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ENERGY EFFICIENT OPPORTUNITIES DURING REMODELING OR RENOVATION

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Energy and Transportation Science Division

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1. INFORMATION FOR HOME OWNERS AND BUYERS

Residential buildings go through many changes during their useful life, which is defined more by their care and maintenance, than age. Many homes that are a century old are still serviceable and desirable and even older homes that have been abandoned can be renovated. In contrast, many newly built homes are good candidates for energy efficiency retrofit measures before occupancy.

1.1 ENERGY EFFICIENCY IS IMPORTANT TO MODERN HOME BUYERS

The National Association of Realtors *2010 Profile of Home Buyers and Sellers* includes some interesting data about buyers' preferences for energy efficient features in a home (NAR, 2010). Findings show that:

- Buyers in the East South Central (Alabama, Mississippi, Kentucky, Tennessee) and West South Central (Arkansas, Oklahoma, Louisiana, East Texas) regions tended to place the highest premium on heating and cooling costs with 47.1% and 47.5% of buyers, respectively, saying that these costs were a very important feature.
- Heating and cooling costs were at least "somewhat" important to 88% of all buyers.
- Both first-time and repeat buyers recognize the importance of heating and cooling costs with 89.1% and 86.8%, respectively, saying these costs were very or somewhat important.

Section 3 of this report summarizes results of five homes in the Knoxville, Tennessee, area that completed "deep" energy efficiency retrofit projects with recommendations and assistance from Oak Ridge National Laboratory (ORNL) and other contributors. The priorities and feedback of those homeowners were captured for each project. The various priorities of all ten (although ten homeowners were originally interested in deep retrofits, only five completed all recommended retrofits) candidate homeowners included:

- Four planned on renovation or remodeling already and realized that recommended retrofit measures were small additions to the total project cost if done at the same time,
- Six had a goal for energy efficiency and environmental benefits that should be an example and social responsibility for others,
- Three considered the retrofit measures as an investment to offset future energy price escalation,
- One was primarily concerned about resolving IAQ and health issues,
- Two primarily wanted to reduce utility bills, but all appreciated that outcome,
- Two wanted to improve the comfort of all areas in the home, and
- One wanted to increase the resale value of the home.

1.2 ENERGY EFFICIENCY MEASURES FOR NEW AND EXISTING HOMES ARE TESTED AND MARKET READY

DOE's Weatherization and Assistance Program (WAP) enables low-income families to permanently reduce their energy bills by making their homes more energy efficient. Funds are used to improve the energy performance using the most advanced technologies and testing protocols available in the housing industry. The weatherization services are provided by community action agencies, nonprofit organizations, and local governments in every state, the District of Columbia, U.S. territories, and among Native American tribes. During the past 33 years, the WAP has provided weatherization services to more than 6.4 million low-income households. During that time, the program has developed and tested advanced technologies and diagnostic procedures and developed comprehensive training facilities for weatherization providers. This is far from the original "sealing and weather stripping" approach used in early years.

The average expenditure per home is $6,500 and each retrofit measure plus the whole package of measures must be shown to be "cost effective". That means that the cost is estimated to be repaid by dollar savings over the life of the measures by including the effects of inflation and fuel cost escalation.

There are private companies with trained technicians that provide the latest technology and retrofit services to mid and upper income homes and additional research is underway to demonstrate higher percentage savings. The design goal of planned research projects is to deliver 50% savings of whole house energy use as determined by 12 months of monitored energy performance data.

1.3 MANY EXCELLENT BUILDERS NOW FOCUS ON ENERGY EFFICIENCY DURING HOME REMODELING AND RENOVATION

Successful builders have followed the market to home remodeling as the demand for new construction decreased. A Tennessee Home Builders Association that is forming a Remodelers Council reports that most members have adapted their business models to include remodeling. Companies that install renewable energy systems such as photovoltaic and hot water solar panels recommend a first step of making the house as energy efficient as practical because that is usually the best investment and may help reduce the size of the solar array.

1.4 THERE ARE MANY BENEFITS FROM ADDING ENERGY EFFICIENCY MEASURES DURING REMODELING OR RENOVATION

There are events during the life of a house that lead to renovation or remodeling projects with opportunities for improving energy efficiency at minimal additional cost and inconvenience. In addition to meeting the owner's purpose for remodeling, energy efficiency improvements can increase comfort, reduce maintenance, improve indoor air quality, and reduce utility bills.

The warning that "the house is a system" with interactions between energy efficiency retrofit measures is true. If you have rooms that are uncomfortable or need to add living space, you may be able to avoid adding to the heating and air conditioning (HVAC) capacity by making other parts of the house more energy efficient. Air sealing of the house and ducts and addition of attic insulation may reduce the heating and cooling load enough to handle the new demands with existing equipment. An uncomfortable room may be the result of disconnected or leaking ducts, inefficient or leaky windows, or of missing wall or ceiling insulation. The HVAC system may be ready for replacement; but why not reduce air infiltration, add insulation, and replace windows in order to install a smaller system at a lower cost? Need to add a room? Consider the use of a standard foundation with structural insulation (foam) panels that can be assembled in 12 hours with R-30 walls and an R-50 roof.

1.5 REMODELING AND ENERGY EFFICIENCY INCREASE A HOME'S RESALE VALUE.

The *Remodeling Magazine* published a comparison of the average cost for 35 popular remodeling projects with the value those projects retain at resale (*Remodeling Magazine*, 2012). In the East South Central region, the remodel projects that recoup 70% or more of cost include:

- Attic bedroom,
- Basement remodel,
- Entry door replacement,
- Garage door replacement,
- Minor kitchen remodel,
- Siding replacement, and
- Window replacement.

Homeowner satisfaction with each of these remodeling projects will depend on taking the opportunities to reduce air leakage, increase thermal insulation, and to incorporate ENERGY STAR rated appliances and products; as is being shown by the results of deep retrofit homes in section 3.

The Proud Green Home website also reports examples of increased sale prices for green and energy efficient homes (Proud Green Home, 2012). In an article "Green Homes Sell for More", the Portland-based nonprofit Earth Advantage Institute analyzed sales data from the Portland Regional MLS and found that the sale price of existing certified green homes was higher than conventional homes for the fourth year in a row. The average sale price increase was 30% and one county reported a premium of more than 61%. Certifications came from ENERGY STAR, LEED for Homes, Earth Advantage, or an Earth Advantage/ENERGY STAR combination.

Another article "Energy-efficient renovations in existing homes" was contributed by Green Canopy Homes in Seattle that buys homes in walkable neighborhoods and renovates them with high-performance, energy-efficient upgrades with an Energy Performance Score and Built Green certification (Proud Green Home, 2012). The renovations for a 1,822 square foot home included air and duct sealing, foam and rigid insulation, new energy-efficient windows, a ductless mini-split heat pump system, low-flow faucets and showerheads, new fluorescent lights, and a TED 5000 wireless energy monitor that streams directly to an included iPad2. The total cost for energy upgrades was $12,000, but it will result in savings of $861 per year on energy bills at present rates.

The *REALTOR® Magazine's* blog quoted a new study by Lawrence Berkeley National Laboratory that found that solar panels not only save money on electricity bills, but also provide a boost to home owners at resale, particularly when added to existing homes (*Realtor®*, 2012). Researchers analyzed sales of about 2,000 solar homes in California from 2000 through mid-2009 and compared prices of 70,000 non-solar homes. On average, solar panels added about $5.50 per watt to a home's resale value. A home with a typical 3.1 kW electric solar system, that can cost up to $15,000, stands to make an extra $17,000 at resale.

