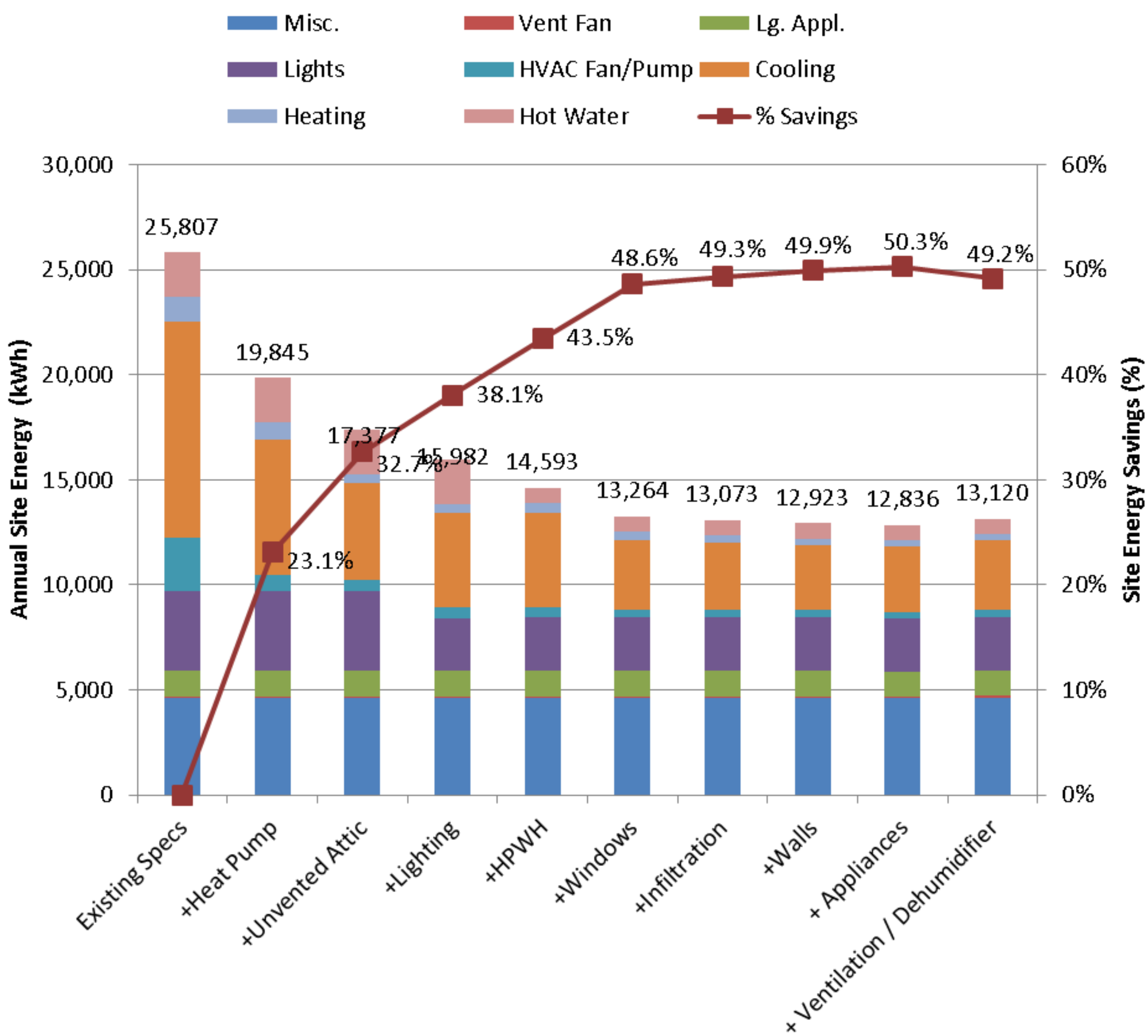

Figure 7. Cumulative contribution to total simulated energy savings, by measure and end use

3 Retrofit Solutions

Once the final recommendations for energy saving measures were confirmed, the team set out to implement the recommended retrofit specifications.

3.1 Above-Grade Walls

CARB took a unique approach to enhancing the home's existing insulation that aligned with the need to be as low impact as possible to interior and exterior finishes. The team cut 6-in. bands in the interior drywall at the 4-ft fire blocking level. This allowed chopped fiberglass product bearing a small amount of adhesive to be blown into the wall cavity (see Figure 8). At first, 4-in. holes were attempted to blow in fiberglass, but did not provide enough access for complete fill, so the team switched to 6-in. band cuts. After the walls were insulated, the 6-in. gaps were sealed and repainted. This new application resulted in a more complete fill of the exterior walls with the combined existing batts and added blown fiberglass. This improved the R-value of the wall assembly and likely decreased air infiltration. However, only stud bay cavities could be accessed in this manner. Three-stud corners, partition Ts, and heavily blocked areas remain inaccessible.

Figure 8. Process of insulating the walls [Images courtesy of BARA]

Table 3. Wall Assembly Rated Insulation Values

	Existing	Post-Retrofit
First Floor Assembly	2 × 6, 16-in. o.c.	2 × 6, 16-in. o.c.
Insulation	R-19 fiberglass, Grade III	R-21, Grade I
Second Floor Assembly	2 × 4, 16-in. o.c.	2 × 4, 16-in. o.c.
Insulation	R-13 fiberglass, Grade III	R-15, Grade I

3.2 Attic

Not only did the energy audit identify air leakage from the unconditioned attic, equipment and ductwork were also located in this space, contributing to energy losses. Rather than upgrading the insulation at the attic floor (Figure 9), the roof deck was insulated by using closed-cell spray polyurethane foam at the inside surface of the roof deck (Figure 10). This increased the R-value from 19 to 30, turned a vented attic into an unvented attic and brought the equipment and ductwork into conditioned space. Added nonenergy benefits of this measure are the improvement to the roof deck’s uplift resistance and its resistance to moisture intrusion, both valuable in this hurricane-prone area.

