Lessons Learned from the Process of Retrofitting Existing Housing for Energy Efficiency

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ABSTRACT

This paper discusses lessons learned from the design and retrofit of two existing homes for improved energy efficiency. Principle findings include the necessity for providing cost-effective, replicable solutions for the energy efficient retrofit of existing homes that address both up-front expenses and the long-term energy costs carried forth by the resident. One major conclusion is that process matters; although there are essential principles for retrofitting existing homes for improved energy-performance, actual solutions must be project specific and should be undertaken through a comprehensive process that engages the contractor from the very beginning of the project.

INTRODUCTION

Residential energy use accounts for 22% of the total energy consumed in the US (EIA 2001). Over the last 10 years, energy prices in the United States have risen on average by 45% (EIA, 2012) and specific to the residential sector electricity prices have increased 37% from 8.6 cents/kWh to 11.8 cents/kWh (EIA, 2010; U.S. Energy Prices, EIA, 2012). With prices ascending annually, improving energy efficiency in homes could potentially save the nation hundreds of billions of kilowatt hours of energy and billions of dollars every year (Electricity End Use, EIA, 2010). Cost-effective measures for the energy-efficient retrofit of existing houses have the significant potential to "save energy, lower utility bill costs for homeowners, and create jobs" (NREL, A Method for Determining Optimal Residential EE retrofit Packages, pg. 1). Retrofitting existing homes can drastically improve the home energy rating while minimizing up-front construction costs and maximizing energy cost savings for the resident. Further, improving the energy performance of existing homes can significantly reduce greenhouse gas emissions from single-family homes (Tracey, 2009). Notably, according to the United Kingdom Department of Energy and Climate Change, "Carbon Emissions from existing homes represent as much as 25% of total emissions in many countries (Hamilton, 2010). The Housing Authority of Union County (UCHA), located in central Pennsylvania, has introduced an initiative to demonstrate the importance of energy efficient home building through its Energy Efficient Housing Program (EEHP). This paper describes the methods applied to retrofit two existing single-family homes as pilot projects for the Energy

Efficient Housing Program and summarizes the lessons learned in the interest of providing a model that can be replicated by other housing authorities, builders or homeowners.

PROJECT BACKGROUND

The Union County Housing Authority Energy Efficient Housing Program was established to reduce utility costs as a way to make homes affordable and more environmentally responsible. UCHA's goal for the Energy Efficient Housing Program (EEHP) is to produce affordable model housing in Union County, Pennsylvania that is highly energy efficient using cost effective current technology. Union County Housing Authority received a $500,000 HOME grant from the U.S. Department of Community & Economic Development to design and construct a new energy efficient duplex and to retrofit two existing homes with energy saving improvements. These homes were constructed and rehabilitated for purchase by income eligible, "Prime Time" home buyers, that is someone age 55 or older that earns less than 80% of the area median income (currently $33,150 for a single person; $37,900 for a couple). The total budget for each home, including new construction and the purchase cost plus costs of renovations and retrofits of the existing homes, was $150,000. Emphasis for the projects was on long-term energy efficiency and energy cost savings as a first priority, "green development" as a second priority, and minimizing the costs associated with the rehabilitation and retrofit of existing homes as a third priority. The new and retrofitted homes were designed to meet ambitious goals for energy performance (exceeding EnergyStar Home Energy Rating System (HERS) scores) and to assure recognized and verified status for green buildings (achieving a minimum of a "Silver" rating using the NAHB Green Building certification system). A building-science oriented integrative design process, engaging the design team and the building performance specialist / home energy rater, was employed from pre-design through construction. All four homes, and the design and construction process, were intended to provide a replicable model for homebuilders, homeowners, and other housing authorities.