2. ENERGY EFFICIENCY OPPORTUNITIES FOR REMODELERS

A Tennessee Home Builders Association that is forming a Remodelers Council reports that most members have adapted their business models to include remodeling due to significant industry changes in recent years. Home owners want to include energy-efficient products in their homes, but have expressed frustration about the lack of affordable options and uncertainty of savings. The Association's goal is to develop a custom Remodeling program that increases awareness and provides comprehensive implementation of the latest building technologies, including indoor air quality, solar, and energy efficiency. They know that home owner participation will depend on having confidence in the estimated extra cost and savings and other benefits based on the measured performance of remodel projects in their own area. The design goal of planned research projects is to deliver 50% savings of whole house energy use as determined by 12 months of monitored energy performance data.

There are events during the life of a house that lead to renovation or remodeling projects with opportunities for improving energy efficiency at minimal additional cost and inconvenience. In addition to meeting the owner's purpose for remodeling, energy efficiency improvements can increase comfort in all rooms, reduce maintenance, improve indoor air quality, reduce utility bills, and increase the value and marketability of the house at the time of resale.

Following are examples of household events and suggested opportunities for increased energy efficiency.

2.1 RENOVATION OF A "HISTORICAL" HOME

A Historical Home includes older homes that may be on the Historic Register or just in a newly recognized prime location of value to a segment of the market. NAR's Smart Growth Program recently released findings of its *2011 Community Preference Survey* (NAR, 2012) that aimed to discover how buyers choose a neighborhood. In summary, 56% preferred the "smart growth" characteristics, such as:

- Walkable mixed-use neighborhoods,
- Smaller lots, and
- Access to public transportation

This is in contrast to the typical growth patterns of the past that expand in suburban areas that require commuting. An article "Energy-efficient renovations in existing homes," at the website Proud Green Home, was contributed to by Green Canopy Homes in Seattle that buys homes in walkable neighborhoods and renovates them with high-performance, energy-efficient upgrades with an Energy Performance Score and Built Green certification (Proud Green Home, 2012).

These growth preferences, as observed in the South Central region, appeal to the retired affluent buyers and the young professionals that value an improved quality of life. Each group will likely have the foresight and the means to evaluate how energy efficiency and renewable energy will fit within their priorities. The search for inner city housing includes older homes in need of renovation and/or remodeling and extensive upgrades of energy efficiency.

Older homes can also be found in prime locations that include lakeside or lake view, mountain view, or remote sites with acreage. They may be small second homes that are now rarely used by the older owners or children who have moved away from the area. Buyers likely obtain the property with significant upgrading and remodeling in mind.

The deep retrofit homes that are over 40-years-old as described in sections 3.4 and 3.5 had several common problems that homeowners agreed should be addressed during their planned renovation and remodeling plans.

- Air infiltration was very large and was mainly from band joists and penetrations to the attic, from vented attics, and from the foundation space. The 102 year old Green House (section 3.5) was balloon framed with the second floor attached to the wall studs and air flow through walls from basement to attic. Sash weighted windows let air in through the pulley ports. Major air leaks were also found in chimney chases and laundry chutes.
- Duct leakage to the outside was too large to measure. Ducts need repair and sealing. Structural cavities often used as air return chases that are not sealed.
- Walls need insulation and air sealing.
- Attics need insulation and air sealing.
- Windows are commonly single pane with wood or aluminum frame.
- Doors are commonly un-insulated wood with single pane glass highlights.
- If heat pumps have been installed, they are commonly 10 or 12 SEER and ready for replacement.

The upside is that these older homes were being partially or totally gutted for planned renovations. Energy efficiency retrofit measures could be installed with higher quality and lower cost while spaces were open. The Green house was owned and being renovated by a Historic Preservation Society that had not considered energy efficiency in past projects. They now accept the dual goals of preservation and energy efficiency as being compatible and plan to use HERS ratings as a guide for future projects.

There are two case studies reported by the NAHB Research Center that provide excellent detail on whole-house energy retrofit methods and estimated energy savings. One is the “Strategies for Energy Efficient Remodeling, SEER 2003 Case Study Report” on a gut rehab of a 1,400 square foot house in west central New Jersey that was uninhabitable and otherwise destined for the landfill (NAHB Research Center, 2004). The estimated reduction of heating and cooling energy consumption was on the order of 60%.

The second report is “Energy Performance Remodeling Case Study: Habitat for Humanity Montgomery County (HFH-MC) Montgomery County, MD” that provides details of 12 fully renovated energy efficient homes ready for occupancy (NAHB Research Center, 2010). Work was completed on 1950’s era homes with a team of professionals and volunteers. The estimated energy efficiency improvements from energy simulations for the group ranged from 9% to 38%.

2.2 SALE OF A HOME AND THE FIRST REMODEL

Every time an older home is sold there will be repairs and maintenance required by the buyer and the new owner will likely undertake some level of remodeling within the first 1-2 years; all depending on the age and condition of the house. For older homes, remodeling the kitchen is likely to be the first major change of the new owner and is the room most likely to be remodeled repeatedly over the life of the house.

The kitchen offers many options for cutting energy costs during remodeling and remodeling is a good buy if done correctly. Energy costs can be reduced, and 77% of the job cost may be recouped in a higher resale value, according to the “Remodeling 2010-11 Cost vs. Value Report” (*Remodeling Magazine*, 2012).

Events that lead to kitchen remodeling can include:

- When a house is sold, there will likely be changes that may include the need to replace outdated or missing appliances, different needs based on the change in number and age of the new occupants, and outdated colors, flooring, and cabinets.
- Changes in family makeup and how kitchens are used occur slowly over 10-15 years until remodeling becomes a priority.
- Older homes in previously low-income neighborhoods will likely need a complete makeover to appeal to younger buyers looking for inner-city mixed-use areas. The kitchen may be their first priority as their gathering place.
- When major appliances wear out.

Energy efficiency opportunities:

- *Lighting.* Remodeling provides a good opportunity to correct outdated lighting design that provides too little light where it is needed and frequently over illumination of the entire space, all controlled with one light switch. Areas that require good task lighting during certain activities and only general background illumination at other times should be identified and wired with separate switches for each set of lights. Repositioning light switches can make it much more likely that only the lighting needed for various activities in each room is energized. The most efficient lighting designs are still those that are turned on only when needed. Recessed overhead lights are frequently used in kitchens, but the fixture should be designed to limit air flow to unconditioned overhead spaces.

  Fluorescent lamps and LED are the most efficient light source suitable for residential use. The compact fluorescent lamps (CFLs) can easily replace incandescent bulbs and there are three “color” (or temperature) options that serve different needs.

- *Refrigerators.* Modern refrigerators are not expensive to operate but they do like at least 1” of clearance at the sides and top for ventilation and should not be placed in a hot location such as next to the dish washer, oven, or in direct sunlight. The July 2011 issue of *Consumer Reports* (ConsumerReports.org) featured test results of a wide variety of models. The range of energy cost /year based on their test procedures are:

Top Freezer	$45-$58
Conventional Bottom Freezers	$50-$68
French Door Bottom Freezers	$49-$88
Side-by-Sides	$60-$85

  The features of their top-rated refrigerators were ease of access, flexible interior space, consistent temperatures, and energy efficiency. Careful selection of a new energy-efficient refrigerator during remodel should help avoid the need to keep the old one for occasional overflow. It would be best to have a slightly larger energy efficient unit rather than a smaller new efficient unit and roll the old one into the garage or basement. The ENERGY STAR ratings also provide guidance for making comparisons.

  The efficiency of refrigerators has improved dramatically over the years. A 15 year old refrigerator may use 2-3 times the energy of a new one and should be recycled during remodeling.

- *Dishwashers.* The latest tests show that the best models can power away tough left overs while saving water and energy, but it requires patience. Cycle times ran from over 1.5-hours to over 3-hours. They now use less heated water over longer periods to meet tougher federal efficiency rules and the ENERGY STAR standards are expected to get tougher in January 2013. Recommendations are to choose models that don’t need pre-rinsing (that wastes water), are quiet, have a water heating booster, and that allow delayed starts.