Figure 9. Attic floor insulation, pre-retrofit

Figure 10. Attic roof deck insulation, post-retrofit [Images courtesy of BARA]

3.3 Windows

Existing windows were aluminum-framed, double-paned in most of the house, except for the single-pane wood-framed French-doors at the rear. Glazing certainly contributed to the high cooling load (40% of the home's design cooling load was due to solar heat gain). Although some of the fenestration was doubled-glazed, energy modeling indicated it was worth the effort and cost to replace the windows and French doors. However, the double-wall, brick-veneer construction presented an installation challenge. The team had to determine how to retroactively flash the window openings to prevent moisture migration into the building envelope.

Figure 11. Rough opening after window removal [Images courtesy of BARA]

The homeowner also wanted the replacement vinyl windows (U-0.28, SHGC-0.21) to look like the originals, so the builder had to flash and install them at the interface between the brick veneer and the framed wall. The solution was to wrap the entire rough opening with a treated wood buck detail that lapped over the air space between the brick veneer and the wall framing. The new head, jamb, and sill buck were wrapped with butyl flashing tape, which also formed a pan flashing at the sill. The new window frame was secured to the new wood buck (Figure 12). Snap-on exterior window trim components covered the tape, with a caulk bead added between the trim and the brick to finish the installation.

Figure 12. Foam sealant at window unit interior [Image courtesy of BARA]

3.4 Heating and Cooling

The first floor system had been poorly maintained and had an improperly matched indoor coil as a result of just the outdoor unit being replaced in 2002, so this SEER 10 rated unit, based on BEopt library options, was estimated at SEER 7 for analysis purposes. Although the second floor system had been replaced four years earlier, both systems were completely replaced with new, more efficient, and slightly smaller capacity heat pumps (Table 4 and Table 5). The new indoor coils were properly matched to the outdoor coils and with efficient fan motors, were able to reduce air handler fan energy use. On the efficiency side, replacing the two systems raised the average cooling efficiency from an average of SEER 10 to SEER 17.5. To avoid relocating any ductwork, air handler locations were kept the same. Because of the new roof insulation, the air handlers are now within the conditioned attic space.

Table 4. First Floor HVAC System Specifications

	Existing	Post-Retrofit
First Floor Heat Pump	Trane XE 1000	Lennox XP17
Year Installed	1995/2002	2012
Rated Cooling Capacity	29,600 Btu/h	25,000 Btu/h
Rated SEER	10.0	17.5
Rated Heating Capacity	30,200 Btu/h	22,200 Btu/h
Rated HSPF	7.0	9.5

Table 5. Second Floor HVAC System Specifications

	Existing	Post-Retrofit
Second and Third Floor Heat Pump	Trane XB13	Lennox XP17
Year Installed	2008	2012
Rated Cooling Capacity	33,400 Btu/h	25,000 Btu/h
Rated SEER	13.0	17.5
Rated Heating Capacity	31,800 Btu/h	22,200 Btu/h
Rated HSPF	7.7	9.5

Figure 13. Heat pump compressors, pre- and post-retrofit

3.5 Domestic Hot Water

The 16-year-old electric resistance storage water heaters were previously also located in the vented attic. These were removed and replaced with two new HPWHs (Figure 14), increasing the rated energy factor from 0.91 to 2.4 and reducing hot water energy use by 67%. One of the new units was placed in a first floor closet in the new addition and the other in the unvented attic.

Figure 14. Electric resistance storage water heaters, pre-retrofit (left) and one of two electric HPWHs, post-retrofit (right)

3.6 Indoor Air Quality

The existing home only had provisions for some local mechanical exhaust. A goal of the renovation was to provide improved local exhaust and add whole-house ventilation at rates that would comply with ASHRAE 62.2-2010 minimum ventilation standards. With the introduction of additional fresh air, an approach was needed that could simultaneously provide dehumidification.

3.6.1 Local Exhaust Ventilation

As part of the renovation, each full bathroom was equipped with a new Panasonic WhisperGreen exhaust fan that should provide 80 CFM of local exhaust ventilation when operated. These fans also include an internal delay-off timer (set to 20 minutes) to allow the fan to continue to remove moisture even after the fan and lights are switched off. Rather than a recirculating range hood, the new range hood in the kitchen was ducted directly to the exterior.

3.6.2 Whole-House Supply Ventilation and Dehumidification

To meet ASHRAE 62.2 whole-house ventilation rate recommendations for this renovated four-bedroom, 4,700-ft^2 home, meant providing at least 85 CFM of fresh air. In hot-humid climates, a supply ventilation strategy is often preferred over an exhaust only strategy, so that the incoming ventilation air can be pre-conditioned. The Honeywell TrueDRY DH150 was installed to provide whole-house supply-only ventilation as well as dehumidification. A 6-in. duct brings in fresh outdoor air, mixes with air from a 10-in. return duct from the stairwell of the home, is dehumidified as needed, and supplied back to the home via a 10-in. duct. The 10-in. supply duct feeds three branches going to the master bedroom, upstairs landing, and downstairs family room.

