WASHINGTON STATE UNIVERSITY
EXTENSION ENERGY PROGRAM

Cost Implications of Retrofit vs. Replacement of Manufactured Housing

Washington State University Energy Program
and
Habitat for Humanity

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Cost Implications of Retrofit vs. Replacement of Manufactured Housing

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Dedication

This report is dedicated to the memory of Doctor Subrato Chandra. In over 15 years of collaboration, our staff have benefitted from his support, leadership and wisdom. He was passionate about energy efficiency, and inspired others to do their best work. His guidance was instrumental in shaping the project described in this report, and the report itself. He will be deeply missed.

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Definitions

BEopt	Building Energy Optimization Tool
BPA	Bonneville Power Administration
ESTAR	Energy Star Manufactured Housing Program
HASCO	Housing Authority of Snohomish County
HfH	Habitat for Humanity
HfHI	Habitat for Humanity International
HUD	U.S. Department of Housing and Urban Development
HVAC	Heating Ventilation and Air Conditioning
IRB	Institutional Review Board
KCHA	King County Housing Authority
MHCP	Manufactured Housing Community Preservationists
NEEM	Northwest Energy Efficient Manufactured Housing Program
NEW	Northwest Energy Works
WSU Energy Program	Washington State University Energy Program

Executive Summary

This report focuses on the evaluation of both new and retrofit energy efficiency measures in electrically heated manufactured homes, located in the marine climates of Washington State. The report uses energy efficiency cost and energy use information, collected in these homes to help answer the three key research questions:

- *What is the cost/benefit of retrofitting existing pre-HUD and HUD 1976-1994 code homes?*
- *What is the cost/benefit of improving the energy efficiency of HUD 1994 homes to an equivalency of 2012 IECC and beyond ENERGYSTAR?*
- *What is the typical monthly cash flow (energy bill, mortgage or weatherization financing costs and park rental lot fees) of manufactured home occupants in the marine climate of Seattle, WA?*

This project allowed Washington State University (WSU) Energy Program researchers to investigate the energy use and energy measure costs of existing manufactured homes located in three manufactured home communities in Western Washington. Researchers worked with Habitat for Humanity (HfH) and King County Housing Authority to gain access to homes in the communities so researchers could acquire utility data, field test homes and survey occupants.

Researchers also conducted retrofit cost data research from a variety of sources including Washington State Department of Commerce, Snohomish and King County Housing Authorities, manufactured home community managers and low income weatherization program staff. Researchers used cost data on new construction energy measures that was collected as part of a research project funded by the Bonneville Power Administration (BPA).

Researchers conducted BEopt energy modeling of typical single and double section prototype manufactured homes. BEopt was used to estimate the:

- Energy use of each prototype home,
- Energy savings from retrofits of pre-HUD, HUD 1976 and HUD 1994 homes
- Energy use of homes constructed to the 2012 International Energy Conservation Code and two improved ENERGY STAR cases (with and without ductless heat pumps).

Three financing scenarios were used to determine the overall monthly cost to finance energy improvements in both retrofit and new construction cases:

1. Zero percent, 30-year loan typically provided by HfH,
2. 7 percent, 30-year conventional home equity or other loan,
3. 15 percent, 15-year chattel mortgage typical of manufactured housing.

The monthly energy savings estimates from BEopt were then subtracted from the monthly cost of financing the energy measures to determine overall monthly cash flow.

Based on the modeled results, the retrofits of HUD 1976 and HUD 1994 homes financed at a 0 percent HfH loan resulted in a positive monthly cash flow. Financed at 7 percent, both the single wide and double wide 1976 vintage home resulted in a positive monthly cash flow, but neither the single and double wide 1976-1994 home cash flows were positive. No positive cash flows resulted under chattel mortgage financing.

All new home efficiency packages resulted in a positive monthly cash flow compared to the 1994 HUD Code Standard with the exception of the chattel mortgage used to finance the beyond ENERGY STAR package and the beyond ENERGY STAR with ductless heat pump package.

The cost benefit analysis suggests that it is much more expensive to retrofit a home than build it right the first time. The cost implications of these "lost opportunities" (created by the current 1994 HUD code) burdens the homeowner and society by increasing the need for low income weatherization subsidies and utility assistance to low income homeowners living in manufactured homes.

The research also suggests that there are significant cost challenges for moderate- to low-income owners of HUD code homes to consider when replacing their home based on energy savings alone. To make replacement a viable option, significantly greater leveraging of federal, state, local and utility resources is needed.

When considering the benefits of potential retrofit measures, it is important to acknowledge that while the customers may realize other benefits from the improvements (such as warmer, more comfortable homes), these benefits are difficult to assess. The improvements may also provide benefits to health and safety, increased durability and useful life of the home. While additional investigations in the area of these benefits may be warranted, this report focuses only on the energy implications.

Experiments were conducted on BEopt modeling and the results compared to actual data. More accurate modeling of duct systems was researched, with positive results. However, BEopt over-estimated total energy use and savings from duct tightening.

Finally, while this BEopt analysis evaluated the use of ductless mini-split high performance heat pumps in new construction, their use in retrofits may be an area for future investigation.

Conclusions

Based on the BEopt analysis, researchers reached the following conclusions:

- Energy savings alone does not offset the cost of financing new, energy efficient construction. The difference between retrofitting an existing home and purchasing a new home is roughly $200 per month for a typical single wide prototype.
- A new manufactured homebuyer purchasing 1994 HUD code home will have overall higher monthly expenses compared to a home built to the 2012 IECC (or beyond).
- Mortgage rates have a significant impact on the cost-effectiveness and affordability of energy efficiency measures in both retrofit and new homes.

1. Introduction

A large percentage of manufactured housing is occupied by low income residents[1]. New manufactured home energy efficiency is typically substandard in comparison to site-built construction. As a result, energy costs can comprise a large portion of the occupant's monthly expenses. The energy provisions of the Housing and Urban Development (HUD) code, which applies to all manufactured homes nationally, was introduced in 1976 and has not been updated since 1994.

Low income homeowners living in older, inefficient manufactured homes face three choices in reducing their energy use: conservation, weatherization of the existing home, or replacement. While conservation is not a focus of this study, anecdotal information suggests that low-income occupants make compromises to their comfort levels by reducing thermostat settings, limiting the use of appliances, and using plug-in zonal heating. To properly assess the viability of weatherization and replacement options, the cost-effectiveness of manufactured housing retrofit measures needs to be better understood.

Research Approach

In an effort to evaluate the cost effectiveness of weatherization of existing manufactured housing versus replacing the same dwelling unit with a new manufactured home, WSU Energy Program partnered with HfH of Seattle/South King County to address this question. The project took place at a manufactured home community in Renton, Washington called Wonderland. The partners also included the King County Housing Authority. WSU Energy Program worked closely with these organizations to coordinate audits and obtain information on measure costs and other project details.

The following research question guided the investigation:

> *What is the cost benefit of retrofitting existing manufactured homes when compared to replacing the home with a new, efficient home?*

To answer this question, the following approach was undertaken by researchers:

- Audit a sample of the homes to better understand parameters for BEopt modeling,
- Identify and acquire cost data for energy efficiency measures (retrofit and new construction),
- Conduct parametric analysis of the energy use of the homes using BEopt for a variety of home vintages and energy code assumptions, and
- Determine the cost benefit of retrofit and new construction measures in terms of monthly cash flow for a variety of financing scenarios.

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[1] http://www.eia.gov/emeu/recs/recs2005/hc2005_tables/hc3demographics/excel/tablehc2.3.xls

The investigation focused on three manufactured home communities in the Seattle, Washington area:

- Wonderland Estates in Renton, with 109 units for those 55 and older. The development is owned by the King County Housing Authority and operated by the Manufactured Housing Community Preservationists (MHCP);
- The Vue in Seattle, with 47 units for all ages is owned and operated by MHCP; and
- Alpine Ridge in Lynnwood, with 93 units for those 55 and older. Alpine Ridge is owned and operated by the Housing Authority of Snohomish County.

Habitat for Humanity Perspective

HfH of Seattle/South King County is an affiliate of Habitat for Humanity International (HfHI). The affiliate was established in 1986 and is a non-profit organization that builds affordable homes with families that are income qualified. Habitat homeowners invest hundreds of hours of "sweat equity" labor into building their home, and pay a zero interest mortgage. Habitat's primary mission is to eliminate substandard housing.

The affiliate knows that the hurdle from transitional and supportive housing to permanent housing is far too high for many low-income households, and was interested in determining what the most cost-effective approach is:

- Purchase of new or newer homes to locate in empty lots in parks, or
- Performing retrofits on occupied units determined to be unsafe, unhealthy and/or in significant disrepair.

Prior to engaging with WSU Energy Program researchers, the affiliate has engaged with local housing authorities, banks, and other non-profit organizations, with a goal of understanding the issues surrounding retrofit and replacement of existing manufactured homes.

Manufactured housing supplements, and does not replace the work that the affiliate is already undertaking with site-built homes. Manufactured housing occupied by low-income families is believed to be some of the most substandard housing on the market. The affiliate receives calls every year from desperate manufactured home owners (or their families) asking for assistance in repairing homes not fit for occupancy.

The affiliate investigated developing a program to assist homeowners in these situations. The investigations led the affiliate to conclude that the work needed, and the cost associated with that work, would make such a program impractical. Some examples of the problems identified included electrical systems with attempted homeowner repairs so poorly accomplished that the entire home needed to be replaced, and floors with no structural support in need of replacement.

The scope of the issues identified, and the potential cost of remediation led Habitat to choose not to proceed with a program. Many units simply needed to be replaced, but homeowners could not afford even Habitat's zero interest mortgage. Working with local non-profit organizations, the affiliate was able to provide repairs to address significant health and safety issues.

The home itself was only a portion of the affordability issue for the homeowners. Some properties had had very high land lease costs, some as high as $650 per month. This cost, added to the mortgage payment, was as high or higher that the cost of a new home.

Manufactured home parks are owned and operated by many different entities, including: Housing Authorities, for-profit developers, manufactured home preservation groups, and residents themselves. The land under the manufactured home parks is increasingly being sold to developers who force the residents to move so they can build homes, condos, or apartments on the site. To ensure stability for residents, Habitat's priority is to identify parks that charge low land leases. Investigation of the parks in South King County showed there were 10 parks that were stable enough for Habitat to place units within these communities.