The first pilot project for the EEHP, the new duplex in Lewisburg, Pennsylvania, was completed in the summer of 2010 meeting high standards for energy performance using modular construction. To assure that EEHP could be a model project where the lessons learned could be applied to the broadest audience, The Union County Housing Authority (UCHA) purchased two existing single-family homes in Union County, Pennsylvania. These existing structures were evaluated for energy efficiency and retrofit design solutions were applied in order to 1) improve the energy performance of the building envelope and 2) renovate the homes for 'aging in place'. Energy efficient improvements were undertaken by a local contractor to earn a HERS Index score of 85 (to comply with minimum expectations for EnergyStar version 2.5 performance) or better and a NAHB Green Home rating of "Silver."

Existing Conditions. The existing homes acquired by UCHA each fulfilled goals for "green development" in that they were located in existing neighborhoods, with some resources within walking distance, and would contribute to a sense of community and could enhance living conditions for the new residents. Each of the two homes had the major living spaces on a single level and therefore, with minor modifications, would accommodate residents' needs as they aged (Fig.1).

Figure 1: Existing Homes for retrofit as part of Union County's EEHP (Mifflinburg on left and Lewisburg Home on right) were selected because they were located in established developments and could accommodate single floor living.

Overview of Approach. For benchmarking purposes, an initial energy audit and baseline energy simulation model was prepared based on actual energy bills that were collected over the period of about one year prior to the retrofit of the existing homes (homes unoccupied at the time). The design team, including the project architect and a home energy rater, were selected based on an RFP for the EEHP, including the new duplex and the retrofit of the existing homes. A systems integrated approach based on building science principles and testing via energy simulation tools was employed during the design process. Because UCHA is a public agency there were rigorous requirements for a public bid process, including affirmative action goals for female and minority participation and bond requirements for the contractors. Very basic drawing documentation, a single 11"x17" sheet to convey the scope of work for the renovation of each property, and basic specifications were prepared for each retrofit home. The contractor was responsible for surveying the properties to obtain quantitative information for bidding and to coordinate construction with the verified field conditions. Basic work was performed in each home to insulate and isolate the existing basements from the living space of the homes and to replace existing electrical wiring with new code-compliant systems. Minor interior renovation work was completed to update the homes, assure that spaces were reasonably ADA adaptable and complied with *Visitabilty* standards, and to maximize views and daylighting while minimizing extraneous openings in the building envelope. Retrofit of the homes included building envelope and fenestration improvements, replacement of HVAC systems, installation of EnergyStar certified electric appliances and replacement of existing lighting fixtures to accommodate low-energy lighting sources. Aerators were installed on existing sinks and new water efficient roll-in showers and water closets were installed. Materials and equipment selected for the EEHP projects were based on three criteria: cost, performance (energy performance and durability), and locally manufactured and/or supplied.

Energy Efficiency Retrofit Strategies Specified. Although constructed about 40 years apart, both homes had framed exterior walls with little or no insulation, unfinished full basements and open attic space above the living space. The specified retrofit measures applied to the homes were consistent with "best practices" for the U.S. industry and summarized in an international report prepared by the UK Department of Energy and Climate Change:

> *Blower-door guided draught sealing is typically the most cost-effective measure and is applicable to virtually all existing homes. Draught sealing in lofts [attics] is deemed necessary before adding insulation. Blown-in cellulose (recycled) has been found to be widely applicable, effective and inexpensive for both loft and wall-cavity insulation. Heating and cooling system efficiency is approached to address not just equipment efficiency, but also quality installation, controls, and distribution systems efficiency.* (Hamilton, 2010, p.20).

<u>Building Envelope</u>:

Attic: Specifications called for existing fiberglass insulation to be salvaged and reused in the attic space. 1" of closed cell insulation (zero ozone depletion potential blowing agent) was to be installed between joists on top of any ceiling material and at the top plates. Where the condition of any existing fiberglass batt insulation was acceptable for reuse the facing paper was to be removed and the insulation reinstalled over closed cell foam insulation. Vent baffles were to be installed at the roof eaves and blown cellulose insulation was to be installed over the entire attic space to bring the total assembly to a minimum R-60 rating.

Basement: 1-1/2" of closed cell foam insulation (min. R-10) was to be installed on the foundation wall and thermal barrier paint applied as needed. Closed cell foam insulation was to be installed at the Rim Joists (min. 3") and sealed to the foam on the foundation walls.