- *Air Sealing and Insulation.* When remodeling involves removal of old cabinets, changes in plumbing or electrical circuits, updating floor and ceiling finishes, window replacement, or other changes that open the thermal envelope of the kitchen; there are a whole new set of energy saving opportunities. This is the time to seal air leaks at all plumbing, electrical, gas, and exhaust air duct penetrations. Also stop air flow behind cabinets, above false ceilings, in soffits, and through floors. Next, fill the walls, ceilings, and floors with as much insulation as is economically feasible.

Even if the project focused on the remodel of one room, this is a good time to consider air sealing, wall insulation, and new windows for the entire house. The crews are on-site, set-up, and prepared to clean up. These are significant parts of the total cost that would have to be paid again if they have to come back later to finish the house. If they finish now, the homeowner will not have to be inconvenienced again later.

Section 4 of this report describes a detailed comparison between two new houses:

- The *Builder House* was representative of a standard, IECC 2006 code-certified, all-electric house built to sell around 2005-2008.
- The *Retrofit House* included modifications that could have been made as retrofit measures to existing houses like the *Builder House* to improve energy efficiency.

This comparison may be representative of cost-effective retrofit measures to be considered after five years of occupancy in a house built in 2006. The retrofit modifications used in the *Retrofit House* included:

- 100% CFL lamps throughout the house,
- ENERGY STAR kitchen and laundry appliances,
- A heat trap in hot water heater outlet pipe,
- Hybrid heat pump water heater,
- Upgraded windows to double pane Low-E and gas filled,
- 16 SEER heat pump,
- HVAC ducts placed inside conditioned space,
- Improved ACH from 5.8 to 3.43 @ 50 Pa.

Results show that, in Tennessee, a homeowner can install a cost-effective retrofit package for a typical new home like the *Builder House* (3 bedroom, 2.5 bath, 2400 ft^2) that has a predicted 42% energy savings and achieves neutral cash flow based on electricity rates of $0.093/kWh, a 10-year mortgage at 6% interest, and available 2010 federal, state, and utility incentives. Based on measured data from almost 100 sensors and a computer simulation of the *Retrofit House*, energy for this all-electric house is predicted to cost only $3.76/day with an average of 39.5 kWh/day. By contrast, the *Builder House* would require $6.46/day. The HERS rating of the retrofit house was 68 after retrofit and 101 before retrofit. For more information see Tennessee Valley Authority's Campbell Creek Energy Efficient Homes project report (Christian, Gehl, Boudreaux, New, and Dockery, 2010).

The opportunity to reduce energy cost by 42% that pays back a 10-year loan with neutral cash flow should be very attractive addition to the homeowner's first remodeling project.

2.3 THE NEW ADDITION

Events that create a need for "adding on" include the birth of children, the time when children need their own rooms and play spaces, the need for home offices, visits or the return of married children and grandchildren, and care of aging parents.

A remodel project that includes a complete addition is an excellent opportunity to use advanced construction methods that are much more energy efficient. All or part of any additional cost for high energy efficiency may be offset if the existing HVAC system can also serve the room addition.

The "SEER 2003 Case Study Report" prepared by the NAHB Research Center (2004) describes a room addition made from pre-manufactured structural EPS foam and steel tube panels that does not require any additional structural supports. The foundation and flooring was conventional construction, but the walls were rated at R-30 and the cathedral ceiling was R-50. The structure was assembled in five hours.

2.4 REPLACEMENT OF SIDING AND WINDOWS

The reasons for siding and window replacements include:

- To improve comfort,
- Reduce costs of heating and cooling,
- Repair damage from hail, wind, or water, and
- Update to improve appearance of the home.

The "Remodeling Cost vs Value Report 2010-2011" (*Remodeling Magazine*, 2012) reported the percentage of costs recouped at sale for replacing siding with vinyl at 85%, with fiber-cement at 88%, and with foam-backed vinyl at 86%. Window replacement with vinyl was estimated to recoup 78% and 80% with wood replacement.

When the old siding and windows are removed the wall is open for air sealing all cracks and penetrations, maximizing insulation between studs, installation of an air barrier or rigid insulation board over the studs, and installation of the new siding. The new windows should be air tight with multi-pane glazing, Low-E coatings, and filled with inert gas; which is almost standard construction.

Additional energy efficiency options that complete the new look include replacement of entry and garage doors with well insulated units and tight weather stripping. The cost recouped at sale was estimated to be 100% for a new steel entry door and 92% for a garage door replacement.

2.5 OBSOLETE OR INOPERATIVE HVAC UNITS (15+ YEARS OLD)

If an HVAC company is called to diagnose an inoperative unit that is at least 15 years old and provide an estimate to fix the problems that is just what they will do. They will likely propose installing new units of the same capacity, which was likely oversized when first installed. If the homeowner has installed some attic insulation, caulking and weather stripping, or any replacement windows; the new units will now be even more oversized. Now is the time to evaluate diagnostic air sealing, duct sealing and insulation, and deep energy efficiency retrofits described in the following section. The approach is to make the house as energy efficient as practical, to install new HVAC units of the proper size, and pay down some of the costs for energy efficiency with savings from smaller HVAC units. Additional information on this approach can be found in the article "Right-Sized HVAC" by Mark LaLiberte published by *EcoHome Magazine* (*Ecohome Magazine*, 2012).

2.6 OBSOLETE HOME WIRING SYSTEMS

The NAHB Research Center has a good article about the need to upgrade home wiring systems to meet the electronic information needs of present and future owners (NAHB Research Center, 2012a). This includes advanced wiring systems for telecommunications, video capabilities, and audio. They provide estimates of $1000 to $3,000 for this type of upgrade, depending on house size, but it may be much easier to pull wire during a major remodeling project. The homeowners will need education about the added convenience and capabilities, but will be very satisfied with being "wired for the future".

2.7 IS AGING-IN-PLACE AN IMPORTANT ISSUE?

If customers are trying to decide whether to remodel or find a new home for aging in place to meet their needs over the long term, a good resource is the "Aging-In-Place Design Checklists" published by the NAHB Research Center (2012b). The complete set of recommendations leads to remodeling throughout the house and should also include the "deep" energy efficiency retrofit measures.

2.8 WHOLE HOUSE DEEP RETROFIT FOR ENERGY EFFICIENCY

This section is for home owners for which a 30% to 50% savings on current energy cost and improved comfort throughout the house would be a significant benefit. This can be achieved if energy efficiency is part of the plan; whether remodeling a single room or the whole house. A significant cost of audits, air sealing, and insulation work is for the auditor/contractor's travel time and set-up. Thus, the incremental cost (per ft^2) of completing the recommended measures for the whole house is lower than that for a specific room.

- A first part of the plan is to identify needed updates in electrical service, plumbing, and low voltage wiring that includes home automation, security, phones, intercoms, computers, and TV to Internet connections. The NAHB Research Center estimates a cost of $1,000 to $3,000 for this type of upgrade in existing construction (NAHB, 2012a). These retrofit upgrades will likely require running various cables, conduit, and piping throughout the house and result in opening parts of the finished walls, floors, or ceilings. This needs to be done before proceeding with the following energy efficiency procedures.

- A thorough energy audit is recommended that identifies homeowner comfort issues, analyzes billing data for symptoms of high energy use, and recommends remedial measures. This will be an excellent basis for a long-term remodeling plan if work must be done in stages.
- Air sealing is usually the first measure during home weatherization because it typically has the highest benefit to cost ratio and should be completed before any additional insulation is installed. Air leaks where electric wires, plumbing, and exhaust ducts enter the conditioned space are common problems. Research has demonstrated that caulking and weather-stripping to seal areas commonly thought to be leaky is much less effective than hiring a professional with modern instrumentation to find and seal the significant leaks. Air sealing the whole house would be a good investment, even if only one room can be remodeled.
- Un-insulated outside walls and single-pane windows make a room feel hot or cold due to radiation heat transfer, heat conduction, and air leakage. Any replacement or addition of a window should be with modern high-performance windows and with consideration of the specific reason for each. Outside walls should be insulated to at least R-11, preferably with dense pack cellulose or blown fiberglass that also seals air leaks and that can cover areas behind cabinets and bath room fixtures. Johns Manville makes a product in which the blowing equipment can be used to inject the chopped fiberglass.
- If the floor is over an unconditioned space, the floor should be insulated to the maximum R-value accommodated by the floor joists.
- Attic insulation should be brought up to R-50.