Habitat chose to partner with Manufactured Housing Community Preservationists (MHCP), a non-profit group that acquires, develops, owns, maintains and manages manufactured housing communities in order to provide decent and affordable low and moderate income homeownership opportunities. MHCP charges land leases on a sliding scale based on income, an important component of making ownership attainable for low-income residents. MHCP owns four manufactured home communities in Washington: two near Skyway and two in Kent. MHCP also operates the King County Housing Authority's Wonderland Estates manufactured housing community in Renton, Washington.

The Communities Studied

All three communities evaluated in this study are considered stabilized, in that they are owned by a housing authority or non-profit whose mission is to maintain affordable housing prices and keep the land that the community is built upon (as opposed to selling it for redevelopment). In each community, the land (including the land that the home is sited on) is owned by the non-profit or housing authority; the home itself is owned by the resident.

When a lot in a community is vacated, viable financing needs to be available for purchase of a new home. Each of the study communities include methods to provide for the financing of new homes. Alpine Ridge has partnered with two local banks to provide loans with terms and rates similar to a conventional site built home loan for purchase of the units. A pilot project was initiated with MHCP and HfH in order for HfH to purchase and install two units in the Vue and provide the loan to the new homeowners for purchase.

Wonderland Estates

The King County Housing Authority (KCHA) purchased Wonderland Estates in order to prevent the land from being sold to a developer to who was planning to evict the residents and construct condominiums. Wonderland Estates has space for 109 units for those 55 and older. Wonderland is operated by MHCP.

There are many pre-HUD code homes in Wonderland that are dilapidated, substandard, inefficient and in need of replacement. Money is very tight for most residents. None of the occupants surveyed stated that they were interested in replacement and the associated mortgage payment. Replacements occur only as residents vacate their homes. At Wonderland six homes were replaced with used 1990's vintage Super Good Cents (SGC) energy efficient homes provided by the Port of Seattle. The homes were well worn when they were set in place, but received aesthetic repairs and were sold to new residents. **Figures 1 and 2** show homes in the Wonderland Community.

Figure 1. Single Wide Home at Wonderland, Built in 1979

Figure 2. Double Wide Rehabilitated Home at Wonderland

Alpine Ridge

Alpine Ridge is located in Lynnwood, Washington and has 93 units for those 55 and older. It is owned and operated by the Housing Authority of Snohomish County (HASCO). The community contains pre-HUD code units. These units are inefficient and, in many cases, unsafe, due to such issues as mold, rotten floors and leaking roofs. HASCO intends to replace as many of these homes as possible with homes certified energy efficiency standards such as Energy Star. Since 2009, Alpine Ridge has seen 28 homes with vacancies:

- 6 units were repaired and resold
- 15 were replaced with newer units
- 4 replaced with new units
- 1 is being rented with no repairs having been implemented
- 2 units were removed to prepare for replacement

Costs were collected at Alpine Ridge for the installation of new units, as well as the costs of repairing the newer units that had already been placed at Alpine Ridge. Purchase, set-up, and administration averaged $78,000 for the new units. Repair of units at Alpine Ridge averaged $36,400 for the buyback of the existing unit, repair, and administration. Alpine Ridge has partnered with 2 local banks that provide loans for purchase of the homes.

The costs used for the cost analysis portion of the study were derived from the data available from Alpine Ridge.

The Vue

The Vue is a 47 home park, owned and managed by MHCP. HfH of Seattle/South King County conducted a pilot project at the Vue to offer high-quality, Energy Star-rated manufactured homes as an option for households who may not be able to afford a conventional (site-built) mortgage for a single section home. This program also focused on supporting the preservation and upgrade of vulnerable manufactured housing communities in King County. These are often neighborhoods with strong social cohesion, making them good candidates for revitalization.

The Manufactured Housing Pilot Project was conducted to evaluate the replacement of aging, dilapidated, and substandard manufactured homes with high-quality, energy efficient manufactured home in order to provide home-ownership opportunities to families graduating from transitional and supportive housing, but unable to afford a site built home in South King County.

Specifically, the Vue project focused on established manufactured housing communities where small investments can significantly improve the residents' quality of life. By removing old homes and replacing them with newer models, not only are partner families provided with decent housing, but substandard housing is taken off the market entirely.

The two homes included in the pilot were constructed by a Northwest manufactured home plant. One home was built to ENERGY STAR standards; the other home was certified to a manufacturer held energy efficiency brand (both standards have efficiency levels lower than site-built ENERGY STAR standard). HFH of Seattle/South King County purchased and placed the homes. Following the Habitat model, volunteers were used where possible in the finishing of the homes. This included installing the skirting, decks, entry stairs, and a small amount of landscaping. The average cost of each of the two homes was $63,500 (including acquisition, set-up, and administration).

One of the goals of the pilot project was to determine the true efficiency of the units. The two unoccupied units' energy usage (heating only) was monitored. Blower door and duct blaster tests were also performed to gauge the performance of the units. Air and duct leakage levels found through testing were greater than assumed for ENERGY STAR manufactured homes built under the Northwest Energy Efficient Manufactured Home program (NEEM). This feedback was provided to Northwest Energy Works (NEW), the company responsible for overseeing the NEEM quality assurance program requirements. Further investigations as to why the duct system leaks at twice the ENERGY STAR standards are warranted, to determine if it is a transportation related issue. Since these single section homes have no after-market cross over duct, one would expect that the duct leakage should be similar to the testing conducted at the factory; however, this was not the case[2].

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[2] Conversations with NEW, May 2011

2. Field Audits at Wonderland: WSU staff field audited six homes in the Wonderland community (shown in **Figure 3**), designated Wonderland A-F to characterize the building stock in the community, determine envelope thermal efficiency, mechanical system efficiency and air leakage rates. These audits included a detailed physical inspection, performance testing with blower door, duct blower and balometer equipment, as well as an occupant survey (at the occupied homes). Three of the six homes audited were unoccupied. Detailed case studies of these audits are provided in **Appendix 1**. Results of these audits are summarized in **Table 1**.

Figure 3. Aerial Photo, Wonderland Estates

Address	Year	Size (ft2)	Heat	DHW	ACH50	Ducts to Ext@50Pa	Occupied
Wonderland A[1]**	1979	576 SW	ER/zonal	Propane	14.9	NA	Y
Wonderland B	1996	1296 DW	ER	ER	5.2	400	Y
Wonderland C	1989	1738 DW	ASHP	ER	7.2	150	Y
Wonderland D	1986	1080 DW	ER	ER	7.6	190	N
Wonderland E	1992	1152 DW	ER	ER	6.5	385	N
Wonderland F	1998	1188 DW	ER	ER	7.7	300	N
AVERAGES	**1990**	**1172**			**8.2**	**285**	

[1] Electrical utility data available – see Table 2. *Air Source Heat Pump **Propane domestic hot water
SW = single wide; DW = double wide

Table 1. Audit Results

Field Audit Summary

All of the homes audited are set up on enclosed, ventilated crawlspaces and are, for the most part, in decent physical condition. These homes have all seen some degree of weatherization since installation.

Two of the occupied homes, Wonderland A and C, were built to the 1976 HUD code envelope standard - R-11 walls and floors and R-22 ceilings. Wonderland A had all of the original windows replaced with vinyl framed units, with an estimated U-factor of 0.40. Wonderland C had 25 percent of the windows replaced with similar vinyl framed units; the majority of the windows in this home were still the original aluminum frame windows.

Wonderland B was manufactured under the HUD code requirements of 1994 - R-11 for the walls and R-22 for the ceiling and floor. Windows in this home were vinyl framed.

The three unoccupied homes had recently been moved to the Wonderland development by the King County Housing Authority. Repairs were then performed on these homes prior to putting them up for sale; there were no obvious energy upgrades made to the homes at the time of repairs. All three of the homes were very similar in age and condition. No energy consumption data was available for these homes.

Wonderland E and F had 2X6 wall construction with R- 19 walls, R-33 in the floor and ceiling. Wonderland D had no indication of insulation levels beyond the 1976 HUD code requirements: R-11 for walls and floors and R-22 for the ceilings. Both homes had newer vinyl framed windows.

With the exception of Wonderland A, all thermal and air barriers appeared to be substantially intact and functional. Wonderland A was well cared for, but seemed to be in need of substantial repairs (for example, the porch structure was failing structurally and the floor assembly didn't appear to be stable.)

Lighting power densities for all homes varied substantially. The unoccupied homes had 0 percent, 2.5 percent and 10 percent high efficiency lighting. Two of the occupied homes had roughly 80 percent and 40 percent high efficiency lighting with the single wide home not having any. Where high efficiency lighting was present it was in the form of compact fluorescent lamps or lineal fluorescent fixtures.

None of the major appliances installed in any of the homes were ENERGY STAR qualified. None of the homes appeared to have any abnormal plug loads, other than auxiliary refrigerators or freezers, which were present in all occupied homes.

All homes audited were electrically heated. Wonderland A was heated with electric resistance zonal heaters; the rest of the units had ducted forced air heating systems. Of these systems, four were heated with electric furnaces; the largest home (1738 square feet) was equipped with a central air source heat pump. All duct systems were insulated and located in the under floor of the home.

Hot water systems for all the double wide homes were electric storage tank type heaters located within the conditioned space. The single wide home's hot water was supplied by naturally drafted, propane fueled storage tank type heaters. All three occupied homes had air conditioning; two via window mount units, and the other via the air source heat pump.

All homes tested had various configurations of source specific ventilation, most having exhaust fans in all bathrooms and all having kitchen range hoods. Three of the homes had whole house ventilation systems. Neither of the two occupied homes with whole house ventilation had the system in use. All fans were switch controlled.

Signs of moisture issues were noted in only one of the audited homes. Wonderland B had experienced some recent plumbing leaks, creating excessive moisture loading under the home. Although the home's whole house ventilation system was not functioning properly there was no evidence of mold or mildew growth in the house. The occupants used a dehumidifier to help evacuate vapor build up in the house.

Testing

Blower door testing results were fairly consistent. The average air change per hour at 50 Pascals of depressurization (ACH_{50}) for the six homes tested was 8.2. The highest infiltration rate of 14.9 ACH_{50} was seen at the 1979 vintage single wide, Wonderland A. The lowest, at 5.2 ACH_{50}, was seen at the 1996 double wide, Wonderland B.

All five homes with forced air systems (Wonderland B-F) were tested for duct leakage rates to the exterior at 50 Pascals of pressure. These duct testing results were much more varied than the blower door tests. Leakage rates varied from 150 CFM at 50 Pascals (CFM_{50}) of pressure to 400 $CFM_{50.}$ Expressed as a leakage rate relative to the homes floor area, the leakage rate range for these homes was between 8.6 percent and 33.4 percent with an average for the five homes of 23.2 percent.