Exterior Walls: In both homes the exterior siding material were to be retained and exterior walls were to be sealed and insulated through holes that were sawcut in the interior wallboard. Any existing fiberglass batt insulation was to be removed and

100% of the wall cavities were to be filled with dense pack cellulose insulation (min. 3.5 lbs / cu. Ft density). Holes in the drywall were to be patched, sanded and painted.

Changes to the specified building envelope strategies will be further explored below. The following systems were realized more or less as specified, but required active coordination between the contractor, the design team and the Home Energy Rater:

HVAC: The existing furnaces were removed and chimneys removed and sealed. Efficient mini split heat pumps were installed to heat and cool the living spaces of the homes.

Plumbing: Heat pump boosted EnergyStar electric tank water heaters were installed, with a condensate drain provided. New insulated 3/8" pex tubing hot water lines were installed and connected through a manifold.

Lighting: New EnergyStar fixtures were installed in the kitchen, bath, bedrooms and living room. Fluorescent bulbs were installed in all remaining fixtures.

Doors and Windows: All exterior doors were replaced with insulated doors and advanced weather-seal accessories. Patio doors in the Mifflinburg home were replaced with double-glazed EnergyStar-rated argon filled low-e doors with a U-factor of 0.30. All windows were replaced with locally produced dual glazed windows with a 0.29 u-value (triple-glazed windows with a u-value of 0.20 were specified as a bid alternative, but rejected due to an imbalance between the cost and improved efficiency).

Monitoring: Since overall energy performance and resident electricity use patterns are important to both the long-term understanding of how the retrofit measures are functioning and to establishing high-performance results, inexpensive but effective energy monitoring devices were installed in each home. The devices provide real-time feedback to the home occupants on how much energy is being consumed and trends can be followed with the web-based interface.

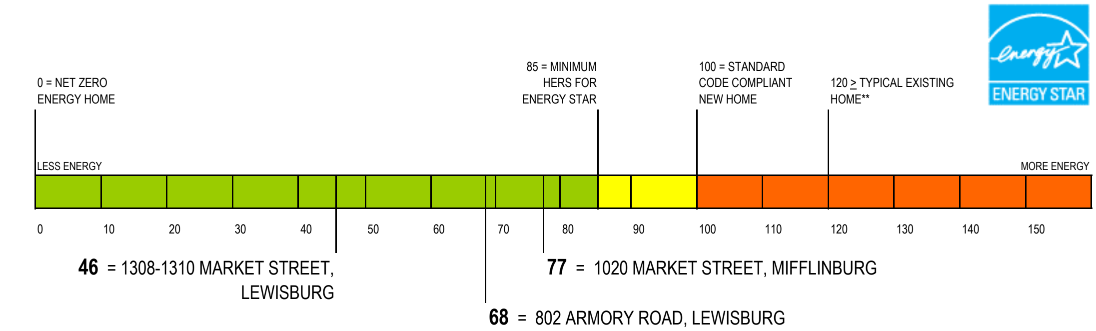
PROJECT SPECIFIC REALIZATIONS & REALITIES