The 16-year-old Summit House (section 3.1) is considered a good example for this case. Before an 8.5 kWh peak solar PV system was installed, the measured post-retrofit source energy savings was 33%. Air infiltration was reduced from 9.1 to 3.9 ACH@50Pa. The homeowner stated that it is the patriotic duty of all citizens to aim for a net-zero home and he was proud of the work done.

3. DEEP HOME RETROFIT PROJECTS – KNOXVILLE, TENNESSEE, AREA[1]

East Tennessee home owners were identified that had plans to remodel and wanted to reduce energy costs and improve comfort by including energy efficiency retrofit measures. Ten houses were selected in the Knoxville, Oak Ridge, Farragut, and Kingston areas. A Home Energy Rating System (HERS) evaluation to determine a “Pre-Retrofit” assessment and a TVA “Energy Right” audit were completed at each home. ORNL recommended energy efficiency retrofit measures based on these audits. It was then the homeowner’s responsibility to decide which measures to accept and to assume all of the cost of retrofit materials and installation.

Although ten homeowners were originally identified as being interested in deep retrofits, only five completed all recommended retrofits. After completion of these retrofits, energy monitoring sensors were

[1] For additional information see “Deep Residential Retrofits in East Tennessee” (Boudreaux, Hendrick, Christian, and Jackson, 2012).

installed and data collected for the following year. Post-retrofit assessments were also completed for comparisons with pre-retrofit conditions.

The five houses (from Summit to Green) are occupied and participating in the Deep Home Retrofit program. Note that the age of the houses range from 16 to 102 years, with the two oldest being rehabilitations of historical homes.

The lower the HERS score the better, with zero being a home that generates as much energy as it consumes and 100 being a home built to code in 2008. Homes built before 2008 usually range from 101 to 250. The score of each of these homes ranged from 100 to 259 before retrofit. After retrofits, the scores were 23 to 75, which indicates that their energy efficiency was improved to be better than the 2008 code. Total house source energy savings were between 8% and 70%, and homeowners noticed significantly reduced energy bills and improved comfort.

The goal of Deep Home Retrofits is to reduce energy consumption of a house by 40-50%. The energy audit and diagnostic inspections lead to a whole house approach to identify all recommended retrofit measures. These retrofits typically start with sealing and insulating the thermal envelope to significantly reduce conduction losses and the infiltration of outside air. Window replacement is usually recommended if existing windows are single pane or low quality. Advanced measures include the use of sprayed foam to completely "encapsulate" an attic or crawl space that puts that space and HVAC ducts within the thermal boundary. After this, the HVAC and duct systems are repaired or replaced with higher efficiency and properly sized equipment. Additional upgrades evaluated include water heating, lighting, appliances, and solar energy production.

3.1 SUMMIT HOUSE

The homeowner was planning to remodel this 16-year-old home and, after hearing a talk on energy efficiency retrofit options, realized that they would only increase the cost of the overall project by about 20%. He adopted the goal of achieving a "net-zero" home with the recommended retrofit measures and installation of solar photovoltaic panels on the south facing roof. Measured source energy savings were 33% before the PV system was added. If considering the PV, the measured site energy savings was 90%.

The energy efficiency improvements included:

- Air sealing and insulation of the attic, walls, rim joists, and basement;
- Replacement of the 13 SEER AC with gas furnace with a high efficiency multi split system;
- Window replacement; and
- Installation of an 8.5 kWh solar photovoltaic system.

Homeowner feedback:

- He was proud of the work on his home, wanted it to be publicized, and thought it was the "patriotic duty" of all to aim for a net-zero energy home.

- The owner recommends doing a project in phases where each phase is small enough not to require financing.
- Energy efficiency investments need to be evaluated based on the expected long term escalation of energy prices.

3.2 COUNTRY HOUSE

This 41-year-old house was 1-story with a finished conditioned basement and small crawl space. They were already conducting a remodel of the home when areas were exposed that had no insulation. They realized that it would be more economical to address air sealing and insulation during the remodeling project and decided to make the home as energy efficient as possible and to prepare it for the future installation of solar PV. Measured source energy savings was 33%.

The energy efficiency improvements included:

- Air sealed the basement walls, crawlspace, attic floor, and rim joists;
- Injected closed cell foam into outside walls and cathedral ceiling;
- Insulated attic knee wall and increased attic floor insulation to R-50;
- Replaced 12 SEER heat pump with electric back-up with a high efficiency 19 SEER (9 AFUE) split heat pump;
- Replaced electric water heater with a heat pump water heater; and
- Replaced windows with ENERGY STAR windows and energy efficient blinds.

Homeowner feedback:

- They saw the increase in energy efficiency as an investment that would offset future increases in the cost of energy during their retirement.
- They recognized it was cheaper to include energy efficiency improvements during remodeling.
- They increased insulation levels for the knee wall and attic access hatch.
- Decided not to air seal and insulate the basement because of the mess made by spray foam contractors.
- Were generally pleased with the work done to their home and appreciated corrections of code violations.

3.3 BAKER HOUSE

The homeowner's goal was to be more comfortable in the winter and to eliminate the draftiness in parts of the home. The motivation for higher energy efficiency was to live a more environmentally friendly life.

This 45-year-old house had very high air infiltration of the envelope and ducts. Inspection revealed a 1-foot by 10-foot opening that was only covered by the drop-ceiling where the porch roof joined the house.

This was a major air leakage pathway into the home through the soffit vents. Duct leakage was too high to be measured due to unsealed building cavities being used as ducts. The HVAC equipment was a 10 SEER 4-ton heat pump with hydronic backup. Measured source energy savings was 8%.

The energy efficiency improvements included:

- The leakage at the porch roof was sealed with spray foam;
- Rim joist and other major air leakage sites were sealed;
- Duct work was repaired and air sealed;
- Attic insulation was increased to R-38; and
- A new 16-SEER heat pump was installed.

Other recommendations not completed included wall insulation in the conditioned unfinished basement, installation of compact fluorescent bulbs. Measurements confirmed that use of a hot water recirculation pump increased water heating energy use by two times.

Homer owner feedback:

- After retrofit, the home owner noted a significant improvement in the comfort level of the home. The draftiness was gone and rooms that once felt chilly were now pleasant.
- Before retrofit, the home owner was unaware of air sealing of a home and ducts. They now see air sealing as the most important task in renovating any home and would benefit any house.
- The retrofit took much longer than expected and some contractors were messy and unpleasant.
- Consumers need better education about what a retrofit entails and should know more about what they are hiring someone to do.

3.4 GAITER HOUSE

Original plans were to renovate this 71-year-old house and simply bring it up to modern code, but the renovations and HVAC replacement required gutting the house. The owner decided to install energy retrofit measures to meet his goal of improved energy efficiency and reduced energy cost. He estimated savings of $175 per month after retrofit and also wanted the home to become a model for energy efficiency for others to follow.

The house was unoccupied when purchased and gutting had started during the energy audit. Pre-retrofit utility bills were not available. Modeled source energy savings was 70%.

The energy efficiency improvements included:

- Attic was air-sealed and insulated with spray foam at the base of the roof and on the underside of the roof deck;
- The un-conditioned basement band joist and framed walls were air sealed;

- Walls were sealed and insulated with spray foam and fiberglass batts;
- Installed a new 18 SEER heat pump and new ductwork that was totally within the conditioned space;
- Installed triple pane high efficiency windows; and
- Installed heat-pump water heater with “home run” plumbing (individual piping to each point of water use).