Flow rates of source specific ventilation systems were tested on bathroom exhaust fans. These rates varied from 8 CFM to 42 CFM for an average tested rate of 30 CFM. Kitchen range hood exhaust fans were tested for operation but not for flow rate. All but one fan functioned properly.

Whole house ventilation was installed in three of the homes. Wonderland F (unoccupied) utilized an exhaust system with a 5" supply air ducted plumbed to the furnace. This fan tested at 55 CFM and was on/off switch controlled. The system at Wonderland B was not operated due the occupants' fear it was not operating properly (occupants smell burning rubber when the fan is on.) This fan was not tested for flow rate. The system at Wonderland C is a fresh air duct integrated into the homes furnace and controlled by a programmable thermostat. This system was never used by the occupant and was not tested for flow rate.

Occupant Survey

Occupant surveys were given to at least one occupant from Wonderland A-C. These surveys addressed occupant load, behavior and comfort levels as well as asking about previous energy conservation efforts in their homes. The home owners were also asked to whether they were willing to replace their home with one that was more energy efficient.

According to the surveys, the home owners were somewhat to very satisfied with the comfort level and energy efficiency of their homes. All home owners have had weatherization work performed on their homes, with the goals of increased comfort and reduced energy bills. The occupants of these homes all practiced some form of nighttime setback of their space conditioning systems in an effort to reduce energy consumption. There was no evidence from the surveys that any of these homes had unusually high or low plug loads (as mentioned before, this was borne out by the audits.)

Despite the occupants' satisfaction with their home's energy efficiency they were still very interested in additional reductions to their energy use. However, they all expressed that it would be difficult for them to make any further investment into their present home.

When presented with the question of whether they would be interested in replacing their homes with newer, more efficient homes, all of the occupants responded no. This reluctance was due to multiple rationales including overall happiness with their homes despite specific concerns and discomforts, not having the energy/interest in ever moving again and lack of appropriate financing.

Analysis

Most of the homes audited in this study were in decent or above average physical condition. The exceptions were the water-damaged floor insulation at Wonderland B and the single wide, 1976 HUD Code home, Wonderland A.

Wonderland A presented special challenges; though it was well cared for by the occupants, it appears to need substantial repairs to maintain livability over the next 10-15 years. The cost of these repairs may exceed the cost of replacing the home. Additionally, utility data indicated that it was the only occupied home with high consumption relative to the home size and occupancy. Given these facts, it is hard to recommend energy efficiency retrofits to the home, other than some level of air sealing. Lowering the home's infiltration to below 10.0 ACH_{50} would reduce the home's energy use, and improve occupant comfort.

An additional potential improvement would be to install a ductless heat pump, which would reduce energy use, improve occupant comfort, has a useful life in keeping with that of the home, and which could be removed and reused if the home were replaced. Making additional improvements to the home's envelope and mechanical systems are harder to justify, given that the home's useful life is limited without major repairs.

Residents of Wonderland B should make all efforts to replace water-damaged floor insulation, to improve energy efficiency, indoor air quality and building durability. This work will require access through the rodent barrier; at the same time, the very leaky ductwork could be sealed.

Utility data suggests that Wonderland C consumes considerably less energy per square foot of any of the other occupied homes tested despite very similar occupant rates and behaviors. This supports a recommendation that four homes with electric furnaces consider replacement of the current system with an air source heat pump when replacement is needed.

In general, duct leakage can contribute significantly to a home's space conditioning energy usage. Of the five homes tested with forced air systems, only Wonderland C had reasonable duct leakage to the exterior. All of the other homes had significant duct leakage, and would benefit from duct sealing efforts. The three unoccupied and recently rehabilitated homes all had significant duct leakage rates. Duct sealing is one of the most cost-effective weatherization measures, and should be prioritized whenever possible.

Compared to typical single family housing, the heating and cooling loads in most of the audited homes are low, likely due to the fact that most of the homes were in decent shape, and are smaller than typical housing stock. A significant portion of the electrical load is given to lighting, appliances and miscellaneous electrical loads. The audits identified significant potential in reducing these loads.

In all but two homes (Wonderland B and C) lighting is primarily incandescent. When these lamps need replacing, they should be replaced with high efficiency fixtures or lamps; this should be a priority when a home is vacated prior to resale.

There were no ENERGY STAR appliances observed in any of the homes audited. ENERGY STAR certified product should be considered when replacing appliances.

Exhaust ventilation systems in these homes were generally functional and appeared to be operated appropriately. There were no significant moisture issues observed that could be attributed to system dysfunction or lack of operation, despite the fact that none of the fans met factory specified flow rates.

The three homes which had whole house exhaust ventilation present were not likely to see increased electrical use, since the systems were not operated. To provide a controlled source of fresh air, improve indoor air quality and reduce unwanted moisture and pollutants, researchers recommend that all of the audited homes implement whole house ventilation strategies to the ASHRAE 62.2, 2010 standard. In the Marine Climate of the Pacific Northwest, the energy impacts of properly designed and operated whole house ventilation systems are not significant.

In general, these case studies reflected the difficulties of making blanket recommendations as to the cost-effectiveness of weatherizing an existing manufactured home versus replacement. Regardless of the cost-effectiveness analysis, the surveys further indicate that both retrofit and replacement require significant investments on the part of the homeowner; in many cases exceeding their interest or financial resources.

When an entity (private or public) takes on the responsibility of rehabilitating an existing manufactured home, weatherization efforts should be a high priority. The costs of weatherization measures are less apparent to a perspective buyer when they are rolled into the home's purchase price. Weatherization at time of rehabilitation may be the most effective way to save energy in low-income manufactured homes, while at the same time creating a more comfortable, durable home.

Utility data for the three occupied homes included in the case study can be found in **Table 2**. Utility data for a sample of four other occupied homes in the Wonderland community (designated Wonderland G-J) is also included.

Address	Sections	All Electric	kWh/yr. 2009	kWh/yr. 2010	kWh/yr. Average	kWh/yr./HDD 2009	kWh/yr./HDD 2010	kWh/yr./HDD Average
Wonderland A[1]**	SW	NO		7370	7370		1.76	1.76
Wonderland B[1]	DW	YES	11416	13855	12635	2.86	3.30	3.08
Wonderland C[1]*	DW	YES	10620	15720	13170	2.66	3.75	3.20
Wonderland G	SW	YES	6773	10026	8399	1.70	2.39	2.04
Wonderland H	SW	YES	7660	10390	9025	1.92	2.48	2.20
Wonderland I**	SW	NO	4990	5140	5065	1.25	1.22	1.24
Wonderland J**	DW	NO	11610	14760	13185	2.91	3.52	3.21

[1]Audited home *Air Source Heat Pump **Propane Present
SW = single wide DW = double wide

Table 2. Sample of Utility Data

3. Modeled Energy Use

BEopt version 1.1 was utilized in the energy modeling segment of this research project. Both single- and double-wide prototypes were modeled. The building components and take-offs were based on the Northwest Power and Conservation Council's manufactured home prototypes created by Ecotope, Inc., and used for energy efficiency economic analysis in the Pacific Northwest for the past three decades.[3] The single wide prototype is 924 square feet; the double wide is 1568 square feet. Both buildings were modeled with three bedrooms to minimize the impact of occupancy in the model.

Both existing and new construction manufactured homes were modeled for the analysis. **Table 3** summarizes the building components included in the existing home analysis and the associated retrofit measures evaluated. A pre-HUD code 1976 vintage manufactured home was modeled and retrofitted. Subsequently, a 1976-1994 vintage manufactured home was modeled and retrofitted. All existing home vintages were assumed to be built prior to the current 1994 HUD code. Retrofit measures evaluated included the building envelope, building air leakage and duct leakage. The mechanical equipment was not upgraded in this portion of the analysis. The ventilation strategy was modeled identically among the units; exhaust only at 50 percent of ASHRAE 62.2 levels.

Envelope	Pre 1976	1976 retro	1976-94	1976-94 retro
Wall framing	16" oc	16" oc	16" oc	16" oc
Walls – R	7	11	11	11
Floors – R	7	33	11	33
Ceiling – R	7	49	22	49
Windows - U	1.45	0.32	1.45	0.32
Mechanical				
Heating	electric furnace 60k BTU/hr		electric furnace 60k BTU/hr	
Water heating	.89 60 gal		.89 60 gal	
Ventilation	exhaust 50% 62.2		exhaust 50% 62.2	
Infiltration				
Envelope	leaky	typical	leaky	typical
Ducts	leaky, uninsulated	sealed	leaky, uninsulated	sealed

Table 3. Existing Home Building Efficiencies

[3] Regional Technical Forum. Additional/Supporting Documents (including manufactured home prototypes). 2011. http://www.nwcouncil.org/energy/rtf/measures/support/Default.asp

Table 4 summarizes the building component features as modeled in the new construction segment of the analysis. A 1994 HUD code base home was modeled and improvements were applied that were roughly based on the 2012 IECC and a theoretical "beyond ENERGY STAR" scenario. The envelope, mechanical, and air leakage characteristics are as follows:

Envelope	94+	2012 IECC	Beyond ESTAR
Wall framing	16" oc	16" oc	24" oc
Walls - R	11	21	21 + 5c.i.
Floors - R	22	33	38
Ceiling - R	22	49	49
Windows - U	0.7	0.32	0.25
Mechanical			
Heating	electric furnace 60k BTU/hr	electric furnace 60k BTU/hr	ductless heat pump
Water heating	.92 60 gal	.95 60 gal	.95 60 gal
Ventilation	exhaust 100% 62.2	exhaust 100% 62.2	HRV 100% 62.2
Infiltration			
Envelope	typical	Tight	tight
Ducts	leaky, R-6	tight, R-6	no ducts

Table 4. New Home Building Efficiencies

Single Wide Units

Table 5 summarizes the modeled energy use by category for the existing construction and retrofitted single wide units. The post-retrofit savings were calculated based on electric utility rates from Puget Sound Energy (PSE)[4], 8.5 cents per kWh. PSE has a low income rate available, but it was not utilized in this analysis. This decision was made since only about half of all HfH families qualify for the low-income rate.

Table 6 summarizes energy use by category for new construction single wide units.