Mifflinburg Home

The first home to be retrofitted was a ranch located in Mifflinburg, Pennsylvania, and most likely constructed in the 1980s. The 1,163 square foot home consisted of three bedrooms, a kitchen, bathroom and living space with an open rear deck and an unfinished basement. The largest expenditure of time and adversity went into the wall insulation and how it was to be installed. Because of the contractor's preference and supplier relationships, dense-pack fiberglass insulation instead of cellulose was blown into the openings in the drywall to fill the inner-wall cavity. As planned, horizontal slots were cut in the drywall, about half way up the wall, so that old insulation could be removed and the new dense-pack insulation added. However, because of horizontal blocking in the walls, this technique proved to be ineffective and, except at the brick-clad front façade, was abandoned in favor of removal and replacement of the worn existing vinyl siding. This allowed for an additional layer of rigid insulation below the exterior siding. There proved to be insufficient space in attic to insulate as specified. Therefore the rim band was sealed and 2" thick polystyrene rigid board insulation was installed in between rafters in the ceiling. This rigid insulation was cut ½ inch smaller than the space between the joists and the edges were sealed with polyurethane expanding foam (proving a better seal than cutting the insulation to fit tightly). The original drafty windows were replaced with double-glazed windows filled with inert Krypton gas. To cut costs, Fiberglass batts were installed in the basement ceiling to thermally isolate the basement from the rest of the house instead of insulating the foundation walls; a wall enclosure and new insulated door were installed at the basement hatch providing a thermal barrier between the basement and rear yard. The building envelope and fenestration improvements helped retain a great deal of heat in the home and contributed significantly to its overall energy performance. However, the home was so tightly sealed that it had to be mechanically ventilated and a heat recovery ventilator (HRV) was installed. The HRV ultimately proved problematic in the small town where neighbors heat with wood, because in certain climatic conditions smoke was drawn into the living space (a solution to this problem is an ongoing effort. Note: avoid venting toward the prevailing wind direction when installing an HRV.). These modifications to the Mifflinburg home improved its HERS rating from approximately 135 to 77; 23% better than code compliancy for new homes (fig.2).

<u>Lewisburg Home</u>
The Lewisburg home was built in 1941 and had very little insulation and extremely poor energy performance. The main living space of the home was 887 square feet with a 160 square foot enclosed porch, attached garage and an unfinished basement. Lessons learned from retrofitting the Mifflinburg home informed the process of improving the energy performance of this home. Here, the plaster interior wall finish was completely stripped off to facilitate proper sealing and thorough insulation of the exterior walls. In removing the wall finish a layer of tin siding underneath the external clapboard was discovered. The layer of tin on the interior surface would create air leakage and moisture problems if insulation was applied directly to the wall cavity. To circumvent this problem, one-inch (1") polystyrene rigid foam insulation board was placed in the wall cavity between the framing members. Blown-in dense-pack fiberglass insulation was then installed to fill the rest of the void and the walls were sealed and finished on the interior with new drywall. Like in the Mifflinburg house, the old windows were replaced with double-pane windows filled with inert Krypton gas and fiberglass batt insulation was installed to the basement ceiling. To save labor and material costs, the attic was isolated from the living space at the ceiling; the existing ceiling insulation was left in place and new insulation was blown overtop. A smart fan, instead of an HRV, was installed for ventilation. These upgrades improved the home's HERS rating to 68; 32% better than standard code compliant new homes and significantly better than the original HERs rating of nearly 160 (fig.2).

UNION COUNTY HOUSING AUTHORITY
HOME ENERGY COMPARISON (HERS INDEX*)