Homeowner feedback:

- The house was among the first ever to receive Alcoa aluminum siding and he rejected recommendations to remove it to preserve the look and historical integrity of the house.
- He found the program through an article and was very pleased with the energy retrofit.
- He was not displeased or frustrated by the length of time required for the project.
- Academic training as an architect helped him understand much of what the project required, and he gained knowledge and experience about energy efficient technologies.
- He appreciated the help and expert recommendations from the ORNL research team.

3.5 THE GREEN HOUSE

At the time of retrofit, this 102-year-old home was owned by a historic preservation organization with a committee to make retrofit decisions. The committee had already decided to seek a LEED certification but added the goal to achieve energy savings of 50% when the decision to retrofit was made. The energy efficiency retrofit measures were installed while the house was gutted for remodeling and preservation. Their objective was to show that it is possible to combine historic preservation and energy efficiency. The house had been renovated and displayed as an “Energy House” at the 1982 World’s Fair in Knoxville, Tennessee.

A historic house of this age has unique features to deal with. The home was balloon framed, with the second floor attached to wall studs. This allows airflow in the walls, from basement to attic, that makes porous wall insulation nearly useless. Sash weighted windows let in air through ports for the pulley because the weight compartment was not sealed from the wall cavity. There was also an unfinished basement with earth floor and no moisture barrier. Measured source energy savings was 58%.

The energy efficiency improvements included:

- Underside of the roof deck was air sealed and insulated to R-38 with spray foam;
- New low-E windows were installed;
- Basement was insulated and the ground was covered with a moisture barrier;
- Installed ENERGY STAR appliances and CFL lamps;

- Installed solar water heater and a thin-film photovoltaic system on the roof; 3-ton 20.5 SEER variable capacity heat pump; installed R-16 insulation to outside walls; and
- Installed fresh air handler.

Homeowner feedback:

- The deep retrofit measures did not have a big impact on the overall project cost since the house was gutted for the planned renovations.
- Energy retrofits delayed the project by about two months, but that may be due to adding those measures after the design phase was completed.
- The Committee had not considered energy efficiency in past renovation projects, but now see it is possible to connect that with historic preservation.
- They plan to use HERS ratings and aim for energy efficiency on all future renovation projects.
- They achieved ENERGY STAR and LEED Platinum certifications.

4. THE CAMPBELL CREEK *RETROFIT HOUSE*

The Campbell Creek House is one of three research homes built in 2009 that consist of:

- A *Builder House* representing a standard all-electric base-line home for sale in 2005-2008,
- A *Retrofit House* that included energy efficiency measures that would be recommended for retrofit of the *Builder House*, and
- A *High Performance House* that included the most advanced energy efficiency and renewable features for the 2012-2015 market.

All three homes were of similar size, design, and solar and wind exposure in the Campbell Creek community in Knoxville, Tennessee. Each house has simulated occupancy for a family of three using automated mechanisms to duplicate energy use by appliances, water heating, lights, and heat added to space from occupants

Results show that, in Tennessee, a homeowner can install a cost-effective retrofit package for a typical new home like the *Builder House* (3 bedroom, 2.5 bath, 2400 ft^2) that has a predicted 42% energy savings and achieves neutral cash flow based on electricity rates of $0.093/kWh, a 10-year mortgage at 6% interest, and available 2010 federal, state, and utility incentives. Based on measured data from almost 100 sensors and a computer simulation of the *Retrofit House*, energy for this all-electric house is predicted to cost only $3.76/day with an average of 39.5 kWh/day. By contrast, *Builder House* would require $6.46/day. The HERS rating of *Retrofit House* was 68 after retrofit and 101 before retrofit. For more information see Tennessee Valley Authority's Campbell Creek Energy Efficient Homes project report (Christian, Gehl, Boudreaux, New, and Dockery, 2010).

The cash flow analysis assumed that windows, heat pump, water heater, and major appliances would not be replaced solely to improve energy efficiency and were not included in the retrofit package. The $10,000 incremental cost of the retrofit package plus interest is paid back in 10 years with a positive cash flow to the homeowner each year. The homeowner's benefits include the total energy cost savings after 10 years, a more comfortable and healthy home from day one, and possibly increased value at time of sale. This investment also reduces the impact from future escalation of energy cost.

The *Retrofit House* is included here because the data collected were used to evaluate the benefit and costs of individual retrofit measures to the envelope, mechanical equipment, appliances, and other electric loads in a house built in 2008. The results for each retrofit measure can provide a basis for consideration during the different types of remodeling projects discussed in section 2 above.

4.1 COMPACT FLOURESCENT LAMPS (CFLS)

This retrofit measure was the use of 100% CFLs in the *Retrofit House* instead of 100% incandescent in house the *Builder House*. The added builder cost, including change of a few fixtures to accommodate the CFLs, was $883. The amortized cost over 10 years at 6% interest is $118/yr, energy savings was $125/year, and the positive cash flow is $7/yr. Results are shown in the following table.

Table 1. High efficient lighting modeled cost savings

Retrofit Measure	Energy Savings ($/yr)	Cost ($)	Amortized Cost ($/yr)	Cost Savings ($/yr)
100% CFL	$125	$883	$118	$7

These results do not account for additional cost savings due to the longer life of CFLs compared to currently available incandescent lamps. Another measure of cost effectiveness is that CFL conversion will have a 7-½ year simple payback which will be reduced by longer service life.

Additional retrofit measures are shown in the order of the easiest to the most difficult application. It's also recommended to evaluate measures that affect heating and cooling loads before sizing HVAC replacement systems. In this case, CFLs will decrease cooling loads and increase heating loads.

4.2 ENERGY STAR REFRIGERATOR

The benefit of replacing an existing refrigerator depends on the energy use of the old refrigerator with an ENERGY STAR model over the same time period. DOE's Weatherization Assistance Program has developed a large data base of the energy use of older refrigerators by manufacturer and model, or there are plug in meters to measure the energy use of an existing refrigerator. New models will have the ENERGY STAR label with the needed data. Refrigerators have improved significantly over the past 10-15 years, but this project found that the builder model of 2008 was not far behind an ENERGY STAR model. The following results demonstrate the value of a benefit/cost assessment that would show the homeowners their net cost/yr for upgrading to a new energy-efficient replacement.

Table 2. ENERGY STAR refrigerator modeled cost savings

Retrofit Measure	Energy Savings ($/yr)	Cost ($)	Amortized Cost ($/yr)	Cost Savings ($/yr)
ENERGY STAR Refrigerator	$7	$132	$18	-$11

4.3 DRYER AND ENERGY STAR WASHER

This is similar to the refrigerator replacement in that the difference in energy use between the builder model of appliances and ENERGY STAR models is small. The energy savings of reduced water heating energy is not captured in the savings below. These data will also help remodelers and homeowners to determine how energy savings "buy down" the cost of new appliances.

Table 3. Dryer and ENERGY STAR washer modeled cost savings

Retrofit Measure	Energy Savings ($/yr)	Cost ($)	Amortized Cost ($/yr)	Cost Savings ($/yr)
Dryer and ENERGY STAR Washer	$76	$700	$93	-$17

With the assumed energy efficiency loan conditions, it would cost $170 to pay off $700 for ENERGY STAR laundry appliances compared to the 2008 builder models.

4.4 WATER HEAT TRAP

The heat trap is a simple change in piping from the water heater that loops up, down, and back up to trap hot water in the upper section and prevent the natural circulation of hot water. Energy Gauge predicts savings of $30/yr at a cost of $30 for a plumber to add when installing a replacement water heater. In this study, the cost was paid off during the loan period and would last the remaining life of the plumbing system.