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[4]Puget Sound Energy, Electric Rates, http://pse.com/aboutpse/Rates/Documents/summ_elec_prices_2011_10_01.pdf

Single Wide	1976	1976 Retro	1976-1994	1976-1994 Retro
Misc. (E)	2860	2860	2860	2860
Vent Fan (E)	45	58	45	58
Lg. Appl. (E)	2135	2135	2135	2135
Lights (E)	1059	1059	1059	1059
HVAC Fan/Pump (E)	866	433	683	433
Heating (E)	16980	8499	13403	8499
Hot Water (E)	3693	3693	3693	3693
Total	27637	18736	23877	18736
Annual energy cost	$2,349.18	$1,592.59	$2,029.58	$1,592.59
Monthly energy cost	$195.76	$132.72	$169.13	$132.72
Monthly upgrade savings		$63.05		$36.42

Table 5. Modeled Energy Use for Existing Single Wide Construction

Single Wide	HUD	2012 IECC	Beyond ESTAR	Beyond ESTAR + DHP
Misc. (E)	2860	2860	2860	2860
Vent Fan (E)	128	128	306	306
Lg. Appl. (E)	2135	2135	2135	2135
Lights (E)	1059	1059	1059	1059
HVAC Fan/Pump (E)	627	280	132	132
Heating (E)	10186	4586	1832	1145
Hot Water (E)	3558	3432	3432	3432
Total	20553	14480	11756	11069
Annual energy cost	$1,746.99	$1,230.78	$999.24	$940.84
Monthly energy cost	$145.58	$102.56	$83.27	$78.40
Upgrade savings		$43.02	$62.31	$67.18

Table 6. Single Wide New Construction Modeled Energy Use

Double Wide Units

Table 7 summarizes the modeled energy use by category for the existing construction and retrofitted double wide units. The post-retrofit savings were calculated based on the same PSE electricity rates utilized in the single wide analysis, 8.5 cents per kWh.

Double Wide	1976	1976 Retro	1976-1994	1976-1994 Retro
Misc. (E)	3118	3118	3118	3118
Vent Fan (E)	36	56	36	56
Lg. Appl. (E)	2135	2135	2135	2135
Lights (E)	1487	1487	1487	1487
HVAC Fan/Pump (E)	1308	639	1018	639
Heating (E)	24364	11924	18974	11924
Hot Water (E)	3693	3693	3693	3693
Total	36140	23051	30460	23051
Annual energy cost	$3,071.93	$1,959.36	$2,589.13	$1,959.36
Monthly energy cost	$255.99	$163.28	$215.76	$163.28
Upgrade savings		$92.71		$52.48

Table 7. Double Wide Existing Construction Modeled Energy Use

Table 8 summarizes the modeled energy use by category for new construction double wide units.

Double Wide	HUD	2012 IECC	Beyond ESTAR	Beyond ESTAR + DHP
Misc. (E)	3118	3118	3118	3118
Vent Fan (E)	145	145	350	350
Lg. Appl. (E)	2135	2135	2135	2135
Lights (E)	1487	1487	1487	1487
HVAC Fan/Pump (E)	827	367	199	199
Heating (E)	13868	6352	2759	1724
Hot Water (E)	3558	3432	3432	3432
Total	25138	17036	13480	12445
Annual energy cost	$2,136.71	$1,448.04	$1,145.78	$1,057.83
Monthly energy cost	$178.06	$120.67	$95.48	$88.15
Upgrade savings		$57.39	$82.58	$89.91

Table 8. Double Wide New Construction Modeled Energy Use

4. Cost Analysis

To calculate the cost effectiveness of retrofitting existing manufactured homes, incremental costs for the upgrade packages need to be derived. The costs of the retrofit packages were calculated based on weatherization work that is currently under way in the state of Washington with American Recovery and Reinvestment Act (ARRA) funds[5].

Cost of Retrofitting Existing Buildings

A summary of costs calculated for the retrofit measures and packages which were applied to the economic analysis for retrofitted homes is summarized in **Table 9.** The costs for the packaged upgrades vary from 6-12 thousand dollars.

	1976 Retro Cost	Single Retro	Double Retro	76-94 Retro Cost	Single Retro	Double Retro
Envelope	per ft^2	per building	per building	per ft^2	per building	per building
Walls	$1.70	$1,904.00	$1,980.50			
Floors	$1.97	$1,820.28	$3,088.96	$1.93	$1,783.32	$3,026.24
Ceiling	$1.99	$1,838.76	$3,120.32	$1.63	$1,506.12	$2,555.84
Windows	$20.67	$2,501.07	$2,707.77	$20.67	$2,501.07	$2,707.77
Infiltration	each	each	each	each	each	each
Envelope	$609.00	$609.00	$904.00	$609.00	$609.00	$904.00
Ducts	$245.00	$245.00	$382.00	$245.00	$245.00	$382.00
Total package cost		**$8,918.11**	**$12,183.55**		**$6,644.51**	**$9,575.85**

Table 9. Existing Construction Cost to Upgrade

5 Housing Association of Snohomish County, 2011. ARRA Grant application for Alpine Ridge.

Incremental Cost of Efficient New Construction

The incremental cost of improving the efficiency of the 1994 HUD code single and double wide manufactured homes was calculated based on a survey of 11 manufacturers in the Pacific Northwest[6]. The incremental cost was added to base cost of a single and double wide. The base cost of $40,000 for a single wide and $95,000 for a double wide was provided by HASCO.

Monthly mortgage payments were calculated for three financing scenarios; a 7 percent 30 year conventional mortgage, a 0 percent 30 year Habitat for Humanity mortgage, and a 15 percent 15 year chattel mortgage. The summary of monthly payments for each financing option is included in **Tables 10 and 11**.

Single Wide	1994 HUD	2012 IECC	Beyond ESTAR	Beyond ESTAR + DHP
Incr. cost of new construction		$2,482.21	$5,555.08	$9,555.08
Total cost	$40,000.00	$42,482.21	$45,555.08	$49,555.08
Monthly payment, 7% for 30 years	$266.12	$282.63	$303.08	$329.69
Monthly payment, 0% for 30 year	$111.11	$118.00	$126.54	$137.65
15% 15 year chattel	$559.83	$594.57	$637.58	$693.57

Table 10. Payments for Incremental Cost of New Construction, Single Wide

Double Wide	1994 HUD	2012 IECC	Beyond ESTAR	Beyond ESTAR + DHP
Incr. cost of new construction		$3,111.13	$6,387.93	$10,387.93
Total cost	$95,000.00	$98,111.13	$101,387.93	$105,387.53
Monthly payment, 7% for 30 years	$632.04	$652.74	$674.54	$701.15
Monthly payment, 0% for 30 years	$263.88	$272.53	$281.63	$292.74
15% for 15 year chattel	$1,329.61	$1,373.15	$1,419.01	$1,475.00

Table 11. Payments for Incremental Cost of New Construction, Double Wide

[6] Eklund, K.; Gordon, A. Costs and incremental cost studies on Manufactured Housing. Spreadsheet prepared for the Bonneville Power Administration. Washington State University Energy Program. 2011.

Analysis of Financing Options

Various financing options are available to homeowners; each of which has implications on the cost effectiveness of efficiency measures and monthly cash flow. The financing options evaluated in this analysis were the same as noted above: a 0 percent 30 year Habitat for Humanity mortgage, a conventional 7 percent 30 year mortgage, and a 15 percent 15 year mortgage chattel mortgage. The financing options were used to calculate the monthly payment for financing both the existing construction retrofit measures and the new construction monthly mortgage payments.

Financing Existing Construction Retrofits

The monthly cost of financing the retrofit of the 1976 pre HUD code home and the monthly cost of financing the retrofit of the 1976-1994 HUD code home was calculated. The modeled monthly upgrade savings in utility costs were subtracted from the monthly mortgage payments to calculate the cash flow. These results are included in **Tables 12 and 13**. Any scenarios leading to a negative monthly cash flow are noted in red.

Based on the modeled results, the retrofits of both vintages of homes financed at a 0 percent HfH loan resulted in a positive monthly cash flow. Financed at 7 percent, both the single wide and double wide 1976 vintage home resulted in a positive monthly cash flow. Retrofitting both the single and double wide 1976-1994 home did not result in a positive monthly cash flow. This is likely due to the fact that the thermal envelope of the home was more efficient pre-retrofit than the 1976 home, and there are not as substantial gains to be made in the retrofit. Applying the chattel mortgage to the existing construction retrofits did not result in a positive monthly cash flow for any of the configurations analyzed.

Single Wide	1976 Retro	1976-1994 Retro
Cost of retrofit package	$8,918.11	$6,644.51
Monthly upgrade savings	$63.05	$36.42
Monthly payment, 7% for 30 years	$59.33	$44.21
Monthly payment, 0% for 30 years	$24.77	$18.46
15% for 15 years	$124.82	$93.00
Monthly cash flow at 7%	$3.72	-$7.79
Monthly cash flow at 0%	$38.28	$17.96
Monthly cash flow at 15%	-$61.77	-$56.58

Table 12. Existing Construction Cash Flow, Single Wide

Double Wide	1976 Retro	1976-1994 Retro
Cost of retrofit package	$12,183.55	$9,575.85
Monthly upgrade savings	$92.71	$52.48
Monthly payment, 7% for 30 years	$81.06	$63.71
Monthly payment, 0% for 30 years	$33.84	$26.60
15% for 15 years	$170.52	$134.02
Monthly cash flow at 7%	$11.65	-$11.23
Monthly cash flow at 0%	$58.87	$25.88
Monthly cash flow at 15%	-$77.81	-$81.54

Table 13. Existing Construction Cash Flow, Double Wide

Financing New Construction Energy Efficiency

The increase to the monthly new construction mortgage payment for financing improved efficiency over the 1994 HUD code home was calculated and is summarized in **Tables 14 and 15**. The monthly cash flow when financed at 0 percent, 7 percent and 15 percent was derived by subtracting the monthly increase in mortgage payment from the modeled energy savings. All scenarios resulted in a positive monthly cash flow with the exception of the chattel mortgage used to finance the beyond ENERGY STAR packages. This clearly illustrates the negative impact that interest rates can have in offsetting energy improvements.