Control of this unit was specified to be the Honeywell's TrueIAQ digital control. This control shows indoor and outdoor temperature and relative humidity, the actual and desired humidity setting, and maintenance/service reminders. Figure 15 shows the designed inlets and outlets of the dehumidifier. Unfortunately, the system was installed with a basic humidistat so whole-house ventilation is provided only when relative humidity levels in the home exceed 60%. For modeling purposes, it was assumed that 50% of ASHRAE 62.2-2010 would be provided over the course of a year (anticipated to be near 100% run time during the summer months and 50% or less for the remainder of the year). Although this whole-house ventilation measure increased annual energy use in the energy model by nearly 300 kWh, reducing the overall savings from 50.3% to 49.2%, it does improve indoor air quality and thermal comfort. The dehumidification of the whole-house ventilation air is also expected to lead to additional savings on the cooling side, but cannot be modeled in BEopt.

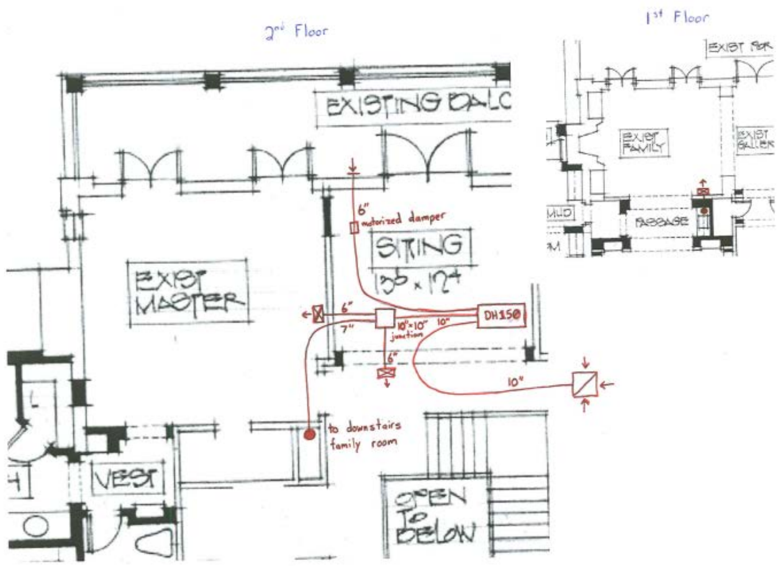

Figure 15. Designed configuration of whole-house dehumidifier

3.7 Performance Testing

As mentioned in Section 2.1, performance testing was conducted during the initial energy audit and revealed sources of envelope air leakage and HVAC system duct leakage. In June 2012, post-retrofit performance testing and evaluations were conducted (see Table 6).

Table 6. Performance Testing Results

	Existing	Post-Retrofit
Blower Door (CFM50)	3,650	3,560*
Infiltration (ACH50)	6.0	4.8
Infiltration (ACH50/100 ft^2 of Enclosure Area)	0.0796	0.0433
Specific Leakage Area	0.00033	0.00027

* The post-retrofit testing includes roughly 8,000 ft^3 of additional conditioned volume from the addition and conversion to an unvented attic.

3.7.1 Infiltration

Using the blower door to depressurize the house to 50 Pascal, infiltration during the initial audit was measured at 3,650 CFM, or approximately 6 ACH, or an estimated 0.33 natural ACH. By adding insulation to the stud wall cavities and properly sealing around windows, infiltration was anticipated to be reduced to 4 air changes per hour at 50 Pascal, or an estimated 0.22 natural ACH. Testing confirmed infiltration at approximately 4.8 ACH50. Although the infiltration rate did decrease by about 20%, the CFM50 did not decrease at the same rate due to the increased volume of the actual post-retrofit house (700-ft^2 addition and conversion to an unvented attic).