Table 4. Water heater trap modeled cost savings

Retrofit Measure	Energy Savings ($/yr)	Cost ($)	Amortized Cost ($/yr)	Cost Savings ($/yr)
Water Heater Trap	$4	$30	$4	0

4.5 WINDOW REPLACEMENT

The incremental cost of using double pane low-emissivity (Low-E) gas filled windows instead of the builder's regular double pane windows was $250 ($0.85/ft2). The cash flow analysis was without incentive payments.

Table 5. Window replacement modeled cost savings

Retrofit Measure	Energy Savings ($/yr)	Cost ($)	Amortized Cost($/yr)	Cost Savings ($/yr)
Window Replacement	$63	$250	$33	$30

4.6 SEER 16 HEAT PUMP

The same contractor and the same Amana heat pump brand were used in both the *Builder* and *Retrofit* houses. The *Builder House* was equipped with a 2.5-ton SEER-13, 7.7-HSPF unit with 4.75 kW of resistance backup in the attic serving the upper level and a 1.5-ton, SEER-13, 7.7-HSPF unit with 4.75 kW of resistance backup in the unconditioned garage serving the main level. The attic unit used 70% of the cooling energy in the *Builder House* for three of the hottest months of the year, July–September 2009. From May to September 2010 the attic HP consumed 67% of the cooling energy and was servicing 59% of the total house floor area. The unit that is in the worst environment, a hot attic, is called upon to provide most of the cooling. The HVAC contractor, who was asked to keep very good cost records for these installations, charged $7143.75 for both the *Builder* and *Retrofit* houses.

For the *Retrofit House* the Manual J calculation found that the right size for the single heat pump to be located in the insulated and sealed attic was 2- or 2.5-tons. The HVAC contractor felt that 3-tons was appropriate based on his experience. The design called for a two-zone system with the single 2-speed compressor unit located in the attic. The layout for the supply and return duct system was very similar for both houses. Motorized dampers, zone-control board, and a 6-inch ventilated air duct connected to the return plenum of the unit were added in the *Retrofit House*. The HVAC contractor found that his expenses were about the same for these two systems. The invoiced cost for the *Retrofit House* HVAC is exactly the same as the *Builder House*, $7,143.75. The incremental cost used in the following table is zero.

Table 6. Downsizing and more efficient HVAC modeled cost savings

Retrofit Measure	Energy Savings ($/yr)	Cost ($)	Amortized Cost ($/yr)	Cost Savings ($/yr)
16 SEER HVAC	$190	$0	$0	$190

These data indicate that the 16 SEER unit would be a better choice than a 13 SEER for new house construction or a case where choosing what to replace an older unit with. Replacing a 13 SEER heat pump with a 16 SEER unit would not be cost effective for energy savings alone.

4.7 DUCTS INSIDE CONDITIONED SPACE

The *Retrofit House* was built with HVAC ducts inside the conditioned space except for two supply run-outs in the garage ceiling leading to the bonus room above the garage. Ducts are zone-controlled to allow for separate operating conditions upstairs and downstairs. This allows for better management of the typically warmer upstairs spaces due to the rising of warm air. The lower-level return vent is between the half-bath and pantry, while the upstairs return vent is adjacent to the utility/laundry room in the hallway.

Placing ducts inside the conditioned space has the largest return on investment. The incremental cost of ductwork is assumed to be zero and the cost of foaming the attic was all charged to the "airtightness improvement in section 4.8. Simulation results from EnergyGauge predict HVAC energy use savings of 3921 kWh/yr and energy cost savings of $365/yr.

Table 7. Moving ducts inside conditioned space modeled cost savings

Retrofit Measure	Energy Savings ($/yr)	Cost ($)	Amortized Cost ($/yr)	Cost Savings ($/yr)
Ducts Inside Conditioned Space	$365	$0	$0	$365

4.8 AIR SEAL AND INSULATION OF ATTIC

The attic in the *Retrofit House* was air sealed and insulated with foam that was covered with 2-inches of JM Spider to obtain R-30 under the roof sheathing and on the gable walls. Air sealing included the soffit, gable, and ridge vents, which placed the heat pump and ducts within conditioned space, and sealing excessive infiltration around the patio and kitchen doors. The result was to reduce the whole house ACH at 50 Pa from 5.7 as measured in the *Builder House* to 3.43 in the *Retrofit House*.

The retrofit cost estimate included removal of attic floor insulation and the extra time required to work around an existing heat pump and ductwork. Attic sealing and insulation had the largest first cost of any of the other retrofit measures.

Table 8. Air sealing and attic insulation modeled cost savings

Retrofit Measure	Energy Savings ($/yr)	Cost ($)	Amortized Cost ($/yr)	Cost Savings ($/yr)
Air Sealing & Attic Insulation	$79	$5,916	$788	-$709

5. PEAK ENERGY SAVINGS

Another benefit of deep energy retrofits is the energy savings realized during the peak load times of the electric utility provider. This benefits the utility because it will minimize brown-outs or outside purchase of more expensive power and can reduce the need to build more power plants to meet peak load demands. It benefits the homeowners, especially if electric utility rates change depending on time-of-use, because the home will likely use less energy during these high energy cost times. ORNL has monitored three homes in Atlanta, Georgia, before and after an energy retrofit so that peak summer energy savings can be calculated. These homes were analyzed for whole house and peak energy savings and peak power savings due to the retrofits. Table 9 shows the yearly electric and whole house (electric and gas) energy savings along with the percentage of whole house site energy savings for these three homes. All homes upgraded the HVAC systems to more efficient systems and increased the attic insulation. The homes North Carolina and Yellow Jackets upgraded the DHW system.

Table 9. Whole house electric and total site (electric + gas) consumption

	Electric Savings (kWh)	Whole House Site Energy Savings (MMBtu)	Whole House Percent Site Savings (%)
North Carolina	6,265	95.6	40%
Yellow Jackets	1,558	33	30%
Eagle	2,497	44	49%

Electric power data from these homes were available at one minute resolution for pre- and post-retrofit cooling seasons. Two 3-day periods, one before the retrofit and the other after the retrofit, were selected with similar average outdoor air temperatures. Power data for each 3-day period was averaged and binned resulting in average power at 15-minute resolution throughout a whole day period. Although a sample of three homes is not statistically significant, these case studies show that peak energy use reduction (reduction in energy use between noon and 8 PM in the post-retrofit case when compared to the pre-retrofit case) can be accomplished and was on the order of 23% for peak summer days for these three homes.

Table 10 shows the electric energy use and peak power savings results from the three homes. The peak load time for the utility provider is 12 PM to 8 PM, and the energy usage during this time for each house is shown below. The off-peak savings is also shown, which after normalized by number of hours has only a slightly higher average load than the peak time period (1.29 kW compared to 1.17 kW respectively). Each of the homes is discussed in detail below.

Table 10. Electric energy and peak power savings for three homes

	North Carolina	Yellow Jackets	Eagle	Average Savings per home
24-hr Energy Savings	38%	18%	21%	29.91 kWh (31%)
Peak Energy Savings (12-8PM)	28%	16%	9%	9.35 kWh (23%)
Off-Peak Energy Savings	44%	19%	27%	20.57 kWh (37%)
Peak Power Savings (15-min)	2%	10%	(8%)	–
Peak Time Shift (Pre, Post)	(7:00PM, 2:30PM)	(4:30PM, 4:00PM)	(9:15PM, 8:00PM)	–

5.1 NORTH CAROLINA

The 3-day average power at 15-minute resolution for North Carolina is shown in Figure 1. The black box shows the peak load time for the local utility. For the bulk of this time there is significant savings in the average power after the retrofit. For the time period from 12 PM – 8 PM the energy consumption was reduced by 28% by the retrofit for the days analyzed. A 2% savings was seen in the peak power due to the retrofit. The 15-minute peak power occurred at 7 PM before the retrofit and 2:30 PM after the retrofit.