Single Wide	2012 IECC	Beyond ESTAR	Beyond ESTAR + DHP
Monthly energy savings	$43.02	$62.31	$67.18
Monthly new construction mortgage 7%	$16.51	$36.96	$63.57
Monthly new construction mortgage 0%	$6.89	$15.43	$26.54
Monthly new construction mortgage 15%	$34.74	$77.75	$133.74
Monthly cash flow at 7%	$26.51	$25.35	$3.61
Monthly cash flow at 0%	$36.13	$46.88	$40.64
Monthly cash flow at 15%	$8.28	-$15.44	-$66.56

Table 14. New Construction Cash Flow, Single Wide

Double Wide	2012 IECC	Beyond ESTAR	Beyond ESTAR + DHP
Monthly energy savings	$57.39	$82.58	$89.91
Monthly new construction mortgage 7%	$20.70	$42.50	$69.11
Monthly new construction mortgage 0%	$8.65	$17.75	$28.86
Monthly new construction mortgage 15%	$43.54	$89.40	$145.39
Monthly cash flow at 7%	$36.69	$40.08	$20.80
Monthly cash flow at 0%	$48.74	$64.83	$61.05
Monthly cash flow at 15%	$13.85	-$6.82	-$55.48

Table 15. New Construction Cash Flow, Double Wide

Conclusions of Energy Modeling Economic Analysis

Table 16 provides the annual and monthly estimated energy use from BEopt for each case and energy savings from retrofitting the pre HUD and HUD 1976 homes in single and double section homes.

Single Wide	1976	1976 Retro	1976-1994	1976-1994 Retro
Total annual energy use, kWh	27637	18736	23877	18736
Annual energy cost	$2,349.18	$1,592.59	$2,029.58	$1,592.59
Monthly energy use, kWh	2303	1561	1990	1561
Monthly energy cost	$195.76	$132.72	$169.13	$132.72
Annual upgrade savings		$756.59		$436.99
Monthly Upgrade savings		$63.05		$36.42
Double Wide	**1976**	**1976 Retro**	**1976-1994**	**1976-1994 Retro**
Total annual energy use, kWh	36140	23051	30460	23051
Annual energy cost	$3,071.93	$1,959.36	$2,589.13	$1,959.36
Monthly energy use, kWh	3012	1921	2538	1921
Monthly energy cost	$255.99	$163.28	$215.76	$163.28
Annual upgrade savings		$1,112.57		$629.77
Monthly upgrade savings		$92.71		$52.48

Table 16. Annual and Monthly Modeled Savings Estimates

Researchers used BEopt to model prototypes used by the Northwest Power and Conservation Council for regional analysis used in its Power Plans rather than attempt to create an average home from those studied. The utility data reported in **Table 2** indicate an average total energy usage of 8,712 kWh/year for electrically heated single wide homes, and 12,903 kWh/year for electrically heated double wide homes. Pre-retrofit energy use predicted by BEopt modeling similarly sized and constructed prototypes is twice to almost three times as much as the utility averages for the homes in this study.

The corresponding energy upgrade savings predicted by BEopt may be overestimated as well. Calibration of the BEopt model to the specific audited homes was not performed as part of this research, because of the magnitude of the difference between reported and modeled energy use, the complexity of the factors that may impact energy use in low income housing, and the lack of guidance on calibration. In spite of the discrepancy, it appears that the relative savings provided by BEopt may be valuable in prioritizing energy efficiency measures in this sector, though the range of benefits may be overstated for the homes in this study.

There are many factors that can potentially be impacting the model over predicting energy use. Occupancy, thermostat set-point, miscellaneous electrical loads and mechanical equipment did not vary in the base case modeled prototypes. In the audited home findings, these factors varied widely.

Experiments in modeling ducts and ventilation in BEOPT

The research team decided to examine three factors to assess potential impact on energy use and the treatment BEopt gave to these measures. The first measure was to vary the ventilation rate. In the main analysis the rates were assumed to be the same pre and post retrofit. In the modified analysis, the pre retrofit model has only spot ventilation and the post retrofit meets ASHRAE 62.2. As expected, this increased fan energy use. The impact on space heat usage was not observable, because of the large energy saving impact of the other measures.

The second measure was a modification in the modeling to better assess duct performance. Rather than attempt to model the ducts inside the floor insulation, a method developed by Ecotope, Inc. of Seattle, Washington was used. This involved placing the ducts outside the floor insulation, but modeling them as if they were insulated to the same R value as the floor. The impact of this modeling change was a significant reduction in heating energy use—almost 4,800 kWh per year on the double-wide 76 to 94 retrofit prototype in Table 6.

For the third change, the research team posited that the manner in which the homes were operated appeared to be zonal—that is the ducted heating system may not be used a significant amount of the time—providing a reason to model the homes with ducts inside. This change produced almost 13% greater difference with the original calculation than the second measure.

All of these experiments tested ways to more accurately model the homes. Both modifications in the duct modeling produced results closer to the actual metered use, though still significantly greater. It is quite likely that the actual performance of the ducts in these homes is described by one of these two models—at least in the efficient cases. The estimated energy use, cost of the retrofit and monthly cost of the savings are included in **Tables 17** for retrofit homes and the estimated use, total cost of the home and monthly payments in **Table 18** for new homes.

Modeled duct and ventilation cases for the 76-94 single wide					
	base	**base ductin**	**retro**	**retro w. vent**	**retro w. vent duct in**
ID number	1	2	3	4	5
Ventilation	spot	spot	spot	100% 62.2	100% 62.2
duct location	out	inside	out	out	inside
duct insulation	R-11	NA	R-33	R-33	NA
duct leakage	leaky	NA	tight	tight	NA
floor insulation	R-11	R-11	R-33	R-33	R-33
Misc. (kWh)	2860	2860	2860	2860	2860
Vent Fan (kWh)	22	22	22	94	94
Lg. Appl. (kWh)	2135	2135	2135	2135	2135
Lights (kWh)	1059	1059	1059	1059	1059
HVAC Fan/Pump (kWh)	521	409	253	277	254
Heating (kWh)	10201	8019	4956	5432	4973
Hot Water (kWh)	3693	3693	3693	3693	3693
Total (kWh)	20490	18196	14977	15549	15067
Annual elec cost	$1,741.68	$1,546.69	$1,273.08	$1,321.70	$1,280.72
Monthly elec cost	$145.14	$128.89	$106.09	$110.14	$106.73
Cost of retrofit			$6,644.51	$7,119.51	$6,874.51
30 year 7%			$44.21	$47.37	$45.74
30 year 0%			$18.46	$19.78	$19.10
15 year 15%			$93.00	$99.64	$96.21
Modeled duct and ventilation cases for the 76-94 double wide					
	base	**base ductin**	**retro**	**retro w. vent**	**retro w. vent duct in**
Misc. (kWh)	3118	3118	3118	3118	3118
Vent Fan (kWh)	22	22	22	89	89
Lg. Appl. (kWh)	2135	2135	2135	2135	2135
Lights (kWh)	1487	1487	1487	1487	1487
HVAC Fan/Pump (kWh)	755	604	366	384	351
Heating (kWh)	14058	11250	6812	7145	6532
Hot Water (kWh)	3693	3693	3693	3693	3693
Total (kWh)	25267	22308	17632	18050	17404
Annual elec cost	$2,147.72	$1,896.21	$1,498.75	$1,534.28	$1,479.37
Monthly elec cost	$178.98	$158.02	$124.90	$127.86	$123.28
Cost of retrofit			$9,575.85	$10,050.85	$9,194.00
30 year 7%			$63.71	$66.87	$61.17
30 year 0%			$26.60	$27.91	$25.53
15 year 15%			$134.02	$140.67	$128.68

Table 17. Comparison of Modeled Savings Estimates for Modified Retrofit Models

New construction models single wide						
	94HUD base	**94HUD duct insulation**	**94HUD ducts inside**	**2012 base**	**2012 duct insulation**	**2012 ducts inside**
ID number	6	7	8	9	10	11
Ventilation	100% 62.2	100% 62.2	100% 62.2	100% 62.2	100% 62.2	100% 62.2
duct location	out	out	inside	out	out	inside
duct insulation	R-6	R-22	NA	R-6	R-33	NA
duct leakage	leaky	leaky	NA	tight	tight	NA
floor insulation	R-22	R-22	R-22	R-33	R-33	R-33
Misc. (E)	2860	2860	2860	2860	2860	2860
Vent Fan (E)	94	94	94	128	128	128
Lg. Appl. (E)	2135	2135	2135	2135	2135	2135
Lights (E)	1059	1059	1059	1059	1059	1059
HVAC Fan/Pump (E)	512	499	361	204	197	180
Heating (E)	10042	9780	7078	3995	3853	3526
Hot Water (E)	3558	3558	3558	3432	3432	3432
Total	20260	19985	17145	13813	13664	13320
Annual elec cost	$1,722.08	$1,698.71	$1,457.31	$1,174.08	$1,161.42	$1,132.18
Monthly elec cost	$143.51	$141.56	$121.44	$97.84	$96.78	$94.35
Incremental cost				$2,482.21	$2,482.21	$2,482.21
Total cost	$40,000.00	$40,000.00	$40,000.00	$42,482.21	$42,482.21	$42,482.21
30 year 7%	$266.12	$266.12	$266.12	$282.63	$282.63	$282.63
30 year 0%	$111.11	$111.11	$111.11	$118.00	$118.00	$118.00
15 year 15%	$559.83	$559.83	$559.83	$594.57	$594.57	$594.57
New construction models double wide						
Misc. (E)	3118	3118	3118	3118	3118	3118
Vent Fan (E)	89	89	89	145	145	145
Lg. Appl. (E)	2135	2135	2135	2135	2135	2135
Lights (E)	1487	1487	1487	1487	1487	1487
HVAC Fan/Pump (E)	729	707	513	282	270	247
Heating (E)	13578	13169	9542	5244	5027	4592
Hot Water (E)	3558	3558	3558	3432	3432	3432
Total	24694	24263	20442	15843	15614	15156
Annual elec cost	$2,098.97	$2,062.34	$1,737.55	$1,346.63	$1,327.17	$1,288.24
Monthly elec cost	$174.91	$171.86	$144.80	$112.22	$110.60	$107.35
Incremental cost				$3,111.13	$3,111.13	$3,111.13
Total cost	$95,000.00	$95,000.00	$95,000.00	$98,111.13	$98,111.00	$98,111.00
30 year 7%	$632.04	$632.04	$632.04	$652.74	$652.74	$652.74
30 year 0%	$263.88	$263.88	$263.88	$272.53	$272.53	$272.53
15 year 15%	$1,329.61	$1,329.61	$1,329.61	$1,373.15	$1,373.15	$1,373.15

Table 18. Comparison of Modeled Savings Estimates for Modified New Models

The experiments show across-the-board overall energy use reductions. Specifically:

- The more accurate modeling of spot only ventilation in the base case reduces energy use of the ventilation fan, and increases ventilation fan, furnace fan and heating energy in the retrofit and new home cases.
- Modeling ducts as being outside the conditioned space but with the duct insulation around them reduces furnace and heating energy.
- Modeling ducts as being inside the conditioned space reduces furnace fan and heating energy more than modeling the ducts outside but with the floor insulation. The difference between these two approaches decreases as the floor insulation increases from R11 to R33.
- Both of the changes in duct modeling increase the cost effectiveness of efficiency measures.