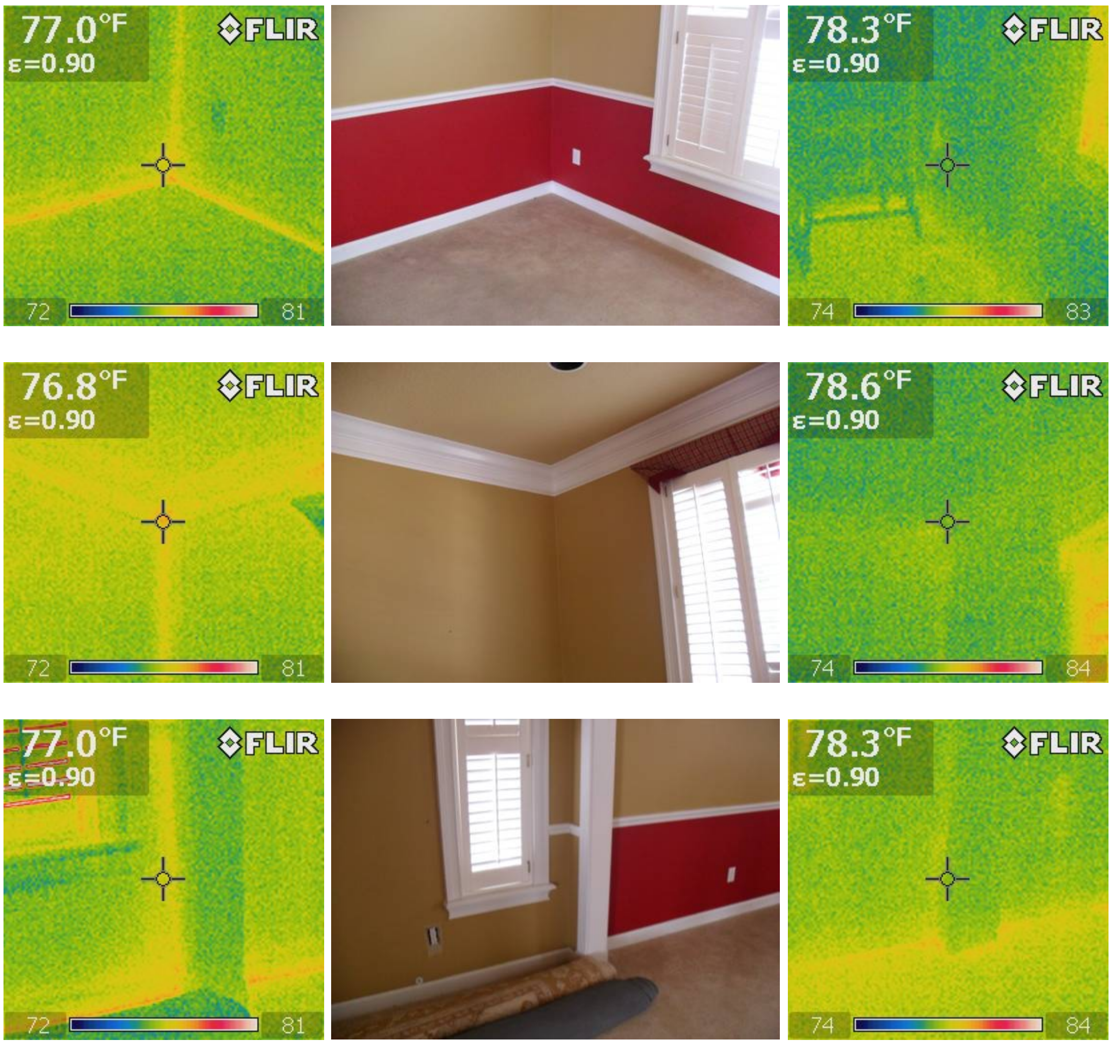

Figure 16. Thermal bridging at framing members in dining room
(left: pre-retrofit IR image, center: digital picture, right: post-retrofit IR image)

By using IR thermal imaging before and after the retrofit, CARB was able to qualitatively assess the improvement in the wall cavity insulation. Heat flows in three ways: convection (transfer of heat by the actual movement of the warmed matter), conduction (transfer of energy through matter from particle to particle), and radiation (electromagnetic energy waves that directly transport energy through space). IR cameras detect radiation in the IR range (7–12 microns). The amount of radiation emitted by an object increases with temperature, so IR cameras allow the user to see variations in surface temperature. The applicable temperature scale is noted on each image, but in general, purple/blue represents colder surfaces and red/white represents warmer surfaces. Figure 16 through Figure 19 show the improved thermal resistance of the wall assembly as evidenced by less temperature variation (typically caused by thermal bypasses or air leakage) across the building assemblies.

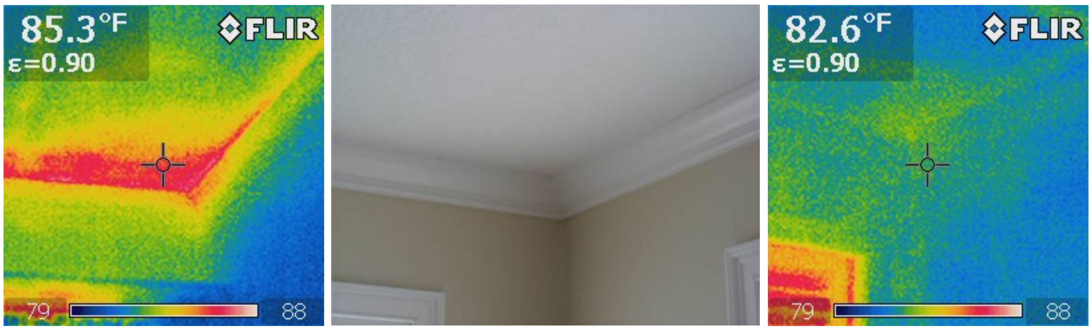

Figure 17. Wind washing of attic insulation at exterior wall corner in the master bedroom (left: pre-retrofit IR image, center: digital picture, right: post-retrofit IR image)

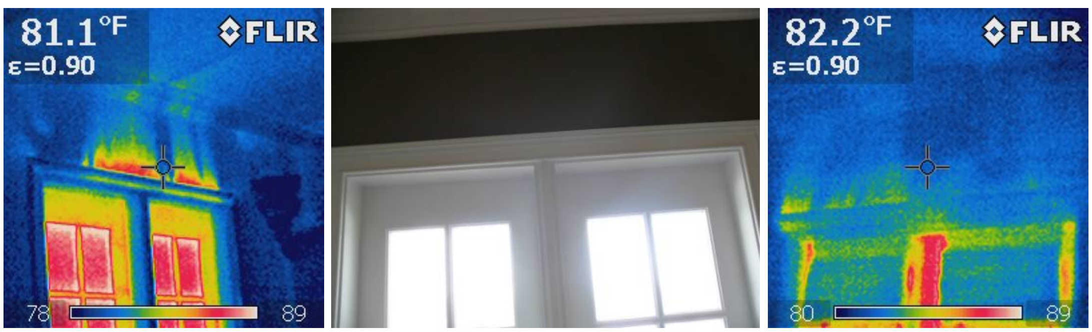

Figure 18. Air leakage at top of framing for the rear entry French doors (left: pre-retrofit IR image, center: digital picture, right: post-retrofit IR image)