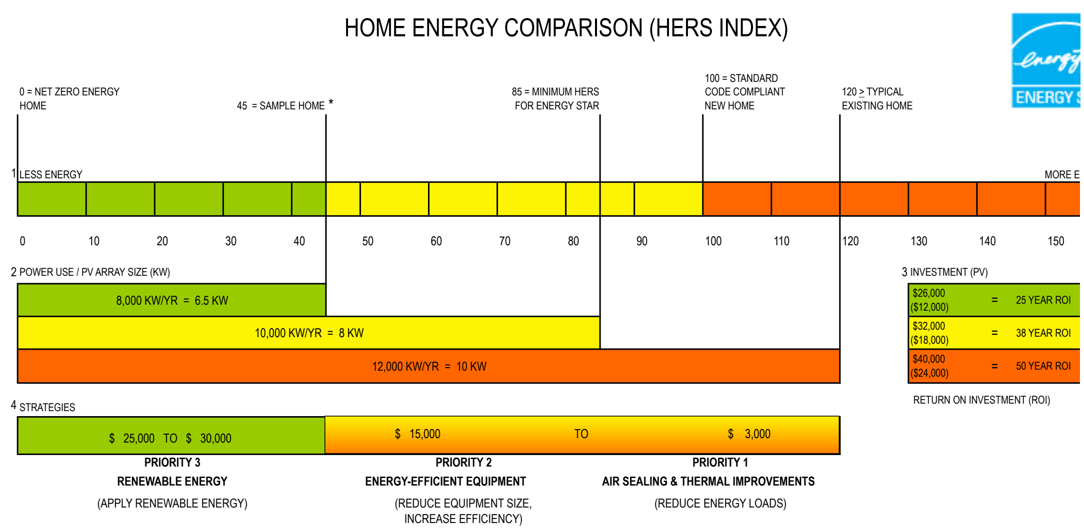


	ADDRESS	HOUSE TYPE	YEAR BUILT	CONDITIONED AREA	ENERGY SOURCE	ESTIMATED MONTHLY ENERGY COST ($0.21/KWH)	ESTIMATED ANNUAL ENERGY COST	ESTIMATED ANNUAL ENERGY CONSUMPTION	HERS RATING	BETTER THAN CODE
1	1308 MARKET STREET, LEWISBURG, PA (NEW CONSTRUCTION)	DUPLEX, SINGLE UNIT	2011	2025 SF	ELECTRIC	$134	$1,609	34.4 MMBtu/yr	**46**	54%
2	1310 MARKET STREET, LEWISBURG, PA (NEW CONSTRUCTION)	DUPLEX, SINGLE UNIT	2011	2025 SF	ELECTRIC	$134	$1,609	34.4 MMBtu/yr	**46**	54%
3	802 ARMORY ROAD, LEWISBURG, PA (RENOVATION)	SINGLE FAMILY, DETACHED	1944	911 SF	ELECTRIC	$157	$1,881	42.6 MMBtu/yr	**68**	32%
4	1020 MARKET STREET, MIFFLINBURG, PA (RENOVATION)	SINGLE FAMILY, DETACHED	1981	1120 SF	ELECTRIC	$121	$1,450	31.0 MMBtu/yr	**77**	23%

* ENERGY STAR VERSION 2.5

** PER ENERGY STAR ENERGY RATING CERTIFICATE

Figure 2: Comparison of EEHP home performance.



* THE SAMPLE HOME IS 55% MORE ENERGY EFFICIENT THAN A HOME BUILT TO THE 2006 INTERNATIONAL ENERGY CONSERVATION CODE AND 47% MORE EFFICIENT THAN A HOME MEETING THE MINIMUM ENERGY STAR REQUIREMENT

1 ADAPTED FROM ENERGY STAR HOME ENERGY RATING SYSTEM (HERS) INDEX

2 POWER USE - BASED ON NATIONAL AVERAGE OF ENERGY CONSUMED BY 2,500 SQUARE FOOT HOME WITH 2.5 PERSONS OCCUPANCY

3 COST OF RENEWABLE ENERGY (PV) BASED ON $4 PER WATT INSTALLED WITH AVERAGE 0.15 CENTS ENERGY COST PER KW/hrs

4 ENERGY IMPROVEMENTS COST BASED ON UNION COUNTY AUTHORITY ENERGY-EFFICIENT RENOVATION HOMES

Figure 3: Comparison of EEHP expenditure for energy improvements.

LESSONS LEARNED

Costs. The general trend realized was that a $10K (between $3,000-$15,000; see fig. 3) investment specific to energy improvements was necessary to bring homes from performing as much as 60% worse than minimal code to performing 23% and 32% better than code (2006 IECC) for the Mifflinburg and Lewisburg homes respectively. For the EEHP, cost constrains were based on the project budget ($150k / project), but all expenditures were weighed against what might be deemed a viable undertaking by a homeowner. Estimated costs for retrofit improvements (building envelope, HVAC, lighting, DHW / appliances, doors and windows) was approximately $30,000 with an additional $30K invested in essential renovations to bring the homes up to current living standards and requirements for aging in place. $60,000 was considered a reasonable expenditure undertaken as a home improvement project or equity loan budget. The project cost was also thought to reflect a reasonable "street" or appraisal value for the completed home. However, despite findings from a majority of home remodelers that buyers are willing to pay more for green homes (McGraw-Hill, 2012), in reality the comparative appraisal methods used do not value energy improvements. During a de-briefing meeting the project team speculated that once more EnergyStar and retrofit projects hit the market the "true value" would be realized in assessments. It was speculated that finance options could begin to absorb the cost of energy efficiency improvements since any added cost would be marginal in the overall loan. From a regulatory standpoint, legislation could be passed to include energy efficiency standards in code compliance for new homes. Comparable information will provide for more realistic ideas about actual cost of energy improvements, the payback times associated, and the market for valuing energy performance.