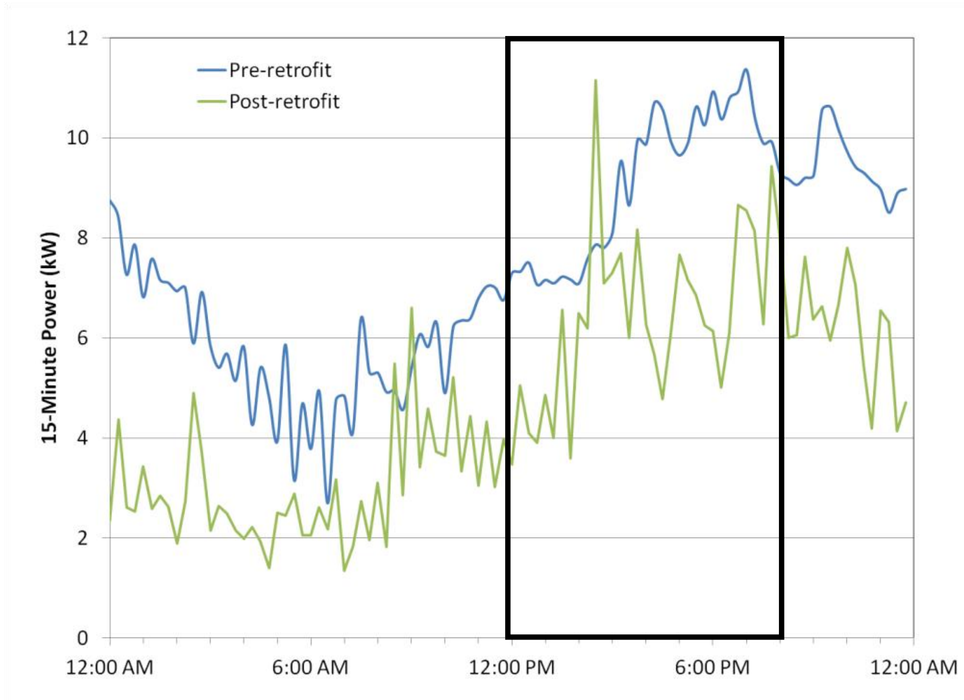

Figure 1. 3-day average 15-minute power for North Carolina

Figure 2 is a plot of cumulative percent of total time that the power demand was below a certain power (shown on the y-axis). The figure shows that before the retrofit the whole house 15-minute average power was below 7 kW for 50% of the time. After the retrofit this power was reduced by 3 kW to about 4 kW. North Carolina consumes more power than the other homes in this study in part because laundry is done 2-3 times a day due to children who are involved in sports. Despite this, the baseline power need of the home was reduced more than any other home.

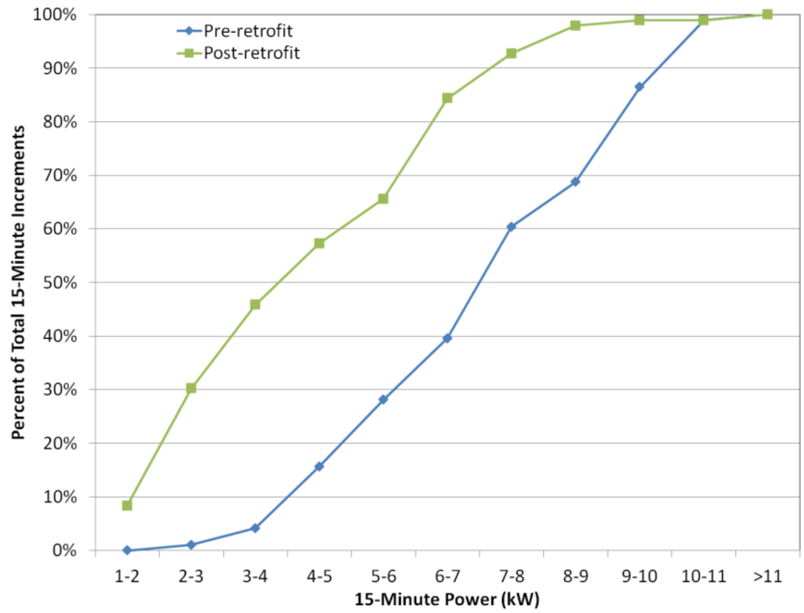

Figure 2. Cumulative binned power for North Carolina

5.2 YELLOW JACKETS

The 3-day average power at 15-minute resolution for Yellow Jackets is shown in Figure 3. The black box shows the peak load time for the local utility. For the time period from 12 PM – 8 PM the energy consumption was reduced by 16% by the retrofit for the days analyzed. A 10% savings was seen in the peak power due to the retrofit. The peak power occurred at 4:30 PM before the retrofit and 4:00 PM after the retrofit.

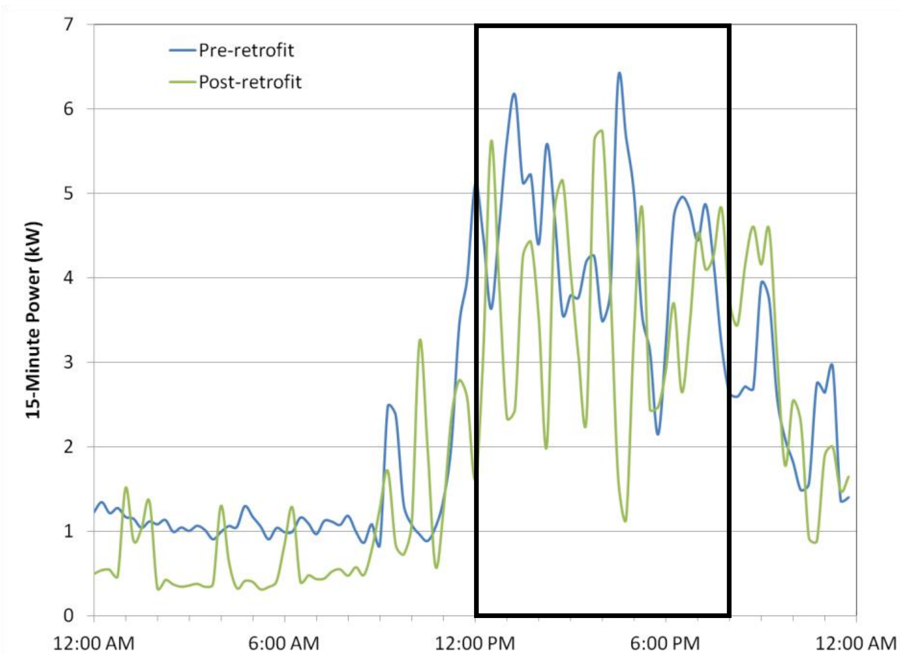

Figure 3. 3-day average 15-minute power for Yellow Jackets

Of all three homes Yellow Jackets had the least amount of power demand shifting as can be seen in Figure 4; a plot of cumulative percent of total time that the home's power demand was below a certain power. The figure shows that before the retrofit the whole house 15-minute average power was below 2 kW for 50% of the time. After the retrofit this power was reduced by about 0.25 kW to about 1.75 kW.