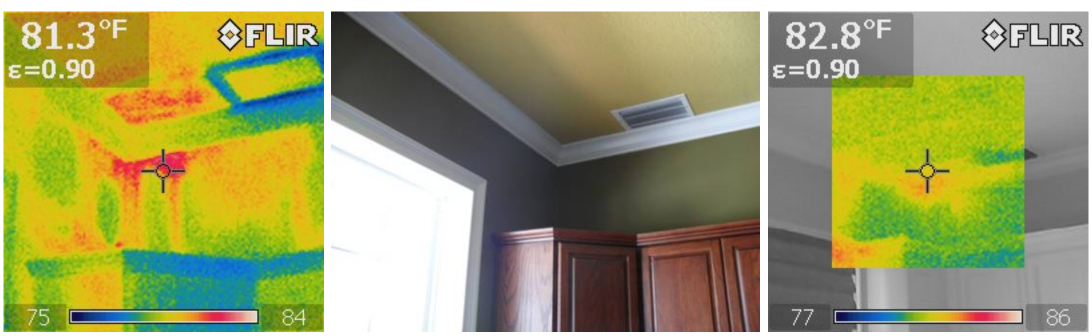

Figure 19. Air leakage in exterior wall corner in kitchen (left: pre-retrofit IR image, center: digital picture, right: post-retrofit IR image)

Still, leakage was found in a couple locations during the final performance testing. One of the interior walls in the downstairs addition between the side room and pool bath appears to be connected to the outside, as evidenced by warm air (orange/yellow) depicted in Figure 20. It is currently unclear how or why this is occurring.

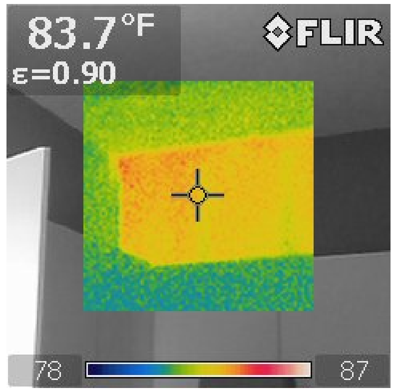

Figure 20. Air leakage in a first floor interior wall in the new addition

The other major source of building infiltration that was found post-retrofit was air movement between the old and new roof in the unvented attic above the master closet. The old soffit of the existing roof was not sealed and then an access cutout between the two roofs opened this soffit space to the unvented attic (Figure 21).