Process. The EEHP operated under a design, bid, build method as stipulated by the federal grant that funded the project. This occurred in different ways for the duplex and the retrofits due to the inherent differences in the projects. In the duplex, the architect was able to completely design the homes and prepare full documentation for the project to be bid by contractors (both conventional construction and modular builders). After the low-bidder – a modular builder - was selected the homes were built and the entire project was carried out relatively seamlessly. The design, bid, build process was not as effective for the retrofitted homes. Although careful evaluation and coordination of the retrofit measures was important, the size and scope of the projects did not warrant and could not support full project documentation. It is important to note that the retrofit projects were bid separately from the new construction project of the EEHP. Perhaps as a result of this, or for other unknown underlying factors, there were issues in acquiring competitive bids for the retrofit projects. Initially the drawings and specifications for the Lewisburg home were completed and put out to bid without response. Thereafter the project was combined with the second renovation / retrofit home and bid as a single job. This yielded a single bid by a small local contractor who had the enthusiasm but not the experience for energy-efficient building. The bid was also significantly over budget. One issue identified was that small contractors are not familiar with the bidding process and normally are not in a position to address the hefty bond requirements for the public project. In response the UCHA assisted with the process and paperwork and as a result the contractor felt that the experience would be beneficial for future projects. To address project budget, negotiations between the contractor, UCHA, and the project design team ensued to fully explore project intents and associated costs, ultimately realizing a favorable solution for all parties. Throughout construction, as the result of existing conditions or expense, some changes had to be considered. Direct and time-consuming team involvement and coordination between the contractor, the architect's construction administrator and the energy rater was necessary throughout the retrofit process. The project was valued and changes were coordinated to maintain the overall project performance goals on a weekly basis as field conditions were revealed. Dialog with the contractor, based on his expertise and local connections, provided insight into more cost effective material choices. It is important to note here that the local economy had a huge part to play in realizing cost-efficiency for this project; if prevailing wage had to be applied the retrofit projects probably would not have been realized. The primary lesson learned was that there is significant benefit to be realized through contractor involvement from the beginning of the project. Such early involvement would have reduced the amount of contract modifications that had to be made during construction process. This may seem a fairly straightforward process issue, but it is complicated by the public bidding requirement since this would have given the contractor involved an unfair advantage. Essentially a primary difference between the new and retrofit EEHP projects was that a front-loaded design process, centered on a coordinated building science approach, was necessary for the new construction whereas the expertise from the design team was desirable during retrofit construction for oversight and coordination. Both cases illustrate a need for the traditional design project fee structure to be readdressed.

Project Time. The time frame for the two retrofit projects could have been more than cut in half by refining the process and changing the bidding requirements. The unscientific conclusion from these retrofits was that "design-build" involving the contractor from the beginning would have taken one quarter of the project time. Contractor experience gained during the retrofit project contributed to streamlining the time on the second retrofit project and would likely reduce time on any subsequent projects. Once again, overall project time could have been reduced by involvement from the contractor in early project decisions and throughout the design process.

CONCLUSIONS

Because of the enormous existing housing stock and energy-use implications, the market for energy-efficiency needs to be focused on retrofit over new construction. In many ways the lessons from the EEHP retrofit homes illustrate significant opportunity. However, in some ways the EEHP retrofit projects are not an ideal model.