Table 19 summarizes the changes in monthly payments and cash flow for the modified home, which includes all ductwork inside conditioned space and ventilating the home at 100 percent of ASHRAE 62.2 when compared to the retrofit where the ducts are sealed rather than assumed to be brought inside. The changes in cost to the retrofit package included backing out the cost of duct sealing ($245) and increasing the cost for fan purchase and installation ($475). The ducts inside case is much more cost effective, although as is shown above, the savings on which this cost effectiveness is based are probably beyond a reasonable expectation of realization.

	retro w.62.2	retro w.62.2 duct in
Cost of retrofit	$7,119.51	$6,874.51
30 year 7%	$47.37	$45.74
30 year 0%	$19.78	$19.10
15 year 15%	$99.64	$96.21
Monthly cash flow at 7%	-$12.37	-$23.58
Monthly cash flow at 0%	$15.22	$3.06
Monthly cash flow at 15%	-$64.64	-$74.05

Table 19. Monthly Payments and Cash Flow for Modified Model

Table 20 summarizes the monthly expenses of the modified 1976-1994 single wide models with different duct configurations.

	P and I at 0%	Energy Cost	Park Rental	Total
Base	$0.00	$145.14	$500.00	$645.14
Base ducts inside	$0.00	$128.89	$500.00	$628.89
retro w.62.2	$19.78	$110.14	$500.00	$629.92
retro w.62.2 ducts inside	$19.10	$106.73	$500.00	$625.83

Table 20. Monthly Expenses for Modified Model Compared to Original Model

Comparison of BEopt results to actual or verified data

Researchers also compared the BEopt duct model using the ducts outside conditioned space but insulated with floor insulation to actual manufactured home duct tightening savings.

Table 21 shows the results of BEopt analysis when the ducts in the base 1976 to 1994 home are tightened. In this situation the floor insulation is only R11 and the impact of tightening the ducts is 3,128 kWh annual savings. The weather file used is Boise, Idaho, to allow comparison to duct tightening data from a utility savings program.

	Base leaky ducts	Base tight ducts
Misc. (E)	2860	2860
Vent Fan (E)	22	22
Lg. Appl. (E)	2134.82	2134.82
Lights (E)	1059	1059
HVAC Fan/Pump (E)	724	565
Heating (E)	13476	10507
Hot Water (E)	3774.49	3774.49
Total	24050.31	20922.31

Table 21. BEOPT Analysis of Duct Tightening

Idaho Power Company recently completed a program evaluation of a duct testing and sealing program involving 1,420 manufactured homes. When the results are adjusted to correlate with the actual duct leakage in the Wonderland sample, the average savings are 1,233 kWh per year. The ratio of the field verified duct savings to the BEopt model is .39.[7]

Table 22 shows the calculation of the average annual kilowatt hours per square foot of conditioned floor area for the Wonderland homes, using billing data. This normalizes the energy use per unit floor area. When this normalization is compared to the same ratio resulting from BEopt modeling for the single wide 1976 to 1994 prototype, the ratio is very close to that of the duct savings comparison above.

[7] Impact Evaluation of the 2010 Energy House Calls Program, Final Report, December 30, 2011, Prepared for Idaho Power by ADM Associates, Inc.

kWh/yr. Average	Size (ft2)	kWh/sq. ft./yr.
7370	576	12.80
12635	1296	9.75
13170	1738	7.58
8399	1080	7.78
9025	1152	7.83
5065	1188	4.26
13185	1172	11.25
Average kWh/ft.^{2}/yr.		8.75
BEopt kWh/ft.^{2}/yr.		22.18
Ratio		0.3945

Table 22. Comparisons of Modified Models to Actual or Verified Data

Another check point for a base case home is a study by Ecotope, Inc., that compared energy efficiency manufactured homes to the 1994 HUD standard base case. The results for that study (expressed in kWh per square foot per year) were 9.3 for the energy efficient home and 11.21 for the 1994 HUD home in Western Washington. The 1994 HUD Code home from the Ecotope study was compared to the single wide prototype base case "76-94" in this report using the modified duct outside model — the homes are of similar construction. Using the total energy use calculated by BEopt the "76-94" prototype home uses 22.18 kWh/sq. ft. /yr. The ratio of the Ecotope study's 1994 HUD code home energy use to that of the BEopt model is .51. This is a model to model comparison, not actual data, but the Ecotope savings estimates based on the model it used have been verified in billing analysis.[8]

The conclusion is that BEopt consistently overestimates savings from duct sealing and overall energy use. Further research is indicated on both the energy use in older, energy inefficient manufactured homes and BEopt's modeling of these homes. That said, the authors believe that the analysis may accurately rank the relative importance of energy efficiency measures and provides a basis for depiction of the impact of various financing mechanisms on affordability.

Chattel Mortgages

Based on the analysis completed, it appears that chattel mortgages are a challenging financing mechanism, when the goal is to finance energy improvements in both existing and new construction. The "traditional" 7 percent, 30-year loans do appear to result in a positive monthly cash flow in most retrofit and new construction scenarios, with the exception of retrofitting the 1976-1994 vintage home. The HfH zero percent financing appears to be cost effective and results in a positive monthly cash flow in all cases.

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[8] Manufactured Home Acquisition Program Analysis of Program Impacts, Final Report, David Baylon, Bob Davis, Larry Palmiter, August 3, 1995, Ecotope, Prepared for BPA under Contract # DE-AM79-91BP1330, Task Order #71945.

Ductless Heat Pumps

In this analysis done for this report ductless heat pumps demonstrate a significant reduction in energy use in the new homes comparisons in the Beyond Energy Star model. While ductless heat pumps were not evaluated as a retrofit measure, this would be a retrofit option that could be evaluated in the future and would likely result in substantial savings in all electrically heated manufactured housing.

5. Findings and Recommendations

Achieving energy efficiency through building practices and materials at the time of construction is more cost-effective than weatherizing existing homes. In addition, implementing efficient measures at the time of construction relieves occupants of significant time and resource investments, and does not disrupt the living space while retrofit work is being completed.

The 1994 version of the HUD code is not in keeping with the improvements seen in site built energy codes. Updating the provisions of the HUD code is needed to address the issue of inefficient new manufactured housing.

Table 23 provides the first costs assumptions for the retrofit and new construction measure packages analyzed with BEopt. The cost of retrofitting the homes is, in some cases, over twice the consumer and societal (e.g. subsidized) cost of building more efficiently from the start.

	1976	1976-1994	2012 IECC	Beyond ESTAR	Beyond ESTAR + DHP
Single Wide					
Incr. cost of new const.			$2,482.21	$5,555.08	$9,555.08
Double Wide					
Incr. cost of new const.			$3,111.13	$6,387.93	$10,387.93
Single Wide					
Incr. cost of retrofit	$8,918.11	$6,644.51			
Double Wide					
Incr. cost of retrofit	$12,183.55	$9,575.85			

Table 23. Incremental New Construction and Retrofit Costs

Table 24 provides a summary of the monthly Principal and Interest (P+I) from the above analysis, energy costs (E) and park rental (R) assuming $500/month, for one financing scenario; 0 percent financing typical of Habitat financing. The table is color coded; green cells correspond to retrofit scenarios, orange corresponds to existing home conditions, and blue is new construction. For the zero interest, 30 year Habitat loan, the lowest monthly payment including P&I+E+R is $632 for both vintages of single wide existing homes with the costs of retrofitting subsidized in order for the homeowner to not take on additional monthly costs to finance the work. The lowest monthly payment for the double wide scenarios is $663, again with the costs of retrofitting subsidized. The difference in monthly payments for retrofitting the home with subsidized funds and purchasing a new standard HUD code home is $123 for the single wide homes and $278 for the double wide homes.

Single wide	P+I at 0 percent	Energy Cost	Park Rental	Total
Single 1976 subsidized retrofit costs		$132.72	$500.00	$632.72
Single 76-94 subsidized retrofit costs		$132.72	$500.00	$632.72
Single retrofit 1976-1994	$18.46	$132.72	$500.00	$651.18
Single retrofit 1976	$24.77	$132.72	$500.00	$657.49
Single 1976-1994 existing home		$169.13	$500.00	$669.13
Single 1976 existing home		$195.76	$500.00	$695.76
Beyond ESTAR single	$126.54	$83.27	$500.00	$709.81
Beyond ESTAR + DHP single	$137.65	$78.40	$500.00	$716.05
2012 IECC new construction single	$118.00	$102.56	$500.00	$720.56
1994 HUD new construction single	$111.11	$145.58	$500.00	$756.69
Double wide	**P+I at 0 percent**	**Energy Cost**	**Park Rental**	**Total**
Double 1976 subsidized retrofit costs		$163.28	$500.00	$663.28
Double 76-94 subsidized retrofit costs		$163.28	$500.00	$663.28
Double retrofit 1976-1994	$26.60	$163.28	$500.00	$689.88
Double retrofit 1976	$33.84	$163.28	$500.00	$697.12
Double 1976-1994 existing home		$215.76	$500.00	$715.76
Double 1976 existing home		$255.99	$500.00	$755.99
Beyond ESTAR double	$281.63	$95.48	$500.00	$877.11
Beyond ESTAR +DHP double	$292.74	$88.15	$500.00	$880.89
2012 IECC new construction double	$272.53	$120.67	$500.00	$893.20
1994 HUD new construction double	$263.88	$178.06	$500.00	$941.94

Table 24. P+I, Energy Cost, Park Rental and Monthly Payment

Research Recommendations

- A robust sample of HUD Code homes from which statistically valid conclusions could be drawn is recommended for future study.
- Expand the cost effectiveness analysis to include costs associated with health and safety, especially in retrofit cases. Analysis should also add increased value to the home in terms of market or rental value.
- Bringing ducts inside the insulation/air barrier should be researched. Recapturing the heat lost outside conditioned space is potentially a very cost-effective retrofit measure.
- BEopt overestimated both the overall energy use in the manufactured homes in this study, but also appeared to find savings beyond the range of those possible from bringing ducts inside. BEopt may not be designed to model HUD code housing, or there

may be other factors to be considered. This is an area for future study, perhaps in the context of expanding the billing sample to a statistically valid number.