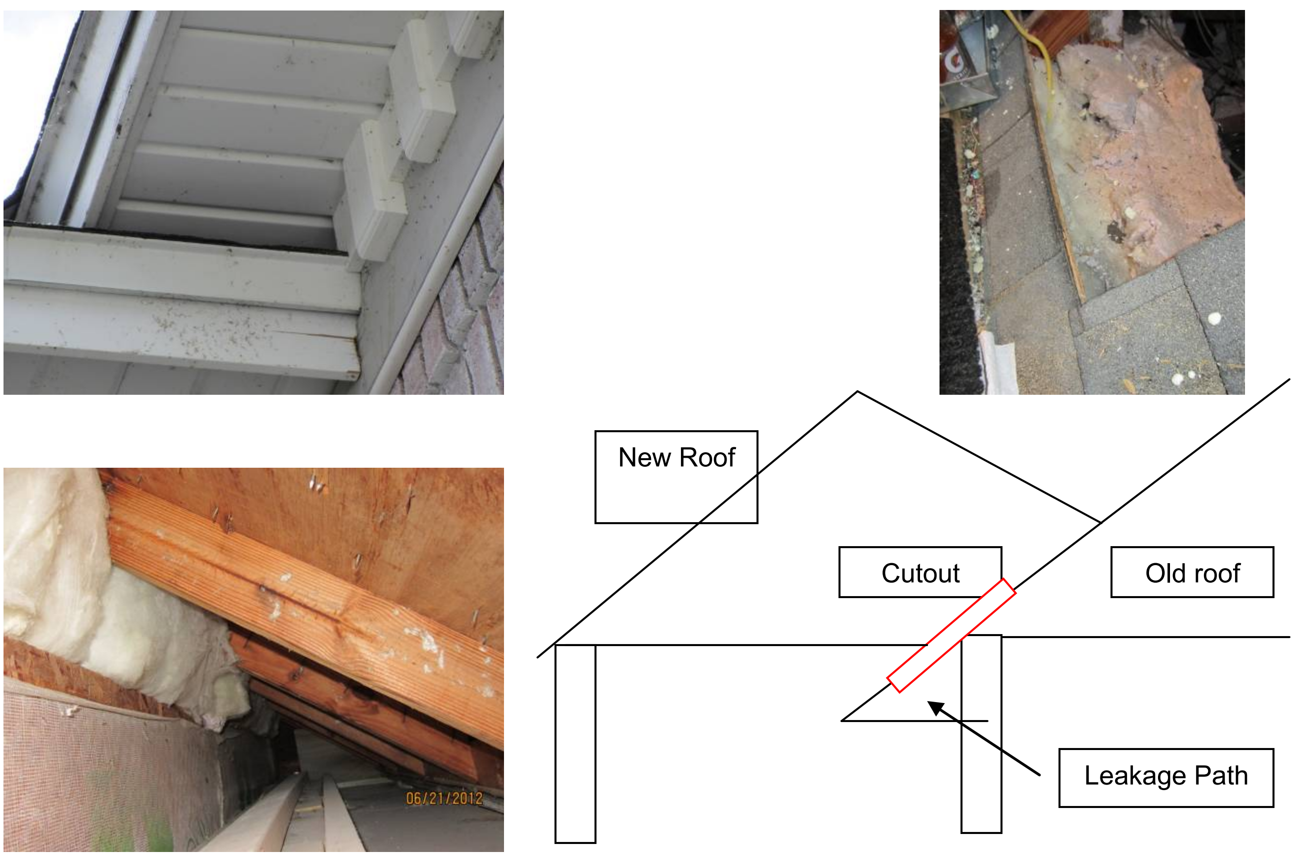

Figure 21. The old soffit is a major leakage pathway as a result of an access opening being cut out between the two attic spaces to allow for the dehumidifier ductwork to run to the existing portion of the home.

3.7.2 Duct Leakage

Temporarily sealing the supply and return registers and pressurizing the separate duct systems to 25 Pascal revealed that the overall pre-retrofit leakage was approximately 18% of the system airflow. To identify the leakage associated with an energy penalty, the pre-retrofit house was simultaneously pressurized and only leakage outside the pressurized boundary was measured. This leakage (7%) was relatively low for a system that was installed 16 years ago, with ductwork and equipment located in an unconditioned attic. Pre-retrofit, both total duct leakage and duct leakage to the outside already met current ENERGY STAR requirements.

Table 7. HVAC Performance Testing Results—Existing

	First Floor	Second and Third Floors
Rated Cooling Capacity	29,600 Btu/h	33,400 Btu/h
Measured Airflow	710 CFM	788 CFM
Total Duct Leakage	130 CFM25	145 CFM25
Total Duct Leakage	7.4 CFM25/100 ft^2	6.7 CFM25/100 ft^2
Duct Leakage to Outside	42 CFM25	70 CFM25
Duct Leakage to Outside	2.4 CFM25/100 ft^2	3.2 CFM25/100 ft^2

Figure 22. Air handler sealing, post-retrofit

The retrofit included duct sealing around junction boxes, boot connections, and the duct board plenums at the air handlers, and brought the ductwork into conditioned space. Post-retrofit, duct leakage to the outside was reduced to 2.5% of the total airflow. Still the total duct leakage actually increased slightly. Possibly one or more connections or joints were disturbed when the ductwork, which was mostly inaccessible in walls, was modified, which created a slightly greater internal duct leakage.

Table 8. HVAC Performance Testing Results—Post-Retrofit

	First Floor	Second and Third Floors
Rated Cooling Capacity	25,000 Btu/h	25,000 Btu/h
Measured Airflow	839 CFM	911 CFM
Total Duct Leakage	196 CFM25	168 CFM25
Total Duct Leakage	11.2 CFM25/100 ft^2	7.8 CFM25/100 ft^2
Duct Leakage to Outside	30 CFM25	14 CFM25
Duct Leakage to Outside	1.7 CFM25/100 ft^2	0.6 CFM25/100 ft^2

3.8 Lights and Appliances

All appliances were replaced with ENERGY STAR qualified products and all lighting was upgraded to either fluorescent lamps or light-emitting diodes, for modeled savings of 1,338 kWh/yr, or almost 5% of the whole-house savings.

4 Results

The simulated post-retrofit home shows significant reduction in energy consumption in all end uses except that associated with ventilation and plug loads, for annual modeled utility bill savings of about $1,522 (assuming $0.12/kWh per rates listed by the Orlando Utility Commission) (see Figure 24).

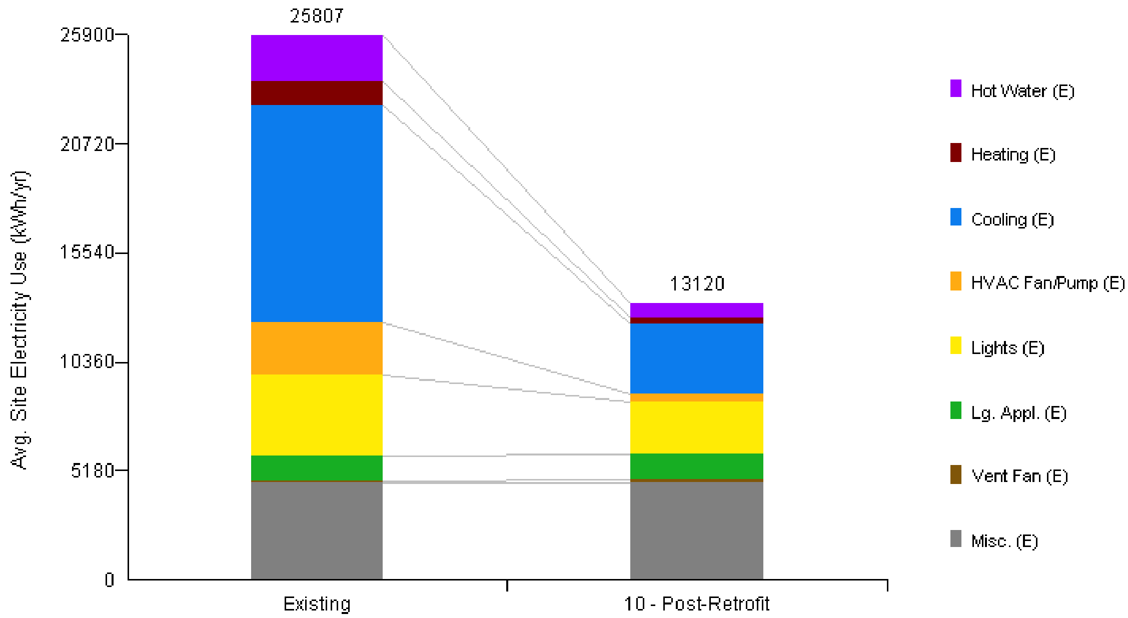

Figure 23. Comparison of simulated site electricity use by end use, pre- and post-retrofit