According to the 2009 Federal Recovery Act, building energy efficiency would result in job creation and a competitive edge for existing small contractors and businesses - ambitious and advantageous goals in today's economic climate. In green building generally, and with energy-efficient retrofits specifically, there is the necessity for a committed party dedicated to making it happen, therefore there is an "act of will" factor at play. Fortunately, predictions show that "despite the downward pressure of home prices, discriminating consumers have helped to keep green in the forefront" and that builders and remodelers have realized several business advantages related to green homes (Mcgraw-Hill, 2012, pg. 1). These findings did not fully prove true on the EEHP retrofit projects. While working on the retrofit projects the contractor became an EnergyStar certified remodeler (small contractor). As a result he received discounts on some materials and became a wholesale distributer for energy efficient products, including HRVs. Unfortunately his EnergyStar status was compromised due to the requirement that each contractor complete two EnergyStar certified projects per year to retain certification; Even though he was the only EnergyStar contractor in four counties he was unable to fulfill this requirement.

Often improvement of the building envelope for energy performance is not enough, and it is important to acknowledge that existing homes must also be updated for contemporary living. In part because the existing wall assemblies for the EEHP homes ended up being significantly modified, they have only limited application to other older housing found in most walkable neighborhoods. The energy performance of historical windows and horsehair plaster walls are difficult and expensive to significantly upgrade without compromising the home's character. Further programmatic changes needed to make older housing stock consistent with today's market may reduce the economic logic of such projects.

Finally, an expensive design-bid-build process including extensive construction phase services by the architect and energy rater proved necessary in realizing the EEHP homes. This was possible only because of money committed to making the EEHP a demonstration. In order for this to be replicated in the market, specialized and expert contracting teams need to emerge so that the design can be simplified a set of performance goals. Realistically, there may be limited potential for these teams to emerge entirely from the existing pool of renovation contractors.

In the end anything that is available for "mass consumption" overly simplifies the issues. However, it is important for projects and stakeholders to try and address policy / transformation of the market. An emphasis on public information regarding the benefits of energy-efficiency and reduced energy use remains an important cause. Despite limitations, the EEHP projects are significant achievements in this regard. UCHA's support of ongoing research and dedication to dissemination of knowledge gained from the EEHP projects has promise to propel the practice of small projects that maintain high standards for long and short term energy expenses and community-oriented development goals.

ACKNOWLEDGMENTS

Learning factory team & R. Allen Kimel, Assistant Professor of Material Science & Engineering, PSU; Jere Engle, UCHA; Dane Stein, Contractor; Pete Vargo, Energy Rater; Office for Planning and Architecture (OPA); Todd Alwine, OPA Project Administrator.

REFERENCES

EIA, (2001). "Electricity Consumption by End Use in U.S. Households," *U.S. Energy Information Administration*. Retrieved April 5, 2012 from http://www.eia.gov/emeu/reps/enduse/er01_us_tab1.html

EIA, (2010). "Average Retail Prices of Electricity, Selected Years, 1960-2010," *U.S. Energy Information Administration*. Retrieved April 11, 2012 from http://www.eia.gov/totalenergy/data/annual/pdf/sec8_39.pdf

EIA, (2010). "Electricity Prices for Households," *U.S. Energy Information Administration*. Retrieved April 11, 2012 from http://www.eia.gov/emeu/international/elecprih.html - EIA 2001

EIA, (2012). "U.S. Energy Prices," *U.S. Energy Information Administration*. Retrieved April 11, 2012 from http://www.eia.gov/forecasts/steo/tables/pdf/2tab.pdf - EIA 2011

Hamilton, B., Project Manager, The Regulatory Assistance Project, (2010). "A Comparison of Energy Efficiency Programs for Existing Homes in Eleven Countries," Prepared for the Department of Energy and Climate Change, United Kingdom, 19 February 2012.

McGraw-Hill Construction (2012). "New and Remodeled Green Homes: Transforming the Residential Marketplace, *Smart Market Report*, Bedford, MA.

Tracey, M. D., (2009). "Retrofitting Existing Homes for Energy Efficiency," in *Green Design,* January 22, 2009. Available (10 November 2012): http://styledstagedsold.blogs.realtor.org/2009/01/22/retrofitting-existing-homes-for-energy-efficiency-is-key/