- Researching financing mechanisms for home replacement appear to be the best way to take these homes to the next level of energy efficiency. Table 25 indicates the dramatic reduction in heating energy use between retrofitting a home and taking it to the Beyond ENERGY STAR plus Ductless Heat Pump stage.

	Single Wide	Double Wide
Retrofit 1976-94	8,499	11,924
New Beyond ES + DHP	1,145	1,724
% drop in annual kWh	87%	86%

Table 25. Heating Energy Comparisons (kWh)

- Reasonable financing for manufactured homes needs to be researched and demonstrated. The example of a bank that provides residential loans to manufactured home buyers in the report is compelling. What kind of efficiency can be purchased if utilities and other interested institutions work with banks to provide lending at the best residential levels or lower?

Financing Ideas for Habitat for Humanity

Other ideas to lower the cost of retrofit and/or new construction energy efficiency improvements for HFH may include:

- Offer zero interest loans for retrofits, where the home condition warrantees a useful life of at least 30 years or the mortgage period.
- Provide sweat equity, volunteers and donations to assist in the retrofits of the existing home.
- Offer zero interest loans for new construction based on energy efficiency levels beyond IECC 2012, to at least Energy Star, and ensure the home's performance is verified by a third party, paying particular attention to envelope and duct leakage, HVAC system commissioning, and occupant training on system operation and maintenance.
- Work with HUD-code manufacturers and retailers to see who will provide the best pricing to Habitat for new, high performance manufactured homes in communities, possibly in a bulk procurement arrangement.
- Investigation of incentives that may lower the monthly rental cost of the lot for an energy efficient home in a community, which may encourage replacement.
- Investigate other approaches, such as that undertaken by HASCO at Alpine Village. HASCO replaced old homes with new Energy Star homes when homes were vacated.

Work with HASCO and the local utility to evaluate energy use of old and new home. Interview HASCO to determine challenges associated with this approach.

- Continue to evaluate the use of ductless heat pumps in homes where the condition of the home may not warrant significant envelope retrofits, and where there may be salvage value of the DHP when the home is no longer a viable living dwelling.
- For areas of the country where electricity is more expensive than natural gas or propane, evaluate space heat and water heat retrofits, such as tankless water heaters, condensing gas furnaces, in both new and existing homes.

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Appendix A: Wonderland Case Studies

Wonderland A

- 576 square foot single wide built in 1979
- Electric resistance zonal heat
- Propane storage tank DHW
- Incandescent lighting
- 14.9 ACH50 envelope air leakage

Audit: This home was built to the 1976 HUD requirements but has seen substantial rehabilitation over the years. In the past ten years this home has seen structural, aesthetic and energy related work including ventilation, dry rot repair, new flooring, new insulation, and new windows. There are no additions or substantial modifications to the original structure.

Above grade wall U-factors were 0.079 (R-11), floors were 0.069 (R-11) and the ceiling was 0.053 (R-22). All of the homes' windows had been upgraded to newer, thermally broken, vinyl framed units with an estimated U-factor of 0.40. The home owner commented that she has received insulation in the past, it was unclear to what extent and where. Insulation levels for this report are based upon HUD requirements for 1979.

Lighting in the home was incandescent lamps in standard Edison base fixtures. All major appliances were present; none were ENERGY STAR qualified. The home did not appear to have any abnormal plug loads, other than an auxiliary chest freezer that was in use year round.

The homes heating system had originally been a propane furnace but it is no longer functional. The duct system has been abandoned but not decommissioned. The occupant now uses two electric space heaters to provide heat to the home. An air conditioner is installed through an exterior window, and left in place throughout the year. Domestic hot water is provided by a propane-fueled, naturally drafted storage tank heater.

Source specific ventilation is presented in the bathroom and over the kitchen range. There is no whole house ventilation system in this home.

Testing: Blower door testing results indicated a fairly compromised air barrier, with an infiltration rate of 14.9 $ACH_{50.}$ This is considerably higher than the average of 8.2 ACH_{50} for the six homes audited in this study, though not unusual for this vintage of home. Weather seals at windows and doors were relatively intact, and appeared functional.

The kitchen range hood was fairly new and operated as expected, although the fan's flow rate was not measured. The bathroom exhaust fan was tested and had a flow rate of 8 CFM. The homeowner stated that fan isn't in use. No signs of mold or mildew were present. Both fans were switch-controlled.

Occupant Survey: This home has been occupied by one 72 year old resident for the last 11 years. The occupant spends 40 hours per week outside of the home.

The occupant was very satisfied with the energy efficiency and comfort of the home, and utility bills, as she understood, were very low (the occupant's daughter paid the bills, so the occupant was not fully aware of her energy costs.)

As the home is heated with zonal electric heaters, the home has no central thermostat, and there is no thermostat set point. The previous system was thermostatically controlled and set to 68 deg. F. The occupant believes the home's operating temperature is similar with the current zonal electric heaters; there is no way to confirm this. The heat and air conditioning is turned off at night and when the home is not occupied.

Although the occupant felt that there was still plenty of opportunity to make her home more energy efficient, having more space was more important to her. Having said that, due to financial considerations, a new home would not be a possibility.

Analysis: Electricity consumption utility data for this home was only available for 2010; 7,370 kWh or 12.8 kWh per square foot of conditioned floor area. This appears to be a high consumption rate, considering the size of the home, single occupant, occupant behavior, and the fact that domestic hot water was not electric. However, this consumption rate is consistent with the findings of the energy audit. Hot water (propane) consumption data was not available.

Relative to two other occupied homes audited in this study, this home uses 158 percent and 123 percent more electricity per square foot. If domestic hot water usage were added, this discrepancy would likely be considerably higher.

This audit and analysis lend support to replacing older mobile homes with newer energy efficient homes, rather than investing in weatherization of the existing units. Although energy efficiency retrofit measures implemented at this home surely had some impact on the home's consumption, it does not appear that the savings were enough to justify the investment.

An additional potential improvement would be to install a ductless heat pump, which would reduce energy use, improve occupant comfort, has a useful life in keeping with that of the home, and which could be removed and reused if the home were replaced. Making additional improvements to the home's envelope and mechanical systems are harder to justify, given that the home's useful life is limited without major repairs.

Wonderland B

- 1296 square foot double wide built in 1996
- Electric force air furnace
- Electric tank DHW
- 80 percent Incandescent lighting
- 5.2 ACH50 envelope air leakage
- 31 percent duct leakage to exterior relative to the conditioned floor area

Audit: This home was fairly typical of the newer homes found in the Wonderland community. The home was built to HUD specifications of 1996; no additions have been made. The home is set up over an enclosed, ventilated crawl space.

Above grade wall U-factors were 0.069 (R-14.5), floors were 0.031 (R-32) and the ceiling was 0.033 (R-33). There was water damage to a significant portion of the floor insulation, which likely significantly degrades the floor assembly's thermal performance. The windows were double pane, vinyl framed with a thermal break (U-factor not determined, typically .58 - .40 for clear windows). An aftermarket window film had been installed by the homeowners on all west facing windows in attempt to reduce overheating of the home in the cooling season.

The homes' lighting was provided by approximately 80 percent compact fluorescent lamps in a variety of different fixtures and lamps. The dishwasher was ENERGY STAR rated; no other major appliances in the home were high efficiency models. In addition to the standard household appliances, this home also had an auxiliary upright freezer in use year round. There were no signs of abnormal plug load use.

Heating for the home was supplied by an Intertherm electric forced air furnace located within the conditioned space of the home. Supply ducts were insulated and located in the crawlspace and floor structure. Peripheral inspection of the duct system found one partially disconnected duct. Domestic hot water is provided by a standard electric storage tank system located within the conditioned space of the home.

This home is equipped with both source specific and whole house ventilation systems. Whole house ventilation is provided via a central exhaust system but has not been run in over a year due to the occupant's observation of a burnt rubber smell when running. Source specific exhaust ventilation is provided at both bathrooms and kitchen. All fans were controlled with on/off switches. The whole house fan control was mounted on wall below the fan but had no identification label as the whole house fan control.

This home had several additional appliances not installed at time of construction, including:

- An electric fireplace used for ambiance,
- Window mounted unit air conditioner,
- Auxiliary stand up freezer, and
- A dehumidifier.

Testing: Performance Blower door testing indicated an infiltration rate of 5.2 $ACH_{50.}$ This leakage rate was the lowest of the 6 homes audited in this study. There were no visible indications that would suggest that this home would have such low infiltration rates, though it was one of the newest homes tested.

Duct leakage testing indicated 400 CFM_{50} of leakage to the exterior, or almost 31 percent leakage relative to the conditioned floor area of the home. This was one of the leakier duct systems tested, despite the fact that the system had recently received prescriptive duct sealing through a local utility program.

Ventilation testing found flow rates of 41 and 36 CFM for the bathrooms. Though the kitchen range hood was not tested for flow, it did appear to operate normally and is rated to 160 CFM. The whole house exhaust fan tested to 48 CFM. There were small and isolated signs of mold and mildew, but no moisture-related issues were noted on the interior of the home. However, on inspection of the crawl space it was noted that there was moisture trapped between the subfloor and the rodent barrier. This was more than likely a significant contributor to the occupant's complaints of high humidity within the home.

Occupant Survey: The home has been occupied full time by the same two adult residents, both over 65 years of age, for the last four years. Both occupants spend most of their time at home. For 4-6 weeks in the summer months the home has 4-6 additional school age residents.

Occupants complained of minor comfort issues – hot or cold walls, as well as uncomfortable window surface temperatures and drafts. The occupants thought that the home could use more insulation and more efficient windows.

The home is kept between 68 and 70 deg. F. during the heating season while the occupants are awake. Although the home is equipped with a programmable thermostat, the occupants do not use its programmable features. Instead, the thermostat setting is set back manually at night to 65 degrees F. The occupants made no mention of opinion regarding the heating system. The furnace filter is changed every two months.

The occupants had upgraded most of their lighting to CFLs, and were eager to upgrade the rest of it; however, the remaining fixture design has made this impractical. It was noted by the occupants that the recessed light fixtures had poor light quality.

Overall, the biggest complaints the occupants had regarding their home were related to quality of construction rather than energy efficiency. And, although the occupants wanted a more energy efficient home, when presented with the question of whether they would be willing to buy a new, more energy efficient home the answer was no. The occupants felt they could not afford a new home nor were they willing to go through the moving process again.