Costs to implement the retrofits are listed in Table 9, along with energy savings and simple payback. When possible, upgrade costs were only listed if they applied to the energy savings achieved. For example, lighting fixtures were replaced for aesthetic reasons but provide no energy savings by themselves. Only the incremental costs associated with the new energy-efficient bulbs were included. For some measures, such as windows, making this separation was not possible and full costs are unfortunately reported, leading to higher paybacks.

Also, the full replacement costs were listed, even if the system was at the end of its useful life. One of the air handlers was due for replacement, so the incremental cost could be reduced to just the incremental cost beyond a code-compliant replacement, but then the energy savings would also need to be reduced.

Table 9. Incremental Costs and Simple Payback by Measure

Component	Existing	Post-Retrofit	Upgrade Cost	Savings (kWh)	Payback (Years)
Foundation Assembly	Uninsulated	Same as Existing	N/A	N/A	N/A
Above-Grade Wall Assembly	1st floor: R-19, Grade III, 2 × 6 16-in. o.c. 2nd floor: R-13, Grade III, 2 × 4 16-in. o.c.	1st floor: R-21, Grade I, 2 × 6 16-in. o.c. 2nd floor: R-15, Grade I, 2 × 4 16-in. o.c.	$3,500	341	86
Ceiling/Attic Assembly	R-19 blown-in fiberglass, 2 × 8 at ceiling, vented attic	R-30 at roof, unvented attic, 5-in. closed-cell spray foam	$4,000	2,468	14
Window Glazing	Rear (East): single pane, U = 0.869, SHGC = 0.619 Elsewhere: double pane, U = 0.447, SHGC = 0.547 wood, aluminum	All: low-e, double pane, U = 0.28, SHGC = 0.21 vinyl	$18,500 (~30 windows and doors)	1,329	116
Building Infiltration	Measured 6 ACH50	Target 4 ACH50	Included in walls	Included in walls	Included in walls
Ventilation	Spot vent only	Spot vent and ASHRAE 62.2	$400	–191	N/A
Space Conditioning System	Two 2.5 ton ~SEER 10, HSPF 7.2 heat pumps	Two 2 ton SEER 17.5, HSPF 9.5 heat pumps	$15,000	5,962	21
Ductwork	R-4 insulation, 18% leakage	Ducts in conditioned space	N/A	N/A	N/A
Water Heating	Two electric resistance, 50-gal, EF = 0.91	Two HPWHs, 50-gal, EF = 2.4	$3,000	1,389	18
Lighting	14% fluorescent	75% high efficacy	$300	1,395	2
Roofing Material	dark asphalt shingles, abs = 0.92, e = 0.91	Same as existing	N/A	N/A	N/A
Appliances	ENERGY STAR refrigerator, standard dishwasher	New ENERGY STAR refrigerator and dishwasher, induction stove	$850	87	81
Dehumidifier	None	150 pints/day, EF = 2.02 L/kWh	$2,000	–93	N/A
Total			$47,550	12,687	31

5 Discussion

The initial objectives of the CEH project included reducing simulated annual energy consumption by 50% compared to the pre-retrofit home. The project team realized from the start that reaching this performance goal in the context of a relatively light (not gut-rehab) renovation was a significant challenge, one that might not be fully accomplished. However, by aggressively pushing the performance level improvements beyond what is typical, and by using the process and the outcomes as teaching and training content for outreach and dissemination, the project team could engage in the research and resource development objectives of the Building America program. Viewed from a whole-house vantage point, and looking at the final simulated performance levels, the numerous integrated energy efficiency measures involved in this project collectively contributed to a 49% reduction. Some of those measures were very successful (and contributory); others were less so, yet yielded valuable information on the limits of their benefits.

5.1 Building Envelope

The thermal performance of the building envelope was key to the overall performance, comfort, and durability of the home. CARB's initial energy audit confirmed what the project team expected to find, but also uncovered what turned out to be an anomaly in Central Florida: relatively well insulated walls in a 1990s specification house. The 2 × 6 frame walls on the first floor and 2 × 4 frame walls on second floor with R-19 and R-13 insulation, respectively, left little nominal room for cost-effective improvement, yet testing showed many gaps, voids, and air leaks. Complicated further by a 100% brick veneer exterior (meaning that exterior access was ruled out), the project team decided to experiment with a fairly light-touch insulation upgrade from the interior. At first, 4-in. holes were used to blow in fiberglass, but did not provide enough access for complete fill. Removing horizontal strips in the gypsum board and blowing in fiberglass insulation into the cavities worked well and produced better results, although its overall cost effectiveness in this hot-humid climate was not optimal (simple payback was ~86 years). This technique could be more viable in colder climate, underinsulated homes.

5.2 Windows and Glazing

Improved windows had significant performance improvement, but again the cost effectiveness was limited by virtue of the added cost caused by the brick veneer exterior. High performance window prices are coming down (at this home, $\$32/ft^2$, on par with average prices listed in NREL's National Residential Efficiency Measures Database), but in this case the labor was relatively high and the physical replacements not production friendly. Much improved comfort and reduced capacity HVAC are valuable outcomes, although maybe not sufficient to justify the long payback. Realistically, this measure should be viewed as being economically viable if the existing windows are approaching or have exceeded their useful lives.