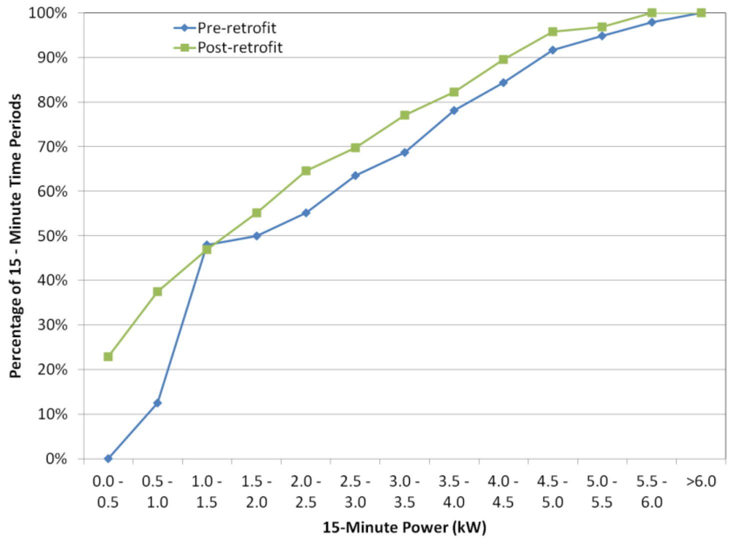

Figure 4. Cumulative binned power for Yellow Jackets

5.3 EAGLE

The 3-day average 15-minute average power for Eagle is shown in Figure 5. The black box shows the peak load time for the local utility. For the time period from 12 PM – 8 PM the energy consumption was reduced 9% by the retrofit for the days analyzed. An 8% increase in the peak power was seen after the retrofit for the analyzed days. The peak power occurred at 9:15 PM before the retrofit and 8:00 PM after the retrofit.

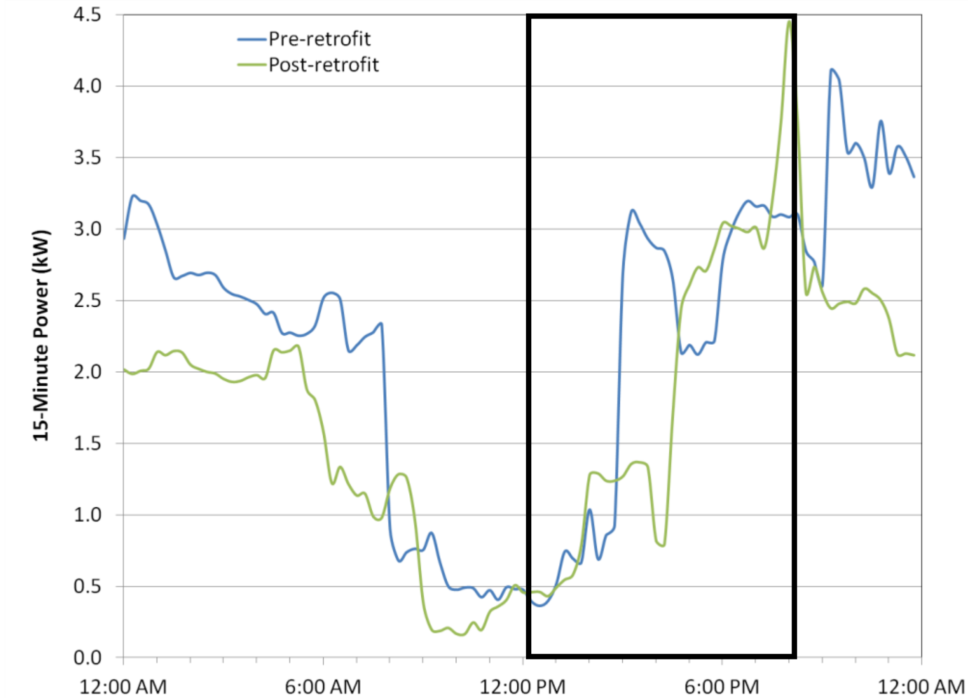

Figure 5. 3-day average 15-minute power for Eagle

Although an increase was seen in peak power after the retrofit, over-all the power demand was shifted by about 0.75 kW. This is seen in Figure 6, which shows the cumulative percent of total time that the home's power demand was below a certain power. Before the retrofit the whole house 15-minute power was below 2.5 kW for 50% of the time. After the retrofit this power was reduced to about 1.75 kW.

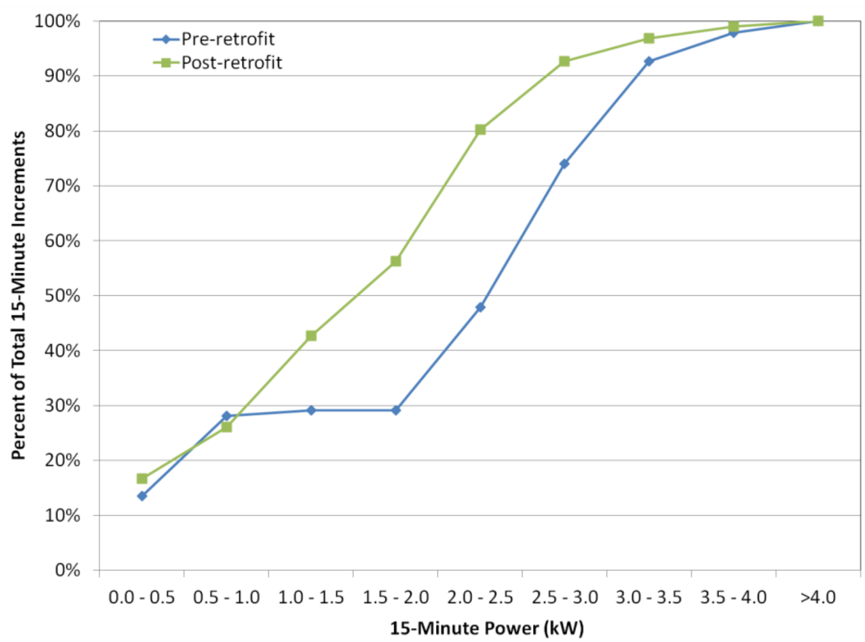

Figure 6. Cumulative binned power for Eagle

6. REMODELER RESOURCES

The NAHB Research Center published an extensive list of links to products, practices, and results to consider when remodeling a home. See http://www.toolbase.org/ToolbaseResources/ under "Home Building Topics" and "Remodeling & Retrofits".

Home Modifications published an extensive list of resources designed to help consumers make good decisions about the products they need to improve their home environment. See http://www.homemods.org/resources/products.shtml.

NAHB published a good article on "Funding for Home Modifications & Programs". See http://www.nahb.org/ under Housing Topics > Remodeling > Aging in Place.

EcoHome Magazine published "Stimulus Package Means Work for Remodelers" in their March-April 2009 issue at http://www.ecohomemagazine.com/green-building-and-design/energy-efficiency/. Use the search bar with the article title.

Training modules on energy efficiency for remodeling, developed in collaboration with ORNL and Southface Energy Institute with support from DOE, are described at http://www.toolbase.org/Home-Building-Topics/Remodeling/energy-efficient-remodeling.

A description, list of resources for builders, and training opportunities in the EarthCraft Programs can be found at http://www.earthcraft.org/renovation.

Home performance with ENERGY STAR, a national program from the EPA and EPA promotes a comprehensive, whole-house approach to making energy-efficiency improvements. The program is available in cities where a local sponsor (typically a utility company, state agency, or local association promoting energy efficiency) has agreed to partner with ENERGY STAR. Details and a comprehensive case study are available at http://www.energystar.gov/homeperformance.

The *EcoHome Magazine* is worth subscribing to because it has many good articles about energy efficiency products and practices. Examples are "Right-Sized HVAC" and "Net-Zero Finds the Mainstream"; all with links to related articles and related topics. Energy efficiency topics can be found at http://www.ecohomemagazine.com/green-building-and-design/energy-efficiency/. Their search window can also be used to find information in older issues.

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APPENDIX A

Economic Lifetime of Retrofit Measures From the

DOE Weatherization Assistance Program

RETROFIT MEASURE	ECONOMIC LIFETIME, YEARS
All building insulation measures	**20**
Window Sealing	**10**
Window Replacement & Low-E Windows	**20**
Vent Dampers, all types	**10**
Intermittent Ignition Devices & High Efficiency Burners	**10**
Furnace & Air Conditioner Tune-up	**3**
Replace Heating System	**18**
High Efficiency Furnace or Boiler	**15**
Smart Thermostat	**15**
Replace Air Conditioner or Heat Pump	**15**
Water Heater Replacement	**13**