Analysis: Beyond the water damaged floor insulation, this audit did not reveal any significant deficiencies in the homes thermal or air barriers. However, duct leakage rates to the exterior were high enough to expect relatively high annual consumption rates. Additionally, high electrical consumption could be expected with the occupant's use of auxiliary appliances, such as the A/C unit, extra freezer, electric fireplace and dehumidifier.

This home consumed an average of 13,451 kWh in 2009-2010, or 10.1 kWh per square foot. This was lower than expected, considering the high plug loads and duct system deficiencies. It is possible that much of the registered duct leakage is relatively new and related to recent work done to fix plumbing leaks. If this is the case, increased consumption would not have been reflected in the utility data received for this study. For 2009 and 2010 this home consumed roughly $1200 of electricity annually.

This home is in decent physical condition and did not show any need for substantial physical repair. Additionally the home's energy consumption was not excessive, despite the floor insulation and duct leakage issues. Given the overall performance of the home, taken with the occupant's lack of interest and financial ability, it would not be recommended to replace this home with a new, energy efficient model.

It is highly recommended that the occupants of this home invest in re-insulation of the floor assembly and sealing of the duct system. Both these measures should bring immediate comfort and energy consumption benefits to the occupants with relatively small financial investment. It is also advised that the occupants consider high efficiency appliances at time of replacement.

At 5.2 $ACH_{50,}$ this home is tight enough that mechanical ventilation is warranted. Repair and proper operation of the whole house fan should also be of priority to increase occupant comfort, improve indoor air quality and durability of the home. Proper use of the ventilation system should negate the need to run the dehumidifier, potentially leading to increased energy savings.

Wonderland C

- 1738 square foot double wide built in 1989
- Air source heat pump
- Electric tank water heater
- 42 percent compact fluorescent lighting
- 7.2 ACH50 envelope air leakage
- 8.6 percent duct leakage to exterior relative to conditioned floor area

Audit: This home was fairly typical of the newer homes found in the Wonderland community. The home was built to HUD specifications in 1989. There were no additions built to the home, though the home has a storage shed, rarely used, but with electrical service. The home is set up over an enclosed, ventilated crawl space.

Above grade wall U-factors were 0.079 (R-11), floors were 0.069 (R-11) and the ceiling was 0.053 (R-22). The U-factor of the windows varied:

- 75 percent of the windows were original thermally broken aluminum framed with a U-factor of 0.55. Three of these windows had broken seals at the insulated glass unit.
- 25 percent of the original windows have been replaced within the last 10 years with thermally broken, vinyl framed windows, with a U-factor of 0.40. These windows were specifically replaced in attempt to reduce overheating of the home.

The home had one skylight of unknown U-factor.

Forty-two percent of the homes' lighting was provided by compact fluorescent lamps. The remaining lighting was incandescent or T-12 lineal fluorescent. All major appliances were present, though however the occupant chose to never use the dishwasher. There were two full size refrigerators used in the kitchen. None of the appliances were ENERGY STAR qualified. The home did not appear to have any abnormal plug loads.

Heating, cooling and ventilation for his home came from a forced air, ducted system powered by an air source heat pump controlled by a programmable thermostat. The heat pump was ten years old and replaced the original electric furnace. Supply ducts were insulated and located within the crawlspace and the floor assembly. Domestic hot water was provided by a standard electric storage tank system inside conditioned space.

The home is equipped with both source-specific and central (whole-house) ventilation systems. Whole house ventilation is provided via supply air ducted to the furnace and distributed through the duct work.

Testing: Blower door testing results showed the homes air barrier to be fairly complete with an infiltration rate of 7.2 ACH_{50}, better than the average of 8.2 ACH_{50} for the six homes audited in this study. There was no visual observation of any significant deficiencies to the homes' air barrier.

Testing of the homes' duct system indicated 150 CFM_{50} to the exterior, or 8.6 percent relative to the homes conditioned floor area. This result was well below the study average of 18 percent leakage to the exterior.

The whole house ventilation system was not tested for flow rate, and it was determined that the occupants of the home do not use the system. The master bathroom has two fans with flow rates measured at 40 and 42 CFM. The flow rate at the other bath fan was 36 CFM. The kitchen range hood was not tested for flow rate but appeared to function properly when switched on. All source-specific exhaust fans were controlled with wall mounted on/off switches.

Occupant Survey: This home has been occupied by two residents, ages 40 and 70, for the last 5 years. One resident works outside the home at least 20 hours per week. The home is rarely unoccupied.

The occupant surveyed was somewhat satisfied with the energy efficiency and comfort of the home. The occupant was of the opinion that the heat pump is energy efficient. The original aluminum windows were noted as the most apparent comfort issue to the occupant.

The occupant believes a new home would be beneficial in increasing comfort, reducing energy use and lowering electrical bills. However, she is very attached to her home and does not feel she would be able to afford a new one.

The homes' programmable thermostat is set between 68 and 72 deg. F; no set back is ever employed. One of the occupants has heat sensitivity and cannot tolerate interior temperatures greater than 74 deg. F. This results in fairly heavy dependence on the homes air conditioning during the cooling season. The furnace filter is changed every 2-3 months.

In addition to the window replacement, the homes duct system was sealed within the past 5 years through a utility conservation program. Additionally, the homeowner has installed many compact fluorescent lights. There is interest in continuing to make the home more energy efficient but paying for any additional work would be a struggle.

Analysis: For 2009-2010, the home consumed an average of 14,065 kWh, or 8.1 kWh per square foot per year. This consumption rate appears to be in agreement with the audit findings.

This home was roughly 25 percent larger than Wonderland B but had very similar loads and occupant behavior. However, this home used only 4.5 percent more energy than the smaller home (which was built under a more stringent HUD code (1994) and had a considerably lower infiltration rate.) It is likely that the lower energy consumption observed in this home was heavily influenced by the home's superior HVAC system.

Although the home is 22 years old, it is in very good shape structurally. The home also appears to perform efficiently, with no major deficiencies noted. It would be beneficial, from both the comfort and energy perspectives, to replace the remaining original aluminum windows with ENERGY STAR qualified products. Additionally, air sealing is recommended in concert with proper operation of the ventilation system.

Wonderland D

- 1080 square foot double wide built in 1986
- Electric resistance forced air furnace
- Electric resistance storage tank DHW
- 10 percent compact fluorescent lighting
- 7.6 ACH50 envelope air leakage
- 17.6 percent duct leakage to exterior at 50 Pascals relative to conditioned floor area

Wonderland E

- 1152 square foot double wide built in 1992
- Electric resistance forced air furnace
- Electric resistance storage tank DHW
- 2.5 percent compact fluorescent lighting
- 6.5 ACH50 envelope air leakage
- 33.4 percent duct leakage to exterior at 50 Pascals relative to conditioned floor area

Wonderland F

- 1188 square foot double wide built in 1998
- Electric resistance forced air furnace
- Electric resistance storage tank DHW
- 100 percent incandescent lighting
- 7.7 ACH50 envelope air leakage
- 25.3 percent duct leakage to exterior at 50 Pascals relative to conditioned floor area

Audit: These homes had recently been moved to the Wonderland development by the King County Housing Authority. Rehabilitation work was then performed on these homes prior to putting them up for sale. All three of these homes were very similar in age and condition and were unoccupied at the time of this audit. As these homes had never been occupied in Wonderland, there is no energy consumption data available for this study.

Wonderland D was built under the 1976 HUD code, but appears to be built to higher energy efficiency standards. Although there was no HUD sticker present to confirm this assumption, the walls were 2X6, allowing for higher insulation R-values than required under 1976 HUD.

Wonderland E was a Super Good Cents home built in 1992. It is estimated that R-values for these two homes are R-19 in the walls and R-33 in the attic and floor.

Wonderland F was built in 1998; there was no indication that it was built to exceed 1994 HUD code standards. R-values for this home are estimated to be R-11 for the walls and R-22 for the floor and ceiling.

Windows in all three units were vinyl framed, thermally broken units with an estimated U-factor of 0.40.

Lighting in these homes varied, with 10 percent compact fluorescent lamps at Wonderland D, 2.5 percent and 0 percent compact fluorescent lamps for the two other homes. All three homes had new dishwashers and refrigerators installed; none of these were ENERGY STAR qualified. No other appliances were present in the homes at the time of the audits.

The homes were all heated with electric furnaces located within the conditioned space. All supply ducts were insulated and located within the enclosed, ventilated crawl space.

Source-specific ventilation is present in the bathrooms and over the kitchen ranges. Wonderland B was the only home with a whole house ventilation system.

Testing: Blower door testing results varied little for these three houses:

- Wonderland E had the lowest infiltration rate at 6.5 ACH50,
- Wonderland D was 7.6 ACH50 and
- Wonderland F was slightly leakier at 7.7 ACH50.

All three homes had less infiltration than the study average of 8.2 ACH_{50}. There was no visual evidence of any air sealing measures employed at time of retrofit, although weather seals at doors were in place and appeared to be functional.

Duct testing results varied significantly between the homes:

- Wonderland E and F had leakage rates of 385 CFM_{50} and 300 CFM_{50} to the exterior, which equates to 33.4 percent and 25.3 percent leakage to the exterior relative to conditioned floor area.
- Wonderland D's duct leakage rate was tested to be 190 CFM_{50} or 17.6 percent relative to the homes conditioned floor area. This was below the average leakage rate (23.2 percent) for the six homes tested in this study.

All of the homes' source specific bathroom exhaust fans were tested for flow rate. Flow rates were between 21 and 30 CFM (one bathroom had no fan.) All bath fans were controlled by on/off switches. All homes had kitchen range hoods with two speed switch controls. These fans were not tested for flow rate; two of the range hoods appeared to work properly, but the fan at Wonderland F did not run.

Whole house ventilation was not present at Wonderland D and Wonderland E. Wonderland F had a whole house exhaust fan installed with a 5" duct into the furnace cabinet to supply the fresh air to the duct system. The exhaust fan flow rate was tested to 55 CFM.

Analysis: There was no electrical consumption data available for the three unoccupied homes tested. However, the audits suggested that the homes thermal and air barriers were fairly sufficient, despite the observation that air sealing measures were (more than likely) not implemented at the time of rehabilitation. The duct systems in two of the units were quite leaky, and will lead to higher heating energy use.

Although these homes have decent thermal envelopes, many opportunities to improve upon the homes energy performance were lost when not implemented at the time of rehabilitation. There were several measures of relatively low additional investment that should have been considered, including air sealing of the ducts, installation of high efficiency lighting and upgrading new appliances to ENERGY STAR qualified models.