5.3 Attic Roof Insulation

Applying closed-cell spray polyurethane foam insulation is typically a very expensive energy retrofit undertaking, and CARB is therefore quite cautious about applying this approach. Because a small portion of the attic space is habitable and because HVAC ducts reside in the vented portion of the attic, the project team decided to enclose, seal, and insulate the entire volume. Although costly, in this instance the expense provides direct and indirect benefits by improving the thermal envelope, placing the ducts in conditioned space without having to move them, creating a more hospitable environment for the finished attic space, and improving the roof deck's resistance to uplift and wind-storm related moisture intrusion (a benefit in this hurricane-prone state).

5.4 Heating, Ventilation, and Air Conditioning

Swapping out the older and far less efficient heat pumps with newer outdoor and indoor sections provide immediate benefit in energy reduction. The availability of high SEER/HSPF heat pumps has increased greatly in the past few years while the prices have steadily dropped. Using prices from this specific project resulted in a 21-year payback, however, using average prices from NREL's National Residential Efficiency Measures Database (NREL 2012b), result in payback of just 12 years.

CARB is beginning the process of monitoring the integrated dehumidifier/ventilation system. Limited access during construction caused the unit to be relocated from the planned location, although the designed supply and return register locations were maintained. During the upcoming monitoring phase, the project team intends to investigate the ventilation and dehumidification capacity and efficiency in the context of an efficient envelope and high-efficiency rightsized HVAC. The team's early perception is that the dehumidifier may be too expensive, large, and unwieldy for large-scale sales, but may enable lower cooling set points and additional energy savings.

5.5 Hot Water

HPWHs are now market available, reliable, and cost effective in many applications. By replacing two electric storage tanks (coefficient of performance < 1.00) with two HPWHs (coefficient of performance of 2.4) and placing the water heaters in different locations closer to the hot water use, generation efficiency is dramatically improved, and distribution losses are reduced. Given where these devices are now located (unvented attic serving the upstairs bathrooms, and mudroom closet serving the kitchen, laundry, powder room, and pool bath) near optimal performance is expected. Simple payback is approximately 16 years, but drops to 11 years if using just incremental costs over code-compliant replacements of the existing tanks, which were at the end of their useful lives.

5.6 Lighting

The existing home had a significant number of built-in light fixtures, all incandescent. Replacing these with high efficacy lamps is typically one of the least expensive/high benefit efficiency measures, as demonstrated by its less than two year simple payback. Here, with the amount of fixtures provided, and in the cooling-dominated climate, reducing the internal load also contributes to cooling energy savings.

6 Conclusions

CARB used the retrofit of a 1990s builder's specification home in an upscale Orlando location to evaluate whether 50% simulated energy savings relative to the existing home was a feasible target for a hot-humid climate non-gut retrofit project. For the first measure of success, reaching the simulated 50% savings plateau, the team came close to achieving its goal. The team knew from the outset that from a pure cost-effectiveness perspective, this was a difficult task, and to achieve it, some (overly expensive) compromises might be required. But as this is a sponsored research home with some manufacturer contribution involved, CARB was able to look beyond the bottom line to explore other less orthodox ways of saving energy and creating a healthy, more durable home.

The experiment with the wall insulation (blown in from the interior into existing batt-filled frame cavities) was a success when viewed as a process, but really does not meet cost effectiveness parameters in this context. In other more rigorous climates, and in homes with less insulation, this method may have significant application potential, with better return on investment. Placing the insulation at the roof deck is effective in the context of this particular context, but it is expensive, and is therefore not a universal solution.

Replacing the electric hot water storage tanks with the HPWHs was easily a success here and is looking to become a standard efficiency measure in many applications. Market offerings have expanded significantly, and reliability has improved markedly. The HVAC heat pumps are also a relatively simple swap out offering immediate savings and performance benefits. The system is quieter, and has better dehumidification control by virtue of its variable speed operation.

Although some of the measures undertaken here are more aggressive than might be attempted in a typical similar retrofit, the compilation of analysis, optimization, and execution has resulted in a comfortable, durable, healthy home close to the targeted 50% savings level.

References

EPA (2012). ENERGY STAR Qualified Homes, Version 3 (Rev. 06) National Program Requirements. Washington, DC: United Stated Environmental Protection Agency. Accessed December 12, 2012. http://www.energystar.gov/ia/partners/bldrs_lenders_raters/ES_Combined_Path_v_65_clean_508.pdf

EDU (2012). “Building America’s Cool Energy House – A Deep Energy Retrofit for Florida.” Energy Design Update. Vol. 32, No. 3, March 2012.

Hendron, R.; Engebrecht, C. (2010). Building America House Simulation Protocols. Golden, CO: National Renewable Energy Laboratory.

NREL (2012a). BEoptE+ 1.2: Building Energy Optimization. Golden, CO: National Renewable Energy Laboratory. Accessed March 12, 2012. http://beopt.nrel.gov/

____ (2012b). “National Residential Efficiency Measures Database.” Golden, CO: National Renewable Energy Laboratory. Accessed October 30, 2012: http://www.nrel.gov/ap/retrofits/about.cfm.

buildingamerica.gov

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

DOE/GO-102013-3824 ▪ February 2013

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 10% post-consumer waste.